Integrated management policies for water resources utilization of Dachia watershed in Taiwan

Shin-Cheng Yeh¹, L. F. Chang² & H. C. Yu³
¹Department of Civil Engineering, National Chi-Nan University, Taiwan, ROC
²University of California at Los Angeles, USA
³Cheng-Shiu Institute of Technology, Taiwan, ROC

Abstract

Water resources of Dachia River in central Taiwan have been used for domestic, agricultural, and hydroelectric sectors. Historically, these sectors have utilized water resources individually and integrated management of water resources is lacking. The most important reservoir for domestic water supply was destroyed in a Ritz Scale 7.3 earthquake in 1999, making efficient water resources planning and management urgent. This research is to identify acceptable management policies for the objectives of domestic and agricultural water uses as well as power generation using problem-specified VBA simulation programs, provided no new hydraulic facilities will be permitted and built in the near future. According to the most important concern of domestic water supply, three non-inferior operating policies were identified, which lead to daily domestic water supplies of 0.59, 1.07, and 1.19 million tons, respectively. The more domestic water can be obtained, the less power can be generated. Furthermore, if 25% of agricultural water demand can be released, daily domestic water supply can be increased by 270 thousand tons. Simulations have also been performed to find out the effects brought about by changing other operating parameters such as the release water volume for power generation, the operating hours of power generators, and the capacity of the domestic water treatment plant. The results of this research point out that integrated management of multiple goals of water resources in this watershed is needed, which can improve its system performance significantly.
1. Introduction

In Taiwan, a variety of water demands, including domestic, agricultural, industrial, and hydroelectrical, have been increasing in last decades. However, planning and construction tasks of a water resources development project usually take many years. Besides, according to growing awakening of public environmental consciousness, protests have been encountered when the government tried to implement large-scale water resources development projects, leading to delay or even cancellation of these projects. Setback of the Mei-Non reservoir project in southern Taiwan is a typical case. Thus, it is necessary to improve the operating efficiencies of the current reservoirs and power generating plants, i.e., to promote their system performances using effective managerial approaches, so that watershed-wide water deficits can be relieved to some extent.

Dachia River is an important “major stream” in central Taiwan, covering about 1,250 km². Important water resources establishments in its watershed, listed from upstream to downstream in series, include De-Chi Reservoir, Chi-Shan Plant, Gu-Gwan Plant, Tien-Lun Plant, New Tien-Lun Plant, Ma-Ann Plant, She-Liaw Plant, and Shi-Gan Dam (Weir). Among them, the De-Chi Reservoir is the pivotal infrastructure for the watershed’s comprehensive development. It supplied most water to various users in this watershed and meanwhile generated large amount of electricity. Those hydroelectrical plants located in series on the river between De-Chi Reservoir and Shi-Gan Weir are capable of regulating time delay of water flows in addition to power generation. As for the Shi-Gan Weir, its main objective is to supply Taichung metropolitan area water for domestic and agricultural uses.

Although De-Chi was designed as a multipurpose reservoir, power generation is its main objective, as it was built and has been operated and maintained by the Taiwan Power Company. The power generated by De-Chi and the following serial power plants shared a significant part of Taiwan’s power supply. Compared with De-Chi Reservoir, Shi-Gan Weir, operated by the Water Conservation Agency of the Ministry of Economic Affairs, is relatively small in scale. However, it is very important for Taichung, the largest metropolitan in central Taiwan, as it supplies most water for public (domestic and agricultural) uses. To enhance the overall utilization efficiency of water resources in this watershed, the upstream De-Chi Reservoir and the downstream Shi-Gan Weir should be operated systematically. Hence, these two public sectors organized a committee in which they can negotiate and reach some conclusions regarding how to allocate water resources and operate their own facilities, based on pre-determined rule curves and other consensuses. Certainly, it was expected that the major objectives for power generation, public water supply, and other minor ones could be balanced and the water resources for the entire watershed could be used in a most efficient way. However, because their operating rules were determined individually and the Taiwan Power Company did not fully abide by the negotiation results of the committee, the negotiation mechanism described above just did not work well. This has led to considerable waste of water resources of the watershed. Thus, the benefits and costs of water uses should be
taken into account on the basis of the whole watershed instead of individual sectors. A framework incorporating all objectives for each water resources sector and aiming at obtaining the best integrated system performance is needed. The goal of this research is then to identify these management policies. Issues discussed in this paper include tradeoffs between different objectives, influences of reallocation of water quota for different uses [1], and evaluation of the operating rules of the power plants [2].

2. Building the water resources system

Dachia River flows westbound from the Central Mountains to the Taiwan Strait, crossing the entire Taichung County in central Taiwan. The De-Chi Reservoir, the hydropower plants, and the Shi-Gan Weir are located along the river in series. De-Chi Reservoir, started operating in 1974, is a huge reservoir with a 180 m high concrete arch-gravity dam and a total storage volume of 234.52 million m³ whose effective part is 174.1 million m³. Its inflows are from the main stream of Dachia River as well as a cross-basin tunnel delivering water from Chi-Lo Weir. The power generators of De-Chi and the serial downstream power plants carry a power generation capacity rated at 1,044,900 KW. They are important since they have served as one of the main power sources for regulating the island-wide system frequencies in peak hours in Taiwan. The downstream Shi-Gan Weir, started operating in 1977, is a relatively small reservoir with a 21.4 high earth-rock dam, a watershed area of 1061 km², and an effective storage volume of 2.2 million m³. Most domestic water demands were fulfilled by Shi-Gan Weir. Agricultural water demands were distributed along the river downstream Tien-Lun Plant. Figure 1 illustrates these water resources facilities and their links.

Figure 1: The water resources system and the important facilities in Dachia Watershed. The numbers in the brackets of each gage show the respective watershed area in km². This illustration is not in scale.
A lot of data should be collected and detailed data processing tasks were needed to make mathematical analysis of the water resources system possible. Data required for this research include: (1) the positions of demand links and all hydropower plants, (2) the operating rules and functions of all hydropower plants, (3) the inflows at the reservoir sites (4) the actual water demands for all uses. Although there are plenty of data available in the literature, they were not consistent. This problem of inconsistency is most serious for the inflow data. The inflow data at gage sites have been recorded by different public sectors, in different time horizons, and with different items. Moreover, some of them were lost due to irresistible reasons. To ensure the inflow data for all necessary sites are reliable, the research team met several governmental officials in charge of other two research projects [3, 4] in the same watershed, working on how to revise existing inflow data and how to interpolate inflows at other specified sites through determining the $n$ value in the formula $Q_2 = Q_1 \left( \frac{A_2}{A_1} \right)^n$. Inflow records at the gages called Chi-Lo Weir (CLW), Chi-Lo River (CLR), Hwan-Shan Intersection (HIS), Da-Pan (DP), Da-Chien (DC), and Shi-Kang II (SKII) from 1979 to 1998 were used to derive synthetic inflows at De-Chi Reservoir, the serial hydroelectrical plants, the Shi-Gan Weir, and other necessary nodes.

In addition to inflow data, water demands, water rights belonging to different users, and corresponding locations are also very important. There are 11 downstream reserved agricultural water rights for De-Chi Reservoir. Six of these water rights are between De-Chi Reservoir and Shi-Gan Weir and they were all fully reserved, i.e., no water released for other users. The remaining 5 water rights are in downstream areas of Shi-Gan Weir. According to large amount of domestic water demands, these 5 water rights were reserved by 48%, i.e., 52% of the agricultural water rights were released for domestic and other uses.

3. Determining the simulation models and scenarios

3.1 Determining the analysis tools

Generally speaking, mathematical tools for water resources planning and management can be classified as “optimization” models, “simulation” models, or their combinations. Many theories and applications can be found in the literature [5~7]. Suitability of a model to a problem depends on many of its characteristics including scale, complexity, objectives, etc. This research is to identify feasible management policies for the water resources facilities that can improve the system performance in a long-term and average point of view. Hence, it is appropriate to incorporate existing policies and possible scenarios into a simulation model, and examine their outcomes.

There are many software packages for water resources system analysis. However, since many local operating rules are complicated and unique, these rules cannot be precisely embedded in those software packages. As a consequence, the simulation model for this research was written specifically using VBA (Visual Basic for Applications) languages.
3.2 Operating rules and simulation scenarios

Operating rules of all facilities in this water resources system are too complicated to state clearly. Since De-Chi Reservoir is the most important, its rule curve needs to be explained (Figure 2). When the water level at a certain time period is higher than the rule curve, the excess water can be released as much as possible until the water level equal to the rule curve. Demands for power generation, domestic use, and agricultural use should all be taken into account. Fundamentally, the release can be expressed as follows:

\[ R_H = \text{Min} \left[ (\text{Storage} - \text{Storage on rule curve} + \text{inflow}), \text{Max} (\text{Power generation demand, domestic and agricultural demand}) \right] \]  

(1)

However, in real operation \( R_H \) was a fixed amount equaling 133.6 cms. On the other hand, if the water level is lower than that on the rule curve, as little as water should be released to make the water level approach the rule curve. However, basic demands for water generation, domestic use, and agricultural use still need to be met. The release is:

\[ R_L = \text{Min} [ \text{Minimum downstream demands, inflow} ] \]  

(2)

Moreover, under any circumstance, the release from De-Chi Reservoir should not less than 5 cms which is the minimum demand for power generation.

Since domestic water supply and power generation are the two objectives emphasized most in this water resources system, several simulation scenarios were designed based on their priorities. Besides, the release rule for power generation when the storage of De-Chi is higher than the rule curve may differ and hence this was also taken into consideration. Thus, four scenarios were designed as follows:

![Figure 2: The rule curve of De-Chi Reservoir.](image-url)
- **Scenario A**: This is the baseline scenario, i.e., consider the objectives of domestic water supply and power generation with similar weights. All rules and parameters were input as there were in reality. $R_H$ equals 133.6 cms and $R_L$ is determined by (2), given the current water level and time period. However, if there exists a domestic water deficit in downstream areas, more water need to be released to meet the domestic water demands.

- **Scenario B**: Domestic water supply is the first priority. De-Chi Reservoir releases water solely based on downstream domestic water demands without considering extra power generation demands.

- **Scenario C**: Power generation is the first priority. When the water level of De-Chi Reservoir is higher than that on the rule curve, an $R_H$ equaling 133.6 cms is released to generate power.

- **Scenario D**: Power generation is the first priority. When the storage of De-Chi Reservoir is higher than the rule curve, only fixed amount of water is released to generate power.

The simulation framework was built based on the detailed version of the network depicted in Figure 1. Basic equations included water mass balance, power generation functions, incremental flow calculation formula, and release rules. Input data included inflows, water demands, and other numerous system parameters such as capacities of the power plants, allocation coefficients of incremental flows, power generation releases of De-Chi Reservoir, operating hours the power plants, capacity of the Chi-Lo cross-basin water channel, and H-V-A curve for De-Chi Reservoir. The time period for simulation is ten days. Table 1 listed important parameters for the baseline scenario, i.e., Scenario A.

## 4. Simulation results and analyses

### 4.1 Influence of operating policy on system output

Table 1: Fundamental system parameters and their ranges assumed in the simulation model

<table>
<thead>
<tr>
<th>parameter</th>
<th>basic value</th>
<th>range of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>objective domestic water supply (10^3 ton / day)</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>capacity of Chi-Lo cross-basin channel (cms)</td>
<td>10</td>
<td>10, 20</td>
</tr>
<tr>
<td>capacity of Shi-Gan Weir (10^3 ton / day)</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>generation time span per day (hours)</td>
<td>6</td>
<td>6, 8, 10, 12</td>
</tr>
<tr>
<td>release of De-Chi Reservoir when the water level is higher than that on the rule curve (cms)</td>
<td>133.6</td>
<td>100, 120, 133.6, 138, 144.5, 150, 174.8, 217.5</td>
</tr>
<tr>
<td>initial storage volume of De-Chi Reservoir (10^3 ton)</td>
<td>156,590</td>
<td></td>
</tr>
<tr>
<td>minimum Power generation release of De-Chi Reservoir (cms)</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

* 1 ton of water in weight = 1 m³ of water in volume
The four scenarios were simulated and corresponding domestic and agricultural water supplies, power production, and water flowing into the sea when the shortage index (S.I.) equals 1.0 were recorded. The S.I. is defined as follows:

\[
S.I. = \frac{100}{N} \times \Sigma \left( \frac{\text{annual deficit}}{\text{annual water supply target}} \right)^2
\]  

(3)

where \( N \) is the total number of simulation years

Thus, these results indicated "potentials" to a certain acceptable extent of water deficit. In the following context of this paper, the meaning of "potential" will not be stated explicitly.

Table 2 and Figure 3 shows the tradeoff relationships of domestic water supplies and annual power production among the scenarios. From the figure,

Table 2: Simulation results of daily domestic water supply and annual power production for the four scenarios and the variation percentages of Scenario B, C, and D compared with the baseline, Scenario A.

<table>
<thead>
<tr>
<th>Prior objective</th>
<th>Domestic water supply (10^3 ton/day)</th>
<th>Power generation (KWH/year)</th>
<th>S.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Both, baseline</td>
<td>1,070 ± %</td>
<td>2,615,362 ± %</td>
<td>1.004</td>
</tr>
<tr>
<td>B Domestic water supply</td>
<td>1,190 +11.2</td>
<td>2,595,003 -0.78</td>
<td>0.995</td>
</tr>
<tr>
<td>C Power generation A</td>
<td>590 -44.9</td>
<td>2,491,108 -4.75</td>
<td>0.981</td>
</tr>
<tr>
<td>D Power generation B</td>
<td>700 -34.6</td>
<td>2,617,703 +0.09</td>
<td>0.997</td>
</tr>
</tbody>
</table>

Figure 3: Tradeoff relationships among the scenarios
Scenario A, B, and D can be identified as non-inferior policies in the decision space. That is, if the objective of more domestic water supply and that of more power generation are the only two of concern, for these three scenarios, no one is better than others in both objectives. If more power can be generated, less water can be supplied to domestic users and vice versa. Scenario C is out of consideration as it is inferior to other ones in an economic point of view. It was shown in Table 2 that 120 thousand tons more water can be supplied daily for domestic uses if domestic water supply is the prior objective (Scenario B). It is possibly because in this case De-Chi Reservoir will save more water for power generation, hence less water will be wasted and flow directly into the sea, which contributed to increasing domestic water supply. For Scenario D, in which power generation was emphasized, more power can be generated at the price of 370 thousand tons of reduction in daily domestic water supply. The results showed that the operating policies in Scenario C would result in waste of water for both objectives. Table 3 listed the percentages of water allocated for domestic and agricultural uses, as well as wasted due to evaporation and flowing into the sea.

4.2 Influence of agricultural water uses

Assuming that De-Chi Reservoir was operated strictly based on its rule curve and the release for power generation when the water level is higher than that on the rule curve is 133.6 cms, simulations were run with respect to different agricultural water demands. Simulation results were listed in Table 4. At present, agricultural water was supplied based on the “planning water demands” proposed by local irrigation associations annually, instead of on the agricultural water rights. Should agricultural water rights were used, the daily domestic water supply would reduce to 630 thousand tons. On the other hand, if the agricultural

| Table 3: Percentages of water allocations for different scenarios |
| --- | --- | --- | --- | --- |
| Domestic % | Agricultural % | Evaporated % | flow into the sea % |
| A | 19.24 | 29.43 | 0.22 | 51.11 |
| B | 21.34 | 29.59 | 0.23 | 48.84 |
| C | 12.27 | 30.66 | 0.20 | 56.87 |
| D | 13.93 | 29.81 | 0.16 | 56.11 |

| Table 4: Simulation results based on different agricultural water demands |
| --- | --- | --- | --- |
| Agricultural water demand | Domestic water supply ($10^3$ ton/day) | Power generation (KWH/year) | S.I. |
| full water right | 630 | 2,629,066 | 1.074 |
| PWD* | 1,070 | 2,615,362 | 1.004 |
| 90% of PWD | 1,170 | 2,615,272 | 1.006 |
| 80% of PWD | 1,270 | 2,618,451 | 1.032 |
| 75% of PWD | 1,340 | 2,618,685 | 1.020 |

* planning water demand
increase significantly and power generated would increase a little as well. A 25% off for the agricultural water demand would lead to 270 thousand tons of increase in daily domestic water supply. These results confirmed that release of agricultural water rights in Taiwan is necessary.

4.3 Influence of release for power generation

Based on Scenario A, the release for power generation if the water level is higher than the rule curve is a fixed amount. Results indicate that as this release amount increases, a little more power can be generated but meanwhile the domestic water supply will decrease obviously. When the power generation release was raised from 100 to 217.5 cms, a loss of 240 thousand tons in daily domestic water supply would be resulted. This could supply 650 thousand people if a per capita daily water consumption of 350 liters were assumed. The possible reasons for the reduction of domestic water supply are:

1. Since the storage capacities of the reservoirs associated with the serial hydropower plants are not large enough to store much water released from the upstream De-Chi Reservoir, more water will flow directly into the sea.
2. Large release amount for power generation will lead to reduction in water stored in wet seasons to be used in dry seasons.

4.4 Influence of other parameters

Influences of several parameters on the system performance were simulated. These include the capacity of the Chi-Lo cross-basin tunnel, daily operating hours of generators, etc. Results indicated that an increase of the capacity of Chi-Lo cross-basin tunnel from 10 to 20 cms could bring about 30 thousand tons more daily domestic water supply. The annual power production will also increase from 2,615,362 to 2,630,748 KWH. The daily operating hours of the generators was shown to have significant impacts on the system output. Figure 4 showed these impacts. As the number of daily operating hours increases, the domestic water supply would decrease because more water was released for power generation.

![Figure 4: Influence of daily operating hours of generators on system performance](image-url)
power generation and hence less water resources could be allocated for domestic uses. Although fundamentally this would increase the annual power production as well, this trend will change if the number of daily operating hours exceeding 12. The reason is that a prolonged operating time would tend to cause depletion of water resources for any kind of use including power generation itself.

5. Conclusion

Simulation analyses were performed to identify management policies for Dachia watershed. Four scenarios were assumed and three of them were found non-inferior in the decision space, which lead to daily domestic water supplies of 0.59, 1.07, and 1.19 million tons, respectively. The more domestic water can be obtained, the less power can be generated. Furthermore, if 25% of agricultural water demand can be released, daily domestic water supply can be increased by 270 thousand tons. Simulations have also been performed to find out the effects brought about by changing other operating parameters such as the release water volume for power generation, the operating hours of power generators, and the capacity of the domestic water treatment plant. The results of this research point out that integrated management of multiple goals of water resources in this watershed is needed, which can improve its system performance significantly. Nevertheless, this research was done in a long-term and average point of view. In reality, real-time controls of the hydroelectric systems associated with other water resources facilities are complicated. Thus, further studies should be done with clear objectives using more precise and accurate system analysis tools.

References