

TABLE OF CONTENTS

	Page
TABLE OF CONTENTS	i
LIST OF TABLES	ii
LIST OF FIGURES	vii
INTRODUCTION	1
LITERATURE REVIEWS	5
The Chao Phraya River Basin	5
Evapotranspiration	8
Rainfall	43
Water Budget	65
MATERIALS AND METHODS	70
Meteorological Data Analyzing	72
Actual Evapotranspiration	76
Rainfall	95
Water Budget	102
RESULTS AND DISCUSSION	108
Meteorological Data Analyzing	108
Actual Evapotranspiration	123
Rainfall	135
Water Budget	142
CONCLUSION AND RECOMMENDATION	156
LITERATURE CITED	161
APPENDIX	180
Appendix A	181
Appendix B	201
Appendix C	218
Appendix D	225
Appendix E	228
Appendix F	239

LIST OF TABLES

Table	Page
1 Landsat 7 mission specification	29
2 Landsat 7 and ETM+ characteristic	30
3 The MODIS spectral bands	33
4 The 44 standard MODIS data products	35
5 The spectral bandpasses of ASTER Satellite Sensors	38
6 Twelve basic cloud classifications	50
7 Relationship between cloud height and cloud temperature	52
8 The three spectral-bands of Meteosat	54
9 Description of GMS channels	56
10 Characteristics of the TRMM instrument	58
11 Water budget components at field, irrigation service, and basin level	68
12 The 27 MODIS images used for actual evapotranspiration calculation	81
13 The 6 Landsat 7 images used for actual evapotranspiration calculation	81
14 The cropping calendar for The Office of Regional Irrigation	88
15 The values of soil water depletion (D) and soil coefficient (Ks)	92
16 Mean actual evapotranspiration and evaporation in eight sub-basins	131
17 The crop coefficient for the rice, maize and sugarcane	134
18 The lengths of crop development stage for various planting periods	134
19 Mean rainfall in eight sub-basins	140
20 Mean irrigation requirement in eight sub-basins	147
21 The water budget calculation in Ping sub-basin	149
22 The water budget calculation in Wang sub-basin	150
23 The water budget calculation in Yom sub-basin	151
24 The water budget calculation in Nan sub-basin	152
25 The water budget calculation in Sakae Krang sub-basin	153
26 The water budget calculation in Pasak sub-basin	154
27 The water budget calculation in Chao Phraya and Tha Chin sub-basin	155

LIST OF TABLES (cont'd)

Appendix Table	Page
B1 The correlation coefficient between pan evaporation and reference evapotranspiration at Nakhon Sawan Station (Recorded evaporation: 1971-1980, 1982-2002)	202
B2 The correlation coefficient between pan evaporation and reference evapotranspiration at Suphan Buri Station (Recorded Evaporation: 1971-1980, 1982-2002)	203
B3 The correlation coefficient between pan evaporation and reference evapotranspiration at Lop Buri Station (Recorded Evaporation: 1982-1984, 1986-2002)	203
B4 The correlation coefficient between pan evaporation and reference evapotranspiration at Bua Chum Station (Recorded Evaporation: 1971-1973, 1975-2002)	204
B5 The correlation coefficient between pan evaporation and reference evapotranspiration at Kanchana Buri Station (Recorded Evaporation: 1976-1980, 1982-2002)	204
B6 The correlation coefficient between pan evaporation and reference evapotranspiration at Thong Phaphum Station (Recorded Evaporation: 1971-2002)	205
B7 The correlation coefficient between pan evaporation and reference evapotranspiration at Bangkok Metropoli Station (Recorded Evaporation: 1971-1980, 1982-1991, 1995-2002)	205
B8 The correlation coefficient between pan evaporation and reference evapotranspiration at Loei Station (Recorded Evaporation: 1971-1980, 1982-2002)	206
B9 The correlation coefficient between pan evaporation and reference evapotranspiration at Mae Hong Son Station (Recorded Evaporation: 1982-1983, 1985-2002)	206

LIST OF TABLES (cont'd)

Appendix Table	Page
B10 The correlation coefficient between pan evaporation and reference evapotranspiration at Mae Sarianng Station (Recorded Evaporation: 1982-2002)	207
B11 The correlation coefficient between pan evaporation and reference evapotranspiration at Chiang Rai Station (Recorded Evaporation: 1971-2002)	207
B12 The correlation coefficient between pan evaporation and reference evapotranspiration at Phayao Station (Recorded Evaporation: 1982-2002)	208
B13 The correlation coefficient between pan evaporation and reference evapotranspiration at Chiang Mai Station (Recorded Evaporation: 1973-1980, 1982-2002)	208
B14 The correlation coefficient between pan evaporation and reference evapotranspiration at Lampang Station (Recorded Evaporation: 1976-1980, 1982-2002)	209
B15 The correlation coefficient between pan evaporation and reference evapotranspiration at Lamphun Station (Recorded Evaporation: 1982-2002)	209
B16 The correlation coefficient between pan evaporation and reference evapotranspiration at Phrae Station (Recorded Evaporation: 1982-2002)	210
B17 The correlation coefficient between pan evaporation and reference evapotranspiration at Nan Station (Recorded Evaporation: 1971-1980, 1982-2002)	210
B18 The correlation coefficient between pan evaporation and reference evapotranspiration at Tha Wangpha Station (Recorded Evaporation: 1971-2002)	211

LIST OF TABLES (cont'd)

Appendix Table	Page
B19 The correlation coefficient between pan evaporation and reference evapotranspiration at Thung Chang Station (Recorded Evaporation: 2000-2002)	211
B20 The correlation coefficient between pan evaporation and reference evapotranspiration at Uttardit Station (Recorded Evaporation: 1982-2002)	212
B21 The correlation coefficient between pan evaporation and reference evapotranspiration at Sukhothai Station (Recorded Evaporation: 2000-2002)	212
B22 The correlation coefficient between pan evaporation and reference evapotranspiration at Tak Station (Recorded Evaporation: 1982-2002)	213
B23 The correlation coefficient between pan evaporation and reference evapotranspiration at Mae Sot Station (Recorded Evaporation: 1975-1980, 1982-2002)	213
B24 The correlation coefficient between pan evaporation and reference evapotranspiration at Bhumibol Dam Station (Recorded Evaporation: 1971-1980, 1982-2002)	214
B25 The correlation coefficient between pan evaporation and reference evapotranspiration at Umphang Station (Recorded Evaporation: 1977-2002)	214
B26 The correlation coefficient between pan evaporation and reference evapotranspiration at Phitsanulok Station (Recorded Evaporation: 1971-1980, 1982-2002)	215
B27 The correlation coefficient between pan evaporation and reference evapotranspiration at Phetchabun Station (Recorded Evaporation: 1974-1980, 1982-2002)	215

LIST OF TABLES (cont'd)

Appendix Table	Page
B28 The correlation coefficient between pan evaporation and reference evapotranspiration at Lom Sak Station (Recorded Evaporation: 1971-2002)	216
B29 The correlation coefficient between pan evaporation and reference evapotranspiration at Wichian Buri Station (Recorded Evaporation: 1982-1983, 1986-2002)	216
B30 The correlation coefficient between pan evaporation and reference evapotranspiration at Kamphaeng Phet Station (Recorded Evaporation: 1982-2002)	217
D1 Student's t-Distributions, Percentage points	226
F1 The weather location and coordinate for the comparison	240
F2 The comparison between actual evapotranspiration calculated by SEBAL and by the Penman-Monteith method and their correlation coefficients	241
F3 The comparison between actual evapotranspiration from SEBAL and from the Penman-Monteith method and their correlation coefficients after there is temporal interpolation of actual evapotranspiration from SEBAL	256
F4 Monthly rainfall from TRMM image and from rain gauge station and their correlation coefficients	269

LIST OF FIGURES

Figure	Page
1 The location of the Chao Phraya River Basin in Thailand	5
2 The location of eight sub-basins in the Chao Phraya River basin	6
3 The location of weather stations recorded by Thai Meteorological Department	71
4 The location of rain gauge stations recorded by Royal Irrigation Department	71
5 The concept of actual evapotranspiration calculation using SEBAL, MODIS, and Landsat 7 images	80
6 The concept of actual evapotranspiration calculation using the FAO Penman-Monteith method and weather data	83
7 The concept of crop coefficient calculation	85
8 The crop coefficient of rice, maize, sugarcane, cassava, small vegetation, and fruit	91
9 The concept of the comparison between actual evapotranspiration calculated by SEBAL and the FAO Penman-Monteith method	93
10 The concept to consider rainfall from rain gauge stations and TRMM (3B42 V6) images	96
11 Accumulated rainfall of TRMM image from January to December	97
12 The components of water budget concept	103
13 The concept of water budget computation	107
14 Mean annual reference evapotranspiration and their linear trends in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, and Tha Chin sub-basin	109
15 Mean annual pan evaporation and their linear trends in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, and Tha Chin sub-basin	110
16 Mean annual net radiation and their linear trends in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, and Tha Chin sub-basin	111

LIST OF FIGURES (cont'd)

Figure	Page
17 Mean annual temperature and their linear trends in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, and Tha Chin sub-basin	112
18 Mean annual relative humidity and their linear trends in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, and Tha Chin sub-basin	113
19 Spatial reference evapotranspiration from January to December	115
20 Mean monthly reference evapotranspiration in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, Tha Chin sub-basin and the upper, lower, and whole catchment of the Chao Phraya River Basin	119
21 Mean monthly net radiation (R_n) in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, and Tha Chin sub-basin	120
22 Mean monthly temperature in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, and Tha Chin sub-basin	120
23 Mean monthly relative humidity in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, and Tha Chin sub-basin	121
24 Mean monthly net radiation, temperature, and relative humidity in the upper, lower, and whole catchment of the Chao Phraya River Basin	122
25 Mean annual rainfall and their linear trends in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, and Tha Chin sub-basin	124
26 The process of SEBAL calculation	125
27 Monthly actual evapotranspiration from MODIS image and weather data from January to December	128
28 Accumulated rainfall from recorded rainfall and TRMM image during January to December	136
29 Mean monthly rainfall in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Chao Phraya, and Tha Chin sub-basin	139
30 Spatial distribution of irrigation requirement from January to December	144

LIST OF FIGURES (cont'd)

Appendix Figure	Page
C1 Data format structure for 3B-42, TRMM and other GPI Calibration	223
E1 Actual evapotranspiration from MODIS image (no. 1-27)	229
E2 The location of Landsat 7 images in the Chao Phraya River Basin and the Spatial actual evapotranspiration of Landsat 7 image (no 1-6)	234
F1 The distribution of all actual evapotranspiration used for comparison in 27 days of MODIS images	255
F2 The distribution between actual evapotranspiration from SEBAL and actual evapotranspiration from the Penman-Monteith after there is temporal interpolation of actual evapotranspiration from SEBAL	255
F3 The distribution of all monthly rainfall used for comparison	293
F4 The distribution of monthly rainfall used for comparison in each month	294

LIST OF ABBREVIATIONS

c_p	=	Air specific heat (J/kg/K)
d	=	Zero plane displacement (m)
d_{e-s}	=	Relative earth-sun distance (-)
d_r	=	Inverse squared relative earth-sun distance (-)
ET_c	=	Actual evapotranspiration rate (mm/hr)
ET_o	=	Reference evapotranspiration (mm/hr)
G	=	Soil heat flux (W/ m ²)
H	=	Sensible heat flux (W/ m ²)
k	=	Von Karman's constant = 0.41
L	=	Monin-Obukhov length (m)
L_λ	=	Spectral radiance for band λ (W/ m ² /sr/ μ m)
r_{ah}	=	Aerodynamic resistance to heat transport (s/m)
R_n	=	Net radiation flux (W/ m ²)
$R_{s\downarrow}$	=	Incoming shortwave radiation (W/ m ²)
$R_{L\downarrow}$	=	Incoming longwave radiation (W/ m ²)
$R_{L\uparrow}$	=	Outgoing longwave radiation (W/ m ²)
R_c	=	Corrected thermal radiance from the surface (W/ m ² /sr/ μ m)
R_p	=	Path radiance in the 10.4 – 12.5 μ m band (W/ m ² /sr/ μ m)
R_{sky}	=	Narrow band downward thermal radiation for a clear sky (W/ m ² /sr/ μ m)
T_a	=	Near surface air temperature (K)
T_s	=	Surface temperature (K)
u	=	Wind velocity (m/s)
u^*	=	Friction velocity (m/s)
z	=	Height (m)
z_{om}	=	Momentum roughness length (m)

α	=	Surface albedo (-)
$\alpha_{path-radiance}$	=	Albedo path radiance (-)
α_{toa}	=	Albedo at top of atmosphere (-)
β	=	Solar elevation angle (degrees)
γ	=	Aspect angle of the pixel (radians)
δ	=	Declination of the earth (radians)
ε_o	=	Broad band surface emissivity (-)
ε_{NB}	=	Narrow band surface emissivity (-)
ε_a	=	Atmospheric emissivity (-)
θ	=	Solar incidence angle (degrees)
λ	=	Latent heat of vaporization (J/kg)
λET	=	Latent heat flux (W/ m ²)
ρ	=	Air density (kg/m ³)
$\rho\lambda$	=	Reflectivity for band λ (-)
σ	=	Stefan-Boltzmann constant (5.67 X10 ⁻⁸ W/m ² /K ⁴)
τ_{sw}	=	Shortwave transmissivity of air (-)
τ_{NB}	=	Narrow band transmissivity of air (-)
ϕ	=	Latitude of the pixel (radians)
ψ_h	=	Stability correction for heat transport (-)
ψ_m	=	Stability correction for momentum transport (-)
ϖ	=	Mountain wind speed weighting coefficient (-)
ω_λ	=	Weighting coefficient for band λ (-)