International Water Resources Association
Water International, Volume 28, Number 4, Pages 454–466, December 2003

Computer Support for Implementation of a Systemic Approach to Water Conflict Resolution

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***Abstract**: Water is an important factor in conflicts among stakeholders at the local, regional, and even international level. Water conflicts have taken many forms, but they almost always arise from the fact that the freshwater resources of the world are not partitioned to match the political borders, nor are they evenly distributed in space and time. Two or more countries share the watersheds of 261 major rivers and nearly half of the land area of the world is in international river basins. Water has been used as a military and political goal. Water has been a weapon of war, and water systems have been targets during the war. A systemic approach has been taken in this research to approach resolution of conflicts over water. By helping stakeholders to explore and resolve the underlying structural causes of conflict our approach offers a significant opportunity for its resolution. We define the five main functional activities for assisting the conflict resolution process as: (i) communication; (ii) problem formulation; (iii) data gathering and information generation; (iv) information sharing; and (v) evaluation of consequences. A computerized technical support is developed in the form of the Conflict Resolution Support System (CRSS) for implementation of a systemic approach to water conflicts. Its principal components include an artificial intelligence-based communication system, a database management system, and a model base management system. At this stage of the development, the model base management system consists of tools for multipurpose reservoir operation, river flow routing, multi-criteria decision-making, spatial data analysis, and other general utilities. A hypothetical river basin with potential conflict between stakeholders with respect to water sharing and flood control is used to demonstrate the utility of the new approach and the computer system developed for its implementation.*

***Keywords**: water conflict, systemic approach; decision support system; computer support.*

Introduction

Water is a unique resource, playing a role in all ecological and societal activities including food and energy production, transportation, waste disposal, industrial production, and human health. On the other side, water resources are not evenly distributed in space and time. The debate is still going on whether these characteristics of the water resource are the source of violent conflicts or motivations for collaboration (Wolf, 1998). History shows and future may confirm that water has a strategic role in conflicts among different stakeholders (Gleick, 1993).

Nature of Conflicts over Water

Contemporary water resources management is a combined process of sharing water and resolving conflicts among stakeholders. Stakeholder in this context refers to an individual organization or institution that has a stake in the outcome of decisions related to water sharing, because the stakeholder is either directly affected by the decision or has the power to influence or block the decision.

Water resources management is a complex process because of numerous uncertainties associated with the physical processes, available data, and level of our knowledge. Though water is a renewable resource, its availability in a particular locality and point of time cannot be accurately predicted in advance. This is the very reason that conflicting scenarios arise among stakeholders in sharing water and protecting their interests. In the case of water shortage, water managers face the problem of dividing the available water among the stakeholders; whereas during a flooding condition, the problem of protecting the property of stakeholders is expected. Power differences between the stakeholders and their internal bureaucracies can also lead to complication of water conflicts.

When the river basin traverses multiple legal, political, and international boundaries, the number of potential

stakeholders and their specific interests increases, making the conflict resolution process rather complicated (Wolf, 1998).

Sources of Water Conflicts

Most environmental conflicts, including those that are water related, spring from three sources (White, 1986): (i) an actual or prospective human intervention in the environment, which provokes changes in natural and societal systems. The conflict arises when one or more of the stakeholder groups see the activity as disturbing the complex interaction between physical, biological, and social processes; (ii) a disagreement over the management of water supply at one location as it affects the use of it elsewhere; and (iii) when climatic variability and change independent of any human activity places new stresses on the water resources and generates fresh adaptations to available resources.

Use of water resources always involves an interaction between human users and the soil, water, air, and organisms of the place. Each is modified to different degree so as to destroy the resource or the people. Two or more systems interact, which motivates the application of the systemic approach to conflict resolution that is proposed here.

Our focus in this paper is on the first source of water conflict. In a river basin that traverses an international boarder, a political regional boundary, or a general boundary of different jurisdiction, the basis of a conflict is the implementation of developments by a concerned stakeholder within its territory. Such implementation impacts at least one of its neighbors during water shortage conditions and usually leads to a number of water conflicts. The key indicators or the water conflicts are related to a number of issues including water quantity, water quality, management of multiple use, political divisions, geopolitical setting, the level of national development, the hydro-political issues at stake, and institutional control of water resources (Wolf, 1998).

Water quantity becomes an issue of conflict when the demand and supply approach each other. Greater upstream use and long-run changes in supply or demand could be the causes for water quantity related conflicts. On the other hand, water quality related conflicts might erupt due to new sources of pollution resulting from extensive agriculture development in the upstream. Return flows from agricultural, industrial, and urban activities may also cause dissatisfaction among the downstream users and may end up in a conflict. In a large river basin, water is generally managed for multiple uses such as power generation, food production, industrial development, municipal water supply, recreation, or a combination of these. Different user groups having different objectives may have conflicts in arriving at a common schedule of quantity and time of water distribution (Yoffe and Ward, 1999).

Past history in different regions of the world indicates that shifting of political boundaries, which demarcate new riparian areas in the international river basins, has induced water conflicts. Wolf (1998) cites examples of conflicts in water bodies that became international when the British Empire dissipated in many countries. Geopolitical setting is another issue where the relative power and riparian position of a group play an important role. A group occupying the upstream area of a basin or that has more political power has more control over the others in implementing development projects (Lowi, 1993). The level of national development may be an indictor of potential water conflict in an international river basin. More developed nations may have better options for alternate sources of water and may be less demanding over a conflict with a neighboring less developed nation. Mandel (1992) relates the intensity of a water conflict with the hydro-political issue at stake. Water conflicts resulting from human-initiated developments such as dams and diversions are found to be more severe than those resulting from natural events like floods, droughts etc.

Approaches to Conflict Resolution

The conflict resolution process has been approached by many disciplines such as law, economics, engineering, political economy, geography, and systems theory. An excellent source of selected disciplinary approaches is available in Wolf (2002).

We will confront traditional versus systemic approaches to conflict. Traditional conflict resolution approaches such as the judicial systems, state legislatures, commissions, and similar governmental systems provide resolutions in which one party gains at the expense of the other. This is referred to as the "zero–sum" or "distributive" solution. In water and environmental conflict resolution, a negotiation process referred to as the Alternative Dispute Resolution (ADR) is adopted. ADR refers to "a wide variety of consensual approaches with which parties in conflict voluntarily seek a mutually acceptable settlement." ADR generally seeks to move parties from "zero-sum" solutions towards those in which all the parties gain, which are referred to as "positive-sum" or "integrative" solutions (Bingham et al., 1994). Negotiation, collaboration, and consensus building are the key issues that facilitate ADR.

Prior to the negotiation, the pre-negotiation process is initiated by a person, the convener, who has sufficient authority and stature to capture the attention of stakeholders. The convener may contract a third party to conduct a preliminary review of the conflict. Review of this type reveals the background information on the conflict and identifies the stakeholders (Carpenter and Kennedy, 1988). If the preliminary review indicates that the negotiation process holds potential promise for improving the situation, the third party will conduct a conflict analysis (Moore, 1986; Schwarz, 1994). This activity composes a combination of data and personal interviews with parties concerned. The third party then designs an appropriate intervention strategy for bringing the stakeholders involved to the negotiation table. At this stage, the third party is referred to as

mediator or facilitator. During the negotiation process, the parties must exchange information and share technical details. They should listen to other parties and the mediator. Above all, they should agree on creative options to seek mutually beneficial outcomes (Moore, 1986; Rothman, 1997).

A new, systemic approach is proposed in the present study to assist the conflict resolution process. It uses the disciplines of systems thinking and mental models to provide powerful alternative to traditional approaches to conflict resolution, which often rely too much on outside mediation. By helping stakeholders explore and resolve the underlying structural causes of conflict, a systemic approach can transform problems into significant opportunities for all parties involved. A systemic approach to conflict resolution has been explored in the management science (Cobble and Huffman, 1999). Some elements of the systemic approach have been present in the work of Bender and Simonovic (1995) and Simonovic and Bender (1996) that proposes collaboration and collaborative process with active involvement of stakeholders that agree to work together to identify problems, share information, and, where possible, develop mutually acceptable solutions. Consensus building processes constitute a form of collaboration that explicitly includes the goal of reaching a consensus agreement on water conflicts. The indigenous approaches to water conflict reduction (Wolf, 2000) are also related to a systemic approach. Such methods include: (a) allocating time, not water; (b) prioritizing different demand sectors; (c) protecting downstream and minority rights; (d) ADR; and (e) practicing the ritual ceremony of forgiveness.

The Role of Computer-Based Support in Conflict Resolution

At certain stage of conflict resolution, alternatives and proposals specific to stakeholders in conflict are analyzed for their technical feasibility and economic viability. Such analyses in water-based conflicts include, among others, processing of vast amount of hydrological and geophysical data, describing system structure, identifying system states by routing of natural and scheduled flows, mapping and graphing system operational strategies, and optimization and multi-criteria analyses of system components and operations. Therefore, a decision support tool that could assist the stakeholders with different technical aspects is vital for the success of a water conflict resolution process. Quite often, the stakeholders have limited or no technical knowledge relevant to water resources management. As a result, in a conflicting situation they generally stay firmly behind their positions irrespective of the technical difficulties associated with satisfying their criteria. It has been shown in the literature that in complex situations of this nature, the availability of computer-based support systems that could convey the technical information to stakeholders in an understandable form is one of the pre-conditions for finding mutually acceptable and sustainable resource management solutions (Simonovic, 1996).

The use of computer-based support systems is the recent development in water conflict resolution (Raiffa, 1982). It is often a challenge, for everyone involved, to handle the complex nature of water conflict on the regional or international scale. Such a complexity led the researchers around the world to develop computer-based decision support systems (DSS) that can provide considerable assistance in determining temporal and spatial distribution of water quantity and quality. Progress in computer software development and its implementation in water resources (Antrim, 1986; Fraser and Hipel, 1986; Anson et al., 1987; Jones, 1988; Kersten, 1988; Anson and Jelassi, 1990; Foroughi and Jelassi, 1990; Meister and Fraser, 1992; Fang et al., 1993; Bender and Simonovic, 1995) provide different kind of negotiation assistance medium. Such tools are also referred to as Negotiation Support Systems. The basis for all these systems is group decision-making process (Lewis, 1993), which assists in solving disagreements among various stakeholders. Lund and Palmer (1997) presented a detailed overview of computer-based modeling for water resources conflict resolution. It is indicated in this presentation that conflict resolution, as a planning approach, is to be dealt with by models that comprehend scientific understanding of the system so that promising alternatives can be developed for negotiation. Shared vision modeling (a common development of a single model by a diverse group of stakeholders) is introduced as the new approach that allows all that are impacted by water resources decisions that result from the model to be part of the model development.

Other water resources related decision support systems (Davis et al., 1991; Ford and Killen, 1995; Andreau et al., 1996; Reitsma, 1996; Dunn et al., 1996; Jamieson and Fedra, 1996; Arumugam and Mohan, 1997; Fredericks et al., 1998; Ito et al., 2001) with one or more tools for the analyses of water quantity and quality distribution, and flood and environmental management, are also helpful in water conflict resolution. The Water Allocation System (WAS), developed at MIT, supports stakeholder participation in the analyses of regional water allocation in a social and economic context.

Simonovic (1996) defines a computerized decision support system as "a tool that allows decision-makers to combine personal judgment with computer output, in a user-machine interface, to produce meaningful information for support in a decision-making process." Such systems are capable of assisting in solution of all problems using information available on request. They use quantitative models and database elements for problem solving. They are an integral part of decision-maker's approach to problem identification and solution. A decision support system for application in water resources management has the following characteristics: accessibility, flexibility, facilitation, learning, interaction and ease of use. Water resources problems are generally ill structured, lack data, associated with

uncertainties, and include non-quantifiable variables (Landry et al., 1985).

A computerized decision support system should also have facilities for data management, data analyses and interaction (Bender and Simonovic, 1995). Such facilities are vital for problem identification, problem solving, and analysis of a decision consequences. Data management functions may vary from simple statistical computation to the ability of calling up optimization and simulation models.

Presentation of data and results in a form that is easily recognized by the stakeholders is important. Participants' interaction in the process of evaluating alternative options and analyzing the impacts is regarded as another important step in conflict resolution. Communication tools based on the natural language processing and artificial intelligence provide the support for interaction between the stakeholders during a conflict resolution process.

The next section of the paper introduces a systemic approach for conflict resolution. The discussion continues with the presentation of the conflict resolution support system and details of its architecture. The paper ends with the description of the hypothetical water conflict case study. The utility of a new approach and the computer-based tool are shown in the conclusions.

A Systemic Approach to Conflict Resolution

A human action disturbs a water system so that the interactions between physical, biological, and/or social components are altered. This provokes some impact in the related systems. Usually, after trading off all impacts, those affected make an explicit or implicit judgment so that the net effect is either advantageous or disadvantageous to them. If those having rights in the area feel they may be damaged, the conflict takes shape (White, 1986).

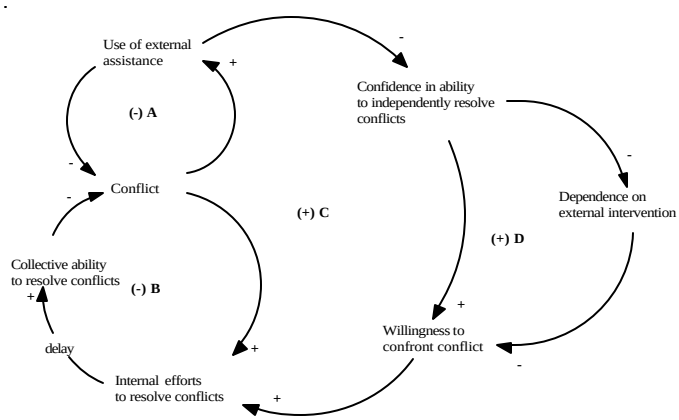
A systemic approach has at least three roles in illuminating grounds on which water conflict resolution may proceed. First, scientific investigation defines the systems that are affected, their structure (components), indicating where there is an established or assumed relationship among the various components. Definition of the system structure is fundamental because often conflicts arise where it has been assumed that the impacts were less-reaching than demonstrated in practice. Second, a systemic approach helps describe the characteristics of the various components, including the physical systems, the ecosystems, affected social groups, and organizations with their preferences and modes of action. To identify the components is to deal with their interactions as they are established. Third, a systemic approach offers means of estimating the significance of impacts not only in terms of physical quantities, but also in terms of the way in which they are perceived by the people and organizations affected.

The difference between traditional and proposed systemic approach to conflict resolution is shown in Table 1. A systemic approach is proposed as a powerful tool for deep inquiry and development of the dialogue among stakeholders. Active participation of stakeholders and development of their skills to deal with conflicting situations is the driving force of a systemic approach.

Table 1. Traditional versus systems approaches to conflict

	Traditional approach	*Systemic approach*
Intention	Conflict resolution	Conflict resolution skill building
Time horizon	Short term	Long term
Point of application	After conflict becomes extreme	Before conflict becomes extreme
Stakeholder response	Defend position	Become reflective and open
Focus	Individual adversaries	System
Processing of complexity	Polarization	Powerful dialogue
Responsibility for conflict	Blaming of others	Own role in conflict

Systemic approach advantages are identified in Figure 1 using the systems language of causal diagrams. Negative (balancing) feedback loop A shows that relying on outside assistance, like hiring an outside mediator for example, to respond to conflict may serve parties involved in the short term. However, over the long term, it reduces stakeholders' confidence in their own ability to resolve problems and willingness to confront conflicting situation as shown by the positive feedback C. Another unintended consequence is a rise in the stakeholders dependence on external intervention, further decreasing their comfort with handling conflicting situations as indicated by the positive feedback D. Proposed approach offers a solution through building the stakeholders conflict resolution skills (negative feedback B).



Legend: (-) negative (balancing) feedback; (+) positive (reinforcing) feedback; + a casual link between two variables where a change in one causes a change in the other in the same direction (one adds to another); - a casual link between two variables where a change in one causes a change in the other in the opposite direction (one subtracts from another).

Figure 1. Advantages of a systemic approach to conflict resolution (modified after Cobble and Huffman, 1999)

Conflict resolution process

A systemic approach application requires four steps that can be implemented with or without the facilitator.

Step 1. The main purpose of the first step is to create the space and the intention between stakeholders to address a conflict. This can be achieved by encouraging participants to explore the source of conflict. Stakeholders should identify critical issues, actions, and the thinking that led to the conflicting situation. Exploration of what solutions are working and what aren't will precede the development of a hypothesis about why. Work should occur in a meeting to increase stakeholders' capacity to learn and work together. At the end of this step stakeholders should identify actions that might have caused problems for others.

Step 2. The objective of the step two is to build shared understanding of the conflict through inquiry and the creation of a systems map. Causal diagrams like one in Figure 1 may be of help. It is important to look for places of disagreement in diagram.

Step 3. At this stage, building of dialogue skills should occur so participants can directly address sources of conflict and understand their own role in it. During this process a shift should occur from general problem structure to "hot spots."

Step 4. The final step involves creating an action plan for developing and implementing alternative solutions and new ways to work and interact. Participants are expected to make agreements for trying new solutions and behaviors.

Generalized steps in each practical case will require major technical assistance. The following section presents a computer-based tool designed to illustrate the support for this process.

Computer-Based Conflict Resolution Support System (CRSS)

Conflict resolution is regarded as an iterative process, which converges to an acceptable resolution to the parties involved. Support for the four-step process presented in the previous section is provided in the form of five functional activities: (i) communication support; (ii) problem formulation; (iii) data gathering and information generation; (iv) information sharing; and (v) evaluation of consequences. These activities are repeated in sequence, until the parties involved accept a resolution that provides an acceptable compromise for all. These five functionalities are incorporated in a computer-based conflict resolution support system (CRSS) that facilitates the resolution process.

Communication Support

Communication between stakeholders leading to an acceptable resolution is the paradigm for the conflict resolution process. However, when the process is carried out in the computer-assisted environment, it encompasses a much broader scope. In the context of the CRSS implementation, communication between the stakeholders and a computer system provides the facilities and various tools available in the computerized form that are required for the resolution process. Through the human-machine communication, a conflict problem can be formulated, various data accessed and analyzed, alternative solutions generated, and their impacts evaluated. Communication with the CRSS using natural language is implemented, enabling the stakeholders to interact with the system directly with little or no help from a technical interpreter. This approach of communication support is different from the traditional expert systems in which the communication facilities are confined to a pre-defined set of dialogs that assist the user to access the tools provided in the system.

Integration of Artificial Intelligence (AI) technology in the CRSS makes the communication as close as possible to the communication between humans. Literature documents application of different AI components with varying types of intelligence in the development of computerized support systems. Typical cases include systems with knowledge base and learning (Maes, 1994), systems using memory based reasoning (Lashkari et al., 1994), and the use of advanced genetic algorithms (Oliver, 1996). AI based communication is closely associated with Natural Language Processing (NLP) in which a human-initiated sentence is processed to a machine-readable form, and a machine-generated sentence is converted into human-readable form. NLP incorporates different search algorithms, heuristic methods, and knowledge representation techniques to understand and generate sentences (Conlon et al., 1993).

Problem Formulation

The problem formulation, or refinement, step in the conflict resolution process determines how effectively the process will lead to an acceptable resolution. In general, stakeholders describe the problem in plain language. There is always a gap between such a description and the technical or analytical form of the problem presentation. When a computer-based tool is deployed for assisting the conflict resolution process, it is important that the problem is expressed in the analytical form. This formulation is required in order to use all the facilities and tools available for effective solution of the conflict. Availability of data is another important issue to be considered in problem formulation. A complex mathematical formulation of the problem at hand with insufficient data is not considered to be an acceptable form of support. However, a poor formulation with adequate data will not be an appropriate form of support either.

Water quantity-related conflicts between the upstream and downstream stakeholders or stakeholders sharing a common water resource from different jurisdictions originate from either water shortage (draught) or water ex-

cess (flood). The conflict caused by the water shortage generally results in the problem of how to share the scarce resource among various users. Such a problem could be mathematically formulated as a water allocation model with varying priority levels assigned to different stakeholders. Every stakeholder has the objective of maximizing his benefits, whatever the alternative resolution is implemented. Hence the water allocation model could be coupled with a multi-objective decision model to arrive at a compromise solution. The conflict caused by excess of water results in the implementation of different protection measures and equitable distribution of potential damages. This problem, for example, could be addressed through the implementation of a flood routing model with wide variety of alternative flood control measures. In this case too, the stakeholders tend to maximize their own benefits (maximize reduction of potential flood damage in their area), and therefore, a multi-objective decision model becomes helpful in searching for a compromise resolution of the conflict.

Problem refinement is important when an initial formulation does not yield an acceptable conflict resolution. Such situations may arise due to an inadequate formulation of the problem, insufficient data, or misinterpretation of results. Alternatively, when the stakeholders strictly adhere to their positions, there is a chance that the resolution becomes unacceptable and requires refinement. Refinement in terms of adopting more detailed temporal and spatial scale improves the quality of results but requires intensive data processing algorithms and more data.

If there is not a transparent and clear presentation of results to the stakeholders, then this may lead to a request for problem refinement. Poor presentation of good results may not be comprehended correctly by the stakeholders, and a resolution of the conflict based on such (mis)understanding may become unacceptable. Situations like these require problem refinement and repetition of the whole resolution process.

Data gathering and information generation

Data is the core element of any decision-making situation. Accurate and timely data can be processed to provide the necessary information for the support of conflict resolution process. In general, the stakeholders are not fully aware of the quantity and quality of data that is needed to analyze a problem. Data for water-related conflict resolution might vary from a single value to multiple-year time series or very large matrices of geographical data. When dealing with large quantities of data, it is important to deploy database management tools for efficient storage and manipulation of data.

Errors, uncertain values, and missing values in water resources data (rainfall, for example) are very common because of date collection difficulties and inaccessibility of gauging stations during the severe weather conditions. Therefore, data should be analyzed for its integrity and completeness. Missing values could be filled up using appropriate hydro-statistical methods and extension of data should be carried out using forecast simulation models. Hence, provision of appropriate hydro-statistical computational tools is necessary for computer-based support systems. Models that can carry out operations such as reservoir routing or flood plain routing are required for generating specific information. Optimization facilities are required for evaluation of alternatives with respect to specific objectives of the stakeholders. Geographic data in the forms of rasterized or vectorized maps are common in water resources management. Appropriate map displays and analyses tools are required to handle spatial data.

Information Sharing

Model-generated information based on solid data needs to be further processed in order to share it between the stakeholders. Existence of multiple objectives specific to the stakeholders and a set of distinct alternatives call for an appropriate analysis technique such as the Compromise Programming that ranks the alternatives according to the preferences of different stakeholders (Zeleny, 1983). The alternative that receives the best rank should be considered with a high priority for the resolution of conflict. The preferences in multi-criteria decision making play an important role in specifying each stakeholder's position in relation to the other stakeholders.

Evaluation of Consequences

Any resolution that results from a conflict is a new proposal to be considered. Consideration of the potential long- and short-term impacts that this new proposal brings to the water resources system is required. Over an appropriate time horizon, these impacts should be analyzed both in economic and technical terms. Stakeholders, while being interested in resolving a current conflict, are also concerned about the potential future impacts.

CRSS Architecture

The present demonstration version of CRSS consists of an Artificial Intelligent Communication System (AICS), a Database Management System (DBMS), and a Model Base Management System (MBMS). The entry point to CRSS is AICS, where a communication begins by opening access to other facilities of the system. Driven by an AI component, AICS connects the database through the DBMS and interacts with the MBMS modules appropriately. Moreover, data exchange between the MBMS modules and the database is carried out efficiently through the AICS. The MBMS modules incorporated in CRSS are: (a) Multi-Criteria Decision Making (MCDM), (b) Map Viewer and Analyzer, (c) Statistical Tools, (d) Reservoir Router, (e) River Flow Router, (f) Image Viewer, and (g) Table Viewer. CRSS is flexible to accommodate additional specific modules that are required to analyze a realistic system. However, application of the present version of

CRSS for a typical conflict resolution case where water allocation from a reservoir and flood control in a river basin is considered in this paper. Therefore modules such as Reservoir Router and River Flow Router are included in addition to the general utility modules. The MCDM module is considered to be the most required one to arrive at a compromise solution in any potential conflict resolution case. The modules have been developed in such a way that exchange of data in the forms of text, table, and pictures among them and the commercially available software is possible through simple operations of copy and paste. Figure 2 shows the structure of CRSS.

MCDM Module

Multi-Criteria Decision Making (MCDM) is carried out using the method of Compromise Programming in which the alternatives are ranked based on their proximity to an ideal solution. Provided a scenario has *n* different criteria that are to be evaluated against *m* alternatives, the proximity of alternative solutions to the ideal one is determined using a distance metric as follows

$$L_j = \left[\sum_{i=1}^{n} \alpha_i^p \left| \frac{f_i^* - f_{i,j}}{f_i^* - f_{i,w}} \right|^p \right]^{1/p} \tag{1}$$

where L_j is the distance metric computed for alternative j; f_i^* is the optimal value of the ith criteria; $f_{i,w}$ is the worst value of the ith criteria; $f_{i,j}$ is the value of the ith criteria for the jth alternative; a_i is the weight assigned to the ith criteria; and p is a parameter ($1 \le p \le \infty$).

A decision maker may influence the computation of distance metric by assigning appropriate values of weights for different criteria. By selecting the appropriate value of the parameter *p*, the deviation of a particular solution from the ideal solution could be further emphasized.

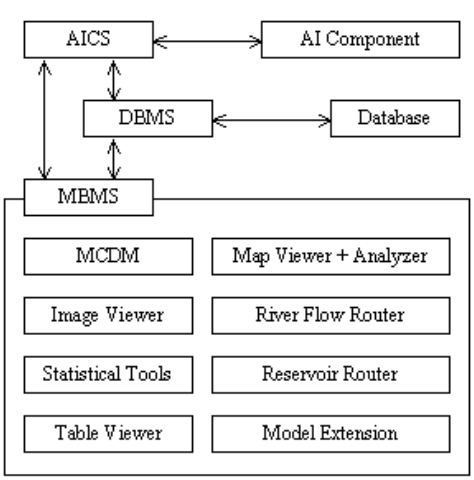


Figure 2. CRSS structure

The MCDM module is comprised of a cell-based grid editor whose columns and rows represent the objectives and alterative decisions, respectively. Depending on the number of objectives and alternatives, the grid size could be suitably adjusted. Data transformed to and from the grid editor could be conveniently handled using the windows clipboard facilities by invoking functions such as "copy," "cut," and "paste." Upon providing the required data, the computation reveals the rank for each alternative decision.

Map Viewer and Analyzer Modules

The Map Viewer module is developed to display and analyze rasterized maps. The module is also capable of layering multiple maps having a common grid domain. The Analyzer module is invoked from the Map Viewer, and all the maps opened in the Map Viewer will be available for operation in the Analyzer. The following operations can be carried out using the Analyzer:

(i) Map Overlay, using the "AND" and "OR" type overlay operations and interpolating the Z-value using appropriate weighting factors for the maps;
(ii) Area selection, using simple queries on X, Y, and Z values; and
(iii) Z-modification of a selected map multiplying the values by a factor or adding a constant to the values.

The result from the Analyzer is presented on an editable grid for exchange of data using the windows clipboard facilities. The result could be saved as a map data file and included in the collection of maps available for analysis.

Image Viewer Module

The Image Viewer module is incorporated to view and edit pictures and images provided in the form of commonly used image formats, including BMP, JPEG, GIF, and TIF. Though this module has no computational importance for CRSS, it is quite useful in presenting data and results that are in the form of images.

River Flow Router Module

The river flow router module is capable of routing flood events through river reaches and flood plains and producing inundation maps. Starting from the topographical map of a river basin, one can define cross sections of the river and carry out flow routing based on the upstream and downstream boundary conditions. The flow routing is carried out using one-dimensional Saint Venant equation for unsteady flow, as follows

$$\frac{\partial h}{\partial t} + h\frac{\partial u}{\partial x} + u\frac{\partial h}{\partial x} = 0 \tag{2}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial h}{\partial x} = gS_o - gn^2\frac{u|u|}{R^{4/3}} \tag{3}$$

where x and t are the spatial and temporal coordinates, respectively; u and h are the velocity and depth, respectively; R is the hydraulic radius; S_o is the bed slope; n is the Manning's coefficient of roughness; and g is the acceleration due to gravity.

The four-point implicit finite difference solution scheme is used for the numerical computation of routing. The upstream boundary condition is the time series of water levels, while the downstream boundary condition is the stage-discharge rating curve, which is derived within the module using the physical properties of the last river reach. However, the Manning's roughness coefficient is a parameter, which must be calibrated using known records of river flow. Result from this module is made available in the form of a map indicating the depth of flood at each grid point. This map can be used for example in flood damage computation.

Statistical Tools Module

A grid-based editor is used to hold data that could be exchanged though the windows clipboard facilities. Selecting a single or multiple columns and multiple rows of data from the grid editor, quantities such as mean, standard deviation, etc. can be determined. This module also has the facility of searching for data that satisfy a particular condition.

Reservoir Router Module

A reservoir system operation module capable of simulating operations of a single reservoir with multiple-diversion points is provided. This module operates on a monthly basis and the reservoir operation rules are specified providing the maximum and minimum water levels for each month. Reservoir operation is governed by the water balance equation as follows

$$S_{i+1} = S_i + I_i - Q_i - E_i - SP_i \tag{4}$$

where i indicates the month; S_i is the reservoir storage at the beginning of month i; I_i is the inflow into the reservoir during month i; Q_i is the summation of releases during month i; E_i is the loss due to evaporation during month i; and SP_i is the spill, if any, during month i.

The water requirement at any diversion point can be specified as a monthly time series. A minimum required flow can be imposed and this requirement will be given priority in the case of water shortage. One of the diversion points can be set to have the highest priority while all others have equal and normal priorities.

On completion of the simulation, the resulting diversion at different diversion points, shortages and the variation of reservoir water level are provided on a monthly basis in a tabular form. Specifying a penalty table for shortage, penalties at different diversion points for not supplying the required amount of water, could be computed.

Table View Module

Linked dynamically with the database of CRSS, the Table View module has the capabilities of viewing, editing, and updating any table available in the database. This module is provided with a grid-based editor and data exchange between the grid and any other application through the windows clipboard facility is available. Selecting a portion of the data, one can invoke the graphing and statistics computational facilities as required.

System Extension

The open architecture of CRSS allows for easy replacement of any module currently used or the addition of new modules as they may be needed. Flexible programming environment of CRSS provides an opportunity for the use of "off-the-shelf" products, commercial packages, or the addition of modules programmed from scratch.

Illustrative Case Study Application of CRSS

The applicability of developed systematic approach and computer support system in conflict resolution is illustrated using a simple hypothetical water resource system. The system comprises a reservoir and downstream service area as shown in Figure 3. The service area is assumed to fall into two administrative authorities. The

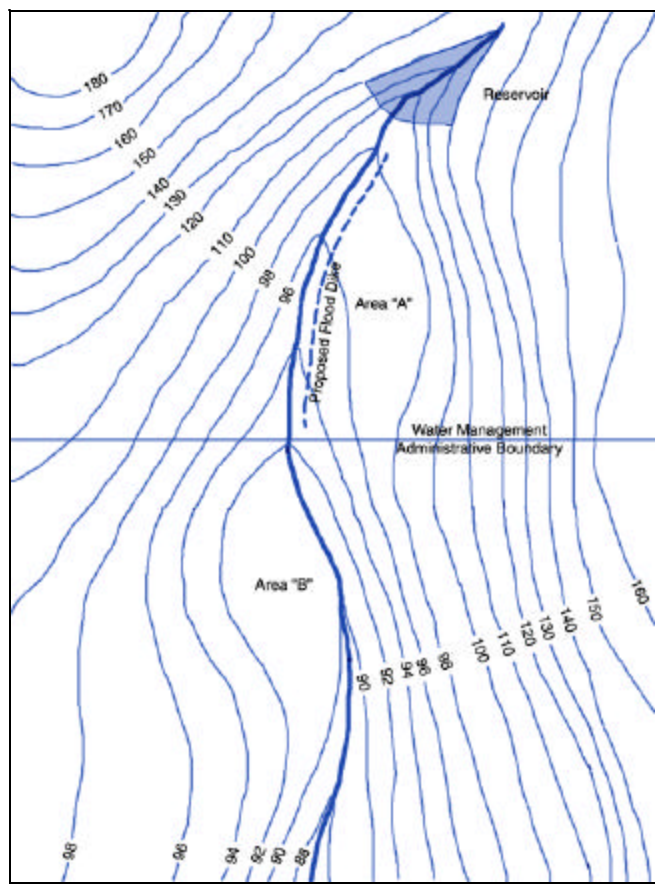


Figure 3. Map of the scheme

stakeholders from these two regions (areas "A" and "B") may confront in fulfilling their objectives of water sharing and flood control. These two issues are selected for system testing and demonstration of its utility.

Water Allocation Problem

The reservoir in the system, which has an active storage capacity of 15×10^6 m^3, regulates river flow to satisfy water requirements of areas "A" and "B." Water supply to these areas is carried out by means of diversion weirs located along the river. Users in these areas have monthly water requirements for pre-planned activities over a time horizon of one year as given in Table 2. However, throughout the total year monthly minimums of 0.25×10^6 m^3 and 0.45×10^6 m^3 of water have to be supplied to the areas "A" and "B," respectively subject to availability. Table 2 includes the anticipated monthly inflows to the reservoir during the year. At the beginning of the operational period the reservoir has 12×10^6 m^3 of stored water. The rule curve presented in Figure 4 is adopted in the operation of the reservoir.

The anticipated inflow during the year along with the initial amount of water available in the reservoir is not sufficient to fulfill the total water requirement, whereas any shortage of supply is subject to penalty. Obviously, each stakeholder is interested in minimizing the penalty involved on his or her side, which may lead to a conflicting situation. Assumed penalty structure for different supply shortages is given in Table 3.

Table 2. Water requirements of service area and inflow to reservoir

Month	*Water requirements (10^6 m^3)* *Area "A"*	*Area "B"*	*Inflow to Reservoir (10^6 m^3)*
April	1.80	2.00	0.63
May	2.10	2.30	1.51
June	2.20	2.00	1.01
July	2.10	1.75	2.65
August	1.25	1.35	3.53
September	0.25	0.45	4.04
October	0.25	0.20	3.91
November	1.50	1.65	2.40
December	1.75	1.42	1.01
January	2.00	1.30	0.76
February	2.50	1.25	0.63
March	1.80	1.20	0.26

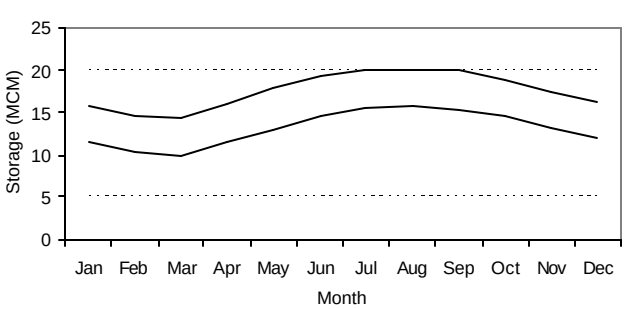


Figure 4. Reservoir operational rule curve

Table 3. Water shortage penalty structure

Shortage (10^6 m^3)	0	2	4	6	8	10
Penalty (M.U.)*	0	35	150	700	1800	5000

* M.U. = monetary units

Table 4. Alternatives examined in the study

Alternative	*Targeted water requirement fulfillment* *Area "A"*	*Area "B"*
1	100 %	100 %
2	50 %	100 %
3	100 %	50 %

Stakeholders facing this water allocation problem may be interested in examining several alternative water allocation scenarios. Table 4 presents the alternatives investigated in the demonstration. For example, the first alternative targets satisfying the total water requirements of both regions.

CRSS could assist in resolving this water allocation problem. The AICS of CRSS, which facilitates communication between parties involved in the conflict and the computer system begins the process by connecting the database through the DBMS. By querying the nature of the problem CRSS would suggest using the appropriate model base routines, namely, the Reservoir Router module and the MCDM module to resolve this conflict. The Reservoir Router module simulates the system operation for the given alternatives and computes the penalties involved with each alternative. Figure 5 shows a typical screen capture of the results window of the module, where the water shortage and penalties for the first alternative

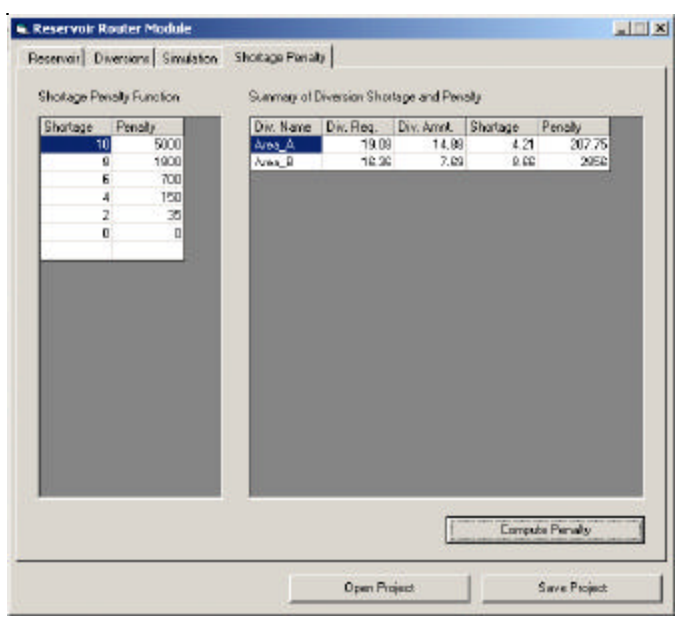


Figure 5. Reservoir Router Module

Table 5. Summary of penalties

Alternative	*Penalties (M.U.)* *Area "A"*	*Area "B"*
1	207.75	2856.00
2	0.00	111.47
3	2.72	32.55

are computed. The penalties obtained for each alternative are presented in Table 5.

Finally, the MCDM module does the comparison of the alternatives to arrive at a compromise solution. The penalties obtained for each alternative are fed to the MCDM module. At this stage the stakeholders can intervene and assign their preference levels to various criteria in the form of weights. Assume that the provided weights are 0.4 and 0.6 for upstream (Area "A") and downstream (Area "B") areas, respectively. Figure 6 shows the screen capture of the MCDM module.

The ranking of the alternatives obtained by running the MCDM module as shown in Figure 6 will assist the stakeholders in the development of compromise solutions. In the demonstration problem, based on the overall objective of minimizing the total penalty involved, the most preferred water allocation scenario is the second one for a fixed set of stakeholders' preferences.

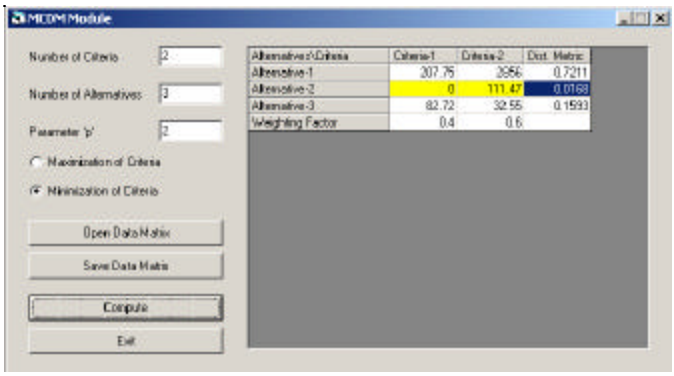


Figure 6. MCDM Module

Flood Control Problem

Both areas "A" and "B" are subject to flooding because of the topography. Anticipating an extreme flood event, stakeholders in area "A" propose constructing a flood dike. Such a construction may increase flooding in area "B" as it is located in the downstream from the area "A." This proposal creates a conflicting situation between areas "A" and "B." Detailed analysis of the impacts of proposed development can be done using the Flow Router module and the MapViewer and Analyzer modules.

Assuming a typical flood event at the upstream end of the river, the flow routing is carried out using the Flow Router module. The typical screen capture, as shown in Figure 7 illustrates an intermediate development stage of the river routing procedure, where the topographic map of the area is assigned with cross sections, and the "Cross Section Editor" screen overlaid on the Flow Router module. The Cross Section Editor automatically generates the cross section based on the map data and presents it in a graphical and tabular form for further editing, if necessary. Simulation of flow routing yields the results in the form of flood map (or inundation map), which indicates the depth of flooding at discrete grid points of the area.

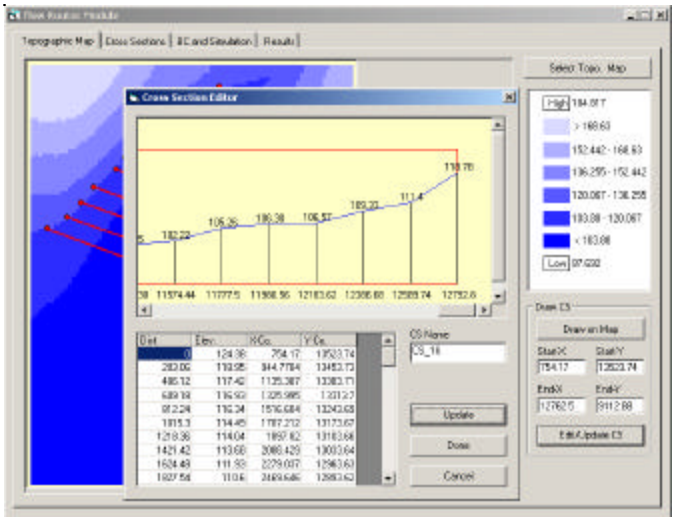


Figure 7. Flow Router Module

The inundation map (indicated as "FloodABNDK" in the legend), derived from the Flow Router module, is illustrated using the Map Viewer module in Figure 8. Other maps, namely "FloodANDK" and "FloodBNDK," are the extracted inundation maps for areas "A" and "B," respectively. On construction of the dike, as shown in the scheme map in Figure 3, flooding in area "B" increases, and the map "FloodBDKA" is constructed under this condition. Flood damage is computed based on the amount of inundation at discrete grid points. Assume that Table 6 represents a typical relationship between the depth of inundation and the flood damage.

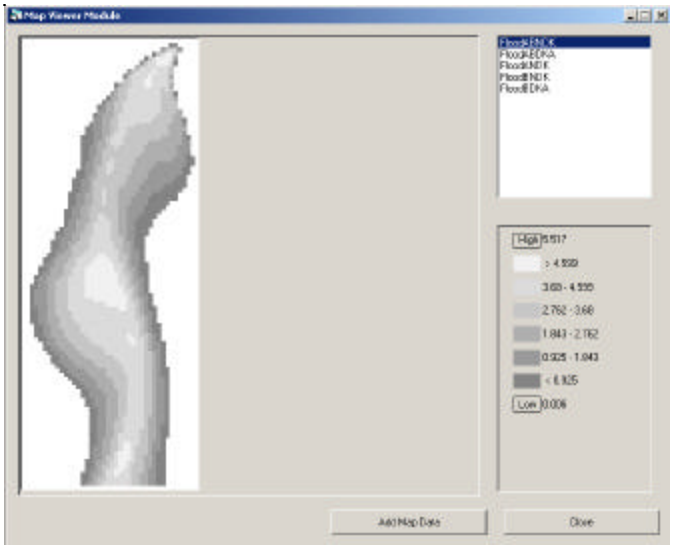


Figure 8. Map Viewer Module

Table 6. Flood damage for different inundation depths

Inundation depth (m)	0	1	2	3	4	5	6
Flood damage (M.U.)*	0	2	8	75	300	1000	3500

Using the Map Analyzer module, the flood damage estimates in areas "A" and "B" with and without the flood dike to protect area "A" are computed and summarized in Table 7.

It is obvious from Table 7 that the construction of a flood dike to protect area "A" has severe impacts on area "B." However, a similar flood dike could be constructed to protect area "B" as well. A thorough analysis of flooding for these alternative construction plans can be carried out using the flow router module and the resulting flood damages as well as the cost of constructing the dikes can be compared using the MCDM module. Then the optimal implementation plan shall be passed for resolution.

Table 7. Flood damage estimates

	Flood damage (M.U)	
Case	*Area "A"*	*Area "B"*
No flood dike to protect area "A"	119,000	304,000
Flood dike to protect area "A"	-	403,000

Conclusions

This paper presents the systemic approach to resolution of conflicts over water. For implementation of this approach a computerized technical support system, CRSS, is developed that provides conflict resolutions support through five functional activities: (i) communication; (ii) problem formulation; (iii) data gathering and information generation; (iv) information sharing; and (v) evaluation of consequences.

The CRSS consists of three main components, an artificial intelligence based communication system, a data base management system and a model base management system. The artificial intelligence based communication system facilitates communication among the stakeholders, and provides access to all the facilities available within the CRSS.

The application of the proposed systemic approach to the analysis and resolution of two typical conflicts encountered in water resources, water sharing and flood mitigation, is used to demonstrate its value in general resolution of conflicts over water. Computer-based implementation of the approach via CRSS helps in the process of generating agreements between parties in conflict that are more lasting and durable. Carefully selected functionalities of the CRSS and their scientific basis provides stakeholders with an environment for effective communication, maintenance of the dialogue, active learning, deep inquiry, assistance in evaluation of alternative options, and development of skills for creative resolution of a conflicting situation.

At this stage of the development, the model based management system consists of tools for multipurpose reservoir operation, river flow routing, multi-criteria decision-making, spatial data analysis, and other general utilities. Flexible system architecture provides for easy addition of other modules that may be necessary in resolution of different water related conflicts.

Acknowledgments

Work presented in this paper is supported by the UNESCO PCCP Project (From Potential Conflict to Conflict Prevention). The authors are gratefully acknowledging this support. Early ideas presented in this paper were developed in communication between Prof. Stevan Bruk and the second author.

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Discussions open until June 1, 2004.

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