Impact of Large Reservoir Development on Water Resource Regime

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Abstract

In this paper, the impact of large reservoir development to the water resource regime was preliminary investigated. Sirikit dam in the Nan river basin, north of Thailand was a case of study. Analysis of pre- and post-dam hydrologic records indicates that the impoundment and the amount of rainfall are one of the major causes of change in the flow regime downstream of the reservoir. But, the post-flow annual hydrograph change, especially the reduction of mean monthly peak runoff magnitude and the higher flow during the low flow period mainly results from the impact of large reservoir development. It is seen that the large strategic scheme play a significant role in capable of storing surplus volume of wet season runoff for the later dry season. However, these overall results are based on a single large storage. For better understanding the response of flow to the large reservoir, further study should emphasize across a range of dam types and catchment characteristics. Some other factors affected, such as the frequency of flood and drought, shift in low flow, timing of high and low flow or change across different flow duration should also be further investigated. It is therefore revealed the necessity to establish the integrated database of the regional hydrological and meteorological properties from intensive field observation. This precious data set should be accessible for all researchers.

Keyword: impact of large reservoir development, Sirikit dam, Nan river, change in the flow regime

1. Introduction

Since the past decades, many urban areas around the world have been experiencing a dramatic increase in natural disasters due to water-related extreme events. The lack of precipitation as well as heavy downpour causes disasters ranging from extreme drought to unprecedented flood. In addition, climate change, environmental degradation, population growth, urbanization and anthropogenic effect cause human society more vulnerable to flood and drought disasters. (Budhakooncharoen, S, 2003)

Various efforts have been set out for establishment of the proper prevention and mitigation measures to cope with this problem. Storage reservoirs have been one of the common developments worldwide over the past decades for the proactive preparedness systems to relief the human vulnerability against water-related extreme events, flood and drought disasters.

2. State of the Problem

Dams have provided various benefits for society including generation of electricity and the reduction of devastating floods as well as a controlled supply of water that can be used for alleviating drought and a variety of municipal and industrial demands. However, due to the complexity of interaction, building a dam has changed forever the flow regime in the river. It generates significant hydro-geomorphic alterations with impacts occur both upstream and downstream of the reservoir. (Magilligan, F.J. (2001). The major visual impacts of the changed flow regime can be found in numerous manners, such as sedimentation, channel / river bank erosion, overgrown of vegetation, salinity intrusion, ecology degradation or affect to the timing, magnitude, duration and frequency of flow in the river.

To avoid the past mistakes and satisfy a wide range of needs are major challenge in water resource planning and management. The situation prompted the necessity to investigate the impact of impoundment and large-scale water resource development scheme on long-term change in the water resource regime. The result obtained may be used as the essential input information for later planning and development.

3. Study Area

Nan river basin in north of Thailand is presented as the case study to determine the impact in the past and the on-going flow regime of pre- and post-impoundment. The basin is located in the tropical monsoon zone between latitude 15^0 42’ 12” to 19^0 37’ 48” N and longitude 99^0 51’ 30” to 101^0 21’ 48” E as shown in Fig.1. It covers an area of some 34,140 sq.km.

The Nan river originates in the mountainous terrain and extends from Nan province in the northern part of Thailand then flows southwards to Nakorn Sawan province to meet with the other tributaries, Ping, Wang and Yom then form the Chao Phraya river.

The multi-purpose Sirikit earthfill dam was constructed almost at the middle reach of the river in 1971. The live storage is approximately 6.0 bcm. The main purposes of this reservoir are for water supply, hydropower generation, irrigation and flood control.

4. Hydrological Data

In this study, the meteorological range of data was conducted from 1952 to 2002. These include the climate data that were collected and analyzed from 5 stations in the basin area. Monthly rainfall data from 76 synoptic stations in and around the study area were compiled and analyzed. Flow data from 92 gauging stations were used to assess the water resource within the basin.

It is revealed from the result of study that the main variation in climatic parameters throughout the basin especially the temperature is due to altitude. The mean annual temperature in the basin area varies from 28.2 ^{0}C at an elevation of some 20 m in southern part of the basin to 25.57 ^{0}C at the elevation of 150 m in northern part of the watershed area.

The arena distribution of rainfall within the Nan river basin is varied between 1,100 – 1,400 mm per annum with a mean annual rainfall of 1,260 mm over the basin as a whole. Temporal distribution of rainfall in the Nan river basin is considerable significant. The amount of rainfall during the rainy season (May to October) is 89% by average.

The average annual runoff from the basin outlet is approximately 12,200 mcm per annum. The specific yield based on the mean annual runoff is 11.33 l/s/sq.km. (Budhakooncharoen, S, 2004)

5. Study Objective

Since the reservoirs vary in size and function, therefore generalizations are difficult (Power, M.E. et. al., 1996). The main goal of this preliminary research is therefore merely aimed to determine the rainfall or flow regulation has most affected to the long-term change of average flow regime in the river after the impoundment of a single large reservoir.

6. Methodology

The lengthy record of river discharges at station N1 upstream of Sirikit dam which is free from significant diversion or regulation were used in comparison with those from station N7 downstream of the river regulated structures to assess the hydrological impact of the reservoir. The rainfall observations during the past 50 years at stations 28013 (near to the non-regulated gauging station N1) and 38012 (near to the regulated gauging station N7) were ultimately used to determine if they caused the tendency change in the flow regime.

The streamflow and rainfall data during 1952 to 2002 were divided into pre- and post-dam hydrologic series. The pre-dam period is during 1952 to 1971, while the post-dam one is during 1972 to 2002. The runoff records both up and downstream of the dam were statistically analyzed to compare the pre- and the post-dam hydrograph with respect to the mean monthly values. The mean annual flow volume was also taken into consideration. The annual rainfall observations were fitted to test for the presence of an increasing or decreasing trend using the whole time series in comparison between the station up and downstream of the impoundment. The average annual rainfall during the pre- and the post-dam periods were investigated.

7. Discussion of Results

In this study, the changes in both shape of streamflow hydrograph and the magnitude of long-term mean monthly hydrological data were investigated. The results obtained can be summarized as follows:

The change in average annual hydrological values to investigate the effect of Sirikit dam on the flow regime in the Nan river is shown in Table 1. The annual rainfall time series were fitted with a least square trend line throughout the period of 1952 to 2002 as shown in Fig.2.

Table 1: Change in average annual hydrological values to investigate the effect of Sirikit dam on flow regime in the Nan river

Station	Average annual value (unit per annum)		Change	
	1952-1971 (Pre-dam)	1972-2002 (Post-dam)	unit per annum	%following Post-dam
28013	1,167.0	1,258.4	+91.5 mm	+7.8
38012	1,460.4	1,223.1	-237.3 mm	-16.2
N1	2,775.7	2,798.8	+23.1 mcm	+0.8
N7	10,227.1	9,520.2	-706.9 mcm	-6.9

<u>Remarks</u>: 28013 is the code of rainfall station near to the non-regulated gauging station N1 upstream of the Sirikit dam while 38012 is that near to the regulated gauging station N7downstream of the reservoir

It is revealed that the long-term statistical analysis of annual rainfall at station 28013 upstream of the reservoir has no discernible trend. In comparison between the pre- and the post-dam periods, the magnitude of average annual rainfall observed at station 28013 has insignificantly increased from 1,167.0 mm per annum during the pre-dam period (during 1952 to 1971) to 1,258.4 mm per annum during the post-dam period (during 1972 to 2002) or has increased by 91.5 mm per annum (or 7.8%) following the impoundment.

The average annual runoff upstream of the dam at the non-regulated gauging station N1 which is located near to rainfall station 28013 has consequently shown no significant difference in comparison between the pre- and the post-dam periods. The average annual runoff during the post-dam period is higher than that during the pre-dam period only 23.1 mcm or increased only 0.8% following the impoundment.

A slight decreasing trend in annual rainfall at station 38012 downstream of the reservoir has been observed from Fig.2. There is no supporting evidence presented in this study concerning the cause of downward trend of the rainfall observed at this station. The decreasing trend of rainfall observed from this station directly affects the flow regime in the river downstream of the dam.

As shown in Table 1, in comparison between the time series before and after the dam, the magnitude of average annual rainfall at station 38012 which is located near to the regulated streamflow station N7 has decreased from 1,460.4 mm per annum during the pre-dam period (during 1952 to 1971) to 1,223.1 mm per annum during the post-dam period (during 1972 to 2002) or decreased by 237.3 mm per annum (or 16.2%) following the impoundment.

As a result of this decreasing rainfall, it becomes one of the reasons the average annual runoff downstream of the dam at the regulated gauging station N7 has decreased from 10,227 mcm per annum to 9,520 mcm per annum or decreased by 6.91% following the impoundment. However, it cannot be completely concluded that the decline of annual runoff at this observed station is singularly due to the river regulation and the amount of rainfall. It might be partially expected in view of either the amount of water that is used for irrigation upstream of the gauging station N7, climate or land coverage change.

Besides the annual runoff volume, comparison of the mean monthly streamflow hydrograph was also taken into investigation. Fig.3 illustrates the hydrologic change on the basis of comparison of mean monthly streamflow hydrograph for the periods 1952 – 1971 (pre-dam period) and 1972 – 2002 (post-dam period).

Before the creation of the dam, the annual streamflow hydrograph of the Nan river at the non-obstructed station N1 had a relatively consistent annual hydrograph with the post-dam hydrograph of the same observed station. But, the magnitude of peak flow regime downstream of the reservoir is evident post-disturbance according to the annual hydrograph at the regulated gauging station N7 downstream of the dam. High runoff seems essentially to be eliminated by dam. In September, the mean monthly peak discharge at gauging station N7 downstream of the dam has decreased by 39%. In addition, it is clearly seen from the graph that low flow in the river downstream of the water resource development scheme during the dry season (during November to April) has increased following the impoundment.

It is seen that the Sirikit dam plays a significant role in capable of storing surplus volume of wet season runoff (during May to October) for the later dry season (during November to April). The substantial surplus storage seems to influence in providing flood mitigation to downstream reach.

8. Conclusions

This preliminary research effort has reported the adjustment of the flow regime following the impoundment of a single large reservoir. It can be concluded that the impoundment and the amount of rainfall are one of the major causes of the flow regime change. But, the post-flow hydrograph change, especially the reduction of peak runoff magnitude and the higher flow during the low flow period downstream of the dam mainly results from the impact of impoundment.

The impoundment effect under the condition in this study is likely to preclude the effects of reservoir functions and appropriate spatial controls. Without these controls, long-term change in the flow regime caused by change of climate or land use may be incorrectly ignored. To cope with the misleading problem due to lack of spatial control, focus should be made also on the un-impounded river basin.

Thus, to observe, understand and model this phenomenon on a macro scale, further study should emphasize on the advance development of precious hydrometeorological data observation and management. The frequency of flood and drought events resulting from flow regulation across a range of dam types and catchment characteristics should be further studied. In addition, shift in low flow, timing of high and low flow or change across different flow duration might be significant. It should be taken also into investigation.

It revealed the necessity to establish the integrated database of the regional long-term hydrological and meteorological properties from intensive observation. This is due to the effect of management on the annual cycle of water flow has been the subject of considerable research on historical flows in the main stem. The study on variability entails uncertainty requires long-term historical records. This precious data set may serve as the robust pre-dam data in the future and these data should be accessible for all researchers.

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Figure 1 Nan River Basin

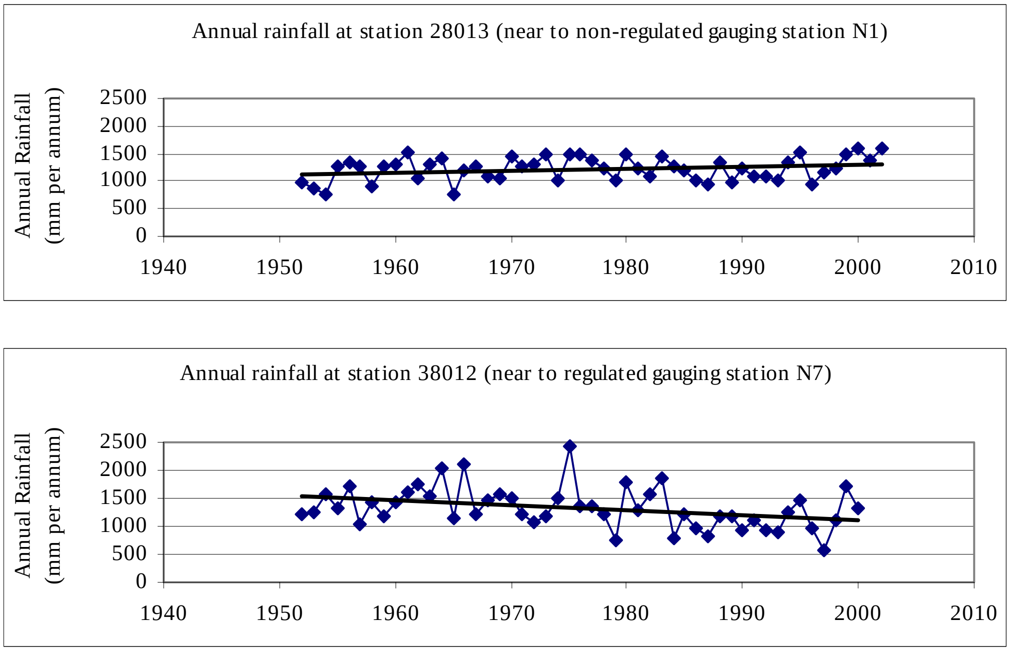

Fig. 2: Trends of annual rainfall

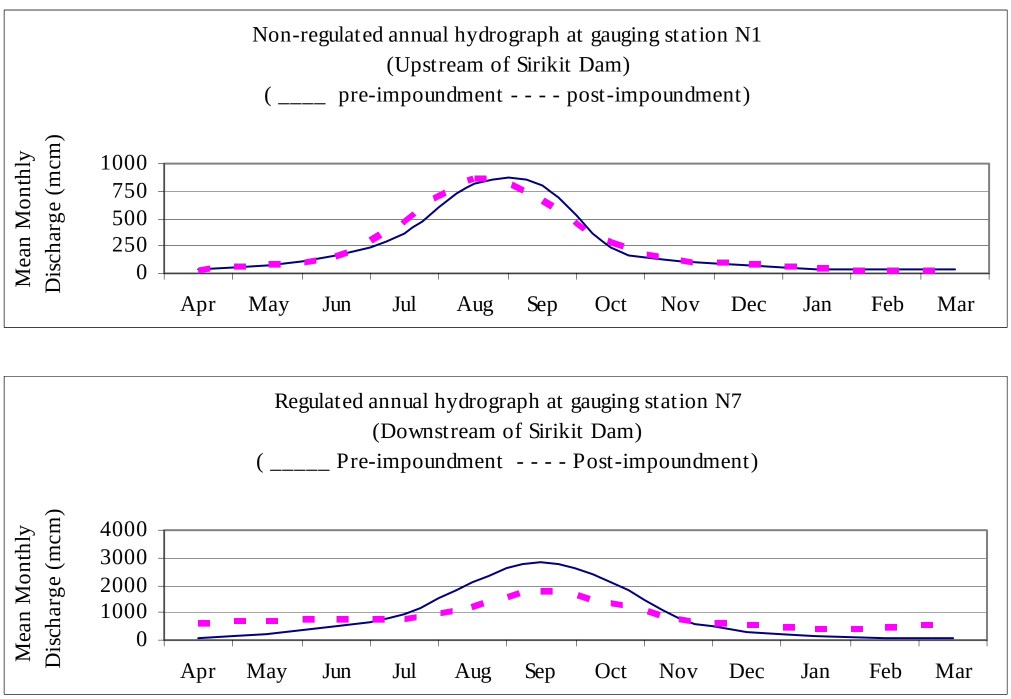

Fig. 3: Annual streamflow hydrograph