CONFLICT RESOLUTION IN WATER RESOURCES ALLOCATION

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In this study, an optimization methodology for conflict resolution in water allocation in river–reservoir systems is presented. The objective function of the optimization model is based on the Nash bargaining theory which can incorporate the utility functions of the decision makers and the stakeholders as well as their relative authorities on the water allocation process. The utility functions are based on the reliability of the allocated water to different sectors especially the environmental water demands, water storage in the reservoir and the quantity of the return flows. The proposed model which includes an integrated GA–based optimization (SGA) is applied for the reservoir operation and water allocation in Karkhe River-Reservoir system in southern part of Iran. Results show that this model can be effectively used in optimal water allocation of river–reservoir systems considering the conflicting utilities and the relative authorities of decision makers and stakeholders.

INTRODUCTION

Development of economic based reservoir operation models is a classical problem in water resources planning and management. Application of explicit conflict resolution methods in reservoir operation has received more attentions recently. Palmer et al. [5] introduced "Shared Vision Model" as a procedure that allows interested participations to achieve consensus by providing a shared vision of a system or process. Palmer et al. [6] developed a conflict resolution model for Kum River Basin in Korea. They derived the trade-off between water supply reliability and in-stream flows using a water resources simulation model, developed in STELLA® software environment. Karamouz and Kerachian [3] used a conflict resolution scheme in order to develop the optimal reservoir operating rules for improving the quality of water supplied focusing on the natural
process of stratification. They showed that this model could be effectively used in optimal water allocation of river–reservoir systems with conflicting objectives.

This paper presents an approach to develop the optimal reservoir operating policies considering the conflicting utilities and the relative authorities of decision makers and stakeholders. In order to include a conflict resolution scheme, the Nash bargaining theory (Nash [4]) is used in the proposed methodology. Considering the computational complexity of the problem, the Sequential Genetic Algorithms (SGA) proposed by Kerachian and Karamouz (2004) is used as the optimization technique.

A CONFLICT RESOLUTION SCHEME

Conflict can occur in water resources planning and management for a variety of reasons, but in general, water conflicts occur when people disagree about how much water of a given quality is available at a given time in a region for a specific purpose. However, when a conflict occurs among two or more individuals/agencies, attempts should be made to reach to an agreement. The Nash bargaining theory is one of the more commonly used methods for resolving conflicts. It includes stakeholders' preferences (presented by a utility function), as well as the disagreement point and the individual risk taking attitudes in the decision process. The general form of the Nash theory as presented by Karamouz et al. [2] is as follows:

Let assume \( f_i(\cdot) \) to be the utility function of decision maker \( i \), and the vector of disagreement points is assigned as \( \vec{d} = (d_1, \ldots, d_n) \), then unique solution of the conflict resolution problem can be obtained by solving the following optimization problem:

Maximize: \[ Z = (f_1 - d_1)^{w_1} (f_2 - d_2)^{w_2} \ldots (f_n - d_n)^{w_n} \]  
Subject to: \( f_i \geq d_i \quad i = 1, 2, \ldots, n \)

Where, \( n \) is the number of stakeholders and the power term, \( w_i \), \( i=1, 2, \ldots, n \), represents their relative authority or risk-taking attitude. The above model, commonly known as the Nash product, can be used to solve a reservoir operation problem in which different decision makers and stakeholders with conflicting utilities are exist.

MODEL FORMULATION

Objective Function

The optimization model provides the optimal monthly releases from each outlet during the planning horizon for each stakeholder. As mentioned before, the objective function of the model is the Nash product. Therefore, the objective function of the model is the multiplication of all user agencies (agricultural, industrial, domestic and environmental units) utilities subtracted from their point of disagreement and the utility of water storage in the reservoir for hydropower targets. The Model formulation is as follows:
Maximize:
\[
\prod_{i=1}^{12 \times \text{year}} (f_{do,i} - d_{do,i})^{w_{do,i}} \times (f_{ind,i} - d_{ind,i})^{w_{ind,i}} \times (f_{env,i} - d_{env,i})^{w_{env,i}} \times (f_{St,i} - d_{St,i})^{w_{St,i}}
\]
\[
\times \prod_{j=1}^{n} (f_{ag,j,i} - d_{ag,j,i})^{w_{ag,j,i}}
\]

Subject to:

\[
R_i = \sum_{l=1}^{nst} R_{l,i}, \quad i = 1, 2, \ldots, 12 \times \text{year}
\]

\[
S_{i+1} = S_i + I_i - R_i, \quad i = 1, 2, \ldots, 12 \times \text{year} - 1
\]

\[
S_{\text{min}} \leq S_i \leq S_{\text{max}}
\]

\[
R_i \leq R_{\text{max},i}
\]

\[
h_i = G(S_i)
\]

\[
R_{\text{max},i} = F(h_i)
\]

\[All \ Variables \ \geq 0\]

Where:

\(i\): month index

\(j\): agricultural unit index

\(nst\): number of stakeholders (agricultural, industrial, domestic and environmental units)

\((f_{ag,j,i}, d_{ag,j,i}, w_{ag,j,i}), (f_{ind,i}, d_{ind,i}, w_{ind,i}), (f_{St,i}, d_{St,i}, w_{St,i}), (f_{env,i}, d_{env,i}, w_{env,i})\): utility function, disagreement point and relative authority of, \(j\)th agricultural unit, domestic unit, industrial unit, water storage in the reservoir, environmental unit respectively.

\(R_i\): total release during month \(i\) (million cubic meters).

\(R_{l,i}\): allocated water to stakeholder \(l\) in month \(i\) (million cubic meters).

\(S_i\): reservoir storage at the beginning of the planning horizon (million cubic meters).

\(S_i\): reservoir storage at the beginning of month \(i\) (million cubic meters).

\(I_i\): inflow during month \(i\) (million cubic meters).

\(S_{\text{min}}\): reservoir storage in its minimum water level.

\(S_{\text{max}}\): reservoir storage in its maximum water level.

\(h_i\): water storage level during month \(i\) (meter).

\(G(\ )\): a function of reservoir storage at the beginning of month \(i\), determining water storage level.

\(R_{\text{max},i}\): maximum possible release during month \(i\) (million cubic meters).

\(F(\ )\): a function of water storage level during month \(i\), determining maximum possible release.

Stakeholders’ utility functions are related to their allocated water each month. In addition, water storage utility function is related to the water storage at the beginning of each month. Equations (8) and (9) are, in fact, reservoir rating-curve that determines the maximum possible release in each month considering water storage level, capacity and position of each outlet.
Sequential Genetic Algorithms

Genetic Algorithms are adaptive methods trying to imitate the biological and genetic process and can be successfully applied to the optimization problems. The main field of application of GAs includes problems with high complexity and non-linear behavior such as reservoir operation. In this study, a GA based optimization algorithm entitled Sequential Genetic Algorithms (SGA), proposed by Kerachian and Karamouz [3], which is based on the sequential game theory is used. In this methodology, the number of chromosome genes (chromosome length) is sequentially increased to effectively lead the initial feasible solutions to the global optimal solution.

In this study, the gene values are the monthly release from the different outlets for each stakeholder. In the first step, a small record of inflow is selected and the optimal monthly releases from outlets for each stakeholder are obtained using the traditional GA based optimization model. Then, the chromosome length is increased for the second step and the optimal solution of the first step is iterated in the second part of the new chromosomes for initial generation. The optimal solution of this step is obtained using traditional GA based optimization model. For future steps, the chromosome length is still increased. For each step, the optimal solution of the previous step and the average of its genes are located in the first and the second part of the new chromosomes consequently; the optimal solution of each step is obtained using traditional GA based optimization model. Each step can vary from one month to 1 or 2 years. The step length is determined based on the convergence characteristics of the GA model. In this study, 1 year is selected for the length of each step. This sequential method effectively reduces the computational burden of GA-based models in long-term planning and management of water resources. Studies show that some characteristics of GA methods such as the number of population, mutation and crossover probability are highly related to the length of chromosomes (Gen and Chang [1], Wardlaw and Sharif [7]). Therefore, in this study, mutation probability, the most sensible characteristic to the variation of chromosomes length, is considered variable so that it can be reduced by increasing the length of chromosomes.

CASE STUDY

The proposed optimization procedure is used for optimal operation of Karkheh river-reservoir system in southern part of Iran. Karkheh reservoir, the largest dam in Iran, with a volume of 7600 million cubic meters, supplies the demands of the agricultural, domestic, industrial, and environmental sectors.

Karkheh Dam has three outlets and one spillway, which can be used for selective withdrawal. There are six agricultural lands with the total area of about 340,000 hectares, an industrial complex, a town and one environmental checkpoint (Hoor-Al-Azim Wetland) downstream of Karkheh Reservoir showed in Figure 1.

For a 20-year planning horizon, each chromosome in SGA model has 10800 bits (5bits×12months×20years×(6agricultural+1industrial+1domestic+1environmental)).
The utility functions of different stakeholders of the system are considered to be as follows:

Agricultural Sector: The main objective of this sector is supplying agricultural water demands of all six zones, which have the most water demands downstream of Karkheh reservoir. The utility of this sector related to the water supply is based on the water supply reliability. The importance of agricultural water supply is varied from one season to another. Therefore, in this study, the utility function for water supply to each agricultural zone is assumed as:

\[
\begin{align*}
    f_{ag,i,j}(A_{ag,j,i}) &= \begin{cases} 
        1 & \text{if } A_{ag,j,i} > 120 \\
        1 - 0.015(125 - A_{ag,j,i}) & \text{if } 60 \leq A_{ag,j,i} \leq 120 \\
        0 & \text{if } 0 < A_{ag,j,i} \leq 60 
    \end{cases} \\
    f_{ag,i,j}(A_{ag,j,i}) &= \begin{cases} 
        1 & \text{if } A_{ag,j,i} > 125 \\
        1 - 0.018(125 - A_{ag,j,i}) & \text{if } 70 \leq A_{ag,j,i} \leq 125 \\
        0 & \text{if } 0 < A_{ag,j,i} < 70
    \end{cases}
\end{align*}
\]
Where $A_{ag,i,j}$ is the percentage of supplied agricultural water demand in agricultural zone $j$ in month $i$.

**Domestic Sector:** The main objective of this sector is supplying water to domestic demands. Considering the importance of the domestic water supply, the most favorite range is 90 to 100 percent. Therefore, the utility function of the decision makers in this sector for the reliability of domestic water supply is assumed as:

$$ f_{do,i}(A_{do,i}) = \begin{cases} 1 & \text{if } A_{do,i} > 100 \\ 1 - 0.1(100 - A_{do,i}) & \text{if } 90 \leq A_{do,i} \leq 100 \\ 0 & \text{if } A_{do,i} < 90 \end{cases} $$

(14)

Where $A_{do,i}$ is the percentage of the supplied domestic water demand in month $i$.

**Industrial Sector:** The main objective of this sector is supplying water to industrial demands. The utility function of the decision makers in this sector for the reliability of industrial water supply is assumed as:

$$ f_{ind,i}(A_{ind,i}) = \begin{cases} 1 & \text{if } A_{ind,i} \geq 100 \\ 0 & \text{if } A_{ind,i} < 100 \end{cases} $$

(15)

Where $A_{ind,i}$ is the percentage of the supplied industrial water demand in month $i$.

**Environmental Sector:** The environmental water supply in the Karkheh River is the main concern of this sector. The available data shows that the discharge of 80 MCM per month is needed for Karkheh ecosystem; the environmental utility function for river flow is formulated as follows:

$$ f_{env,i}(Q_{env,i}) = \begin{cases} 1 & \text{if } Q_{env,i} \geq 80 \ MCM \\ 1 - 0.033(80 - Q_{env,i}) & \text{if } 50 \leq Q_{env,i} < 80 \ MCM \\ 0 & \text{if } Q_{env,i} < 50 \ MCM \end{cases} $$

(16)

Where, $Q_{env,i}$ is the in-stream flow at Hoor-al-Azim control point in month $i$.

**Reservoir Storage Utility:** The reservoir storage utility is developed considering the minimum and maximum allowable water level in each month and the hydropower intake level. The utility function of the decision makers in this sector for reservoir water storage is:
Where $h_{i+1}$ is water level above sea level at the end of month $i$.

**RESULTS and DISCUSSION**

In this study, the available 20 years of Karkheh River monthly stream flow data is used for water allocation from Karkheh reservoir to downstream demands. Demands data were available just in the beginning and at the end of planning horizon. Therefore, required information was produced during these 20 years considering developing plans of the region and using system dynamics simulation. Standard operating policies (SOP) are widely used for reservoir operation in Iran. In this study, a comparison between SOP and the proposed model results is made.

Figure 2 shows the variation of water storage volume during the planning horizon. As it can be seen, water storage is often in the most favorite range in the proposed SGA model while it would not be in the range in about 10 years using standard operating policies.

![Figure 2. Variation of water storage](image)

Table 1 presents the most important results of the developed model consists of reliability of allocated water to different users, minimum percentage of the supplied water demands, average and minimum of water storage in the reservoir. The results...
show that the developed model can be effectively used in the proposed reservoir operation model. In the SGA model, the relative weights (authorities) of the stakeholders are considered to be equal to the values presented in Table 1. SGA model shows that on the average, more than 85 percentage of downstream water demands can be provided at the development stage.

Table 1. Optimal values of allocated water

<table>
<thead>
<tr>
<th>Conflicting sectors</th>
<th>Relative weight (authority)</th>
<th>Results topic</th>
<th>SGA</th>
<th>SOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural</td>
<td>0.21</td>
<td>Reliability of allocated water (%)</td>
<td>88</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum percentage of demand supply (%)</td>
<td>58</td>
<td>28</td>
</tr>
<tr>
<td>Industrial</td>
<td>0.26</td>
<td>Reliability of allocated water (%)</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum percentage of demand supply (%)</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>Domestic</td>
<td>0.26</td>
<td>Reliability of allocated water (%)</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum percentage of demand supply (%)</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>Environmental</td>
<td>0.26</td>
<td>Reliability of allocated water (%)</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum percentage of demand supply (%)</td>
<td>100</td>
<td>28</td>
</tr>
<tr>
<td>Reservoir</td>
<td>0.01</td>
<td>Average water storage (MCM)</td>
<td>5313</td>
<td>2960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum water storage (MCM)</td>
<td>1735</td>
<td>630</td>
</tr>
</tbody>
</table>

REFERENCES


