Bureau of International Cooperation,
Department of Water Resources
Ministry of Natural Resources and Environment
180/3 Rama VI Road Soi 34, Samsennai, Phayathai,
Bangkok 10400

Improved Management of Extreme Events through Ecosystem-based Adaption in Watersheds (ECOSWat)

PN: 12.9012.1-001.00

Final Report

Vulnerability analysis for the river basins of
Huai Sai Bat, Tha Di and Trang

Bangkok, Weinheim 2015-01-16

Prepared for:	Prepared by:
GIZ TH	Dr. Hubert Lohr (h.lohr@sydro.de)

Table of Contents

1 INTRODUCTION 5

2 DATA 5

2.1 Tha Di River Basin 5
2.2 Huai Sai Bat River Basin 6
2.3 Trang River Basin 9
2.4 Time Series 10

3 METHOD 12

3.1 Assessment approach 12
3.2 Stages of the approach 13

4 GEOGRAPHICAL SCALING 15

4.1 Field trip to Tha Di River Basin 15
4.2 Field trip to Huai Sai Bat River Basin 17
4.3 Field trip to Trang River Basin 19

5 SCOPING 22

5.1 Features of Tha Di River Basin 22
5.2 Features of Huai Sai Bat River Basin 23
5.3 Features of Trang River Basin 25

6 CAUSAL-CHAINS 27

6.1 Tha Di River Basin 28
6.2 Huai Sai Bat River Basin 49
6.3 Overview of causal-chains 64

7 DETAILED ASSESSMENT 68

7.1 General assumptions for modelling 68
7.2 Tha Di 74
7.3 Huai Sai Bat 89

8 EXECUTIVE SUMMARY 106

8.1 Tha Di 110
8.2 Huai Sai Bat 112

9 LITERATURE 114

List of figures

Figure 1: Tha Di River Basin 15
Figure 2: Agreed boundaries of Tha Di River Basin 16
Figure 3: Sub-regions of Tha Di River Basin 16
Figure 4: Huai Sai Bat River Basin 17
Figure 5: Agreed boundaries of Huai Sai Bat River Basin 18
Figure 6: Sub-regions of Huai Sai Bat River Basin 19
Figure 7: Trang River Basin 20
Figure 8: Sub-regions of Trang River Basin 21
Figure 9: Selected features of Tha Di River Basin 23
Figure 10: Causal-chain - water quality and effluent disposal within NST 29
Figure 11: Causal-chain - flood protection infrastructure and modification in stream flow, NST 31
Figure 12: Causal-chain - flood protection infrastructure and modification in sediment budget, NST 33
Figure 13: Causal-chain - real estate development upstream of NST 35
Figure 14: Causal-chain - aquaculture with shrimps ponds, coastal area 37
Figure 15: Causal-chain - recreational areas upstream of water withdrawal for water supply 39
Figure 16: Causal-chain - positive effects of ecosystem-based hydraulic structures 41
Figure 17: Causal-chain - conversion of mangroves into aquaculture ponds 43
Figure 18: Causal-chain - deforestation, Tha Di mountain area 45
Figure 19: Causal-chain - urbanization with increasing effluent discharges 47
Figure 20: Causal-chain - agriculture upstream of Nong Yai reservoir 50
Figure 21: Causal-chain - sedimentation into Nong Yai reservoir 52
Figure 22: Causal-chain - water abstraction on irrigation scheme level along Huai Sai Bat River 54
Figure 23: Causal-chain - water abstraction on individual level along Huai Sai Bat 56
Figure 24: Causal-chain - monitoring of water abstraction along Huai Sai Bat 58
Figure 25: Causal-chain - dredging of Huai Sai Bat River 60
Figure 26: Causal-chain - land use development in Huai Sai Bat river basin 62
Figure 27: Root causes and major concerns in Tha Di river basin 65
Figure 28: Root causes and major concerns in Huai Sai Bat river basin 67
Figure 29: Components in water quality modelling of urban systems 72
Figure 30: Flow network of hydrological model of Tha Di river basin 74
Figure 31: Comparison of precipitation and discharge at gauge x55, Tha Di 75
Figure 32: Comparison of observed and computed discharge at gauge x55, Tha Di 76
Figure 33: Mountainous sub-basins with land use and soil alterations, Tha Di 77
Figure 34: Comparison of discharge at gauge x55 with land use alterations, Tha Di 79
Figure 35: Headwater sub-basins used for erosion scenarios, Tha Di 80
Figure 36: Increase of erosion due to conversion of rain forest, Tha Di 81
Figure 37: Urban drainage area and receiving stream, Tha Di 82

Figure 38: Oxygen and BOD concentration versus population growth, Tha Di 83
Figure 39: Statistics of Oxygen and BOD concentration versus population growth, Tha Di....84
Figure 40: Toxic ammonia concentration versus population growth, Tha Di 84
Figure 41: BOD versus population growth, Tha Di 85
Figure 42: Water quality in Thailand (source: Yolthantham, T. 2007) 86
Figure 43: Flow network of hydrological model of Huai Sai Bat river basin 89
Figure 44: Location of the reference gauging station E.68A in Lam Phaniang river basin, (source: (Kittiwet, K, Vichian, 2014) 90
Figure 45: Comparison of annual values of synthetic discharge, TalsimNG and SWAT model without an ARF, Huai Sai Bat 91
Figure 46: Comparison of synthetic discharge, TalsimNG and SWAT KK discharge at the river basin outlet, Huai Sai Bat 93
Figure 47: Schematic supply scheme with priorities for domestic and irrigation, Huai Sai Bat 95
Figure 48: Water balance for Huai Sai Bat river basin 96
Figure 49: Relationship between domestic and irrigation use with varying shares for irrigation at Nong Yai Reservoir 97
Figure 50: Reservoir zoning for irrigation releases at Nong Yai Reservoir 98
Figure 51: Safety of supply depending on different zoning scenarios at Nong Yai Reservoir 99
Figure 52: Crop requirements, derived from (Kittiwet, K, Vichian, 2014b) 100
Figure 53: Impact of changes of crops in regard to inflow to Nong Yai reservoir 101
Figure 54: Grain-size distribution for sedimentation modelling in Nong Yai reservoir 101
Figure 55: Area used for sedimentation modelling in Nong Yai reservoir 102
Figure 56: Results of sedimentation modelling in Nong Yai reservoir 102
Figure 57: Nong Yai reservoir 103
Figure 58: Overview about the project areas 106

List of tables

Table 1: Recognized features of Tha Di River Basin 22
Table 2: Recognized features of Huai Sai Bat River Basin 23
Table 3: Recognized features of Trang River Basin 25
Table 4: Overview of cause-effect relationships in Tha Di river basin 64
Table 5: Overview of cause-effect relationships in Huai Sai Bat river basin 66
Table 6: Parameter of soil horizons after calibration in Tha Di river basin 76
Table 7: Land use parameter modifications in Tha Di river basin 77
Table 8: Soil horizon parameter modifications in Tha Di river basin 78
Table 9: Range of sediment yield of rivers and drainage area size from different regions of Thailand [source: (Henderson, G, Rouysungnern, S., 1984)] 81
Table 10: Scenarios with different reservoir zones at Nong Yai reservoir 98

1 INTRODUCTION

The vulnerability analysis started on Wednesday, 04th, June 2014 in Bangkok. Prior to the start, a detailed timeline was worked out for the first project stage. The steps are:

- Field trip to Tha Di River Basin and meeting with Walailak University
- Field trip to Huai Sai Bat River Basin and meeting with Khon Kaen University
- Workshop with all team members in Khon Kaen

During the field trips, meetings and workshop, the procedure of the assessment was explained to the team by means of presentations, examples and initiation of own activities for each team member. The field trip to the Trang River Basin has been carried in November 2013.

2 DATA

2.1 Tha Di River Basin

2.1.1 Available data

Time Series:

ThaDi							
Name	Type	Unit	Interpretation	Origin	Start	End	Data points
Tha Di Flood synthetic dt=2h	discharge	m3/s	Instantainous	measured	25.12.2002	30.12.2002 04:00	48
ThaDi ETp daily Nakhon Si Thammarat (210703)	evaporation	mm	Accumulative in time step	measured	01.01.1984	31.12.2009	9497
ThaDi N daily Nakhon Si Thammarat (210703)	precipitation	mm	Accumulative in time step	measured	01.01.1983	31.12.2009	9862
ThaDi Q x55 [mm]	discharge	mm	Instantainous	derived	01.04.1967	31.03.2012	16404
ThaDi RelHum daily Nakhon Si Thammarat (210703)	humidity	%	Instantainous	measured	01.01.1985	31.12.2009	9131
ThaDi T dailyMax Nakhon Si Thammarat (210703)	temperature	oC	Instantainous	measured	01.01.1985	31.12.2009	9131
ThaDi T dailyMin Nakhon Si Thammarat (210703)	temperature	oC	Instantainous	measured	01.01.1985	31.12.2009	9131
ThaDi WT dailyAvg Nakhon Si Thammarat (210703)	temperature	oC	Instantainous	measured	01.01.1984	31.12.2009	9497
ThaDi_Prec_ra1	precipitation	mm	Accumulative in time step	measured	01.01.1975	31.03.2011	13117
ThaDi_Prec_ra2	precipitation	mm	Accumulative in time step	measured	01.01.1972	24.05.2011	14389
ThaDi_Q_x203	discharge	m3/s	Instantainous	measured	01.04.2000	31.03.2012	4383
ThaDi_Q_x55	discharge	m3/s	Instantainous	measured	01.04.1967	31.03.2012	16437
ThaiDi T dailyAvg Nakhon Si Thammarat (210703)	temperature	oC	Instantainous	measured	01.01.1985	31.12.2009	9131

GIS:

Issue	Name	Metadata available [Y/N]	Remark
Water resources engineering	Flood risk	N	
	Drought risk	N	
Water resources	Irrigation	N	
Hydrology	River and streams	N	
	Discharge gauging stations	N	
Groundwater	Aquifer	N	
	Geology	N	Only mountain area
Meteorology	Rainfall gauging stations	N	

Issue	Name	Metadata available [Y/N]	Remark
Environment	Land use	N	
	Soil	N	
	Wetlands	N	
Infrastructure	Roads	N	
Institutional	Villages	N	
	Municipality	N	
DEM	5x5 m	N	complete

2.1.2 Required data but not yet available

Time series: NN

Metadata:

- For all time series
- For all fields in the GIS shape files

2.2 Huai Sai Bat River Basin

2.2.1 Available data

Time Series:

Huai Sai Bat								
Name	Id	Type	Unit	Interpretation	Origin	Start	End	Data points
Etp.KhonKaen.381201.mm.1d	22	Evaporation	mm	CummulativePerTimestep	derived	01.01.1987	31.12.2012 00:00	9435
ETp.ThaPhraAgromet.381301.mm.1d	23	Evaporation	mm	CummulativePerTimestep	measured	01.01.1987	31.12.2012 00:00	9438
HSB.Q.TR02_Qin.HEC	31	Discharge	m3/s	Instantaneous_(Linear_Interpo	simulated	01.01.2000	01.12.2012 00:00	4719
N annual = 2000mm	29	Precipitation	mm	CummulativePerTimestep	measured	01.01.1987	01.01.2015 00:00	29
N annual = 4000mm	30	Precipitation	mm	CummulativePerTimestep	measured	01.01.1987	01.01.2015 00:00	29
N.KhoenKaen.381201.mm.1d	18	Precipitation	mm	CummulativePerTimestep	measured	01.01.1987	31.12.2012 00:00	9435
N.ThaPhraAgromet.381301.mm.1d	19	Precipitation	mm	CummulativePerTimestep	measured	01.01.1987	31.12.2012 00:00	9438
Q.E68A.Discharge.HuaiSaiBat.Synthetic	33	Discharge	m3/s	Instantaneous_(Linear_Interpo	synthetic	01.01.2000	31.12.2013 00:00	5114
Q.E68A.Discharge.Observed.Lam Phaniang River	32	Discharge	m3/s	Instantaneous_(Linear_Interpo	measured	01.04.1997	31.12.2013 00:00	6119
Q.HuaiSaiBat.SWAT.FirstResults.daily	35	Discharge	m3/s	Instantaneous_(Linear_Interpo	simulated	01.01.1987	31.12.2012 00:00	9497
Q.HuaiSaiBat.SWAT.Results.daily	34	Discharge	m3/s	Instantaneous_(Linear_Interpo	simulated	01.01.2000	31.12.2012 00:00	4749
T.KhonKaen.381201.oC.1d	20	Temperature	oC	Instantaneous_(Linear_Interpo	measured	01.01.1987	31.12.2012 00:00	9435
T.ThaPhraAgromet.381301.cC.1d	21	Temperature	oC	Instantaneous_(Linear_Interpo	measured	01.01.1987	31.12.2012 00:00	9438

Monthly pattern

- Irrigation water requirement (m3/s), district level, monthly pattern
- Domestic water requirement (m3/s), district level, monthly pattern
- Monthly values for crop coefficients for the dominating crops in HSB (Cassava, Forest or trees, Grass, Integrated farm or mixed crops, Rice, Scrub, Sugarcane)

Area	Tambon	District	Province	Irrigation water requirement (MCM)												
				JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Non-irrigated	T.Sua Thao	Chiang Yuen	Mahasarakham	0.466	0.425	0.391	0.178	0.596	0.751	0.338	0.105	0.005	0.296	0.408	0.457	4.416
Non-irrigated	T.Ku Thong	Chiang Yuen	Mahasarakham	0.388	0.355	0.326	0.146	0.241	0.304	0.158	0.056	0.004	0.197	0.340	0.381	2.896
Irrigated	T.Ku Thong	Chiang Yuen	Mahasarakham	0.246	0.115	0.138	0.114	0.104	0.356	0.133	0.033	0.000	0.050	0.000	0.106	1.393
Non-irrigated	T.Kud Pla Dug	Chuen Chom	Mahasarakham	0.334	0.316	0.278	0.148	0.253	0.311	0.120	0.016	0.002	0.162	0.309	0.331	2.580
Non-irrigated	T.Chuen Chom	Chuen Chom	Mahasarakham	0.484	0.459	0.402	0.212	0.370	0.455	0.174	0.022	0.003	0.231	0.447	0.480	3.741
Non-irrigated	T.Nong Kung	Chuen Chom	Mahasarakham	0.203	0.196	0.169	0.081	0.248	0.305	0.101	0.009	0.001	0.098	0.187	0.202	1.799
Non-irrigated	T.Kham Yai	Huay Mek	Kalasin	0.421	0.388	0.391	0.257	0.295	0.367	0.101	0.012	0.002	0.242	0.415	0.407	3.297
Non-irrigated	T.Sai Thong	Huay Mek	Kalasin	0.446	0.407	0.414	0.285	0.115	0.143	0.061	0.014	0.003	0.242	0.440	0.431	3.002
Non-irrigated	T.Phi Mun	Huay Mek	Kalasin	0.443	0.407	0.411	0.272	0.120	0.150	0.058	0.012	0.003	0.225	0.436	0.428	2.965
Non-irrigated	T.Dun Sad	Kra Nuan	Khon Kaen	0.643	0.611	0.546	0.289	0.176	0.209	0.097	0.008	0.001	0.274	0.612	0.635	4.102
Non-irrigated	T.Nam Orm	Kra Nuan	Khon Kaen	0.243	0.227	0.206	0.118	0.241	0.285	0.090	0.004	0.000	0.141	0.232	0.240	2.026
Non-irrigated	T.Nong Ko	Kra Nuan	Khon Kaen	0.921	0.861	0.782	0.455	0.648	0.767	0.270	0.016	0.002	0.507	0.879	0.909	7.016
Non-irrigated	T.Nong Kung Yai	Kra Nuan	Khon Kaen	0.345	0.324	0.293	0.166	0.561	0.664	0.189	0.005	0.001	0.228	0.329	0.340	3.442
Irrigated	T.Khok Sri	Muang Khon Kaen	Khon Kaen	0.444	0.202	0.242	0.188	0.196	0.659	0.203	0.054	0.000	0.078	0.000	0.196	2.461
Irrigated	T.Nong Tum	Muang Khon Kaen	Khon Kaen	0.405	0.184	0.221	0.172	0.179	0.602	0.185	0.049	0.000	0.071	0.000	0.179	2.247
Non-irrigated	T.Ban Kham	Nam Phong	Khon Kaen	0.118	0.109	0.103	0.050	0.224	0.298	0.103	0.037	0.001	0.083	0.111	0.113	1.351
Irrigated	T.Ban Kham	Nam Phong	Khon Kaen	0.468	0.215	0.265	0.227	0.204	0.743	0.228	0.069	0.000	0.091	0.000	0.206	2.716
Non-irrigated	T.Kra-Nuan	Sum Sung	Khon Kaen	0.828	0.727	0.718	0.448	0.290	0.385	0.190	0.164	0.041	0.534	0.812	0.773	5.912
Non-irrigated	T.Kham Mad	Sum Sung	Khon Kaen	0.210	0.186	0.182	0.109	0.225	0.300	0.099	0.065	0.013	0.161	0.206	0.196	1.952
Non-irrigated	T.Khu Kham	Sum Sung	Khon Kaen	0.072	0.064	0.062	0.035	0.157	0.209	0.060	0.035	0.006	0.069	0.070	0.067	0.906
Non-irrigated	T.Ban Non	Sum Sung	Khon Kaen	0.345	0.310	0.300	0.167	0.269	0.358	0.119	0.080	0.017	0.222	0.338	0.322	2.846
Non-irrigated	T.Huay Toei	Sum Sung	Khon Kaen	0.486	0.425	0.422	0.268	0.264	0.352	0.148	0.117	0.028	0.342	0.477	0.454	3.781
Irrigated	T.Khu Kham	Sum Sung	Khon Kaen	0.200	0.089	0.113	0.104	0.088	0.317	0.084	0.043	0.006	0.052	0.000	0.088	1.184
Irrigated	T.Ban Non	Sum Sung	Khon Kaen	0.119	0.053	0.067	0.062	0.052	0.189	0.050	0.025	0.004	0.031	0.000	0.052	0.705

Tambon	District	Province	Domestic water requirement (MCM)												
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
T.Sua Tao	Chiang Yuen	Mahasarakham	0.0070	0.0063	0.0070	0.0068	0.0070	0.0068	0.0070	0.0070	0.0068	0.0070	0.0068	0.0070	0.0736
T.Ku Thong	Chiang Yuen	Mahasarakham	0.0085	0.0077	0.0085	0.0082	0.0085	0.0082	0.0085	0.0085	0.0082	0.0085	0.0082	0.0085	0.0251
T.Kud Pla Dug	Chuen Chom	Mahasarakham	0.0069	0.0062	0.0069	0.0067	0.0069	0.0067	0.0069	0.0069	0.0067	0.0069	0.0067	0.0069	0.0414
T.Chuen Chom	Chuen Chom	Mahasarakham	0.0051	0.0046	0.0051	0.0049	0.0051	0.0049	0.0051	0.0051	0.0049	0.0051	0.0049	0.0051	0.1112
T.Nong Kung	Chuen Chom	Mahasarakham	0.0035	0.0031	0.0035	0.0034	0.0035	0.0034	0.0035	0.0035	0.0034	0.0035	0.0034	0.0035	0.0924
T.Kham Yai	Huay Mek	Kalasin	0.0063	0.0056	0.0063	0.0061	0.0063	0.0061	0.0063	0.0063	0.0061	0.0063	0.0061	0.0063	0.0994
T.Sai Thong	Huay Mek	Kalasin	0.0021	0.0019	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0596
T.Phi Mun	Huay Mek	Kalasin	0.0035	0.0032	0.0035	0.0034	0.0035	0.0034	0.0035	0.0035	0.0034	0.0035	0.0034	0.0035	0.2694
T.Dun Sad	Kra Nuan	Khon Kaen	0.0084	0.0076	0.0084	0.0082	0.0084	0.0082	0.0084	0.0084	0.0082	0.0084	0.0082	0.0084	0.1301
T.Nam Orm	Kra Nuan	Khon Kaen	0.0051	0.0046	0.0051	0.0049	0.0051	0.0049	0.0051	0.0051	0.0049	0.0051	0.0049	0.0051	0.0655
T.Nong Ko	Kra Nuan	Khon Kaen	0.0229	0.0207	0.0229	0.0221	0.0229	0.0221	0.0229	0.0229	0.0221	0.0229	0.0221	0.0229	0.0427
T.Nong Kung Yai	Kra Nuan	Khon Kaen	0.0111	0.0100	0.0111	0.0107	0.0111	0.0107	0.0111	0.0111	0.0107	0.0111	0.0107	0.0111	0.0578
T.Khok Sri	Muang Khon Kaen	Khon Kaen	0.0094	0.0085	0.0094	0.0091	0.0094	0.0091	0.0094	0.0094	0.0091	0.0094	0.0091	0.0094	0.0734
T.Nong Tum	Muang Khon Kaen	Khon Kaen	0.0078	0.0071	0.0078	0.0076	0.0078	0.0076	0.0078	0.0078	0.0076	0.0078	0.0076	0.0078	0.0552
T.Ban Kham	Nam Phong	Khon Kaen	0.0099	0.0089	0.0099	0.0096	0.0099	0.0096	0.0099	0.0099	0.0096	0.0099	0.0096	0.0099	0.1162
T.Kra Nuan	Sum Sung	Khon Kaen	0.0056	0.0050	0.0056	0.0054	0.0056	0.0054	0.0056	0.0056	0.0054	0.0056	0.0054	0.0056	0.0824
T.Kham Mad	Sum Sung	Khon Kaen	0.0036	0.0033	0.0036	0.0035	0.0036	0.0035	0.0036	0.0036	0.0035	0.0036	0.0035	0.0036	0.1000
T.Khu Kham	Sum Sung	Khon Kaen	0.0049	0.0044	0.0049	0.0047	0.0049	0.0047	0.0049	0.0049	0.0047	0.0049	0.0047	0.0049	0.0814
T.Ban Non	Sum Sung	Khon Kaen	0.0062	0.0056	0.0062	0.0060	0.0062	0.0060	0.0062	0.0062	0.0060	0.0062	0.0060	0.0062	0.0601
T.Huay Toei	Sum Sung	Khon Kaen	0.0047	0.0042	0.0047	0.0045	0.0047	0.0045	0.0047	0.0047	0.0045	0.0047	0.0045	0.0047	0.0409

MONTH:	1	2	3	4	5	6	7	8	9	10	11	12
Cassava	0.77	0.8	0.8	0.78	0.3	0.3	0	0	0	0	0.3	0.45
Forest or trees	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Grass	1	1	1	1	1	1	1	1	1	1	1	1
Integrated farm or mixed crops	0.53	0.54	0.47	0.34	0.33	0.35	0.44	0.46	0.38	0.42	0.52	0.4
Rice	0	0	0	0	0.99	1.28	1.11	0.98	0.88	0.80	0	0
Scrub	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sugarcane	0	0	0	1	1.05	1.1	1.1	1.05	1	0.98	0.95	0

GIS:

Issue	Name	Metadata available [Y/N]	Remark
Water resources engineering	Flood risk	Y	
	Drought risk	Y	
	Inundation flood 2008	Y	
	Inundation flood 2011		
Water resources	Irrigation	Y	
	Total dissolved solids	Y	
	Classification for irrigation	Y	
Hydrology	River and streams	Y	
	Reservoir and lakes	Y	
Environment	Land use	Y	
	Basin classification	Y	
	Soil salinity	Y	
	Forest		
Infrastructure	Roads	Y	
Institutional	Villages	Y	
	Tambon	Y	
	District		
	Province		
DEM	30x30 m	-	complete

2.2.2 Required data but not yet available

NN

2.3 Trang River Basin

2.3.1 Available data

Time series:

No time series for modelling are currently available.

GIS:

Issue	Name	Metadata available [Y/N]	Remark
Hydrology	River and streams	N	
	Reservoir and lakes	N	
Environment	Land use	N	
Infrastructure	Roads	N	
Institutional	Villages	N	
	Municipalitiy		
	Tambon	N	
	Amphoe		
	Province		
DEM	Contour lines		

2.3.2 Required data but not yet available

Time series:

- Discharge
- Precipitation
- Temperature
- Humidity
- Evapotranspiration (if available)

In case that no discharge gauging station is located inside the river basin then stations from neighbour basin have to be transferred and adjusted using yields, catchments size or other methods.

Metadata:

- For all time series
- For all fields in the GIS shape files

2.4 Time Series

Each time series needs additional information. These information are referred to as Metadata. This metadata enable a user of a time series to interpret the values properly. Thus, it is needed that metadata are developed for each time series in the following ASCII readable format. The first line should contain the keyword [HEADER] in capitol letters:

Example:

[HEADER]
TimeSeriesName= Daily precipitation
Location= ThaDi river, 2.56km

Latitude= 8°2424'05.27''N
Longitude= 99°48'19.2''E
Unit= mm
Type= precipitation
Origin= measured
Interpretation= accumulative in time step
Description= This is a description of the time series
which had been obtained from RID as an example

The values should come in an ASCII readable information as well with one row for each value containing date and time. Between the time and the value is one blank. The format of the date and time is

YYYYMMDD hhmmss

The first line above the values should contain the keyword [VALUES] in capital letters.

Example:

[VALUES]
20101101 070000;0.0

3 METHOD

3.1 Assessment approach

The assessment approach is based on the following methodologies and protocols:

- GIWA (Global International Water Assessment Methodology)
- HSAP (Hydropower Sustainability Assessment Protocol)

GIWA has been developed by UNEP and is supported by GEF (Global Environment Facility). The Global Environment Facility is a partnership for international cooperation where 183 countries work together with international institutions, civil society organizations and the private sector, to address global environmental issues. The GEF serves as financial mechanism for the following conventions:

- Convention on Biological Diversity (CBD)
- United Nations Framework Convention on Climate Change (UNFCCC)
- Stockholm Convention on Persistent Organic Pollutants (POPs)
- UN Convention to Combat Desertification (UNCCD)
- Minamata Convention on Mercury

The Hydropower Sustainability Assessment Protocol (HSAP) is an enhanced sustainability assessment tool used to measure and guide performance in the hydropower sector. The Protocol:

- Is a framework for assessing the sustainability of hydropower projects
- Distils hydropower sustainability into more than 20 clearly-defined topic
- Provides a consistent, globally-applicable methodology
- Is governed by a multi-stakeholder Council
- Regulated by a Charter and Terms and Conditions of use

The Protocol is the result of intensive work from 2008 to 2010 by the Hydropower Sustainability Assessment Forum, a multi-stakeholder body with representatives from social and environmental NGOs (Oxfam, The Nature Conservancy, Transparency International, WWF); governments (China, Germany, Iceland, Norway, Zambia); commercial and development banks (Equator Principles Financial Institutions Group, The World Bank); and the hydropower sector, represented by IHA. Although not originally developed for vulnerability analysis, it serves as a helpful instrument to provide criteria and information about relevant topics of an assessment.

3.2 Stages of the approach

The approach consist of several stages:

- Geographical scaling
- Scoping
- Causal chain analysis
- Policy option analysis
- Detailed assessment (=integral activity)

Geographical Scaling

Geographical scaling defines the geographic boundaries of the pilot areas to be analysed which is given by the watershed and additional determinations. Subsequently, sub-regions are identified within each project area and major hydrosystem features and economic activities need to be mapped out.

Scoping

Within the scoping procedure the critical major concerns and issues by assessing their environmental and socio-economic impacts are addressed. Considering the near future, estimates of the likely environmental and socio-economic impacts are conducted which is followed by establishing priorities among the major concerns and issues.

Causal chain analysis

This analysis traces the proximate to the root causative factors behind the selected concerns and issues and is conducted to serve as the foundation of the selection of policy options. This stage will mainly be done by the Universities supported by the author. The Cause-Effect Relationships shall be submitted to the author who will restructure the findings according a pattern to easily identify major concerns and their manifold root causes.

Policy option analysis

A policy option analysis indicates potential policy interventions based on the identification of the root causes conducted in the Causal Chain Analysis. For example, it includes the evaluation of alternative scenarios, developed on the basis of projected actions taken to address the identified root causes of environmental degradation.

Detailed assessment

The detailed assessment accompanies the scoping and causal chain analysis process and is therefore not confined to one stage in the assessment process. Since it is an integral activity within the other components, it is carried out at several stages in the assessment process. Is should aim to substantiates the experts conclusions in the other components by identifying and documenting the nature and availability of information related to the selected priority concerns and issues and quantifying the severity of the impacts of the selected concerns and issues.

Unlike the data acquisition process for modelling purposes, it must be noted that the Detailed Assessment is not meant to be a massive data gathering process, but rather a documentation of existing information related to the assessments of impacts of selected priority Major Concerns and Issue(s). These information may come from various sources including previous assessments, research papers, scientific publications, surveys, government reports, status reports, EIA reports, economic reviews, etc. As in this report, however, Detailed Assessment consists of applying different types of models, results from these models constitute the main source complemented by literature that is used to obtain and verify model parameters.

During the Detailed Assessment a more precise indication of geographical locations of Major Concerns and Issues will emerge. Environmental problems may be localized to a certain hot spot, a part of the river or other particular areas.

4 GEOGRAPHICAL SCALING

4.1 Field trip to Tha Di River Basin

The field trip was carried out on 5th of June 2014. The minutes of the field trip including the subsequent meeting on the 6th of June are accessible on the project homepage and are added at the end of this document.

The Tha Di River Basin comprises approximately 546 km² according to the GIS data. The highest point upstream has an elevation of about 1750 masl. The elevation drops to about 40 masl within a distance of about 14 km. The extremely steep slopes generate a high energy potential of water which had led to landslides in the past in the upper part of the river basin and is still a threat considering any kind of land use change. The precipitation between May to September amounts to 100 to 150 mm and 250 to 750 mm from October to January. Nakhon Si Thammarat is the largest town in the project area.

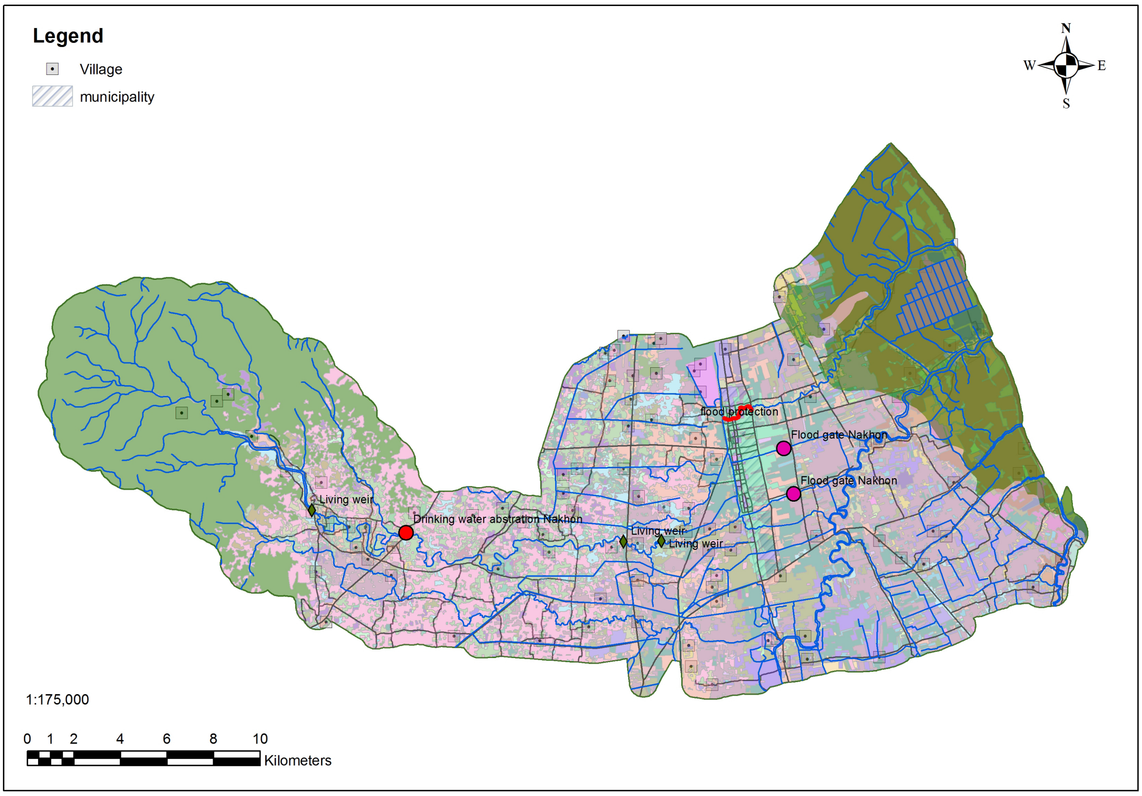


Figure 1: Tha Di River Basin

4.1.1 Agreed boundaries

Additional water is transferred from adjacent river basins via canals into the area in the downstream part of the Tha Di River Basin. Despite that, it was agreed upon using the project area as given in Figure 1 for any further analysis.

The quantity of water conveyed into the project area will be evaluated or estimated by the Walailak University as an overall mean value depending on available data.

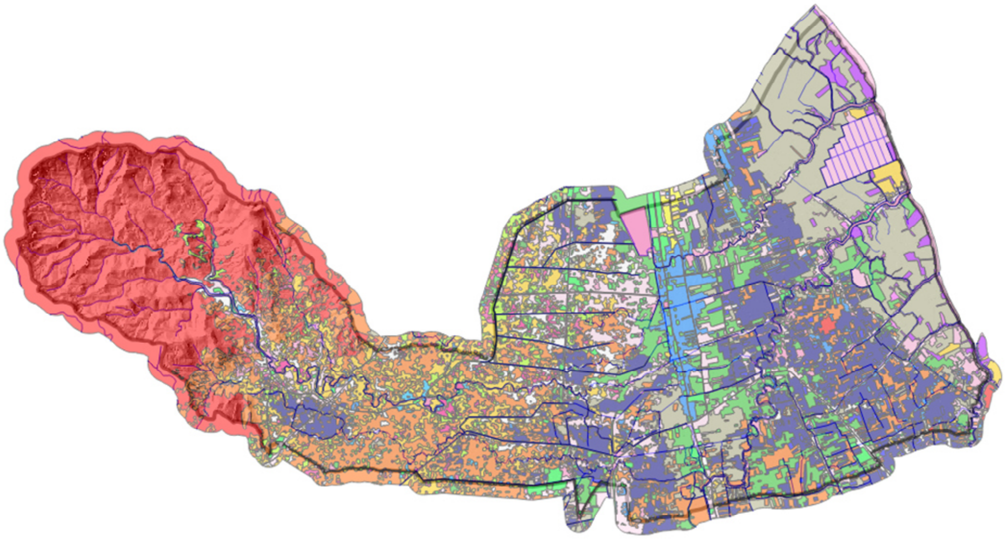


Figure 2: Agreed boundaries of Tha Di River Basin

4.1.2 Sub-regions

Dividing the river basin in sub-regions is one of the first steps towards modelling and helps to identify areas which different characteristics.

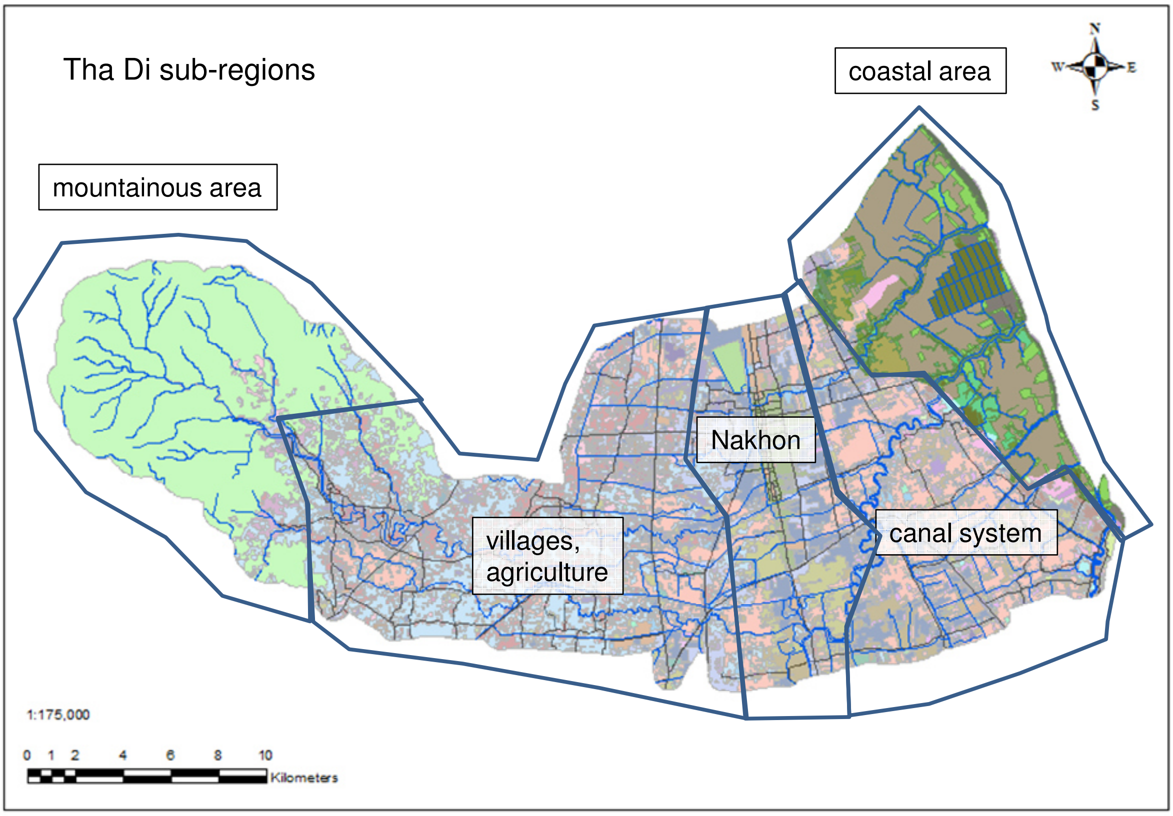


Figure 3: Sub-regions of Tha Di River Basin

4.2 Field trip to Huai Sai Bat River Basin

The field trip was carried out on 10th of June 2014. The minutes of the field trip including the subsequent meeting on the 11th of June are accessible on the project homepage.

The Huai Sai Bat River Basin comprises approximately 678 km² taken from the GIS data. The highest point upstream has an elevation of about 550 masl. The elevation drops to about 150 masl within a distance of about 60 km. Only the headwaters area is covered with forest, where the watercourses stretch over 10 km with steep slopes generating high energy potential of water. The precipitation sums up to 1000 mm/yr. inducing an average discharge of 200mm/yr. Approximately 65000 people live in the river basin which results in 95 inhabitants per sq km.

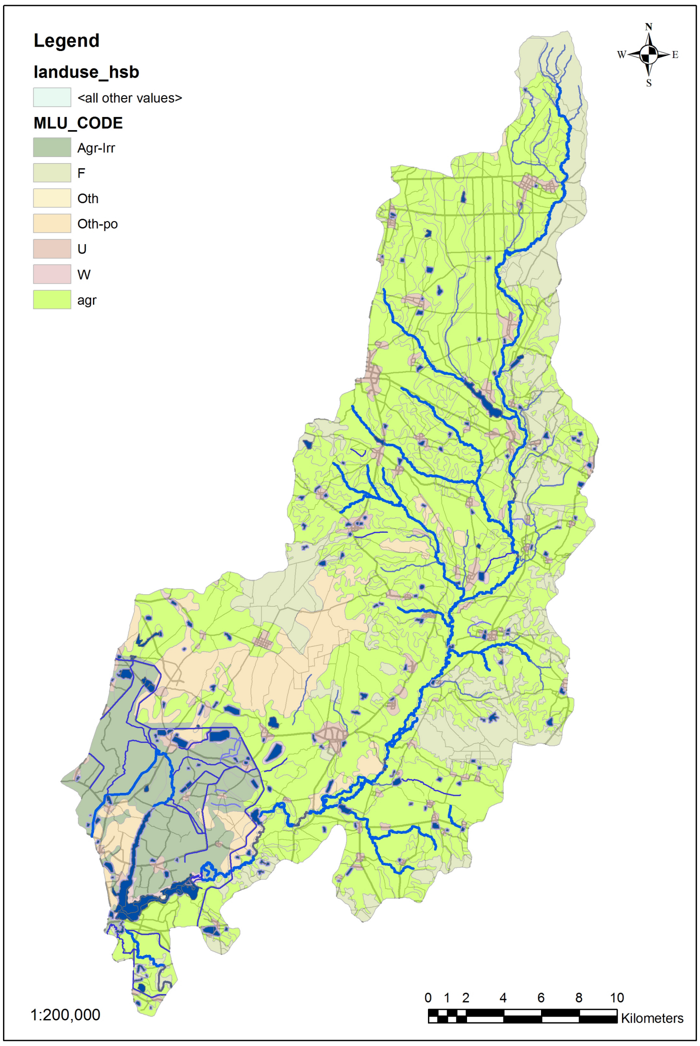


Figure 4: Huai Sai Bat River Basin

4.2.1 Agreed boundaries

Additional water is transferred from the River Nam Phong into the river basin by a large irrigation canal. The diversion is located at the Nong Wai Dam in Naam Pong. As it is not feasible to include the River Nam Phong, it was agreed upon using the project area as given in Figure 5 for any further analysis.

The quantity of water conveyed into the project area will be evaluated or estimated by the Khon Kaen University as an overall mean value depending on available data.

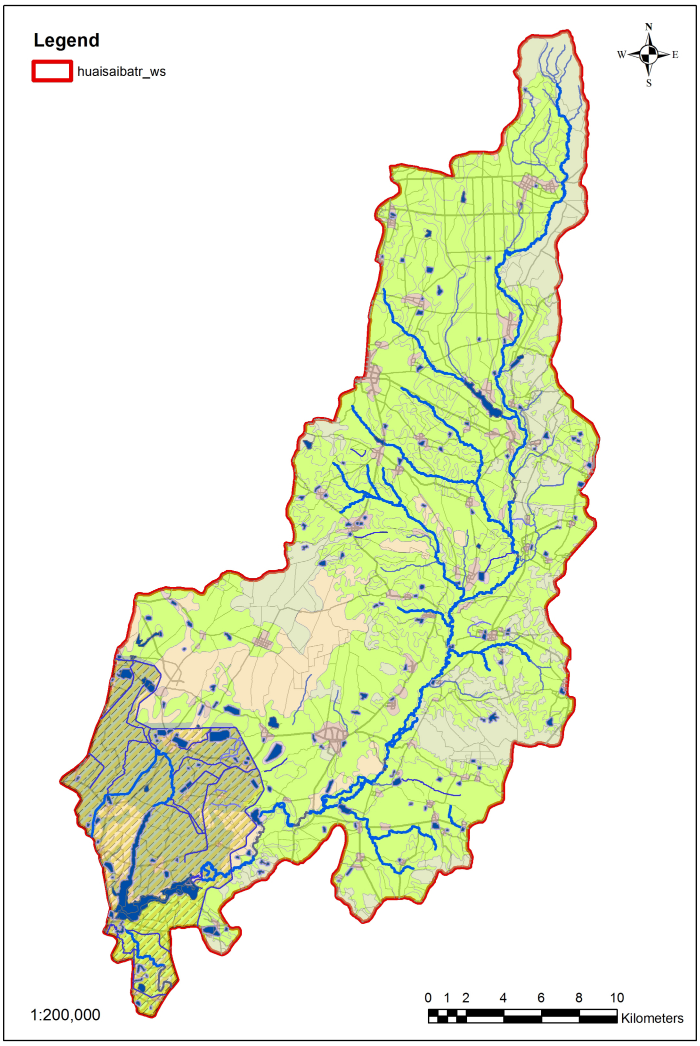


Figure 5: Agreed boundaries of Huai Sai Bat River Basin

4.2.2 Sub-regions

To divide the river basin in sub-regions is one of the first steps towards modelling and helps to identify areas which different characteristics.

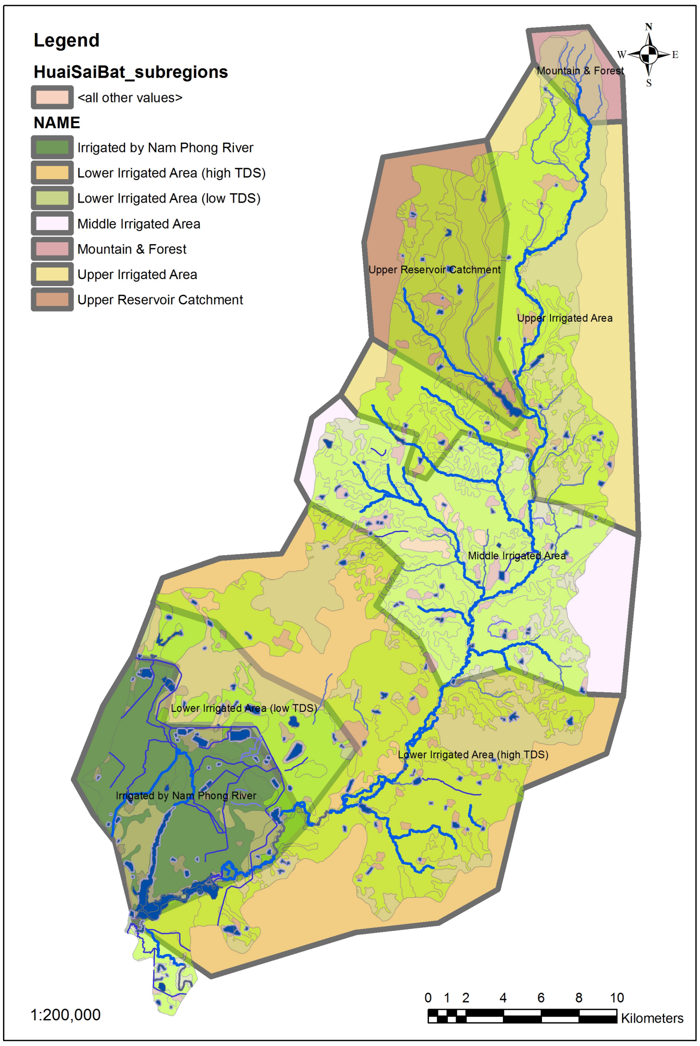


Figure 6: Sub-regions of Huai Sai Bat River Basin

4.3 Field trip to Trang River Basin

The field trip was carried out in November 2013.

The project area is part of the South West river basin. The adjacent river basins are the Tapi river basin in the east and the South East river basin in the north and north-east. The area is demarcated to the north by the Namtok Yong National Park which is part of the Nakhon Si Thammarat mountain ridge extending from Surat Thani in the north up to the border to Malaysia close to Satun in the south. The water divide between the South West and the South East river basin rises up to an altitude of 1000 m.a.s.l. gradually descending from north to northwest to an altitude of about 800 m.a.s.l.. The mountains stretch out to the south with steep slopes. The altitude declines within a rather short distance of 4 to 7 km to the south from 1000 to 100 m.a.s.l.. These high gradients diminish further south where the terrain widens up and changes to be more slightly undulating and finally reaches almost a character of a plain.

The average precipitation amounts to 1800 mm per year and has one distinct “dry” season between January up to March.

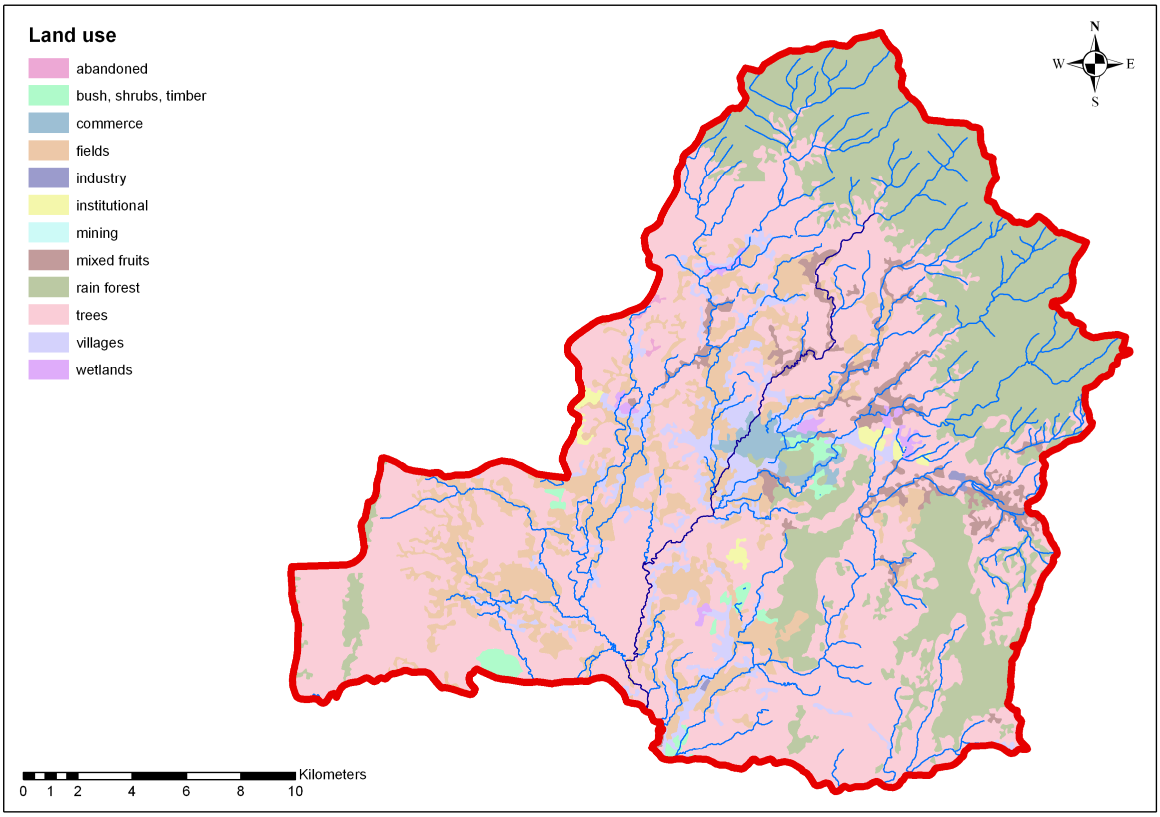


Figure 7: Trang River Basin

4.3.1 Agreed boundaries

The boundaries of the Trang River Basin follows the surface watershed as depicted in Figure 7.

4.3.2 Sub-regions

To divide the river basin in sub-regions is one of the first steps towards modelling and helps to identify areas which different characteristics.

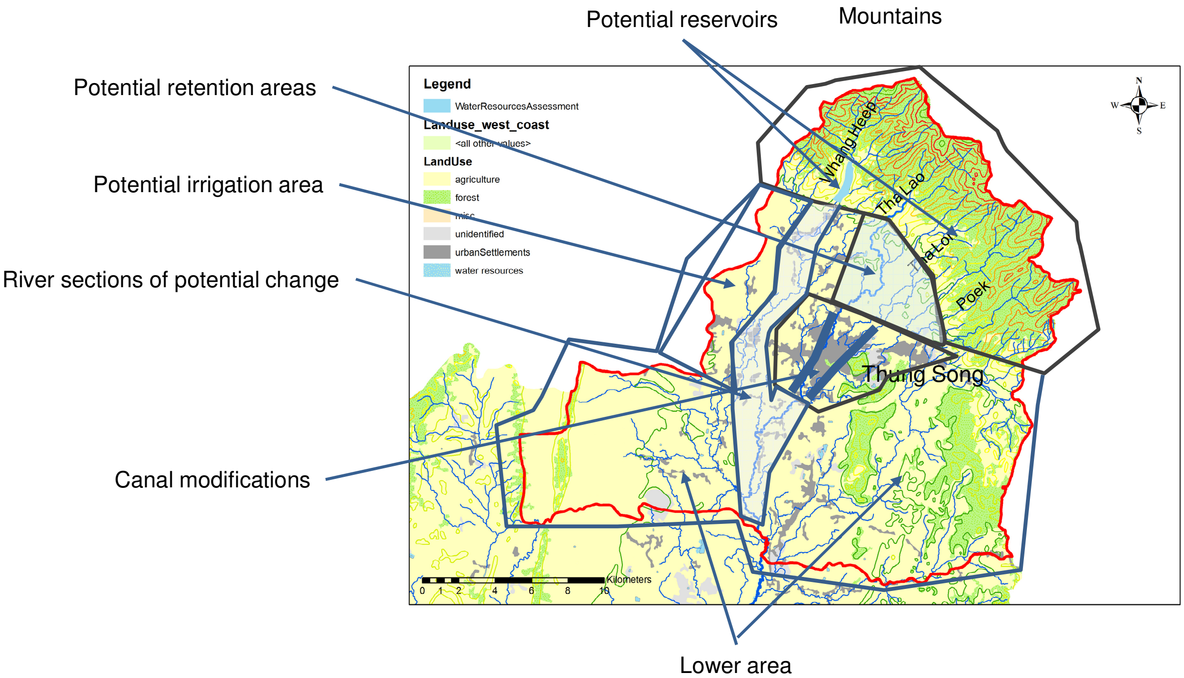


Figure 8: Sub-regions of Trang River Basin

5 SCOPING

5.1 Features of Tha Di River Basin

During and after the field trip, the team identified the following major features:

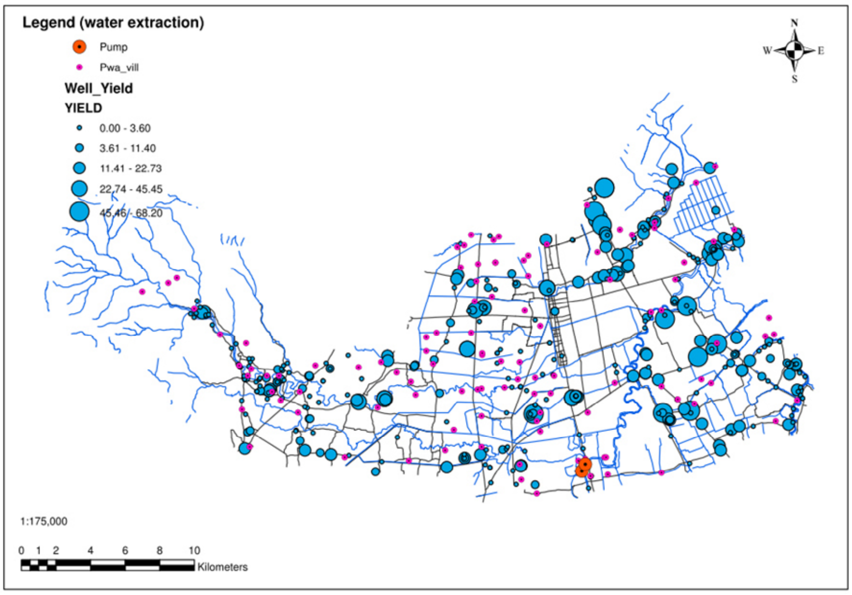
Table 1: Recognized features of Tha Di River Basin

Sector	Features	Rational
Coastal zone	Salt water intrusion	Data about chloride in wells indicate the area affected by salt water intrusion. It is not known whether or not water abstractions from wells enhance intrusion.
Flood control	Flood control gates	Flood control gates exist downstream of Nakhon Si Thammarat in order to prevent salt water flow further upstream. RID is in charge of the gates.
Surface water	Withdrawal for water supply	There is one large pumping station for water supply in the upstream river section of Tha Di River.
Groundwater	Withdrawal for water supply and irrigation	However, water abstraction takes place at every village either from the river or from the groundwater.
Flood protection	Canal modifications	Large modifications within Nakhon Si Thammarat are being undertaken protecting parts of the inner city.
Mining	Soil mining	An area at the edge of the river basin is subject to soil mining. Slopes are cleared to get access to the soil. A larger open pit has been developed over the years.
Fishery	Aquaculture (shrimps)	Close to the shore line ponds are used to breed shrimps. The ponds are filled with water from the river and can be drained into the river.
Fishery	Sea fish	Fishery activities are common along the shore line and can be attributed as an own sector for employment and subsistence.
Fishery	Coastal area	Fishery activities are common in the river close to the coastal zone. However, it is based on individual activities.
Recreation	Recreation areas	Recreation areas exist where the area flattens downstream of the unaccessible mountainous regions. The activities take place at the river banks and in the river itself.
Water resources	Wastewater disposal	Effluents from Nakhon's sewer system directly discharge into canals, only some percent are conveyed to the treatment plant.
Water resources	Waste disposal	Solid waste from Nakhon is transported to a landfill north of project area. However, solid waste pollutes the canals within Nakhon visibly.
Water resources	Mountains	The mountainous area with steep slopes, high water energy potential, fast runoff reveals a distinct difference concerning hydrological characteristics.
Water resources	River improvement	Living weirs which are passable for fish exist at three locations upstream of Nakhon Si Thammarat.
Water resources	River	The diversity of river beds and flow conditions (upstream to downstream) can be considered as a features and might be important for modelling purposes.
Water resources	Canal system	The canal system downstream of Nakhon Si Thammarat is highly interconnected and can be regulated to some extent for irrigation. RID is in charge of the regulations.

Sector	Features	Rational
Irrigation and agriculture	Villages area	The area downstream the mountains and still upstream of Nakhon Si Thammarat is widely used for agriculture and is occupied with countless small villages. This area would constitute a preferred retention area if not occupied by widespread human activities.

Other attributes of the Tha Di river basin are:

- Traditional house construction are built on stilts and therefore have space underneath to help reducing damage during floods. This design principle is surprisingly not visible at new buildings.
- Dredging of canals close to the coast normally takes place once a year according to available budget.



Water abstraction and quantity

Figure 9: Selected features of Tha Di River Basin

5.2 Features of Huai Sai Bat River Basin

During and after the field trip, the team identified the following major features:

Table 2: Recognized features of Huai Sai Bat River Basin

Sector	Features	Rational
Forests	Deforestation and conversion into cultivated land	Official figures maintain that about 30% of the area is covered with forest. This cannot be confirmed according to current satellite images, land use maps, experience and the field trip. Only the mountainous area in the far north is covered with forest.
Water resources	Reservoirs Yong Nai	The reservoir in the upstream area is under pressure concerning water quantity and quality. Considerations are being carried out to abandon the reservoir and to substitute the water with a pipeline from the River Nam Phong. The usable amount of water decreased so drastically due to low inflow and pollution from farmer's

Sector	Features	Rational
		activities. The reservoir is unregulated. The spillway is the only release downstream, no bottom outlets exist.
Water resources	Reservoir Nong Lerng Yai	The reservoir located close to the confluence with River Nam Phong is the biggest freshwater source in the river basin. Obtaining water from the catchment area and from the River Nam Phong irrigation canal, it serves for drinking water purpose and small scale fishery. The spillway is the only release downstream, no bottom outlets exist.
Water resources	Weirs along the river	The Huai Sai Bat River is entirely regulated by weirs. Entirely means that the backwater of a downstream weir reaches the next upstream weir. Each weir is constructed to block the flow completely unless the water level rises over the crest of the weir. Some of the smaller weirs are either damaged or destroyed. Apart from flood events, there is hardly any flow velocity visible along the whole river.
Water resources	Withdrawals for irrigation	Water abstraction takes place upstream of weirs. There are 4 stationary pumping stations along the river and numerous mobile pumps.
Water resources	Withdrawals during flood events	Extensive water abstractions take place at the largest pumping station in order to lower the water level and to avoid inundation of small cultivated fields. These field are located at the river banks, directly upstream the pumps.
Water resources	Effluents from irrigation	Effluents from irrigated areas may contain fertilizers to some extent facilitating growth of algae and increase of deoxygenation.
Water resources	Debris and weirs	Each weir serves as a collector for debris. Only during flood events, debris is relocated and transported further downstream.
Floods	Mountains	The mountainous area in the far north of the river basin reveals a different hydrological characteristic due to steeper slopes, forest land cover and higher water energy potential resulting in fast runoff.
Irrigation and agriculture	Groundwater use	There is only one area within the river basin which relies largely on groundwater.
Floods	Levees and dredging	RID is in charge of the weirs and the maintenance of the river. Dredging is carried out depending on budget and time. When dredging is conducted the sediment is dumped next to the river banks and has led to levees along the river. The area behind the levees are connected by pipes so that during a flood event water can flow into the plains. Elementary structures for regulation are often available like wooden sluices or gates.
Irrigation and agriculture	Soil texture	The soil characteristic and soil salinity is considered to be difficult. About 35% of the soils are classified as low yield for irrigation and over 70% are assign to high salinity.
Water resources	Villages and ponds for water supply	Villages which are not connected to the water supply from the reservoirs often rely on ponds for drinking water. Equipped with small hydraulic structures to withdraw water, the water is pumped to elevated tanks and basic purification methods like mechanical filters are mostly applied.
Irrigation, agriculture and livestock	Villages and small ponds	Small ponds individually dug out by farmers are widespread over the basin. These small structures are commonly used to water fields and for livestock
Fishery	Reservoir Nong Lerng Yai	Fishery activities exist at the reservoir on individual

Sector	Features	Rational
		basis. There is no commercial fishery in place.

Other attributes of the Huai Sai Bat river basin are:

- Water allocation policies on river basin scale or even within irrigation schemes are obviously not in place. It seems to be as if water management follows the rules first come first serve. Water abstractions upstream do not take downstream needs into account and allocation of water within irrigation schemes apparently works without specified contingents. Inquiries during the field trip confirmed conflicts or at least the potential of conflicts.
- Generally, weirs are in good conditions when they are used as roads.

5.3 Features of Trang River Basin

During and after the field trip, the team identified the following major features:

Table 3: Recognized features of Trang River Basin

Sector	Features	Rational
Urban development	Urban and land use planning	Thung Song is supposed to grow. Import and export of products shall enhance logistic capacities and create new job opportunities. As a consequence, coordination of urban/land use planning with flood protection and water resources development is a must.
Water resources	Reservoir development	Two potential location for reservoirs have been identified by RID. Reservoir development needs to address sedimentation, water quality, land use in the catchment area, design of spillway and operation rules and requires further hydrologic and hydraulic analysis.
Flood protection	Canal modifications	Large modifications within Thung Song would be necessary to protect parts of the inner city. However, Additional measures upstream of the city are unconditionally required since canal improvement are limited.
Flood protection	Weirs	Large weirs exist upstream of Thung Song with the potential to divert water but are currently not equipped with regulation structures.
Flood protection	Canal system	The canal system downstream of Thung Song has caused backwater due to insufficient capacities.
Urban development	Informal settlements	There are informal settlements in the national park which hamper water resources development and contradict the conservation of the national park.
Urban development	Flood area zoning	At this time, no flood area zoning is in place which is in turn a prerequisite for sustainable flood protection. Hence, flood protection calls for strong coordination of land use and water resources planning.
Water resources	Erosion and sedimentation	Erosion is generally an issue in Thailand and in particular at steep mountainous area in the headwaters of the Trang river basin. Coping with this problem is complex as different topics has to be addressed like:

Sector	Features	Rational
		Disturbance of sediment budget downstream a reservoir River bank erosion along the river developed Change of river morphology Sedimentation of reservoir storage Components or chemical parameter in the sediment with effects on water quality Land use change and erosion/sediment rates
Surface water	Withdrawal for water supply	There is one pumping station for water supply in the upstream river section of Khlong Poek.
Water resources	Mountains	The mountainous area with steep slopes, high water energy potential, fast runoff reveals a distinct difference concerning hydrological characteristics.
Water resources	River	The diversity of river beds and flow conditions (upstream to downstream) can be considered as a features and might be important for modelling purposes.
Irrigation and agriculture	Villages area	The area downstream the mountains is widely used for agriculture and is occupied with small villages. This area would constitute a preferred user of future supply by a reservoir for the extension of irrigation.
Not verified but assumed features:		
Water resources	Wastewater disposal	Effluents from Nakhon's sewer system directly discharge into canals, only some percent are conveyed to the treatment plant.
Water resources	Waste disposal	Solid waste from Nakhon is transported to a landfill north of project area. However, solid waste pollutes the canals within Nakhon visibly.

Other attributes of the Trang river basin are:

- The current situation for Thung Song in terms of flood protection is unsatisfactory. Flooding of the city takes places every year over a few days which can be confirmed theoretically by using flood frequency analysis and comparing with canal capacity.
- Water resources development is a major issue of Thung Song. The town will face development in regard to an increase of water demand so that the likelihood of water scarcity rises.
- An optimal solution can be identified as a combined measure which covers the needs of flood protection in conjunction with the development of storage capacity for water supply. However, any development needs an integrated and holistic approach to avoid adverse effects and to achieve sustainable solution on the long term.

6 CAUSAL-CHAINS

In the following chapter, causal-chains for the three project areas are given according to a formalized pattern. The pattern consists of three parts.

Header:

No	River basin	Sector activity: …

No: number is ascending within each river basin, the colour indicates the evidence

River basin: Name of the river basin

Sector activity: Indication which sector is concerned

low evidence	middle	middle to high	high

Causal-chain:

The causal-chain itself consists of keywords about root causes, immediate causes, impacts and final environmental or socio-economic impacts.

Verification:

Verification substantiates the causal-chains. Whenever it is possible, it is backed with data, calculations or any other proven indicators. However, some chains still lack of any data and are based on visual estimation during the field trips.

Overview:

The causal chain analysis closes with an overview given in a matrix. The matrix summarises all cause-effect relationships and indicates whether or not further verification, for instance by modelling, was carried out. This matrix serves also as an introductory table for the following section about verification and modelling.

6.1 Tha Di River Basin

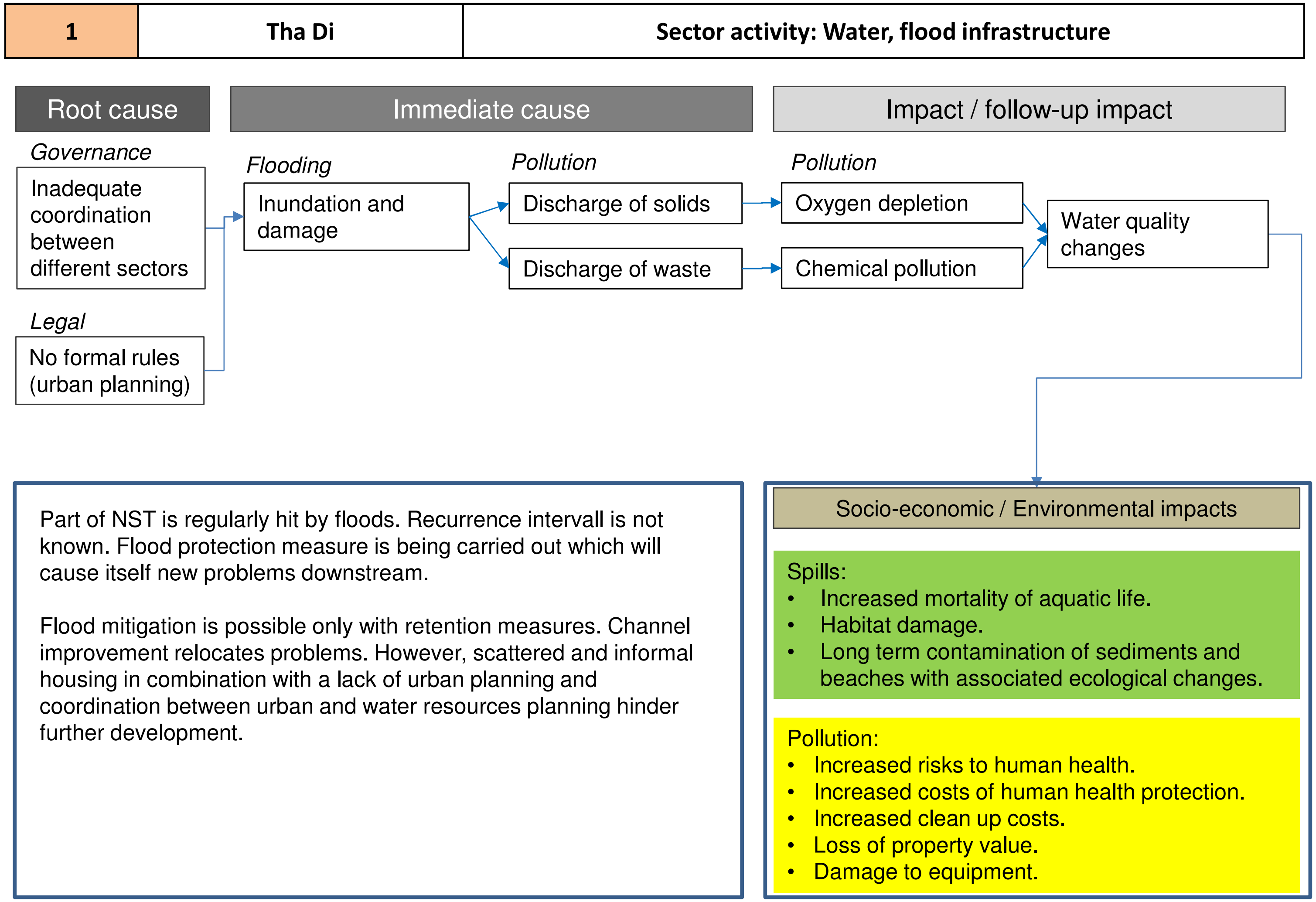


Figure 10: Causal-chain - water quality and effluent disposal within NST

Verification:

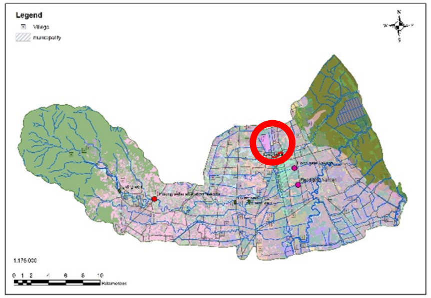
The river passing Nahkon Si Tammarat is widely used to litter waste which is exacerbated during flood events when water level overtops the river banks and flushes streets and its immediate vicinity. The change in water quality is visible from upstream to downstream of NST. Also the sewer system is in inadequate conditions as it is visible within NST.

Indicator or supporting information & unit	Changes are clearly visible in the canals downstream
Format (map, report, data, etc.)	Field trip
Extent or area covered	Nakhon Si Tammarat, centre
Duration	Sewer system spills waste water even during dry conditions, sewers lack maintenance
Reliability	high
Availability	-
Sources of data or contact to obtain data and information	Field trip
Brief explanation or justification	Assumption according to visible indicators

2	Tha Di	Sector activity: Water, flood infrastructure

Root cause	Immediate cause	Impact / follow-up impact
Legal / Governance No formal rules (urban planning) *Technology* Inadequate knowledge of technological and technical response functions	*Flooding* Increase of flow velocity Increase of peak flows	*Flooding* Loss of retention

The infrastructure relocates the problem downstream. There is a lack of upstream compensatory measures like detention ponds, retention etc.. Needless to say that the measure is a negative eye-catcher!



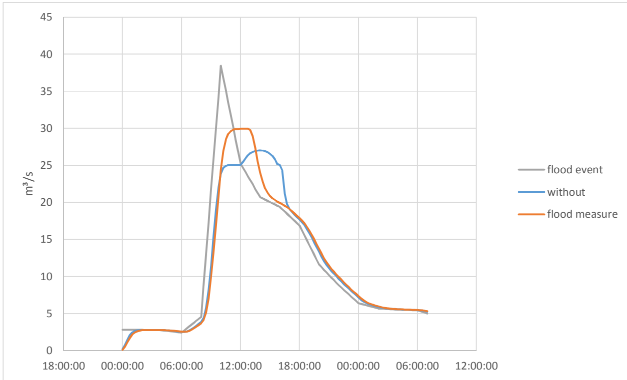
Socio-economic / Environmental impacts

Flooding:
- Relocation of problems
- Inundation and damage to human life and property (downstream)
- Response costs for extreme events (downstream)
- Loss of well-being, increase of fear and uncertainty
- Unequal treatment

Figure 11: Causal-chain - flood protection infrastructure and modification in stream flow, NST

Verification:

The river passing Nahkon Si Tammarat is widely used to litter waste which is exacerbated during flood events when the water level overtops the river banks and flushes streets and its immediate surrounding. The change in water quality is visible from upstream to downstream of NST. Also the sewer system is believed to be in inadequate conditions as it is visible within NST.

channel modification	rough hydraulic estimate about change of peak flow
	

Indicator or supporting information & unit	responsible for design = RID
Format (map, report, data, etc.)	field trip, design flood needed, report from RID would be useful
Extent or area covered	Nakhon, down town
Duration	flood events since years are obvious, more information from RID report needed
Reliability	high
Availability	-
Sources of data or contact to obtain data and information	field trip, contact to RID necessary
Brief explanation or justification	proven effects due to such measures, flow accelleration, less retention, flood problem is propagated downstream

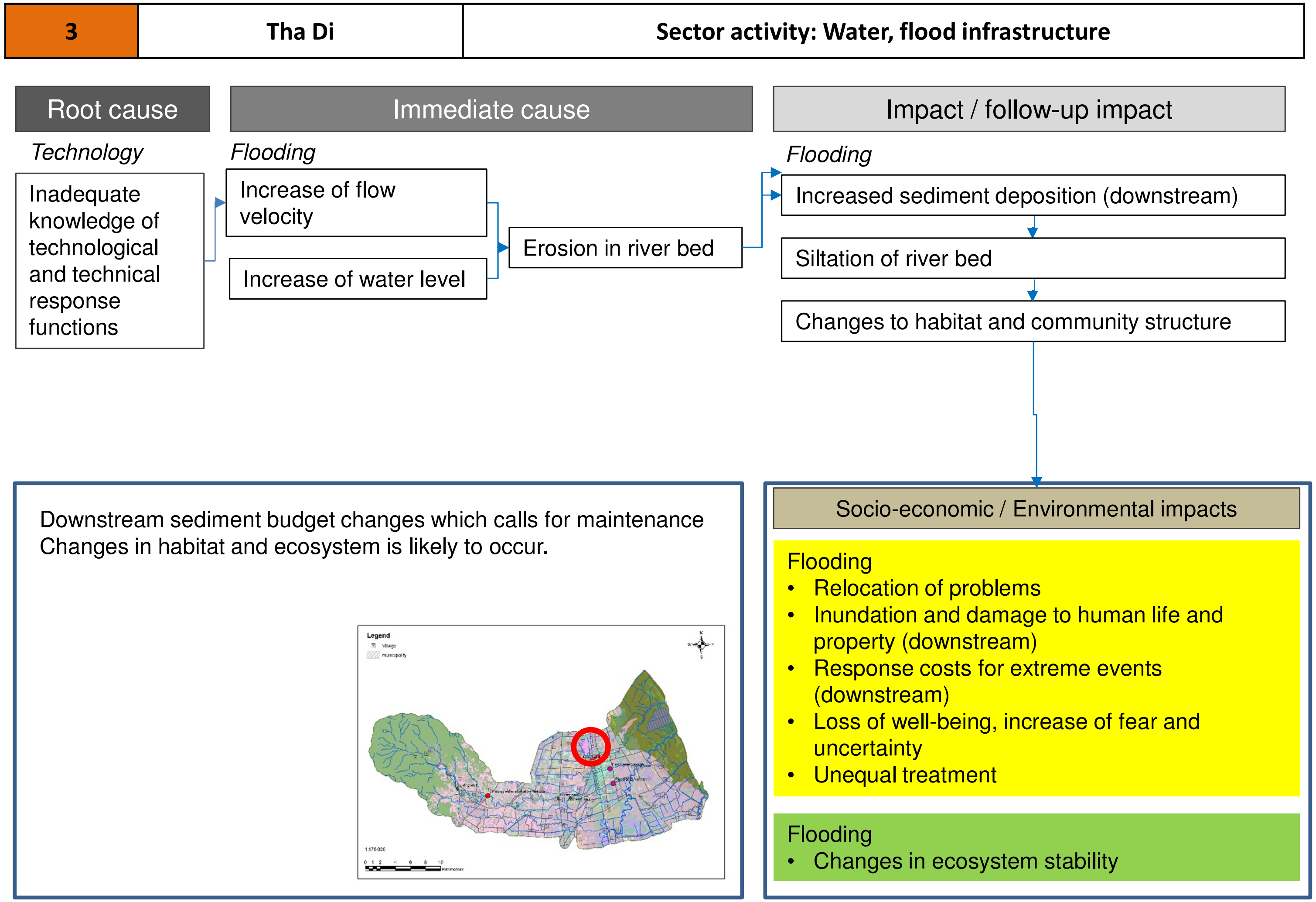


Figure 12: Causal-chain - flood protection infrastructure and modification in sediment budget, NST

Verification:

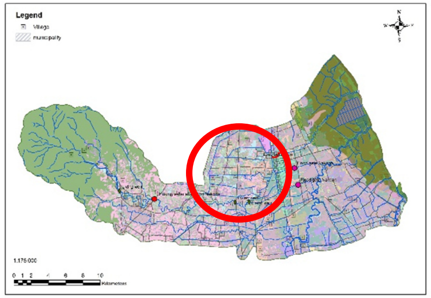
The assumption is that the river bed has not been fortified along the reach of channel modification. If so, erosion will unavoidably take place and sediment is deposited further downstream when flow velocity and water transport energy accordingly is reduced.

Indicator or supporting information & unit	responsible for design = RID
Format (map, report, data, etc.)	field trip, design flood needed, report from RID would be useful
Extent or area covered	Nakhon, down town
Duration	flood events since years are obvious, more information from RID report needed
Reliability	high
Availability	-
Sources of data or contact to obtain data and information	field trip, contact to RID necessary
Brief explanation or justification	proven effects, hydraulic principle, higher flow depth with increasing flow velocity causes erosion

4	Tha Di	Sector activity: Urbanization

Root cause	Immediate cause	Impact / follow-up impact
Legal Laws and regulations *Demographic* Urbanization trend	*Flooding* Loss of retention area	*Flooding* Modification of stream flow

Real estate development in retention area upstream of NST. They are built on artificially raised ground to protect the buildings against floods. There are no compensatory measures to balance lost retention area.



Socio-economic / Environmental impacts

Flooding:
- Inadequate compensatory measures
- Inundation and damage to human life and property (downstream)
- Response costs for extreme events (downstream)

Freshwater shortage:
- Reduction in options for future use
- Loss of agricultural uses

Figure 13: Causal-chain - real estate development upstream of NST

Verification:

Aerial photographs and satellite images give rise to verify the erection of buildings upstream of NST.

Indicator or supporting information & unit	community, land development department, provincial officers
Format (map, report, data, etc.)	field trip, time series of aerial photography & satellite images, land use change report, city planning
Extent or area covered	Nakhon, down town
Duration	flood events since years are obvious, more information from DPM (department of disaster prevention and mitigation department) report needed
Reliability	high
Availability	-
Sources of data or contact to obtain data and information	field trip, community, NST-DPM
Brief explanation or justification	Increate of flood related problems

5	Tha Di	Sector activity: Aquaculture, operation

Root cause | Immediate cause | Impact / follow-up impact

Economic

Inadequate valuation of environmental goods and services

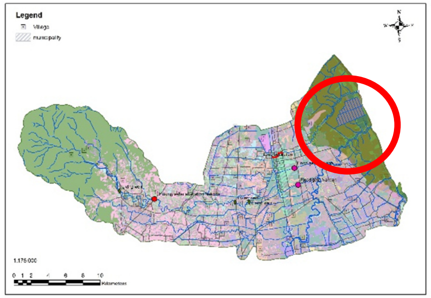
Pollution

Chemical releases (not proven)

Pollution

Long term contamination of sediments and beaches with associated ecological changes downstream

Large shrimp ponds are located close to the cost. The following is not proven but assumed:
The aquaculture uses chemicals to enhance shrimps production. After one production circle, water from the ponds is released into river,
As well the sediment after harvesting, which may contain chemicals. .



Socio-economic / Environmental impacts

Pollution:

- Increased clean up costs.
- Loss in fisheries.
- Endangerment of species.

Figure 14: Causal-chain - aquaculture with shrimps ponds, coastal area

Verification:

No verification at this time.

Verification needed, addressing the following

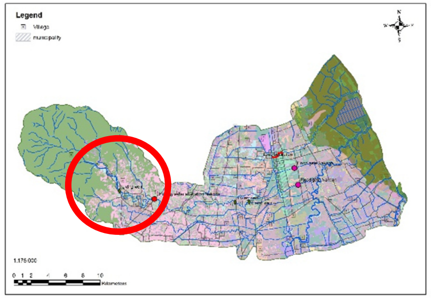
Indicator or supporting information & unit	Clean up procedures of the fish ponds after harvesting and type of chemicals they use?
Format (map, report, data, etc.)	Material which is drained out of the fish ponds and where this is somehow documented?
Extent or area covered	Coastal zones, wetlands close to the shoreline
Duration	How often does cleaning and disposal happen within one year and since when it is recorded?
Reliability	How is this practice proven (reports, anything else, etc.)
Availability	Source for information
Sources of data or contact to obtain data and information	Contact person for further information
Brief explanation or justification	

6	Tha Di	Sector activity: other (recreation)

Root cause	Immediate cause	Impact / follow-up impact
Socio-cultural	*Pollution*	*Pollution*
Lifestyles →	Inadequate treatment of point sources discharges →	Water quality changes

Recreational areas are developed upstream of the water supply intake.

The area is large enough to suit several hundred people. However, the immediate causes are only assumptions.



Socio-economic / Environmental impacts

Pollution:
- Increased clean up costs..

Figure 15: Causal-chain - recreational areas upstream of water withdrawal for water supply

Verification:

No verification at this time.

Needs verification addressing the following

Indicator or supporting information & unit	How are waste and sewer systems implemented or in place at the site? How is safety of water quality guaranteed?
Format (map, report, data, etc.)	Indicate here data used for verification
Extent or area covered	River banks and immediate surrounding upstream of withdrawal for water supply of NST
Duration	How often is this area used for events?
Reliability	How is this practice proven (reports, anything else, etc.)
Availability	Source for further information?
Sources of data or contact to obtain data and information	Contact person for further information
Brief explanation or justification	

7	Tha Di	Sector activity: Water infrastructure

Root cause	Immediate cause	Impact / follow-up impact

Knowledge

Knowledge of technology and technical response functions

Freshwater

Increase of water table

Modification of stream flow

Diversity of flow velocities

Diversity of river bed structures

Increase of water table

Increased aquifer capacity

Recovery of ecosystems or ecotones

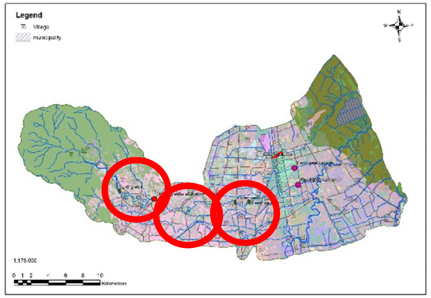
As a result of adequate flow conditions

As a result of developing habitats

As a result of adequate river bed diversity

Living weirs are weirs made with natural material like bamboo and sandbags and function like normal weirs but allow water and fine sediments to pass the structure.

Source: Deutsche Welle



Socio-economic / Environmental impacts

Freshwater:
- Gain of agricultural uses
- Fostering of solidarity and responsibility
- Use of biologically friendly material with business case potential

Figure 16: Causal-chain - positive effects of ecosystem-based hydraulic structures

Verification:

Living weirs are build, maintained since a couple of years. Since the first erection, experience was and still is gathered mainly under supervision of Khun Suthira, Professor at Wailalak University. Positive effects are proven. Reported negative effects downstream in the sense of having less water available may stem from misinterpretation of real root causes as the size and geometry of the weirs do not allow for large scale retention of water.

Indicator or supporting information & unit	Measurements in the field observed by Wailalak University
Format (map, report, data, etc.)	Foto documentation, field trips, recorded water levels
Extent or area covered	Immediate surrounding of the weirs
Duration	Permanent structure with maintenance required after rainy season
Reliability	High
Availability	-
Sources of data or contact to obtain data and information	Khun Suthira, Wailalak University
Brief explanation or justification	

8	Tha Di	Sector activity: Coastal zones, aquaculture, biodiversity

Root cause

Economic

Economic growth

Technological

Inadequate knowledge of technological and technical response functions

Immediate cause

Loss of ecosystems or ecotones

Conversion of mangroves in aquaculture and other land use forms

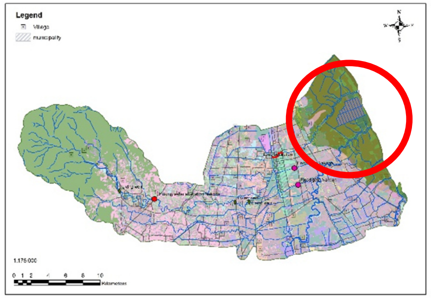
Impact / follow-up impact

Habitat and Community Modification

- Loss of mangrove ecosystems
- Loss of biodiversity
- Loss of storm buffer
- Loss of sediment and nutrient buffer

Mangroves have been reduces significantly over the past years resulting in severe consequencies which will be fully isible in future

Reducing mangroves is a long-term effect with could become irreversible when a certain tipping point is exceeded.



Socio-economic / Environmental impacts

Pollution:
- Increased clean up costs
- Increased costs of human health protection
- Increased risks to human health

Figure 17: Causal-chain - conversion of mangroves into aquaculture ponds

Verification:

Reduction of mangroves observed over time by NASA Landsat programme

1994 2001 2005 2013

Source: Presentation Khun Suthira, 06 Nov 14

Indicator or supporting information & unit	Satellite images
Format (map, report, data, etc.)	Satellite images
Extent or area covered	Complete extent of coastal area of Tha Di river basin
Duration	Permanent, long-lasting process
Reliability	High
Availability	-
Sources of data or contact to obtain data and information	NASA Landsat programme, visible on the ground
Brief explanation or justification	

9	Tha Di	Sector activity: Agriculture, forestry

Root cause	Immediate cause	Impact / follow-up impact

Economics

- Prices (inputs, outputs, consumption goods).
- Market structure

Technological

- Infrastructure provision ► roads

Deforestation

- Remobilization of suspended solids
- Changes in sediment budgets
- Change in soil characteristics
- Increased soil erosion

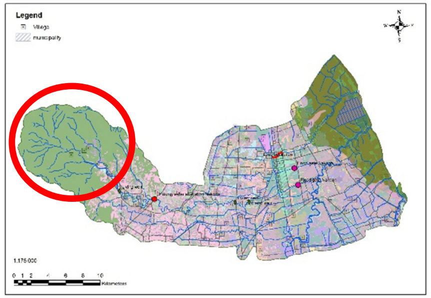
Modification of stream flow

- River bed siltation with impacts on macro-zoobenthos
- Increase of peak flows
- Increase risk of landslides

River and stream alteration

Land use change takes place in the mountainous area causing land degradation accompanied with erosion and sedimentation

The process is mainly initiated because of access roads. Once the topsoil is lost, the process is irreversible. Effects concern hydrologic regime and sediment budgets which in turn affects flow regime due to alteration of river bed and cross sections.



Socio-economic / Environmental impacts

Freshwater shortage:

- Increased maintenance costs
- Increased damage to water related equipment

Flooding:

- Inundation and damage

Figure 18: Causal-chain - deforestation, Tha Di mountain area

Verification:

Land use changes are visible in the field. The process increases with population growth causing higher pressure on the mountainous area. Verification is carried out by means of modelling

Indicator or supporting information & unit	Field trip
Format (map, report, data, etc.)	Fotos, land use maps
Extent or area covered	Mountain area
Duration	Long-term process
Reliability	High
Availability	-
Sources of data or contact to obtain data and information	Among other, Wailalak University, municipalities
Brief explanation or justification	

10	Tha Di	Sector activity: Urbanization

Root cause | **Immediate cause** | **Impact / follow-up impact**

Demographic
- Population growth
- Urbanization trends

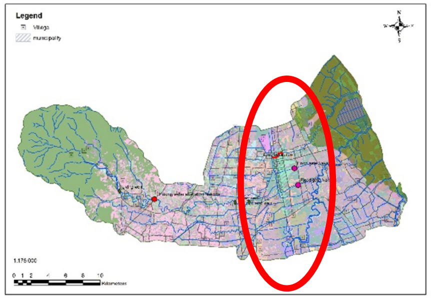
Technological
- Lack of maintenance

Pollution
- Discharge of effluents
- Runoff and storm waters

Suspended solids and chemical
- Oxygen depletion
- Generation of fish toxic ammonia

The urbanization trend is believed to be in existence for Nakhon sind population is increasing. The threat arises in situation when the sewer systems spills but natural discharge is still low.

This happens quite often within one years time and has the potential to generate fish toxic ammonia.



Socio-economic / Environmental impacts

Pollution:
- Increased mortality of aquatic life.
- Habitat damage.
- Long term contamination of sediments and beaches with associated ecological changes.

Pollution:
- Increased risks to human health.
- Increased costs of human health protection.
- Increased clean up costs.
- Loss of property value.
- Damage to equipment.

Figure 19: Causal-chain - urbanization with increasing effluent discharges

Verification:

Verification can be carried out by means of water quality modelling with a combined sewer system, water quality and hydrological model. As no measured values are available assumptions about pollution loads are necessary which take conditions of Thailand as good as possible into account.

Indicator or supporting information & unit	Assumption
Format (map, report, data, etc.)	Modelling approach
Extent or area covered	Nakhon and downstream river reaches
Duration	Single events
Reliability	Medium to high
Availability	-
Sources of data or contact to obtain data and information	Literature and field trip
Brief explanation or justification	

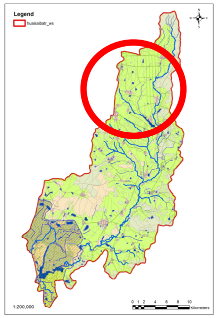
6.2 Huai Sai Bat River Basin

1	Huai Sai Bat	Sector activity: Agriculture, Water resources management

Root cause	Immediate cause	Impact / follow-up impact
Knowledge	*Pollution*	*Pollution*
Inadequate valuation of environmental goods and services	Agricultural runoff	Trapping of nutrients
	Remobilization of suspended solids	Increased algal blooms

The reservoir Nong Yai is at risk to be abandoned since problems to obtain drinking water are rising. Ongoing agriculture activities excarbate an obviously scarce water supply situation.

It is most likely that not only water quality is a concern but also water abstraction and use for irrigation and probably wrong priorities.



Socio-economic / Environmental impacts

Freshwater shortage

- Loss of human drinking water supplies
- Increased potential for conflicts
- Reduction in options for future use
- Increased costs for alternative sources for water supply

Figure 20: Causal-chain - agriculture upstream of Nong Yai reservoir

Verification:

No water quality or quantity records are at hand. However, reservoir operators confirmed the ongoing critical situation.

Indicator or supporting information & unit	In June 2014, reservoir was almost empty. Operators complaint about the water quality and quantity situation
Format (map, report, data, etc.)	Interview in the field.
Extent or area covered	Reservoir and catchment area
Duration	Long-term activity
Reliability	High, as the supply situation worsened in recent years
Availability	Reservoir water level records and quality records (if any)
Sources of data or contact to obtain data and information	Reservoir operators and municipal drinking water suppliers
Brief explanation or justification	

2	Huai Sai Bat	Sector activity: Agriculture, Water resources management

Root cause	Immediate cause	Impact / follow-up impact

Knowledge

Inadequate valuation of environmental goods and services

Eonomic

Subsidies, Income

Pollution

Agricultural runoff

Remobilization of suspended solids

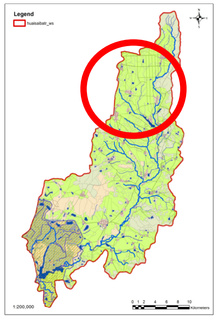
Modification of stream flow

Increased sediment deposition

Contaminated sediment

The reservoir Nong Yai is at risk to be abandoned since problems to obtain drinking water are rising. Ongoing agriculture activities excarbate an obviously scarce water supply situation.

This causal-chain addresses sediment deposition in the reservoir body which might be contaminated or at least tend to pollute the drinking water quality.



Socio-economic / Environmental impacts

Pollution
- Long term contamination of sediments with associated ecological impacts

Pollution:
- Increased clean up costs.

Figure 21: Causal-chain - sedimentation into Nong Yai reservoir

Verification:

No records about sedimentation and its quality are at hand. However, according to the second causal-chain, it is very likely that sedimentation will constitute a problem during low flow conditions.

Indicator or supporting information & unit	In June 2014, reservoir was almost empty. Operators complaint about the water quality and quantity situation
Format (map, report, data, etc.)	Interview in the field.
Extent or area covered	Reservoir and catchment area
Duration	Long-term activity
Reliability	High, as the supply situation worsened in recent years
Availability	Reservoir water level records and quality records (if any)
Sources of data or contact to obtain data and information	Reservoir operators and municipal drinking water suppliers
Brief explanation or justification	

3	Huai Sai Bat	Sector activity: Agriculture, Water resources management

Root cause

Economic
- Prices (inputs, outputs, consumption goods)
- Income
- Market structure

Immediate cause

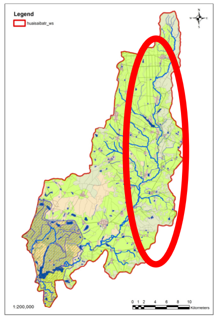
Modification of stream flow
- Increased diversion

Impact / follow-up impact

Unsustainable exploitation
- Potentially severe impacts on ecosystems
- Ecosystem degradation

The River Huai Sai Bat is completly developed with weirs. They provide backwater and allow pumping of water even in times where flow tends to be zero.

Water abstraction takes place in less coordinated manner. First come, first serve is the principle causing potential conflicts. Upstream users are in the best position to profit from any flow.



Socio-economic / Environmental impacts

Freshwater shortage:
- Increased potential for conflicts
- Reduction in options for future use
- Conflicts among user groups

Unsustainable exploitation of living resources:
- Conflicts among user groups

Figure 22: Causal-chain - water abstraction on irrigation scheme level along Huai Sai Bat River

Verification:

No water quantity records are at hand yet. However, farmers and pump operators confirmed that those reporting first obtain water first. Whether or not a water allocation scheme is in place is unknown.

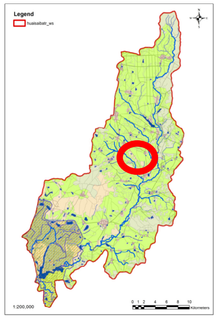
Indicator or supporting information & unit	In June 2014, almost 100% or the area is agriculturally used whereas only some parts of the area actually obtain water from the river.
Format (map, report, data, etc.)	Interview in the field.
Extent or area covered	River basin
Duration	Long-term activity
Reliability	High, as it is visible, confirmed by stakeholders and a known issue at Khon Kaen University gathered during several field trips
Availability	
Sources of data or contact to obtain data and information	Farmer association and RID
Brief explanation or justification	

4	Huai Sai Bat	Sector activity: Agriculture, Water resources management

Root cause	Immediate cause	Impact / follow-up impact
Economic Income *Knowledge* Inadequate scientific understanding	*Modification of stream flow* Increased diversion (single location)	*Unsustainable exploitation* Potentially severe impacts on ecosystems Ecosystem degradation

The River Huai Sai Bat is completly developed with weirs. They provide backwater and allow pumping of water even in times where flow tends to be zero.

Extensive pumping during floods to lower the water level so as to avoid flooding of fields takes place. Because the capacity of the pumps are lage, the effect is high.



Socio-economic / Environmental impacts

Freshwater shortage:
- Increased potential for conflicts
- Reduction in options for future use
- Conflicts among user groups

Unsustainable exploitation of living resources:
- Conflicts among user groups

Figure 23: Causal-chain - water abstraction on individual level along Huai Sai Bat

Verification:

No water quantity or pump records are at hand yet. The case was reported by the pump operator.

Indicator or supporting information & unit	In June 2014, personal information by the pump operator
Format (map, report, data, etc.)	Interview in the field.
Extent or area covered	One location
Duration	Every rainy season
Reliability	High, as it is visible, confirmed by stakeholders and a known issue at Khon Kaen University gathered during several field trips
Availability	.
Sources of data or contact to obtain data and information	Pump operator
Brief explanation or justification	

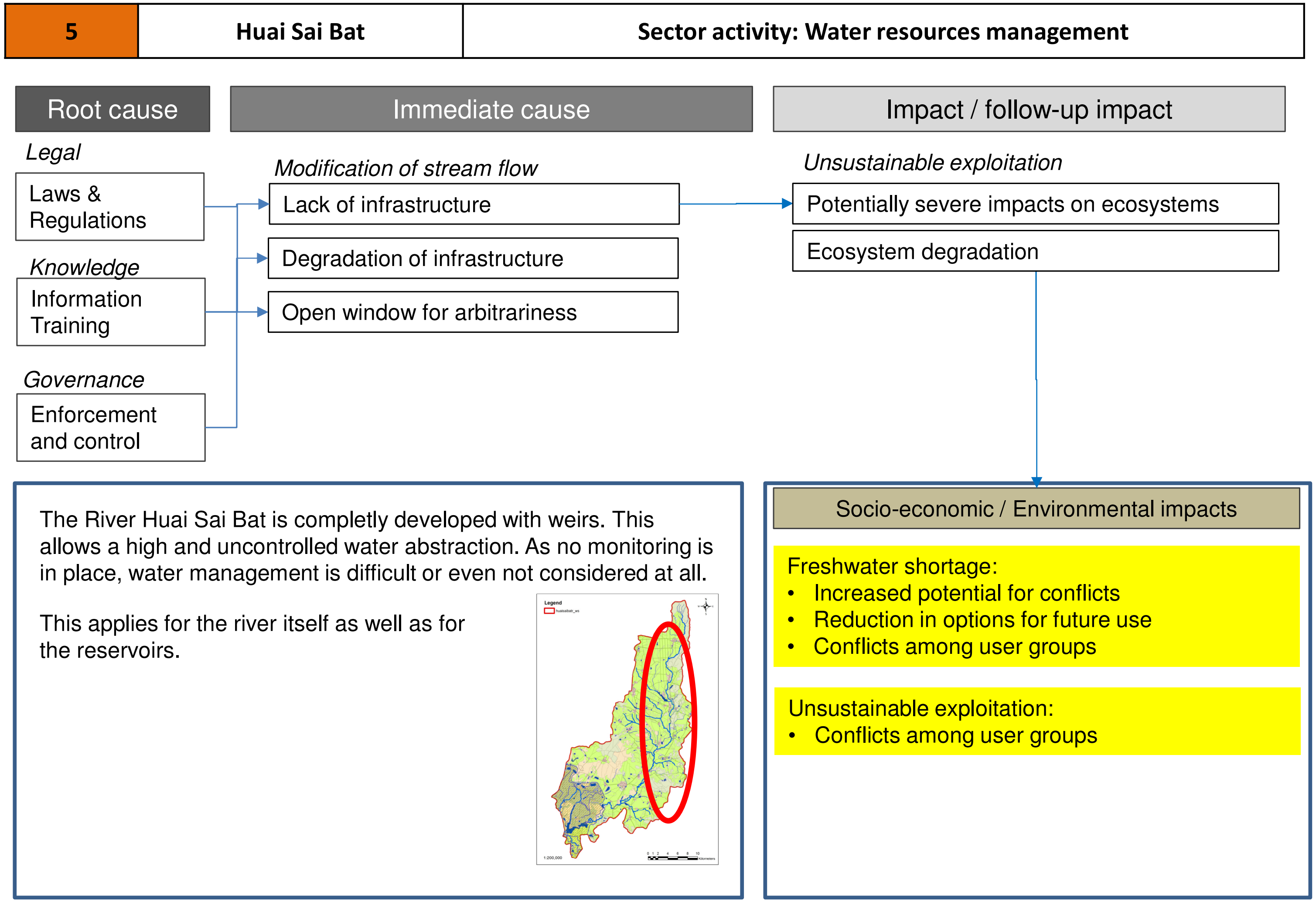


Figure 24: Causal-chain - monitoring of water abstraction along Huai Sai Bat

Verification:

No records about water abstraction seem to be available. This applies for the river as well as the reservoir. In addition, no discharge gauge and rain station exist within the river basin. Any enforcement of rules and regulations, if any would exist, needs monitoring and control.

Need verification

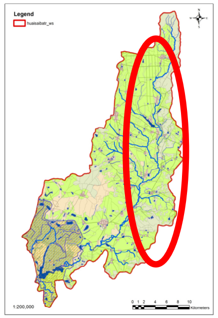
Indicator or supporting information & unit	Field trip, communciation
Format (map, report, data, etc.)	-
Extent or area covered	All abstractions in the river basin
Duration	Long-term activity
Reliability	High
Availability	-
Sources of data or contact to obtain data and information	-
Brief explanation or justification	

6	Huai Sai Bat	Sector activity: Water

Root cause	Immediate cause	Impact / follow-up impact
Knowledge Information Training	*Modification of stream flow* Increase of flow velocity	*Infrastructure* Loss of retention
Socio & cultural Tradition		

The River Huai Sai Bat is regularly dredged by RID (information from field trip). The sediment is put along the river banks forming a dyke. This in turn provides a barrier so as to prevent water to entering the flood plain.

Wether this happens intenionally or not, the effect is a change in the stream flow and provides for less retention and more water entering the reservoir. The reservoir is therefore more likely to spill, which would constitue an avoidable loss of water.



Socio-economic / Environmental impacts

Infrastructure:
- Relocation of problems
- Inadequate compensatory measures

Figure 25: Causal-chain - dredging of Huai Sai Bat River

Verification:

The dykes are visible along the stream. It is possible to identify different stages of development. It seems to be tradition and definitively the easiest way to dispose river bed material.

Need verification

Indicator or supporting information & unit	Field trip, visible
Format (map, report, data, etc.)	-
Extent or area covered	River
Duration	Long-term activity
Reliability	High (dykes), medium (impact on flood)
Availability	-
Sources of data or contact to obtain data and information	-
Brief explanation or justification	

7	Huai Sai Bat	Sector activity: Agriculture

Root cause	Immediate cause	Impact / follow-up impact

Economic
Subsidies, Market structure

Socio & cultural
Tradition

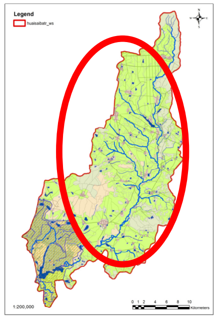
Lowering of water table
Increased consumption by vegetation cover

Freshwater shortage
Demand exceed possible supply level

Pollution
Increased use of fertilizers for compensation

Main crops are rice and sugarcane. This is due to subsidies for rice which do not reflect real market prices. Drought resistant crops are less cultivated.

Water demand for sugarcane and rice is high compared to cassava, for instance which hinders a full growth of the crops under water scarcity conditions. This might call for increased used of fertilizers to accelerate growth and compensate any reduced supply level.



Socio-economic / Environmental impacts

Freshwater shortage:
- Loss of agricultural uses
- Reduction in options for future use

Unsustainable exploitation:
- Conflicts among user groups

Figure 26: Causal-chain - land use development in Huai Sai Bat river basin

Verification:

Land use maps indicate that rice and sugarcane are the dominating crops in Huai Sai Bat river basin. Both require a high water supply during the whole rainy season or even beyond, for instance Sugarcane. No full supply level can be reached comparing water demand and water supply.

Need verification

Indicator or supporting information & unit	Land use maps, crop coefficient
Format (map, report, data, etc.)	Shape files, tables
Extent or area covered	River basin
Duration	Long-term activity
Reliability	High
Availability	-
Sources of data or contact to obtain data and information	Crop coefficients
Brief explanation or justification	

6.3 Overview of causal-chains

The following tables summarise the aforementioned causal-chains and indicate with the colour in the left column the reliability and evidence. Red means negative effects, green refers to as positive effects with darker colours show a higher degree of reliability. The column *Model* show whether or not the cause-effect relationship is supported by a model application.

6.3.1 Tha Di

Table 4: Overview of cause-effect relationships in Tha Di river basin

No	Location	Sectors	Subjects	Description	Root cause	Verification	Parameters	Model
1	Tha Di, Nakhon Si Tammarat	Water, Public health, Coastal zones, Biodiversity, Fisheries	Water quality	Inundation in combination with disposal of debris, solids and waste	Governance, Legal, Urban planning	Model, field trip	Water quality, oxygen, nitrogen, ammonium	Model
2, 3	Tha Di, Nakhon Si Tammarat	Water, Agriculture	Flood infrastructure	Implementation of flood mitigation infrastructure without compensatory measures	Governance, Legal, Technology	Model, field trip	Flood hydrograph, flow velocity, erosion, sedimentation	Model
4	Tha Di, Villages & Agriculture	Water, Agriculture, Urbanization	Establishment of real estates, urban spread	Urbanization, loss or retention area	Legal, Demographic	Field trip, satellite images	Land use	
5	Tha Di, Coastal area, mangroves	Water, Aquaculture, Fisheries	Shrimps ponds, use of chemicals. Effluent disposal	Disposal of pond water	Economic	-	-	
6	Tha Di, Villages & Agriculture	Water, Socio-economic	Recreational areas	Point source disposal of waste and waste water	Social & cultural, lifestyle	-	-	
7	Tha Di, Villages & Agriculture	Water	Hydraulic structures, water resources development	Living weirs	Social & cultural, lifestyle	Experience over years	Groundwater level, water quality, biodiversity	
8	Tha Di, Coastal area, mangroves	Coastal zones, Aquaculture, Biodiversity	Land use change, coastal area degradation	Conversion of mangroves into aquaculture and agricultural land	Economics, Technical	Satellite images	Land use, binding of sediments, buffer for nutrients, storm buffer	
9	Tha Di, Mountainous area	Agriculture	Land use change	Conversion of rain forests to cultivated land, rubber plants, etc.	Demographic, Economics	Model, field trip	Land use, erosion, sedimentation	Model
10	Tha Di, Nakhon Si Tammarat	Urbanization	Migration, Water quality, Environment, Public health	Effluents discharge causing crictical water quality conditions in receiving streams	Demographic, Economics, Technology	Model	Water quality, pollution loads, sewer system conditions	Model

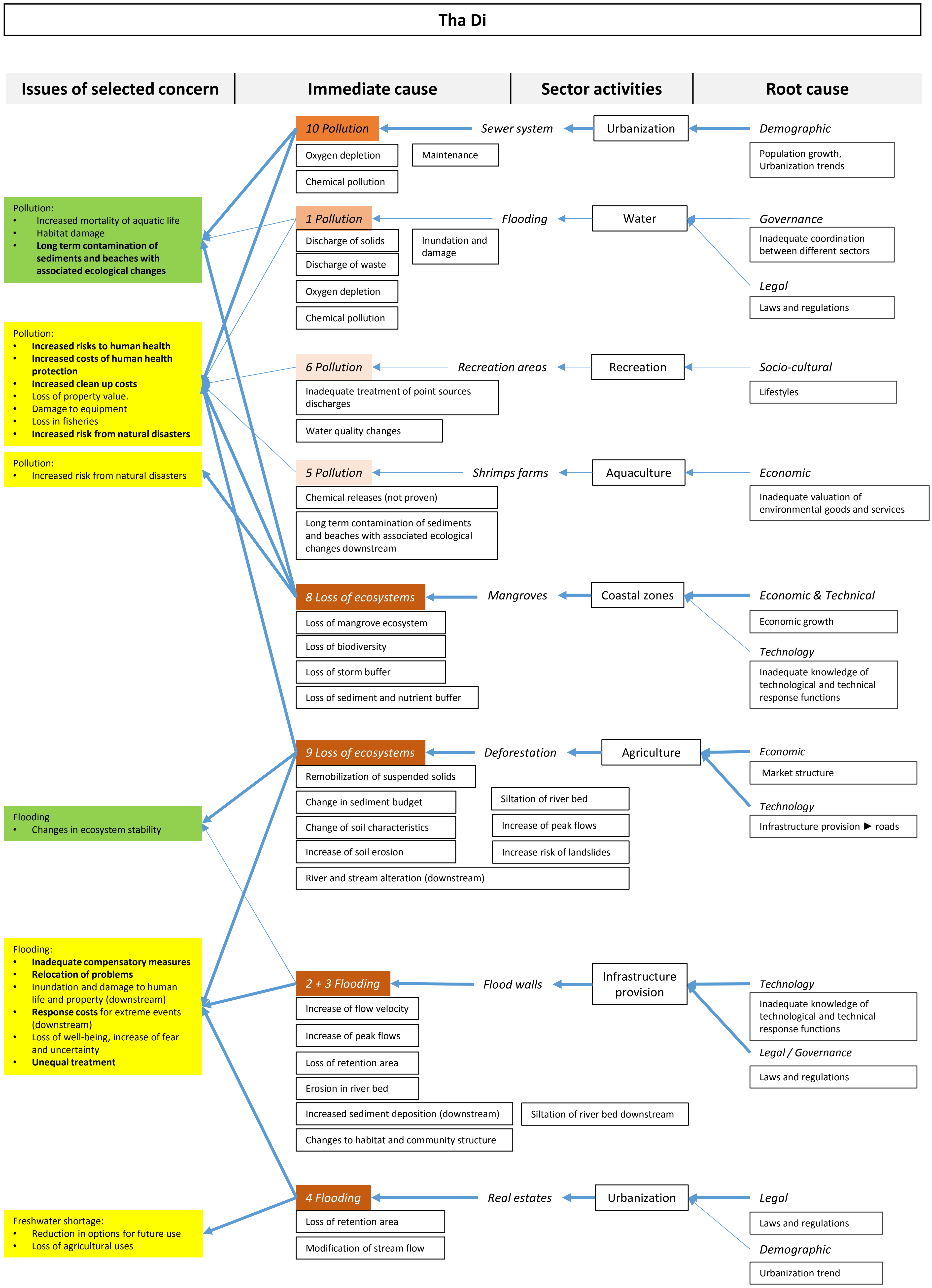


Figure 27: Root causes and major concerns in Tha Di river basin

6.3.2 Huai Sai Bat

Table 5: Overview of cause-effect relationships in Huai Sai Bat river basin

No	Location	Sectors	Subjects	Description	Root cause	Verification	Parameters	Model
1	Huai Sai Bat, Nong Yai Reservoir	Water, Agriculture	Water quality and suspended solids	Agriculture runoff and suspended solids washed into the reservoir	Prices, knowledge and technical understanding	Field trip and communication	Water quality	
2	Huai Sai Bat, Nong Yai Reservoir	Water, Agriculture	Water quality and suspended solids	Agriculture runoff and suspended solids washed into the reservoir	Prices, knowledge and technical understanding	Model, field trip	Contanimated sediments	Model
3	Huai Sai Bat, River	Water, Agriculture	Water abstraction	The River Huai Sai Bat is completly developed with weirs for abstracting water with the potential to cause conflicts between water users	Prices, income, market structure	Model, field trip	Water quantity	Model
4	Huai Sai Bat, Pumping station	Water, Agriculture	Water abstraction at a single point	Extensive pumping during floods to lower the water level so as to avoid flooding of fields takes place.	Income, poverty, knowledge	Model, field trip	Water quantity	Model
5	Huai Sai Bat, River	Water	Monitoring, Maintenance, Operation	No monitoring is in place to control water abstraction and allows water management enforcement	Laws & regulations, enforcement & control	Field trip and communication	Water quantity	
6	Huai Sai Bat, River	Water	River maintenance	The River is regularly dredged by RID (information from field trip). The sediment is put along the river banks forming a dyke.	Information & training, tradition	Field trip and communication	Water quantity, flood management	Model
7	Huai Sai Bat, cultivated land	Agriculture	Land use, crops	Main crops are rice and sugarcane. This is due to subsidies for rice which do not reflect real market prices. Drought resistant crops are less cultivated.	Prices, income, market structure	Field trip, land use maps	Water consumption, crop coefficients	Model

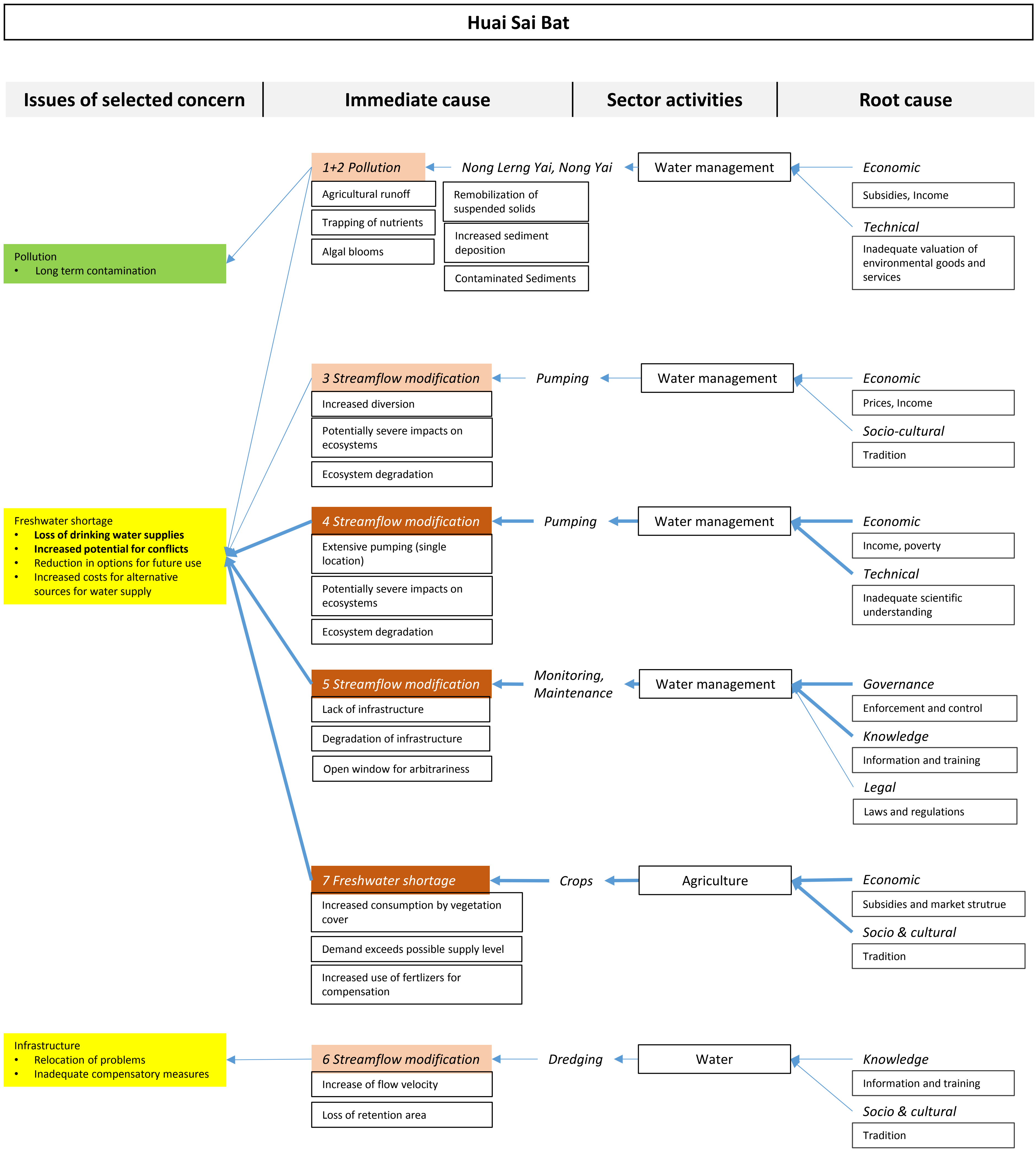


Figure 28: Root causes and major concerns in Huai Sai Bat river basin

7 DETAILED ASSESSMENT

The detailed assessment builds on the cause-effect relationships and is intended to verify and quantify them. The methodologies used are based mainly on modelling each of which either physically deterministic or conceptual models. Three kinds of modelling approaches came into use:

- Hydrologic modelling
- Erosion and sedimentation modelling
- Water quality modelling

Since not all data and model parameters required were available, assumption had to be made which are listed below. Some parameters are highly sensitive and uncertain so that results should be rather considered as relative changes than absolute values. Despite uncertainties, modelling allows relevant parameters of the cause-effect relationships to be addressed and highlights vulnerabilities when alterations occur and thus reveals most susceptible issues.

7.1 General assumptions for modelling

7.1.1 Hydrologic modelling

7.1.1.1 Program used

The program TalsimNG was used for hydrologic modelling. The software was developed 1995-2001 at the Technical University of Darmstadt. It allows modelling of precipitation-runoff behaviour based on SCS or Hydrological Response Units with non-linear soil moisture accounting, river routing, implementation of point sources, sinks/sources as well as reservoirs with operation rules and water resources management. It has been greatly extended by SYDRO since its first release in 2001. The software was and still is applied to all scales of river basins (< 10 km² to > 50,000 km²) in Europe, Africa and Asia for

- climate change scenarios and assessments
- reservoir operation and optimisation
- flood control
- water-quality assessment
- hydropower development
- real-time operation of reservoirs

A list of application in overseas of TalsimNG is provided below:

- Operation of the Koka-Dam in Ethiopia for flood protection, hydropower and environmental protection of Awash River (Ethiopia)
- Study about Windhoek water supply reservoirs operated by Namwater (Namibia)
- Prediction of sedimentation yields and reservoir performance in arid regions (Israel)
- Optimization of irrigation systems as part of integrated water resources management, case study (Ethiopia)
- Application of Talsim on Mtera-Kidatu reservoir system, Rufiji river basin (Tanzania)
- River basin modelling and deriving design floods for major dams in Swaziland

In addition, SWAT model was used by Khon Kaen University at Huai Sai Bat river basin. Details can be taken from (Kittiwet, Vichian, 2014).

7.1.1.2 Main parameters

Important parameters are

- topography (DEM, elevations)
- soil (physical properties like saturation, field capacity, wilting point, hydraulic conductivity, max. infiltration rate)
- land use (root depth, plant coverage, leaf area index, interception capacity, crop coefficients)
- river cross sections (geometry, height-width relationship, roughness)
- hydraulic structures (geometry, crest levels of spillways, weirs, width, hydraulic coefficients, bathymetry of reservoirs, etc.)

and driving forces like

- precipitation
- temperature and evaporation

as well as water management related parameters

- water requirements for domestic use and irrigation
- water abstraction at weirs
- reservoir operation rules
- utilization of small ponds for domestic use and irrigation

Soil and land use properties were provided by the cooperation partners (Khon Kaen, Walailak Universities) or by GIS data respectively. Geometry data were either taken from topographical maps or digital elevation models. Assumptions about elevation-height relationships were necessary for the implementation of reservoirs in Huai Sai Bat river basin. Time series about water abstraction was neither at Tha Di nor at Huai Sai Bat available. However, water demand for Huai Sai Bat was given as monthly pattern separated by districts and requirements for irrigation on a crop-specific level.

7.1.1.3 Calibration

Hydrologic modelling requires calibration in regard to soil properties affecting runoff and parameters concerning time of concentration. Details about calibration are explained in Section 7.2 and 7.3.

7.1.2 Erosion and sedimentation modelling

7.1.2.1 Program used

A widely used approach to compute erosion is the **M**odified **U**niform **S**oil **L**oss **E**quation (MUSLE). Erosion using MUSLE and sedimentation based on various concepts is implemented in the HEC-HMS program (**H**ydrologic **E**ngineering **C**enter - **H**ydrologic **M**odelling **S**ystem developed by the US Army Corps of Engineers). HEC-HMS uses widely similar parameters than TalsimNG so that parameters from TalsimNG could be converted to HEC-HMS.

The original USLE was developed from erosion plot and rainfall simulator experiments to predict the long-term average annual soil loss. By introducing surface runoff for erosion computation instead of rainfall intensity, the USLE became MUSLE and is capable of calculating erosion behaviour more realistically.

7.1.2.2 Main parameters

In addition to hydrologic modelling, erosion and sedimentation requires the following parameters:

- Erodibility factor:
  The factor describes the difficulty of eroding soil. The factor is a function of the soil texture, organic matter content and permeability and highly complex and variable. Typical values range from 0.05 for unconsolidated loamy sand to 0.75 for silty and clayey loam soils.
  Values were chosen between 0.4 and 0.5
- Topographic factor:
  The factor describes susceptibility to erosion due to length and slope of a plot. Values were computed using an equation suggested by (Pongsai et.al, 2010) that uses slope and slope length.
- Cover factor:
  The influence of plant cover is described by the Cover factor. Bare soil is most susceptible to erosion whereas a thick vegetation cover reduces erosion significantly. Typical

values range from 1.0 for bare ground to 0.1 for fully covered soil to as small as 0.0001 for forest with a dense tree canopy. This factor was used for the sensitivity analysis by keeping all other erosion parameters constant.
Rain forest: 0.001
Agriculture: 0.1

- Practice factor:
  Practice factor is used to account for specific soil conservation practice. The factor was not used and therefore was always set to 1.0.
- Threshold:
  A threshold can be used to restrict erosion to rainfall events exceeding certain minimum intensities or runoff respectively. No threshold was used and all values were set to zero.
- Gradation curve:
  The curve defines the distribution of sediment load into grain size classes. Three different grain size distributions were used:
  Canal & coastal area zone: higher percentage of clay and silt
  Agriculture & village zone: less clay and silt but more sand
  Mountain zone: higher percentage of coarse sand and gravel
  The grain size distribution is an estimation and taken from observation during the field trip and based on experience that with reduction of slope and increase of stream length, sediments tend to become smaller grain sizes.

7.1.2.3 Calibration

Erosion and sedimentation modelling requires calibration in regard to annual sediment load depending on slope and land cover. Experience and values for Thailand are available to some extent and thus computed loads can be compared to observed values. Details about calibration are explained in Section 7.2 and 7.3.

7.1.3 Water quality modelling

7.1.3.1 Program used

Water quality modelling was performed by using GISMO. This program has been developed by SYDRO parallel with TalsimNG and is used to model urban areas, pollution load, built-up and wash-off processes, transport, concentration and spill of pollution within and from sewer systems and impacts on receiving streams and rivers. Simulations were confined to Nakhon Si Tammarat and its receiving canals and streams.

Some general remarks about water quality simulation and assumptions are necessary to understand the modelling approach and uncertainties.

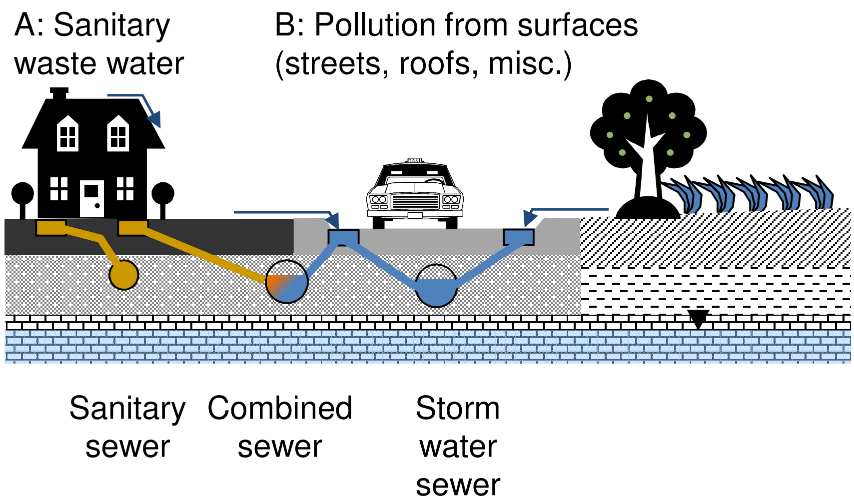


Figure 29: Components in water quality modelling of urban systems

Sanitary sewers convey wastewaters from households, industry etc. exclusive of other waste water fluxes. The flow in sanitary sewers is independent from rain and is referred to as dry weather flow and exhibits mostly a daily pattern following the activities of inhabitants and industry with a peak either in the morning or during noon. Storm water sewers receive only water from surfaces connected to the sewers during rainfall. During rain all kind of pollutants are washed off from surfaces and conveyed to storm water sewers. The pollution originates from traffic, litter, dust, decomposed plants etc.. Combined sewers mix both dry weather flow and storm water flow and are assumed to be in place in Nakhon Si Tammarat. The constituents of contaminants are given in the next section. All parameters are considered to be in existence in both dry weather and storm water flow.

Two additional assumptions regard the distribution of wastewater and point sources of effluents. The urban areas must be assigned to overflow points which spill into receiving rivers which has been done by means of topography.

7.1.3.2 Main parameters

Water quality and pollution load modelling was carried out concentrating on dissolved oxygen and fish toxic substances. This requires a couple of parameters so as to take mutual dependencies into account all of which affect each other. The figures apply to wastewater arising from urban areas and reflect the default values used during modelling derived from (Simachaya, W., Yolthantham, T., 2010) or from default values that are generally considered in wastewater models indicated with a *.

- Total dissolved solids (TDS) = 400 mg/l
- Biological oxygen demand (BOD) = 80 mg/l

- Chemical oxygen demand (COD) = 600 mg/l
- Total organic carbon (TOC) = 200 mg/l
- Ammonia, proportions of Nitrogen, Nitrate (NH_4-N, NO_3-N) = 22 mg/l *
- Ortho- and total phosphate (PO_4-P) = 15 mg/l *
- Oxygen content (O_2) = 0 mg/l *
- Temperature (T) = 26 °C
- pH = 7.5 *

To run a storm water and water quality model, additional assumptions have to be made in regard to following components:

Sources of wastewater:

- Domestic wastewater per capita and day in litre
- Industrial wastewater per hectare
- External and mostly undesired inflow into sewers per hectare due to leaky sewers
- Pollution load on surfaces expressed as kg/ha*a washed-off during rain

Sewer system:

- Percentage of urban area which is connected to sewers.
  This parameter increases with a higher proportion of impervious surfaces and is considered to be 45 to 80 % in a city centre.
- Capacity of sewers to convey water to a treatment plant.
  This indicates maximum possible flow to a treatment plant. Excess water exits the system at overflows weirs and enters receiving streams.

Receiving streams:

- Oxygen concentration of receiving streams upstream of wastewater overflows
- pH value of receiving streams upstream of wastewater overflows

Given the list of all parameters, it is obvious that rather a sound guess than evaluation of observed values is necessary to set all variables required.

7.1.3.3 Calibration

Only less information was available indicating the range of the most important parameters like BOD, TOC or oxygen content. Effects after discharging wastewater into receiving streams under various flow conditions could not be found. Consequently, calibration concentrated only on obtaining plausible results rather than comparison with observations. Details about calibration are explained in Section 7.2 and 7.3.

7.2 Tha Di

7.2.1 Calibration

Any spatially distributed hydrologic model requires the model region to be split into several sub-basins. This is necessary to address site-specific parameters and effects thereof.

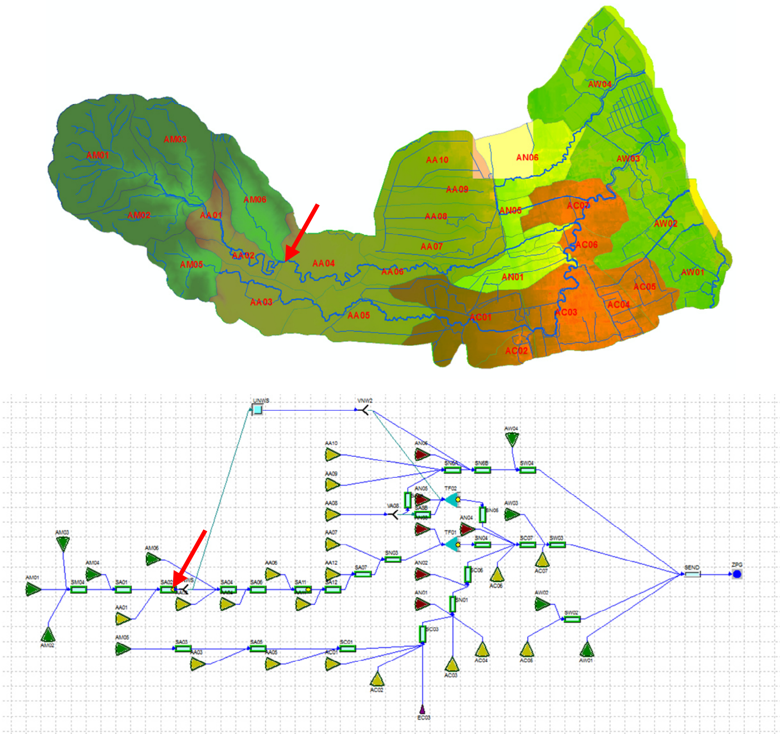


Figure 30: Flow network of hydrological model of Tha Di river basin

The arrow indicates the location of the discharge gauge x55 that was used for calibration.

In order to prevent calibration from being misled by error-prone data at station x55, annual values of precipitation and discharge in Mio.m³/a were calculated and compared.

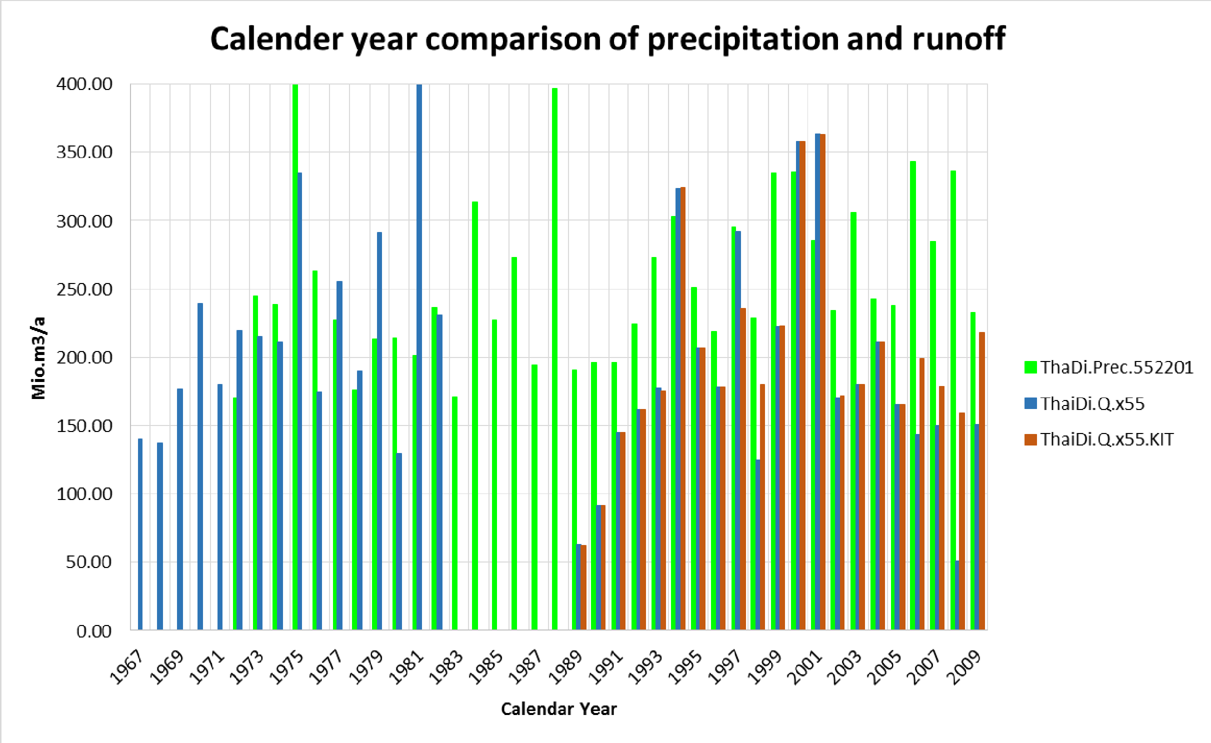
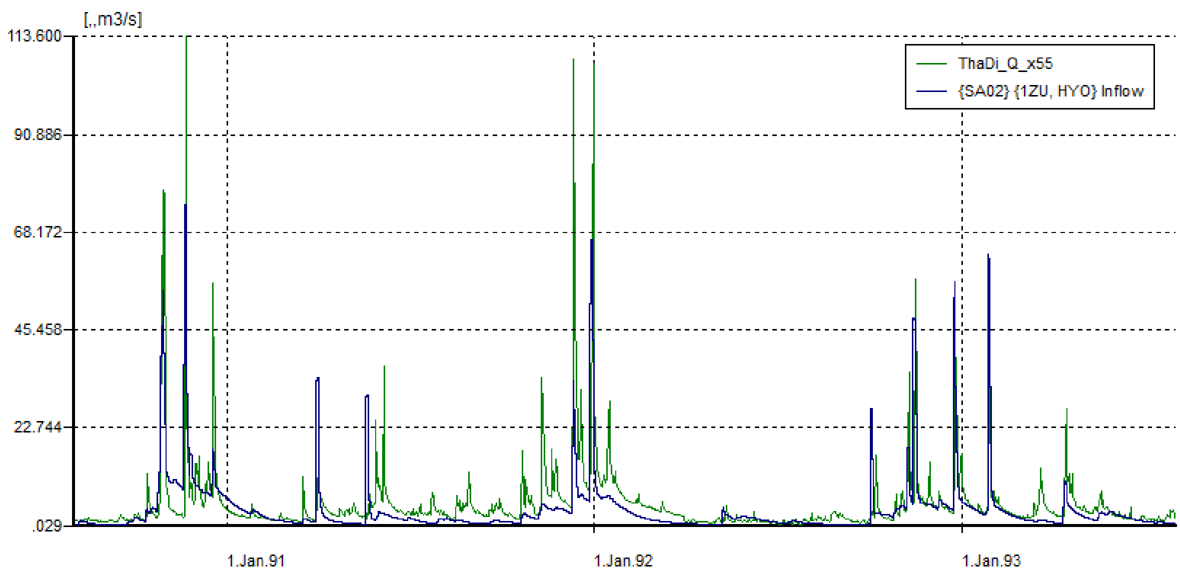


Figure 31: Comparison of precipitation and discharge at gauge x55, Tha Di

Provided that precipitation reflects the real conditions which is not always the case as it can be seen later, precipitation taken from the station 552201 (Nakhon) must always be larger than discharge. Equal quantites would mean a runoff coefficient of 1.0 which is unrealistic. Figure 31 shows that the runoff coefficient varies in the range of 0.15 (2008) to 3.4 (1981). The years 1972, 1977, 1978, 1979, 1981, 1994, 2000 and 2001 depict coefficients larger than 1 (years with missing discharge values were omitted). As a result, these years are not suitable to adjust model parameters.



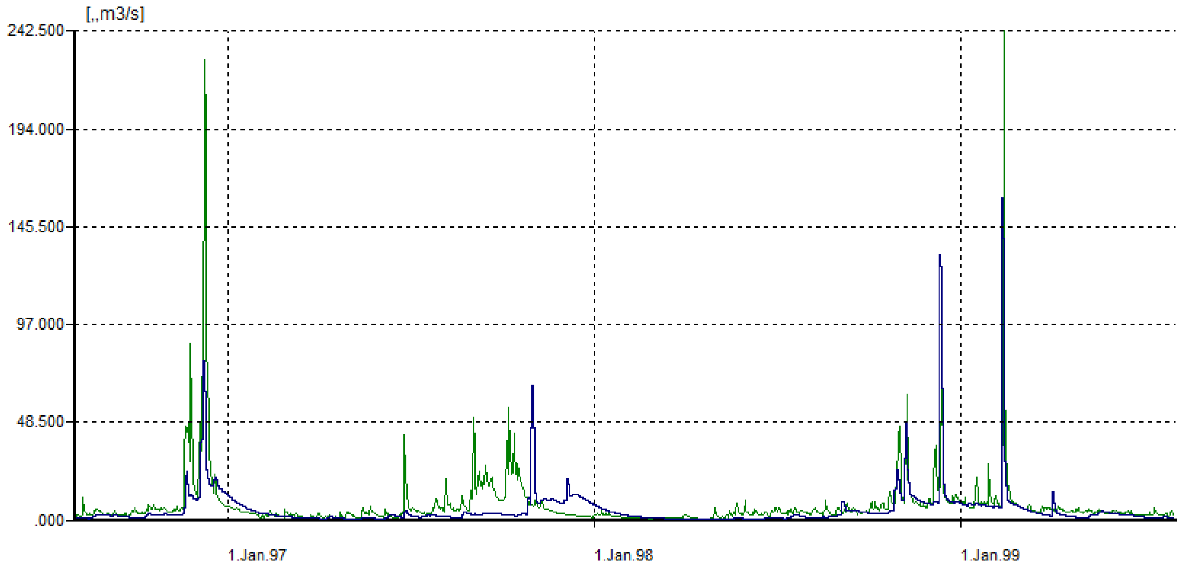


Figure 32: Comparison of observed and computed discharge at gauge x55, Tha Di

The year 1997/98 indicates the difficulty as precipitation does not necessarily reflect the reality due to the distance between Nakhon and the mountains, difference in elevation and hence different rainfall genesis.

Although calibration is difficult the model might be able to reflect major characteristics of the catchment and thus can be used to assess alterations of crucial parameters.

Soil characteristic, as the most sensitive parameters, were derived from (LDD, 2014) and adjusted during calibration.

Table 6: Parameter of soil horizons after calibration in Tha Di river basin

Name	Category	WP	FC	Saturation	kf	Max. Inf.
A, sand, well drained, low u	1	10	80	400	30	35
B, high kf, drained, low uFC	2	20	100	400	2	5
C, mud/silt, low kf, high uF	2	50	150	400	2	5
D, storage	1	50	200	250	30	31
E, low uFC, low kf	2	10	20	200	2	5
F, wetlands, swamps	3	150	210	400	1	10

7.2.2 Land use alterations and impacts on flow regime

This section refers to causal-chain 9 in Tha Di river basin.

Land use was modified only for mountainous sub-basins comprising a total area of approximately 122 km² of which 107 km² drain to gauge x55.

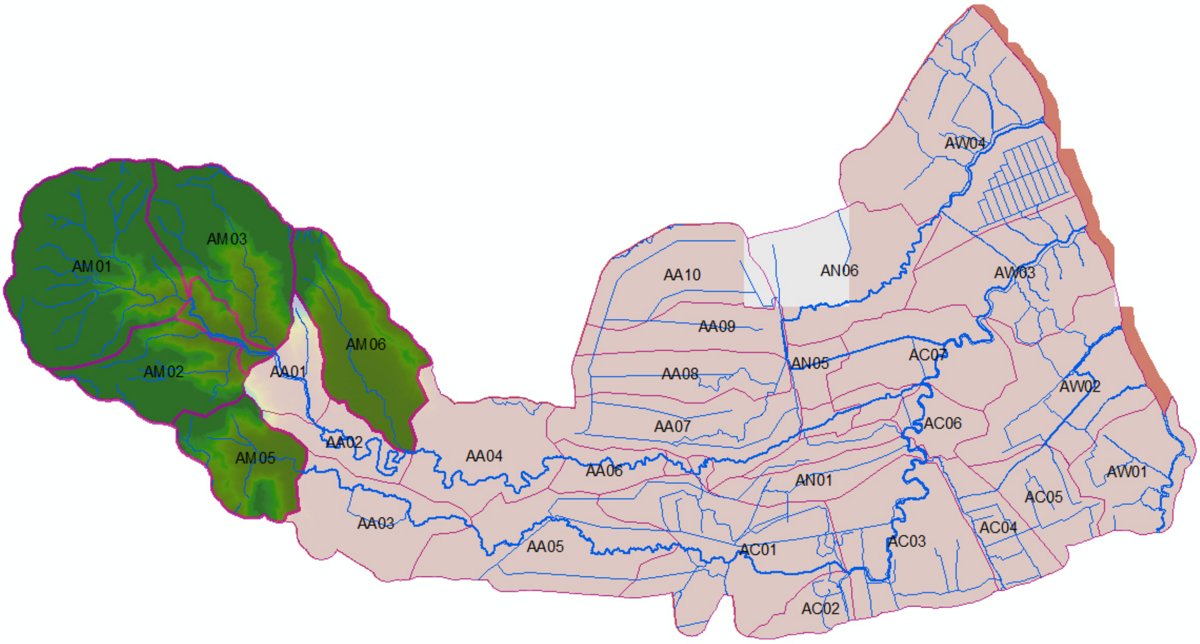


Figure 33: Mountainous sub-basins with land use and soil alterations, Tha Di

Changes were made concerning root depth, plant coverage and leaf area index which are common properties describing vegetation in hydrologic modelling. The parameters are attributable to rain forest or rubber plants respectively.

Table 7: Land use parameter modifications in Tha Di river basin

Land use	Root depth [m]	Plant coverage [%]	Leaf area index [-]
Rain forest	2	100	8
Para rubber	0.3	50	0.5

The first consequence of different vegetation parameters is a change in interception which is the ability to retain rainfall on a plant's surface and is subject to evaporation. A second consequence is the modification in transpiration due to different root depths. Larger root depths enable vegetation to draw more water out of the soil moisture provided soils are developed deep enough. Both affects net precipitation and soil moisture budget resulting in different runoff behaviour. However, effects on runoff by modified land use parameters is low because interception and transpiration are directly limited by potential evaporation and are less sensitive compared to soil characteristics.

Actually, land use alterations are often followed by soil modifications in regard to soil density and infiltration that affects runoff much more than vegetation parameters. Research on land use changes in USA (Simmons, 2008) showed:

(1)… Major differences in terms of biogeochemistry occur. Total C, N, and P pools were all substantially lower after alteration, mainly due to the removal of woody biomass but also, in the case of P, to reductions in soil pools…

(2)… Although annual runoff from the watersheds was similar, the mined watershed exhibited taller, narrower storm peaks as a result of a higher soil bulk density and decreased infiltration rates…

(3)… Stream export of N was much lower after alteration due to lower net nitrification rates and nitrate concentrations in soil. However, stream export of sediment and P were much higher…

As biochemistry is not modelled statement (1) cannot be verified for Tha Di river basin. However, similar effects are very likely to occur. (2) and (3) can be confirmed with the results from detailed assessment.

Following changes of soil horizon parameters were assumed:

Table 8: Soil horizon parameter modifications in Tha Di river basin

Name	Category	WP	FC	Saturation	kf	Max. Inf.	Cap. Rise
without alteration							
D, storage	1	50	200	250	30	31	
E, low uFC, low kf	2	10	20	200	2	5	
with alteration							
D*, storage	1	50	100	125	15	16	0
E*, low uFC, low kf	2	10	15	100	1	2.5	0

Soil D and E resulted from calibration and constitute the soil type for mountainous area. Top horizon E has a depth of 0.2 m followed by D with a depth of 1.0 m. The depths were not changed.

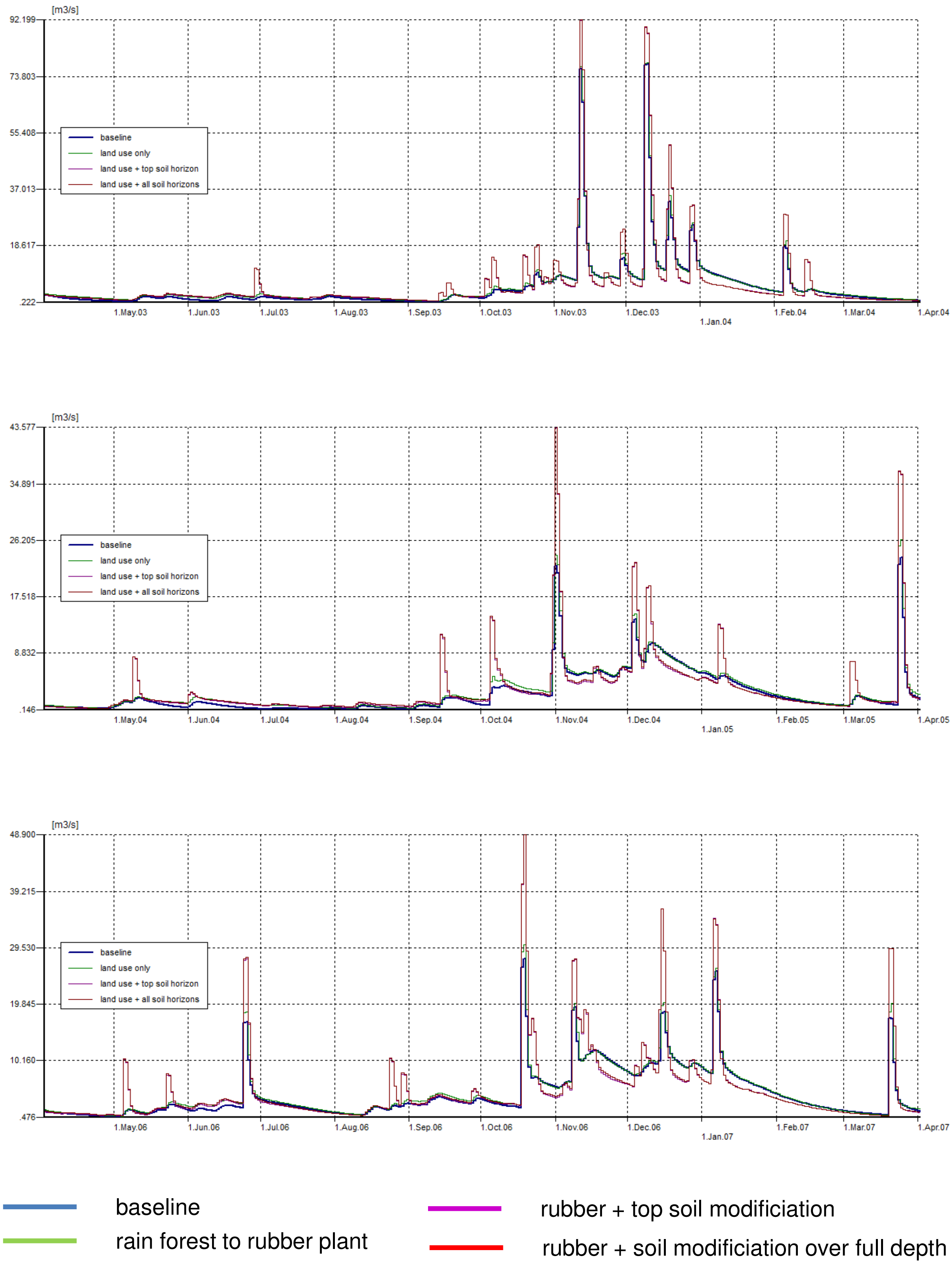


Figure 34: Comparison of discharge at gauge x55 with land use alterations, Tha Di

It is obvious that the flow regime is drastically affected. However, severe modifications arise due to change of soil parameters and only slightly because of land use parameters. Flood events occur more often with accelerated rising and falling limbs and higher peak flows.

Consequently, water storage capacity will be reduced as well. To worsen the effect, erosion and sedimentation rates will rise and come on top which are dealt with in the following section.

7.2.3 Erosion and sedimentation due to land use change

Clearing of rain forest always implies erosion. Eroded soil is remobilised and conveyed downstream with runoff and settles in rivers. The amount of erosion depends on soil erodibility, land cover, topography and rainfall intensity. An erosion and sedimentation model based on HEC-HMS was established so as to quantify erosion. The model parameters were derived from TalsimNG and adjusted such that HEC-HMS revealed comparable results like the calibrated TalsimNG model. Sediment yields were checked against common values given in literature about Thailand as no observed rates were at hand.

Two scenarios have been conducted with HEC-HMS:

- 5% of area is cleared and converted into agricultural land
- 15% of area is cleared and converted into agricultural land

The area comprises the headwater of Tha Di River indicated with marked borders.

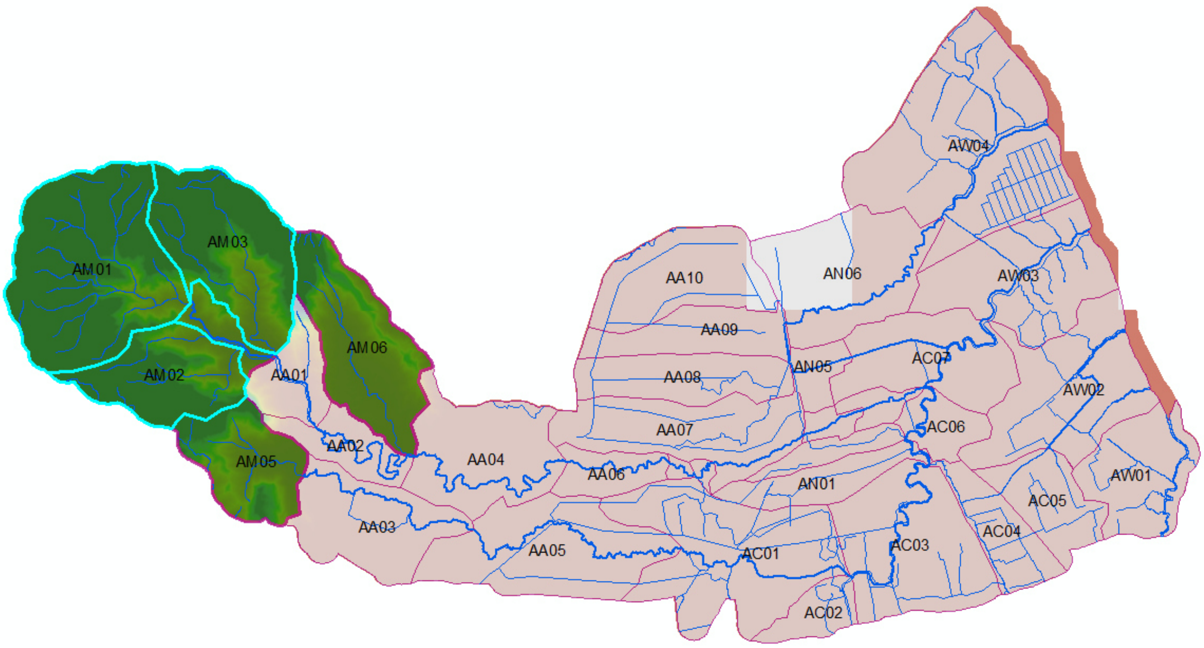


Figure 35: Headwater sub-basins used for erosion scenarios, Tha Di

It must be noted that flow regime change which would automatically complement land use changes as mentioned in Section 7.1.1 was not considered, hence, results would be even worse in reality.

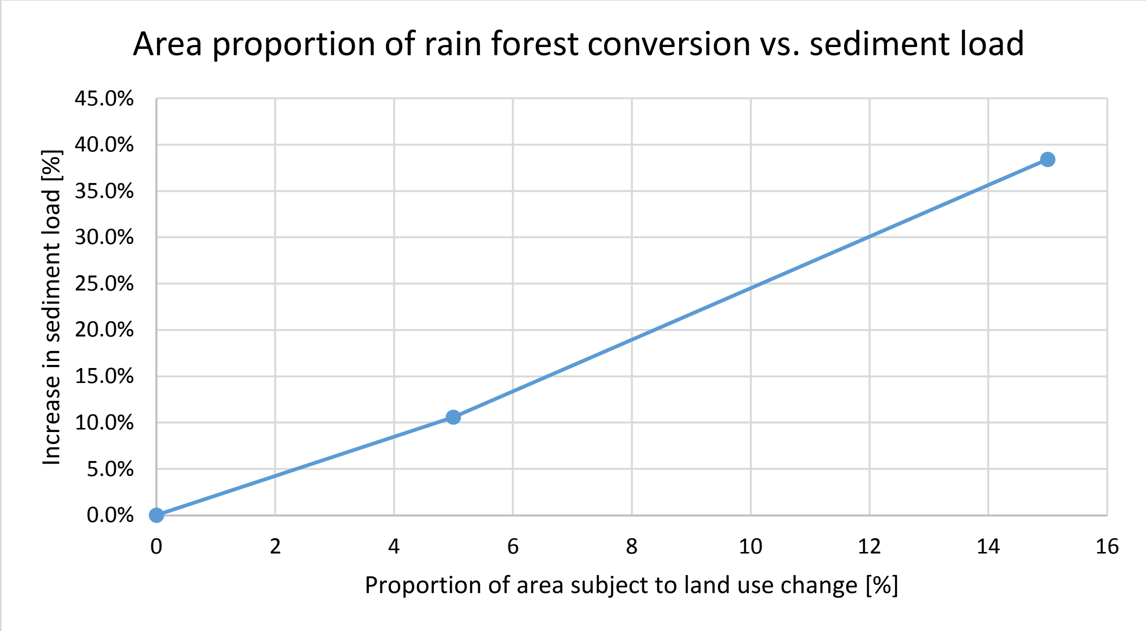


Figure 36: Increase of erosion due to conversion of rain forest, Tha Di

Current sediment yield was calculated to approximately 280 tons/km²/year and would rise up to about 390 tons/km²/year which represents a rise of almost 40%. In other words, if 15% rain forest were cleared and converted into vegetation with less dense canopies, it would cause an increase in sediment rates of 40%. These overproportional relationship gives rise to any effort to prevent rain forest from being deforested.

Table 9: Range of sediment yield of rivers and drainage area size from different regions of Thailand [source: (Henderson, G, Rouysungnern, S., 1984)]

Region	Forest area [%]	No. of rivers report-ed	Range	
			Drainage area [km²]	Sediment Yield [tonnes km^{-2} yr^{-1}]
North	39.9	28	12 to 20,203	12 to 2,045
Northeast	15.8	23	42 to 104,000	8 to 3,874
Central	18.4	4	351 to 11,104	20 to 570
Southern	23.9	16	8 to 2,690	30 to 1,787
East	17.9	7	133 to 2,523	27 to 356

7.2.4 Water quality and population growth

This section refers to causal-chain 1 and 10 in Tha Di river basin.

The effect of population growth of Nakhon Si Tammarat on water quality has been analysed as it constitutes a very likely scenario since urbanization trend is apparent. It must be noted that due to all required assumptions results demonstrate one possible solution among a wide range of possibilities. For this reason, relative changes between different scenarios are much more relevant than absolute figures.

The scenarios carried out comprise effects of an increasing population in and varying oxygen concentrations in streams upstream of Nakhon Si Tammarat.

It is assumed that any increase of population takes place in Nakhon Si Tammarat itself and is associated with a rise of pollution load on surfaces because of more traffic and more litter. Hence, a relationship between population and pollution load was applied such that population growth and rise of pollution load are proportional until 40% of increase. More than 40% increase of population growth causes less rise of pollution load so that doubling of population results in 50% increase of pollution load. For example, 20% increase of population results in 54000 inhabitants and 72 mg/l BOD pollution load on surfaces with start conditions of 45000 inhabitants and 60 mg/l.

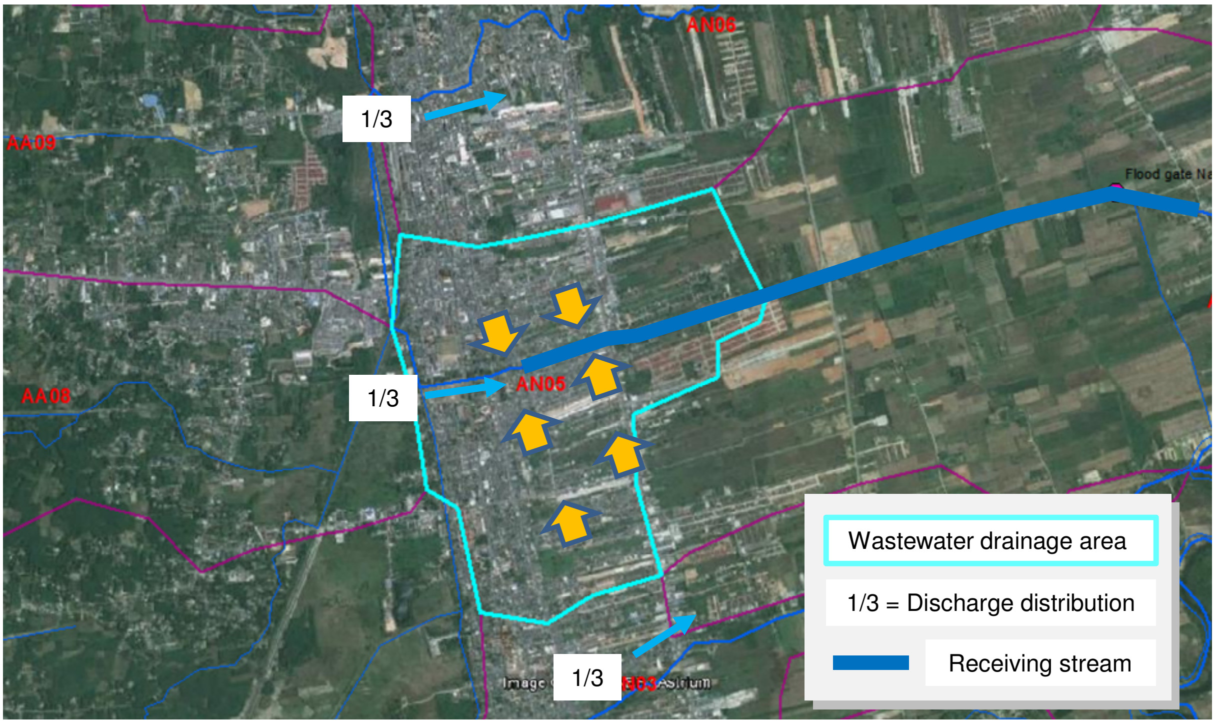


Figure 37: Urban drainage area and receiving stream, Tha Di

The transport capacity of Nakhon's sewer system was estimated to 500 l/s conveying 100% of dry weather to the treatment plant. This assumption is not very likely, but is less relevant as long as only relative changes of concentrations are of interest. However, the waste water from additional population was completely released into the receiving river.

Oxygen concentrations are compared downstream the waste water overflow points after about 1500m where decomposition of BOD is already in process.

Relative changes show that with an increase of population oxygen concentration shifts towards lower values in the range of delta = 1 mg/l under dry weather conditions and during intensive spills from the sewer systems about delta = 0.4 mg/l.

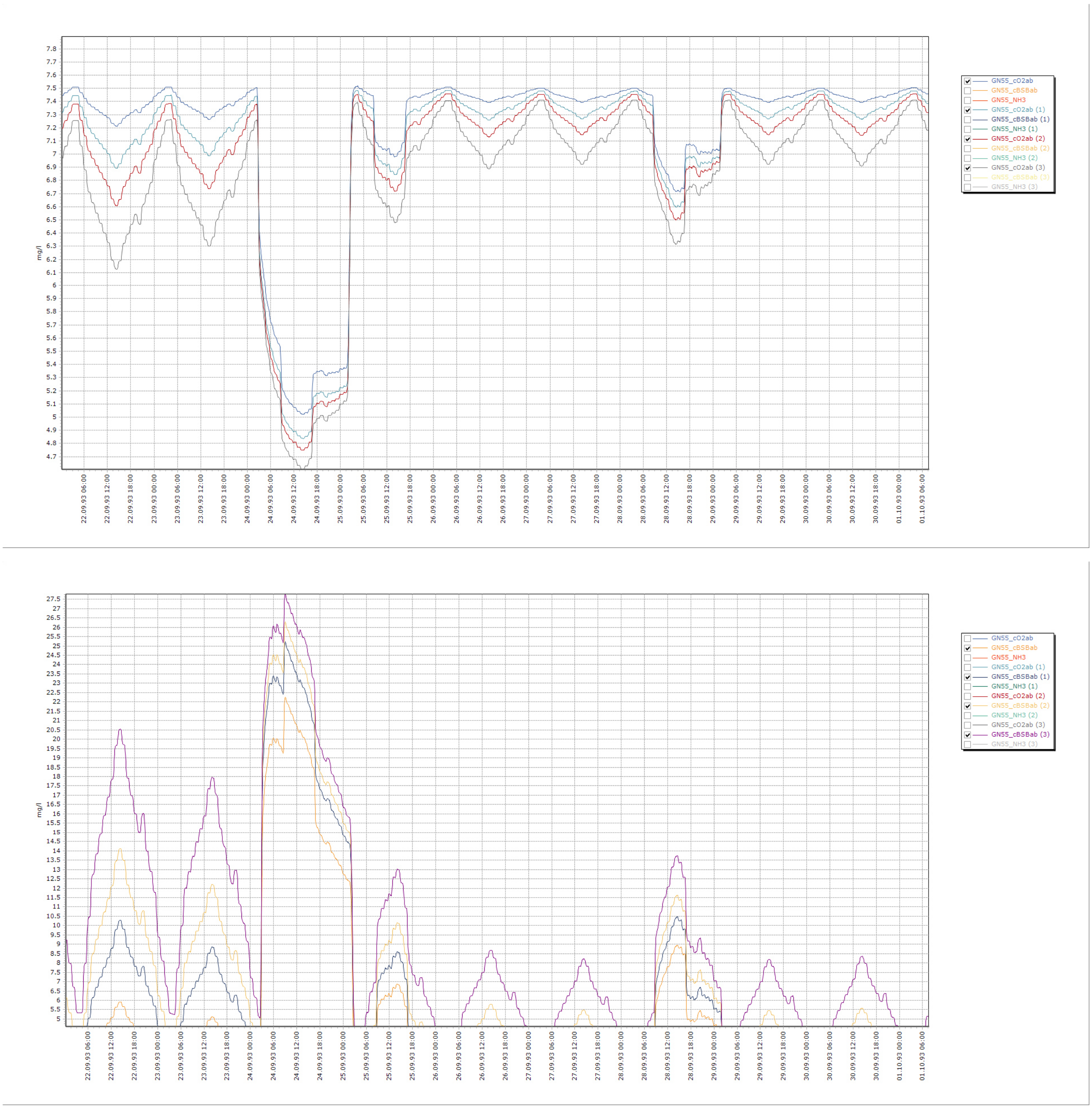
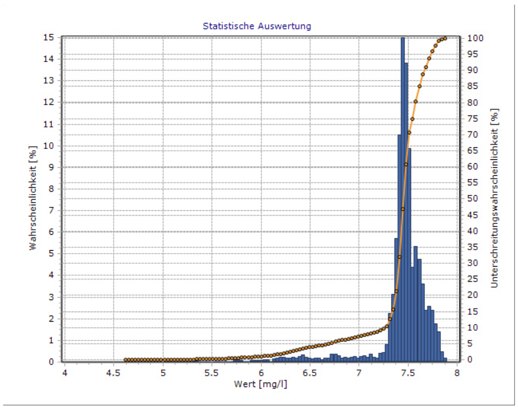
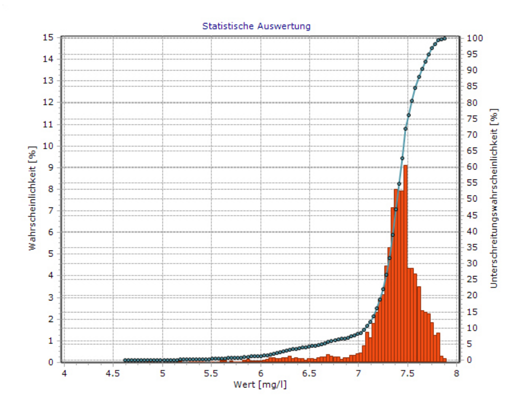


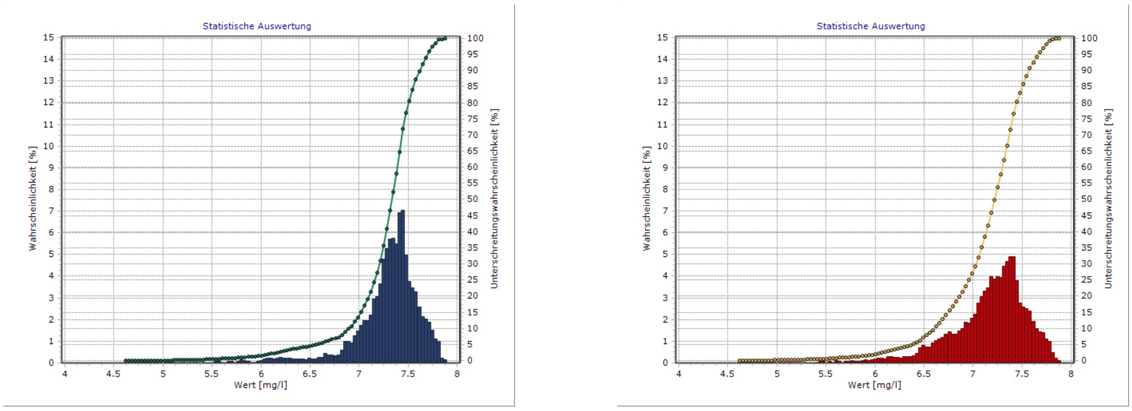
Figure 38: Oxygen and BOD concentration versus population growth, Tha Di



+20%



+40%



+60% +100%

Figure 39: Statistics of Oxygen and BOD concentration versus population growth, Tha Di

A closer look into NH3 (fish toxic ammonia) reveals a critical aspect. Changes occur in the range of delta = 0.05 mg/l. This is of importance in terms of lethal concentrations for fish. Studies have shown that lethal concentration for adult fish is normally considered as 0.6 to 1.2 mg/l. Juvenile fish, however, is expected to have a lethal threshold 0.2 to 0.4 mg/l and values above 0.1 mg/l are already harmful for all fish.

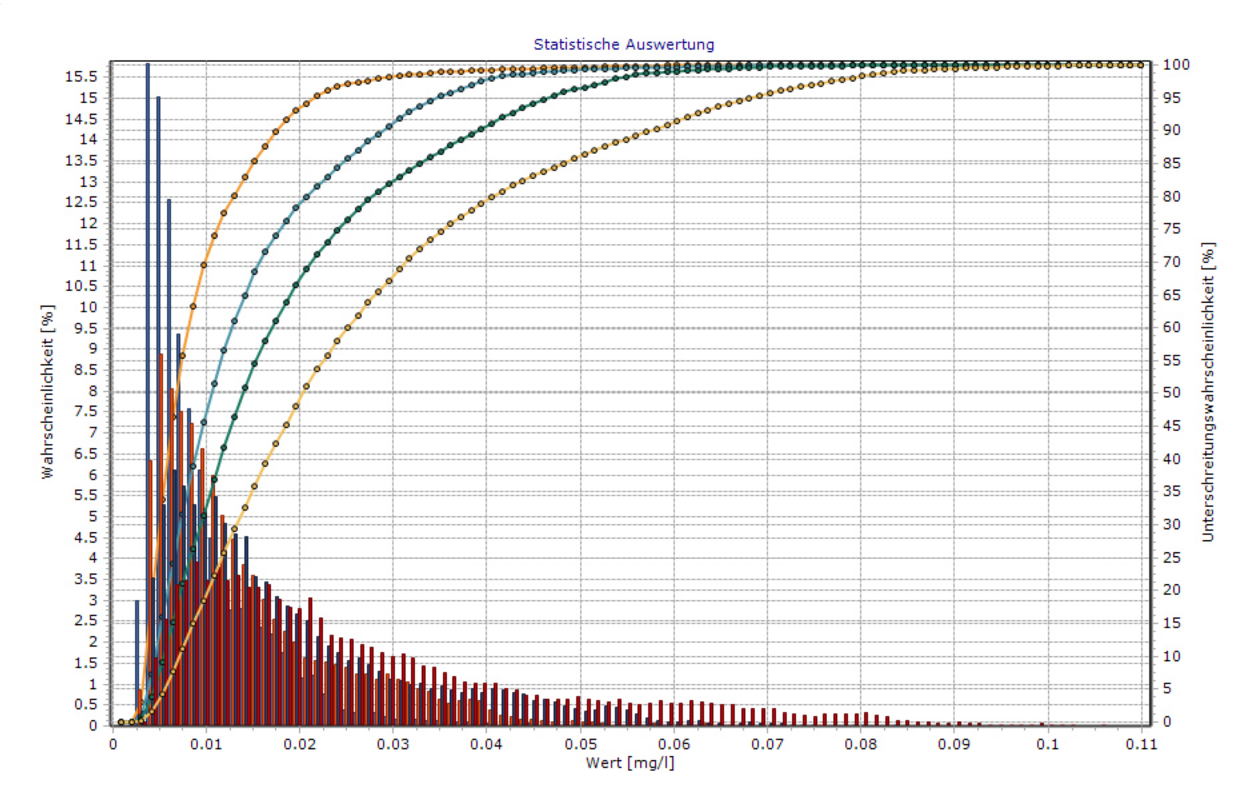
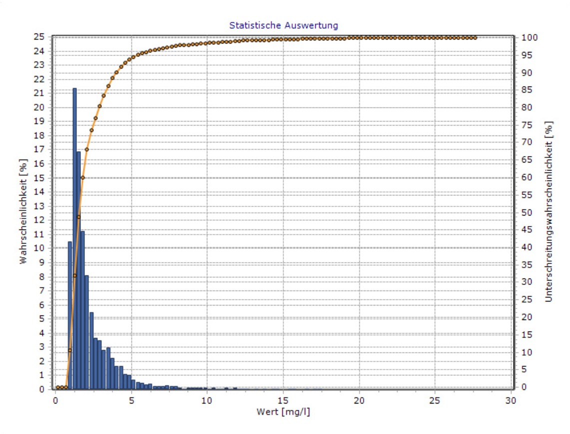
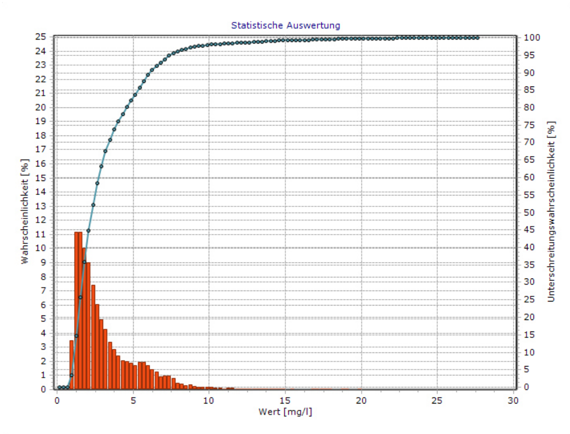


Figure 40: Toxic ammonia concentration versus population growth, Tha Di

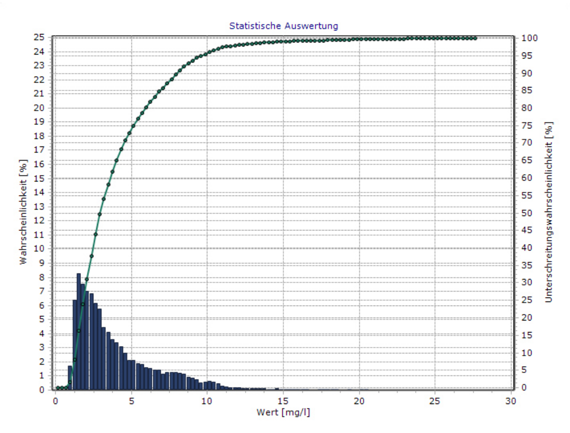
In conclusion, ammonia can pose a threat to fish population and leakage of sewers in conjunction with more waste water calls for measures with regard to rehabilitation of the sewer system and .



+20%



+40%



+60%

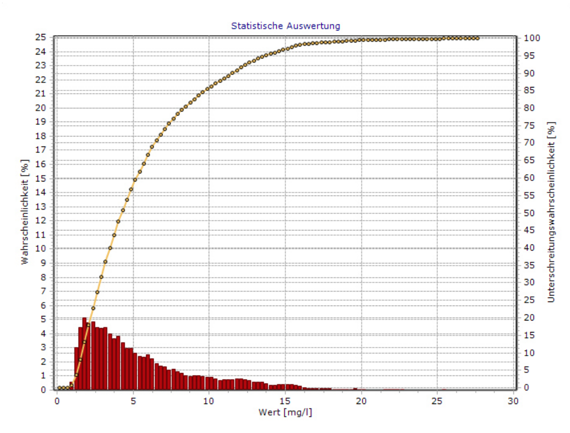


Figure 41: BOD versus population growth, Tha Di

Summarizing the water quality modelling, results fit into a generalized view of Thailand's water quality in streams and rivers. Apart from a few exceptions water quality downstream of cities deteriorates considerably country wide. Nakhon Si Tammarat is in line in that regard. During storm events with spill from the sewer system, BOD changes in the range of delta = 5 mg/l which is, compared to 10 mg/l allowed discharges from aquaculture ponds in Thailand (Boyd, 1996?), 50%.

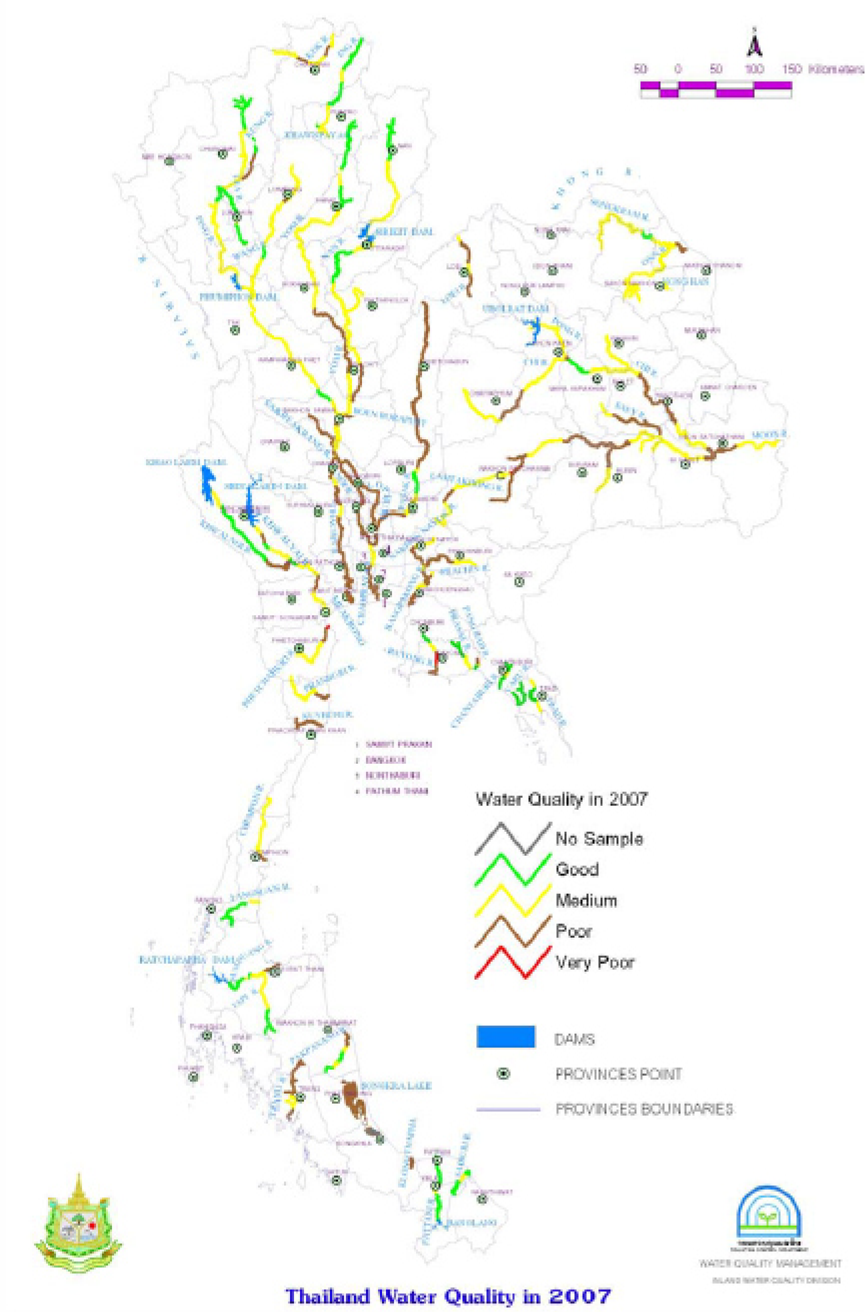


Figure 42: Water quality in Thailand (source: Yolthantham, T. 2007)

The problem of untreated wastewater from households, farms and the poor connectivity of buildings to proper sewer systems is elaboratively discussed in (Yolthantham, 2007) and confirms the tendency of the aforementioned.

7.2.5 Summary

Assuming only rain forest conversion into arable land without affecting soil, simulations show:

- When rain forest is chopped and replaced by vegetation with less developed canopies, interception can drop more than 60% consuming only more than 200 mm/a instead of more than 600 mm/a on average.

- Surface runoff can increase up to 5%. On the other hand, interflow and groundwater recharge increase by 7 to 20%.

Modelling of rain forest conversion inducing soil property modification which has strong evidence proofed by numerous investigations (Simmons 2008, Maidment 1992) indicates:

- Halving infiltration capacity will lead to doubling runoff rates and a reduction up to 20% of interflow and 15% of groundwater recharge. This scenario is much more likely to occur than a scenario without soil characteristic modifications mentioned above.
- Reduction of interflow and groundwater recharge reduces water availability
- It is not relevant whether top soil horizon only or all soil horizons are affected since results remain almost identical.

Erosion as a consequence of rain forest conversion demonstrates:

- Rain forest conversion causes overproportional erosion and sediment yields. Only 15% of converted rain forest induces an increase of sediment yields up to 40%.

In conclusion, any conversion of rain forest affects flow regime and sediment budgets which will worsen over time and are partially irreversible. Thus, the following features will be highly vulnerable and at risk:

- Water abstraction for domestic use due to river bed and cross section alterations
- Flood protection due to river bed and cross section alterations
- Operational life span and viability of living weirs due to sedimentation
- Macrozoobenthos and river bed habitats due to river bed changes and/or siltation

In addition, landslides are very likely to occur exacerbating the situation.

Such negative impacts must be prevented by any means as, for instance, erosion is irreversible and substantial sediment budget modifications raise problems to all aspects of water related issues.

Wastewater disposal harms considerably downstream reaches:

- Almost pre-saturated conditions of oxygen upstream of point-sources of effluents compensate oxygen consumptive discharges like BOD
- Population growth in conjunction with poor maintenance of sewer system generated relative changes of oxygen in the range of 1 mg/l during dry weather conditions and up to 0.4 mg/l during storm water events. For comparison, 4 mg/l (absolute value) is the threshold to be classified as poor water quality.

- Increase of population associated with poor maintenance of sewer system is likely to generate almost critical fish toxic ammonia (NH_3) concentrations

Conversion of mangroves into aquaponds paves the way for more vulnerability:

- A reduction of mangrove area is obvious and proven
- A substantial buffer against natural hazards and for nutrients is disappearing
- Natural resources linked to mangrove like fish will suffer and be more exposed to contamination from urban effluents discharged at Nakhon Si Tammarat

7.3 Huai Sai Bat

7.3.1 Calibration

Any spatially distributed hydrologic model requires the model region to be split into several sub-basins. This is necessary to address site-specific parameters and effects thereof.

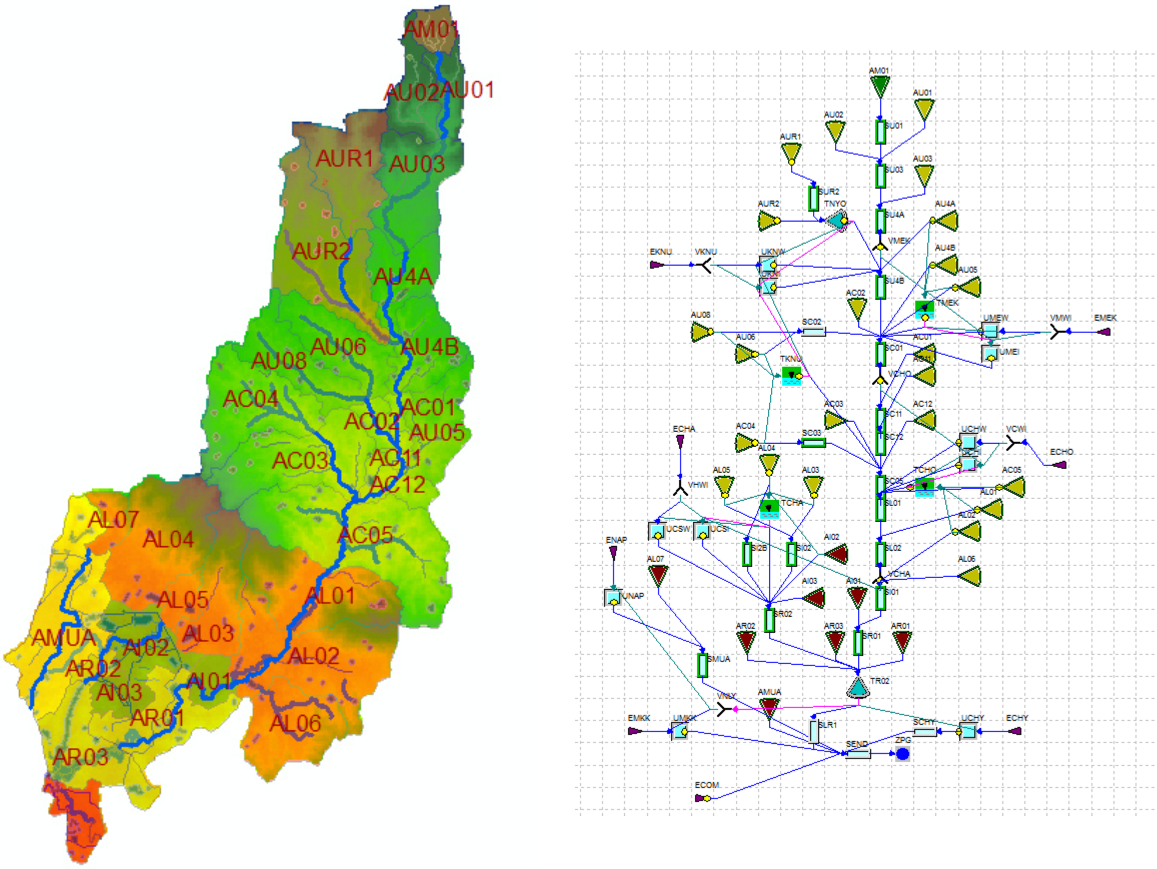


Figure 43: Flow network of hydrological model of Huai Sai Bat river basin

A prominent feature of the Huai Sai Bat model are the structures for water management including two reservoirs, weirs along Huai Sai Bat and some tributaries and countless small ponds scattered throughout the river basin mostly used for livestock and irrigation. Elevation-storage curves for the reservoirs were not available but necessary for modelling. The Nong Yai Reservoir in the north was visited twice, first time in June 2014, when the reservoir was almost empty. Thus, an estimate about bottom and geometry of the impoundment could be gained based on visual inspection. Sedimentation is obvious and considerably reduces the storage volume. Remedial works were being carried out in June 2014. The aim was to excavate sediments to create a channel enabling water to flow through the reservoir to the pumping station. The excavated sediments were dumped left and right of the channel and build a visible wall.

Another aspect which turned out as important during calibration was the hydraulic behaviour of river reaches of Huai Sai Bat and their ability to detain water. Without implementing parameters for open channel calculation, peak inflows of the model into Nong Lerng Yai Reservoir in the South were implausibly high.

No discharge gauge station exists in the Huai Sai Bat river basin. KIT installed in Huai Sai Bat River a pressure cell to derive discharge. However, the selected location was close upstream of a weir and thus subject to backwater which renders the measurements useless. Therefore, Khon Kaen University derived a synthetic discharge time series for Huai Sai Bat from a comparable river basin (see (Kittiwet, K, Vichian, 2014)).

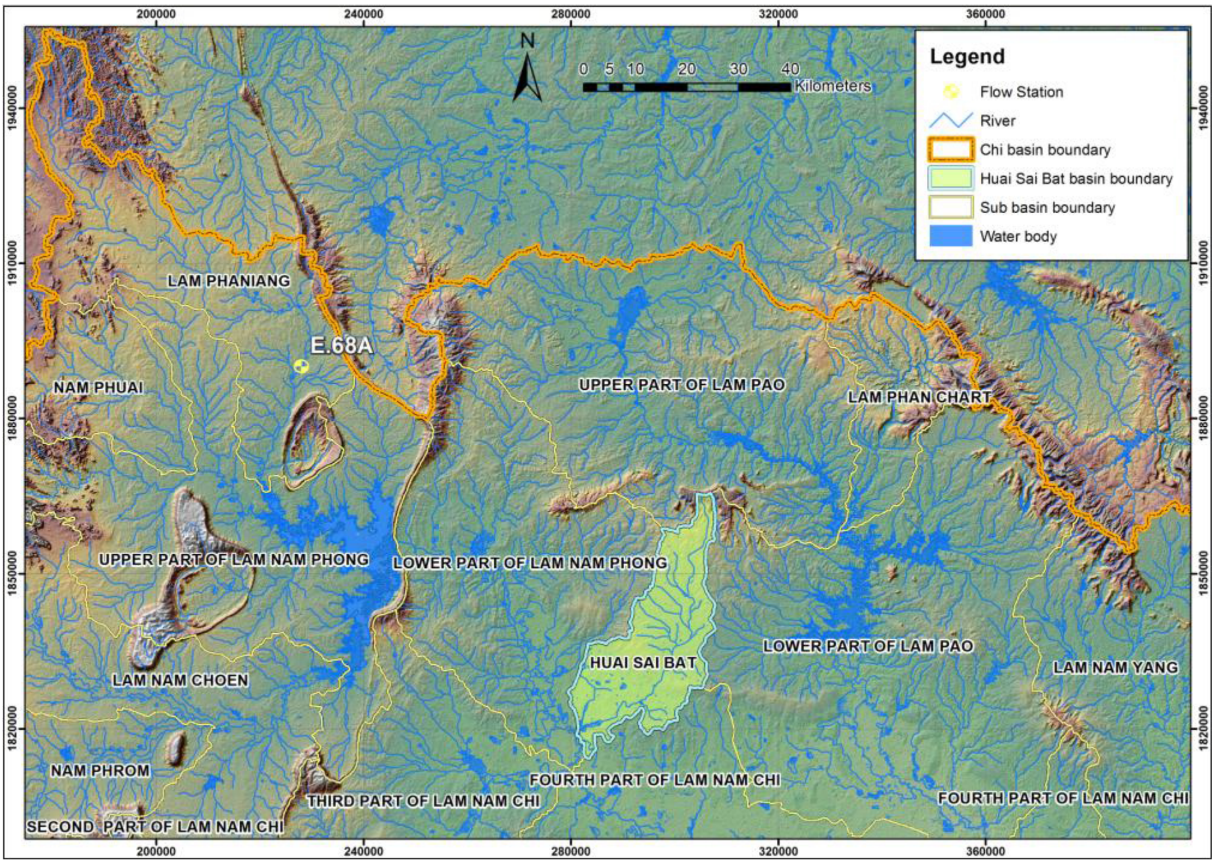


Figure 44: Location of the reference gauging station E.68A in Lam Phaniang river basin, (source: (Kittiwet, K, Vichian, 2014)

To decrease uncertainty due to ungauged discharges, two different hydrologic models have been established.

- TalsimNG (set up by the author)
- SWAT (set up by Khon Kaen University)

TalsimNG and SWAT KKU Model use precipitation either from rainfall station 381201, Khoen Kaen or rainfall station 381301, Tha Phra Agromet both with a daily resolution, however, transfering rainfall from a point source to a watershed is difficult. Moreover, rainfall at Huai

Sai Bat and Lang Phaniang river basin will differ significantly and might explain deviances which occurred during simulation. The behaviour of stream flow with fast rising and falling limbs of flood events and longer periods of almost zero discharge, however, pertains to both Huai Sai Bat and Lang Phaniang.

Both models have been calibrated independently using the synthetic discharge time series so as to achieve qualitatively similar hydrographs. Comparison of results showed that both models indicate similar behaviour concerning daily values as well as for aggregated annual values. Both models obtain approximately 270 Mio.m³/year without applying an area reduction factor (ARF) for converting point precipitation to area precipitation. However, a river basin of more than 600 km² requires the application of an ARF. (Chaiyapong, T., Viraphol T., 2003) suggest empirical equations for ARF depending on catchment area, rainfall duration and return periods. Applying these equations calculation of ARF ranges between 0.74 and 0.79. DWR estimates an annual discharge of approximately 135 Mio.m³/year which can be achieved with TalsimNG with an ARF of 0.77, that is, this coincidence gives strong evidence to apply an ARF. Consequently, all following simulation runs with TalsimNG were calculated with an ARF of 0.77.

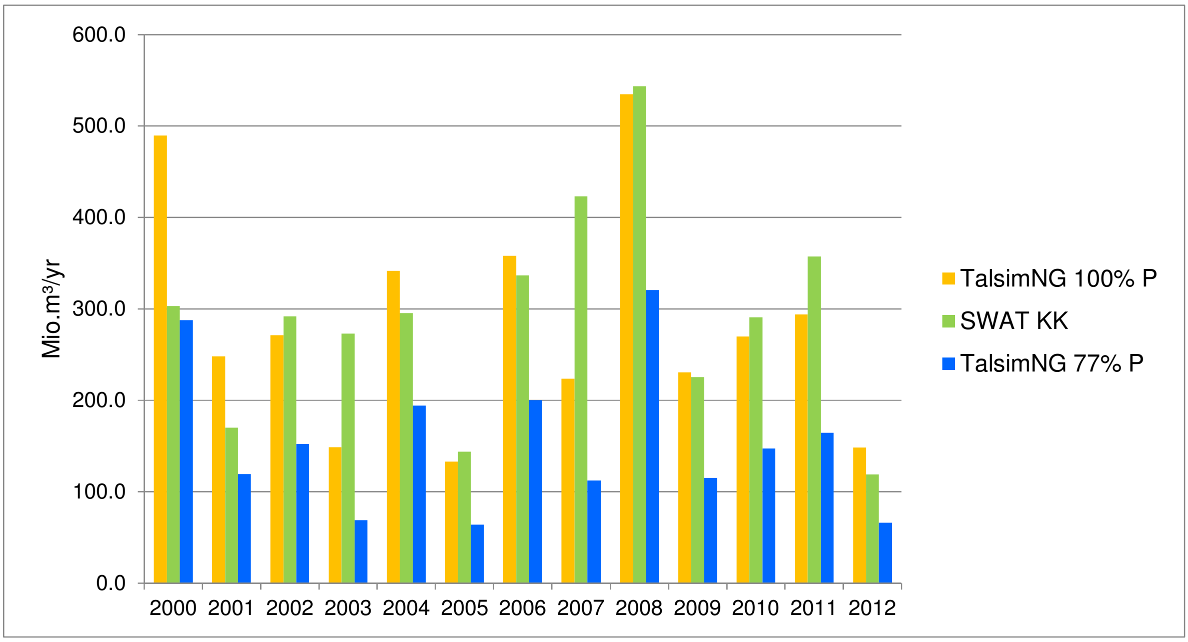
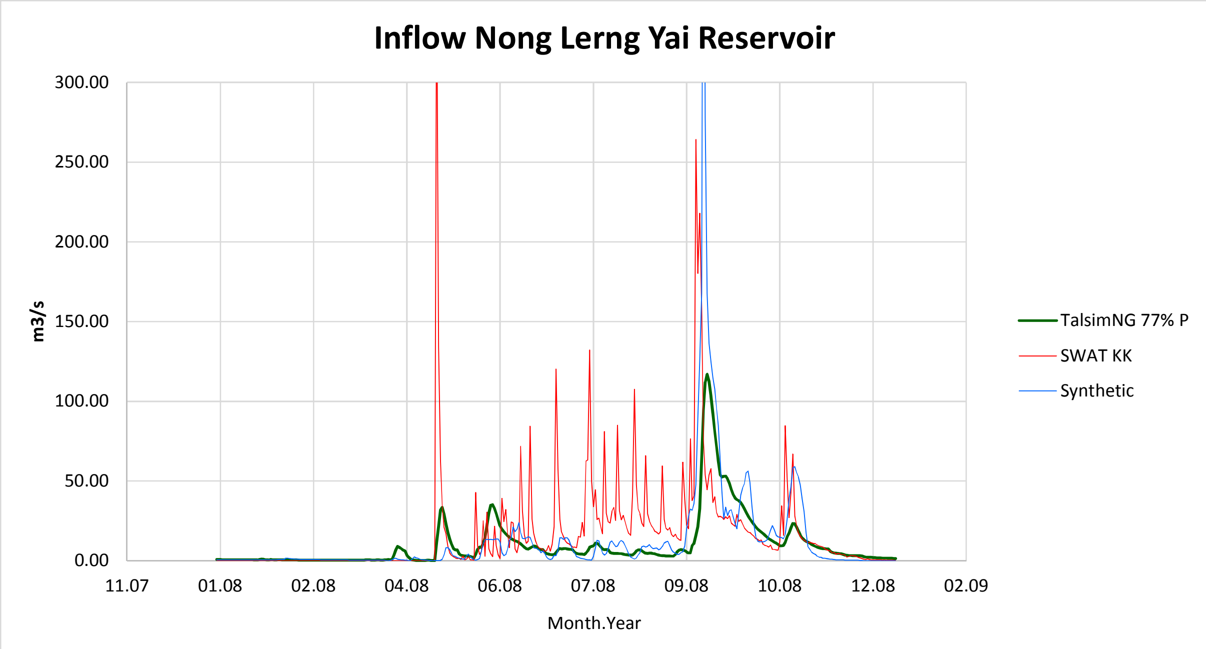
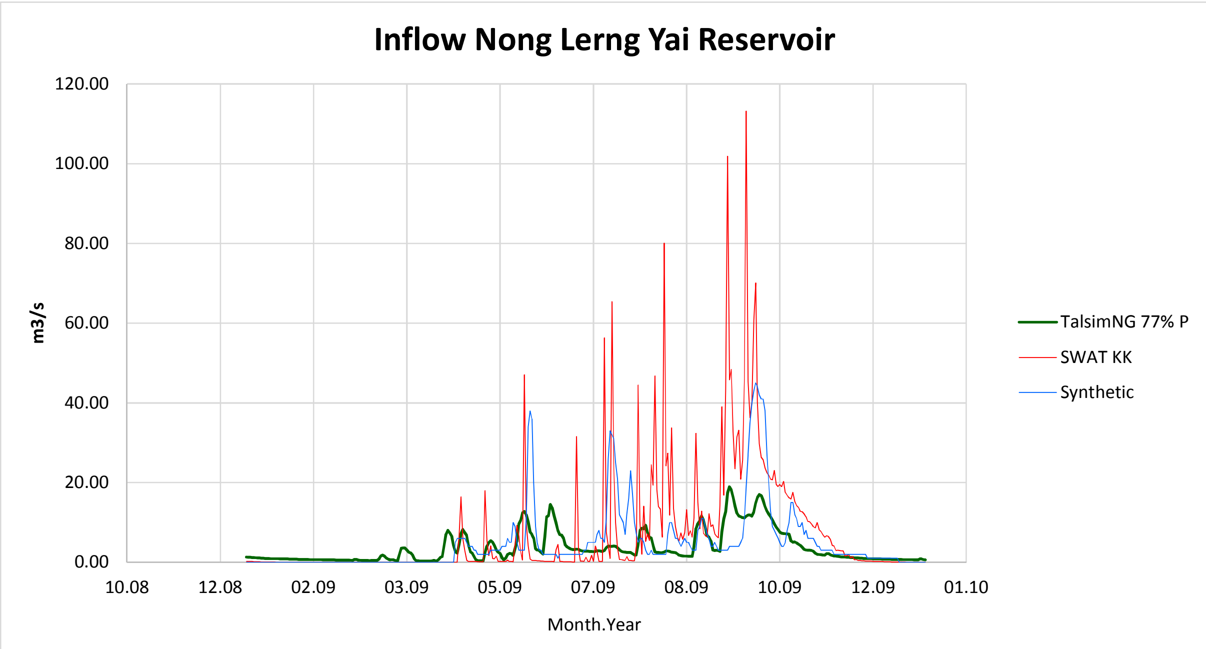


Figure 45: Comparison of annual values of synthetic discharge, TalsimNG and SWAT model without an ARF, Huai Sai Bat


Inflow Nong Lerng Yai Reservoir
m3/s
300.00
250.00
200.00
150.00
100.00
50.00
0.00
11.07
01.08
02.08
04.08
06.08
07.08
09.08
10.08
12.08
02.09
Month.Year
TalsimNG 77% P
SWAT KK
Synthetic


Inflow Nong Lerng Yai Reservoir
m3/s
120.00
100.00
80.00
60.00
40.00
20.00
0.00
10.08
12.08
02.09
03.09
05.09
07.09
08.09
10.09
12.09
01.10
Month.Year
TalsimNG 77% P
SWAT KK
Synthetic

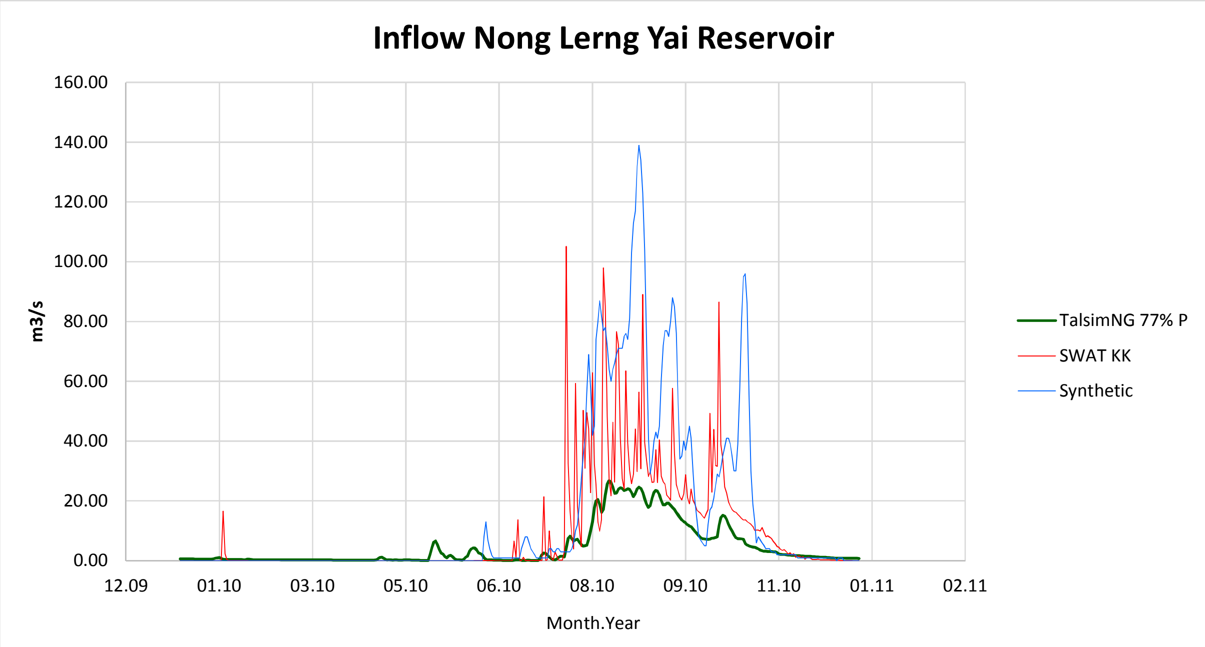


Figure 46: Comparison of synthetic discharge, TalsimNG and SWAT KK discharge at the river basin outlet, Huai Sai Bat

In essence, TalsimNG and SWAT model results show are coherent in principle and reflect a runoff and flow behaviour which corresponds to long-term experience from local institutions and expectations. Due to the application of an ARF of 0.77, TalsimNG corresponds to a long-term average of 135 Mio.m³ of annual discharge which is suggested by DWR.

7.3.2 Water management

This section refers to causal-chain 1, 2, 3, 4 and 5 in Huai Sai Bat river basin.

The causal-chain analysis and information gathered during the field trips revealed problems in regard to water management. Water is needed for domestic use and irrigation both spatially distributed over different districts. Environmental flow is not considered in Huai Sai Bat basin so far. Water demand is almost constant for domestic use whereas irrigation demand varies over the year depending on crop requirements. Sources for water abstraction are two reservoirs (Nong Yai and Nong Lerng Yai), the river Huai Sai Bat and some tributaries, small ponds and to some extent groundwater. Water abstraction along Huai Sai Bat and tributaries takes place immediate upstream of weirs in backwater areas.

Generally, average annual discharge exceeds the current total demand including domestic and irrigation. Provided enough impoundment volume were in place, all needs could be covered. As this theoretical assumption is not true, water storage and allocation is of crucial importance in Huai Sai Bat river basin. For that reason, scenarios were carried out demonstrating the vulnerability of domestic and irrigation supply due to different water management rules. Consequently, incorporating water management elements and operation rules in the model is mandatory. Moreover, it is necessary to simplify the reality such that the model implements the most important water infrastructure elements only and applies manageable operation rules under conditions of available data. In addition, district's related demands must be assigned to water resources infrastructure which has been set according to the location.

Operational principles for Nong Yai Reservoir:

The demand from Kra Nuan district - second largest requirements of all districts - was assigned to Nong Yai reservoir and ponds located within the district. Abstraction is separated by domestic and irrigation whereas irrigation supply is shared between the reservoir and the ponds within the Kra Nuan district. For the baseline scenario 70% of irrigation demand were assumed to be taken from the reservoir and 30% from the ponds. This proportion has been used as a parameter and was changed in the water management scenarios. Within the reservoir no particular priority has been given neither to domestic nor irrigation.

Weirs for Huay Mek, Chuen Chom and Chamsong dicstrict:

For the districts Huay Mek, Chuen Chom and Chamsong weirs have been implemented in the model from which water has been abstracted for supply. The water demand of one district was summarised and withdrawn at the weir assigned to the district. As long as district's demand is covered by withdrawals at the weir, no water from ponds is used. This assumption uses discharge in the river with a higher priority and regards water abstraction out of ponds as a secondary option. This reflects a general water management principle taking maximum advantage of uncontrollable flow before controllable sources are used.

Ponds:

All ponds within one district were summarised to one impoundment. Their catchment areas were estimated by means of GIS and implemented in the model accordingly. Water abstraction rules differ depending whether a district has a weir or is assigned to a reservoir

- District with a weir:
  Water abstraction out of ponds takes place only if not enough water can be withdrawn at the location of the district's weir
- District with or designated to a reservoir:
  Reservoir and the pond share the water demand for irrigation with a fixed proportion.

Operation principles for Nong Lerng Yai Reservoir:

It was assumed that Nong Lerng Yai Reservoir supplies exclusively Chiang Yuen and Muang Khon Kaen district for domestic and irrigation use. No other sources has been used. Within the reservoir no particular priority has been given neither to domestic nor irrigation.

A joint supply with a reservoir in combination with a weir was not considered in the model.

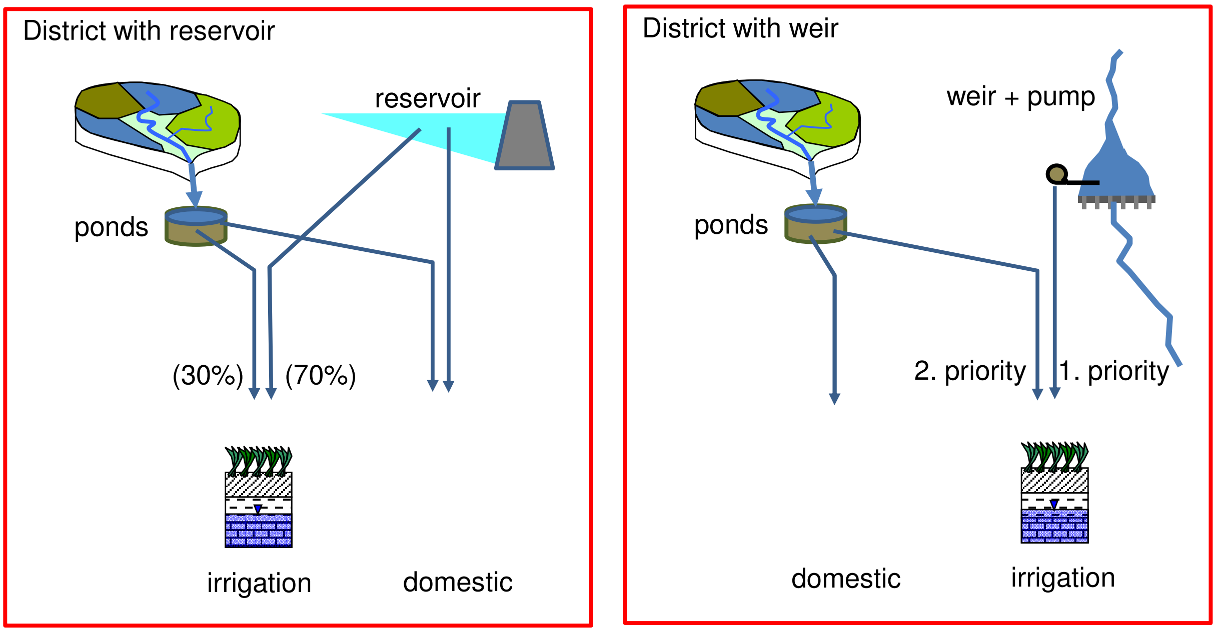


Figure 47: Schematic supply scheme with priorities for domestic and irrigation, Huai Sai Bat

Parameters which have been changed were:

- shares for irrigation supply between reservoir and ponds
- reservoir zoning

Domestic use:

Domestic use was uniformly distributed over the year with a constant rate. Only water either from reservoirs or ponds were considered as suitable for drinking water as purification and treatment for out-of-the-river abstraction from Huai Sai Bat seem inappropriate. It must be noted that domestic water in the small villages taken from ponds with only little treatment in place do not fulfil commonly required and acknowledged water quality standards.

Irrigation:

Irrigation requirements are covered by either rainfall or additional supply by structures like reservoirs, ponds or weirs. Additional supply is used only when the amount of rainfall falls short of current requirements balanced on a daily basis. Rain-fed irrigation was not part of the water management and thus not further considered.

Water balance

By comparing precipitation, evaporation, discharge and water consumption, difficulties in terms of managing water resources become apparent.

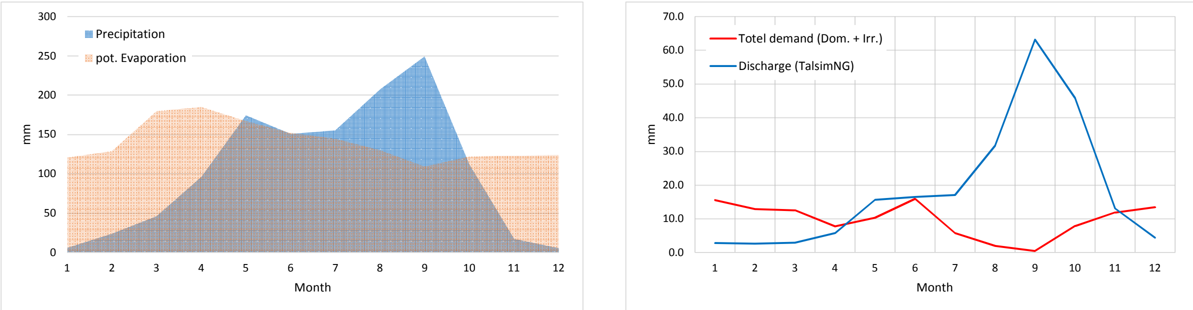


Figure 48: Water balance for Huai Sai Bat river basin

The left chart in Figure 48 indicates that on average precipitation exceeds potential evaporation for four month only per year. The figures represent long-term average quantities based on available time series given in Section 2.2.1. Applying the classification according to humidity, Huai Sai Bat is considered as semi-arid despite Monsoon and rainy season. The slow onset of rainfall from April to May is overcompensated by evaporation implicating very low discharge. During this time discharge results from precipitation with high intensities exceeding the retaining capacities of vegetation and soil. Precipitation distinctly exceeds potential evaporation only during the main rainy season between July and October in which discharge rises significantly. January to March and to some extent November and December are more or less dry with negligible discharge leading to a nearly dry river bed with very little flow and no opportunity to extract water.

As a result, Huai Sai Bat relies much on the capacities to store water within a rather short period of time in the year. It is obvious that more storage volume enhances safety for water supply, however, capacities are restricted due to topography, environment and financial resources. This is why the surplus during the main rainy season is not utilisable to full extent. In essence, water management must focus on storing water in times of surplus with given capacities in combination with foresighted water release strategies by timely reducing full supply levels to lower quantities to keep supply for a longer period on a higher level and to avoid running reservoirs empty.

7.3.2.1 Shares for irrigation supply between reservoir and ponds

Considering the Nong Yai dam, drinking water supply and irrigation are competing purposes with mutual dependencies. To demonstrate the vulnerability of inefficient water management at Nong Yai reservoir, scenarios were established in which the proportion for irrigation withdrawn from the dam was varied. It was tested to which extent irrigation consumption must be reduced to enhance safety for drinking water. Domestic use was assumed to be taken only from the reservoir, whereas water for irrigation has two potential sources: Nong Yai dam and the ponds. The less water are taken from the reservoir, the more must be abstracted from the ponds and the higher the safety for drinking water supply will be. The first scenario considered 70% of all irrigation requirements (Kra Nuan district only) extracted from the reservoir and 30% from the ponds. In the second scenario irrigation requirements were reduced to 50% taken from the reservoir and the ponds. Finally, a scenario accomplishing almost 100% safety for drinking water was evaluated iteratively.

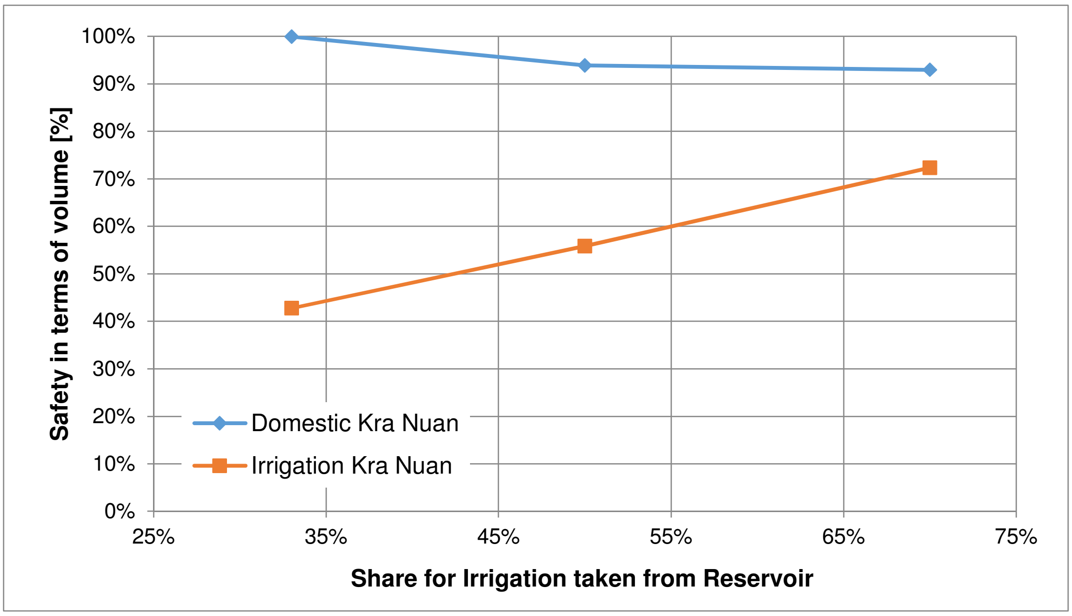


Figure 49: Relationship between domestic and irrigation use with varying shares for irrigation at Nong Yai Reservoir

Figure 49 illustrates that improving safety for drinking water was achieved only with notable losses for irrigation. That is, simple operation rules sharing irrigation requirements only by means of a simple allocation rule between reservoir and ponds do have the potential to improve safety for drinking water supply but result in disproportionate losses for irrigation.

7.3.2.2 Reservoir zoning

Reservoir zoning defines releases according to water level and time of the year. Such an operation rule splits reservoir volume in different segments and anticipates expected inflow volumes according to their probability of occurrence. Following this, different zones were established defining releases for irrigation at Nong Yai Reservoir. A line of equal release indicates the amount of water to be released depending on current water level or storage volume respectively throughout the year. In Figure 50 the lines are given as proportion of the total irrigation requirements of Kra Nuan district.

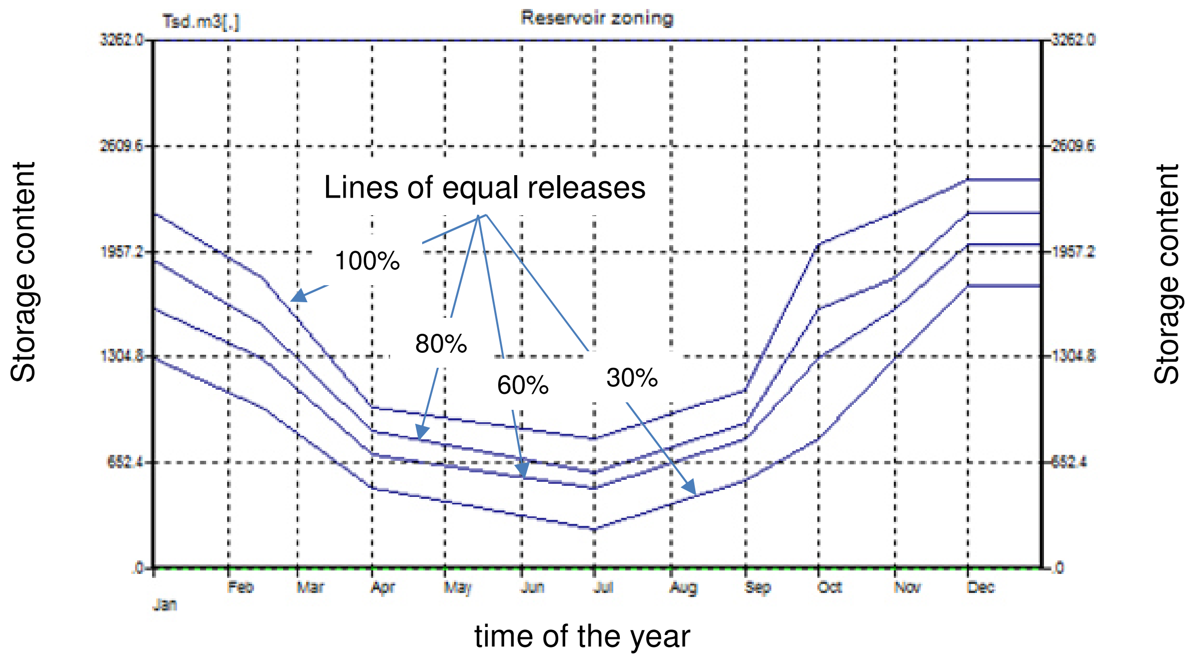


Figure 50: Reservoir zoning for irrigation releases at Nong Yai Reservoir

The zones anticipates expected inflow in that a nearly empty reservoir can still release water for irrigation prior to the onset of rainy season (April to August) as the likelihood for substantial inflow is high. In contrast, releases for irrigation are associated with high water levels in the reservoir at the end of the rainy season as this is the time of the year which faces the longest forthcoming period of low or zero inflow.

The zones have been iteratively established and accommodate the flow regime at Huai Sai Bat whereas proportions of total amount required are parameters subject to change.

Table 10: Scenarios with different reservoir zones at Nong Yai reservoir

Release lines	ZONE2	ZONE3	ZONE4
1	33%	33%	50%
2	50%	67%	90%
3	67%	83%	93%
4	75%	97%	97%

It must be noted, that results constitute rather an example of reservoirs zones than an optimised solution event though safety could be enhanced considerably.

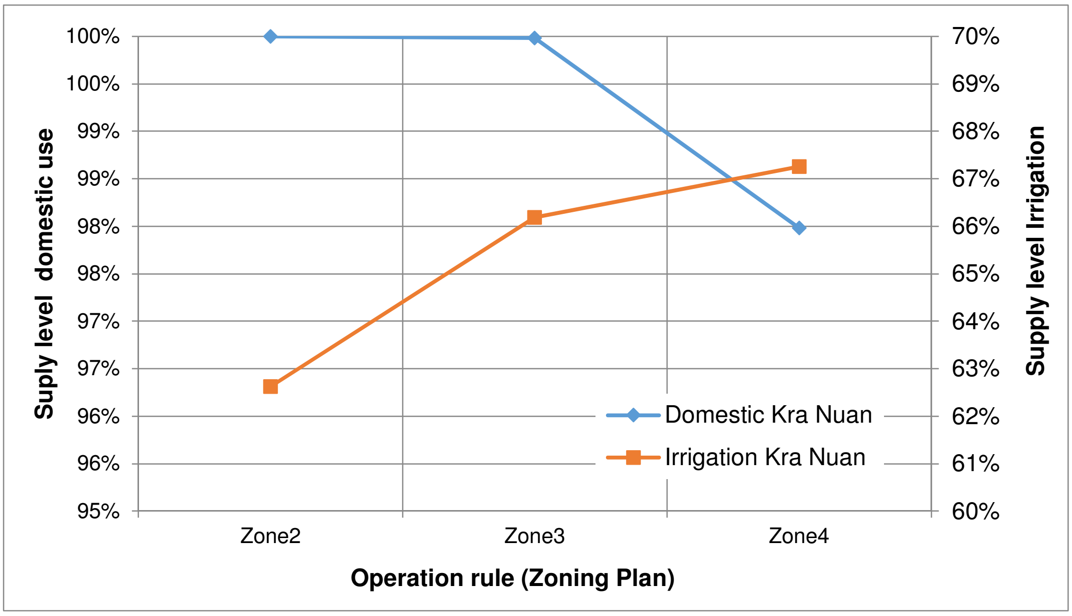


Figure 51: Safety of supply depending on different zoning scenarios at Nong Yai Reservoir

The results illustrate safety for irrigation as 62.5% associated with nearly 100% safety for drinking water supply compared to approximately 42% safety for irrigation with simple proportionate operation rules (see Figure 49). This clearly indicates advantages of applying reservoir zoning. Performance can be increased for irrigation at the expense of a slightly reduction of safety for drinking water up to more than 66%. Further improvements in irrigation, however, cause excessive losses for domestic use.

7.3.2.3 Conclusion

The causal-chain analysis revealed water resources management as one crucial component driven by different root causes in the Huai Sai Bat river basin. Vulnerability of safety for drinking water and irrigation use could be shown by applying different operation rules. Hence, any inefficient water resources management will lead to underperforming use of available water resources with adverse economic, social and environmental consequences.

The absolute figures about safety must be taken with care due to the uncertainties associated with missing observed discharge and assumptions concerning model parameters. However, relative changes are more reliable and yield enough evidence in terms of importance of a sound water management.

7.3.3 Agriculture and crop requirements

This section refers to causal-chain 7 in Huai Sai Bat river basin.

Crops affect the flow regime by their capacity to retain water but even more with regard to requirements due to transpiration. Annual patterns of requirements are collected in Figure 52 for dominating crops in the Huai Sai Bat river basin and compared with average rainfall distribution over the year.

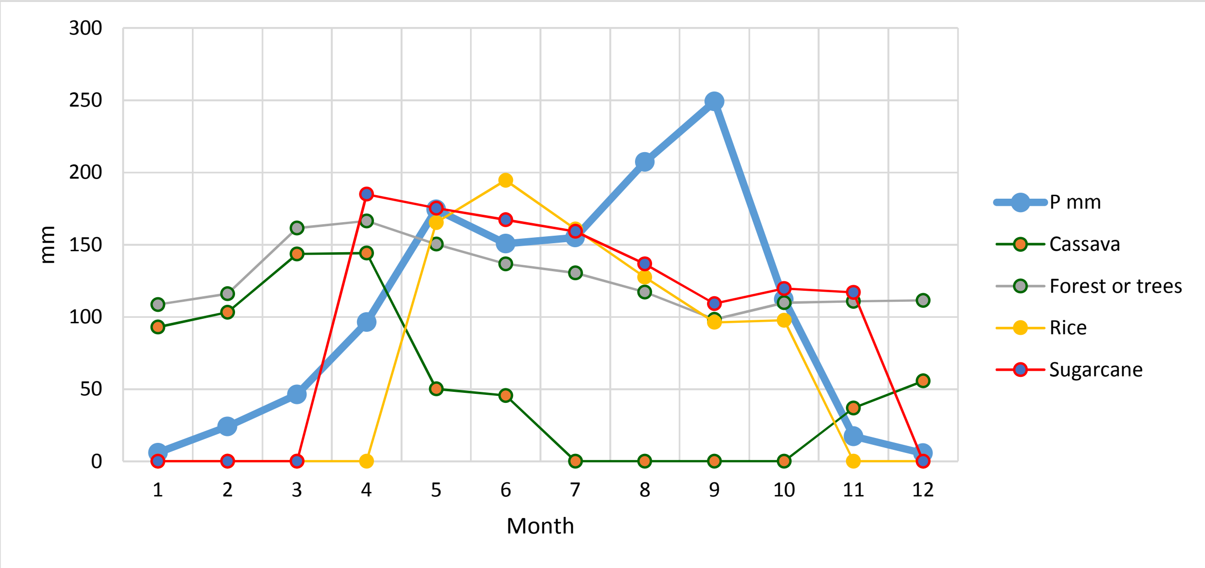


Figure 52: Crop requirements, derived from (Kittiwet, K, Vichian, 2014b)

Sugarcane and rice constitute the main crops cultivated either by irrigation schemes or rainfed irrigation. Periods of growth from seeding, maturity to harvest are indicated and show a significantly higher demand for sugarcane and rice compared to cassava.

To obtain effects of different crops, sugarcane and rice were substituted completely by cassava in scenario 1. In scenario 2 cassava and sugarcane are compensated by rice and scenario 3 uses sugarcane instead of cassava and rice. All three scenarios are compared with the baseline scenario corresponding the current situation. Results are then compared by the inflow to the Nong Yai reservoir.

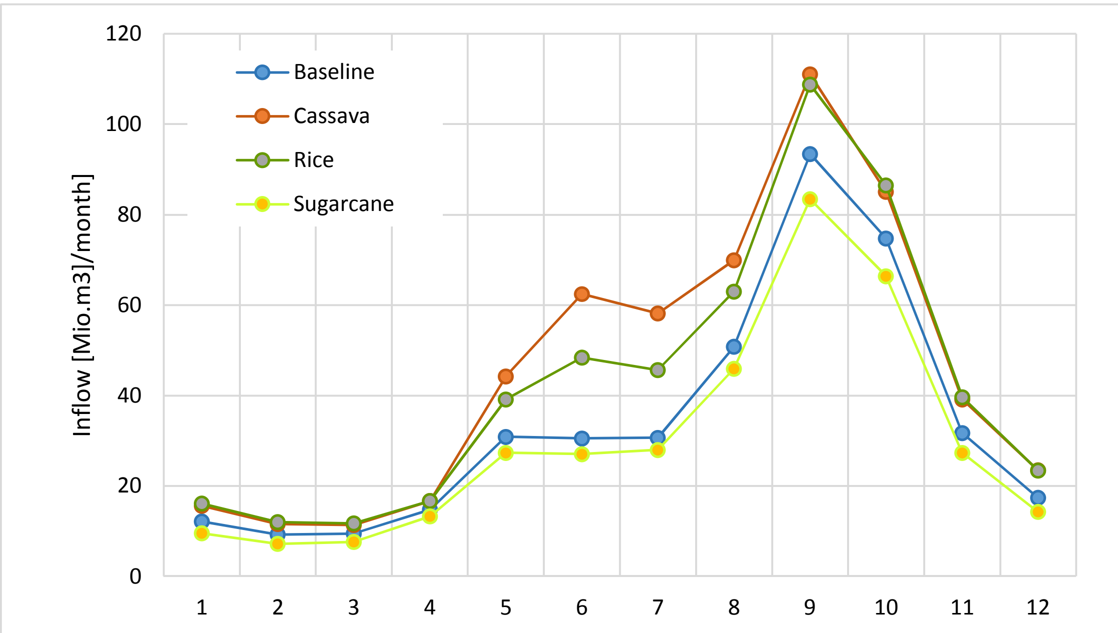


Figure 53: Impact of changes of crops in regard to inflow to Nong Yai reservoir

The baseline representing the current situation is the second largest consumer of water by agriculture. Only a scenario with agriculture completely based on sugarcane tops the high consumption. A shift to more rice cultivation would, however, provide for more inflow. A scenario based on cassava yields the lowest consumption and the highest inflow to Nong Yai reservoir.

Consequently, any shift to more cassava production would entail a benefit for safety of drinking water and thus would increase the amount of available water for irrigation purposes. In reality, shifting to monoculture is neither an objective nor sustainable but is a suitable mean for identifying consequences and vulnerabilities by modelling. The results provide evidence for the cause-effect relationship leading to freshwater shortage as a result of subsidies for rice from the government (Kedmey, 2014).

7.3.4 Erosion and sediment modelling

This section refers to causal-chain 1 in Huai Sai Bat river basin.

Erosion and sedimentation rises often due to conversion of rain forest into cultivated land. Such a scenario is unlikely in Huai Sai Bat river basin as rain forest is hardly left and is confined to the remote north of the watershed. Nevertheless, erosion constitutes a problem in conjunction with agricultural runoff, transport into the river, followed by deposition in the reservoirs reducing the storage content year by year. In combination with a lack of maintenance and/or missing sediment ponds upstream of a reservoir, sedimentation aggravates freshwater shortage considerably. To quantify the effect of sedimentation, HEC-HMS model was used to estimate sediment yields into the reservoir. Again, inflow into the Nong Yai reservoir is used to demonstrate the effects. As less is known about grain-size distribution, it was used as a parameter to check sensitivity.

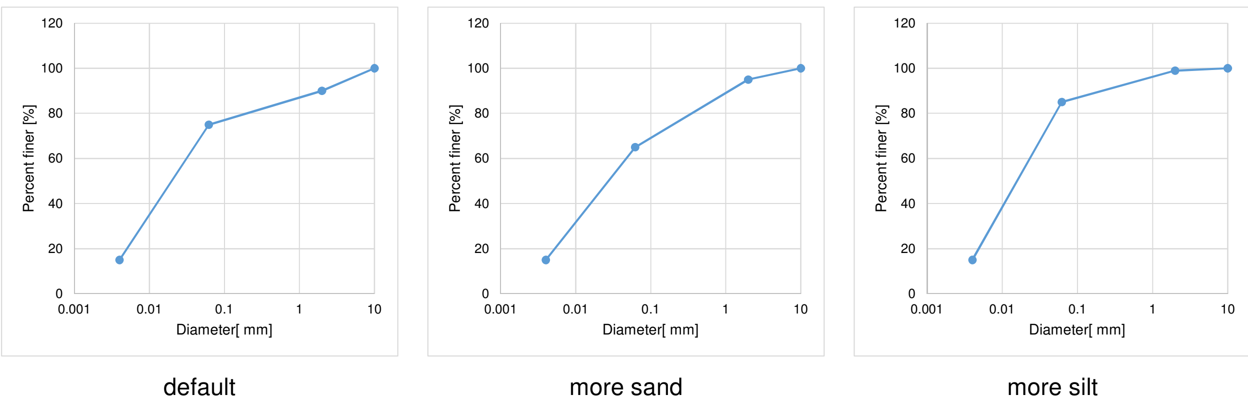
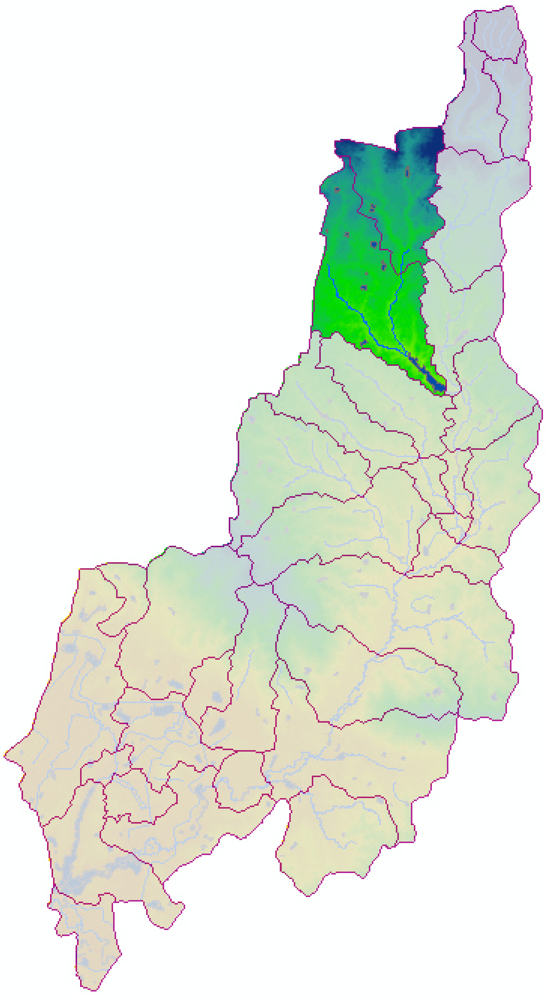


Figure 54: Grain-size distribution for sedimentation modelling in Nong Yai reservoir



The indicated area was used to calculate sediment yields. Densities for a assumed grain size distribution were set to:

Clay	480	kg/m3
Silt:	1040	kg/m3
Sand:	1490	kg/m3
Gravel:	1490	kg/m3

Figure 55: Area used for sedimentation modelling in Nong Yai reservoir

Simulation runs were carried out with standard parameters for erosion parameters according to Section 7.1.2.2 over a period of 13 years from 2000 to 2012. Grain size distribution was varied according to Figure 54.

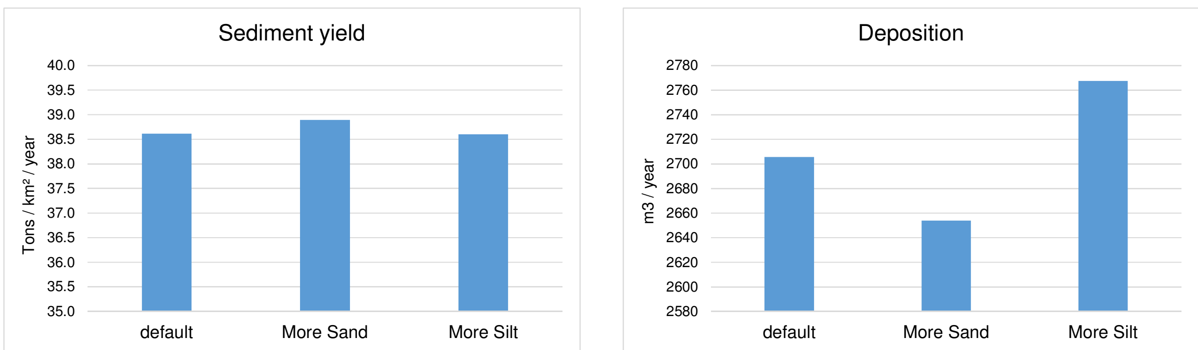


Figure 56: Results of sedimentation modelling in Nong Yai reservoir

38 to 39 tons/km²/year on average express an expected value with less dependency on grain size distribution. On the other hand, sediment which settle in the reservoir differs significant-

ly. At least 2600 m3/year remain in the reservoir considering different grain size distributions, or in other words, more than 220 ordinary trucks (4 axis, no trailer, 12 m3 carrying capacity) were necessary to remove the material.

These figures seem to be a minimum estimate as sediment which is actually visible in the reservoir imply even higher sedimentation rates.

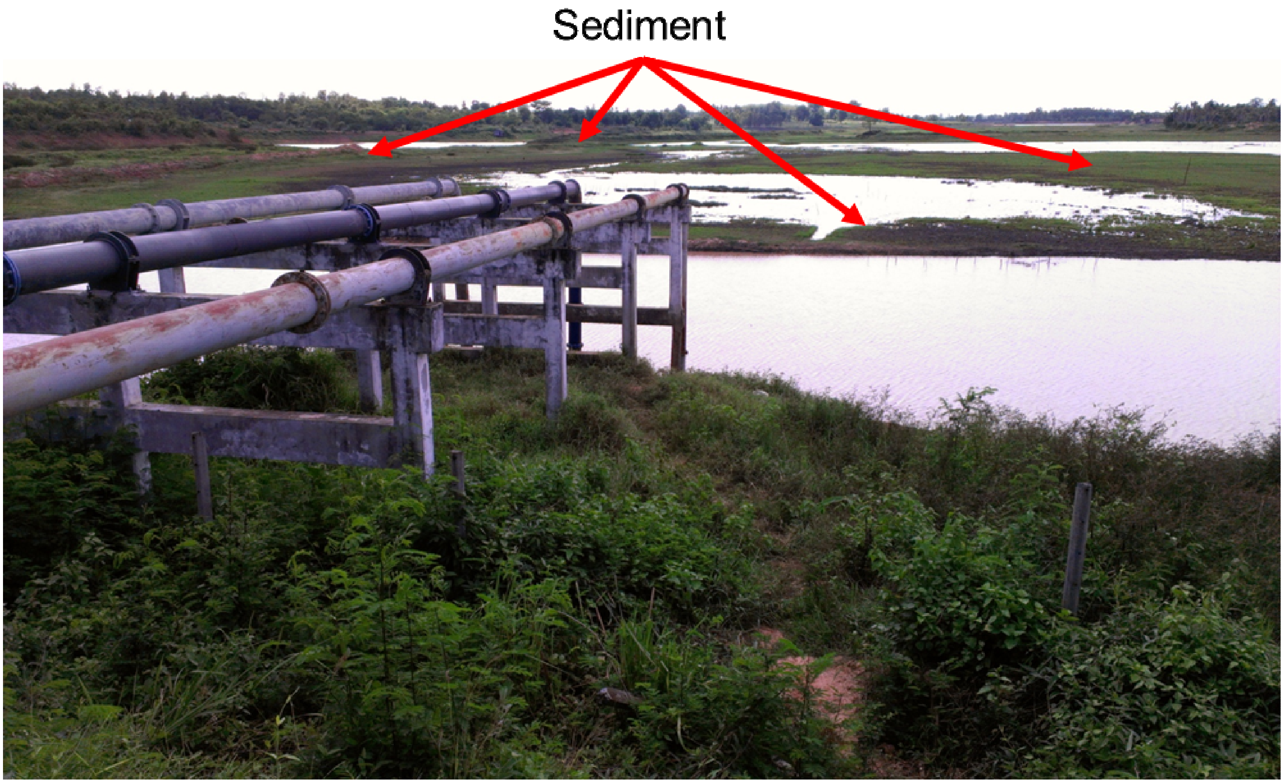


Figure 57: Nong Yai reservoir

7.3.5 Summary

Efficiency of water allocation rules is of crucial importance to ensure safety of drinking water supply and irrigation use:

- Priority of drinking water is unconditionally necessary to achieve reasonable safety
- With a simple operation rule sharing releases for irrigation between Nong Yai reservoir and ponds safety for drinking water can reach a satisfactory value at the expense of unsatisfactory performance for irrigation supply.
- Reservoir zoning improves the overall performance for both domestic and irrigation use significantly
- Operation rules require monitoring, controlling and enforcement. Individual abstraction for irrigation should be replaced by controllable centralized hydraulic structures at Nong Yai reservoir

- Implementation of operation rules considering reservoir water level, water level in ponds and time of the year would enhance water resources performance as it could be shown for Nong Yai reservoir

Crop requirement affect water management significantly:

- Compared to the current conditions, increase of sugarcane has the potential to reduce inflow into Nong Yai reservoir up to 12%
- Decrease of sugarcane substituted by an increase of rice could enlarge inflow into Nong Yai reservoir up to 25%
- Promotion of cassava at the expense of rice and sugarcane could increase inflow to Nong Yai reservoir up to 35%
- Sugarcane is the biggest water consumer followed by rice. Cassava is a drought resistant and less water demanding plant improving flow regime for drinking and irrigation purposes.
- Subsidies supporting water demanding plants aggravate safety for domestic use and irrigation schemes

Sedimentation as a consequence of runoff from agricultural areas gives rise to:

- considerable deposition with more than 2600 m3/year into Nong Yai reservoir
- degrading performance of all water resources structures, in particular reservoirs and weirs, whose storage content decreases from year to year exacerbating climate change effects
- increasing efforts in regard to sediment removal and maintenance to counter adverse impacts
- additional hydraulic structures like sediment ponds upstream of reservoirs

Detailed assessment highlights the necessity to improve water resources management as it was already ascertained in the causal-chain analysis. Therefore, flexible and anticipating operation rules constitute the first pillar towards long-term mitigation of vulnerability. Intelligent release strategies do have a big potential to improve safety of drinking water and irrigation supply. At the same time, they

- provide concise and clear regulations to be followed by all stakeholders
- reduce potential conflicts due to undetermined water allocation
- require adequate monitoring and enforcement by water authorities which is still an unresolved problem
- necessitate rehabilitation of hydraulic structures along Huai Sai Bat river and reservoirs respectively

- constitute an important step towards integrated water resources management

The second pillar to reduce vulnerability is the review of agricultural practices. Update of land use data in association with an inventory of individual irrigation practices and irrigation schemes would pave the way for further improvement of foresighted cross-sectoral integrated water management. Measures to reduce erosion, rehabilitate reservoirs, river beds and weirs represent the third pillar aiming at sustainable water resource management in Huai Sai Bat river basin.

8 EXECUTIVE SUMMARY

Within the scope of Improved Management of Extreme Events through Ecosystem-based Adaption in Watersheds (ECOSWat) pilot areas have been selected and were evaluated in terms of their vulnerability.

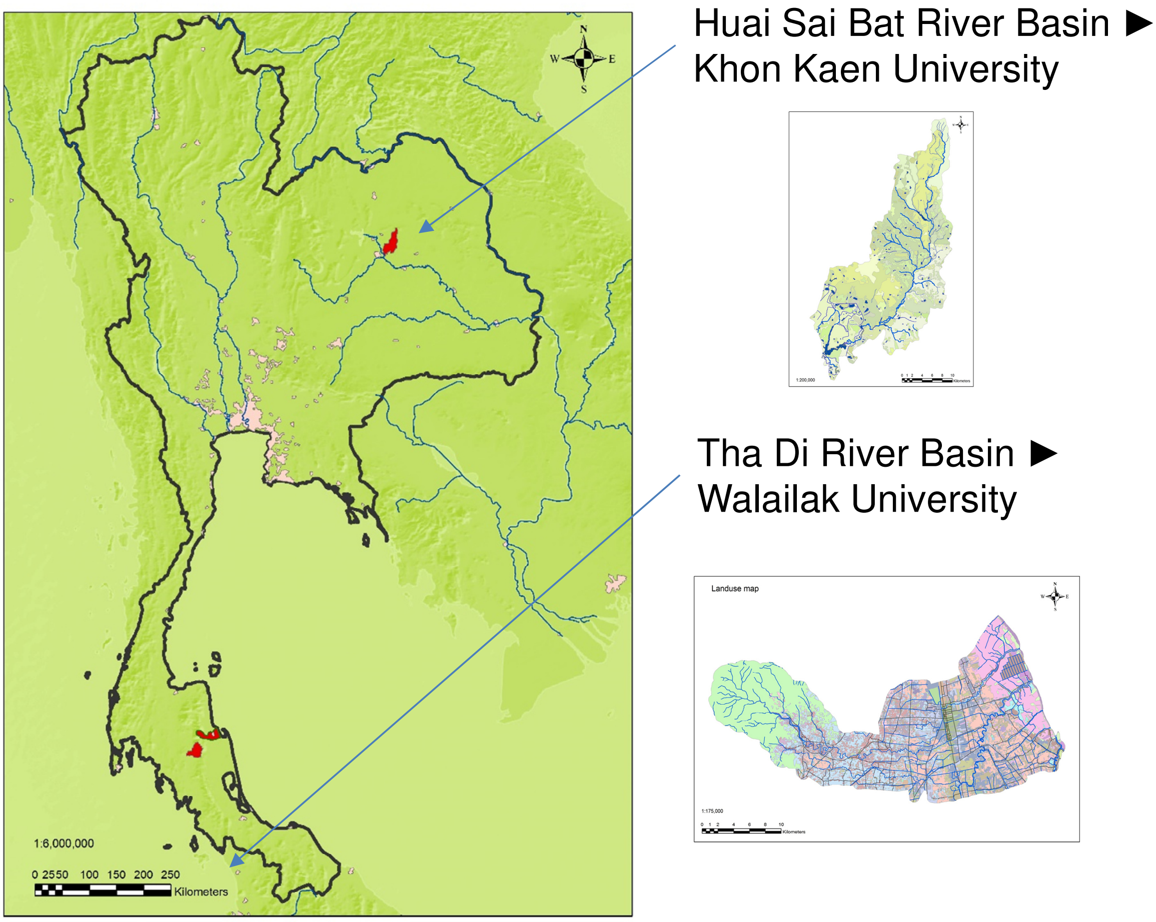


Figure 58: Overview about the project areas

The project involved the Khon Kaen University (KKU) and the Walailak University (WU). Both institutions supported this study in close collaboration with the ECOSWat project team.

The vulnerability study was carried out based on cause-effect relationships identified and verified in different stages:

- Geographical scaling
- Scoping
- Causal chain analysis
- Detailed assessment accompanied by modelling and policy option analysis

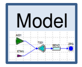
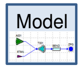
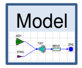
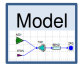
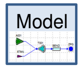
Geographical scaling defines the geographic boundaries of the pilot areas to be analysed and creates sub-regions within each project area and major hydrosystem features and economic activities. Within the scoping procedure critical major concerns and issues by assessing their environmental and socio-economic impacts are addressed and yield information used during the detailed assessment. The cause-effect analysis traces the proximate to the root causative factors and was substantially supported by KKU and WU. A policy option analysis indicates potential policy interventions based on the identification of the root causes conducted in the Causal Chain Analysis. This was integrated in the scenarios during the detailed assessment. The detailed assessment accompanies the scoping and causal chain analysis process. It substantiates the conclusions by identifying, verifying and documenting the selected causal-chains.

The major cause-effect relationships are given in the following tables.

Tha Di:

No	Location	Sectors	Subjects	Description	Root cause	Verification	Parameters	Model
1	Tha Di, Nakhon Si Tammarat	Water, Public health, Coastal zones, Biodiversity, Fisheries	Water quality	Inundation in combination with disposal of debris, solids and waste	Governance, Legal, Urban planning	Model, field trip	Water quality, oxygen, nitrogen, ammonium	Model
2, 3	Tha Di, Nakhon Si Tammarat	Water, Agriculture	Flood infrastructure	Implementation of flood mitigation infrastructure without compensatory measures	Governance, Legal, Technology	Model, field trip	Flood hydrograph, flow velocity, erosion, sedimentation	Model
4	Tha Di, Villages & Agriculture	Water, Agriculture, Urbanization	Establishment of real estates, urban spread	Urbanization, loss or retention area	Legal, Demographic	Field trip, satellite images	Land use	
5	Tha Di, Coastal area, mangroves	Water, Aquaculture, Fisheries	Shrimps ponds, use of chemicals. Effluent disposal	Disposal of pond water	Economic	-	-	
6	Tha Di, Villages & Agriculture	Water, Socio-economic	Recreational areas	Point source disposal of waste and waste water	Social & cultural, lifestyle	-	-	
7	Tha Di, Villages & Agriculture	Water	Hydraulic structures, water resources development	Living weirs	Social & cultural, lifestyle	Experience over years	Groundwater level, water quality, biodiversity	
8	Tha Di, Coastal area, mangroves	Coastal zones, Aquaculture, Biodiversity	Land use change, coastal area degradation	Conversion of mangroves into aquaculture and agricultural land	Economics, Technical	Satellite images	Land use, binding of sediments, buffer for nutrients, storm buffer	
9	Tha Di, Mountainous area	Agriculture	Land use change	Conversion of rain forests to cultivated land, rubber plants, etc.	Demographic, Economics	Model, field trip	Land use, erosion, sedimentation	Model
10	Tha Di, Nakhon Si Tammarat	Urbanization	Migration, Water quality, Environment, Public health	Effluents discharge causing crictical water quality conditions in receiving streams	Demographic, Economics, Technology	Model	Water quality, pollution loads, sewer system conditions	Model

Huai Sai Bat:

No	Location	Sectors	Subjects	Description	Root cause	Verification	Parameters	Model
1	Huai Sai Bat, Nong Yai Reservoir	Water, Agriculture	Water quality and suspended solids	Agriculture runoff and suspended solids washed into the reservoir	Prices, knowledge and technical understanding	Field trip and communication	Water quality	
2	Huai Sai Bat, Nong Yai Reservoir	Water, Agriculture	Water quality and suspended solids	Agriculture runoff and suspended solids washed into the reservoir	Prices, knowledge and technical understanding	Model, field trip	Contanimated sediments	
3	Huai Sai Bat, River	Water, Agriculture	Water abstraction	The River Huai Sai Bat is completly developed with weirs for abstracting water with the potential to cause conflicts between water users	Prices, income, market structure	Model, field trip	Water quantity	
4	Huai Sai Bat, Pumping station	Water, Agriculture	Water abstraction at a single point	Extensive pumping during floods to lower the water level so as to avoid flooding of fields takes place.	Income, poverty, knowledge	Model, field trip	Water quantity	
5	Huai Sai Bat, River	Water	Monitoring, Maintenance, Operation	No monitoring is in place to control water abstraction and allows water management enforcement	Laws & regulations, enforcement & control	Field trip and communication	Water quantity	
6	Huai Sai Bat, River	Water	River maintenance	The River is regularly dredged by RID (information from field trip). The sediment is put along the river banks forming a dyke.	Information & training, tradition	Field trip and communication	Water quantity, flood management	
7	Huai Sai Bat, cultivated land	Agriculture	Land use, crops	Main crops are rice and sugarcane. This is due to subsidies for rice which do not reflect real market prices. Drought resistant crops are less cultivated.	Prices, income, market structure	Field trip, land use maps	Water consumption, crop coefficients	

8.1 Tha Di

The most important vulnerabilities are explained below each of which has a strong evidence.

Land use change

Assuming only rain forest conversion into arable land without affecting soil, simulations show that when rain forest is chopped and replaced by vegetation with less developed canopies, interception can drop more than 60% consuming only more than 200 mm/a instead of more than 600 mm/a on average. Surface runoff can increase up to 5%, on the other hand, interflow and groundwater recharge increase by 7 to 20%.

Modelling of rain forest conversion inducing soil property modification which has strong evidence proofed by numerous investigations (Simmons 2008, Maidment 1992) indicates that halving infiltration capacity will lead to doubling of runoff rates and a reduction up to 20% of interflow and 15% of groundwater recharge. This scenario is much more likely to occur than a scenario without soil characteristic modifications mentioned above. As a result, reduction of interflow and groundwater recharge reduces water availability. It is not relevant whether top soil horizon only or all soil horizons are affected due to land use change since results remain almost identical.

Erosion as a consequence of rain forest conversion demonstrates that rain forest conversion causes overproportional erosion and sediment yields. Only 15% of converted rain forest induces an increase of sediment yields up to 40%.

In conclusion, any conversion of rain forest affects flow regime and sediment budgets which will worsen over time and are partially irreversible. Thus, the following features will be highly vulnerable and at risk:

- Water abstraction for domestic use due to river bed and cross section alterations
- Flood protection due to river bed and cross section alterations
- Operational life span and viability of living weirs due to sedimentation
- Macrozoobenthos and river bed habitats due to river bed changes and/or siltation

In addition, landslides are very likely to occur exacerbating the situation.

Such negative impacts must be prevented by any means as, for instance, erosion is irreversible and substantial sediment budget modifications raise problems to all aspects of water related issues.

Water quality and urbanisation

Wastewater disposals from urban areas harm considerably downstream reaches. Almost pre-saturated conditions of oxygen upstream of point-sources of effluents can compensate oxygen consumptive discharges like BOD. Population growth in conjunction with poor maintenance of sewer system generated relative changes of oxygen in the range of 1 mg/l during dry weather conditions and up to 0.4 mg/l during storm water events. For comparison, 4 mg/l (absolute value) is the threshold to be classified as poor water quality. Increase of population associated with poor maintenance of sewer system is likely to generate almost critical fish toxic ammonia (NH3) concentrations.

Degradation of mangroves

Conversion of mangroves into aquaponds paves the way for more vulnerability. A reduction of mangrove area is obvious and proven. A substantial buffer against natural hazards and for nutrients is disappearing and natural resources linked to mangrove like fish will suffer and be more exposed to contamination from urban effluents discharged at Nakhon Si Tammarat.

8.2 Huai Sai Bat

The most important vulnerabilities are explained below each of which has a strong evidence.

Water management

Efficiency of water allocation rules is of crucial importance to ensure safety of drinking water supply and irrigation use. Drinking water must obtain highest priority to achieve reasonable safety for supply. With a simple operation rule sharing releases for irrigation between Nong Yai reservoir and ponds safety for drinking water can reach a satisfactory value at the expense of unsatisfactory performance for irrigation supply. Reservoir zoning, however, improves the overall performance for both domestic and irrigation use significantly. In addition, intelligent and flexible operation rules require monitoring, controlling and enforcement. Individual abstraction for irrigation should be replaced by controllable centralized hydraulic structures at Nong Yai reservoir. Implementation of operation rules considering reservoir water level, water level in ponds and time of the year would enhance water resources performance as it could be shown for Nong Yai reservoir.

Agriculture

Crop requirement affect water management significantly. Compared with the current conditions, increase of sugarcane has the potential to reduce inflow into Nong Yai reservoir up to 12%. Decrease of sugarcane substituted by an increase of rice could enlarge inflow into Nong Yai reservoir up to 25%. Promotion of cassava at the expense of rice and sugarcane could increase inflow to Nong Yai reservoir up to 35%. In essence, crops and crop pattern affect the flow regime considerably. Sugarcane is the biggest water consumer followed by rice. Cassava is a drought resistant and less water demanding plant improving flow regime for drinking and irrigation purposes. It must be noted, that subsidies supporting water demanding plants aggravate safety for domestic use and irrigation schemes. Such agricultural policy lead to additional water stress and promote exploitation of natural resources.

Erosion and sedimentation

Sedimentation as a consequence of runoff from agricultural areas gives rise to considerable deposition with more than 2600 m3/year into Nong Yai reservoir. Consequently, degrading performance of all water resources structures is visible, in particular reservoirs and weirs, whose storage content decreases from year to year exacerbating climate change effects. Broad efforts in regard to sediment removal and maintenance are necessary to counter adverse impacts. It is recommended to implement additional and simple hydraulic structures like sediment ponds upstream of reservoirs.

Integrated water resources management associated with ecosystem-based measures

Detailed assessment highlights the necessity to improve noticeably water resources management. Therefore, flexible and anticipating operation rules constitute the first pillar towards long-term mitigation of vulnerability. Intelligent release strategies do have a big potential to improve safety of drinking water and irrigation supply. At the same time, they

- provide concise and clear regulations to be followed by all stakeholders
- reduce potential conflicts due to undetermined water allocation
- require adequate monitoring and enforcement by water authorities which is still an unresolved problem
- necessitate rehabilitation of hydraulic structures along Huai Sai Bat river and reservoirs respectively
- constitute an important step towards integrated water resources management

The second pillar to reduce vulnerability is the review of agricultural practices. Update of land use data in association with an inventory of individual irrigation practices and irrigation schemes would pave the way for further improvement of foresighted cross-sectoral integrated water management.

Measures to reduce erosion, rehabilitate reservoirs, river beds and weirs represent the third pillar aiming at sustainable water resource management in Huai Sai Bat river basin and allow integrated water resources management to come into being..

Bangkok, Weinheim, 2015-01-16

(Dr.-Ing. Hubert Lohr)

9 LITERATURE

Boyd, C. (1996?): Pond Aquaculture Water Quality Management. Thailand Department of Fisheries. Waste Management in the Coastal Areas of ASEAN Region.

Chaiyapong, T., Viraphol T. 2003: Areal Rainfall Reduction Factor and Areal Flood Peak Reduction Factor for Upper Chao Phraya River Basin. Kasetsart Journal (Nat. Sci.) 37: 224 - 233 (2003). Kasetsart University of Bangkok.

Henderson, G, Rouysungnern, S. (1984): Erosion and Sedimentation Thailand. Research Section, Watershed Management Division, 1 Royal Forest Department, Bangkok 10900.

Kittiwet, K, Vichian, 2014: Vulnerability assessment of the Huai Sai Bat sub-basin. The fine-tuning of SWAT parameters: SWAT results (to be compared with Talsim-NG). Khon Kaen University.

Kittiwet, K, Vichian, 2014b: Crop requirements in the Huai Sai Bat river basin. Excel-based list of crop coefficients for dominating crops in Huai Sai Bat river basin. Khon Kaen University.

Maidment, D. et al, 1993: Handbook of Hydrology, Chapter 13: Hydrologic effects of Land Use Change. McGraw-Hill Inc., New York.

LDD, 2014: Thai Soil Groups. Land Development Department. Bureau of Soil Survey and Soil Resources. http://oss101.ldd.go.th/web_thaisoils/62_soilgroup/main_62soilgroup.htm

Pongsai, S, et.al, 2010: Calibration and validation of the Modified Universal Soil Loss Equation for estimating sediment yield on sloping plots: A case study in Khun Satan catchment of northern Thailand. Canadian Journal of Soil Science, 2010, 90(4): 585-596, 10.4141/cjss09076.

SEI 2012. Northeast Thailand Futures: A Local Study of the Exploring Mekong Region Futures Project. Final Report. Stockholm Environment Institute and Khon Kaen University.

Simachaya, W., Yolthantham, T., 2010: Wastewater Management in Urban Area: Bangkok, Thailand. Power Point Presentation. Pollution Control Department of Thailand. Ministry of Natural Resources and Environment.

Simmons, J. A. et al 2008: Forest to reclaimed mine land use change leads to altered ecosystem structure and function. Ecological Applications 18:104–118. http://dx.doi.org/10.1890/07-1117.1

Kedmey, D. 2014: How Thailand's Botched Rice Scheme Blew a Big Hole in its Economy. Homepage of Time Magazine, http://world.time.com/2013/07/12/how-thailands-botched-rice-scheme-blew-a-big-hole-in-its-economy/.

Yolthantham, T., 2007: Water Quality Monitoring and Water Quality Situation in Thailand. Inland Water Division Pollution Control Department (PCD).