A decision support system for water supply emergency management with multiple sources

SUPPLEMENTARY MATERIAL

DETAILS OF SYSTEM ARCHITECTURE

The introduction of models in model layer

The model layer is the core part of DSS to implement model computation, and consists of five models. The model of hedging rules is used in making scheduling decisions. The model of Food and Agriculture Organization of the United Nations (FAO) is used for forecasting water demand of agriculture. Trend analysis is used in forecasting water demand for urban and industry. The parameterization–simulation–optimization (PSO) (Celeste & Billib 2009) model is used to formulate the water transfer operation problems based on hedging rules. ε-NSGAII is used as an optimization tool to solve the relevant optimization problems in the DSS as it has been proven effective for many application problems (Fu et al. 2012, 2013; Zhu et al. 2013; Sweetapple et al. 2014).

The introduction of sources of data

All the data used in this paper, including hydrologic data, reservoir characteristic parameters, and water demand, are acquired from reports of government and the Municipal Water Resource Competent Authority.

The introduction of standards and regulations


METHODS

Reservoir operation rules

Reservoir operation for water supply is not always rational to satisfy the full current demand, because of the possibility of larger water shortages in the future. Hedging rule policies are designed for rationing water supply in appropriate preparation for potential low inflows in the near future. These policies accept some present deficits to reduce the probability of greater water shortage in the future (You & Cai 2008). Hedging rules (Bayazit & Unal 1990; Shiau & Lee 2005; Tu et al. 2008; You & Cai 2008; Guo et al. 2013; Taghian et al. 2014) have been widely used in reservoir operations. The most common operation rule form used in China consists of reservoir water supply operation rule curves and reservoir water diversion rule curves, which is a kind of zone-based operation rule. Details of the operation rule curves are illustrated as follows. First, the forms of reservoir water supply operation rule curves and reservoir water diversion rule curves, which is a kind of zone-based operation rule. Details of the operation rule curves are illustrated as follows. First, the forms of reservoir water supply operation rule curves based on 36 ten-day periods are shown in Figure S1(a). In general, the dynamic water storage of reservoir is the only factor that determines water supply operation rule curves. Then, different kinds of water demand often require different reliability and priority, so each kind of water demand has a corresponding related rule curve and a corresponding rational coefficient with them. In this study, water rational coefficient of water supply operation rule curve is assumed as λ. As is shown in Figure S1(a), water supply rule curve divides the active water storage into two parts, which are marked as zone 1 and zone 2. When water storage lies in zone 1, water demand can be fully met, and the amount of water supply is D. Water storage lying in zone 2 indicates that the current water storage cannot provide enough water for water demand, therefore the amount of water supply must be multiplied by the water rational coefficient λ, and takes its value...
as $\lambda^0D$. Second, the forms of reservoir water diversion rule curves are shown in Figure S1(b). Similarly, water diversion rule curve divides the active water storage into three parts, which are marked as zone I, zone II, and zone III. When the water storage of the reservoir lies in zone I, there is no need to import water, so the amount of water diversion is 0. When in zone III, the maximum amount of water diversion is restricted by the capacity of water diversion pipelines. When in zone II, the amount of water diversion is calculated by multiplying a rational coefficient, which is determined by the water storage of the receiving reservoir.

**Water demand forecasting**

How to determine the water demand is one of the most difficult and complex problems, due to the uncertainty of different requirements, regions, and time. Considering the importance of water demand forecasting and the characteristics of the uncertainty, in this DSS, two methods are provided to determine the water demands, including model calculation, and user input. First of all, model calculation is the primary method used in this system. The model from the FAO is selected to calculate the water demands from agriculture, due to its practicability and applicability. Then, a trend analysis method is used to forecast the water demand from urban and industry. It takes several factors into consideration, including trends in population growth,

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**Figure S1** | Schematics of reservoir operational rule curves: (a) reservoir water supply operation rule curves; (b) water diversion rules.

**Figure S2** | Regular scheduling management process.
development of urban and industry, and so on. This method tries to acquire a more reasonable, logical, and practical water demand forecast among numerous developmental factors. For example, the water demand of agriculture increases with the decrease of rainfall, and the water demands of urban and industry are impacted by economic development (Huang et al. 2014). Second, user direct input of water demand enhances the flexibility of DSS and realizes user-centered design in order to help users to do more analysis work on water demand forecast. Above all, for water demand forecast, this DSS takes model calculation as the main method, and provides methods based on historical data and user input additionally.

### Table S1 | The water supply strategies of emergency scheduling plans

<table>
<thead>
<tr>
<th>Emergency scheduling plan</th>
<th>Plan 1</th>
<th>Plan 2</th>
<th>Plan 3</th>
<th>Plan 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rational coefficient of urban water supply</td>
<td>1.0</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Rational coefficient of agriculture water supply</td>
<td>0.7</td>
<td>0.7</td>
<td>0.5</td>
<td>0</td>
</tr>
</tbody>
</table>

### Figure S3 | The interface of DSS.

**THE APPLICATION OF DSS**

**The regular scheduling management**

First, during data input process, users could input runoff forecast information and water demand, which may be obtained by model prediction, trend prediction, historical data, or manual input. Second, scheduling plans of water diversion and water supply can be obtained by operation rules. Third, the scheduling plan is modified at each period according to measured runoff and updated runoff forecast. In case of emergency situations, regular scheduling management turns to emergency scheduling management, otherwise regular scheduling management proceeds to the next period. Regular scheduling management process is shown in Figure S2.

**The emergency scheduling management**

In a severe drought year, to avoid significant losses brought about by a serious shortage of water supply, a rational water supply strategy is adopted in advance. First, a limited degree of water supply is determined by the degree of drought. The
severer the drought is, the more the water supply is limited. Second, a basic principle is to ensure the urban and industrial water supply at the cost of agriculture because urban and industry may suffer a greater loss by the water supply shortages than agriculture. Therefore, these four emergency scheduling plans are determined by historical simulation optimization where the PSO (Celeste & Billib 2009) approach is used. The differences among them are reflected in different rational coefficients of urban water supply and agriculture water supply. These four emergency scheduling plans and their water supply strategies are shown in Table S1 as follows.

In addition, the emergency scheduling management processes is explicated as follows. First, when routine scheduling turns to emergency scheduling, four emergency
scheduling plans can be obtained according to runoff forecast and emergency strategies. Second, emergency scheduling plans are optimized on the basis of scheduling results and decision-makers’ preference for agriculture and industry. Third, the optimal scheduling plan is carried out. Then, this scheduling plan is adjusted during the executive process by measured runoff and updated runoff forecast. For example, supposing plan 3 is being executed, if the actual runoff is larger than the forecasted runoff, plan 2, whose rational coefficients are smaller, would be chosen. For the opposite, plan 4 would be chosen. All in all, four emergency scheduling plans represent different degrees of reduction, especially for agriculture. The decision-maker can choose one of them on the basis of runoff, updated runoff forecast, and degree of water shortage.

The interface of DSS

The system interface is shown in Figure S3, including log-in panel, main interface, operation rules of Biliuhe Reservoir and Yinnahe Reservoir, and scheduling plan establishment.

CASE STUDY DATA

Historical inflows of Biliuhe Reservoir and Yingnahe Reservoir are shown in Figure S4 and average annual water demand of the case study is shown in Figure S5. In Figure S5, the agricultural water demand, which is the side demand of the reservoirs, is presented by two polylines and the urban water demand, which is the common task of Biliuhe Reservoir and Yingnahe Reservoir, is presented by one polyline. In addition, the fluctuation of urban water supply is caused by the different number of days in a month.

REFERENCES


