Application of Geo-Informatics on Assessment of Mini-Hydropower Potential in Khao Luang Mountain Range, Nakhon Si Thammarat Province

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KEYWORDS: Geo-Informatics, Mini Hydropower, Khao Luang Mountain Range, SCS Curve Number

Abstract : Most of the energy used in Thailand is derived mainly from fossil fuel sources. It is generally accepted that such conventional energy causes adverse impacts to the environments and global warming. Thus, a research study to use clean and renewable energy such as hydropower, wind power, and solar energy is vitally needed. Previous research reports on sustainable energy indicate that hydropower is the most feasible alternative energy in the South of Thailand and the Mini-Hydropower Plants (MHP) can be designed to be economical and environmentally friendly. The proper sites of MHP are available in hilly regions for the higher "Head," and in moisture-filled tropical rainforests for the consistency of "Runoff". Construction of large dams, due to many environmental impacts, is often faced with resistance from conservation groups, whereas the demand of diversion weirs for irrigation purpose and check dams for forest restoration is on the increase. The diversion weirs and check dams can be modified to be the headwork for Mini-Hydro Power project. Khao Luang mountain range, which is the highest mountain in Southern Thailand, was selected for the feasibility study. This study area covers 15 districts of Nakorn Si Thammarat Province and 4 districts of Surat Thani Province. The upstream of Khao Luang mountain range is mostly covered by tropical rainforest. The average annual rainfall is more than 2,000 mm and the rainy season prevails more than 8 months a year. Thus, the runoff is abundant all year round. The terrain around Khao Luang mountain is rather steep, which is suitable for Mini-Hydro Power project. This study applied spatial data analysis techniques in GIS to evaluate the hydropower potential. The runoff was computed by SCS Curve Number hydrological model developed by U.S. Natural Resources Conservation Service. The findings of the study indicate 215 sites of mini hydropower plants around Khao Luang mountain range with the electricity production capacity of 35,9000 kW. This study report is specifically useful for promoting hydropower as the selective sustainable energy in Thailand.

INTRODUCTION

Present-day's concern of every country is with the problem related to energy. This is due to the fact that most energy sources widely used at present such as oil, natural gas, coals, uranium, etc. are derived from fossil fuels. Utilization of such fuels inevitably produces adverse effects to environment and causes global warming at an alarming rate. With an ever-increasing quantity of fuels consumed in all countries at present, it is estimated that energy from fossil sources will be depleted within a foreseeable period. Critical situations of energy shortage require searches for clean and alternative energy, such as solar energy, wind power and hydropower. Findings from such studies can be used to redress the problem of renewable energy sources and global warming in the future.

Hydropower is a clean energy which has been widely used in generating electricity efficiently. Nowadays, the construction of a large-scale hydropower dam is often met with resistance from the public due to its adverse impacts to the environment. In comparison, the construction of a small diversion weir is welcomed by farming communities around the watershed areas. The diversion weirs not only serve the irrigation and water utilization purposes but they also provide natural moistures to the forests. The concept of tapping hydropower from conversion weirs or check dams for generating electricity is feasible and can be a proper alternative for Thailand's future energy management.

Khao Luang mountain range is located in the areas of Nakhon Si Thammarat and Surat Thani provinces. The mountain range is characterized by steep and complex terrains, high annual rainfall index and degree of biodiversity. The watershed forests are intact in some areas and thus become the main water sources of water utilization for residents of both Nakhon Si Thammarat and Surat Thani. With all these rationales, the research team consider that it is viable to conduct a study into a potential utilization of the cascades around Khao Luang Hills for generating electricity. The study involved data collection from various agencies concerned as well as fieldwork and applied spatial data analysis techniques in GIS and hydrological model to evaluate the hydropower potential.

METHODS AND EQUATION

Assessment of Hydropower Potential

Assessment of hydropower potential (Figure 1) consists of major factors of discharge and head, having the following relationship:

$$P = \gamma Q H$$

When P is the potential of electricity (watt)

γ is unit of water weight (9,807 Newton/cubic meter)

Q is water flow rate (cubic meter/sec.)

H is head (meter)

Assessment of Head

Head is the difference of upstream elevation and downstream elevation. The value of upstream elevation is the level of water designed for the intake of the weir, whereas the value of downstream elevation is the level of water at the outlet leading to the power house, which can be calculated from the following formulation:

$$H = E_{US} - E_{DS}$$

When E_{US} is the value of upstream elevation (meter)

E_{DS} is the value of downstream elevation (meter)

In this study, elevations are identified from typographical map of the 1:50,000 scale and the Overlay Function of the water routes and Digital Elevation Model: DEM) in the GIS.

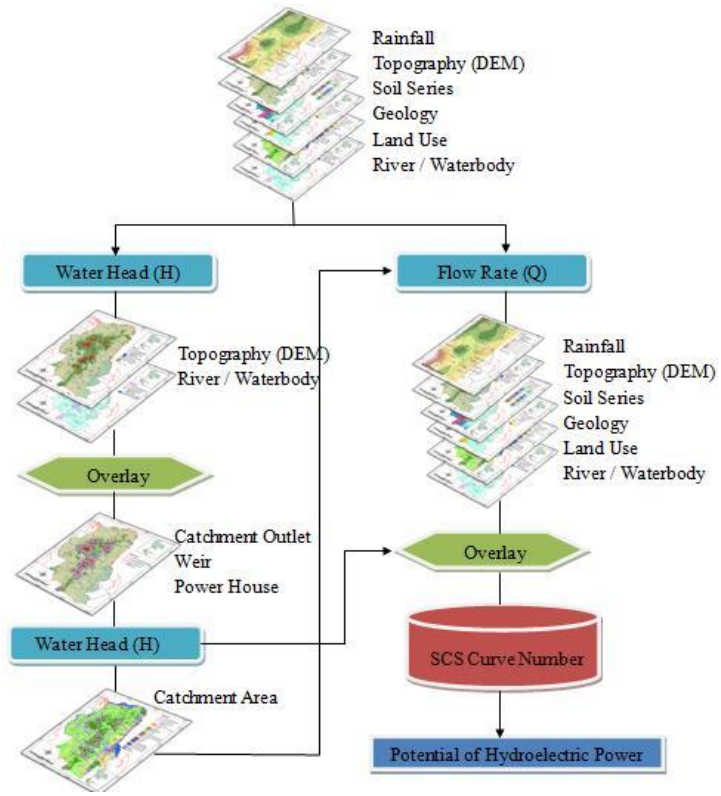

Figure 1: Steps of hydro potential assessment

Identification of Watershed Boundary

Watershed boundary is identified by Digital Elevation Model: DEM using Extension 3D Analysis and Hydrology Model Analysis, consisting of Fill and Flow Direction, Flow Accumulation, Stream Order and construction of watershed.

Assessment of Flow Rate

Flow rate or mass of runoff can be calculated using SCS-CN, which was established in 1954 by Soil Conservation Services (SCS) of the USA. Data on the condition of watershed areas facing the weir such as information on terrains, soil infiltration and vegetation are used in the calculation, thus producing the coefficient of the Runoff Curve Number or the average of CN for each watershed and then multiplied by the Catchment Area, resulting in the mass of runoff for each period in a year.

Coefficient of Runoff

Coefficient of runoff is based on 4 factors:

1) Terrain (Figure 2): gradients, which affect flow rate for both surface flow and subsurface flow during retention period and capacity of surface infiltration
2) Infiltration (Figure 3): type of soil, soil compactness and depth of layer and absorbance capacity of soil layer all have a direct effect on runoff.

3) Vegetation (figure 4) reduces the impact of raindrops on soil surface. Vegetation factor is correlated with absorbance capacity, reduction of flow rate of raindrops to the surface as well as with soil infiltration, thus delaying fast overflowing after raining.
4) Reservoirs at the surface (Figure 5): lake, swamp and marsh retain the water in the basin, thus reducing the runoff mass due to the retention and prevention of flow through the surface.

All factors can be given scores which determine the extent for which the basin accommodate the runoff, known as Runoff Curve Number of CN (Table 1), with a normal range of 0-100. If the CN is close to 0, it indicates that the basin has a good capacity in the absorbance and retention of the rainwater. On the contrary, if the CN is closer to 100, it shows that the basin is in the state of doubtful in absorbing and retaining the rainwater. The formulation is given in 5.6

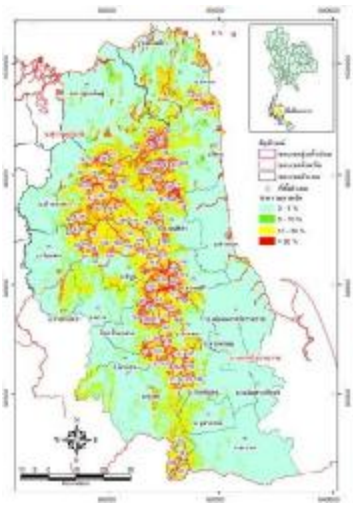

Figure 2: Terrain

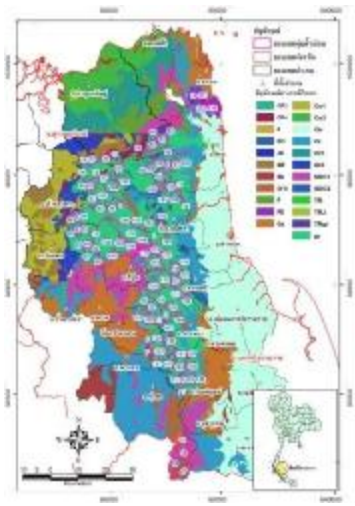

Figure 3: Infiltration

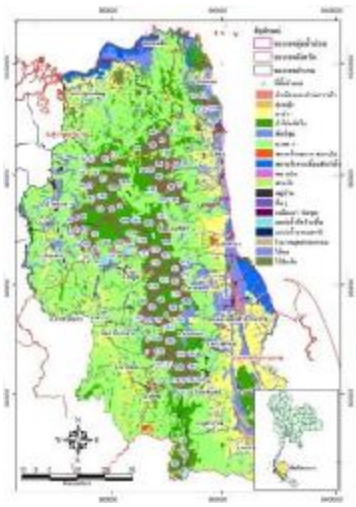

Figure 4: Vegetation

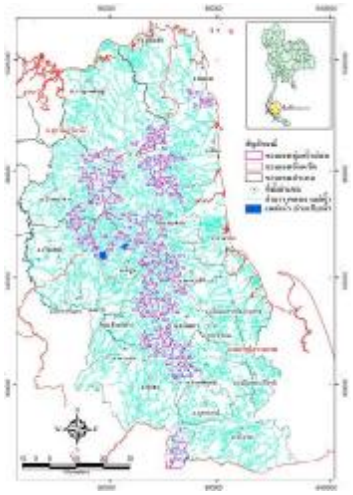

Figure 5: Reservoirs at the surface

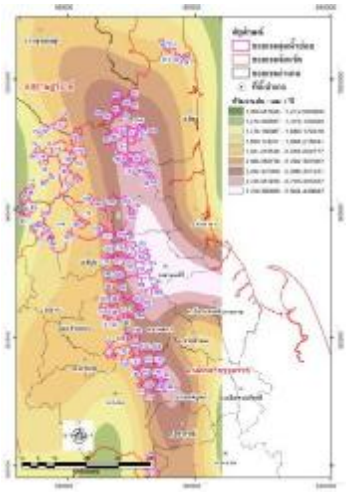

Figure 6: contours of rainfalls

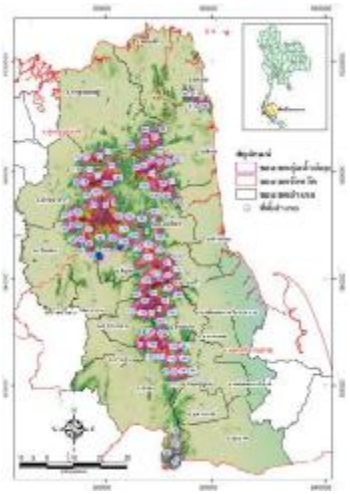

Figure 7: Khao Luang Hills catchment areas

Calculation of Runoff

Runoff can be calculated in the following:

$$P_e = \frac{(P_t - I_a)^2}{P_t - I_a + S}$$

When P_e is the depth of excess rain (inch)

P_t is the total rain (inch)

I_a is the starting absorbance (inch)

S is the highest potential of flow delay (inch)

From the study, it is found that $I_a = 0.2S$. Therefore, the above formula can be rewritten as the following:

$$P_e = \frac{(P_t - 0.2I_a)^2}{P_t + 0.8S}$$

Where S can be calculated from CN through the formulation

$$S = \frac{1000}{CN} - 10$$

Then the runoff mass Q is calculated for each month from

$$Q = \sum_{i=1}^{N} CN_i A_i$$

Rainfall

In this study a rainfall is calculated from daily rainfall indices as reported by the Meteorological Department. Monthly rainfalls are calculated for the past 10 years (2000-2009) based on records from 21 Rain Monitor Stations around the watershed or cascade areas of Khao Luang Hills and the surrounding areas covering 15 stations in Nakhon Si Thammarat, 4 stations in Surat Thani and 1 station in Phatthalung. The data gathered were used to formulate the contours of rainfalls for 12 months using the Spatial Interpolation in the GIS (Figure 6).

Table 1: Runoff Curve Number of SCS Curve Number

Characteristics	**I. Extreme CN (100)**	**II. High CN (75)**	**III. Normal CN (50)**	**IV. Low CN (25)**
Relief **(A)**	Mountainous area Slope > 30 % **(30-40)**	Hilly with slope slope10-30 % **(25-32)**	Rolling terrain Slope5-10 % **(17-24)**	Relatively flat slope 0-5 % **(5-16)**
Soil Infiltration **(B)**	Rocky, thin soil mantle **(17-20)**	Clay, slow infiltration **(12-16)**	Prairie soil, loam, deep soil mantle **(7-11)**	Sand, deep soil, rapid infiltration **(2-6)**
Vegetative cover **(C)**	No effective cover, plant cover bare **(17-20)**	Less than 10 % of area under good cover **(12-16)**	50 % of area in good grassland, woodland **(7-11)**	90 % of area in good grassland, woodland **(2-6)**
Surface storage **(D)**	No surface detention no pond **(17-20)**	Small drainage way **(12-16)**	Lakes, ponds and marshes less than 2% **(7-11)**	Large number of lakes, ponds and marshes **(2-6)**
CN = A+B+C+D				

Source : Schwab et al, 1971. Referred by Witthawatchutikul, 1997.

RESULTS

Catchment Areas

All 215 sites identified as catchment areas have potential for developing mini-hydropower plants. These include 176 sites in Nakhon Si Thammarat Province 27 sites in Nopphitam District, 27 sites in Sichon District, 23 sites in Lan Saka District, 23 sites in Phipun District, 19 sites in Thung Song District, 12 sites in Chang Klang District, 11 sites in Ron Phibun District, 10 sites in Phrom Khiri District, 8 sites in Chawang District, 7 sites in Khanom District, 4 sites in Tha Sala District, 2 sites in Cha-uat District, 2 sites in Na Bon District and 1 site in Muang District). In addition, 39 catchment areas are located in Surat Thani Province. There are 19 sites in Ban Na San District, 12 sites in Kanchanadit District and 8 sites in Wiang Sa District, as shown in Figure 7 and Table 2. Of all catchment areas, 156 sites are classified as 'very small sized catchment areas' (0-5 squire kilometer); 34 sites as 'small sized catchment areas (5-10 square kilometers), 13 sites as 'medium sized catchment areas' (10-15 square kilometers), 6 sites as 'large sized catchment areas' (15-20 square kilometers) and 6 sites as 'very large sized catchment areas' (> 20 square kilometers).

Head

Assessments of each catchment reveal the following: a 'very low head potential' – 5 sites (16-50 meters) (Table 2), a 'low head potential' – 25 sites (50-100 meters), a 'medium head potential' – 104 sites (100-150 meters), and a 'high head potential' – 66 sites (150-200 meters) and a 'very high heads potential' – 15 sites (200-250 meters). Most of these catchment areas are located in the forest reserves, national parks or wildlife sanctuaries, the areas prohibited from any structural changes. For practical purpose, there is a need to amend the Forest Reserve Acts to allow the construction of mini-hydropower plants in the areas since such constructions have little impacts on the forests and the environment.

Rainfalls

The amount of rainfalls in the watershed areas of Khao Luang Hills is approximately 1,056 mm/year. There are 83 watershed areas classified as having little rain (1,100-2,000 mm/year), most of which are located in Khanom, Chawang and Chang Klang Districts of Nakhon Si Thammarat and Ban Na San and Wiang Sa Districts of Surat Thani. 84 watershed areas are classified as having moderate rain (2,000-2,500 mm/year), most of which are located in Lan Saka, Phipun and Sichon Districts of Nakhon Si Thammarat and Kanchanadit District of Surat Thani. Furthermore, 48 watershed areas are classified as having high rain (2,500-2,800 mm/year), most of which are located in Phrom Khiri, Nopphitam, Ron Phibun and Muang Districts of Nakhon Si Thammarat.\

Runoff

Assessment of flow of runoffs using SCS Curve Number reveals 136 sites as having a 'very low flow' (<100 liters/sec.) (Table 2), 40 sites a 'low flow' (100-200 liters/sec.), 17 sites a 'moderate flow' (200-300 liters/sec.), 7 sites a 'high flow' (300-400 liters/sec.) and 15 sites a 'very high flow' (>400 liters/sec.).

Power Generation Capacity

Data analysis of the watershed or cascade areas around Khao Luang Hills reveals potentials for the development of the areas for mini-hydropower plants, with a total production capacity of 35,944 kilowatts (kW) (Table 2). The

production outputs come from 3 categories of mini-hydropower plants: 108 Micro Hydro Power Plants (5-100 kilowatts); Mini Hydro Power Plants (100-1,000 kilowatts) and 2 Small Hydro Power Plants (1,000-10,000 kilowatts).

CONCLUSIONS & RECOMMENDATIONS

The watershed areas around Khao Luang Hills cover 15 districts of Nakhon Si Thammarat and 4 districts of Surat Thani. The areas are classified as having a good potential for development of mini-hydropower plants at 215 sites, 176 of which are located in Nakhon Si Thammarat and 39 sites are in Surat Thani. Of all catchment areas, 156 sites are classified as 'very small sized catchment areas' (0-5 square kilometer); 34 sites as 'small sized catchment areas (5-10 square kilometers), 13 sites as 'medium sized catchment areas (10-15 square kilometers), 6 sites as 'large sized catchment areas (15-20 square kilometers) and 6 sites as 'very large sized catchment areas (> 20 square kilometers). Assessment of each catchment area reveals 5 sites having a 'very low head potential' (16-50 meters), 25 sites a 'low head potential' (50-100 meters), 104 sites a 'medium potential' (100-150 meters), 66 sites a 'high head potential' (150-200 meters) and 15 sites a 'very high head potential' (200-250 meters). Assessment of flow of runoff reveals 136 sites as having a 'very low flow' (<100 liters/sec.), 40 sites a 'low flow' (100-200 liters/sec.), 17 sites a 'moderate flow' (200-300 liters/sec.), 7 sites a 'high flow' (300-400 liters/sec.) and 15 sites a 'very high flow' (>400 liters/sec.). Finally, analyses of the watershed areas reveal potential for the development of the areas for mini-hydropower plants of different sizes: 108 tiny-sized plants (5-100 kilowatts); very small sized plants (100-1,000 kilowatts) and 2 small sized plants (1,000-1,500 kilowatts).

The assessment of potentials for development of hydropower plants reveals the suitability and pragmatism in using the GIS technique for the calculation of the Head. When applied with the SCS Curve Number hydrological model, it reveals ease of operation for the analysis of the CN sum total of each factor. However, due to the complication of the factors involved, there exist some limitations when the calculation for power generating capacity is made. Therefore, the Microsoft Excel software is also used in the calculation of electricity generation capacity.

There are also some constraints in the application of the Geo-Informatics on the assessment of hydropower potential. These shortcomings include the calculation of runoff in each catchment area, which is based on the data of amount of corresponding rainfalls from the rain monitoring station usually located in the district seat away from the catchment site, thus resulting in the figures of reported rainfalls lower than the actual amount. In fact, the watershed areas, which are covered with rainforests, naturally have a higher level of moisture and rainfall. In addition, the typographical maps with the scale of 1: 50,000 show inadequate details for data analysis of small sized catchment areas. Thus, in actual operation of the mini-hydropower project, it is recommended that the maps with the scale of 1:4,000 should be consulted, where the outcomes of DEM analysis are more observable. The fact that no Antecedence Moisture Content (AMC), which is an essential factor, is taken into account and this may cause an error in the analysis of the runoff. AMC is an essential factor which may cause errors in analysis of runoff. The amount of runoff derived from the calculation has not been verified and calibrated with the actual amount, due to lack of runoff monitoring station in each catchment site. In the actual implementation of the project, risk analyses should be made on possible landslides and soil erosions at each catchment site.

Table 2 : Outcomes of the Design Power

CODE	List of Hydro Power Site	District	Province	Catchment (sq.km.)	Head (m)	Discharge (LPS)	Hydro Potential (kW)	Design Power (kW)
001	Krung Ching Waterfall	Nopphitam	Nakhon Si Thammarat	52.65	174.84	1,677.73	2,877.60	1,000
002	Ka Rome Waterfall	Lan Saka	Nakhon Si Thammarat	17.52	221.29	541.68	1,175.89	900
003	Phrom Lok Waterfall	Phrom Khiri	Nakhon Si Thammarat	12.95	181.04	473.75	841.39	600
004	Ai Kiew Waterfall	Phrom Khiri	Nakhon Si Thammarat	9.69	176.11	359.38	620.90	500
005	Tapi River Site No. 5	Phipun	Nakhon Si Thammarat	24.34	102.96	642.10	648.53	500
006	Khlong Chum Kling No. 1	Phrom Khiri	Nakhon Si Thammarat	12.78	135.87	467.57	623.21	500
007	Khlong Phod	Nopphitam	Nakhon Si Thammarat	16.96	141.74	423.18	588.43	450
008	Suan Khun Waterfall	Chang Klang	Nakhon Si Thammarat	13.08	164.30	324.27	522.64	400
009	Khlong Ban Tal	Mueang Nakhon	Nakhon Si Thammarat	10.35	153.75	349.05	526.48	400
010	Khlong Klai No.1	Nopphitam	Nakhon Si Thammarat	12.62	125.10	426.36	523.25	400
011	Tha Phae Waterfall	Chang Klang	Nakhon Si Thammarat	13.02	150.55	329.08	486.00	350
012	Mae Sesthi Waterfall	Ron Phibun	Nakhon Si Thammarat	8.00	186.90	261.39	479.27	350
013	Ka Toon Reservoir	Phipun	Nakhon Si Thammarat	108.42	16.64	2,706.38	441.81	350
014	Khlong Din Daeng Reservoir	Phipun	Nakhon Si Thammarat	101.28	18.36	2,533.47	456.33	350
015	Khlong Ra Neia No. 3	Phipun	Nakhon Si Thammarat	20.54	88.72	545.87	475.11	350
016	Khlong Rung Kiat	Chang Klang	Nakhon Si Thammarat	9.47	197.38	238.61	462.01	350
017	Khlong Mhaen	Chang Klang	Nakhon Si Thammarat	11.93	155.55	297.14	453.42	350
018	Yong Waterfall No. 1	Thung Song	Nakhon Si Thammarat	11.79	158.15	265.57	412.03	300
019	Khlong Tha Thon No. 1	Sichon	Nakhon Si Thammarat	16.92	92.92	431.68	393.48	300
020	Khlong Krung Chung	Kanchanadit	Surat Thani	9.90	153.68	262.40	395.60	300
021	Khlong Perk	Thung Song	Nakhon Si Thammarat	11.40	162.12	257.29	409.19	300
022	Khlong Phong No. 1	Lan Saka	Nakhon Si Thammarat	9.01	138.78	287.47	391.37	300
023	Khlong Klai No. 2	Nopphitam	Nakhon Si Thammarat	15.78	81.41	527.68	421.44	300
024	Huay Jik	Nopphitam	Nakhon Si Thammarat	9.55	122.09	327.07	391.74	300
025	Khlong Pook	Chawang	Nakhon Si Thammarat	9.32	164.25	231.12	372.39	275
026	Khlong Khun Phung No. 6	Ron Phibun	Nakhon Si Thammarat	10.73	109.50	345.48	371.11	275
027	Khlong Jae Dee No. 1	Lan Saka	Nakhon Si Thammarat	5.86	192.13	191.35	360.66	275
028	Khlong Huay Noppitam No.2	Nopphitam	Nakhon Si Thammarat	6.72	164.20	234.19	377.24	275
029	Khlong Dai	Sichon	Nakhon Si Thammarat	5.44	210.31	147.42	304.16	250
030	Khlong Thao No. 2	Sichon	Nakhon Si Thammarat	8.87	136.55	233.76	313.13	250
031	Khlong Hai	Nopphitam	Nakhon Si Thammarat	11.82	91.62	400.35	359.84	250
032	Khlong Kun	Nopphitam	Nakhon Si Thammarat	8.33	116.44	287.20	328.06	250
033	Play Jawuk Waterfall	Phrom Khiri	Nakhon Si Thammarat	4.03	182.05	156.53	279.55	200
034	Nhan Jon Waterfall	Phipun	Nakhon Si Thammarat	14.27	80.22	385.60	303.44	200
035	Khlong Wang Heeb No. 3	Thung Song	Nakhon Si Thammarat	12.87	103.13	288.59	291.97	200
036	Khlong Wang Hong	Lan Saka	Nakhon Si Thammarat	8.29	100.14	265.56	260.87	200
037	Khlong Klai No. 1	Nopphitam	Nakhon Si Thammarat	4.14	178.12	148.31	259.16	200
038	Khlong Phitam No. 1	Nopphitam	Nakhon Si Thammarat	4.84	158.63	171.76	267.29	200
039	Khlong Lan Saka	Lan Saka	Nakhon Si Thammarat	4.30	182.32	142.90	255.59	180
040	Khlong Tha Pud	Nopphitam	Nakhon Si Thammarat	5.81	127.85	204.18	256.08	180
041	Khlong Jung	Ban Bon	Nakhon Si Thammarat	5.12	172.95	136.24	231.15	175
042	Soy Dao Waterfall	Lan Saka	Nakhon Si Thammarat	3.78	196.31	126.76	244.11	175
043	Khlong Thao No.	Sichon	Nakhon Si Thammarat	6.70	132.87	179.21	233.60	175

Table 2 : Outcomes of the Design Power (Continued)

CODE	List of Hydro Power Site	District	Province	Catchment (sq.km.)	Head (m)	Discharge (LPS)	Hydro Potential (kW)	Design Power (kW)
044	Huay Keow No. 1	Nopphitam	Nakhon Si Thammarat	7.52	96.34	260.77	246.46	175
045	Khlong Khud Lek	Kanchanadit	Surat Thani	4.70	193.77	129.85	246.83	175
046	Khlong Thong Ork	Chang Klang	Nakhon Si Thammarat	5.60	165.41	145.36	235.87	175
047	Khlong Phun Tal	Nopphitam	Nakhon Si Thammarat	5.27	128.61	186.04	234.72	175
048	Khlong Huay Noppitam No.1	Nopphitam	Nakhon Si Thammarat	4.18	160.03	149.65	234.94	175
049	Krung Nang	Nopphitam	Nakhon Si Thammarat	3.29	177.84	119.53	208.54	150
050	Nhan Chong Fah	Sichon	Nakhon Si Thammarat	6.85	109.48	182.96	196.49	150
051	Khlong Tha Lao No. 1	Thung Song	Nakhon Si Thammarat	8.37	114.51	192.05	215.73	150
052	Huay Tha Sai	Lan Saka	Nakhon Si Thammarat	3.89	172.56	130.17	220.36	150
053	Khlong Yha No. 1	Nopphitam	Nakhon Si Thammarat	3.44	165.20	124.72	202.13	150
054	Khlong Tha Lheek	Sichon	Nakhon Si Thammarat	6.70	107.65	179.23	189.28	140
055	Khlong Sa Laow	Chawang	Nakhon Si Thammarat	5.29	141.67	135.54	188.38	140
056	Khlong Sra	Kanchanadit	Surat Thani	5.44	128.22	148.99	187.39	140
057	Khlong Khlong Naok Tha	Phrom Khiri	Nakhon Si Thammarat	2.38	196.55	95.42	183.99	140
058	Wang Pring	Thung Song	Nakhon Si Thammarat	4.01	186.08	96.05	175.33	125
059	Huay Mod	Sichon	Nakhon Si Thammarat	5.14	127.05	139.75	174.18	125
060	Khlong Khram No. 1	Kanchanadit	Surat Thani	9.71	68.33	257.67	172.73	125
061	Khlong Yha No. 2	Nopphitam	Nakhon Si Thammarat	2.70	184.62	99.25	179.75	125
062	Khlong La Ai Yai	Chawang	Nakhon Si Thammarat	4.54	145.91	117.30	167.90	120
063	Khlong Kong Sied	Ban Na San	Surat Thani	16.12	71.44	239.76	168.04	120
064	Huay Yang Daeng	Phipun	Nakhon Si Thammarat	2.54	214.81	75.87	159.87	120
065	Khlong Ra Neia No. 1	Phipun	Nakhon Si Thammarat	5.49	102.89	156.10	157.56	120
066	Khlong Pien No. 1	Lan Saka	Nakhon Si Thammarat	4.20	119.59	139.78	163.99	120
067	Khlong Khun Bed No.	Lan Saka	Nakhon Si Thammarat	3.26	148.57	110.32	160.78	120
068	Song Ruk Waterfall	Phrom Khiri	Nakhon Si Thammarat	2.58	160.41	103.02	162.11	120
069	Khlong Pien No. 1	Sichon	Nakhon Si Thammarat	4.24	134.50	116.52	153.75	110
070	Tha Noy	Khanom	Nakhon Si Thammarat	3.61	158.20	98.01	152.11	110
071	Khlong Hyee Phong	Chawang	Nakhon Si Thammarat	5.87	107.58	149.44	157.71	110
072	Khlong Nhong Yai	Ban Na San	Surat Thani	7.13	141.84	111.17	154.69	110
073	Khlong Phuen	Phipun	Nakhon Si Thammarat	3.40	160.94	99.55	157.17	110
074	Khlong Ra Neia No. 2	Phipun	Nakhon Si Thammarat	4.86	110.71	139.14	151.11	110
075	Khlong Tha Praeng	Nopphitam	Nakhon Si Thammarat	2.54	167.98	93.69	154.39	110
076	Huay Thong Yang	Sichon	Nakhon Si Thammarat	4.13	133.55	113.64	148.88	110
077	Khlong Khao Keow	Lan Saka	Nakhon Si Thammarat	3.69	118.74	123.68	144.07	100
078	Khlong Play Aun	Phrom Khiri	Nakhon Si Thammarat	1.92	182.31	78.01	139.52	100
079	Khlong Chum Kling No. 2	Phrom Khiri	Nakhon Si Thammarat	2.22	163.17	89.51	143.28	100
080	Khlong Khae	Nopphitam	Nakhon Si Thammarat	2.17	181.73	80.97	144.36	100
081	Su Nan Ta Waterfall	Tha Sala	Nakhon Si Thammarat	2.86	160.39	79.55	125.16	90
082	Khlong Khud Yai	Kanchanadit	Surat Thani	2.88	149.00	82.21	120.17	90
083	Khlong Huay Khoon No.	Phipun	Nakhon Si Thammarat	4.46	109.07	128.44	137.43	90
084	Khlong Wang Heeb No. 4	Thung Song	Nakhon Si Thammarat	6.14	99.77	143.42	140.37	90
085	Khlong Khoo Ha	Ron Phibun	Nakhon Si Thammarat	4.64	82.13	156.39	126.00	90
086	Khlong San Khoon No. 2	Lan Saka	Nakhon Si Thammarat	2.26	168.57	78.25	129.40	90

Table 2 : Outcomes of the Design Power (Continued)

CODE	List of Hydro Power Site	District	Province	Catchment (sq.km.)	Head (m)	Discharge (LPS)	Hydro Potential (kW)	Design Power (kW)
087	Khlong Chon	Nopphitam	Nakhon Si Thammarat	2.29	154.72	85.06	129.10	90
088	Khlong Klai No. 3	Nopphitam	Nakhon Si Thammarat	2.71	140.52	99.71	137.45	90
089	Khlong Klai No. 4	Nopphitam	Nakhon Si Thammarat	2.60	139.08	95.66	130.52	90
090	Khlong Chang Hai	Sichon	Nakhon Si Thammarat	2.93	158.09	82.40	127.80	90
091	Khlong Nam Thao No. 1	Wiang Sa	Surat Thani	9.53	80.03	146.40	114.94	80
092	Huay Nam Sai Reservoir	Cha-uat	Nakhon Si Thammarat	31.59	22.62	537.94	119.35	80
093	Khlong Tha Thong	Kanchanadit	Surat Thani	2.72	148.00	77.82	112.99	80
094	Khlong Ther	Ban Na San	Surat Thani	4.34	168.35	69.89	115.42	80
095	Khlong Huay Thao	Phipun	Nakhon Si Thammarat	3.27	114.93	96.04	108.29	80
096	Khlong Traow	Chang Klang	Nakhon Si Thammarat	3.33	133.40	89.23	116.77	80
097	Huay Na Mhed	Phrom Khiri	Nakhon Si Thammarat	1.32	211.20	55.02	113.99	80
098	Khlong Ai Kiew	Phrom Khiri	Nakhon Si Thammarat	1.39	195.60	57.79	110.89	80
099	Khlong Phitam No. 2	Nopphitam	Nakhon Si Thammarat	1.88	156.15	70.82	108.48	80
100	Wang Si La Ruk	Ron Phibun	Nakhon Si Thammarat	2.21	139.59	78.09	106.93	75
101	Khlong Whad No. 1	Sichon	Nakhon Si Thammarat	2.10	181.88	60.42	107.81	75
102	Huay Ton Phor	Kanchanadit	Surat Thani	3.33	112.67	94.03	103.93	75
103	Khlong Tha Laow No. 2	Thung Song	Nakhon Si Thammarat	3.93	109.64	94.42	101.55	75
104	Khlong Jae Dee No. 2	Lan Saka	Nakhon Si Thammarat	1.47	204.93	52.28	105.09	75
105	Khlong Khun Bed No.	Lan Saka	Nakhon Si Thammarat	1.31	219.85	46.96	101.29	75
106	Khlong San Khoon No. 1	Lan Saka	Nakhon Si Thammarat	1.96	156.22	68.50	104.97	75
107	Khlong Tha Thon No. 2	Sichon	Nakhon Si Thammarat	3.67	106.65	101.70	106.41	75
108	Khlong Khun Bed No. 1	Ban Na San	Surat Thani	4.04	147.46	65.39	94.60	60
109	Dad Fah Waterfall	Ban Na San	Surat Thani	5.79	101.19	91.45	90.78	60
110	Wang Mheun Plarn	Lan Saka	Nakhon Si Thammarat	1.41	173.99	50.44	86.09	60
111	Suan Ai	Chawang	Nakhon Si Thammarat	2.54	128.03	68.19	85.64	60
112	Khlong Plien	Sichon	Nakhon Si Thammarat	2.54	125.93	72.14	89.12	60
113	Khlong Mheun Hed	Sichon	Nakhon Si Thammarat	3.14	100.98	88.07	87.24	60
114	Huay Sao	Phipun	Nakhon Si Thammarat	2.27	131.31	68.32	88.01	60
115	Khlong Khun Phung No. 5	Ron Phibun	Nakhon Si Thammarat	2.38	105.48	83.58	86.49	60
116	Khlong Phitam No. 3	Nopphitam	Nakhon Si Thammarat	1.94	128.08	72.91	91.60	60
117	Huay Ward	Nopphitam	Nakhon Si Thammarat	1.45	164.72	55.65	89.93	60
118	Khlong Tha Thon No. 3	Sichon	Nakhon Si Thammarat	1.68	175.08	49.15	84.41	60
119	Khlong Tha Kwai No. 2	Sichon	Nakhon Si Thammarat	1.63	196.30	47.91	92.27	60
120	Khao Mhaen	Chang Klang	Nakhon Si Thammarat	2.10	119.50	58.01	68.00	50
121	Khlong Nhae No. 1	Chang Klang	Nakhon Si Thammarat	1.77	166.11	50.44	82.20	50
122	Tara Warin Waterfall	Thung Song	Nakhon Si Thammarat	19.77	18.03	434.12	76.78	50
123	Pliew Waterfall	Thung Song	Nakhon Si Thammarat	2.00	154.86	50.36	76.51	50
124	Tha Chana Waterfall	Tha Sala	Nakhon Si Thammarat	1.06	224.49	31.72	69.85	50
125	Khlong Khoo Phamar No. 2	Tha Sala	Nakhon Si Thammarat	2.33	125.44	65.85	81.04	50
126	Khlong Whad No. 2	Sichon	Nakhon Si Thammarat	2.83	99.06	79.81	77.56	50
127	Huay Nam Ron	Sichon	Nakhon Si Thammarat	1.35	205.20	40.13	80.78	50
128	Huay King Yao	Ban Na San	Surat Thani	2.99	142.76	49.48	69.29	50
129	Khlong La	Wiang Sa	Surat Thani	5.12	90.20	81.70	72.29	50

Table 2 : Outcomes of the Design Power (Continued)

CODE	List of Hydro Power Site	District	Province	Catchment (sq.km.)	Head (m)	Discharge (LPS)	Hydro Potential (kW)	Design Power (kW)
130	Khlong Ka Biead No. 2	Chawang	Nakhon Si Thammarat	4.03	78.39	104.97	80.72	50
131	Khlong Nad	Phipun	Nakhon Si Thammarat	2.70	85.96	80.13	67.57	50
132	Tapi River Site No. 4	Phipun	Nakhon Si Thammarat	3.03	91.15	89.35	79.90	50
133	Khlong Nhae No. 3	Chang Klang	Nakhon Si Thammarat	1.41	174.36	40.02	68.46	50
134	Huay Pud	Ron Phibun	Nakhon Si Thammarat	0.90	214.28	34.02	71.51	50
135	Khlong Ka Rome Branch	Lan Saka	Nakhon Si Thammarat	0.99	220.36	36.51	78.92	50
136	Khlong Tha Noy No. 2	Sichon	Nakhon Si Thammarat	2.10	116.84	60.47	69.32	50
137	Huay Keow No. 2	Nopphitam	Nakhon Si Thammarat	1.51	142.01	57.73	80.43	50
138	Nhan Sawan Waterfall	Cha-uat	Nakhon Si Thammarat	5.08	66.07	95.50	61.89	40
139	Hin Lad Waterfall	Khanom	Nakhon Si Thammarat	1.68	160.49	39.50	62.19	40
140	Khlong Nam Sai	Sichon	Nakhon Si Thammarat	1.43	149.35	42.39	62.11	40
141	Khlong Khram No. 2	Kanchanadit	Surat Thani	2.03	103.37	59.32	60.16	40
142	Khlong Whad No. 3	Sichon	Nakhon Si Thammarat	1.98	104.89	57.20	58.85	40
143	Huay Ta Phap Nam	Kanchanadit	Surat Thani	1.59	142.94	47.15	66.11	40
144	Huay Song Pe Nong	Kanchanadit	Surat Thani	1.52	131.14	45.23	58.19	40
145	Khlong Yha	Ban Na San	Surat Thani	2.71	147.95	45.18	65.58	40
146	Huay Yot	Ban Na San	Surat Thani	3.34	104.92	54.78	56.38	40
147	Khlong Pik	Chang Klang	Nakhon Si Thammarat	1.53	158.15	43.31	67.19	40
148	Khlong Wang Heeb No. 1	Ban Bon	Nakhon Si Thammarat	1.13	187.75	33.44	61.58	40
149	Khlong Khun Phung No. 1	Ron Phibun	Nakhon Si Thammarat	0.68	218.00	26.03	55.66	40
150	Khlong Wang Khae	Lan Saka	Nakhon Si Thammarat	1.25	136.68	44.98	60.31	40
151	Khlong Prik No. 1	Lan Saka	Nakhon Si Thammarat	1.37	128.91	49.01	61.98	40
152	Khlong Khoo Phamar No. 1	Tha Sala	Nakhon Si Thammarat	0.97	211.89	29.27	60.85	40
153	Khlong Tha Noy No. 1	Sichon	Nakhon Si Thammarat	1.40	149.17	41.41	60.60	40
154	Khlong Bang Mod	Khanom	Nakhon Si Thammarat	1.69	148.65	39.66	57.84	40
155	Khlong Ta Mheun	Sichon	Nakhon Si Thammarat	1.45	148.04	42.85	62.22	40
156	Khu Ha Sawan	Ron Phibun	Nakhon Si Thammarat	1.81	86.89	64.62	55.08	30
157	Phai Tong	Sichon	Nakhon Si Thammarat	1.77	97.75	51.57	49.45	30
158	Khlong Kong Tak	Kanchanadit	Surat Thani	1.15	138.69	34.93	47.52	30
159	Khlong Nhong Noy	Ban Na San	Surat Thani	3.51	82.65	57.42	46.55	30
160	Huay Khlang	Phipun	Nakhon Si Thammarat	0.84	161.81	27.17	43.12	30
161	Khlong Huay Khoon No. 2	Phipun	Nakhon Si Thammarat	1.49	95.91	46.19	43.46	30
162	Khlong Khud Duan	Chang Klang	Nakhon Si Thammarat	1.88	82.78	52.34	42.50	30
163	Khlong Nhae No. 2	Chang Klang	Nakhon Si Thammarat	0.89	165.70	26.21	42.61	30
164	Khlong Wang Heeb No. 5	Thung Song	Nakhon Si Thammarat	0.91	189.95	24.39	45.45	30
165	Khlong Tha Jon No. 3	Thung Song	Nakhon Si Thammarat	1.32	153.45	34.33	51.67	30
166	Khlong Tha Jon No. 1	Thung Song	Nakhon Si Thammarat	2.04	103.37	51.29	52.01	30
167	Khlong Yong No. 2	Thung Song	Nakhon Si Thammarat	1.90	105.18	47.92	49.44	30
168	Khlong Thalerng	Ron Phibun	Nakhon Si Thammarat	0.46	251.65	18.16	44.82	30
169	Khlong Phong No. 3	Lan Saka	Nakhon Si Thammarat	0.53	207.65	20.64	42.05	30
170	Khlong Tha Noy No. 3	Sichon	Nakhon Si Thammarat	1.06	146.91	32.20	46.41	30
171	Khlong Khlong Tha Coke	Sichon	Nakhon Si Thammarat	0.95	166.01	28.99	47.21	30
172	Khlong Tha Nai	Khanom	Nakhon Si Thammarat	1.26	138.66	30.21	41.09	30

Table 2 : Outcomes of the Design Power (Continued)

CODE	List of Hydro Power Site	District	Province	Catchment (sq.km.)	Head (m)	Discharge (LPS)	Hydro Potential (kW)	Design Power (kW)
173	Khlong Plao	Khanom	Nakhon Si Thammarat	1.20	161.88	28.95	45.97	30
174	Sarm Hah Jed	Wiang Sa	Surat Thani	2.27	109.65	38.40	41.31	25
175	Khlong Chawang No. 1	Ban Na San	Surat Thani	2.02	114.48	34.45	38.69	25
176	Huay Thon	Ban Na San	Surat Thani	1.37	157.24	24.01	37.03	25
177	Khlong Phung Poon	Ban Na San	Surat Thani	2.40	102.92	40.35	40.74	25
178	Huay Mhak	Phipun	Nakhon Si Thammarat	1.03	119.80	32.77	38.51	25
179	Khlong Tha Jon No. 2	Thung Song	Nakhon Si Thammarat	1.49	101.58	38.17	38.04	25
180	Kiri Rob	Kanchanadit	Surat Thani	0.98	99.58	29.20	28.52	20
181	Yod Rhueng or Muang Mai	Nopphitam	Nakhon Si Thammarat	0.56	133.43	23.22	30.39	20
182	Samed Choon	Khanom	Nakhon Si Thammarat	0.91	150.68	22.32	32.99	20
183	Huay Ta Kien	Wiang Sa	Surat Thani	1.48	128.42	25.94	32.68	20
184	Mhueng Taud	Ban Na San	Surat Thani	1.59	109.85	27.54	29.68	20
185	Khlong Lhong Thong	Ban Na San	Surat Thani	1.84	103.03	31.55	31.89	20
186	Khlong Ro	Ban Na San	Surat Thani	1.51	127.94	26.39	33.12	20
187	Khlong Chawang No. 3	Ban Na San	Surat Thani	1.12	146.86	20.06	28.89	20
188	Huay Khling	Wiang Sa	Surat Thani	1.26	121.78	22.27	26.61	20
189	Khlong Tal	Wiang Sa	Surat Thani	1.64	110.75	28.42	30.88	20
190	Huay Sai Khao	Wiang Sa	Surat Thani	1.31	131.24	23.23	29.91	20
191	Khlong Ka Biead No. 3	Chawang	Nakhon Si Thammarat	0.98	108.39	28.30	30.09	20
192	Tapi River Site No. 2	Phipun	Nakhon Si Thammarat	0.67	131.40	21.98	28.33	20
193	Khlong Wang Heeb No. 2	Thung Song	Nakhon Si Thammarat	0.92	130.05	24.63	31.42	20
194	Khlong Tha Lao No. 3	Thung Song	Nakhon Si Thammarat	0.88	124.25	23.61	28.78	20
195	Khlong Phong No. 2	Lan Saka	Nakhon Si Thammarat	0.75	110.14	28.15	30.41	20
196	Khlong Tha Kwai No. 1	Sichon	Nakhon Si Thammarat	0.53	184.53	17.16	31.06	20
197	Khlong Thong Hyee	Khanom	Nakhon Si Thammarat	1.15	100.13	27.83	27.33	20
198	Khlong Ka Biead No. 1	Chawang	Nakhon Si Thammarat	0.69	115.09	20.41	23.05	15
199	Huay Thub Kruer	Phipun	Nakhon Si Thammarat	0.61	121.60	20.25	24.16	15
200	Tapi River Site No. 3	Phipun	Nakhon Si Thammarat	0.46	152.03	15.74	23.48	15
201	Tapi River Site No. 6	Phipun	Nakhon Si Thammarat	0.58	130.77	19.32	24.78	15
202	Khlong Tha Jon No. 4	Thung Song	Nakhon Si Thammarat	0.40	204.51	11.46	22.99	15
203	Khlong Khun Phung No. 2	Ron Phibun	Nakhon Si Thammarat	0.36	143.70	14.80	20.86	15
204	Khlong Pien No. 2	Lan Saka	Nakhon Si Thammarat	0.43	138.52	16.95	23.04	15
205	Khlong Prik No. 2	Lan Saka	Nakhon Si Thammarat	0.45	135.47	17.64	23.44	15
206	Tharn Thip Waterfall	Thung Song	Nakhon Si Thammarat	3.75	16.68	101.75	16.65	10
207	Nhan Pliew Waterfall	Thung Song	Nakhon Si Thammarat	0.50	100.22	14.18	13.94	10
208	Khlong Chawang No. 2	Ban Na San	Surat Thani	0.76	124.65	14.00	17.12	10
209	Khlong Nam Thao No. 2	Ban Na San	Surat Thani	0.90	121.98	16.37	19.58	10
210	Huay Sai Khao	Phipun	Nakhon Si Thammarat	0.47	125.44	15.85	19.50	10
211	Tapi River Site No. 1	Phipun	Nakhon Si Thammarat	0.44	112.72	15.17	16.78	10
212	Khao Luang Waterfall	Lan Saka	Nakhon Si Thammarat	0.40	65.25	15.99	10.24	5
213	Khlong Khun Bed No. 2	Ban Na San	Surat Thani	0.50	81.32	9.58	7.65	5
214	Khlong Nam Thao No. 3	Wiang Sa	Surat Thani	0.36	149.79	7.23	10.62	5
215	Khlong Khun Phung No. 3	Ron Phibun	Nakhon Si Thammarat	0.22	136.46	9.50	12.72	5

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