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## APPENDIX A

### The Climate of Southeast Asia

Southeast Asia is located between 10°S to about 20°N latitude and between 94°E to 145° E longitude. It is bordered by the Australian continent in the south and the Eurasian continent in the north, while the east and west is bordered by the Pacific and Indian Oceans. The climate in Southeast Asia is hot and humid conditioned by its geographic position and by local topographic difference. The climate varies from extremely dry zone (500 mm/yr) to extremely wet zone (7,000 mm/yr). The climate of Southeast Asia is controlled by a very large extent of Asian monsoon system (Northeast monsoon and Southwest monsoon). In Southeast Asia, the climate changes significantly from month-to-month due to air circulation over this part of the world. In the equatorial ( $\pm 30^\circ$ ) region, earth surface absorbs more heat by solar radiation. Unequal surface heating creates air streams in the atmosphere in a particular (zonal) direction. Due to the earth's rotation, these air streams do not have a constant speed and direction. Near the earth's surface, air streams deviate from zonal direction due to the obstacle by mountain chains and the influence of ocean streams.

In the equator, air pressure is low and water evaporates from the ocean, river and forests. The ascending air with high moisture content is unstable. When the ascending air cools off, the heavy clouds are formed until it reaches the saturation point, then heavy rain and thunderstorms occur. After that energy is released and the air will ascend to attitude over 10 km.

In the low-pressure zone due to the highest heat of the earth-surface, air streams convene in to this low-pressure zone. This zone is called the Intertropical Convergence Zone (ITCZ) or sometimes called equatorial trough, monsoon trough. Weather condition in this zone includes widespread cloudiness, convective rains and precipitation. The ITCZ zone moves from the northern direction to the southern direction and vice versa corresponding to the sun-track movement. This ITCZ movement plays significant roles to the rainfall pattern over Southeast Asia and causes seasonal variation. The season in Southeast Asia can be classified as two or three seasons (hot or dry season, rainy season and cold season.) In Low latitude ( $\pm 50^\circ$ ) closed to the equator, only two seasons exist (rainy and dry season) in Malaysia, Singapore, Indonesia while above latitude  $\pm 10^\circ$  (Thailand, The Philippines, Vietnam) has three seasons.

During the northern hemisphere winter, high pressure areas develop over Siberia. This high pressure area is caused by intense cooling of the earth's atmosphere. But, in the southern hemisphere summer, low pressure area develops over Australia due to the hot earth surface. The consequence of the effects of different pressure over Southeast Asia causes several effects as follows:

- 1) The north wind from Siberia brings relatively cool and dry air over Thailand and Indo-china and the northeastern coast of Sumatra. Rainfalls are rarely found during this period.
- 2) The northeast wind from the north Pacific Ocean brings moderately warm up and humid toward the east coast of the Philippines and pass the South China Sea and direct toward to Malaysia. This wind brings more moisture causing heavy rainfall along the east coast of Thailand Peninsular and Malaysia Peninsular.
- 3) The northwest wind across the equator changes direction due to the earth's rotation. This wind brings humid air towards the northern coast of Java and intensifies the rainfall particularly in west-Java due to the East-West chain of volcanoes.

During the northern hemisphere summer, the Eurasian continent is heated up much more intensively than the tropical region causing a consequence air streams from different direction reaching the Southeast Asia region. The consequence of air streams brings several influences:

- 1) Southeast winds from the Australian continent are cool and relatively dry and effect the climate of particularly the southern part of Indonesia,
- 2) Southwest monsoon wind affects the eastern cost of Sumatra, Malaysia, Thailand Peninsular and Indo-China. Rainfall due to Southwest monsoon is relatively high in those regions,
- 3) Southwest wind brings humid air from the Indian Ocean towards Sumatra north-coast, Malaysia Peninsular and Thailand west-cost Peninsular and major paths of Thailand and Indo-china,
- 4) East-Northeast streams arrive from the North-Pacific. The easterly waves may cause into cyclonic disturbances and reach the Philippines in various stages of development, from tropical depression to tropical typhoons during July to October and brings heavy rainfall in north Mindanao, the Philippines, Vietnam, Laos, and the north-eastern part of Thailand.

It is clearly indicated that air streams and locally wind change the direction and strength month by month. This behavior influences the rainfall distribution and also varies from month-to-month. Therefore the monthly rainfall map for the entire region can be composed from various sources that shall be explained in the following.

In January, the ITCZ is located in the south of Indonesia and the air streams from the northern hemisphere winter prevail from the north to south direction. It causes extremely dryness in

the major parts of north and center of Thailand and the west-coast of the Malaysian Peninsula. However, most parts of Indonesia are wet and have high precipitation. And, the east coast of the Philippines islands are relatively wet due to easterly winds from the Pacific Ocean.

In February, the Northeast monsoon becomes weaker. The ITCZ is still located around Australia. All regions located in the north of the equator become drier except the Luzon's east coast of the Philippines which is still wet. Thailand and Malaysia Peninsular influences of dry wind from the north and the Sumatra's east coast are relatively dry.

In March, the ITCZ is just located at the south of Java. As the sun moved towards the north, the north winds over Thailand are much weaker and increasing temperature on the mainland. When the ITCZ approach Sumatra, heavy rainfall occurs over the path of Sumatra and Java.

In April, the ITCZ moves further north and locates over Sumatra and Kalimantan islands. As a result, winds start to change direction. Southeast Indonesia becomes drier and the east of Java and the north of Java have less rainfall than in March. The southwest coast of Malaysia and the southwest cost of Thailand Peninsular become wet and have high rainfall. The mainland of Thailand becomes more humid.

In May, the ITCZ moves rapidly to the north of Indo-China and the climate change is considerable. The east coast of Kalimantan is relatively dry. At the north of the equator, the wind changes direction and becomes southwesterly. Therefore, this leads to the increasing rainfall along the northwest coast of Thailand Peninsular and the northwest coast of Malaysia. Increasing rainfall over Thailand compared to April appears in the western area of the mountain ranges. Most of the Midanao island of the Philippines become wet.

In June, the ITCZ moves to the northern of Indo-China. The southeasterly winds have gained in strength an influence to the most part of Java, south of Sumatra and Malaysia peninsular. The peninsular of Thailand obtains heavy rainfall along the west coast, but it is relatively dry on the reward side of the mountains. The southwest monsoon also influence the climate of Thailand, the Philippines.

In July and August, the southeast monsoon develops strength causing more rainfall in Thailand, Malaysia and some moderate rain in Sumatra. The southeast air streams at the south of the equator have become more intense causing dry weather over Java, South and Southeast of Sulawesi and Kalimantan which are relatively dry. Typhoons are also developed and affect the northern part of Luzon.



In September, the southwest monsoon is at a maximum strength in Southeast Asia. Some parts of north Sumatra, north Malaysia, Thailand, Kalimantan, Sarawak and the entire Philippines have heavy rainfall. The typhoon track is over the Luzon and the Vietnam. At the same time the southeast air stream has maximum strength on the south of equator.

In October, the ITCZ makes toward the central of Thailand to the south. The north latitude above 10°N becomes cold and dry. Rainfall occurs in the low latitude above Malaysia and Indonesia. The typhoon track tends to move to the southwest. The southeast wind brings dry air towards the southeast of Indonesia

In November, the ITCZ moves towards a position around 5°N. The central-northern part of Thailand becomes significantly drier. But the east coast of the Philippines is significantly wetter while the east-coast of Malaysia and Thailand peninsular become wetter, and the entire Java, Kalimantan and Sulawesi become wetter.

In December, the ITCZ is located between the equator and the South of equator (0-8°S) The coastal areas of Java are extremely dry due to orographic lifting and cause extremely heavy rainfall on both northern and southern sides. All parts of Thailand except the peninsula are extremely dry and cold. The extremely rainfall occurs on the east-coast of Thailand and Malaysia Peninsulars.



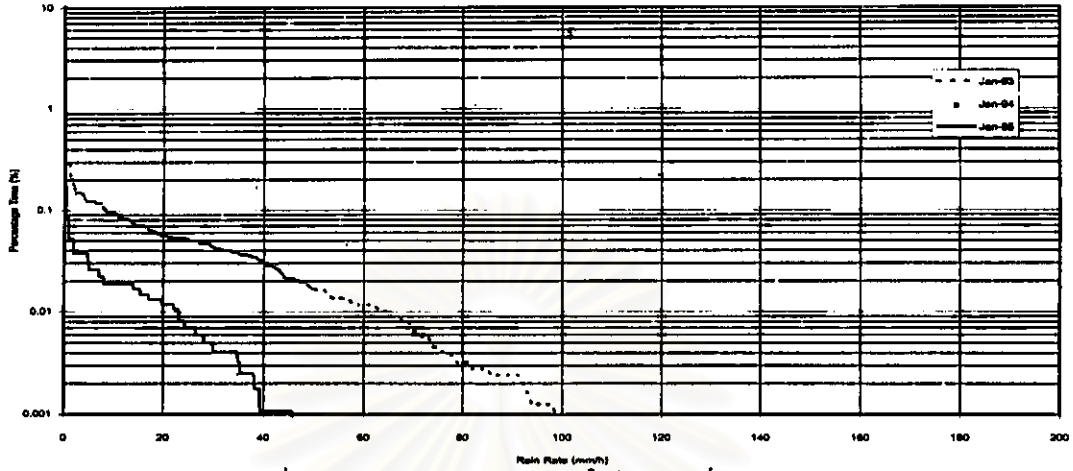
สถาบันวิทยบริการ  
จุฬาลงกรณ์มหาวิทยาลัย

## APPENDIX B

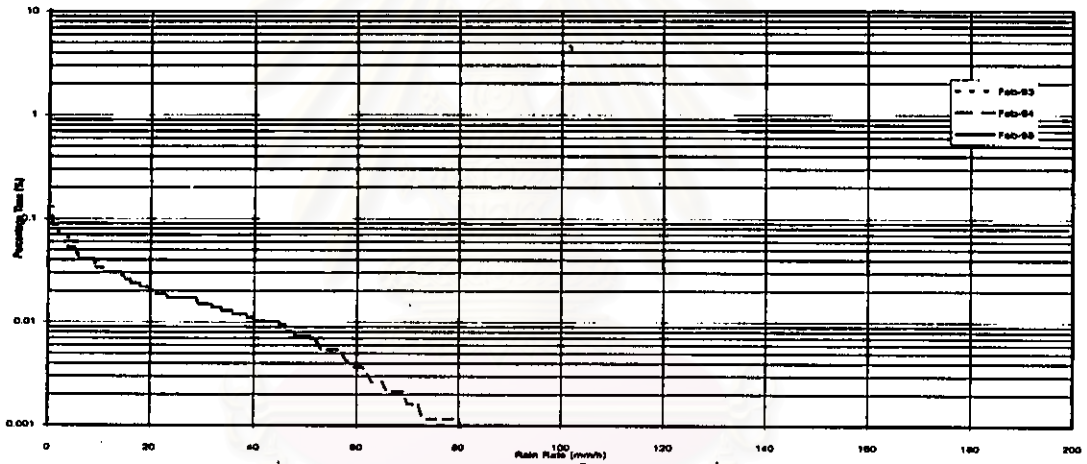
### RAINFALL MEASUREMENT RESULTS

#### 1. Monthly Cumulative Rain Intensity Distributions, 1/Mar/92 - 28/Feb/95, N. Yoothanorm [1997]

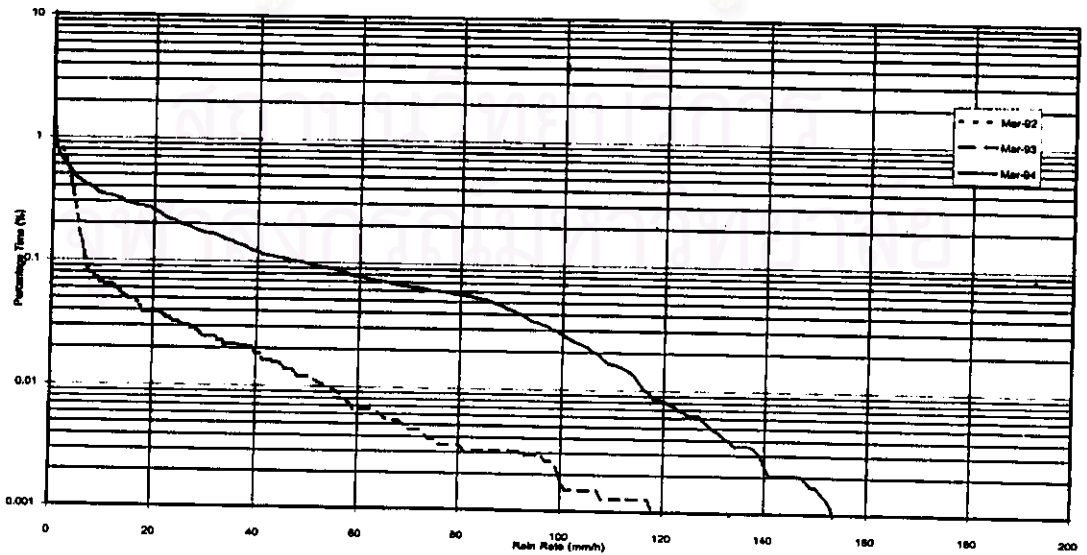
Monthly Rainfall Rate Statistic, Bangkok, January, 1993(676 hours), 1994(No Rain), 1995(720 hours)



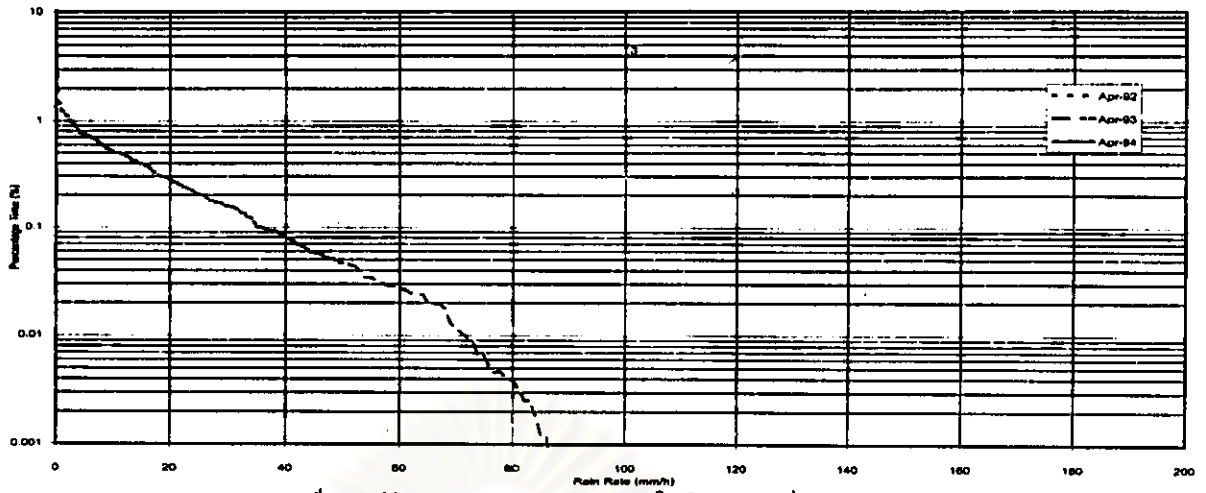
Monthly Rainfall Rate Statistic, Bangkok, February, 1993(No Rain), 1994(600 hours), 1995(No Rain)



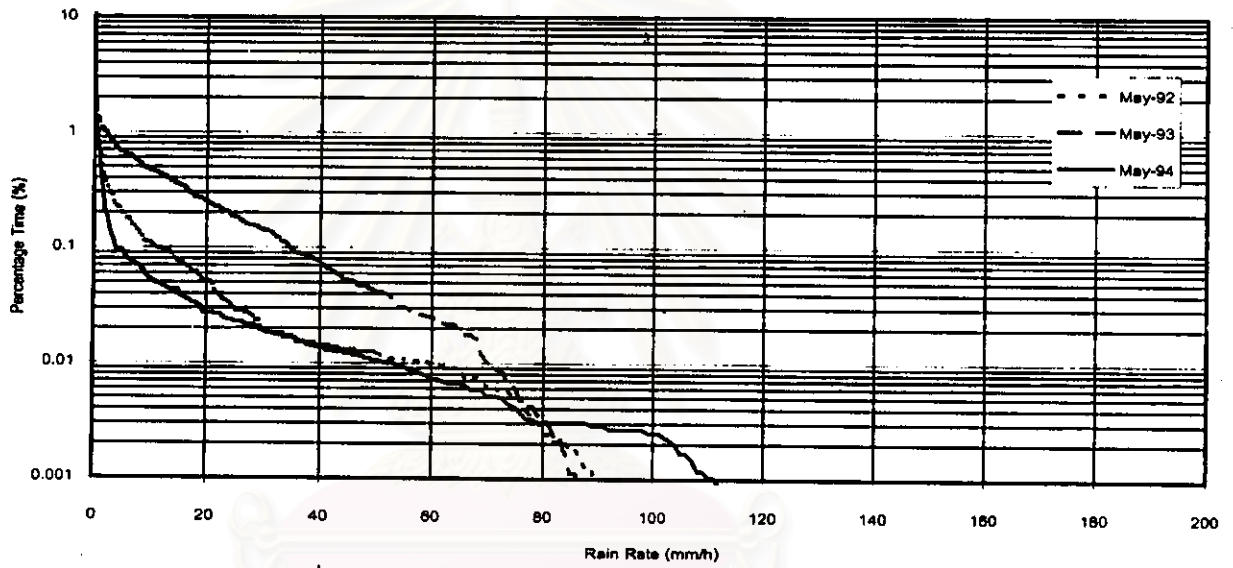
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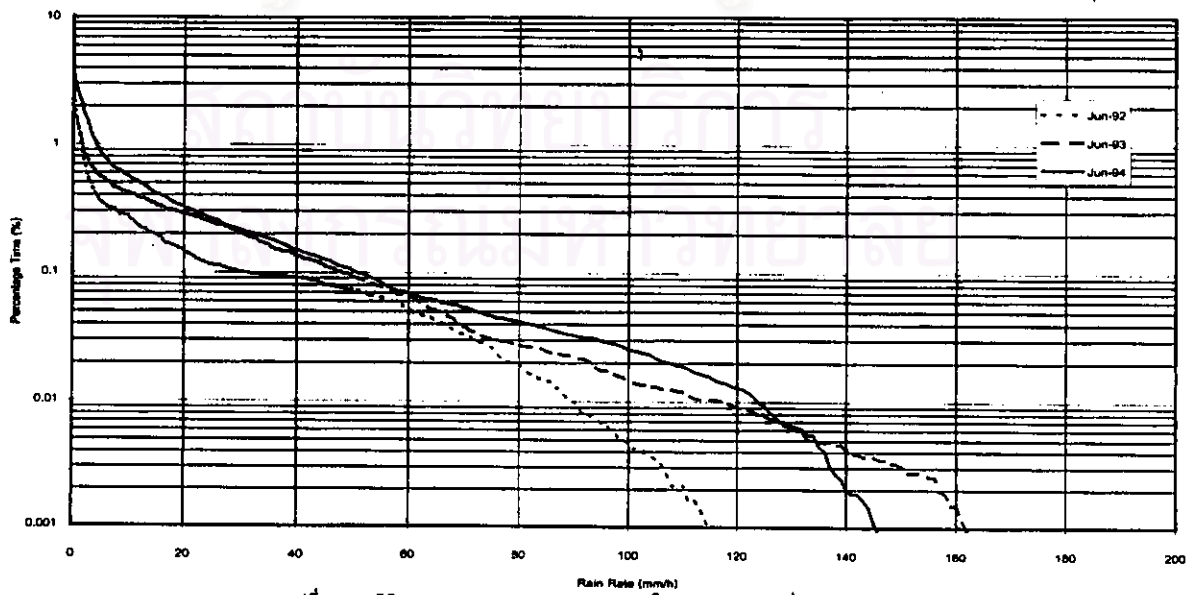
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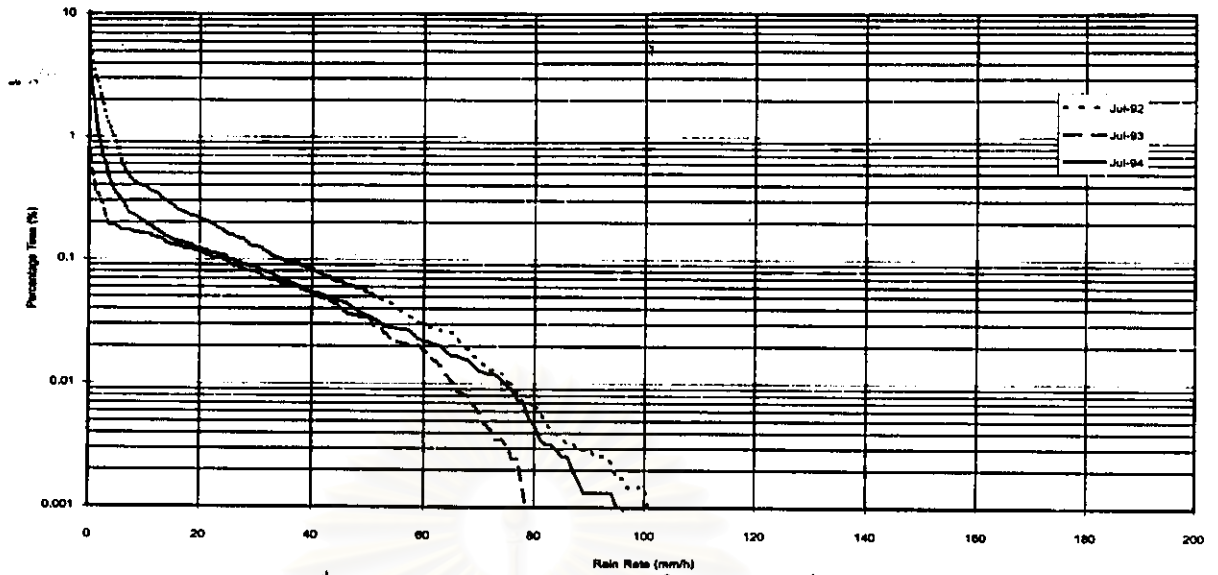
Monthly Rainfall Rate Statistic, Bangkok, May, 1992(744 hours), 1993(672 hours), 1995(432 hours)



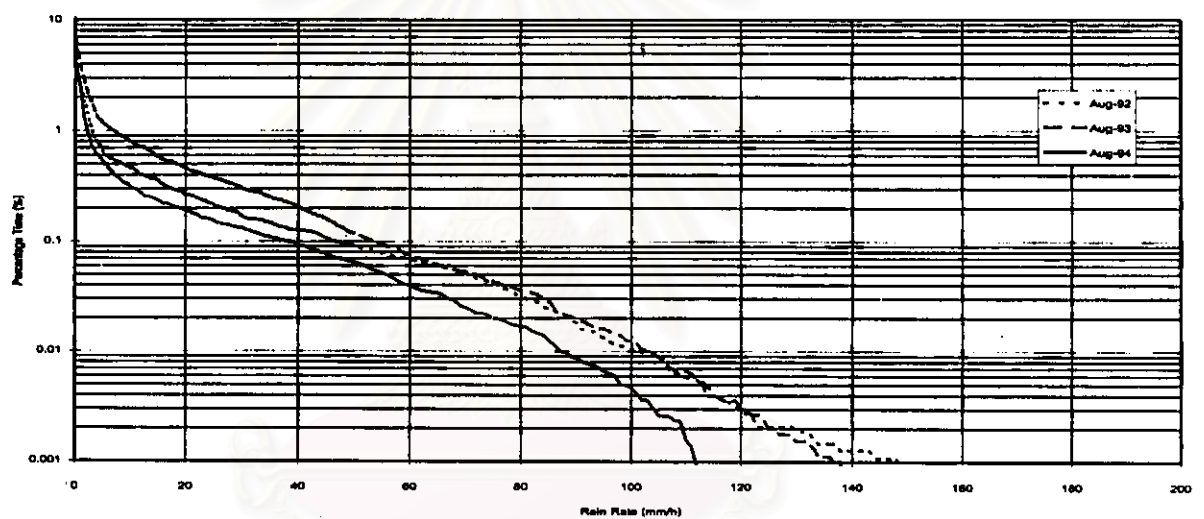
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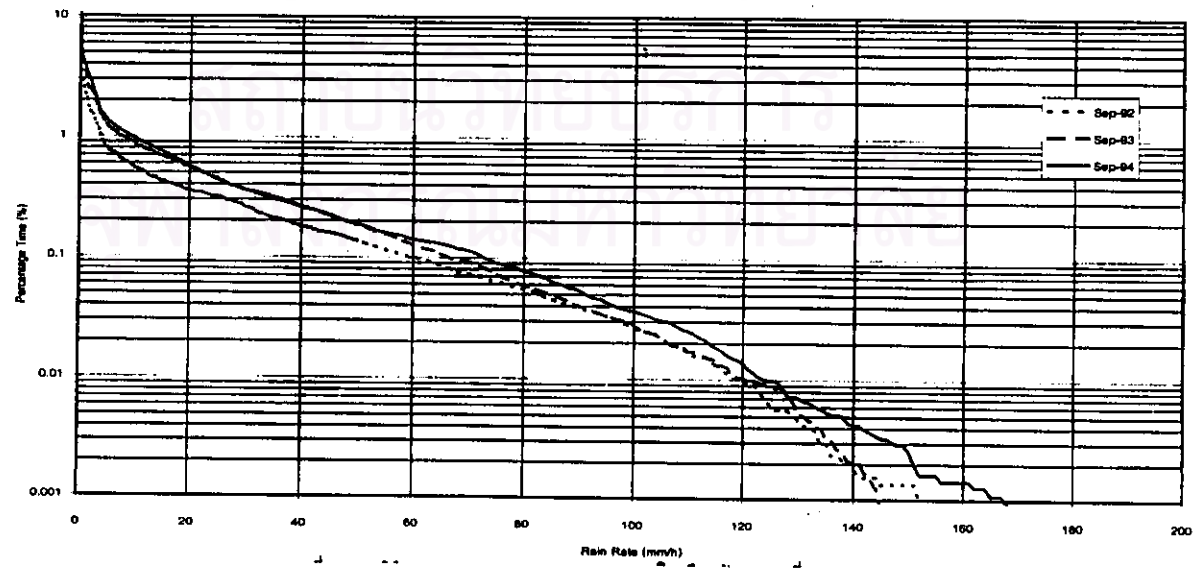
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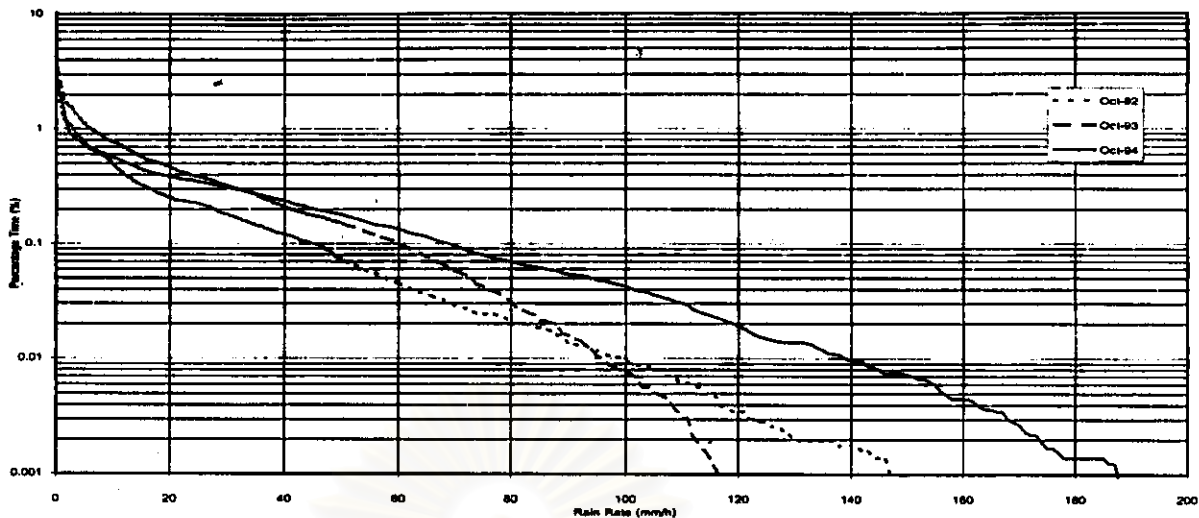
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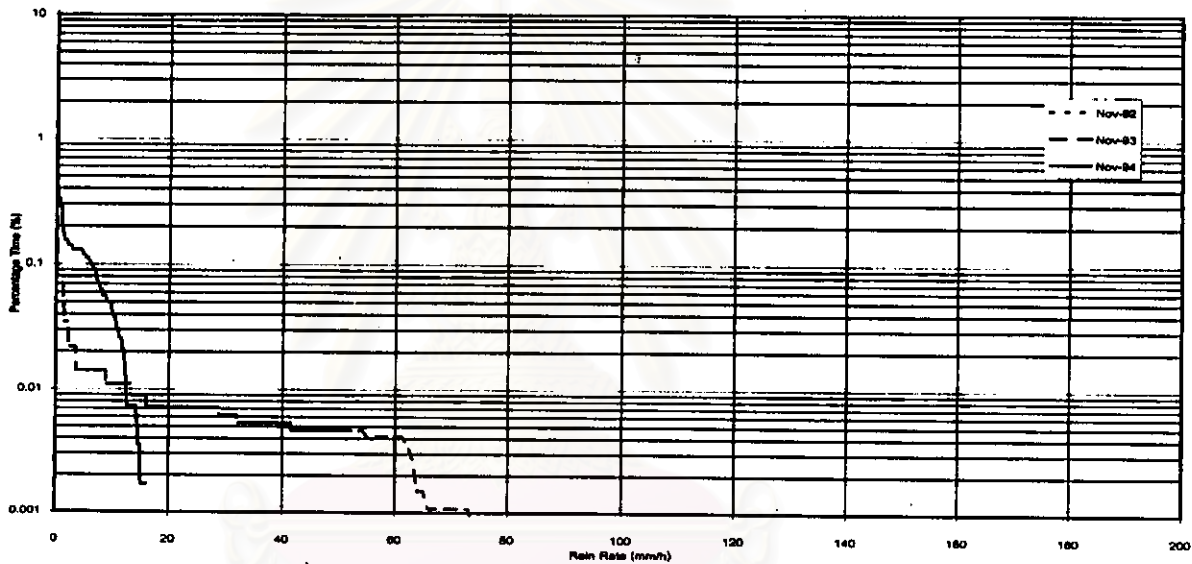
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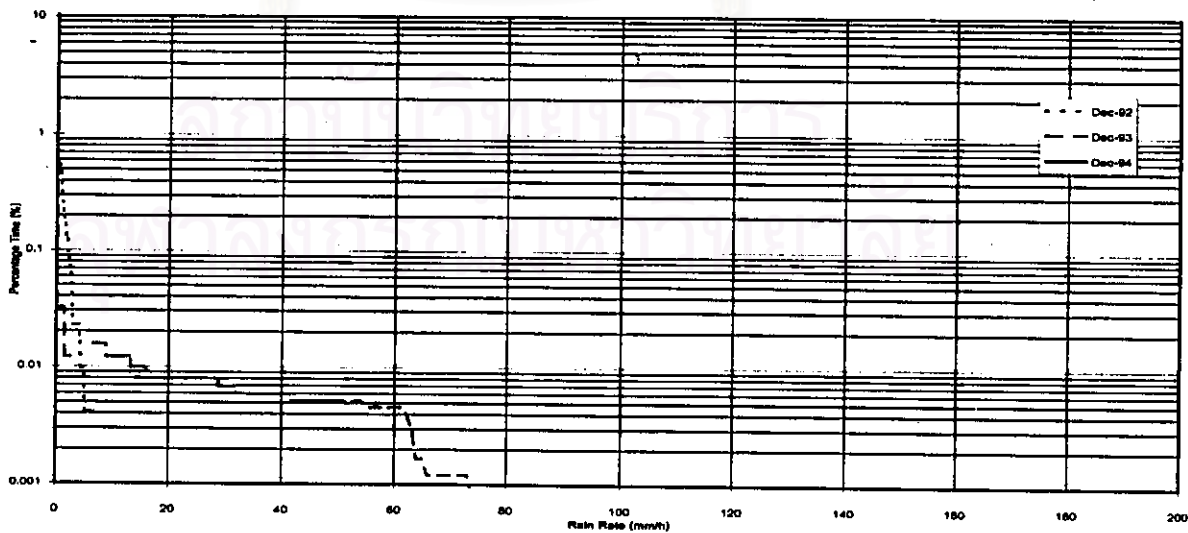
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Monthly Rainfall Rate Statistic, Bangkok, November, 1992(No Rainfall), 1993(720 hours), 1995(720 hours)

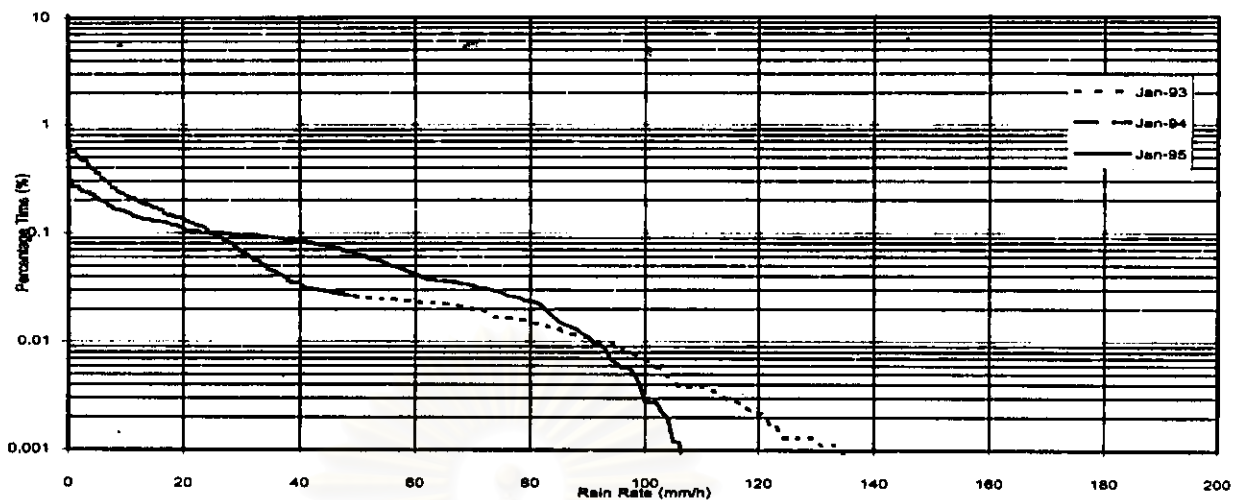


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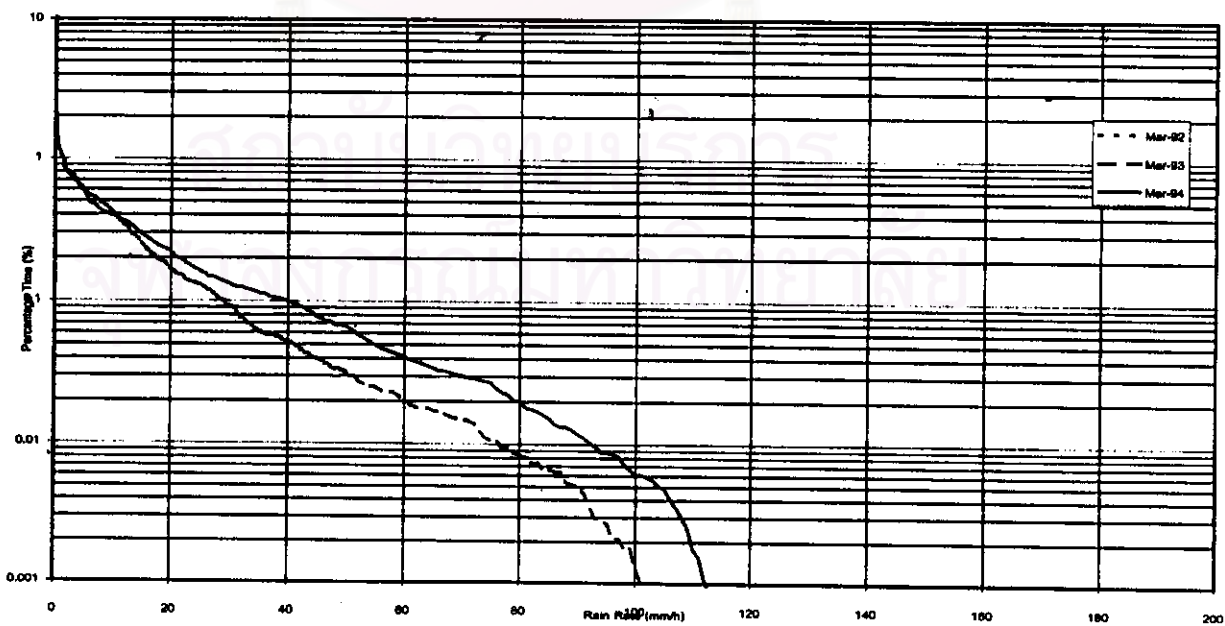
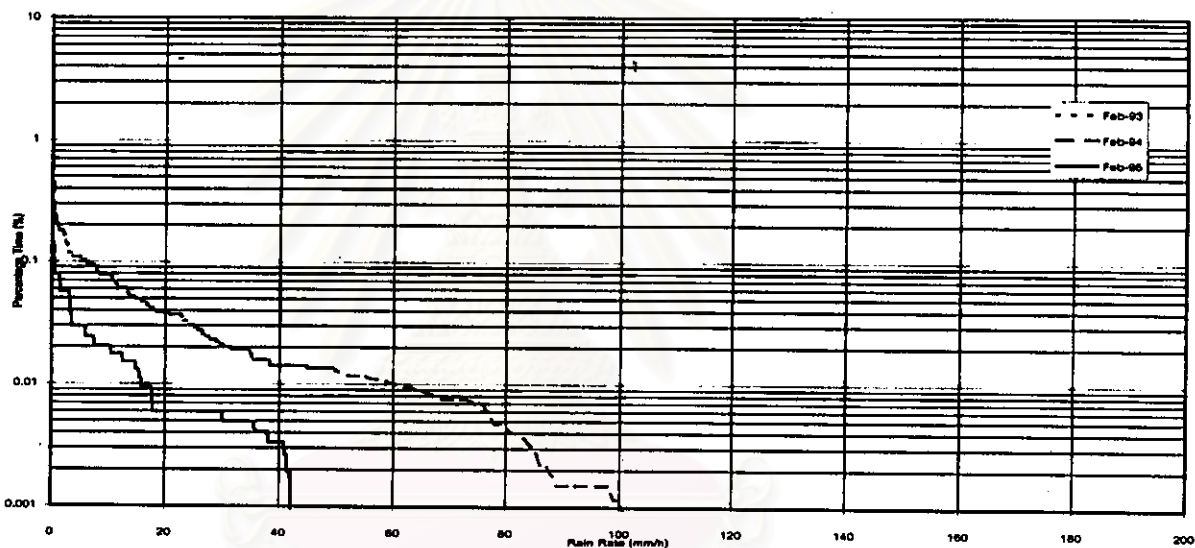


2. Si-Racha, 1/Mar./92 - 28/Feb/05, N. Yoothanorm, et . al., [1997]

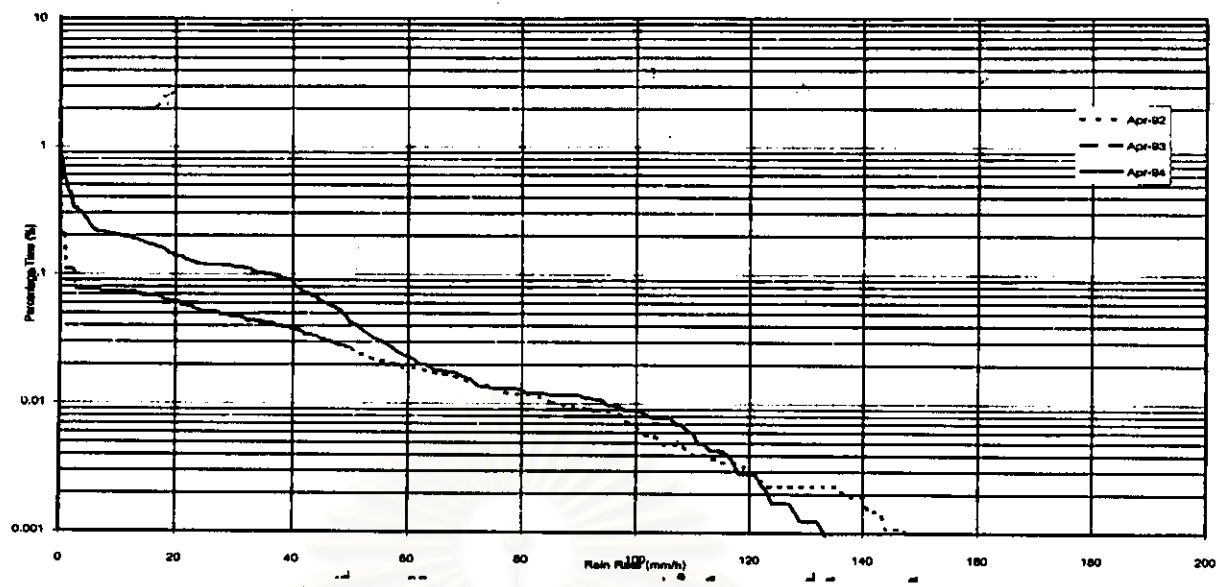
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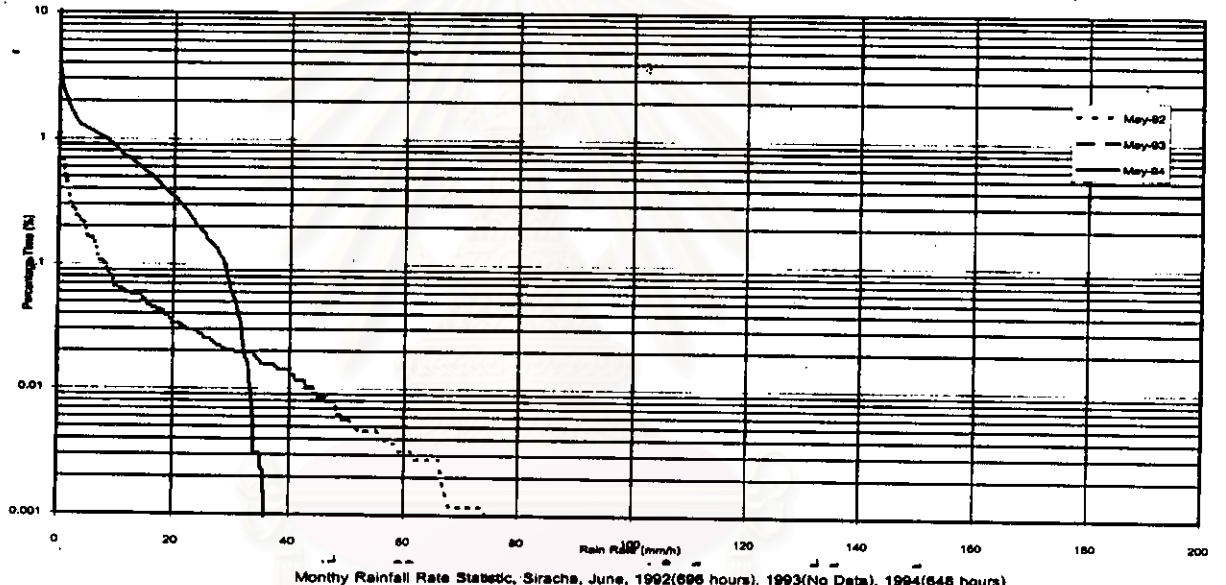
Monthly Rainfall Rate Statistic, Siracha, 1993(No Rainfall), 1994(648 hours), 1995(672 hours)



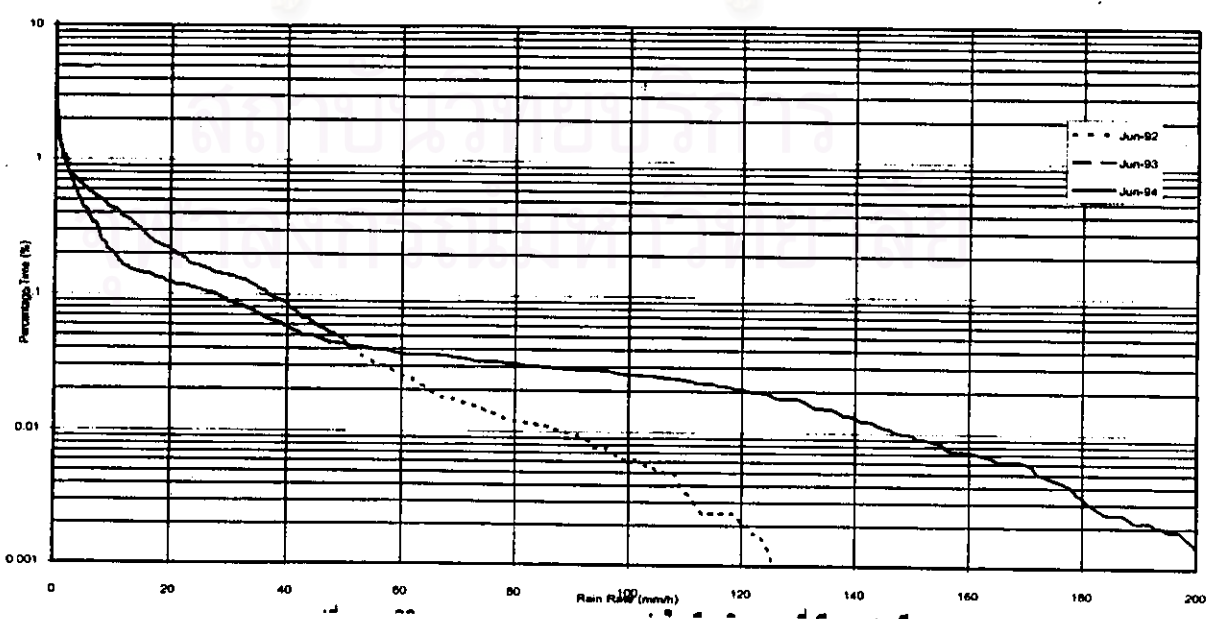
Monthly Rainfall Rate Statistic, Siracha, 1992(696 hours), 1993(No Rainfall), 1994(696 hours)



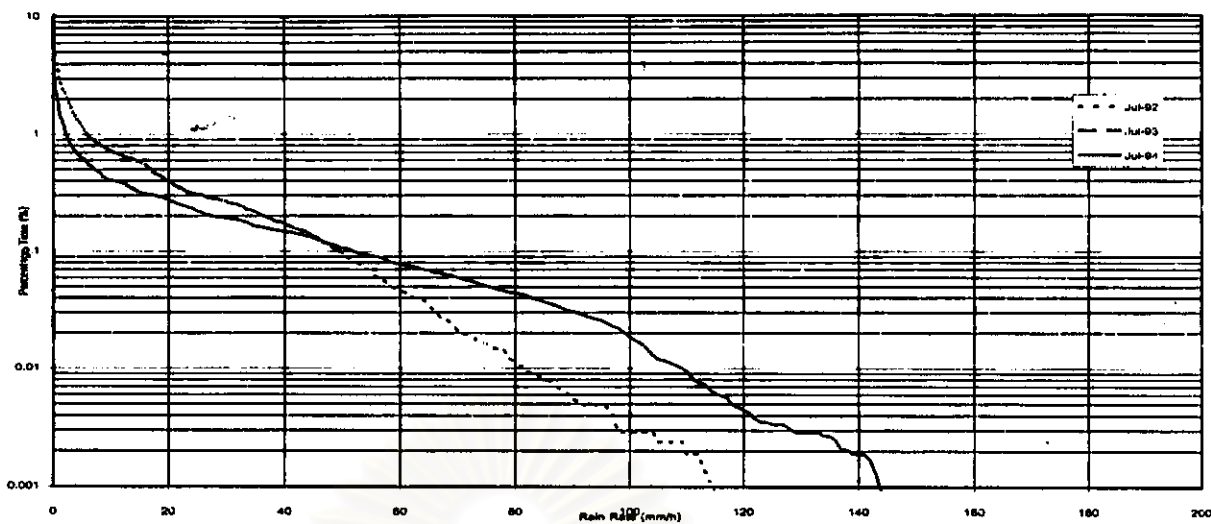
Monthly Rainfall Rate Statistic, Siracha, May, 1992(744 hours), 1993(No Data), 1994(720 hours)



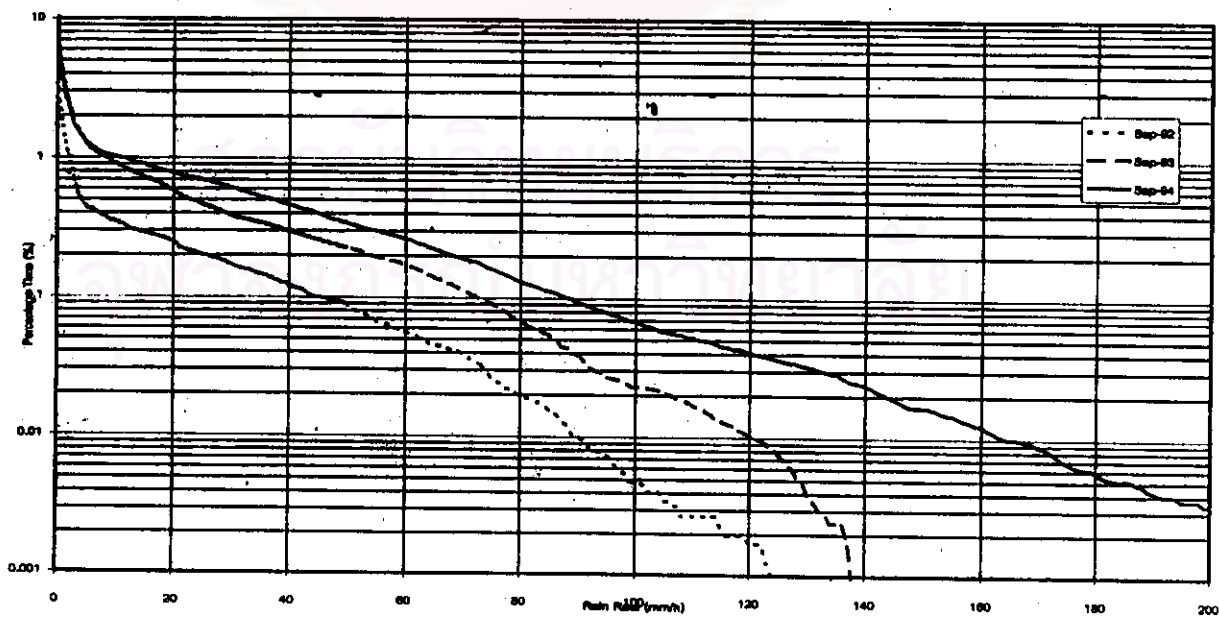
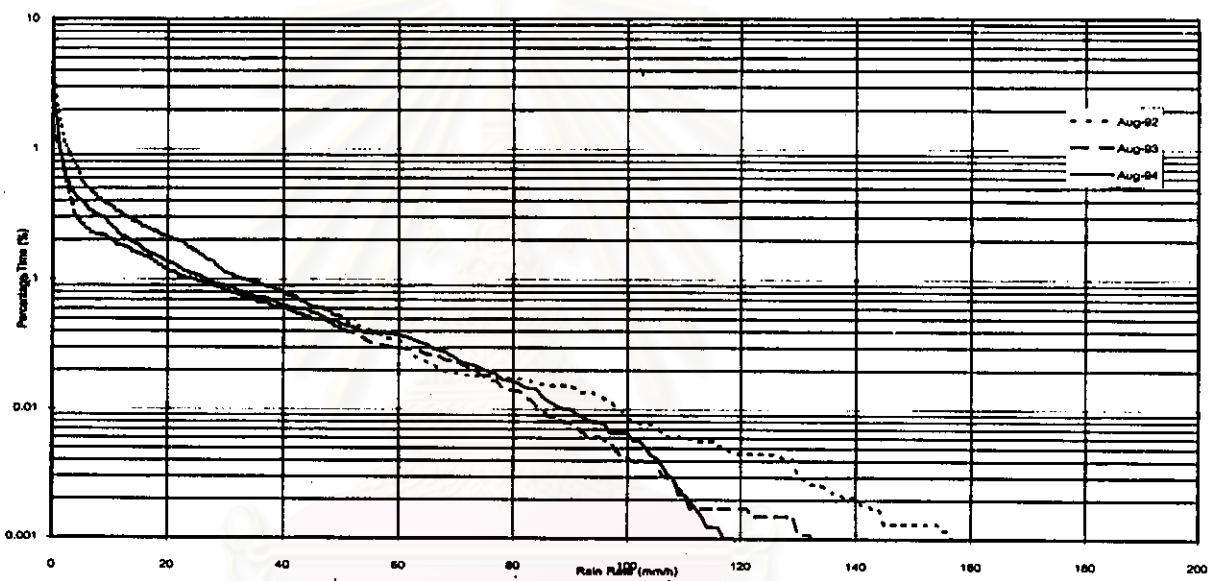
Monthly Rainfall Rate Statistic, Siracha, June, 1992(696 hours), 1993(No Data), 1994(648 hours)



Monthly Rainfall Rate Statistic, Siracha, July, 1992(720 hours), 1993(No Data), 1994(720 hours)

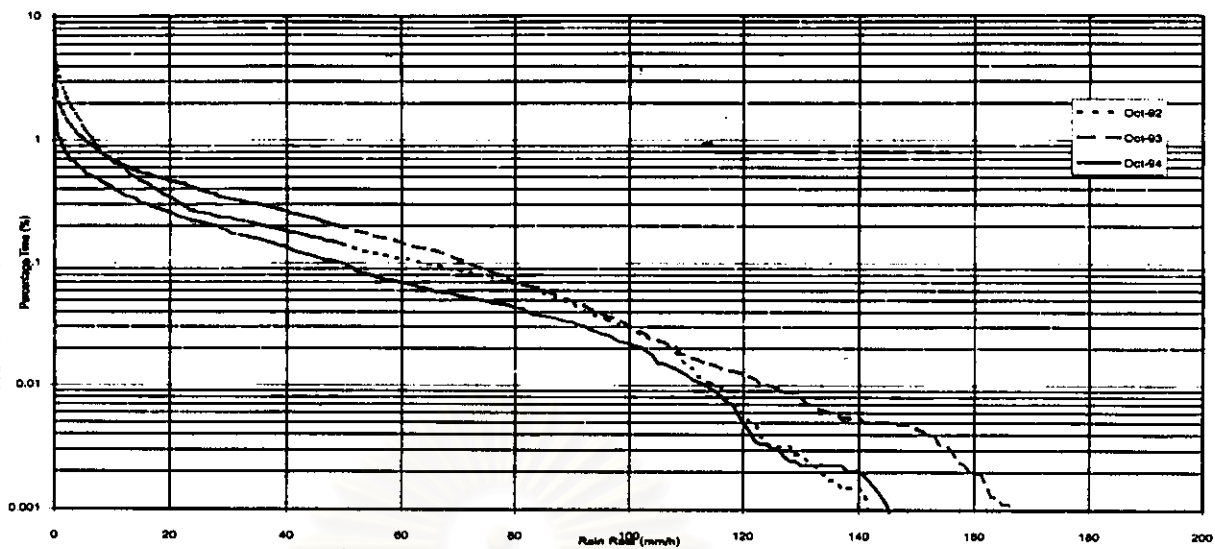


Monthly Rainfall Rate Statistic, Siracha, August, 1992(744 hours), 1993(720 hours), 1994(672 hours)

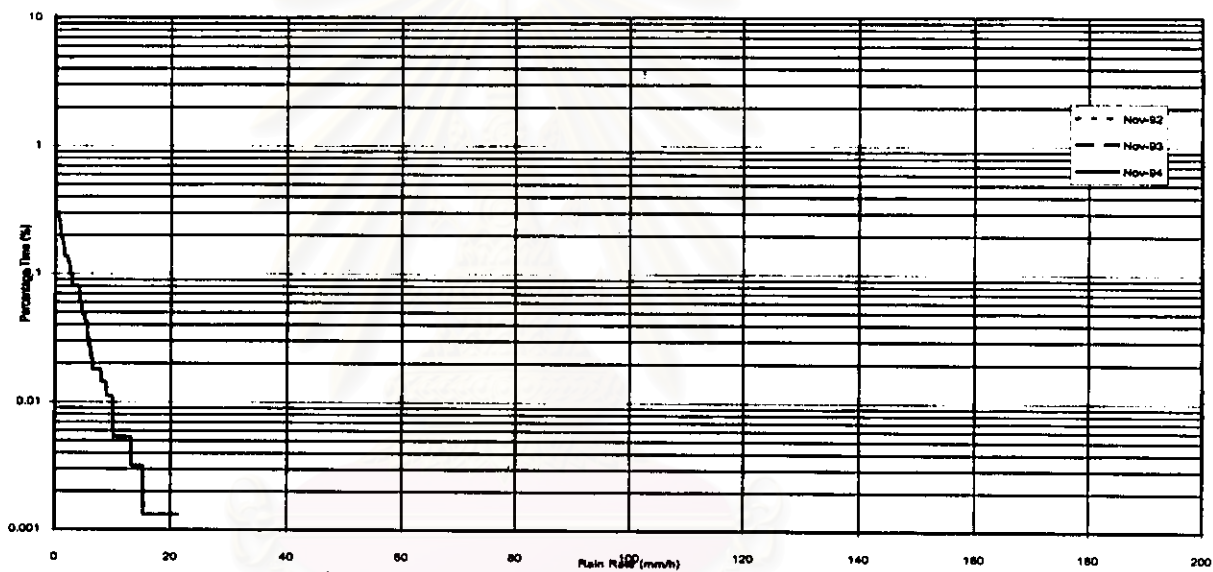




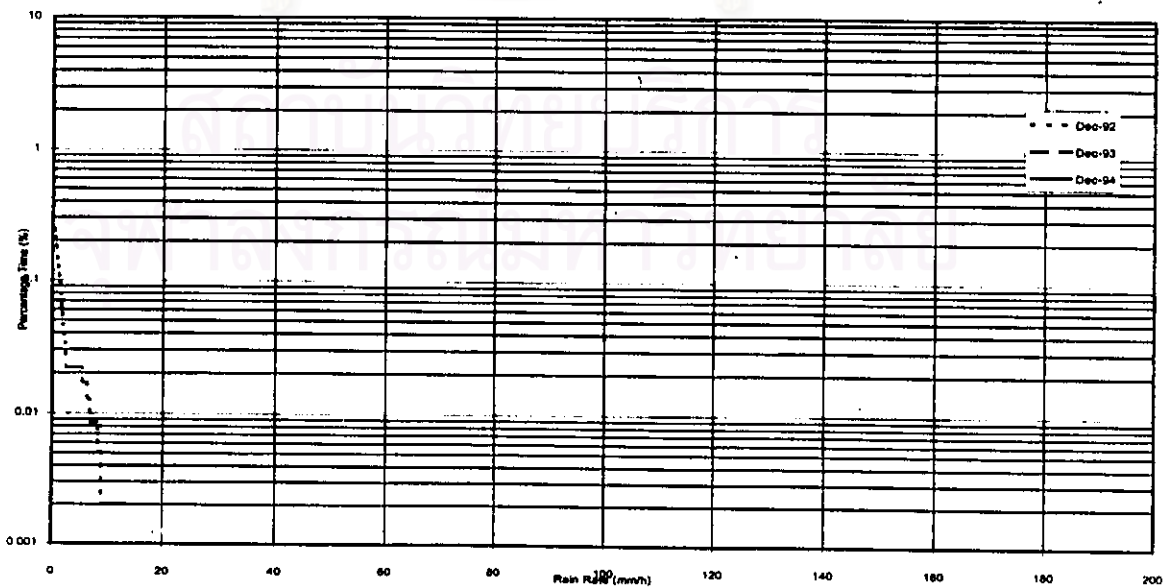
Monthly Rainfall Rate Statistic, Siracha, October, 1992(720 hours), 1993(720 hours), 1994(720 hours)



Monthly Rainfall Rate Statistic, Siracha, November, 1992(No Rainfall), 1993(No Rainfall), 1994(696 hours)

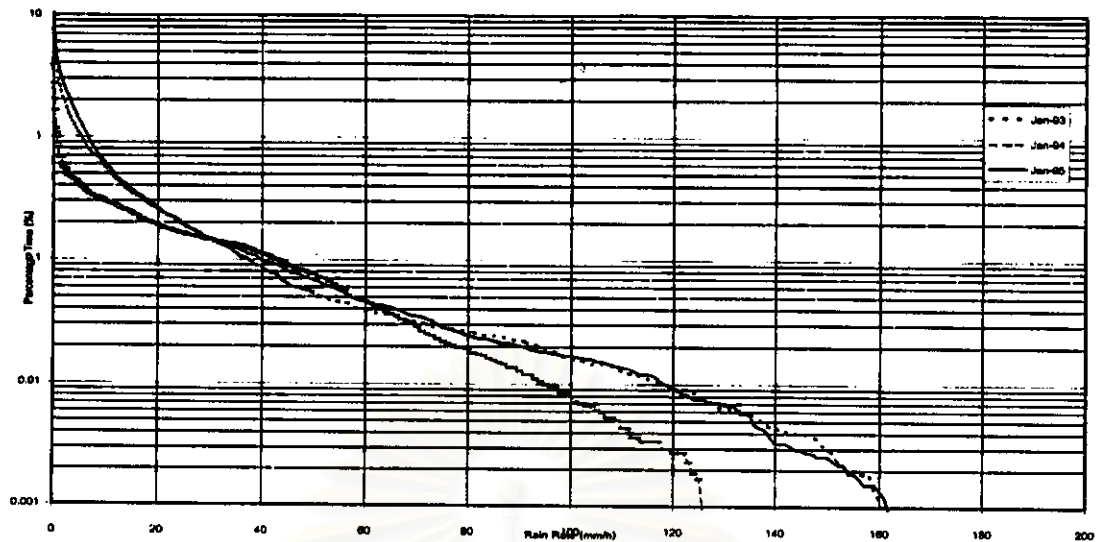


Monthly Rainfall Rate Statistic, Siracha, December, 1992(720 hours), 1993(No Rainfall), 1994(No Rainfall)

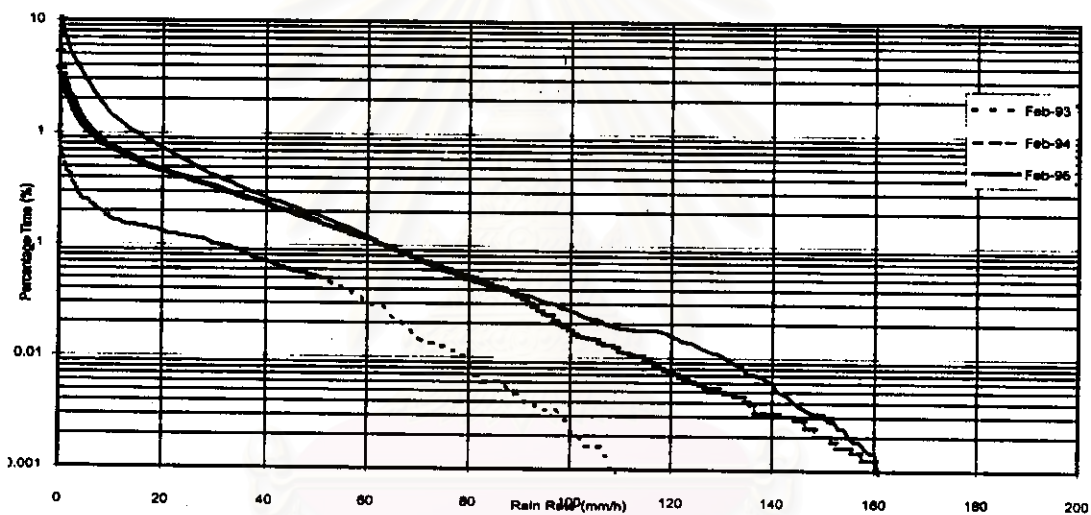


3. Singapore, Monthly Cumulative Distribution, 1/Mar/92 - 28/Feb/95

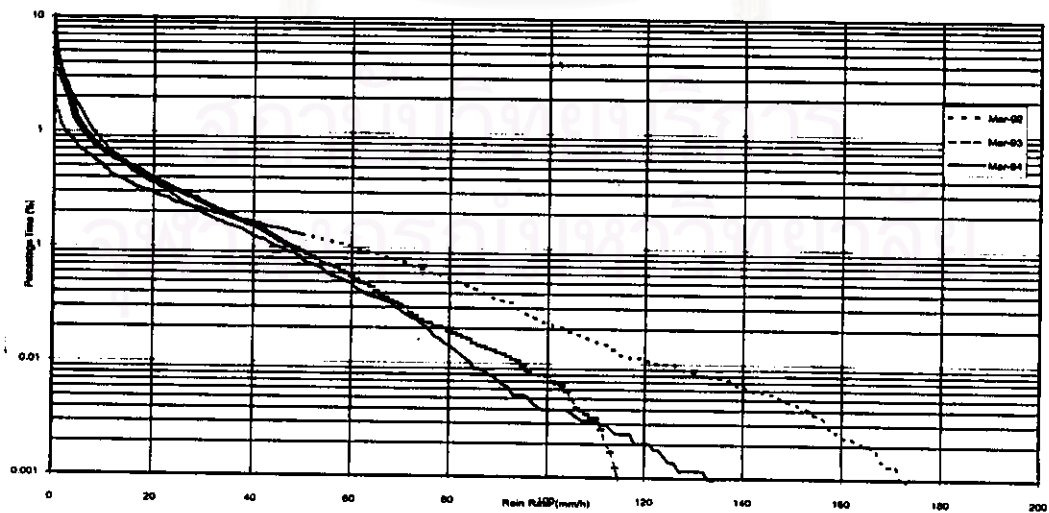
Monthly Rainfall Rate Statistic, Singapore, 1993(744 hour), 1994(744 hours), 1995(744 hours)



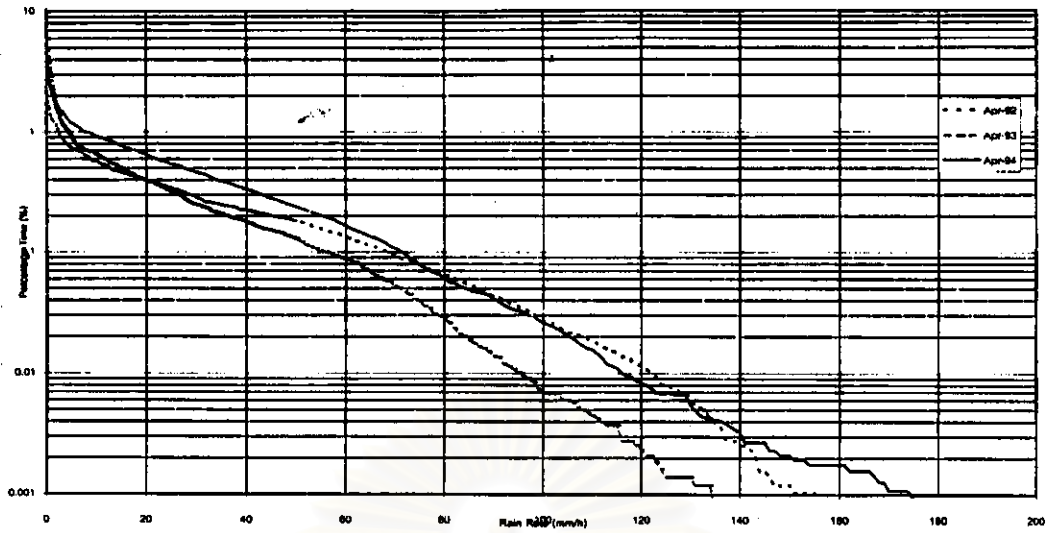
Monthly Rainfall Rate Statistic, Singapore, February 1993(672 hour), 1994(672 hours), 1995(672 hours)



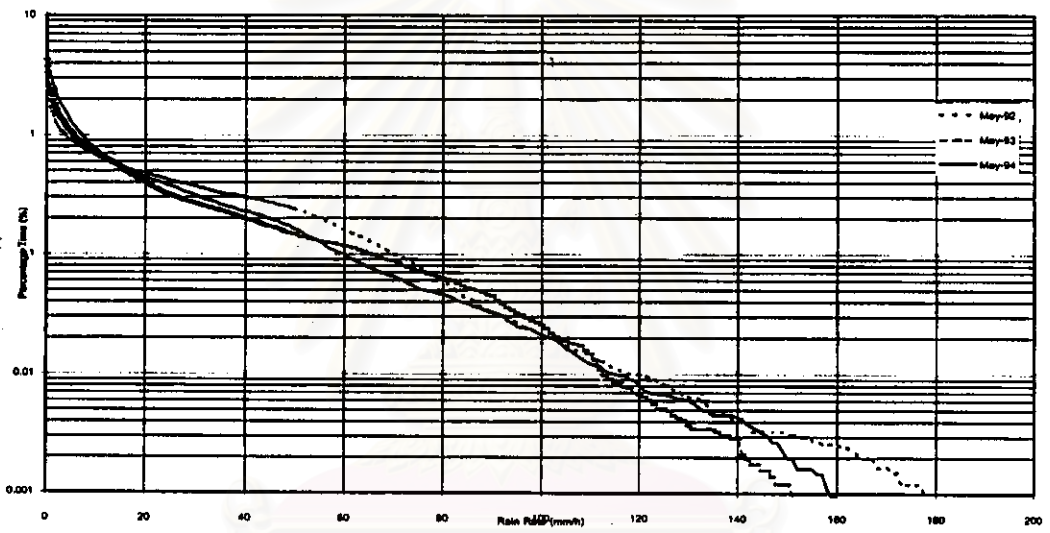
Monthly Rainfall Rate Statistic, Singapore, March 1992(744 hour), 1993(744 hours), 1994(696 hours)



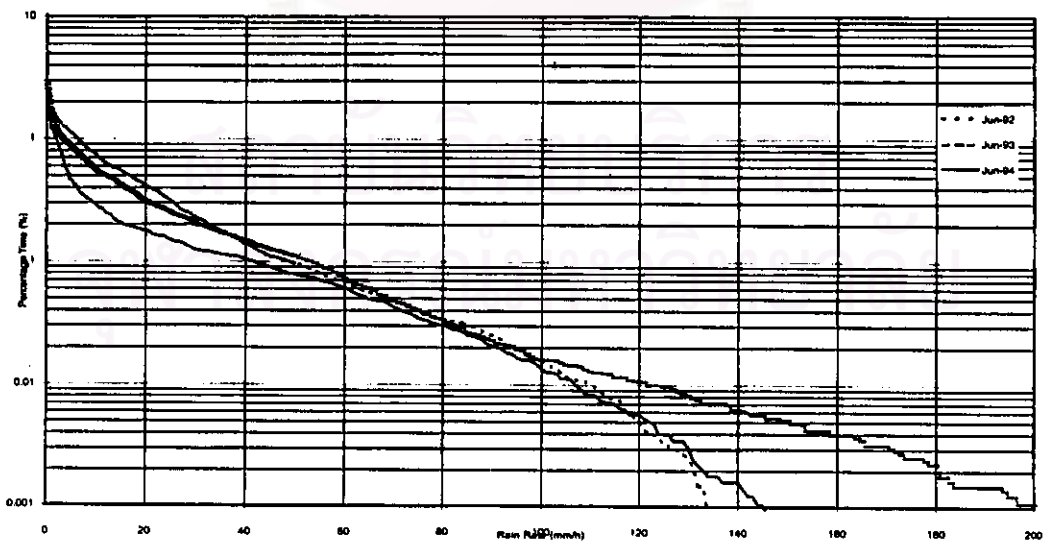
Monthly Rainfall Rate Statistic, Singapore, April 1992(720 hour), 1993(720 hours), 1994(696 hours)



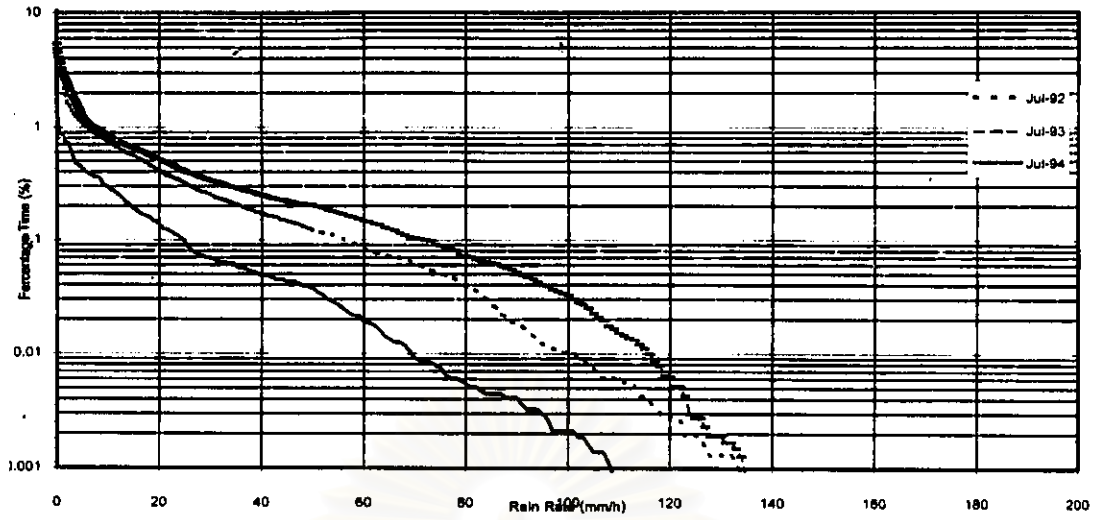
Monthly Rainfall Rate Statistic, Singapore, May 1992(744 hour), 1993(744 hours), 1994(744 hours)



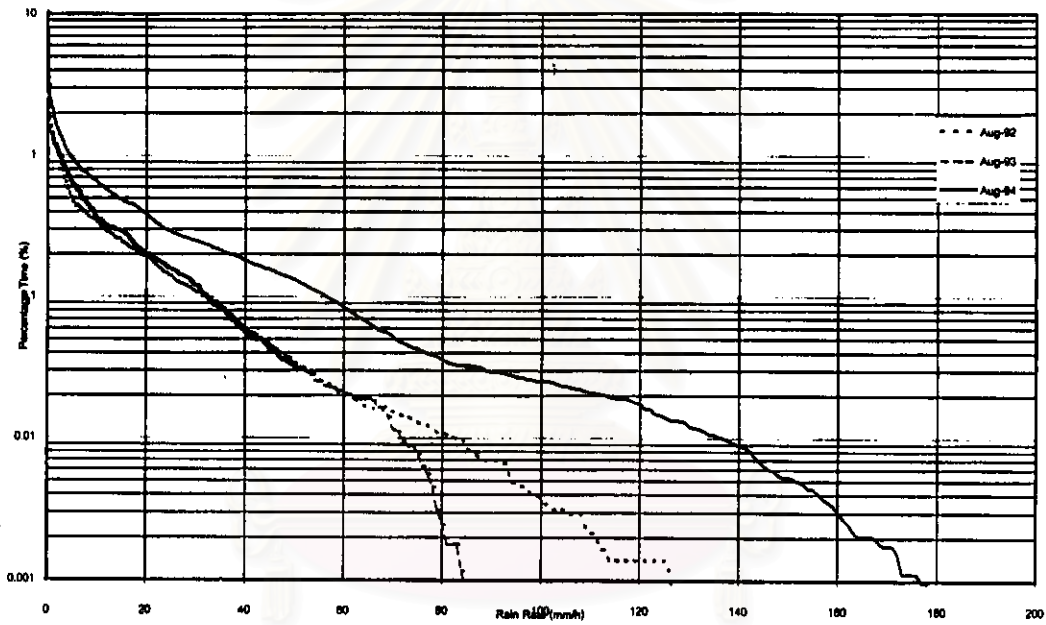
Monthly Rainfall Rate Statistic, Singapore, June 1992(720 hour), 1993(720 hours), 1994(804 hours)



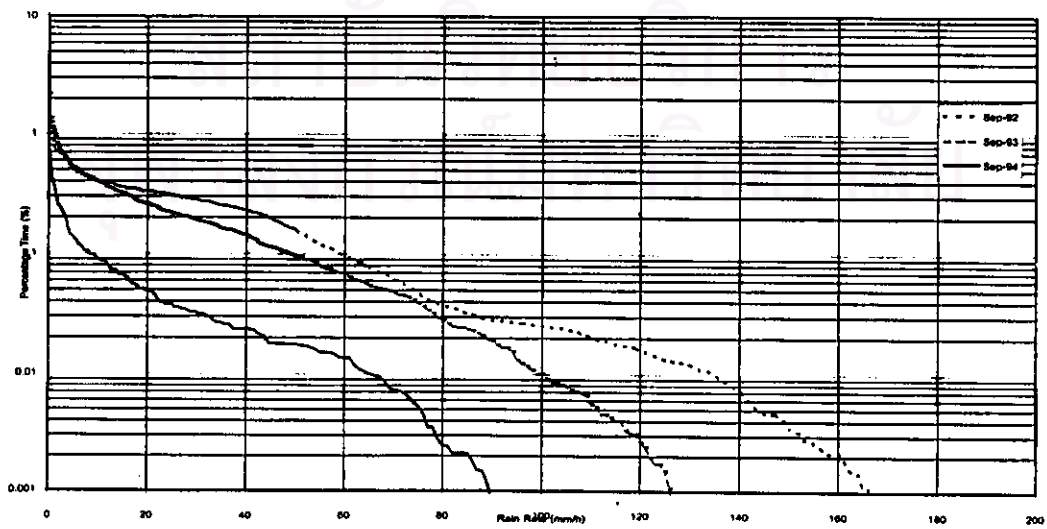
Monthly Rainfall Rate Statistic, Singapore, July 1992(744 hour), 1993(744 hours), 1994(744 hours)



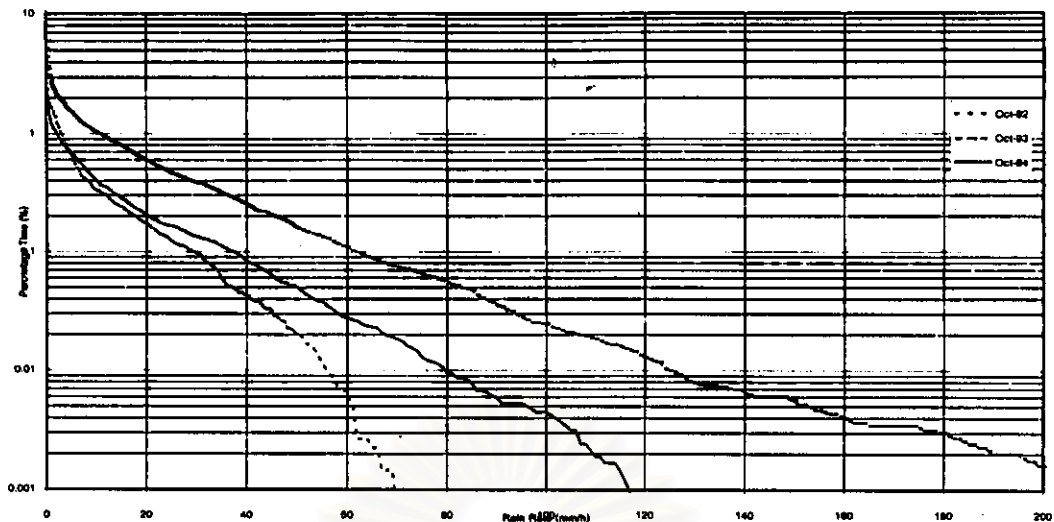
Monthly Rainfall Rate Statistic, Singapore, August 1992(720 hour), 1993(744 hours), 1994(744 hours)



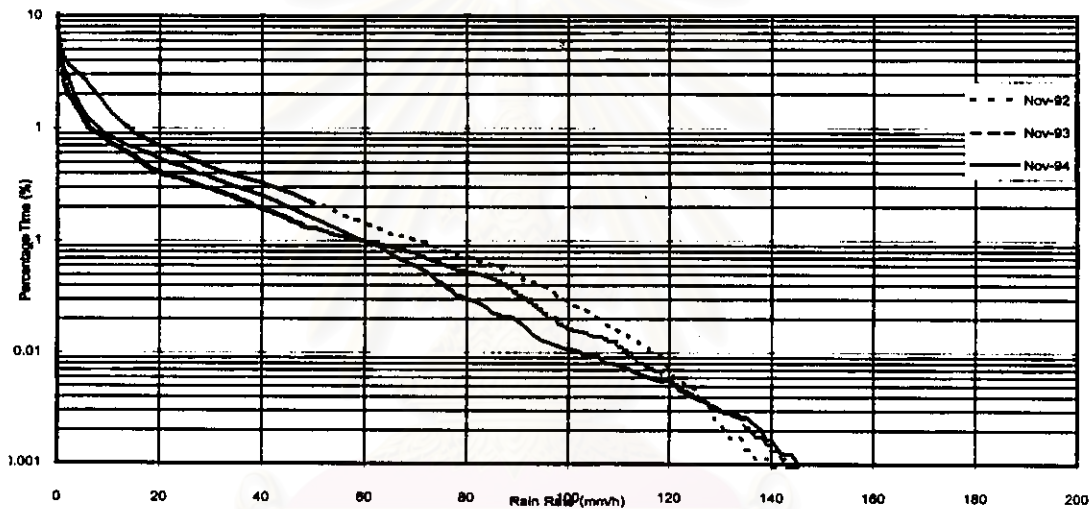
Monthly Rainfall Rate Statistic, Singapore, September 1992(720 hour), 1993(720 hours), 1994(806 hours)



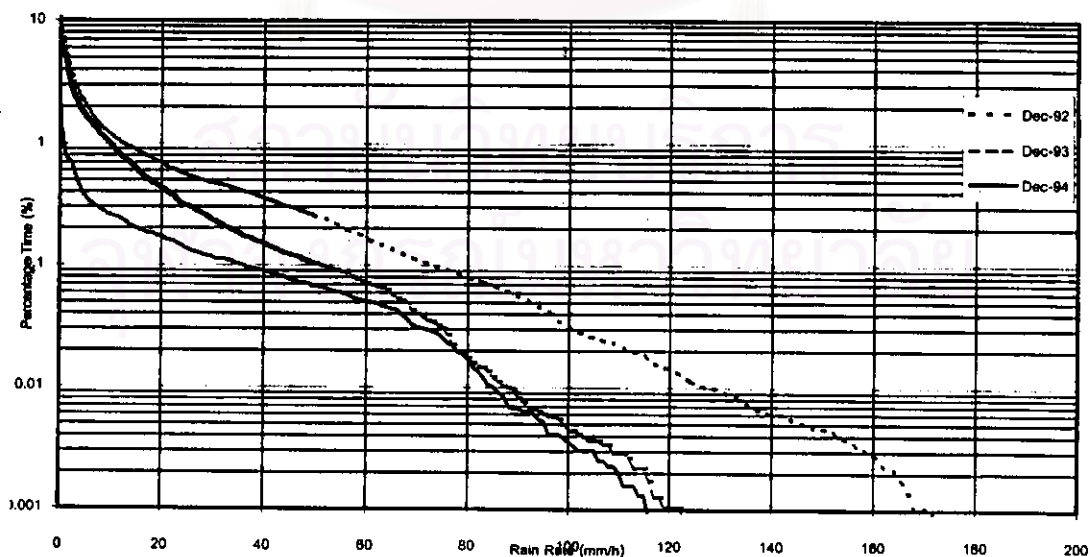
Monthly Rainfall Rate Statistic, Singapore, October 1992(480 hour), 1993(744 hours), 1994(744 hours)



Monthly Rainfall Rate Statistic, Singapore, November 1992(720 hour), 1993(720 hours), 1994(696 hours)

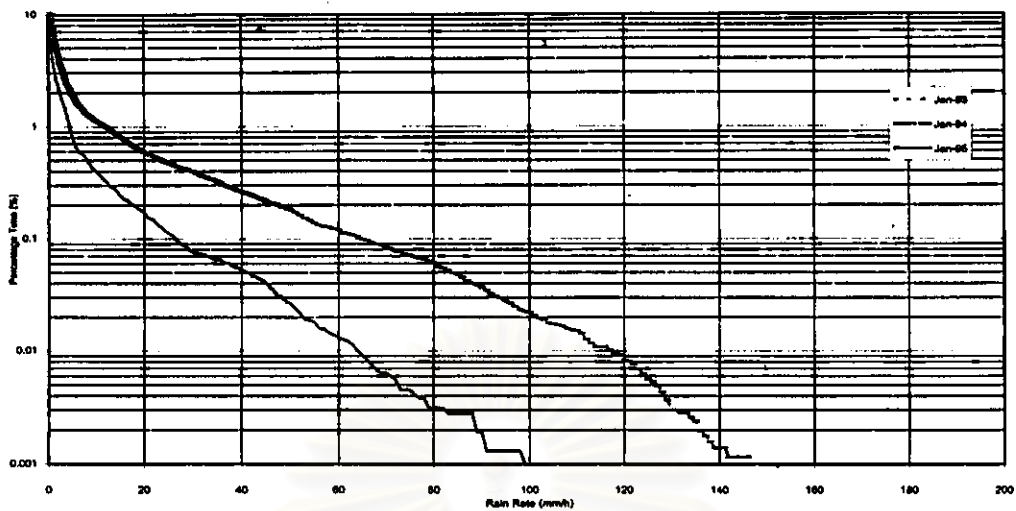


Monthly Rainfall Rate Statistic, Singapore, December 1992(744 hour), 1993(744 hours), 1994(288 hours)

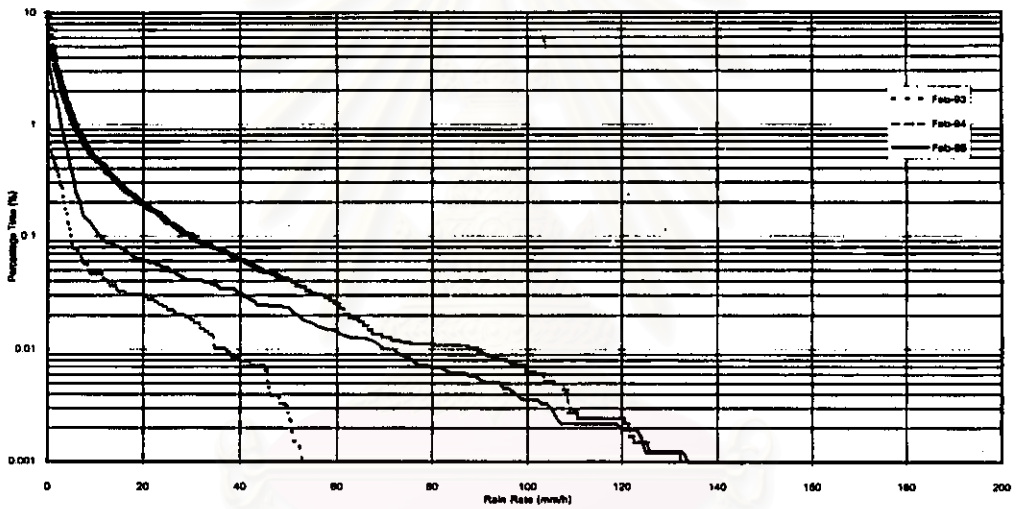


#### 4. Bundung, Monthly Cumulative Distribution, 1/Mar/92 - 28/Feb/95

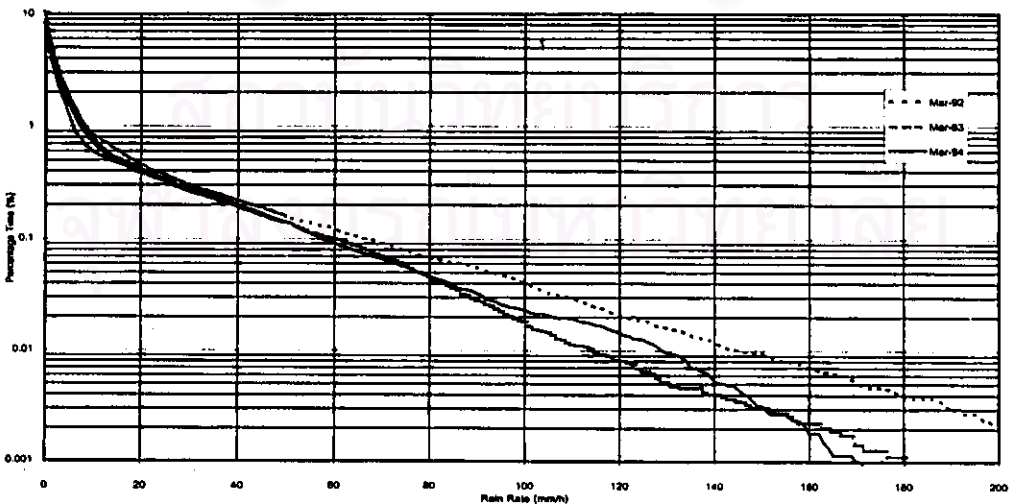
Monthly Rainfall Rate Statistic, Bundung, January, 1993(Loss Date), 1994(720 hours), 1995(744 hours)



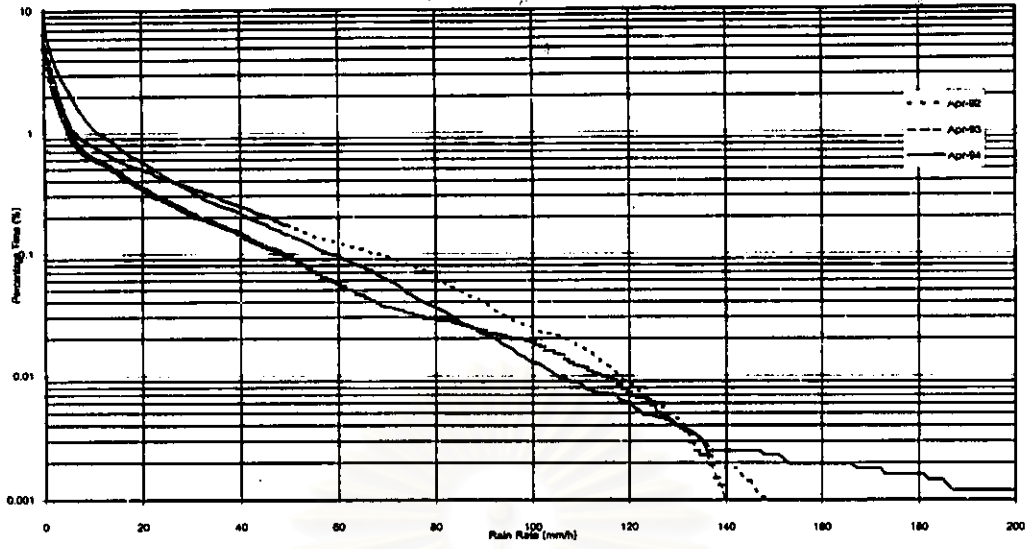
Monthly Rainfall Rate Statistic, Bundung, February, 1993(380hour), 1994(672 hours), 1995(504 hours)



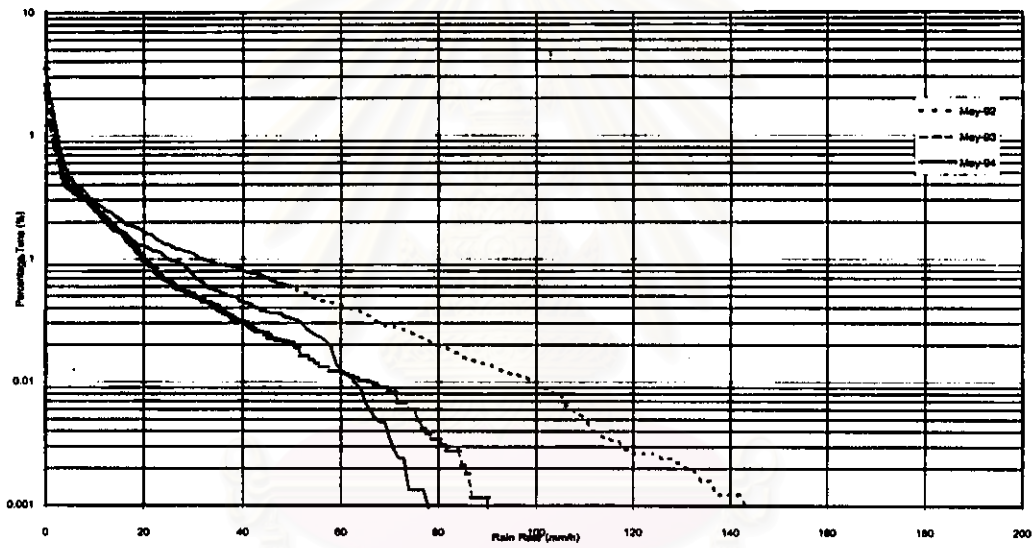
Monthly Rainfall Rate Statistic, Bundung, March, 1992(744 hour), 1993(744 hours), 1994(744 hours)



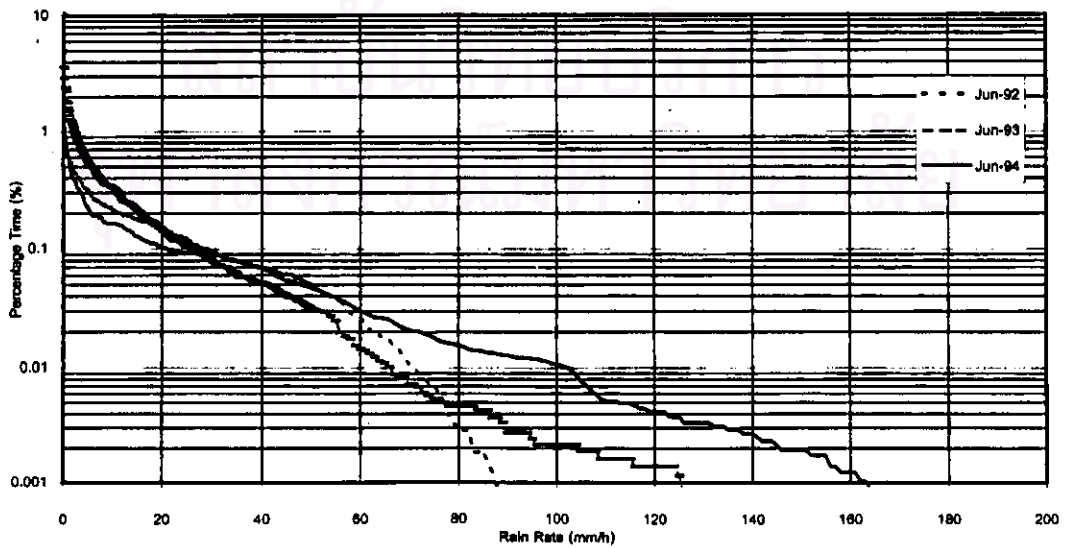
Monthly Rainfall Rate Statistic, Bundung, April, 1992(576 hour), 1993(608 hours), 1994(720 hours)



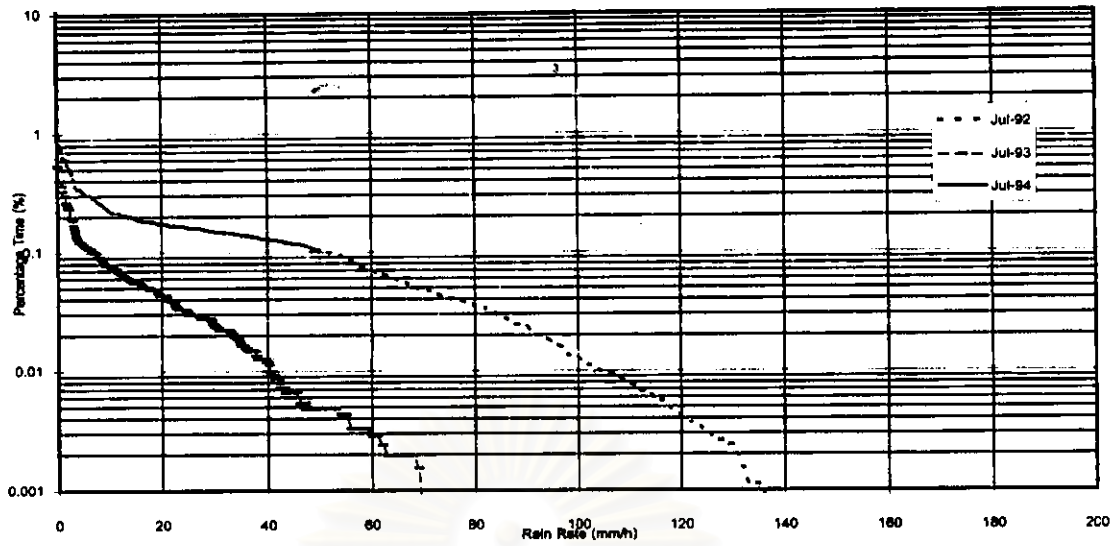
Monthly Rainfall Rate Statistic, Bundung, May, 1992(744 hour), 1993(720 hours), 1994(744 hours)



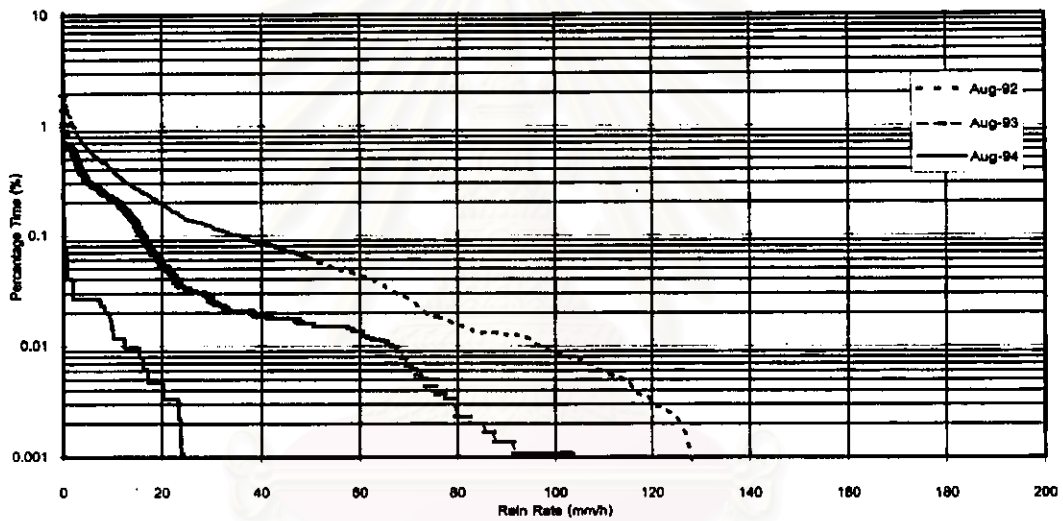
Monthly Rainfall Rate Statistic, Bundung, June, 1992(720 hour), 1993(720 hours), 1994(720 hours)



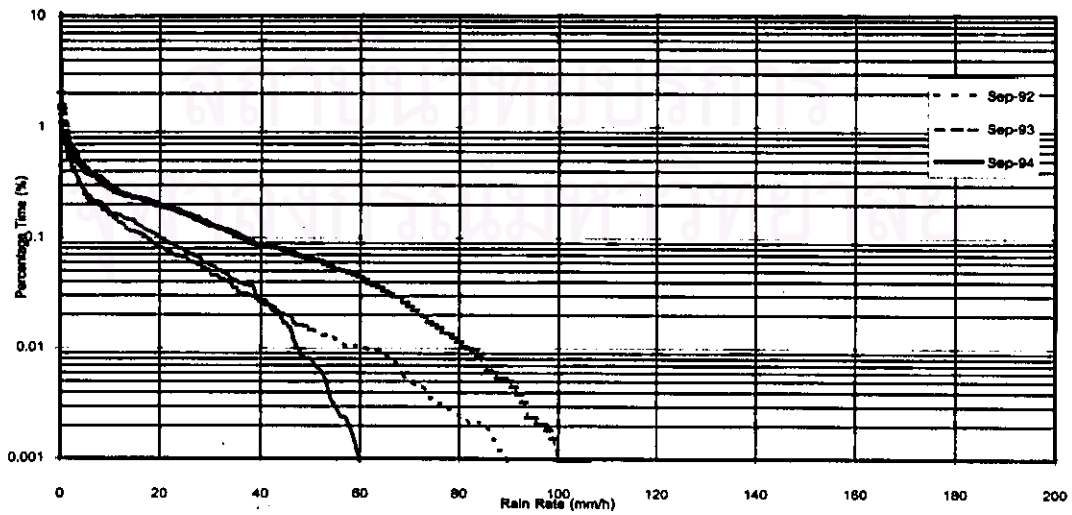
Monthly Rainfall Rate Statistic, Bundung, July, 1992(744 hour), 1993(744 hours), 1994(Loss Data)



Monthly Rainfall Rate Statistic, Bundung, August, 1992(744 hour), 1993(744 hours), 1994(744 hours)

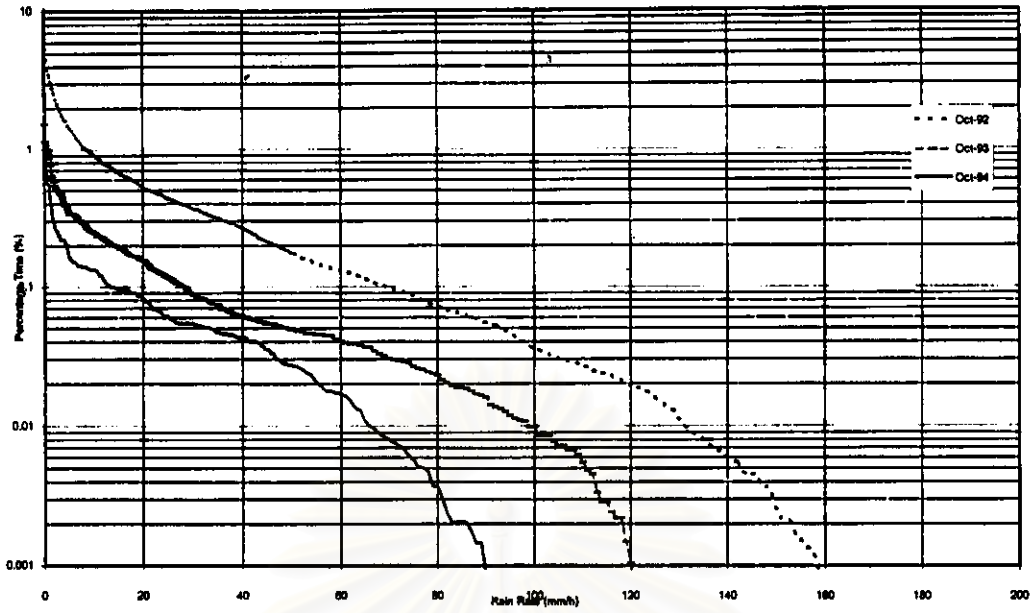


Monthly Rainfall Rate Statistic, Bundung, September, 1992(720 hour), 1993(720 hours), 1994(672 hours)

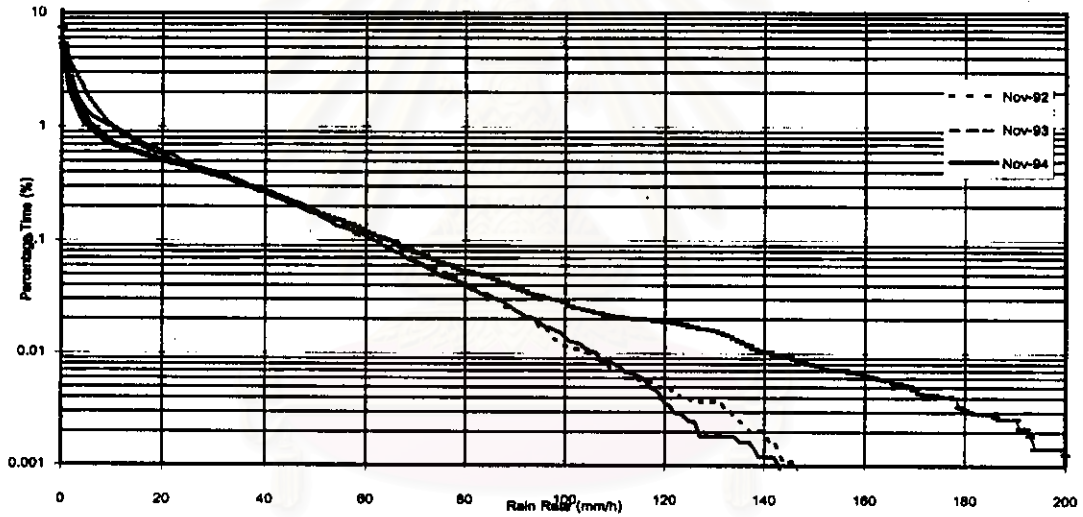




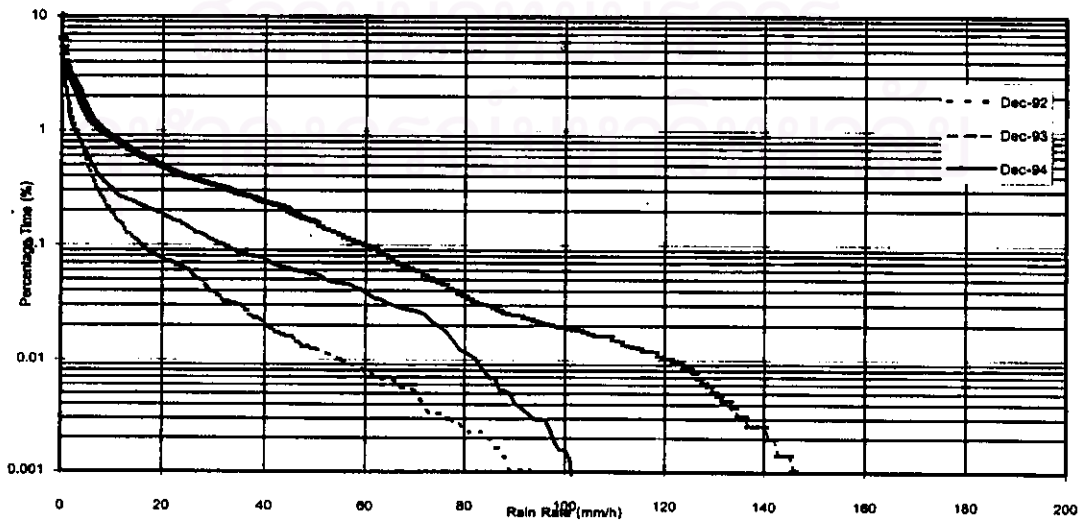
Monthly Rainfall Rate Statistic, Bundung, October, 1992(744 hour), 1993(744 hours), 1994(744 hours)



Monthly Rainfall Rate Statistic, Bundung, November, 1992(720 hour), 1993(720 hours), 1994(696 hours)



Monthly Rainfall Rate Statistic, Bundung, December, 1992(408 hour), 1993(744 hours), 1994(744 hours)



Bangkok

1/03/92 - 28/02/95 (3-Years)

Unit: mm/h

MM/YY	1%	0.5%	0.3%	0.2%	0.1%	0.05%	0.03%	0.02%	0.01%	0.005%	0.003%	0.002%	0.001%
Mar-92	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr-92	0	0	0	0	0	0	0	0	0	0	0	0	0
May-92	0	0.5	2.7	4.8	11.1	20.8	24.9	29.6	59	74	79	84	89
Jun-92	1.4	3.1	7.9	14.6	31.5	60	72	79	89	99	106	110	114
Jul-92	4.6	6.9	13.9	21.7	34.6	51	87	94	75	81	87	94	100
Aug-92	3	8.6	17.5	26.6	46.6	71	80	88	101	112	119	129	148
Sep-92	3.8	11.9	26.3	37	60	82	97	106	119	129	133	139	152
Oct-92	3	9.9	18.7	28	45.5	57	69	81	99	113	123	129	153
Nov-92	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec-92	0	0.6	0.9	1.2	2	2.8	2.9	4.1	4.3	5	-	-	-
Jan-93	0	0	0.1	1.6	8.2	27	40.2	47.2	65	73	81	92	98
Feb-93	0	0	0	0	0	0	0	0	0	0	0	0	0
Year-1	1.2	3.1	5.9	11	25.3	45.2	59	70	86	102	113	120	125
Mar-93	0.1	3.2	4.3	5.1	6.6	14.9	27.2	39.3	53	68	92	99	133
Apr-93	2.5	11.2	18.4	25.6	35.6	48.6	57	65	71	76	81	83	86
May-93	2.1	8.7	17.1	23.9	34.5	46.4	55	64	70	75	80	83	86
Jun-93	1.6	6.6	18.4	30.3	48.1	65	76	93	117	134	150	157	161
Jul-93	0.1	0.6	1.9	3.3	24	44.1	50	59	65	70	75	77.5	78
Aug-93	6.9	18.4	30	40.3	53	71	84	90	103	113	120	126	136
Sep-93	7.6	22.2	36.6	47.7	66	84	99	106	120	131	136	141	144
Oct-93	6.3	18.4	36.6	14.1	60	72	80	87	96	105	111	112	116
Nov-93	0	0	0	0	0	1.3	2.1	3.5	13.2	41.4	62	63	73
Dec-93	0	0	0	0	0.1	1	1.5	2	2.5	-	-	-	-
Jan-94	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb-94	0	0	0	0	0.7	5.1	14.1	21.1	44.9	56	62	69	80
Year-2	1.4	4.3	10.7	19	36.5	53	65	74	89	106	117	128	133
Mar-94	0.5	4	14.1	25.2	48.6	86	98	106	116	129	139	147	153
Apr-94	Loss	Data	-	-	-	-	-	-	-	-	-	-	-
May-94	0.5	1	1.6	2	3.8	11.1	19.2	29.2	51	72	88	103	111
Jun-94	4.2	12.1	21.6	32.4	50	72	94	107	123	134	137	140	145
Jul-94	17	3.4	5.8	10.1	25	42.3	52	63	74	79	83	86	96
Aug-94	2.2	5.7	10.6	18.8	37.8	55	66	75	86	98	104	109	111
Sep-94	9.4	22.6	35.1	48.1	72	91	106	113	123	138	147	150	167
Oct-94	2	12.8	31.4	45.4	69	93	110	119	138	156	168	173	187
Nov-94	0	0	0.5	0.9	6	9.6	11	12	12.4	14.5	15	15.1	16.1
Dec-94	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan-95	0	0	0	0.2	0.3	1.8	4.9	7.9	23	30	35.2	38	45.8
Feb-95	0	0	0	0	0	0	0	0	0	0	0	0	0
Year-3	2.8	8.9	19.3	29.9	50	70	84	95	111	125	136	146	153
3-Years	1.36	4.7	9.7	19.6	37.8	56	70	79	96	111	120	128	140

Remark: The rows indicate the monthly names starting from March 1992 to February 1995. The columns show the measured rain intensity exceeded the threshold at particular percentage time.

Si-Racha	Cumulative Rainrate Distribution												3-years	Units:mm/h
MM/YY	1%	0.5%	0.3%	0.2%	0.1%	0.05%	0.03%	0.02%	0.01%	0.005%	0.003%	0.002%	0.001%	
Mar-92	0	0	0	0	0	0	0	0	0	0	0	0	0	
Apr-92	0	0	0	0.8	2.4	27.4	46.5	58	86	104	120	136	147	
May-92	0.2	1	2.1	4.6	8	15.5	22.2	30.6	43.9	51	61	66	74	
Jun-92	2	8	15	21.1	36.8	49.1	56	64	88	106	111	119	125	
Jul-92	5.8	16.8	26	36.3	49.4	56	66	70	81	91	98	109	112	
Aug-92	2.5	5.9	12.9	21.7	33.3	50	61	67	98	117	130	140	156	
Sep-92	2	4.1	13.4	25.2	45.3	62	73	79	90	98	107	115	123	
Oct-92	6.7	13.9	22.1	36.3	64	88	99	107	115	122	126	133	141	
Nov-92	0	0	0	0	0	0	0	0	0	0	0	0	0	
Dec-92	0	0.1	0.3	0.7	1.2	1.9	2.4	5.4	6.8	8.8	10	13.6	-	
Jan-93	0	1.9	6.4	11.7	24.2	34	43.2	71	91	103	114	121	134	
Feb-93	0	0	0	0	0	0	0	0	0	0	0	0	0	
Year-1	1.1	3.7	7.5	13.7	27.2	45.3	57	68	88	104	114	122	129	
Mar-93	1.3	7.4	13	17.4	29.1	41.51	51	60	76	90	92	97	104	
Apr-93	Loss	Data	-	-	-	-	-	-	-	-	-	-	-	
May-93	Loss	Data	-	-	-	-	-	-	-	-	-	-	-	
Jun-93	Loss	Data	-	-	-	-	-	-	-	-	-	-	-	
Jul-93	Loss	Data	-	-	-	-	-	-	-	-	-	-	-	
Aug-93	1.2	2.6	4	10.4	24.7	44.8	58	73	85	97	106	110	132	
Sep-93	8.4	22.9	39.8	54	72	85	93	106	120	129	132	136	137	
Oct-93	5.3	17.7	35.2	24.9	71	89	100	108	124	146	156	159	166	
Nov-93	0	0	0	0	0	0	0	0	0	0	0	0	0	
Dec-93	0	0	0	0	0	0	0	0	0	0	0	0	0	
Jan-94	0	0	0	0	0	0	0	0	0	0	0	0	0	
Feb-94	0	0.1	0.3	1.1	9.1	14.4	25.1	31.6	59	77	84	87	100	
Year-2	0.8	3.2	8.7	16	33.6	57	71	80	94	109	122	130	136	
Mar-94	1.3	5.7	14.6	21.1	39.7	54	70	80	92	104	108	109	112	
Apr-94	0	1.1	3.9	10.4	36.6	48.8	55	63	84	110	117	123	133	
May-94	8.2	16.3	21.4	24.1	28.8	30.6	31.7	32.1	33.2	33.8	35	35.5	35.8	
Jun-94	1.5	4.3	7.5	10.2	27.8	42.7	84	121	147	172	180	191	208	
Jul-94	2.2	7.1	17.6	27.7	52	75	90	99	109	117	128	138	143	
Aug-94	1.2	3.1	8.9	1.4	26.6	47.1	65	75	90	103	107	110	119	
Sep-94	10.9	37.5	55	68	88	111	133	143	164	186	202	213	230	
Oct-94	1.1	6.7	16.1	28.2	49.5	73	92	102	113	119	126	140	144	
Nov-94	0	0	0.6	0.9	2.8	4.6	5.8	6.4	9.9	13.1	15.2	18	21.3	
Dec-94	0	0	0	0	0	0	0	0	0	0	0	0	0	
Jan-95	0	0	0.6	6.4	33.4	57	75	83	92	98	100	104	106	
Feb-95	0	0	0	0	0.4	3.1	3.5	10.3	15.7	30.1	40.8	41.3	42	
Year-3	1.1	4	11	18.9	36.2	54	72	86	106	131	144	162	174	
3-Years	1	3.7	8.9	16.2	32	52	68	79	97	114	129	141	151	

Remark: The rows indicate the monthly names starting from March 1992 to February 1995. The columns show the measured rain intensity exceeded the threshold at particular percentage time.

## Cumulative Rain-rate Distribution

Singapore

1/03/92 - 28/02/95

Unit:mm/h

MMYY	1%	0.50%	0.30%	0.20%	0.10%	0.05%	0.03%	0.02%	0.01%	0.005%	0.003%	0.002%	0.001%
Mar-92	2.1	9.9	19.7	31.4	60	82	94	103	126	151	159	167	171
Apr-92	2.5	13	28.8	45.4	68	87	98	108	122	133	141	145	155
May-92	3.8	17.8	39.9	54	70	82	93	102	121	138	160	170	177
Jun-92	6.1	16.8	25.5	32.7	48.9	68	84	94	111	120	130	133	134
Jul-92	5.8	17	26.2	35.9	56	75	84	88	101	113	122	127	133
Aug-92	2.2	4.8	11.4	19.1	31.8	43.4	53	61	84	97	108	113	126
Sep-92	0.6	5.2	26.4	44.5	59	74	88	111	135	147	155	162	166
Oct-92	3	6.5	12	17.7	29.6	37.3	45.3	50	56	61	64	66	69
Nov-92	14	27.7	42.4	52	70	89	99	106	118	125	129	134	139
Dec-92	12.4	27.9	45	55	73	93	101	113	129	151	161	166	171
Jan-93	5.2	10.8	17.3	24.5	37.3	52	72	94	119	140	151	158	161
Feb-93	0.2	1	3.6	8.1	30.7	51	60	67	79	90	97	106	109
Year-1	5.6	14.5	26	38	58	75	88	97	115	131	142	154	160
Mar-93	6	15.4	25.1	33.8	48.1	62	71	79	94	105	111	113	114
Apr-93	4.2	14.9	26.4	36.1	56	71	78	84	95	109	119	124	134
May-93	5.4	16	26.3	39.4	65	87	96	104	113	127	140	146	151
Jun-93	32	12.1	20.7	30.4	53	69	83	95	126	153	177	193	201
Jul-93	7.2	20.4	33.6	51	72	91	101	107	114	122	126	132	134
Aug-93	2.2	6.6	13.5	20.2	32	43.1	52	61	72	78	79	83	84
Sep-93	1	5.5	16.3	28.3	48.9	68	79	89	100	133	120	125	124
Oct-93	10.6	23.3	36	45.3	61	83	94	108	126	155	184	200	224
Nov-93	58	16	28.1	38.7	59	82	91	97	111	123	134	139	142
Dec-93	9.5	17.3	25.2	32.9	36.1	61	72	78	85	95	107	113	115
Jan-94	0.6	2.6	9.8	18.7	43.3	58	69	79	96	109	122	125	-
Feb-94	6.1	17.8	32.5	44.7	36	82	92	98	131	143	152	158	160
Year-2	5.1	14.9	25.1	35.8	55	73	85	93	108	121	131	144	153
Mar-94	7.8	14.6	23	29.5	45.2	59	69	79	114	105	111	113	114
Apr-94	8	27.8	43.3	55	71	85	97	105	116	132	145	166	174
May-94	7.1	17.4	30.9	44.5	60	76	92	102	117	139	148	155	158
Jun-94	2	4.6	9.4	15.4	41.8	65	81	91	107	123	130	140	145
Jul-94	0.3	3.6	9.6	14.4	24.8	39.6	53	60	70	83	96	104	108
Aug-94	4.4	14.3	24.1	36.9	56	70	89	113	138	153	162	172	176
Sep-94	0	0.5	1.6	3.4	8.4	19.3	23.8	43.8	67	76	79	88	89
Oct-94	2.1	8	14.3	20.4	37.5	50	58	68	79	97	106	114	117
Nov-94	8.1	21.6	35.3	45.1	60	73	80	90	105	122	135	140	145
Dec-94	0.7	3.4	7.4	14.9	36.1	61	72	78	84	95	107	113	115
Jan-95	6.5	11.6	18.4	24.2	39.6	57	74	91	119	136	150	159	161
Feb-95	14.8	26.9	37	47.8	63	79	97	107	131	143	152	158	160
Year-3	6.1	14.3	24	35	53	69	80	91	110	130	140	150	157
3- Years	5.6	14.5	25.2	36.2	55	72	85	94	111	127	139	150	157

Remark: The rows indicate the monthly names starting from March 1992 to February 1995. The columns show the measured rain intensity exceeded the threshold at particular percentage time.

## Cumulative Rain-rate Distribution, Bundung

Bundung	Indonesia													1/03/92 - 28/02/95	Unit:mm/h
MMYY	1%	0.50%	0.30%	0.20%	0.10%	0.05%	0.03%	0.02%	0.01%	0.005%	0.003%	0.002%	0.001%		
Mar-92	8.3	18.4	30.1	42	66	93	109	120	145	170	192	202	216		
Apr-92	6.4	19.7	34.6	45.8	67	84	85	107	117	128	135	139	147		
May-92	2.1	4.8	9.1	15.7	31.8	53	68	79	99	110	117	132	143		
Jun-92	0.2	1.8	5.4	11.7	29	50	57	63	71	77	82	86	87		
Jul-92	0.2	2.3	6.3	14.1	51	68	84	92	104	117	125	131	136		
Aug-92	2	7.3	13.3	19.4	35.7	55	67	73	98	115	123	127	128		
Sep-92	1	2.3	4	7.8	17.5	30	38.4	45.8	64	72	81	87	89		
Oct-92	8.6	21.6	36.8	47.1	69	93	106	119	131	146	150	155	158		
Nov-92	10	22.3	36.5	46.5	61	77	86	93	105	121	134	142	146		
Dec-92	2.8	5.2	7.2	9.6	15.8	27.9	35.4	40.7	56	70	79	87	93		
Jan-93	Equipment Malfunction														
Feb-93	0.3	1	2.5	3.4	4.8	8.8	20.1	28.4	37	46.1	50	52	53		
Year-1	3.4	8.1	15.7	25	45.3	64	78	89	107	125	135	146	153		
Mar-93	7.6	15.7	27.2	39.4	59	78	88	97	114	130	151	164	180		
Apr-93	5.3	14	22.3	31.1	48.3	62	77	95	114	126	132	136	139		
May-93	1.6	3.3	9	12.5	19.7	30.1	40.6	50	65	76	81	85	90		
Jun-93	2.2	5.7	11.1	15.7	26.1	41.3	52	56	66	83	94	115	125		
Jul-93	0	0.2	1	2.4	7	17.6	25.3	33.6	40.3	14.1	59	62	69		
Aug-93	0.3	2.7	5.6	11.4	16	21.2	28.7	38.6	67	73	79	87	103		
Sep-93	0.7	3.4	9.3	19.4	36.1	57	66	72	83	90	93	99	106		
Oct-93	0.7	2.9	7.5	14.4	28.5	49.6	71	82	100	112	115	118	120		
Nov-93	5.8	20.7	36.8	47.3	64	83	98	117	143	170	190	193	205		
Dec-93	7.8	19.4	33.3	44.6	59	74	85	98	121	131	140	142	146		
Jan-94	11.9	23.7	36.7	47.7	64	84	94	102	117	127	134	138	152		
Feb-94	5.5	9.8	14.8	19.4	30	44.1	57	62	89	104	110	122	132		
Year-2	4.3	10	18.1	26.8	44.7	62	74	84	102	122	133	143	152		
Mar-94	5.4	13.3	26.8	40.1	57	77	91	105	129	142	150	159	171		
Apr-94	11	22.5	31.7	41.2	58	73	83	92	104	122	135	152	206		
May-94	2.4	4.3	8.2	13.7	25.1	37.6	51	57	62	67	70	73	77		
Jun-94	0.1	1.2	3.5	5.4	21.2	48.3	60	72	103	155	141	155	163		
Jul-94	Equipment Malfunction														
Aug-94	0	0	0	0	0	0.8	2	9.5	15.3	20.2	23.3	23.8	24.4		
Sep-94	0	1.9	4.2	8.6	20	32.3	39.3	44	47.7	53	55	58	59		
Oct-94	0.2	1.1	1.9	4.5	13.3	33.6	47.3	55	67	78	81	87	89		
Nov-94	10	24	37	46.5	61	74	87	94	106	118	124	137	143		
Dec-94	2.6	6	10.3	18.2	32	52	66	74	82	89	96	100	101		
Jan-95	4.3	8	12.7	18	26.3	41.7	48	52	64	75	88	90	99		
Feb-95	2.8	4.3	5.5	6.7	11	25.6	40.8	52	72	96	105	124	133		
Year-3	3	6.5	18.1	20.1	36	52	63	72	88	104	120	133	142		
3- Years	3.9	8.6	16.8	25.4	43.9	61	73	83	101	120	133	142	152		

Remark: The rows indicate the monthly names starting from March 1992 to February 1995. The columns show the measured rain intensity exceeded the threshold at particular percentage time.

## Estimation of Parameters for the Best fit Probability Distribution

After a candidate of distribution e.g., an exponential distribution, have been hypothesized. We must selected the approximated value of their parameters to be the best fit to the measured distribution. There are many methods to evaluate the quality of the estimators such as: the maximum-likelihood estimators (MLE), the lease-squares estimators (LSE), the moment method. The MLE has good potential to justify the chi-square goodness-of-fit test. In our analysis, the MLE was selected to evaluate the quality of estimation.

### Estimation of parameters $(\mu, \rho)$ of point-rain intensity distribution

The exponential distribution of the measured rain-intensity is given in equation (4.4) as

$$P(R > \gamma) = (\rho/\mu)\exp(-R/\mu) \quad \text{-----(A1)}$$

where:  $\rho$  is a constant that scales the curves and  $\mu$  is a constant that modifies the shape and the slope of the curve.

The MLE is defined as:  $L(\mu, \rho) = P_{\mu\rho}(R_1) P_{\mu\rho}(R_2) \dots P_{\mu\rho}(R_n)$  -----(A2)

$$= (\rho/\mu)\exp(-R_1/\mu) (\rho/\mu)\exp(-R_2/\mu) \dots (\rho/\mu)\exp(-R_n/\mu) \quad \text{---(A3)}$$

$$= (\rho/\mu)^n \exp(-1/\mu \sum_{i=1}^n R_i) \quad \text{---(A4)}$$

Take the Logarithm function

$$\ln(L(\mu, \rho)) = n \ln(\rho/\mu) - 1/\mu \sum_{i=1}^n R_i \quad \text{---(A5)}$$

Maximizing  $L(\mu, \rho)$  is equivalent to maximizing  $\ln(\mu, \rho)$  and  $\bar{\mu}, \bar{\rho}$  maximized  $L(\mu, \rho)$  if and only if  $\bar{\mu}, \bar{\rho}$  maximized  $\ln(\mu, \rho)$ . The standard differential calculus can be used to maximized  $\ln(\mu, \rho)$  by setting its derivative to zero and solving for  $\mu$  and  $\rho$ .

$$\frac{d(\ln(\mu, \rho))}{d\mu} = n\rho/\mu + 1/\mu^2 \sum_{i=1}^n R_i = 0 \quad \text{----- (A6)}$$

and

$$\frac{d(\ln(\mu, \rho))}{d\rho} = n/\rho\mu + = 0 \quad \text{----- (A7)}$$

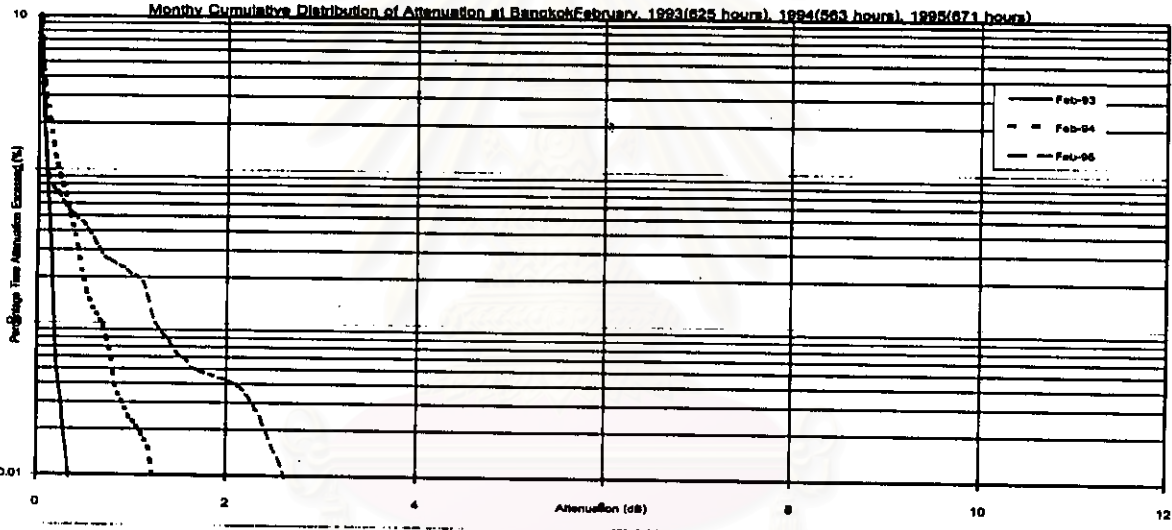
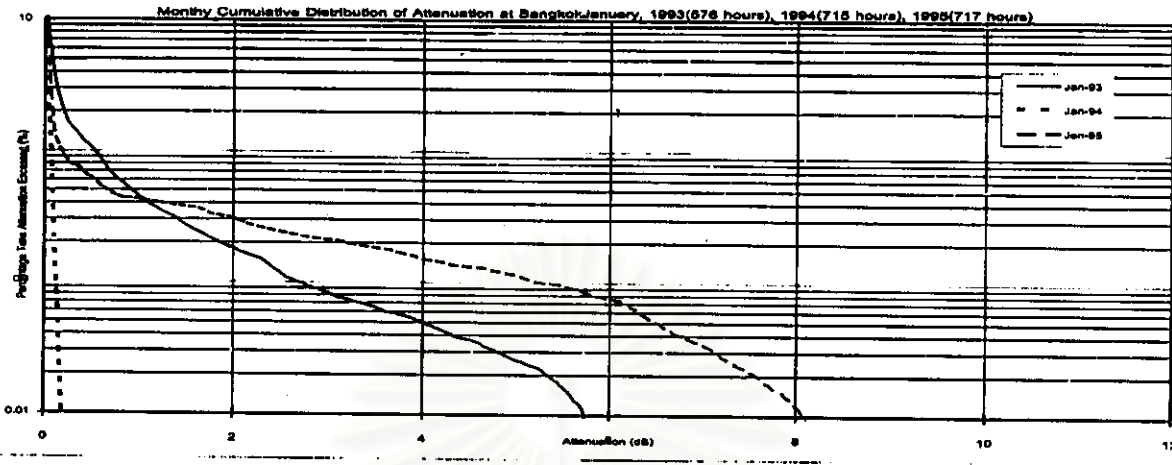
To make sure that  $\mu, \rho$  is maximized of  $\ln(\mu, \rho)$ , the second derivative of  $\ln(\mu, \rho)$  must be negative. The correlation coefficient is used to evaluate to fit parameters.

By solving equation (A6) and (A7), result of the parameters  $\mu, \rho$  and correlation coefficient for the exponential fit to the measured value is shown in table 4.2.

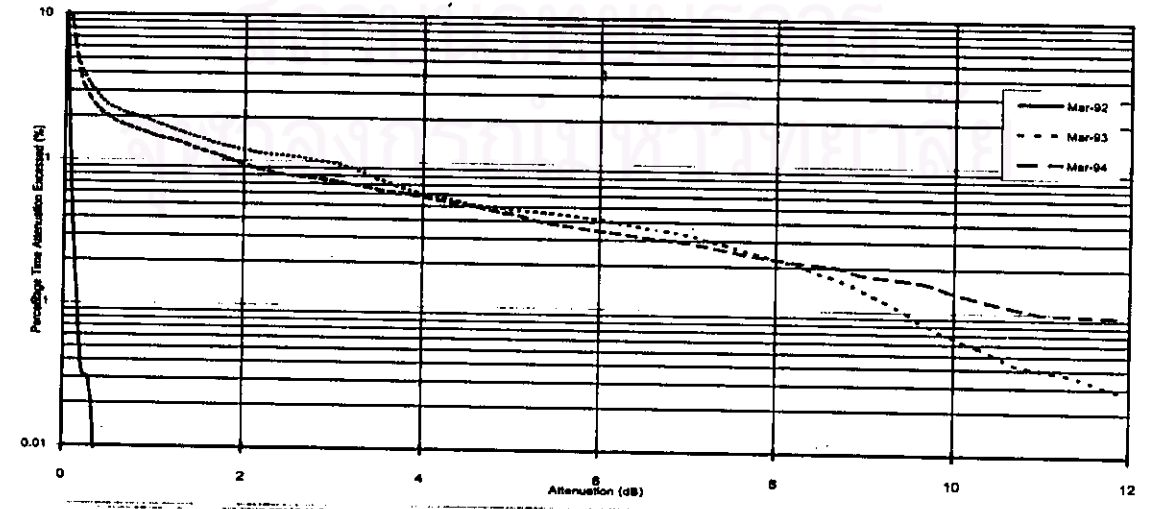
APPENDIX - C

Monthly Cumulative Attenuation Distributions

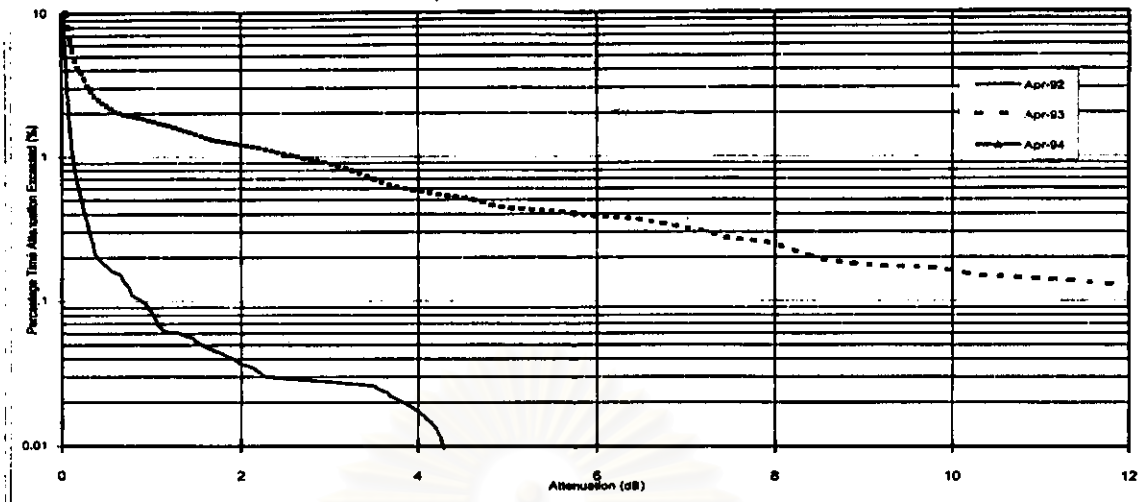
1. Bangkok Attenuation Distribution 1/March/92 - 28/Feb./95, N. Yoothanorm et al.,[1997]



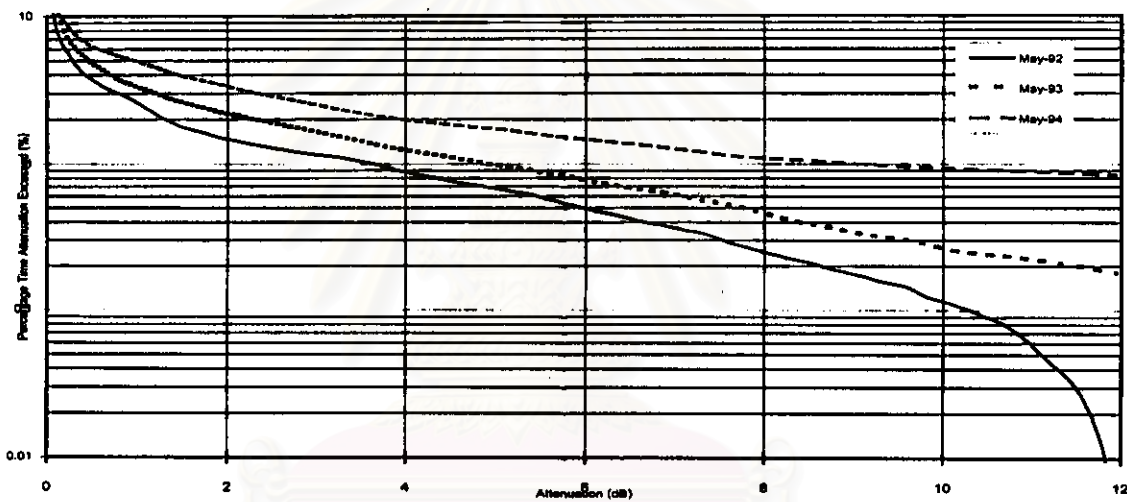
Monthly Cumulative Distribution of Attenuation, Bangkok, March 1992(744 hours), 1993 (744 hours), 1994(613 hours)



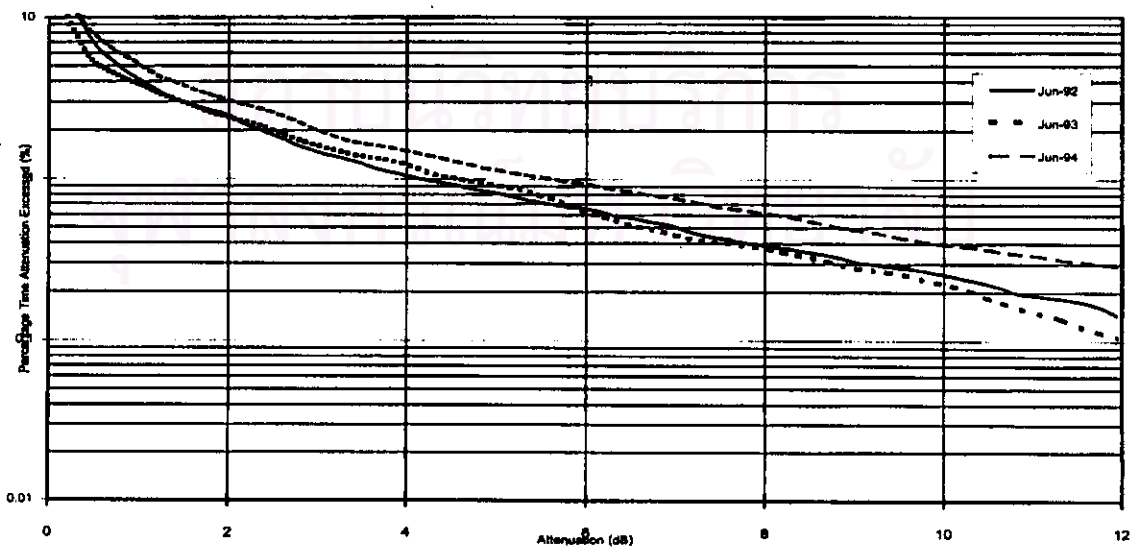
Monthly Cumulative Distribution of Attenuation at Bangkok, April, 92 (694 hours), 93 (360 hours), 94(No Data)



Monthly Cumulative Distribution of Attenuation at Bangkok, May, 1992 (744 hours), 1993 (666 hours), 1994(406hours)

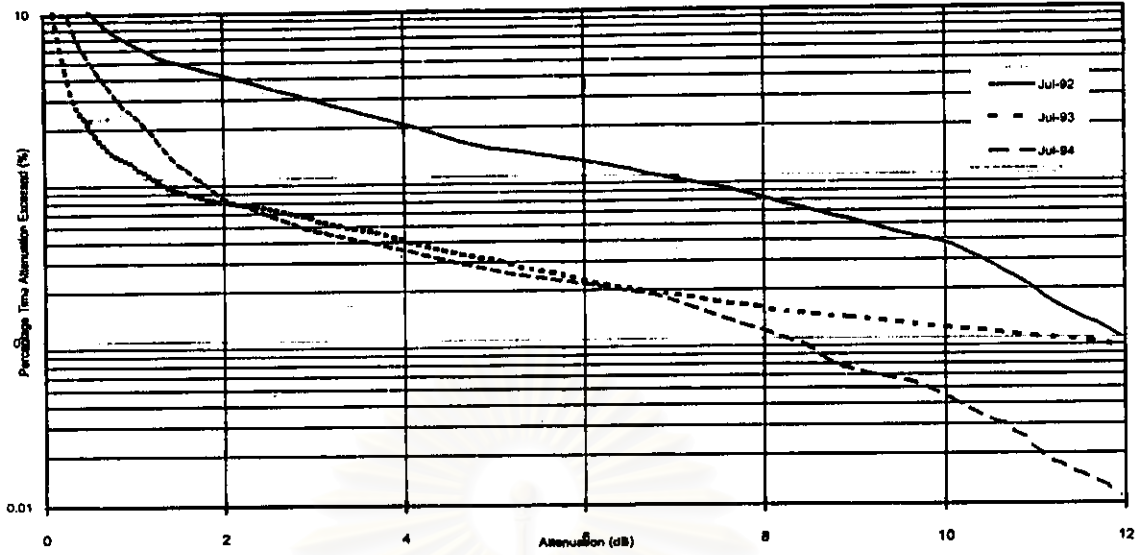


Monthly Cumulative Distribution of Attenuation at Bangkok, June, 92 (720 hours), 93 (711 hours), 94 (515 hours)

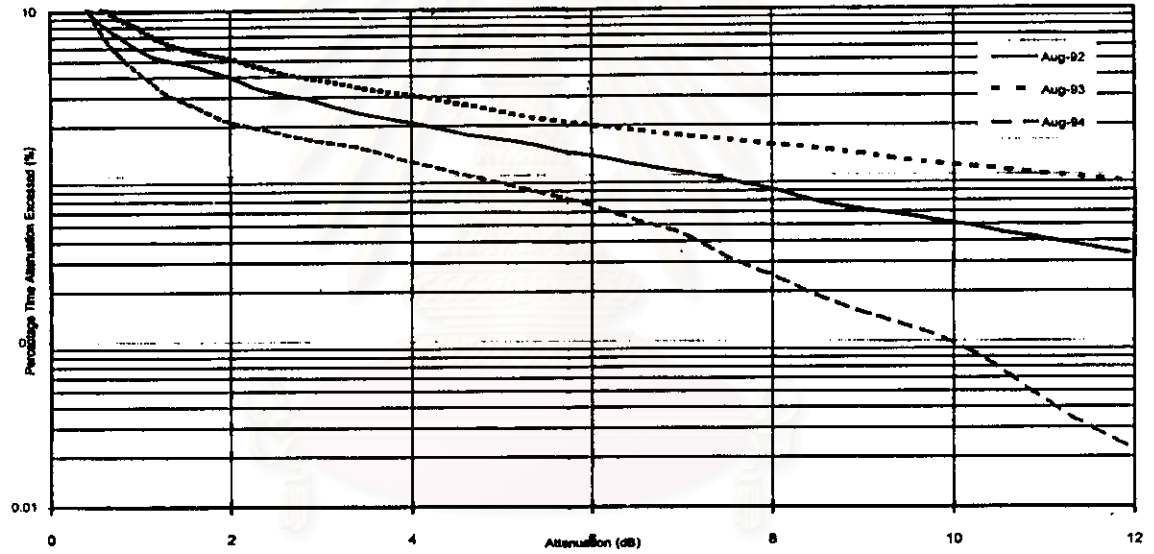




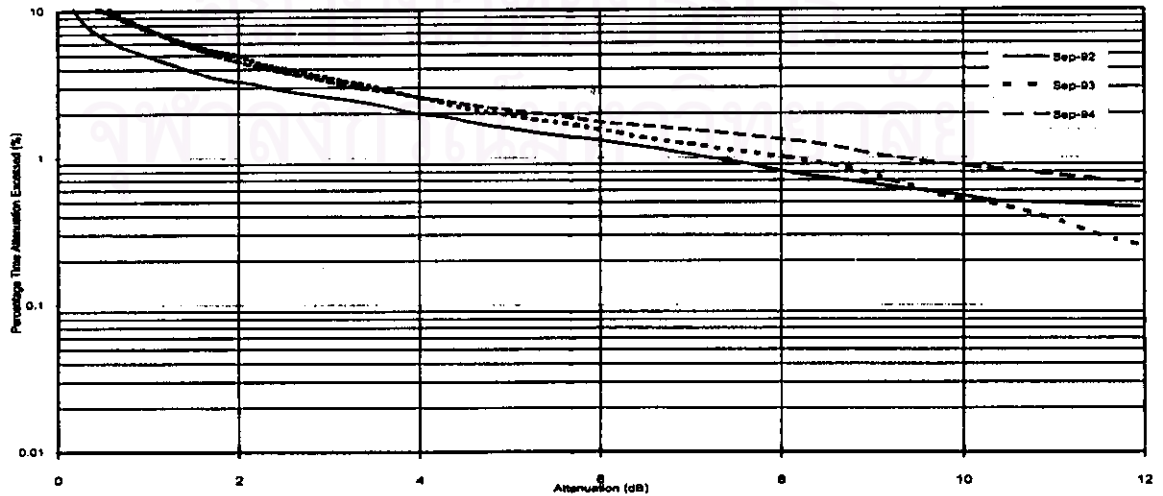
Monthly Cumulative Distribution of Attenuation at Bangkok, July, 1992 (720 hours), 1993 (653 hours), 1994 (534 hours)



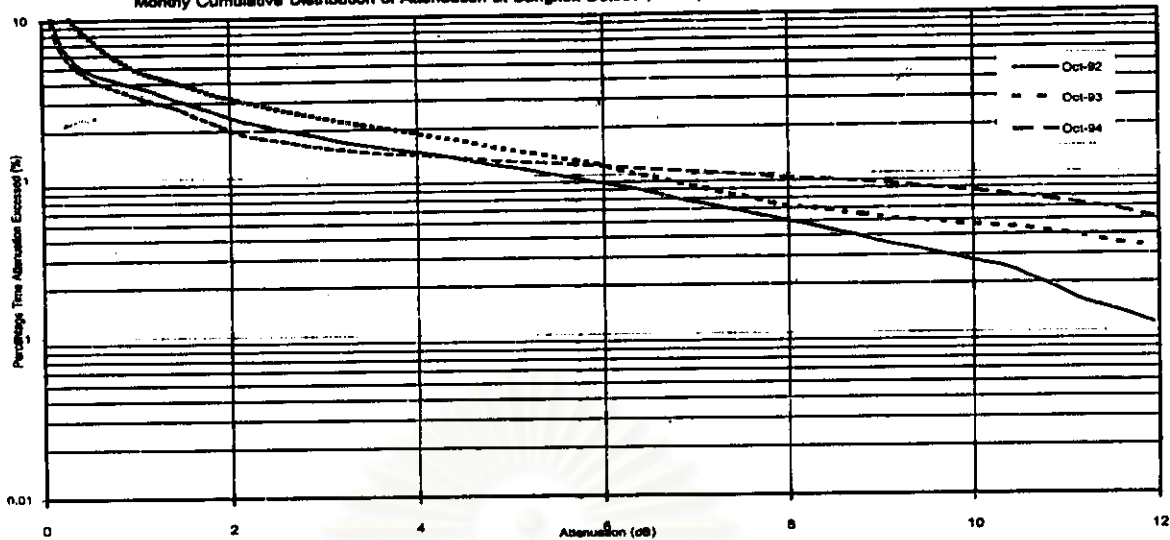
Monthly Cumulative Distribution of Attenuation at Bangkok August, 1992(744 hours), 1993(742 hours), 1994(742 hours)



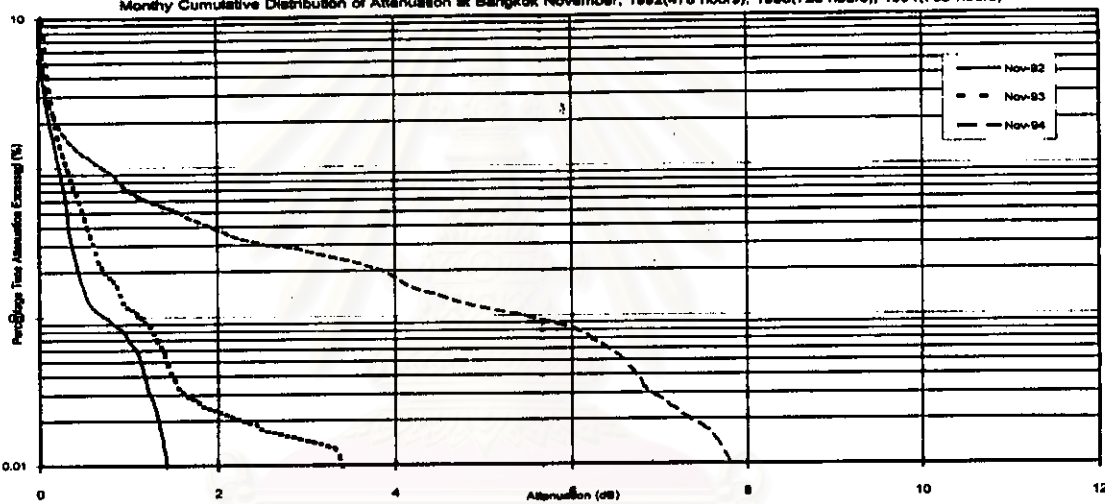
Monthly Cumulative Distribution of Attenuation at Bangkok September, 1992(720 hours), 1993(600 hours), 1994(720 hours)



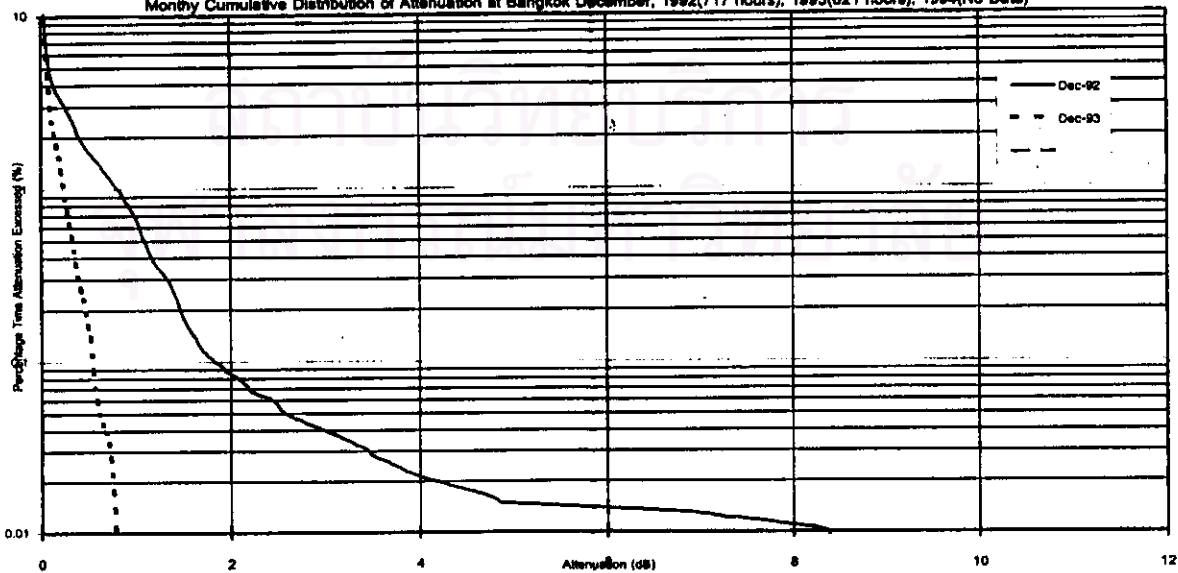
Monthly Cumulative Distribution of Attenuation at Bangkok October, 1992(318 hours), 1993(712 hours), 1994(708 hours)



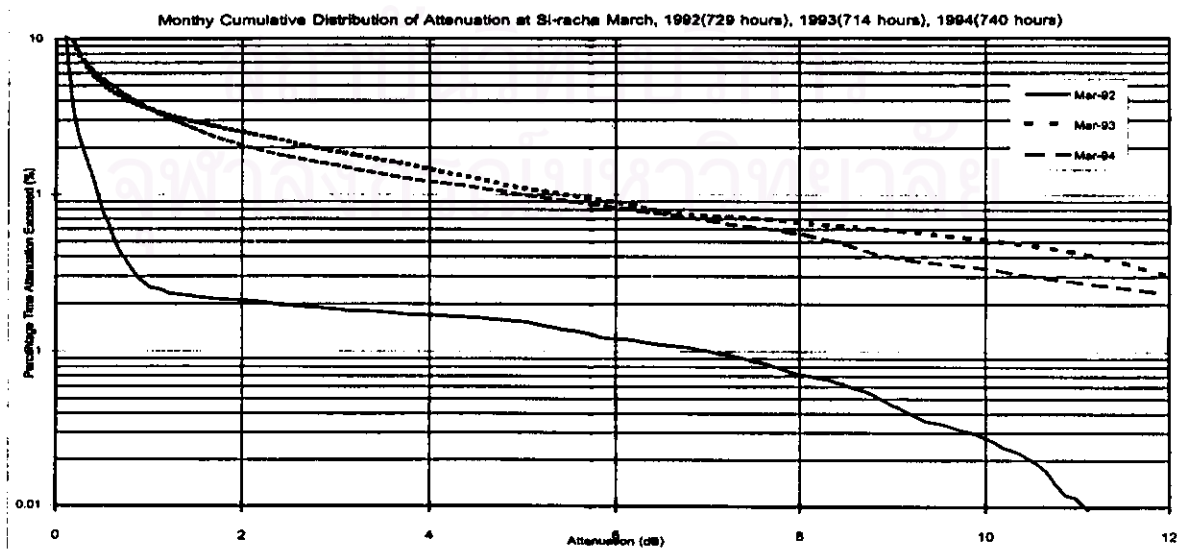
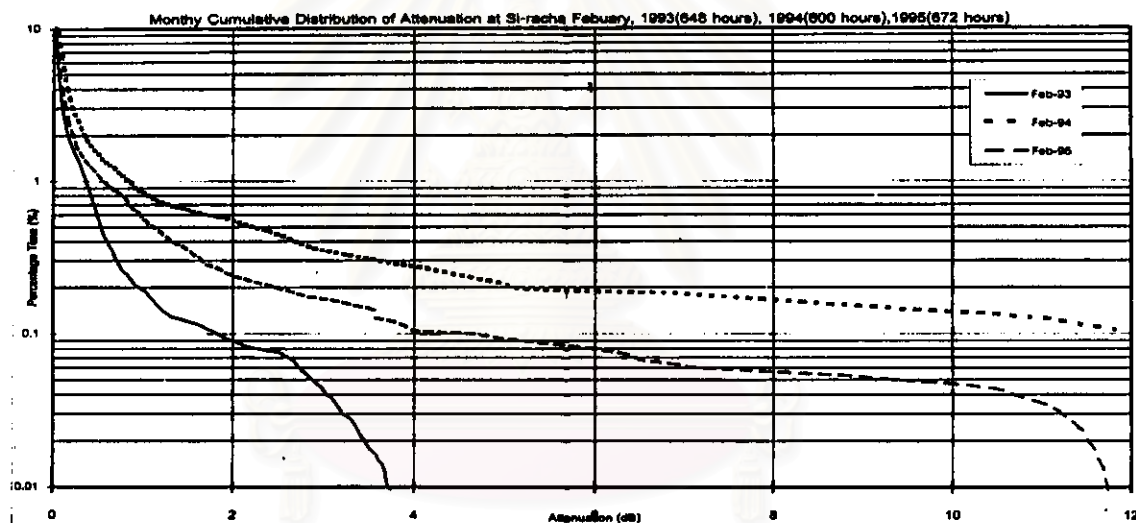
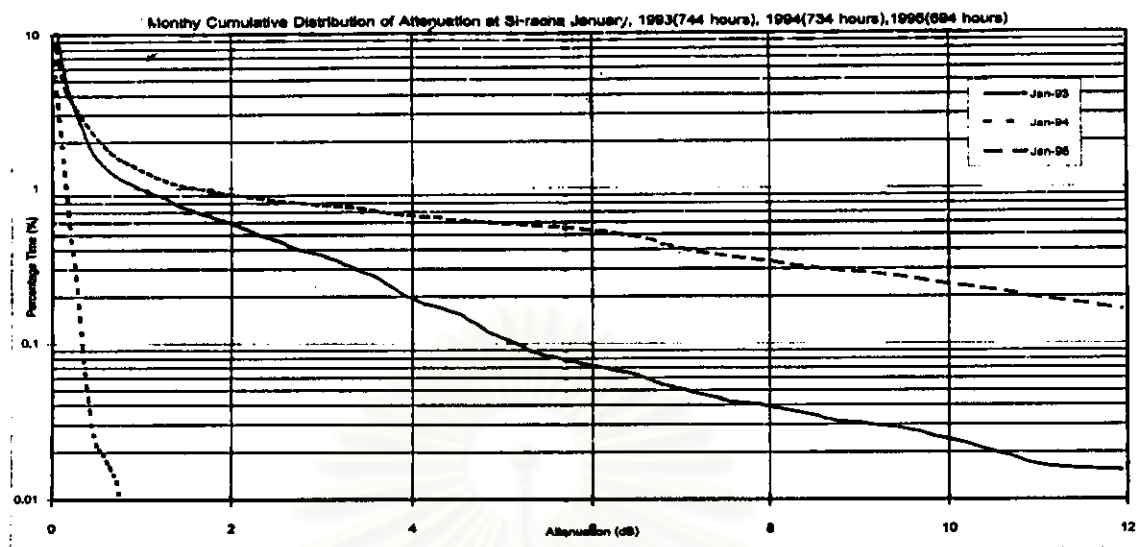
Monthly Cumulative Distribution of Attenuation at Bangkok November, 1992(478 hours), 1993(720 hours), 1994(709 hours)

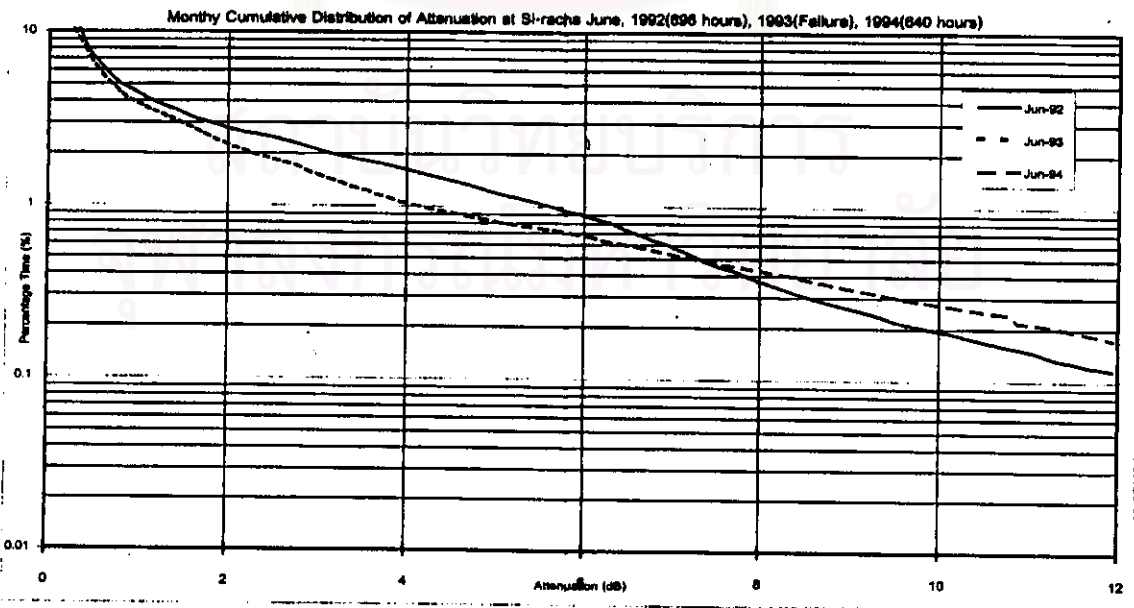
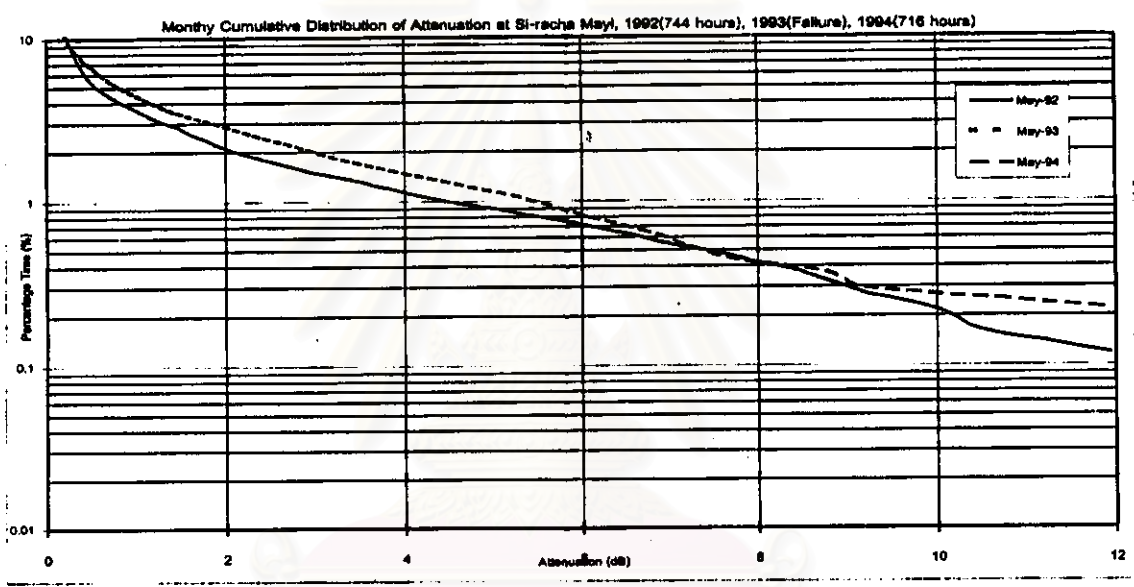
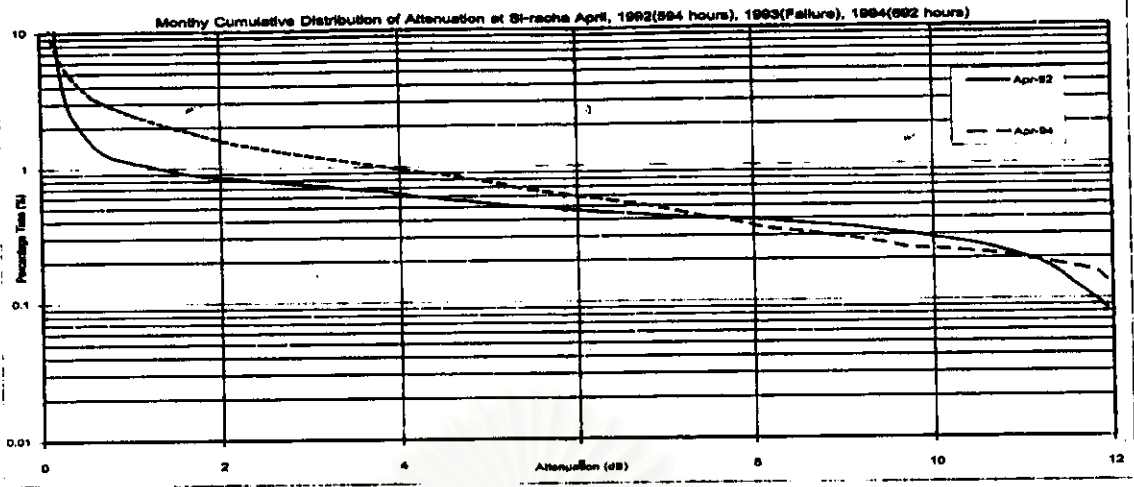


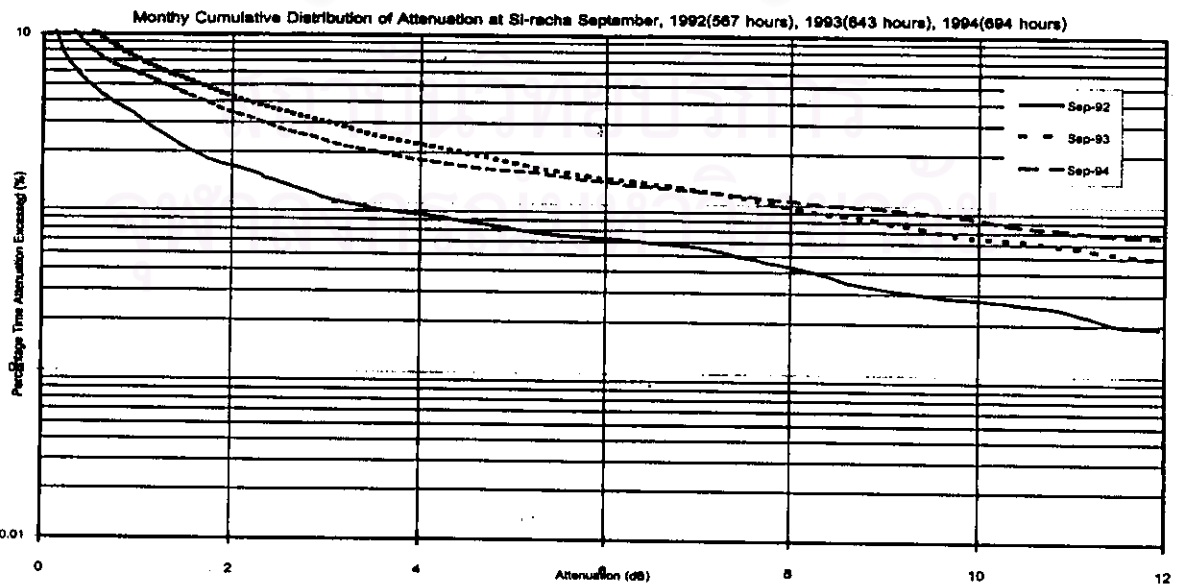
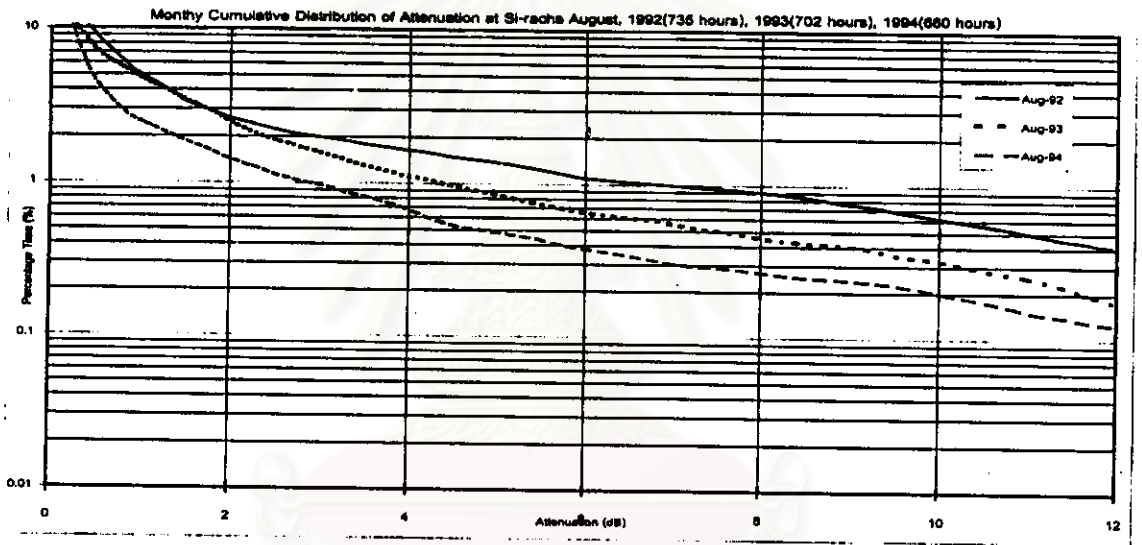
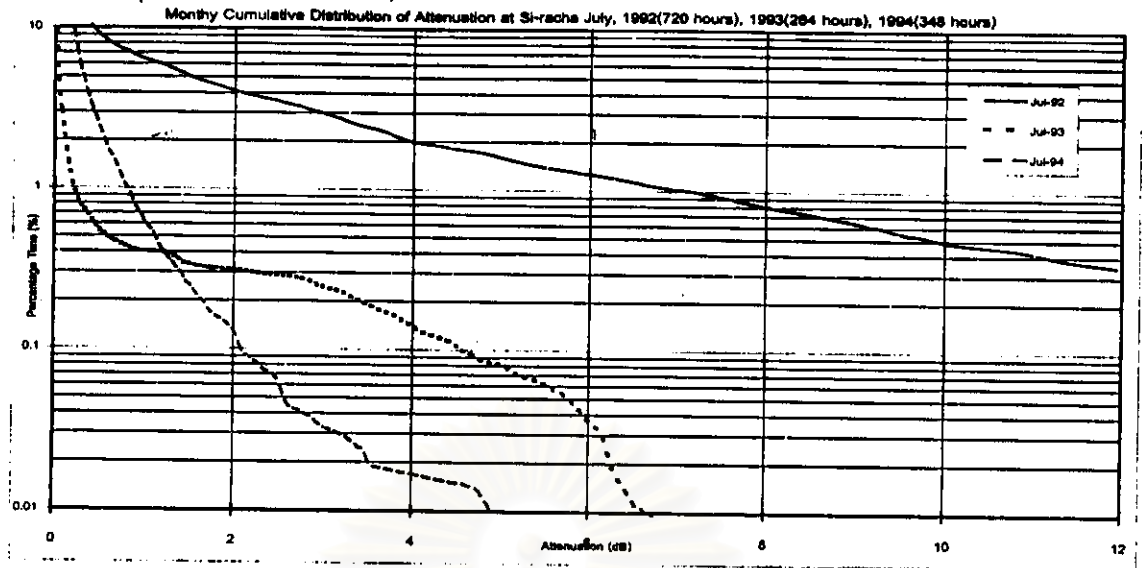
Monthly Cumulative Distribution of Attenuation at Bangkok December, 1992(717 hours), 1993(621 hours), 1994(No Data)

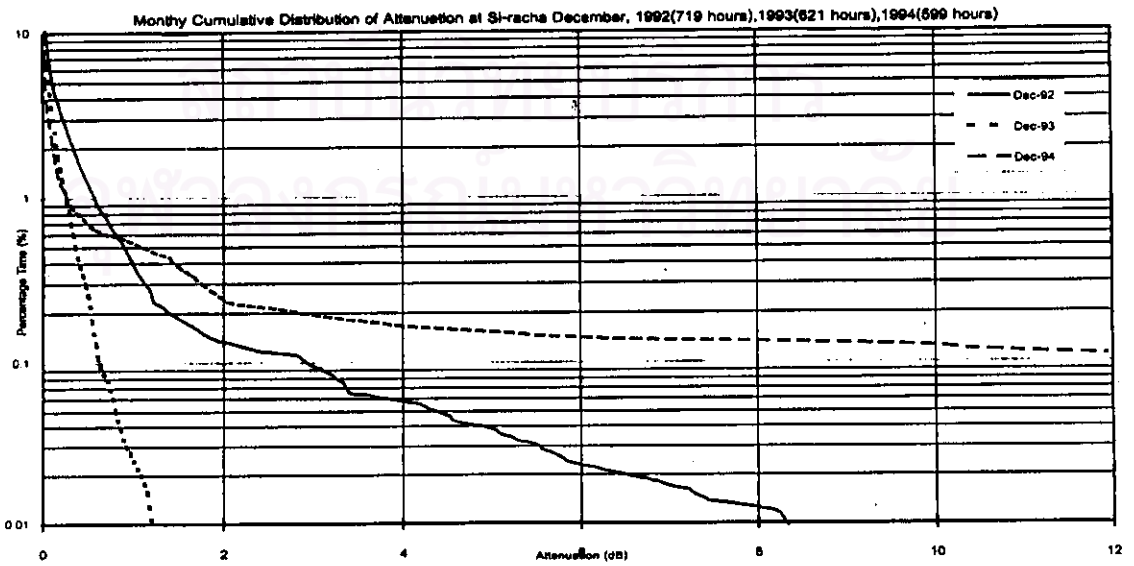
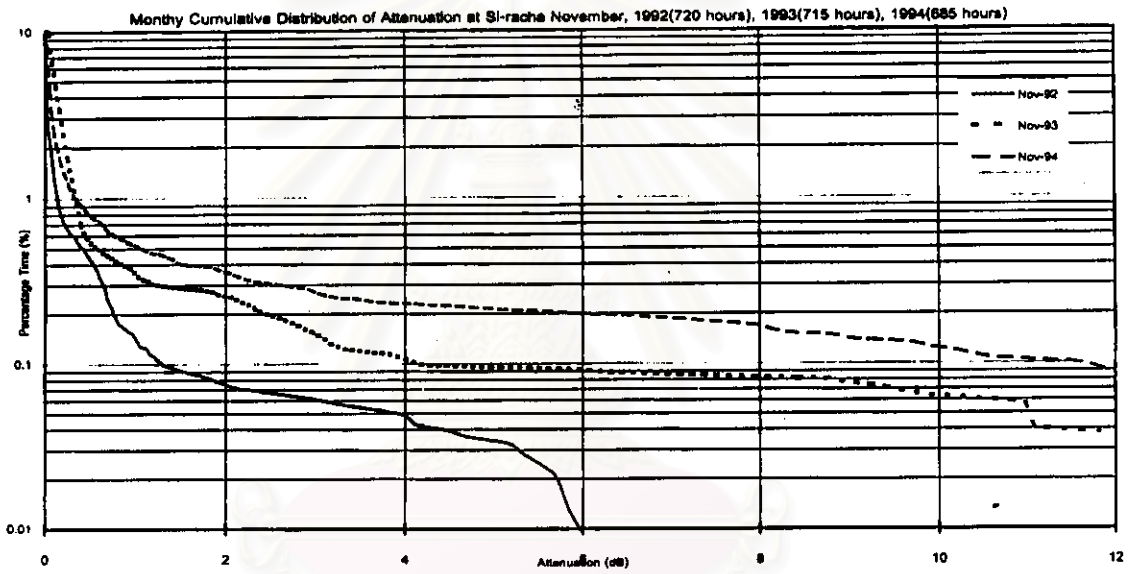
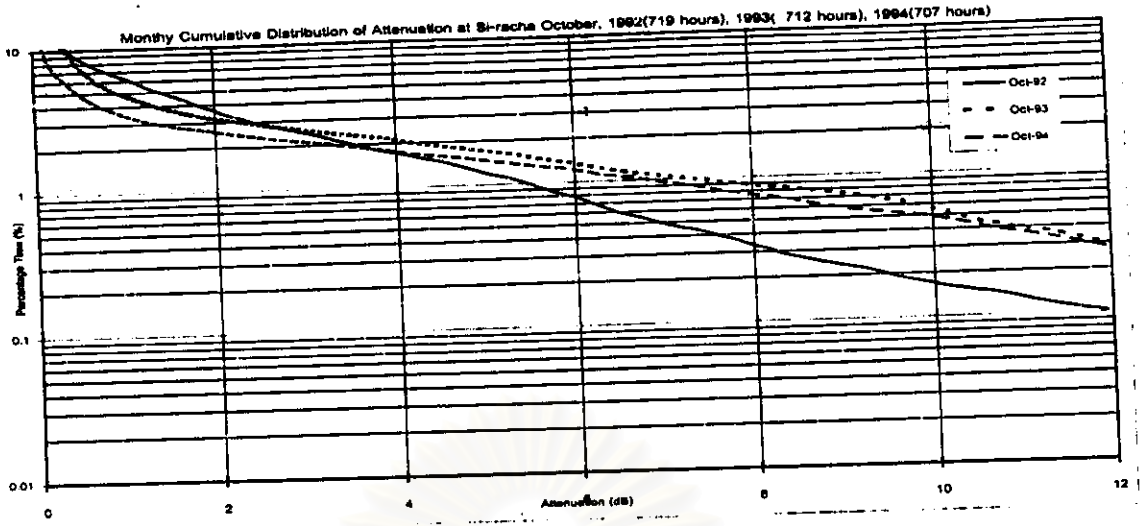


2. Si-racha, Attenuation Distribution 1/Mar/92 - 28/Feb./95, N. Yoothanorm et. al., [1997]

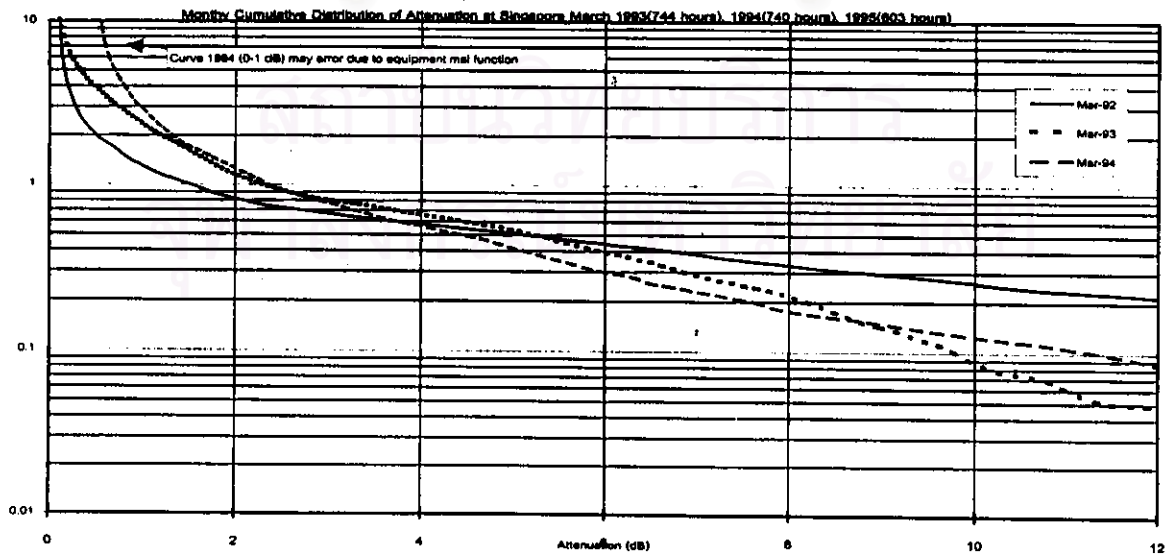
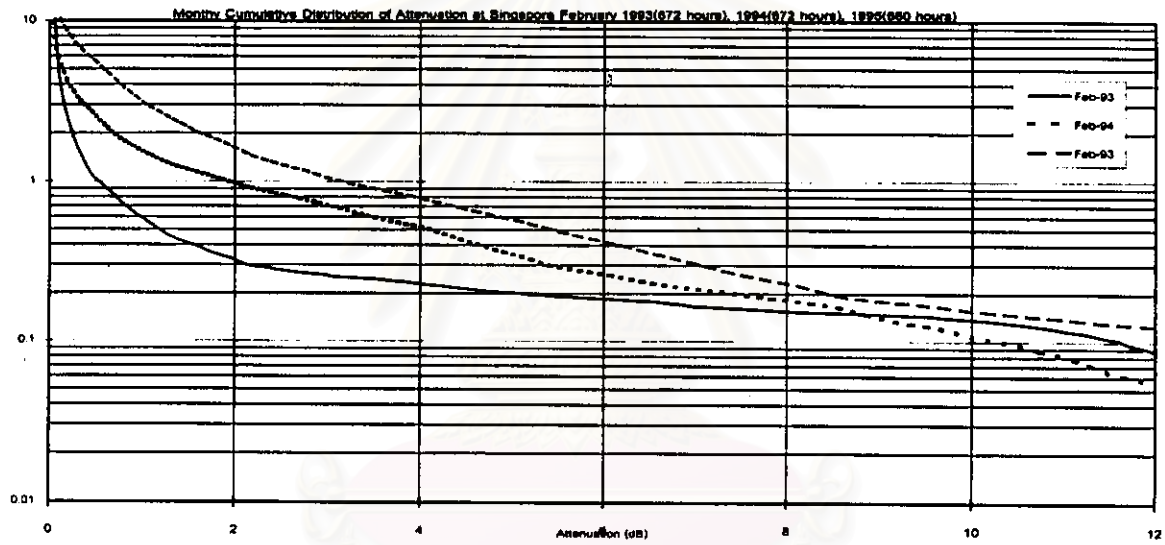
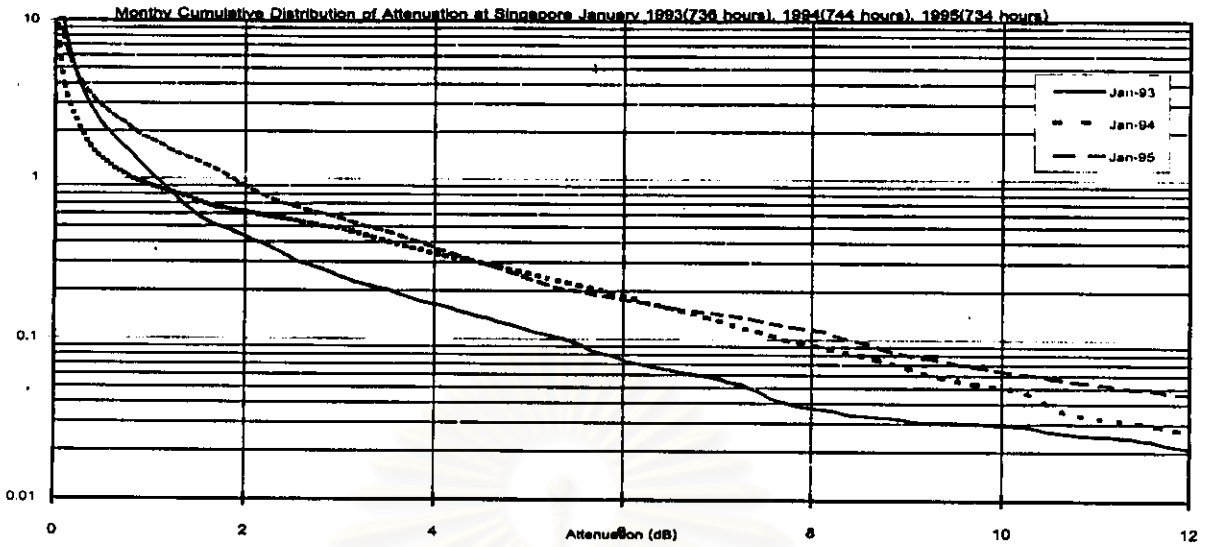


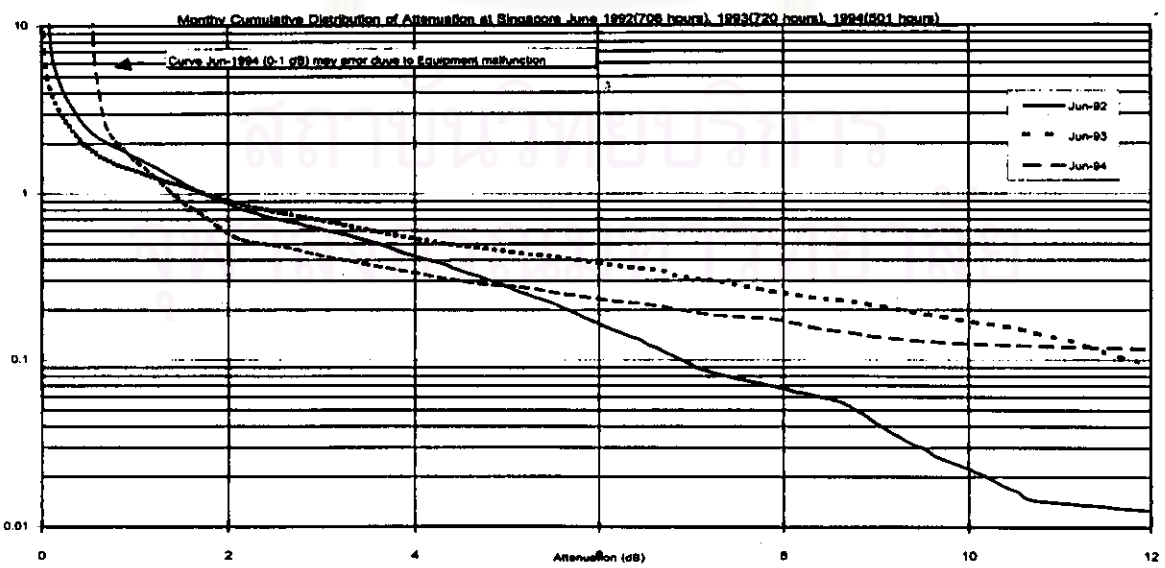
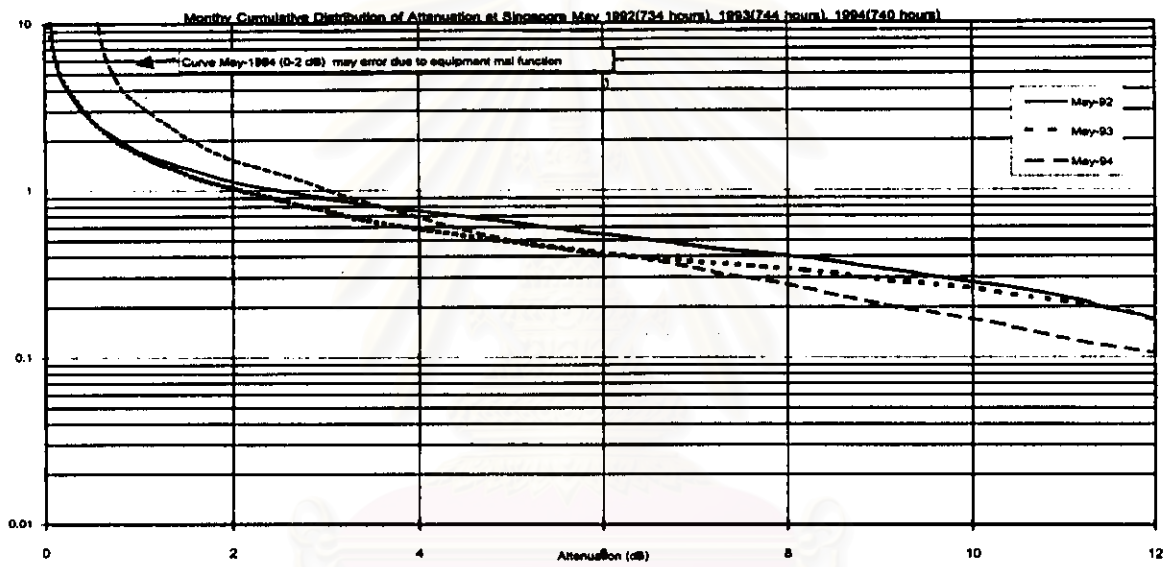
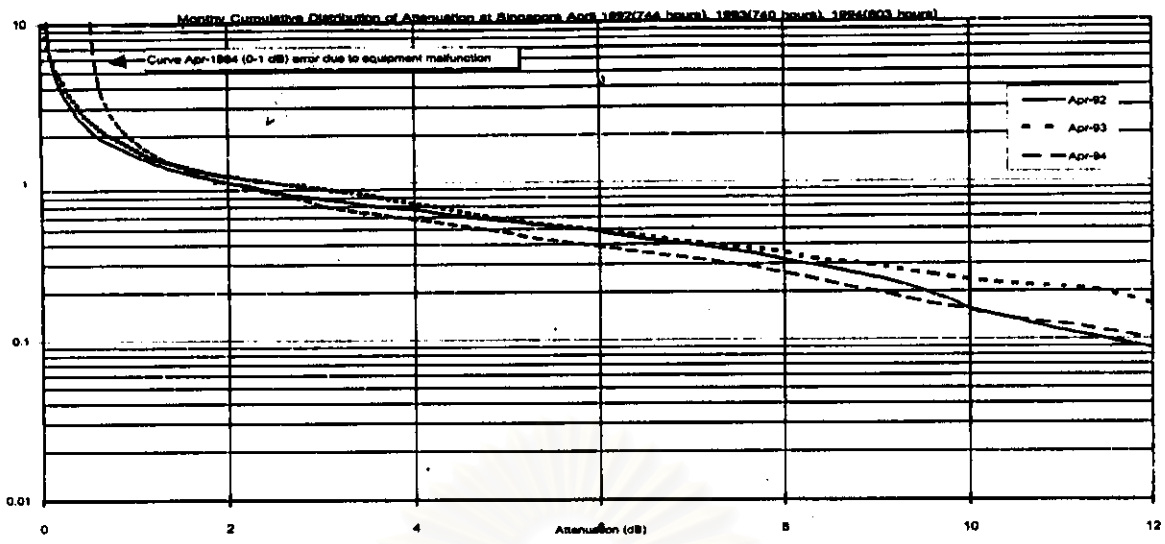




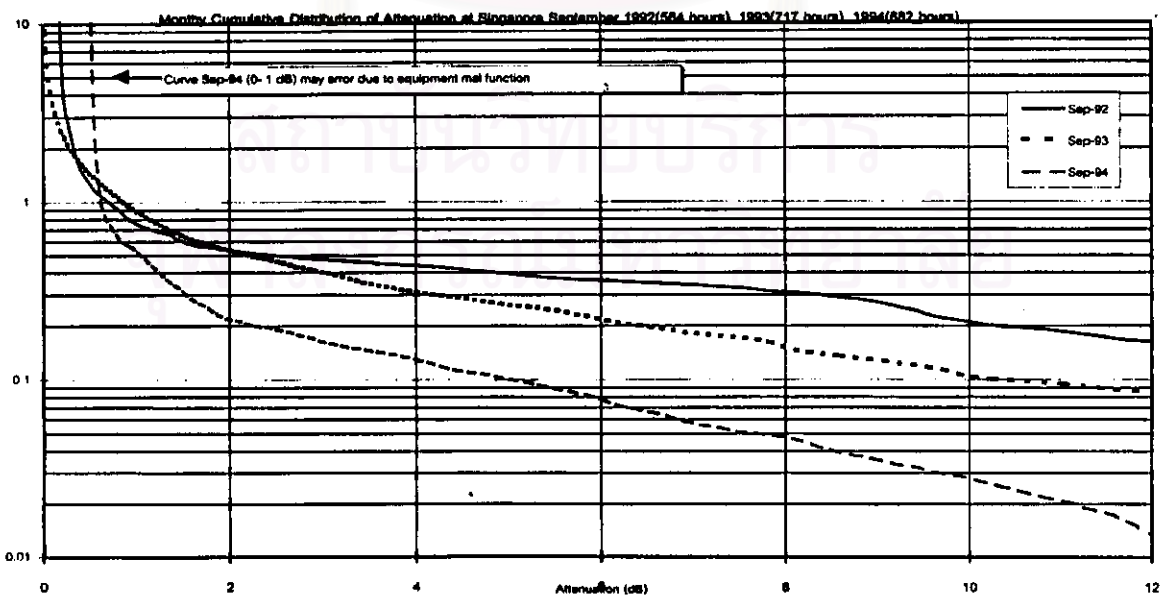
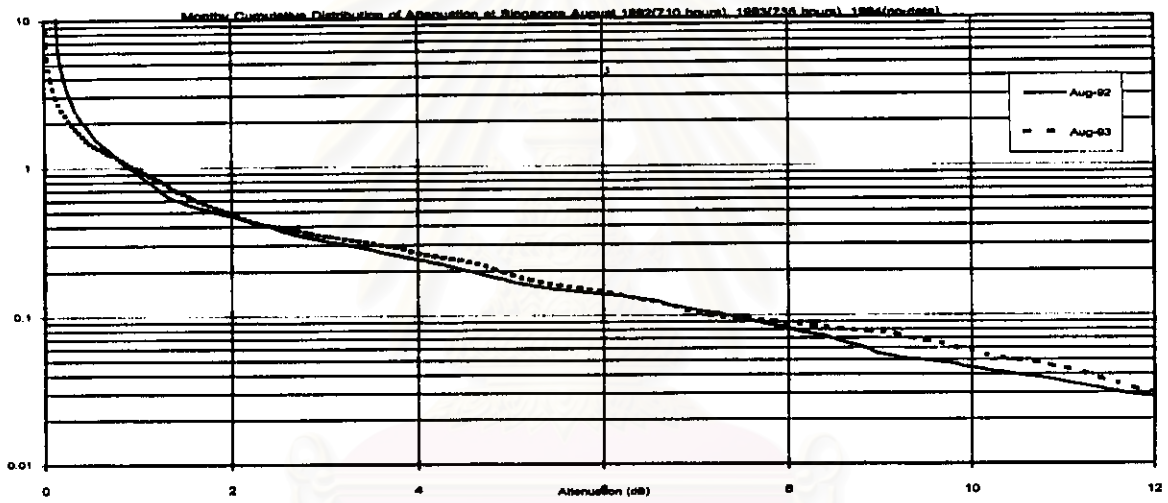
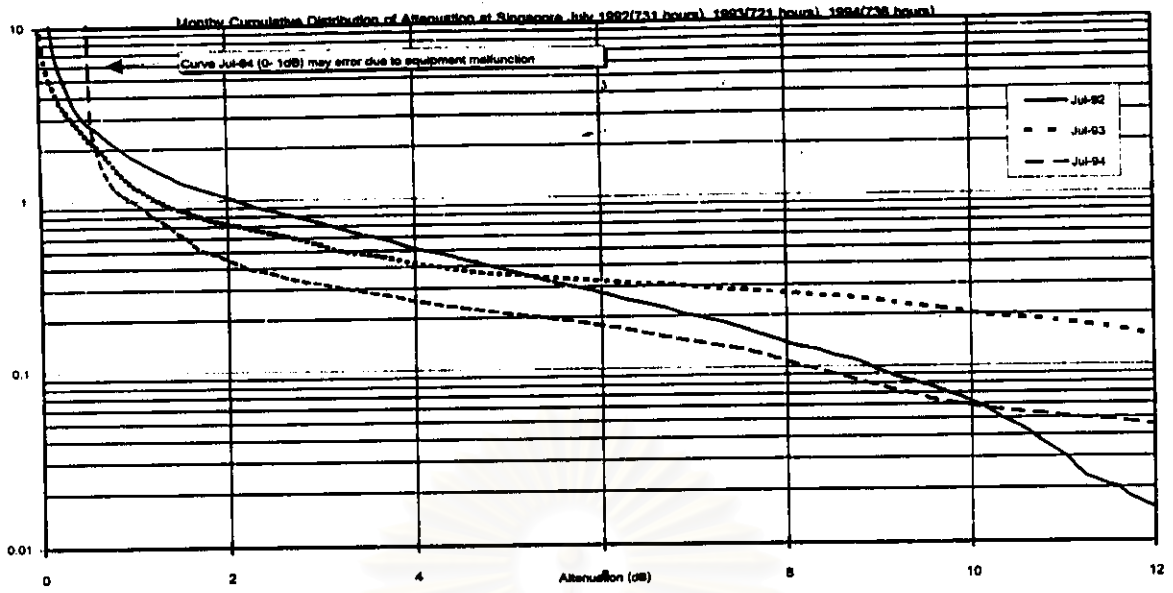


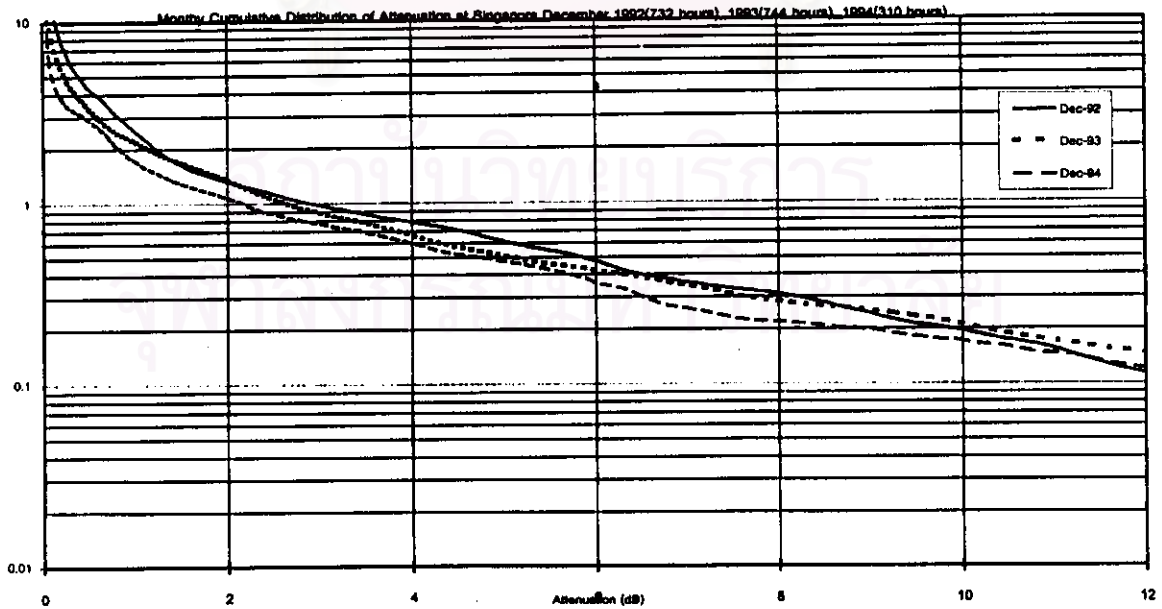
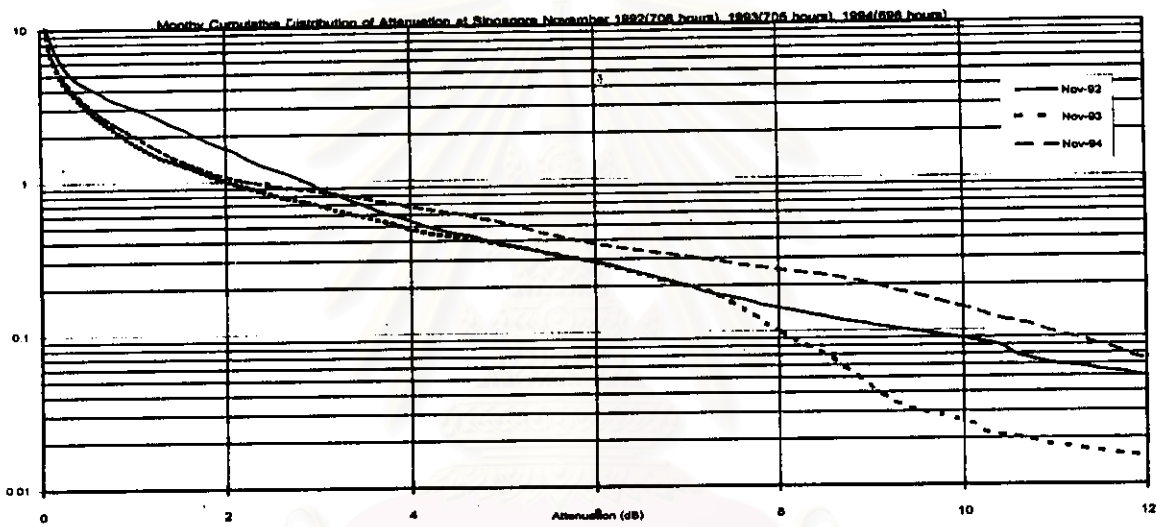
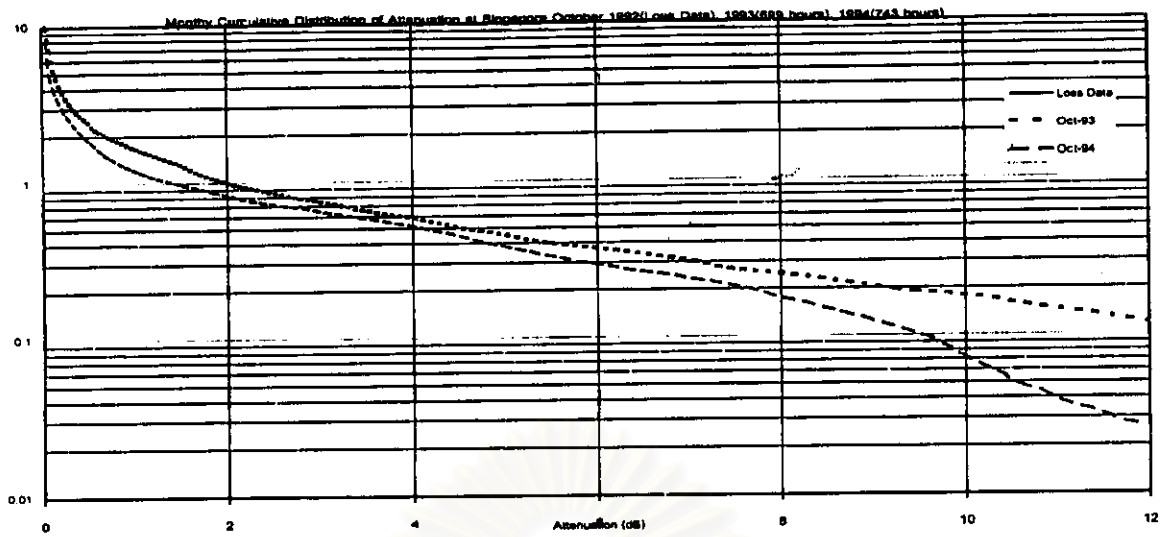
### 3. Singapore, Attenuation Distribution, 1/Mar/92- 28/Feb/95



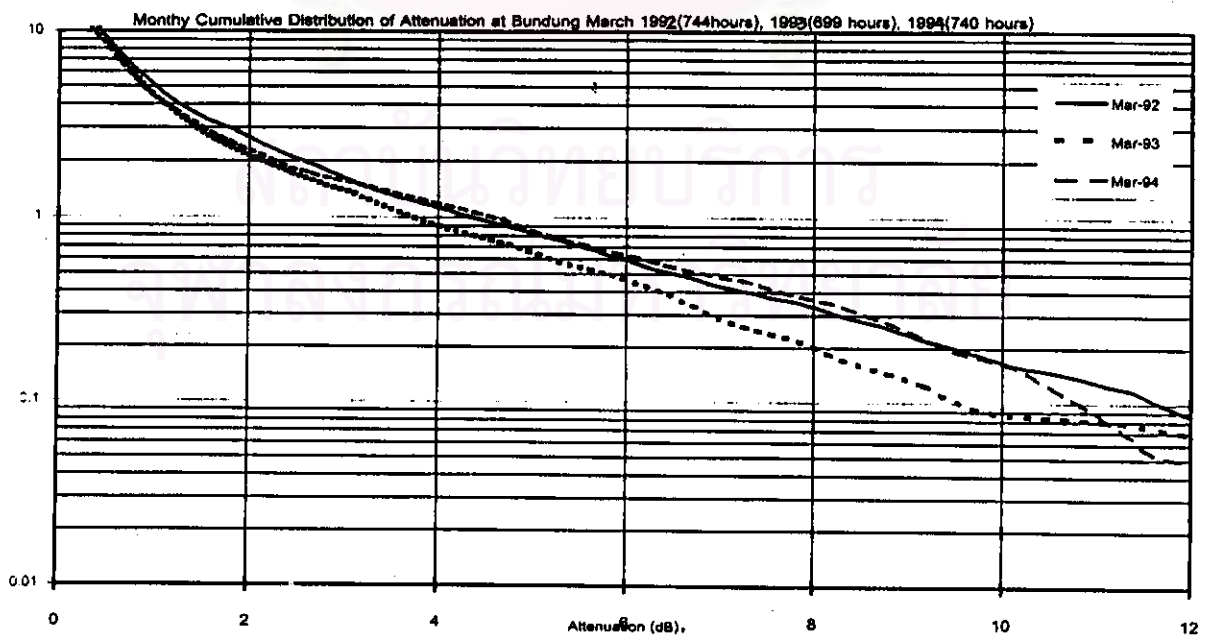
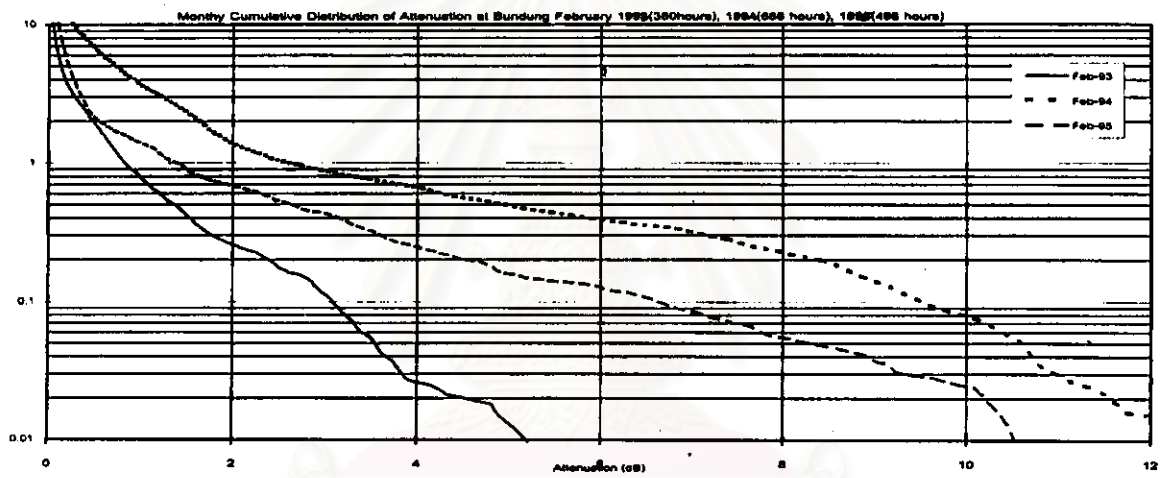
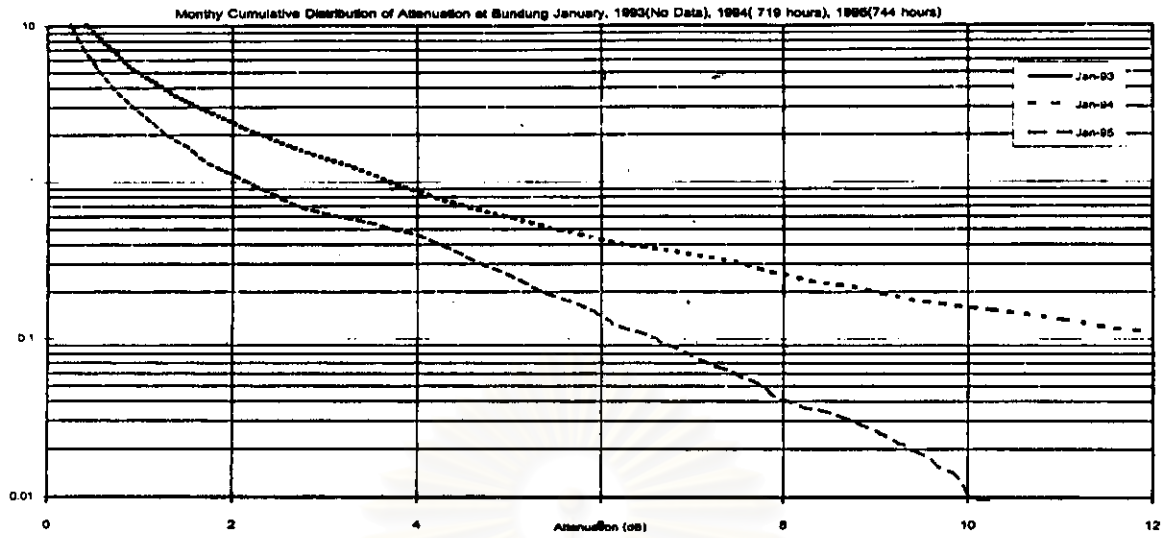


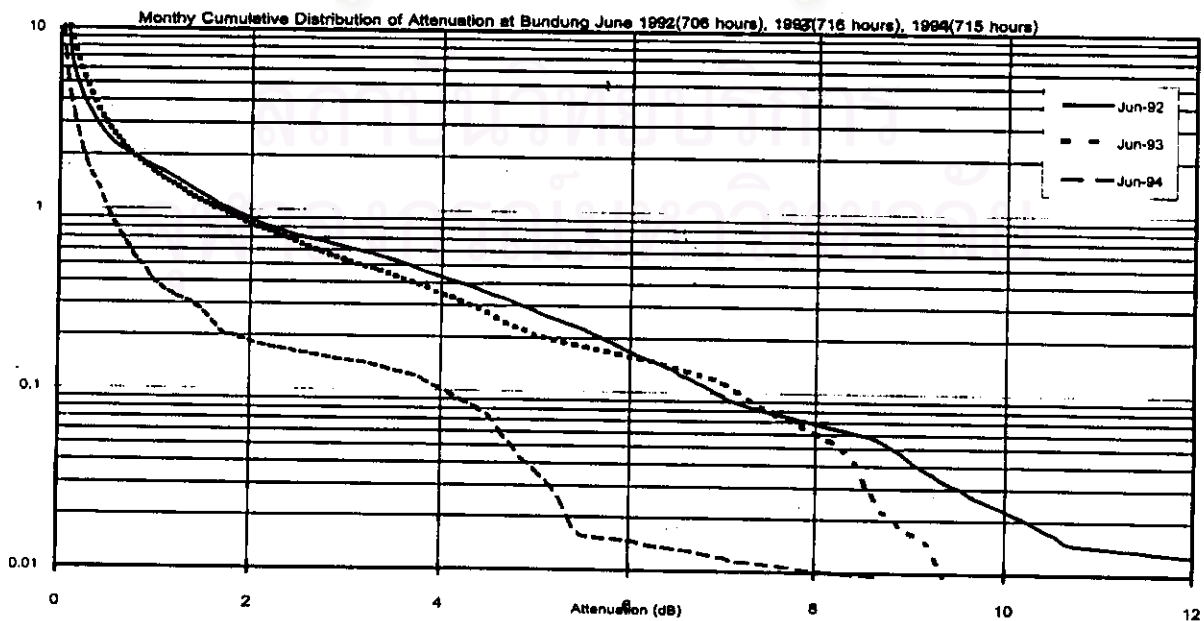
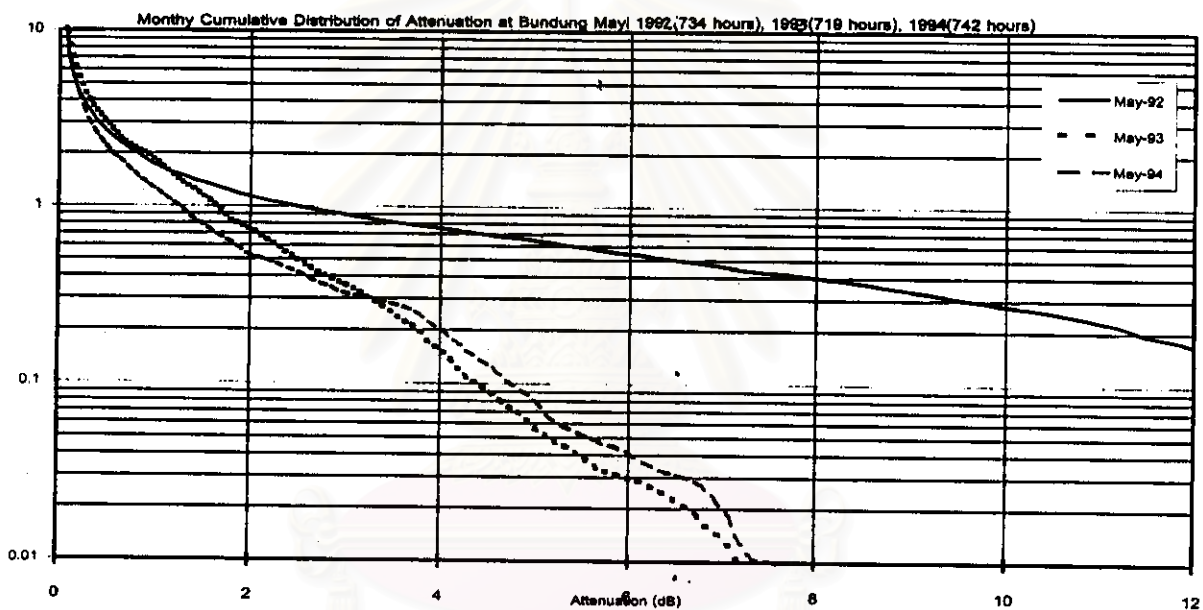
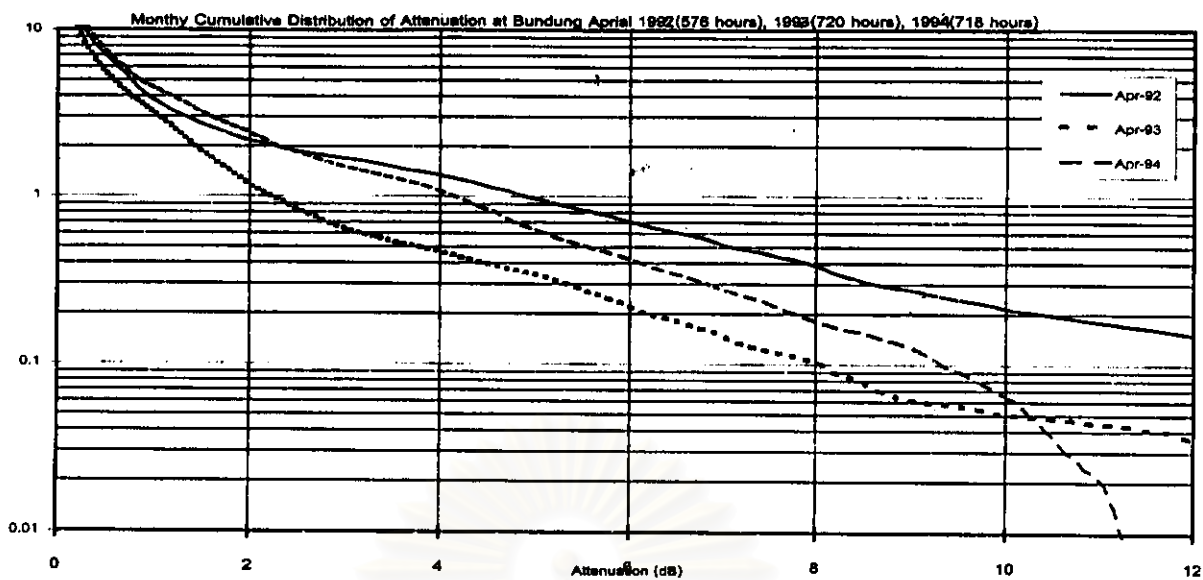


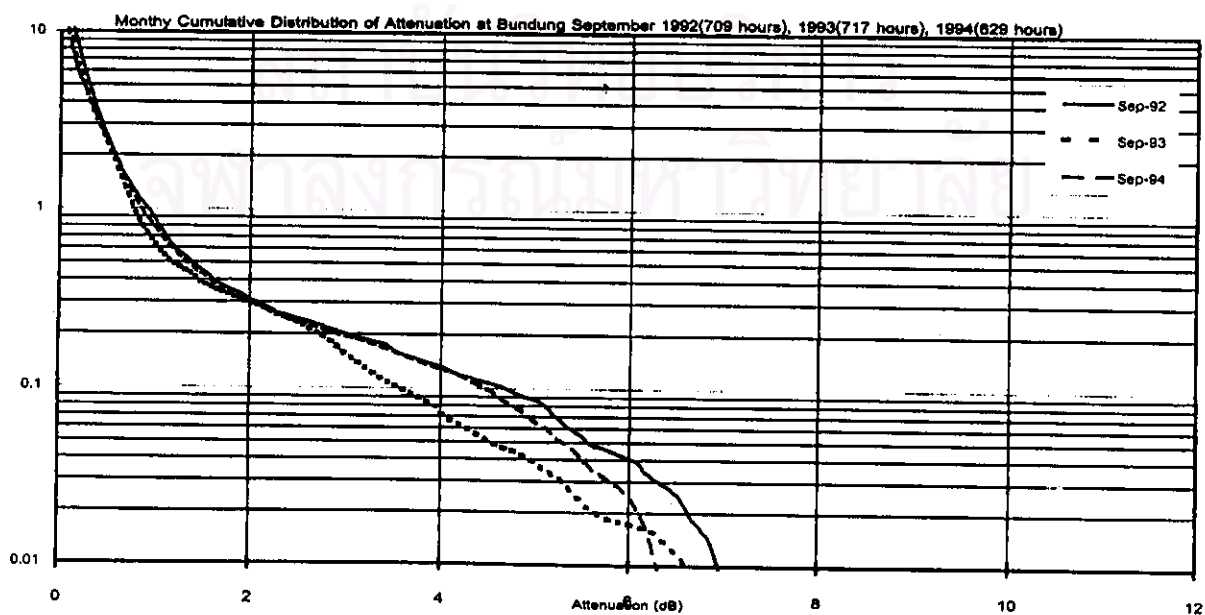
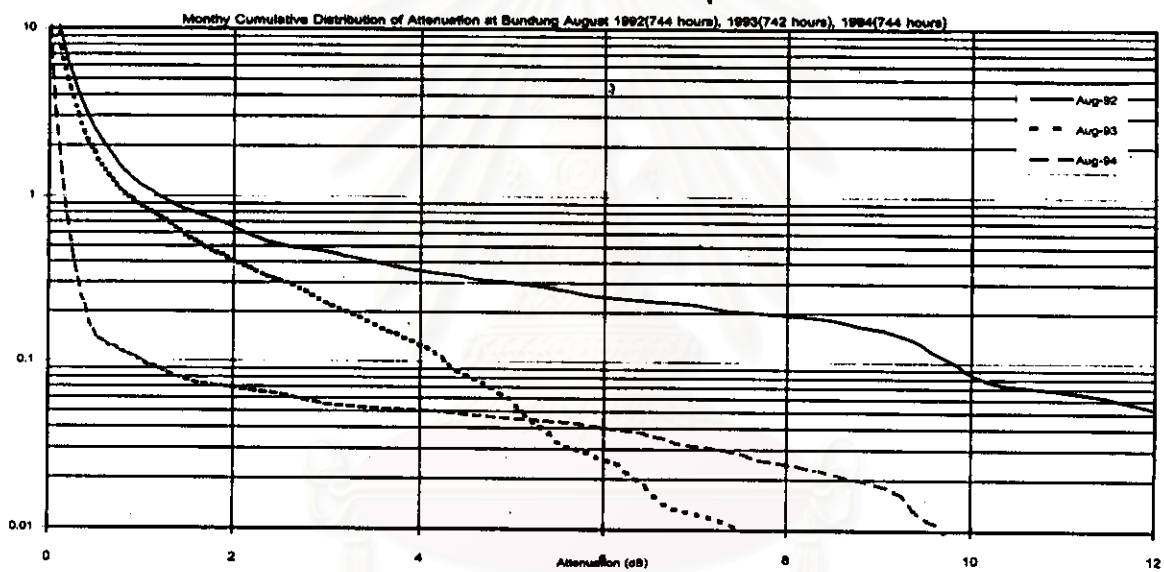
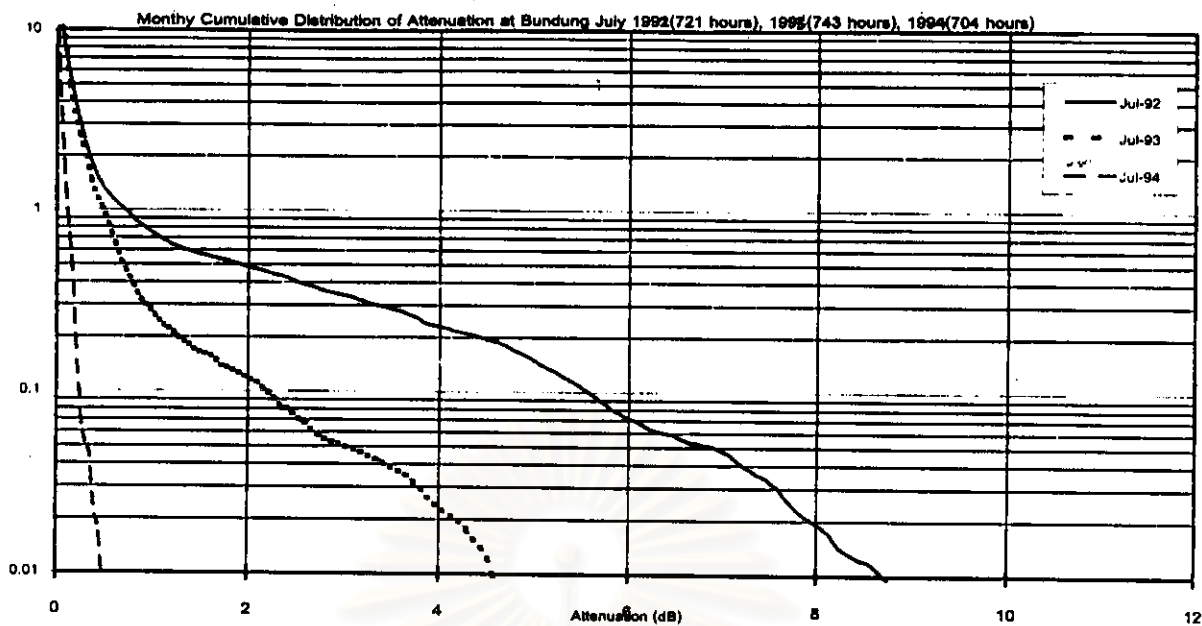




#### 4. Bundung; Attenuation Distribution, 1/Mar/92 - 28/Feb/95







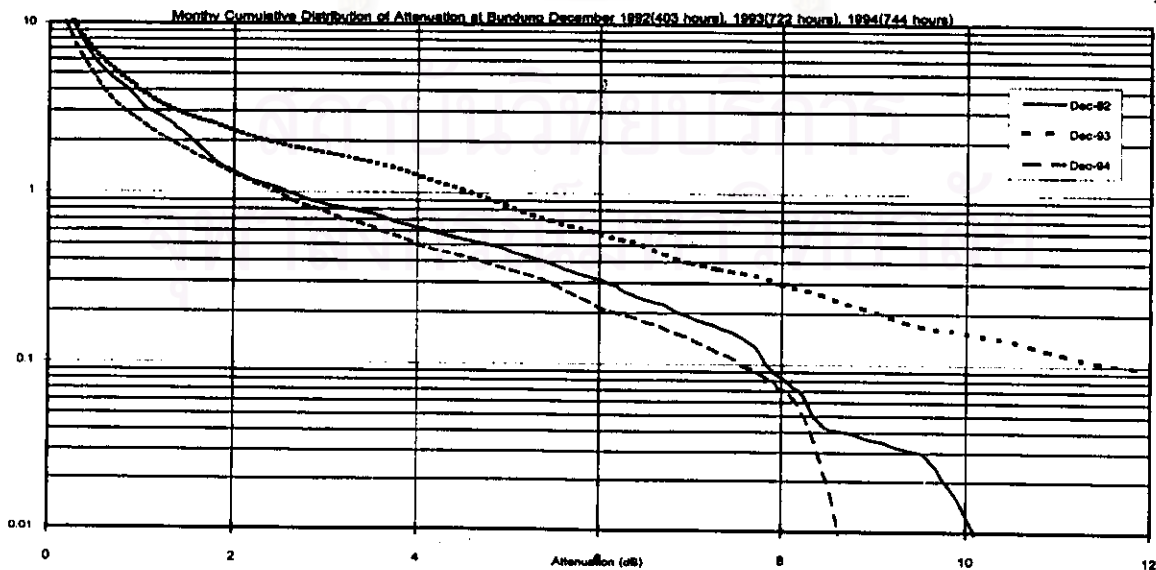
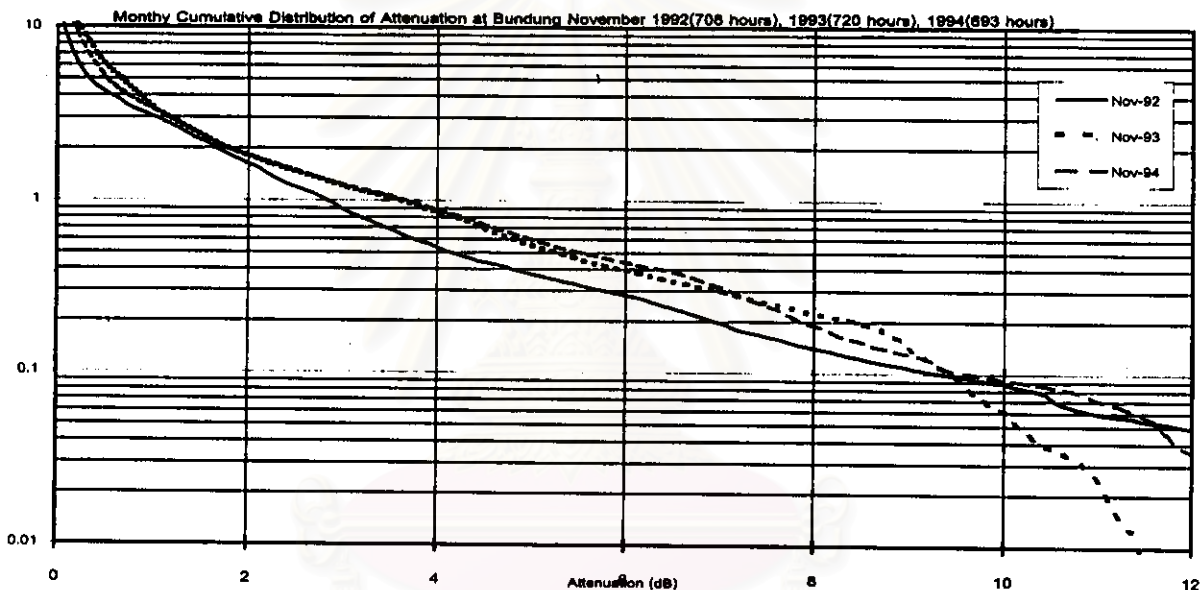
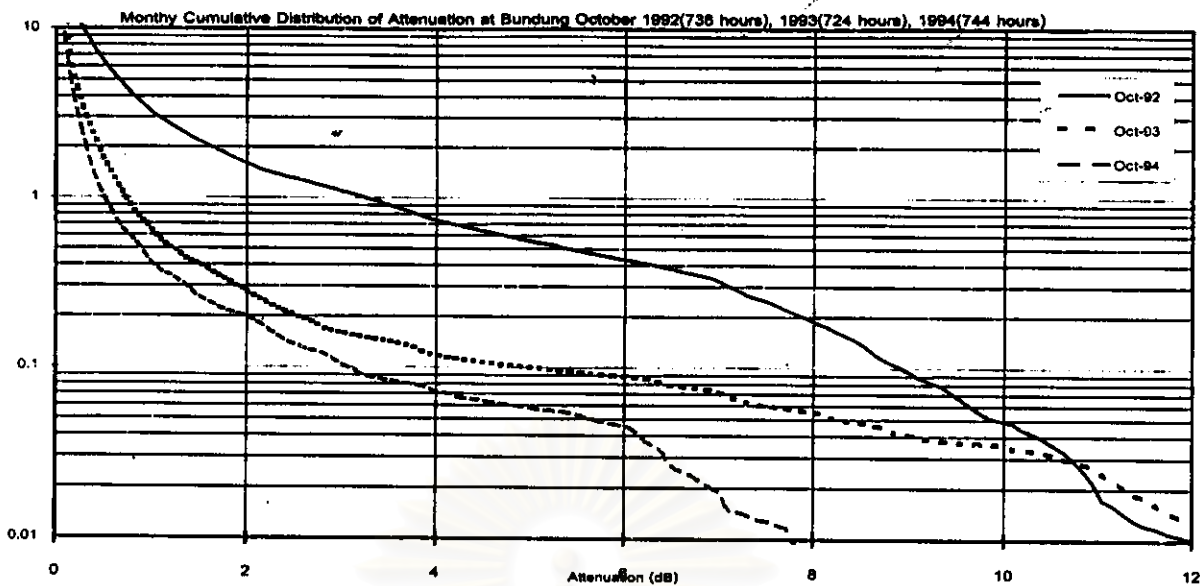


Table 1-1. Cumulative Statistic of Rain Attenuation at Bangkok, Thailand (1992-1995)

MM/YY	10%	5.0%	3.0%	2.0%	1.0%	0.50%	0.30%	0.20%	0.10%	0.050%	0.030%	0.020%	0.010%
Mar-92	0	0	0	0	0	0.08	0.1	0.12	0.15	0.18	0.27	0.31	0.35
Apr-92	0	0	0	0	0.12	0.21	0.3	0.39	0.88	1.54	2.33	3.8	4.27
May-92	0.07	0.28	0.79	1.3	3.64	5.95	7.54	8.6	10.26	11.07	11.42	11.54	-
Jun-92	0.32	0.77	1.49	2.35	4.15	6.98	9.13	10.75	13	-	-	-	-
Jul-92	0.53	1.49	2.95	4.11	6.77	9.06	10.36	10.96	11.93	-	-	-	-
Aug-92	0.43	1.34	2.74	4.17	7.21	10	12.21	-	-	-	-	-	-
Sep-92	0.19	1	2.35	3.97	7.16	10.65	-	-	-	-	-	-	-
Oct-92	0.1	0.43	1.54	2.58	5.49	7.95	9.66	10.75	12.07	-	-	-	-
Nov-92	0	0	0	0	0.22	0.3	0.36	0.42	0.74	1.13	1.23	1.33	1.42
Dec-92	0	0	0.25	0.4	0.8	1.09	1.33	1.47	0.1	2.56	3.44	4.15	8.35
Jan-93	0	0	0	0.2	0.52	0.92	1.41	1.84	2.67	3.97	4.78	5.31	5.71
Feb-93	0	0	0	0	0	0.12	0.15	0.15	0.17	0.2	0.25	0.27	0.34
Year-1	0.12	0.37	0.86	1.56	3.6	6.38	8.23	9.82	12.21	-	-	-	-
Mar-93	0.06	0.14	0.33	0.84	2.85	4.7	7.21	8.29	9.43	10.45	11.67	12.21	-
Apr-93	0.05	0.13	0.29	0.66	2.62	4.6	7.21	8.41	-	-	-	-	-
May-93	0.13	0.46	1.21	2.32	4.94	7.74	9.58	11.54	-	-	-	-	-
Jun-93	0.2	0.56	1.47	2.5	4.58	6.61	8.79	10.26	12	-	-	-	-
Jul-93	0.1	0.21	0.32	0.5	1.21	3.3	5.08	6.61	11.07	-	-	-	-
Aug-93	0.64	2.07	4.11	6.02	10.96	-	-	-	-	-	-	-	-
Sep-93	0.51	1.96	3.54	4.86	8.06	10.17	11.42	-	-	-	-	-	-
Oct-93	0.31	0.96	2.18	3.74	6.38	9.35	12.67	-	-	-	-	-	-
Nov-93	0	0	0	0	0.3	0.48	0.6	0.72	1.12	1.42	1.62	2.23	3.37
Dec-93	0	0	0	0	0.23	0.32	0.39	0.45	0.53	0.61	0.76	0.74	0.77
Jan-94	0	0	0	0	0	0	0	0	0.12	0.22	0.24	0.25	0.26
Feb-94	0	0	0	0	0.21	0.34	0.42	0.47	6.67	0.79	0.9	1.06	1.22
Year-2	0.13	0.37	0.94	1.8	4.13	7.07	9.43	11.3	-	-	-	-	-
Mar-94	0	0.13	0.23	0.48	1.88	4.58	6.77	8.66	10.86	-	-	-	-
Apr-94	Loss	Data	-	-	-	-	-	-	-	-	-	-	-
May-94	0.15	0.97	2.35	3.95	8.99	-	-	-	-	-	-	-	-
Jun-94	0.34	1.02	2.04	3	5.62	8.79	11.67	-	-	-	-	-	-
Jul-94	0.25	0.51	0.81	1.07	1.7	2.8	4.53	6.42	8.23	9.74	10.65	10.96	12.07
Aug-94	0.41	0.83	1.37	2.2	4.6	6.65	7.59	8.35	9.91	10.8	-	-	-
Sep-94	0.61	1.75	3.29	5.31	9.28	-	-	-	-	-	-	-	-
Oct-94	0.08	0.36	1.23	2.03	7.39	12.07	-	-	-	-	-	-	-
Nov-94	0	0	0	0.19	0.7	1.57	2.56	3.85	5.43	6.57	6.9	7.3	7.79
Dec-94	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan-95	0	0	0	0	0.17	0.66	2.03	3.18	5.25	6.49	7.12	7.54	8
Feb-95	0	0	0	0	0.1	0.34	0.65	1.06	1.24	1.67	2.27	2.41	2.6
Year-3	0.15	0.43	0.97	1.64	3.85	7.44	10.55	-	-	-	-	-	-
3-Years	0.15	0.43	1.02	1.83	4.13	7.26	9.67	11.67	-	-	-	-	-

Remark: The rows indicate the monthly names starting from March 1992 to February 1995. The columns show the measured rain attenuation exceeded the threshold at particular percentage time.

Table c-2, Cumulative Attenuation Distributions, Si-racha

Unit: dB

MM/YY	10%	5.0%	3.0%	2.0%	1.0%	0.50%	0.30%	0.20%	0.10%	0.050%	0.030%	0.020%	0.010%
Mar-92	0	0.15	0.2	0.27	0.44	0.62	0.86	2.35	6.98	8.86	9.82	10.45	10.96
Apr-92	0.16	0.21	0.28	0.42	1.3	5.46	9.74	10.96	11.67	-	-	-	-
May-92	0.23	0.56	1.33	2.13	4.46	7.4	8.92	10	12.67	-	-	-	-
Jun-92	0.34	0.8	1.79	3.15	5.59	7.3	8.53	9.82	12.21	-	-	-	-
Jul-92	0.41	1.51	2.97	3.97	7.16	10	-	-	-	-	-	-	-
Aug-92	0.42	1	1.72	2.95	6.9	10.96	-	-	-	-	-	-	-
Sep-92	0.14	0.49	1.06	1.58	3.18	7.4	9.28	11.42	-	-	-	-	-
Oct-92	0.38	1.4	2.39	3.5	5.46	6.9	8.23	9.43	12.07	-	-	-	-
Nov-92	0	0	0	0	0.13	0.42	0.64	0.75	1.29	3.91	5.25	5.68	5.95
Dec-92	0	0.1	0.22	0.34	0.56	0.9	1.13	1.4	2.9	4.36	5.52	6.5	8.3
Jan-93	0	0.15	0.26	0.39	0.97	2.3	3.37	3.93	5.14	7.03	9.06	10.45	-
Feb-93	0	0	0	0.16	0.36	0.52	0.7	0.96	1.83	2.87	3.18	3.42	3.7
Year-1	0.17	0.4	0.87	1.52	3.46	6.12	8.29	9.91	-	-	-	-	-
Mar-93	0.16	0.51	1.42	2.79	5.46	10.17	12.07	13.18	-	-	-	-	-
Apr-93	Loss Data		-	-	-	-	-	-	-	-	-	-	-
May-93	Loss Data		-	-	-	-	-	-	-	-	-	-	-
Jun-93	Loss Data		-	-	-	-	-	-	-	-	-	-	-
Jul-93	0	0	0	0.11	0.21	0.57	2.24	3.41	4.56	5.75	6.12	6.23	6.61
Aug-93	0.3	0.94	1.73	2.38	4.38	7.54	10.26	11.67	-	-	-	-	-
Sep-93	0.57	1.67	3.02	4.48	7.85	11.8	-	-	-	-	-	-	-
Oct-93	0.34	0.92	2.26	4.2	7.25	10.26	11.93	-	-	-	-	-	-
Nov-93	0	0	0	0	0.33	0.59	1.27	2.4	4.15	10.96	12.51	-	-
Dec-93	0	0	0.11	0.16	0.25	0.36	0.46	0.52	0.61	0.8	0.92	1.09	1.2
Jan-94	0	0	0	0	0.15	0.2	0.25	0.27	0.32	0.39	0.42	0.54	0.74
Feb-94			0.2	0.33	0.84	2.21	3.6	5.08	12.7	-	-	-	-
Year-2	0.13	0.36	0.5	1.52	3.54	6.42	9.43	11.3	-	-	-	-	-
Mar-94	0.16	0.59	1.26	0.09	4.97	8.35	10.45	12.67	-	-	-	-	-
Apr-94	0	0.3	0.71	1.46	3.85	6.77	8.79	10.96	-	-	-	-	-
May-94	0.2	0.83	1.88	3	5.43	7.35	9.06	12.36	-	-	-	-	-
Jun-94	0.28	0.69	1.47	2.27	4.13	7.25	9.5	11.3	-	-	-	-	-
Jul-94	0.2	0.31	0.43	0.55	0.8	1.12	1.39	1.64	2.07	2.56	3.16	3.5	4.86
Aug-94	0.24	0.44	0.77	1.36	2.87	4.81	7.12	10	-	-	-	-	-
Sep-94	0.36	1.28	2.32	3.56	8.41	16.2	-	-	-	-	-	-	-
Oct-94	0.1	0.49	1.36	3.31	6.81	9.91	11.67	-	-	-	-	-	-
Nov-94	0	0	0	0.13	0.34	1.1	2.61	5.95	11.54	-	-	-	-
Dec-94	0	0	0	0.1	0.26	1.11	1.75	2.85	-	-	-	-	-
Jan-95	0	0	0.32	0.53	1.63	6.34	8.53	10.86	-	-	-	-	-
Feb-95	0	0	0.13	0.21	0.55	1.12	1.66	2.47	4.65	9.35	11.2	11.42	12
Year-3	0.15	0.4	0.85	1.56	3.66	7.03	9.74	11.93	-	-	-	-	-
3-Years	0.15	0.38	0.74	1.53	3.55	6.52	9.15	11.04	-	-	-	-	-

Remark: The rows indicate the monthly names starting from March 1992 to February 1995. The columns show the measured rain attenuation exceeded the threshold at particular percentage time.



Table 4-3, Cumulative Attenuation Distributions, Singapore

MYY	Remark:										Data May Error		Unit: dB
	10.0%	5.0%	3.00%	2.00%	1.00%	0.50%	0.30%	0.20%	0.10%	0.050%	0.030%	0.020%	0.010%
Mar-92	0.1	0.17	0.27	0.5	1.51	5.12	8.84	12.54					
Apr-92	0	0.162	0.348	0.6	2.02	5.86	8.24	9.53	11.48				
May-92	0	0.16	0.402	0.815	2.5	6.51	9.6	11.36	13.74				
Jun-92	0	0.18	0.37	0.716	1.74	3.6	4.8	5.7	6.9	8.7	9.45	10.17	
Jul-92	0.13	0.27	0.46	0.86	2	4	5.73	7	8.9	10.4			
Aug-92	0	0.18	0.28	0.411	0.9	1.83	3.25	4.54	7.34	9.53	11.6	12.85	
Sep-92	0.181	0.2	0.26	0.33	0.7	9.2	8.4	10					
Oct-92				Loss Data									
Nov-92	0	0.33	1	1.67	2.87	4.2	5.8	7	9.45	12			
Dec-92	0	0.4	0.78	1.28	3	6	8.4	10	12.1				
Jan-93	0	0.2	0.36	0.56	1	1.73	2.57	3.54	5.37	7.34	10		
Feb-93	0	0.1	0.14	0.24	0.52	1.18	2.12	5.1	11.6	12.25			
Mar-93	0.144	0.2	0.384	0.73	1.73	4	6.26	6.35	11.5				
Apr-93	0.1	0.33	0.735	1.19	2.27	5.26	6.87	8.18	9.76	11.6			
May-93	0	0.18	0.41	0.745	2.5	5.92	8.83	11.36					
Jun-93	0	0	0.2	0.45	1.76	4.37	7.25	9.24	11.85				
Jul-93	0	0.11	0.34	0.62	1.25	3.21	6.9	10					
Aug-93	0	0	0.12	0.26	0.94	1.97	3.6	4.9	7.16	10.53	12		
Sep-93	0	0	0.136	0.285	0.85	2.22	4.24	6.5	10.45				
Oct-93	0	0.136	0.34	0.7	2	4.5	7	9.167					
Nov-93	0	0.2	0.51	0.9	2	3.92	5.82	7	9.4	12			
Dec-93	0	0.23	0.6	1.15	2.59	5.12	7.6	10.17					
Jan-94	0	0	0.14	0.28	1.06	2.87	4.46	5.8	7.72	10.08	11.48		
Feb-94	0	0.14	0.38	0.67	1.93	4.1	5.4	7.43	10.28	12.25			
Mar-94	0.04	0.13	0.35	0.67	1.77	4	8.4	8.35	11.6				
Apr-94	0.55	0.7	0.97	1.32	2.36	4.42	6	7.6	11.36				
May-94	0.5	0.6	0.76	0.93	2.02	4.76	7.47	9.37	11.57				
Jun-94	0.57	0.72	1.1	1.57	3	5	7.52	9.1	12.5				
Jul-94	0.55	0.59	0.66	0.82	1.4	2.4	4.5	6.9					
Aug-94	0	0	0.52	0.4	0.98	1.79	3.3	5.37	8.2	11.14			
Sep-94			Loss Data										
Oct-94	0	0	0	0.5	0.62	1	1.54	2.29	5	7.8	9.7	11.14	
Nov-94	0	0	0.21	0.45	1.44	4.13	5.86	7.7	9.45	10.53	11.6		
Dec-94	0	0.2	0.51	0.9	2	3.92	5.9	7.3	8	8.8	9.4	10.8	
Jan-95	0	0.1	0.45	0.83	2.18	4.78	6.5	8.9					
Feb-95	0	0.2	0.46	0.84	1.87	3.29	4.49	5.52	8.4	11.36			
Mar-95	0.1	0.57	1	1.6	3.16	5.46	7.07	8.4	12.85				
Apr-95	0.54	0.58	0.73	1.05	2.05	4.24	6.23	8	10.93				
May-95	0.5	0.54	0.59	0.84	1.87	4.1	6.3	8.2	11.98				

Remark: The rows indicate the monthly names starting from March 1992 to February 1995. The columns show the measured rain attenuation exceeded the threshold at particular percentage time.

Table C-4. Cumulative Attenuation Distributions of Bundung

Unit: dB

MM/YY	10.0%	5.0%	3.00%	2.00%	1.00%	0.50%	0.30%	0.20%	0.10%	0.050%	0.030%	0.020%	0.010%
Mar-92	0.44	1	1.78	2.57	4.35	6.51	8.24	9.45	11.6				
Apr-92	0.28	0.77	1.34	2.27	4.9	7.07	8.65	10.35					
May-92	0	0.17	0.4	0.82	2.5	6.52	9.6	11.36					
Jun-92	0	0.18	0.38	0.75	1.78	3.68	4.85	5.73	6.9	8.8	9.52	10.26	
Jul-92	0	0.16	0.25	0.34	0.76	1.92	3.34	4.42	5.57	6.9	7.57	7.9	
Aug-92	0.12	0.28	0.43	0.62	1.19	2.58	5	7.7	9.75	12.1			
Sep-92	0.144	0.3	0.44	0.57	0.9	1.38	2.06	3.01	4.68	5.54	6.3	6.63	6.95
Oct-92	0.28	0.67	1	1.62	3.25	5.4	7.1	7.86	8.9	9.9	10.63	10.93	12.11
Nov-92	0	0.32	1.02	1.64	2.76	4.13	5.76	6.95	9.3	11.85			
Dec-92	0.26	0.63	1	1.55	2.58	4.78	6.02	6.9	7.8	8.35	9.45	10	
Jan-93	Loss Data												
Feb-93	0.14	0.36	0.61	0.8	1.32	1.98	2.7	3	3.52	4	4.89	5.17	5.43
Mar-93	0.17	0.44	0.82	1.14	2.5	4.7	6.3	7.5	9.45	11.6	12.85		
Apr-93	0.21	0.6	1	1.43	2.22	3.8	5.34	6.2	8	10.1	12.4		
May-93	0	0.23	0.5	0.9	1.64	2.5	3.27	3.75	4.4	5.17	6		
Jun-93	0.1	0.28	0.47	0.75	1.7	3.15	4.33	5.12	7.2	8.3	8.6	8.8	
Jul-93	0	0.14	0.21	0.29	0.49	0.68	0.94	1.27	2.2	3	3.8	4.2	
Aug-93	0	0.2	0.33	0.45	0.86	1.67	6.57	10.21	4.28	5.12	5.7	6.4	7.43
Sep-93	0.127	0.25	0.4	0.54	0.78	1.18	2	2.7	3.56	4.51	5.28	5.67	7.25
Oct-93	0.12	0.2	0.32	0.45	0.73	1.23	1.9	2.5	5	8.3	10.63	11.25	
Nov-93	0.2	0.66	1.16	1.78	3.6	5.3	7	8.4	9.45	10.17	10.93	11.5	12
Dec-93	0.26	0.74	1.38	2.37	4.6	6.4	7.9	9	11.72				
Jan-94	0.43	1	1.63	2.32	3.72	5.52	7.57	9	12.54				
Feb-94	0.27	0.74	1.25	1.64	2.61	4.95	7.16	8.4	9.53	10.6	11	11.6	
Mar-94	0.17	0.45	0.8	1.22	2.28	3.92	5.2	6.44	8.4	10.08	11.72		
Apr-94	0.37	0.88	1.53	2.26	4.58	6.87	8.52	9.38	10.73	11.85			
May-94	0.33	0.86	1.6	2.31	4.15	5.55	6.82	7.76	9.37	10.26	10.63	11.85	
Jun-94	0	0.17	0.32	0.5	1.26	2.14	3.29	4	4.76	6.6	6.7	7	8.9
Jul-94	0	0	0.1	0.25	0.5	0.86	1.4	1.82	4	4.76	5.17	5.34	8.53
Aug-94	0	0	0	0.11	0.17	0.25	0.33	0.42	2	4.3	7.34	8.83	10.26
Sep-94	0	0.24	0.41	0.57	0.86	1.32	2.08	2.93	4.46	5.29	5.8	6	6.3
Oct-94	0	0.153	0.24	0.312	0.5	0.89	1.37	2	3.07	5.67	6.4	6.9	8.46
Nov-94	0.18	0.5	1.16	1.76	3.65	5.5	7.12	7.86	9.6	11.4	12.25	12.85	13.7
Dec-94	0.18	0.47	0.82	1.3	2.46	4	5.43	5.05	7.52	8.24	8.9		
Jan-95	0.25	0.57	0.93	1.3	2.17	3.74	4.7	5.37	6.6	7.8	8.77	9.38	10.17
Feb-95	0.14	0.3	0.48	0.95	1.8	3.27	4.33	5.34	7.39	9	10.17		
Mar-95	0.12	0.32	0.6	0.95	1.88	3.58	4.78	5.8	7.6	9	10.08	10.73	11.6
Years	0.15	0.4	0.74	1.13	2.2	4	5.4	5.63	6.47	10.17	11.6	12.7	

Remark: The rows indicate the monthly names starting from March 1992 to February 1995. The columns show the measured rain attenuation exceeded the threshold at particular percentage time.

## Estimation of Log-normal Distribution Parameters of Rain Attenuation Distribution

The fitted log-normal distribution of the measured rain attenuation is given in equation (5.3)

$$P(A \geq \alpha) = F(\alpha) \quad \text{-----} \quad (B1)$$

$$= F(\ln(a)) \quad \text{-----} \quad (B2)$$

$$= [1/(\sigma\sqrt{2\pi})] \int_{\ln(a)}^{\infty} \exp[-(x-m)^2/2\sigma^2] dx \quad \text{-----} \quad (B3)$$

where  $m$  (mean) and  $\sigma$  (standard deviation) are unknown parameters that we need to find

$$P(A \geq \alpha) = Q((\ln(a) - m)/\sigma) \quad \text{-----} \quad (B4)$$

$$= 1/2\pi \int_{(\ln(a) - m)/\sigma}^{\infty} \exp(-x^2/2) dx \quad \text{-----} \quad (B5)$$

so that

$$Q^{-1}(F(\alpha)) = (\ln(a) - m)/\sigma \quad \text{-----} \quad (B6)$$

If the random variable "a" was log-normal, the the linear relation can be expressed as:

$$Q^{-1}(F(\alpha)) = X \ln(a) + Y \quad \text{-----} \quad (B7)$$

The slope  $X$  and intercept  $Y$  can be obtained by linear regression analysis of data pair.

Equation (B6) and (B7) are combined as:

$$(\ln(a) - m)/\sigma = X \ln(a) + Y \quad \text{-----} \quad (B8)$$

From equation (B8), we can obtain the mean ( $m$ ) and standard deviation ( $\sigma$ ) from

$$m = -Y/X, \quad \sigma = 1/X \quad \text{-----} \quad (B9)$$

Result of the parameters ( $m$ ,  $\sigma$ ) for the log-normal that is reasonable fit to the measured value in Bangkok, Si-racha, Singapore, and Bundung are shown blows:

Site Name	mean (dB)	Standard Deviation ( $\sigma$ )
Bangkok	-3.7	2.2
Si-racha	-3.7	2.15
Singapore	-4.2	2.2
Bundung	-4.0	2.0

## APPENDIX - D

Diurnal Variation of 12 GHz Rain Attenuation in Thailand

Bangkok, 1/Mar/92 - 28/Feb/93 (Year -1) Available Data = 89%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.	Total (Sec)
2 dB	19840	13882	13418	33216	30560	68884	63422	69030	62958	49038	27614	22480	19840	474320
4 dB	10400	6854	7202	18472	17278	45086	31134	32958	32798	28982	10368	10518	10400	252050
6 dB	6156	4456	4268	11642	11984	28538	21110	17382	17676	18326	5134	7252	6156	153902
8 dB	1628	2854	1826	6380	6260	16388	16376	9704	10188	14590	1498	3772	1628	91442
10 dB	448	1648	1138	2214	3258	9504	10768	6380	5818	11244	456	2100	448	54972
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)
2 dB	4.18%	2.93%	2.83%	7.00%	6.44%	14.52%	13.37%	14.55%	13.27%	10.34%	5.82%	4.74%	4.18%	100.00%
4 dB	4.13%	2.72%	2.86%	7.33%	6.85%	17.89%	12.35%	13.08%	13.01%	11.50%	4.11%	4.17%	4.13%	100.00%
6 dB	4.00%	2.90%	2.77%	7.56%	7.77%	18.54%	13.72%	11.29%	11.49%	11.91%	3.34%	4.71%	4.00%	100.00%
8 dB	1.78%	3.10%	2.00%	6.98%	6.85%	17.92%	17.91%	10.61%	11.14%	15.96%	1.64%	4.13%	1.78%	100.00%
10 dB	0.81%	3.00%	2.07%	4.03%	5.92%	17.29%	19.59%	11.61%	10.58%	20.45%	0.83%	3.82%	0.81%	100.00%

Diurnal Variation of 12 GHz Rain Attenuation in Thailand

Bangkok, 1/Mar/93 - 29/Feb/94 (Year -2) Available Data = 89.2%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.	Total (Sec)
2 dB	24304	26252	15268	27182	55314	81538	96932	57336	40616	35104	30444	38998	24304	529288
4 dB	9946	10873	8316	17284	34958	50194	55678	26172	20538	20704	17526	20624	9946	292913
6 dB	6718	4828	5452	11758	21268	36716	33530	13318	10542	11706	10310	13006	6718	179152
8 dB	3953	2246	4164	9318	11716	27586	21976	9522	6698	6652	6028	6972	3953	116836
10 dB	2434	812	3080	7960	6710	17922	14382	7740	3496	3252	4576	2140	2434	74504
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)
2 dB	4.59%	4.96%	2.88%	5.14%	10.45%	15.41%	18.31%	10.83%	7.67%	6.63%	5.75%	7.37%	4.59%	100.00%
4 dB	3.40%	3.71%	2.84%	5.90%	11.93%	17.14%	19.01%	8.94%	7.01%	7.07%	6.02%	7.04%	3.40%	100.00%
6 dB	3.75%	2.69%	3.04%	6.56%	11.87%	20.49%	18.72%	7.43%	5.89%	6.53%	5.75%	7.28%	3.75%	100.00%
8 dB	3.39%	1.92%	3.58%	7.98%	10.03%	23.61%	18.81%	8.15%	5.73%	5.69%	5.16%	5.97%	3.39%	100.00%
10 dB	3.27%	1.09%	4.13%	10.68%	9.01%	24.06%	19.30%	10.39%	4.69%	4.36%	6.14%	2.87%	3.27%	100.00%

## Diurnal Variation of 12 GHz Rain Attenuation in Thailand

Bangkok, 1/Mar/94 - 28/Feb/95 (Year -3) Available Data =73.2%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.	Total (Sec)
2 dB	4446	9394	30460	25288	45060	81772	85360	65180	58882	31690	24522	17354	4446	479108
4 dB	1454	4962	18736	12604	28038	51818	50120	37199	31440	19030	7362	8992	1454	271834
6 dB	0	2298	13846	7826	18346	33858	38190	27550	21434	10732	3748	5602	0	183430
8 dB	0	1232	10616	4548	10938	21414	29152	22456	14114	7918	2030	3320	0	127798
10 dB	0	764	7624	3748	7572	13202	21534	16344	10612	6794	1118	2440	0	92352
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)
2 dB	0.93%	1.90%	6.36%	5.28%	9.40%	17.07%	17.82%	13.67%	12.29%	6.61%	5.12%	3.62%	0.93%	100.00%
4 dB	0.53%	1.63%	6.09%	4.67%	10.31%	19.08%	18.44%	13.66%	11.57%	7.00%	2.71%	3.31%	0.53%	100.00%
6 dB	0.00%	1.25%	7.55%	4.27%	10.00%	18.46%	20.82%	15.07%	11.69%	5.85%	2.04%	3.05%	0.00%	100.00%
8 dB	0.00%	0.56%	8.31%	3.56%	8.56%	16.76%	22.81%	17.57%	11.04%	6.20%	1.64%	2.60%	0.00%	100.00%
10 dB	0.00%	0.83%	8.26%	4.06%	8.20%	14.30%	23.32%	18.35%	11.49%	7.36%	1.21%	2.64%	0.00%	100.00%

## Diurnal Variation of 12 GHz Rain Attenuation in Thailand

Bangkok, 1/Mar/92 - 28/Feb/95 (3 Years) Available Data = 83%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.	Total (Sec)
2 dB	48590	49228	59138	85688	130934	232194	245714	191546	162456	116830	82580	78812	48590	1482708
4 dB	21800	22689	34254	48440	80274	147098	138932	96329	84776	68716	35356	40134	21800	816797
6 dB	12874	11582	23568	31228	51578	99110	92830	58250	49652	40764	19192	25860	12874	516404
8 dB	5586	6312	16606	20246	28914	65388	67504	41682	30396	29160	9616	14064	5586	336078
10 dB	2882	3224	11842	13922	17538	40628	46684	31064	19922	21290	6150	6680	2882	221828
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)
2 dB	3.28%	3.32%	3.99%	5.78%	8.83%	15.66%	16.57%	12.92%	10.96%	7.81%	5.57%	5.32%	3.28%	100.00%
4 dB	2.67%	2.78%	4.19%	5.93%	9.83%	18.01%	16.78%	11.79%	10.38%	8.41%	4.33%	4.91%	2.67%	100.00%
6 dB	2.49%	2.24%	4.50%	6.05%	9.99%	19.19%	17.97%	11.28%	9.81%	7.89%	3.72%	5.01%	2.49%	100.00%
8 dB	1.66%	1.88%	4.94%	6.02%	8.60%	19.46%	20.09%	12.40%	9.22%	8.68%	2.86%	4.18%	1.66%	100.00%
10 dB	1.30%	1.45%	5.34%	6.28%	7.91%	18.32%	21.05%	14.00%	8.98%	9.60%	2.77%	3.01%	1.30%	100.00%

## Diurnal Variation of 12 GHz Rain Attenuation in Thailand

Si-racha 1/Mar/92 - 29/Feb/93 (Year -1)

Data Available =98%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.
2 dB	33338	38186	47604	80580	54118	36202	20090	44698	35978	37640	29978	28680	33338
4 dB	21224	20500	26268	52220	27012	13470	7094	29574	19444	11624	20394	11458	21224
6 dB	12940	7138	17032	34270	15422	6912	5464	16580	12998	6224	15010	6234	12940
8 dB	8104	3140	9928	20422	9872	4168	4240	12038	7346	3872	11172	3280	8104
10 dB	5656	1950	4718	10732	5462	2344	3310	9258	4230	2126	7840	2012	5656
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT
2 dB	6.84%	7.34%	9.77%	16.54%	11.11%	7.43%	4.12%	9.18%	7.39%	7.73%	6.15%	5.89%	6.84%
4 dB	8.15%	7.88%	10.09%	20.06%	10.38%	5.18%	2.73%	11.36%	7.47%	4.47%	7.84%	4.40%	8.15%
6 dB	8.28%	4.57%	10.90%	21.94%	9.87%	4.42%	3.50%	10.61%	8.31%	3.98%	9.61%	3.99%	8.28%
8 dB	8.30%	3.22%	10.17%	20.93%	10.12%	4.27%	4.35%	12.34%	7.63%	3.97%	11.45%	3.35%	8.30%
10 dB	9.48%	3.27%	7.91%	18.00%	9.16%	3.93%	5.55%	15.52%	7.09%	3.56%	13.16%	3.37%	9.48%

## Diurnal Variation of 12 Ghz Rain Attenuation in Thailand

Si-racha 1/Mar/93 - 29/Feb/94 (Year -2)

Data Available = 68.3%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.
2 dB	1086	7696	46734	91978	40458	30230	25966	45652	19328	16870	14288	11140	1086
4 dB	0	1380	24758	56526	23232	15142	11678	25712	13536	6618	7736	5884	0
6 dB	0	294	14338	33608	15558	6796	6242	19800	11080	2962	4546	4008	0
8 dB	0	46	9134	22998	10892	2646	4532	14432	9204	2288	3284	3388	0
10 dB	0	0	5802	17700	6670	834	3398	9006	6688	1802	2824	3160	0
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT
2 dB	0.31%	2.19%	13.30%	26.17%	11.51%	8.60%	7.39%	12.99%	5.50%	4.80%	4.07%	3.17%	0.31%
4 dB	0.00%	1.05%	12.84%	29.32%	12.05%	7.85%	6.06%	13.34%	7.02%	3.43%	4.01%	3.05%	0.00%
6 dB	0.00%	0.25%	12.13%	28.43%	13.16%	5.75%	5.28%	15.90%	9.37%	2.51%	3.84%	3.39%	0.00%
8 dB	0.00%	0.36%	11.05%	27.83%	12.94%	3.20%	5.48%	17.46%	11.14%	2.77%	3.97%	4.10%	0.00%
10 dB	0.00%	0.00%	10.02%	30.58%	11.52%	1.44%	5.87%	15.56%	11.55%	3.11%	4.88%	5.46%	0.00%

## Diurnal Variation of 12 Ghz Rain Attenuation in Thailand

Siracha 1/Mar/94 - 28/Feb/95 (Year -3)

Data Available = 90%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.	Total(Sec)
2 dB	7396	14566	51130	93526	79190	47618	50402	40730	21590	32268	22368	7114	7396	487898
4 dB	4758	6428	31312	59470	53018	27330	27190	18268	7746	15638	8996	1676	4758	261828
6 dB	2648	5136	20902	40096	39050	17828	17900	10694	5818	10730	4330	186	2648	175508
8 dB	676	5940	12010	24500	27940	11760	12250	7324	5172	7982	2784	0	676	116938
10 dB	0	2953	6550	15708	20002	9290	8690	5642	4820	6500	1768	0	0	81928
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)
2 dB	1.53%	3.11%	10.93%	19.99%	16.92%	10.18%	10.77%	8.70%	4.61%	6.90%	4.78%	1.52%	1.58%	100.00%
4 dB	1.82%	2.46%	11.96%	22.71%	20.25%	10.44%	10.38%	6.86%	2.06%	5.37%	3.44%	0.64%	1.82%	100.00%
6 dB	1.82%	2.63%	11.91%	22.85%	22.25%	10.16%	10.20%	6.09%	3.31%	6.11%	2.47%	0.11%	1.82%	100.00%
8 dB	0.58%	3.37%	10.27%	20.95%	23.89%	10.07%	10.48%	6.76%	4.42%	6.83%	2.36%	0.00%	0.58%	100.00%
10 dB	0.00%	3.61%	7.39%	19.17%	24.41%	11.34%	10.61%	6.89%	5.88%	7.93%	2.16%	0.00%	0.00%	100.00%

## Diurnal Variation of 12 Ghz Rain Attenuation in Thailand

Siracha, 1/Mar/92 - 28/Feb/95 (3 - Years) Available Data = 85%

	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT
2 dB	41820	60448	145468	266084	173766	144050	96458	131080	76894	86778	66634	48934	41820
4 dB	25982	29508	82338	168216	103262	55942	45960	73554	40726	33878	37126	19018	25982
6 dB	15788	12568	52272	107974	70030	31536	23606	46064	23884	19916	23886	10428	15788
8 dB	8780	7126	31072	67920	48504	18594	21022	34394	21722	14142	17220	6668	8780
10 dB	5656	4908	17070	44140	32134	12468	15398	23906	15738	10428	12432	5172	5656
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT
2 dB	3.13%	4.52%	10.88%	19.91%	13.00%	10.78%	7.22%	9.61%	5.75%	6.48%	4.99%	3.51%	3.13%
4 dB	3.63%	4.04%	11.52%	23.53%	14.44%	7.83%	6.43%	10.29%	5.70%	4.74%	5.19%	2.66%	3.63%
6 dB	3.51%	2.79%	11.62%	24.00%	15.56%	7.01%	6.58%	10.24%	6.64%	4.43%	5.31%	2.32%	3.51%
8 dB	2.95%	2.40%	10.46%	22.86%	16.32%	6.26%	7.07%	11.57%	7.31%	4.76%	5.79%	2.24%	2.95%
10 dB	2.64%	2.46%	8.56%	22.13%	16.11%	6.25%	7.72%	11.99%	7.89%	5.23%	6.23%	2.59%	2.64%

## Diurnal Variation of 12 GHz Rain Attenuation in Singapore

Singapore 1/Mar/92 - 28/Feb/93 (Year -1) Data Available 7835.31 Hours 89.4%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.	Total (Sec)
2 dB	15590	36414	36870	57912	55876	5080	2798	3786	2974	4818	17282	13366	15590	252368
4 dB	8350	18236	17936	32394	36760	2048	1082	1932	1530	2138	9982	8138	8350	140524
6 dB	5540	9680	9582	23724	24454	1172	518	1478	1132	1512	6918	4146	5540	89858
8 dB	2410	5374	6238	17190	18122	846	158	1100	850	664	4984	2292	2410	60028
10 dB	2152	4998	5918	16082	17484	792	104	1006	600	504	4748	2204	2152	56582
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)
2 dB	6.18%	14.43%	14.81%	22.95%	22.06%	2.01%	1.11%	1.50%	1.18%	1.83%	6.85%	5.30%	6.18%	100.00%
4 dB	5.84%	12.98%	12.76%	23.05%	26.18%	1.48%	0.77%	1.37%	1.09%	1.52%	7.10%	5.79%	5.84%	100.00%
6 dB	6.17%	10.77%	10.66%	26.40%	27.21%	1.30%	0.58%	1.64%	1.26%	1.68%	7.70%	4.61%	6.17%	100.00%
8 dB	4.01%	8.95%	10.39%	28.64%	30.19%	1.41%	0.26%	1.83%	1.08%	1.11%	8.30%	3.82%	4.01%	100.00%
10 dB	3.80%	8.83%	10.46%	28.42%	30.89%	1.40%	0.18%	1.78%	1.06%	0.89%	8.39%	3.89%	3.80%	100.00%

## Diurnal Variation of 12 GHz Rain Attenuation in Singapore

Singapore 1/Mar/93 - 28/Feb/94 (Year -2) Data Available 6507.00 Hours 97.1%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.	Total (Sec)
2 dB	17898	27404	25488	57912	55876	17292	16738	32962	29772	25664	15608	20112	17898	347608
4 dB	10638	16226	14678	32394	36760	9090	10278	17473	15890	13746	9784	12474	10638	199234
6 dB	7276	10012	11212	23724	24454	4938	7794	9940	10188	8238	6818	9858	7276	134458
8 dB	4780	6908	8794	17190	18122	3086	6608	5218	7214	4048	4440	6484	4780	92892
10 dB	4428	6666	8306	16082	17484	2800	6438	4762	6730	3840	3994	6002	4428	87358
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)
2 dB	5.22%	8.02%	7.44%	16.90%	16.25%	5.05%	4.89%	9.62%	8.69%	7.49%	4.56%	5.87%	5.22%	100.00%
4 dB	5.34%	8.14%	7.37%	16.26%	18.45%	4.58%	5.16%	8.77%	7.88%	6.90%	4.91%	6.26%	5.34%	100.00%
6 dB	5.41%	7.45%	8.34%	17.64%	18.19%	3.67%	5.80%	7.39%	7.58%	6.13%	5.07%	7.33%	5.41%	100.00%
8 dB	5.15%	7.44%	9.47%	18.51%	19.51%	3.32%	7.11%	5.62%	7.77%	4.36%	4.78%	6.98%	5.15%	100.00%
10 dB	5.07%	7.63%	9.51%	18.41%	20.01%	3.21%	7.37%	5.46%	7.73%	4.17%	4.57%	6.87%	5.07%	100.00%



Diurnal Variation of 12 GHz Rain Attenuation in Singapore

Singapore 1/Mar/93 - 28/Feb/94 (Year -3) Data Available 7914.01 Hours 90.3%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.	Total (Sec)
2 dB	27084	27252	51306	45740	46510	25622	12614	8770	9014	7186	16168	15536	27084	292802
4 dB	16872	13008	29456	22134	27040	12074	4470	4048	4792	3946	7872	6334	16872	152046
6 dB	10788	7718	18428	10868	15730	6874	2182	1266	3132	2674	4918	4508	10788	89086
8 dB	6738	4738	12060	6310	10072	4118	888	956	2482	1528	3480	2388	6738	56358
10 dB	5974	4372	11024	5734	9328	3828	772	854	2408	1434	3282	2740	5974	51748
Attenuation	07-08LT	09-10LT	11-12LT	13-14LT	15-16LT	17-18LT	19-20LT	21-22LT	23-24LT	01-02LT	03-04LT	05-06LT	07-08LT	Total (sec)
2 dB	9.25%	9.21%	17.52%	15.62%	15.88%	8.75%	4.31%	3.00%	3.08%	2.45%	5.52%	5.31%	9.25%	100.00%
4 dB	11.10%	8.56%	19.37%	14.58%	17.78%	7.94%	2.94%	2.65%	3.15%	2.60%	5.18%	4.17%	11.10%	100.00%
6 dB	12.11%	8.66%	20.69%	12.20%	17.66%	7.72%	2.45%	1.42%	3.52%	3.00%	5.52%	5.06%	12.11%	100.00%
8 dB	11.88%	8.41%	21.40%	11.20%	17.87%	7.31%	1.58%	1.79%	4.40%	2.71%	6.17%	5.30%	11.88%	100.00%
10 dB	11.54%	8.45%	21.30%	11.08%	18.03%	7.40%	1.49%	1.65%	4.65%	2.77%	6.34%	5.29%	11.54%	100.00%

Diurnal Variation of 12 GHz Rain Attenuation in Singapore

1/Mar/92 - 28/Feb/95 (3 Years) Total Measurement Time

Singapore Local Time = GMT+8 Hours

Attenuation	08-09LT	10-11LT	12-13LT	14-15LT	16-17LT	18-19LT	20-21LT	22-23LT	00-01LT	02-03LT	04-05LT	06-07LT	08-09LT
2 dB	60572	91150	113664	137560	122526	47994	32150	45518	41760	37468	49058	49056	60572
4 dB	35860	47470	62070	75162	71404	23212	15830	23456	22012	19828	27638	27638	35860
6 dB	23604	27410	39222	46248	43282	12982	10494	12684	14462	12422	18654	18654	23604
8 dB	13928	17020	27090	30984	29798	8050	7654	7274	10346	6240	12904	12904	13928
10 dB	7936	11572	17880	20018	20152	4658	6052	3056	6556	3228	8180	8180	7936
Attenuation	08-09LT	10-11LT	12-13LT	14-15LT	16-17LT	18-19LT	20-21LT	22-23LT	00-01LT	02-03LT	04-05LT	06-07LT	08-09LT
2 dB	7.31%	11.00%	13.72%	16.60%	14.79%	5.79%	3.88%	5.49%	5.04%	4.52%	5.92%	5.92%	7.31%
4 dB	7.95%	10.53%	13.77%	16.67%	15.84%	5.15%	3.51%	5.29%	4.88%	4.40%	6.13%	6.13%	7.95%
6 dB	8.43%	9.79%	14.01%	16.52%	15.45%	4.64%	3.75%	4.53%	5.17%	4.44%	6.66%	6.66%	8.43%
8 dB	7.61%	9.30%	14.80%	16.93%	16.28%	4.40%	4.18%	3.97%	5.65%	3.41%	7.05%	7.05%	7.61%
10 dB	6.75%	9.84%	15.21%	17.03%	17.14%	3.96%	5.15%	2.60%	5.58%	2.75%	6.96%	6.96%	6.75%



Diurnal Variation of 12 GHz Rain Attenuation in Bundung, Indonesia

1/Mar/94 - 28/Feb/95 (Year - 3) Data Available 8415.01 Hours 36.1%

Attenuation	07-08 hr.	09-10 hr.	11-12 hr.	13-14 hr.	15-16 hr.	17-18 hr.	19-20 hr.	21-22 hr.	23-24 hr.	01-02 hr.	03-04 hr.	05-06 hr.	07-08 hr.	Total (Sec)
2 dB	92	2130	34550	70222	73980	45114	21412	22456	10642	1964	1924	289	92	284774
4 dB	18	78	16968	34048	36230	20500	4252	7772	6964	472	1534	28	18	128862
6 dB	0	0	9044	15100	17810	9154	1510	636	1452	10	1022	0	0	55738
8 dB	0	0	4508	7350	8184	4194	190	0	268	0	90	0	0	24782
10 dB	0	0	3638	6300	7206	3674	132	0	222	0	38	0	0	21210
Atten (dB)	07-08LT	09-10LT	11-12LT	13-14LT	15-16LT	17-18LT	19-20LT	21-22LT	23-24LT	01-02LT	03-04LT	05-06LT	07-08LT	Total (sec)
2 dB	0.03%	0.75%	12.13%	24.66%	25.98%	15.84%	7.52%	7.89%	3.74%	0.69%	0.68%	0.10%	0.03%	100.00%
4 dB	0.01%	0.06%	13.17%	26.42%	28.12%	15.91%	3.30%	6.03%	5.40%	0.37%	1.19%	0.02%	0.01%	100.00%
6 dB	0.00%	0.00%	16.23%	27.09%	31.95%	16.42%	2.71%	1.14%	2.61%	0.02%	1.83%	0.00%	0.00%	100.00%
8 dB	0.00%	0.00%	18.19%	29.66%	33.02%	16.92%	0.77%	0.00%	1.07%	0.00%	0.36%	0.00%	0.00%	100.00%
10 dB	0.00%	0.00%	17.15%	29.70%	33.97%	17.32%	0.62%	0.00%	1.05%	0.00%	0.18%	0.00%	0.00%	100.00%

Diurnal Variation of 12 GHz Rain Attenuation in BUNDUNG

1/Mar/92 - 28/Feb/95 (3 Years) Total Measurement Time 24203 Hours

Bundung, Indonesia Local Time = GMT+7 Hours

Attenuation	07-08LT	09-10LT	11-12LT	13-14LT	15-16LT	17-18LT	19-20LT	21-22LT	23-00LT	01-02LT	03-04LT	05-06LT	07-08LT
2 dB	92	10884	131486	292842	225468	134096	94886	49946	21762	5868	2402	512	92
4 dB	18	4444	64812	140410	112768	51896	33506	18592	9064	1728	1624	26	18
6 dB	0	2288	31776	65934	60362	23346	16592	8412	2098	10	1022	0	0
8 dB	0	1084	16964	30694	31496	11416	6954	5598	398	0	90	0	0
10 dB	0	152	7420	13012	15710	4936	2336	2916	0	0	0	0	0
Attenuation	07-08LT	09-10LT	11-12LT	13-14LT	15-16LT	17-18LT	19-20LT	21-22LT	23-00LT	01-02LT	03-04LT	05-06LT	07-08LT
2 dB	0.01%	1.12%	13.55%	30.18%	23.24%	13.62%	9.78%	5.15%	2.24%	0.62%	0.25%	0.05%	0.01%
4 dB	0.00%	1.01%	14.77%	31.99%	25.65%	11.82%	7.63%	4.24%	2.07%	0.39%	0.37%	0.01%	0.00%
6 dB	0.00%	1.08%	15.02%	31.03%	28.53%	11.04%	7.84%	3.98%	0.99%	0.00%	0.48%	0.00%	0.00%
8 dB	0.00%	1.04%	16.20%	29.32%	30.02%	10.90%	6.64%	5.35%	0.38%	0.00%	0.06%	0.00%	0.00%
10 dB	0.00%	0.33%	15.86%	27.99%	33.89%	10.62%	5.03%	6.27%	0.00%	0.00%	0.00%	0.00%	0.00%

3-years Diurnal Variation of Rainfalls at Bangkok, Thailand (1/MAR/92 -28/FEB/95) Data Available = 85.2% (1868 Hours)

	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)	% Total
10 mm/hr	3858	5610	19176	24718	32276	52647	44869	22718	20948	16769	10787	8326	3856	282798	3.907908
25 mm/hr	618	2837	10318	14233	18070	25025	16880	12063	12308	8228	4837	4516	618	128723	1.829024
50 mm/hr	193	905	4440	5730	8220	9900	4734	5967	3969	3469	2105	1988	193	52326	0.778106
75 mm/hr	116	226	2075	2136	4889	3547	747	1546	1099	1623	730	959	116	19673	0.292544
100 mm/hr	72	55	960	1110	1779	1358	80	278	310	549	53	380	72	3984	0.103854
125 mm/hr	0	16	332	484	412	377	0	10	73	129	0	49	0	1882	0.027826

Percent of 3-years Diurnal Variation of Rainfalls at Bangkok, Thailand (1/MAR/92 -28/FEB/95) Data Available = 85.2%

	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)	% Total
10 mm/hr.	1.467281	2.134711	7.296451	9.405867	12.28163	20.143318	17.11917	8.64463	7.971111	6.380822	4.097048	3.168201	1.467281	100	3.907908
25 mm/hr.	0.4764	2.186968	7.953871	10.97184	13.82368	16.2911	12.85817	9.291338	9.487909	6.342748	3.728714	3.481264	0.4764	100	1.829024
50 mm/hr.	0.388841	1.729542	8.485265	10.86205	17.6203	19.34852	9.047128	11.40351	7.585139	6.529591	4.022957	3.799258	0.388841	100	0.778105
75 mm/hr.	0.583641	1.148783	10.54745	10.85752	24.74968	18.02879	3.797082	7.858486	6.586337	8.249888	3.710669	4.874701	0.583641	100	0.292544
100 mm/hr	1.030628	0.787514	13.7457	15.89347	25.47251	16.44444	1.145475	3.980527	4.438717	7.860825	0.758877	5.441008	1.030628	100	0.103854
125 mm/hr	0	0.850159	17.84081	25.71732	21.8918	20.03108	0	0.53135	3.878852	6.85441	0	2.603813	0	100	0.027886

3-years Diurnal Variation of Rainfalls in Thailand Data Available = 85.7%

Siracha 1/Mar/92-28/Feb/95

	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)	% Total
10 mm/hr.	8521	8823	14126	31714	24883	19989	19905	27772	25026	22504	20174	6764	9521	227191	3.379405
25 mm/hr.	3396	2508	7243	13441	13573	7324	9437	14872	12088	10869	8612	2855	3396	106318	1.580384
50 mm/hr.	1096	568	4275	5855	6103	1908	4537	6908	4040	4998	2710	888	1096	43792	0.651202
75 mm/hr.	484	148	2230	2857	2523	690	1909	1760	2503	2595	1071	102	484	18872	0.270633
100 mm/hr	144	0	1005	974	602	215	1084	209	1119	1173	294	0	144	6799	0.101103
125 mm/hr	21	0	187	314	26	0	542	31	650	550	35	0	0	2335	0.034722
														406307	
Percent of 3-years Diurnal Variation of Rainfalls at Siracha, Thailand (1/MAR/92 -28/FEB/95) Data Available = 85.7%															
	07-08LT	09-10LT	11-12 LT	13-14 LT	15-16LT	17-18 LT	19-20LT	21-22 LT	23-24 LT	01-02 LT	03-04 LT	05-06 LT	07-08 LT	Total (sec)	% Total
10 mm/hr.	3.750589	3.883517	6.217676	13.95918	10.94368	7.482261	3.781351	12.22408	11.0154	9.905322	8.878753	2.977231	3.750589	100	3.378405
25 mm/hr.	3.194191	2.358961	6.812581	12.64226	12.78642	6.388768	8.876202	13.98822	11.38889	10.31718	8.100228	2.88534	3.194191	100	1.580384
50 mm/hr.	2.50274	1.297041	9.782057	13.39286	13.53634	4.128608	10.36034	15.77457	9.225428	11.40848	8.186345	2.023201	2.50274	100	0.651202
75 mm/hr.	2.564646	0.784231	11.81645	15.13883	13.38801	3.65621	10.11652	8.325996	13.26304	13.75053	5.675074	0.540483	2.564646	100	0.280633
100 mm/hr	2.117959	0	14.78159	14.32654	8.854243	3.18223	15.64936	3.073881	18.4583	17.25254	4.324165	0	2.117959	100	0.101103
125 mm/hr	0.819358	0	8.008565	13.44754	1.11349	0	23.21199	1.327823	27.83726	23.5548	1.498929	0	0	100	0.034722

## BIOGRAPHICAL NOTE



Mr. Rachan Lekkla was born in Ubonrajchathani province Thailand, on December 7, 1961. He received the B.Eng. degree in electrical engineering from Rajamongklala Institute of Technology, Bangkok, Thailand, in 1988. During 1989 -1991, he awarded a master degree scholarship from the Communications Authority of Thailand (CAT). In 1991, he receives the M.S. degree in electrical engineering from the George Washington University. After his graduation in 1991, he attained an internship program at INTELSAT (International Telecommunication Satellite Organization). From 1983 to the present time, he has been working with CAT, where he involves in the field of satellite communications over fourteen years.

During 1992 - 1995, he participated in "the Canada-ASEAN Cooperation in the Ku-band Propagation Measurement Program on Earth-Space part" as a researcher and project coordinator. He is currently working towards the Ph.D. degree in electrical engineering at the Chulalongkorn University, Bangkok, Thailand.

During his study, he contributes various research papers as follows:

- 1) R. Lekkla, P. Hetrakul. 1993. Ku-band Rain Attenuation Measurement in Thailand Proceedings, UN/Indonesia Regional Conference on space and technology for sustainable development, Bandung, Indonesia.
- 2) R. Lekkla, P. Prapinmongkolkarn, P. Hetrakul. 1993. Performance Analysis of Ku-band VSAT System in Thailand Proceeding APSITT'93 Symposium, Bangkok Thailand.
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