CHAPTER 5

Research Results

This research is analyzed by HEC-ResSim 3.1 software to create the simulation model for reservoir operational management of multi-reservoir case on a same river. The study case is Namkhan 2 and 3 hydropower plants for optimizing electricity production, which used the HEC-ResSim 3.1 model for designing and planning the multi-reservoir management. Data used is the basic design data for inputing the simulation model. Because, both power plants are new hydropower plants, which just constructed completely. Water inflow data was collected from the statistic data since 1960-2009 of Namkhan River. This research is divided into five cases to analyze of each criterions as: very watery criterion (VWC), watery criterion that very rather (WCVR), normal watery criterion (NWC), watery criterion that less rather (WCLR), and little watery criterion (LWC). The figure 5.1 is shown the located of namkhan 2 and 3 HPP in Luangprabang, which show in HEC-ResSim3.1 program for the simulation model.

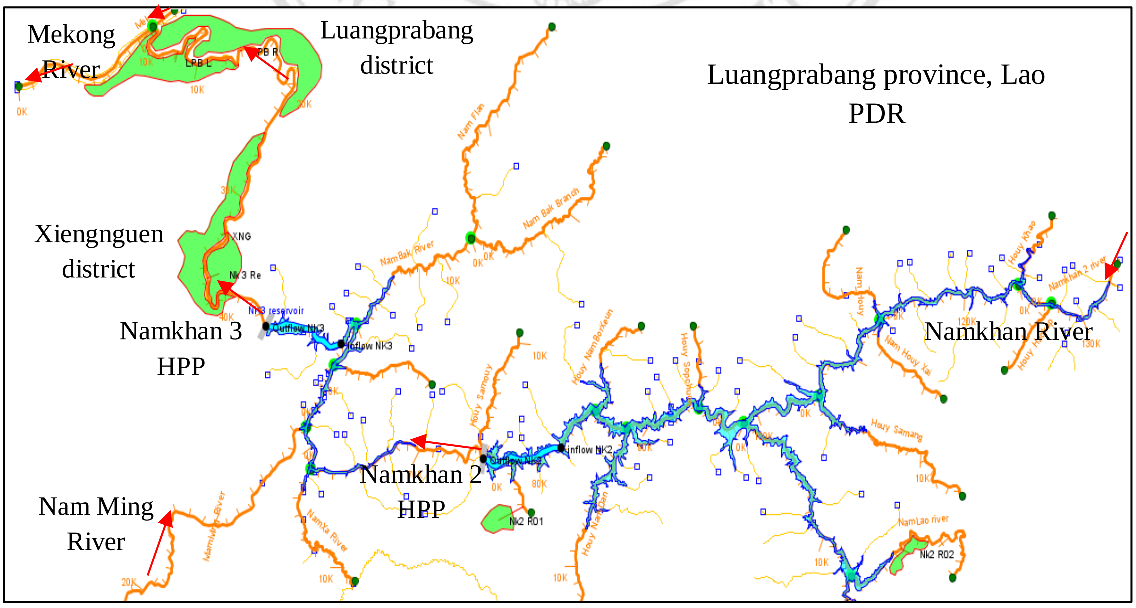

Figure 5.1 Simulation dialog box in HEC-ResSim3.1 modelling.

The simulation results from the HEC-ResSim 3.1 model, it will be revised for useful appropriateness such as: upper and lower curve, electricity production, water storage in reservoir and all water release. Then, the results after revised will be used to find the parameters that affect to optimum electricity production and water regulation.

5.1 Simulation Results of Little Water Criterion Year (Dry year)

The simulation model of Namkhan 2 and 3 HPP used water inflow to be main parameter. That is an variable for simulation model of HEC-ResSim3.1 software to find the operation curve in dry yeasr case. These results got from the revised the upper and lower role curve. the optimization technique is used for reservoir management to useful operation. Then, results after using optimization is shown the volume difference of energy generated for before-after revising, which shown in table 5.1 for describtion the Namkhan 2 and 3 hydropower plants. The optimization technique is to revise by defining power production and generation schedule for reservoir operation of each hydropower plants.

Table 5.1 Energy generation for before-after revised of LWC case

Month	**Energy generation of Namkan 2 HPP (KWh)**			**Energy generation of Namkan 3 HPP (KWh)**		
	Before revised	After revised	Difference	Before revised	After revised	Difference
January	25,001,328	25,259,064	257,736	11,739,624	11,929,032	189,408
February	20,202,936	20,411,184	208,248	10,087,992	10,121,664	33,672
March	19,387,224	20,055,720	668,496	9,042,696	9,380,928	338,232
April	16,444,992	17,181,984	736,992	7,601,040	7,853,304	252,264
May	14,473,776	15,076,224	602,448	6,559,536	6,724,008	164,472
June	12,607,776	12,934,056	326,280	5,732,472	5,880,432	147,960
July	16,023,960	16,481,352	457,392	8,561,736	8,769,192	207,456
August	24,526,200	23,815,584	-710,616	14,195,424	13,964,856	-230,568
September	33,100,392	32,557,008	-543,384	16,349,976	16,205,616	-144,360
October	28,797,672	28,806,168	8,496	14,195,088	14,340,312	145,224
November	21,815,424	21,995,712	180,288	11,093,208	11,115,912	22,704
December	20,774,424	20,970,240	195,816	10,207,920	10,245,768	37,848
Total	**253,156,104**	**255,544,296**	**2,388,192**	**125,366,712**	**126,531,024**	**1,164,312**

From the above table was shown the energy difference in each months. Specially in August and September, the energy generation after operation revised is the energy generated less than before revised. Because, in the dry season during June and July is producted maximum electricity for supporting the reservoir for water storage in the rainy season. The reason of energy of before revised more than is to storage for maximum water volume in rainy season and to produce electricity in dry season on next year. Rainfall in during August and September has water very rather. Therefore, energy generation of each periods is different volume, which shown monthly energy generated in figure 5.2 and 5.3 of Namkhan 2 and 3 hydropower plants respectively.

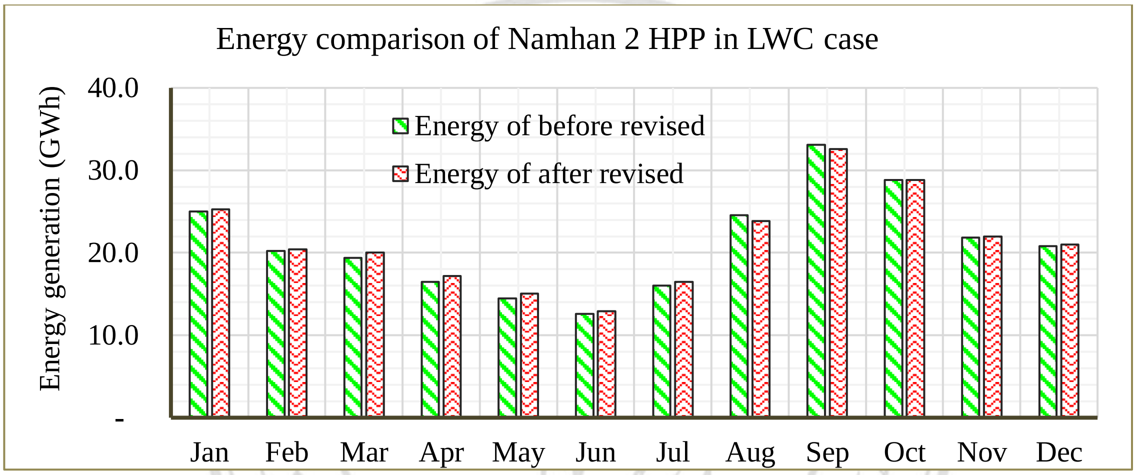

Figure 5.2 Energy comparison of Namkhan 2 hydropower plant in LWC case.

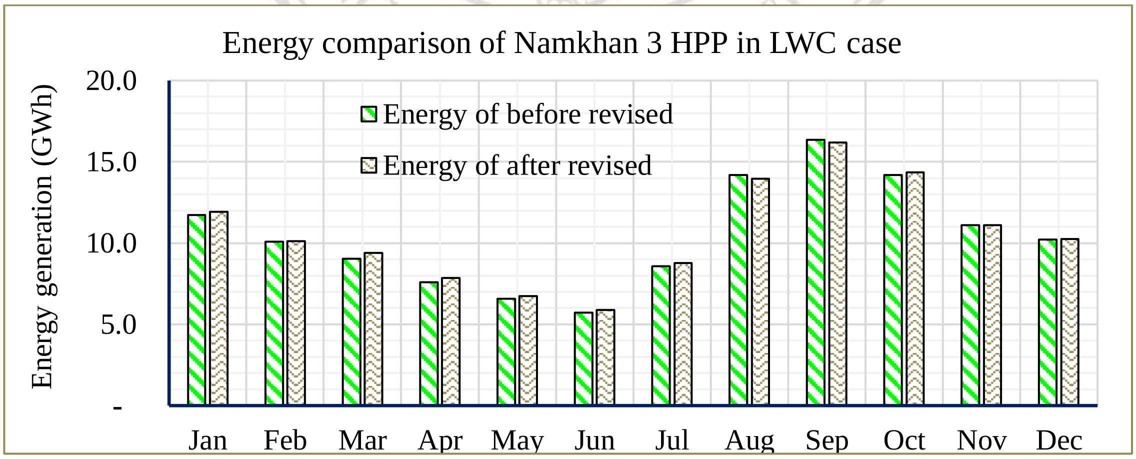

Figure 5.3 Energy comparison of Namkhan 3 hydropower plant in LWC case.

Simulation results of reservoir operation are shown in Figure 5.4 and 5.5 of Namkhan 2 and 3 hydropower plants respectively, in dry year case. That shows the relationship between the reservoir elevation, water inflow and water release after using optimization technique for optimizing the reservoir operational management.

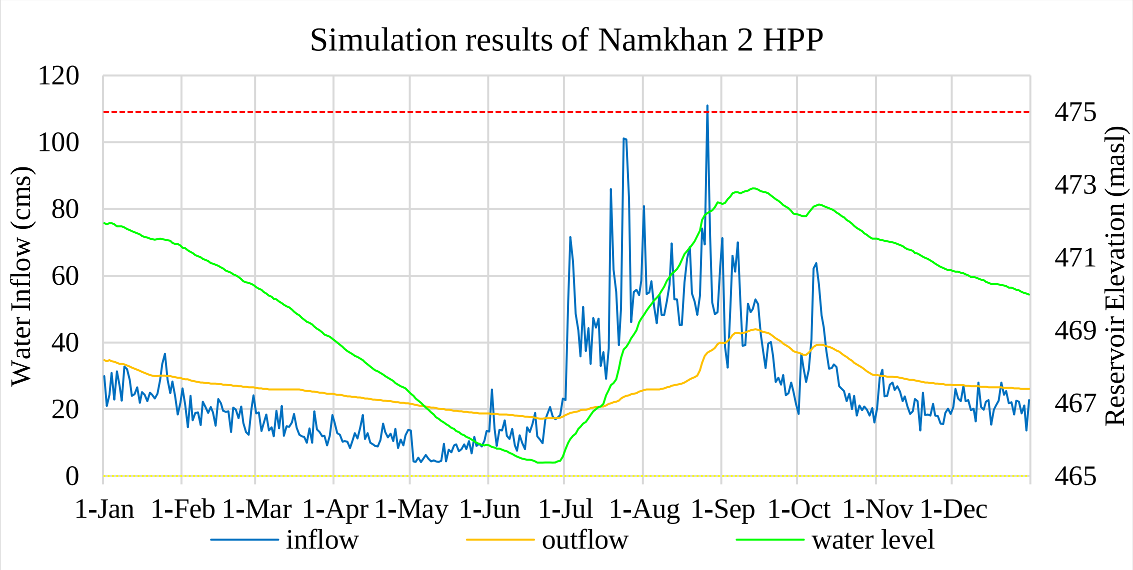

Figure 5.4 Reservoir operation relationship of Namkhan 2 HPP in dry year case.

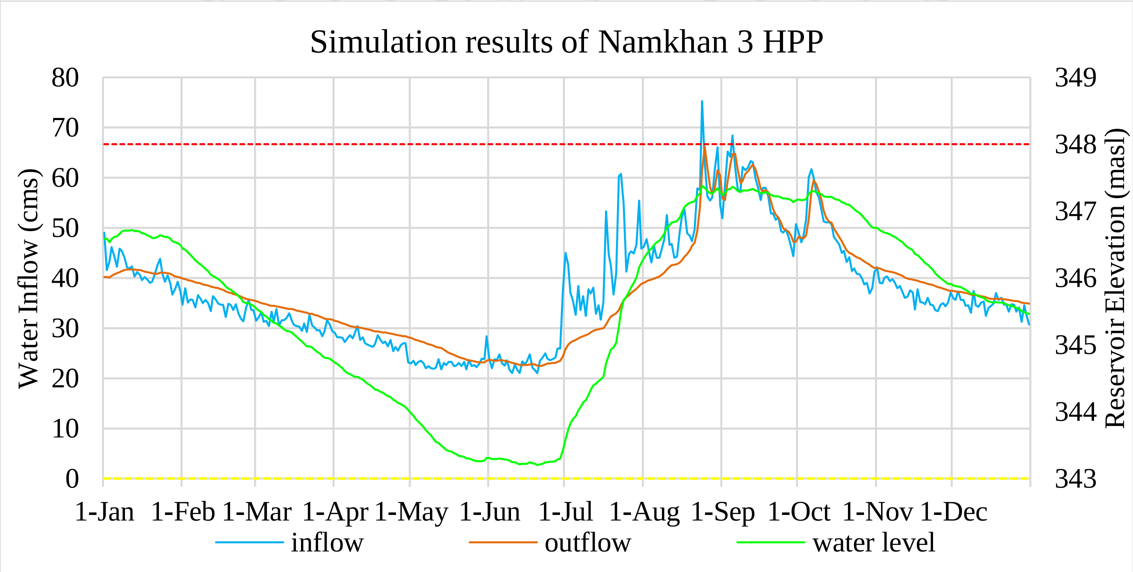

Figure 5.5 Reservoir operation relationship of Namkhan 3 HPP in dry year case.

5.2 Simulation Results of Water Criterion that Less Rather (Average dry year)

Simulation model of water criterion that less rather is one of five cases, which will be analyzed and revised operation model for several factors to find the optimal reservoir operation. The simulation model used the water inflow to be main parameter. it is an variable in the simulation model. The HEC-ResSim3.1 software can be simulated to find the operation curve in the average dry year case. The results are got from the operation revised for the upper and lower role curve and operational optimization technique of reservoir management. After using optimization technique, it was shown the energy difference for before - after revised, which are shown monthly energy generated in table 5.2. The optimization technique is to revise the operational process by defining power production and periods for reservoir operation of each hydropower plants.

Table 5.2 Energy generation for before-after revised of WCLR case

Month	**Energy generation of Namkan 2 HPP (KWh)**			**Energy generation of Namkan 3 HPP (KWh)**		
	Before revised	After revised	Difference	Before revised	After revised	Difference
January	24,415,680	27,049,680	2,634,000	11,508,432	12,997,920	1,489,488
February	19,780,560	21,615,120	1,834,560	9,706,560	10,027,848	321,288
March	18,992,880	19,423,440	430,560	8,781,168	9,233,592	452,424
April	16,478,160	16,734,720	256,560	7,696,872	7,725,744	28,872
May	15,490,560	15,685,920	195,360	7,299,768	7,135,104	-164,664
June	14,361,840	14,460,720	98,880	6,929,064	6,894,576	-34,488
July	16,958,880	17,036,880	78,000	8,859,672	9,044,976	185,304
August	46,765,200	40,761,600	-6,003,600	25,600,344	23,045,256	-2,555,088
September	68,877,360	68,540,400	-336,960	33,922,248	33,805,272	-116,976
October	41,259,360	41,258,880	-480	19,605,144	19,695,720	90,576
November	28,536,240	29,712,240	1,176,000	13,798,824	14,450,304	651,480
December	22,857,360	25,232,880	2,375,520	11,625,600	12,523,848	898,248
Total	**334,774,080**	**337,512,480**	**2,738,400**	**165,333,696**	**166,580,160**	**1,246,464**

From the above table is shown the energy difference in each months. In this case is described the energy enerated in August to October of Namkhan 2 and 3 hydropower plants, which are energy generation of after revised less than energy of before revised. Because, in the dry season during June and July is maximum electricity production to support the reservoirs for water storage in the rainy season. The reasonal of energy generated of before revised more than is to storage the maximum water volume in rainy season and to produce the electricity on the dry season. In August and September of each years is rainfall more rather. However, energy generation of each months have difference which can be supplied all constraints of reservoir operation. Figure 5.6 and 5.7 shown the monthly energy eneration of Namkhan 2 and 3 hydropower plants respectively.

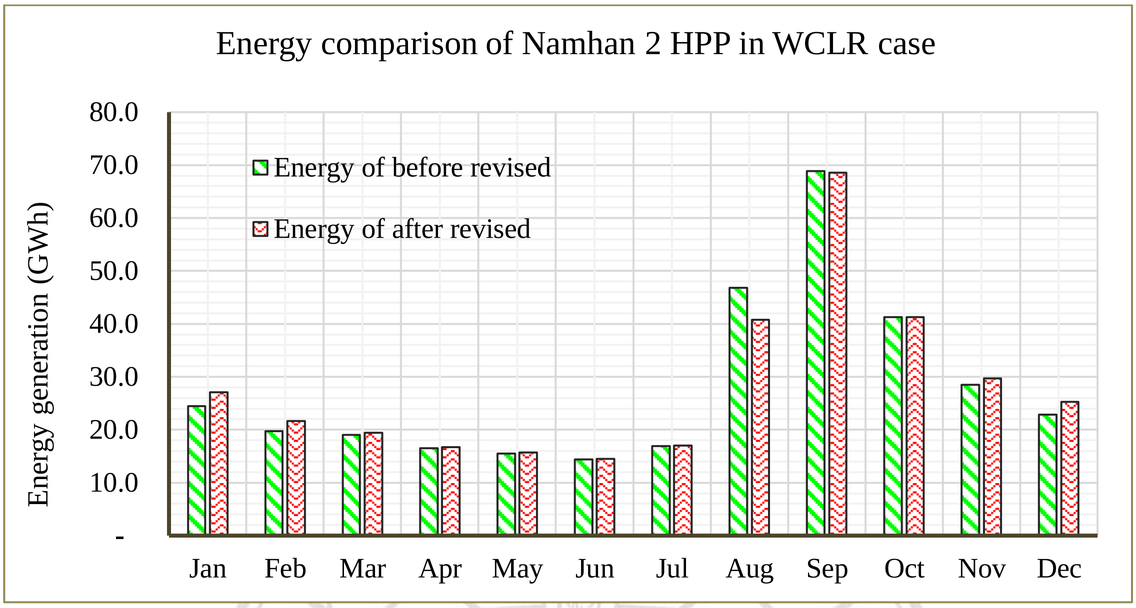

Figure 5.6 Energy comparison for before–after revised of Namkhan 2 hydropower plant.

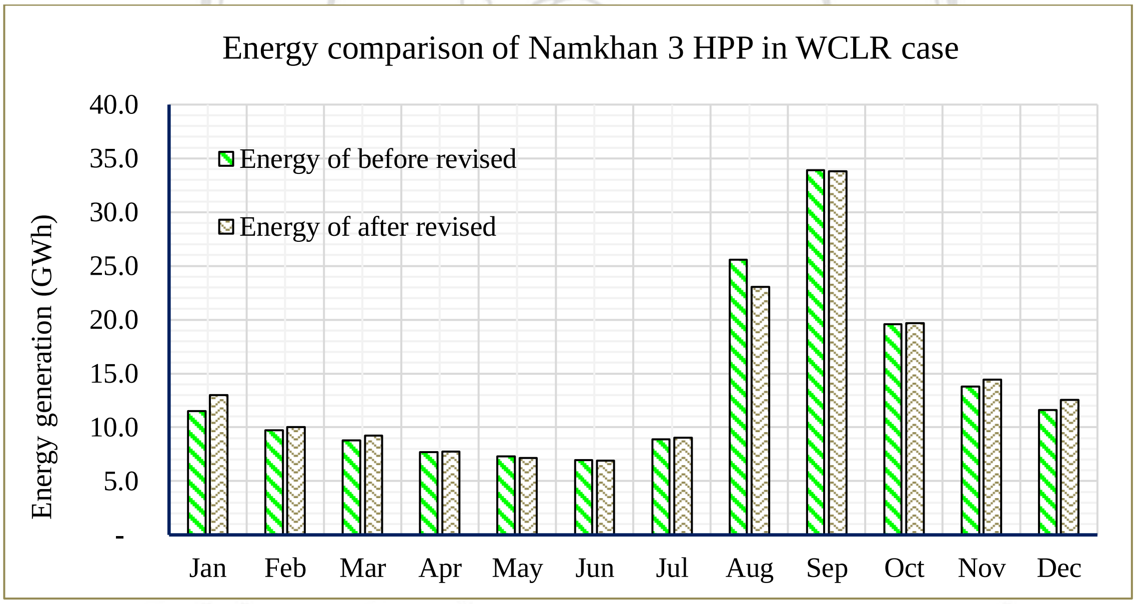

Figure 5.7 Energy comparison for before–after revised of Namkhan 3 hydropower plant.

Simulation results of reservoir operation are shown in Figure 5.8 and 5.9 of Namkhan 2 and 3 hydropower plants respectively, in average dry year case. That shows the relationship between the reservoir elevation, water inflow and water release after using optimization technique for optimizing the reservoir operational management.

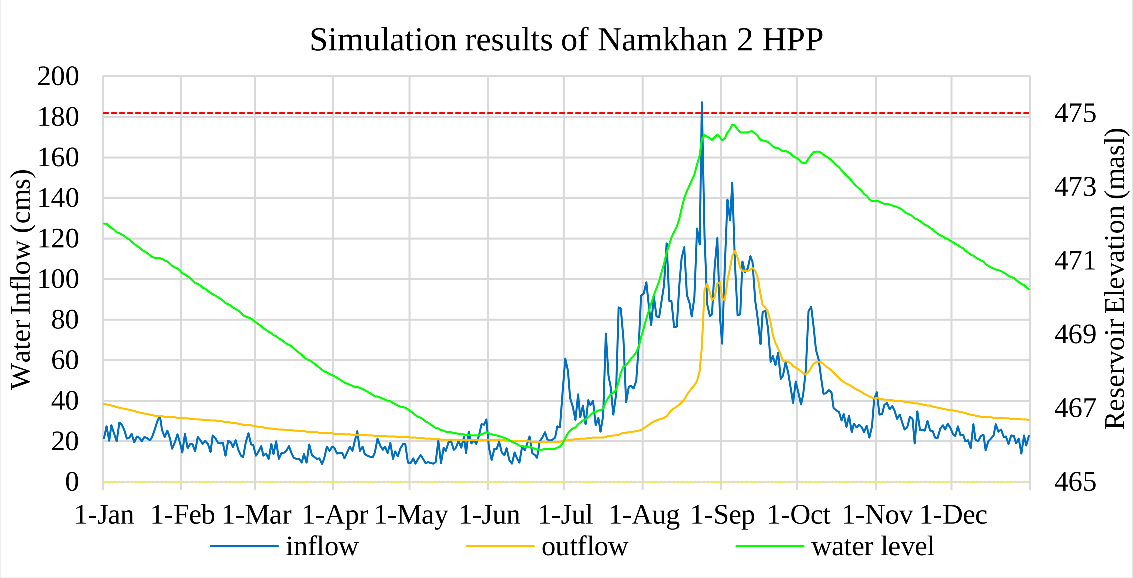

Figure 5.8 Reservoir operation relationship of Namkhan 2 HPP in average dry year case.

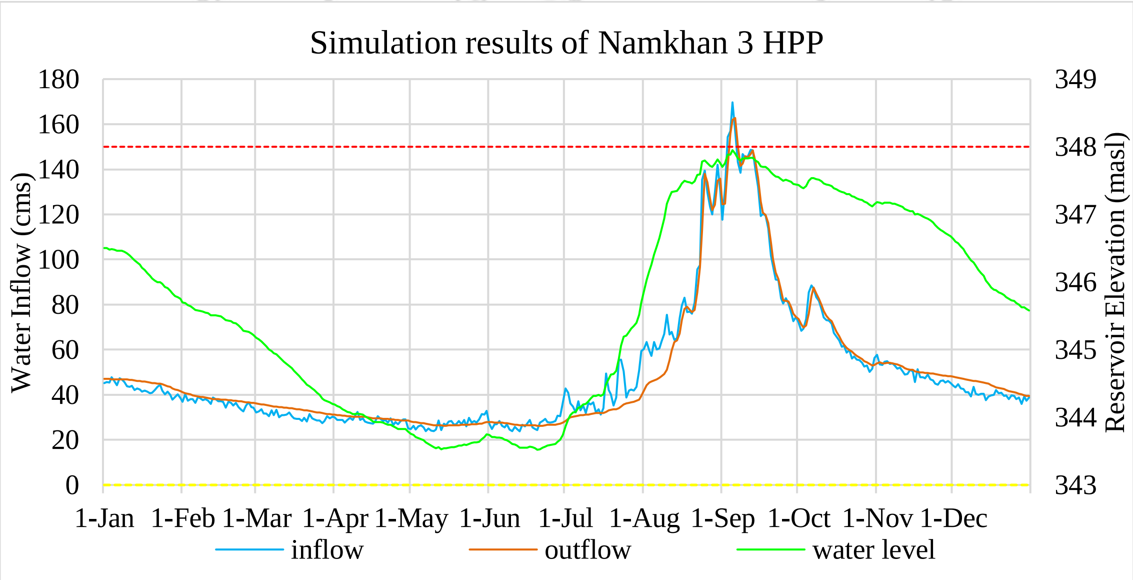

Figure 5.9 Reservoir operation relationship of Namkhan 3 HPP in average dry year case.

5.3 Simulation results of normal water criterion year (Normal year)

Simulation model of normal water criterion is one of all cases, which will be analyzed and revised the operation model for several factors. The target is to find the oppropriate model for optimizing reservoir operation. Water inflow is main parameter for using in the simulation model. It is an variable of many variables, which used in HEC-ResSim3.1 software to find the optimal operation curve in the WCLR case. These results from simulation model will be revised by using optimization technique, which modified the upper and lower role curve for the appropriately reservoir operation. The optimization technique for reservoir management is to define the parameters that relate with operation system. The results after using optimization technique is shown the energy difference and water released volume from spillway, which shown in table 3 for normal year case. The table 3 is shown that operation volume of before-after revised for the simulation model. The optimization technique is to revise by defining the power production capacity and energy generation schedules for reservoir management of each hydropower plants.

Table 5.3 Energy generation for before-after revised of NWC case

Month	**Energy generation of Namkan 2 HPP (KWh)**			**Energy generation of Namkan 3 HPP (KWh)**		
	Before revised	After revised	Difference	Before revised	After revised	Difference
January	26,614,800	29,322,240	2,707,440	12,195,888	13,270,728	1,074,840
February	22,172,400	22,616,400	444,000	10,090,488	9,951,552	-138,936
March	20,678,640	20,114,160	-564,480	9,484,056	9,233,808	-250,248
April	16,268,640	16,306,320	37,680	7,538,688	7,762,944	224,256
May	15,453,120	22,048,800	6,595,680	7,402,512	8,467,632	1,065,120
June	22,506,960	47,553,840	25,046,880	12,583,248	23,250,072	10,666,824
July	67,544,640	48,253,920	-19,290,720	34,037,904	29,584,176	-4,453,728
August	96,720,000	96,720,000	0	44,640,000	44,640,000	0
September	93,600,000	93,600,000	0	43,200,000	43,200,000	0
October	66,744,960	77,427,360	10,682,400	33,180,456	36,364,080	3,183,624
November	38,326,080	34,512,480	-3,813,600	18,255,024	17,314,152	-940,872
December	33,051,600	29,343,840	-3,707,760	15,565,080	14,237,208	-1,327,872
Total	**519,681,840**	**537,819,360**	**18,137,520**	**248,173,344**	**257,276,352**	**9,103,008**

From the above table is described the energy difference in each months. In NWC case, Specially in July for energy generation after revised is less than energy generation of before revised operational model. Because in May and June is produced maximum energy to prepare the reservoir area for water storage in the rainy season. Furthermore, energy generation on August and September is not energy difference of before-after operation revised. Due, this periods is maximum production of full installed capacity.

However, energy generation of each months have difference, which were shown in figure 5.10 and 5.11 for Namkhan 2 and 3 hydropower plants respectively.

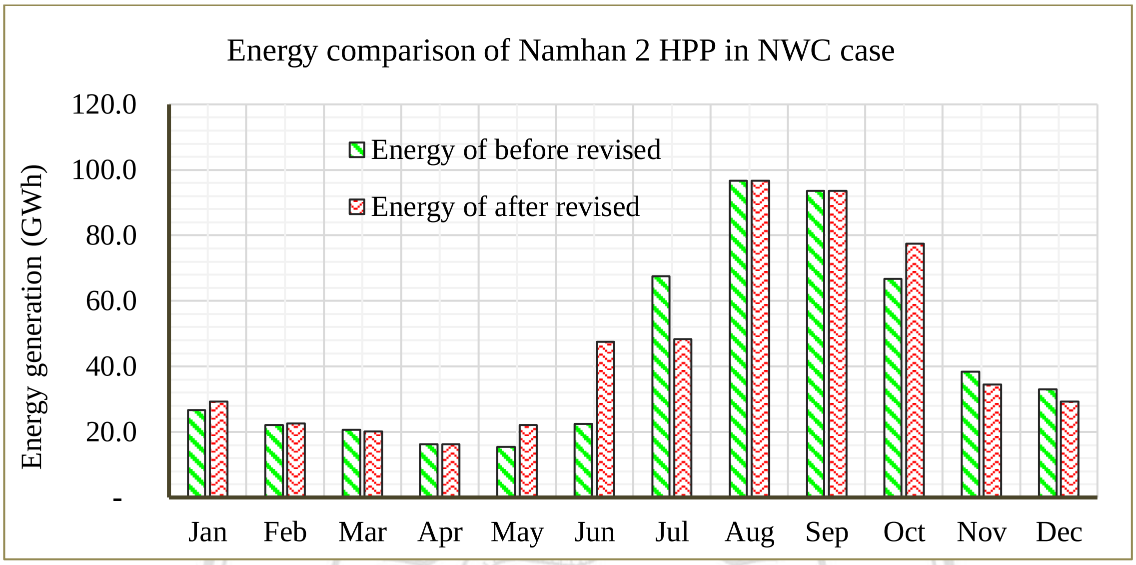

Figure 5.10 Energy comparison for before–after revised of Namkhan 2 HPP.

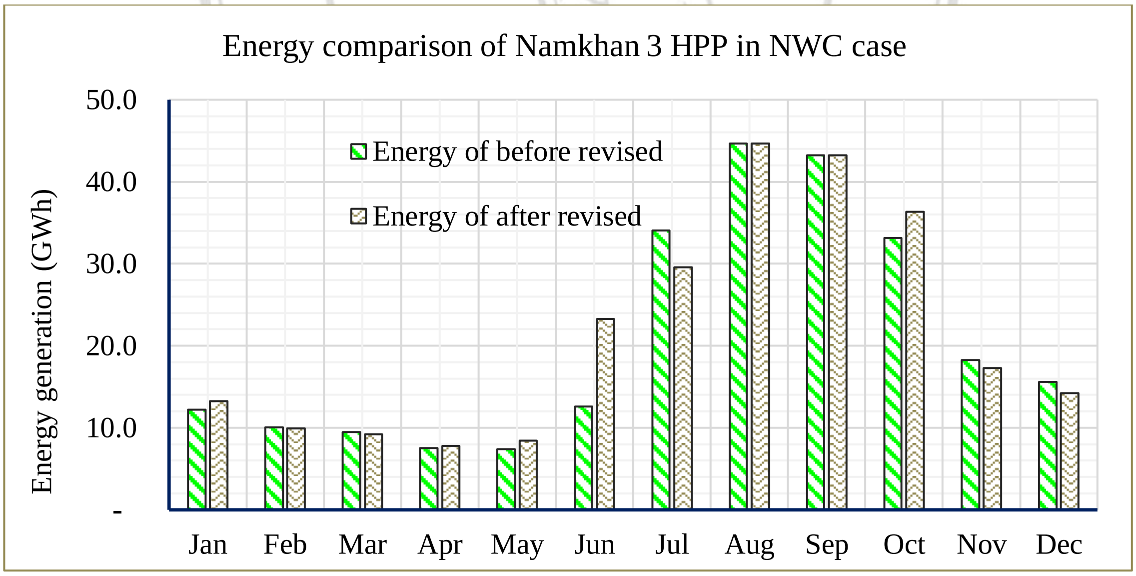

Figure 5.11 Energy comparison for before–after revised of Namkhan 3 HPP.

Simulation results of reservoir operation are shown in figure 5.12 and 5.13 of Namkhan 2 and 3 hydropower plants respectively, in average normal year case. That shows the relationship between the reservoir elevation, water inflow and water release after using optimization technique for optimizing the reservoir operational management.

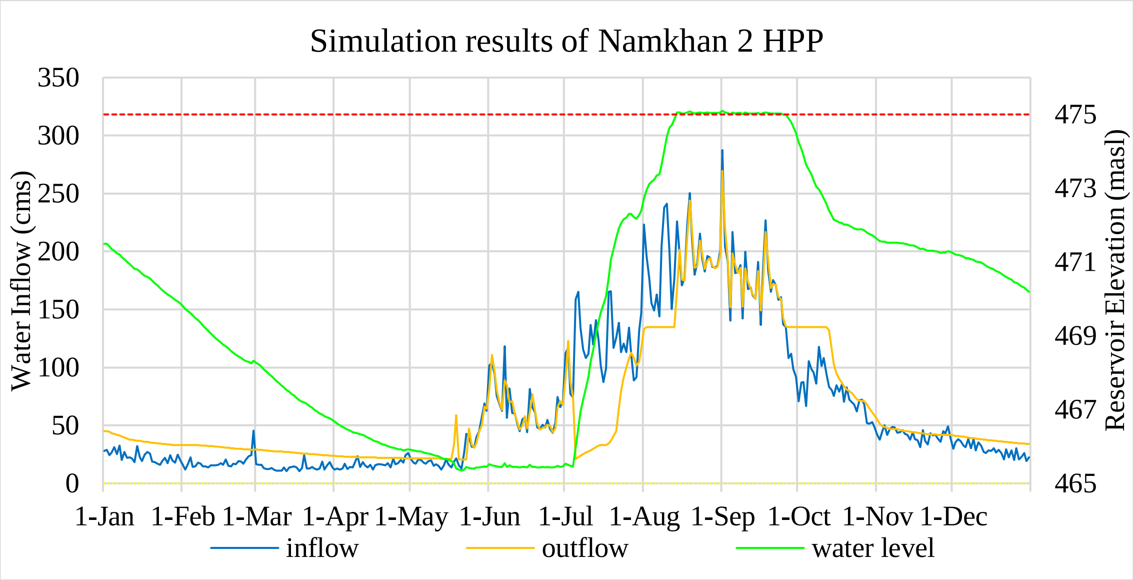

Figure 5.12 Reservoir operation relationship of Namkhan 2 HPP in normal year case.

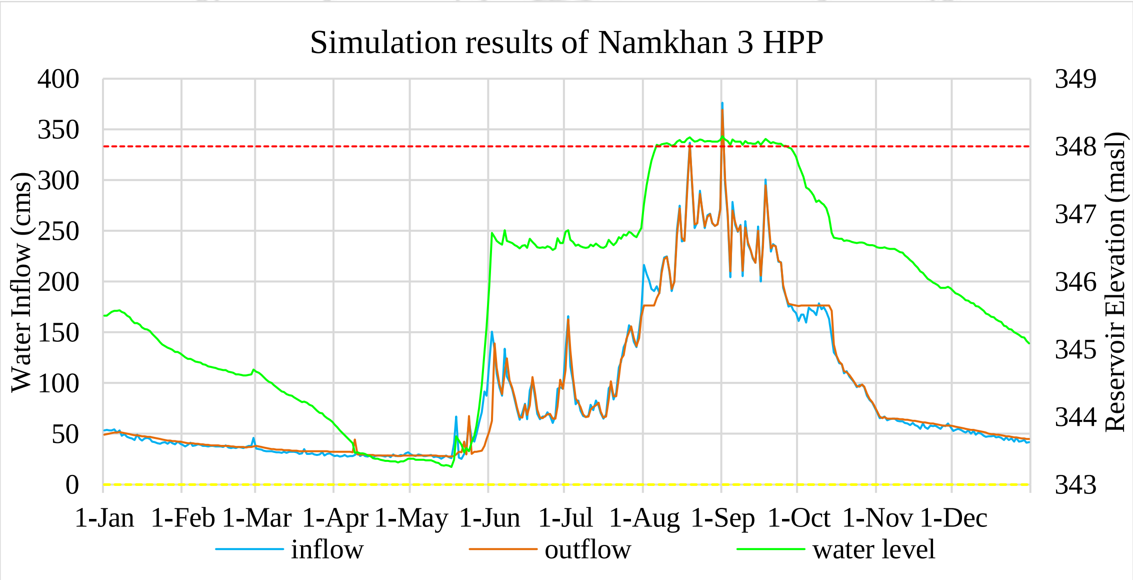

Figure 5.13 Reservoir operation relationship of Namkhan 3 HPP in normal year case.

5.4 Simulation Results of Water Criterion that Very Rather (Average wet year)

Simulation model of water criterion that very rather is one of all cases, which will be analyzed and revised the operation model for several factors to find the oppropriately model. Data used in the simulation model is technical data of Namkhan 2 and 3 HPP. Water inflow is an variable of all varibles for using in simulation model. The HEC-ResSim3.1 software can be simulated to find the optimal operation curve. The results from simulation model will be revised the operation process to get the appropriately upper and lower role curve. The optimization technique is used for optimizing the reservoir management and electricity production. The optimization methodology is to modify by defining power production capacity and energy generation schedules of electricity production of each hydropower plants. The results after using optimization technique is shown the volume difference of energy generation and water released volume through spillway. Table 5.4 shown the energy generate difference for before-after revised the operation process of Namkhan 2 and 3 hydropower plants.

Table 5.4 Energy generation for before-after revised of WCVR case

Month	Energy generation of Namkan 2 HPP (KWh)			Energy generation of Namkan 3 HPP (KWh)		
	Before revised	**After revised**	**Difference**	**Before revised**	**After revised**	**Difference**
January	29,733,120	33,297,600	3,564,480	14,803,800	15,265,032	461,232
February	22,995,360	22,764,480	-230,880	10,524,672	10,591,560	66,888
March	22,914,480	22,656,720	-257,760	9,992,376	10,504,584	512,208
April	19,273,440	21,210,720	1,937,280	8,947,608	9,584,232	636,624
May	17,148,000	25,735,200	8,587,200	8,348,712	11,673,384	3,324,672
June	22,156,800	45,446,880	23,290,080	12,658,920	18,917,520	6,258,600
July	81,984,000	70,584,000	-11,400,000	39,835,968	38,936,184	-899,784
August	96,720,000	96,720,000	0	44,640,000	44,640,000	0
September	93,600,000	93,600,000	0	43,200,000	43,200,000	0
October	90,935,280	96,720,000	5,784,720	42,740,136	44,640,000	1,899,864
November	56,705,520	57,850,320	1,144,800	28,067,352	28,196,064	128,712
December	40,780,800	36,743,280	-4,037,520	19,507,992	18,092,856	-1,415,136
Total	**594,946,800**	**623,329,200**	**28,382,400**	**283,267,536**	**294,241,416**	**10,973,880**

From the above table is described the difference of energy generation in each months. Specially, energy generation of after revised in July is less than energy generation of before revised. Because, in May and June is maximum electricity production to prepare the reservoir area for water storage in the rainy season, which cause the energy of after revised less than before revised. The energy generation in August and September is not different for the electricity production. Because, this periods is same maximum for electricity production of full installed capacity. However, mostly energy generation of each month have difference, which are shown in figure 5.14 and 5.15 of the Namkhan 2 and 3 hydropower plants respectively.

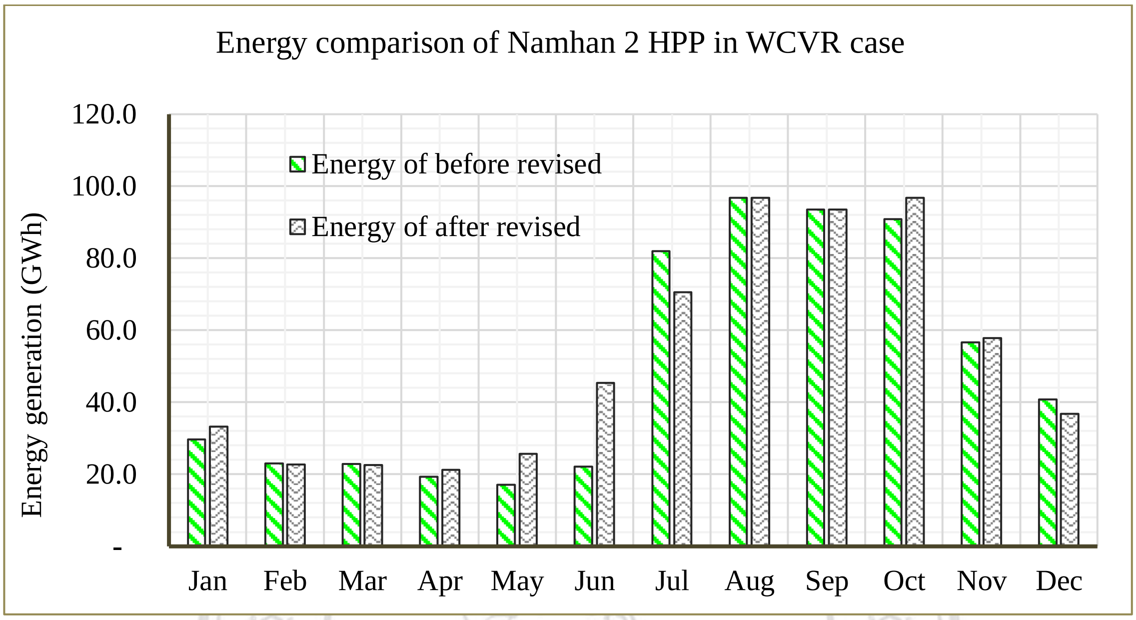

Figure 5.14 Energy comparison for before–after revised of Namkhan 2 hydropower plant.

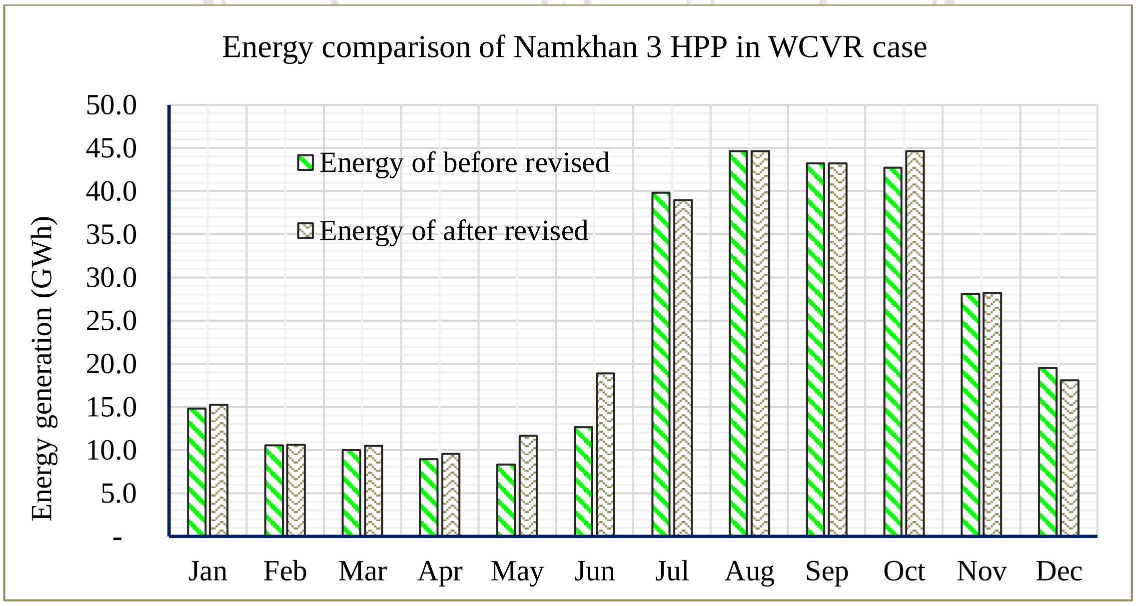

Figure 5.15 Energy comparison for before–after revised of Namkhan 3 hydropower plant.

Simulation results of reservoir operation are shown in Figure 5.16 and 5.17 of Namkhan 2 and 3 hydropower plants respectively, in average wet year case. That shows the relationship between the reservoir elevation, water inflow and water release after using optimization technique for optimizing the reservoir operational management.

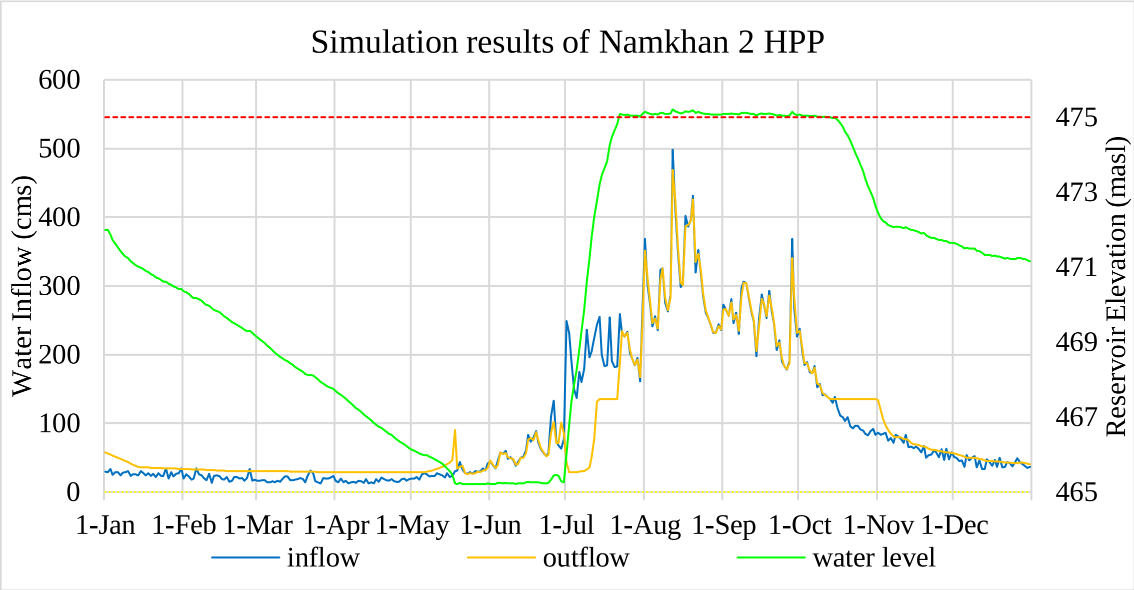

Figure 5.16 Reservoir operation relationship of Namkhan 2 HPP in average wet year case.

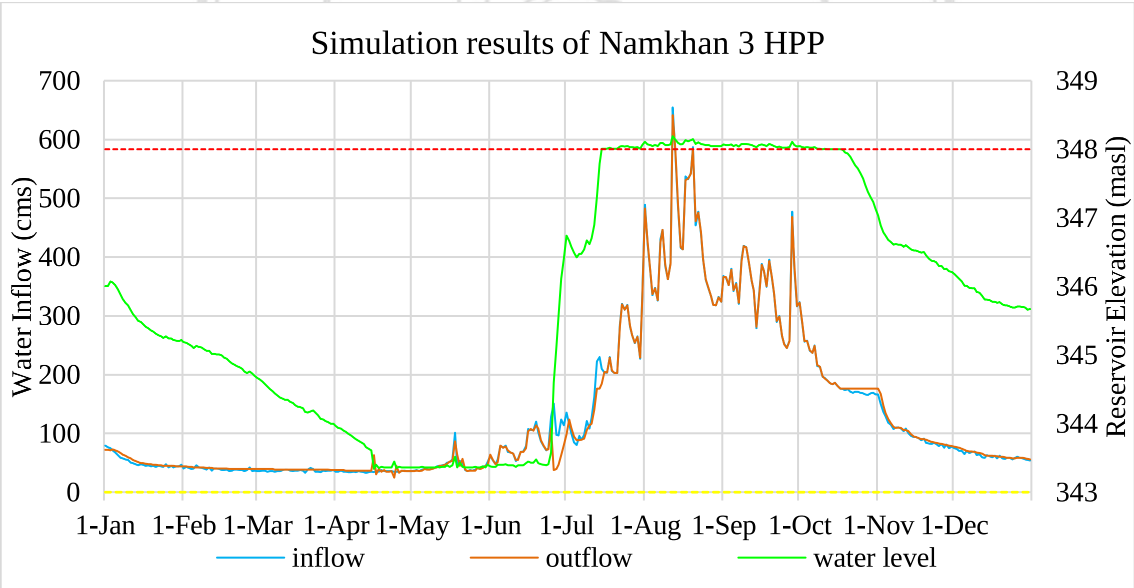

Figure 5.17 Reservoir operation relationship of Namkhan 3 HPP in average wet year case.

5.5 Simulation Results of Very Water Criterion (Wet year)

Simulation model of very water criterion is one of all cases, which will be analyzed and revised the operation model for several factors to find the oppropriately model. Data used in the simulation model is technical data of Namkhan 2 and 3 HPP. Water inflow is an variable of all varibles for using in simulation model. The HEC-ResSim3.1 software can be simulated to find the optimal operation curve. The results from simulation model will be revised the operation process to get the appropriately upper and lower role curve. The optimization technique is used for optimizing the reservoir management and electricity production. The optimization methodology is to modify by defining power production capacity and energy generation schedules of electricity production of each hydropower plants. The results after using optimization technique is shown the volume difference of energy generation and water released volume through spillway. Table 5.5 shown the energy generate difference for before-after revised the operation process of Namkhan 2 and 3 hydropower plants.

Table 5.5 Energy generation for before-after revised of VWC case

Month	**Energy generation of Namkan 2 HPP (KWh)**			**Energy generation of Namkan 3 HPP (KWh)**		
	Before revised	**After revised**	**Difference**	**Before revised**	**After revised**	**Difference**
January	26,465,520	34,790,160	8,324,640	14,724,792	15,841,440	1,116,648
February	21,613,680	22,963,440	1,349,760	9,746,952	10,352,352	605,400
March	22,133,520	22,844,400	710,880	9,602,424	9,710,280	107,856
April	14,438,880	17,374,560	2,935,680	7,014,456	7,913,376	898,920
May	13,272,720	18,545,280	5,272,560	6,461,472	8,689,680	2,228,208
June	23,106,480	48,999,360	25,892,880	13,820,568	24,010,104	10,189,536
July	92,575,440	83,510,160	-9,065,280	43,903,800	43,843,440	-60,360
August	96,720,000	96,720,000	0	44,640,000	44,640,000	0
September	93,600,000	93,600,000	0	43,200,000	43,200,000	0
October	83,522,160	93,899,520	10,377,360	39,719,088	43,575,264	3,856,176
November	62,610,720	61,103,520	-1,507,200	30,606,216	29,989,944	-616,272
December	46,921,680	41,893,200	-5,028,480	22,764,240	20,730,240	-2,034,000
Total	**596,980,800**	**636,243,600**	**39,262,800**	**286,204,008**	**302,496,120**	**16,292,112**

From the above table is described the difference of energy generation in each months. Specially, energy generation of after revised in July is less than energy generated of before revised. Due, electricity production in May and June is maximum to prepare the reservoir area for water storage in the rainy season. The energy generation on August and September is not difference for energy generation of before-after revised. Because, this periods is maximum production of full installed capacity. However, mostly energy generation of each months have difference, which are shown in figure 5.18 and 5.19 for the energy comparison of Namkhan 2 and 3 hydropower plants respectively.

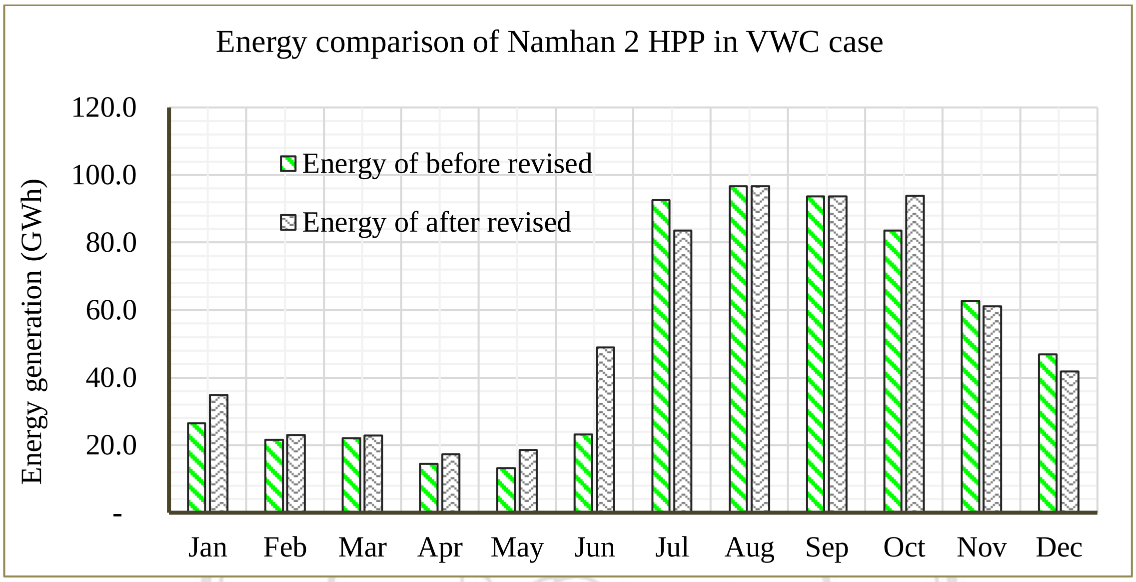

Figure 5.18 Energy comparison for before–after revised of Namkhan 2 hydropower plant.

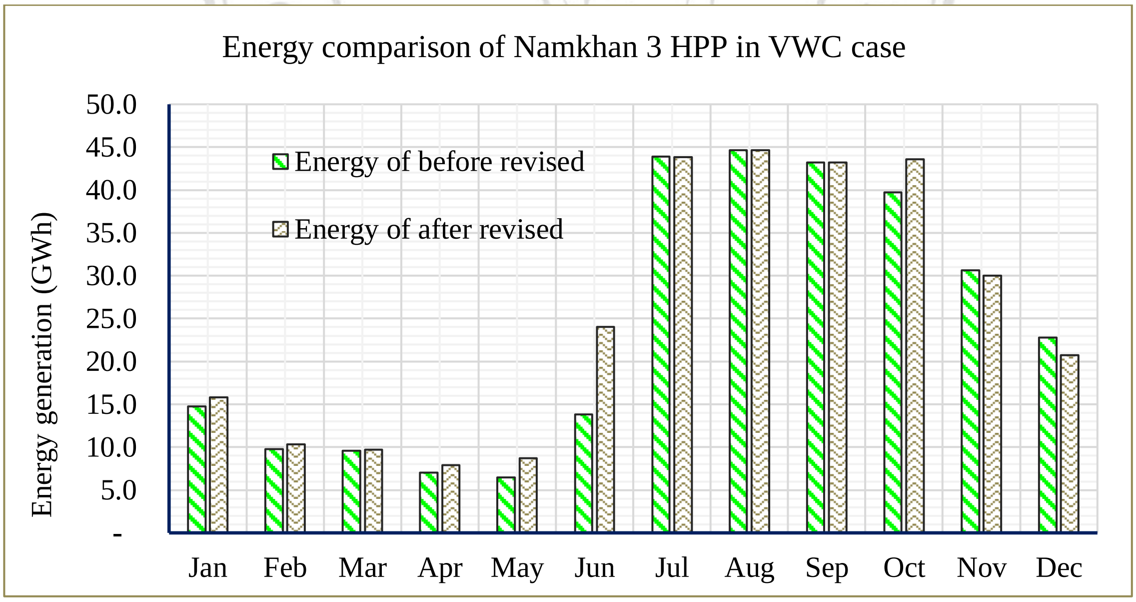

Figure 5.19 Energy comparison for before–after revised of Namkhan 3 hydropower plant.

Simulation results of reservoir operation are shown in Figure 5.20 and 5.21 of Namkhan 2 and 3 hydropower plants respectively, in wet year case. That shows the relationship between the reservoir elevation, water inflow and water release after using optimization technique for optimizing the reservoir operational management.

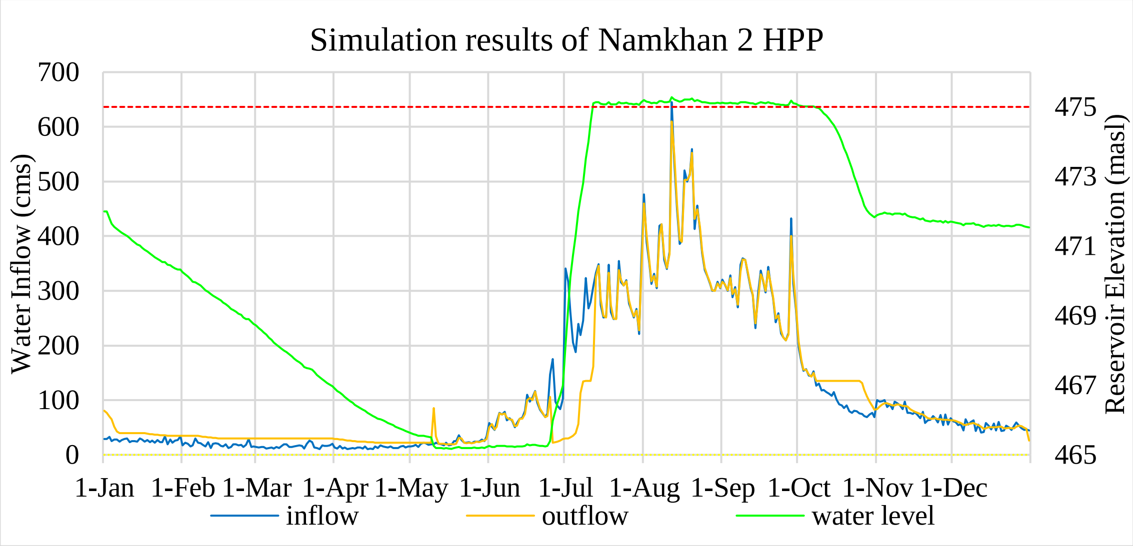

Figure 5.20 Reservoir operation relationship of Namkhan 2 HPP in wet year case.

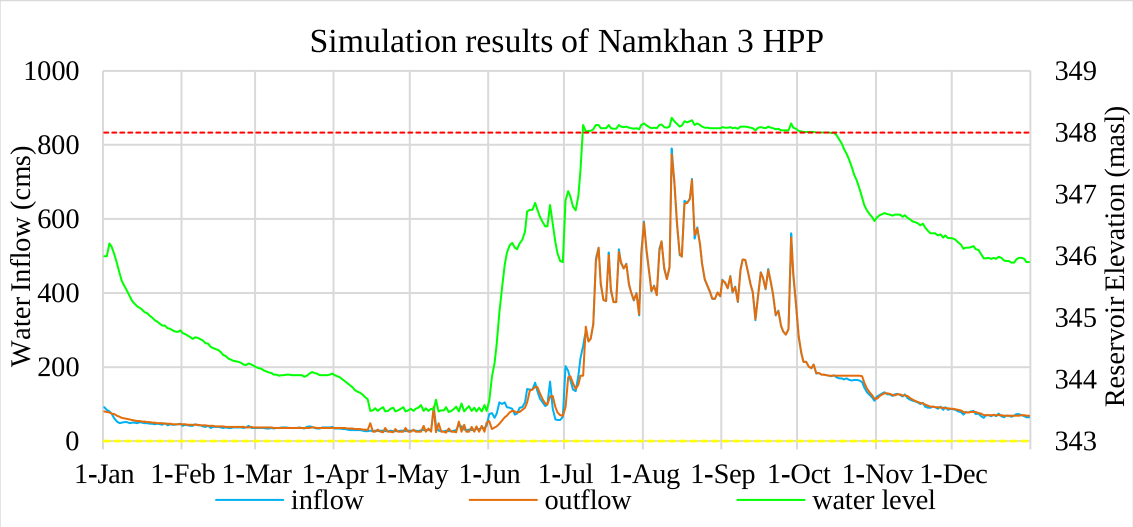

Figure 5.21 Reservoir operation relationship of Namkhan 3 HPP in wet year case.

5.6 Evaluation of simulation results after revised by using optimization technique

5.6.1 Energy generation and water release volume of LWC

Simulation rults of after revised shown that energy generation increased in the dry year. The energy generation of Namkhan 2 HPP increased from 253,156,104 KWh to 255,544,296 KWh, which increased 2,388,192 KWh per year. The energy generation of Namkan 3 HPP increased from 125,366,712 KWh to 126,531,024 KWh, which increased 1,164,312 KWh per year. Total energy generation increased 3,652,504 KWh for both hydropower plants.

5.6.2 Energy generation and water release volume of WCLR

Simulation rults of after revised shown that energy generation increased in the average dry year. the energy generation of Namkhan 2 HPP increased from 334,774,080 KWh to 337,512,480 KWh, which increased 2,738,400 KWh per year. The energy generation of Namkan 3 HPP increased from 165,333,696 KWh to 166,580,160 KWh, which increased 1,246,464 KWh per year. Total energy generation increased is 3,984,864 KWh per year of both hydropower plants.

5.6.3 Energy generation and water release volume of NWC

Simulation rults of after revised can be decreased the water release through spillway from 175,964,486 m^3 to 139,913,136 m^3, which decreased 36,051,350 m^3 per year of Namkhan 2 HPP. Namkhan 3 HPP can be decreased the water release through spillway from 349,411,968 m^3 to 294,562,656 m^3, which decreased 54,849,312 m^3 per year. Total energy generation increased from 767,855,184 KWh to 795,095,712 KWh, which increased 27,240,528 KWh per year of both hydropower plants.

5.6.4 Energy generation and water release volume of WCVR

Simulation rults of after revised can be decreased the water release throgh spillway from 628,471,008 m^3 to 577,421,568 m^3, which decreased 51,049,440 m^3 per year of Namkhan 2 HPP. Namkhan 3 HPP can be decreased the water release through spillway from 1,342,790,784 m^3 to 1,253,853,216 m^3, which decreased 88,937,568 m^3 per year. Total energy generation increased from 878,214,336 KWh to 917,570,616 KWh, which increased 39,356,280 KWh per year of both hydropower plants.

5.6.5 Energy generation and water release volume of VWC

Simulation rults of after revised can be decreased the water release through spillway from 924,002,208 m^3 to 859,962,528 m^3, which decreased 64,039,680 m^3 per year of Namkhan 2 HPP. Namkhan 3 HPP can be decreased the water release through spillway from 2,039,543,712 m^3 to 1,899,307,008 m^3, which decreased 140,236,704 m^3 per year. Total energy generation of both hydropower plants increased from 883,184,808 KWh to 938,739,720 KWh, which increased 55,554,912 KWh per year.

5.7 Comparison Results after Revised by Optimization Technique

5.7.1 Reservoir elevation of results after revised by optimization

The simulation results after using the optimization technique are shown in figure 5.22 and 5.23 of Namkhan 2 and 3 hydropower plants, respectively. it shown the relationship between the reservoir elevation and water release of the after revised by using optimization technique. The figure is consisted the flood control line, inactive line, upper rule curve (URC), lower rule curve (LRC), and the reservoir elevation (masl) and water release line(cms), which have included the five cases.

For each lines are explained as below:

- The cyan line is the very watery criterion of the reservoir operation.
- The blue line is the watery criterion that very rather of the reservoir operation.
- The yellow line is the average normal criterion of the reservoir operation.
- The green line is the watery criterion that little rather of the reservoir operation.
- The red line is the little watery criterion of the reservoir operation.

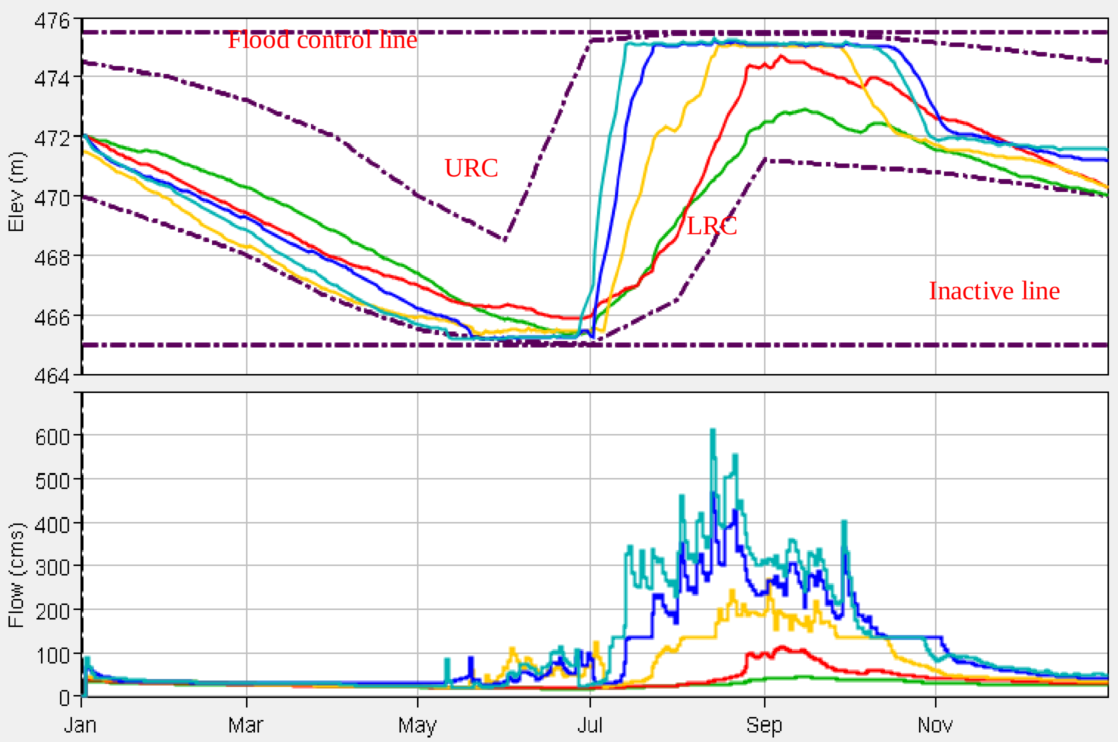

Figure 5.22 Reservoir elevation and water discharge of Namkhan 2 HPP.

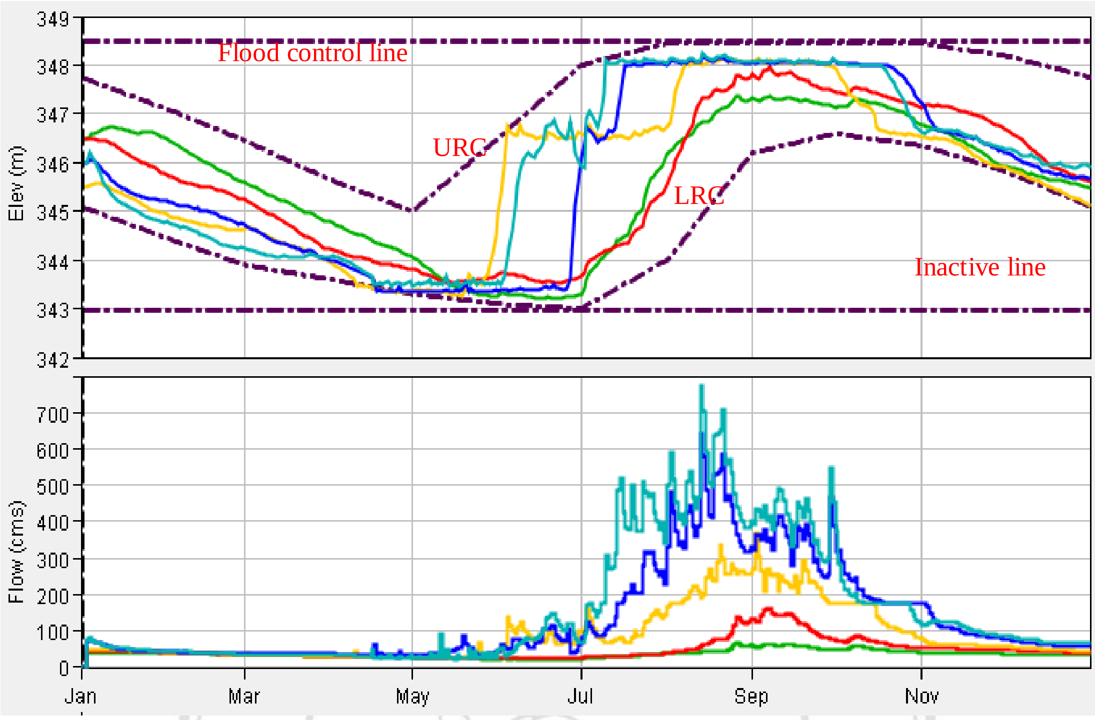

Figure 5.23 Reservoir elevation and water discharge of Namkhan 3 HPP.

5.7.2 Comparison of upper and lower cuvre after revised to appropriate

Upper and lower rule curve or called operation curve is defined to manage the operation limit of reservoir. The better operating curve will be helped for optimal electricity production and sustainable reservoir management. The best operation can be supplied all constraints of the demands such as: to meet the water and energy for whole year and to protect the impact from the hydropower plant operation.

After, simulation of several cases was shown the old operation curve, which is not appropriate for reservoir operation of Namkhan 2 and 3 HPPs. Because during rainy season of wet year must released the a lot of water through spillway.

Differently during the dry season of dry year can not supplied enough for the water and energy demand. The several parameter get from simulation model such as: energy generation, water release, reservoir elevation and water storage, which indicated the capability for improving operation curve to appropriate with our operation.

The comparison between the old operation curve and new operation curve are show in figure 5.24 and 5.25 for Namkhan 2 and 3 HPP respectively.

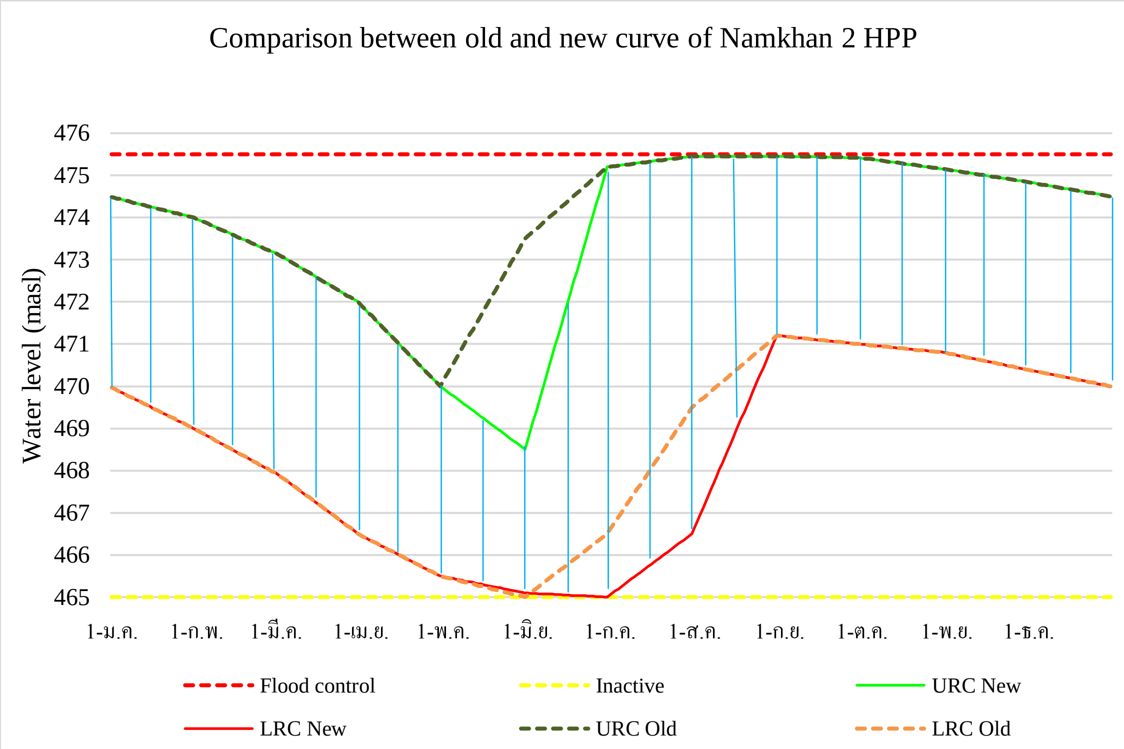

Figure 5.24 Comparison between old and new curve of Namkhan 2 HPP.

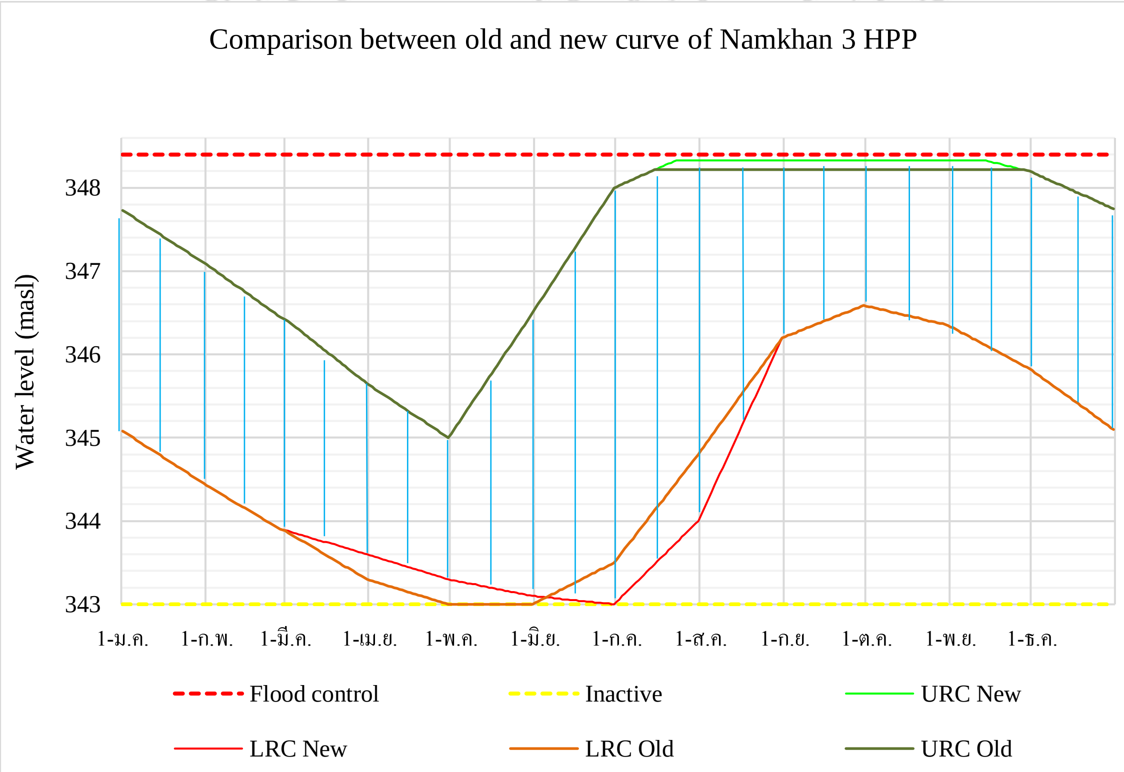

Figure 5.25 Comparison between old and new curve of Namkhan 3 HPP.