Conflict Resolution Support System

A Software for the Resolution of Conflicts in Water Resource Management

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Abstract

Water is an important factor in conflicts among stakeholders at the local, regional, and 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. Sharing a limited water resource by several stakeholders can create conflicts among them when their requirements exceed availability. In such situations, water allocation based on a traditional optimization or simulation modeling may not resolve the dispute among them due to the lack of their participation in the solution process. Direct involvement of the stakeholders in the conflict resolution process provides for a better understanding of the conflict and offers a significant opportunity for its resolution.

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. The CRSS includes computational modules necessary to resolve conflicts resulting from water shortages in irrigation, drinking water supply, and hydropower generation and flood control. Its principal components include an artificial intelligence-based communication system, a database management system, and a model base management system.

The use of CRSS is demonstrated through its application to three types of water sharing conflicts. The CRSS is developed as a tool to assist a conflict resolution process and a tool for training stakeholders in the conflict resolution process.

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1 INTRODUCTION

Fresh water is an essential resource for all human beings and is an important part of the ecological system. In almost every region of the world, supply of water is becoming more difficult because of increasing demands associated with industrialization, increasing urbanization and growing population. According to the World Water Vision report (Cosgrove and Rijsberman, 2000) the world population has tripled in the past century and water use for human purposes has increased six-fold. In addition, dimatic conditions, such as global warming, may worsen the situation in the future.

1.1 Water related conflicts

Water is very unevenly distributed both temporally and spatially. Frequent and regular rainfall in some regions contrasts sharply with prolonged droughts in others. Some regions are blessed with an abundance of freshwater while others face scarcity. Moreover, the freshwater resources of the world are not partitioned to match the political borders. Today, two or more countries share nearly 261 river basins. The shortages, and the inequitable and multilateral distribution of water can create conflicts at local, regional, and even international level. History shows and future may confirm that water has a strategic role in conflicts among different stakeholders (Gleick, 1993).

Conflicts resulting from water sharing problems may jeopardize economic and social order both within and between countries. Improved water management, conflict resolution and cooperation could ameliorate such conflicts. Water management and conflict resolution process has been approached by many disciplines such as law, economics, engineering, political economy, geography, anthropology and systems theory (Wolf, 2002).

Conflicts should not be looked upon as always negative. It can be healthy when effectively managed. Healthy conflict management can lead to growth and innovation, new ways of thinking and additional management options. Understanding the conflict clearly is primary in that process. Then it could be effectively managed by reaching consensus that meets both stakeholders' needs. This may result in mutual benefits and strengthens the relationship. The goal is for all to "win" by having at least some of their needs met.

1.2 Nature of conflicts over water

Conflict is a natural disagreement resulting from individuals or groups that differ in attitudes, beliefs, values or needs. Conflicts in water management often involve interactions between various sub sectors and stakeholders engaged in the water resource management process. Contemporary water resource management is a combined process of sharing water and resolving conflicts among stakeholders. A stakeholder in this context refers to an individual, organization or institution that has a stake in the outcome of a decision related to water sharing, because he, she or it is either directly affected by the decision or has the power to influence or block the decision.

Water resource 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 uncertainties as well as scarcity are typically the reasons why conflicting scenarios arise among stakeholders, in sharing water and protecting their interests. Water resource 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.

1.3 Role of decision support systems in conflict resolution and management

Traditional conflict resolution approaches such as the judicial systems, state legislatures, commissions and similar governmental instruments mostly provide resolutions in which one party gains at the expense of the other. When the river basin traverses across 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). It is often a challenge, for everyone involved in handling such complex water related conflicts on the regional or international scale.

Those complexities led the researchers around the world to develop computer-based Decision Support Systems (DSS) that can provide assistance in determining temporal and spatial distribution of water quantity and quality. These DSS are interactive computer-based systems and subsystems intended to help decision makers use data, documents, knowledge and/or models to identify and solve problems and make decisions. Simonovic (1996) defines a computerized DSS 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”.

1.4 Proposed approach

The computerized DSS assist decision makers in making favorable decisions when confronted with conflicts. However, the ability for the stakeholders, who are impacted by the conflict to actively participate in the resolution process by generating and evaluating management alternatives by themselves, would undoubtedly be the most effective way to arrive at an acceptable decision.

The conflict resolution support system presented in this work offers stakeholders a support in; (a) defining the conflict, (b) identifying and (c) evaluating possible alternative solutions through continuous interaction with the DSS until an acceptable solution can be reached. A communication between the stakeholders and the computer system based on natural language processing and artificial intelligence is integrated into the DSS to provide support for interaction among the stakeholders and computer. The decision-making process is one of informed negotiation and compromise, but from it comes the decision that has the best chance of being the most effective, i.e., accepted by all stakeholders. Each stakeholder or interest group has its' own objectives, interests and agendas and therefore, their active support is required to resolve the conflicts successfully using the conflict resolution support system presented.

1.5 Organization of the report

Chapter one of the report introduces the approach proposed in conflict resolution. It is followed by a literature survey on relevant previous work in water related conflicts and the role of decision support systems in conflict resolution. A detailed description of the conflict resolution support system follows. In the next chapter, conflict resolution support system is described through its application to a hypothetical system, in which two stakeholder groups are involved in a conflict in sharing water for irrigation. Presentation of three case studies follows next. These three case studies cover resolution of conflicts between two stakeholder groups interested in sharing water for (a) irrigation and drinking water supply, (b) hydropower generation and drinking water supply, and (c) irrigation and flood protection. A discussion on the advantages of the system and possible expansions to handle other types of conflicts is provided next. Finally, a user manual that can be used to implement the conflict resolution support system is given. The manual is in the form of three training sessions covering the three types of conflicts mentioned before. A CD Rom with the conflict resolution support system, data for the three types of conflicts it can handle and the user manual (training sessions) is provided with the report.

2 LITERATURE REVIEW

2.1 Water related conflicts

Population and economic development pressures will continue to put increasing stress on the environment, especially on scarce water sources. In water resource systems, water stress lends itself to conflict or to cooperation. Water, unlike other scarce resources, is used to fuel all facets of society, from biology to economy to aesthetics and religious practice. As such, there is no such thing as managing water for a single purpose – all water management is multi-objective and is therefore, by definition, based on conflicting interests. Within a nation these interests include general public, farming community, energy producers and environmentalists – any two of which are regularly at odds. The chances of finding mutually acceptable solutions drop exponentially as more actors are involved.

Greater upstream use and long-run changes in supply or demand could be a cause for water quantity related conflicts. On the other hand, water quality related conflicts might erupt due to new source of pollution resulting from extensive agricultural activities in the upstream region. Return flows from agriculture, industry and urban centers may also cause dissatisfaction among the downstream users creating conditions for 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 them. 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. A more developed nation 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 issues 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.

2.2 Approaches to conflict resolution

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).

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 instruments 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. In this process the third party is referred to as mediator or facilitator. During the negotiation process, the parties must exchange information and share technical knowledge. 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).

The systemic approach, which uses the disciplines of systems thinking and mental models is a powerful alternative to traditional approaches for conflict resolution. Traditional approaches 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 (Bender and Simonovic, 1995; Simonovic and Bender, 1996; Nandalal and Simonovic, 2003) 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.

2.3 Conflict negotiation

Negotiation is a process where two or more parties with conflicting objectives attempt to reach an agreement. This process includes not only the presentation and exchange of proposals for addressing particular issues, but also the attempts by each party to discover the preferences, strengths and weaknesses of their opponents, and the use of that knowledge to help reach a satisfactory resolution. Negotiating parties may be individuals or teams representing their own interests or the interests of their organizations. Negotiation can be a constructive alternative to other means (e.g., physical violence, litigation, stalemate) of settling disputes (Holznagel, 1986; McDonald, 1988; Delli-Priscoli, 1988).

The main purpose of a negotiator is to try to identify alternatives that all parties in conflict will find acceptable. Negotiators must identify and explore the impacts of various decisions, and begin to understand the tradeoffs among these impacts. Various optimization and simulation models of water resource systems serve as the "context" models for gaining such an understanding. Negotiators must also determine, for each proposed solution to the conflict, what they, or whoever they represent, will gain, and what they will lose, and whether or not what they gain will be worth more than what they will lose.

A third-party mediator or facilitator may be included in a negotiation process to help manage the interactions and make suggestions for negotiating parties to consider. Alternatively, an arbitrator may be involved with the power to draft and perhaps dictate settlements for the parties (Anson et al, 1987). It is commonly recognized (e.g., Gulliver, 1979; Mastenbroek, 1989) that such disinterested parties can significantly help negotiators in their quest for an agreement.

Recent development in modeling negotiation processes is motivating work in the use of computer-based analyses of negotiation problems (Raiffa, 1982). The complexity of many negotiation problems involving regional water resources development and use conflicts pose a challenge. This complexity motivates the development of computer models that are beginning to be able to address many of these complexities with increasing effectiveness. These models and their supporting programs require that the issues of the stakeholders (those who are in conflict or who will be affected by the agreement) are adequately defined. But these issues can change. Hence, any analysis of negotiation problems must permit for updating of issues, preferences, and interested stakeholders as the negotiation process proceeds. This analysis must be sufficiently flexible not to constrain or limit the options and thinking of those negotiating, yet not overload them with information that may divert or distract them from reaching mutually satisfactory agreement (Poole et al, 1991).

To resolve water resources disputes in the Washington metropolitan area, Las Vegas and the Kansas River basin a conflict negotiation model called Computer Assisted Negotiation (CAN) has been used (WRMI, Internet) successfully. The experience with the application of this model suggests that in multi-objective disputes with numerous parties a neutral outsider may have the broader perspective necessary to integrate the operations and actions of all parties. Often this allows the development of more acceptable, or even win-win alternative solutions.

2.4 Role of decision support systems in conflict resolution and management

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 a water conflict on the regional or international scale. Such a complexity led the researchers around the world to develop computer-based 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; Simonovic, 1996) provides 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. Other water resources related decision support systems (Davis et al, 1991; Fredericks et al, 1998; Andreau et al, 1996; Reitsma, 1996; Dunn et al, 1996; Jamieson and Fedra, 1996; Arumugam and Mohan, 1997; Ford and Killen, 1995; Ito et al, 2001) with one or more tools for the analyses of water quantity and quality distribution, flood and environmental management, are also helpful in water conflict resolution.

Computer models do not resolve conflicts directly, but serve several roles in helping stakeholders resolve water resources conflicts among themselves. Their contributions include (Lund and Palmer, 1997), further understanding of the problem, formalizing performance objectives, developing promising alternatives, evaluation of alternatives, providing confidence in solutions and providing a forum for negotiation.

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 (Simonovic, 1996). Such facilities are vital for problem identification, problem solving, and analysis of a decision consequences. Data management function 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. Participant's interaction in the process of evaluating alternative options and analyzing the impacts is regarded 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.

It is evident that decision makers could benefit from improved tools to assist them in making favorable decisions, especially when confronted with conflicting objectives and demands (Hipel, 1992). Jelassi et al, (1990) document a need for more rigorous research on the role computers can play in group decision making and in conflict resolution and on the impact computers can have on the outcomes of negotiation processes as well as on the participants' attitudes. The ultimate objective is to offer negotiating parties a means by which they, or a third party facilitator, could directly define and evaluate possible settlements. Achieving this objective would be a significant step toward improving the efficiency and effectiveness of the negotiation process.

Computer assisted negotiation models/software can be used to facilitate multi-party discussions of water-related conflicts. However, developers attempting to produce models to aid in trans-boundary negotiation often find it difficult to collect data from multiple jurisdictions regarding surface water use, groundwater use, groundwater recharge or climatic variables. Further, challenges arise in the reconciliation of regulations, operational policies, guidelines and legal doctrines affecting day-to-day management of trans-boundary riverine systems.

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 other 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).

2.5 Use of Artificial Intelligence in decision support systems

Integration of Artificial Intelligence (AI) technology in a DSS makes the communication between the computer and the stakeholders as close as possible to the communication between humans. Literature documents application of different AI tools 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 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).

Expert systems are a branch of the artificial intelligence community that specializes in the mundane task of encoding experience and processes for making decisions. In this type of decision support systems, knowledge is encoded in Boolean logic and accessed by searching mechanisms called inference engines. The use of expert systems in describing operating policies for reservoirs and other water management problems is an approach that easily adapts to system simulation and experimentation of decision rules. Simonovic (1991) outlines general areas for application of expert system technologies. Eberhardt (1994) used an expert system to describe regulatory decision-making on Lake Ontario. An expert system application for a water resource design problem for fish passage can be found in Bender et al (1992). Examples of expert systems in water management problems can be found in Simonovic and Savic (1989) and Simonovic (1992).

3 METHODOLOGY

3.1 Purpose

Most environmental conflicts, including water related, spring from three sources (White, 1986). First source is 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. The second source is a disagreement over the management of water supply at one location as it affects the use of it elsewhere. The third source is where climatic variability and change, independent of direct human activity, places new stresses on the water resources and generates fresh adaptations to available resources.

The conflict resolution support system developed focuses on the first two sources of water conflict. A river basin, which traverses across an international boarder, a political regional boundary or a general boundary of different jurisdiction, is considered. The basis of a conflict is the implementation of a development (a reservoir) and its management by a stakeholder concerned within its territory. Such decisions impact its neighbor during water shortage conditions, and create conditions for a number of water conflicts.

Conflict resolution process is regarded as an iterative process that should converge to an acceptable resolution to the parties involved. It comprises 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 the computer-based conflict resolution support system (CRSS) that facilitates the resolution process. Introductory presentation of the CRSS system is given in Rajasekaram et al (2003).

3.2 Architecture

Conflict resolution support system consists of an Artificial Intelligent Communication System (AICS), a Data Base 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 basically consists of three modules capable in analyzing three typical conflicts encountered in water resource management. The MBMS modules incorporated in CRSS are, (a) Conflict Type 1 Simulator, (b) Conflict Type 2 Simulator, (c) Conflict Type 3 Simulator (d) Multi-Criteria Decision Making (MCDM) module, (e) Table Viewers, (f) Graph Viewers and (g) Statistical tools.

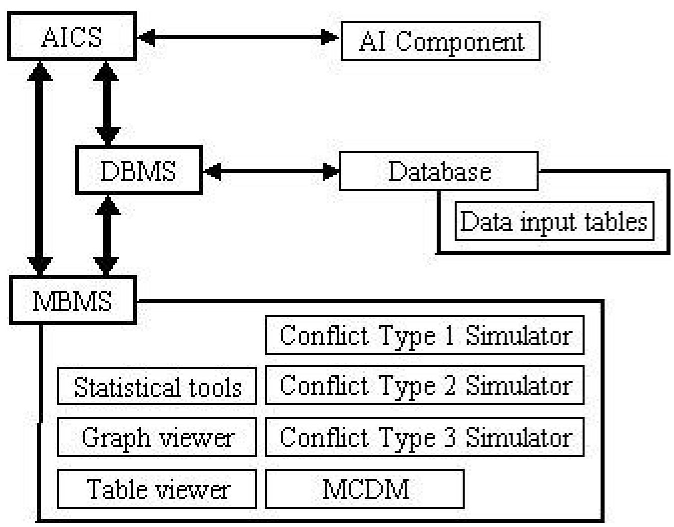


Figure 3.1 Structure of the Conflict Resolution Support System

3.3 Functions of a computerized decision support system

3.3.1 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 much broader scope. In the context of the CRSS implementation, communication between the stakeholders and a computer system provides the facilities and various tools 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.

Integration of Artificial Intelligence (AI) technology in the CRSS makes the communication as close as possible to the communication between humans. The CRSS uses ALICE (Artificial Linguistic Internet Computer Entity) software (Wallace, 2000), which implements AIML (Artificial Intelligence Markup Language), a non-standard evolving markup language for creating its communications (chat robots). The ALICE algorithm employs the pattern recognition concept to find the best-matching pattern to respond for an input (chat). The basic unit of knowledge in AIML is called a category. Each category consists of an input question and an output answer. The question, or stimulus, is called the pattern. The answer, or response, is called the template.

An example of a simple but complete chat robot in AIML is as given below.

```
<alice>
<category>
<pattern>*</pattern>
<template> Hello! </template>
</category>
```

</alice>

The tags <alice>...</alice> indicate that this markup contains a chat robot. The <category> tag indicates an AIML category, the basic unit of chat robot knowledge. The category has a <pattern> and a <template>. The pattern in this case is the wild-card symbol '*' that matches any input. The template is just the text “Hello!”. This simple chat robot just responds by saying "Hello!" to any input.

3.3.2 Problem formulation

Problem formulation step (or formulation refinement) in the conflict resolution process determines how effectively will the process lead to an acceptable resolution. In general, stakeholders describe the problem using 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. 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.

A water quantity-related conflict between the upstream and downstream stakeholders or stakeholders sharing a common water resource from different jurisdictions originate from either, water shortage (draught) or water excess (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 problem with varying priority levels assigned to different stakeholders. Every stakeholder has the objective of maximizing 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 (management alternatives) and minimization of potential damages. In this case too, the stakeholders tend to maximize their own benefits (for example, maximize reduction of potential flood damage) 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 great 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.

Insufficiently, transparent and clear presentation of results to the stakeholders may lead to request for problem refinement. The stakeholders may not comprehend poor presentation of good results correctly 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.

3.3.3 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 time series or very large matrices of geographic 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 the 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.

3.3.4 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 highest 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.

3.3.5 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.

3.4 Modules of a computerized decision support

The model based management system of the CRSS consists of several modules. It has modules for the simulation of water resource systems, multi-criteria decision making and calculating statistical parameters. It further consists of modules for general utilities such as viewing tables, viewing graphs and entering data.

3.4.1 Reservoir Simulation Modules

Three reservoir system operation modules capable of simulating three different water resource systems are provided. This section presents them.

<u>Problem Type 1: Conflict in sharing water for irrigation and/or drinking water supplies</u>

In the system, two communities ("A" and "B") share water in a reservoir for irrigation water supply and/or drinking water supply.

This module operates on monthly basis. Reservoir operation is governed by the water balance equation shown below. The definitions of the variables in the equation are given in Figure 3.2.

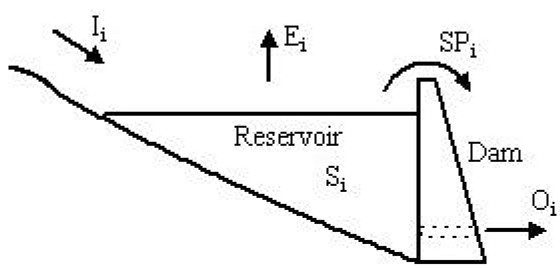


Figure 3.2 Cross-section of a reservoir

$$S_{i+1} = S_i + I_i - Q_i - E_i - SP_i \tag{3.1}$$

Where,

S_i = reservoir storage at the beginning of month *i*,

I_i = inflow into the reservoir during month *i*,

Q_i = total release from the reservoir during month *i*,

E_i = evaporation loss during month i, and

SP_i = spill, if any, during month i.

If the water available in the reservoir, in a certain month exceeds the total requirement during that month, the release equals demand in the two areas. (i.e., if $S_i + I_i - E_i \geq D_{A,i} + D_{B,i} + Q_{min}$)

$$Q_{A,i} = D_{A,i} \quad ; \; Q_{B,i} = D_{B,i} \tag{3.2}$$

Where,

$D_{A,i}$ = demand (either irrigation or drinking water) of area "A" during month i, and

$D_{B,i}$ = demand (either irrigation or drinking water) of area "B" during month i.

If the water available in the reservoir in a certain month is less than the total requirement during that month, the release is distributed proportionally to the demand.

$$Q_{A,i} = Q_i \left(\frac{D_{A,i}}{D_{A,i} + D_{B,i}} \right) \quad ; \quad Q_{B,i} = Q_i \left(\frac{D_{B,i}}{D_{A,i} + D_{B,i}} \right) \tag{3.3}$$

A minimum required flow to each area can be imposed and this requirement will be given priority in the case of water shortage.

$$Q_{A,i} \geq Q_{\mathrm{A,min}} \quad ; \quad Q_{B,i} \geq Q_{B,\mathrm{min}} \tag{3.4}$$

Where,

$Q_{A,min}$ = minimum water requirement of area "A" during month i, and

$Q_{B,min}$ = minimum water requirement of area "B" during month i.

Reservoir storage should be within the maximum and minimum levels for each month.

$$S_{\min} \leq S_i \leq S_{\max} \tag{3.5}$$

Where,

S_{min} = Minimum reservoir storage, and

S_{max} = Maximum reservoir storage.

The reservoir has to satisfy a certain minimum monthly downstream environmental water release requirement if water is available in the reservoir. This release has priority over all the other demands.

$$Q_i \geq Q_{\min} \tag{3.6}$$

On completion of the simulation, the resulting water supplies and deficits in the two areas and the variation of reservoir water level, and storage are provided on a monthly basis in graphical and tabular forms.

Problem Type 2: Conflict between hydropower generation and drinking water supply

In the system, a reservoir is managed for the purposes of hydropower generation and drinking water supply.

This module operates on a monthly basis. Water balance equation (3.1) governs the reservoir operation. The management tries to follow already available reservoir operating rule curve. Then the resulting total release is compared with the demand. The reservoir has to satisfy a certain minimum monthly downstream environmental water release requirement. This release has the priority over all the other demands and it is deducted from the computed release to obtain the water available for hydropower generation and satisfy drinking water demand. If the computed release is less than the minimum requirement and if the water is available in the reservoir for release, then the minimum requirement is released. If the water is available equation (3.6) has to be satisfied first.

If the total release exceeds minimum downstream requirement, then the balance is compared with the water requirement for the two objectives. The quantity of water required to generate the hydropower during the month is estimated on the basis of available head at the beginning of the month. Thus, if the total release exceeds the total requirement during that month, then the demand for water is met first. If the release is higher than the requirement, the balance is stored in the reservoir.

$$Q_{drk,i} = Dem_{drk,i} \quad ; \; Q_{hyd,i} = QDem_{hyd,i} \tag{3.7}$$

Where,

$Q_{drk,i}$ = release for drinking water demand during month i,

$Q_{hyd,i}$ = release for hydropower generation during month i,

$Dem_{drk,i}$ = drinking water demand during month i, and

$QDem_{hyd,i}$ = release for hydropower generation during month i.

If the available release from the reservoir is less than the total requirement during that month, the release is distributed between the two purposes proportional to their demands.

$$Q_{drk,i} = Q_i \left(\frac{Dem_{drk,i}}{Dem_{drk,i} + QDem_{hyd,i}} \right) \quad ; \quad Q_{hyd,i} = Q_i \left(\frac{QDem_{hyd,i}}{Dem_{drk,i} + QDem_{hyd,i}} \right) \tag{3.8}$$

Reservoir storage should be within the maximum and minimum levels for each month as given in Eq.(3.5).

The hydro-energy generation is estimated on the basis of the available release and head.

$$Eng_i = \eta g Q_{hyd,i} h_i \tag{3.9}$$

Where,

η = efficiency of the power plant

g = gravity

h_i = power-head during month $i = (EL_i - TWL)$

EL_i = average reservoir elevation during month i, and

TWL = tail water elevation.

The hydropower release is limited by the power outlet capacity.

$$Q_{hyd,i} \leq Q_{powerout,\max} \tag{3.10}$$

Where,

$Q_{powerout, max}$ = power outlet capacity.

Similarly, drinking water release is limited by its outlet pipe capacity.

$$Q_{drk,i} \leq Q_{drkout,\max} \tag{3.11}$$

Where,

$Q_{drkout,max}$ = drinking water pipe capacity.

On completion of the simulation, the resulting hydropower generations, drinking water supplies and their deficits are given in graphical and tabular forms. The variation of reservoir water level and storage etc., are also provided on a monthly basis similarly.

<u>Problem Type 3: Conflict in downstream flood protection and irrigation water supply</u>

In the system, a reservoir is managed for the purposes of downstream flood protection and irrigation water supply.

This module operates on monthly basis. Water balance equation (3.1) governs the reservoir operation. The management tries to follow a certain already available (developed based on long term hydrology) reservoir operating rule curve. Then the resulting total release is compared with the demand. The reservoir has to satisfy a certain minimum monthly downstream environmental water release requirement. This release has priority over all the other demands and it is deducted from the computed release to obtain the water available for irrigation water supply. If the computed release is less than the minimum requirement and if water is available in the reservoir for release, then the minimum requirement is released. That is, if water is available equation (3.6) has to be satisfied first.

If the total release exceeds minimum downstream requirement, then the balance is compared with the irrigation water requirement during the month. If the release is less than or equal to the demand, then the release is diverted towards the irrigation area. If the release available for irrigation area is less than the demand and if water is further available in the reservoir, water is released from the reservoir for satisfying the irrigation demand.

If the reservoir release exceeds the irrigation demand, the excess water flows downstream along the river as only the irrigation demand is diverted to the irrigation area. If the flow along the river is high, it can cause floods in the downstream area. The damage due to floods depends on the downstream river flow (and thus its elevation/flooding area).

On completion of the simulation, the resulting irrigation water supply and the deficit and flood damage costs are given in both graphical and tabular forms. The variation of reservoir water level and storage is also provided on a monthly basis.

3.4.2 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 *m* different alternatives that are to be evaluated against *n* criteria, the proximity of alternative solutions to the ideal one is determined using a distance metric as follows:

$$L_j = \left[\sum_{i=1}^{n} a_i^{\,p} \left| \frac{f_i^* - f_{i,j}}{f_i^* - f_{i,w}} \right|^p \right]^{1/p} \tag{3.12}$$

Where,

L_j = distance metric computed for alternative j,

f_i^* = optimal value of the i^{th} criteria,

$f_{i,w}$ = worst value of the i^{th} criteria,

$f_{i,j}$ = value of the i^{th} criteria for the j^{th} alternative,

a_i = weight assigned to the i^{th} criteria, and

p = a parameter ($1 \le p \le \infty$).

Figure 3.3 further clarifies the above values for an alternative (alternative j). The distance metric for the alternative j is determined using Eq.3.12. Similarly, distance metrics are calculated for all the alternatives to rank them.

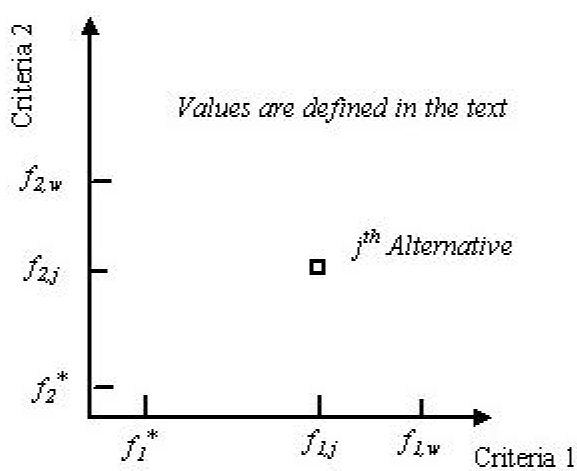


Figure 3.3 Values used to determine distance metric for an alternative

Assigning appropriate weights for different criteria could influence the values of distance metric. By selecting the appropriate value of the parameter *p*, the deviation of a particular solution from the ideal solution could be further emphasized.

At the end of each system simulation the CRSS reveals the rank of all the alternatives already developed. Further, it has the facility to rank a selected set of alternatives from the available ones.

3.4.3 Statistical tools

The CRSS has a module to compute average of the inflow series. It also gives the maximum and minimum inflows to the reservoir with the months those events are occurring.

3.4.4 General utilities

The CRSS includes several modules to view results of the simulations in tabular form and/or graphical form. These presentations or results are very important during the conflict resolution process to arrive at an acceptable allocation of water among the stakeholders. The modules have been designed to show the results in the best comprehensive manner.

4 DESCRIPTION OF THE CONFLICT RESOLUTION SUPPORT SYSTEM

This chapter presents a detailed description of the CRSS application to a hypothetical water resource system. The CRSS can assist in resolving three main types of water allocation conflicts. For the purpose of detailed system description, this chapter presents a conflict encountered between two stakeholders in sharing water for irrigation.

4.1 Description of the conflict

The system comprises a reservoir and a downstream service area as shown in Figure 4.1. The service area falls into two administrative authorities. The stakeholders from these two regions (areas "A" and "B") confront in fulfilling their objectives of water sharing for irrigation water supply.

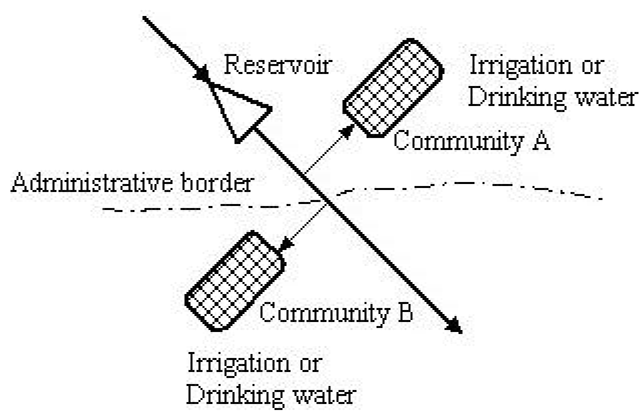


Figure 4.1 Schematic diagram of the water resource system

The reservoir's active storage capacity is $242.1x10^6$ m^3 and its maximum and minimum operating levels are 88.4 masl and 74.1 masl, respectively. It regulates river flow to satisfy irrigation water requirements of areas "A" and "B". Water supply to these areas is carried out by means of two diversion weirs located along the river. The two stakeholder groups have plans to irrigate certain areas in the year to come. Anticipated monthly inflows into the reservoir during the year are available. 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 of the two regions during the year. Each stakeholder is interested in minimizing the deficit on his or her side, which leads to a conflicting situation.

The CRSS can assist the stakeholders in creating several water allocation scenarios. The artificial intelligence based communication module of CRSS assists the stakeholders in that process. The following description provides various facilities available in the CRSS for the creation of different alternatives to arrive at a consensus resolution.

4.2 Application of the CRSS

The execution of the CRSS starts with an introductory window as shown in Figure 4.2. It shows the different types of problems that the system is capable in handling. Continuation of the consultation process takes the stakeholders to the “CRSS communication” window shown in Figure 4.3. All the interactions of the stakeholders or the operator (queries, answers etc.) with the system should be typed in the space (box) at the bottom of the “CRSS Communication” window. The conflict resolution process starts by the introduction of a member of one stakeholder group. Then the member selects the conflict type the group is facing from the three types presented in the window in Figure 4.2. The conflict used in this chapter for the detailed description of CRSS belongs to type one.

This communication with the CRSS continues by the description of stakeholders’ water use, i.e., irrigation water supply in the present problem. The area the group intends to irrigate during the forthcoming year is next given.

The CRSS then requests the requirements of the other stakeholder group. The introduction of a member of the stakeholder group initiates their consultation process. The water use of the group, i.e., irrigation water supply, is provided next. The area to be irrigated by the group in the coming year follows that.

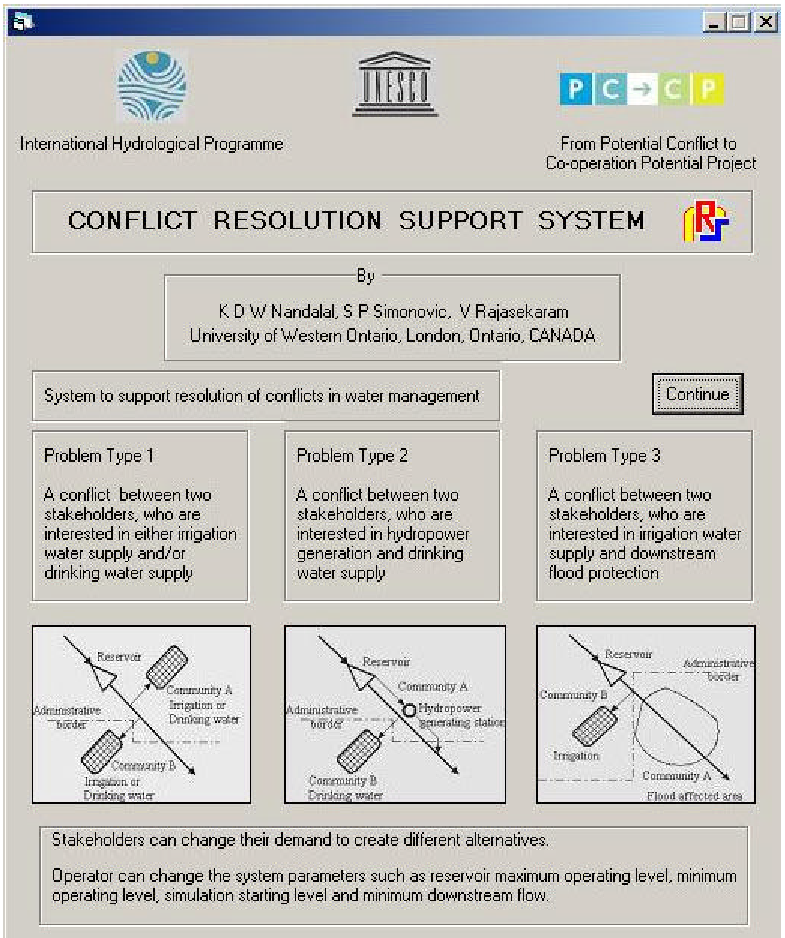


Figure 4.2 Introductory window of CRSS with the three types of conflicts

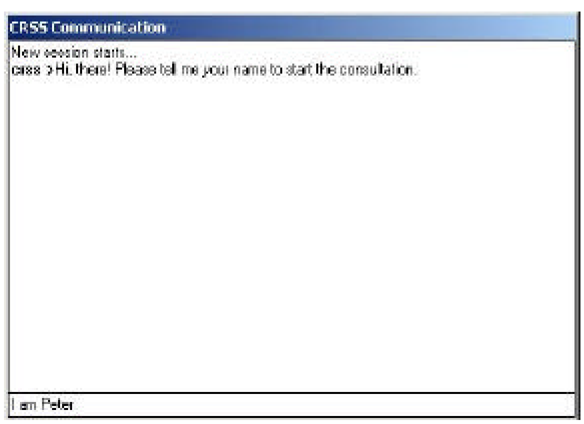


Figure 4.3 CRSS Communication window

The stakeholder groups obtain services of an operator during the consultation process. The operator's involvement is limited for providing both stakeholders the required technical assistance to use the CRSS in the resolution of their conflict.

Next, the CRSS indicates that an operator could log in and simulate the system to evaluate the availability of water for irrigation in the two regions during the year. After the introduction of the operator various options available for the continuation of the conflict resolution process could be viewed. Figure 4.4 shows the window with the various "Options" available in the resolution of a "Type One" conflict. Table 4.1 shows the users authorized to perform different tasks.

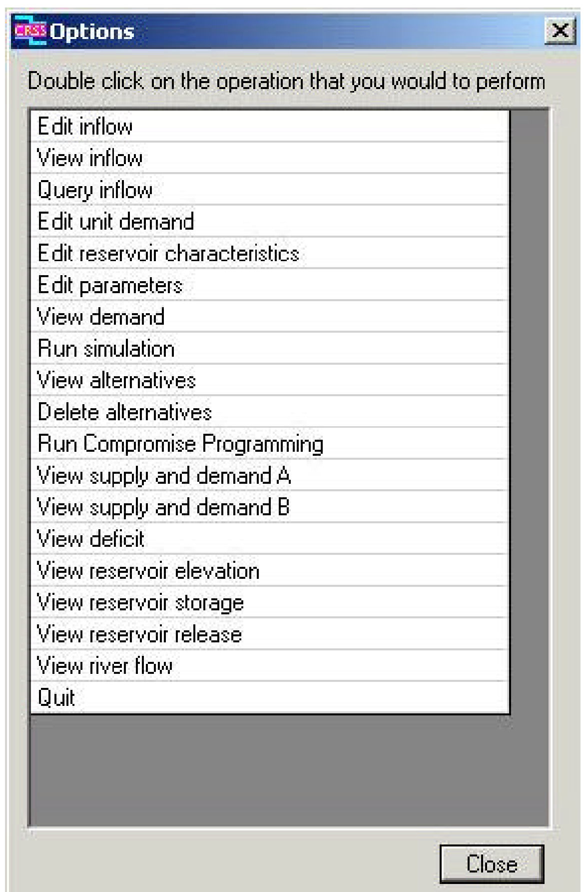


Figure 4.4 Various options available in the resolution process - Type 1

Table 4.1 Different tasks and authorized users – Type 1

Task	Authorized user	
Edit inflow	Operator	
View inflow	Operator	Stakeholders
Query inflow	Operator	Stakeholders
Edit unit demand	Operator	
Edit reservoir characteristics	Operator	
Edit parameters	Operator	
View demand	Operator	Stakeholders
Run simulation	Operator	
View alternatives	Operator	Stakeholders
Delete alternatives	Operator	
Run Compromise Programming	Operator	
View supply and demand A	Operator	Stakeholder A
View supply and demand B	Operator	Stakeholder B
View deficit	Operator	Stakeholders
View reservoir elevation	Operator	Stakeholders
View reservoir storage	Operator	Stakeholders
View reservoir release	Operator	Stakeholders
View river flow	Operator	Stakeholders
Quit	Operator	Stakeholders
** Change irrigation/drinking water demand		Stakeholders

** Task is not included in the “Options” window.

The operator and the stakeholders can invoke the tasks either by double clicking the selection in the list or through interacting with the CRSS using “CRSS Communication” window by typing the requested task in the box at the bottom of the window. These requests can be given in full sentences. For example, instead of selecting “Edit inflow” the operator can type, “I want to change inflow” in the chat box at the bottom of the “CRSS Communication” window.

4.3 Viewing and editing data

If required, at the outset the operator can make sure whether the details of the reservoir (reservoir characteristics and reservoir parameters) are correct. He can look at the reservoir characteristics and make necessary changes. The reservoir parameters such as maximum and minimum reservoir levels etc., could be edited by invoking “Edit parameters” window. Figure 4.5 shows “Reservoir Characteristics” window. If necessary, elevation, area and storage relationships of the reservoir could be changed in this window. Note that the number of points on these curves is limited to 10 values.

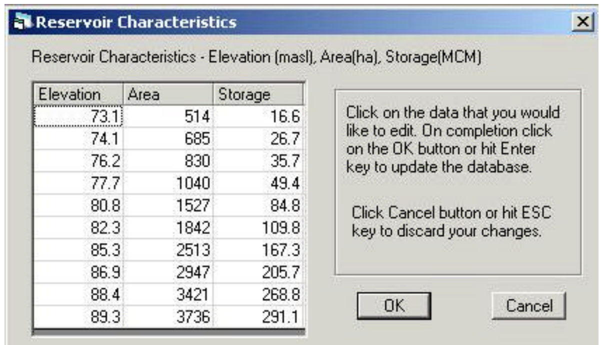


Figure 4.5 Reservoir characteristics editing window

The reservoir maximum operating level, minimum operating level and reservoir water level at the beginning of the simulation period should be given through the “System Operation Parameters” window shown in Figure 4.6. The required river flow is the minimum amount of water that must remain in the river for ecological purposes. Changing all these values is the responsibility of the operator. The stakeholders’ irrigation areas or drinking water requirements (either of them) are also shown in the window. If required, they can request the operator to change the current values. The minimum required flow is the amount of water that the stakeholder wishes to receive if its demand could not be satisfied. An attempt is made at least to satisfy these requirements if sufficient water is not available to satisfy the total demand.

If the stakeholders use the communication window to change the irrigation areas, they first have to introduce themselves to the CRSS again. However, they do not have the authority to change the system parameters, such as the different water levels of the reservoir and the required river flow.

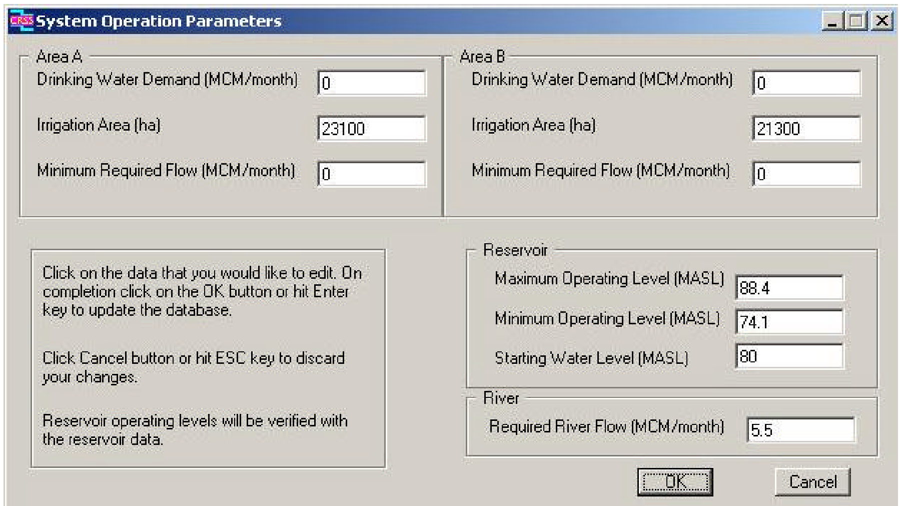


Figure 4.6 Edit parameters window

The operator and/or the stakeholders can view monthly inflow series as shown in Figure 4.7. However, only the operator is allowed to change the inflow series. The "Reservoir Inflow Data" window shown in Figure 4.8 is used for changing the inflow series.

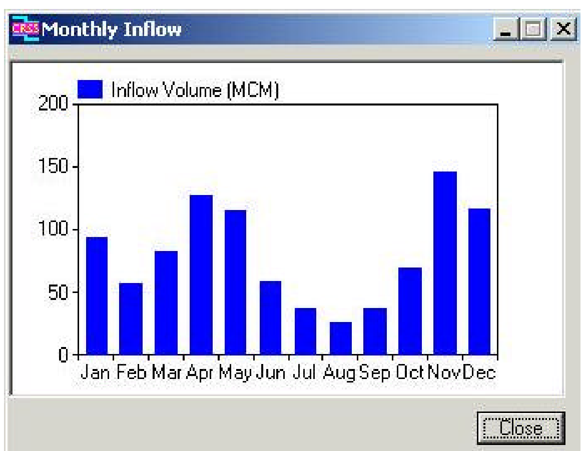


Figure 4.7 Monthly inflow series

To determine the irrigation water requirements of the stakeholders the monthly irrigation water requirements per unit area are needed. The "Unit Irrigation Demand Data" window in Figure 4.9 shows the monthly irrigation water requirements (mm) per unit area (ha) for the two groups. The operator is allowed to edit this data if required. The stakeholders can request the operator to edit those values if they feel necessary.

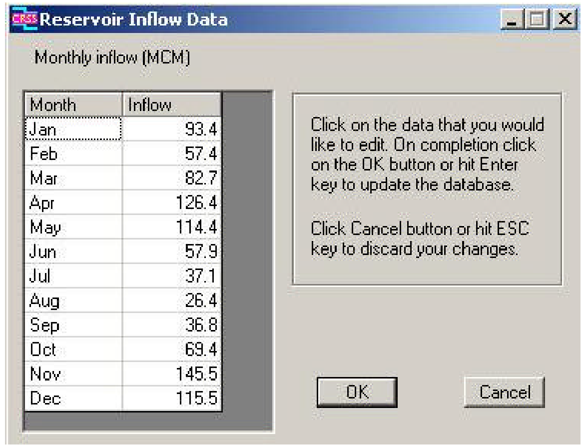


Figure 4.8 Inflow editing window

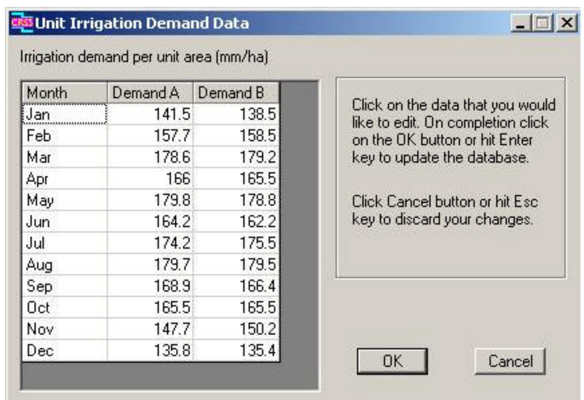


Figure 4.9 Unit irrigation demand

The total monthly irrigation demand is determined by multiplying the requirement per unit area by the size of interested area. A request to view demand will show the monthly irrigation demand in graphical form as Figure 4.10 depicts. The irrigation areas of stakeholder "A" and stakeholder "B" are 23100 ha and 21300 ha, respectively.

After all the data are changed (if required) and verified, the operator can simulate the reservoir operation (Eq.3.1 through 3.6) to determine the availability of water during the year. The simulation run, which is named as Alter1, shows deficits in the two areas. The annual total deficit of the stakeholder "A" and stakeholder "B" resulted from the simulation is 24.56 MCM and 22.38 MCM, respectively.

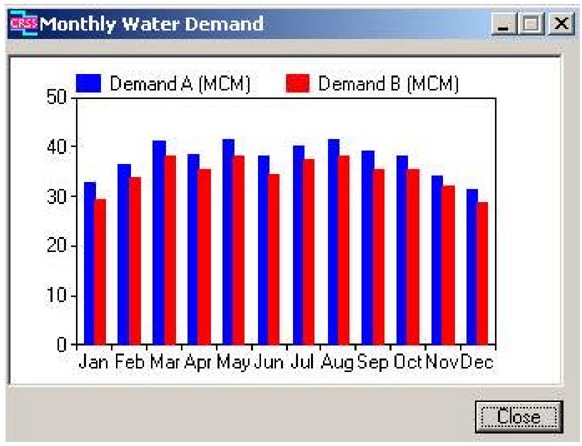


Figure 4.10 Irrigation water requirements

4.4 Results of a water allocation alternative

The detailed results of the simulation can be viewed for the purpose of further communication. For example, if the stakeholder "A" wants to see their water allocation along with their demand, they can request the CRSS to show that. The demand of stakeholder "A" and the water allocated to them are shown in Figure 4.11. Similarly, demand and allocation of stakeholder "B" also could be viewed.

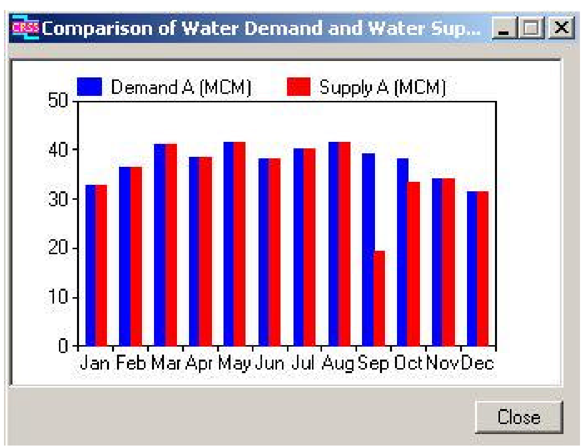


Figure 4.11 Irrigation demand and water supply - Group A

The deficits of both groups could be viewed, if “View deficit” in “Options” window is activated. Figure 4.12 shows the deficits of both groups in both tabular and graphical form. The table in this window includes demand and supply, too.

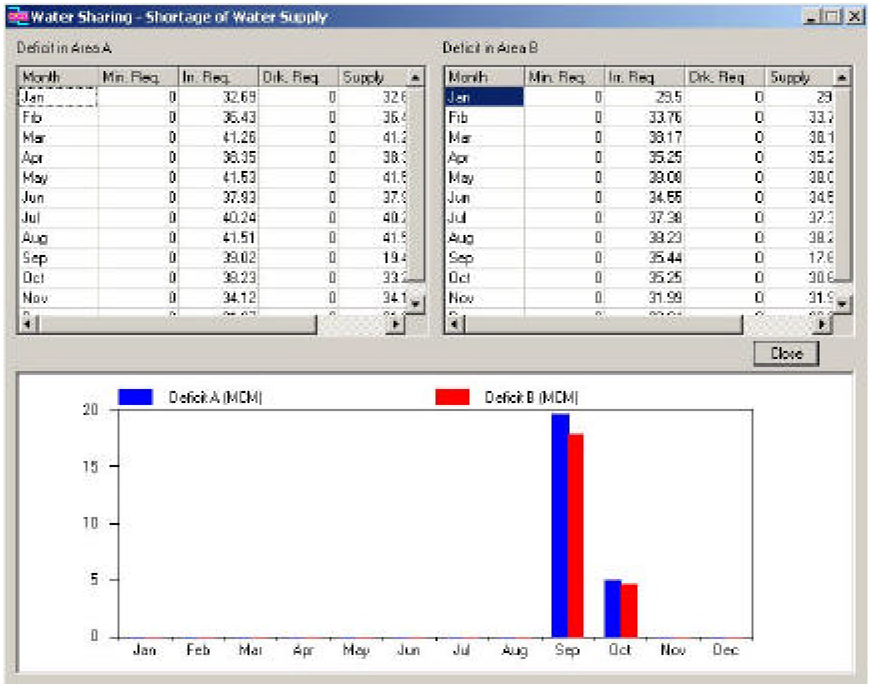


Figure 4.12 Deficit of irrigation water supply

The behaviour of the reservoir, i.e., the variation of reservoir water level and variation of reservoir storage could be viewed as shown in Figure 4.13 and Figure 4.14, respectively.

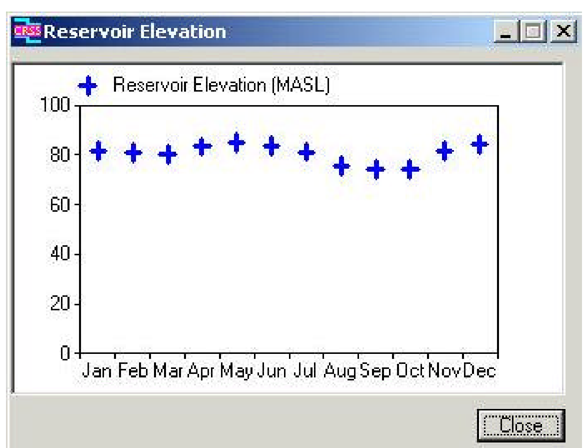


Figure 4.13 Variation of reservoir elevation

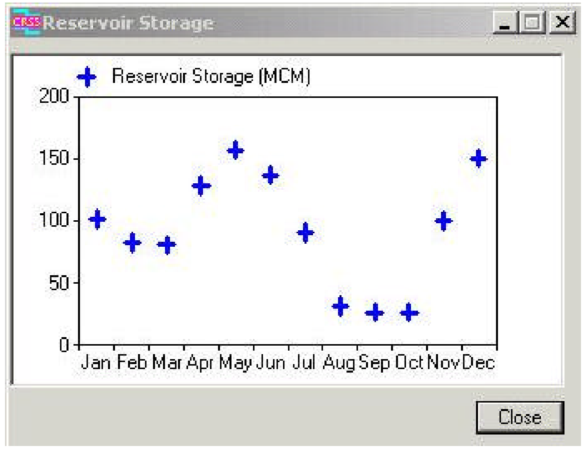


Figure 4.14 Variation of reservoir storage

The satisfaction of downstream minimum water requirement can be viewed by activating "View river flow" in the "Options" window. The river flows are as shown in Figure 4.15.

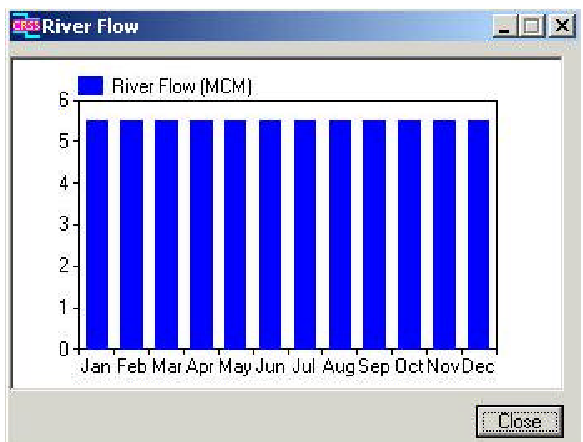


Figure 4.15 Downstream river flow

4.5 Development and evaluation of alternatives

The simulation shows that both groups encounter deficits if they want to irrigate the requested areas. Therefore, to reach the compromise they try several other alternatives. A member from the community "A" communicates with the CRSS (it can be the same person or a different person in the group) and agrees to reduce irrigation area to 23000 ha but requests a minimum flow of 20 MCM/month towards their area. Both requests can be made through the communication window. The stakeholder "B" does not change its requirement. Therefore, the operator comes and simulates the system again. The simulation results in irrigation deficits of 23.63 MCM and 21.62 MCM for the stakeholder "A" and stakeholder "B", respectively. The stakeholders can see and compare the two alternatives that they have studied thus far by invoking the "Water Sharing - Alternatives" window. The two alternatives developed thus far are included in Table 4.2.

Subsequently, the stakeholder "B" may want to evaluate the situation if their irrigation area is increased to 21500 ha. However, they are not interested in a minimum flow towards their area. So, a member of community "B" joins CRSS and type in the requirement. The stakeholder "A" does not change their requirements. Therefore, the operator simulates the system with new data. The simulation results in 25.26 MCM and 23.34 MCM of deficits.

Both stakeholder groups agree to study the system behaviour if downstream water requirement is decreased to 5 MCM/moth. The operator does this change and simulates the system, which results in deficits of 22.66 MCM and 20.93 MCM to stakeholder "A" and stakeholder "B", respectively.

The community "B" now wants to have a minimum flow to their area during the year. A member of their community joins the CRSS and requests a minimum flow of 22 MCM/month throughout the year. Then the operator simulates the system to see the performance. The deficits with these requirements are 24.45 MCM and 19.14 MCM for the stakeholder "A" and stakeholder "B", respectively. The alternatives developed in the consultation process are presented in Table 4.2.

The stakeholders now plan to compare the alternatives studied so far. By activating the "View alternatives" in the "Options" window, a comparison of the alternatives can be seen. Figure 4.16 presents the window that includes details of all the alternatives developed. It shows the different requirements and the resulting deficits. It also includes the rank of the different alternatives. The alternatives are ranked based on their proximity to an ideal solution as described in Eq.3.12 in Chapter 3.9.

Table 4.2 Details of Alternatives

	Group A			Group B			Minimum river flow (MCM)
	Area requested (ha)	Flow Deficit (MCM)	Minimum flow (MCM)	Area requested (ha)	Flow Deficit (MCM)	Minimum flow (MCM)	
Alt 1	23100	24.56	0	21300	22.38	0	5.5
Alt 2	23000	23.63	20	21300	21.62	0	5.5
Alt 3	23000	25.26	20	21500	23.34	0	5.5
Alt 4	23000	22.66	20	21500	20.93	0	5
Alt 5	23000	24.45	20	21500	19.14	22	5

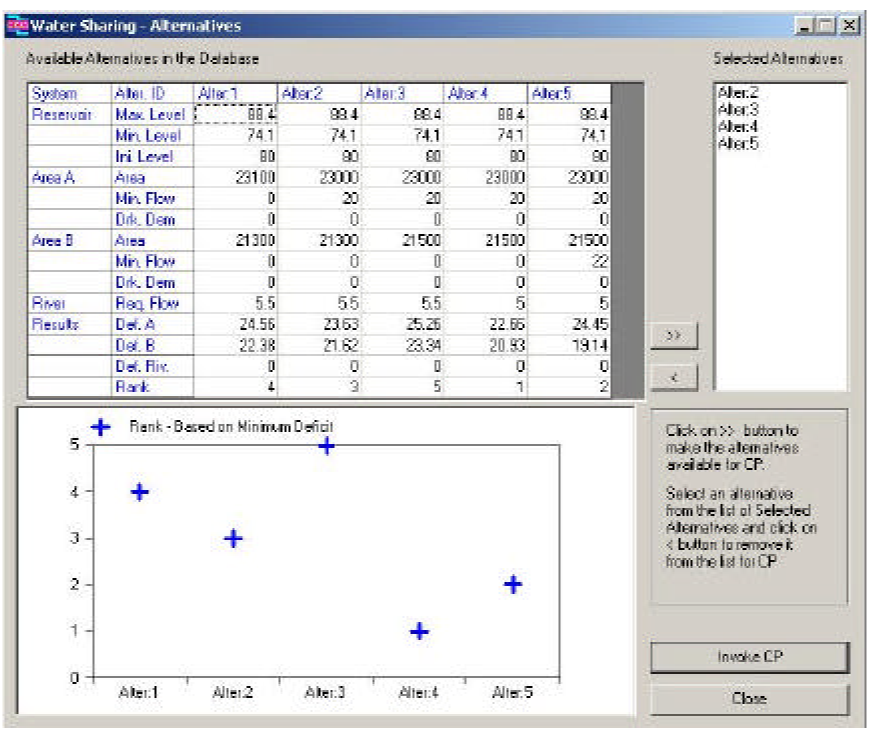


Figure 4.16 Details of the different alternatives studied

If required, the stakeholders can choose several alternatives of interest from the list and rank them by invoking the Compromise Programming window. For example, as shown in the window in Figure 4.16, the Alternatives 2, 3, 4 and 5 are selected for further analysis. The Compromise Programming is invoked after selecting the alternatives. The rank given to the alternatives in that window have been determined by giving equal weights to the requests of both stakeholders.

However, the Compromise Programming window enables the operator to give different weights to the stakeholders and rank the alternatives. Figure 4.17 shows the weights given to the two groups as 0.4 and 0.6, respectively. The Compromise Programming calculation results in the rank given in the last column of the window.

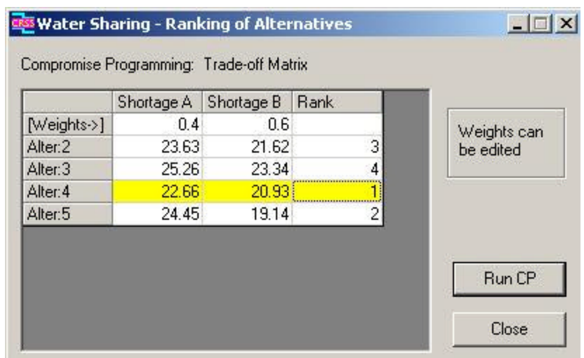


Figure 4.17 Rank calculation of selected alternatives based on the Compromise Programming algorithm

If the stakeholders can agree on one of the alternatives from the ranked list, either the operator or the stakeholders can wind up the session by quitting the CRSS. Otherwise they can continue the process by creating more alternatives and repeating the process again.

4.6 Discussion

The development of alternatives could continue until the two stakeholders arrive at an agreement on water allocation. The stakeholders and the operator can communicate with the CRSS through the "CRSS Communication" window throughout the conflict resolution process. Communication will be in the form of answering queries of the CRSS or making queries to the CRSS. Some basic tasks could be activated by selecting them from the

"Options" window, too. If the stakeholders or the operator raise an irrelevant query, the CRSS will point out that and will request the user to enter the correct one.

The role of the operator is to assist stakeholders in operating the CRSS and making changes to the common system parameters. The stakeholders can directly communicate with the CRSS to provide their requirements and look at the system response. They can keep on changing the requirements and evaluating the results until an agreement between them is reached.

Whenever, a new consultation is commenced, the database is initialized to the set of data given in the report. When the consultation is over, the process should be stopped by typing "Quit".

5 USE OF THE CONFLICT RESOLUTION SUPPORT SYSTEM FOR DIFFERENT TYPES OF CONFLICT

CRSS can assist in resolving three types of water allocation conflicts. This chapter presents its application to these three different types of conflicts.

5.1 Case 1: Conflict in sharing water for Irrigation and/or Drinking Water Supply

The application of CRSS to assist two stakeholder groups in sharing water for irrigation was presented in Chapter 4. In that application, both groups were interested in irrigation water supply to their cultivation areas. However, “Type 1” problems in the CRSS include sharing of water for either irrigation or drinking water supply. Thus conflicts in sharing water can be in one of the following forms: (a) irrigation – irrigation; (b) drinking water - drinking water; and (c) irrigation - drinking water.

Since, Chapter 4 presented application of the CRSS to a conflict in sharing water for irrigation, this section shows how it can be used to resolve a conflict in sharing water between irrigation and drinking water supply. That is, one stakeholder group is interested in irrigation while the other group is interested in drinking water supply.

5.1.1 Description of the conflict

The water resource system considered in the study comprises a reservoir and a downstream service area as shown in Figure 5.1. The service area is assumed to fall into two administrative authorities. The stakeholders from these two regions (areas “A” and “B”) may confront in fulfilling their objectives of water sharing for irrigation and drinking water supply.

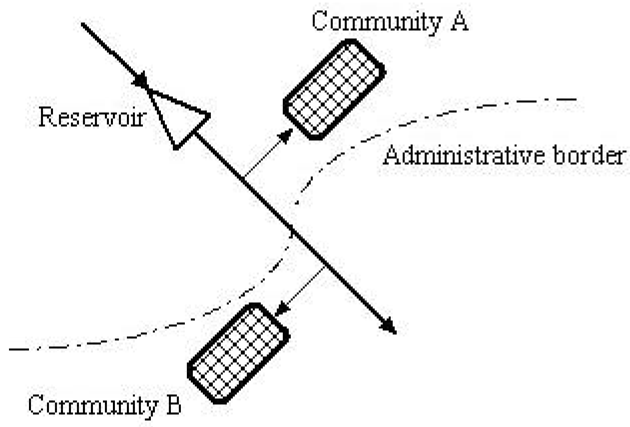


Figure 5.1 Schematic diagram of the water resource system: Conflict Type 1

The active storage capacity of the reservoir is 242.1×10^6 m^3. Its maximum and minimum operating levels are 88.4 masl and 74.1 masl, respectively. The reservoir regulates river flow to satisfy irrigation water requirement of community "A" and drinking water supply requirement of community "B". Water supply to these two communities is carried out by means of diversion weirs located along the river. Anticipated monthly inflows to the reservoir during the year are available. The inflow during the year along with the initial amount of water available in the reservoir is not sufficient to fulfill the total water requirement of the two stakeholders during the year. Each stakeholder is interested in minimizing the deficit on his or her side, which may lead to a conflicting situation. The artificial intelligence based communication module of the CRSS assists the stakeholders in the development of several water allocation scenarios to arrive at an agreement on the allocation of water. The detailed communication log used by the stakeholders to analyse this problem is provided in Appendix A.

5.1.2 Application of CRSS

The execution of the CRSS starts with an introductory window as shown in Figure 5.2. It shows the different types of problems that the system is capable in handling. Continuation of the consultation process takes the stakeholders to the "CRSS communication" window shown in Figure 5.3. All the interactions of the stakeholders or an operator (queries, answers etc.) with the system should be typed in the box at the bottom of the "CRSS Communication" window. The conflict resolution process starts by the introduction of a member of one stakeholder group. Then the member selects the conflict type the group is facing from the three types described in the window presented in Figure 5.2. The conflict described in this section belongs to “Type one” conflict.

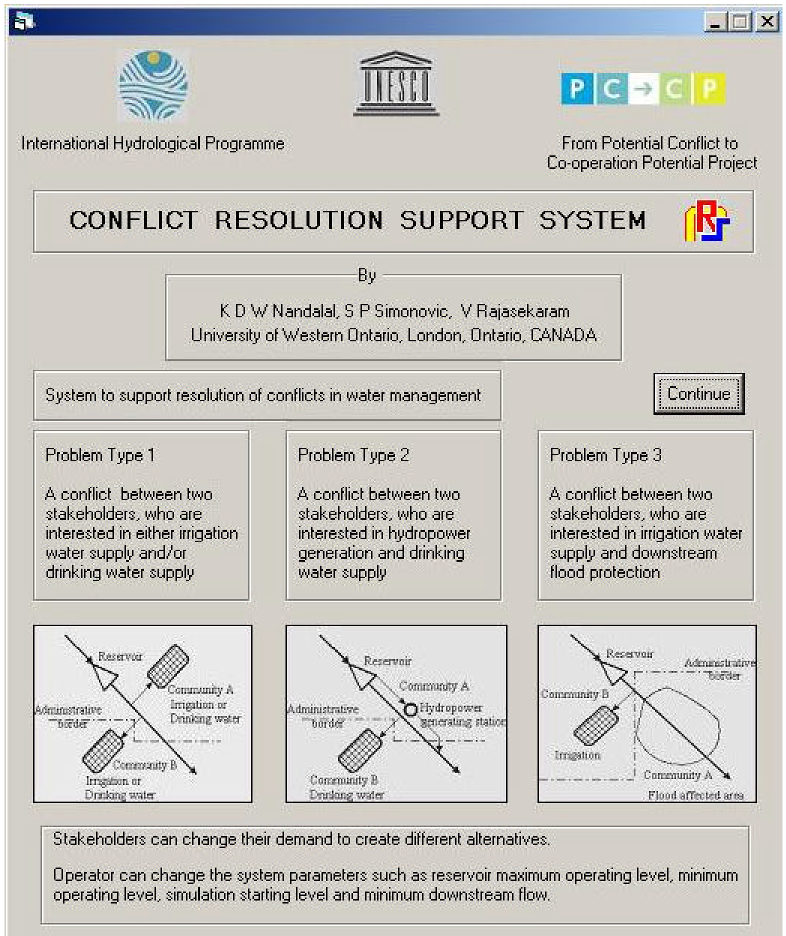


Figure 5.2 Introductory window: Three types of conflicts

The communication with the CRSS continues by identifying the stakeholder’s water use, i.e., irrigation water supply in the present case. Next, the size of the area (24000 ha) planned to be irrigated during the forthcoming year is given.

Then the second group introduces itself and provides its water use, i.e., supplying drinking water in this case. Next, the monthly drinking water demand ($40x10^6$ m^3/month) is entered.

Afterwards, as the CRSS suggests an operator log in and check the data such as reservoir characteristics, inflow, unit irrigation demands, etc., and makes the necessary changes. These changes could be done by typing the requests in the “CRSS Communication” window or by selecting different tasks in the “Options” window. The window showing the options available to the operator and stakeholders is presented in Figure 5.4. Table 5.1 shows the users authorized to perform different tasks.

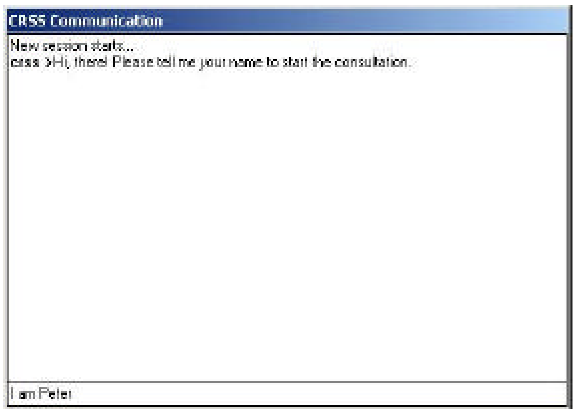


Figure 5.3 CRSS Communication window – Type 1

Table 5.1 Different tasks and authorized users – Type 1

Task	Authorized user	
Edit inflow	Operator	
View inflow	Operator	Stakeholders
Query inflow	Operator	Stakeholders
Edit unit demand	Operator	
Edit reservoir characteristics	Operator	
Edit parameters	Operator	
View demand	Operator	Stakeholders
Run simulation	Operator	
View alternatives	Operator	Stakeholders
Delete alternatives	Operator	
Run Compromise Programming	Operator	
View supply and demand A	Operator	Stakeholder A
View supply and demand B	Operator	Stakeholder B
View deficit	Operator	Stakeholders
View reservoir elevation	Operator	Stakeholders
View reservoir storage	Operator	Stakeholders
View reservoir release	Operator	Stakeholders
View river flow	Operator	Stakeholders

Table 5.1 Continued..		
Quit	Operator	Stakeholders
** Change irrigation/drinking water demand		Stakeholders

** Task is not included in the "Options" window.

The operator and the stakeholders can invoke the tasks either by double clicking the selection in the list or through interacting with the CRSS using "CRSS Communication" window by typing the requested task in the box at the bottom of the window. These requests can be given in full sentences. For example, instead of double clicking "Edit inflow" the operator can type, "I want to change inflow" in the chat box at the bottom of the "CRSS Communication" window.

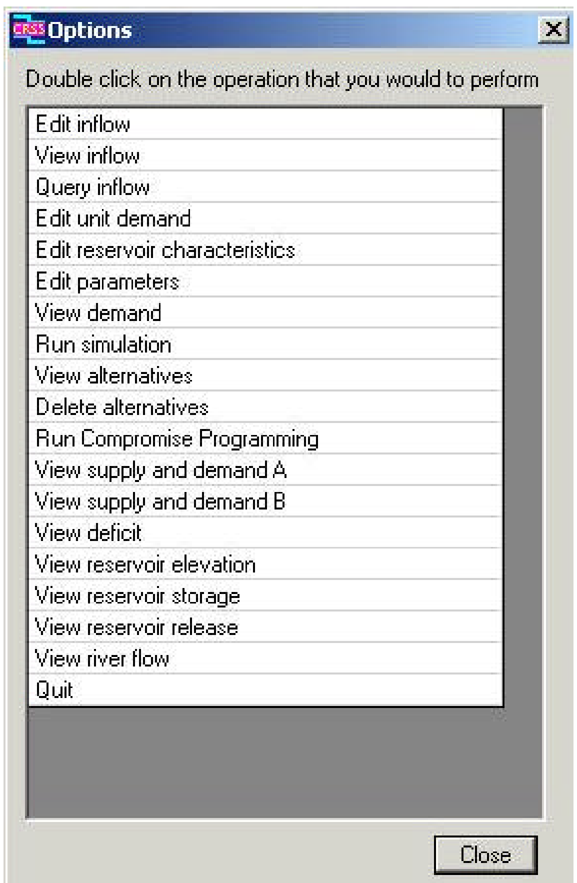


Figure 5.4 Available options - Type 1

5.1.3 Viewing and editing data

The operator can check the inflows as shown in Figure 5.5. If there is a need to change the inflow, that can be done by invoking the "Reservoir Inflow Data" window shown in Figure 5.6. "Query inflow" will give the average monthly inflow, maximum inflow and minimum inflow.

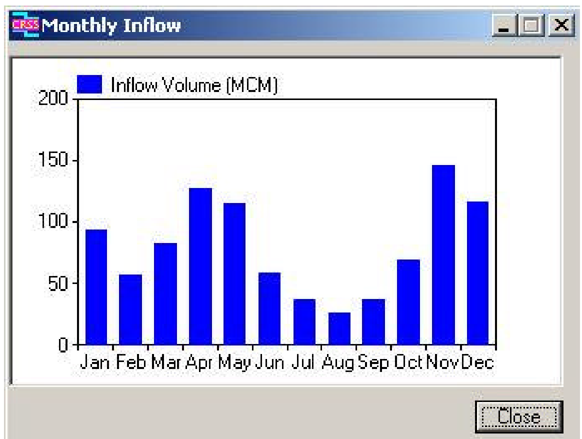


Figure 5.5 Inflow to the reservoir - Type 1

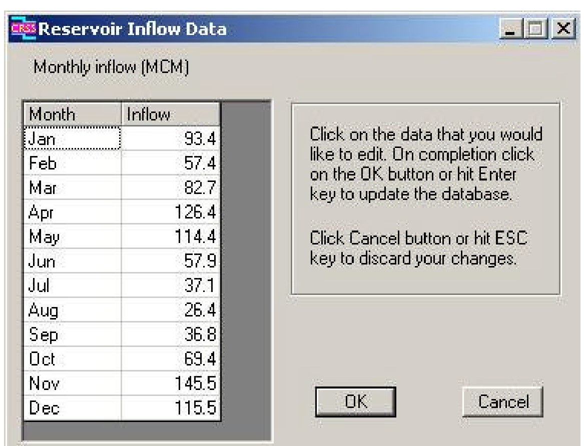


Figure 5.6 Reservoir inflow data – Type 1

The operator can view and change the unit irrigation water demand by invoking "Unit Irrigation Demand Data" window shown in Figure 5.7.

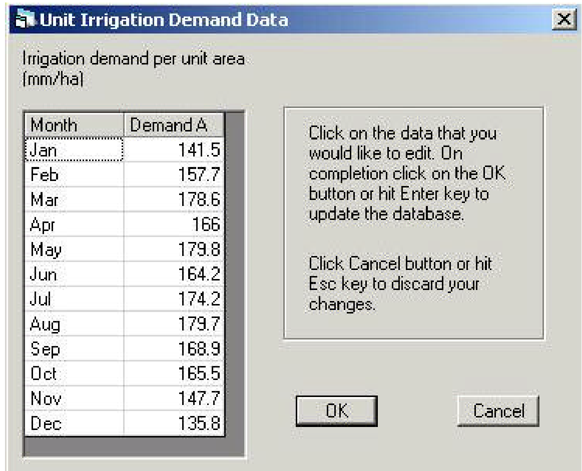


Figure 5.7 Unit irrigation demand – Type 1

The operator is responsible for examining the accuracy of the reservoir storage, area and elevation characteristics. The "Reservoir Characteristics" window, which allows access to these data, is shown in Figure 5.8.

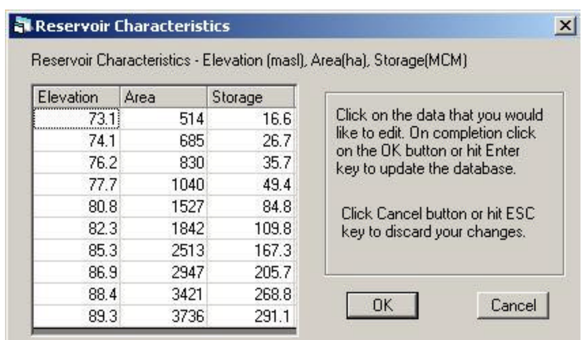


Figure 5.8 Reservoir characteristics – Type 1

The "System Operation Parameters" window shows the system operation parameters (Figure 5.9). The reservoir maximum and minimum operating levels, starting reservoir level and downstream required flow could be edited in this window. The operator can change the various demands of the stakeholders through this window too.

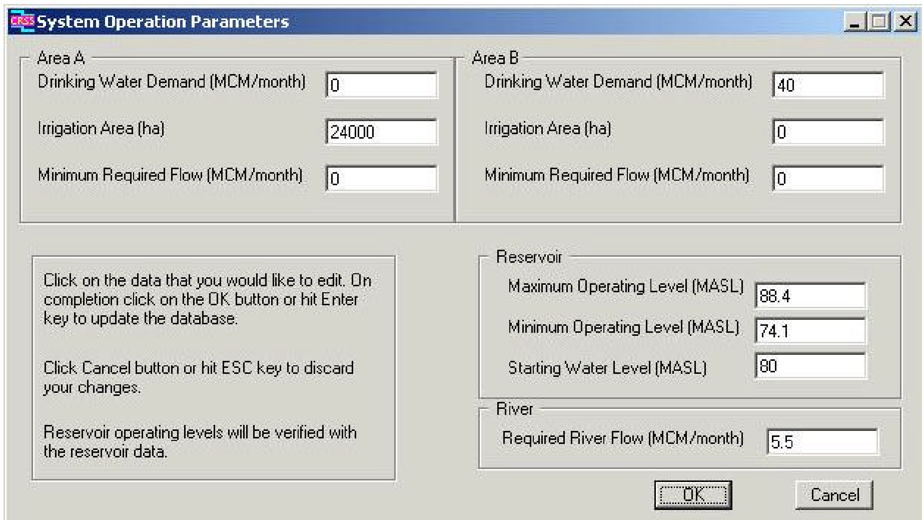


Figure 5.9 Parameters of the system – Type 1

Before simulating the system, the monthly demands of the two stakeholder groups can be reviewed as presented in Figure 5.10.

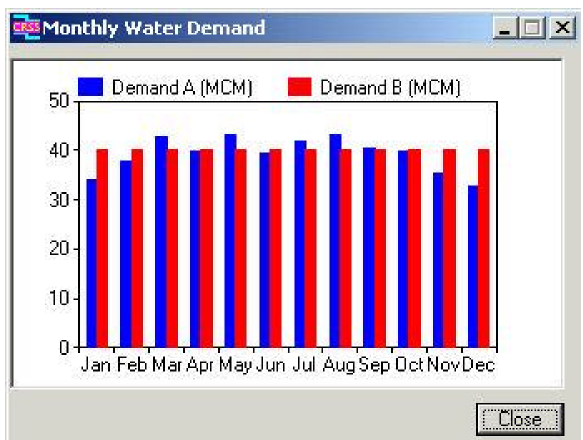


Figure 5.10 Demands of the two stakeholders – Type 1

After all the reservoir parameters, inflows and demands are given, the operator simulates the reservoir operation to determine the availability of water during the year. The simulation run, which is named Alter1, shows deficits in both areas. The deficit of the stakeholder "A" and stakeholder "B" resulted from the simulation are 54.11×10^6 m^3 and 52.28×10^6 m^3, respectively.

5.1.4 Results of a water allocation alternative

If both groups show an interest in reviewing their deficits, the operator or the stakeholders can access them from the CRSS. The deficits during the year are shown in Figure 5.11. If needed, the two stakeholder groups can review their demand and supply separately, too. For example, if stakeholder "A" wants to see their demand and supply, those will be as shown in Figure 5.12. Similarly, stakeholder "B" can review their demand and supply.

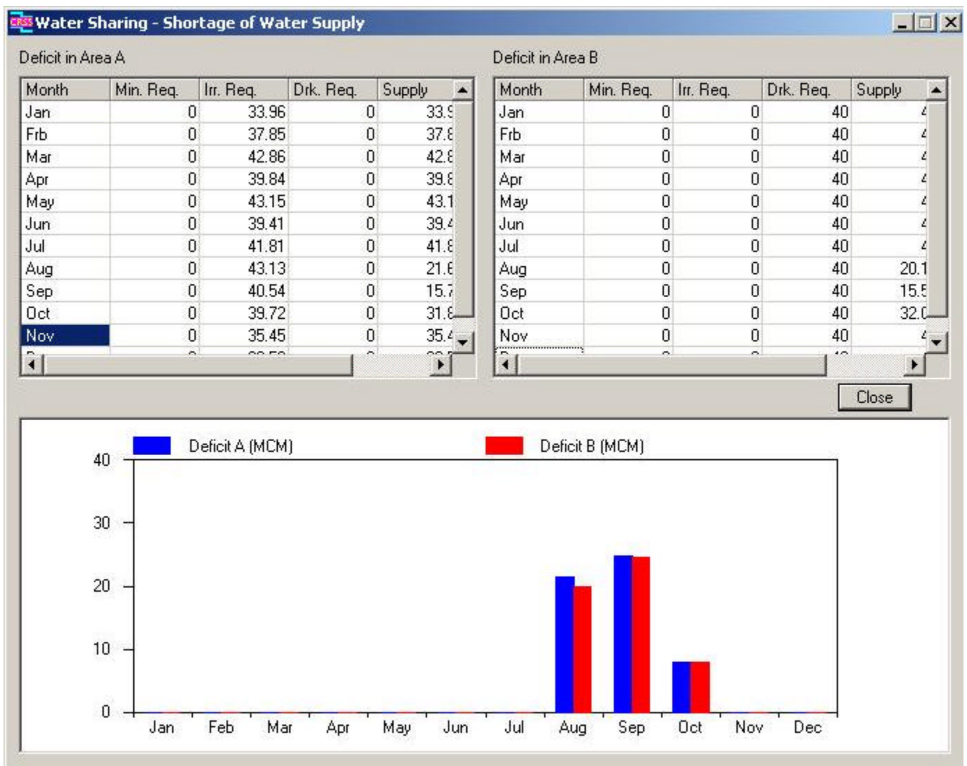


Figure 5.11 Deficits in the satisfaction of demands – Type 1

The behaviour of the reservoir is of importance. The variation of reservoir storage and elevation are shown in Figures 5.13 and 5.14, respectively. The downstream river flow (required releases) is shown in Figure 5.15.

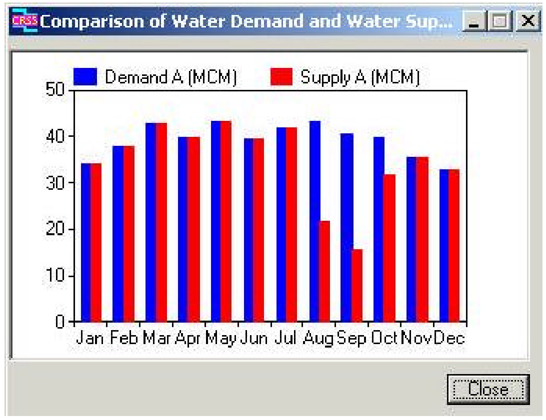


Figure 5.12 Demand and supply for stakeholder " A" – Type 1

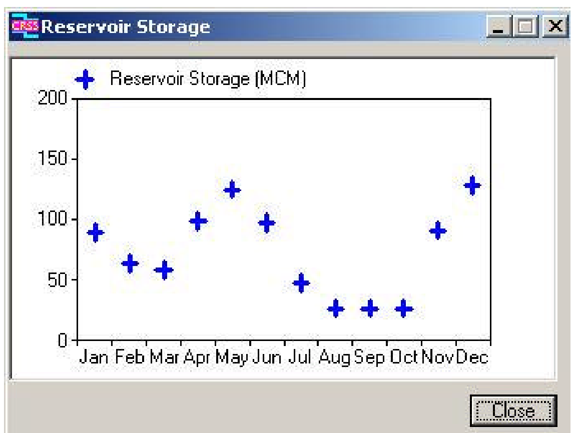


Figure 5.13 Variation of reservoir storage – Type 1

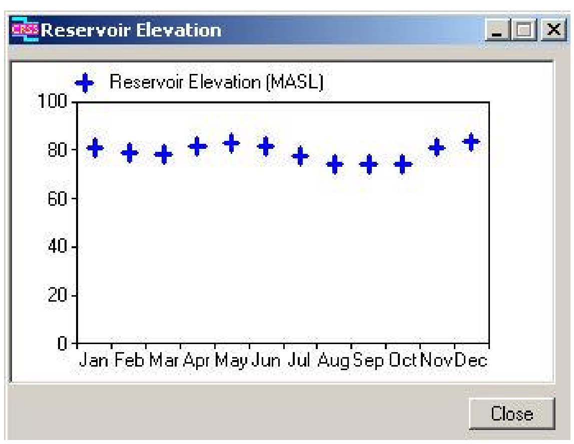


Figure 5.14 Variation of reservoir elevation – Type 1

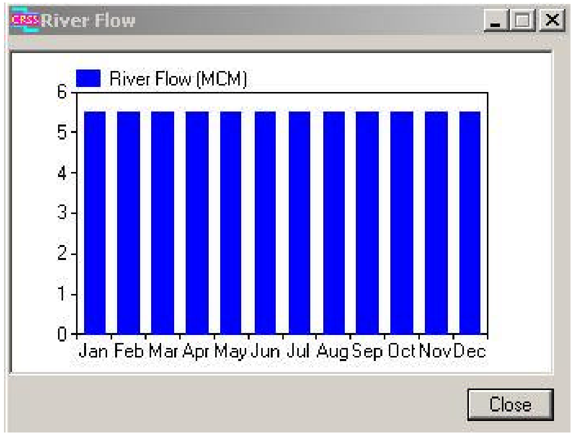


Figure 5.15 Downstream river flow – Type 1

5.1.5 Development and evaluation of alternatives

Since the deficits in the studied alternative are high, both groups agree to bring down their demand and review the situation. First, a member of community "A" logs in and changes their irrigable area demand to 23500 ha. Then, community "B" changes its drinking water supply demand to $36x10^6$ m^3/month. Subsequently, the operator simulates the system to evaluate the performance. The simulation results in deficits of $30.41x10^6$ m^3 and $27.60x10^3$ m^6 for stakeholder "A" and stakeholder "B", respectively.

Next, the stakeholder "B" shows an interest in evaluating the situation with further reduction of their monthly drinking water demand to $34x10^6$ m^3/month. However, they request a minimum supply of $20x10^6$ m^3/month. The stakeholder "A" does not change their demand. The simulation of this alternative results in deficits of $20.43x10^6$ m^3 and $17.58x10^6$ m^3 for stakeholder "A" and stakeholder "B", respectively.

Then the stakeholder "B" requests their previous demand of $36x10^6$ m^3/month with a minimum supply of $20x10^6$ m^3/month. The operator simulates the system with these requirements and found the deficits to be $30.41x10^6$ m^3 and $27.60x10^6$ m^3 for stakeholder "A" and stakeholder "B", respectively.

The operator suggests reducing the downstream water release requirement to $5.2x10^6$ m^3/month and both groups agree to evaluate the consequences of that change. The simulation with the new requirement results in deficits of $28.80x10^6$ m^3 and $26.22x10^6$ m^3 for stakeholder "A" and stakeholder "B", respectively.

The stakeholder groups want to look at all the alternatives studied so far shown in Table 5.2. The CRSS can present all the alternatives as shown in Figure 5.16. The corresponding rank for each alternative is also shown in the figure.

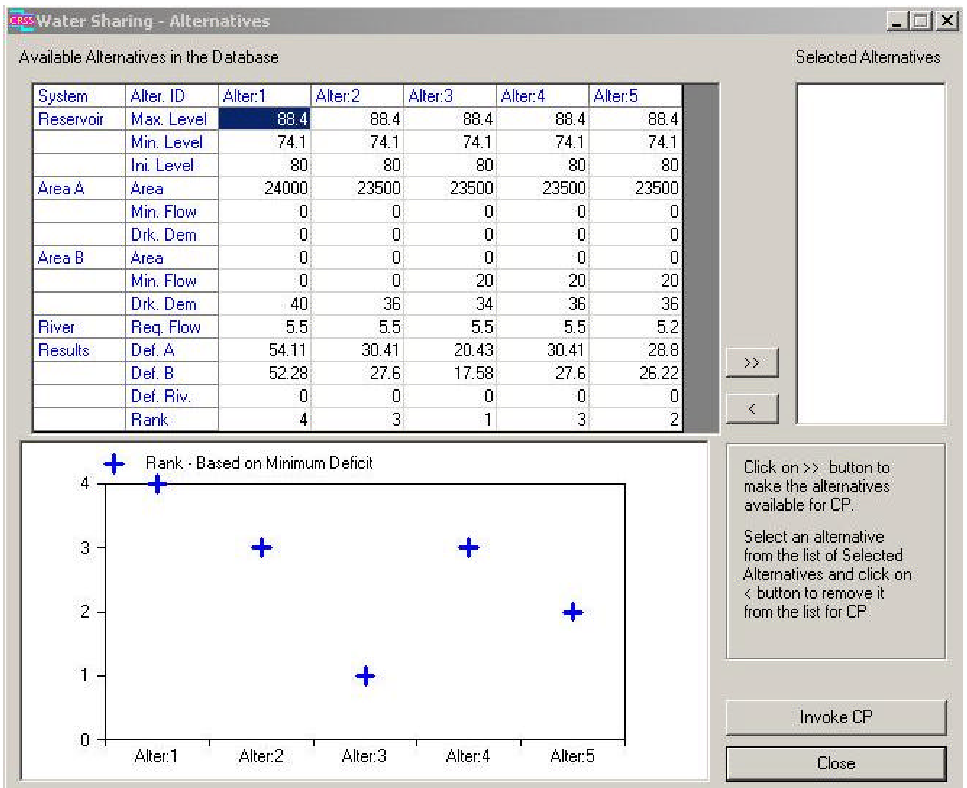


Figure 5.16 Comparison of alternatives – Type 1

If required, the comparison of only a few alternatives selected from the above set could be carried out. Also, different weights could be assigned to the stakeholders' requests at that stage. The operator is requested to rank the alternative 2, 3, 4 and 5 assigning weights of 0.6 and 0.4 to community "A" and community "B", respectively. Figure 5.17 shows the rank of the selected alternatives after assigning a new set of weights.

Table 5.2 Details of alternatives – Type 1

	Group A		Group B		Minimum river flow (MCM)
Alternative	Requested Irrigation Area (ha)	Annual Flow Deficit (MCM)	Monthly drinking demand (MCM)	Annual Deficit (MCM)	
Alt 1	24000	54.11	40	52.28	5.5
Alt 2	23500	30.41	36	26.70	5.5
Alt 3	23500	20.43	34	17.58	5.5
Alt 4	23500	30.41	36	27.60	5.5
Alt 5	23500	28.80	36	26.22	5.2

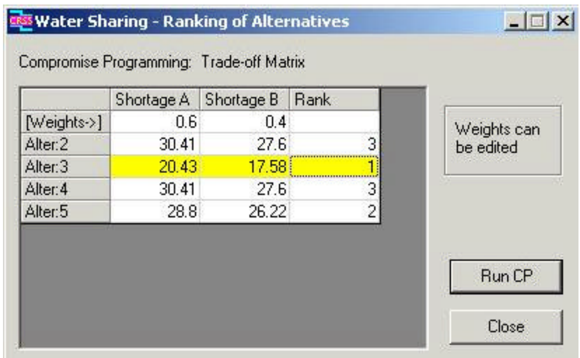


Figure 5.17 Compromise Programming based rank with a new set of weights – Type 1

If the two stakeholder groups agree on one of the water allocation alternatives, they can stop the consultation. Otherwise, they can continue to change their requirements and simulate the system until an agreement between them is reached regarding the water allocation.

5.2 Case 2: Conflict between Hydropower Generation and Drinking Water Supply

5.2.1 Description of the conflict

The system comprises a reservoir, a hydropower generating station and a downstream town area as shown in Figure 5.18. The stakeholder group, who owns the generating station wishes to generate hydro energy as much as possible to match their target level. To meet their needs the reservoir level has to be kept high so that the head available for power generation remains high. However, this affects the other stakeholder, who needs water for his drinking water supply. Thus, the two stakeholders confront in meeting their objectives of water sharing for hydropower generation and drinking water supply.

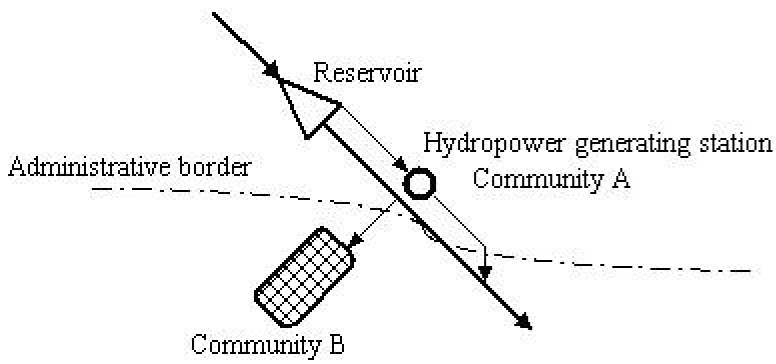


Figure 5.18 Schematic diagram of the water resource system: Conflict Type 2

The reservoir with active storage capacity of 153.4×10^6 m^3 regulates the river flow to generate hydropower and to satisfy drinking water requirements of the downstream community "B" as shown in Figure 5.18. Reservoir maximum and minimum operating levels are 1010 masl and 725 masl, respectively. The artificial intelligence based communication module of the CRSS assists the stakeholders in the development of several water allocation scenarios to arrive at an agreement on the allocation of water. The communication used by the stakeholders to analyse this conflict is available in Appendix B.

5.2.2 Application of CRSS

The two stakeholder groups rely on the assistance of the CRSS to resolve the conflict. The execution of the CRSS starts with an introductory window as shown in Figure 5.19. It shows the different types of problems that the system is capable in handling. Continuation of the consultation process takes the stakeholders to the “CRSS communication” window shown in Figure 5.20. All the interactions of the stakeholders or the operator (queries, answers etc.) with the system should be typed in the box at the bottom of the “CRSS Communication” window.

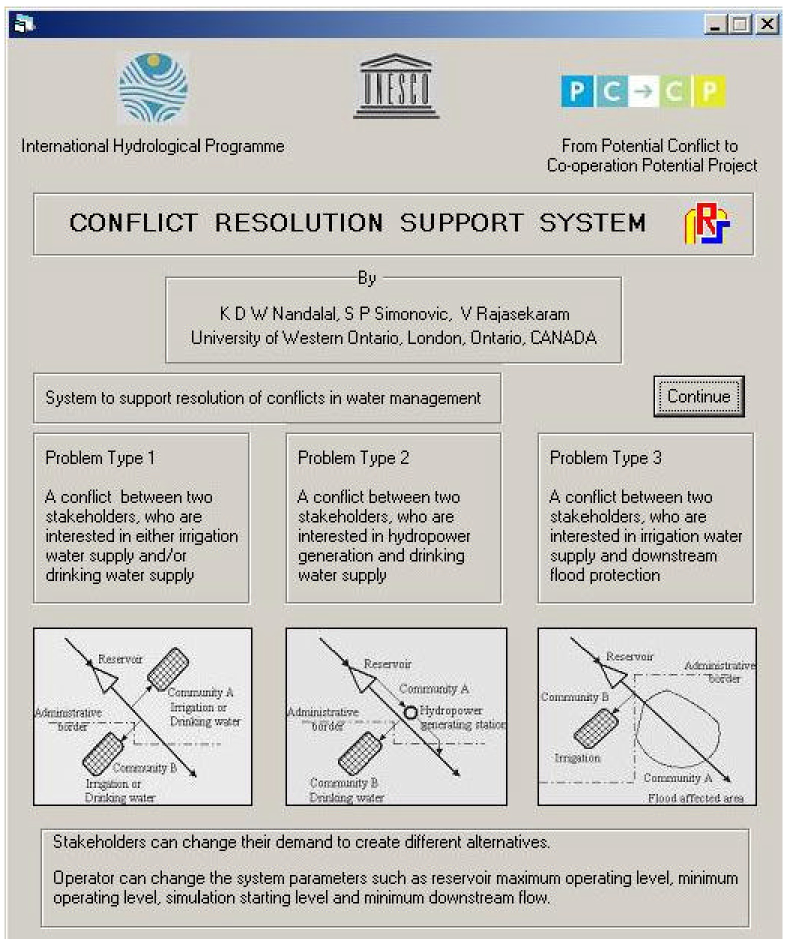


Figure 5.19 Introductory window: Three types of conflicts

The conflict resolution process starts by the introduction of a member of one stakeholder group (stakeholder “A”). Then the member selects the conflict type the group is facing from the three types described in the window presented in Figure 5.19. The conflict described in this section belongs to “Type two” conflict.

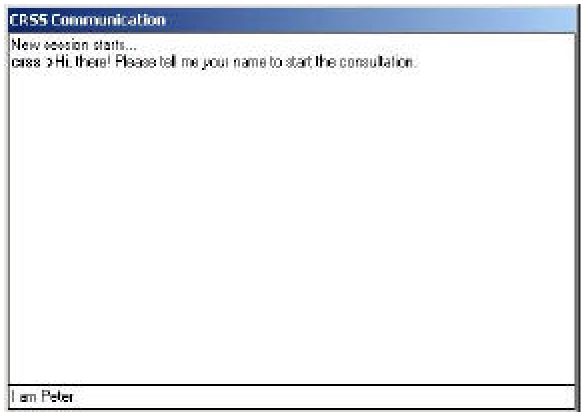


Figure 5.20 CRSS Communication window – Type 2

The communication with CRSS continues by identification of stakeholders water use, i.e., hydropower generation. Then the stakeholder can provide the hydropower demand through the window shown in Figure 5.21.

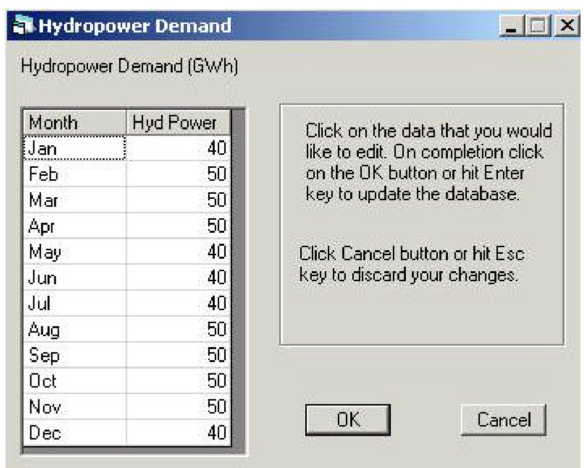


Figure 5.21 Monthly hydropower demand – Type 2

The CRSS then requests the requirements of the other stakeholder group. A member of the other stakeholder group (stakeholder “B”) similarly logs in and provides group’s concern, i.e., drinking water supply. Similar to the previous one, a table showing monthly drinking water demand as given on Figure 5.22 appears in the screen. The second group can provide their monthly drinking water demand and move forward by accepting changes.

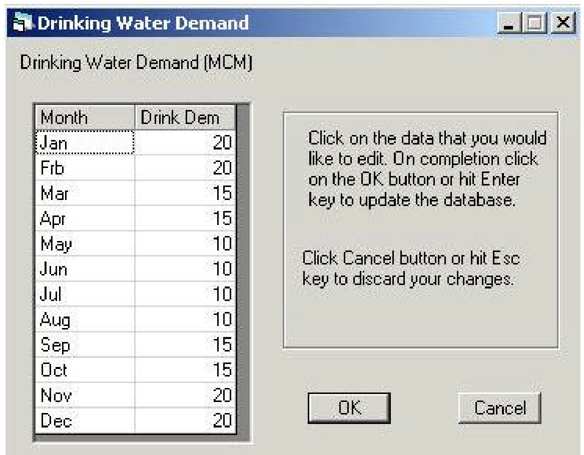


Figure 5.22 Monthly drinking water demand – Type 2

Then, the CRSS indicates that an operator could log in and simulate the system to see the availability of water for different needs during the year. An operator can review various options available for the continuation of the conflict resolution process. Figure 5.23 shows the window that includes the various "Options" available in the resolution of a "Type 2" conflict. Table 5.2 shows the users authorized to perform different tasks.

Table 5.3 Different tasks and authorized users – Type 2

Task	Authorized user	
Edit inflow	Operator	
View inflow	Operator	Stakeholders
Query inflow	Operator	Stakeholders
Edit reservoir characteristics	Operator	
Edit rule curve	Operator	
Edit hydropower demand		Stakeholders
Edit drinking water demand		Stakeholders
Edit parameters	Operator	
View hydropower demand	Operator	Stakeholders
View drinking water demand	Operator	Stakeholders
Run simulation	Operator	
View alternatives	Operator	Stakeholders

Table 5.3 Continued..

Delete alternatives	Operator	
Run Compromise Programming	Operator	
View hydropower demand and supply	Operator	Stakeholders
View drinking water demand and supply	Operator	Stakeholders
View reservoir elevation	Operator	Stakeholders
View reservoir storage	Operator	Stakeholders
View reservoir release	Operator	Stakeholders
View river flow	Operator	Stakeholders
Quit	Operator	Stakeholders

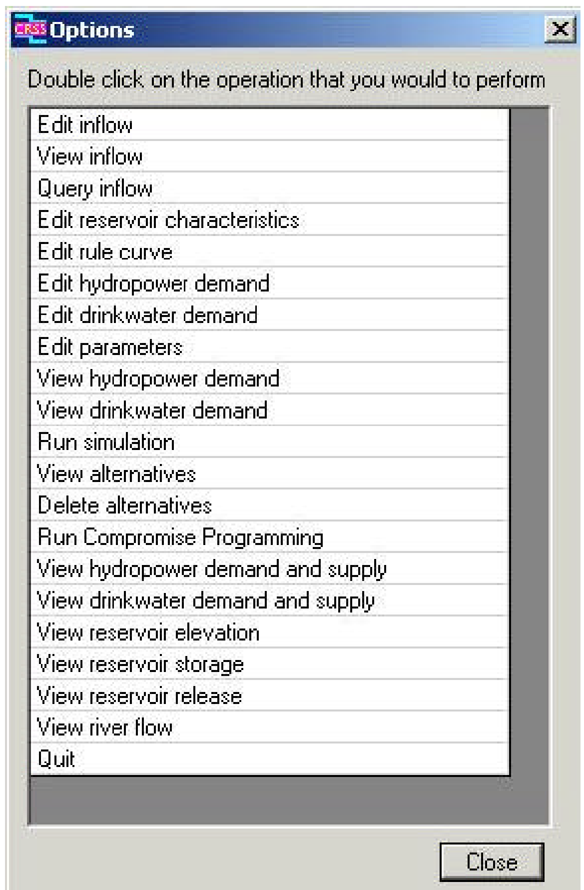


Figure 5.23 Available options – Type 2

The operator and the stakeholders can invoke the tasks either by double clicking the selection in the list or through interacting with the CRSS using "CRSS Communication" window by typing the requested task in the box at the bottom of the window. These requests can be given in full sentences. For example, instead of double clicking "Edit inflow" the operator can type, "I want to change inflow" in the chat box at the bottom of the "CRSS Communication" window.

5.2.3 Viewing and editing data

The operator can verify whether the reservoir characteristics are correct at the outset of the conflict resolution process. The reservoir parameters such as maximum and minimum reservoir levels etc., could be edited by invoking "System Operation Parameters" window shown in Figure 5.24.

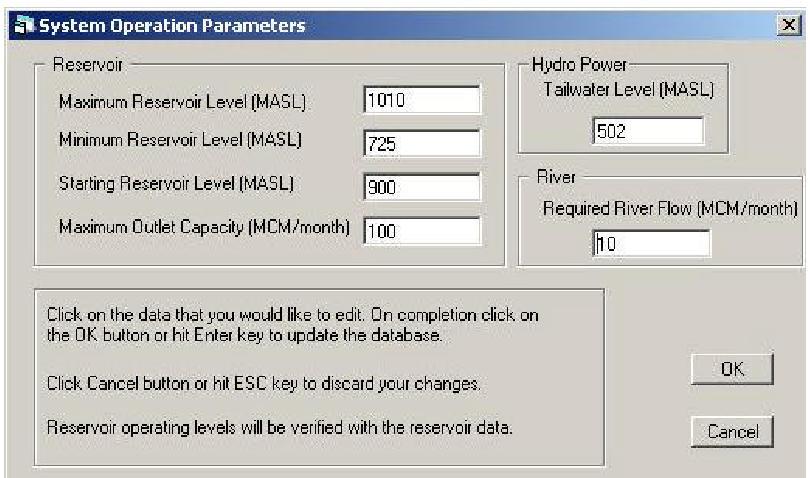


Figure 5.24 Parameters of the system - Type 2

The reservoir parameters, maximum operating level, minimum operating level and reservoir water level at the beginning of the simulation period could be changed if necessary. The maximum outlet capacity and the tail water level of the hydropower plant also can be changed through this window. The required river flow is the minimum amount of water that is required to flow along the river for ecological purposes. Changing all these values is the responsibility of the operator. The operator can see the reservoir storage-area-elevation relationship by invoking "Reservoir Characteristics" window shown in Figure 5.25. The operator can also review the reservoir operating rule curve shown in Figure 5.26 and make necessary changes.

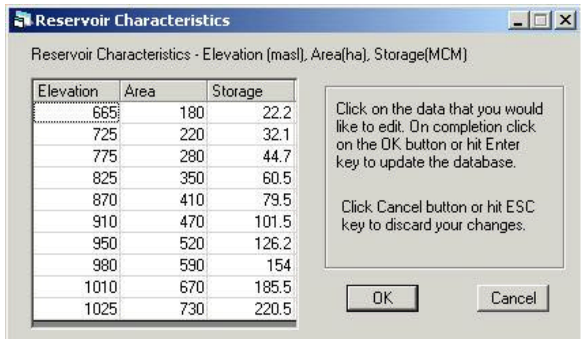


Figure 5.25 Reservoir characteristics – Type 2

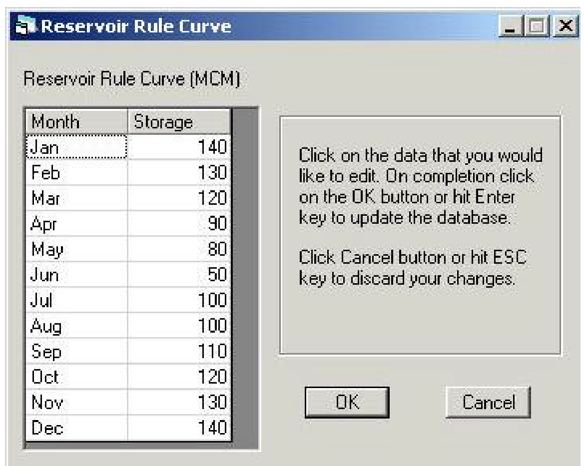


Figure 5.26 Reservoir operating rule curve - Type 2

Reservoir inflows can be reviewed and edited using the “Reservoir Inflow Data” window shown in Figure 5.27.

The monthly hydropower and drinking water demand could be reviewed before simulating the system performance. These demands are shown in Figure 5.28. Changing hydropower or drinking water demand is the responsibility of stakeholders. The operator is not allowed to do that. For example, if the first stakeholder group wants to change their hydropower demand, a member of that group will need to log into the CRSS and change the demand.

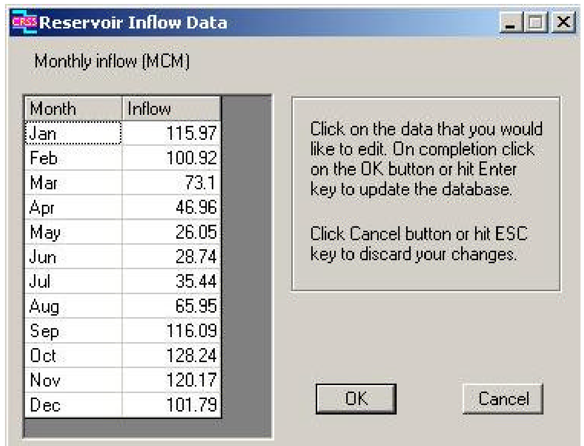


Figure 5.27 Inflow to the reservoir – Type 2

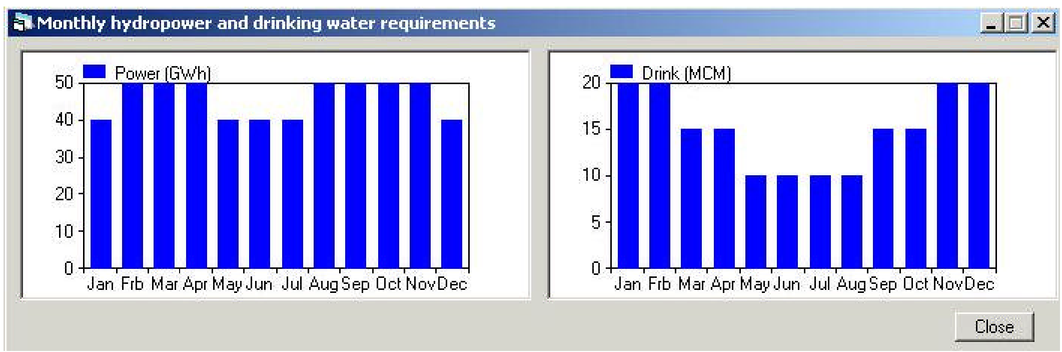


Figure 5.28 Monthly hydropower and drinking water requirements – Type 2

The simulation of the system by the operator with the given information results in 51.61 GWh of hydropower deficit and 11.52×10^6 m^3 of drinking water deficit.

5.2.4 Results of a water allocation alternative

Both the operator and/or the stakeholders could assess the hydropower and drinking water demands and allocations. Figure 5.29 shows the demands and supplies.

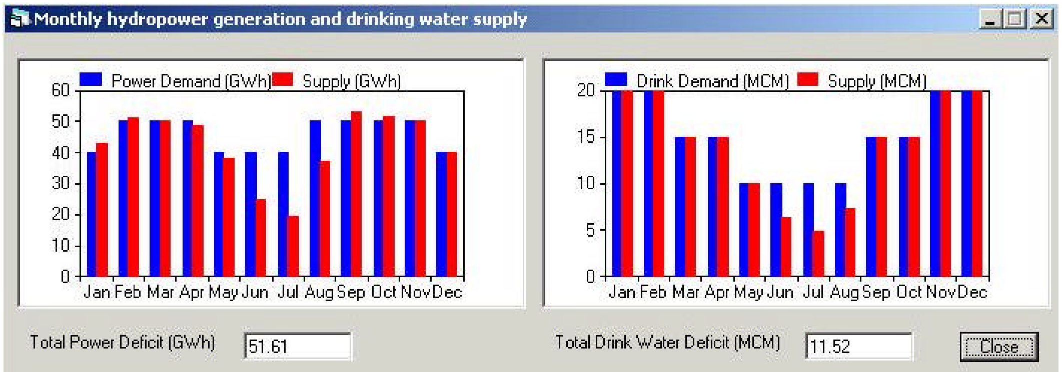


Figure 5.29 Monthly hydropower and drinking water requirements and allocations – Type 2

The variation of the reservoir storage and elevation are shown in Figure 5.30 and Figure 5.31, respectively. Figure 5.32 presents the total monthly release from the reservoir. Total release includes release for power generation, drinking water supply and downstream minimum water flow.

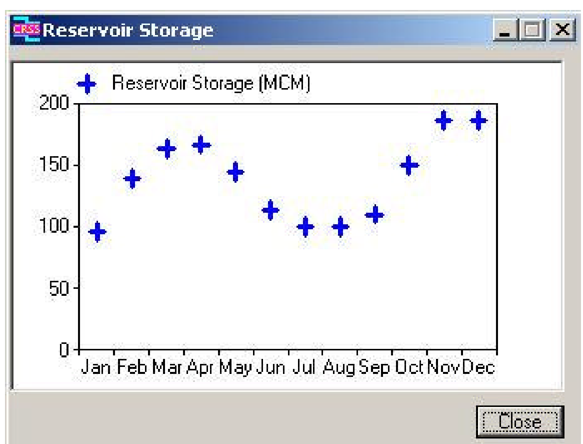


Figure 5.30 Variation of reservoir storage – Type 2

The downstream river flow that includes the minimum required downstream flow and the reservoir spill (if any) is shown in Figure 5.33.

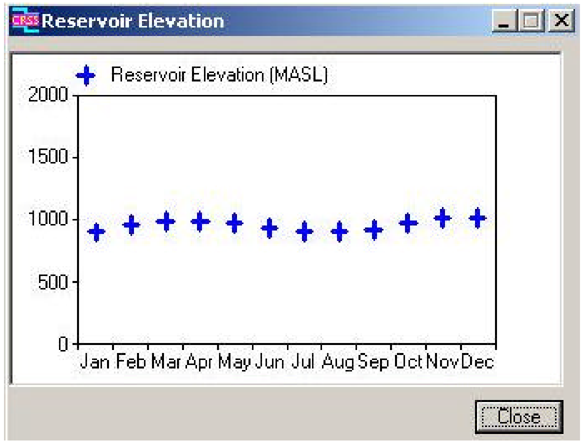


Figure 5.31 Variation of reservoir elevation – Type 2

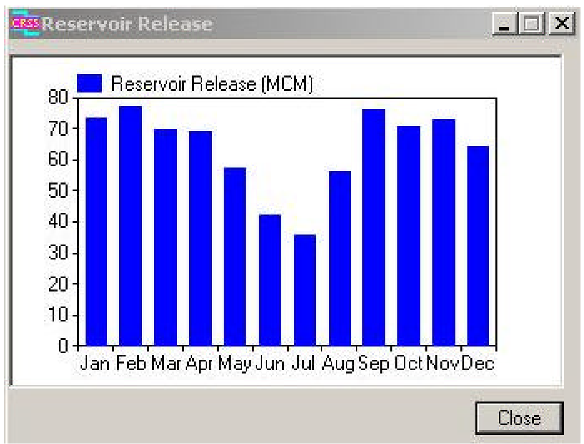


Figure 5.32 Monthly reservoir releases – Type 2

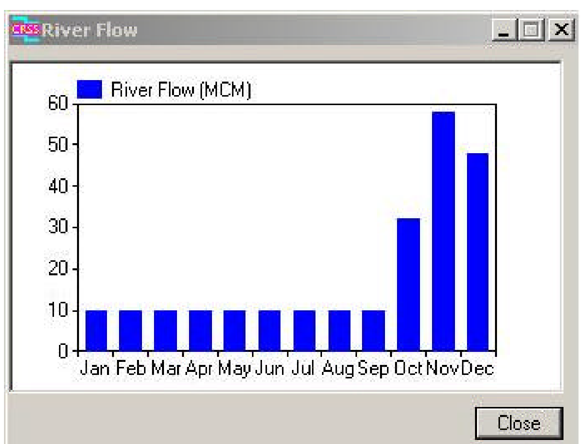


Figure 5.33 Downstream river flow – Type 2

5.2.5 Development and evaluation of alternatives

The simulation of reservoir performance shows that both groups will experience deficits in water allocation. Therefore, they are interested in developing several other demand alternatives. A member of the community “A” (the same person or a different person in the group) can agree to change the hydropower demand to the values shown in Figure 5.34. The stakeholder “B” does not change its requirement. The operator logs in and simulates the system water availability.

The simulation results in hydropower generation deficit of 38.44 GWh and drinking water supply deficit of 9.59×10^6 m^3 for the stakeholder “A” and stakeholder “B”, respectively. The stakeholders can assess and compare the two alternatives that they have studied thus far by activating the “Water Sharing - Alternatives” window.

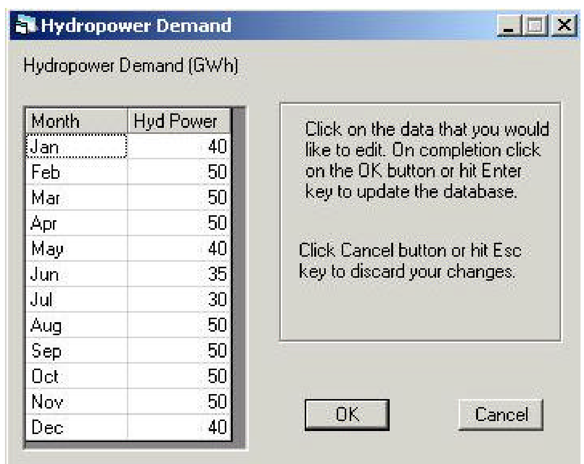


Figure 5.34 Modified hydropower demand – Type 2

However, since there are high deficits, the community “B” agrees to reduce their demand. A member of the group logs in and reduces the drinking water demand to the values shown in Figure 5.35. The deficit with these requirements is 36.42 GWh and 7.72×10^6 m^3 for the stakeholder “A” and stakeholder “B”, respectively.

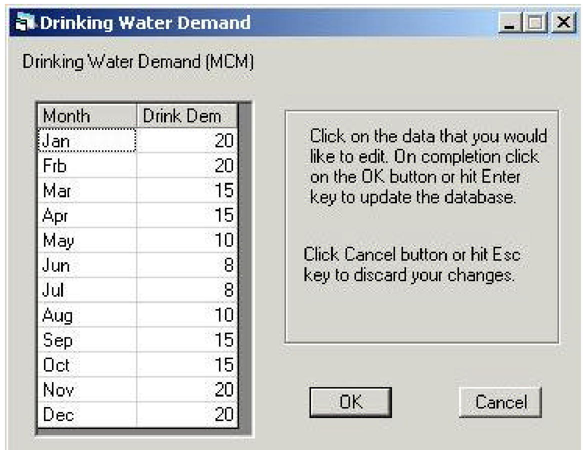


Figure 5.35 Modified drinking water demands – Type 2

Both parties do not agree to change their demands further. The operation of the reservoir is based on an operating rule curve developed on the basis of a long inflow series. Changing the rule curve could affect the hydropower generation and drinking water supply. The stakeholder “A” knows that they can increase the hydropower generation by keeping the reservoir elevation high so that the head available for hydropower generation is high. They propose a modification to the rule curve to keep the reservoir elevation at a higher level. The operator can modify the rule curve to, for example, values shown in Figure 5.36 and simulates the system performance again. The results show the hydropower deficit of 32.92 GWh and drinking water deficit of 6.17x10^{6} m^{3}, a better solution than the previous one.

However, the stakeholder “A” insists on more power generation and the operator changes the rule curve once more to the one given in Figure 5.37. The simulation of the system by the operator with the new set of data results in hydropower deficit of 31.34 GWh and drinking water deficit of 6.35x10^{6} m^{3} for the stakeholder “A” and stakeholder “B”, respectively.

The members of community “A” request the operator to change the rule curve once again to the values shown in Figure 5.38. The simulation of the system with the modified rule curve results in the hydropower deficit of 29.85 GWh and the drinking water deficit of 6.42x10^{6} m^{3}for the stakeholder “A” and stakeholder “B”, respectively.

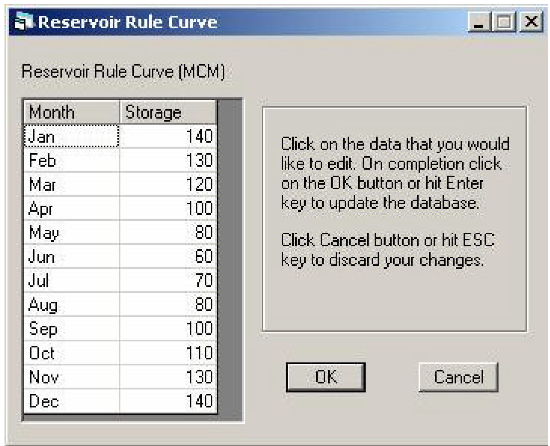


Figure 5.36 Modified rule curve; First attempt – Type 2

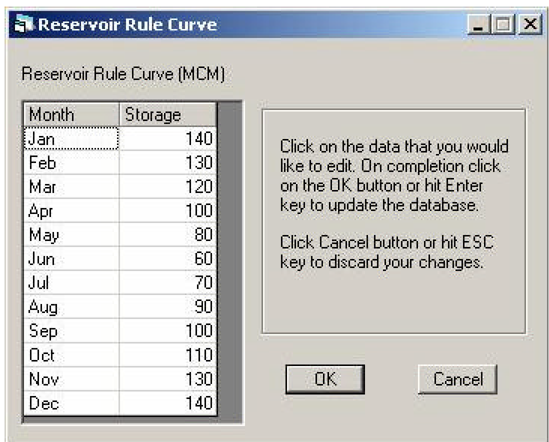


Figure 5.37 Modified rule curve; Second attempt – Type 2

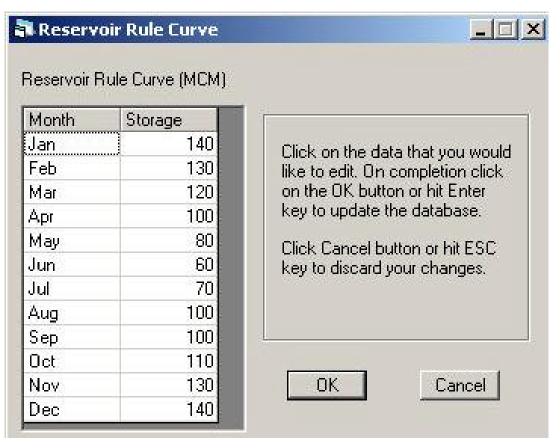


Figure 5.38 Modified rule curve; Third attempt – Type 2

The operator changes the rule curve for the fourth time to the values shown in Figure 5.39 as requested by both groups. The simulation of the system with the present rule curve results in hydropower deficits of 37.02 GWh and drinking water deficits of 8.0×10^6 m^3 for the stakeholder “A” and stakeholder “B”, respectively.

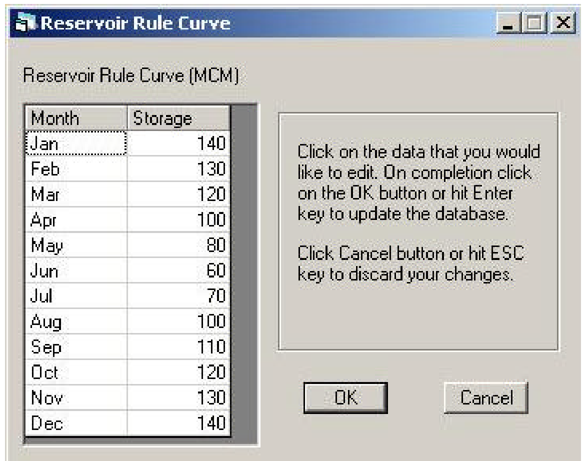


Figure 5.39 Modified rule curve; Fourth attempt – Type 2

The groups are now interested in reviewing all the alternatives they have developed shown in Table 5.4. A request to show the alternatives presents all of them in the window as shown in Figure 5.40.

Table 5.4 Details of alternatives – Type 2

	Group A	Group B	
Alternative	Annual Power Deficit (GWh)	Annual Drinkwater Deficit (MCM)	Minimum river flow (MCM)
Alt 1	51.61	11.52	10
Alt 2	38.44	9.59	10
Alt 3	36.42	7.72	10
Alt 4	32.92	6.17	10
Alt 5	31.34	6.35	10
Alt 6	29.85	6.42	10
Alt 7	37.02	8.00	10

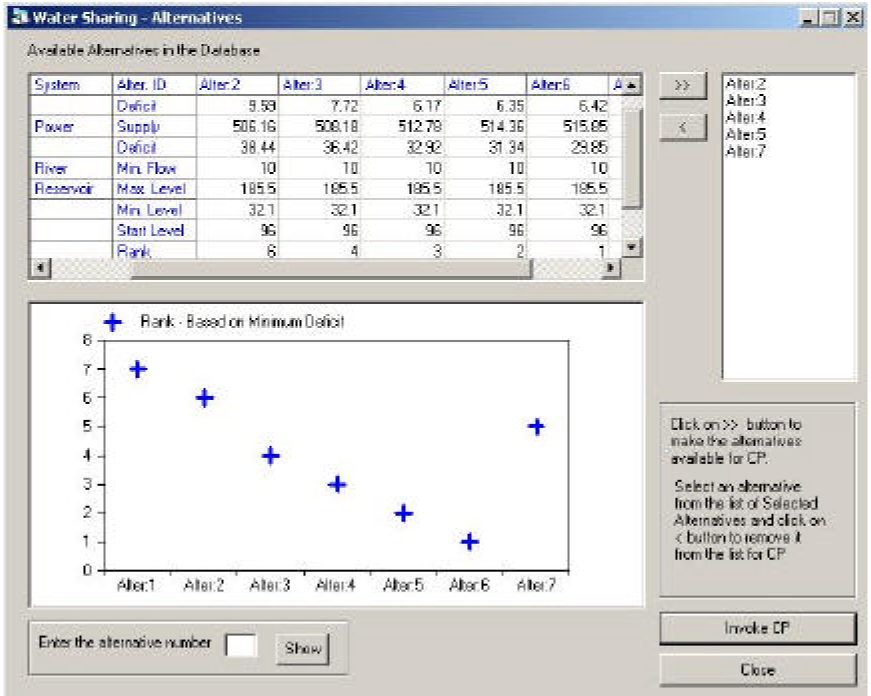
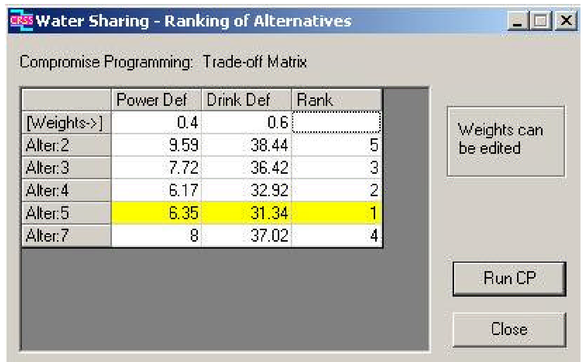


Figure 5.40 Comparison of alternatives – Type 2

According to that figure the “Alternative 6” seems to be the best. An equal importance is given to the two stakeholders to arrive at that solution. However, if different importance (or weight) is to be given to the stakeholders, the Compromise Programming module must be activated. Also, if only a few selected alternatives is needed to be ranked, that can be done by selecting the alternatives in the “Water Sharing - Alternatives” window and activating the Compromise Programming module.

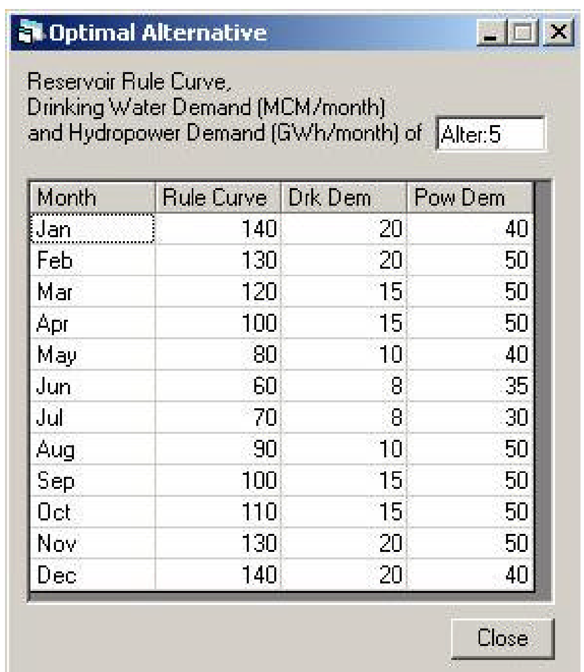
If required, the comparison of only a few alternatives selected from the above set could be carried out. Also, different weights could be assigned to the stakeholders’ requests at that stage. If the comparison of alternatives 2, 3, 4, 5 and 7 is done with weights of 0.4 and 0.6 to hydropower generation and drinking water supply, respectively, the Compromise Programming window shown in Figure 5.41 presents the resulting ranks. It is noted that the “Alternative 5” is the best compromise.

If the rule curve adopted in the "Alternative 5" is of interest, it can be obtained by requesting the presentation of the details in the "Water Sharing - Alternatives" window. Figure 5.42 shows the rule curve and the demands corresponding to the "Alternative 5".



	Power Def	Drink Def	Rank
[Weights->]	0.4	0.6	
Alter:2	9.59	38.44	5
Alter:3	7.72	36.42	3
Alter:4	6.17	32.92	2
Alter:5	6.35	31.34	1
Alter:7	8	37.02	4

Figure 5.41 Compromise Programming based rank with a new set of weights – Type 2



Month	Rule Curve	Drk Dem	Pow Dem
Jan	140	20	40
Feb	130	20	50
Mar	120	15	50
Apr	100	15	50
May	80	10	40
Jun	60	8	35
Jul	70	8	30
Aug	90	10	50
Sep	100	15	50
Oct	110	15	50
Nov	130	20	50
Dec	140	20	40

Figure 5.42 Details of Alternative 5 - Type 2

If the two stakeholder groups are satisfied with the compromise they can stop the consultation process. Otherwise, they can continue to develop and investigate more alternatives in addition to the existing ones. They can delete the exiting alternatives and develop a new set of alternatives for comparison, too. This consultation process can continue until an agreement is achieved.

5.3 Case 3: Conflict between Flood Protection and Irrigation Water Supply

5.3.1 Description of the conflict

The system comprises a reservoir, an irrigation area and a downstream area to be protected from floods as shown in Figure 5.43. The stakeholder “B” is interested in irrigation needs water to be released during the dry season and stored during the wet season while the stakeholder “B” downstream wants to keep the reservoir storage at a low level in order to maximize the flood protection during the wet season. Thus, the two stakeholder groups confront in fulfilling their objectives in the management of the reservoir for flood protection and irrigation water supply.

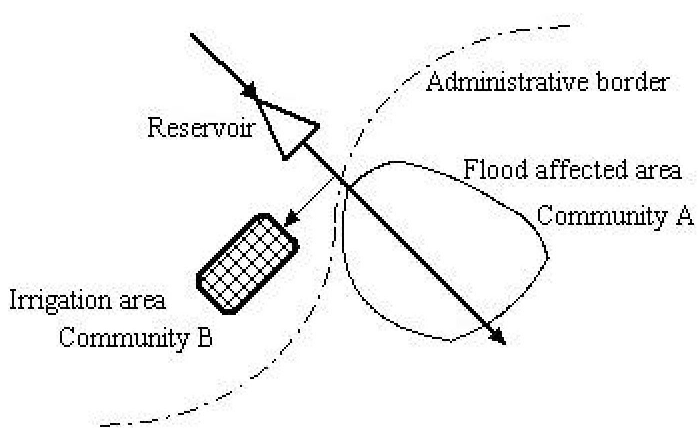


Figure 5.43 Schematic diagram of the water resource system: Conflict Type 3

The reservoir, with active storage capacity of 153.4×10^6 m^3 regulates the river flow to protect downstream area from floods and to satisfy irrigation water requirements. Its maximum and minimum operating levels are 705 masl and 670 masl respectively. The artificial intelligence based communication module of the CRSS assists the stakeholders in the development of several water allocation alternatives to arrive at an agreement on the final allocation of water. One example of the communication by the stakeholders to analyse this problem is available in Appendix C.

5.3.2 Application of CRSS

The two stakeholder groups will use the assistance of the CRSS to resolve their conflict. The application of the CRSS starts with an introductory window as shown in Figure 5.44. It shows the different types of problems that the system is capable in handling. Continuation of the consultation process takes the stakeholders to the "CRSS communication" window shown in Figure 5.45. All the interactions of the stakeholders or the operator (queries, answers etc.) with the system should be typed in the box at the bottom of the "CRSS Communication" window. The conflict resolution process starts by the introduction of a member of one stakeholder group (community "A"). Then the member selects the conflict type the group is facing from the three types described in the window presented in Figure 5.44. The conflict described in this section belongs to "Type three" conflict.

The communication of the stakeholder with CRSS continues by expression of concern, i.e., flood protection. Then the stakeholder is asked to provide the downstream flood level the group would consider acceptable. The stakeholder "A" requires the flood level to be below 2.2 m (above the river bottom level). The group is well aware of the flooding levels in their area and they can review the levels at a later stage.

The CRSS then requests the requirements of the other group. A member of the other stakeholder group (community "B") similarly logs in and provides the group's concern, i.e., irrigation water supply. Then the member of the group is asked to identify the irrigation area the group intends to cultivate in the coming year. Their request is for an area of 60,000 ha.

Subsequently, the CRSS indicates that an operator could log in and simulate the system performance to assess the irrigation water supply and flood levels. An operator can log in, next and review various tasks available for the continuation of the conflict resolution process. Figure 5.46 shows the "Options" window available in the resolution of a "Type 3" conflict. Table 5.3 shows the users authorized to perform different tasks.

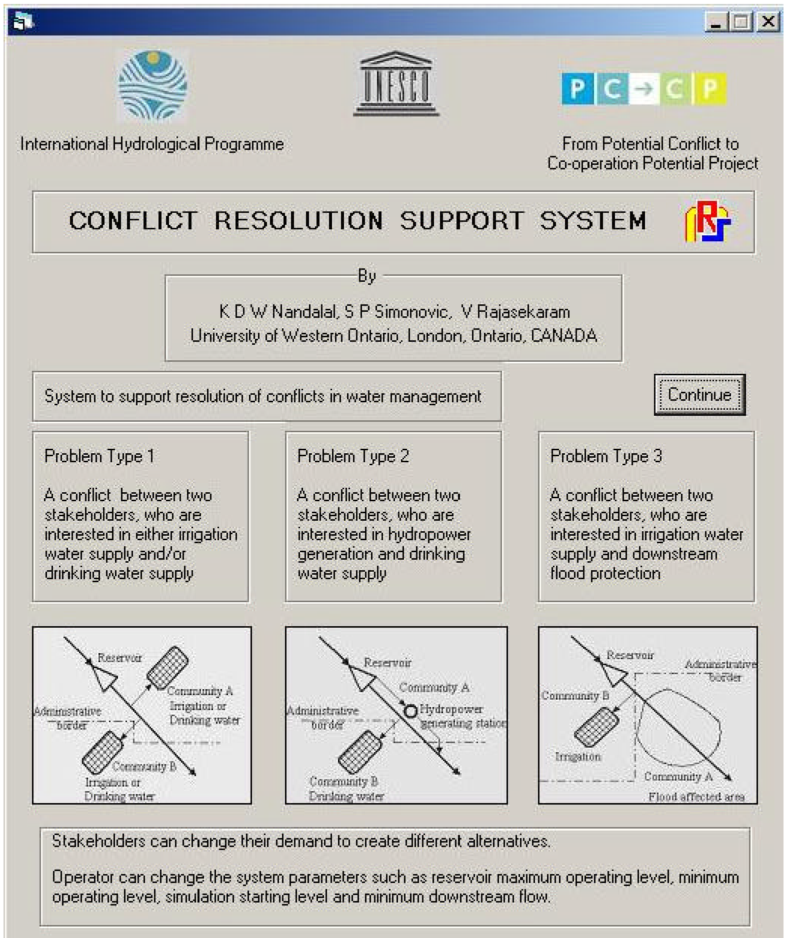


Figure 5.44 Introductory window: Three types of conflicts

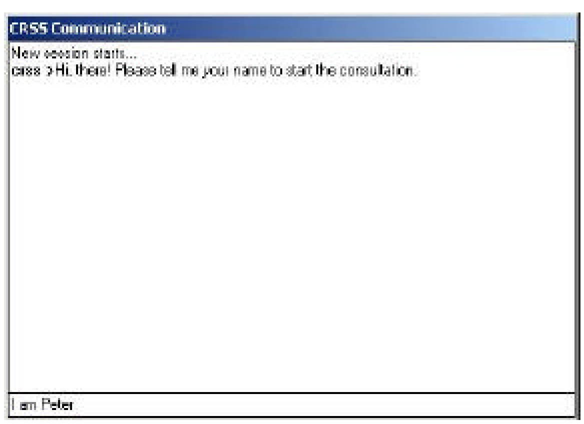


Figure 5.45 CRSS Communication window – Type 3

Table 5.5 Different tasks and authorized users – Type 3

Task	Authorized user	
Edit inflow	Operator	
View inflow	Operator	Stakeholders
Query inflow	Operator	Stakeholders
Edit reservoir characteristics	Operator	
Edit rule curve	Operator	
Edit unit demand	Operator	
Edit parameters	Operator	
Edit river rating data	Operator	
Edit flood damage	Operator	
View demand	Operator	Stakeholders
Run simulation	Operator	
View alternatives	Operator	Stakeholders
Delete alternatives	Operator	
Run Compromise Programming	Operator	
View irrigation supply and demand	Operator	Stakeholders
View flood level	Operator	Stakeholders
View flood damage	Operator	Stakeholders
View irrigation deficit	Operator	Stakeholders
View reservoir elevation	Operator	Stakeholders
View reservoir storage	Operator	Stakeholders
View reservoir release	Operator	Stakeholders
View river flow	Operator	Stakeholders
Quit	Operator	Stakeholders

The operator and the stakeholders can invoke the tasks either by double clicking the selection in the list or through interacting with the CRSS using the "CRSS Communication" window by typing the requested task in the box at the bottom of the window. These requests can be given in full sentences. For example, instead of double clicking "Edit inflow" the operator can type, "I want to change inflow" in the chat box at the bottom of the "CRSS Communication" window.

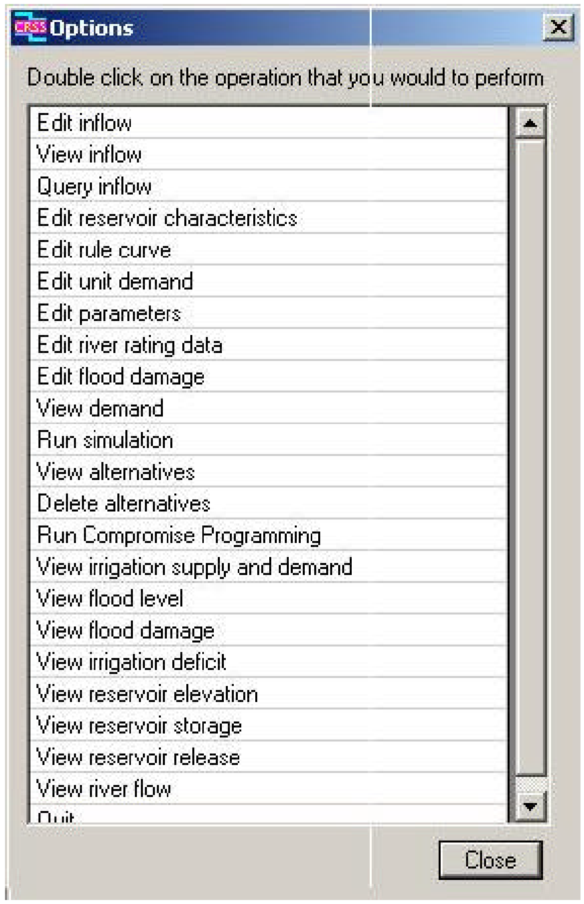


Figure 5.46 Available options - Type 3

5.3.3 Viewing and editing data

The operator can review and verify the reservoir characteristics at the outset of the conflict resolution process. The reservoir parameters such as maximum and minimum reservoir levels etc., could be edited by invoking "System Parameters" window shown in Figure 5.47.

The reservoir parameters, maximum operating level, minimum operating level and reservoir water level at the beginning of the simulation period could be changed if necessary. The maximum outlet capacity also can be changed through this window. The required river flow is the minimum amount of water that is required to flow along the river for ecological purposes. Changing all these values is the responsibility of the operator. If required, the stakeholders can change the irrigation area requirement with the help of the operator at this stage.

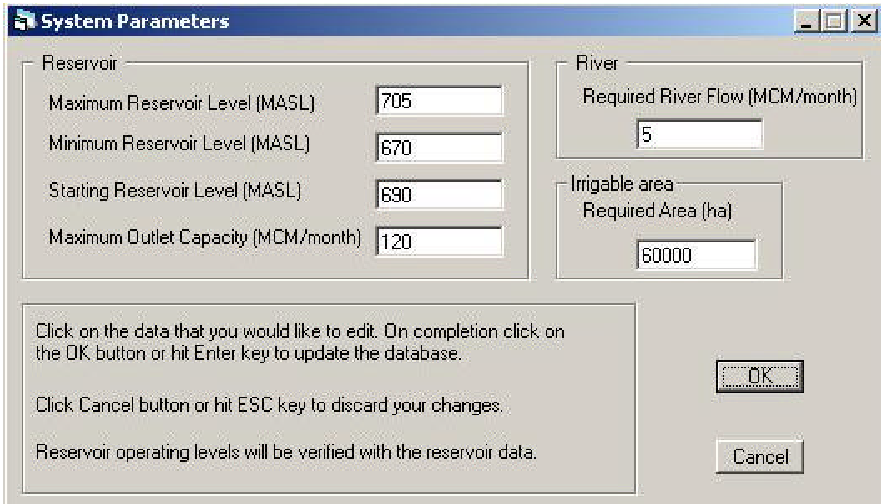


Figure 5.47 Parameters of the system - Type 3

The operator can review and if necessary, change the reservoir storage-area-elevation relationship by invoking “Reservoir Characteristics” window shown in Figure 5.48. Review of reservoir inflows and possible editing could be done through the “Reservoir Inflow Data” window as shown in Figure 5.49. The operator can do the necessary modifications to the unit irrigation demand by invoking “Unit Irrigation Demand Data” window in Figure 5.50.

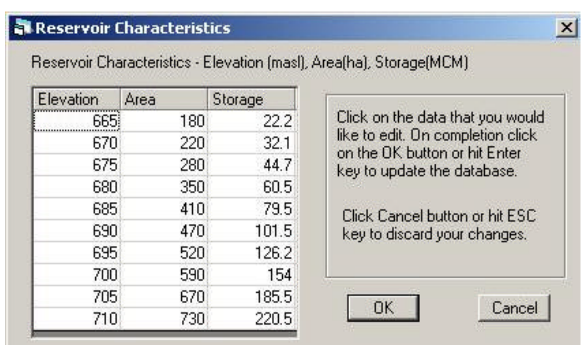


Figure 5.48 Reservoir characteristics – Type 3

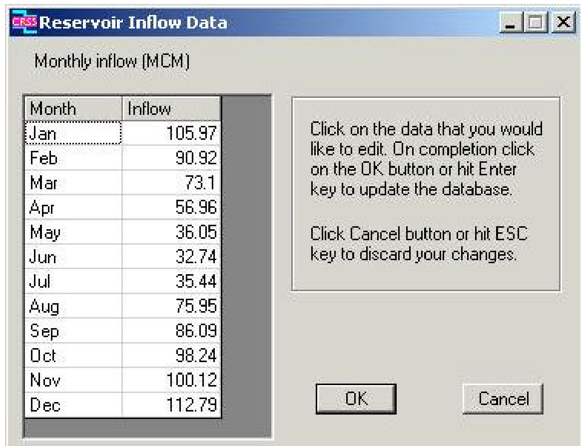


Figure 5.49 Inflow to the reservoir – Type 3

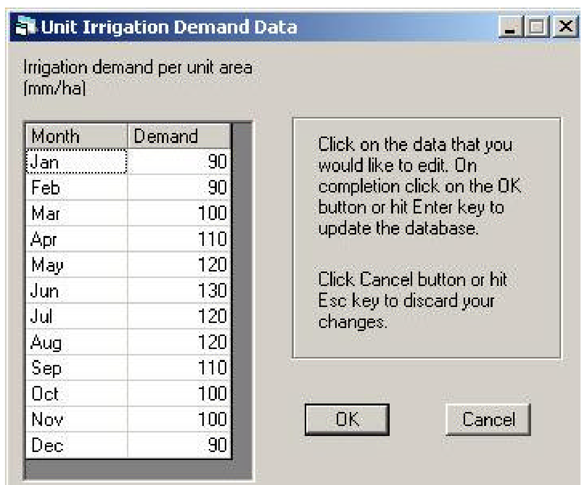


Figure 5.50 Unit irrigation demand – Type 3

The inundation of the area downstream of the reservoir depends on the downstream flow in the river. The river rating data (flow-elevation relationship) is required for the estimation of flood levels. The operator can review the rating data by activating "Edit river rating data" task in "Options" window. The "Rating Curve" window is as shown in Figure 5.51. Note that the number of data points is limited to ten.

The operator has to provide the flood damage involved with the different levels of inundation. The "Flood Damage" window presented in Figure 5.52 enables this operation.

The number of data points in this table is also limited to ten. The total irrigation demand can be reviewed and verified too.

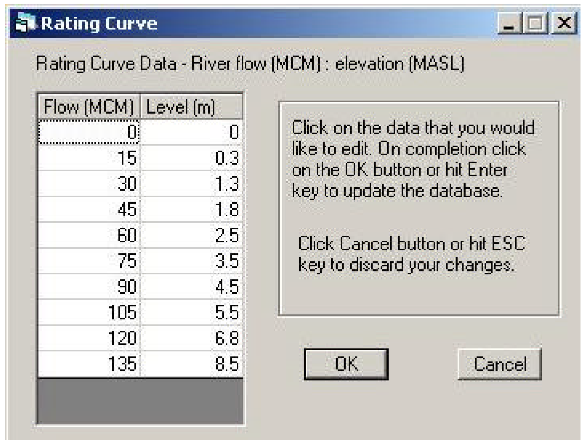


Figure 5.51 River rating data - downstream of the reservoir – Type 3

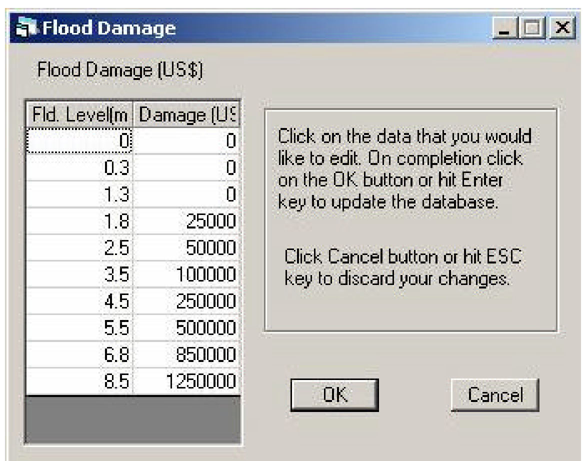


Figure 5.52 Flood cost for different levels – Type 3

Next, the operator can assess the reservoir operating rule curve shown in Figure 5.53 and make necessary changes.

Thus, after examining (and changing if required) the data the operator can simulate the system performance. The simulation with the given set of data results in the irrigation deficit of 130.35×10^6 m^3 and the flood damage of 89,883.34 US$.

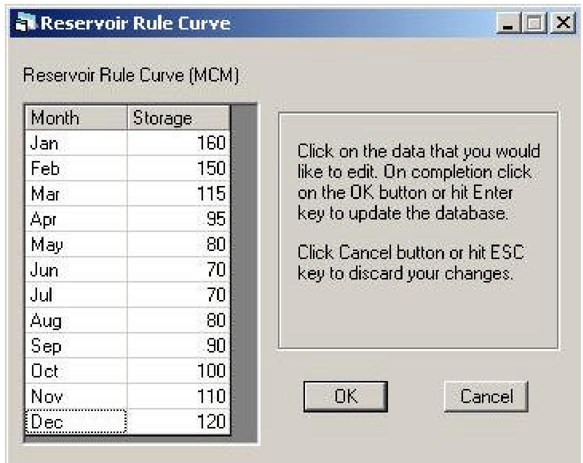


Figure 5.53 Reservoir operating rule curve – Type 3

5.3.4 *Results of a water allocation alternative*

The stakeholder "B" is interested in reviewing the monthly satisfaction of their demand. The request to show the demand and supply will result in Figure 5.54.

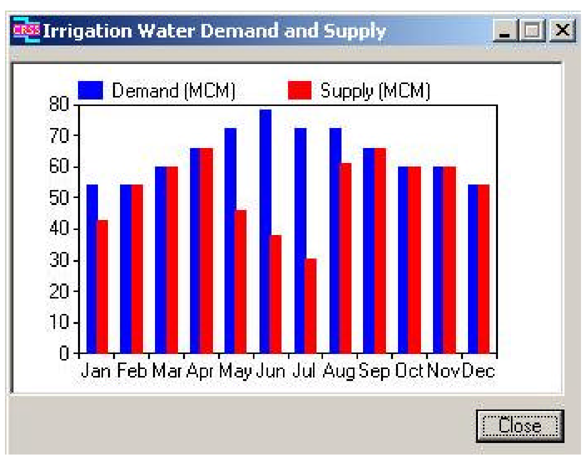


Figure 5.54 Irrigation demand and supply – Type 3

If they are interested in the deficit, a request will provide details as shown in Figure 5.55.

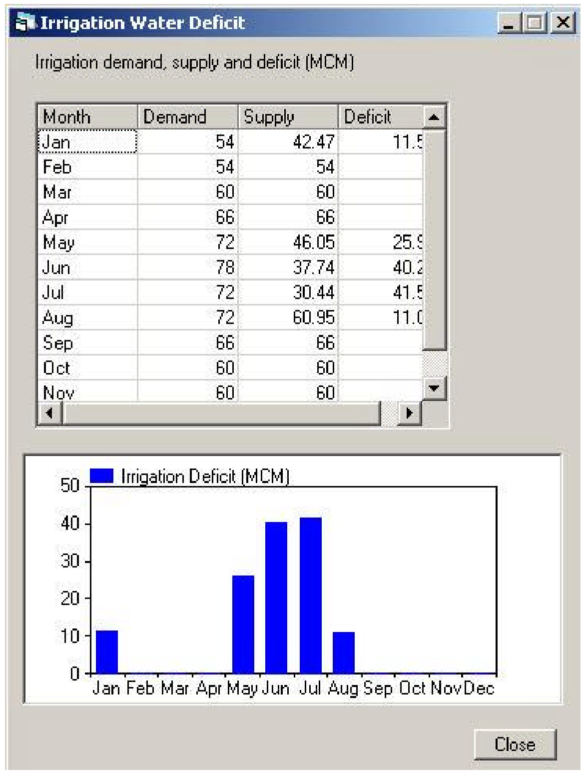


Figure 5.55 Irrigation deficit – Type 3

The other stakeholder group (community "A") wants to review the downstream flood level and the associated monthly flood damage. The request results in the graph as given in Figure 5.56.

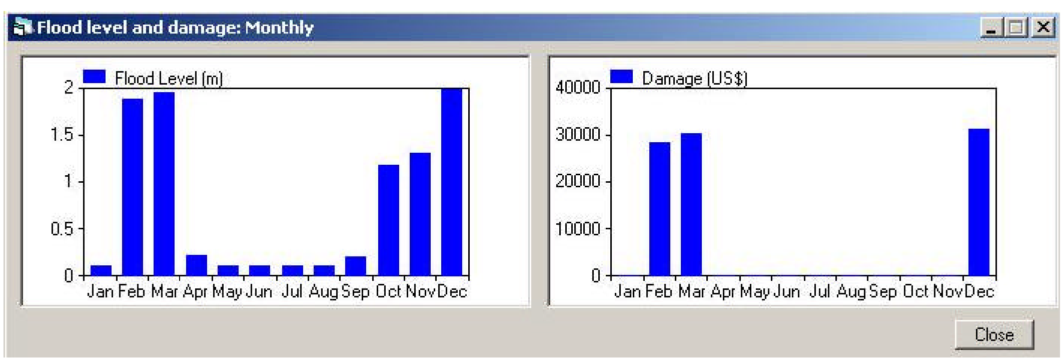


Figure 5.56 Downstream flood level and flood damage – Type 3

Both groups may need to look at the variation of reservoir storage and reservoir elevation as shown Figures 5.57 and 5.58.

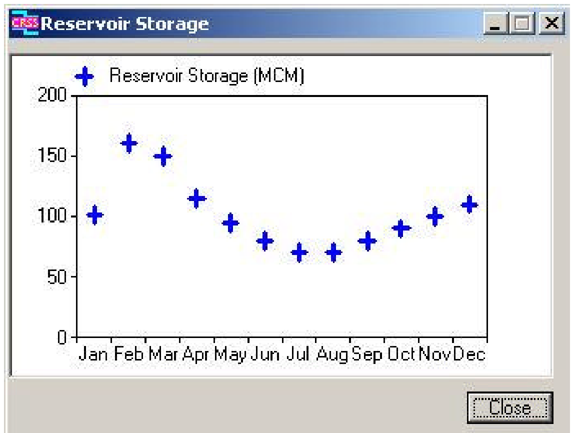


Figure 5.57 Variation of reservoir storage – Type 3

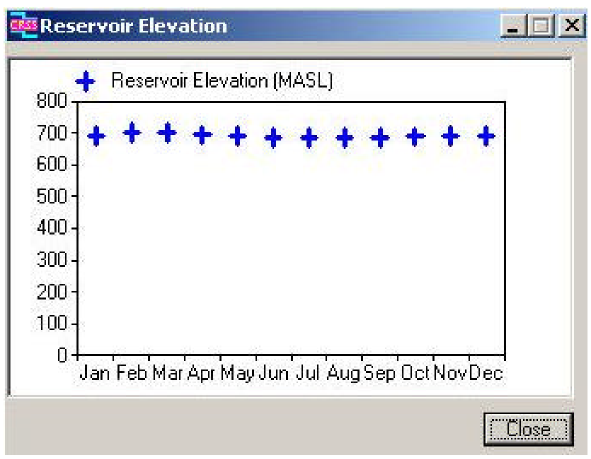


Figure 5.58 Variation of reservoir elevation - Type 3

The downstream water release should satisfy minimum (ecological) requirements. The request to review the river flow will result in the screen as shown in Figure 5.59. It is the flow in the river downstream of the diversion point.

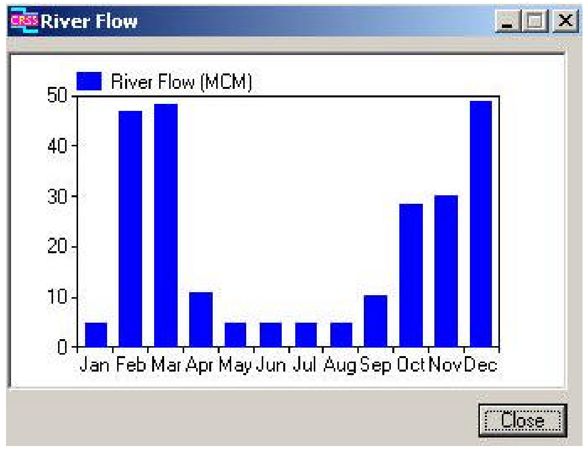


Figure 5.59 Downstream river flow – Type 3

5.3.5 Development and evaluation of alternatives

The stakeholder "B" does not like to experience the irrigation deficit obtained and wants to reduce their area requirement and analyse its impact. Therefore, a member of the community logs in and changes the area to 55000 ha. Subsequently, the operator simulates the system performance to see the irrigation deficit to be 101.35x10^{6} m^{3} and flood damage to be 126,950.00 US$.

Since the flood level exceeds the maximum allowable level in the previous solution, stakeholder "A" initiates one more simulation run with a reduced allowable flood level. A member of community logs in and enters the new flood level of 2.0 m. With this modification, the operator simulates the system and finds the irrigation deficit to be 101.35x10^{6} m^{3} and flood damage to be 110,283.30 US$.

Then both parties request the operator to evaluate whether the solution can be improved by changing the reservoir rule curve. The operator changes the rule curve to the one shown in Figure 5.60 and simulates the system again. With the modified rule curve, the annual irrigation deficit is 101.35x10^{6} m^{3} and flood damage is 87,716.66 US$, clearly a better solution than the previous one.

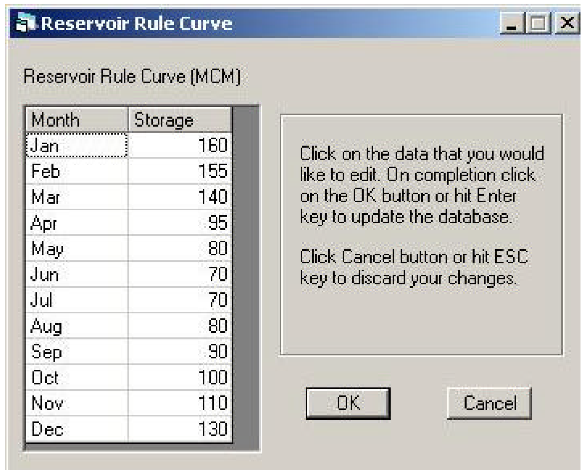


Figure 5.60 Modified rule curve; First attempt - Type 3

The stakeholder "B" wants to reduce their irrigation deficit further and requests the operator to modify the reservoir operating rule curve further. The operator changes the rule curve to the values shown in Figure 5.61 and simulates the system. The simulation results in the irrigation deficit of 96.35×10^6 m^3 and the flood damage of 93,616.67 US$.

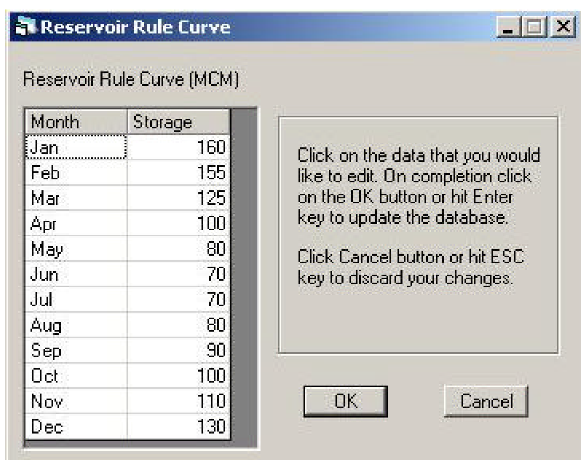


Figure 5.61 Modified rule curve; Second attempt – Type 3

The stakeholder "A" realizes that the maximum flood level has exceeded their allowable level and requests another simulation. Thus, a member of the community "A" logs in and enters the allowable flood level of 1.8 m. The simulation with this new data results in the irrigation deficit of 96.35×10^6 m^3 and the flood damage of 85,283.33 US$.

Both stakeholder groups decide to look at the alternatives created up to now shown in Table 5.6. The request to show the alternatives will result in the window as shown in Figure 5.62. Based on the minimum of irrigation deficit and flood damage, the "Alternative 6" seems to be the best. However, the flood level at "A" is 1.94 m with this alternative. For the second best "Alternative 4" (based on minimum irrigation deficit and flood damage) the maximum flood level is 1.87 m only, though the total annual flood damage is high. For the stakeholder "A", who are interested in flooding "Alternative 4" may be an acceptable solution. Note that the irrigation deficit is lower with this solution and therefore, for the stakeholder "B" interested in irrigation, "Alternative 4" is a better solution when compared with the "Alternative 6".

Table 5.6 Details of alternatives – Type 3

	Group A		Group B	Minimum river flow (MCM)
Alternative	Irrigation Area (ha)	Annual Flow Deficit (MCM)	Flood damage (US$)	
Alt 1	60000	130.35	89883.34	10
Alt 2	55000	101.35	126950.00	10
Alt 3	55000	101.35	110283.30	10
Alt 4	55000	101.35	87716.66	10
Alt 5	55000	96.35	93616.67	10
Alt 6	55000	96.35	85283.33	10

The number of months with irrigation deficit and the maximum irrigation deficit observed in a month could also be used to compare the alternatives, if required. Thus the groups in conflict should not purely depend on the rank based on annual irrigation deficit and flood damage.

Equal weights are assumed for annual irrigation deficit and annual flood damage when the rank is determined. If the groups agree that they should be given different weights that can be done by selecting alternatives and activating the Compromise Programming window.

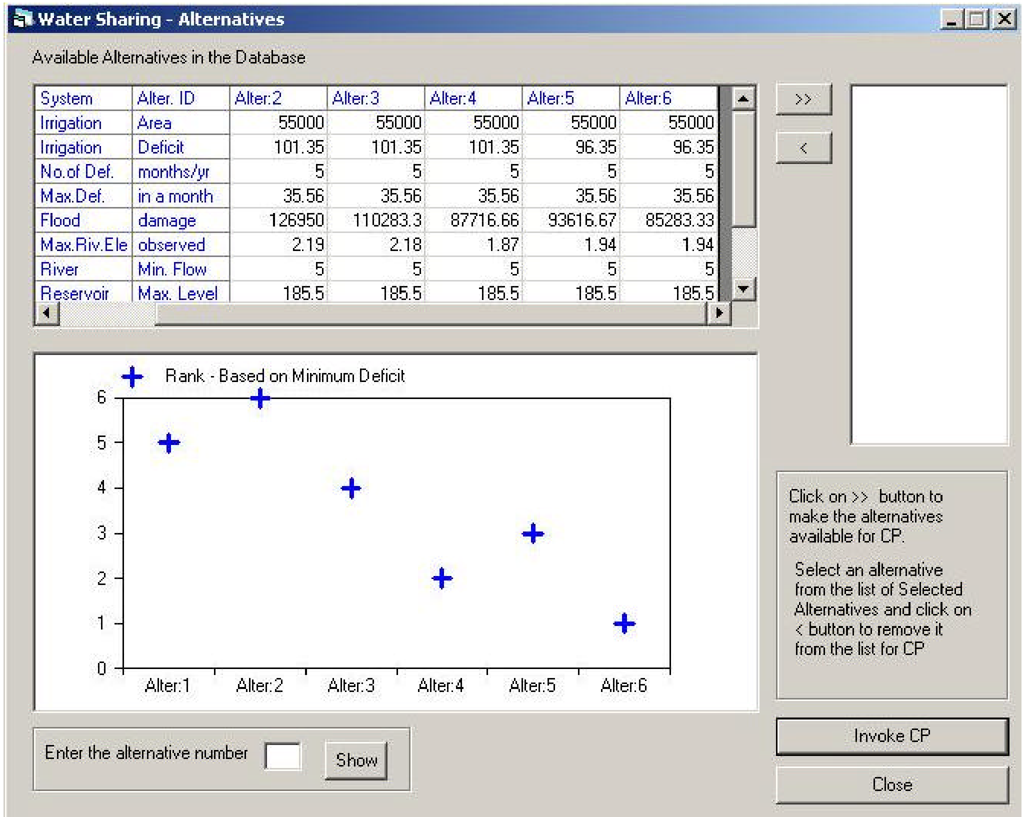


Figure 5.62 Comparison of alternatives –Type 3

The group interested in irrigation has priority over downstream flood protection and therefore the two groups agree on 0.6 and 0.4 weights for irrigation and flood protection. Figure 5.63 shows the Compromise Programming window with the comparison of all six alternatives and the new weights. The rank of the alternatives is slightly changed as the figure indicates. However, the alternative six remains the best.

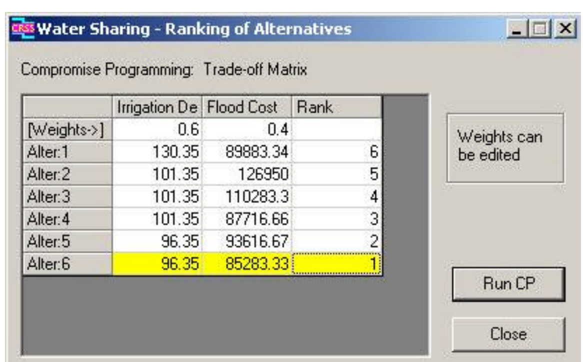


Figure 5.63 Compromise Programme based rank with a new set of weights – Type 3

If the stakeholders select a certain alternative, then they can review the reservoir rule curve corresponding to that alternative by typing in the alternative number. The operating rule curve for the alternative six (selected) is shown in Figure 5.64. Stakeholders' demand corresponding to that alternative are available in the "Water Sharing - Alternatives" window shown in Figure 5.62. Then the stakeholders can request the operator to change the rule curve to the selected one and simulate the system again to see the performances of the system in detail.

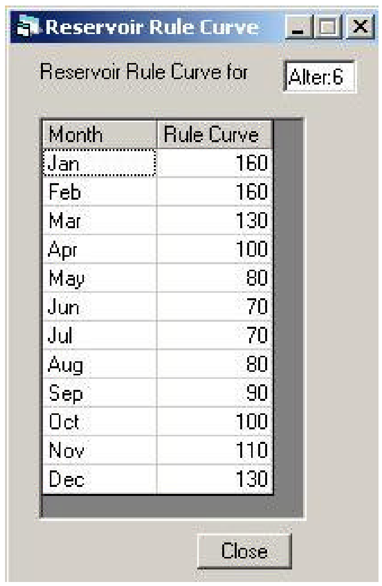


Figure 5.64 Rule curve of the selected alternative – Type 3

If the two stakeholder groups are satisfied with the results they can stop the consultation process. Otherwise, they can continue to develop new alternatives in addition to the available. They can also delete the exiting alternatives and develop a new set of alternatives for comparison. This can be done until an agreement is achieved.

6 DISCUSSION

A computerized decision support system (CRSS) has been developed to assist in resolving conflicts over water. Two stakeholders involved in the conflict directly interact with the system during its resolution process until an agreeable solution is attained. Though an operator is involved in the conflict resolution process, his/her service is limited to providing the stakeholders with the necessary technical assistance.

Initially, the two stakeholders introduce themselves and provide details of the conflict, water use and their requirements to the CRSS. Subsequently, an operator, who assists the stakeholders during the consultation process reviews the water resources system data and prepares the system for simulation. The system performance obtained from a simulation carried out by the operator enables the stakeholders to evaluate their position with respect to the conflict. If the stakeholders are not satisfied with the result, they can change the requirements and review the performances. The stakeholders can also change the system parameters with the assistance of the operator to develop alternative solutions. In this way, the development of the alternatives could be carried out until an agreement is reached between the stakeholders. The direct involvement of the stakeholders in the development and evaluation of alternatives provides for a better understanding of the conflict and offers a significant opportunity for it resolution.

The CRSS consists of an Artificial Intelligent Communication System (AICS), a Data Base Management System (DBMS) and a Model Base Management System (MBMS). The AI component of the AICS connects the database through the DBMS and interacts with the MBMS modules. The MBMS basically consists of three modules capable in analyzing three typical conflicts encountered in water resource management. The other modules in MBMS are, a Multi-Criteria Decision Making module, Table Viewers, Graph Viewers and Statistical tools. The DBMS consists of modules in the form of input data tables.

An important feature of the CRSS is its artificial intelligence based communication system. It facilitates communication among the stakeholders, and provides access to all the facilities available within the CRSS for the resolution of a conflict.

The CRSS is capable to assist in the resolution of three typical conflicts encountered in water resource management. They are; (a) a conflict in sharing water for irrigation and/or drinking water supply, (b) a conflict between hydropower generation and drinking water supply, and (c) a conflict between flood protection and irrigation.

The CRSS could assist in generating lasting agreements between two stakeholders confronted with the above three types of water sharing conflicts. It provides the 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.

Three case studies are presented in the report to demonstrate the applicability of the CRSS to different types of conflicts and training of the users. Appendices to the report provide a user manual for the implementation of the three case studies.

Though the present CRSS is capable of handling the above three types of conflicts, its flexible system architecture provides easy addition of modules that may be necessary to resolve different types of water related conflicts. For example, modules to assist resolution of conflicts in water resource systems having many reservoirs or systems with surface water and groundwater interactions, etc., could be easily added to the CRSS.

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Appendix A

The use of CRSS for Type 1 Conflict

Conflict Type 1: Conflict in sharing water for Irrigation and/or Drinking Water Supply

Consultation for Case 1 in Chapter 5

Action	**Model Response**	**Conflicting Parties**	**Operator**
	Hi, there! Please tell me your name to start the consultation.		
Introduce the first stakeholder		I am Peter	
	OK Peter, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
		A	
	Thank you Peter. I can accept you as a member of Group A. But, wait a second to check your name and status... *Welcome Peter. I am ready. Please tell me the type of water resource problem you have. Is it Type 1, Type 2 or Type 3 ?*		
Introduce the problem type		Type 1	
	What type of water sharing problem do you have Peter ? Is it for irrigation or drinking water supply?		
Identify the water use		Irrigation	
	I can determine the amount of water available for irrigation. What is the size of your irrigation area (ha) ?		
Enter the irrigation area		24000 ha	
	Your irrigation area is noted. Let the other group present their demands.		
Introduce the second stakeholder.		I am John	

	OK John, I want to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
		B	
	Thank you John. I can accept you as a member of Group B. But, wait a second to check your name and status... *Welcome John. I assume that you are interested in problem Type1. What is your water use?*		
Identify the water use		Drinking water supply	
	OK John, What is your drinking water requirement (MCM/month)?		
Enter the drinking water demand		I need 40 MCM/month	
	OK John, your drinking water demand is noted. Now the operator should simulate the system performance.		
Introduce the operator			I am Smith
	Hi! Smith, please tell me which group you belong to: Group A(A); Group B(B); Operator(O).		
			O
	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *OK Smith, You can "simulate the system" or if you want you may "change the system parameters". "View options" will display the possible options.*		
Review of the available options			View options
	Option window is open.		

Select and click on the option to be performed. Same operation can be invoked by typing the command in the "communication line", too			
Review inflows			View inflow
	Inflow is presented in the graphical display now.		
Leave the inflow graph in the screen or close it			
Change monthly inflows			We want to change inflow
	Inflow editor is open now.		
Edit and click "OK"	*Your inflow data has been updated. What do you plan to do next?*		
Change the unit irrigation demand. Click "Edit unit demand" or type it in			
	Unit demand editor is open now.		
Change the demand and click "OK"	*Done. To determine water availability, simulate the system. However, if you want to change other reservoir parameters, please do that first.*		
View the reservoir characteristics			Show me the reservoir characteristics
	Reservoir characteristics editor is open now.		
Change values and click "OK"	*Your reservoir characteristics have been updated. What do you want to do next?*		
			I want to change reservoir parameters
	System operation parameters editor is open now.		
Change values and click "OK"	*Hi, system operation data is updated. Come up with your next request.*		

View the demand			I want to see demands
	Demand is presented in the graphical form now.		
Simulate the system performance. Click “Run simulation” (Or type “I want to simulate the system”)			
	Hey, I have carried out a complete simulation with your data. The new alternative, Alter:1 is ready now. Water deficit for stakeholder A is 54.12 MCM and stakeholder B is 52.28 MCM. Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.		
Review the water deficit			We would like to see the shortages
	The shortage is displayed in tabular and graphical form now for the last simulation.		
Review the water demand and supply for A			I want to see supply and demand A
	Supply and demand for A are compared in the graphical display now.		
View the variation of reservoir storage			Show us the reservoir storages
	Reservoir storage is presented in the graphical form now.		
View the variation of reservoir elevation			I like to see the reservoir elevations
	Reservoir elevation is displayed in graphical form now.		

View downstream river flow			Show downstream river flow
	Downstream river flow is provided in the graphical display now.		
Group A wants to change their irrigation area			
Introduce a member of Group A (a new member or the same one)		My name is Pamela	
	OK Pamela, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
		A	
	Thank you Pamela. I can accept you as a member of Group A. But, wait a second to check your name and status... *Pamela, one or more members of your group (A) had already consulted with me. What is your interest?*		
Change the irrigation area		I want to change Irrigation area	
	OK Pamela, enter the new area (ha).		
Enter the irrigation area		23500 ha	
	Done. I am waiting for the continuation of consultation. The operator can simulate the system.		
The other group wants to reduce the demand		I am John	
	Hi! John, please tell me which group you belong to: Group A(A); Group B(B); Operator(O).		
		B	
	Thank you John. I can accept you as a member of Group B. But, wait a second to check your name and status...		

	Welcome back John. I am ready to assist you again. You may now go ahead with your request.		
Enter the drinking water demand		I want to change drinking water demand	
	Please, let me know your drinking water demand (MCM/month).		
		36	
	Your drinking water demand is noted. Now, the operator should simulate the system performance.		
Introduce the operator			I am smith
	Hi! Smith, please tell me which group you belong to: Group A(A); Group B(B); Operator(O).		
			O
	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *Welcome back Smith. I am ready to assist you again. You may now go ahead with your request.*		
Run the Simulation			I would like to run simulation
	Wow, simulation completed. The new alternative, Alter:2 is ready now. Water deficit for stakeholder A is 30.41 MCM and stakeholder B is 27.6 MCM. It appears that the new alternative is the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		

Group B wants to reduce their demand, but needs a minimum flow			
Introduce a member of Group B		My name is Peter	
	OK Peter, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
		B	
	Thank you Peter. I can accept you as a member of Group B. But, wait a second to check your name and status... *Peter, your group (B) already consulted with me. Anyway, I am ready to assist you. What do you want me to do?*		
Change the drinking water demand		First, I want to change drinking water demand	
	Please, let me know your drinking water demand (MCM/month).		
Enter the demand		34	
	Done. If both parties are ready with the demands, the operator should simulate the system performance.		
Peter wants a minimum monthly flow for group B		Wait, I would like to have a minimum flow	
	OK Peter, please enter your minimum flow requirement (MCM/month).		
Enter the minimum requirement		We need 20 MCM/month	
	Your minimum flow is noted. If you are ready with the demands let the operator simulate the system performance.		

Introduce the operator			I am smith
	OK Smith, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
			O
	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *Welcome back Smith. I am ready to assist you again. You may now go ahead with your request.*		
			Simulate the system
	Wow, simulation completed. The new alternative, Alter:3 is ready now. Water deficit for stakeholder A is 20.43 MCM and stakeholder B is 17.58 MCM. It appears that the new alternative is the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Group B wants to increase their water demand			
Introduce Peter again		I am Peter	
	Hi! Peter, please tell me which group you belong to: Group A(A); Group B(B); Operator(O).		
		B	
	Thank you Peter. I can accept you as a member of Group B. But, wait a second to check your name and status... *Welcome back Peter. I am ready to assist you again. What do you want to do?*		

Change the water demand		I want to increase drinking water demand	
	Enter your new drinking water demand (MCM/month).		
Enter the demand		36	
	Done. If both parties are ready with the demands, the operator should simulate the system performance.		
Introduce the operator			I am smith
	OK Smith, I want to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
			O
	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *Welcome back Smith. I am ready to assist you again. May I know what do you want me to do.*		
Simulate the system performance			Simulate the system
	Congratulations! You are ready with another simulation. The new alternative, Alter:4 is ready now. Water deficit for stakeholder A is 30.41 MCM and stakeholder B is 27.6 MCM. However, alternative Alter:3 appears to be the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Both groups want to review the situation if downstream environmental release is reduced			

Change the minimum river flow			I want to change minimum downstream river flow
	OK Smith, please enter your minimum river flow (MCM/month).		
Enter the minimum flow			5.2
	The minimum flow is changed. I am waiting for your instructions.		
Simulate the system performance			Run simulation
	I am done with your simulation. The new alternative, Alter:5 is ready now. Water deficit for stakeholder A is 28.8 MCM and stakeholder B is 26.22 MCM. However, alternative Alter:3 appears to be the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Review of the alternatives by the stakeholders			
To view the alternatives either click "View alternatives" or type the request on the "communication line"			May I see alternatives
The alternatives are displayed	*The alternatives generated so far are presented in tabular and graphical form. If you want to develop a different alternative, that can be done by stakeholders changing their requirements or operator changing system parameters.*		
Selection of a set of alternatives for comparison.	*The Compromise Programming window is open now. You may edit the weights, if necessary. Run*		

(Select all and deselect the unwanted ones). Activation of Compromise Programming tool	*CP selecting the Run CP button*		
To rank the selected alternatives, run CP in the displayed "CP window"			
Stop the process by typing "**Quit**"			Quit

Following are the options available in the "Options" window

EDIT INFLOW – To change inflows
VIEW INFLOW – To view monthly inflow series graphically
QUERY INFLOW – To view average, maximum and minimum flows in the series
EDIT UNIT DEMAND – To view and change unit monthly demands (MCM/ha)
EDIT RESERVOIR CHARACTERISTICS – To view and change reservoir storage-area-elevation relationship
EDIT PARAMETERS – To view and change irrigation area, minimum water requirement, minimum downstream flow, reservoir minimum and maximum operating levels and initial water level
VIEW DEMAND – To view monthly demand of the two stakeholders
RUN SIMULATION – To simulate the reservoir operation
VIEW ALTERNATIVES – To view data and simulation results of the alternatives
DELETE ALTERNATIVES – To delete all previous alternatives
RUN COMPROMISE PROGRAMMING – To run the Compromise Programme and get the results
If a detailed Compromise Programming analysis is required, then go to view alternatives and select the alternatives of interest and activate CP
VIEW SUPPLY AND DEMAND A – To view monthly demand and supply (the last alternative) of stakeholder A
VIEW SUPPLY AND DEMAND B – To view monthly demand and supply (the last alternative) of stakeholder B.
VIEW DEFICIT – To view shortages for both stakeholders after the reservoir simulation
VIEW RESERVOIR ELEVATION – To view reservoir elevation variation
VIEW RESERVOIR STORAGE – To view reservoir storage variation
VIEW RESERVOIR RELEASE – To view total reservoir release
VIEW RIVER FLOW – To view downstream river flow
QUIT – To exit the programme

Appendix B

The use of CRSS for Type 2 Conflict

Conflict Type 2: Conflict between Hydropower Generation and Drinking Water Supply

Consultation for Case 2 in Chapter 5

Action	**Model Response**	**Conflicting Parties**	**Operator**
	Hi, there! Please tell me your name to start the consultation.		
Introduce the first stakeholder		I am Peter	
	OK Peter, I want to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
		A	
	Thank you Peter. I can accept you as a member of Group A. But, wait a second to check your name and status... *Welcome Peter. I am ready. Please tell me the type of water resource problem you have. Is it Type 1, Type 2 or Type 3 ?*		
Introduce the problem type		Type 2	
	OK Peter, let me know your interest. Is it hydropower or drinking water supply?		
Identify the water use		Hydropower	
	OK Peter, Let me know your hydropower requirement (GWh/month).		
A table of monthly hydropower is displayed. Make changes (if required) and click "OK"			
	Your hydropower demand is noted. Let the other group present their demands.		
Introduce the second stakeholder		I am John	

	OK John, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
		B	
	Thank you John. I can accept you as a member of Group B. But, wait a second to check your name and status... *Welcome John. I know you want to share water between hydropower generation and drinking water supply. What is your interest?*		
Identify the water use		Drinking Water	
	OK John, What is your drinking water requirement (MCM/month)?		
A table of monthly drinking water demand is displayed. Make changes and click "OK".			
	Done. If both parties are ready with the demands, the operator should simulate the system performance.		
Introduce the operator			I am Smith
	OK Smith, I want to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
			O
	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *Well Smith, "View options" will show you the possible tasks. However, you can "simulate the system" or if you want you can "change the system parameters".*		
Review the available options			View options
	Option window is open.		

Select and click on the option to be performed. Same operation can be activated by typing it in the “communication line”			I want to edit reservoir parameters
	System operation parameters editor is open now.		
Apply changes (if necessary) and click “OK”	*Hi, system operation data is updated. Come up with your next request.*		
			I want to see reservoir characteristics
	Reservoir characteristics editor is open now.		
Apply changes (if necessary) and click “OK”	*Reservoir characteristics updated. Come up with your next task.*		
			I want to see reservoir rule curve
	Rule curve editor is open now.		
No changes. Click “Cancel”	*Rule curve remains the same. Come up with your next task.*		
Review the inflows			View inflow
	Inflow is presented in the graphical display now.		
View and close the window			
Change inflow			I want to edit inflow
	Inflow editor is open now.		
Apply changes (if necessary) and lick “OK”	*Done. I am waiting for your next request.*		
Review demand			I want to see demands
	Demand is presented in the graphical form now.		
Simulate the system performance			I want to simulate the system

	The new alternative, Alter:1 is ready now. Drinking water deficit is 11.52 MCM and hydropower deficit is 51.61 GWh. Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.		
View hydropower generation			View hydropower
	The supply and demand are displayed now.		
View the variation of reservoir storage			show reservoir storage
	Reservoir storage is presented in the graphical form now.		
View the variation reservoir elevation			show reservoir elevations
	Reservoir elevation is displayed in graphical form now.		
View the reservoir releases			show reservoir releases
	Reservoir release is provided in the graphical display now.		
View the downstream flow			I want to see downstream river flow
	Downstream river flow is provided in the graphical display now.		
Group A wants to change their hydropower demand			
Introduce a member of Group A (a new member or the same one)		My name is Pamela	
	Hi! Pamela, please tell me which group you belong to: Group A(A); Group B(B); Operator(O).		

		A	
	Thank you Pamela. I can accept you as a member of Group A. But, wait a second to check your name and status... *Pamela, one or more members of your group (A) had already consulted with me. What is your interest?*		
Change the hydropower demand		Can I change hydropower demand	
Present hydropower demand is displayed. Make changes and click “OK”	*Hydropower demand editor is open now.*		
	Your hydropower demand is noted. Now the operator can simulate the system performance.		
Introduce the operator			I am Smith
	Hi! Smith, please tell me which group you belong to: Group A(A); Group B(B); Operator(O).		
			O
	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *Welcome back Smith. I am ready to assist you again. May I know what do you want me to do.*		
Simulate the system performance			Run simulation
	The new alternative, Alter:2 is ready now. Drinking water deficit is 9.59 MCM and hydropower deficit is 38.44 GWh. It appears that the new alternative is the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		

Group B changes the drinking water demand			
Introduce a member of Group B		I am Eric	
	OK Eric, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
		B	
	Thank you Eric. I can accept you as a member of Group B. But, wait a second to check your name and status... *Eric, your group (B) already consulted with me. Anyway, I am ready to assist you. What do you want me to do?*		
Change the drinking water demand		I want to change the drinking water demand	
Present drinking water demands is displayed. Make changes and click "OK"	*Enter your new drinking water demand (MCM/month).*		
	Done. If both parties are ready with the demands, the operator should simulate the system performance.		
Introduce the operator			I am smith
	OK Smith, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
			O
	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *Welcome back Smith. I am ready to assist you again. May I know what do you want me to do.*		

Simulate the system performance			I would like to run simulation
	The new alternative, Alter:3 is ready now. Drinking water deficit is 7.72 MCM and hydropower deficit is 36.42 GWh. It appears that the new alternative is the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Both parties want to change the reservoir rule curve			
Change the reservoir rule curve			I want to change the reservoir rule curve
The reservoir rule curve is open. Make changes and click “OK”	*Rule curve editor is open now.*		
	Your rule curve has been updated. What are you planning to do next?		
Simulate the system performance			Run simulation
	The new alternative, Alter:4 is ready now. *Drinking water deficit is 6.17 MCM and hydropower deficit is 32.92 GWh. It appears that the new alternative is the best.* *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Group A insists on changing the reservoir rule curve			
Change the reservoir rule curve			May I edit rule curve

The reservoir rule curve is open. Make changes and click “OK”	*Rule curve editor is open now.*		
	Your rule curve has been updated. What are you planning to do next?		
Simulate the system performance			Run simulation
	The new alternative, Alter:5 is ready now. Drinking water deficit is 6.35 MCM and hydropower deficit is 31.34 GWh. It appears that the new alternative is the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Group A requests to develop another alternative by changing the reservoir rule curve			
To edit the reservoir rule curve click “Edit rule curve” in options window.			
The reservoir rule curve is open. Make changes and click “OK”	*Rule curve editor is open now.*		
	Rule curve is updated. Come up with your next task.		
Simulate the system performance			I want to simulate the system
	The new alternative, Alter:6 is ready now. Drinking water deficit is 6.42 MCM and hydropower deficit is 29.85 GWh. It appears that the new alternative is the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		

Both groups request to create another alternative by changing the reservoir rule curve			
Change the reservoir rule curve			Change rule curve
The reservoir rule curve is open. Make changes and click “OK”	*Change rule curve*		
	Rule curve is updated. Come up with your next task.		
Simulate the system performance			Run simulation
	The new alternative, Alter:7 is ready now. Drinking water deficit is 8 MCM and hydropower deficit is 37.02 GWh. However, alternative Alter:6 appears to be the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Review of the alternatives by the stakeholders			
To view the alternatives either click “View alternatives” or type the request on the “communication line”			May I see the alternatives
The alternatives are displayed	*The alternatives generated so far are presented in tabular and graphical form. If you want to develop a different alternative, that can be done by stakeholders changing their requirements or operator changing system parameters.*		
Selection of a set of alternatives for comparison (Select all and deselect the unwanted ones). Activation of Compromise Programming tool	*The Compromise Programming window is open now. You may edit the weights, if necessary. Run CP selecting the Run CP button*		

To rank the selected alternatives, run CP in the displayed “CP window”			
View the reservoir rule curve and the demand of an alternative. Enter its number	*Rule curve for the selected alternative is shown*		
Stop the process by typing “**Quit**”.			Quit

Following are the options available in the "Options" window

EDIT INFLOW – To view and change inflows
VIEW INFLOW – To view monthly inflow series graphically
QUERY INFLOW – To view average, maximum and minimum flows in the series
EDIT RESERVOIR CHARACTERISTICS – To view and change reservoir storage-area-elevation relationship
EDIT RULE CURVE – To view and change the reservoir rule curve
EDIT HYDROPOWER DEMAND – To view and change hydropower demand
EDIT DRINKWATER DEMAND – To view and change drinking water demand
EDIT PARAMETERS – To view and change minimum river flow, reservoir minimum and maximum operating levels, initial water level, outlet capacity and tailwater level
VIEW HYDROPOWER DEMAND – To view the monthly power demand graphically
VIEW DRINKWATER DEMAND – To view the monthly drinking water demands graphically
RUN SIMULATION – To simulate the reservoir operation
VIEW ALTERNATIVES – To view data and simulation results of the alternatives
DELETE ALTERNATIVES –To delete all previous alternatives
RUN COMPROMISE PROGRAMMING – To run the Compromise Programme and get the results
If a detailed Compromise Programming analysis is required, then go to view alternatives and select the alternatives of interest and activate CP
VIEW HYDROPOWER DEMAND AND SUPPLY – To view the hydropower demand and supply
VIEW DRINKWATER DEMAND AND SUPPLY – To view the hydropower demand and supply
VIEW RESERVOIR ELEVATION – To view the monthly reservoir elevations
VIEW RESERVOIR STORAGE – To view the monthly reservoir storages
VIEW RESERVOIR RELEASE – To view the releases from the reservoir
VIEW RIVER FLOW – To view the downstream river flow
QUIT – Exit the programme

Appendix C

The use of CRSS for Type 3 Conflict

Conflict Type 3: Conflict between Downstream Flood Protection and Irrigation Water Supply

Consultation for Case 3 in Chapter 5

Action	**Model Response**	**Conflicting Parties**	**Operator**
	Hi, there! Please tell me your name to start the consultation.		
Introduce the first stakeholder		I am Peter	
	OK Peter, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
		A	
	Thank you Peter. I can accept you as a member of Group A. But, wait a second to check your name and status... *Welcome Peter. I am ready. Please tell me the type of water resource problem you have. Is it Type 1, Type 2 or Type 3 ?*		
Introduce of the problem type		Type 3	
	OK Peter, Let me know your interest. Is it flooding or irrigation?		
Enter the interest		Flooding	
	OK Peter, I noted your interest. What is the maximum flood level you would allow ?		
Enter the allowable flood level		2.2 m	
	OK, your interest is noted. Other group can present their interest.		
Introduce the second stakeholder		I am John	
	Hi! John, please tell me which group you belong to: Group A(A); Group B(B); Operator(O).		

		B	
	Thank you John. I can accept you as a member of Group B. But, wait a second to check your name and status... *Welcome John. I know that you are facing problem Type3. What is your interest?*		
Identify the water use		Irrigation water	
	John, the amount of water available could be determined. Please, tell me the size of your irrigation area (ha).		
Enter the irrigation area		I need water for 60000 ha	
	Your irrigation area is noted. Let the operator simulate the system.		
Introduce the operator			I am Smith
	OK Smith, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
			O
	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *OK Smith, I am ready now. You may "simulate the system" or "change the system parameters". "View options" will show you the possible options.*		
Review of the available operations			View options
	Option window is open.		
Select and click on the option to be performed. Same operation can be invoked by typing the command in the			I want to edit the reservoir parameters

“communication line”, too			
	System operation parameters editor is open now.		
Make changes and click “OK”	*It's your turn to come up with your next request. System operation data is updated.*		
View the reservoir characteristics			I want to see the reservoir characteristics
	Reservoir characteristics editor is open now.		
Change values and click “OK”	*Reservoir characteristics updated. Come up with your next task.*		
Change the inflows			I want to edit inflow
	Inflow editor is open now.		
Change values and click “OK”.	*Inflow data is updated. Come up with your next task.*		
View the unit irrigation demand			I like to see unit demands
	Unit demand editor is open now.		
Make changes and click “OK”	*Done. To determine water availability, simulate the system. However, if you want to change other reservoir parameters, please do that first.*		
View river rating data			I want to see the river rating data
	Rating curve editor is open now.		
Make changes and click “OK”	*River rating data updated. Come up with your next task.*		
Change flood damage			Show me flood damage
	Flood damage editor is open now.		
Make changes and click “OK”	*Damage related to flooding updated. Come up with your next task.*		

View and change reservoir rule curve			I want to see reservoir rule curve
	Rule curve editor is open now.		
Make changes and click “OK”	*Rule curve is updated. Come up with your next task.*		
Simulate the system performance			I want to simulate the system
	The new alternative, Alter:1 is ready now. *Irrigation water deficit is 130.35 MCM and flood damage is 89883.34, US$.* *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
View the irrigation demand and supply			I want to see irrigation supply and demand
	The supply and demand are displayed now.		
View the irrigation deficit			Show irrigation Deficits
	The shortage is displayed in tabular and graphical form now for the last simulation.		
View the flood level			Show the flood Levels
	Flood level and damage are displayed now.		
View the variation of reservoir storage			Show reservoir Storage
	Reservoir storage is presented in the graphical form now.		
View the variation of reservoir elevation			Show reservoir elevations

	Reservoir elevation is displayed in graphical form now.		
View the downstream flow			Show me the downstream flow
	Downstream river flow is provided in the graphical display now.		
Group B reduces the irrigation demand			
Introduce a member of Group B (a new member or the same one)		My name is Pamela	
	OK Pamela, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
		B	
	Thank you Pamela. I can accept you as a member of Group B. But, wait a second to check your name and status... *Pamela, your group (B) already consulted with me. Anyway, you may continue with consultation. What do you want to do?*		
Change the irrigation area		I want to change irrigation area	
	OK Pamela, what is the new area (ha)?		
Enter the new irrigation area		55000 ha	
	Done. I am waiting for the continuation of consultation. The operator can simulate the system.		
Introduce the operator			I am Smith
	Hi! Smith, please tell me which group you belong to: Group A(A); Group B(B); Operator(O).		
			O

	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *Welcome back Smith. I am ready to assist you again. What do you want to do?*		
Simulate the system performance			Run simulation
	The new alternative, Alter:2 is ready now. Irrigation water deficit is 101.35 MCM and flood damage is 126950, US$. However, alternative Alter:1 appears to be the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Group A requests to limit the flood level to 2.0m			
Introduce a member of Group A		My name is Eric	
	OK Eric, I want to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
		A	
	Thank you Eric. I can accept you as a member of Group A. But, wait a second to check your name and status... *Eric, one or more members of your group (A) had already consulted with me. What is your interest?*		
Change flood level		I want to change flood level	
	OK Eric, What is the maximum flood level you would allow ?		
Enter the allowable flood level		2 m	

	OK Eric, New flood level is noted. Rule curve is modified. Simulate the system performance.		
Introduce the operator			I am Smith
	Hi! Smith, please tell me which group you belong to: Group A(A); Group B(B); Operator(O).		
			O
	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *Welcome back Smith. I am ready to assist you again. You may now go ahead with your request.*		
Simulate the system performance			I want to simulate the system
	The new alternative, Alter:3 is ready now. Irrigation water deficit is 101.35 MCM and flood damage is 110283.3, US$. It appears that the new alternative is the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Operator changes the reservoir rule curve			
Change the reservoir rule curve			I want to change rule curve
	Rule curve editor is open now.		
The reservoir rule curve is open. Make changes and click "OK"	*Your rule curve has been updated. What are you planning to do next?*		
Simulate the system performance			Simulate the system
	The new alternative, Alter:4 is ready now. Irrigation water deficit is 101.35 MCM and flood		

	damage is 87716.66, US$. It appears that the new alternative is the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Operator changes the reservoir rule curve			
Change the reservoir rule curve			I want to change rule curve
	Rule curve editor is open now.		
The reservoir rule curve is open. Make changes and click “OK”	*Done. I am waiting for your next request.*		
Simulate the system performance			Simulate the system
	The new alternative, Alter:5 is ready now. Irrigation water deficit is 96.35 MCM and flood damage is 93616.67, US$. However, alternative Alter:4 appears to be the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Group A wants to reduce the flood level			
Introduce a member of Group A		I am Eric	
	Hi! Eric, please tell me which group you belong to: Group A(A); Group B(B); Operator(O).		
		A	
	Thank you Eric. I can accept you as a member of Group A. But, wait a second to check your name and status...		

	Welcome back Eric. I am ready to assist you again. You may now go ahead with your request.		
Change the flood level		I want to change flood level	
	OK Eric, What is the maximum flood level you would allow ?		
Enter the allowable flood level		1.8 m	
	OK Eric, New flood level is noted. Rule curve is modified. Simulate the system performance.		
Introduce the operator			I am Smith
	OK Smith, I would like to know the group you belong to. Is it Group A(A); Group B(B); Operator(O) ?		
			O
	Thank you Smith. I can consider you as the Operator. Give me a second to register your name... *Welcome back Smith. I am ready to assist you again. You may now go ahead with your request.*		
Simulate the system performance			I want to simulate the system
	The new alternative, Alter:6 is ready now. Irrigation water deficit is 96.35 MCM and flood damage is 85283.33, US$. It appears that the new alternative is the best. *Would you like to view all the alternatives developed so far? If so, please let me know. If you want you can review the details of the present simulation, too.*		
Review of the alternatives by the stakeholders			
To view the alternatives, either click "View alternatives" or			Show alternatives

type the request on the "communication line"			
The alternatives are displayed	*The alternatives generated so far are presented in tabular and graphical form. If you want to develop a different alternative, that can be done by stakeholders changing their requirements or operator changing system parameters.*		
Selection of a set of alternatives for comparison (Select all and deselect the unwanted ones). Activation of Compromise Programming tool	*The Compromise Programming window is open now. You may edit the weights, if necessary. Run CP by selecting the Run CP button*		
To rank the selected alternatives, run CP in the displayed "CP window"			
View the reservoir rule curve of an alternative enter its number.	*Rule curve for the selected alternative is shown*		
Stop the process by typing "**Quit**"			Quit

Following are the options available in the "Options" window

EDIT INFLOW – To view and change inflow
VIEW INFLOW – To view monthly inflow series graphically
QUERY INFLOW – To view average, maximum and minimum flows in the series
EDIT RESERVOIR CHARACTERISTICS – To view and change the reservoir storage-area-elevation relationship
EDIT RULE CURVE – To view and change the reservoir rule curve
EDIT UNIT DEMAND – To view and change monthly irrigation demand per unit area (MCM/ha)
EDIT PARAMETERS – To view and change minimum river flow, reservoir minimum and maximum operating levels, initial water level, outlet capacity and irrigation area
EDIT RIVER RATING DATA – To view and change downstream river flow-river elevation data
EDIT FLOOD DAMAGE – To view and change damage involved with different levels of flood
VIEW DEMAND – To view monthly irrigation demand
RUN SIMULATION – To simulate the reservoir operation
VIEW ALTERNATIVES – To view data and simulation results of the alternatives
DELETE ALTERNATIVES – To delete all previous alternatives
RUN COMPROMISE PROGRAMMING – To run the Compromise Programme and get the results
If a detailed Compromise Programming analysis is required, then go to view alternatives and select the alternatives of interest and activate CP
VIEW IRRIGATION SUPPLY AND DEMAND – To view the irrigation supply and demand
VIEW FLOOD LEVEL – To view monthly flood level and flood damage
VIEW FLOOD DAMAGE - To view monthly flood level and flood damage
VIEW IRRIGATION DEFICIT – To view the monthly irrigation deficit graphically and demand, supply and deficit in a table
VIEW RESERVOIR ELEVATION – To view reservoir elevation variation
VIEW RESERVOIR STORAGE – To view reservoir storage variation
VIEW RESERVOIR RELEASE – To view total reservoir release
VIEW RIVER FLOW – To view downstream river flow
QUIT – To exit the programme

Appendix D

Software CD Rom

The CD Rom contains two folders.

1. Document : CRSS.doc
2. Software : CRSS (Zip file)

   setup (Application file)

   SETUP (LST file)

Whenever, a new consultation commences, the database initializes to the set of data given in the report.