TA-139S

TACKLING THE 2021 TROPICAL STORM DIANMU FLOOD IN THE GREATER CHAO PHRAYA RIVER BASIN, THAILAND: THE PERSPECTIVE VIEWS THROUGH CO–RUN EXERCISE UNDER THE SPEARHEAD RESEARCH PROGRAM

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ABSTRACT
The descriptive study on flooding triggered by the tropical storm Dianmu in late rainy season in the Greater Chao Phraya River Basin (GCPYRB) was conducted. The status of water storage of major dams; Bhumibol (BB), Sirikit (SK), Khwaenoi Bumrung Dan (KNB), Pasak Jolasid (PS) before and after Dianmu storm periods were considerably analyzed and compared. The inundated areas of flooding were also investigated and visualized to unveil the extent of flood damage in the Greater Chao Phraya Irrigation Scheme (GCPYIS) during late–September 2021. The dam and reservoir operation, water flows at key gauging stations, and discharges at Chao Phraya Diversion Dam were also explored to brighten up the operational practice of water resources in GCPYRB during the critical Dianmu flood periods. In addition, the results of co–run exercise under the Spearhead Research Program (SIP) including reservoir inflow forecast using Machine Learning (ML) technique and predetermined dam release by the Constraint Programming (CP) model were also presented. The tropical storm Dianmu in 2021 has become a lesson learned particularly for the operational actors to reconsider the water resource management plan due to the abnormality of regional climate data. Importantly, tackling the critical floods through the well–prepared plan and rapid framework for decision making based upon recent information with supportive tools can help assist flood moderation to a considerable extent.

Key words: Tropical Storm Dianmu, Greater Chao Phraya River Basin, Spearhead Research Program

1 INTRODUCTION

The influence of the tropical storm Dianmu hitting parts of Thailand during late– September 2021 caused considerable flood damages particularly in the north, northeast and central regions. The tropical storm

Dianmu brought the heavy rainfall and resulted in flash floods in the upper regions of Thailand on September 23–24. The Department of Disaster Prevention and Mitigation (PWA) has reported that thousands of household area in at least 30 provinces have been affected and some agricultural land areas specifically in the Greater Chao Phraya Irrigation Scheme have been devastated due to flooding [1]. Floodwater caused by the tropical storm Dianmu combined with the seasonal monsoon rains and concurrent storms has still persisted at the end of October and widespread on the left and right banks of the Chao Phraya River.

It was reported that the tropical storm Dianmu was originated from the South China Sea on September 21 and tracked west–northwestwards across Indochina affecting several parts of Vietnam, Lao, Cambodia, and Thailand [2]. A distinct change in rainfall amount and extreme weather was reported and monitored in various parts of the central Vietnam, southern Laos, northeastern Cambodia, and northeastern Thailand. In Vietnam, the tropical storm Dianmu made the landfall, mudslide, and flooding in the mountainous areas of the northern region. The arrival of the tropical storm Dianmu also led to flooding in some parts of southern Lao. Several low–lying areas near streams and rivers, and urbans areas with poor drainage system have been sparsely inundated over this region. In addition, fatality and injury, and property damages were also reported.

In Thailand, according to the past 7–day satellite–based flood map published by the Geo–Informatics and Space Technology Development Agency (GISTDA) of Thailand on September 30 [3], it was exhibited that the inundated areas covered 6 provinces in the north; Sukhothai, Phitsanulok, Kamphaeng Phet, Phichit, Tak, and Phetchabun, 8 provinces in the northeast; Loei, Khon Kaen, Roi Et, Kalasin, Chaiyaphum, Nakhon Ratchasima, Buriram and Surin, 7 provinces in the east; Nakhon Nayok, Prachin Buri, Sa Kaeo, Chachoengsao, Chonburi, Rayong, and Trat and 9 provinces in the upper part of central region; Nakhon Sawan, Lop Buri, Uthai Thani, Chai Nat, Saraburi, Sing Buri, Ang thong, Ayutthaya, and Suphan buri. In addition, flooding is expected to be prolonged and receded in the Pathum Thani, Nonthaburi, Bangkok and metropolitan areas in the Lower Chao Phraya River Basin.

The role of the researchers under the Spearhead Research Program, the National Research Council of Thailand (NRCT) on water resources management has been undertaken through the co–run exercise in the Greater Chao Phraya River Basin (GCPYRB) to deliver clear and straightforward information and possible guideline for dam operation. Therefore, the objective of this study aims at reporting the current situation in views of water storage status in reservoirs, the associated inundated areas, and operational practice during the 2021 Dianmu storm.

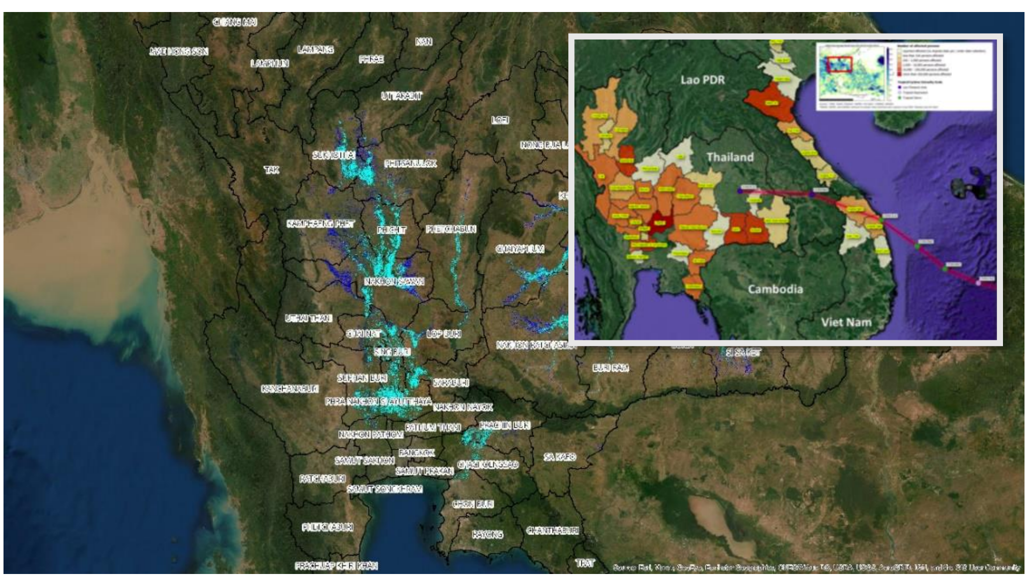


Fig. 1. The map of inundated areas in the Greater Chao Phraya River Basin due to the 2021 Dianmu flood; Dark blue–dated on Sep 30, Light blue–dated on Oct 8.

2 METHODOLOGY

The descriptive study on flooding in GCPYRB was conducted due to the occurrence of the tropical storm Dianmu in September 2021. The status of water storage of major dams; BB, SK, KNB, PS before and after Dianmu storm was considerably analyzed and compared. The inundated areas of flooding were also investigated and visualized to unveil the extent of flood damage particularly in GCPYIS during late–September 2021. The dam and reservoir operation, water flows at key gauging stations, and discharges at Chao Phraya Diversion Dam were also explored to brighten up the operational practice of water resources in GCPYRB during the critical Dianmu flood periods. In addition, the results of co–run exercise under the Spearhead Research Program including reservoir inflow forecast using machine learning technique [4] and predetermined water release by the constraint programming model [5] were also presented.

3 RESULT AND DISCUSSION

3.1 Water storage status of major dams before and after Dianmu

The current status of reservoir water storages of four storage dams; BB, SK, KNB, and PS before the Dianmu hit some areas in Thailand, were considerably investigated. It is found that the available water storage on September 5, were at 9.09%, 12.14%, 30.16% and 12.77% of active storage for BB, SK, KNB, and PS Dams, respectively signifying high holding capacity of all reservoirs to collect incoming floodwater as can be seen in Fig. 2 and Fig. 3. The cumulative observed inflows till the 5th of September 2021 were 1,249, 2,281, 555, and 201 mcm, for BB, SK, KNB, and PS Reservoirs, respectively which were relatively low by comparing with the long–term average values for all the dams. In other words, the water availability in reservoirs were likely declined due to unbalancing between inflows and outflows before the Dianmu hit. The cumulative volume of released water till the 5th of September 2021 were merely 1,703, 3,772, 634, and 612 mcm for BB, SK, KNB, and PS Dams, respectively which were determined corresponding to the target water allocation plan for dry year operation.

However, it is investigated that the influence of the tropical storm Dianmu led to the minor increase of active water storage of BB and SK Dams accounting for 29.08% and 19.77% of active storages on September 30. During the storm period, zero or minimum discharges were determined for the dam release. However, this tropical storm had significant impact on high likelihood of reservoir inflows of KNB and PS Dams particularly since September 26. It was reported that the water storage of KNB and PS Dams reached up to 90.70% and 107% of active capacity on September 30. Accordingly, the extra water were released from KNB and PS Dams creating floodwater on the downstream side of PS Dam. Trends of reservoir inflows and water released from all dams in 2021 are presented in Fig. 4. It is investigated that the ratio of average reservoir inflows to reservoir capacity of KNB and PS Dams were at 1.44 and 1.55 in 2021 after the tropical storm Dianmu as shown in Table 1. This implies the sudden changes of reservoir inflows of these two dams which were definitely critical and tough in terms of dam operation and flood prevention.

Table 1 Ratio of average reservoir inflows to reservoir capacity of major dams in GCPYRB

Avg. Reservoir Inflow: Capacity Ratio	Long–Term Data	Short–Term Data				
		Wet Year	Normal Year	Dry Year	Before Dianmu	After Dianmu
BB	0.40[1/]	0.73	0.39	0.20	0.09[4/]	0.24[5/]
SK	0.64[1/]	0.89	0.64	0.45	0.24[4/]	0.30[5/]
KNB	1.72[2/]	3.92	1.90	0.92	0.72[4/]	1.44[5/]
PS	2.83[3/]	5.33	3.02	1.09	0.26[4/]	1.52[5/]

Remark: [1/]Long–term data during 2000–2020 [2/]Long–term data during 2009–2020
[3/]Long–term data during 2003–2020 [4/]Data on September 5, 2021
[5/]Data on September 30, 2021

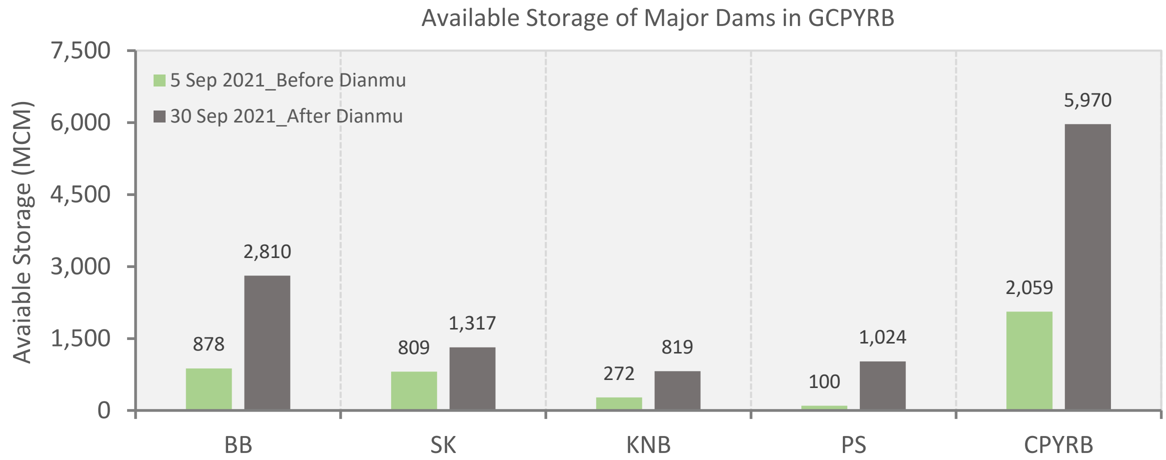


Fig. 2. Avaiable water storage of major dams in GCPYRB in September 2021

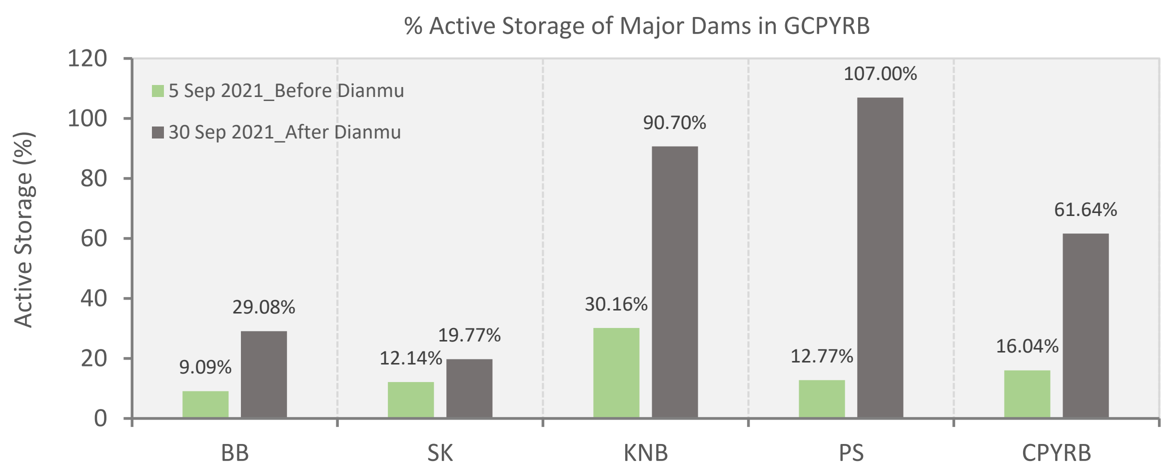


Fig. 3. Percent of active storage of major dams in GCPYRB in September 2021

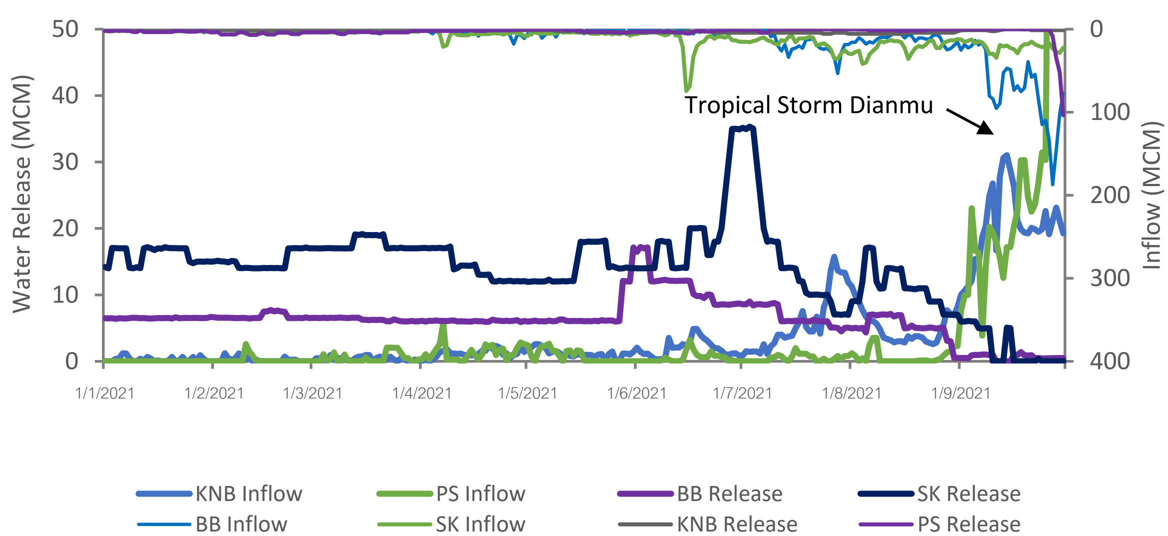


Fig. 4. Trends of reservoir inflows and water released from BB–SK–KNB–PS Dams in 2021

3.2 Evaluation of inundated areas caused by the 2021 Dianmu Flood

The undated areas caused by the 2021 Dianmu flood were evaluated using the past 7–day satellite–based flood map and compared the results in late September–early October. It is apparently found that the total inundated area in GCPYRB on September 27–October 2 was 4,168 sq.km. which was equivalent to 2,605,000 rai. Approximately 942,694 rai of the inundated areas was existed in the agricultural land areas in GCPYIS as shown in Table 2. The flood inundation in agricultural land areas on October 8 was decreased by 33.26%. Although the decline of flood inundation areas was found in the north and upper central regions on October 8, however, the water levels in the main rivers and streamflow rates were still high. Moreover, effect of flooding triggered by the tropical storm Dianmu was transported over a wide area in the lower central and eastern regions of Thailand. More than 50% of the inundated areas in GCPYRB was definitely persisted in the Yom–Nan, Chaochet Bangyeehon, Phak Hai, and Khokkathiam Irrigation Schemes as can be seen in Fig. 4.

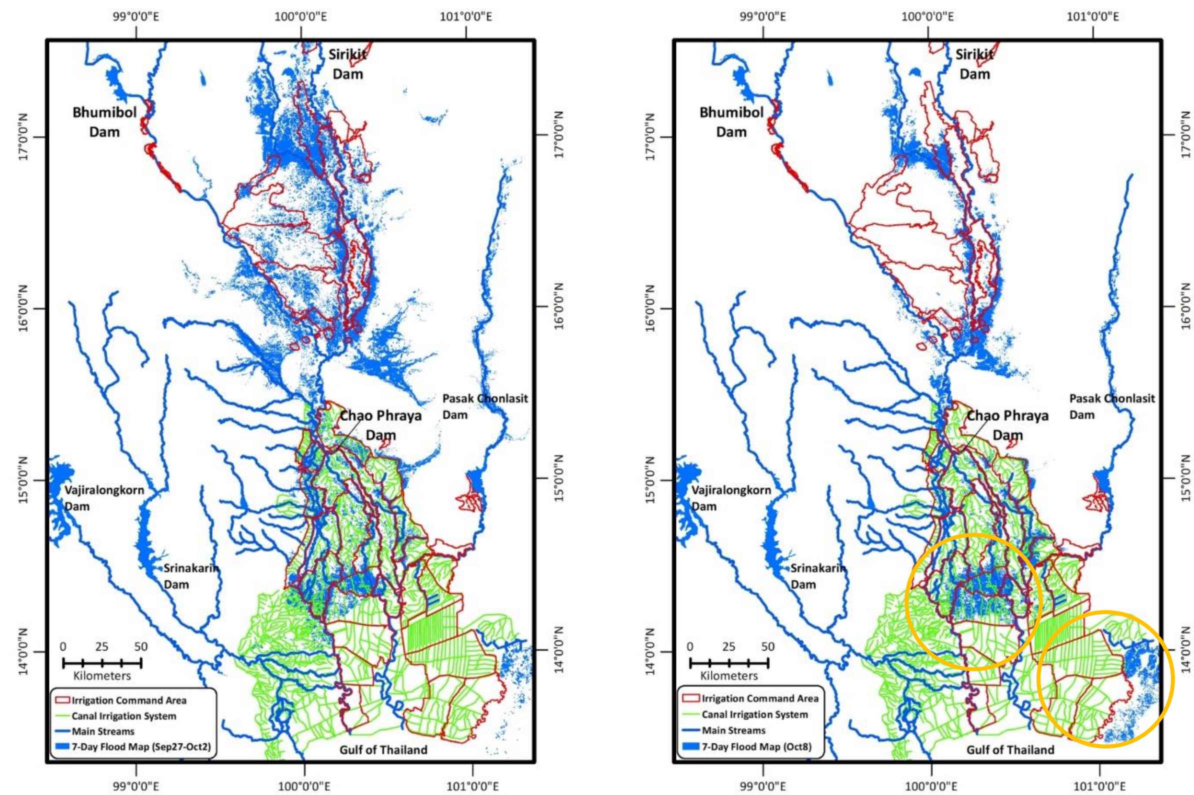


Fig. 4. Comparison of inundated areas on September 27–October 2 and October 8 due to the 2021 Dianmu flood.

Table 2 The inundated areas in the Greater Chao Phraya Irrigation Scheme

Name of Irrigation Scheme	Type of Irrigation Scheme	Cultivated Area in 2020/2021 (rai)1/	Inundated Area	
			(rai)	(percentage)2/
Lower Ping Irrigation Zone				
Tortongdang	Inundation	651,037	52,183	8.02
Wangbua	Inundation	694,566	49,322	7.10
Wangyang– Nongkwan	Inundation	439,511	72,380	16.47
Lower Nan Irrigation Zone				
Dongsetthee	Gravity	151,982	19,596	12.89
Plaichumpol	Gravity	255,377	41,325	16.18
Naresuan	Gravity	95,215	309	0.32
Thabua	Gravity	157,489	25,564	16.23

Name of Irrigation Scheme	Type of Irrigation Scheme	Cultivated Area in 2020/2021 (rai)[1/]	Inundated Area	
			(rai)	(percentage)[2/]
Yom–Nan	Inundation	368,180	131,497	35.72
Chao Phraya–Thachin Irrigation Zone				
Bang Bal	Pumping	176,627	10,100	5.72
Borommathat	Gravity	212,101	21,614	10.19
Chanasute	Gravity	307,503	39,640	12.89
Chaochet Bangyeehon	Inundation	629,072	31,948	5.08
Donjedee	Gravity	91,961	13,497	14.68
Phak Hai	Gravity	278,899	96,187	34.49
Phophraya	Gravity	537,783	71,779	13.35
Pollathep	Gravity	170,204	15,821	9.30
Samchuk	Gravity	243,499	12,658	5.20
Thabot	Gravity	114,138	31,563	27.65
Wat Sing	Pumping	6,616	–	–
Yangmanee	Gravity	142,808	18,332	12.84
Pasicharoen	Inundation	44,668	–	–
Phayabunlue	Inundation	382,642	528	0.14
Prapimon	Inundation	205,285	–	–
Chong Kae	Gravity	116,219	14,100	12.13
Khokkathiam	Gravity	208,183	16,752	8.05
Maharaj	Gravity	210,765	31,687	15.03
Manorom	Gravity	202,231	41,146	20.35
Roeng Rang	Gravity	143,533	7,386	5.15
Klong Dan	Inundation	221,970	–	–
Nakhon Luang	Gravity	94,640	–	–
Northern Rangsit	Gravity	181,898	–	–
Praong Chao Chaiya Nuchit	Inundation	495,845	–	–
Southern Pasak	Gravity	140,407	–	–
Southern Rangsit	Gravity	682,143	–	–
Additional Cultivated Area in 2020/2021				
Tak	–	19,900	–	–
Khwae Noi Bamrung Dan	–	21,469	21,745	101.29
Samut Sakhon	–	37,638	–	–
Khlong Priew–Sao Hai	–	36,250	–	–
Pasak Jolasid	–	79,234	–	–
Lop Buri	–	70,690	–	–
Chainat	–	–	3,338	–
Uttaradit	–	–	4,716	–
Total	–	9,481,953	942,694	9.94

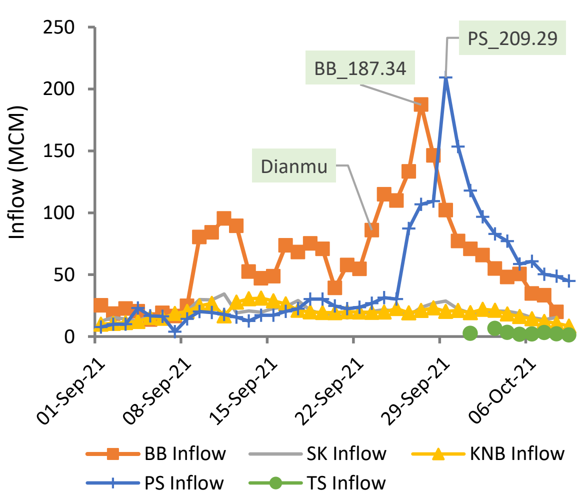
Remark: [1/] The cumulative area size cultivated from November 1, 2020 to July 12, 2021.
[2/] The percentage values were calculated as the ratio of flooded area to cultivated area in 2020/2021.

3.3 Evaluation of reservoir operational data triggered by the tropical storm Dianmu

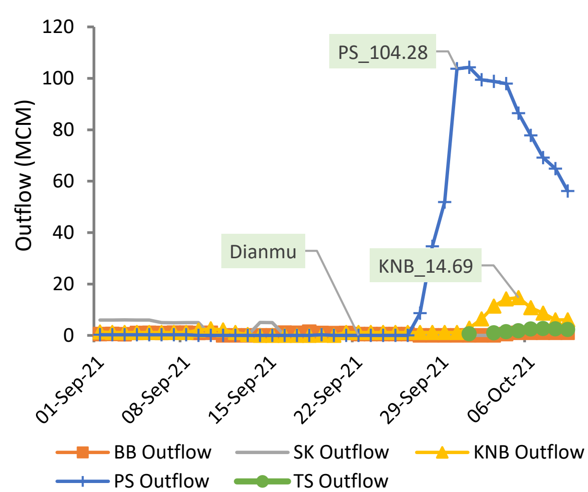
The tropical storm Dianmu and seasonal monsoon rains producing substantial amounts of rainwater in the northern and central Thailand significantly led to the increase of the reservoir inflows of all major dams in GCPYRB in late September. It is investigated that the reservoir inflows of BB and PS were considerably increased during the storm periods. The reservoir inflows reached up to 187.34 MCM per day for BB Dam and 209.29 MCM per day for PS Dam as explicitly shown in Fig. 5(a). However, after September 30, the tendency of observed inflows of all major dams were likely decreased which was associated with those predicted results of reservoir inflow performed by using machine learning technique and 2–week rainfall forecast by using WRF–ROMS (CFSV2) model in the upstream areas of these four major dams.

It is found that releasing water from all major dams in early October 2021 were kept as zero or minimum requirement to reduce flood damage downstream except PS Dam. The surplus water was released from PS Dam to increase holding capacity of reservoir and dam safety. It is reported that the reservoir outflow of PS Dam climbed up to 104.28 MCM per day on October 1 when it reached full capacity as shown in Fig. 5(b). This led to widespread flooding on the Lower Eastern Chao Phraya Irrigation Scheme which is located downstream of PS Dam. In addition, it caused rapid change of increased water level in the Pasak River downstream of Rama 6 Dam which flows eastward into the Chao Phraya River. Since October 1, the amount of water release from PS Dam tended to be continuously decreased corresponding to the decline of reservoir inflow.

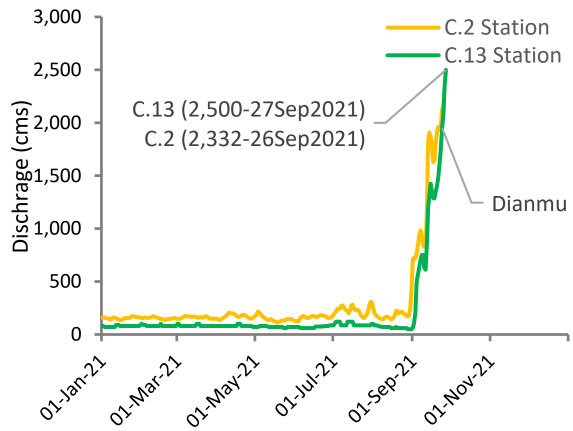
The floodwater travelled from the upper north in the Ping, Wang, Yom, and Nan River Basins combined with the seasonal monsoon rainfall downstream led to the rising water levels in the Chao Phraya River inevitably. Therefore, the operational practice during the critical flood periods was undertaken by cutting off the peak flows in the Chao Phraya River into the canal irrigation system on the left and right banks of the Chao Phraya River and the potential flood retention areas. It is observable that the river discharge at C.2 gauged station monitored at Nakhon Sawan Province started increasing at the beginning of September before the occurrence of the Dianmu storm and ascending to the peak flow of more than 2,500 cms during late September. The decision to increase the discharge rates at Chao Phraya Dam (C.13 gauged station) to accommodate the huge flow and transported floodwater in the main river was implemented by the Royal Irrigation Department (RID) of Thailand as can be seen in Fig. 5(c). Consequently, flood warning for the results of the increased discharge rates through the Chao Phraya Dam were made especially in the low lying areas and communities along the river banks with poor flood levee structures in Chainat, Sing Buri, Ang Thong, and Ayutthaya. It would be seen in Fig. 5(d) that the increasing discharge rates at Chao Phraya Dam was allowed since the beginning of September and it reached the highest peak in late September–early October. In recent days (October 23), it was reported that flood situation in the CPYRB has progressively improved. The discharge rates passing through the Chao Phraya Dam downstream was reduced by fluctuating around 2,000 cms at the end of October. In addition, the official authorities said that flood situation in GCPYRB is expected to return to normal by the end of November [7].



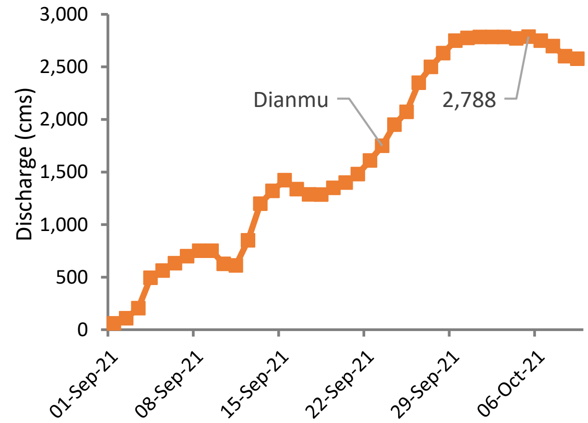
(a) Reservoir inflow



(b) Reservoir outflow



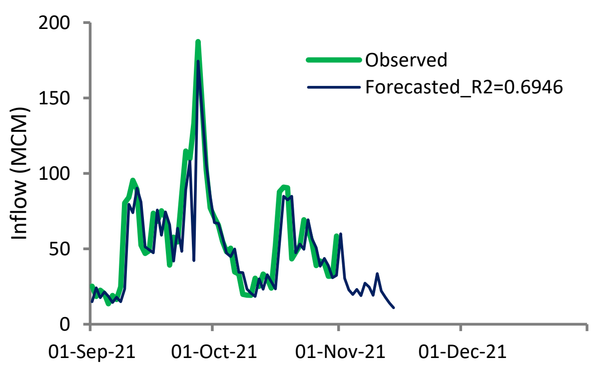
(c) Discharge at key runoff stations



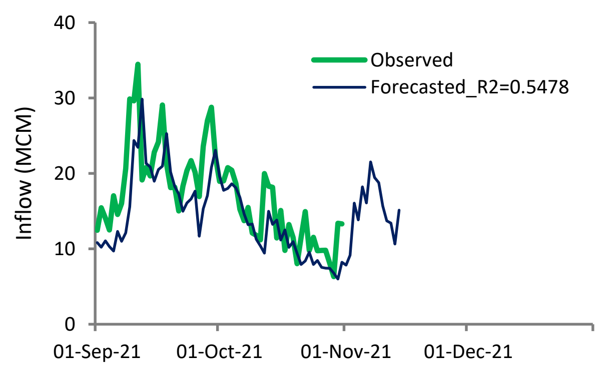
(d) Discharge at CPY Dam

Fig. 5. Reservoir operational data before and after Dianmu

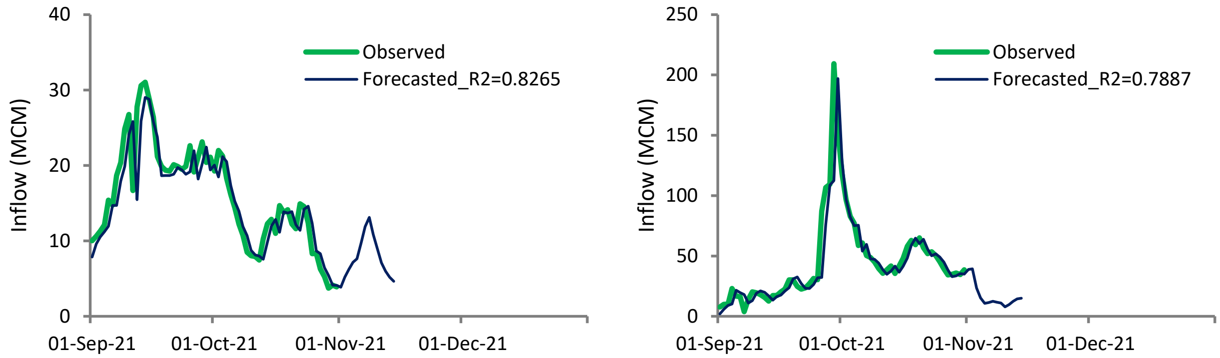
The results of modelling works through the co–run exercise were presented for real time multi–reservoir operation in GCPYRB during the storm periods. The machine learning which is branch of artificial intelligence, has been widely applied in the field of water resources engineering with the great success for hydrological predictions [6]. Therefore, machine learning with Long Short–Term Memory (LSTM) algorithm was used to develop the daily reservoir inflow prediction models of BB, SK, KNB and PS Dams. Multi–objective optimization by constraint programming model was applied by aiming to minimize the water deficit and spilled water as well as to reduce the excessive water in GCPYRB. The CP model with yearly and seasonal constraints were developed based upon the dam–reservoir system and physical conditions in GCPYRB. In addition, the observed sideflow data and the predicted outputs of reservoir inflow were also used to identify the constraints of multi–objective optimization model to predetermine the amount of water release of four major dams. The results of reservoir inflow forecast by machine learning technique and predetermined water release by the constraint programming model during September 1–Noveber 11 were presented in Fig. 6 and Fig. 7.



(a) BB Dam

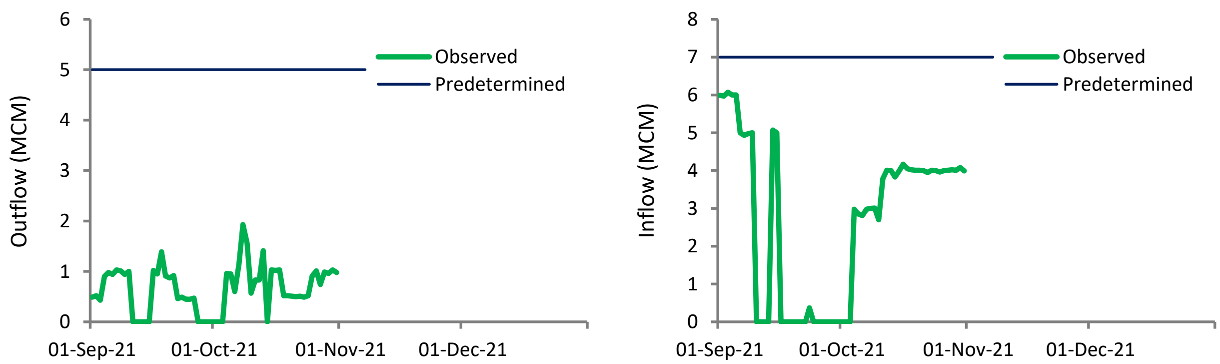


(b) SK Dam

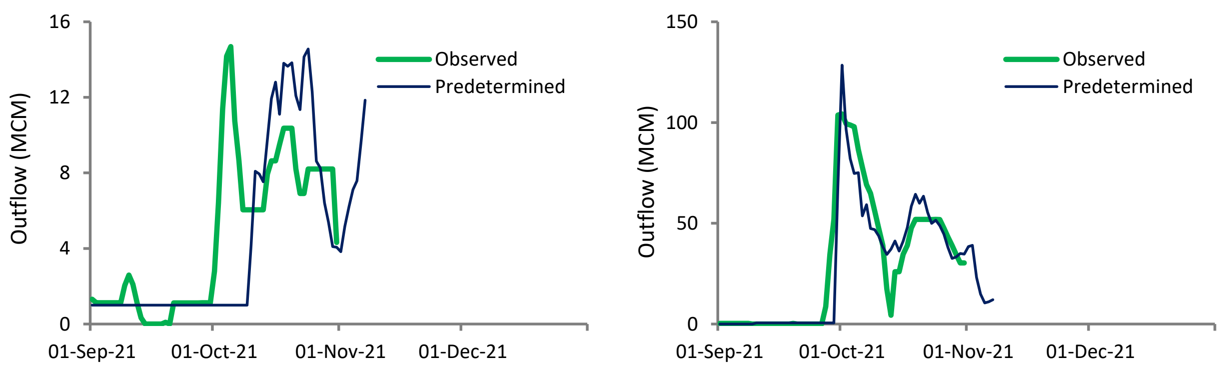


(c) KNB Dam (d) PS Dam

Fig. 6. The predicted reservoir inflows of major dams in GCPYRB during the Dianmu storm period.



(a) BB Dam (b) SK Dam



(c) KNB Dam (d) PS Dam

Fig. 7. The predetermined water release of major dams in GCPYRB during the Dianmu storm period.

It is found that the one–step ahead daily inflow prediction with 14–day lead time could provide good predictive results of R^2 of 0.6946, 0.5478, 0.8265, and 0.7887 for BB, SK, KNB, and PS Reservoirs during September 1–November 11. The best structure of predictive model developed requires the past and current reservoir inflows as major inputs to capture and forecast the future trends and predicted values of reservoir inflows. The rising trends of predicted inflows were found for these four reservoirs from late–September to the first week of October. However, it tended to be decreased in the second week of October which was relative to the behaviors of observed inflows. The predicted reservoir inflows with 14–day lead time were then used as inputs to predetermine the released water by constraint programming model. Releasing water from BB and SK reservoirs with minimum water requirement was accordingly recommended by the CP model for the next 14 days in November. However, it recommended to increase the amount of released water from KNB and PS reservoirs since September 26 due to the rapid increase of the reservoir inflows.

Even the flooding situation caused by the tropical storm Dianmu in GCPYRB is expected to recede in November 2021 [7]. However, flooding continues to affect some areas in the Western Chao Phraya Irrigation Scheme along the Thachin River and low–lying areas near the stream channels in GCPYRB. The massive amounts of water transporting from the north to the Lower Chao Phraya River Basin have still overwhelmed the small to medium size reservoirs to reach full capacity such as Krasiew, Thap Salao, and Pasak Jolasid Dams inevitably at the end of October. Moreover, the intense rainfall is still forecasted in some regions. Therefore, keeping close attention to current situation of water and the new developing storms is important to reduce impact of flood events in this region.

4 CONCLUSION

Flooding triggered by the tropical storm Dianmu in late rainy season in Thailand has become a lesson learned particularly for the operational actors to reconsider the water resource management plan due to the abnormality of regional climate data. Coping with rapid change of water availability and compound flood from the concurrent storms in a short period of time is not a simple task. However, tackling the critical floods through the well–prepared plan and rapid framework for decision making based upon recent information with supportive tools can help assist flood moderation to a considerable extent. Importantly, weighting the operational strategy applicable for GCPYRB by storing floodwater in the potential flood retention areas for later use in the system or by directing surplus water to the sea immediately to reduce impact of flood inundation, plays significant role in the prospective views of sustainable development of water resources and risk–based management.

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