The Total Control of Water Supply and Water Consumption in Tianjin City Based on WAS Model

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Abstract. Water resources planning and management should constitute an integral part of the socio-economic development planning process. Models have become the core part of water resources management. In this paper, the Water Simulation and Allocation Model (WAS) was developed and applied in Tianjin City, China. The aim of the research is to provide the water control value based on pragmatic modeling approach to water planning and management in order to promote water allocation, recover ecosystem recovery. In 2030, in accordance with WAS model calculated, the ET goal control is the 643mm; the volume of sea water into the goal for 1.649 billion m³. Exploitation of deep underground water is about 3.06 billion m³. Domestic economy in rural areas are being met and the water control of domestic economy is about 37.87 billion m³; water for the Ecology is 9.51 billion m³.

Introduction

The basin water cycle affected by human activities takes into consideration both natural as well as human characteristics. Before, the hydrological cycle was based on precipitation, surface runoff, river and groundwater[1-4]. But now, the cycle must also incorporate four human water cycle aspects: taking water, transporting water, using water, drainage and regres[5-6]. Water resources planning and management should constitute an integral part of the socio-economic development planning process[7-10]. Therefore, models have become the core part of water resources planning and management.

However, the most hydrological models tend to be specialized and unilateral, and limited in the use of reservoir routing or local hydraulic control, especially when they are used in ‘dualistic’ water cycle having both natural and artificial characteristics. Indeed, it has been recognized that the need exists for comprehensive integration of management features in streamflow-ground water coupled hydrological models[11].

In this paper, the Water Simulation and Allocation Model (WAS) was developed and applied in Tianjin City, China[12]. The aim of the research is to provide the water control value based on pragmatic modeling approach to water planning and management in order to promote water allocation, recover ecosystem recovery.

Methods

Objective Function

Interacting with socio-economic and environmental issues, Water resource planning is typically guided by multiple objectives. Optimal water allocation and planning must be consistent with the existing institutions. Brownet recognized four objectives of concern to water planning institutions [4]: economic improvement, environmental preservation, maintenance of agricultural lifestyle, and equitable access to water. In this study, the objectives of WAS includes economic improvement, with
economic benefit maximization as the index; ecology preservation, with ecologic consumptive water maximization as the index; environmental preservation, with drainage of pollution minimization as the index; and crop harvest safety, with income maximization from crop harvest as the index. The objective function is mathematically expressed as maximize:

\[
C_{obj} = \max (f[\text{Max}(f_{eco}), \text{Max}(Q_{bio}), \text{Min}(Q_{pl}), \text{Max}(f_{food})))
\]

where: \(f_{eco}\) is the economy benefit, \(Q_{bio}\) is ecologic consumptive water, \(Q_{pl}\) is drainage of pollution, \(f_{food}\) is the income of crop harvest.

Constraints

The objective function is subject to the following constraints including three components: natural, artificial and controlling aspects.

(1) Natural constrains

1. Constrain on surface water balance

\[
V_{\text{stored,}2} = V_{\text{stored,}1} + V_{\text{in}} - V_{\text{out}} - V_{\text{los}} - E_{\text{ch}} + V_{\text{div}} + V_{\text{bank}}
\]

where \(V_{\text{stored,}1}\) and \(V_{\text{stored,}2}\) are the volume of water in the reach at the beginning and end of the time step (m\(^3\) H\(_2\)O), \(V_{\text{in}}\) and \(V_{\text{out}}\) are the water volume of inflow and outflow at the beginning and end of the time step (m\(^3\) H\(_2\)O), \(E_{\text{los}}\) is the volume of water lost from the reach via transmission through the bed (m\(^3\) H\(_2\)O), \(E_{\text{ch}}\) is the evaporation from the reach for the day (m\(^3\) H\(_2\)O), \(E_{\text{div}}\) is the volume of water added or removed from the reach for the day through diversions (m\(^3\) H\(_2\)O), and \(E_{\text{bank}}\) is the volume of water added to the reach via return flow from bank storage(m\(^3\) H\(_2\)O).

2. Constrain on groundwater balance

\[
GW_i = GW_{i-1} + Q_{\text{rchrg}} + Q_{\text{dnin}} - Q_{\text{dout}} - E_{\text{gw}} - Q_{\text{div}}
\]

where \(GW_i\) and \(SW_{i-1}\) are the amount of water stored in the ground aquifer on day \(i\) and \(i-1\) (m\(^3\) H\(_2\)O), \(Q_{\text{rchrg}}\) is the amount of recharge entering the aquifer on day \(i\) (m\(^3\) H\(_2\)O), \(Q_{\text{dnin}}\) is the amount of lateral inflow on day \(i\) (m\(^3\) H\(_2\)O), \(Q_{\text{dout}}\) is the amount of lateral outflow on day \(i\) (m\(^3\) H\(_2\)O), \(E_{\text{gw}}\) is the amount of water evapotranspiration on day \(i\) (m\(^3\) H\(_2\)O), and \(Q_{\text{div}}\) is the amount of water removed from the shallow aquifer by pumping on day \(i\) (m\(^3\) H\(_2\)O).

(2) Artificial constrains

1. Constrain on water balance for subzone

\[
QU_i(u, m, y) = Q_{\text{resu}}(u, m, y) + Q_{\text{rivu}}(u, m, y) + Q_{\text{shalu}}(u, m, y) + Q_{\text{depu}}(u, m, y) + Q_{\text{rnu}}(u, m, y) + Q_{\text{rsvu}}(u, m, y)
\]

where \(QU_i\) is the total consumptive volume of water (m\(^3\) H\(_2\)O), \(Q_{\text{resu}}\) is the volume of water supplied from reserves (m\(^3\) H\(_2\)O), \(Q_{\text{rivu}}\) is the volume of water supplied from rivers (m\(^3\) H\(_2\)O), \(Q_{\text{shalu}}\) is the volume of water supplied from shallow aquifers (m\(^3\) H\(_2\)O), \(Q_{\text{depu}}\) is the volume of water supplied from deep aquifers (m\(^3\) H\(_2\)O), \(Q_{\text{rnu}}\) is the volume of water supplied by re-use water, desalted seawater and saltish groundwater, (m\(^3\) H\(_2\)O), \(Q_{\text{rsvu}}\) the volume of water supplied by diversion water from other places (m\(^3\) H\(_2\)O), \(u\) is the id of subzone, \(m\) represents month, and \(y\) represents year.

2. Constrain on reservoir water balance

\[
QR(r, m + 1, y) = QR(r, m, y) + Q_{\text{rin}}(r, m + 1, y) + Q_{\text{prin}}(r, m + 1, y) - Q_{\text{res}}(r, m + 1, y) - Q_{\text{rsvu}}(r, m + 1, y) - Q_{\text{rsv}}(r, m + 1, y)
\]

where \(QR\) is the volume of water in the reservoir (m\(^3\) H\(_2\)O), \(Q_{\text{rin}}\) is the volume of water flowing in the reservoir(m\(^3\) H\(_2\)O), \(Q_{\text{prin}}\) is the volume of precipitation to the reservoir (m\(^3\) H\(_2\)O), \(Q_{\text{res}}\) is the volume of diversions (m\(^3\) H\(_2\)O), \(Q_{\text{rsvu}}\) is the volume of water flowing out the reservoir (m\(^3\) H\(_2\)O), \(Q_{\text{rsv}}\) is the volume of water lost from the reservoir via transmission through the bed (m\(^3\) H\(_2\)O), \(Q_{\text{rsv}}\) is the
evaporation from the reservoir (m$^3$ H$_2$O), $r$ is the id of reservoir, $m$ represents month, and $y$ represents year.

**Application and Discussion**

**Study Area**

The model described above is applied to Tianjin City, 11,920 km$^2$ area and 9.33 million population, which is located in the north western part of China and also the last downstream of Hai river flowing in the Bo sea.

The Tianjin water resource in an average year amounts to 1.55 km$^3$, with 1.06 km$^3$ surface water and 0.49 km$^3$ underground water according to Tianjin Statistics Almanac. Record shows the total average consumptive water in Tianjin in last 25 years was 1.5 km$^3$, in which 0.8 km$^3$ was surface water, and 0.7 km$^3$ was groundwater. The exploitation of groundwater is 1.4 times of permitted volume and the area of overexploitation is 8,000 km$^2$ accounting for 67% of the whole area. But Tianjin city has about only 160 cubic meters per capita, which is only one-third of Chinese average and one-twelfth of the world average, and is the lowest per capita city of China. Meanwhile, water quality in the Tianjin basin is seriously affected by anthropogenic activities in the basin.

To manage the stution of scarce resource is crucial for the further development in this region, otherwise, it will become a bottleneck for urban growth and agricultural development. The WAS$^{[12]}$ described in this paper is applied to the Tianjin basin with a multi-years’ time.

**Scene**

At the settings in the scenes, three basic contents are considered as follows: first of all, the status of the structure of water and water level, water supply structure and layout of the project, the status quo of ecological patterns and so on; second, considering various planning including the regional socio-economic development, environmental protection, industrial restructuring, water saving and pollution control in areas; Third, full consideration to factors should be considered, such as the outside water diversion, re-water recycle supply, water-saving factor, ecological factor and environmental factors, and so on. The specific scenes showed as table 1.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Codes of scenes</th>
<th>Sence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transferring water</td>
<td>Luan River and Huang River</td>
<td>√</td>
</tr>
<tr>
<td></td>
<td>The middle Route of south-to-north water transfer</td>
<td>√</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Control of overexploitation</td>
<td>√</td>
</tr>
<tr>
<td>Nonconventional Water</td>
<td>Reclaimed water</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Sea water</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Saline water</td>
<td>√</td>
</tr>
<tr>
<td></td>
<td>Rain</td>
<td>√</td>
</tr>
<tr>
<td>Saving Water</td>
<td>Water-saving measures in farm</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Water saving in living and industry</td>
<td>H</td>
</tr>
<tr>
<td>Ecology</td>
<td>Watercourse outside water demand</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Control of water flowing into sea</td>
<td>√</td>
</tr>
</tbody>
</table>

Note: “√” represents efficient, “×” represents inefficient; “H” and “L” in the nonconventional water are respective the higher supply and lower supply water; “H” and “L” in the saving water are respective the higher and lower water-saving level. “H” and “L” in the ecology represent the higher and lower water-demand.
**Discussion**

In order to effectively ease the contradiction between supply and demand of water resources in Tianjin, Tianjin Municipality to improve the situation of water resources, the six-gross control target discussed above was get in this paper in order to meet the demand planning of water recourse and environment based on ET showed as the table 2.

<table>
<thead>
<tr>
<th>Subzone</th>
<th>chengqu zones</th>
<th>binhai zones</th>
<th>country others</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water consumption control</td>
<td>591.03</td>
<td>839.13</td>
<td>640.55</td>
<td>643.07</td>
</tr>
<tr>
<td>Surface water control</td>
<td>14.97</td>
<td>16.94</td>
<td>12.40</td>
<td>44.31</td>
</tr>
<tr>
<td>Groundwater control</td>
<td>2.93</td>
<td>0.11</td>
<td>0.02</td>
<td>3.06</td>
</tr>
<tr>
<td>Domestic economy water control</td>
<td>13.98</td>
<td>13.81</td>
<td>10.08</td>
<td>37.87</td>
</tr>
<tr>
<td>Ecology water control</td>
<td>3.92</td>
<td>3.25</td>
<td>2.33</td>
<td>9.51</td>
</tr>
<tr>
<td>Water flowing in sea</td>
<td>16.49</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Annotation: The unit of ET control is mm and the others are 10^8 m^3

In 2030, in accordance with WAS model calculated, the ET goal control is the 643mm. Program in the volume of sea water into the 1.64 billion m^3 ~ 1.68 billion m^3, the volume of sea water into the goal for 1.649 billion m^3, the program are met. Exploitation of deep underground water is about 3.06 billion m^3 in 2030. Domestic economy in rural areas are being met and the water control of domestic economy is about 37.87 billion m^3; water for the Ecology is 9.51 billion m^3. The results of six-gross water control of different subzones showed as table 4.

**Conclusions**

In this paper, a regional water simulation and allocation model (WAS) was developed to realize the control of surface water and groundwater supply and the water allocation of water demand. A case study is provided to explore some of the capabilities of the model in Tianjin basin.

The model developed in this paper can be used as the tool to control water resource use for water planning and simulate in the scenario of 2030, and provide the data for regional water control planning to promote rational management of water resources, alleviate contradiction of water demand over supply, and improve flow into the river at regional and even national levels.

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**References**


