MODELING FOR CONFLICT RESOLUTION USING PARAMETERIZATION OF OPERATIONS AND STRONG STAKEHOLDER INITIATIVES

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Abstract. The collapse of the ACT/ACF compacts disclosed potential shortcomings of using a conventional water resources model under highly contentious negotiating circumstances. The authors envision an alternative conflict-resolution platform using a different approach, one that was used in an earlier investigation into uncertainty in water quality research. The platform employs Monte Carlo simulation parameterizing water resources operations, randomly selecting parameter combinations, and inputting these as forcing functions to a core water resources operation model. The core model uses constraints determined and quantified by stakeholders, and simulation results can be evaluated by these constraints (visualized as corridors for a simulated quantity to pass through). If a certain parameter combination provides satisfactory simulation results, then the operational policy it represents constitutes a potential solution for the conflict. Iterative model application enables continuous refinement of constraints, parameters and operation rules, until a potential solution is found. The computation results can also be analyzed for the sensitivities of the system to changes in parameters (operations), and thus key operations can be identified.

INTRODUCTION

Conflicts often arise over management of water resource systems serving multiple purposes and stakeholders. The Apalachicola-Chattahoochee-Flint River (ACF) system and the Alabama-Coosa-Tallapoosa River (ACT) system are such systems. In 1997, Congress established the ACF and ACT Compacts as the framework for water resource allocation negotiations among the federal government and the States of Georgia, Florida and Alabama. After years of negotiations and evaluation of numerous management alternatives, the three States failed to reach agreement, and the ACF Compact expired in 2003. Similarly, the States of Alabama and Georgia also failed to reach agreement, and the ACT Compact dissolved in July of 2004.

The authors, having participated in the technical aspects (assembling models and conducting simulations of numerous hypothetical scenarios) of the allocation negotiation process, fully understand the advantages and limitations of the models applied and the data and assumptions on which the models are based. The collapse of both ACF and ACT Compacts prompted the authors to speculate whether there are intrinsic deficiencies with the models or the circumstances under which the models were run.

In an interesting and yet unrelated study done for water quality purposes, the principal author came across the practice of using Monte Carlo simulation approach to assess the sensitivities and uncertainties of parameters in a model. The practice starts with setting reasonable ranges for different parameters of the model. Then a random selection of parameter combinations is conducted. The selected parameter combination is then input to the model for simulation. A set of artificial constraints (visualized as corridors along a time scale) is set for a simulation to pass through. In the previous study, these constraints reflect "expert" opinions on what a particular state variable should be at a given time. The "success" of a simulation is determined by determining whether simulation results violate the pre-set constraints. After each simulation, the "success" (or failure), together with the corresponding parameter combination, is recorded. Statistical analysis may be conducted to determine the sensitivity of the parameters and determine which ones(and the operating policies they represent) are most significant (Osidele et al., 2003).

The methodology in this previous investigation is quite enlightening in two respects. First, it provides a way of analyzing an infinite number of scenarios (since the values of the parameters in the model are continuous, instead of discrete) by studying a finite sub-group. Second, the analysis may be indicative in determining what parameter (and thus the process this parameter represents) is more critical in making a simulation a "success" (meaning simulation results which do not violate the constraints).

It is conceivable that this methodology can be adopted in building a framework that can be used to resolve a conflicting situation for the following reasons. First, the alternative operations in a system of conflicts can all be represented by discrete parameters (as long as the value of a particular parameter is monotonic against the magnitude of operations it represents). Second, because of the potentially large number of parameters and their values, the number of scenarios can be prohibitive for a thorough simulation for all of them. However, a sampling scheme like the one used in the previous investigation can be used to test a limited number of scenarios for a complete analysis. Third, the "expert" opinions about how a simulation should be constrained within a certain boundary can be replaced by "non-expert" stakeholder demands that can function (as constraints) just as well. Fourth, a sensitivity analysis can determine the operations that are most critical to achieving a simulation deemed a "success".

Based on these understandings, the authors introduce the following framework in the hope that it may provide a useful tool in addressing problems rising from systems of conflicts.

SYSTEM CONFIGURATION

To illustrate the feasibility of this modeling platform, the authors chose a hydrologic system that is physically similar to the Upper Chattahoochee River (from the headwaters of Lake Lanier to Whitesburg) with arbitrary constraints that are not intended to reflect reality. The system has been kept simple enough for iterative computations to be made without substantial computational time. The studied system has a multi-purpose reservoir (Lake A) into which its headwaters drain. It has a stretch of river downstream of Lake A. Along the river, there is a metropolitan area (City B). This configuration is shown in Fig. 1.

Alternative operating objectives and constraints have been considered together, since they both involve stakeholder participation and are interconnected. Objectives include power generation, flood control, navigation, minimum release, minimum in-stream flow target operation, wastewater assimilation, and water supply at both Lake A and City B. Constraints include low elevations at Lake A, shortages in power generation, flow target violations, flood hazards, and water supply shortages. It is apparent that some of the operations/constraints are in conflict with others (e.g. low lake elevations vs. power generation). The operations and constraints are listed in Table 1.

Table 1. Operations and Constrains of the Studied System

Point of Interest	Lake A	City B
Operations	1. <u>Hydropower generation</u>	1. water supply
	2. Flood control	2. assimilation of treated waste water
	3. <u>Water supply</u>	
	4. <u>Flow target</u>	
	5. Navigation	
	6. Minimum release	
Constraints	1. <u>low elevation</u>	1. <u>minimum flow</u>
	2. <u>diversion shortage</u>	2. diversion shortage
	3. minimum release	3. <u>long term average flow</u>
	4. power generation shortage	4. flooding

Note:

1. The lists contain possible operations and constraints.
2. The underlined entries have been used in this demonstration.
3. The power generation alternatives are 1, 2, and 3 hours of scheduled power generation when power pool is 60% or more full.
4. The water supply (at Lake A) alternatives are 200, 250, and 300 mgd of net withdrawal.
5. The flow target alternatives are 1500, 1750, and 2000 cfs operated for City B.

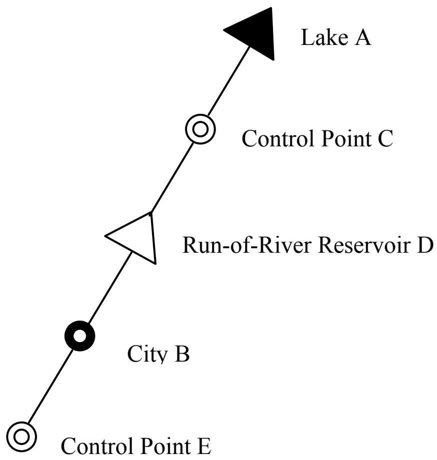

Fig. 1 System schematic

MODELING FRAMEWORK

The modeling framework employs iterative applications of its three aspects — choosing a set of parameterized operations, running a core simulation model, and evaluation of simulation results.

The stakeholder participation takes place before the beginning of a series of simulations. Alternative operations may be proposed by reservoir operating agencies (e.g. Army Corps of Engineers), water resources management agencies (e.g. Georgia Environmental Protection Division), and various stakeholder groups (e.g. lake shore residents, public utilities, environmentalists, and power beneficiaries). These alternatives will be categorized to form various seed groups of operations. For example, the Flow Target seed group may contain different levels of possible flow targets at the downstream protected city. Each seed group will be assigned a parameter index, and each alternative operation will be given a parameter value. At this stage, no argument will be made regarding the merit or practicality of any alternatives.

Stakeholders are also heavily involved in determining how to evaluate the results of a simulation. Each stakeholder group may have its own interest in one or more aspects of the hydrologic system. For instance, lake shore residents may have concerns over the lake level being too low; or city officials may be concerned over the river's capability to assimilate treated wastewater during prolonged periods of low flow. Each stakeholder group will be asked to present its view of what is required and what is desired of these aspects of the system. Moreover, the stakeholders will be asked to quantify the impact of an adverse condition (violation of a condition which is required or desired) using a scoring mechanism. The scoring mechanism can be visualized as several constraining layers of corridors for a simulated state variable to pass through. Some of the layers can be "soft", indicating desired conditions which can be violated occasionally. The scores for bumping into these "soft" layers may reflect the severity of associated violations. There can be "hard" layers, which represent the required conditions, and indicate highly unacceptable impact if violated. This concept is visualized in Fig. 2. The design of this mechanism will not be discussed in great detail in this paper.

After the alternative operations and the scoring mechanism have been determined, Monte Carlo simulations can be conducted. For a large project, given the possibly large number of parameters (representing different categories of operations) and multiple candidate values (representing alternative operations in each category) for each of the parameters, the total number of iterations can be prohibitive if simulations were to be conducted for the entire population of possible parameter combinations. For example, if there are 10 different categories of operations with each category of operations having 5 different values, then the simulation would require 5^{10} = 9,765,625 iterations. This will be impractical. With the assumption that all parameters have a uniform distribution of all possible values, a more practical way would be to conduct simulations over a sample of randomly selected parameter combinations out of the entire population. A similar approach has been employed in a previous investigation into uncertainties in water quality modeling (Osidele et al., 2003).

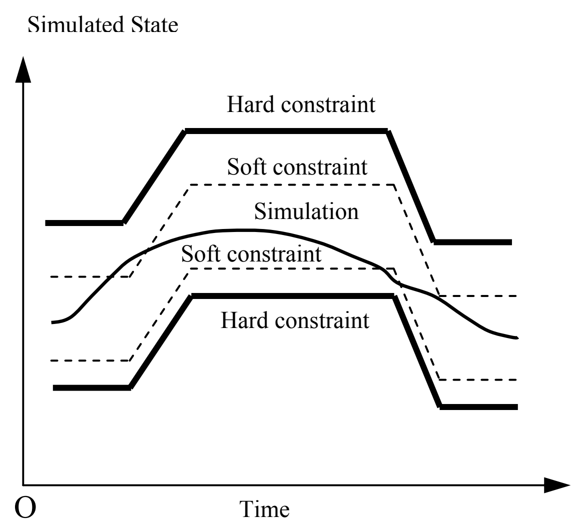

Fig. 2 Visualization of a Scoring Mechanism

To demonstrate the potential application of this modeling framework, small numbers of operations and parameter values were chosen (3 in both cases), making simulation of the entire combination of parameters possible (the total number of iterations here is $3^3 = 27$), and the use of random selection of parameters unnecessary. HEC-5 has been selected as the core simulation model for this framework. A period of 8 years (Jan. 1, 1979 to Dec. 31, 1986) of hydrologic events (Unimpaired flow developed by U.S. Army Corps of Engineers) has been selected for this demonstration. The operational alternatives are listed in Table 2.

After each simulation, the results are evaluated according to the scoring mechanism set up by the stakeholders, and the scores are recorded together with the parameter values. A pass/fail judgment will be made for each simulation according to the scores. For a particular system, it is possible that all the simulations will pass the test, which indicates that either the system has not been stressed, or that the stakeholders have a high tolerance to adverse conditions. The other extreme is also possible, which indicates that the "pain" of stress has been felt to be severe by all the stakeholders, and that a compromise is necessary to achieve a solution for "sharing the pain". It is also possible that a particular simulation based on a set of parameter combination would pass judgment and thus provide a set of operations that are acceptable to all parties. Regardless of the situation, the modeling framework will record the scores and the judgment into a matrix which can be analyzed after the simulations. The authors have formulated a very simple scoring mechanism for this study. In reality, the mechanism can be much more complicated, may contain much more information, and may set more obstacles for a simulation to pass the test. However, for simplicity and demonstration purposes, the authors opted to use the simple mechanism in this study, which is listed in Table 3. These constraints, from a modeler's standpoint, reflect the interests of reservoir, downstream city, water supply, and downstream environmental parties. In this study, any simulation that scores less than the "minimum non-acceptable value" in all four aspects of the evaluation is considered to be potentially acceptable. The modeling framework is illustrated in Fig. 3.

SIMULATION RESULTS AND DISCUSSION

After all 27 simulations were conducted, a matrix was created to record the parameter combinations and the simulation results. This matrix is shown in Table 4. By the standards set up before the simulations were made, only those having a score less than 100 – 50 – 50 – 100, with respect to the four constraints, would pass the test. The standards have been set up so that a passing simulation must have (1) less than 100 days when Lake A elevation is below 1055', (2) less than 50 days when daily average flow at City B is less than 1500-cfs, (3) less than 50 days when diversion shortage at Lake A is more than 25-mgd, and (4) the long-term (over the entirety of the simulated 8 years) daily average flow is above 2300-cfs. Only 3 simulations (No. 1, 10, and 19) out of 27 passed the test. This low passing rate was anticipated, since we have arbitrarily set up requirements that are high, strict, and sometimes conflicting.

Among the simulations that passed the test, Simulation 1 has the lowest amount of hydropower generation, and the lowest levels of both water supply and flow target operations. Simulations 10 and 19 have the mid-level and higher amount of hydropower generation respectively, and both have the lowest amount of water supply and flow target operations. It is noted that, in the current study, the simulation results are very sensitive to the increase in water supply and flow target operations, while not so sensitive to the amount of hydropower generated (as shown in Table 4). The reason for this, the authors speculate, might be that a 1500-cfs flow target at City B is high enough to provide adequate flow for a 3-hour peaking generation; under the current scoring mechanism, given the 1500-cfs flow target, any other candidate net withdrawal higher than 200-mgd from Lake A might be in conflict for the system to deliver a 2300-cfs long term average daily flow.

Table 2. Parameter Values (Operational Alternatives)

Parameter	A. Scheduled Power Generation When Power Pool More than 60% Full	B. Amount of Net Withdrawal from Lake A	C. Flow Target Operated for City B
Candidate Values	1 – 1.0 hour	1 – 200 mgd	1 – 1500 cfs
	2 – 2.0 hour	2 – 250 mgd	2 – 1750 cfs
	3 – 3.0 hour	3 – 300 mgd	3 – 2000 cfs

Table 3. Scoring Mechanism for Evaluating Simulation Results

Constraint	Score (Severity of Impact)	Minimum non-acceptable value
1. Surface elevation at Lake A less than 1055' for one day	1	100
2. Flow rate at City B less than 1500 cfs for one day	1	50
3. Diversion shortage at Lake A larger than 25 mgd for one day	1	50
4. Long term daily average flow rate less than 2300 cfs	100	100

Table 4. Computational Results

Simu-lation No	Parameters			Resulting Scores				Pass/ Fail
	Scheduled Power Generation (hour)	Net Withdrawal from Lake A (mgd)	Flow Target at City B (cfs)	Days Lake A Elevation Lower than 1055'	Days Flow at City B Less than 1500 cfs	Days Diversion Shortage at Lake A Greater than 25 mgd	Long Term Daily Average Flow at City B Less than 2300 cfs (100 for occurrences)	
1	**1**	**200**	**1500**	**0**	**0**	**0**	**0**	**P**
2	1	200	1750	254	0	0	0	F
3	1	200	2000	254	0	0	0	F
4	1	250	1500	73	0	0	100	F
5	1	250	1750	335	0	0	0	F
6	1	250	2000	1009	66	37	0	F
7	1	300	1500	188	0	0	100	F
8	1	300	1750	479	0	0	100	F
9	1	300	2000	1179	96	74	100	F
10	**2**	**200**	**1500**	**0**	**0**	**0**	**0**	**P**
11	2	200	1750	260	0	0	0	F
12	2	200	2000	786	32	10	0	F
13	2	250	1500	93	0	0	100	F
14	2	250	1750	347	0	0	0	F
15	2	250	2000	1011	66	37	0	F
16	2	300	1500	198	0	0	100	F
17	2	300	1750	483	0	0	100	F
18	2	300	2000	1180	97	74	100	F
19	**3**	**200**	**1500**	**43**	**0**	**0**	**0**	**P**
20	3	200	1750	269	0	0	0	F
21	3	200	2000	790	34	10	0	F
22	3	250	1500	141	0	0	100	F
23	3	250	1750	359	0	0	0	F
24	3	250	2000	1015	67	38	0	F
25	3	300	1500	226	0	0	100	F
26	3	300	1750	493	0	0	100	F
27	3	300	2000	1182	99	75	100	F

The simulated elevation at Lake A and flow rate at City B of simulation No. 19 are shown in Fig. 4 and 5 respectively. It can be seen that elevation at Lake A is above the level 1055' for most of the simulated time frame, except a short period in 1988 (statistics shown in Table 4). Also, flow rate at City B is above the minimum requirement of 1500-cfs. Table 4 shows that there is neither diversion shortage nor any violation of the 2300-cfs downstream long-term average flow requirement.

It would be interesting to see a similar set of simulations with a higher set of hours of hydropower generation, a set of flow targets that are higher than but

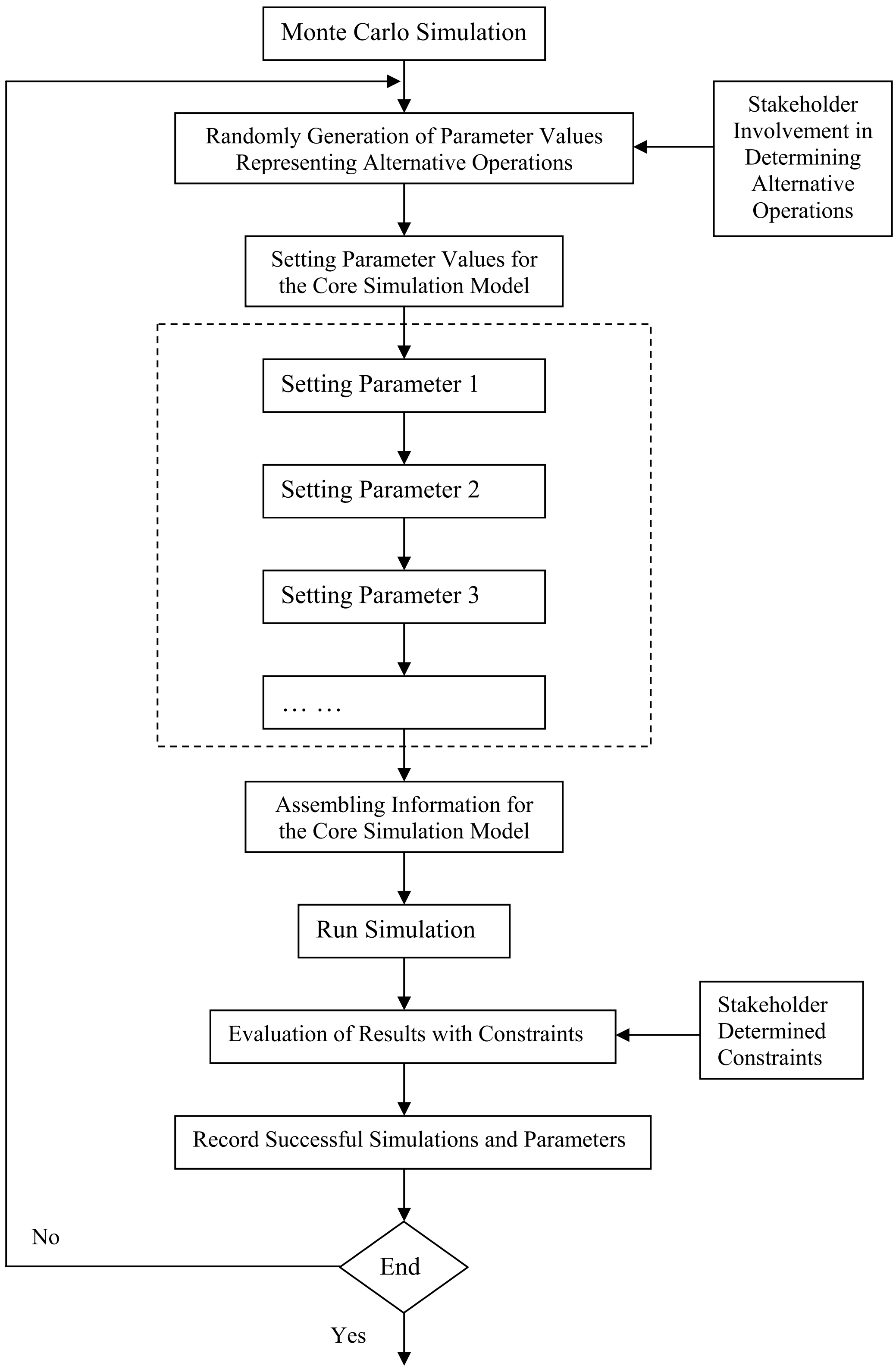

Fig. 3 Flow Chart of Conflict Resolution Modeling Framework

Fig. 4 Simulated Elevation at Lake A (Simulation No. 19)

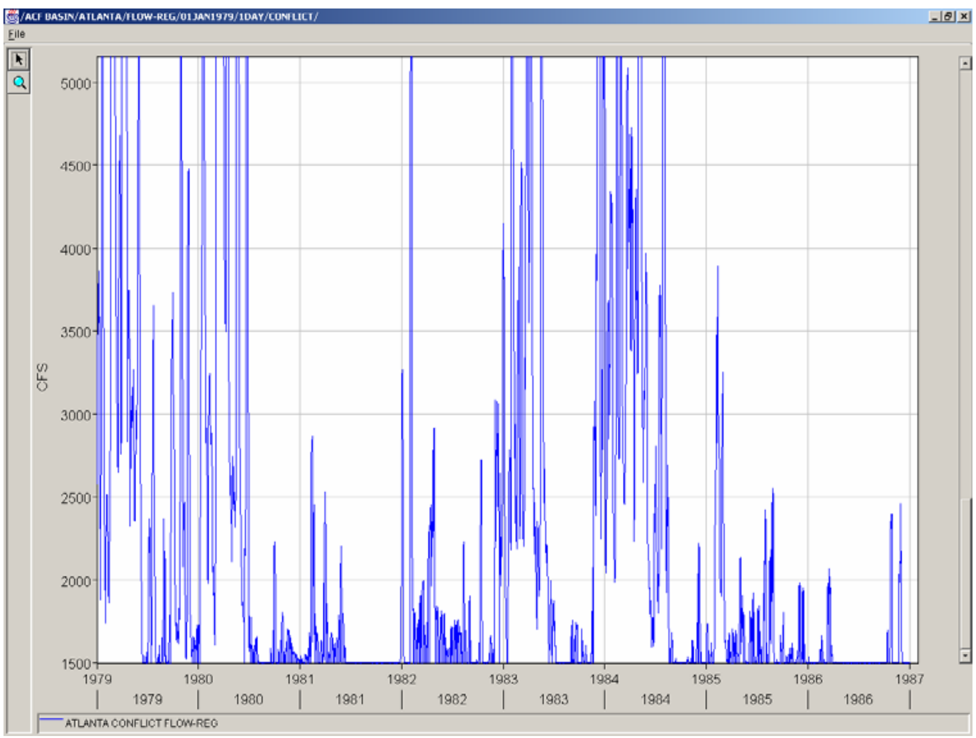

Fig. 5 Simulated Flow Rate at City B (Simulation No. 19)

close to 1500-cfs, and a set of net withdrawals that are higher than but close to 200-mgd. It is conceivable that such a set may reveal where the upper limit of hydropower generation is with this set of constraints. This practice would be meaningful in an actual conflict, since the beneficiaries of hydropower generation may have a stake in how much hydropower is generated by the set of operations, and thus may request a constraint of their own.

In the current study, the downstream interest has been protected by the long-term daily average flow at City B set at 2300-cfs. The authors recognize that the magnitude of this flow, together with the fact that it was set as a constant may not reflect what a real downstream stakeholder wants. This flow minimum was set merely to induce conflicts in a simple and easy way. More complicated downstream flow requirements (e.g. a flow regime that reflects seasonal changes) can certainly be considered by this conflict-resolution methodology.

Water supply requirements can also be studied in a realistic and complex manner. Diversion of seasonal patterns, with different return rates and different return locations, may be incorporated. This modeling framework can handle the complexity of such complex operational alternatives and constraints in the preprocessing stage.

It is worth reiterating that the authors are not discussing any real numbers with regard to how such a system is to be managed. Instead, these arbitrarily high and restrictive numbers have been put forward merely to demonstrate and magnify any potential conflicts, and to show how the studied modeling framework could be used to analyze such a conflict-prone system. Also, the demonstration of the conflict resolution framework shown here is not exactly the same as the one the authors envision. In the current demonstration (proof of concept), the random search of parameter values has not been employed, as a more realistic and more complicated system would, as a result of the limited number of possible combinations of parameter values. The process of random selection of parameter values will be much more important in an envisioned more complicated system, given the large number of possible parameter combinations.

Even after an apparently acceptable solution has been found, stakeholders may alter their view of either the operation alternatives or the constraints. As a matter of fact, the authors expect participating parties to review the computational results and to revise the operation alternatives and the constraints as they see fit. It is conceivable that some parties may have reservations about others' operation alternatives or constraints after seeing the results of a successful simulation. Exchange of ideas and views is considered a vital part of the process. Any operation alternatives and constraints can be proposed before a set of simulations are conducted. The legitimacy of the proposed constraints can be determined by comparison of the constraints (and scoring mechanism) to historic statistics, and negotiated before a series of tests. The legitimacy and practicality of the alternatives need not be argued. Instead, they can be tested by the simulations, and the tests are rather objective. Only the passing ones bear the chances of being accepted by all participating parties. If the participants would like to revise some of the alternatives or the constraints, they are welcome to do so. However, any change would have to be tested by a new set of simulations. And again, only the passing ones have the possibility of being accepted by all parties. The analytical procedures described in this paper can be applied in a variety of negotiation, mediation, consensus management and conflict-resolution frameworks.

CONCLUSIONS

This paper conceptually demonstrates the feasibility of conflict resolution aided by a computational framework combining parameterization of alternative operations, random selection of parameter combinations, Monte Carlo simulations of the selected combinations, and strong stakeholder involvement in determining both operational alternatives and constraints. It has been shown that satisfactory outcomes can be disclosed by this process. The authors envision that the computational framework can be useful in understanding tradeoffs and interdependencies for decision-making on the management of complex systems.

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