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Cross-border conflict resolution: sediment contamination dispute in Lake Roosevelt

Jing Ma[a]*, Keith W. Hipel[b] and Stéphane M. McLachlan[c]

[a]*Department of Environment and Geography, University of Manitoba, Winnipeg, MB R3T 2N2;* [b]*Department of Systems Design Engineering, University of Waterloo, Waterloo, ON N2L 3G1;* [c]*Department of Environment and Geography, University of Manitoba, Winnipeg, MB R3T 2N2*

A transboundary conflict between Canada and the United States due to slag contamination in Lake Roosevelt is formally studied using the Graph Model for Conflict Resolution. Three key decision makers (DMs) were identified: 1) Teck Cominco, the largest mining, mineral processing and metallurgical company in Canada; 2) the United States Environmental Protection Agency; and 3) the Colville Indian Tribes, whose traditional territories are located in the Lake Roosevelt area. After a careful background investigation, the conflict among these three groups is modeled by identifying three key DMs, potential courses of action for each DM, and the relative preferences of each DM with respect to the states or scenarios that could occur as of May 2006, just before the settlement agreement was signed. Subsequently, a stability analysis is carried out and several strong equilibria or potential solutions to the conflict are identified. The analytical results verify the suitability of the developed analytical model, suggest mutual agreements between the stakeholders as a potential solution for the conflict, and highlight the importance of establishing new or strictly enforcing existing water policies in order to resolve current conflicts and to avoid any future controversies.

Le Modèle de Graph pour Résolution de Conflit est utilisé pour examiner formellement un conflit transfrontière entre le Canada et les États-Unis causé par la contamination de crassier au Lac de Roosevelt. Trois décideurs clés sont identifiés : i) Teck Cominco, la plus grande compagnie en exploitation minière, traitement minéral et métallurgie au Canada. ii) L'Agent de Protection Environnementale des Etats-Unis. iii) La tribu indienne de Colville, dont les territoires traditionnels se trouvent dans la zone du lac de Roosevelt. Après une enquête sérieuse du contexte, le conflit parmi ces trois groupes est modelé en distinguant trois décideurs, processus d'action potentiel et les préférences relatives de chacun à l'égard de l'état et le scénario qui pourraient se passer à partir du Mai 2006, juste avant la signature de l'accord de compromis. Par la suite, une analyse de stabilité est réalisée et quelques équilibres forts ou solutions potentielles pour le conflit sont proposés. Les résultats détaillés vérifient la convenance des modèles analytiques développés, suggèrent un agrément mutuel entre les actionnaires comme une solution potentielle pour le conflit et soulignent l'importance de faire des nouvelles lois d'eau ou renforcer strictement celles qui sont existées afin de résoudre les conflits actuels et évider tous les controverses futures.

Introduction

Lake Roosevelt, a reservoir created by the Grand Coulee Dam, is located on the Columbia River, a large watercourse that has its source in the Rocky Mountains of British Columbia, Canada (Figure 1). It flows northwest and then south into the state of Washington, USA, where it eventually turns west and flows into the Pacific Ocean (United States Geological Survey (USGS 2009). The Lake Roosevelt area is the homeland of the Colville and Spokane Indian Tribes and is also designated as a United States national recreation area (Lake Roosevelt Forum 2010; Washington Department of Transportation 2004).

Teck Cominco (TC), the largest mining, mineral processing and metallurgical company in Canada, has been processing ore near the banks of the Columbia River in British Columbia since the early 1900s (Teck Cominco 2009a, 2009b). The TC smelter discharged slag into the Columbia River until 1995 (Teck Cominco 2009c). In the late 1990s, concerns about risks from slag contamination to people's health and the environment emerged. In August 1999, the Colville Confederated Tribes (CT) asked the United States Environmental Protection Agency (USEPA, hereafter referred to as EPA) to investigate the effects of contamination in the Upper Columbia River (USEPA 2009). In 2001 and 2002, EPA evaluated sediment from the Columbia River and Lake Roosevelt, and the investigation verified the existence of heavy metal contamination in the sediments (USEPA 2009). Since EPA identified TC as the largest contributor, a dispute arose among TC, EPA and CT (USEPA 2004; Ma et al. 2010).

At the beginning of the dispute, EPA tried to include the Upper Columbia River under a Superfund Alternative Site (SAS), so that Superfund cleanup standards could be applied (USEPA 2004). The Superfund was initiated by the Comprehensive Environmental Response,

*Corresponding author. Email: umma43@cc.umanitoba.ca

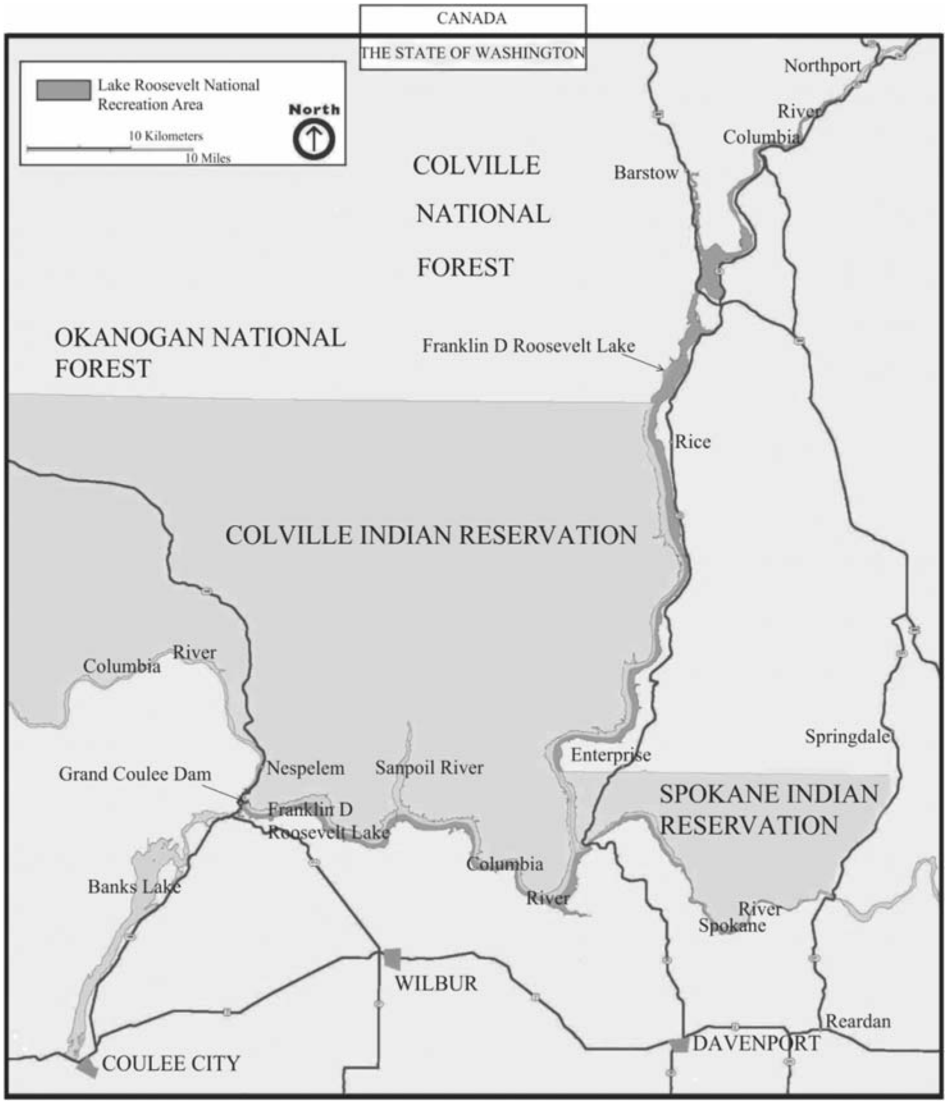

Figure 1. Lake Roosevelt region (available from http://www.bentler.us/eastern-washington/recreation/lake-roosevelt-map.aspx) (accessed February 2010).

Compensation and Liability Act (CERCLA). On October 22, 2003, TC proposed a draft voluntary cooperative agreement for EPA consideration, which offered a total of $13 million (US) ($8 million (US) for further study and $5 million (US) for regulatory oversight) for an investigation of Lake Roosevelt regarding human health and ecological concerns. The proposal also requested a legally enforceable agreement on risk assessment of metals residues in the lake and appropriate remedies (The Northern Miner 2004). However, this offer was rejected by EPA on November 7, 2003, arguing that TC refused to follow the CERCLA standards for further studies and remedies (USEPA 2004). On December 11, 2003, EPA issued a Unilateral Administrative Order (UAO) to force TC to carry out a contamination study that would comply with CERCLA standards. The UAO warned that EPA would initiate its own investigation if TC did not comply with the order and would then recover the cost of the investigation through legal action (Stiffler 2003). On January 12, 2004, TC rejected the UAO. EPA subsequently started its own investigation, which put forth two alternative solutions: 1) to get a judgment against TC in the US first and then enforce it in Canada; and 2) to punish the TC's US operations (Chase and Stueck 2004). The TC spokesperson, Tom Merinsky, refused to comment on possible legal actions by EPA, while emphasizing that TC would be willing to pay for the studies under EPA direction and any potential remedies. But TC refused to invoke US legislation in its Canadian-based operations (Chase and Stueck 2004).

In July 2004, CT in Washington State sued TC for polluting Lake Roosevelt (Geranios 2004a). On August 26, 2004, TC took legal action in the US District Court to "dismiss the unprecedented attempt to force a Canadian company to submit to CERCLA, the US Superfund law" (The Free Library 2004). One month later, the State of Washington joined the lawsuit, and on November 4, 2004, the federal court in Yakima set a hearing on the motion to dismiss the lawsuit (Geranios 2004b). On November 8, 2004, TC's motion was rejected and an appeal to the 9th US Circuit Court of Appeals was certified (Dininny 2004). On November 26, 2004, TC filed for permission to appeal and in February, 2005, the 9th US Court of Appeals agreed to hear the Canadian company's appeal (Steele 2005). In April and May 2005, the first phase of EPA's unilateral study was finished, in which sediment samples from the Upper Columbia River were successfully collected and evaluated. One month later, on June 2, 2006, TC and EPA signed a Settlement Agreement. The agreement was the substitute for the UAO, and TC agreed to a long-standing commitment on contamination investigation and compensation (over $1 million per year) (Teck Cominco 2006). However, there is still an ongoing conflict and a lawsuit is presently underway between TC and CT.

The objective of this study is to carry out a strategic analysis of the Lake Roosevelt conflict by using the Graph Model for Conflict Resolution (Fang et al. 1993). After presenting an overview of the graph model, the conflict is modeled in terms of the decision makers (DMs) and their options and preferences, followed by a stability analysis to determine the equilibria or compromise resolutions. The decision support system, GMCR II® (Fang et al. 2003a, 2003b; Hipel et al. 1997, 2001), is employed to conduct the stability analysis.

Conflict resolution methodology

Graph model for conflict resolution

The application of the Graph Model for Conflict Resolution follows three main stages: modeling, stability analysis and output interpretation (Fang et al. 1993).

The modeling stage is important to the whole conflict study, since a well-defined model is necessary for the correctness of results in the ensuing analysis. In this stage, the DMs and their options and preferences are specified. Theoretically, the established graph model consists of a set of directed graphs with a common vertex set, along with preferences over vertices (possible scenarios or states) for each DM in the conflict. Each directed graph D can be denoted by a 2-tuple (V, A), where $V = \{V_1, V_{2,...,}V_n\}$ is the set of n vertices, and $A = \{a_1, a_{2,...,}a_m\}$ is the set of elements of the Cartesian product V x V called arcs. Any component $a_k \in A$ $a_{aj} \in A$ can be further represented in a variable with two subscripts, $a_k = b_{ij}$, which means there is a directional connection from vertical V_i to V_j. For a DM i, the existence of an arc from S_m to S_n denotes that the DM can unilaterally move from state S_m to state S_n. Hence, a finitely directed graph for each DM models the possible moves and countermoves that can take place in the conflict. In the graph model, $S_n >_i S_m$ means that DM i strictly prefers S_n to S_m, and $S_n \sim_i S_m$ means that DM i is indifferent between S_n and $S_{m.}$ If a unilateral move from a particular state to some preferred states is available for a given DM i, then it is said that this DM has a unilateral improvement from the initial state.

In a stability analysis, the stability of every state for each DM is evaluated first. Here, a state is stable for DM i if and only if (IFF) DM i has no incentive to move away from this state unilaterally. In the stability analysis, not all unilateral improvements for a DM will be carried out, since other DMs may have countermoves that can put the DM in a less preferred situation. Thus, if all unilateral improvements are sanctioned, the state is stable for the DM. A state that is stable for all DMs is called an equilibrium or predicted outcome of the model since the conflict will stop here. Different solution concepts or stability definitions can be used in searching for equilibria and are summarized in Table 1 (Fang et al. 1993; Hipel et al. 2001). The theoreticall graph model definitions for these solution concepts are furnished by Fang et al. (1993), while the original sources for the definitions are given in the left column of Table 1. Here, a description of how each solution concept works is given, as well as a qualitative categorization of the solution concepts according to four characteristics. As can be seen, different solution concepts imply different levels of foresight, or measures of a DM's ability to consider possible moves and countermoves that could take place in the future. A DM with high foresight thinks further ahead. Nash stability (R) has low foresight, while Nonmyopic stability (NM) has the highest. The foresight level of limited-move stability (L_h) is variable depending on the parameter h. Some solution concepts, such as L_h and NM, allow strategic disimprovements by moving to a worse state in order to reach a more preferred state eventually; while other solution concepts, such as R and sequential stability (SEQ), never allow disimprovements. General metarationality (GMR) and symmetric metarationality (SMR) permit strategic disimprovements by opponents only. Different solution concepts also imply different levels of preference knowledge. Under R, GMR and SMR, a DM needs only to know its own preferences, while a DM must be aware of the preference information for all DMs for the solution concepts SEQ, L_h and NM.

All stability analysis results are further interpreted in the output interpretation stage in terms of the real-world conflict under study. Analytical outcomes provide the potential solutions to the conflict and a guideline for its

Table 1. Solution concepts and human behavior.

Solution Concepts	Characteristics: Foresight	Dis-improvement	Knowledge of Preference	Strategic Risk	Stability Descriptions
Nash Stability (R) (Nash 1950, 1951)	Low	Never	Own	Ignore	DM cannot unilaterally move to a more preferred state.
General Metarationality (GMR) (Howard 1971)	Medium	By opponents	Own	Avoid	All DMs' unilateral improvements are sanctioned by subsequent unilateral moves by others.
Symmetric Metarationality (SMR) (Howard 1971)	Medium	By opponents	Own	Avoid	All DMs' unilateral improvements are still sanctioned even after a possible response by the original DM.
Sequential Stability (SEQ) (Fraser and Hipel 1984)	Medium	Never	Own	Takes some risks	All DMs' unilateral improvements are sanctioned by subsequent unilateral improvements by others.
Limited-move Stability (L_h) (Kilgour 1985, Fang et al. 1993)	Variable	Strategic	All	Accepts	All DMs are assumed to act optimally and a fixed number of state transitions (h) are specified.
Non-myopic Stability (NM) (Brams and Wittman 1981)	Unlimited	Strategic	All	Accepts	Limiting case of limited-move stability as the number of state transitions increases to infinity.

future evolution. The practically-infeasible solutions may also be helpful for model calibration.

The decision support system GMCR II®

The decision support system GMCR II® implements the Graph Model for Conflict Resolution within a Windows environment (Hipel et al. 1997; Fang et al. 2003a, 2003b) and has been widely applied in many areas, such as hydroelectric power development (Ma et al. 2005), environmental management (Kilgour et al. 2001), and trade (Hipel et al. 2001). The structure of GMCR II® consists of a modeling subsystem, an analysis engine, and an output data subsystem, as shown in Figure 2.

The modeling subsystem of GMCR II® allows a user to enter a conflict model conveniently and expeditiously. The user can input DMs and options, patterns of infeasible states, and preference information. Then, GMCR II® will generate the required input for a stability analysis, including feasible states, permissible state transitions and ranking of states from most to least preferred (allowing ties) for each DM.

Based on the information generated at the modeling stage, the analysis engine performs a thorough stability analysis of the conflict model. The analysis engine can produce a large amount of output data, including the stability results for every state and for each DM under the wide variety of solution concepts listed in Table 1. The output interpretation subsystem presents the results from the analysis engine in a user-friendly manner, so that useful results with respect to individual stability, equilibria, and coalition stability can be easily identified and compared.

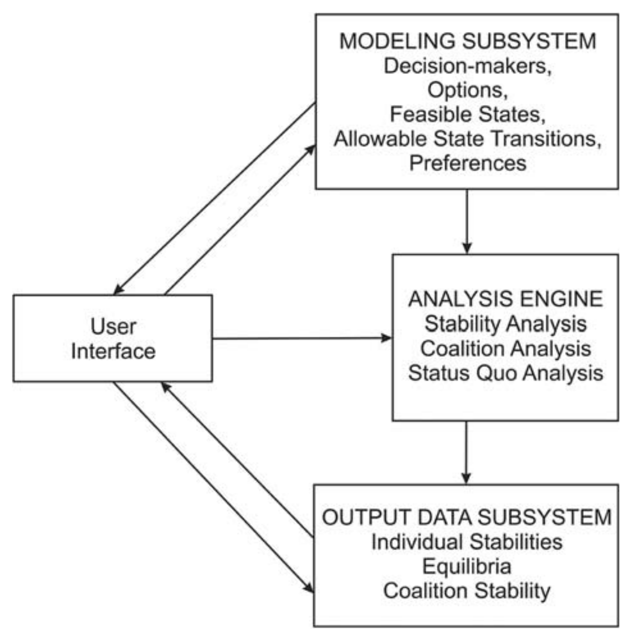

Figure 2. The structure of the decision support system, GMCR II (Hipel et al. 1997; Fang et al. 2003a, 2003b).

Decision makers and their options for the Lake Roosevelt conflict

As explained in the Introduction, the key DMs in the Lake Roosevelt conflict are Teck Cominco (TC), the Colville Tribes (CT), and the US Environmental Protection Agency (EPA). The options or courses of action available to each of these DMs are described below and listed in Table 2.

Table 2. DMs and their options.

DMs	Options	Status Quo State (May 2006)
Teck Cominco (TC)	1. Negotiate with EPA	N
	2. Initiate counter-lawsuits in the US against CT's legal action	Y
	3. Negotiate with Colville Tribes	N
	4. Refer the matter to the IJC through the Canadian Government	N
	5. Carry out remedial investigation under US legislation	N
Colville Tribes (CT)	6. Take legal action to force Teck Cominco to follow the Superfund law	Y
	7. Negotiate with Teck Cominco	N
EPA	8. Negotiate with Teck Cominco	N
	9. Carry out own study and then charge the cost to Teck Cominco	Y
	10. Refer the matter to the IJC through the US Government	N
	11. Levy lawsuits in Canada	N

Teck Cominco

As one of the largest smelting mining operators in the world, TC has been processing ore near the banks of the Columbia River, close to the US border for a long time (Roberts 2006). After EPA judged TC to be the main contributor to the contamination of Lake Roosevelt by discharging slag, disputes with TC were invoked by Native American groups and EPA with regards to pollution investigation and compensation. With respect to these disputes, TC is assessed to have five possible options or courses of action. The first is to negotiate with EPA, aiming to reach a settlement agreement to solve the dispute. The second option is to initiate counter-lawsuits in the US against CT's legal action. The third option is to find a way to negotiate with CT. The fourth is to refer the matter to the International Joint Commission (IJC) through the Canadian Government, and the last option is to carry out a remedial investigation under US legislation.

The Colville Tribes

The CT are Native American communities living in the Lake Roosevelt area. Because of concerns that the contamination in the lake would greatly affect the health of their children, their community, and their environment, CT took a steadfast position against TC. This DM has two main options. The first is to take legal action to force TC to conduct remedial investigation under the Superfund law. The second is to negotiate with TC about related environmental study, remediation and compensation.

United States Environmental Protection Agency

The USEPA was founded in July 1970. Its mandates are environmental conservation and policy making, leading to a cleaner and healthier environment for people living in the US (USEPA 2010). EPA became involved in this contamination conflict due to the request from CT. According to our background review, EPA has five options in the Lake Roosevelt conflict. The first is to force TC to follow the Superfund law. The second is to negotiate with TC to reach a settlement agreement. The third is to carry out its own study and then recover the cost of the study from TC through legal action. The fourth is to refer the matter to the IJC through the US Government, and the last option is to levy lawsuits in Canada.

Modeling the Lake Roosevelt conflict using GMCR II®

In this section, the analysis of the Lake Roosevelt conflict is carried out using the decision support system GMCR II®. A description of how the Lake Roosevelt conflict was modeled and analyzed is reflected below.

Input of DMs and options

The three main DMs and eleven options in the Lake Roosevelt conflict mentioned in the previous section are as shown in Table 2. This information constitutes the input for GMCR II®'s dialog box for entering DMs and options.

Status quo state

The status quo state is the state of the conflict at the time for which a conflict study is executed. For the Lake Roosevelt dispute, the status quo state is represented by a column of Y's and N's, as shown on the right in Table 2, where the combination of each DM's options is called the DM's strategy. For example, the DM, CT, selects the option "take legal action to force TC to follow the Superfund law" (indicated by "Y" for "yes," the option is taken) and rejects the option "negotiate with Teck Cominco" (as denoted by "N" for "no," the option is not chosen) in order to form its strategy. After all DMs have selected their strategies, a state is created. The status quo state indicates that CT took legal action to force TC to follow the US legislation. TC levied lawsuits in the US against CT's legal action. EPA, as one of the major

Table 3. Teck Cominco's preference statements.

Descriptions	Preference Statements
Do not carry out remedial investigation under US legislation	−5
Negotiate with EPA and EPA is willing to negotiate with TC as well	1 & 8
Levy lawsuits in the US only if CT takes legal action to force TC to follow the Superfund law	2 IFF 6
Both TC and CT want to negotiate with each other	3 & 7
Request the Canadian Federal Government to refer the matter to the IJC	4

opponents, chose to carry out its own study and then to charge the cost to TC.

Removing infeasible states

In many conflicts, the number of mathematically possible states may be large. However, many of them are infeasible and, hence, should be safely removed to simplify the analysis process. There are a number of possible types of infeasible states to remove from the overall conflict. The safest and easiest states to identify for removal are those that are mutually exclusive. For example, for TC, it is impossible to choose to negotiate with EPA, to refer the matter to the IJC through the Canadian Government and to carry out remedial investigation under US legislation simultaneously. Therefore, no more than one option could be selected from options 1, 4, and 5 at the same time. Similar mutually exclusive options exist for options 2, 3, and 5; as well as options 3, 4, and 5. "At Least One" indicates that for a list of options, at least one option must be taken. Here, options under the control of all DMs fall into this category. For example, a status quo state would become meaningless if EPA did not respond to the slag contamination from TC. Likewise, TC would not dismiss all of its options. After removing infeasible states, the number of states is reduced from 2^{11} or 2048 (reflecting the 11 options available to all DMs that can be either taken or not) to 64.

Ranking of states

Before performing a stability analysis, the feasible states have to be ordered from most to least preferred for each DM, with ties permitted. GMCR II® offers two approaches for ranking. They are option weighting and option prioritization. "option weighting" assigns a numerical weight to each option from the perspective of a specified DM, where a larger positive weight means that an option is more preferred and a negative sign indicates less preferred. "option prioritization", on the other hand, expresses the preference in a hierarchical fashion and is used in our analysis. Different from "option weighting", "option prioritization" specifies preference statements regarding option selections from most to least important, irrespective of how much the truth of one preference statement is preferred to the truth of the rest. Both conditional ("IF" and "IFF") and unconditional preference statements are available. Moreover, the operators "not", "and" and "or", denoted by "-", "&" and "|", respectively, are permitted. To simplify the recording of preference information, a DM's preference statements can be written in terms of the option numbers specified in Table 2.

Table 3 shows the preference statement for TC. A statement of higher priority or importance in determining preferences appears higher in the list. Specifically, for TC, its highest priority is to carry out remedial investigation without following the US legislation (-5 means do not choose option 5). Next, TC wishes that both TC and EPA are willing to negotiate with each other (1 & 8). Following this, TC would prefer to levy lawsuits in the

Table 4. The Colville Tribes' preference statements.

Descriptions	Preference Statements
Teck Cominco carries out remedial investigation under US legislation	5
Take legal action to force TC to follow the US legislation and EPA carries out own study and then charges the cost to TC later if TC refuses to carry out remedial investigation under US legislation	(6 & 9) IF -5
Negotiate with Teck Cominco and TC willing to negotiate as well	3 & 7
Both Teck Cominco and EPA want to negotiate with each other	1 & 8
TC does not levy lawsuits in US	−2

Table 5. Environmental Protection Agency's preference statements.

Descriptions	Preference Statements
TC carries out remedial investigation under US legislation	5
Negotiate with TC	1 & 8
Carry out own study and then charge the cost to TC if EPA fails to negotiate with TC	9 IF −8
EPA will choose to refer the matter to IJC or levy lawsuits in Canada with equal preference by considering them as the other aggressive actions	10|11

United States if and only if CT takes legal action to force TC to follow US legislation (2 IFF 6). TC would next choose that both TC and CT negotiate with each other (3 & 7). Finally, TC would prefer to request the Canadian Government to refer the matter to the IJC (4). Following a similar approach, the preference statements for CT and EPA can be obtained, as shown in Tables 4 and 5, respectively. The details are discussed below.

As indicated in Table 4, CT would most prefer that TC carries out remedial investigation under the US legislation (option 5). Next, they would prefer to take legal action to force TC to follow the Superfund law, and that EPA carries out its own study and then charges the cost to TC later if TC does not carry out a remedial investigation under the US legislation ((6 & 9) if -5). CT would next wish that both TC and CT negotiate with each other (3 & 7). Following this, CT would prefer that both TC and EPA negotiate with each other (1 & 8). The last preference statement for CT is that TC does not levy lawsuits in the US against its legal action (-2).

As can be seen in Table 5, EPA would most prefer that TC carries out remedial investigation under the US legislation (option 5). Next, it would prefer to negotiate with TC (1 & 8). If negotiation with TC failed, EPA would prefer to carry out its own study and then charge the cost to TC (9 if -8). Lastly, EPA would choose to refer the matter to IJC or to levy lawsuits in Canada with equal preference (10|11).

Assuming transitivity of preferences when applying GMCR II, all feasible states can be ordered from the most to the least preferred for any given DM based on its preference statements, where ties are allowed. Table 6 shows an example of a state list after preference ranking for TC. Only the first 11 feasible states are shown in option form due to the space limitation. A horizontal bracket above a set of states indicates that the states under the bracket are equally preferred. For example, States 9 and 3 are equally preferred for TC. To explain how the states are ordered in Table 6, one must examine the preference statements in Table 3. Because the highest preference statement in Table 3 for TC is -5, all states shown in Table 6 have N's opposite this option. The next preferred preference statement is 1 & 8. Therefore, States 13, 9, 3, 1, 11, and 5, which have a Y opposite option 1 and a Y beside option 8, are more preferred than the other states in Table 6, which have an N beside either option 1 or option 8. The statement 2 IFF 6 further separates the left 6 states into two groups ("13, 9, 3" and "1, 11, 5"), where the states in the higher priority group have either Y's or N's on both options 2 and 6. The next statement, 3 & 7, makes State 13 have the highest priority with a Y beside options 3 and 7. One can review the other preference statements in Table 3 to see how they affect the ranking of states in Table 6.

Table 6. Ranking of states for Teck Cominco in the Lake Roosevelt conflict.

DMs	Options	States										
		13	9	3	1	11	5	60	44	61	45	29
Teck Cominco (TC)	1. Negotiate with EPA	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y
	2. Initiate counter-lawsuits in US against CT's legal action	N	N	Y	N	Y	N	N	N	N	N	N
	3. Negotiate with Colville Tribes	Y	N	N	N	N	Y	Y	Y	Y	Y	Y
	4. Refer the matter to the IJC through the Canadian Government	N	N	N	N	N	N	N	N	N	N	N
	5. Carry out remedial investigation under US legislation	N	N	N	N	N	N	N	N	N	N	N
Colville Tribes (CT)	6. Take legal action to force TC to follow the Superfund law	N	N	Y	Y	N	Y	N	N	N	N	N
	7. Negotiate with Teck Cominco	Y	Y	N	N	Y	N	Y	Y	Y	Y	Y
EPA	8. Negotiate with Teck Cominco	Y	Y	Y	Y	Y	Y	N	N	N	N	N
	9. Carry out own study and then charge the cost to TC	N	N	N	N	N	N	N	N	N	N	Y
	10. Refer the matter to the IJC through the US Government	N	N	N	N	N	N	N	Y	N	Y	N
	11. Levy lawsuits in Canada	N	N	N	N	N	N	Y	N	Y	N	N

Table 7. Strong equilibria.

Decision Makers (DMs)	Options	States		
		3	13	23
Teck Cominco (TC)	1. Negotiate with EPA	Y	Y	N
	2. Initiate counter-lawsuits in the US against CT's legal action	Y	N	Y
	3. Negotiate with Colville Tribes	N	Y	N
	4. Refer the matter to the IJC through the Canadian Government	N	N	Y
	5. Carry out remedial investigation under US legislation	N	N	N
Colville Tribes (CT)	6. Take legal action to force TC to follow the Superfund law	Y	N	Y
	7. Negotiate with Teck Cominco	N	Y	N
EPA	8. Negotiate with Teck Cominco	Y	Y	N
	9. Carry out own study and then charge the cost to TC	N	N	Y
	10. Refer the matter to the IJC through the US Government	N	N	N
	11. Levy lawsuits in Canada	N	N	N

Table 8. Evolution of the conflict from the status quo to a final equilibrium.

DMs	Options	Status Quo State		Transitional State		Final Equilibrium
Teck Cominco	1. Negotiate with EPA	N	→	Y		Y
	2. Initiate counter-lawsuits in the US against CT's legal action	Y		Y		Y
	3. Negotiate with Colville Tribes	N		N		N
	4. Refer the matter to the IJC through the Canadian Government	N		N		N
	5. Carry out remedial investigation under US legislation	N		N		N
Colville Tribes	6. Take legal action to force TC to follow the Superfund law	Y		Y		Y
	7. Negotiate with Teck Cominco	N		N		N
EPA	8. Negotiate with Teck Cominco	N		N	→	Y
	9. Carry out own study and then charge the cost to TC	Y		Y		N
	10. Refer the matter to the IJC through the US Government	N		N		N
	11. Levy lawsuits in Canada	N		N		N

Stability analysis and output interpretation

In this section, a stability analysis of the established conflict model is conducted using GMCR II®. The feasible states for each DM are analyzed by checking their stability based on solution concepts listed in Table 1. In analysis, reversible unilateral moves in each step are assumed for every DM.

The analytical results indicate that there were a total of 21 equilibria for this conflict model according to at least one solution concept from Table 1. Only three of these, however, are strong equilibria, in the sense that they are equilibria according to all of the solution concepts given in Table 1. Table 7 lists these three strong equilibria. The strong equilibria provide insights into the possible resolutions to the Lake Roosevelt dispute. Each equilibrium is described separately below.

Equilibrium 3 indicates that TC and EPA will negotiate with each other to reach a settlement agreement, while TC and CT will continue to be in dispute with each other through levying lawsuits. The evolution of the conflict from the status quo state via a transitional state to state 3 is shown in Table 8. In this table, an arrow indicates a change in an option choice as the conflict evolves from the status quo state on the left to an intermediate state in the center and finally to a strong equilibrium on the right. As can be seen, TC causes the conflict to move to an intermediate state by offering to negotiate with EPA. Subsequently, EPA moves the conflict to a strong equilibrium by accepting TC's offer of negotiation. In reality, in 2006, TC and EPA reached an agreement that defined a long-standing commitment by TC to a contamination investigation and over $1 million compensation to CT, Washington State and the Department of the Interior (Teck Cominco 2006). The analytical results from this study closely reflect the final agreement that was actually reached.

Equilibrium 13 indicates another possible solution such that TC will reach agreements with both CT and EPA. By recognizing that the conflict between TC and CT is ongoing, equilibrium 13 provides a potential solution in the future to completely solve the Lake Roosevelt conflict.

Equilibrium 23 is an aggressive solution to the conflict under consideration. According to this equilibrium, TC levies a lawsuit and refers the matter to the IJC through the Canadian Government to counterattack the legal action from CT and the unilateral study carried out by EPA, respectively. Because of its aggressive nature, in practice, DMs may refrain from causing the conflict to evolve to this state.

Conclusions

In this paper, the Lake Roosevelt conflict was analyzed using the Graph Model for Conflict Resolution. A comprehensive stability analysis was carried out. One of the analysis outcomes (equilibrium 3) reflected what ultimately took place in 2006. The results also indicated that negotiation among TC, CT, and EPA may be the only potential solution for the Lake Roosevelt conflict (equilibrium 13). Moreover, the study showed that one of the major reasons for the lengthy dispute is the absence of a mutually agreed upon policy with sufficient enforcement for managing transboundary environmental issues. This latter observation further highlights the importance of strictly enforcing existing or establishing new water-related policies in order to resolve the current conflicts and to avoid any future controversies (Ma et al. 2008). Other factors, such as “cross-border management of environmental issues and assets”, “inter-state relationships”, “international legal responsibilities and jurisdictions”, “extraterritoriality”, and “sovereignty” suggested by Roberts (2006), should also be taken into account in the management of border relations.

GMCR II® is a flexible and efficient decision support system for analytically investigating strategic disputes. Because of the inevitable conflicts in the area of water resource management, GMCR II can help to provide significant insights that can assist DMs in taking steps towards more favorable results and to help mitigate or even avoid conflicts among DMs regarding natural resources.

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