Chapter 5
Results and Discussion

This thesis uses the computer software for creating model for reservoir management of Nam Ngum-1 hydropower plant for optimum electricity production by designing the model in HEC-ResSim3.0 software. The model will be simulated by using 2003 to 2012 year data. These data consist of the water inflow, the water outflow and the water elevation data. There are three cases as wet, drought and normal year cases. The result of reservoir management from HEC-ResSim3.0 models will get the revised rule curve, the electricity production, the water inflow, the water outflow and the water elevation. After that, the results of three cases will be used to find out for optimum electricity production.

5.1 Result of the drought year case

The Nam Ngum-1 hydropower plant's historical data consist of water inflow, water outflow, water elevation and energy production. These data are required to manage for reservoir and hydropower plant to research. As drought case, which the data input to model are main data by using 2003, 2007 and 2010 year; due to these data are groups of dry years. The analyzing method of drought case has following items: If the water inflow is less than 9,730 MCM, this case is called drought year case. (e.g., in years : 2003, 2007 and 2010).

There are three steps in drought case for simulation model to find the result. When the results are obtained from step1, step2 and step3, comparing and considering the water release, water elevation, revising upper and lower rule curve for optimum electricity production.

5.1.1 Step one of drought case

Step1 studies to modify guide rule curves and Figure 5.1 are the old upper and lower rule curves which are inactive. The HEC-ResSim3.0 model revises upper and lower rule curve to guideline for the reservoir operation. This step can be modified and used for comparison with other steps in drought case.

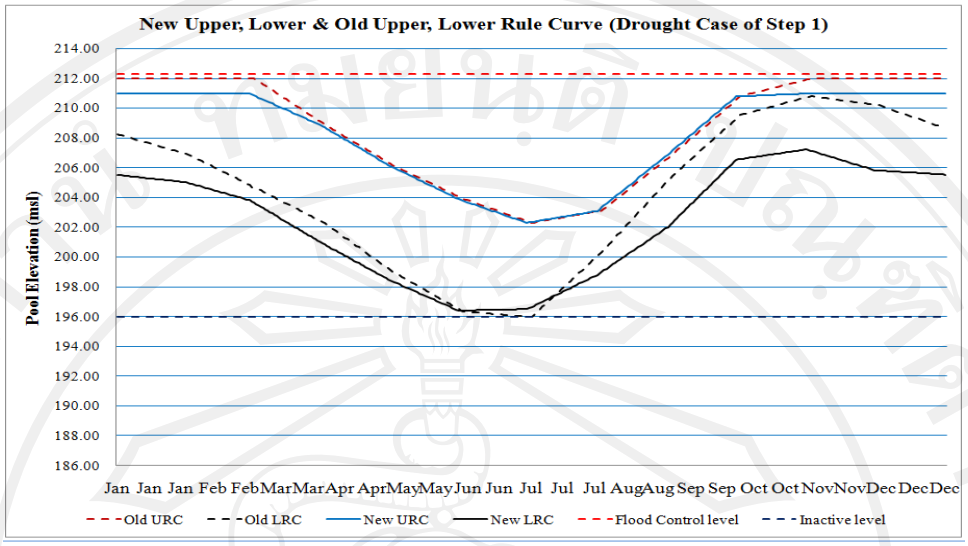

Figure 5.1 The result of revised upper and lower rule curve for NN-1 HPP

Figure 5.2 is a new rule curve. The result from the simulation model for the reservoir management of Nam Ngum-1 hydropower plant. This simulation is analyzed and compared between the actual elevations with simulation elevations. By using new rule curve as guideline for the reservoir operation and considers turbine release for energy generation and end of water level of the year.

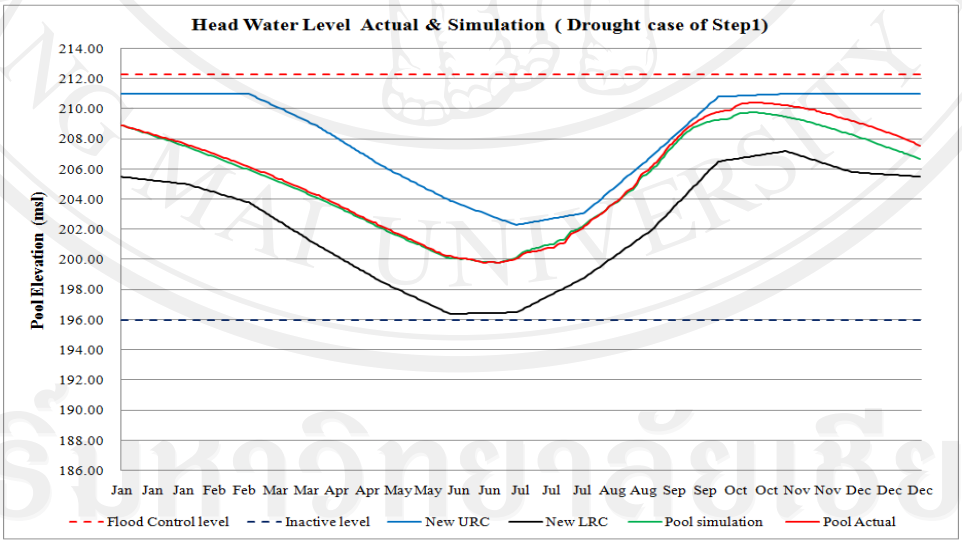

Figure 5.2 The simulation result for operation of NN-1 HPP in step 1

Figure 5.3 shows the annual actual and simulation model energy generation of Nam Ngum-1 hydropower plants which its actual data of 868.60 GWh/y and the simulation model provided 902.85 GWh/y. Due to this case, the starting water

elevation of the year is 208.91 m.a.s.l. On the other hand, the ending water elevation of the year has different level. The actual at end of the year was 207.56 m.a.s.l, the model provided 206.69 m.a.s.l.

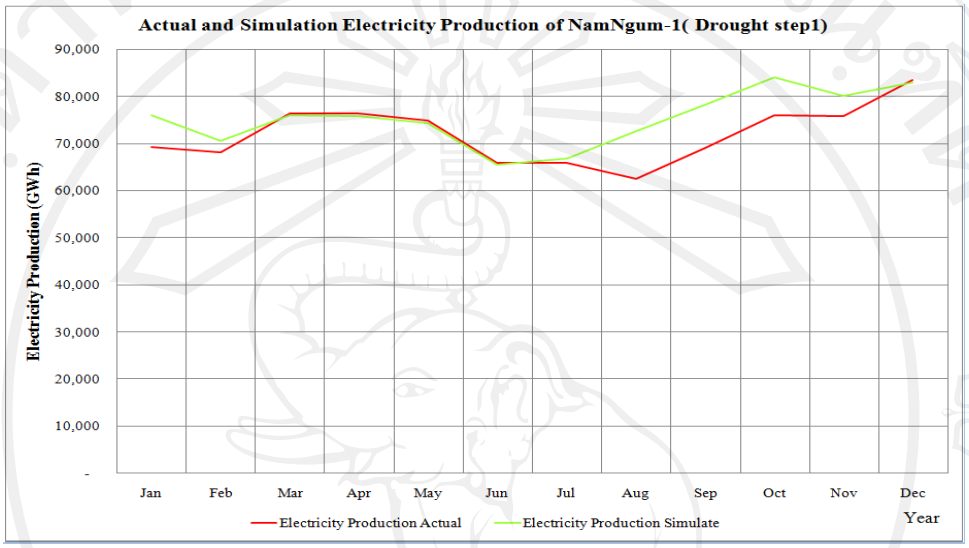

Figure 5.3 The simulation result for energy production of NN-1HPP in step 1

5.1.2 Step two of drought case

Step2 studies to modify guide rule curves and Figure 5.4 are the old upper and lower rule curves which are inactive. The HEC-ResSim3.0 model revises upper and lower rule curve as guideline for the reservoir operation. This step can be modified and used for comparison with other steps in drought case.

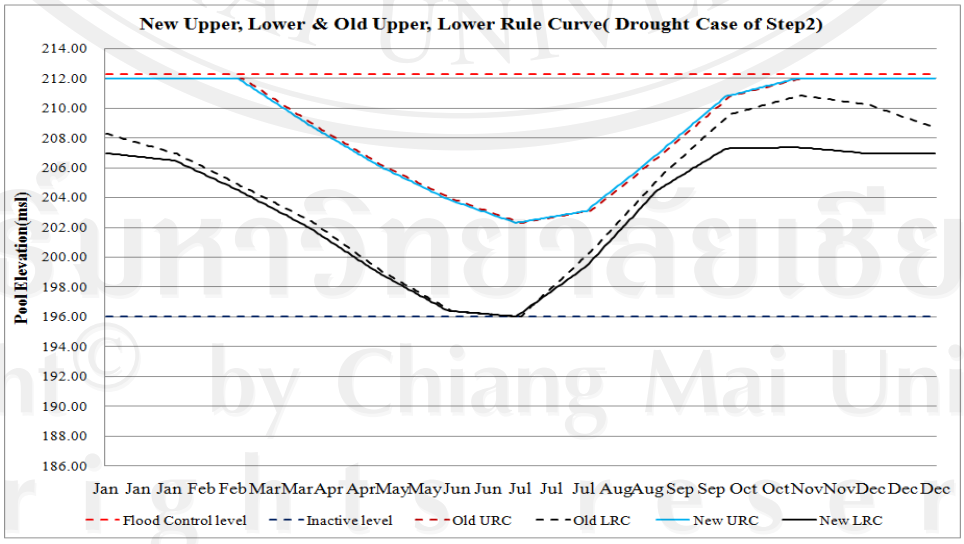

Figure 5.4 The result of revised upper and lower rule curve for NN-1 HPP

Figure 5.5 is a new rule curve. The result from the simulation model for the reservoir management of Nam Ngum-1 hydropower plant. This simulation is analyzed and compared between the actual elevations with simulation elevations. By using new rule curve as guideline for the reservoir operation and considers turbine release for energy generation and end of water level of the year.

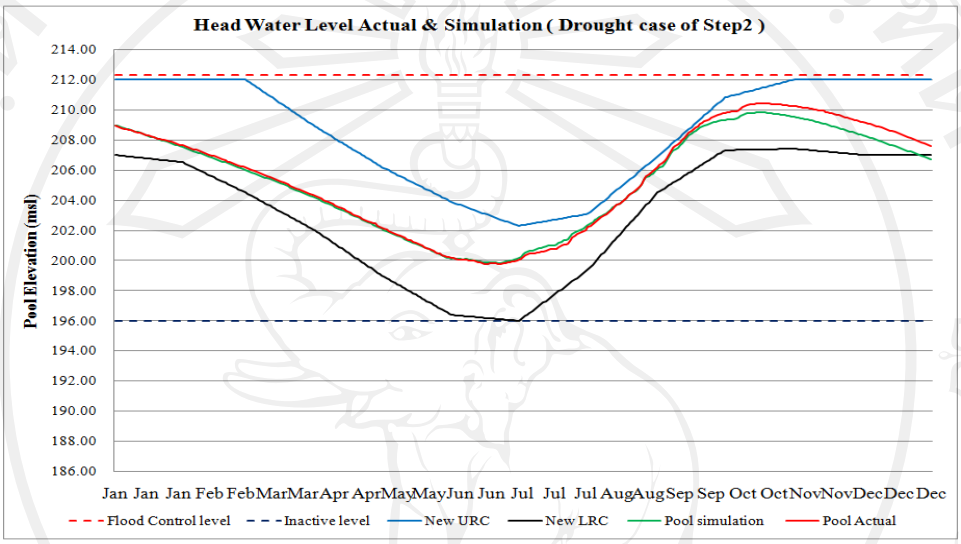

Figure 5.5 The simulation result for operation of NN-1HPP in step 2

Figure 5.6 shows the annual actual and simulation model energy generation of Nam Ngum-1 hydropower plant which its actual data of 868.60 GWh/y and the simulation model provided 902.11 GWh/y. Due to this case, the starting water elevation of the year is 208.91m.a.s.l. On the other hand, the ending water elevation of the year has different level. The actual at end of the year was 207.56 m.a.s.l, the model provided 206.71 m.a.s.l.

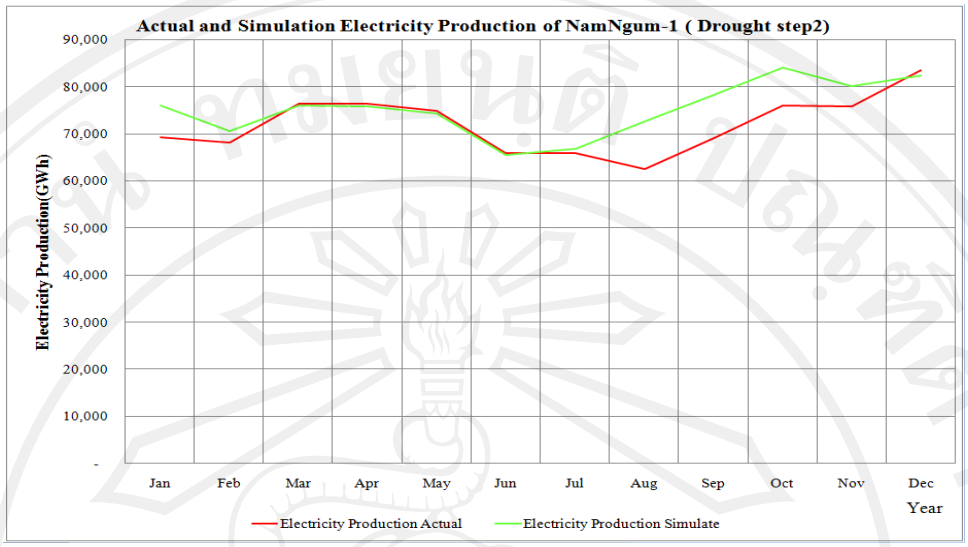

Figure 5.6 The simulation result for energy production of NN-1 HPP in step 2

5.1.3 Step three of drought case

Step 3 studies to modify guide rule curves and Figure 5.7 are the old upper and lower rule curves which are inactive. The HEC-ResSim3.0 model revises upper and lower rule curve to guideline for the reservoir operation. This step can be modified and used for comparison with other steps in drought case.

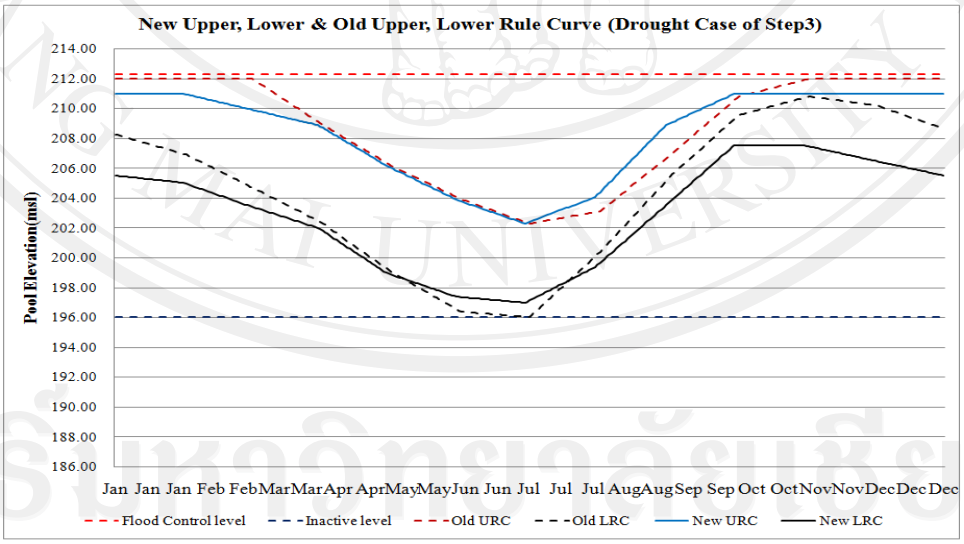

Figure. 5.7 The result of revised upper and lower rule curve for NN-1 HPP

Figure 5.8 is a new rule curve. The result from the simulation model for the reservoir management of Nam Ngum-1 hydropower plant. This simulation is analyzed and compared between the actual elevations with simulation elevations. By using new

rule curve as guideline for the reservoir operation and considers turbine release for energy generation and end of water level of the year.

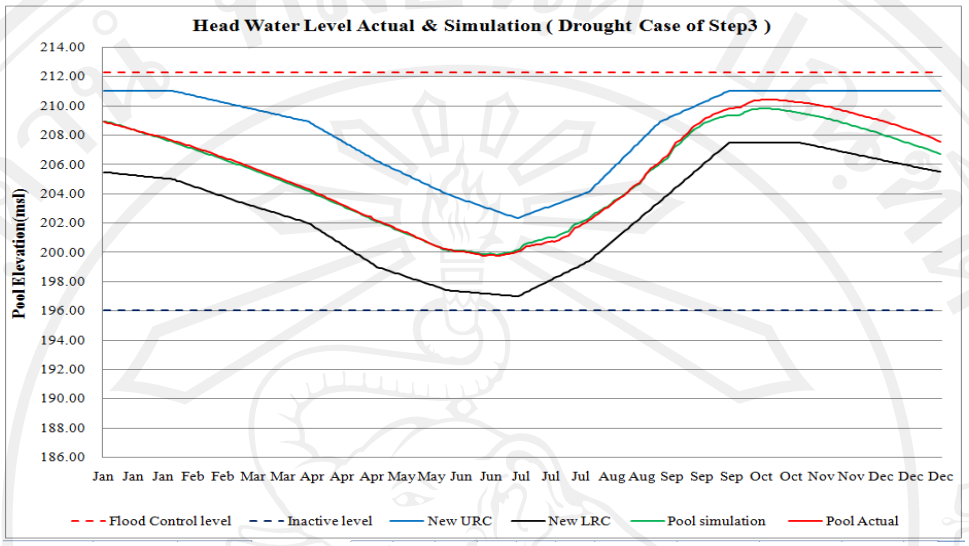

Figure 5.8 The simulation result for operation of NN-1 HPP in step 3

Figure 5.9 shows the annual actual and simulation model energy generation of Nam Ngum-1 hydropower plant which its actual data of 868.60 GWh/y and the simulation model provided 903.06 GWh/y. Due to this case, the starting water elevation of the year is 208.91 m.a.s.l. On the other hand, the ending water elevation of the year is different level. The actual at end of the year was 207.56 m.a.s.l, the model provided 206.68 m.a.s.l.

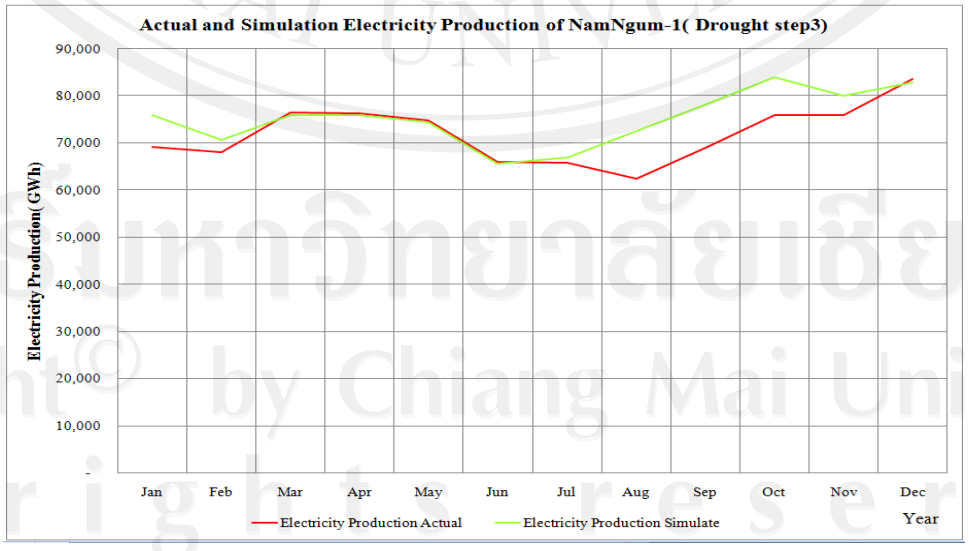

Figure 5.9 The simulation result for energy production of NN-1 HPP in step 3

The energy production of the model is generated from the power data input to the reservoir. The HEC-ResSim3.0 models provides the step 1, step 2 and step 3 amount of energy production, energy planning, water inflow, turbine release, spillway release, start of water elevation, end of water elevation, and revised upper rule curve and lower rule curve. The basic data are required as: generation requirements, installed capacity, an over load factor, overall efficiency, hydraulic loss and tail water level. Three steps are stimulated to find out the new rule curve for optimum electricity generation.

Third step is the best choice for optimum electricity generation for drought case. Hence, it is considered as best alternatives and all the results obtained under this case and this alternative are discussed below. As shown in Table 5.1, the following general reports are obtained from third step.

- Energy actual (GWh/y) = 868.60
- Energy simulation (GWh/y) = 903.06
- Starting water elevation = 208.91 m.a.s.l
- Ending water elevation = 206.68 m.a.s.l
- Average generation efficiency = 0.97
- Hydraulic loss = 2 m
- Water station use = 2 cms
- Average inflow = 100.52 cms
- Average turbine release = 108.3 cms
- Average spillway release =0.00 cms

Finally, the third step has provided the new rule curve for drought case. That is shown in Table 5.2 and the detail is shown in Appendix E.

Table 5.1 Result of simulation model of drought case years

Alternative	Location/Parameter	Units	Result of Simulation		
			Step 1	Step 2	Step 3
Drought Case	Start elevation	(m.a.s.l)	208.91	208.91	208.91
	End elevation	(m.a.s.l)	206.69	206.71	206.68
	Water inflow	(cms)	100.52	100.52	100.52
	Energy actual	(GWh/y)	868.60	868.60	868.60
	Energy simulation	(GWh/y)	902.85	902.11	903.06
	Minimum release	(cms)	289.76	289.76	289.76
	Turbine release	(cms)	108.26	108.17	108.30
	Spillway release	(cms)	0.00	0.00	0.0
	Time of spill	(days)	0.00	0.00	0.00
	Total release	(cms)	108.26	108.17	108.30
	Water station use	(m)	2.00	2.00	2.00
	Hydraulic loss	(cms)	2.00	2.00	2.00
	Efficiency	(%)	0.97	0.97	0.97

Table 5.2 Result for revised the rule curve of drought case years

Month	Old Rule Curve		Step 1		Step 2		Step 3	
			New Rule Curve		New Rule Curve		New Rule Curve	
	URC	LRC	URC	LRC	URC	LRC	URC	LRC
Jan	212.00	208.30	211.00	205.50	212.00	207.00	210.00	205.00
Feb	212.00	206.90	211.00	205.00	212.00	206.50	210.00	205.00
Mar	212.00	204.70	211.00	203.80	212.00	204.50	210.00	204.50
Apr	208.90	202.30	208.90	201.00	208.90	202.00	208.90	202.00
May	206.20	199.00	206.20	198.50	206.20	199.00	206.20	199.00
Jun	203.90	196.40	203.90	196.40	203.90	196.40	203.90	196.40
Jul	202.30	196.00	202.30	196.50	202.30	196.00	202.30	196.00
Aug	203.10	200.40	203.10	198.80	203.10	199.40	203.10	199.40
Sep	206.90	205.50	206.90	202.00	206.90	204.50	206.90	203.50
Oct	210.80	209.60	210.80	206.50	210.80	207.30	210.30	206.90
Nov	212.00	210.80	211.00	207.20	212.00	207.40	210.00	206.90
Dec	212.00	210.20	211.00	205.80	212.00	207.00	210.00	205.40

5.2 Result of the normal year case

The Nam Ngum-1 hydropower plant's the historical data consist of water inflow, water outflow, water elevation and energy production. These data are required to manage for reservoir and hydropower Plant to research. A normal case, which the data input to model are main data by using 2006, 2009 and 2012, year; due to these data are groups of normal years. The analyzing method of normal case has following items: If the water inflow is from 9,730 to 10,800 MCM, this case is called normal year case (e.g., is years : 2006, 2009 and 2012).

There are three steps in normal case for simulation model to find the result. When the results are obtained from step 1, step 2 and step 3, comparing and considering the water release, water elevation, revising upper and lower rule curve for optimum electricity production.

5.2.1 Step one of normal case

Step 1 studies to modify guide rule curves and Figure 5.10 are the old upper and lower rule curves which are inactive. The HEC-ResSim3.0 model revises upper and lower rule curve as guideline for the reservoir operation. This step can be modified and used for comparison with other steps in normal case.

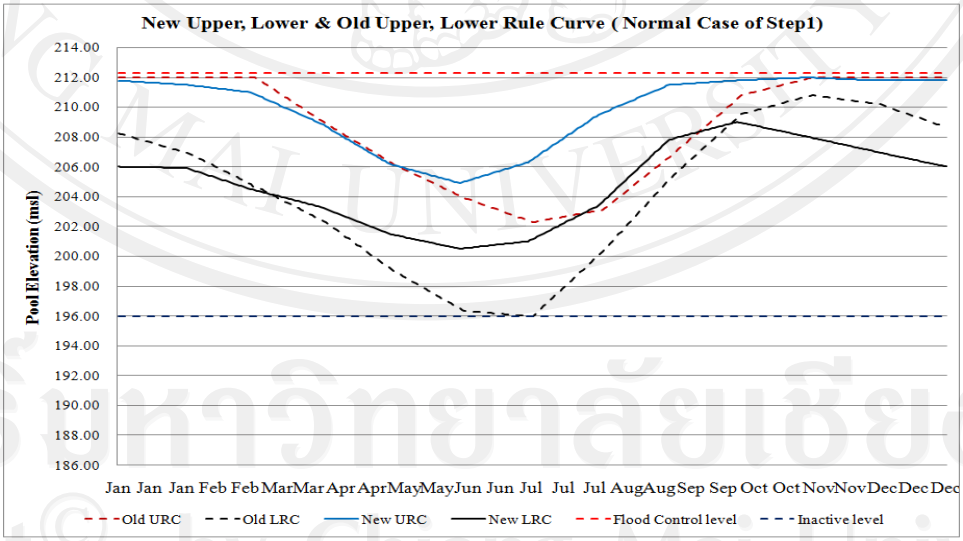

Figure 5.10 The result of revised upper and lower rule curve for NN-1 HPP

Figure 5.11 is a new rule curve. The result from the simulation model for the reservoir management of Nam Ngum-1 hydropower plant. This simulation is analyzed and compared between the actual elevations with simulation elevations. By using new rule curve as guideline for the reservoir operation and considers turbine release for energy generation and end of water level of the year.

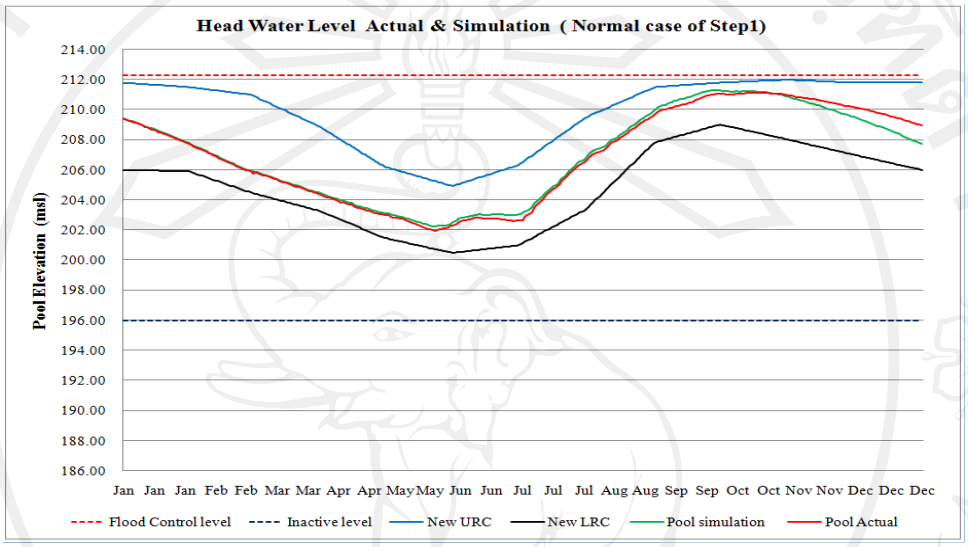

Figure 5.11 The simulation result for operation of NN-1 HPP in step 1

Figure 5.12 shows the annual actual and simulation model energy generation of Nam Ngum-1 Hydropower Plants which its actual data of 1,034.70 GWh/y and the simulation model provided 1,081.81 GWh/y. Due to this case, the starting water elevation of the year is 209.40 m.a.s.l. On the other hand, the ending water elevation of the year has different level. The actual at end of the year was 208.93 m.a.s.l, the model provided 207.73 m.a.s.l.

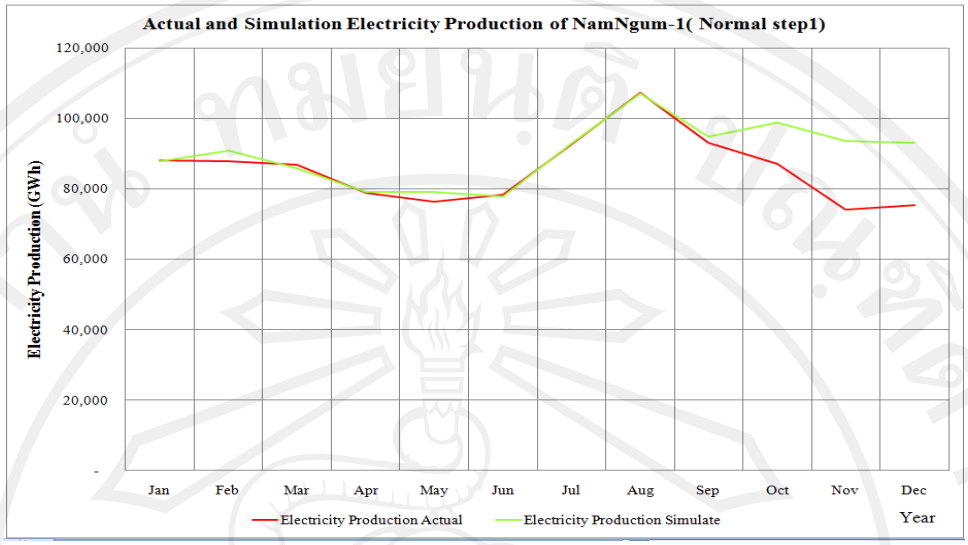

Figure 5.12 The simulation result for energy production of NN-1 HPP in step 1

5.2.2 Step two of normal case

Step 2 studies to modify guide rule curves and Figure 5.13 are the old upper and lower rule curves which are inactive. The HEC-ResSim3.0 model revises upper and lower rule curve as guideline for the reservoir operation. This step can be modified and used for comparison with other steps in normal case.

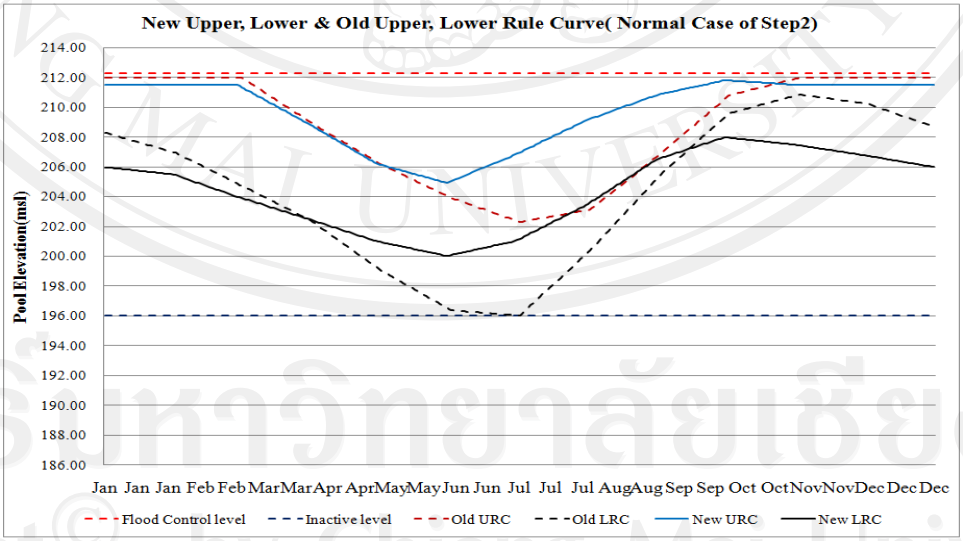

Figure 5.13 The result of revised upper and lower rule curve for NN-1 HPP

Figure 5.14 is a new rule curve. The result from the simulation model for the reservoir management of Nam Ngum-1 hydropower plant. This simulation is analyzed and compared between the actual elevations with simulation elevations. By using new rule curve as guideline for the reservoir operation and considers turbine release for energy generation and end of water level of the year.

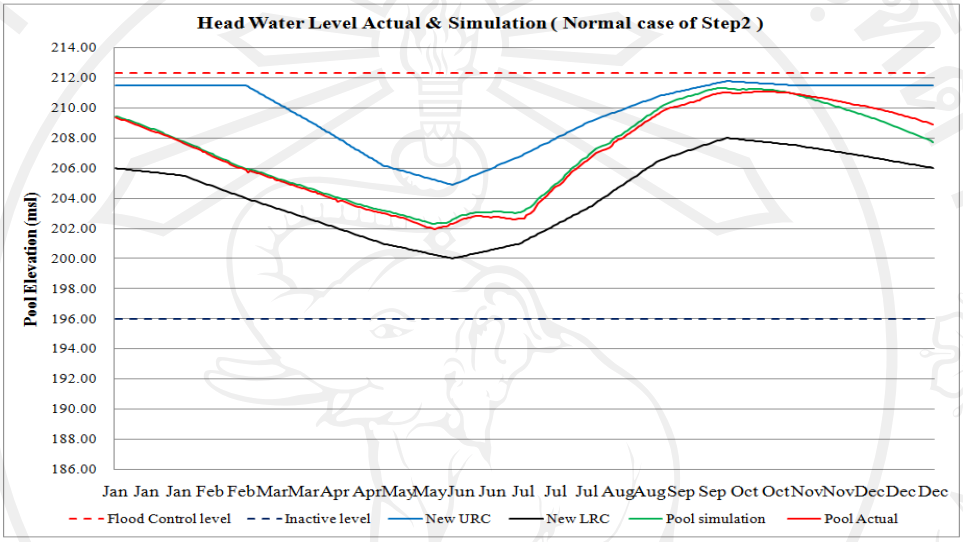

Figure 5.14 The simulation result for operation of NN-1 HPP in step 2

Figure 5.15 shows the annual actual and simulation model energy generation of Nam Ngum-1 Hydropower Plant which its actual data of 1,034.70 GWh/y. and the simulation model provided 1,081.81 GWh/y. Due to this case, the starting water elevation of the year is 209.40 m.a.s.l. On the other hand, the ending water elevation of the year has different level. The actual at end of the year was 208.93 m.a.s.l, the model provided 207.73 m.a.s.l.

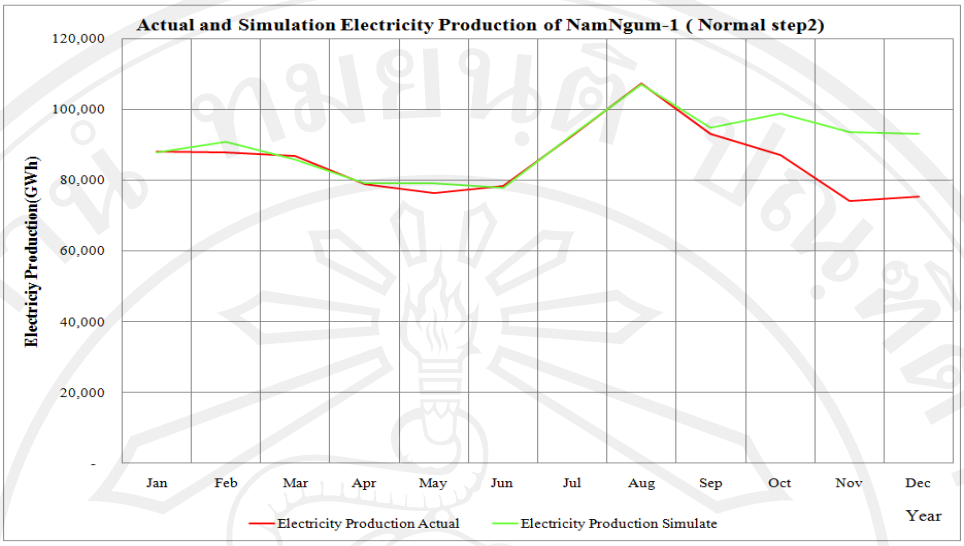

Figure 5.15 The simulation result for energy production of NN-1 HPP in step 2

5.2.3 Step three of normal case

Step 3 studies to modify guide rule curves and Figure 5.16 are the old upper and lower rule curves which are inactive. The HEC-ResSim3.0 model revises upper and lower rule curve as guideline for the reservoir operation. This step can be modified and used for comparison with other steps in normal case.

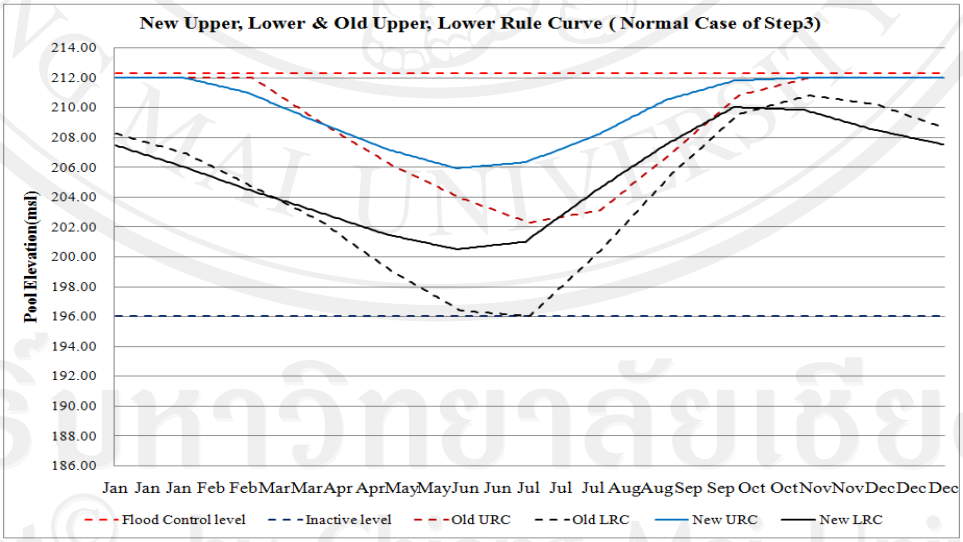

Figure 5.16 The result of revised upper and lower rule curve for NN-1 HPP

Figure 5.17 is a new rule curve. The result from the simulation model for the reservoir management of Nam Ngum-1 hydropower plant. This simulation is analyzed and compared between the actual elevations with simulation elevations. By using new rule curve as guideline for the reservoir operation and considers turbine release for energy generation and end of water level of the year.

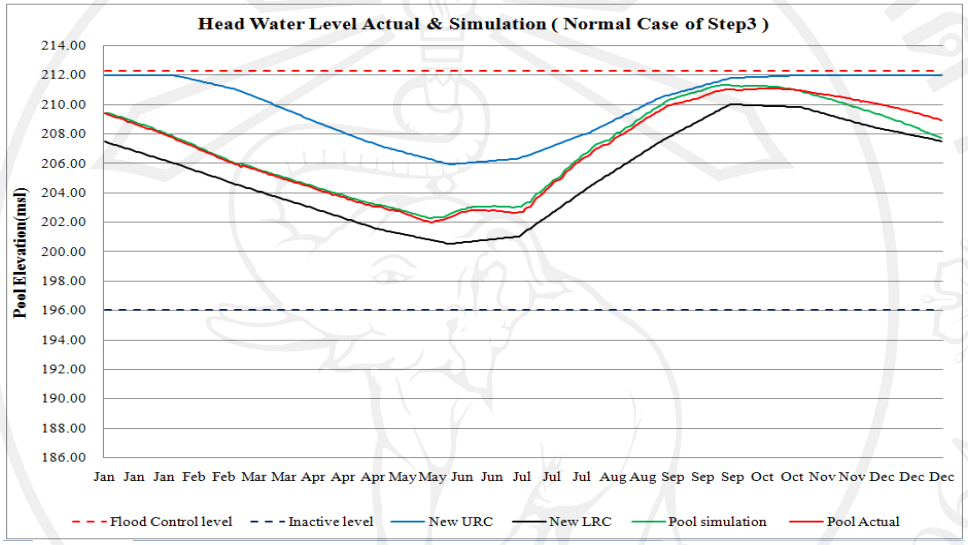

Figure 5.17 The simulation result for operation of NN-1 HPP in step 3

Figure 5.18 shows the annual actual and simulation model energy generation of Nam Ngum-1 hydropower plant which its actual data of 1,034.70 GWh/y and the simulation model is provided 1,082.71 GWh/y. Due to this case, the starting water elevation of the year is 209.40 m.a.s.l. On the others hand, the ending water elevation of the year is different level. The actual at end of the year was 208.93 m.a.s.l, the model provided 207.69 m.a.s.l.

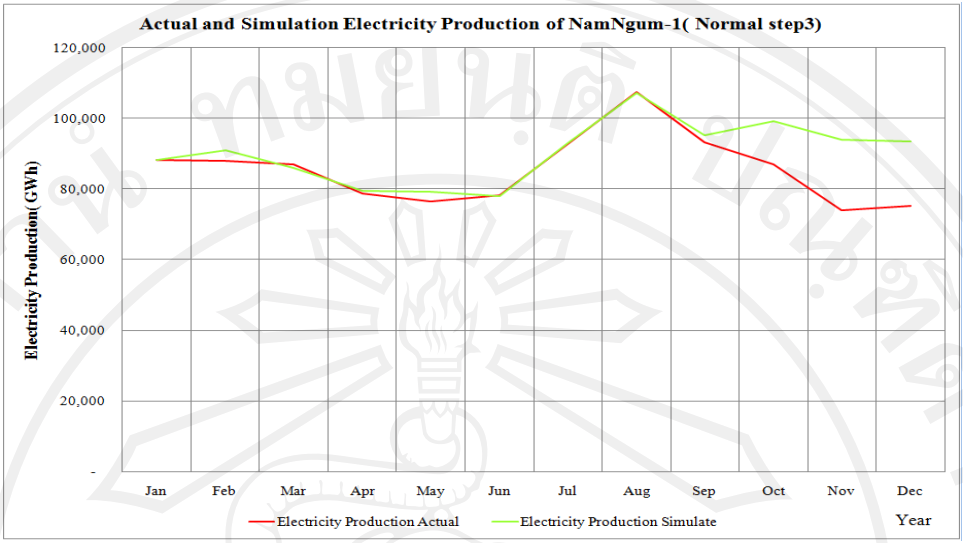

Figure 5.18 The simulation result for energy production of NN-1 HPP in step 3

The energy production of the model is generated from the power data input to the reservoir. The HEC-ResSim3.0 models provides the step 1, step 2 and step 3 amount of energy production, energy planning, water inflow, turbine release, spillway release, start of water elevation, end of water elevation, and revised upper rule curve and lower rule curve. The basic data are required as: generation requirements, installed capacity, an over load factor, overall efficiency, hydraulic loss and tail water level. Three steps are stimulated to find out the new rule curve for optimum electricity generation.

Third step is the best choice for optimum electricity generation for normal case. Hence, it is considered as best alternatives and all the results obtained under this case and this alternative are discussed below. As shown in Table 5.3, the following general reports are obtained from third step.

- Energy actual (GWh/y) = 1,034.70
- Energy simulation (GWh/y) = 1,082.71
- Starting water elevation = 209.40 m.a.s.l
- Ending water elevation = 207.69 m.a.s.l
- Average generation efficiency = 0.97
- Hydraulic loss = 2 m
- Water station use = 2 cms
- Average inflow = 119.16 cms

- Average turbine release = 124.86 cms
- Average spillway release =0.00 cms

Finally, the third step has provided the new rule curve for normal case. That is shown in Table 5.4 and the detail is shown in Appendix E.

Table 5.3 Result simulation model of normal case years

Alternative	Location/Parameter	Units	Result of Simulation		
			Step 1	Step 2	Step 3
Normal Case	Start elevation	(m.a.s.l)	209.40	209.40	209.40
	End elevation	(m.a.s.l)	207.73	207.73	207.69
	Water inflow	(cms)	119.16	119.16	119.16
	Energy actual	(GWh/y)	1,034.70	1,034.70	1,034.70
	Energy simulation	(GWh/y)	1,081.81	1,081.81	1,082.71
	Minimum release	(cms)	331.00	331.00	331.00
	Turbine release	(cms)	124.69	124.69	124.86
	Spillway release	(cms)	0.00	0.00	0.00
	Time of spill	(days)	0.00	0.00	0.00
	Total release	(cms)	124.69	124.69	124.86
	Water station use	(m)	2.00	2.00	2.00
	Hydraulic loss	(cms)	2.00	2.00	2.00
	Efficiency	(%)	0.97	0.97	0.97

Table 5.4 Result for revised rule curve of normal case years

Month	Old Rule Curve		Step 1		Step 2		Step 3	
			New Rule Curve		New Rule Curve		New Rule Curve	
	URC	LRC	URC	LRC	URC	LRC	URC	LRC
Jan	212.00	208.30	211.80	206.00	211.50	206.00	212.00	207.50
Feb	212.00	206.90	211.50	205.90	211.50	205.50	212.00	206.00
Mar	212.00	204.70	211.00	204.50	211.50	204.00	211.00	204.50
Apr	208.90	202.30	208.90	203.30	208.90	202.50	209.00	203.00
May	206.20	199.00	206.20	201.50	206.20	201.00	207.20	201.50
Jun	203.90	196.40	204.90	200.50	204.90	200.00	205.90	200.50
Jul	202.30	196.00	206.30	201.00	206.80	201.00	206.30	201.00
Aug	203.10	200.40	209.50	203.40	209.10	203.40	208.10	204.40
Sep	206.90	205.50	211.50	207.80	210.80	206.50	210.50	207.50
Oct	210.80	209.60	211.80	209.00	211.80	208.00	211.80	210.00
Nov	212.00	210.80	212.00	208.00	211.50	207.50	212.00	209.80
Dec	212.00	210.20	211.80	207.00	211.50	206.80	212.00	208.50

5.3 Result of the wet year case

The Nam Ngum-1 hydropower plant's the historical data consist of water inflow, water outflow, water elevation and energy production. These data are required to manage the reservoir and hydropower plant to research. As wet case, which the data input to model are main data by using 2004, 2005, 2008 and 2011, year; due to these data are groups of normal years. The analyzing method of wet case has following items: If the water inflow is more than 10,800 MCM, this case is called wet year case

(e.g., on years : 2004, 2005,2008 and 2011).

There are three steps in wet case for simulation model to find the result. When the results are obtained from step 1, step 2 and step 3, comparing and considering the water release, water elevation, revising upper and lower rule curve for optimum electricity production.

5.3.1 Step one of wet case

Step 1 studies to modify guide rule curves and Figure 5.19 are the old upper and lower rule curves which are inactive. The HEC-ResSim3.0 model revises upper and lower rule curve as guideline for the reservoir operation. This step can be modified and used for comparison with other steps in wet case.

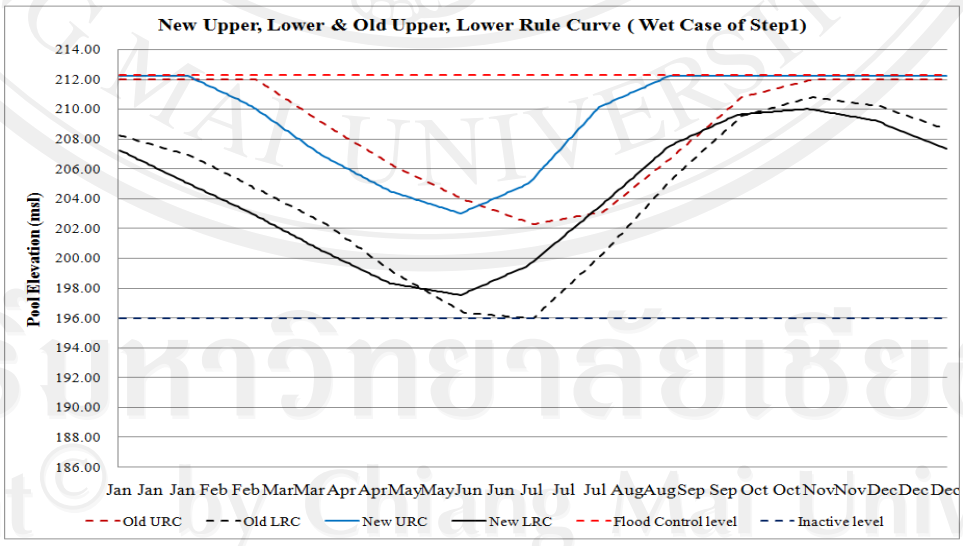

Figure 5.19 The result of revised upper and lower rule curve for NN-1 HPP

Figure 5.20 is a new rule curve. The result from the simulation model for the reservoir management of Nam Ngum-1 hydropower plant. This simulation is analyzed and compared between the actual elevations with simulation elevations. By using new rule curve as guideline for the reservoir operation and considers turbine release for energy generation and end of water level of the year.

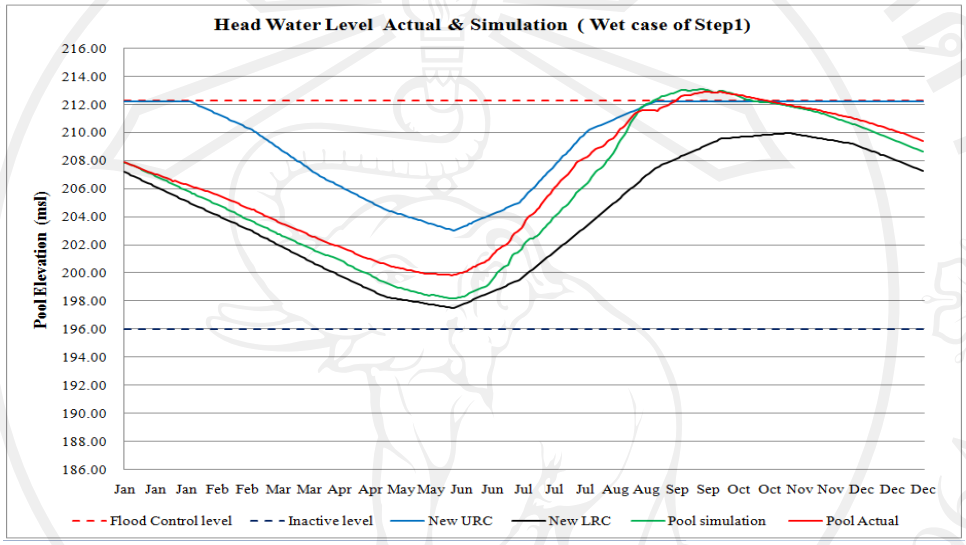

Figure 5.20 The simulation result for operation of NN-1 HPP in step 1

Figure 5.21 shows the annual actual and simulation model energy generation of Nam Ngum-1 Hydropower Plants which its actual data of 1,121.69 GWh/y and the simulation model provided 1,189.16 GWh/y. Due to this case, the starting water elevation of the year is 207.87 m.a.s.l. On the other hand, the ending water elevation of the year is different level. The actual at end of the year was 209.36 m.a.s.l, the model provided 208.59 m.a.s.l.

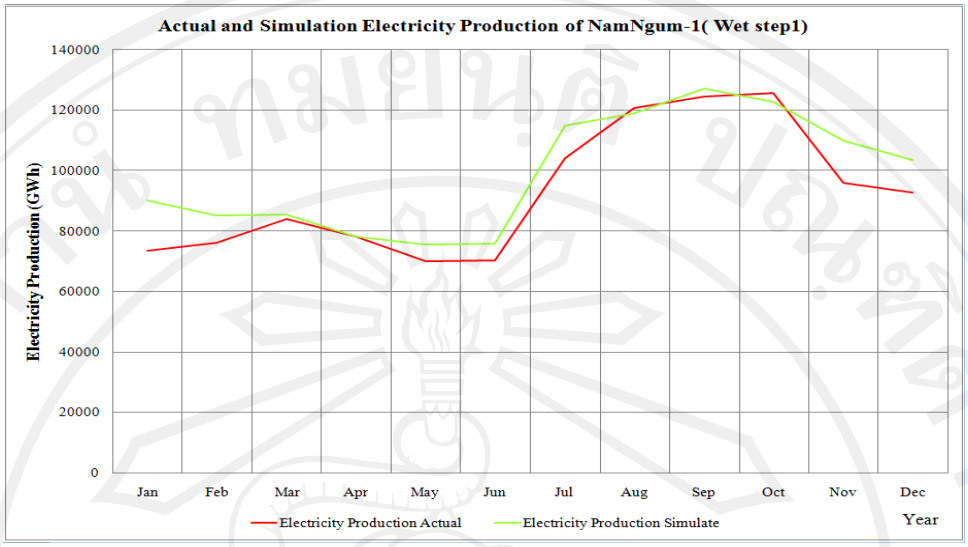

Figure 5.21 The simulation result for energy production of NN-1 HPP in step 1

5.3.2 Step two of wet case

Step 2 studies to modify guide rule curves and Figure 5.22 are the old upper and lower rule curves which are inactive. The HEC-ResSim3.0 model revises upper and lower rule curve as guideline for the reservoir operation. This step can be modified and used for comparison with other steps in wet case.

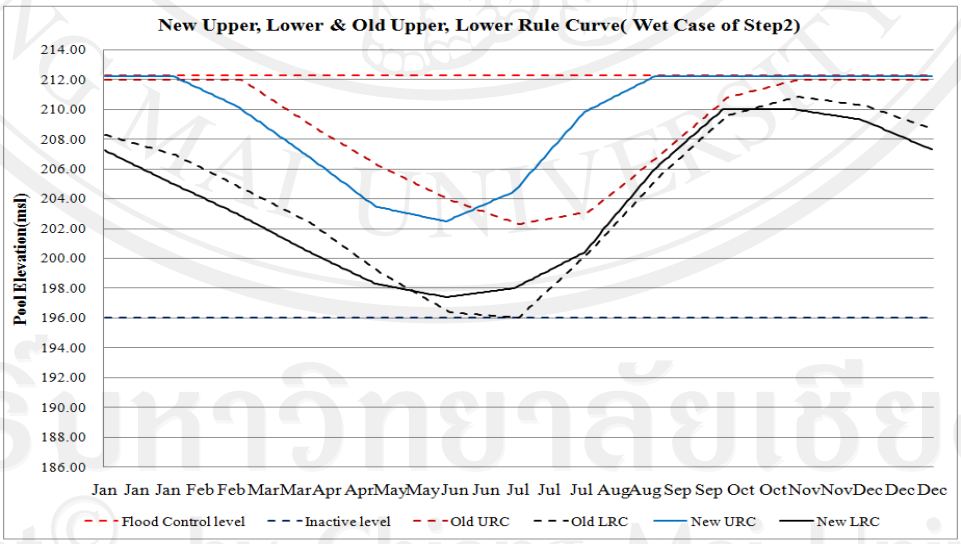

Figure 5.22 The result of revised upper and lower rule curve for NN-1 HPP

Figure 5.23 is a new rule curve. The result from the simulation model for the reservoir management of Nam Ngum-1 hydropower plant. This simulation is analyzed and compared between the actual elevations with simulation elevations. By using new rule curve as guideline for the reservoir operation and considers turbine release for energy generation and end of water level of the year.

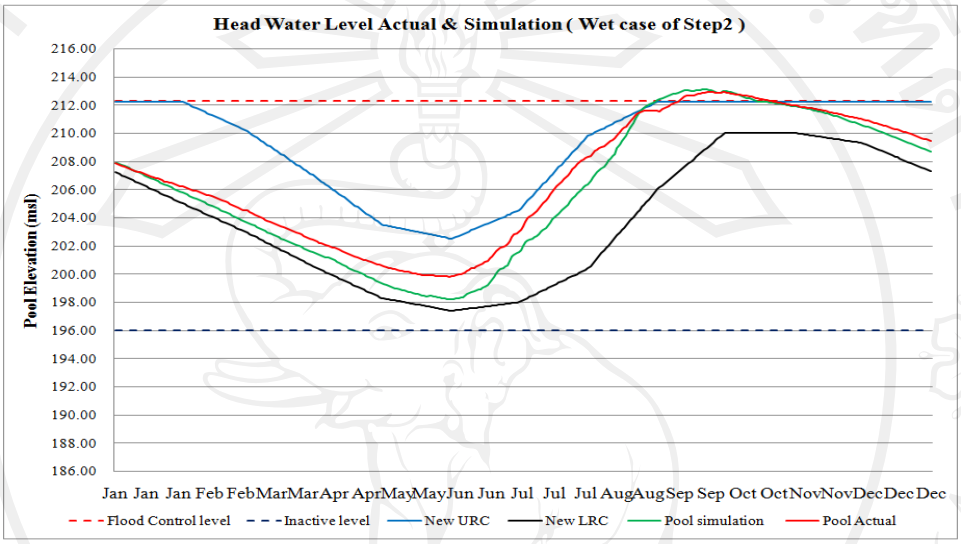

Figure 5.23 The simulation result for operation of NN-1 HPP in step 2

Figure 5.24 shows the annual actual and simulation model energy generation of Nam Ngum-1 hydropower plants which its actual data of 1,121.69 GWh/y and the simulation model provided 1,189.70 GWh/y. Due to these case are used the starting water elevation of the year is 207.87 m.a.s.l. On the other hand, the ending water elevation of the year has different level. The actual at end of the year was 209.36 m.a.s.l, the model provided 208.59 m.a.s.l.

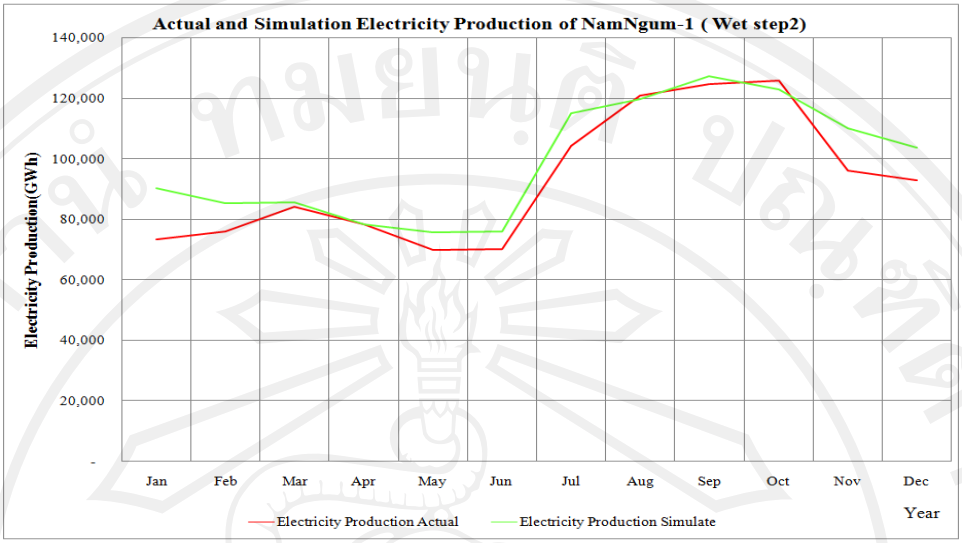

Figure 5.24 The simulation result for energy production of NN-1 HPP in step 2

5.3.3 Step three of wet case

Step 3 studies to modify guide rule curves and Figure 5.25 are the old upper and lower rule curves which are inactive. The HEC-ResSim3.0 model revises upper and lower rule curve as guideline for the reservoir operation. This step can be modified and used for comparison with other steps in wet case.

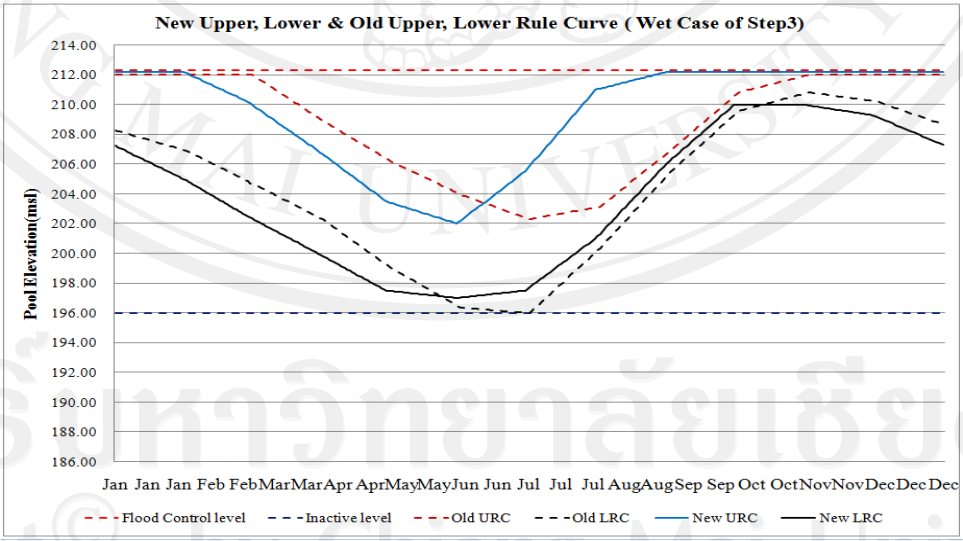

Figure 5.25 The result of revised upper and lower rule curve for NN-1 HPP

Figure 5.26 is a new rule curve. The result from the simulation model for the reservoir management of Nam Ngum-1 hydropower plant. This simulation is analyzed and compared between the actual elevations with simulation elevations. By using new rule curve as guideline for the reservoir operation and considers turbine release for energy generation and end of water level of the year.

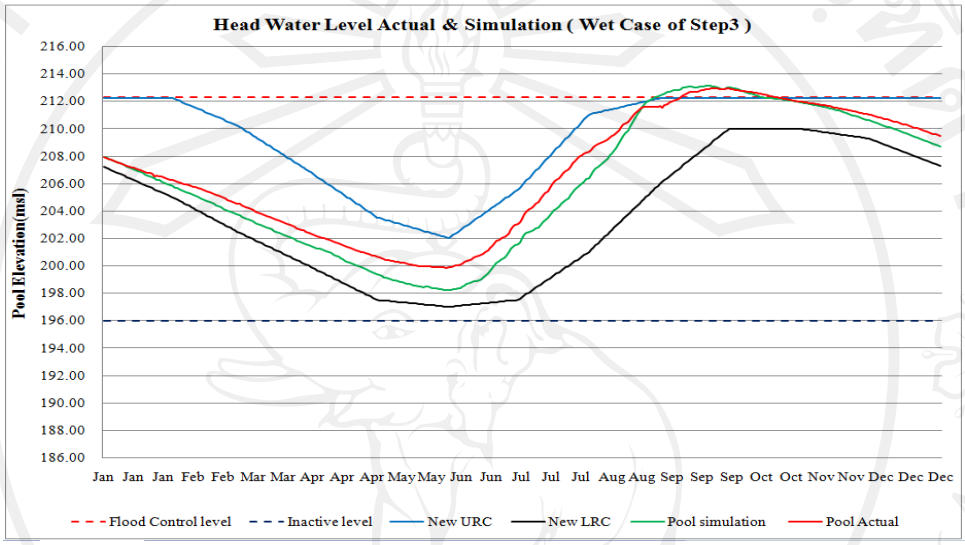

Figure 5.26 The simulation result for operation of NN-1 HPP in step 3

Figure 5.27 shows the annual actual and simulation model energy generation of Nam Ngum-1 hydropower plant which its actual data of 1,121.69 GWh/y and the simulation model provided 1,188.63 GWh/y. Due to this case, the starting water elevation of the year is 207.87 m.a.s.l. On the other hand, the ending water elevation of the year has different level. The actual at end of the year was 209.36 m.a.s.l, the model provided 208.59 m.a.s.l.

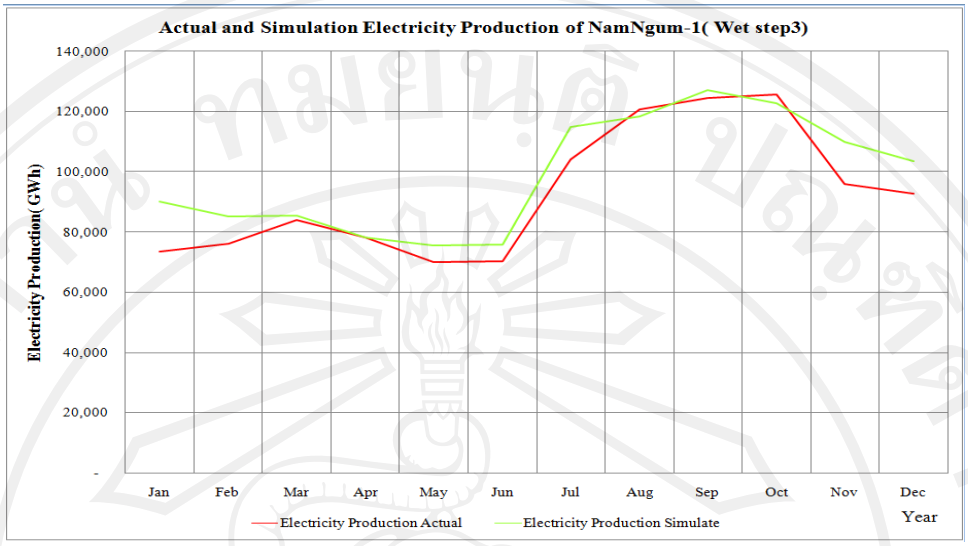

Figure 5.27 The simulation result for energy production of NN-1 HPP in step 3

The energy production of the model is generated from the power data input to the reservoir. The HEC-ResSim3.0 models provides the step 1, step 2 and step 3 amount of energy production, energy planning, water inflow, turbine release, spillway release, start of water elevation, end of water elevation, and revised upper rule curve and lower rule curve. The basic data are required as: generation requirements, installed capacity, an over load factor, overall efficiency, hydraulic loss and tail water level. Three steps are stimulated to find out the new rule curve for optimum electricity generation.

Third step is the best choice for optimum electricity generation for wet case. Hence, it is considered as best alternatives and all the results obtained under this case and this alternative are discussed below. As shown in table 5.5 the following general reports are obtained from second step.

- Energy actual (GWh/y) = 1,121.69
- Energy simulation (GWh/y) = 1,189.70
- Starting water elevation = 207.87 m.a.s.l
- Ending water elevation = 208.59 m.a.s.l
- Average generation efficiency = 0.97
- Hydraulic loss = 2 m
- Water station Use = 2 cms
- Average inflow = 162.32 cms

- Average turbine release = 159.00 cms
- Average spillway release = 8.92 cms

Finally, the second step has provided the new rule curve for wet case. That is shown in Table 5.6 and the detail is shown in Appendix E.

Table 5.5 Result simulation model of wet case years

Alternative	Location/Parameter	Units	Result of Simulation		
			Step 1	Step 2	Step 3
Wet Case	Start elevation	(m.a.s.l)	207.87	207.87	207.87
	End elevation	(m.a.s.l)	208.59	208.59	208.59
	Water inflow	(cms)	162.32	162.32	162.32
	Energy actual	(GWh/y)	1,121.69	1,121.69	1,121.69
	Energy simulation	(GWh/y)	1,189.16	1,189.70	1,188.63
	Minimum release	(cms)	361.80	361.80	361.80
	Turbine release	(cms)	159.00	159.00	159.00
	Spillway release	(cms)	9.10	8.92	9.35
	Time of spill	(days)	45.00	44.00	46.00
	Total release	(cms)	168.10	167.92	168.35
	Water station use	(m)	2.00	2.00	2.00
	Hydraulic loss	(cms)	2.00	2.00	2.00
	Efficiency	(%)	0.97	0.97	0.97

Table 5.6 Result for revised rule curve of wet case years

Month	Old Rule Curve		Step 1		Step 2		Step 3	
			New Rule Curve		New Rule Curve		New Rule Curve	
	URC	LRC	URC	LRC	URC	LRC	URC	LRC
Jan	212.00	208.30	212.20	207.30	212.20	207.30	212.20	207.30
Feb	212.00	206.90	212.20	205.00	212.20	205.00	212.20	205.00
Mar	212.00	204.70	210.20	203.00	210.20	203.00	210.20	202.50
Apr	208.90	202.30	206.90	200.50	206.90	200.50	206.90	200.00
May	206.20	199.00	204.50	198.30	203.50	198.30	203.50	197.50
Jun	203.90	196.40	203.00	197.50	202.50	197.40	202.00	197.00
Jul	202.30	196.00	205.00	199.50	204.50	198.00	205.50	197.50
Aug	203.10	200.40	210.10	203.40	209.80	200.40	211.00	201.00
Sep	206.90	205.50	212.20	207.50	212.20	206.00	212.20	206.00
Oct	210.80	209.60	212.20	209.60	212.20	210.00	212.20	210.00
Nov	212.00	210.80	212.20	210.00	212.20	210.00	212.20	210.00
Dec	212.00	210.20	212.20	209.20	212.20	209.30	212.20	209.30