Attachment 07

Damage Estimation of Large Floods

1. Estimated Damages in case of a flood exceeding the 2011 flood

The DALA method (the Damage and Loss Assessment methodology) was used for estimating the 2011 flood damage by the World Bank and Thailand's Ministry of Finance (Thailand Flooding 2554 Rapid Assessment for Resilient Recovery and Reconstruction). The same method was employed to have a rough estimate of damages in case of a flood exceeding the 2011 flood.

2. Sectors of Damage Estimation

The table below indicates the sectors, damages and loss of which are to be estimated.

Table Sectors of Damage Estimation

Sectors	Damages/Losses		
	Direct Damages	Indirect Losses	Macro-economic Influences
Social Sector			
Domestic	○	○	○
Education/Culture	○	○	○
Health/Medical	○	○	○
Infrastructure			
Energy	○	○	−
Water Supply and Hygiene	○	○	○
Transport/Communication	○	○	−
Economic Sector			
Agriculture	○	○	−
Industry	○	○	○
Commerce	○	○	○
Tourism	○	○	○
Comprehensive Influences of disasters			
Environment	○	○	−
Women	○	○	−
Macro-economic Influences	−	−	○

3. Damage Evaluation Criteria

The following two criteria are used to evaluate disaster damages.

(1) Depreciated Price (Book Value) of Damaged Assets:
Evaluate the value of damaged assets before the disaster, and estimate the value considering the remaining life

(2) Replacement Cost
Cost for replacing the damaged assets. Add the additional cost for disaster preparedness to the value of damaged assets before the disaster.

One of the criteria is used considering the characteristics of assets to be evaluated, the availability of necessary information, and the time allowed tor the evaluation.

4. Method Employed for Estimating Damages of a Flood Exceeding 2011 Flood

The results of inundation calculation are combined with the 2011 flood damages estimated by the DALA method to estimate the damages of a flood exceeding the scale of 2011 flood.
Conditions are:
(1) Damages are to be estimated by the provinces indicated in the Rapid Assessment
(2) Damage of a province is proportional to the inundation volume of the province

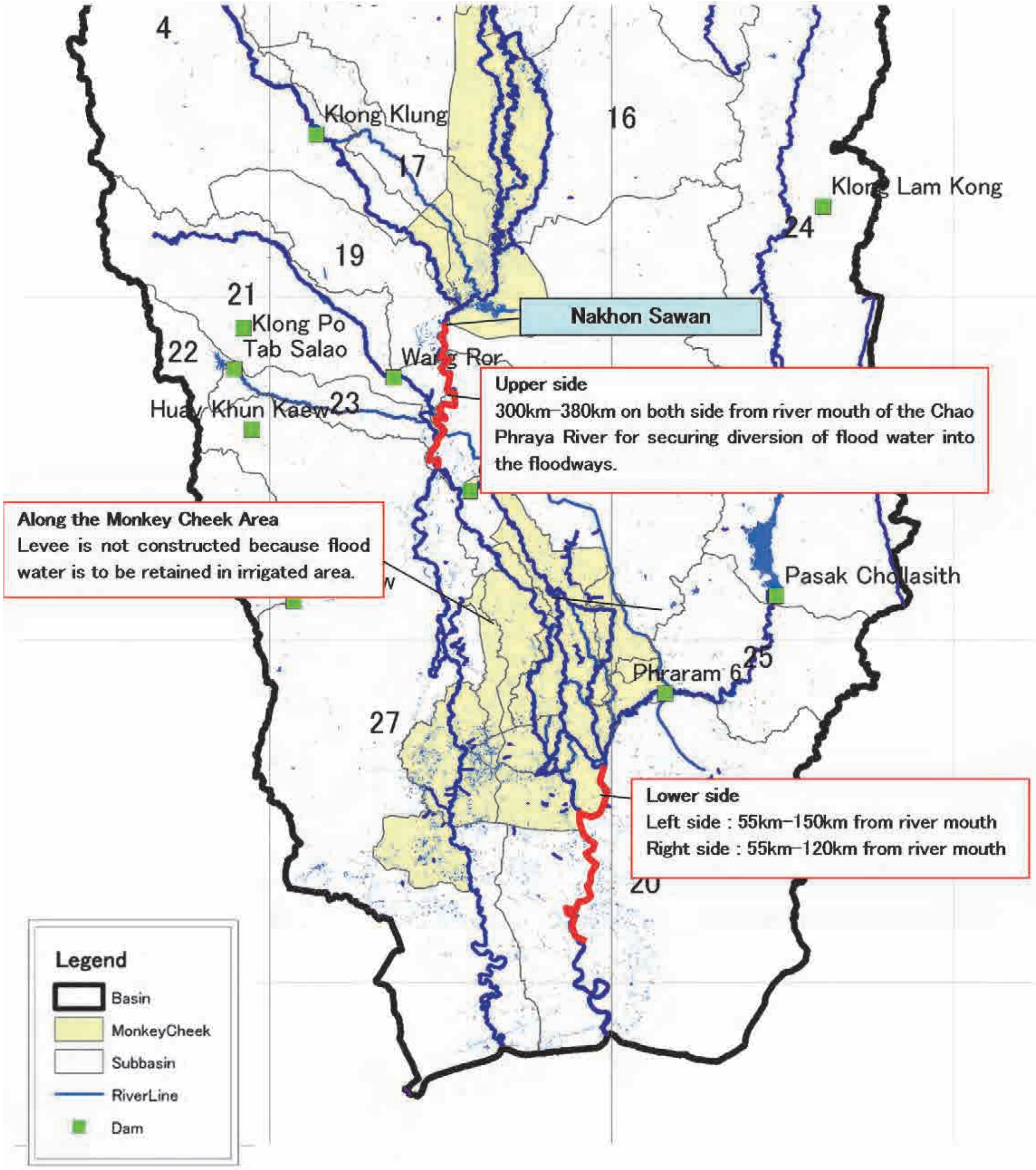
Procedures are:
(1) Inundation volume by provinces is calculated based on the results of inundation simulation of "2011 flood with existing structure"
(2) Input damages by provinces estimated by the DALA method with "2011 flood with existing structure"
(3) Calculated damages per unit inundation volume by provinces
(4) Inundation volume by provinces is calculated based on the results of inundation simulation of "food exceeding 2011 flood"
(5) Estimate damages in case of a flood exceeding the scale of 2011 flood by
(damages per unit inundation volume by provinces) x (inundation volume by province)

Table Cases for damage estimation

	Rainfall	
	2011 flood	2011 food x 1.1
Existing Structure	○	
Future Structure	○	○

5. Future Structure Assumed

The following structure improvement was assumed.
(1) Rule curves of existing dams (Bhumipol, Sirikit) changed
(2) Dam construction
(3) Monkey Cheeks construction
(4) Floodways construction
(5) Levee construction and raising dykes



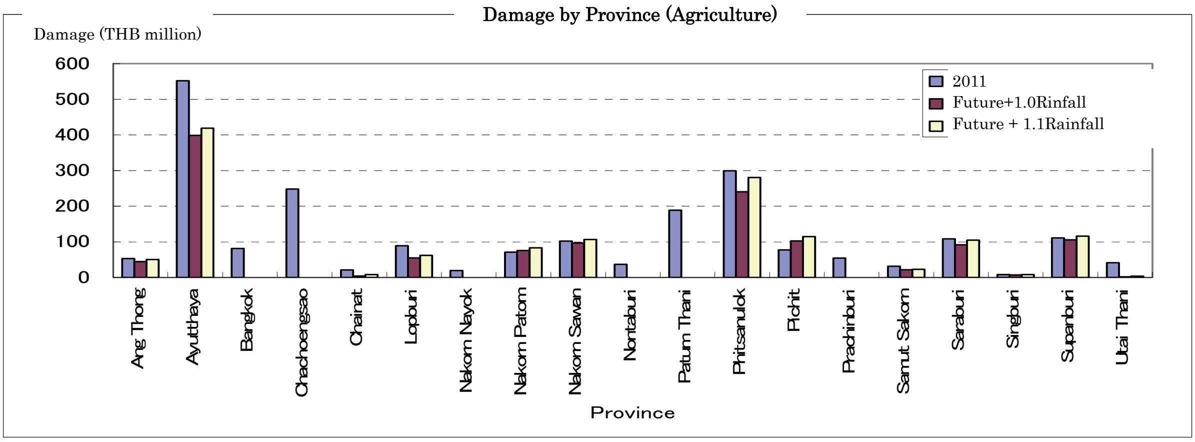
Levee Construction Sites

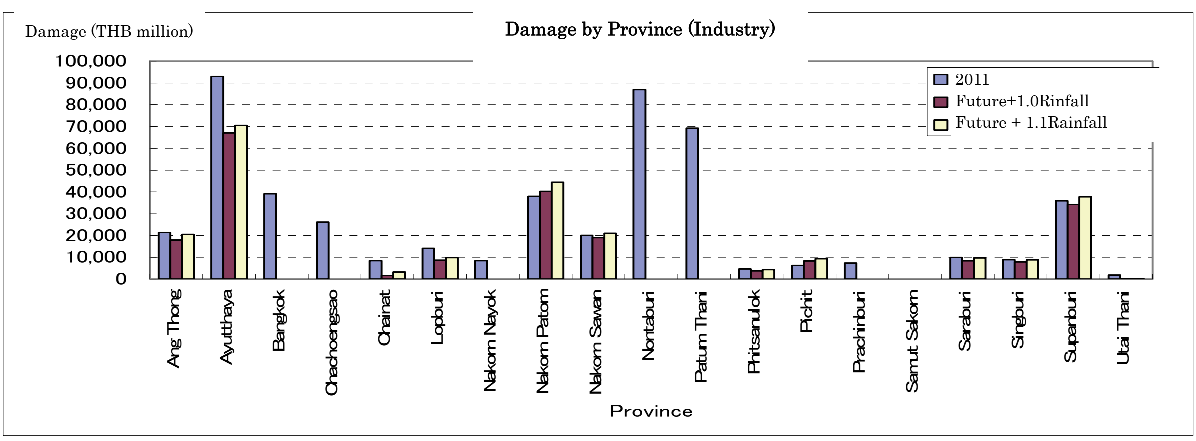
6. Summary

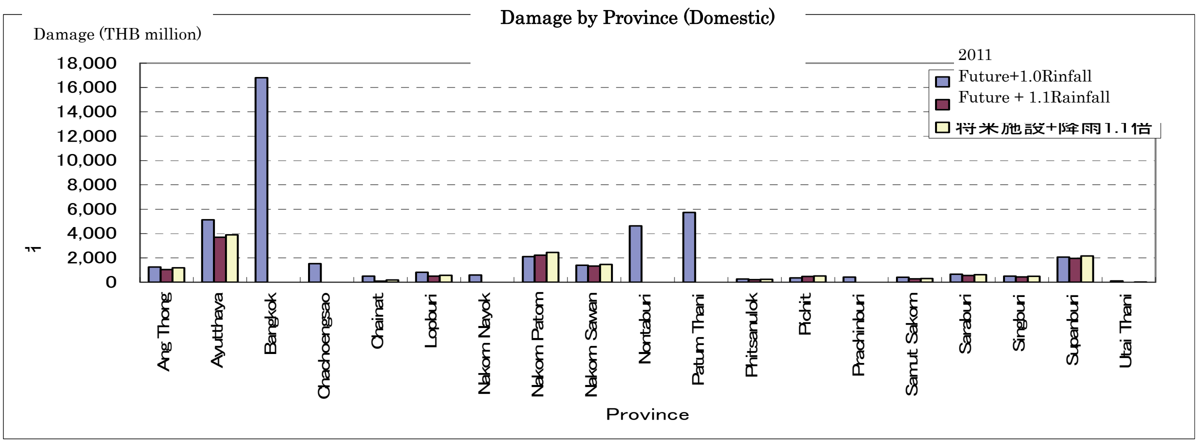
Comparison was made among “2011 damage of existing structure” and the case of “2011 flood with future structure”, and “2011 flood x 1.1 with future structure” for the sectors of industry, domestic, and agriculture. The following can be observed.

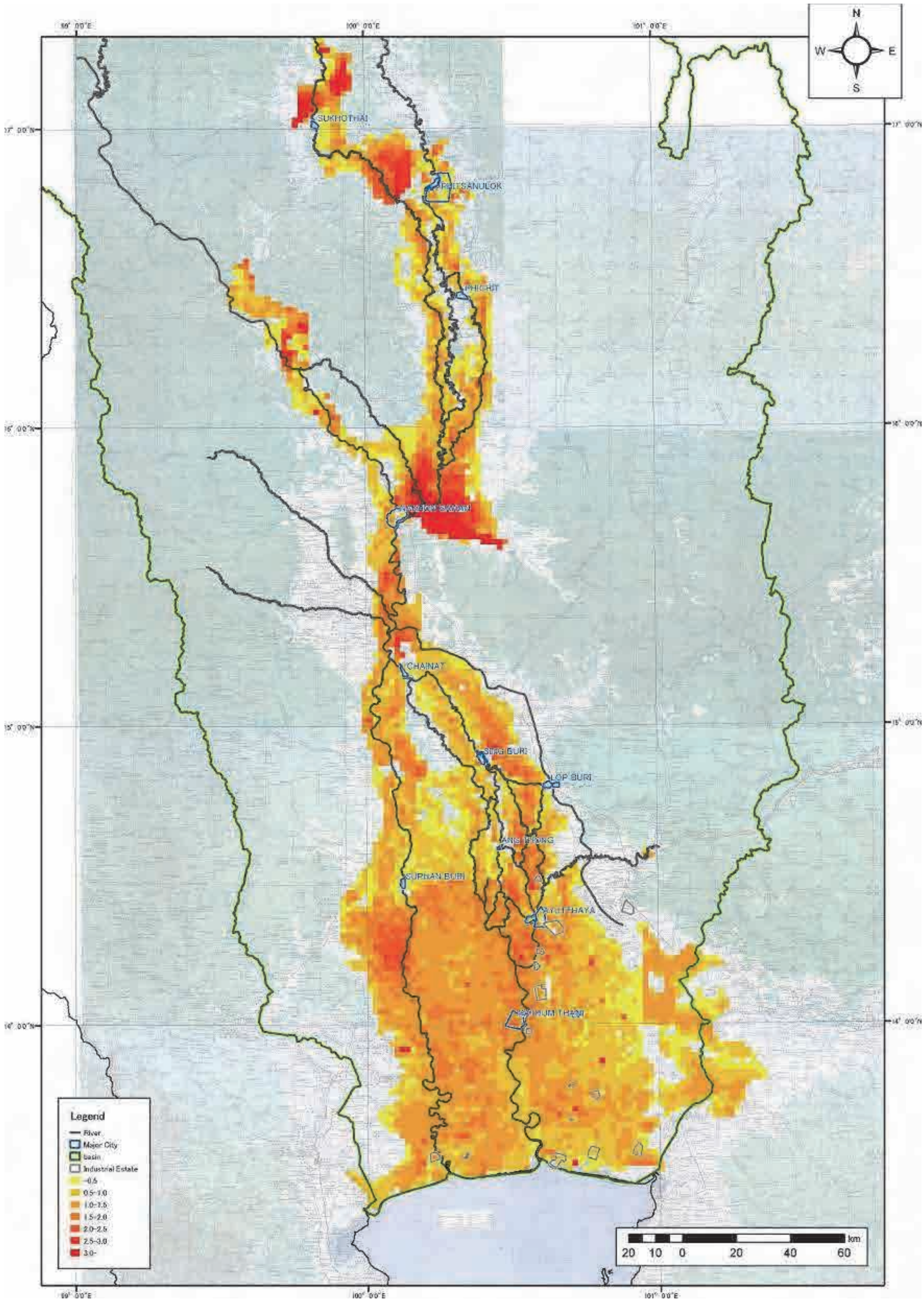
(1) In most of the provinces, damages decrease with future structure. In some provinces such as Nakorn Patom, Pichit the damage increases. The reasons are the increase in inundation depth because of road raising for strengthening the King’s Dyke, or the construction of Monkey Cheeks.

(2) In thee provinces of Bangkok, Nontaburi, and Patum Thani, damages would be zero even if a larger flood than 2011 flood happens with future structure.

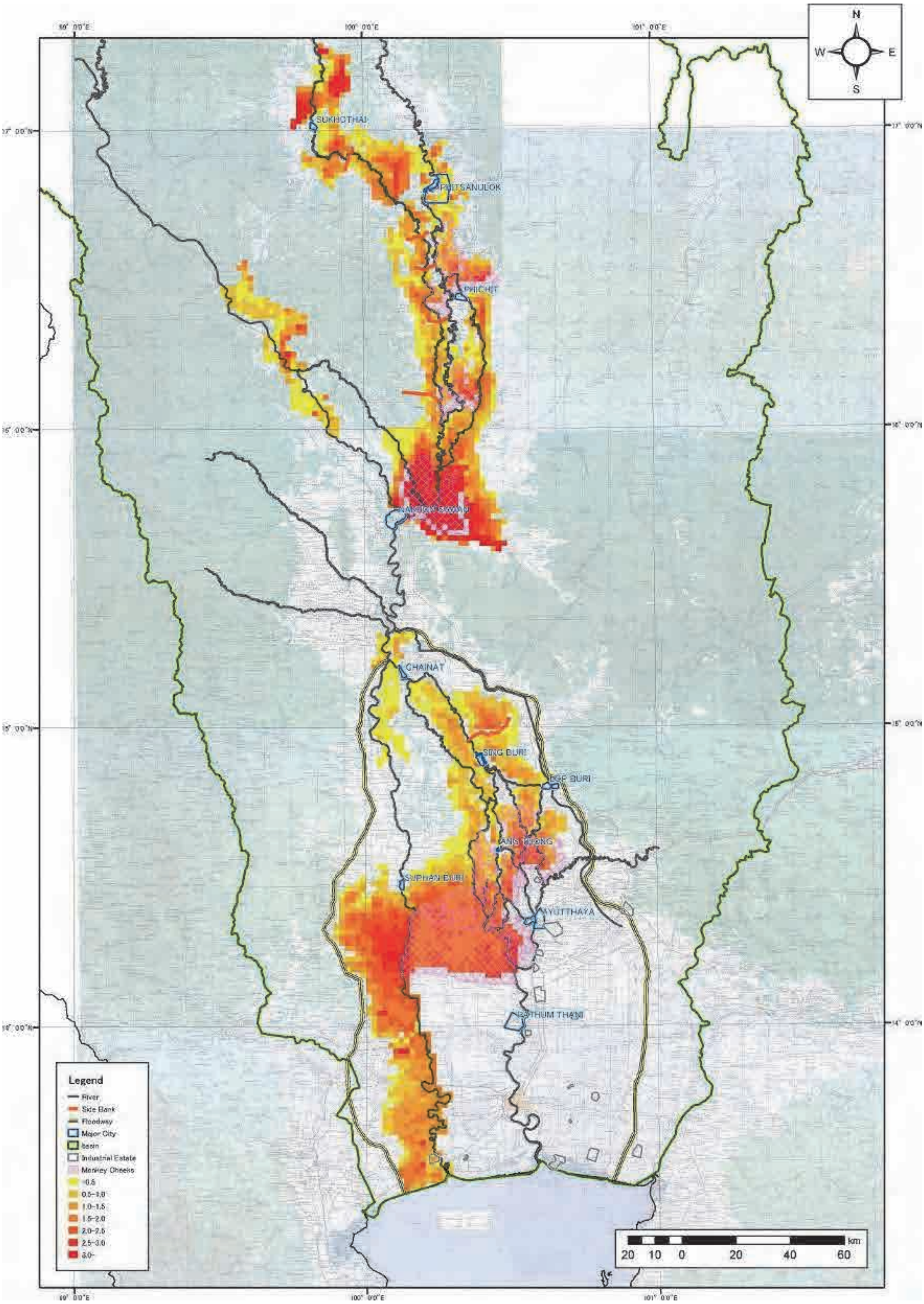








Maximum Inundation Depth 2011 Flood (Existing Structures)



Maximum Inundation Depth 2011Flood (Future Structures)

Table 1. Damages and Losses in Housing, by province

	HOUSING + HOUSEHOLD GOODS		HOUSING DAMAGE		HOUSEHOLD GOODS DAMAGE	LOSSES		TOTAL
Province	damage (in Thai Baht, millions)	LOSSES (in Thai Baht, millions)	NUMBER OF DAMAGED HOUSES	ESTIMATE OF COSTS (THB)		temporary shelter & utilities including stay in house	Debris cleaning (also cleaning of goods)	
Ang Thong	1244.70	1065.41	50,579	263,596,605	981,101,020	1,014,706,272	50,704,836	2,310,159,312
Ayutthaya	5129.61	4751.04	196,929	1,294,170,947	3,835,439,603	4,552,823,011	198,221,520	9,880,852,010
Bangkok	16797.21	13926.69	761,725	1,954,019,947	14,843,185,266	13,159,573,053	767,119,039	30,724,659,030
Chachoengsao	1525.11	1134.36	61,780	326,727,732	1,198,379,785	1,072,425,632	61,934,142	2,659,529,071
Chainat	495.81	327.45	20,088	106,147,303	389,659,610	307,313,926	20,138,218	823,279,145
Lopburi	818.62	531.64	33,280	173,079,512	645,544,641	498,277,196	33,362,757	1,350,297,386
Nakorn Nayok	586.45	333.34	19,942	199,611,144	386,834,426	313,347,540	19,992,208	919,805,262
Nakorn Patom	2096.63	1645.93	89,571	358,681,824	1,737,944,848	1,556,109,343	89,819,709	3,742,645,295
Nakorn Sawan	1401.45	808.57	51,411	396,007,505	1,005,446,475	757,030,699	51,539,236	2,210,075,327
Nontaburi	4629.13	4133.75	204,920	654,200,726	3,974,928,829	3,928,319,660	205,430,541	8,763,084,676
Patum Thani	5732.91	5466.74	237,394	1,116,013,729	4,616,898,235	5,228,136,293	238,608,525	11,199,894,175
Phitsanulok	256.56	159.30	10,946	44,233,906	212,321,607	148,331,015	10,973,113	415,870,586
Pichit	350.45	220.50	14,826	62,511,270	287,934,620	205,633,421	14,863,045	570,957,182
Prachinburi	427.19	276.99	17,366	90,338,776	336,854,416	259,578,883	17,409,163	704,198,604
Samut Sakorn	409.12	308.17	19,378	30,860,681	378,261,881	288,622,666	19,549,166	717,313,771
Saraburi	647.20	368.94	23,459	192,143,896	455,055,168	345,421,798	23,517,963	1,016,162,285
Singburi	500.02	370.49	21,078	91,156,043	408,865,300	349,356,254	21,130,798	870,529,473
Supanburi	2064.17	1591.49	84,841	418,463,976	1,645,707,059	1,506,432,468	85,052,716	3,655,741,060
Utai Thani	108.88	47.66	4,440	22,748,651	86,128,026	43,212,333	4,451,231	156,544,681
	45907.69	37892.47		7,848,349,383	38,059,345,564	35,925,945,652	1,966,524,852	
			1,956,578			*		83,800,165,452

Note: Shelter costs paid by schools that served as shelters were counted in the education sector loss calculations.

Table 2: Education Sector – Damage and Losses by Province in Thai Baht, millions

	Province	Damages	Losses
1	Ang Thong	16.80	31.50
2	Ayutthaya	932.20	66.00
3	Bangkok	4686.10	603.40
4	Chachoengsao	59.60	23.20
5	Chainat	34.30	22.10
8	Lopburi	121.50	45.50
10	Nakorn Nayok	48.40	26.10
11	Nakorn Patom	234.20	40.30
12	Nakorn Sawan	583.20	73.20
13	Nontaburi	155.80	257.80
14	Patum Thani	5480.00	310.80
15	Phitsanulok	87.20	20.00
16	Pichit	141.50	26.60
17	Prachinburi	87.30	23.70
19	Samut Sakorn	69.50	20.00
20	Saraburi	34.80	33.80
21	Singburi	25.50	19.70
23	Supanburi	52.60	21.60
26	Utai Thani	30.80	25.10
	Total	13051.00	1797.90

Table 3: Heritage Sector – Summary of damages by province and subsector in Thai Baht, millions

	Province	Damages	Losses
1	Ang Thong	94.43	65.56
2	Ayutthaya	64.28	44.62
3	Bangkok	2824.33	1960.70
4	Chachoengsao	373.04	258.97
5	Chainat	58.80	40.82
8	Lopburi	2.80	1.94
10	Nakorn Nayok	1.10	0.76
11	Nakorn Patom	26.20	18.19
12	Nakorn Sawan	6.72	4.67
13	Nontaburi	119.71	83.10
14	Patum Thani	117.73	81.73
15	Phitsanulok	5.47	3.80
16	Pichit	21.46	14.90
17	Prachinburi	56.42	39.17
19	Samut Sakorn	15.75	10.93
20	Saraburi	5.84	4.05
21	Singburi	0.00	0.00
23	Supanburi	123.05	85.42
26	Utai Thani	81.05	56.27
	Total	4431.57	3076.48

Table 4: Sector Electricity – Damages and Losses by Province in Thai Baht, millions

	Province	Damages	Losses
1	Ang Thong	5.51	3.02
2	Ayutthaya	2803.64	3359.97
3	Bangkok	2.80	2262.43
4	Chachoengsao	0.00	0.00
5	Chainat	1.04	0.65
8	Lopburi	4.78	2.73
10	Nakorn Nayok	1.11	0.54
11	Nakorn Patom	1.03	0.56
12	Nakorn Sawan	11.27	6.24
13	Nontaburi	2.63	72.86
14	Patum Thani	310.79	4.06
15	Phitsanulok	0.31	0.21
16	Pichit	0.28	0.20
17	Prachinburi	0.72	0.45
19	Samut Sakorn	0.29	0.16
20	Saraburi	37.76	0.17
21	Singburi	0.30	0.19
23	Supanburi	1.31	1.07
26	Utai Thani	0.19	0.13
	Total	3185.76	5715.63

Table 5: Total Damages in the Flood Control, Drainage and Irrigation Sector, in Thai Baht, millions

	Province	Damages	Losses
1	Ang Thong	50.30	3.90
2	Ayutthaya	264.60	49.60
3	Bangkok	281.90	1822.60
4	Chachoengsao	296.40	0.40
5	Chainat	86.10	1.40
8	Lopburi	80.00	7.50
10	Nakorn Nayok	24.10	0.30
11	Nakorn Patom	123.30	(0.70)
12	Nakorn Sawan	213.70	4.90
13	Nontaburi	149.40	0.20
14	Patum Thani	103.10	26.30
15	Phitsanulok	185.00	2.70
16	Pichit	117.80	2.60
17	Prachinburi	42.60	2.30
19	Samut Sakorn	20.20	(0.40)
20	Saraburi	64.20	3.80
21	Singburi	66.50	(1.00)
23	Supanburi	210.80	1.40
26	Utai Thani	3.30	0.10
	Total	3497.00	1983.50

Table 6: Transport – Damages and Losses by Province in Thai Baht, millions

	Province	Damages	Losses
1	Ang Thong	599.23	167.69
2	Ayutthaya	1448.64	405.28
3	Bangkok	1749.68	842.30
4	Chachoengsao	113.45	31.74
5	Chainat	486.24	136.06
8	Lopburi	1582.83	442.79
10	Nakorn Nayok	82.97	23.19
11	Nakorn Patom	558.21	156.15
12	Nakorn Sawan	2459.85	688.29
13	Nontaburi	962.28	269.23
14	Patum Thani	1570.80	439.48
15	Phitsanulok	2103.56	588.58
16	Pichit	1086.16	303.96
17	Prachinburi	550.19	153.90
19	Samut Sakorn	340.13	95.12
20	Saraburi	1491.95	417.46
21	Singburi	892.15	249.67
23	Supanburi	880.69	246.35
26	Utai Thani	331.65	92.77
	Total	23538.11	6938.29

Table 7: Telecommunications Sector - Damage, Losses in 26 provinces, in Thai Baht, millions

	Province	Damages	Losses
1	Ang Thong	33.35	66.13
2	Ayutthaya	129.84	257.46
3	Bangkok	502.22	995.87
4	Chachoengsao	40.73	80.77
5	Chainat	13.24	26.26
8	Lopburi	21.94	43.51
10	Nakorn Nayok	13.15	26.07
11	Nakorn Patom	59.06	117.10
12	Nakorn Sawan	33.90	67.21
13	Nontaburi	135.11	267.91
14	Patum Thani	156.52	310.37
15	Phitsanulok	7.22	14.31
16	Pichit	9.77	19.38
17	Prachinburi	11.45	22.70
19	Samut Sakorn	12.78	25.33
20	Saraburi	15.47	30.67
21	Singburi	13.90	27.56
23	Supanburi	55.94	110.92
26	Utai Thani	2.93	5.80
	Total	1290.00	2558.00

Table 8: Agriculture Sector . Damage and Losses by Province in Thai baht, millions

	Province	2011				2012	2013	2014
		Damages	Losses_2011-2014	Losses	Total	Losses	Losses	Losses
1	Ang Thong	53.00	352.00	297	350	55	0	0
2	Ayutthaya	552.00	4009.00	3,906	4,458	97	4	2
3	Bangkok	81.00	798.00	788	869	10	0	0
4	Chachoengsao	248.00	2109.00	1,962	2,210	99	34	14
5	Chainat	21.00	196.00	166	187	25	4	1
8	Lopburi	89.00	1014.00	883	972	123	6	2
10	Nakorn Nayok	19.00	175.00	172	191	3	0	0
11	Nakorn Patom	71.00	641.00	593	664	37	8	3
12	Nakorn Sawan	102.00	807.00	461	563	217	92	37
13	Nontaburi	37.00	366.00	362	399	4	0	0
14	Patum Thani	189.00	1723.00	1,645	1,834	47	22	9
15	Phitsanulok	299.00	1350.00	1,258	1,557	53	28	11
16	Pichit	77.00	376.00	323	401	42	8	3
17	Prachinburi	54.00	512.00	476	530	27	6	3
19	Samut Sakorn	31.00	906.00	344	374	300	187	75
20	Saraburi	108.00	1254.00	1,184	1,292	57	9	4
21	Singburi	8.00	132.00	112	120	20	0	0
23	Supanburi	111.00	864.00	792	902	71	1	0
26	Utai Thani	41.00	292.00	163	204	72	41	16
	Total	5666.00	34715.00	30,328	35,994	2,701	1,204	482

Table 9: Industry Sector: Estimated Total Damages and Losses in 26 provinces, in Thai Baht, millions

	Disaster Effects		NUMBER OF DAMAGED HOUSES
Province	Damage	Losses	
Ang Thong	21449.66	31516.90	50579
Ayutthaya	**92907.00**	**17137.00**	196929
Bangkok	**39131.00**	**20051.00**	761725
Chachoengsao	26199.81	38496.50	61780
Chainat	8518.97	12517.28	20088
Lopburi	14113.46	20737.51	33280
Nakorn Nayok	8457.05	12426.30	19942
Nakorn Patom	37985.48	55813.69	89571
Nakorn Sawan	**20064.00**	**7238.00**	51411
Nontaburi	86902.96	127690.22	204920
Patum Thani	**69272.00**	**17117.00**	237394
Phitsanulok	4642.01	6820.70	10946
Pichit	6287.45	9238.41	14826
Prachinburi	7364.61	10821.14	17366
Samut Sakorn	**0.00**	**1922.00**	19378
Saraburi	9948.55	14617.83	23459
Singburi	8938.81	13134.17	21078
Supanburi	35979.57	52866.32	84841
Utai Thani	1882.93	2766.66	4440
	513881.00	**493258.00**	1956578

Table 10: Financial Sector - Damage, Losses in 26 provinces, in Thai Baht, millions

	Province	Damages	Losses
1	Ang Thong	0.00	2979.97
2	Ayutthaya	0.00	11602.50
3	Bangkok	0.00	44878.67
4	Chachoengsao	0.00	3639.90
5	Chainat	0.00	1183.53
8	Lopburi	0.00	1960.76
10	Nakorn Nayok	0.00	1174.93
11	Nakorn Patom	0.00	5277.27
12	Nakorn Sawan	0.00	3028.99
13	Nontaburi	0.00	12073.30
14	Patum Thani	0.00	13986.58
15	Phitsanulok	0.00	644.91
16	Pichit	0.00	873.51
17	Prachinburi	0.00	1023.16
19	Samut Sakorn	0.00	1141.70
20	Saraburi	0.00	1382.14
21	Singburi	0.00	1241.86
23	Supanburi	0.00	4998.59
26	Utai Thani	0.00	261.59
	Total	0.00	115276.00

Table 11: Tourism Sector – Damages and Losses by Province in Thai Baht, millions

	Province	Damages	Losses
1	Ang Thong	54.50	34.70
2	Ayutthaya	104.00	2447.40
3	Bangkok	328.60	68884.90
4	Chachoengsao	111.80	238.00
5	Chainat	100.50	38.70
8	Lopburi	270.00	411.10
10	Nakorn Nayok	347.90	294.20
11	Nakorn Patom	188.30	251.80
12	Nakorn Sawan	321.60	343.50
13	Nontaburi	205.50	345.40
14	Patum Thani	202.80	151.10
15	Phitsanulok	50.10	45.20
16	Pichit	437.60	729.00
17	Prachinburi	238.20	285.70
19	Samut Sakorn	81.60	57.50
20	Saraburi	249.30	484.70
21	Singburi	42.60	43.50
23	Supanburi	263.80	216.50
26	Utai Thani	209.70	69.10
	Total	5134.40	77639.00

Table 12: Environment Sector – Damage and Losses by Province in Thai Baht, millions

	Province	Damages	Losses
1	Ang Thong	3.21	1.20
2	Ayutthaya	209.00	10.12
3	Bangkok	19.80	88.30
4	Chachoengsao	1.00	15.91
5	Chainat	0.00	0.00
8	Lopburi	29.88	0.96
10	Nakorn Nayok	0.00	0.00
11	Nakorn Patom	11.07	0.36
12	Nakorn Sawan	1.81	4.92
13	Nontaburi	0.00	0.00
14	Patum Thani	30.95	2.86
15	Phitsanulok	14.66	8.04
16	Pichit	0.00	0.00
17	Prachinburi	43.22	1.42
19	Samut Sakorn	1.50	41.21
20	Saraburi	3.13	0.10
21	Singburi	5.83	0.19
23	Supanburi	0.00	0.00
26	Utai Thani	0.00	0.00
	Total	375.06	175.61

Table 13 Damage and Loss (2011 Flood + Future Structures) (1)

Million Baht

Province	Housing		Education		Heritage	
	DAMAGE	LOSSES	DAMAGE	LOSS	DAMAGE	LOSS
Ang Thong	1041.27	891.28	14.05	26.35	79.00	54.85
Ayutthaya	3702.19	3428.97	672.80	47.63	46.39	32.20
Bangkok	0.00	0.00	0.00	0.00	0.00	0.00
Chachoengsao	0.00	0.00	0.00	0.00	0.00	0.00
Chainat	93.70	61.88	6.48	4.18	11.11	7.71
Kalasin	0.00	0.00	0.00	0.00	0.00	0.00
Khon Kaen	0.00	0.00	0.00	0.00	0.00	0.00
Lopburi	502.37	326.26	74.56	27.92	1.72	1.19
Mahasarakham	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Nayok	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Patom	2222.60	1744.82	248.27	42.72	27.77	19.28
Nakorn Sawan	1328.41	766.43	552.81	69.39	6.37	4.43
Nontaburi	0.00	0.00	0.00	0.00	0.00	0.00
Patum Thani	0.00	0.00	0.00	0.00	0.00	0.00
Phitsanulok	206.22	128.04	70.09	16.08	4.40	3.05
Pichit	466.25	293.36	188.26	35.39	28.55	19.82
Prachinburi	0.00	0.00	0.00	0.00	0.00	0.00
Roi Et	0.00	0.00	0.00	0.00	0.00	0.00
Samut Sakorn	281.47	212.02	47.82	13.76	10.84	7.52
Saraburi	547.94	312.35	29.46	28.62	4.94	3.43
Singburi	439.62	325.74	22.42	17.32	0.00	0.00
Sri Saket	0.00	0.00	0.00	0.00	0.00	0.00
Supanburi	1965.16	1515.15	50.08	20.56	117.15	81.32
Surin	0.00	0.00	0.00	0.00	0.00	0.00
Ubon Ratchathani	0.00	0.00	0.00	0.00	0.00	0.00
Utai Thani	3.93	1.72	1.11	0.91	2.93	2.03
Total	**12801.13**	**10008.02**	**1978.21**	**350.83**	**341.17**	**236.83**

Table 13 Damage and Loss (2011 Flood + Future Structures) (2)

Million Baht

Province	Health		Electricity		Flood Control, Drainage	
	DAMAGE	LOSS	DAMAGE	LOSS	DAMAGE	LOSS
Ang Thong	25.85	102.65	4.61	2.53	42.08	3.26
Ayutthaya	204.47	143.55	2023.47	2424.99	190.97	35.80
Bangkok	0.00	0.00	0.00	0.00	0.00	0.00
Chachoengsao	0.00	0.00	0.00	0.00	0.00	0.00
Chainat	0.34	7.79	0.20	0.12	16.27	0.26
Kalasin	0.00	0.00	0.00	0.00	0.00	0.00
Khon Kaen	0.00	0.00	0.00	0.00	0.00	0.00
Lopburi	9.27	45.29	2.93	1.68	49.09	4.60
Mahasarakham	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Nayok	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Patom	9.75	29.89	1.09	0.59	130.71	−0.74
Nakorn Sawan	104.17	116.97	10.68	5.91	202.56	4.64
Nontaburi	0.00	0.00	0.00	0.00	0.00	0.00
Patum Thani	0.00	0.00	0.00	0.00	0.00	0.00
Phitsanulok	19.85	6.83	0.25	0.17	148.70	2.17
Pichit	8.38	13.44	0.37	0.27	156.72	3.46
Prachinburi	0.00	0.00	0.00	0.00	0.00	0.00
Roi Et	0.00	0.00	0.00	0.00	0.00	0.00
Samut Sakorn	2.61	10.53	0.20	0.11	13.90	−0.28
Saraburi	29.89	14.90	31.97	0.14	54.35	3.22
Singburi	17.85	46.86	0.26	0.17	58.47	−0.88
Sri Saket	0.00	0.00	0.00	0.00	0.00	0.00
Supanburi	10.09	28.94	1.25	1.02	200.69	1.33
Surin	0.00	0.00	0.00	0.00	0.00	0.00
Ubon Ratchathani	0.00	0.00	0.00	0.00	0.00	0.00
Utai Thani	0.24	0.27	0.01	0.00	0.12	0.00
Total	**442.76**	**567.91**	**2077.29**	**2437.70**	**1264.63**	**56.84**

Table 13 Damage and Loss (2011 Flood + Future Structures) (3)

Million Baht

Province	Transport		Telecommunications		Agriculture	
	DAMAGE	LOSS	DAMAGE	LOSS	DAMAGE	LOSS
Ang Thong	501.29	140.28	27.90	55.32	44.34	294.47
Ayutthaya	1045.53	292.50	93.71	185.82	398.39	2893.41
Bangkok	0.00	0.00	0.00	0.00	0.00	0.00
Chachoengsao	0.00	0.00	0.00	0.00	0.00	0.00
Chainat	91.89	25.71	2.50	4.96	3.97	37.04
Kalasin	0.00	0.00	0.00	0.00	0.00	0.00
Khon Kaen	0.00	0.00	0.00	0.00	0.00	0.00
Lopburi	971.36	271.73	13.46	26.70	54.62	622.27
Mahasarakham	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Nayok	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Patom	591.75	165.53	62.61	124.14	75.27	679.51
Nakorn Sawan	2331.66	652.42	32.13	63.71	96.68	764.94
Nontaburi	0.00	0.00	0.00	0.00	0.00	0.00
Patum Thani	0.00	0.00	0.00	0.00	0.00	0.00
Phitsanulok	1690.78	473.08	5.80	11.50	240.33	1085.09
Pichit	1445.06	404.40	13.00	25.78	102.44	500.24
Prachinburi	0.00	0.00	0.00	0.00	0.00	0.00
Roi Et	0.00	0.00	0.00	0.00	0.00	0.00
Samut Sakorn	234.01	65.44	8.79	17.43	21.33	623.32
Saraburi	1263.13	353.43	13.10	25.97	91.44	1061.67
Singburi	784.38	219.51	12.22	24.23	7.03	116.06
Sri Saket	0.00	0.00	0.00	0.00	0.00	0.00
Supanburi	838.45	234.53	53.26	105.60	105.68	822.56
Surin	0.00	0.00	0.00	0.00	0.00	0.00
Ubon Ratchathani	0.00	0.00	0.00	0.00	0.00	0.00
Utai Thani	11.97	3.35	0.11	0.21	1.48	10.54
Total	**11801.26**	**3301.91**	**338.59**	**671.37**	**1243.00**	**9511.12**

Table 13 Damage and Loss (2011 Flood + Future Structures) (4)

Million Baht

Province	Industry		Financial		Tourism	
	DAMAGE	LOSS	DAMAGE	LOSS	DAMAGE	LOSS
Ang Thong	17944.01	26365.89	0.00	2492.93	45.59	29.03
Ayutthaya	67053.72	12368.28	0.00	8373.87	75.06	1766.36
Bangkok	0.00	0.00	0.00	0.00	0.00	0.00
Chachoengsao	0.00	0.00	0.00	0.00	0.00	0.00
Chainat	1609.90	2365.49	0.00	223.66	18.99	7.31
Kalasin	0.00	0.00	0.00	0.00	0.00	0.00
Khon Kaen	0.00	0.00	0.00	0.00	0.00	0.00
Lopburi	8661.19	12726.26	0.00	1203.29	165.69	252.29
Mahasarakham	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Nayok	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Patom	40267.65	59166.98	0.00	5594.33	199.61	266.93
Nakorn Sawan	19018.38	6860.80	0.00	2871.14	304.84	325.60
Nontaburi	0.00	0.00	0.00	0.00	0.00	0.00
Patum Thani	0.00	0.00	0.00	0.00	0.00	0.00
Phitsanulok	3731.12	5482.29	0.00	518.36	40.27	36.33
Pichit	8365.03	12291.08	0.00	1162.15	582.20	969.89
Prachinburi	0.00	0.00	0.00	0.00	0.00	0.00
Roi Et	0.00	0.00	0.00	0.00	0.00	0.00
Samut Sakorn	0.00	1322.33	0.00	785.48	56.14	39.56
Saraburi	8422.71	12375.85	0.00	1170.16	211.06	410.36
Singburi	7859.04	11547.62	0.00	1091.85	37.45	38.25
Sri Saket	0.00	0.00	0.00	0.00	0.00	0.00
Supanburi	34253.74	50330.49	0.00	4758.82	251.15	206.12
Surin	0.00	0.00	0.00	0.00	0.00	0.00
Ubon Ratchathani	0.00	0.00	0.00	0.00	0.00	0.00
Utai Thani	67.99	99.89	0.00	9.45	7.57	2.49
Total	**217254.48**	**213303.25**	**0.00**	**30255.49**	**1995.62**	**4350.52**

Table 13 Damage and Loss (2011 Flood + Future Structures) (5)

Million Baht

Province	Environment	
	DAMAGE	LOSS
Ang Thong	2.69	1.00
Ayutthaya	150.84	7.30
Bangkok	0.00	0.00
Chachoengsao	0.00	0.00
Chainat	0.00	0.00
Kalasin	0.00	0.00
Khon Kaen	0.00	0.00
Lopburi	18.34	0.59
Mahasarakham	0.00	0.00
Nakorn Nayok	0.00	0.00
Nakorn Patom	11.74	0.38
Nakorn Sawan	1.72	4.66
Nontaburi	0.00	0.00
Patum Thani	0.00	0.00
Phitsanulok	11.78	6.46
Pichit	0.00	0.00
Prachinburi	0.00	0.00
Roi Et	0.00	0.00
Samut Sakorn	1.03	28.35
Saraburi	2.65	0.08
Singburi	5.13	0.17
Sri Saket	0.00	0.00
Supanburi	0.00	0.00
Surin	0.00	0.00
Ubon Ratchathani	0.00	0.00
Utai Thani	0.00	0.00
Total	**205.92**	**48.99**

Table 14 Damage and Loss (2011 Flood x 1.1 + Future Structures) (1)

Million Baht

Province	Housing		Education		Heritage	
	DAMAGE	LOSSES	DAMAGE	LOSS	DAMAGE	LOSS
Ang Thong	1185.83	1015.02	16.01	30.01	89.96	62.46
Ayutthaya	3893.96	3606.58	707.65	50.10	48.80	33.87
Bangkok	0.00	0.00	0.00	0.00	0.00	0.00
Chachoengsao	0.00	0.00	0.00	0.00	0.00	0.00
Chainat	185.88	122.76	12.86	8.29	22.04	15.30
Kalasin	0.00	0.00	0.00	0.00	0.00	0.00
Khon Kaen	0.00	0.00	0.00	0.00	0.00	0.00
Lopburi	569.82	370.06	84.57	31.67	1.95	1.35
Mahasarakham	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Nayok	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Patom	2452.42	1925.24	273.94	47.14	30.65	21.28
Nakorn Sawan	1465.80	845.70	609.98	76.56	7.03	4.88
Nontaburi	0.00	0.00	0.00	0.00	0.00	0.00
Patum Thani	0.00	0.00	0.00	0.00	0.00	0.00
Phitsanulok	240.73	149.47	81.82	18.77	5.13	3.57
Pichit	520.36	327.41	210.10	39.50	31.86	22.12
Prachinburi	0.00	0.00	0.00	0.00	0.00	0.00
Roi Et	0.00	0.00	0.00	0.00	0.00	0.00
Samut Sakorn	300.01	225.98	50.96	14.67	11.55	8.01
Saraburi	627.98	357.98	33.77	32.80	5.67	3.93
Singburi	493.33	365.53	25.16	19.44	0.00	0.00
Sri Saket	0.00	0.00	0.00	0.00	0.00	0.00
Supanburi	2162.60	1667.38	55.11	22.63	128.92	89.49
Surin	0.00	0.00	0.00	0.00	0.00	0.00
Ubon Ratchathani	0.00	0.00	0.00	0.00	0.00	0.00
Utai Thani	9.44	4.13	2.67	2.18	7.03	4.88
Total	**14108.16**	**10983.24**	**2164.60**	**393.76**	**390.59**	**271.14**

Table 14 Damage and Loss (2011 Flood x 1.1 + Future Structures) (2)

Million Baht

Province	Health		Electricity		Flood Control, Drainage	
	DAMAGE	LOSS	DAMAGE	LOSS	DAMAGE	LOSS
Ang Thong	29.44	116.90	5.25	2.88	47.92	3.72
Ayutthaya	215.06	150.99	2128.28	2550.60	200.86	37.65
Bangkok	0.00	0.00	0.00	0.00	0.00	0.00
Chachoengsao	0.00	0.00	0.00	0.00	0.00	0.00
Chainat	0.67	15.45	0.39	0.24	32.28	0.52
Kalasin	0.00	0.00	0.00	0.00	0.00	0.00
Khon Kaen	0.00	0.00	0.00	0.00	0.00	0.00
Lopburi	10.51	51.37	3.33	1.90	55.69	5.22
Mahasarakham	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Nayok	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Patom	10.76	32.99	1.20	0.66	144.22	−0.82
Nakorn Sawan	114.95	129.07	11.79	6.53	223.51	5.12
Nontaburi	0.00	0.00	0.00	0.00	0.00	0.00
Patum Thani	0.00	0.00	0.00	0.00	0.00	0.00
Phitsanulok	23.18	7.98	0.29	0.20	173.58	2.53
Pichit	9.35	15.00	0.42	0.30	174.91	3.86
Prachinburi	0.00	0.00	0.00	0.00	0.00	0.00
Roi Et	0.00	0.00	0.00	0.00	0.00	0.00
Samut Sakorn	2.79	11.22	0.21	0.12	14.81	−0.29
Saraburi	34.25	17.08	36.64	0.16	62.29	3.69
Singburi	20.03	52.59	0.30	0.19	65.61	−0.99
Sri Saket	0.00	0.00	0.00	0.00	0.00	0.00
Supanburi	11.11	31.85	1.37	1.12	220.85	1.47
Surin	0.00	0.00	0.00	0.00	0.00	0.00
Ubon Ratchathani	0.00	0.00	0.00	0.00	0.00	0.00
Utai Thani	0.58	0.64	0.02	0.01	0.29	0.01
Total	**482.68**	**633.13**	**2189.49**	**2564.91**	**1416.82**	**61.69**

Table 14 Damage and Loss (2011 Flood x 1.1 + Future Structures) (3)

Million Baht

Province	Transport		Telecommunications		Agriculture	
	DAMAGE	LOSS	DAMAGE	LOSS	DAMAGE	LOSS
Ang Thong	570.89	159.76	31.77	63.00	50.49	335.35
Ayutthaya	1099.68	307.65	98.56	195.44	419.03	3043.29
Bangkok	0.00	0.00	0.00	0.00	0.00	0.00
Chachoengsao	0.00	0.00	0.00	0.00	0.00	0.00
Chainat	182.29	51.01	4.96	9.84	7.87	73.48
Kalasin	0.00	0.00	0.00	0.00	0.00	0.00
Khon Kaen	0.00	0.00	0.00	0.00	0.00	0.00
Lopburi	1101.76	308.21	15.27	30.29	61.95	705.82
Mahasarakham	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Nayok	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Patom	652.94	182.65	69.08	136.97	83.05	749.77
Nakorn Sawan	2572.79	719.89	35.46	70.30	106.68	844.05
Nontaburi	0.00	0.00	0.00	0.00	0.00	0.00
Patum Thani	0.00	0.00	0.00	0.00	0.00	0.00
Phitsanulok	1973.73	552.25	6.77	13.43	280.55	1266.68
Pichit	1612.76	451.33	14.51	28.78	114.33	558.30
Prachinburi	0.00	0.00	0.00	0.00	0.00	0.00
Roi Et	0.00	0.00	0.00	0.00	0.00	0.00
Samut Sakorn	249.42	69.75	9.37	18.57	22.73	664.36
Saraburi	1447.64	405.06	15.01	29.76	104.79	1216.76
Singburi	880.21	246.33	13.71	27.19	7.89	130.23
Sri Saket	0.00	0.00	0.00	0.00	0.00	0.00
Supanburi	922.68	258.10	58.61	116.21	116.29	905.20
Surin	0.00	0.00	0.00	0.00	0.00	0.00
Ubon Ratchathani	0.00	0.00	0.00	0.00	0.00	0.00
Utai Thani	28.75	8.04	0.25	0.50	3.55	25.31
Total	**13295.54**	**3720.03**	**373.33**	**740.28**	**1379.20**	**10518.60**

Table 14 Damage and Loss (2011 Flood x 1.1 + Future Structures) (4)

Million Baht

Province	Industry		Financial		Tourism	
	DAMAGE	LOSS	DAMAGE	LOSS	DAMAGE	LOSS
Ang Thong	20435.11	30026.17	0.00	2839.02	51.92	33.06
Ayutthaya	70527.05	13008.94	0.00	8807.63	78.95	1857.86
Bangkok	0.00	0.00	0.00	0.00	0.00	0.00
Chachoengsao	0.00	0.00	0.00	0.00	0.00	0.00
Chainat	3193.74	4692.69	0.00	443.70	37.68	14.51
Kalasin	0.00	0.00	0.00	0.00	0.00	0.00
Khon Kaen	0.00	0.00	0.00	0.00	0.00	0.00
Lopburi	9823.98	14434.80	0.00	1364.83	187.94	286.16
Mahasarakham	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Nayok	0.00	0.00	0.00	0.00	0.00	0.00
Nakorn Patom	44431.40	65284.96	0.00	6172.79	220.25	294.53
Nakorn Sawan	20985.23	7570.33	0.00	3168.06	336.37	359.27
Nontaburi	0.00	0.00	0.00	0.00	0.00	0.00
Patum Thani	0.00	0.00	0.00	0.00	0.00	0.00
Phitsanulok	4355.50	6399.73	0.00	605.11	47.01	42.41
Pichit	9335.80	13717.47	0.00	1297.01	649.76	1082.44
Prachinburi	0.00	0.00	0.00	0.00	0.00	0.00
Roi Et	0.00	0.00	0.00	0.00	0.00	0.00
Samut Sakorn	0.00	1409.39	0.00	837.20	59.84	42.16
Saraburi	9653.08	14183.69	0.00	1341.09	241.90	470.30
Singburi	8819.17	12958.38	0.00	1225.24	42.03	42.92
Sri Saket	0.00	0.00	0.00	0.00	0.00	0.00
Supanburi	37695.19	55387.15	0.00	5236.94	276.38	226.82
Surin	0.00	0.00	0.00	0.00	0.00	0.00
Ubon Ratchathani	0.00	0.00	0.00	0.00	0.00	0.00
Utai Thani	163.22	239.83	0.00	22.68	18.18	5.99
Total	**239418.47**	**239313.53**	**0.00**	**33361.30**	**2248.21**	**4758.43**

Table 14 Damage and Loss (2011 Flood x 1.1 + Future Structures) (5)

Million Baht

Province	Environment	
	DAMAGE	LOSS
Ang Thong	3.06	1.14
Ayutthaya	158.65	7.68
Bangkok	0.00	0.00
Chachoengsao	0.00	0.00
Chainat	0.00	0.00
Kalasin	0.00	0.00
Khon Kaen	0.00	0.00
Lopburi	20.80	0.67
Mahasarakham	0.00	0.00
Nakorn Nayok	0.00	0.00
Nakorn Patom	12.95	0.42
Nakorn Sawan	1.89	5.15
Nontaburi	0.00	0.00
Patum Thani	0.00	0.00
Phitsanulok	13.76	7.54
Pichit	0.00	0.00
Prachinburi	0.00	0.00
Roi Et	0.00	0.00
Samut Sakorn	1.10	30.22
Saraburi	3.04	0.10
Singburi	5.75	0.19
Sri Saket	0.00	0.00
Supanburi	0.00	0.00
Surin	0.00	0.00
Ubon Ratchathani	0.00	0.00
Utai Thani	0.00	0.00
Total	221.00	53.11

Table 15 Damage and Loss with Future Structures

Million Baht

		2011 Flood + Future Structure	2011 Flood x 1.1 + Future Structure
Housing	DAMAGE	12,801.13	14,108.16
	LOSSES	10,008.02	10,983.24
Education	DAMAGE	1,978.21	2,164.60
	LOSSES	350.83	393.76
Heritage	DAMAGE	341.17	390.59
	LOSSES	236.83	271.14
Health	DAMAGE	442.76	482.68
	LOSSES	567.91	633.13
Electricity	DAMAGE	2,077.29	2,189.49
	LOSSES	2,437.70	2,564.91
Flood Control	DAMAGE	1,264.63	1,416.82
	LOSSES	56.84	61.69
Transport	DAMAGE	11,801.26	13,295.54
	LOSSES	3,301.91	3,720.03
Telecomunications	DAMAGE	338.59	373.33
	LOSSES	671.37	740.28
Agriculture	DAMAGE	1,243.00	1,379.20
	LOSSES	9,511.12	10,518.60
Industry	DAMAGE	217,254.48	239,418.47
	LOSSES	213,303.25	239,313.53
Financial	DAMAGE	0.00	0.00
	LOSSES	30,255.49	33,361.30
Tourism	DAMAGE	1,995.62	2,248.21
	LOSSES	4,350.52	4,758.43
Environment	DAMAGE	205.92	221.00
	LOSSES	48.99	53.11
Total	DAMAGE	251,744.06	277,688.09
	LOSSES	275,100.78	307,373.15

Attachment 08

Technical Proposal for DWR Early Warning System

Established for Preventing Heavy Rain Disasters in the Mountainous Areas of Thailand

1. Actual State of Heavy Rain Disasters in the Mountainous Areas of Thailand

1.1 Hearing survey

- DWR (Early Warning Center): Mr. Ruangwit
- DWR (Regional Office 9): Mr. Noppadol and others
- Office of the National Water and Flood Management Policy: Ms. Supranee
- Kasetsart University: Dr. Suttisak Soralump
- DMR (Geohazards Operation Center): Mr. Tinnakorn

→ Appendices (collected materials, etc.)

1.2 Actual State of Heavy Rain Disasters in Mountainous Areas of Thailand

(1) Localized disasters that occur relatively frequently

- In the village communities of mountainous areas in Thailand, the following type of disaster occurs repeatedly: when it rains relatively heavily, small and medium rivers in the community overflow, causing damage to humans and inundation damage to houses, household goods, and farmlands in parts of the community.
  (e.g.) A disaster that occurred in Baan Huai Thanu (Nan Province) on Sept. 5, 2008 (Fig. 1-1)

Fig. 1-1　A disaster that occurred in Baan Huai Thanu (Nan Province) on Sept. 5, 2008

(2) Disasters that occur with less frequency but cause severe damage

- In the mountainous areas of Thailand, the following type of disaster occurs roughly once every several years: when heavy rains continue for several hours, it will trigger flooding that accompanies sediment-related disasters (debris or mud flow (“Nam Paa” containing a large volume of sediment) (Fig. 1-2) or large-scale multiple landslides (“Pan Din Talom”) (Fig.1-3), causing a number of deaths and severe damage in a wide area (affecting a large part of the community or multiple communities).

(e.g.) A widespread disaster that occurred in Uttaradit Province (Fig. 1-4) on May 22 and 23, 2006 (Fig. 1-4), and a disaster that occurred in Khao Panom (Krabi Province) on March 28, 2011 (Fig. 1-5)

・Flooding disasters that accompany sediment-related disasters tend to occur more often in the northern and southern regions (due to rainfall and geological conditions) (Fig. 1-6).

These pictures are offered by DWR Water Resources Regional office 9

Fig. 1-2 Example of a debris and mud flow
("Nam Paa" containing a large volume of sediment)

These pictures are offered by DWR Water Resources Regional office 9

Fig. 1-3 Example of large-scale or multiple landslides ("Pan Din Talom")

Utraradit

These pictures are offered by Dr. Suttisak Soralump

These pictures are offered by Dr. Suttisak Soralump

These pictures are offered by Dr. Suttisak Soralump

Fig. 1-4 A widespread disaster in Uttaradit Province on May 22 and 23, 2006

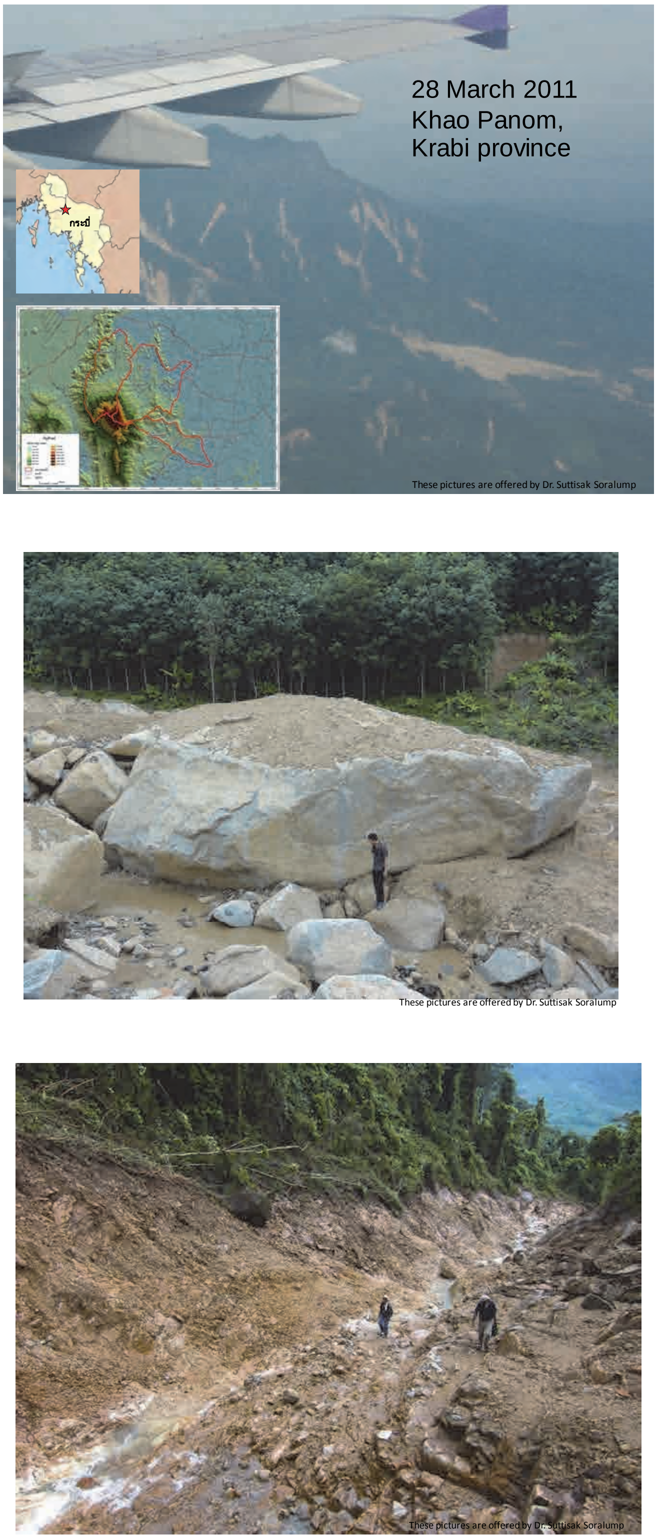


Fig. 1-5 A disaster that occurred in Khao Panom (Krabi Province) on March 28, 2011

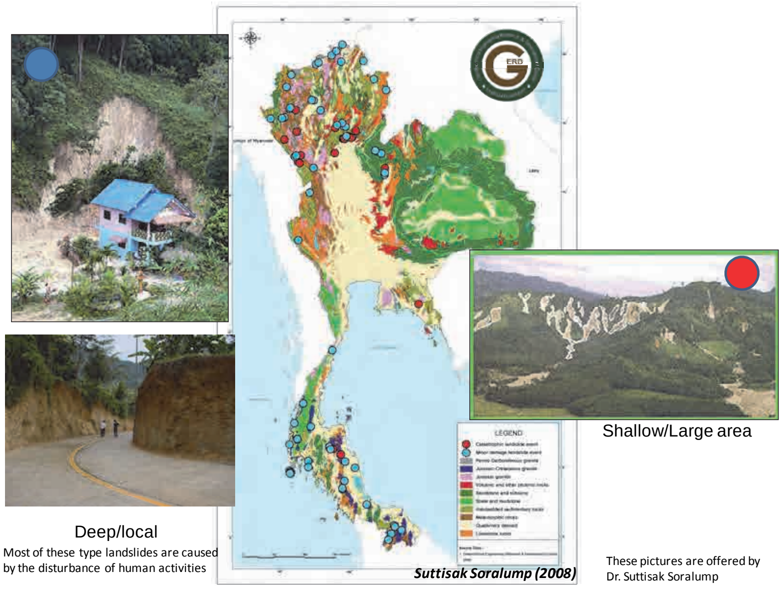


Fig. 1-6 Landslide events in Thailand from 1970-2006

2. Present Status and Problems related to the Early Warning System

2.1 Hearing survey and site survey

(Hearing survey)

- DWR (Early Warning Center): Mr. Ruangwit
- DWR (Regional Office 9): Mr. Noppadol and others
- Office of the National Water and Flood Management Policy：Ms. Supranee

(Site survey of a rain alarm station)

- Baan Huay Thanu (Nan Province)

→Appendices (collected materials, photos, etc.)

2.2 Present status of the Early Warning System

2.2.1 System structure and operation

○ Rain alarm stations will be installed in 4,427 villages (communities) in the mountainous areas that possess a high risk of heavy rain disaster (Figs. 2-1, 2-2)

- As of 2012, 1,052 rain alarm stations spanning 3,206 villages have been installed.
- The rain alarm station (mountainous area type) consists of an automatic rain gauge, manual rain gauge, transmission device, warning signal and speaker, thermometer, and soil moisture gauge.
- The rainfall measured by the automatic rain gauge is recorded in the data logger as a 15-minute rainfall. The recorded data is then transmitted in real-time to the main station at DWR headquarters.
- If the measured rainfall exceeds a warning criterion (three tier: green, yellow, red), a warning signal and speaker will be activated.

○ If a warning criteria is met, and a warning signal and speaker are activated, village volunteers in charge will start monitoring factors, such as river conditions, and will instruct villagers on whether to evacuate. (Figs. 2-3, 2-4).

Green (Level 1): Start to monitor rainfall amounts and river conditions (Alert)

Yellow (Level 2): Intensify monitoring activities and prepare for evacuation (Alarm)

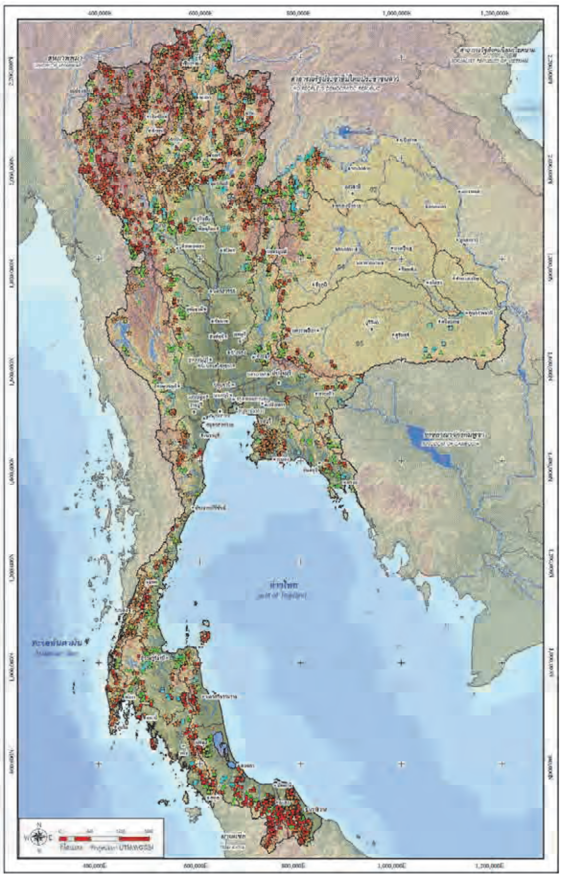
Red (Level 3): Decide to evacuate (Action)

○ If green warning criteria is met, DWR regional officials in charge of the Early Warning System in the region will start monitoring conditions by communicating with the village volunteers.

○ When installing a rain alarm station, a volunteer leader is appointed and a volunteer network will be established to assist him.

・A 24-hour communication system is set up between them and the DWR officials in charge.

・A training session is held when a rain alarm station is installed and once a year thereafter (Fig. 2-5).



High risk 4,427 villages (2011)

This picture is offered by DWR Early Warning Center

Fig. 2-1 4,427 villages (communities) in mountainous areas with a high risk of heavy rain disaster

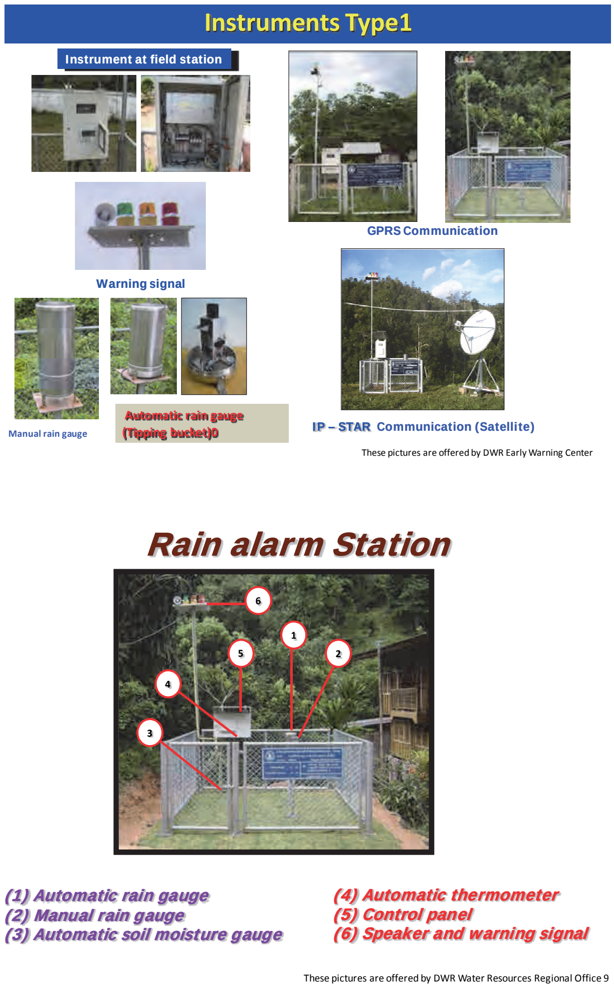


Fig. 2-2 Instruments located at the rain alarm station

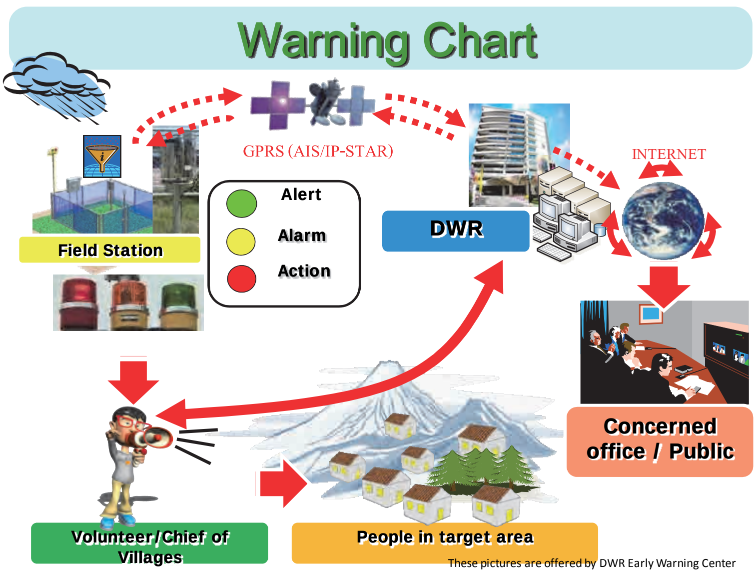


Fig. 2-3 Early Warning System Warning Chart

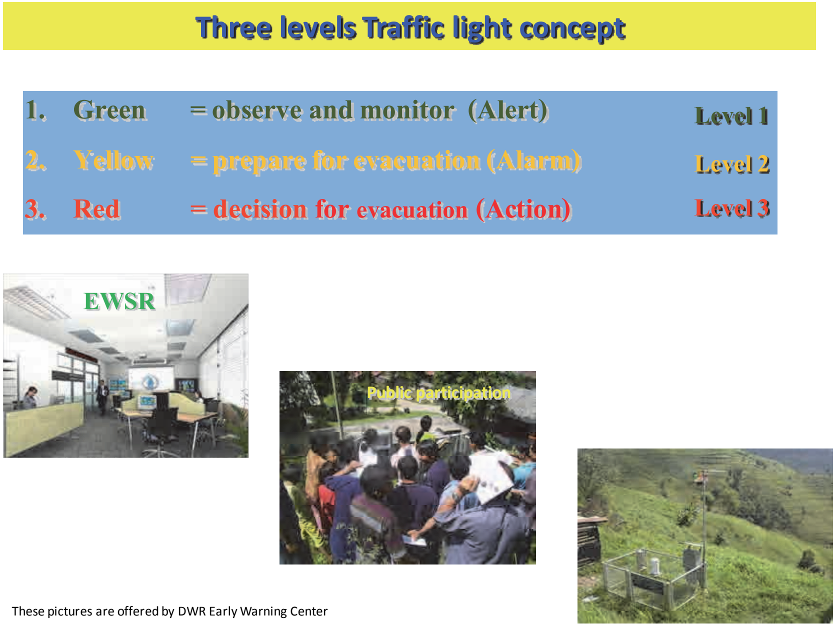


Fig. 2-4 Concept of the three-tier warnings of the Early Warning System

This picture is offered by DWR Water Resources Regional Office 9

Fig. 2-5 Training sessions

2.2.2 Basics behind the setting of the warning criteria

○ The reference rainfalls that are used as warning criteria are determined as follows:

Standard reference rainfall: 150 mm/12hr (180 mm/12hr for the southern region) (Fig. 2-6)

Red: standard reference rainfall ×80% 150mm×0.80＝120mm

Yellow: standard reference rainfall ×65% 150mm×0.65＝97.5mm

Green: standard reference rainfall ×55% 150mm×0.55＝82.5mm

* The 12-hour rainfall is used in accordance with the fixed monitoring interval of village volunteers.

○ Warning criterion are determined based on the following conditions (inference from hearings).

<Standard reference rainfall (150mm/12hr), Red warning (120mm/12hr) >

- This rainfall total is roughly equivalent to that of a heavy rain that could potentially trigger a severe disaster as described in 1.2 (2)
- Approximately 300 mm if converted into daily rainfall.

  (Ref.) The daily rainfall total when a large-scale disaster occurred in Uttaradit Province on May 22, 2006 was 200 to 300 mm.

<Green warning (82.5mm/12hr) >

- This rainfall total is roughly equivalent to that which may cause a river to overflow
- The criteria for a Green warning is determined in each community by referring to the reference rainfall and by considering actual conditions, namely, the amount of rainfall necessary for a river to overflow in the community.

○ From the above, we can say that the warning criterion have the following characteristics.

- The warning criterion can cover various levels of phenomena, including those described in 1.2 (1) and 1.2 (2).
- The warning criterion assume that "villagers can evacuate swiftly even if there is an increased risk of a severe disaster like that shown in 1.2 (2) as long as monitoring activities are started at the stage when a risk of a disaster like that described in 1.2 (1) has been identified and monitoring is continued thereafter."

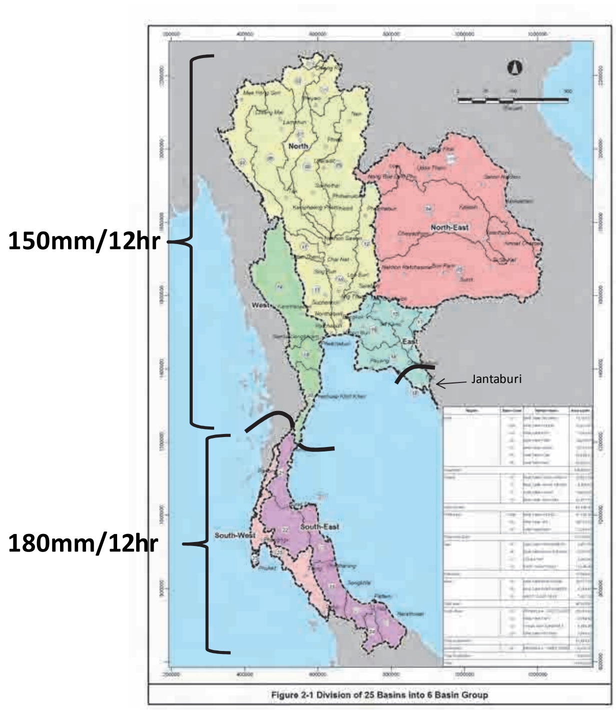


Figure 2-1 Division of 25 Basins into 6 Basin Group

This figure is quoted from the DWR's report "Final Report The Strategic Plans for Water Resources Management in 25 Basins"

Fig. 2-6 Grouping of areas by warning criteria (standard reference rainfall)

2.3 Evaluation results of the Early Warning System (advantages)

○ The Early Warning System can promptly provide information to local people through real time rainfall gauging and the issuance of automatic alerts.

○ Telemetric rain alarm stations have been installed in locales where rainfall gauging has not been carried out, such as mountainous regions, and locations where only daily rainfall was monitored previously. This made it possible to continuously accumulate 15-minute rainfall data.

○ Since its warning criteria is based on the rainfall index, which is easy to understand and measure, it is a system that allows for the active participation of local people.

○ A risk communication and mutual reporting system has been established between the local people and the government.

2.4 Remaining Problems of the Current Early Warning System

2.4.1 Improvement of warning criteria accuracy

○ It is necessary to verify the accuracy of a criterion for Red warnings based on disaster occurrence data across the country.

・Green warnings target phenomena that occur relatively frequently. Therefore, there is no problem with the current operating method in which the warning criterion is determined in each area based on the actual phenomena of the area.

・In contrast, the Red warning targets phenomena that occur rarely in most of areas. Therefore, verification of the accuracy of Red warnings should not be delegated to each area.

○ In addition to the above reasons, the verification of the accuracy of Red warnings which convey the urgency of a severe disaster like that described in 1.2 ⑵ is important for the following reasons:

・Local people may not be able to detect the danger of any type of disaster they have never experienced if they depend only on their own monitoring.

・Even if they make preparations or evacuate by making projections based on an event they have experienced, there is still the possibility that an event that cannot be addressed sufficiently by such measures could occur.

・A large-scale debris flow disaster that occurred in Atsumari river, Minamata City, Kumamoto Prefecture on July 20, 2003 is an example of above-mentioned events (Fig. 2-7).

－Because most of residents who lived close to the stream line had experienced inundation damage in the past, they had evacuated before the debris flow attacked their houses.

－There was the high ground on the both side of the stream. The debris flow ran onto the high ground that was 6-10m higher than front stream bed.

－Because people of this village had not experience flood up to the high ground in the past, they thought that the high ground are safety.

－Therefore, most of the people who stayed on the high ground was attacked by the debris flow.

・Therefore, a special warning is necessary to make them fully appreciate that an unprecedented situation is occurring in cases where there is a real threat of danger.

・People will come to distrust the warning system if no disaster occurs every time a special warning is issued (false warning). Therefore, it is important to improve the accuracy of the special warning to ensure that it is issued only when danger is truly imminent.

・It is unacceptable if a serious disaster occurs before a special warning is issued (failure of detection).

○ From the above, it is obvious that we should improve the accuracy of the Red warning by verifying the followings based on the disaster data from across the country: (a) the warning is issued only when a severe disaster is truly imminent and (b) there is no possibility of a detection failure.

Fig. 2-7 A disaster that occurred in Minamata City, Kumamoto Pref. on July 20, 2003

2.4.2 Issuance of an alert based on terrestrial phenomena

○ We should also study issuing alerts based on terrestrial phenomena as information to convey that a severe disaster like that described in 1.2 (2) is approaching.

・Important indicators that a situation is becoming imminent include terrestrial phenomena and other events occurring at the site, such as the overflowing of rivers, sediment movements (landslids, debris flows, mud flows, etc.), the start of evacuation, and the occurrence of damage.

2.4.3 Measuring rainfall at upper reach of the watersheds and in the mountains

○ Presently, rain alarm stations are installed in village communities because of the problems associated with alarm transmission, the receipt of radio waves, maintenance, the availability of power sources, etc.

○ The causes of disasters, namely, floods and sediment production, start from upper reach of the watershed. Nonetheless, sometimes, they occur far away from village communities (Fig. 2-8).

○ In some cases, a large difference exists between the rainfall at the rain alarm station and the rainfall at upper reach of the watershed due to the distance from the village community and the topographic differences of the two locations.

○ Accordingly, we should find a better way to gauge rainfall at upper reach of the watershed and in the mountain.

Fig. 2-8 Rain alarm station in Baan Huai Thanu (Nan Province) and a map of the basin

3. Technical Proposal for the Improvement of the Early Warning System

3.1 Improvement of warning criteria accuracy

○ We should study the implementation of more accurate warning criterion that focuses on sediment-related disaster-criterion as an equivalent to Red warning, and put it into test operation in order to establish a mechanism that can convey the urgency of large-scale disasters without failure.

○ For the new warning criterion, the rainfall amounts measured by telemetric rain gauges should be plotted as a curved line (snake line of real rainfall) on the graph that shows the long and short-term rainfall indices on the abscissa and ordinate axes, respectively. Monitoring should be continued by watching for whether the snake line crosses the criterion value (critical line) (Fig. 3-1).

○ The threshold value of the warning criterion should be set as a boundary line separating "the range distributed with rainfalls that did not cause flood disasters accompanied by sediment-related disasters" and "the range distributed with rainfalls that caused flood disasters accompanied by sediment-related disasters" on the graph plotted with the past rainfall data.

○ The warning criterion currently being used for the Early Warning System should be operated as it is for the time being. In the meantime, the new warning criterion should be test-operated internally by the DWR, with its accuracy being verified each time.

○ Even during the period of test operation, the new warning criterion should be utilized for actions, such as conveying an alert to village volunteers, checking site conditions, intensifying the monitoring operation of the DWR, providing information to related organizations, and posting information on the web, in the event a possibility arises that the snake line will go beyond the criterion value (critical line).

○ It is desirable to proceed with the study on the new warning criterion in cooperation with experts (university professors) and by exchanging information with them.

○ For details (setting of a warning criterion, etc.), see the Appendix1.

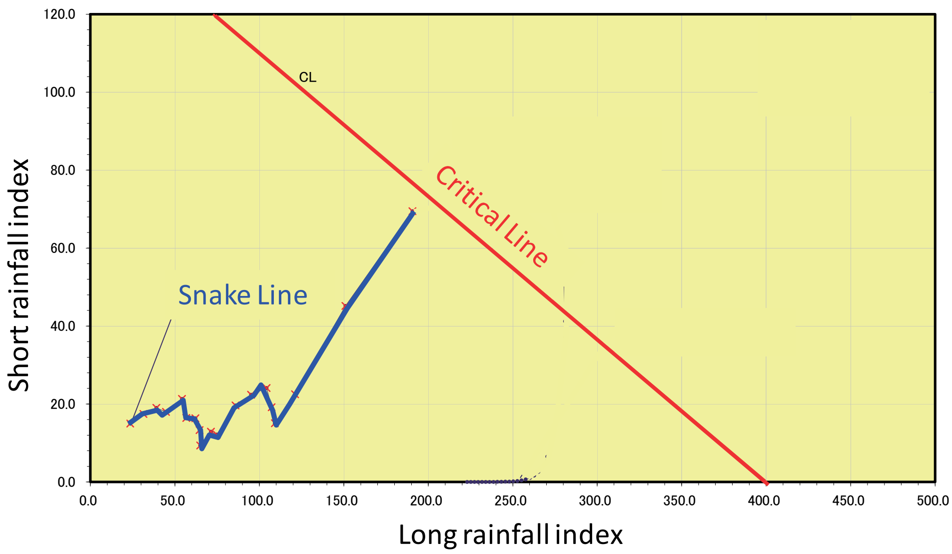


Fig. 3-1 Concept of monitoring using a snake line of real rainfall

→Appendix1 Setting method of a warning criterion with a focus on sediment-related disasters

3.2 Issuance of an alert based on terrestrial phenomena

○ Terrestrial phenomena and other events at the site, such as river overflow, sediment movements (landslides, debris flows, mudflows, etc.), the start of evacuation, and the occurrence of damage, are important information indicating that a large scale disaster is imminent.

○ The Early Warning System should possess a mechanism that enables village volunteers to report terrestrial phenomena and other information to DWR (DWR headquarters and the regional officials in charge of the Early Warning System in the region) quickly, and allowing for the prompt sharing of information with other village volunteers.

・Examples of ways to report this kind of information to DWR.

－Reporting buttons can be provided for the rain alarm station so that this kind of reporting is added to the information transmitted via the telemetric network.

－Alternatively, we can introduce a mechanism in which a village volunteer inputs a report to the host server via the web.

・Examples of ways to provide the information to other village volunteers by DWR.

－Constructing a system that can simultaneously distribute e-mail to all volunteers in designated area (for example, the area under the regional official's jurisdiction) .

－Constructing a system that can post the information on the web.

○ Conveying the reported information on terrestrial phenomena, etc. to the neighboring areas and related organizations via the web or the telemetric network will help to make local people be on alert and provide for the rapid enhancement of the monitoring operation of the DWR or other governmental organizations.

3.3 Measuring rainfall at upper reach of the watershed and in the mountain

○ A rain alarm station (telemetric rain gauge) should be installed in the village communities in the upper mountain, in addition to ordinary installation locations, such as communities that have a disaster history and communities where rain gauges can be installed easily.

3.4 Actions for the practical use of radar-analyzed rainfall

○ It is impossible to cover all source areas of sediment-related disasters using only the ground level rain gauges. Therefore, practical use of radar rain gauges should be promoted in collaboration with related organizations.

○ In addition, the use of ground level rain gauges should be continued steadily because the telemetric ground rain gauge network is indispensable to the calibration and accuracy improvement of radar-analyzed rainfall.

3.5 Survey of the flooding and deposition areas of debris and mud flow

○ Surveys of flooding and deposition areas should be conducted at the sites of debris and mud flows in order to use the obtained data for purposes such as identifying the occurrence mechanism of sediment-related disasters, verifying hazard maps and improving their accuracy, and evaluating the importance (effect) of policies regarding sediment-related disasters.

Appendix 1

Method for Setting a Warning Criterion with a Focus on Sediment-related Disasters

1. Target Phenomena

○ Disasters that cause damage in a wide area (a large part of the community or in multiple communities) or cause a number of deaths due to flooding accompanied by sediment-related disasters (debris flows, mud flows ("Nam Paa" containing a large volume of sediment) or large-scale or multiple landslides triggered by heavy rain.

・Disasters that occur once every several years that are reported as national news.

2. Concept of the Warning Criterion to be Set

○ The rainfall amounts measured by telemetric rain gauges are plotted as a curved line (snake line of real rainfall) on the graph that shows long-term and short-term rainfall indices on the abscissa and ordinate axes, respectively. Monitoring should be continued by watching whether the snake line will cross the criterion value (critical line) (Fig. 1).

○ The critical line is set as a boundary line separating "the range distributed with rainfalls that did not cause target phenomena (non-occurrence rainfalls)" and "the range distributed with rainfalls that caused target phenomena (occurrence rainfalls)" on the graph plotted with the past rainfall data.

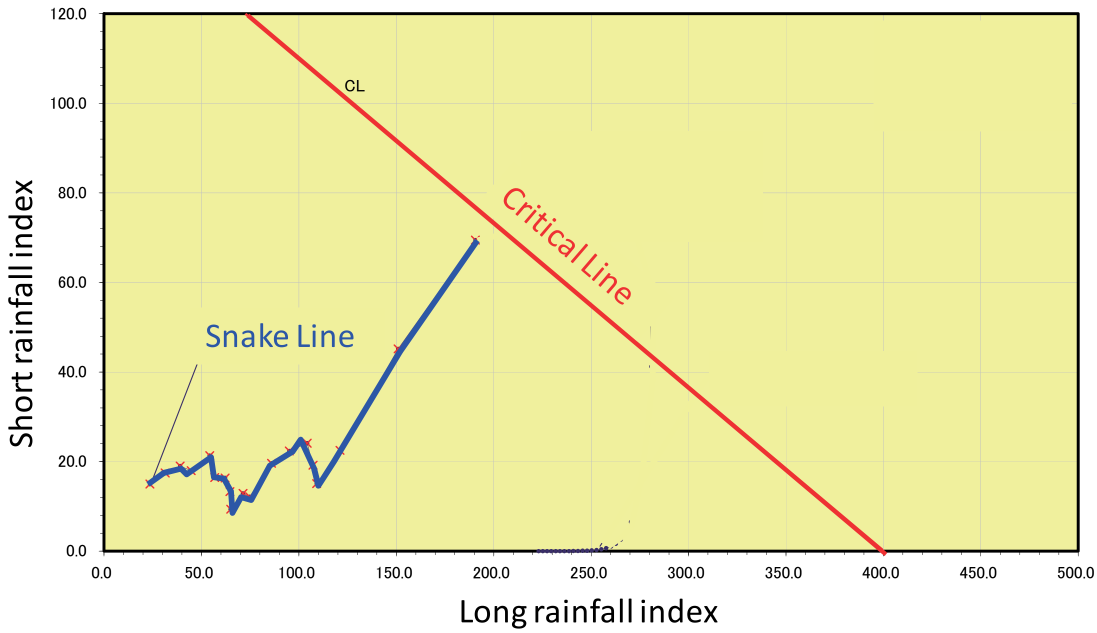


Fig. 1 Concept of monitoring using a snake line of real rainfalls

3. Rainfall Indices

○ Long-term rainfall index (X-axis)

- Cumulative rainfall obtained by accounting for the effect of antecedent rainfall (obtained by adding each rainfall total in unit time multiplied by a reduction coefficient). This is an index used for evaluating the amount of water that has accumulated in the ground due to long rain.
- The Antecedent Precipitation Index (API) studied by the DWR and Dr. Suttisak Soralump can also be used as a long-term rainfall index.

○ Short-term rainfall index (Y-axis)

- This is an index to express rainfall intensity over a short period.
- The short-term rainfall index should be used in addition to the long-term rainfall index, because the onset of sediment-related disasters is concentrated around the time of peak rainfall.

○ Examples of rainfall indices

- Examples of a combination of long-term and short-term rainfall indices are shown below.

【Example (1): One of methods had be used in Japan】

Long-term rainfall index (X-axis)	Working rainfall (half life: 72 hours) $R_{Wt} = R_t + 0.5^{1/T} \times R_{Wt-1}$ (T＝72 hours)
Short-term rainfall index (Y-axis)	Working rainfall (half life: 1.5 hours) $R_{Wt} = R_t + 0.5^{1/T} \times R_{Wt-1}$ (T＝1.5 hours)

R_{Wt} : working rainfall at Time t (mm)　　R_{Wt-1} : working rainfall at Time t -1 (mm)

R_t : hourly rainfall at Time t (mm/hr)　　T : half-life (hour)

【Example (2): One of methods had be used in Japan】

Long-term rainfall index (X-axis)	Working rainfall (select a half-life with better suitability from 24, 48, or 72 hours.) $R_{Wt} = R_t + 0.5^{1/T} \times R_{Wt-1}$ (T＝24, 48, or 72 hours)
Short-term rainfall index (Y-axis)	Hourly rainfall R_t (mm/hr)

R_{Wt} : working rainfall at Time t (mm)　　R_{Wt-1} : working rainfall at Time t -1 (mm)

R_t : hourly rainfall at Time t (mm/hr)　　T : half-life (hour)

【Example (3): when the only usable rainfall data is a daily rainfall data】

Long-term rainfall index (X-axis)	Working rainfall (select a half-life (day) with better suitability by trial and error.) $R_{Wd} = R_d + 0.5^{1/T} \times R_{Wd-1}$
Short-term rainfall index (Y-axis)	Daily rainfall R_d (mm/day)

R_{Wd}: working rainfall on Day d (mm)　　R_{Wd-1}: working rainfall on Day d-1 (mm)

R_d: daily rainfall on Day d (mm/day)　　T : half-life (day)

4. Target Areas for Application of the Warning Criterion

○ For the time being, the warning criterion should be applied to the areas where 4,427 villages are located, which have been evaluated as having a high risk of heavy rain disaster occurrence in the mountainous areas of Thailand.

○ The areas where those 4,427 villages are located should be divided into groups in terms of the similarity of rainfall and geological conditions, administrative boundaries (boundaries of DWR’s regional offices, provincial government, etc.), and other features, and the same criterion should be applied to all areas included in each group.

○ At this moment, the number of areas which have both the sediment-related disaster data and rainfall data necessary for setting a warning criterion may be limited. Therefore, the warning criterion should be set only in the areas which have such data. In areas that do not have the necessary data, the warning criterion set for some of those areas that considers the similarity of areal features should be used.

5. Extraction of Areas to Set the Warning Criterion

○ Select sediment-related disasters whose occurrence rainfall (rainfall that caused a disaster) can be identified.

- The sediment-related disasters to be selected are those that caused damage in a large part of the community, or in multiple communities, or killed a number of people due to flooding accompanied by debris flow, mud flow, or large-scale or multiple landslides (the kind of disasters that are reported on the national news).
- In addition, disasters to be selected should have, in its vicinity, a rain gauge station with an observation history of more than several years, and rainfall data which can be used as the real rainfall at the time of disaster.

○ Identify the date and time of occurrence of the selected disasters.

- If the date of occurrence is known, but the time of occurrence is not known from the disaster records, assume the time of peak rainfall on that day to be the occurrence time for the disaster.

○ From among the areas in each group divided in Item 4, select an area which has sediment-related disasters mentioned above as the area for setting a warning criterion (hereinafter referred to as the “criterion setting area”).

6. Production of a rainfall distribution graph for the criterion setting area (Fig. 2)

○ Convert the data obtained from rain gauges in the criterion setting area which was selected in Item 5 into the dataset consisting of rainfall indices defined in Item 3.

- Be sure to extract rainfall data from all rain gauges that have record of occurrence rainfall. As for other rain gauges, data extraction can be limited to only the rain gauges that have a relatively long history of data accumulation.

○ Enter the rainfall index data from each rain gauge station into the scatter graph (distribution graph of real rainfalls) that shows a long-term rainfall index and a short-term rainfall index on the abscissa and the ordinate axes, respectively.

○ Examine the rainfall index data on the date and at the time of disaster which were measured by rain gauges installed in the vicinity of the disaster site, and put them in the distribution graph of real rainfalls.

7. Setting of Warning Criterion (Fig. 2)

○ Draw a boundary line separating "the range distributed with non-occurrence rainfalls" and "the range distributed with occurrence rainfalls" in the distribution graph of real rainfalls produced in Item 6. Use the line as the warning criterion (critical line). The line should be drawn in such a way that:

・Occurrence rainfalls should not fall below the critical line.

・Non-occurrence rainfalls should not cross the critical line to the extent possible.

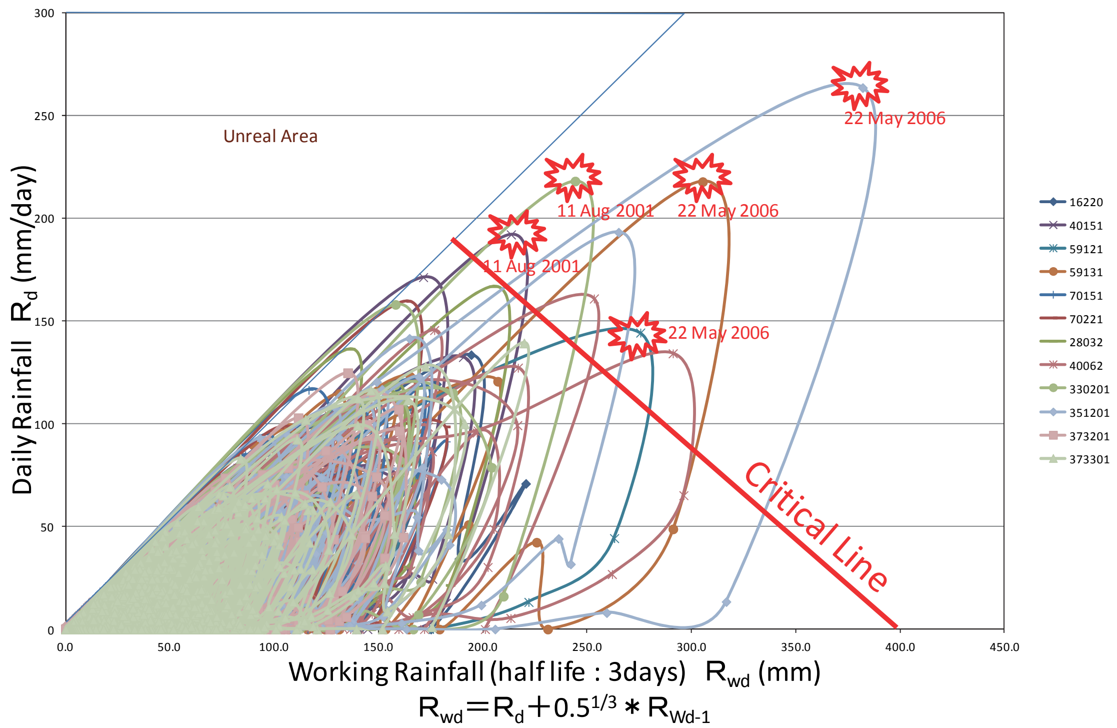


Fig. 2 A distribution graph of real rainfall amounts and setting of a critical line

(Note) This is a conceptual graph.

・This graph shows the concept for how to set a critical line using actual daily rainfall data in 2001-2011 taken from rain gauges at 12 locations in Uttaradit Province, Sukhothai Province, a part of Prea Province, and a part of Nan Province.

・Occurrence rainfalls in the graph are assumed rainfalls. However, a large-scale sediment-related disaster actually occurred in Uttaradit Province on May 22, 2006. A large-scale sediment disaster also occurred in an area in northern Thailand on Aug. 11, 2001.

・This graph shows the concept for setting a critical line based on daily rainfalls. If data from telemetric rain gauges is available, the critical line based on hourly rainfall can be set by following a similar procedure (the procedure is the same, but the data volume will increase to 24 times).

8. A Method to Represent the Distribution Range of Non-occurrence Rainfalls Quantitatively (How to set a critical line to reduce false warnings) (Fig. 3)

○ Divide the graph paper for the production of a distribution graph of real rainfalls into meshes of the same size in both the ordinate and abscissa directions.

○ Using a spreadsheet software, count how many times the indices of non-occurrence rainfalls come into each mesh from the dataset of rainfall indices and fill in the number in each mesh. The meshes having many numbers are the range where disasters do not occur.

○ If a critical line is drawn in such a way that the non-occurrence range outside the critical line is reduced as much as possible, false warnings may be decreased (adoption of a solid line instead of a dotted line in Fig. 3)

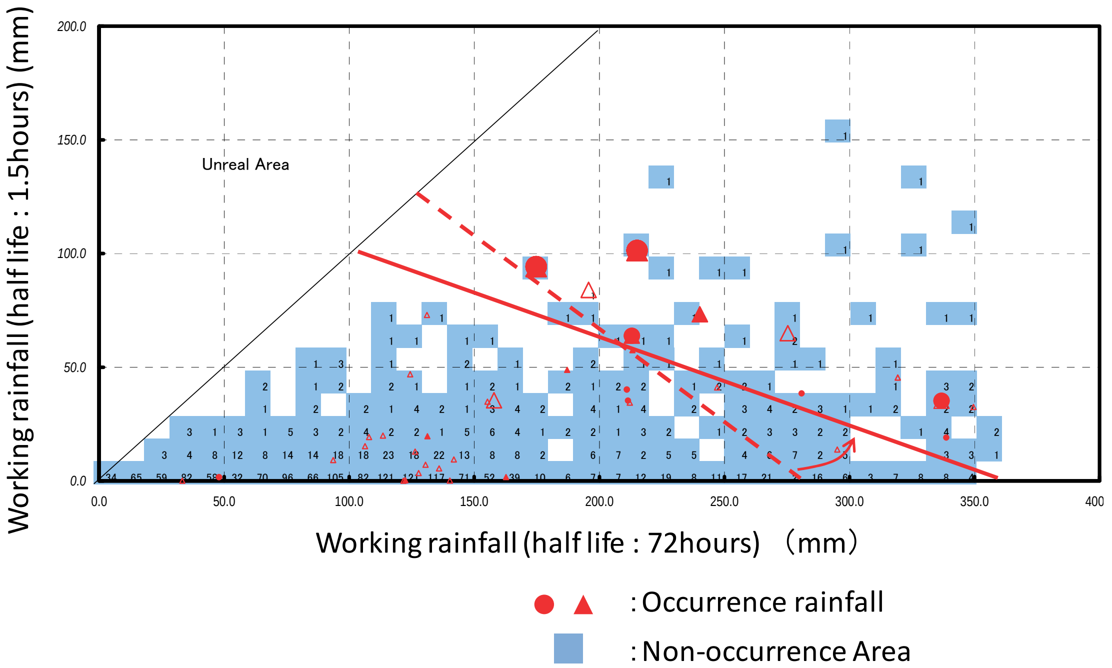


Fig. 3 Setting of a critical line by taking into account the distribution range of non-occurrence rainfalls

9. Activities for improving the Accuracy of Warning Criterion

○ Organize rainfall data on a regular basis.

・Convert observation data into rainfall indices and produce a database regularly.

○ Collect and organize information regarding sediment-related disasters.

・Time of occurrence

・Place of occurrence

・Type of phenomenon (debris flow, mud flow, multiple or large-scale landslide, etc.)

・Damage

○ Verification of the critical line using non-occurrence rainfall data

- The non-occurrence range will change as the accumulation of non-occurrence rainfall data increases.
- If the non-occurrence range crosses over the critical line significantly, it means an increase in false warnings. Therefore, it is necessary to reexamine the setting of the critical line.

○ Verification of the critical line using the data of occurrence rainfalls

- Verification should be made when a target disaster has occurred.
- Verification should include a check if some occurrence rainfall falls below the critical line (failure of detection).

Water Level Standards

1. General

Current water level standards of the Chao Phraya River basin are defined as two different types according to the difference of warning target area. One is applied for warning to the area nearby station, and another is applied for warning to the downstream basin. Standards are based on the flow capacity at every station. Each of them is designated and used as follows:

(1) Water level standard for warning to the area nearby each station

- Water level of river is sectioned by three zones, as colored by green, yellow and red. Threshold between these zones are defined as “Warning level” and “Critical level”, respectively. Critical level of stations is listed in Table 1.
- “Critical level” is determined as the water level of overflow from the river. It is equal to the lower side of bank level or the bank level at the point with highest risk surrounding the observation station.
- “Warning level” is defined as the water level for warning issuance. Actual value of warning level is based on critical level of each station, considering various conditions on land use or economic situation of the surrounding area, and so forth. “Warning level” of stations is also listed in Table 1.
- The early warning method based on correlation between two adjacent stations was established. Some water level corresponding to the severity of a flood was defined from the correlation with upstream station at an important station in the Ping, Wang, Yom, Nan River (see Table 2).
- The severity of a flood was defined as flood start, medium flood, heavy flood and severe flood. The water level corresponding to and indicating the severity of a flood was determined. Flood arrival time was determined according to hydrograph during a past flood event.
- Residents are notified with water level at upstream station and estimated arrival time when a flood would occur and how a flood would extend.
- For some cities, possible inundation area maps were created based on the past flood event. Among the cities using early warning method listed in Table 2, only the cities, such as Chiang Mai (P.1), Phrae (Y.1C), Lampang (W.1C), Nan (N.1), Lamphun (P.5) published possible inundation area map.
- At the area of downstream of the Chao Phraya Dam, a flood risk in near future could be judged by comparing with dam discharge and flow rate standard at each station.

Table 1 Critical level of stations (in the area of Hydro-1, 2 and 5)

Station	Water level standard (m, AD)	Flow rate standard (m^3/s)
P.67	4.0	420
P.1	3.7	440
P.82	3.8	150
P.84	4.0	100
P.81	5.8	110
P.5	5.0	140
P.76	5.4	320
P.85	3.5	260
P.77	3.8	240
P.87	4.1	120
W.10A	6.6	570
W.1C	5.2	640
Y.20	12.0	3,100
Y.1C	8.2	1,000
N.64	9.5	1,228
N.1	7.0	1,265
G.10	3.5	260
G.8	4.0	310
I.17	3.5	120
Sw.5A	5.0	700
P.4A	5.8	360
P.14A	6.4	-
P.20	5.7	840
P.21	5.4	90
P.24A	5.0	175
P.56A	7.4	160
P.64	6.0	360
P.65	5.0	100
P.71A	5.3	241
P.73	5.3	1,450
P.75	7.4	500
P.79	3.8	300
P.80	6.8	200
P.85A	-	-
P.86	4.2	25
P.90	3.0	200
P.91	5.7	-
P.92	6.7	-
P.93	3.5	57
W.3A	6.0	800
W.5A	6.0	-
W.6A	6.2	-
W.16A	6.1	200
W.17	2.5	300
W.17A	3.9	487
W.18A	6.0	-
W.20	5.6	400
W.21	7.8	500
W.22	6.0	350
W.25	5.3	400
W.26	2.9	207
Y.13A	6.5	500
Y.24	8.4	50
Y.30	8.2	100
Y.31	10.0	500
Y.34	10.2	120
Y.36	8.8	500
Y.37	11.0	1,500
Y.38	6.0	300
Y.43	-	-
Y.44	-	-
Y.45	-	-
Y.46	-	-
Y.47	-	-
Y.48	-	-
N.13A	7.6	1,959
N.49	9.2	500
N.65	7.8	500
N.75	10.0	1,400
G.4	4.0	100
G.9	6.9	200
G.11	6.0	500
I.6	8.7	120
I.14	6.5	400
Kh.72	3.6	80
Kh.89	2.7	70
W.23	6.3	506
W.4A	6.1	458
P.2A	5.7	4,230
P.7A	5.9	4,035
Y.14	12.0	2,319
Y.6	10.0	2,524
Y.3A	10.2	1,198
Y.33	9.6	800
Y.4	7.4	563
Y.16	7.0	368
Y.17	7.0	480
Y.5	8.3	652
N.12A	12.2	3,043
N.2B	7.6	1,614
N.60	9.7	2,055
N.27A	10.6	1,233
N.22	9.2	476
N.5A	10.5	1,452
N.36	7.9	336
N.24A	13.2	878
N.55	7.8	199
N.7A	10.8	1,350
N.8A	11.3	1,454
S.33	8.8	384
S.4B	10.1	190
S.42	10.2	170
P.17	6.1	1,815
N.67	15.2	1,520
C.2	26.2	3,590
C.13(US)	-	-
C.13(DS)	16.34	2,840
C.3	11.70	2,340
C.7A	9.32	2,690
C.35	4.58	1,155
C.36	4.00	388
C.37	3.80	134
C.29	3.90	3,500
C.30	108.30	830
Ct.4	71.96	235
Ct.7	104.88	170
Ct.9	127.47	280
Ct.19	24.35	338
C.2A	21.17	616
S.39	52.59	1,230
S.28	31.46	1,175
S.9	22.56	1,740
S.32	12.78	1,500
S.26	8.67	556
S.5	4.70	1,400

Table 2 Upstream water level corresponding to the severity of a flood used in the early warning method

Station	Severity of a flood	Water level at upstream station (m, AD)		Arrival time (hrs)	Distance (km)	Water level at downstream station (m, AD)	
Chiang Mai (P.1)	Start	P.67	4.00	7	32	P.1	**3.70**
	Medium		5.00	7			4.20
	Heavy		6.00	7			4.80
	Severe		6.28	6			4.90
Lampang (W.1C)	Start	W.10A	6.60	10	43	W.1C	**5.20**
	Medium		7.00	10			5.60
	Heavy		7.82	9			6.55
Lamphun (P.5)	Start	P.81	5.80	7	19	P.5	**5.00**
	Medium		6.00	7			5.20
	Heavy		6.50	6			5.50
Nan (N.1)	Start	N.64	9.50	6-7	42	N.1	**7.00**
	Medium		11.00	6-7			7.50
	Heavy		14.25	6-7			8.42
Phrae (Y.1C)	Start	Y.20	8.10	24	91	Y.1C	**8.20**
	Medium		10.0	24			9.80
	Heavy		12.0	23			11.2
	Severe		13.1	16			11.8
Pasang Lamphun (P.87)	Start	P.77	3.80	8-9	31	P.87	**4.10**
	Medium		4.00	7-8			3.90
	Heavy		6.00	6-7			5.10
Lamphun (P.85)	Start	P.76	5.40	15	44	P.85	**3.50**
Maewang Chiang Mai (P.84)	Start	P.82	3.80	4-5	18	P.84	**4.00**
	Medium		4.00	4-5			4.20
	Heavy		4.15	5-6			4.40
Kamphaeng Phet (P.7A)	Start	P.2A	2.58	24	68	P.7A	2.47
	Medium		4.02	24			3.09
	Heavy		5.03	24			3.56
	Severe		5.70	22			4.00

(2) Water level standard for warning to the downstream basin

- Main stations in the Chao Phraya River basin, including branch rivers such as Ping, Wang, Yom and Nan River, have the water level that indicates the risk of flooding at the downstream area. This water level is defined as “Critical level” and designated to indicate the risk as a kind of alert system after the 2011 flood occurrence.
- “Critical level” for this alert system is applied for only 38 stations in the Chao Phraya River basin.
- “Flood level” is defined as the water level at starting overflow from the river or flow capacity of the river. The value of “Flood level” is exactly equal to that of “Critical level” for the warning to the area nearby each station.
- “Critical level” is also designated by flow rate of river as well as water level. “Flood level” and “Critical level” indicated by water level and by flow rate are listed in Table 3 and 4, respectively.
- “Critical level” is used as the alert indicator for flood management officials. “Critical level” defined here isn’t determined based on “Flood level” at that station. This “Critical level” indicates not the risk at the station but the risk at downstream basin. When the water level at one of upstream station exceed “Critical level”, flood management officials start to monitor the upstream flow continuously and to consider a preparation of flood measures at downstream basin, such as central plain.
- “Critical level” of flow rate at upstream station is based on “Flood level” of Ayutthaya C.35 (1,155m^3/s), which is a bottleneck of the downstream of Chao Phraya River, considering diversion volume into canals and branch rivers. “Critical level” of flow rate in the upstream area north of Nakhon Sawan and the downstream area south of Nakhon Sawan is illustrated in Fig. 1 and 2. If there is a station with flow rate more than “Critical level” at downstream of the Chao Phraya Dam, flood occurs definitely in and around Ayutthaya.
- North of Nakhon Sawan C.2 station, “Critical level” of flow rate at each station is based on flow rate equal to 2,000m^3/s as maximum controllable flow rate at the Chao Phraya Dam. At every confluent point, “Critical level” of upstream stations is determined according to flow capacity of branch river. In case of an excess of “Critical level” at any station, but sum of flow rate at two stations in the upstream of confluence doesn’t exceeds “Critical level” of the station in the downstream of confluence, it will be substantially unaffected. For instance, even if flow rate at P.17 is 1,200 m^3/s (more than critical level) but that of N.67 is less than 800 m^3/s, there is no flooding in the downstream area (see Fig. 3).
- In order to judge actual risk at downstream basin, not only flow rate exceeding “Critical level” but also increasing trend of water level or flow rate is verified.
- In case of excess of “Critical level”, Single Command Center (SCC) is sole authority to command a facility operation.
- In the downstream area of the Chao Phraya Dam, there is less importance on “Critical level” as alert information, than upstream area.
- This standard is the system to know future trend of river flow and coming flood basically, thus it isn’t established as warning system.

Table 3 Water level standard used as caution and warning information to the downstream of Chao Phraya River

จังหวัด	สถานีเฝ้าระวัง	ระดับปกติ ระดับน้ำ (เมตร ร.ท.ก.)		ระดับวิกฤติ ระดับน้ำ (เมตร ร.ท.ก.)	ระดับน้ำท่วม ระดับน้ำ (เมตร ร.ท.ก.)	
เชียงใหม่	P.67	ต่ำกว่า	318.25	318.25 - 319.93	มากกว่า	319.93
	P.1	ต่ำกว่า	303.47	303.47 - 304.20	มากกว่า	304.20
ลำปาง	W.10A	ต่ำกว่า	262.30	262.30 - 265.60	มากกว่า	265.60
	W.1C	ต่ำกว่า	231.63	231.63 - 234.50	มากกว่า	234.50
ตาก	W.4A	ต่ำกว่า	134.00	134.00 - 136.10	มากกว่า	136.10
	P.2A	ต่ำกว่า	106.55	106.55 - 109.72	มากกว่า	109.72
กำแพงเพชร	P.7A	ต่ำกว่า	74.30	74.30 - 77.60	มากกว่า	77.60
แพร่	Y.20	ต่ำกว่า	185.90	185.90 - 193.00	มากกว่า	193.00
	Y.1C	ต่ำกว่า	147.00	147.00 - 151.70	มากกว่า	151.70
น่าน	N.64	ต่ำกว่า	218.10	218.10 - 220.40	มากกว่า	220.40
	N.1	ต่ำกว่า	197.60	197.60 - 199.20	มากกว่า	199.20
อุตรดิตถ์	N.12A	ต่ำกว่า	74.25	74.25 - 81.24	มากกว่า	81.24
	N.60	ต่ำกว่า	53.55	53.55 - 58.20	มากกว่า	58.20
พิษณุโลก	Y.16	ต่ำกว่า	36.70	36.70 - 38.63	มากกว่า	38.63
	N.27A	ต่ำกว่า	44.84	44.84 - 49.04	มากกว่า	49.04
	N.22	ต่ำกว่า	45.60	45.60 - 51.84	มากกว่า	51.84
	N.5A	ต่ำกว่า	41.60	41.60 - 45.04	มากกว่า	45.04
พิจิตร	Y.17	ต่ำกว่า	35.75	35.75 - 38.53	มากกว่า	38.53
	Y.5	ต่ำกว่า	29.05	29.05 - 30.30	มากกว่า	30.30
	N.7A	ต่ำกว่า	33.22	33.22 - 36.78	มากกว่า	36.78
	N.8A	ต่ำกว่า	28.85	28.85 - 31.29	มากกว่า	31.29
สุโขทัย	Y.14	ต่ำกว่า	68.55	68.55 - 77.10	มากกว่า	77.10
	Y.6	ต่ำกว่า	62.95	62.95 - 69.00	มากกว่า	69.00
	Y.3A	ต่ำกว่า	55.00	55.00 - 61.15	มากกว่า	61.15
	Y.4	ต่ำกว่า	48.65	48.65 - 50.87	มากกว่า	50.87
นครสวรรค์	P.17	ต่ำกว่า	36.50	36.50 - 38.08	มากกว่า	38.08
	N.67	ต่ำกว่า	26.25	26.25 - 28.30	มากกว่า	28.30
	C.2	ต่ำกว่า	23.70	23.70 - 26.20	มากกว่า	26.20
อุทัยธานี	Ct.19	ต่ำกว่า	22.45	22.45 - 24.35	มากกว่า	24.35
	Ct.2A	ต่ำกว่า	19.75	19.75 - 21.34	มากกว่า	21.34
ชัยนาท	C.13	ต่ำกว่า	14.00	14.00 - 16.34	มากกว่า	16.34
สิงห์บุรี	C.3	ต่ำกว่า	10.35	10.35 - 11.70	มากกว่า	11.70
อ่างทอง	C.7A	ต่ำกว่า	7.15	7.15 - 9.32	มากกว่า	9.32
สระบุรี	S.9	ต่ำกว่า	15.95	15.95 - 22.56	มากกว่า	22.56
พระนครศรีอยุธยา	S.26	ต่ำกว่า	6.75	6.75 - 7.11	มากกว่า	7.11
	S.5	ต่ำกว่า	2.70	2.70 - 4.70	มากกว่า	4.70
	C.35	ต่ำกว่า	3.22	3.22 - 4.58	มากกว่า	4.58
	C.29A	ต่ำกว่า	3.40	3.40 - 3.90	มากกว่า	3.90

Table 4 Flow rate standard used as caution and warning information to the downstream of Chao Phraya River

จังหวัด	สถานีเฝ้าระวัง	ระดับปกติ ปริมาณน้ำ (ลบ.ม/วินาที)	ระดับวิกฤติ ปริมาณน้ำ (ลบ.ม/วินาที)	ระดับน้ำท่วม ปริมาณน้ำ (ลบ.ม/วินาที)
เชียงใหม่	P.67	ต่ำกว่า 260	260 - 420	มากกว่า 420
	P.1	ต่ำกว่า 300	300 - 440	มากกว่า 440
ลำปาง	W.10A	ต่ำกว่า 200	200 - 570	มากกว่า 570
	W.1C	ต่ำกว่า 200	200 - 640	มากกว่า 640
ตาก	W.4A	ต่ำกว่า 200	200 - 458	มากกว่า 458
	P.2A	ต่ำกว่า 1,000	1,000 - 4,230	มากกว่า 4,230
กำแพงเพชร	P.7A	ต่ำกว่า 1,000	1,000 - 4,035	มากกว่า 4,035
แพร่	Y.20	ต่ำกว่า 300	300 - 3,100	มากกว่า 3,100
	Y.1C	ต่ำกว่า 300	300 - 1,000	มากกว่า 1,000
น่าน	N.64	ต่ำกว่า 800	800 - 1,060	มากกว่า 1,060
	N.1	ต่ำกว่า 800	800 - 1,300	มากกว่า 1,300
อุตรดิตถ์	N.12A	ต่ำกว่า 800	800 - 3,043	มากกว่า 3,043
	N.60	ต่ำกว่า 800	800 - 2,055	มากกว่า 2,055
พิษณุโลก	Y.16	ต่ำกว่า 200	200 - 368	มากกว่า 368
	N.27A	ต่ำกว่า 600	600 - 1,233	มากกว่า 1,233
	N.22	ต่ำกว่า 100	100 - 476	มากกว่า 476
	N.5A	ต่ำกว่า 700	700 - 1,452	มากกว่า 1,452
พิจิตร	Y.17	ต่ำกว่า 200	200 - 480	มากกว่า 480
	Y.5	ต่ำกว่า 300	300 - 652	มากกว่า 652
	N.7A	ต่ำกว่า 700	700 - 1,350	มากกว่า 1,350
	N.8A	ต่ำกว่า 700	700 - 1,454	มากกว่า 1,454
สุโขทัย	Y.14	ต่ำกว่า 300	300 - 2,319	มากกว่า 2,319
	Y.6	ต่ำกว่า 300	300 - 2,524	มากกว่า 2,524
	Y.3A	ต่ำกว่า 300	300 - 1,198	มากกว่า 1,198
	Y.4	ต่ำกว่า 300	300 - 563	มากกว่า 563
นครสวรรค์	P.17	ต่ำกว่า 1,000	1,000 - 1,815	มากกว่า 1,815
	N.67	ต่ำกว่า 1,000	1,000 - 1,520	มากกว่า 1,520
	C.2	ต่ำกว่า 2,000	2,000 - 3,590	มากกว่า 3,590
อุทัยธานี	Ct.19	ต่ำกว่า 200	200 - 338	มากกว่า 338
	Ct.2A	ต่ำกว่า 300	300 - 616	มากกว่า 616
ชัยนาท	C.13	ต่ำกว่า 1,800	1,800 - 2,840	มากกว่า 2,840
สิงห์บุรี	C.3	ต่ำกว่า 1,800	1,800 - 2,340	มากกว่า 2,340
อ่างทอง	C.7A	ต่ำกว่า 1,800	1,800 - 2,690	มากกว่า 2,690
สระบุรี	S.9	ต่ำกว่า 700	700 - 1,740	มากกว่า 1,740
พระนครศรีอยุธยา	S.26	ต่ำกว่า 400	400 - 556	มากกว่า 556
	S.5	ต่ำกว่า 700	700 - 1,400	มากกว่า 1,400
	C.35	ต่ำกว่า 800	800 - 1,155	มากกว่า 1,155
	C.29A	ต่ำกว่า 2,500	2,500 - 3,500	มากกว่า 3,500

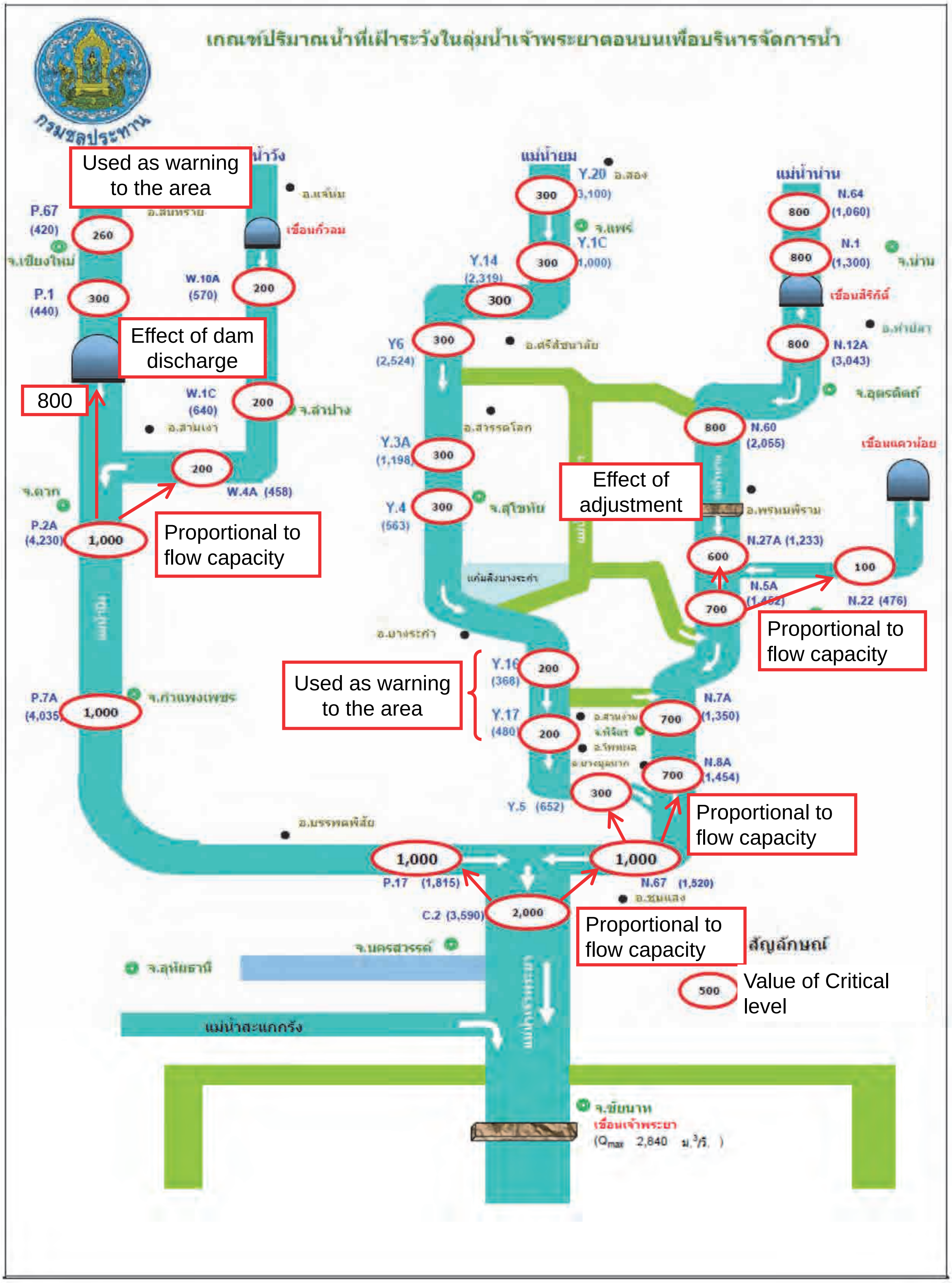


Fig. 1 Value of critical levels in the north Nakhon Sawan

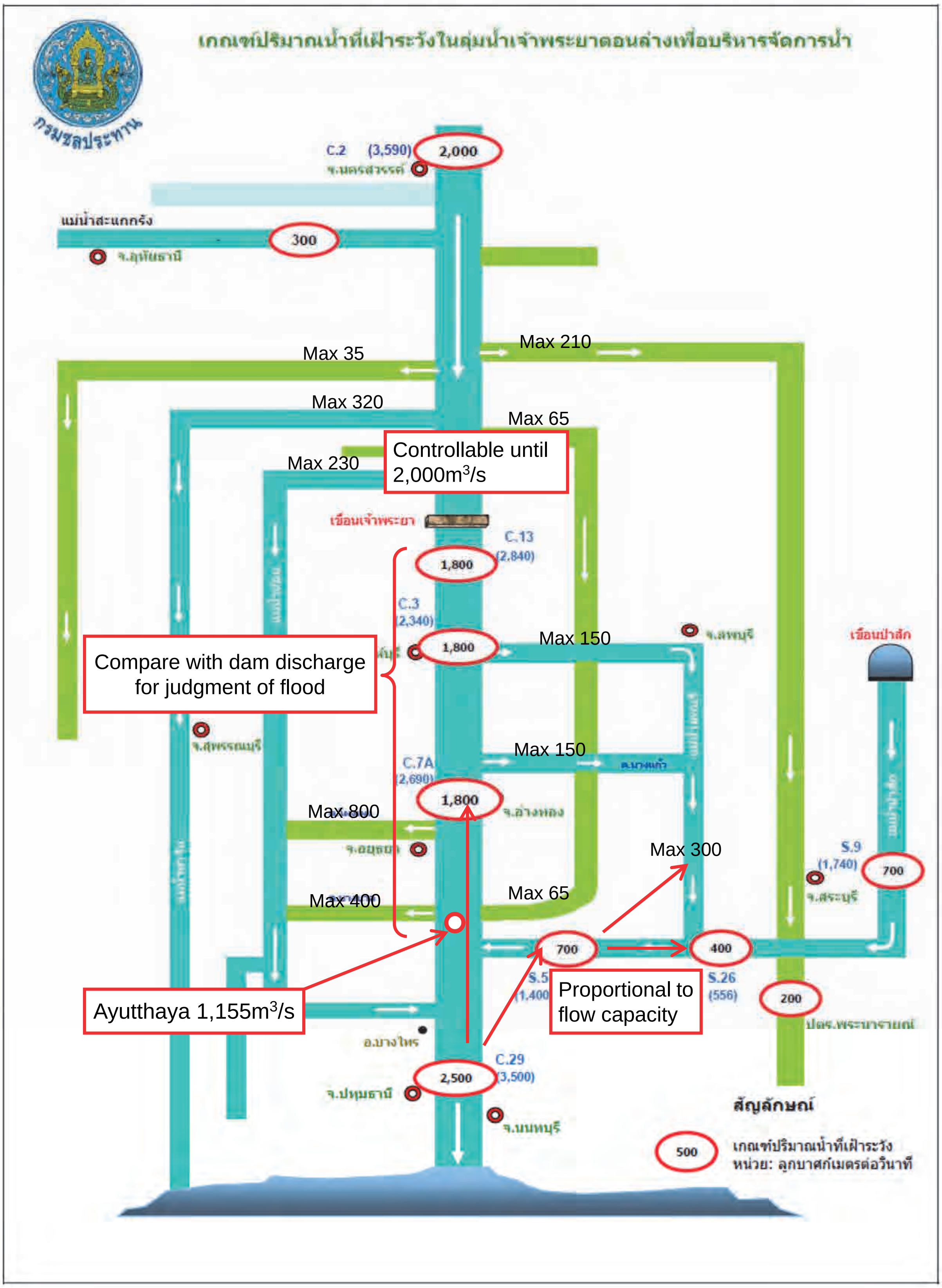


Fig. 2 Value of critical levels in the south Nakhon Sawan

2. **Specific usage of water level standards**

As specific example, usage of water level standards at Chiang Mai (P.1) as early warning method is illustrated below.

Chiang Mai

- Critical level at P.1 station is 3.70m in water level and 440m^3/s in flow rate.
- Set P.67 station located at 32km upstream away from P.1 as monitoring point. Find the water level at P.67 corresponding to the flow rate same as critical level at P.1 (440 m^3/s) by using rating curve. It results in 4.00m.
- Estimate the time of travel from historical hydrograph. It results in approximately 7 hours.
- This information suggests that the neighbor area of P.1 is going to be flooded after 7 hours when water level at P.67 becomes 4.00m. People can watch it through a signboard at P.1 station or a CCTV image on the web site.
- According to the past event of heaviest flooding, set water level at P.1 corresponding to medium, heavy and severe flood as 4.20, 4.80 and 4.90m, respectively, and then, estimate the flow rate corresponding to the water level above based on the rating curves at both P.67 and P.1. These result in 5.00, 6.00, 6.28m, respectively.
- Meanwhile, according to the 2005 flood, a map indicating relationship between P.1 water level and inundation area created and distributed. The water levels were not determined as standard, however, the map is utilized to alert reminder to the residents in this area (see Fig. 3). In Fig. 3, when the Critical level at P.1 became, area 1 in this figure located downstream of P.1 would inundate at first. Higher P.1 water level is, wider specific extent of inundation area (2-7) is, illustrated in this figure.

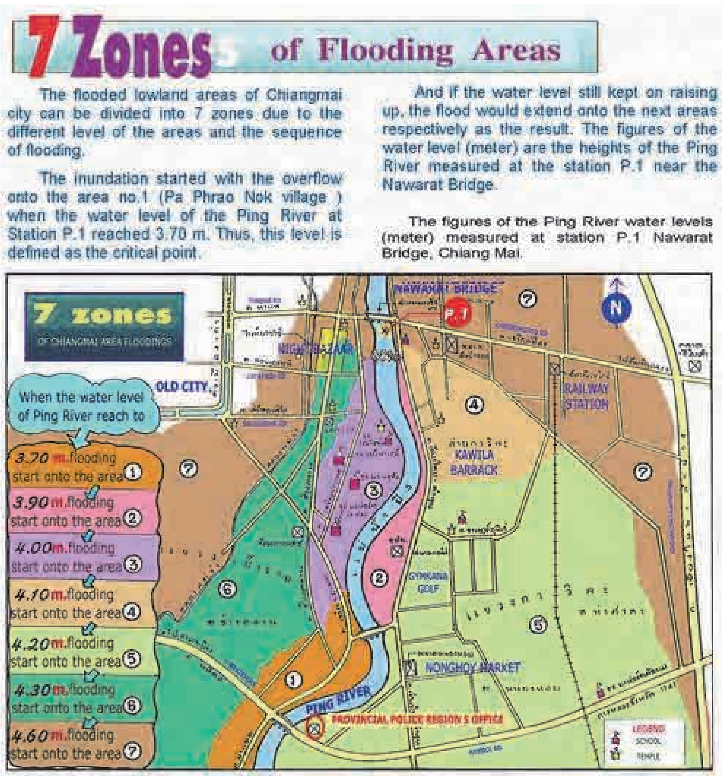


Fig. 3 Relationship between possible inundation area and water level at Chiang Mai city

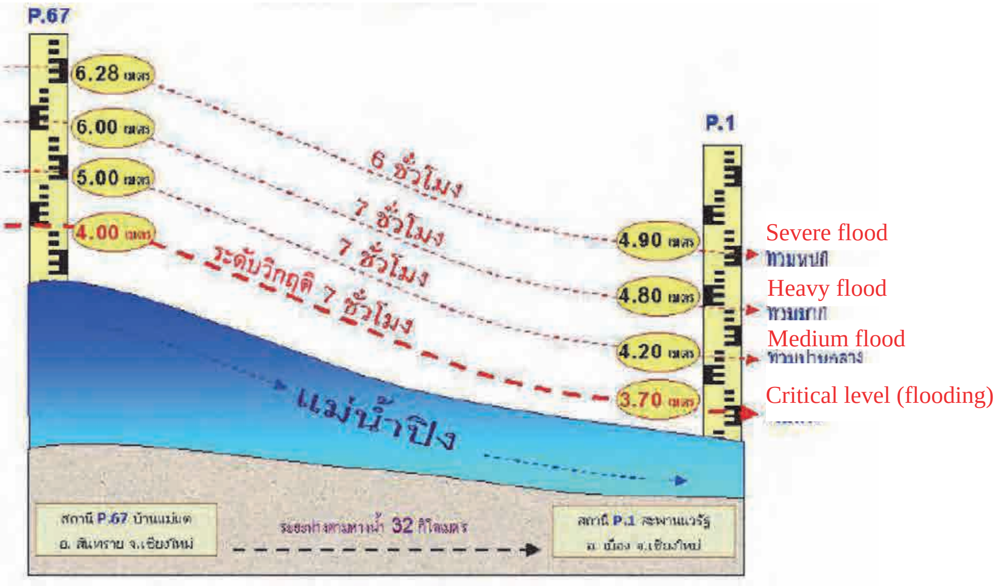


Fig. 4 Early warning method using correlation with water level (Chiang Mai, P.1)

3. Observation station

Current telemetering stations in the Chao Phraya River basin had been evaluated in the Basic Plan. Based on the analysis of rainfall data density, necessary density was estimated at less than 500km^2 of catchment area per one telemetering station. Furthermore, from the viewpoint of operation of the Flood Risk Information System, the sub basin which would require allocating more rainfall telemeter station are narrowed down and prioritized. For a flood forecasting at the downstream of Chao Phraya River basin, catchment area of dam has relatively less importance as rainfall input, since dam discharge are used as model input to simulate runoff and inundation. Rainfall in the lower basin also relatively less importance, since there is not so large influence on the future flow rate in the downstream. Table 5 shows that deficiency of telemetering station in sub basins (only RID, and RID with TMD). The upper basin of C.2 and the lower basin of several dams should be focused as vacant data area to be improved a telemetering system.

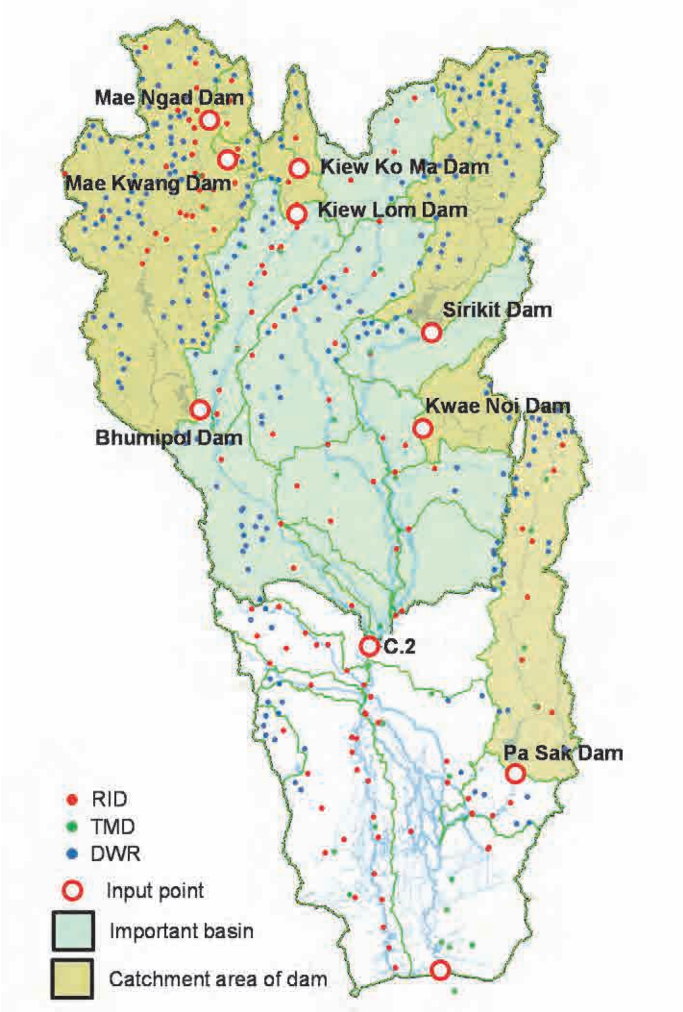


Fig. 4 Location of rainfall telemeter station and data vacant area in sub-basins in the Chao Phraya River basin

Table 5 Deficiency of telemeter station in sub basins

Sub basin	Catchment area (Km^2)	RID			RID+TMD		
		Number of telemeters	Catchment area per one telemeter (Km^2)	Deficiency	Number of telemeters	Catchment area per one telemeter (Km^2)	Deficiency
Bhumipol dam	26,315	39	675	14	42	627	11
Kiew Lom dam	3,975	7	568	1	7	568	1
Wang downstream	6,885	12	574	2	15	459	0
Ping downstream	8,436	4	2,109	13	7	1,205	10
Yom upstream	5,612	5	1,122	7	5	1,122	7
Yom middle stream	12,194	13	938	12	15	813	10
Yom downstream	8,114	7	1,159	10	9	902	8

Srikit dam	13,119	0	-	27	4	3,280	23
Kwae Noi dam	4,254	0	-	9	0	-	9
Nan middle stream	7,580	4	1,895	12	5	1,516	11
Nan downstream	8,111	4	2,028	13	5	1,622	12
Pasak dam	12,929	14	924	12	18	718	8
Lower (ex. Pasak)	45,672	41	1,114	51	55	830	37

4. Issues

Water level standards and related matters were evaluated as follows.

(1) Definition of water level standard

Water level at which a flood starts (threshold between red and yellow zone) and water level for making warning (threshold between yellow and green zone) have two names, respectively. It would lead to confusion if the same water level as standard was defined and named differently.

(2) Early warning method was applied to the limited area

Only 8 stations are applying to the early warning method using water level correlation with upper adjacent station. Most of other stations haven't introduced such a warning method.

(3) Public announcement of possible inundation area is not enough

Possible inundation area wasn't examined or announced to the public, in most of cities. As the flood alert information, extent of flood and river water level should be correlated to possible inundation area. Water level standards might be reviewed after examining possible inundation area.

(4) No association with action to be taken by residents or officials

There is no definition on associations between water level standards and concrete actions to be taken by residents, local officials or flood defense. Moreover, water level standard doesn't indicate the time to take any action. It would be possible to mitigate flood damages by defining the actions to be taken associated with water level standards.

(5) Distance to station to be monitored in the early warning method

As illustrated in above, distance to upstream station to be monitored in the existing method vary considerably, flood arrival time has also wide variability, such as 4 – 24 hours. It would be required to find optimum distance by examining the actions necessary for residents, farmers, factories and flood defense agencies, and the time for taking and completing their actions.

(6) River flow status indicates just on a point of the station

It is not clear how far a river reach represented by an observation station is. People living in local area along a river, not in a city area nearby the station, cannot understand flow status correctly from color indication on a point.

(7) Vacancy of rainfall telemetering station

Based on the analysis for necessary density of rainfall telemetering station, there is still some data vacant area in the Chao Phraya River basin. To develop a flood forecasting system with high accuracy and high reliability for simulating flood and inundation, replacing the existing early warning method, the number of rainfall station is not enough at all.

(8) Information on the water level standard is much disorganized

At least, water level information on the web site is not organized well. Some old information can also be available for browsing on the web site, and user may not understand which would be the latest information.

4. Proposal

Example case of water level standards setting was introduced as a reference. In Japan, people should prepare to evacuate from a flood swiftly, because a flood would spread very rapidly and threaten people's life in the most of cases. Therefore, some water level standards are set by associated with an action to be taken by flood defense agencies and residents as illustrated below (Table 6). These water level standards are guidelines for issuance of flood forecast. National and prefectural agencies issue caution or warning information and this information is delivered to other agencies, local government and local residents.

Table 6 Water level standards setting and its meaning in Japan

Standard	Meaning	Actions to be taken
Flood warning level	Water level at being a risk of flooding with a considerable damage on houses	[Residents] completion of evacuation
Evacuation judgment level	Water level as guideline for judgment on issuance of evacuation recommendation by local government, and on residents' evacuation	[Local government] judge an issuance of evacuation recommendation, issue it depending on the situation [Residents] judge and start evacuation
Flood caution level	Water level as guideline for judgment on issuance of evacuation preparation by local government, and as alert for flood information, and as guideline for mobilization of flood defense	[Local government] flood defense being mobilized [Residents] pay attention to flood information, start preparation of evacuation
Flood defense standby level	Water level as guideline for flood defense standby	[Local government] start preparation of flood defense

The following proposals were presented for further improving the water level standards and its setting used for a flood warning in Thailand.

Redefinition and notification of warning level standard

- Water level standard indicating the start of a flood is called either Flood level or Critical level, and that for warning is called either Critical level or Warning level. To avoid confusion and to make them more understandable, water level standards should be redefined reflecting exact meaning and renamed corresponding to the definition. For example, the standard indicating the start of a flood could be Critical level as it represents the threshold of not flooding and flooding, and the standard for warning people could be literally Warning level.

- Warning level of each station has been determined according to minimum flow capacity of downstream of the Chao Phraya River. In some station, therefore, it doesn't represent the warning to the residents at that station. Correct meaning of Warning level should be explained to the general public, since it would resolve confusion which hinders people's understanding of the actual river flow situation.
- Warning level of each station should be related to the action to be taken by the residents and officials. In case the river flow reaches to the warning level, people may get alert for their preparation for measures to prevent damages.
- Correct installation of water gauge is required to notify flood warning to the general public. In some stations, paint on the gauge indicating normal, warning and critical (green, yellow and red) are not properly updated, in spite of the changes in standards.
- The most vulnerable point should be selected as the setting point for Critical level and Warning level. To cover all area along the river, color indication (green, yellow and red) of flow status in a river reach, not on a point, would be desirable.

Utilization and extension of the existing early warning method indicated by the severity of a flood

- The existing early warning method based on correlation between two adjacent stations should be introduced for necessary stations according to their importance. At present, only 8 stations in upper basin use the method. Upstream station to be monitored should be selected according to the required time for flood measures and its preparation.
- Utilization of the early warning method should be informed widely to the general public. They need to know clearly which station is to be monitored and what level corresponds to the severity of flood at their area.
- In order to inform the relationship between inundation depth at specific places and the severity of a flood to the general public, inundation forecast map should be created and distributed. The map would be based on the past flood events or inundation simulation results. Moreover, signage or scale to indicate the past or expected inundation depth based on the map should be installed to notify throughout the city. Water Management Simulator will be useful to study inundation area and create such a map.

Observation station upgrading

- The existing early warning method will be replaced by a flood forecasting system with high accuracy and reliability for simulating flood and inundation. In order to establish high performance forecasting system, rainfall telemetering station should be installed more at the necessary density.
- In the simulation of the Flood Risk Information System to forecast inundation risk in the central plain of Thailand, additional rainfall telemeter stations would be effective and given priority to the Yom river basin, Ping river downstream basin, Wang river downstream basin, and Nan river middle and downstream basin.
- In order to reduce data vacant area, integration of telemeter station among organizations (e.g., RID and TMD) would be effective.