CHAPTER 4

Optimization Technique of Reservoir Operation Management

4.1 Concept

The optimization of any work operating is make better than the original works. Mean that: optimizing is a making the yield greater than first, operating that benefit greater than original or decreasing the impact from the works operation. Throughout is a decreasing cost of the production process but the yield is an equaty in first or greater. Conclusion, the concept optimization is an optimizing of the operation, which can be saving the resource, cost, time but yield greater of the operations. These is the development process from the original process to change the new process to conformity with the operating optimization.

Techniques application for the reservoir operation is making an appropriate operation of each cases or locations. This research is the multi-reservoir operation management to optimum the electricity production, which use the optimization technique in two methods. First method is a determination the power generation of the generators in the each period, which will define the minimum to maximum of the power installation of each hydropower plants. Second method is a determination the time of the energy generation in each days. Specially, on the dry season or the energy demand during the peak load such as: the summer season in every year during 17h:00-22h:00 in each day. The details of operation process is analyzed and explained in the below of this chapter for the optimizing in the reservoir management to greater benefit.

4.2 Physical Data for Using in the Optimization Model

4.2.1 Water inflow into reservoir management

In the basic designed data of Namkhan 2 and 3 hydropower projects before the construction. The projects were collected the historical data that analyze to find the water inflow, water outflow, power output production(MW), and energy production data

(GWh) since 1960-2009. These data were divided into the five case as: wet case, average wet case, average normal case, average drought case, and drought case. In which the water inflow of both dams are the main data that use to analyze of simulation model. For dividing of the each flow case, it was defined by standard of Namkhan 2 hydropower plant, which have the detail as below:

- Average rainfall more than 100 cubic meter per year or 150% of average water inflow was called the very watery criterion (VWC).
- Average rainfall more than 80-100 cubic meter per year or 120% of average water inflow was called the watery criterion that very rather (WCVR).
- Average rainfall more than 60-80 cubic meter per year or 90% of average water inflow was called the normal watery criterion (NWC).
- Average rainfall during 40-60 cubic meter per year or 60% of average water inflow was called the watery criterion that little rather (WCLR).
- Average rainfall less than 40 cubic meter per year or 60% of average water inflow was called the little watery criterion (LWC).

The basic designed data of Namkhan 2 and 3 hydropower projects for the constructed projects, which were collected the historical data of annual and monthly average inflow reservoir discharge data (1960-2009), which were concluded in table 4.1, 4.2 of Namkhan 2 and 3 hydropower plants, respectively.

Table 4.1 Annual and monthly average inflow reservoir discharge data (1960-2009) of Namkhan 2 HPP

Watery Criterion of NK 2 HPP	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. VWC case	26.5	18.5	15.6	13.2	21.9	82.5	300.6	380.4	297.1	107.9	78.3	51.9
2. WCVR case	26.8	21.0	18.4	16.0	27.0	62.4	204.8	309.4	253.3	129.9	67.1	42.6
3. ANC case	23.0	18.0	13.8	15.5	26.1	64.9	120.8	193.0	167.5	79.0	42.0	28.8
4. WCLR case	23.2	17.7	13.7	15.3	15.7	21.5	46.1	98.0	83.4	41.8	30.2	21.9
5. LWC case	26.1	18.0	14.4	11.2	7.48	18.2	54.4	58.1	39.6	30.9	21.8	21.6

Table 4.2 Monthly average inflow reservoir discharge data of Namkhan 3 HPP

Watery Criterion	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. VWC case	36.4	25.4	21.5	18.2	30.1	113.1	412.7	522.2	407.9	148.2	107.5	71.3
2. WCVR case	36.8	28.9	25.2	22.1	37.0	85.7	281.2	424.8	347.9	178.4	92.1	58.5
3. ANC case	31.6	24.7	19.0	21.4	35.8	89.7	165.0	264.9	229.7	108.4	57.6	39.4
4. WCLR case	31.9	24.4	18.8	21.0	21.6	30.1	63.4	134.0	116.5	57.3	41.5	30.0
5. LWC case	35.9	24.8	19.8	15.5	10.2	25.0	74.7	79.8	54.4	42.4	29.9	29.7

The basic designed data of Namkhan 2 and 3 hydropower projects for the constructed projects were collected the historical data of annual and monthly average inflow reservoir discharge data (1960-2009), which were shown in figure 4.1 and 4.2 of Namkhan 2 and 3 hydropower plants, respectively.

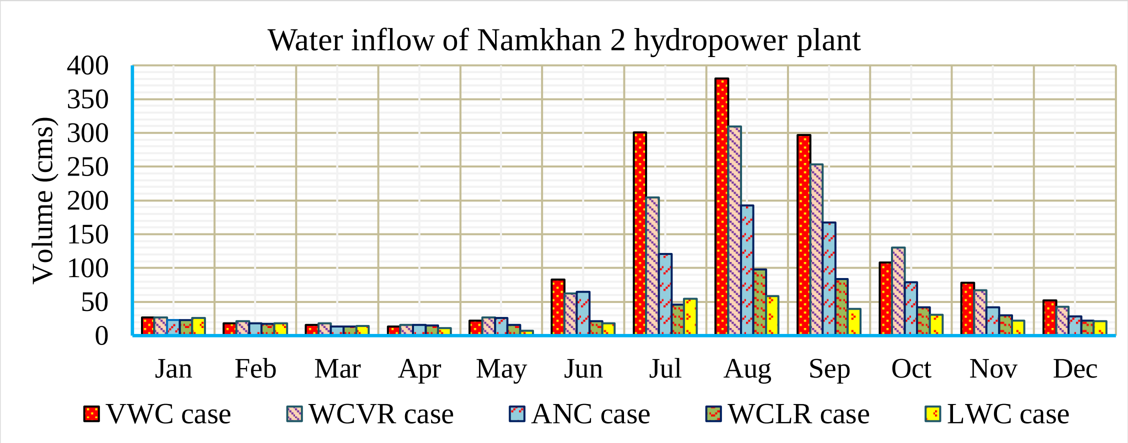

Figure 4.1 Monthly average inflow to reservoir discharge of Namkhan 2 HPP.

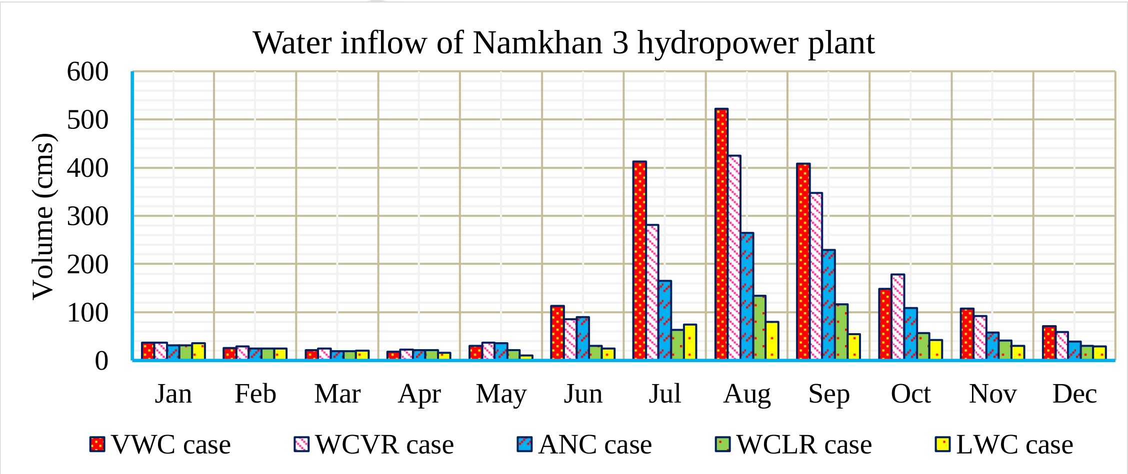

Figure 4.2 Monthly average inflow reservoir discharge of Namkhan 3 HPP.

4.2.2 Reservoir storage capacity

The Namkhan 2 and 3 hydropower plants are constructed on the same river of the Namkhan River, which the both dams have the reservoir size differently. Namkhan 2 reservoir has greater size than the Namkhan 3 reservoir, which Namkhan 2 reservoir can be storage the water capacity at 686.2 MCM(million cubic meter) and Namkhan 3 reservoir can be storages the water capacity at 224 MCM. Normal pool level of the Namkhan 2 reservoir is 475 masl(meters above sea level) and tail water level is 356 masl. Normal pool level of the Namkhan 3 reservoir is 348 masl and tail water level is 304 masl. The ratio relationship between the elevation of reservoir, water storage capacity and reservoir area of Namkhan 2 and 3 HPP were shown in table 4.3 and 4.4 respectively.

Table 4.3 Relationship of elevation, storage, and area of Namkhan 2 HPP

Elevation (masl)	Storage (MCM)	Area (ha)
370.00	0.00	0.00
380.00	1,150,000.00	5.94
390.00	2,950,000.00	15.24
400.00	6,060,000.00	31.30
410.00	10,700,000.00	55.26
420.00	19,100,000.00	98.65
430.00	37,100,000.00	191.61
440.00	89,800,000.00	463.79
450.00	216,100,000.00	1,116.09
460.00	342,500,000.00	1,768.90
465.00	457,100,000.00	2,360.77
466.00	480,010,000.00	2,479.10
467.00	502,920,000.00	2,597.42
468.00	525,830,000.00	2,715.74
469.00	548,740,000.00	2,834.06
470.00	571,750,000.00	2,952.90
471.00	594,560,000.00	3,070.71
472.00	617,410,000.00	3,188.72
473.00	640,380,000.00	3,307.35
474.00	663,290,000.00	3,425.68
475.00	686,200,000.00	3,544.00

Table 4.4 Relationship of elevation, storage, and area of Namkhan 3 HPP

Elevation (masl)	Storage (MCM)	Area (ha)
315.00	0.00	0.00
320.00	300,000.00	2.49
325.00	1,200,000.00	5.98
330.00	13,500,000.00	67.26
335.00	65,000,000.00	323.87
340.00	160,000,000.00	797.21
341.00	164,000,000.00	817.14
342.00	170,000,000.00	847.04
343.00	176,000,000.00	876.94
344.00	185,600,000.00	924.77
345.00	195,200,000.00	972.60
346.00	204,800,000.00	1,020.43
347.00	214,400,000.00	1,068.27
348.00	224,000,000.00	1,116.10

4.2.3 Reservoir evaporation net

Historical of evaporation net from the average monthly must be used to simulate software of the reservoir operation management, which was shown in table 4.5 as below. Mean monthly evaporation data for the reservoir were obtained from feasibility study of Namkhan 2 and 3 Hydropower.

Table 4.5 The reservoir evaporation net

Monthly	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Evaporation	58.5	83.6	108.4	103.2	85.7	71.5	55.3	46.5	51.8	56.0	53.4	52.6	826.1

4.2.4 Tail water data of hydropower plants

The relationship between the tail water elevation and tail water discharge is the rating curve from the basic design of Namkhan 2 and 3 HPP. These are need to use in the simulation model, which were shown in table 4.6.

Table 4.6 Tail water elevation and discharge of Namkhan 2 and 3 HPP

Namkhan 2 Hydropower plant		Namkhan 3 Hydropower plant	
Elevation (masl)	Discharge (cms)	Elevation (masl)	Discharge (cms)
350.00	0.00	304.0	0.0
355.00	30.00	304.5	50.0
355.50	60.00	305.0	70.0
356.00	80.00	305.5	100.0
356.50	110.00	306.0	170.0
357.00	134.00	306.09	176.0
357.50	270.00	307.00	262.0
358.00	540.00	308.00	504.00
359.00	1,080.00	309.00	948.00
362.00	3,240.00	310.00	1,800.00
368.56	9,974.00	314.00	5,710.00

4.2.5 Spillway discharge data of Namkhan 2 and 3 Hydropower plants

The relationship between the reservoir elevation and spillway discharge is the rating curve from the basic design of Namkhan 2 and 3 HPP. These need to use in the simulation model, which were shown in table 4.7 and 4.8 of Namkhan 2 and 3 hydropower plants, respectively.

Table 4.7 Spillway discharge data of Namkhan 2 hydropower plant

Elevation (masl)	Outflow (cms)
475.00	0.00
475.50	500.00
476.00	1,000.00
476.50	2,000.00
477.00	5,000.00
477.50	7,000.00
477.86	9,974.00

Table 4.8 Spillway discharge data of Namkhan 3 hydropower plant

Elevation (masl)	Outflow (cms)
348.00	0.00
348.50	1,000.00
349.00	2,000.00
349.50	3,000.00
350.00	5,710.00

4.2.6 Technical data of hydropower plants

The techniquecial data of hydropower plants have an importance for the ResSim simulation model, which were consisted of the installed capacity, efficiency, water using in station (station use), hydraulic losses, and limited water of discharge turbine. These are the relation together in the HEC-ResSim software or called the constraints of the program that need configured to fully conditions. For these data are shown in table 4.9 as below of Namkhan 2 and 3 hydropower plants.

Table 4.9 The technique data of power plants

Technique data of power plants	Namkhan 2 HPP	Namkhan3 HPP
Installed capacity (MW)	130	60
Efficiency (%)	97	97
Station use (cms)	1.2	1
Hydraulic losses (m)	1.1	0.4
Water discharge turbine(cms)	134	176

4.3 Methodology Process for Optimizing Operation

4.3.1 Simulation model process

Before using the optimization technique should be created the model for the simulation and analysis to find the system results such as: energy (kWh), water release from spillway, reservoir elevation (masl), and others. These results are considered to fine the appropriation of the optimal results that better or not? The operation method of optimization technique is presented in the topic 4.4 of this chapter. Figure 4.3 is shown the operation process of the simulation, which steps and method will make following this flowchart. After using the optimization technique, it should be comparable and verifyable of the results simulation to find the software accuracy, which detail will presents in the appendix C. The checking of the software accuracy will be analyzed and decided by Pearson correlation coefficient (r should be more 0.6), root mean squared error (RMES should be more 0.7), and efficiency index (EI = 0 is high reliable) of the simulation model.

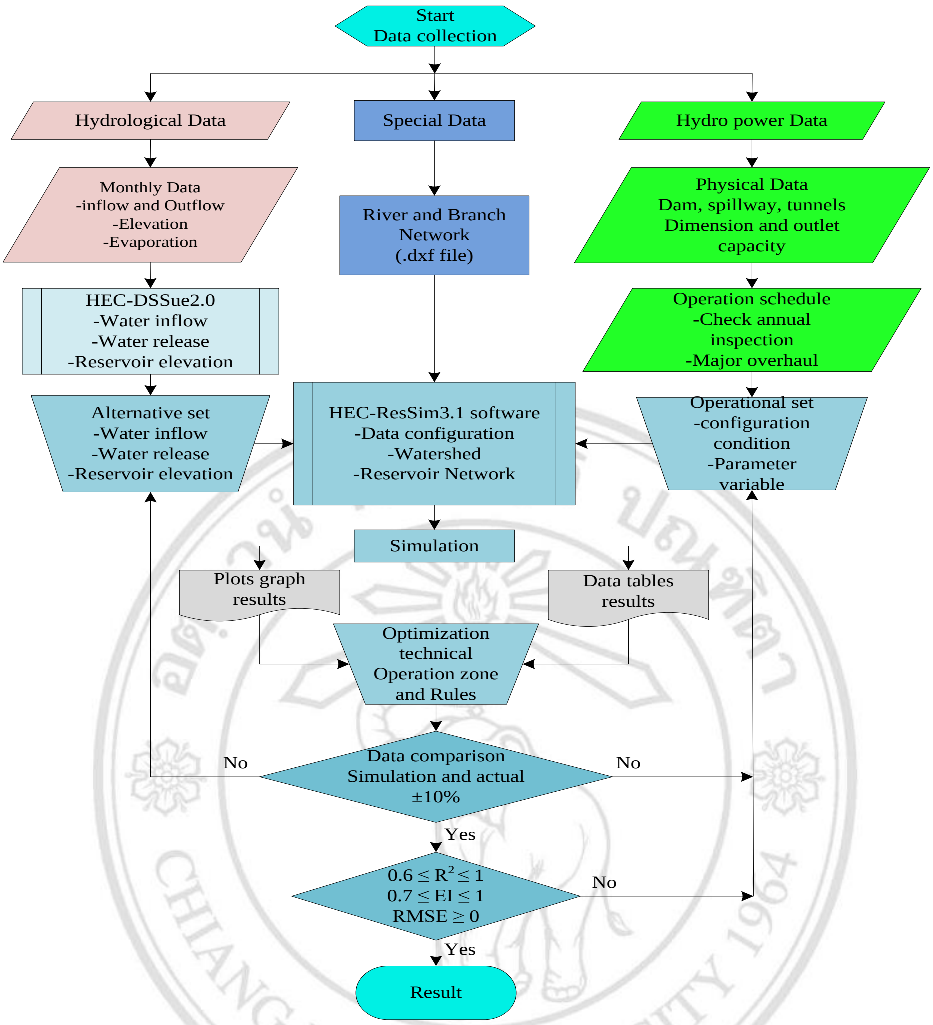

Figure 4.3 Simulation model process for operation and verify.

4.3.2 Methodology process of operating simulation

Before, operating simulation should be prepared the several data that has relationship with the simulation model. HeC-ResSim3.1 model has three sections as: watershed module, reservoir network module, and simulation module, in which each sections were described in the appendix A. The first module is the watershed setup that defines the conditions in the software module. Second module is reservoir network, which in module will defines the physical set and operational set in the network section. The creating a DSS file is the important variables because it is the main variables in the simulation model. Also, reservoir network must be configured the alternative to add the fully conditions of the software module. Third module is the simulation, which is module for determination of the simulation model case and should be defined the time-series to conformity with the DSS files data. If time series determination of the simulation model is wrong, so the software cannot simulate or compute failed. The step was shown in figure 4.4 that was divided of each sections. For simulation results will be shown the graphical and tabulate data.

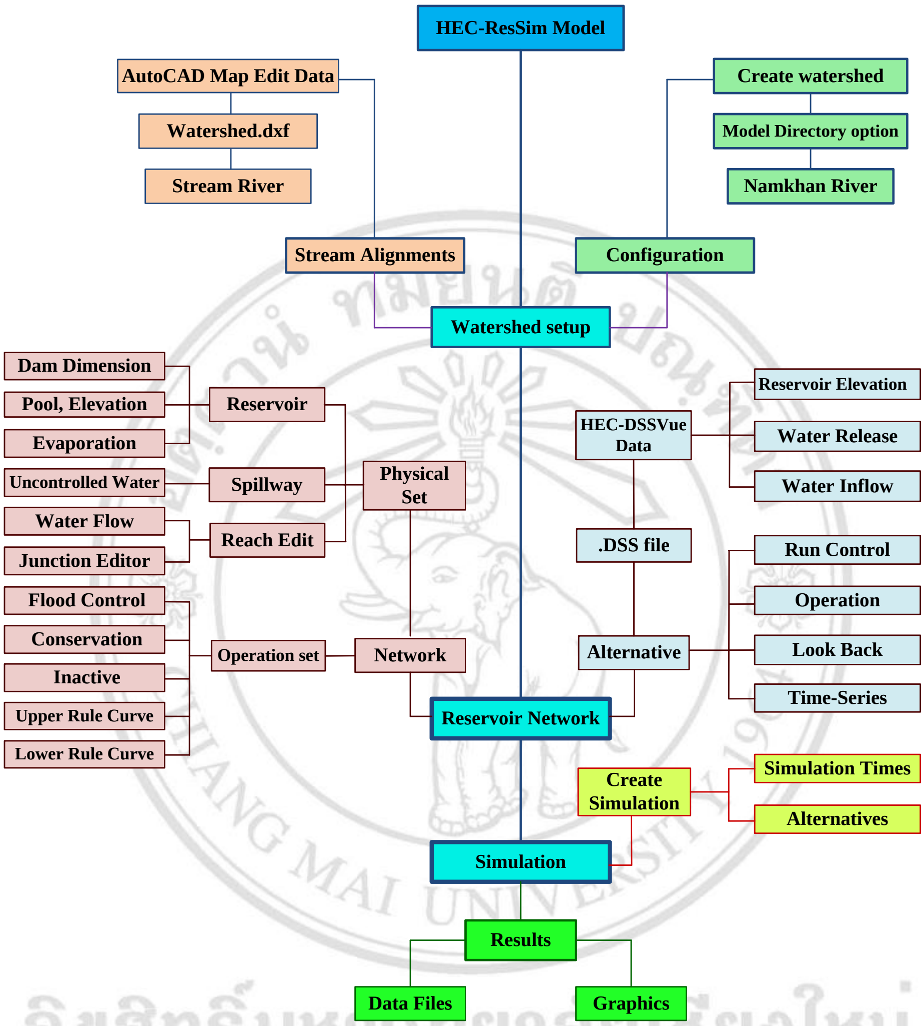

Figure 4.4 Methodology detail of operation and simulation process.

4.4 Optimization Technique of Multi-Reservoir Management

Reservoir operation management of the each watery criterion has operated differently because each case operation will have the conditions and benefits that different of demand. The objective of using the optimization technique is to optimal electricity production, to decrease the water release through spillway, to control the upstream and downstream river, to guarantee the energy supply in all year(specially in dry season), and to protect the natural disasters such as: drought and flood disaster.

Methodology process of the optimization technique for the electricity production and water management is explained the details step as below:

- Analyzed and considered the results from the simulation model to find the optimal point.
- Checking of switching rule curve (operation curve) should be in between upper rule curve(URC) and lower rule curve(LRC).
- Modified the power production that correlation with the reservoir elevation because in HEC-ResSim 3.1 used the Operate Release function until to find better value.
- Adjusted the periods for the electricity production of each month to supply the energy demand all year.
- May be revised the upper and lower rule curve to appropriate with actually operation of each reservoir.
- Concluded and compared the simulation results for before and after optimization, which various result must be under the constraints of the operation management.

4.4.1 Little watery criterion case (LWC)

Before, the model simulation should be entered the among data that relate with the software. If data entrance is wrong in the modelling as well as the model cannot simulate or run the program. Every time should be checked the all conditions of each modules in the HEC-ResSim model before the model simulation.

In which simulation results of reservoir operation were shown in figure 4.5 and 4.6 of Namkhan 2 and hydropower plants respectively in LWC case that show the relationship between the reservoir elevation and water release of before using optimization technique.

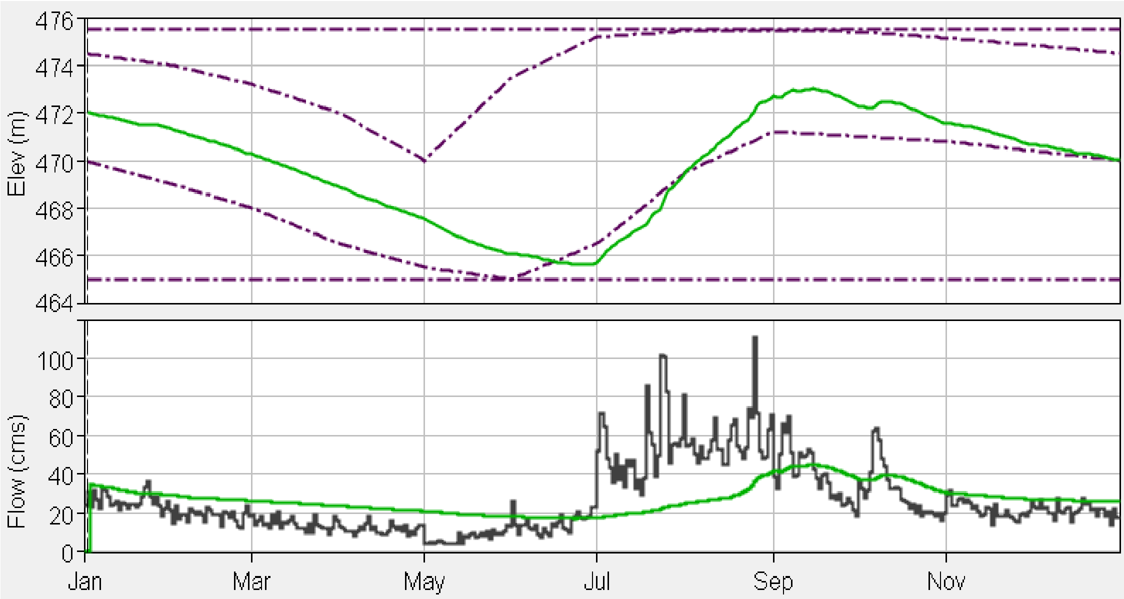

Figure 4.5 Reservoir elevation and water discharge of Namkhan 2 HPP (LWC).

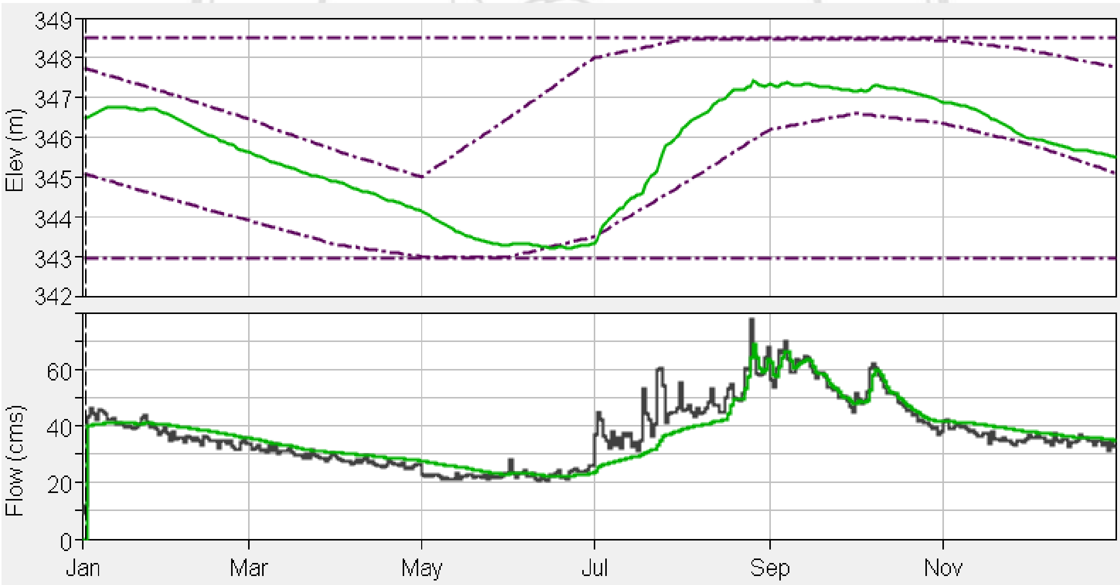

Figure 4.6 Reservoir elevation and water discharge of Namkhan 3 HPP (LWC).

In the table 4.10 was shown the power production of physical limitations for before and after modify of Namhan 2 and 3 hydropower plants in LWC case that relate between the reservoir elevation and water release before and after using optimization technique.

Table 4.10 The power production of physical limitations in LWC case

Namkhan 2 HPP			Namkhan 3 HPP		
Reservoir Elecvation	Max capacity (cms)		Reservoir Elecvation	Max capacity (cms)	
	Before	After		Before	After
465.00	15.00	15.00	343.00	20.00	20.00
466.00	18.00	19.00	343.50	25.00	26.00
467.00	20.00	21.00	344.00	27.00	28.00
468.00	22.00	23.00	344.50	29.00	30.00
469.00	24.00	25.00	345.00	31.00	33.00
470.00	26.00	26.00	345.50	35.00	35.00
471.00	28.00	28.00	346.00	38.00	38.00
472.00	35.00	35.00	346.50	40.00	40.00
473.00	45.00	45.00	347.00	42.00	44.00
474.00	60.00	60.00	347.50	80.00	80.00
475.00	135.00	135.00	348.00	176.60	176.60

In the table 4.11 and 4.12 were shown the time of power generation pattern of Namkhan 2 and 3 hydropower plants in LWC case, respectively. These tables are shown the average power generation in the each months, and time for the power generation capacity in the each day. That shows the relationship between the power generation and time of each days before and after using optimization technique.

Table 4.11 Time of power generation pattern of Namkhan 2 HPP in LWC case

Item	Simulation result before optimization			Simulation result after optimization		
Month	Average per month		Reservoir level (masl)	Average per month		Reservoir level (masl)
	Power(MW)	Hour/Day(h)		Power(MW)	Hour/Day(h)	
Jan	33.64	24.00	471.33	33.98	24.00	471.33
Feb	32.50	21.47	470.27	32.50	21.69	470.27
Mar	32.50	19.32	468.92	32.50	19.96	468.82
Apr	32.50	16.94	467.98	32.50	17.70	467.40
May	32.50	14.44	466.08	32.50	15.05	465.84
Jun	32.50	12.95	465.65	32.50	13.29	465.41
Jul	32.50	15.70	469.32	32.50	16.15	469.22
Aug	32.50	23.89	472.58	32.50	23.24	472.51
Sep	46.13	24.00	472.34	45.33	24.00	472.21
Oct	38.97	24.00	471.58	38.97	24.00	471.52
Nov	32.50	22.46	470.70	32.50	22.64	470.66
Dec	32.50	20.66	470.04	32.50	20.85	470.00

Table 4.12 Time of power generation pattern of Namkhan 3 HPP in LWC case

Item	Simulation result before optimization			Simulation result after optimization		
Month	Average per month		Reservoir level (masl)	Average per month		Reservoir level (masl)
	Power(MW)	Hour/Day(h)		Power(MW)	Hour/Day(h)	
Jan	15.77	24.00	346.60	16.02	24.00	346.49
Feb	15.00	23.25	345.64	15.00	23.33	345.6
Mar	15.00	19.56	344.90	15.00	20.26	344.79
Apr	15.00	16.96	344.17	15.00	17.53	344.07
May	15.00	14.20	343.29	15.00	14.56	343.27
Jun	15.00	12.72	343.31	15.00	13.05	343.3
Jul	15.00	18.08	346.07	15.00	18.53	346.16
Aug	18.77	24.00	347.32	18.48	24.00	347.34
Sep	22.90	24.00	347.17	22.68	24.00	347.13
Oct	19.17	24.00	346.90	19.35	24.00	346.76
Nov	15.46	24.00	346.01	15.51	24.00	345.91
Dec	15.00	22.02	345.51	15.00	22.09	345.47

4.4.2 Watery criterion that less rather(WCLR) case

Before, the model simulation should be entered the among data that relate with the software. If data is entrance wrong in the modelling as well as the model cannot simulate or run the program. Every time should be checked the all conditions of each modules in the HEC-ResSim model before the model simulation.

In which simulation results of reservoir operation were shown in figure 4.7 and 4.8 of Namkhan 2 and hydropower plants respectively in WCLR case that show the relationship between the reservoir elevation and water release of before using optimization technique.

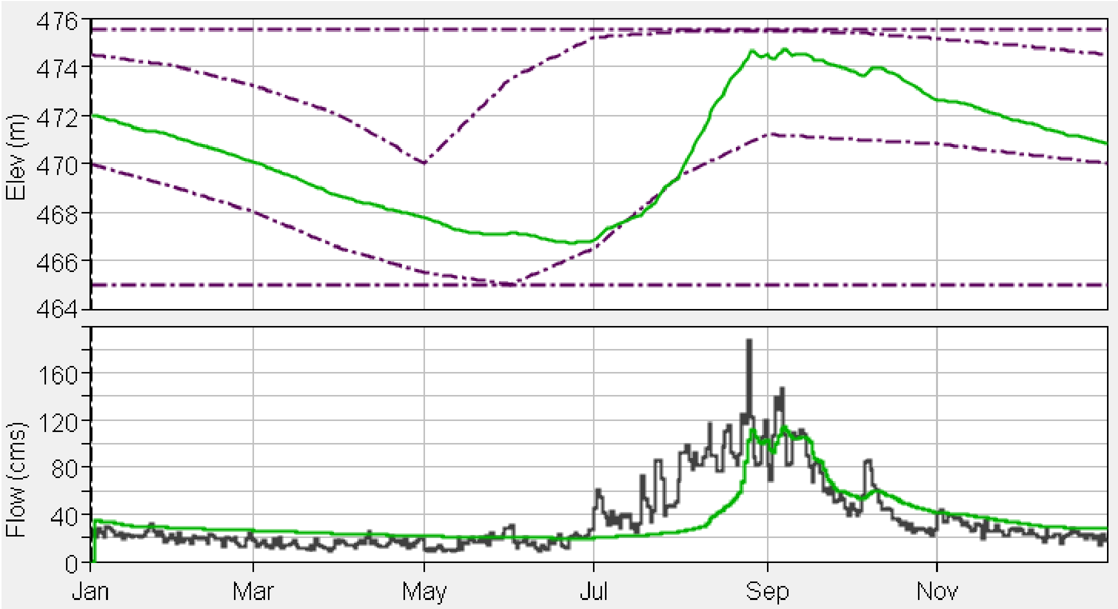

Figure 4.7 Reservoir elevation and water discharge of Namkhan 2 HPP (WCLR).

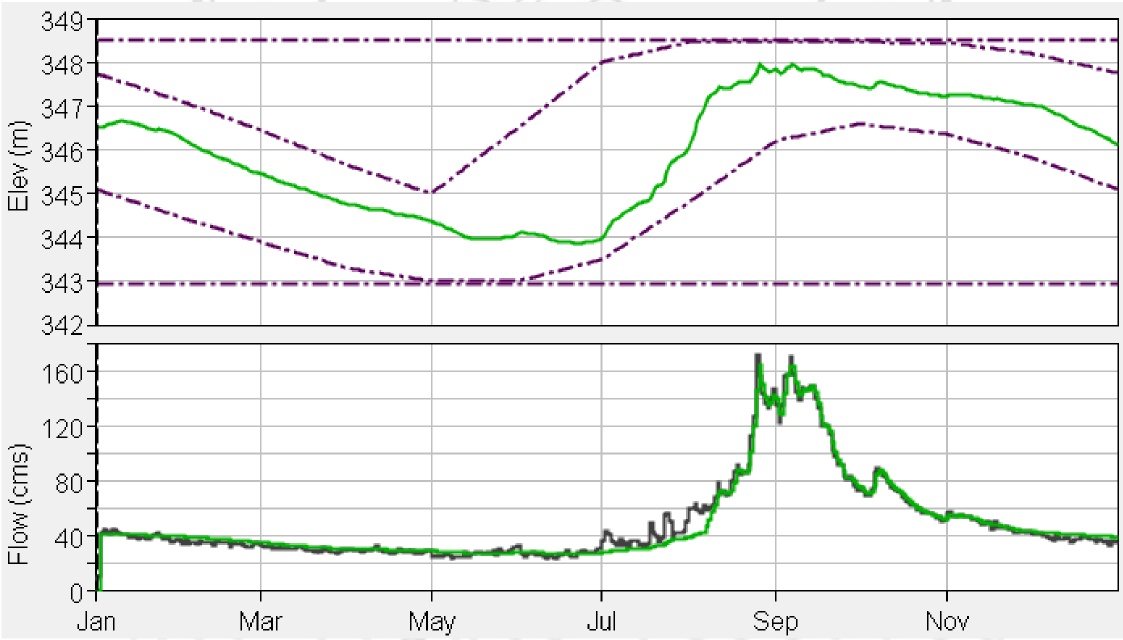

Figure 4.8 Reservoir elevation and water discharge of Namkhan 3 HPP(WCLR).

In the table 4.13 was shown the power production of physical limitations for before and after modify of Namhan 2 and 3 hydropower plants in WCLR case that relate between the reservoir elevation and water discharge(Max capacity) before and after using optimization technique.

Table 4.13 The power production of physical limitations in WCLR case

Namkhan 2 HPP			Namkhan 3 HPP		
Reservoir Elecvation	Max capacity (cms)		Reservoir Elecvation	Max capacity (cms)	
	Before	After		Before	After
465.00	15.00	16.00	343.00	20.00	24.00
466.00	18.00	20.00	343.50	25.00	26.00
467.00	20.00	22.00	344.00	27.00	30.00
468.00	22.00	24.00	344.50	29.00	33.00
469.00	24.00	26.00	345.00	31.00	35.00
470.00	26.00	30.00	345.50	35.00	38.00
471.00	28.00	32.00	346.00	38.00	45.00
472.00	35.00	38.00	346.50	40.00	47.00
473.00	45.00	45.00	347.00	42.00	50.00
474.00	60.00	60.00	347.50	80.00	80.00
475.00	135.00	135.00	348.00	176.60	176.60

In the table 4.14 and 4.15 were shown the time of power generation pattern of Namkhan 2 and 3 hydropower plants in WCLR case, respectively. These tables are shown the average power generation in the each months, and time for the power generation capacity in the each day. That shows the relationship between the power generation and time of each days before and after using optimization technique.

Table 4.14 Time of power generation pattern of Namkhan 2 HPP in WCLR case

Item	Simulation result before optimization			Simulation result after optimization		
Month	Average per month		Reservoir level (masl)	Average per month		Reservoir level (masl)
	Power(MW)	Hour/Day(h)		Power(MW)	Hour/Day(h)	
Jan	32.86	24.00	471.09	36.39	24.00	470.73
Feb	32.50	21.02	470.06	32.50	23.00	469.42
Mar	32.50	18.93	468.65	32.50	19.38	467.92
Apr	32.50	16.95	467.79	32.50	17.22	467.01
May	32.50	15.41	467.13	32.50	15.60	466.31
Jun	32.50	14.75	466.80	32.50	14.85	465.95
Jul	32.50	16.68	469.55	32.50	16.76	468.67
Aug	60.09	24.00	474.48	52.15	24.00	474.42
Sep	97.36	24.00	473.82	96.75	24.00	473.82
Oct	56.01	24.00	472.61	56.01	24.00	472.61
Nov	39.97	24.00	471.74	41.49	24.00	471.58
Dec	32.50	22.81	470.80	34.09	24.00	470.28

Table 4.15 Time of power generation pattern of Namkhan 3 HPP in WCLR case

Item	Simulation result before optimization			Simulation result after optimization		
Month	Average per month		Reservoir level (masl)	Average per month		Reservoir level (masl)
	Power(MW)	Hour/Day(h)		Power(MW)	Hour/Day(h)	
Jan	15.46	24.00	346.26	17.47	24.00	345.75
Feb	15.00	22.37	345.46	15.00	23.10	345.24
Mar	15.00	18.98	344.76	15.00	19.97	344.22
Apr	15.00	17.14	344.39	15.00	17.23	343.83
May	15.00	15.72	344.07	15.00	15.36	343.71
Jun	15.00	15.40	343.98	15.00	15.33	343.67
Jul	15.00	18.79	346.04	15.00	19.19	345.52
Aug	33.11	24.00	347.83	29.73	24.00	347.81
Sep	47.97	24.00	347.45	47.75	24.00	347.45
Oct	26.63	24.00	347.21	26.75	24.00	347.12
Nov	19.30	24.00	347.03	20.14	24.00	346.7
Dec	15.69	24.00	346.12	16.95	24.00	345.6

4.4.3 Normal watery criterion (NWC) case

Before, the model simulation should be entered the among data that relate with the software. If data entrance is wrong in the modelling as well as the model cannot simulate or run the program. Every time should be checked the all conditions of each modules in the HEC-ResSim model before the model simulation.

In which simulation results of reservoir operation were shown in figure 4.9 and 4.10 of Namkhan 2 and 3 hydropower plants respectively in NWC case that show the relationship between the reservoir elevation and water release of before using optimization technique.

Figure 4.9 Reservoir elevation and water discharge of Namkhan 2 HPP (NWC).

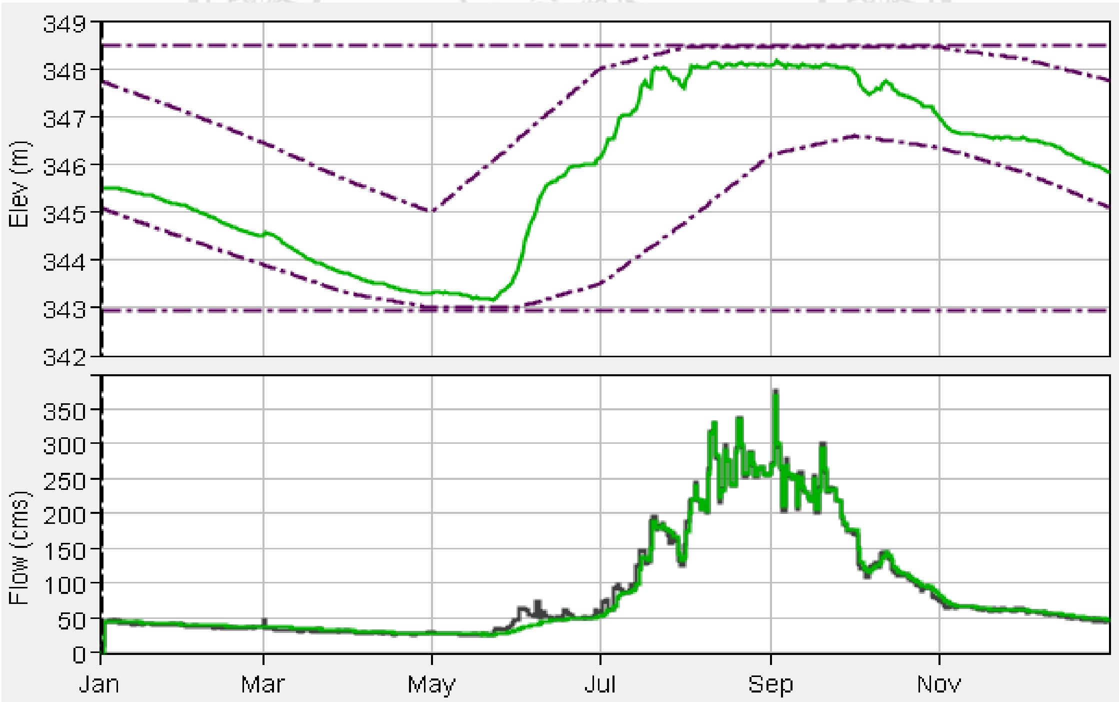

Figure 4.10 Reservoir elevation and water discharge of Namkhan 3 HPP (NWC).

In the table 4.16 was shown the power production of physical limitations for before and after modify of Namhan 2 and 3 hydropower plants in NWC case that relate between the reservoir elevation and water discharge(Max capacity) before and after using optimization technique.

Table 4.16 The power production of physical limitations in NWC case

Namkhan 2 Hydropower Plant			Namkhan 3 Hydropower Plant		
Reservoir Elecvation	Max capacity (cms)		Reservoir Elecvation	Max capacity (cms)	
	Before	After		Before	After
465.00	16.00	20.00	343.00	20.00	25.00
466.00	20.00	22.00	343.50	25.00	30.00
467.00	25.00	25.00	344.00	30.00	32.00
468.00	28.00	28.00	344.50	35.00	35.00
469.00	30.00	32.00	345.00	40.00	40.00
470.00	32.00	33.00	345.50	45.00	50.00
471.00	34.00	38.00	346.00	50.00	55.00
472.00	38.00	80.00	346.50	60.00	60.00
473.00	45.00	135.00	347.00	85.00	100.00
474.00	50.00	135.00	347.50	120.00	176.60
475.00	135.00	135.00	348.00	176.60	176.60

In the table 4.17 and 4.18 were shown the time of power generation pattern of Namkhan 2 and 3 hydropower plants in NWC case, respectively. These tables are shown the average power generation in the each months, and time for the power generation capacity in the each day. That shows the relationship between the power generation and time of each days before and after using optimization technique.

Table 4.17 Time of power generation pattern of Namkhan 2 HPP in NWC case

Item	Simulation result before optimization			Simulation result after optimization		
Month	Average per month		Reservoir level (masl)	Average per month		Reservoir level (masl)
	Power(MW)	Hour/Day(h)		Power(MW)	Hour/Day(h)	
Jan	35.78	24.00	470.21	39.52	24.00	469.88
Feb	32.50	23.57	468.67	32.58	24.00	468.26
Mar	32.50	20.64	467.09	32.50	20.10	466.76
Apr	32.50	16.79	466.24	32.50	16.79	465.91
May	32.50	15.28	466.65	32.50	15.93	466.22
Jun	32.50	22.81	470.51	32.50	22.90	470.04
Jul	87.72	24.00	474.49	103.86	24.00	472.30
Aug	130.00	24.00	475.04	129.92	24.00	475.04
Sep	130.00	24.00	474.66	130.00	24.00	474.66
Oct	91.91	24.00	474.15	106.23	24.00	471.72
Nov	53.60	24.00	473.3	48.54	24.00	471.29
Dec	44.79	24.00	471.79	39.73	24.00	470.25

Table 4.18 Time of power generation pattern of Namkhan 3 HPP in NWC case

Item	Simulation result before optimization			Simulation result after optimization		
Month	Average per month		Reservoir level (masl)	Average per month		Reservoir level (masl)
	Power(MW)	Hour/Day(h)		Power(MW)	Hour/Day(h)	
Jan	16.40	24.00	345.13	17.66	24.00	345.07
Feb	15.00	23.22	344.51	15.00	23.04	344.73
Mar	15.00	20.53	343.71	15.00	20.17	343.99
Apr	15.00	16.83	343.31	15.00	17.33	343.41
May	15.00	15.82	343.77	15.00	16.37	343.87
Jun	17.19	24.00	346.15	17.85	24.00	345.81
Jul	44.48	24.00	347.77	49.78	24.00	347.12
Aug	60.00	24.00	348.07	60.00	24.00	348.07
Sep	60.00	24.00	347.92	60.00	24.00	347.92
Oct	45.52	24.00	346.96	50.04	24.00	346.8
Nov	25.59	24.00	346.57	24.25	24.00	346.31
Dec	21.11	24.00	345.83	19.82	24.00	345.22

In the table 4.19 was shown the simulation results for the water released from spillway in the NWC case,which was optimized for before and after the revising model of operating the Namhan 2 and 3 hydropower plants.

Table 4.19 Water released from spillway of simulation result in NWC case

Month	Namkhan 2 Hydropower Plant Water released (MCM)		Namkhan 3 Hydropower Plant Water released (MCM)	
	Before	After	Before	After
Jul	-	-	2,462,400.00	-
Aug	100,605,542.00	64,554,192.00	198,215,424.00	145,828,512.00
Sep	75,358,944.00	75,358,944.00	148,734,144.00	148,734,144.00
Oct	-	-	-	-

4.4.4 Watery criterion that very rather(WCVR) case

Before, the model simulation should be entered the among data that relate with the software. If data entrance is wrong in the modelling as well as the model cannot simulate or run the program. Every time should be checked the all conditions of each modules in the HEC-ResSim model before the model simulation.

In which simulation results of reservoir operation were shown in figure 4.11 and 4.12 of Namkhan 2 and 3 hydropower plants, respectively in WCVR case that show the relationship between the reservoir elevation and water release of before using optimization technique.

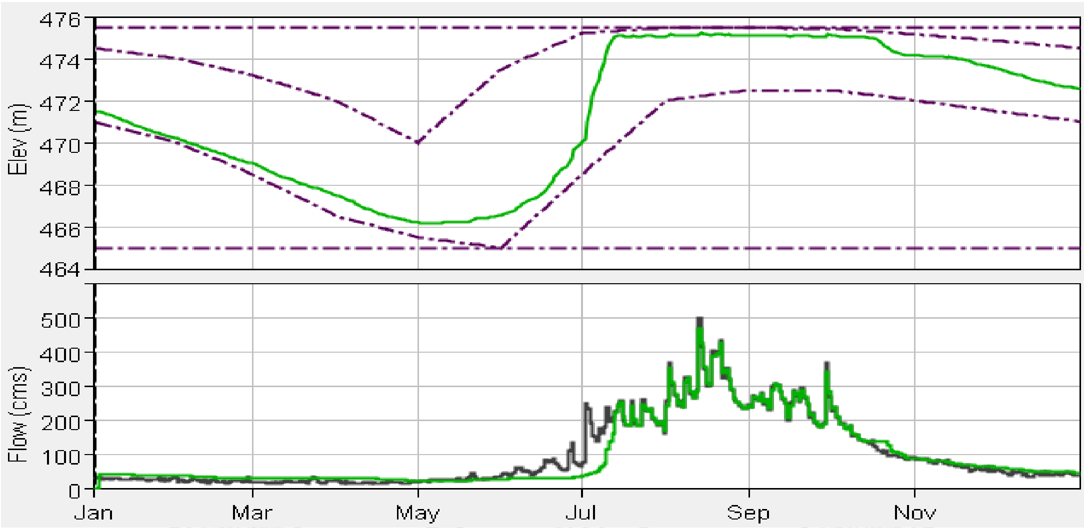

Figure 4.11 Reservoir elevation and water discharge of Namkhan 2 HPP (WCVR).

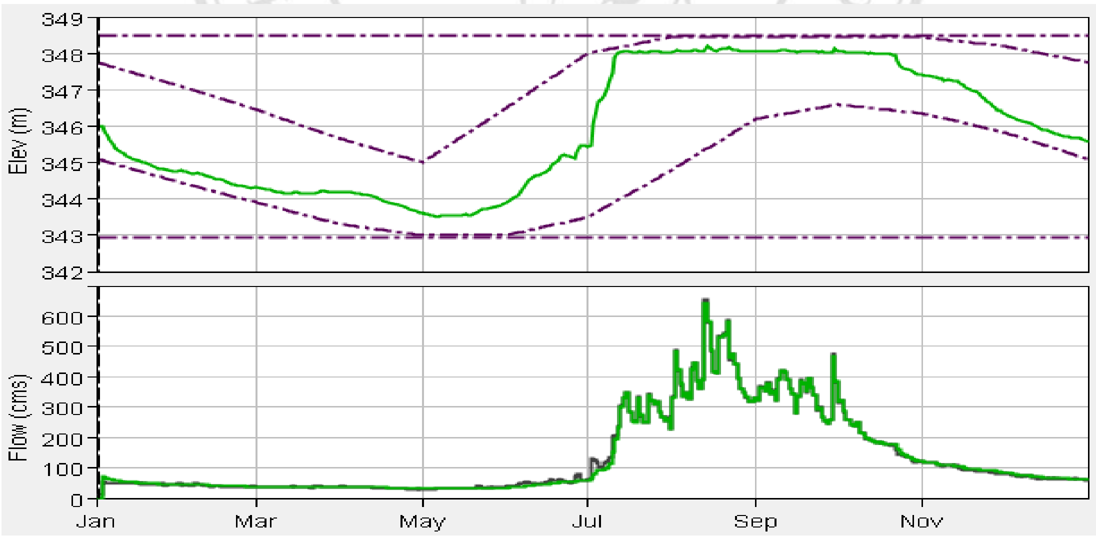

Figure 4.12 Reservoir elevation and water discharge of Namkhan 3 HPP (WCVR).

In the table 4.20 was shown the power production of physical limitations for before and after modify of Namhan 2 and 3 hydropower plants in WCVR case that relate between the reservoir elevation and water discharge(Max capacity) before and after using optimization technique.

Table 4.20 The power production of physical limitations in WCVR case

Namkhan 2 Hydropower Plant			Namkhan 3 Hydropower Plant		
Reservoir Elecvation	Max capacity (cms)		Reservoir Elecvation	Max capacity (cms)	
	Before	After		Before	After
465.00	10.00	10.00	343.00	20.00	30.00
466.00	20.00	29.00	343.50	30.00	37.00
467.00	30.00	29.00	344.00	35.00	38.00
468.00	30.00	29.00	344.50	40.00	39.00
469.00	30.00	30.00	345.00	50.00	40.00
470.00	35.00	32.00	345.50	60.00	50.00
471.00	40.00	36.00	346.00	70.00	70.00
472.00	45.00	70.00	346.50	90.00	90.00
473.00	50.00	135.00	347.00	95.00	176.60
474.00	70.00	135.00	347.50	130.00	176.60
475.00	135.00	135.00	348.00	176.60	176.60

In the table 4.21 and 4.22 were shown the time of power generation pattern of Namkhan 2 and 3 hydropower plants in WCVR case, respectively. These tables are shown the average power generation in the each months, and time for the power generation capacity in the each day. That shows the relationship between the power generation and time of each days before and after using optimization technique.

Table 4.21 Time of power generation pattern of Namkhan 2 HPP in WCVR case

Item	Simulation result before optimization			Simulation result after optimization		
Month	Average per month		Reservoir level (masl)	Average per month		Reservoir level (masl)
	Power(MW)	Hour/Day(h)		Power(MW)	Hour/Day(h)	
Jan	39.97	24.00	470.22	45.34	24.00	470.42
Feb	33.11	24.00	469.00	32.77	24.00	469.24
Mar	32.50	22.75	467.50	32.50	22.52	467.78
Apr	32.50	19.98	466.20	32.50	21.76	466.22
May	32.50	16.93	466.52	34.38	24.00	465.21
Jun	32.50	22.46	470.01	61.36	24.00	465.28
Jul	107.18	24.00	475.02	93.53	24.00	475.02
Aug	130.00	24.00	475.07	130.00	24.00	475.07
Sep	130.00	24.00	475.09	130.00	24.00	475.09
Oct	123.33	24.00	474.15	130.00	24.00	472.83
Nov	79.76	24.00	473.53	82.66	24.00	471.66
Dec	55.35	24.00	472.54	49.93	24.00	471.18

Table 4.22 Time of power generation pattern of Namkhan 3 HPP in WCVR case

Item	Simulation result before optimization			Simulation result after optimization		
Month	Average per month		Reservoir level (masl)	Average per month		Reservoir level (masl)
	Power(MW)	Hour/Day(h)		Power(MW)	Hour/Day(h)	
Jan	20.01	24.00	344.78	20.47	24.00	345.22
Feb	15.16	24.00	344.32	15.24	24.00	344.73
Mar	15.00	21.52	344.18	15.00	22.63	344.00
Apr	15.00	20.01	343.61	15.00	21.80	343.16
May	15.00	17.89	343.88	15.48	24.00	343.18
Jun	17.25	24.00	345.44	25.55	24.00	346.04
Jul	52.33	24.00	348.01	51.30	24.00	348.01
Aug	60.00	24.00	348.05	60.00	24.00	348.05
Sep	60.00	24.00	348.06	60.00	24.00	348.06
Oct	57.87	24.00	347.41	60.00	24.00	347.23
Nov	39.48	24.00	346.35	40.16	24.00	346.22
Dec	26.50	24.00	345.59	24.59	24.00	345.66

In the table 4.23 was shown the simulation results for the water released from spillway in the WCVR case,which was optimized for before and after the revising model of operating the Namhan 2 and 3 hydropower plants.

Table 4.23 Water released from spillway of simulation result in WCVR case

Month	Namkhan 2 Hydropower Plant Water released (MCM)		Namkhan 3 Hydropower Plant Water released (MCM)	
	Before	After	Before	After
Jun	-	-	-	-
Jul	89,079,264.00	38,029,824.00	185,364,288.00	96,426,720.00
Aug	296,987,040.00	296,987,040.00	646,237,440.00	646,237,440.00
Sep	206,297,280.00	206,297,280.00	433,438,560.00	433,438,560.00
Oct	36,107,424.00	36,107,424.00	77,750,496.00	77,750,496.00
Nov	-	-	-	-

4.4.5 Very watery criterion (VWC) case

Before, the model simulation should be entered the among data that relate with the software. If data entranec is wrong in the modelling as well as the model cannot simulate or run the program. Every time should be checked the all conditions of each modules in the HEC-ResSim model before the model simulation.

In which simulation results of reservoir operation were shown in figure 4.13 and 4.14 of Namkhan 2 and 3 hydropower plants, respectively in VWC case that show the relationship between the reservoir elevation and water release of before using optimization technique.

Figure 4.13 Reservoir elevation and water discharge of Namkhan 2 HPP (VWC).

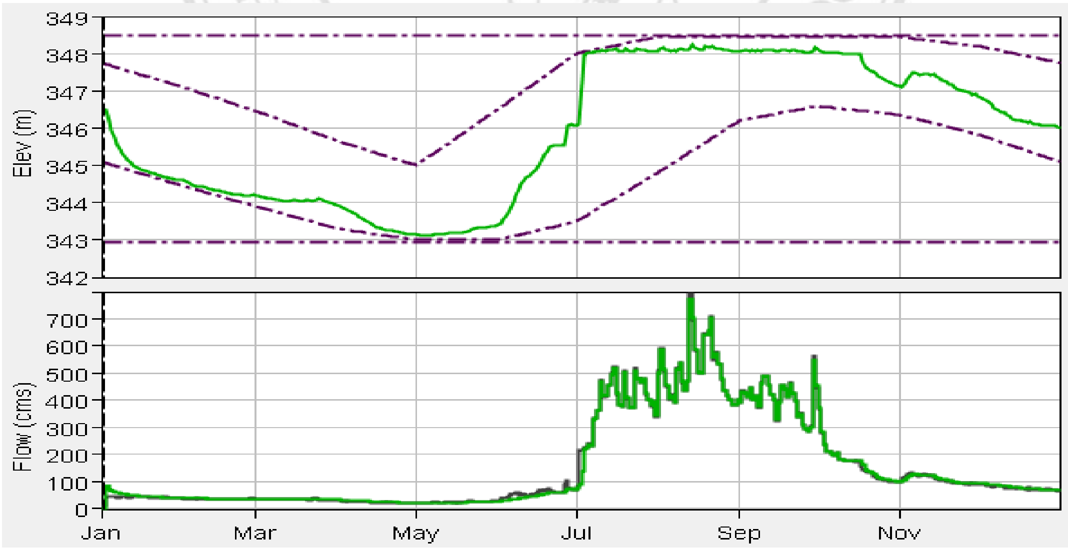

Figure 4.14 Reservoir elevation and water discharge of Namkhan 3 HPP (VWC).

In the table 4.24 was shown the power production of physical limitations for before and after modify of Namhan 2 and 3 hydropower plants in VWC case that relate between the reservoir elevation and water discharge(Max capacity) before and after using optimization technique.

Table 4.24 The power production of physical limitations in VWC case

Namkhan 2 Hydropower Plant			Namkhan 3 Hydropower Plant		
Reservoir Elecvation	Max capacity (cms)		Reservoir Elecvation	Max capacity (cms)	
	Before	After		Before	After
465.00	10.00	15.00	343.00	20.00	20.00
466.00	20.00	20.00	343.50	30.00	176.60
467.00	30.00	30.00	344.00	35.00	35.00
468.00	30.00	30.00	344.50	40.00	40.00
469.00	30.00	30.00	345.00	50.00	50.00
470.00	35.00	35.00	345.50	60.00	60.00
471.00	40.00	40.00	346.00	70.00	70.00
472.00	45.00	100.00	346.50	90.00	100.00
473.00	50.00	135.00	347.00	95.00	176.60
474.00	70.00	135.00	347.50	130.00	176.60
475.00	135.00	135.00	348.00	176.60	176.60

In the table 4.25 and 4.26 were shown the time of power generation pattern of Namkhan 2 and 3 hydropower plants in VWC case, respectively. These tables are shown the average power generation in the each months, and time for the power generation capacity in the each day. That shows the relationship between the power generation and time of each days before and after using optimization technique.

Table 4.25 Time of power generation pattern of Namkhan 2 HPP in VWC case

Item	Simulation result before optimization			Simulation result after optimization		
Month	Average per month		Reservoir level (masl)	Average per month		Reservoir level (masl)
	Power(MW)	Hour/Day(h)		Power(MW)	Hour/Day(h)	
Jan	35.57	24.00	469.61	46.76	24.00	470.32
Feb	32.50	22.94	468.31	33.07	24.00	468.83
Mar	32.50	22.09	466.57	32.50	22.69	467.01
Apr	32.50	15.04	465.68	32.50	21.70	465.13
May	32.50	13.09	466.00	32.50	14.66	465.20
Jun	32.50	23.10	471.58	79.96	24.00	465.25
Jul	121.68	24.00	475.06	104.89	24.00	475.06
Aug	130.00	24.00	475.12	130.00	24.00	475.12
Sep	130.00	24.00	475.11	130.00	24.00	475.11
Oct	113.88	24.00	474.04	127.53	24.00	471.88
Nov	87.19	24.00	473.84	85.59	24.00	471.68
Dec	63.60	24.00	473.08	56.84	24.00	471.55

Table 4.26 Time of power generation pattern of Namkhan 3 HPP in VWC case

Item	Simulation result before optimization			Simulation result after optimization		
Month	Average per month		Reservoir level (masl)	Average per month		Reservoir level (masl)
	Power(MW)	Hour/Day(h)		Power(MW)	Hour/Day(h)	
Jan	20.22	24.00	344.61	21.29	24.00	344.79
Feb	15.00	22.44	344.19	15.00	23.87	344.24
Mar	15.00	20.70	343.93	15.00	20.91	344.08
Apr	15.00	15.82	343.14	15.00	21.03	343.18
May	15.00	13.79	343.39	15.00	15.53	343.21
Jun	18.60	24.00	346.06	34.68	24.00	346.70
Jul	57.98	24.00	348.05	59.29	24.00	348.05
Aug	60.00	24.00	348.07	60.00	24.00	348.07
Sep	60.00	24.00	348.08	60.00	24.00	348.08
Oct	54.06	24.00	347.13	59.09	24.00	346.63
Nov	42.61	24.00	346.85	42.00	24.00	346.29
Dec	30.89	24.00	346.01	28.10	24.00	345.90

In the table 4.27 was shown the simulation results for the water released from spillway in the VWC case,which was optimized for before and after the revising model of operating the Namhan 2 and 3 hydropower plants.

Table 4.27 Water released from spillway of simulation result in VWC case

Month	Namkhan 2 Hydropower Plant Water released (cubic meter)		Namkhan 3 Hydropower Plant Water released (cubic meter)	
	Before	After	Before	After
Jul	205,192,224.00	141,152,544.00	529,303,680.00	389,066,976.00
Aug	425,656,512.00	425,656,512.00	879,705,792.00	879,705,792.00
Sep	272,631,744.00	272,631,744.00	585,258,048.00	585,258,048.00
Oct	20,521,728.00	20,521,728.00	45,276,192.00	45,276,192.00

4.5 Comparison Results Before-After Using Optimization Technique

4.5.1 Evaluation and comparison of energy generation after using the optimization technique

After, the model was revised by using the optimization technique, which shows the different yield for energy generation in the each months that not same and yield of after improving is better than yield of before improving. The energy of before and after improving for five case were shown in table 4.28 and 4.29 of Namkhan 2 and 3 hydropower plants, respectively.

Table 4.28 Comparing energy generation of before-after revised by using optimization technique of Namkhan 2 hydropower plant

Months	VWC(GWh)		WCVR(GWh)		ANC(GWh)		WCLR(GWh)		LWC(GWh)	
	Before	After	Before	After	Before	After	Before	After	Before	After
Jan	26.5	34.8	29.7	33.3	26.6	29.3	24.4	27.0	25.0	25.3
Feb	21.6	23.0	23.0	22.8	22.2	22.6	19.8	21.6	20.2	20.4
Mar	22.1	22.8	22.9	22.7	20.7	20.1	19.0	19.4	19.4	20.1
Apr	14.4	17.4	19.3	21.2	16.3	16.3	16.5	16.7	16.4	17.2
May	13.3	18.5	17.1	25.7	15.5	22.0	15.5	15.7	14.5	15.1
Jun	23.1	49.0	22.2	45.4	22.5	47.6	14.4	14.5	12.6	12.9
Jul	92.6	83.5	82.0	70.6	67.5	48.3	17.0	17.0	16.0	16.5
Aug	96.7	96.7	96.7	96.7	96.7	96.7	46.8	40.8	24.5	23.8
Sep	93.6	93.6	93.6	93.6	93.6	93.6	68.9	68.5	33.1	32.6
Oct	83.5	93.9	90.9	96.7	66.7	77.4	41.3	41.3	28.8	28.8
Nov	62.6	61.1	56.7	57.9	38.3	34.5	28.5	29.7	21.8	22.0
Dec	46.9	41.9	40.8	36.7	33.1	29.3	22.9	25.2	20.8	21.0
Total	596.9	636.2	594.9	623.3	519.7	537.7	335	337.4	253.1	255.7

Table 4.29 Comparing energy generation of before-after revised by using optimization technique of Namkhan 3 hydropower plant

Months	VWC(GWh)		WCVR(GWh)		ANC(GWh)		WCLR(GWh)		LWC(GWh)	
	Before	After	Before	After	Before	After	Before	After	Before	After
Jan	14.7	15.8	14.8	15.3	12.2	13.3	11.5	13.0	11.7	11.9
Feb	9.7	10.4	10.5	10.6	10.1	10.0	9.7	10.0	10.1	10.1
Mar	9.6	9.7	10.0	10.5	9.5	9.2	8.8	9.2	9.0	9.4
Apr	7.0	7.9	8.9	9.6	7.5	7.8	7.7	7.7	7.6	7.9
May	6.5	8.7	8.3	11.7	7.4	8.5	7.3	7.1	6.6	6.7
Jun	13.8	24.0	12.7	18.9	12.6	23.3	6.9	6.9	5.7	5.9
Jul	43.9	43.8	39.8	38.9	34.0	29.6	8.9	9.0	8.6	8.8
Aug	44.6	44.6	44.6	44.6	44.6	44.6	25.6	23.0	14.2	14.0
Sep	43.2	43.2	43.2	43.2	43.2	43.2	33.9	33.8	16.3	16.2
Oct	39.7	43.6	42.7	44.6	33.2	36.4	19.6	19.7	14.2	14.3
Nov	30.6	30.0	28.1	28.2	18.3	17.3	13.8	14.5	11.1	11.1
Dec	22.8	20.7	19.5	18.1	15.6	14.2	11.6	12.5	10.2	10.2
Total	286.1	302.4	283.1	294.2	248.2	257.4	165.3	166.4	125.3	126.5

4.5.2 Evaluation and comparison of water release from spillway after using the optimization technique

After, the model was improved by using the optimization technique, which can be decreased the water release volume from spillway that save the water volume into electricity production. The water release volume from spillway of before and after improving for five cases were shown in table 4.30 and 4.31 of Namkhan 2 and 3 hydropower plants, respectively.

Table 4.30 Comparing the water released from spillway of before-after the using optimization technique of Namkhan 2 hydropower plant

Month	VWC(cubic meter)		WCVR(cubic meter)		ANC(cubic meter)	
	Before	After	Before	After	Before	After
Jul	205,192,224	141,152,544	89,079,264	38,029,824	-	-
Aug	425,656,512	425,656,512	296,987,040	296,987,040	100,605,542	64,554,192
Sep	272,631,744	72,631,744	206,297,280	206,297,280	75,358,944	75,358,944
Oct	20,521,728	20,521,728	36,107,424	36,107,424	-	-
Total	924,002,208	659,962,528	628,471,008	577,421,568	175,964,486	139,913,136

Table 4.31 comparing the water released from spillway of before-after the using optimization technique of Namkhan 3 hydropower plant

Month	VWC (cubic meter)		WCVR (cubic meter)		ANC (cubic meter)	
	Before	After	Before	After	Before	After
Jul	529,303,680	389,066,976	185,364,288	96,426,720	2,462,400.	-
Aug	879,705,792	879,705,792	646,237,440	646,237,440	198,215,424	145,828,512
Sep	585,258,048	585,258,048	433,438,560	433,438,560	148,734,144	148,734,144
Oct	45,276,192	45,276,192	77,750,496	77,750,496	-	-
Total	2,039,543,712	1,899,307,008	1,342,790,784	1,253,853,216	349,411,968	294,562,656

Note: The maximum energy generation is not the best answer but the best answer should be supplied to meet the all demand for the appropriation of reservoir operational management and electricity production for balanceness and sustainability.