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THE IMPACT OF PEAK HYDROGENERATION FOR RESERVING ENVIRONMENTAL FLOW IN DACHIA RIVER, TAIWAN

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ABSTRACT

Water resources facilities are necessary for socio-economic development, but it would cause negative influences in the river environment. To conserve a healthy river ecosystem, the environmental flow is vital. For example, one has to release a minimum streamflow to downstream river channel before diverting water out from the river. This minimum flow will (i) prevent the ecological environment from degradation, (ii) maintain the bio-diversity and water course, and (iii) ensure the sustainable development of the ecosystem of a river.

Some opined that the environmental flow is a minimum required flow in a river. Every water resources facility in Taiwan today has to release environmental flow prior to supplies water. However those facilities were planned to fulfill the future demands or to generate peak hydroelectricity without considering environmental flow. Therefore, the water supply capability or peak hydrogeneration of exiting system will be decreasing.

The joint operation system of the Dachia River and Daan River was selected as a case study to analyze the impact on water supply and peak hydrogeneration due to preserving different environmental flows. Water is usually released in six hours in a day from the reservoir for peak hydrogenation. Therefore the unsteady flow is routed through the river channel within a day. This approach can simulate the water supply and hydrogeneration accurately. The impact to the joint operation system due to releasing environmental flow can be evaluated.

Keywords: environmental flow, peak power generation, simulation

1. FOREWORD

To preserve a healthy river ecosystem, release of the environmental flow would get the priority during hydrogenation, but it would reduce the hydrogenation. Therefore, the planned system and estimated demand for the year 2011 were analyzed in this paper and the minimum flow of different levels was used to replace the inconclusive environmental flow. The model which can improve analysis of hydropower and water supply by incorporating the temporal phenomena of unsteady flows and time lag of flows throughout the system was used to simulate the hydrogenation process. From this research, the impacts of peak or off-peak hydrogeneration would be determined under the condition of the dams in the Dachia River to maintain different levels of environmental flow. The results of this research also could be provided to the Taiwan Power Corporation to avoid the damage of the stable powergeneration.

2. SYSTEM SUMMARY AND ANALYSIS CONDITIONS

2.1 The joint operating system of the Dachia River and the Daan River

The joint operating system of the Dachia River and the Daan River supplies water to the Taichung public and industrial water use demand, and the system is shown in the Figure 1.

In the Dachia River system, the primary reservoirs are the Deji Reservoir, the Babao Weir and the Shihgang Dam, and the main treatment facility is Fongyuan Water Treatment Plant. The Deji Reservoir stores water from upstream, as well as water diverted from the Jhihle River basin through a tunnel with a maximum capacity of 10 cms. The Babao Weir and the Shihgang Dam store the uncontrolled water between the Deji Reservoir and the Shihgang Dam, as well as water released from hydropower plants. Flows released from the Shihgang Dam or released from the Babao Weir supply the Fongyuan Water Treatment Plant, which was constructed at the downstream end of the Dachia River with a design yield capability of 1,300,000 CMD. The Fongyuan Water Treatment Plant supplies municipal and industrial water to Taichung with a actual yield capability in the site of 850,000 CMD due to the limited capacity of the pipes between the plant and the Taichung district.

Along the Daan River system, the Liyutan Reservoir and the Shihlin Weir store water, which the Liyutan Water Treatment Plant purifies. The Liyutan Reservoir was constructed along the Jingshan River, which is a branch of the Daan River. The Shihlin Weir was constructed on the Daan River to supplement the limited water resources of the Liyutan Reservoir. The Shihlin Weir diverts water to the Liyutan Reservoir through the Jhuolan Power Plant. The Liyutan Water Treatment Plant, which treats outflow from the Liyutan Reservoir, has a design yield capability of 1,100,000 CMD. This plant provides municipal and industrial water to Taichung.

Four weirs were constructed by the Taiwan Power Corporation, to ensure the requirement of peak hydroelectricity in Taiwan. These four weirs: Chinshan, Gugwan, Tienlun and Maan can be used to raise the water level between Deji reservoir and Shihgang dam in Dachia River and divert water to the hydropower plants. The total capacity of these power plants in the Dachia River is 1,100,000 KWHs and the annual average hydropower generation is 26 billion KWH.

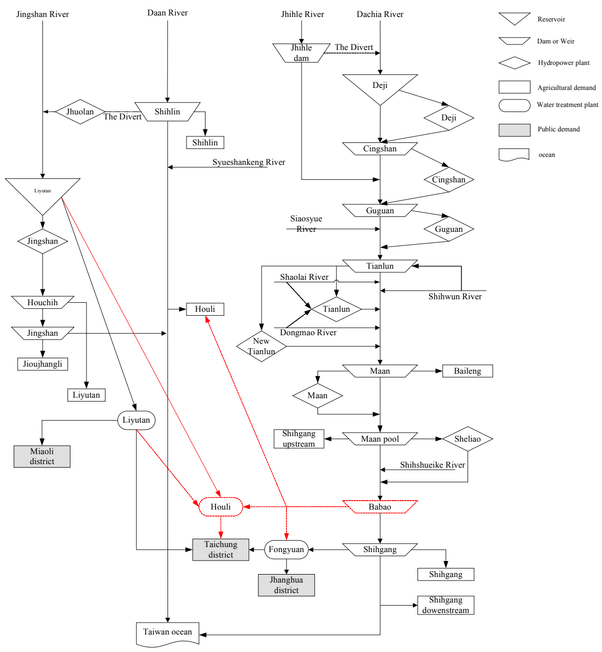

Figure 1: The joint water supply system of Dachia and Daan Rivers

2.2 The analytical conditions

(1) The amount of resources in the joint water supply system of the Dachia and the Daan Rivers.

The average annual inflow of the Deji reservoir in Dachia River is 10.09 billion cubic meters and the average annual amount diverted from the Jhihle weir to the Deji reservoir is 1.41 billion cubic meters. The amount of uncontrolled flow between the Deji reservoir and Shihgang dam is 10.72 billion cubic meters which includes the amount flows from the downstream of Jhihle Dam. The average annual inflow of the Shihlin weir in Daan River is 10.32 billion cubic meters and the average annual inflow of the Liyutan reservoir in Jingshan River is 0.93 billion cubic meters. Therefore, the main resource of Liyutan reservoir having maximal capability of 1.5 billion cubic meters comes from the Shihlin weir.

(2) The water use demand

The recent data estimated by the Water Resources Agency are shown in the Table 1. The middle level development demand in the year 2011 was used as the public water use demand during simulation in this paper. The average amount calculated for the recent five years of the planned water demand prodided by Taichung Irrigation Association can not exceed the amount of water right in the agricultural water use demand. The total agricultural water use demand in one year is 6.969 billion cubic meters in the Dachia River and 4.585 billion cubic meters in the Daan River.

(3) The operation principles of the reservoirs and its hydropower plant

Taiwan Power Corporation used the power use demand and the capacity of the regulation pools at the downstream criteria to decide the operation strategy of the power plants in the Dachia River. When a series of the power plants in the Dachia River are ready, the Deji Reservoir releases water to generate power in accordance with the available capacity of the Gugwan Dam. If the power use demand is fulfilled, the weir or the reservoir would stop releasing water. But if the capacity of the regulation pond is full, the Taiwan Power Corporation would stop releasing water to generate power, and the lack of the peak power would be satisfied by the other systems.

The uncertainty of frequent hydrogenation is very high. This paper used the alternative of the peak-hours to simulate the approximate hydrogenation process of the hydropower plants in the Daji River. When the series of the hydropower plants generated the power, the Deji Hydropower Plant was considering the control point and 6 hours were the peak-hours. The water released from the power plants would be regulated at the Maan regulation pond and the Shihgang Dam. Therefore, it was considered that the power plants in this system generated peak hydropower by releasing water from reservoirs for six hours daily and the power releases were routed through downstream river channels in this study for simulating their unsteady processes. The above mentioned method would ensure that the simulation process is approximately to the real process. This paper assumed the hydrogenation efficiency is of 95% because of the maintenance of the power plants and some other losses.

(4) The analytical conditions for water allocation

The analytical conditions were used for water allocation are as follows:

<1> The dam and reservoir should have priority to release water to the reserved water use demand at the downstream and if any surplus water, would be allowed to store.

<2> In this system, the Shihgang dam gets priority to release approximately 6.44 cms of water as environmental flow to the downstream. Accordingly the Shihlin weir and the Liyutan reservoir get priority to release approximately 2.7 cms and 0.14 cms of water respectively as environmental flow to the downstream.

<3> The storage of the Shihgang dam only could be used to supply the Taichung public water use demand and industrial demand. It would not be allowed to supply the agricultural water use demand.

<4> The capacity of the pipe or the intake include, (i) the maximal capacity of the pipe from the Jhihle dam to the Deji reservoir is 10 cms, (ii) the maximal capacity of the intake of the southern channel in the Shihgang dam is 50 cms, (iii) the maximal capacity of the Divert from the Shihgang dam to the Liyutan water treatment plant is 15 cms.

<5> 5% loss during the treatment for the above three water treatment plants was considered in the analysis.

<6> If the turbidity of the raw water is lower than 6,000 ntu, the yield capability of the Fongyuan Water Treatment Plant would be 500,000 CMD. If the turbidity of the raw water greater than 6,000 ntu, the yield capability would be decreased, and if the turbidity of the raw water greater than 10,000 ntu, the Fongyuan Water Treatment Plant would stop treating water. The relationship between the yield capability of the Fongyuan Water Treatment Plant and the turbidity of the raw water is shown in table 1.

<7> In order to avoid the sedimentation into the Liyutan reservoir, when the inflow of the Shihlin weir exceeds 800 cms, the Divert would stop withdrawing water.

(5) The priority of water allocation

The existing agricultural water use demand should get the most priority. In the analysis, the amount of the reserved water for agricultural water use demand would be confirmed first by simulation without any stored facilities. Then the water would be allocated for increasing public and industrial water use demand.

Furthermore, the water allocation priorities of the Taichung public water use demand and industrial water use demand are illustrated as below:

<1> The water released from the hydropower plants, the excess water of the Dachia River and the Daan River would be used first.

<2> When the water use demand could not be fulfilled by the uncontrolled water, the reservoirs should release water to satisfy the demand. But the amount of water released would be less than the responsible amount of water of the Deji reservoir for the public and industrial water use demand.

Table 1: The relationship between the yield capability of the Fongyuan Water Treatment Plant and the turbidity of the raw water (in 104 CMD)

The turbidity of the raw water (NTU)	The yield capability (If there is flow in the Shihshueike River)	The yield capability (If there is no flow in the Shihshueike River)
Lower than 10	85	85
10~250	80	80
250~1000	75	50
1001~3000	60	30
3001~5000	50	15
5001~6000	50	10
Higher than 6000	50	0
Higher than 10000	0	—

3. METHODOLOGY

In this study, the Routing module of the General Water Allocation Simulation Model (GWASIM) was used to analyze the water resources utilization of the joint operation system of the Dachia River and the Daan River. The GWASIM model was developed based on the theory of Minimum Cost Network Flow Programming (MCNFP) and the Out-of-Kilter (OKA) method (Fulkerson, 1961 and Barr, 1974), specifically for Taiwan's water resources system. Day was used as its unit, because most of the Taiwan's water resources system had developed joint operation system including the reservoirs, the tributaries at the downstream, and the other systems in the neighborhood water basin and all of the systems are using day as unit. The GWASIM model has the ability to simulate: (i) the special operation rules of the reservoirs in Taiwan, (ii) the through demand i.e., the minimum environmental flow or the power generation demand, (iii) the losses in the water supply system, (iv) the restricted yield of the water treatment plant due to high turbid water, (v) the water allocation process comply with the site operation by setting the minimum cost on the arcs, (vi) the unsteady flow due to the peak hydropower generation is routed through the river channel to the downstream.

3.1 Minimum Cost Network Flow Programming

MCNFP is a special linear programming, and its features are: (1) It can display the mathematical formulation, equation and results clearly in the network graphics, and (2) Its unique network structure leads to a special algorithm, and it is faster than that of the conventional Simplex method. The network graphics mentioned above are formed by a number of nodes and arcs. Nodes may represent certain elements, i.e., storage facilities, demand areas, diversions, power plants, water treatment facilities, confluence or bifurcation of river reaches. Arcs represent the directed links between nodes, i.e. river reaches, canals, pipes. For a pure and conservation network flow problem, the total flow into and out of a node should be the same. There is an upper limit, a lower limit and a given unit conveyance cost coefficient to every directed arc. MCNFP is intended to find a minimum cost conveyance way while in accordance with flow conservation between nodes, and flow in every arc obeying the upper and lower limits. If there are m nodes in an MCNFP problem, then its mathematical formulation could be shown as below:

$$Minimize \quad \sum_{i=1}^{m}\sum_{j=1}^{m} c_{ij} \cdot x_{ij} \qquad (3.1\text{-}1)$$

subject to

$$\sum_{j=1}^{m} x_{ij} - \sum_{k=1}^{m} x_{ki} = 0 \qquad i = 1, \dots m \qquad (3.1\text{-}2)$$

$$l_{ij} \le x_{ij} \le u_{ij} \qquad i, j = 1, \dots m \qquad (3.1\text{-}3)$$

where,

m = total number of nodes,
i, j, k = numbering of nodes,
x_{ij} = flow entering arc from node *i* to node *j*,
c_{ij} = costs per unit flow in arc from node *i* to node *j*,
l_{ij} = lower bound on flow in arc from node *i* to node *j*,
u_{ij} = upper bound on flow in arc from node *i* to node *j*.

3.2 The GWASIM-R module

The GWASIM-R is an improved analysis of hydropower and water supply by incorporating the temporal phenomena of unsteady flows and time lag of flows throughout the system. In this study, GWASIM-R was used to analyze the peak hydrogeneration process. It divided each day into hours and conceptualized water supply allocation as an hourly dynamic allocation process within a day, which is shown in Figure 2. The module simulated the time lag that occurred during water transmission by an iterative procedure and allocated water supply spatially and temporally for each day of simulation, which is shown in Figure 3. This feature may reduce or eliminate the error generated by the wrong assumption, i.e., flow is steady for whole day and that water may be conveyed between any two sites in the system within one time step. This improved method of simulating hydropower generation yields more accurate results of spatial and temporal water supply and shortage.

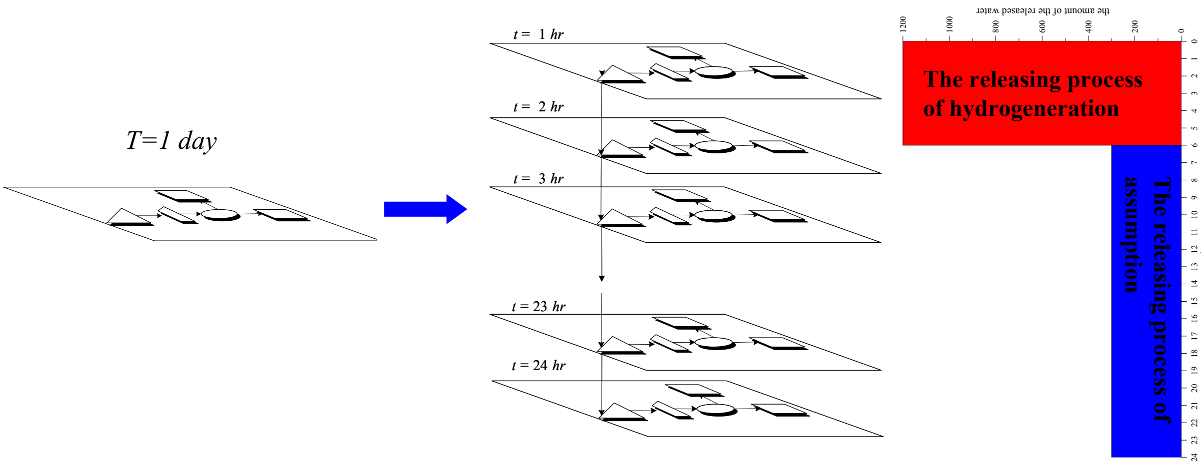

Figure 2: The method of simulating the hydrogenation process

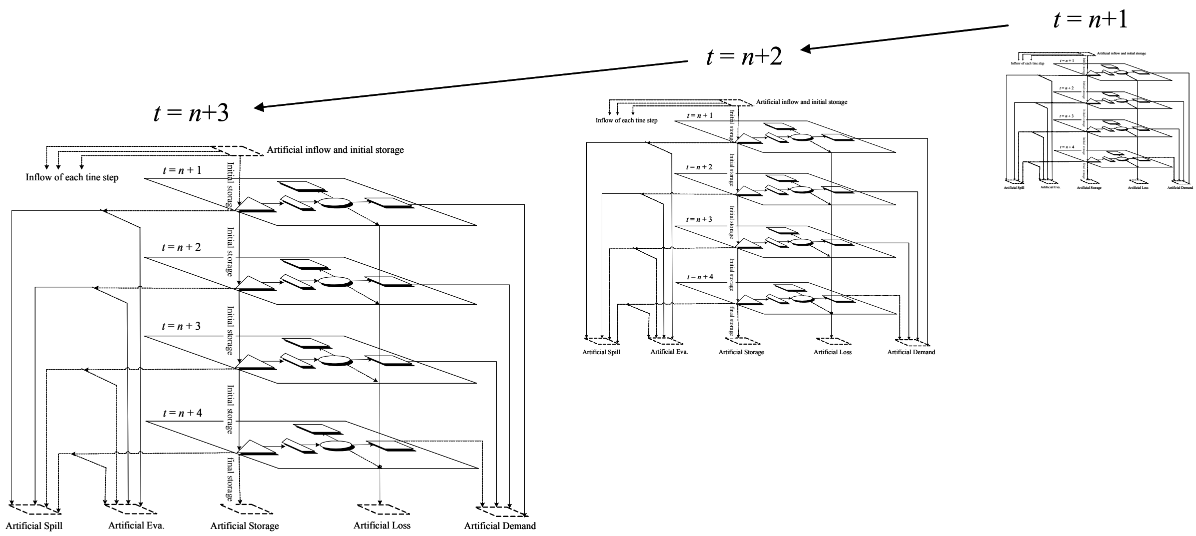

Figure 3: The analytical concept for the simulation of peak hydrogeneeration process

4. ANALYTICAL SCENARIOS

In this study, in order to analyze the impact of the peak hydrogenation of each power plant in Dachia River for reserving different levels of environmental flow, the system and demand in 2011 was used for the simulation. The conditions: (i) the minimum required flow estimated with the regulation of the Taiwanese Water Resources Development Guiding Principles (per 100 square kilometer need reserving 0.135 cms as the minimum required flow) and (ii) the flows associated with Q97, Q96, Q95, Q94 of a 10-year recurrence period were used as the different levels of environmental flow in the analytical scenarios. The detailed are shown in Table 2.

Table 2: The level of the environmental flow in each water resources facilities (in cms)

Scenarios and Illustrations \ Water resources facilities		Deji Redervoir	Chinshan Dam	Gugwan Dam	Tienlun Dam	Maan Dam
Scenario 0	A comparing scenario	0.00	0.00	0.00	0.00	0.00
Scenario P	The environmental flow estimated with the regulation of the Taiwanese Water Resources Development Guiding Principles	0.69	0.70	0.93	1.03	1.30
Scenario Q_{97}	Environmental flows associated with Q_{97} of a 10-year recurrence period	4.81	4.84	6.36	6.98	8.85
Scenario Q_{96}	Environmental flows associated with Q_{96} of a 10-year recurrence period	4.87	4.90	6.44	7.07	8.96
Scenario Q_{95}	Environmental flows associated with Q_{95} of a 10-year recurrence period	4.90	4.93	6.48	7.12	9.02
Scenario Q_{94}	Environmental flows associated with Q_{94} of a 10-year recurrence period	5.05	5.08	6.68	7.34	9.30

5. ANALYTICAL RESULTS AND DISCUSSIONS

According to the results of each scenario, the impact of the average annual peak hydrogenation in each power plant and of the yield capability for reserving various levesl of environmental flow is shown in Table 3 and 4. The peak hydrogenation in each year during the simulation period is shown in Figure 4. The decrement of the hydrogenation and the peak hydrogenation between the scenarios which reserved the environmental flow and the scenario which did not reserved the environmental flow were compared and are shown in the Figure 5. The results are summarized as follows:

(1) Scenario Q_{97} : The flow associated with Q_{97} of a 10-year recurrence period calculated from the recorded data was used as the environmental flow of the dams in the Dachia River in the scenario.

Comparing with the results of the scenario 0, the results are depicted as below:

<1> Annual peak hydrogenation: The average decrement of the Deji hydropower plant was 46.7 million KWH and its range was closed to 12.33%. The average decrement of the Chinshan hydropower plant was 71.1 million KWH and its range was closed to 12.87%. The average decrement of the Gugwan hydropower plant was 56.9 million KWH and its range was closed to 13.69%. The average decrement of the Tienlun hydropower plant was 65.2 million KWH and its range was closed to 13.37%. The average decrement of the Maan hydropower plant was 48.6 million KWH and its range was closed to 13.56%. The total average decrement of the plants in the Dachia River was 288.5 million KWH and its range was closed to 13.16%.

(2) Synthetic Results

If the minimum flow estimated by the regulation of the Taiwanese Water Resources Development Guiding Principles as the environmental flow of the water resources facilities in the Dachia River is used, the impact of hydrogeneration would be lower and its reduction range is approximately 2%. If the flows associated with Q_{97}, Q_{96}, Q_{95}, Q_{94} of a 10-year recurrence period as the environmental flow of the water resources facilities in the Dachia River are used, the annual hydrogeneration and peak hydrogeneration would be reduced approximately 12% ~ 14%. However, the impact level of hydrogeneration would have an increasing tendency accompanied with the larger environmental flow.

Table 3: The impact of average annual peak hydrogenation due to the environmental flow (in billion KWH)

Power plants \ Scenarios		0	P	Q_{97}	Q_{96}	Q_{95}	Q_{94}
Deji	The total	3.788	3.714	3.321	3.314	3.306	3.287
	The lack	—	-0.074	-0.467	-0.475	-0.482	-0.502
	Rate	—	-1.95%	-12.33%	-12.53%	-12.73%	-13.25%
Chinshan	The total	5.521	5.410	4.811	4.800	4.787	4.759
	The lack	—	-0.112	-0.711	-0.722	-0.735	-0.763
	Rate	—	-2.02%	-12.87%	-13.07%	-13.31%	-13.81%
Gugwan	The total	4.156	4.067	3.587	3.578	3.568	3.545
	The lack	—	-0.090	-0.569	-0.578	-0.588	-0.611
	Rate	—	-2.16%	-13.69%	-13.90%	-14.15%	-14.71%
Tienlun	The total	4.875	4.771	4.223	4.214	4.203	4.176
	The lack	—	-0.104	-0.652	-0.661	-0.672	-0.699
	Rate	—	-2.12%	-13.37%	-13.56%	-13.78%	-14.35%
Maan	The total	3.582	3.507	3.097	3.090	3.082	3.061
	The lack	—	-0.076	-0.486	-0.492	-0.501	-0.521
	Rate	—	-2.11%	-13.56%	-13.75%	-13.98%	-14.56%
Total	The total	21.923	21.469	19.039	18.995	18.946	18.827
	The lack	—	-0.454	-2.885	-2.928	-2.978	-3.096
	Rate	—	-2.07%	-13.16%	-13.36%	-13.58%	-14.12%

Table 4: The impact of water supply capability due to the environmental flow

Criteria \ Scenarios	0	P	Q_{97}	Q_{96}	Q_{95}	Q_{94}
The planned demand(10^4 CMD)	173.0	173.0	173.0	173.0	173.0	173.0
The yield (10^4 CMD)	158.7	158.8	158.9	158.9	158.9	158.9
Shortage Index	1.917	1.908	1.841	1.841	1.843	1.846

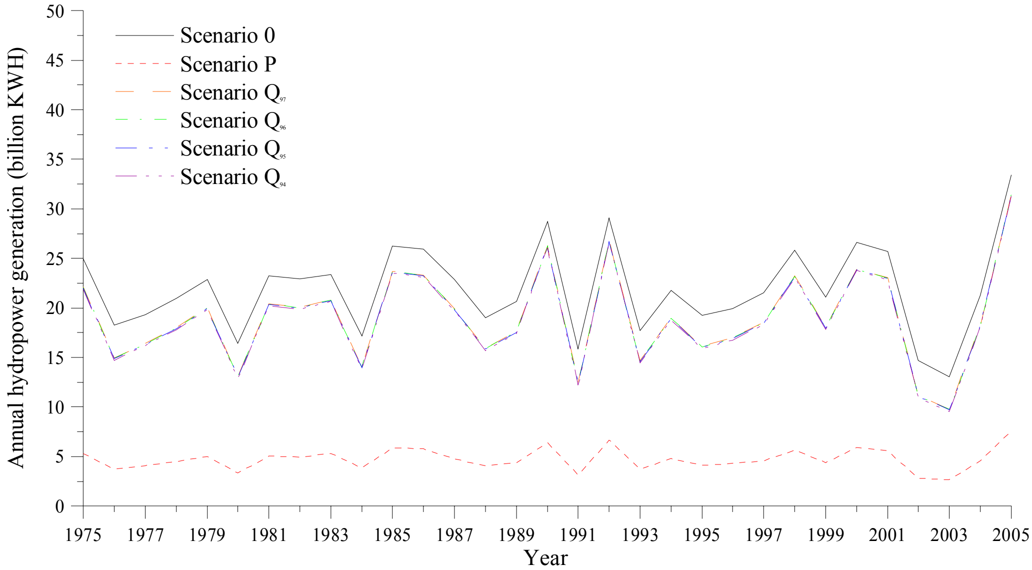

Figure 4: The annual peak hydrogenation during the analytical period

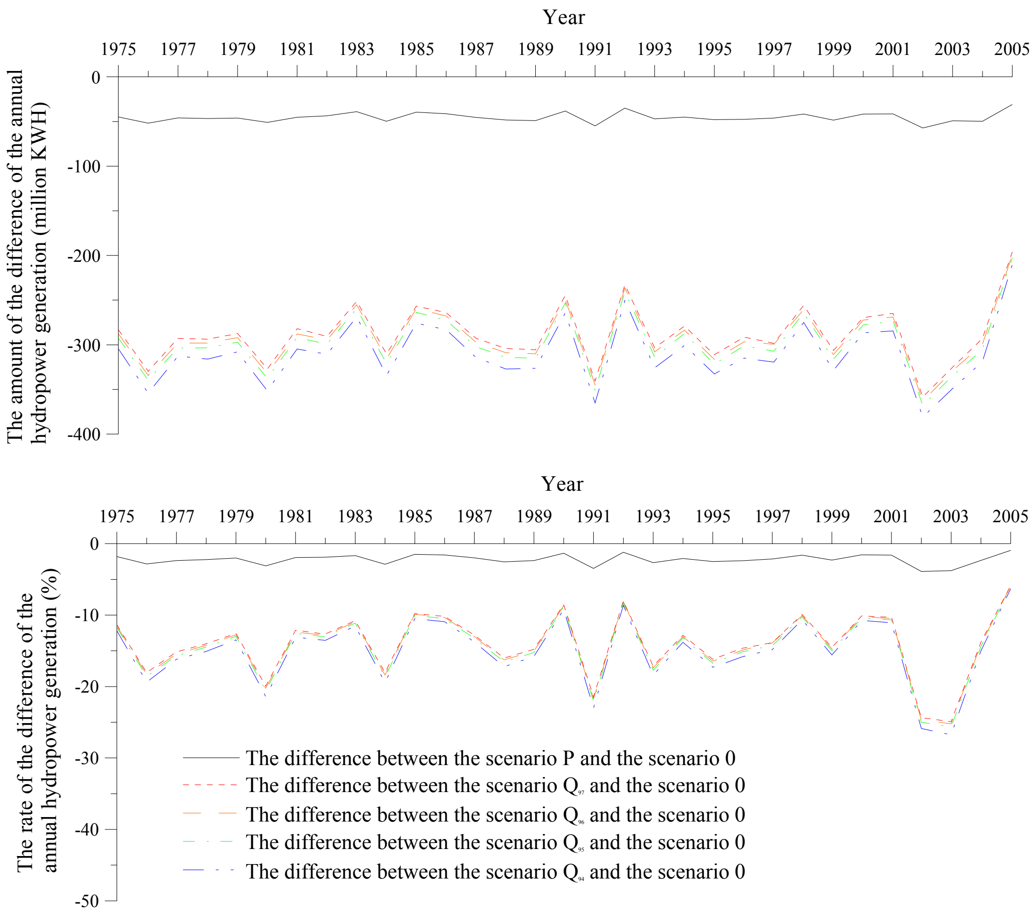

Figure 5: The lack of the annual peak hydrogenation between the no reserved scenario and the different level reserved scenarios

6. CONCLUSIONS AND RECOMMENDATIONS

The GWASIM model which is specifically developed for Taiwan's water resources system was used to analyze the impact of hydrogenation for reserving the environmental flow.

The model can correctly simulate the hydrogenation and water supply processes by incorporating the temporal phenomena of unsteady flows and time lag of flows throughout the system.

The results showed that if the reserving environmental flow increases, the reduce range of the hydrogenation also increases. When the flows associated with Q_{97}, Q_{96}, Q_{95}, Q_{94} of a 10-year recurrence period was used as the environmental flow of the dams in the Dachia River, the reduced amount and range of annual peak hydrogenation was from 288.5 million KWH to 309.6 million KWH approximately and from 13.16% to 14.12%, and the reduced amount and range of annual hydrogenation was from 333.2 million KWH to 358.4 million KWH approximate and from 12.48% to 13.43%.

The Taiwan Power Corporation could utilized the results of this paper to evaluate the impact of hydrogeneration, especially the peak hydrogeneration for reserving a suitable environmental flow invented from the researchers and scholars.

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