Water Resources Management Sector Development Program: Rapid Assessments on the Status of Water Resources and Eco-hydrological Environments for the Tonle Sap and Mekong Delta River Basin Groups and River Basin Surface Water Resource Assessments

Detailed Surface Water Resources Assessment for the Tonle Sap and Mekong Delta River Basins, Cambodia

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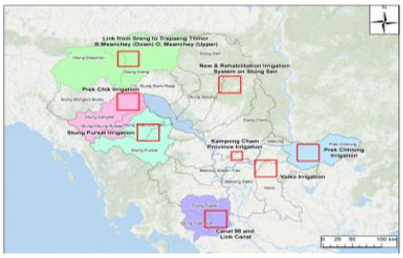

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Purpose

This document has been prepared as the Report “Detailed Surface Water and Resources Assessment for the Tonle Sap River Basin Group and Mekong Delta River Basin Group” for ADB. FutureWater accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared. FutureWater has no liability regarding the use of this report except to ADB.

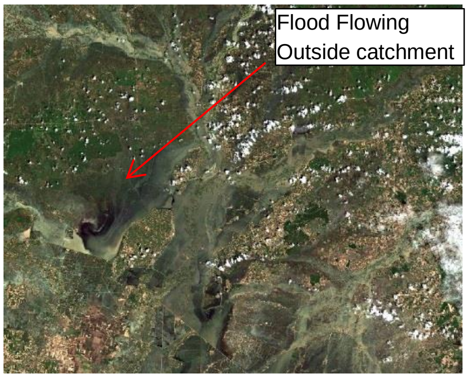
Abbreviations

ADB = Asian Development Bank
AFD = the Agence Française de Développement
AMSL = Above Mean Sea Level
BOD = Biological Oxygen Demand
CARM = Cambodia Resident Mission of ADB
CCAI = Climate Change Adaptation Initiative (MRC)
CDTA = Technical Assistance for Capacity Development
CFi = Community Fisheries
CFR = Community Fish Refuge
CNMC = Cambodian National Mekong Committee
COD = Chemical Oxygen Demand
CSIS = Center for Strategic and International Studies
DFAT = Australian Department of Foreign Affairs and Trade
DHRW = Department of Hydrology and River Works
DOM = Department of Meteorology
DO = Dissolved Oxygen
E – Flow = Environmental Flow
ECMWF = European centre for medium range weather forecasts
EFR = Environmental Flow Requirement
EIA = Environmental Impact Assessment
EMC = Environment Management Classes
EN = Endangered (in reference to species)
ERA5 = 31km spatial resolution historic weather information reanalysis product
EU = European Union
EWD = Environment Water Demand
FiA = Fisheries Administration of MAFF
FFI = Flora and Fauna International
FW/MMA = FutureWater/Mekong Modelling Associates JV
IBA = Important Bird Area
IFR = Instream Flow Requirement
IFREDI = Inland Fisheries Research and Development Centre
IRRI = International Rice Research Institute
IUCN = International Union for Conservation of Nature
IWMI = International Water Management Institute
JICA = Japan International Cooperation Agency
JRC = Joint Research Centre (EU)
KBA = Key Biodiversity Area
KOICA = Korean International Cooperation Agency
LMB = Lower Mekong Basin
LULC = Land Use and Land Cover
MAFF = Ministry of Agriculture, Forestry and Fisheries
MAFF = Ministry of Agriculture, Forestry and Fisheries
MAR = Mean Annual Runoff
MoE = Ministry of Environment
MOWRAM = Ministry of Water Resources and Meteorology
MRC = Mekong River Commission
OAA = Other Aquatic Animals
PA = Protected Area
PMFM = Procedures to Maintain Flow in the Mainstream
RAMSAR = Wetlands of International Importance under the RAMSAR convention
RBG = River Basin Group
RUPP = Royal University of Phnom Penh
TA = Technical Assistance
TSS = Total Suspended Solid
TOTN = Total Nitrogen
TOTP = Total Phosphorous
ToR = Terms of Reference
VNMC = Viet Nam National Mekong Committee
VU = Vulnerable (in reference to species)
WCS = Wildlife Conservation Society
WDPA = World Database on Protected Areas
WEAP = Water and Environment Assessment Program (WEAP)
WMO = World Meteorological Organization
WUP – FIN = MRC Water Use Project (Finnish Component)

Executive Summary

This study, embedded in the ADB Technical Assistance (TA) 7610-CAM: *Supporting Policy and Institutional Reforms and Capacity Development in the Water Sector* and supporting the Water Resources Management Sector Development Program in Cambodia aims at supporting MOWRAM to make more informed, evidence-based water resources management and irrigation investment decisions through better understanding of water resources and ecosystems of two river basin groups: the Tonle Sap and the Mekong Delta in Cambodia.

The main activities completed are (i) rapid water resources assessment of the Tonle Sap and the Mekong Delta river basin groups; (ii) Hydro-ecological assessment of these two river basin groups to identify water demands for conservation; (iii) detailed surface water resources assessment for a selection of river basins within these groups. Component (i) and (ii) have been presented in two reports previously. This report presents results of the third component of the assignment: the Detailed Surface Water Resources Assessment, which focuses on a number of subbasins of interest where investments in water resources are being considered.



In the Cambodian context a medium sized catchment such as the Sreng (for which a previous river basin assessment was been prepared without reference to neighbouring area) is **not a unique hydrological unit**. For example due to the low lying topography, in 2019 significant flood flows spilt from within the Sreng catchment to the Sisopon via Trapaeng Thmar reservoir. In other cases, old river courses exist that are activated during floods, transfer canals have already been built or are proposed. It is thus desirable to consider a grouping of river basins rather than subbasins in isolation.

Based on the findings presented in the Rapid Assessment report, a list of river basin groupings was proposed on which to conduct the detailed surface water resources assessment (SWRA). It was agreed with MOWRAM and ADB to perform the detailed assessment in a total of 8 river basins, 6 river basins in Tonle Sap River Basin Group and 2 river basins in Mekong Delta River Basin Group. The selection and groupings were based on the current water shortage situations, potential for additional water resources development, ecological interests, and alignment with MOWRAM's existing studies and plans for future water resources development.

In two more basins (Stung Sen and Prek Chhlong) two specific additional appraisal studies were performed with respect to development potential. Climate risk screening analysis was performed, from which the main conclusions related to water availability are included in the respective sections of this report.

MOWRAM recently completed and published its strategy for water resource development up to 2033 (National Water Resources Management and Sustainable Irrigation Road Map and Investment Program 2019-2033). Within the strategy it is the aim to ensure better use of irrigation facilities through improved water use and allocation, modernization and significantly higher cropping intensities than present. How this strategy might be achieved for the basins chosen for study whilst considering the domestic water supply and environmental demands is thus a key aspect of this report.

The impacts of these water allocation options are investigated, to assess how future demands can be met sustainably by supplies, considering environmental features and demands.

Based on interactions with MOWRAM and data collected in the field, for each basin group, a number of scenarios are studied for each of the basins:

- Baseline, or reference scenario - current infrastructure and irrigation areas
- A scenarios assessing the impact of changed water allocation priorities, irrigation system modernization and irrigation system cropping intensification. These scenarios include interventions that influence the demand for water resources.
- A second set of scenarios that combines modernization and agricultural development investments with water supply-side investments in water resources infrastructure (storage and water transfers mainly). These scenarios assess the feasibility of the planned investments, from a water resources perspective to reduce water shortages.

For the eco-hydrological assessment, on top of the work done in Phase I, additional surveys were done in priority ecosystems within the three targeted catchment groupings to obtain more substantial information, plus information in a wider context (including additional priority ecosystems). Also, priority ecosystems were identified, to assess the hydrological requirements for maintaining key features and ecosystem services and analyse how these may be impacted by anticipated water resources interventions.

The analysis makes use of data collection and modelling development that has taken place for the River Basins in Phase I but zooms further into specific areas and possible interventions. Several fieldwork missions took place together with the counterpart staff of MOWRAM, both to look and discuss with provincial planners the water resources issues as well as eco-hydrological issues. In Phase II, additional data has been collected in collaboration with the PMU of MOWRAM. Also, additional reports and strategic documents have been consulted to inform the scenario studies. Detailed basin models were built, based on the Water Supply and Demand Framework (WSDF) as was used in the Phase I. Couplings of WSDF has been implemented with a detailed hydrological model (SWAT) and hydraulic model (ISIS).

Results of this assessment are summarized here per basin group. For the **Stung Sreng and Stung Sisophon basin group, t**he assessment focused on effective utilization and upgrading of existing reservoirs and canals, irrigation modernization, and crop intensification using a matrix of scenarios as shown in the Table below. The scenarios exist with a operational developments (A to C) and Infrastructure/water resource development (Scheme Modernisation, Link canals and storage) (D to I) as shown below. Various combinations of those measures were integrated in the scenarios explored:

Operations and Agriculture
A: Rational priorities during water shortage periods
B: Rice intensification
C: Diversification and intensification
Infrastructure
D: Modernization of irrigation systems
E: Sreng to Trapaeng Thmar current canal link
F: Sreng to Trapaeng Thmar extended canal links
G: Irrigation expansion in Oddar Meanchey
H: Increased reservoir capacity upstream in the Sreng basin
I: Increased capacity of Trapaeng Thmar Reservoir

SRENG GROUP	Management Options			Infrastructure investment options					
Scenarios	Prioritisation	Rice Intensification	Diversification	Modernisation	Link Canals and Storage				
Options	A	B	C	D	E	F	G	H	I
00_Reference									
01_Priority Operations for domestic supply + Irrigation Modernisation	X			X					
02_Modernisation and Intensification to 200% for rice	X	X		X					
03_Priority, Modernisation+ Dry season Crop Diversification	X		X	X					
04_Trapeang Thmar Capacity Increase and Link canal to Sreng	X	X		X	X				X
05_As 4 with Irrigation Expansion in Oddar Meanchey	X	X		X		X	X		
06_As 5 with additional Sreng Reservoirs	X	X		X		X	X	X	X

The analysis showed that the impact of the scenario interventions varies significantly. In general, performance indicators (crop water consumption, and coverage) go up compared to the baseline (current situation) scenario. A few key outcomes are:

1. Modernization of irrigation schemes leads to a slightly more effective crop water use but the impact is relatively small. The main reason is that most of the irrigation occurs in the wet season when much of the water which the crop consumes is coming from direct rainfall, so improvements in the irrigation infrastructure have only a small impact.
2. When cropping intensities are increased in this basin group, water demand and actual water consumption increases substantially. Shortages increase also and coverage is lower, but certainly total crop production can be expected to be higher (given the increase in productive crop water consumption). In other words, individual farmers will experience more water shortage, but production of the entire basin group will increase. If a mix of rice and vegetables are grown outside of the wet season, the water resources situation remains similar, however, economic benefits are potentially higher (not assessed here);
3. Using the recently constructed secondary irrigation canal to supply the Trapaeng Thmar Reservoir from Stung Sreng has some positive effects in terms of irrigation supplied relative to demand. However, if capacity is further extended by a new canal with higher capacity, significantly more crop can be expected to be produced by improved transfer of water, in a scenario with additional storage in the upper catchments.
4. The analysis shows for this basin group that there can be considerable negative impact on the flow regime downstream where the ecohydrological assessment identified key

environmental values which currently are already under pressure. Mean annual flows will reduce under all scenarios as more water will be consumed by the irrigation sector and for domestic water use. Also, low flows at this location is expected to occur more frequently.

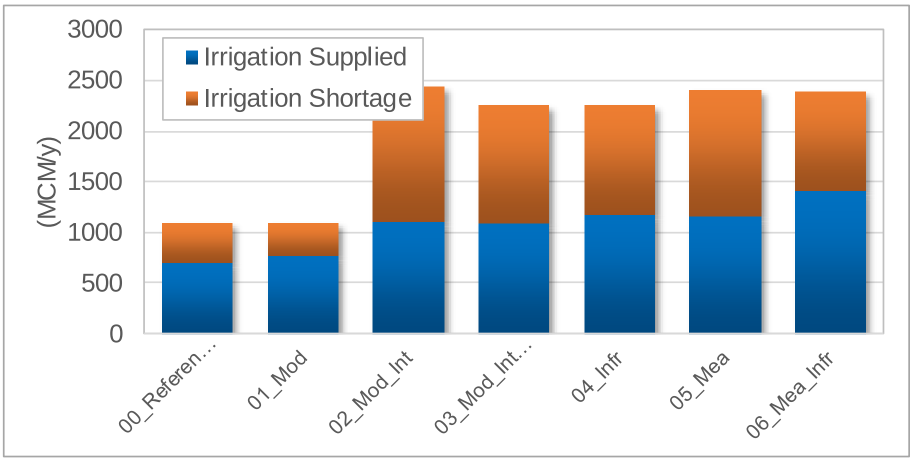


Figure 0-1 Summary of Scenario Irrigation demands and supply for Sreng/Sisopon

For the **Stung Sangker, Stung Pursat, Stung Moung Russei and Stung Svay Don Keo basin group**, the analysis focused on potential water resources development and interbasin transfer to Stung Moung Russei, and irrigation modernization, link canals and reservoirs in either Pursat or Sangker or a combination of all as shown below.

The scenarios exist with a combination of Management/water use options (A to C) and infrastructure investment options (D to L) as shown below. Various combinations of those measures were integrated in the actual scenarios explored.

A: Rational priorities during water shortage periods
B: Rice intensification (rice only)
C: Diversification and intensification

D: Modernization of irrigation systems
E: Prek Chik expansion
F: Link Sangker to Moung Russei
G: Link Svay Don Keo to Moung Russei.
H: Increased reservoir capacity – Pursat
I: Increased reservoir capacity Sangker
J: Large irrigation expansion
K: Diversion to Kamping Puoy
L: Dauntry reservoir completed (already under construction)

Sanker/Pursat/Roussei/ SDK Group	Management options				Infrastructure investment options							
	A	B	C	D	E	F	G	H	I	J	K	L
00_Reference												X
01_Modernization	X			X								X
02_Mod_Intensive	X	X		X								X
03_Mod_Int_Crop Diversification	X		X	X								X
04_Pursat to Prek Chik canals. Additional Reservoir Sangker	X	X		X	X		X		X			X
05_Prek Chit Expansion, Reservoir in Pursat	X	X		X	X	X	X	X		X	X	X
06_Sangker and Pursat Reservoirs	X	X		X	X	X	X	X	X	X	X	X

The main conclusions are:

1. Modernization of the irrigation schemes leads to a slightly more effective crop water use but the impact is relatively small.
2. Intensification to double cropping systems is possible in the river basin group only in combination with modernization and expansion of reservoir capacity and canals.
3. There is not sufficient water for the expansion of the irrigated areas of Kamping Pouy and Battambang unless additional reservoir capacity is developed in the Sangker (*06_Prek_Batt_Infr*).
4. Also, for this basin group, the analysis shows that there can be considerable negative impact on the flow regime at the locations downstream where the key environmental values were identified. Mean annual flows will reduce under all scenarios as more water will be consumed by the irrigation sector and for domestic water use. Also, low flows at this location is expected to occur frequently.

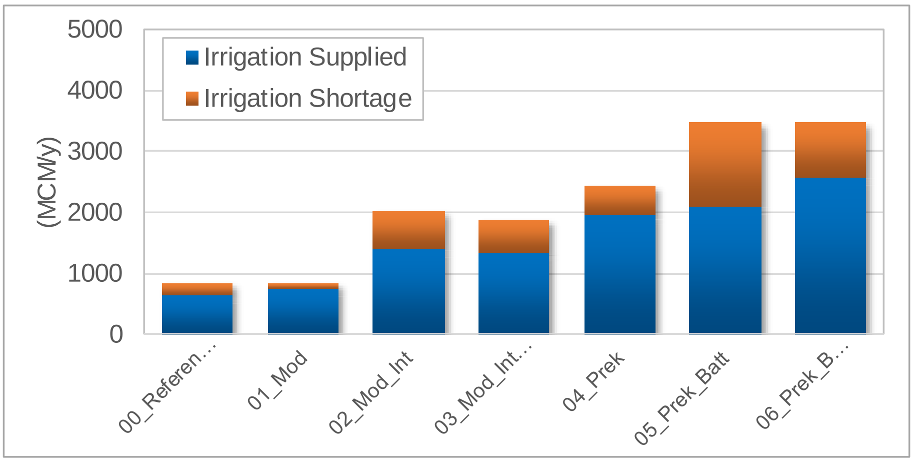


Figure 0-2 Irrigation demand and supplied in different scenarios

Table 0-1. Results of the Water Supply and Demand Analysis for the six potential investment scenarios. Results reflect annual averages over a period of 20 years using climate conditions from 1996-2015.

Annual Scenario	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
00_Reference	2578	2576	2227	840	648	192	77%
01_Modernisation	2578	2576	2278	840	734	106	87%
02_M/Intensification	4911	4743	3982	2026	1391	635	69%
03_M/I/Diversification	4911	4509	3843	1868	1329	539	71%
04_Prek Chit/Pursat	5165	4804	4237	2443	1957	485	80%
05_Prek_Sanker	5622	5334	4486	3483	2106	1377	60%
06_Sanker+Pursat	5622	5334	4667	3478	2590	888	74%

Domestic availability is high in all cases with little difference between scenarios. For environmental flows, the analysis shows that the double cropping (intensification) intervention will have a considerable impact. The analysis further indicates that there may be quite some variation between the different rivers, thus project feasibility and design should carefully look at these likely environmental impacts.

In the **Stung Slakou and Stung Toan Han basin group** the assessment focused on the impact of improvement of canal linkages, flood control, provision of water for municipal and ecological purposes. A few relevant conclusions are

1. Rehabilitating Canal 98 and the new connection with the Toan Han basin will allow for a considerable increase in total crop production in the basin group. It will also benefit coverage of domestic supply in the Toan Han basin and provide water to irrigated areas in Toan Han.
2. Additionally, if further investments are done for flood protection of the area north of Canal 98 there is scope to boost productive crop water consumption (and thus crop production) of the area considerably.
3. The BPL Sarus Crane Reserve could be aided to control water levels more appropriately for the important bird species through construction of a bank around the core area with overshot sluices gates for water level control.
4. Not all of the system can be supplied without pumping depending on the tidal levels and relative ground levels. The tidal circulations in the area are complex and flows may originate from the upper catchments in the wet season or from circulation of fresh water in the Mekong Bassac system in the dry season.
5. It was found that if the canal 98 route is used as a flood bank then effects on water levels are small but there could be up to 6cm rise in the equivalent of a year 2000 event near the border at Chau Doc Vietnam and a similar lowering near the Road 2 crossing to Vietnam. It may be necessary to include some flood release gates for high water levels or adopt a system of early flood protection until mid August to resolve the transboundary issue.

In the **Stung Sen** basin, the assessment focused on the possibility to develop water storage upstream and irrigation area in the downstream part of the basin. The main conclusions from this analysis are:

1. Without additional storage capacity upstream, potential for more than one cropping season downstream is limited. If storage is developed upstream, cropping intensity can go up considerably, even for the projected 300,000 hectares depending on the capacity of storage constructed;

2. Flood occurrence may reduce if storage is developed upstream. However, the most extreme floods, with low frequency but high impacts, will likely still occur and may cause additional risks as typically exposure increases after flood protection measures.
3. At the same time, environmental impacts in the downstream areas may be high, given the dependence of the ecosystems of flooding and the current flow regime. The ecological flow requirements would thus need further study which was not fully included in this preliminary assessment.

In the **Prek Chhlong** basin the analysis focused on the hydraulic and technical feasibility of developing a link canal from the Chhlong to the Vaico/Prey Veng Irrigation system that has recently been completed but relies on two major pump stations that cannot be fully utilised.

Principal findings of the analysis are:

1. The Chhlong has potential to supply around 2000 MCM/y to the Vaico system through a link canal and barrage though flows would be limited in the dry season if further storage in the Chhlong is not developed;
2. The link canal would be around 100km long and can follow a favourable topographic route to the start of the Vaico canal or link into Boeng Krapek.
3. Reservoir storage development on the the Chhlong would give more potential for full dry season irrigation.
4. A 500 MCM reservoir storage site has earlier been considered for hydropower development and possible sites identified.
5. The catchment is degraded but still has environmental and fisheries interest. Any barrage or weir for diversion should have a suitable fishpass and compensation eFlows.
6. The proposal is worthy of further study including water resource modelling of the full system.

Overall recommendations for the Project Preparation phase (more focused feasibility, pre-design and design evaluations are required) of the proposed investments are:

- To achieve the MOWRAM strategy for improved and modernized irrigation, rehabilitation and improvement at scheme level must be accompanied by water resource development taking account full account of all demands including domestic supplies, environment, fisheries and the increasing irrigation demand especially in the dry season in line with IWRM principles.
- Project feasibility studies should carefully look at mitigation measures to reduce water shortages, including measures on the demand-side.
- Given the impact on the basin-level of many of the projected investments, as was shown in this detailed study, it is recommended to use basin-level (rather than scheme) water balance approaches to account adequately for upstream-downstream interactions and assess mitigation measures that can offset negative impacts downstream.
- Project feasibility studies should be accompanied with detailed environmental assessments, given the highly vulnerable and sensitive ecosystems in the basins that were studied.
- MOWRAM needs to develop design guidelines for hydraulic structure that are ‘fish friendly’ through use of overshot gates and fish passage appropriate for Mekong fish;

- Community Fish Refuges should explicitly be considered in supply requirements in irrigation system development;
- The variation in Tonle Sap Lake levels is important for many of the environmentally important areas within the part of catchments of Sangker and Sisopon in the Tonle Sap protected area. The variation in level of the Great Lake appears to have a declining trend in mean level and lower peak levels in the rainy season. The tributary flows have little influence on this trend which is due to changes in the Mekong regime and the connection to the Tonle Sap. This must be more closely monitored and remedial measures considered to improve control of the water regime.

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1 Introduction

1.1 Project relevance and objectives

ADB Technical Assistance (TA) 7610-CAM: *Supporting Policy and Institutional Reforms and Capacity Development in the Water Sector* supports the Water Resources Management Sector Development Program in Cambodia with the impact of enhanced food security. The expected outcome of the TA is better management of water resources and irrigation services. The TA has two outputs: (i) Output A: enhanced capacity for sustainable water resources management; and (ii) Output B: enhanced capacity of the Ministry of Water Resources and Meteorology (MOWRAM) to manage and deliver irrigation services.

MOWRAM has developed the Roadmap and Investment Program for Irrigation and Water Resources Management, 2019-2033, in 2019. This investment program builds on the experiences of ongoing projects in the water resources management and irrigation sector to provide a comprehensive and strategic framework for the country's investment in the water resources and irrigation sector. Its guiding principles include significant change for MOWRAM in terms of moving from providing the infrastructure necessary for subsistence level farming to focus on works that target profitable agriculture, with investment based on farmers' needs and paid partly for by farmers, ensuring quality investment.

The overall objective of the assignment is to *support MOWRAM to make more informed, evidence-based water resources management and irrigation investment decisions through better understanding of water resources and ecosystems of two river basin groups: the Tonle Sap and the Mekong Delta in Cambodia.*

Under this assignment, TA 7610-CAM supports critical activities including (i) rapid water resources assessment of the Tonle Sap and the Mekong Delta river basin groups; (ii) ecological assessment of these two river basin groups to identify areas for development and conservation; (iii) detailed surface water resources assessment for a selection of river basins within these groups. Component (i) and (ii) have been finished, and presented in two reports, which are shortly summarized in the next sections:

(i) Rapid Assessment report of the State of Water Resources

(ii) Rapid Eco-hydrological Assessment report

This report presents results of the third component of the assignment: the Detailed Surface Water Resources Assessment (onwards referred to as Detailed Assessment), which zooms into certain basins of interest where investments in water resources are considered.

1.2 Summary of outcomes of the Rapid Assessment of the State of Water Resources

The Rapid Assessment of the State of Water Resources report (onwards referred to as Rapid Assessment) presents an overview of the agricultural, domestic/industrial and ecological water demands as well as surface water resources availability of each of the river basins with identification of river basins that are currently under high water stress.

A few take-away messages from this study are:

- Apart from the Great Lake protected area, water resources of the Tonle Sap River Basin Group (83,000 km^2) are restricted to the rainfall that fall in the given region. Most of this rainfall is consumed by the (natural) vegetation as evapotranspiration. Some smaller amounts are consumed by environmental sites and used to meet domestic requirements. Water not consumed by vegetation, environment, irrigation and domestic supply flows to the Tonle Sap Great Lake and subsequently to the Delta.
- Demands for water in the Tonle Sap River Basin Group are quite substantial for paddy cultivation; domestic demands are smaller but more essential to be delivered year-round.
- Overall, the analyses reveal that the Tonle Sap River Basin Group without additional storage is unable to match water demands in the current climate. The situation is exacerbated outside of the wet season.
- Water resources of the Mekong Delta River Basin Group (36,000 km^2) are more plentiful given its downstream location in the entire Mekong River Basin. Water resources from the main river are over five times bigger compared to the rainfall in the area itself.
- Total water resources of the Mekong Delta River Basin Group are in total sufficient to meet the demands of urban, paddy cultivation and environmental flow requirements. However, given the irregularity in resource availability in terms of timing (dry season), location (distance to rivers and streams) and source (flood recession, rivers and streams), still water shortages are frequent.

In the Tonle Sap River Basin Group the uneven distribution (spatially and temporally) stresses urges to improve the beneficial and productive use of water and modernize existing irrigation infrastructure, while at the same time preserving environmental features and demands. The Tonle Sap Basin is critically short of water and overall there is limited scope for irrigation expansion. Thus, broadly measures that should be considered are

- Water demand reduction
- Storage development to regulate flows and increase availability in the dry season

Also, interbasin transfers can be an option in areas of critical importance. However, these infrastructural measures may have a negative impact on the environmental demands, and should thus be considered only after careful analysis of sensitivities and risks.

The Mekong Delta Basin has adequate water on a yearly basis and is not critically short of water overall though there are limitations on delivery. There is some scope for irrigation expansion, although only in specific basins and locations. The type of measures that could be considered to improve the water resources situation are:

- Measures and infrastructure to preserve designated wetland reserves and other environmental features
- Improve the linkage of canals between basins to balance demands
- Small scale Pumping schemes
- Flood Control
- Drinking Water Expansion

Based on the analysis, a number of basins and areas where possible investments are considered were selected, and these are presented in this Detailed Assessment report.

1.3 Summary of outcomes of the Rapid Assessment of Eco-Hydrology

The Rapid Assessment of Ecohydrology report presents the findings of the eco-hydrological investigations in Phase I of the study. The major wetland ecosystems of the Tonle Sap and

Mekong Delta River Basin Groups have been appraised, using both a review of available literature and data and a rapid field assessment covering ecology, fisheries and Birds. Also, an initial estimation of the ecological flow requirements has been carried out.

Given the eco-hydrological complexity of the Tonle Sap and Mekong Delta River Basin groups, a site-specific method that considers all aspects of the hydrological regime is most suitable, including magnitude, timing, frequency, duration and variability. The Detailed Assessment phase therefore puts emphasis on site-specific and critical components of the eco-hydrological system.

On fish and fisheries, it is concluded that most lowland fishes appear to be widely distributed, as a large and predictable monsoon flood drowns out many of the barriers in the rivers and connects the rivers to their floodplains over vast areas, allowing warm-water species to migrate to feed, reproduce and grow. Other aquatic animals (OAAs) which are also highly diverse and exploited by millions of people throughout the LMB include vertebrates (reptiles, amphibians) and invertebrates (including crustaceans, molluscs and insects).

The threats to the large river-floodplain fishery from regional impacts from major hydropower developments upstream of the Study area, as well as irrigation development that blocks fish passage need to be addressed in an integrated way to avoid serious negative impacts on fisheries production and biodiversity.

1.4 Scope of this report

Based on the findings presented in the Rapid Assessment reports, a list of river basins is proposed to conduct the detailed surface water resources assessment. It was agreed with MOWRAM and ADB to perform the detailed assessment in a total of 8 river basins, 6 river basins in Tonle Sap River Basin Group and 2 river basins in Mekong Delta River Basin Group. The selection was based on the current water shortage situations, potential for additional water resources development, ecological interests, and alignment with MOWRAM's existing studies and plans for future water resources development.
The river basins are:

- (i) Stung Sreng and Stung Sisophon basin group. The assessment focuses on changes in water allocation, effective utilization of water resources, increased cropping intensities and upgrading of existing reservoirs and canals.
- (ii) Stung Sangker, Stung Pursat, Stung Moung Russei and Stung Svay Don Keo basin group. The analysis focuses on modernization, agricultural development and potential water resources development and interbasin transfer to Stung Moung Russei, among others
- (iii) Stung Slakou and Stung Toan Han basin group. The assessment focuses on the impact of modernization, improvement of canal linkages, flood control, provision of water for municipal and ecological purposes.

Besides, it was decided, due to specific interests in two other basins, to extend the study, including assessments of specific scenarios of water resources development in

- (iv) Stung Sen. The assessment focuses on the possibility to develop water storage and irrigation area in the downstream part of the basin.
- (v) Prek Chhlong basin. The analysis focuses on specific questions related to water resources development

Besides, a climate risk screening analysis is performed which is presented in a separate report. Conclusions related to the targeted basins groups are included in this report in the respective section.

The report is laid out according to the river basin groupings studied:

- Chapter 2 describes the data, model approach and scenarios.
- Chapter 3 presents the results of the detailed water resources assessment for the Sreng-Sisophon basin group,
- Chapter 4 for the Sangker-Pursat basin group,
- Chapter 5 for the Slakou-Toan Han basin group,
- Chapter 6 presents the flood risk analysis for the Slakou-Toan Han basin group,
- Chapter 7 presents the additional studies for Stung Sen and
- Chapter 8 for Prek Chhlong.

2 Methods

2.1 Approach to Phase II

2.1.1 *Water resources*

Based on the work done in Phase I, it followed that the Detailed Assessment phase will focus on a total of 8 River Basins, extended with two more basins in which specific questions are addressed. The analysis will make use of data collection and modeling development that has taken place for the River Basins in Phase I but will further zoom into specific areas and possible interventions. Several fieldwork missions related to these already took place during Phase I, together with the counterpart staff of MOWRAM, and were reported in Phase I. Besides additional fieldwork for the eco-hydrological assessments took place in Phase II, reported here.

The main target river basins are (total eight):

(i) Stung Sreng and Stung Sisophon basin group. Demand exceeds supply in the irrigated areas, mainly around the Trapaeng Thmar reservoir, and several protected areas are threatened

(ii) Stung Sangker, Stung Pursat, Stung Moung Russei and Stung Svay Don Keo basin group. Increased water resources utilization may impact habitats along the banks of the Tonle Sap. Also several agricultural areas are currently scarce of water.

(iii) Stung Slakou and Stung Toan Han basin group. The flood dynamics of the Mekong delta cause several challenges for agricultural development and environmental conservation in this area.

The additional considered river basins are:

(iv) Stung Sen. Flooding issues, and threatened ecosystems downstream, but also reservoir developments upstream changing the hydrological regime, are of concern in this basin

(v) Prek Chhlong. Several ecosystems may be impacted by planned interventions in this basin.

More detailed data has been collected in collaboration with the PMU of MOWRAM. Also, additional reports and strategic documents have been consulted to inform the scenario studies. A list of the additionally collected data is presented in the next section.

The detailed basin models are based on the same Water Supply and Demand Framework (WSDF) as in the rapid phase but zoom into the areas of interest. This required a refinement of the Rapid Assessment models. Close collaboration between the international and local modeling experts took place to make schematics of the water resources system that reflect correctly the planned investments. The refined models include more detail in terms of irrigation areas and water resources infrastructure.

The detailed basin models have also made use of more accurate rainfall-runoff estimates, coupling the model with a detailed hydrological model. Also, in one of the models a coupling with the hydraulic model ISIS is needed to correctly include flow levels in the Mekong-Basaac system. The WSDF model is also used to obtain a first-order approximation of how the investments influence crop production.

Based on interactions with MOWRAM and data collected in the field, for each RB, a number of scenarios are studied for each of the basins:

- Baseline, or reference scenario - current infrastructure and irrigation areas
- A first set of scenarios assessing the impact of changed water allocation priorities, modernization of irrigation systems and cropping intensities.
- A second set of scenarios that combines modernization and agricultural development investments with investments in water resources infrastructure (storage and water transfers mainly). These scenarios assess the feasibility of the potential investments, from a water resources perspective to reduce water shortages.

Models and all spatiotemporal data is delivered in a format suitable for incorporation into the national Water Resources Information System (WRIS). Spatial outputs will be delivered in the conventional GIS formats, and temporal data will be prepared in csv files that are compatible with any data system to be adopted in the near future as soon as the WRIS starts to be developed in 2020. The full dataset will be accompanied with a guiding document that details the specifics of each dataset.

2.1.2 *Eco-hydrology Assessment*

The purpose of this eco-hydrological assessment is to ensure that water infrastructure developments do not cause any significant adverse environmental impacts.

The basis of the Phase-2 eco-hydrological assessment is the characterization of ecosystems and their current condition carried out in Phase-1, including their hydrology, intactness, vegetation types and status, aquatic ecology and fisheries and ornithological data.
In Phase-2 of the eco-hydrological assessment, surveys were carried out from 14-24 October 2019 in the three areas short-listed by MOWRAM, namely i) Slakou-Toan Han (Mekong Delta River Basin Group), ii) Sreng /Sisophon, and iii) Sangker / Pursat / Moung Russei / Svay Don Keo (both in the Tonle Sap River Basin Group). General field survey notes are included in Annex 1 while the map (Figure 2-1) indicates the location of the surveyed points. A list of wetland plant species recorded in phases 1-2 is provided in Annex 2. Ornithological survey notes are included in Annex 3, while Annex 4 includes field survey notes on fisheries aspects from a short survey.

A comprehensive eco-hydrological desktop review was also conducted for all prioritised catchments, reviewing links between flow regime and key riverine resources. Where information was not available for specific sites, general broader knowledge on riverine processes was used.

Phase-1

- *Desk-based Review* - Initial and review data collection of Key Biodiversity Areas (KBAs), Important Bird and Biodiversity Areas (IBAs), Protected Areas (follow the methodology for E-flow requirements). Field site selection is based on a desk review to identify key environmental assets. The KBAs focus on safeguarding global biodiversity and are recognised as vital land, freshwater, and marine sites for threatened plants and animals. They are currently identified using the “Global Standard for the Identification of Key Biodiversity Areas” set out by the IUCN in 2016. These criteria have quantitative thresholds devised over years of planning. The KBAs Partnership formed of 11 organisations at the forefront of nature conservation has been created specifically to monitor and expand KBAs’ global progress. Additionally, the IBA concept has been developed and applied for over 30 years. Initially, IBAs were identified only for terrestrial and freshwater environments, but over the past decade, the IBA process and method has been adapted and applied in the marine realm. The IBAs include (i) places of international significance for the conservation of birds and other biodiversity; (ii) recognised world-wide as practical tools for conservation; (iii) distinct areas amenable to practical conservation action; (iv) identified using robust, standardised criteria; and (v) sites that together form part of a wider integrated approach to the conservation and sustainable use of the natural environment.

- *Rapid Assessment Surveys* - were conducted over 2 weeks to assess habitat type, status and condition, and conservation requirements; as well as their water regime requirement and extent of flood. This included an assessment of fish and bird populations (including identification of threatened/rare species) and habitat requirements.

Phase-2

- *Additional Surveys* – in priority ecosystems within the three targeted catchments to obtain more substantial information, plus information in a wider context (including additional priority ecosystems).
- *Identification of Priority Ecosystems and Estimation of E-flows* – for the three priority catchments, an estimation was made of the hydrological requirements for maintaining key features and ecosystem services, and how these may be impacted by anticipated hydrological interventions.

2.1.2.1 Environmental Flow (E-flow)

An environmental flow (e-flow) is "the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated" (IUCN, 2003). As stated in Phase-1 of the assessment ecosystems can be maintained at a less than pristine condition as defined by the established objectives and to compromise with competing water resources (IUCN, 2003). These limits to negative impacts must be decided upon, for example the extent to which one can negatively impact ecosystems and the livelihoods that depend on them in the context of competing water resources and avoid unwanted regime shifts (Laize et al., 2014).

In e-flows, the prime variable to maintain ecosystem processes is considered to be the water regime (Power et al. 1995), i.e. hydrological alteration equates to an ecological disruption. If relevant parts of the hydrological regime are identified and reintroduced, ecosystem function can be restored (Laize et al., 2014). However, in order to get to this point decision makers must decide which areas need to be protected. A common way to categorise these decisions are though environmental management classes (EMCs) (Papadonikolaki et al., 2018), which defines the level of ecological health that is wished to be maintained at a site. EMCs range from A-F and are decided by stakeholders, allowing for balance between different competing activities.

Once e-flow is determined, these flows required to maintain ecosystem services need to be implemented. This can be done by a) setting abstraction limits (restrictive management) or by defining the ecologically appropriate flow releases from reservoirs. This requires however, being able to make accurate predictions of the outcomes on ecosystem functioning of alterations in flow.

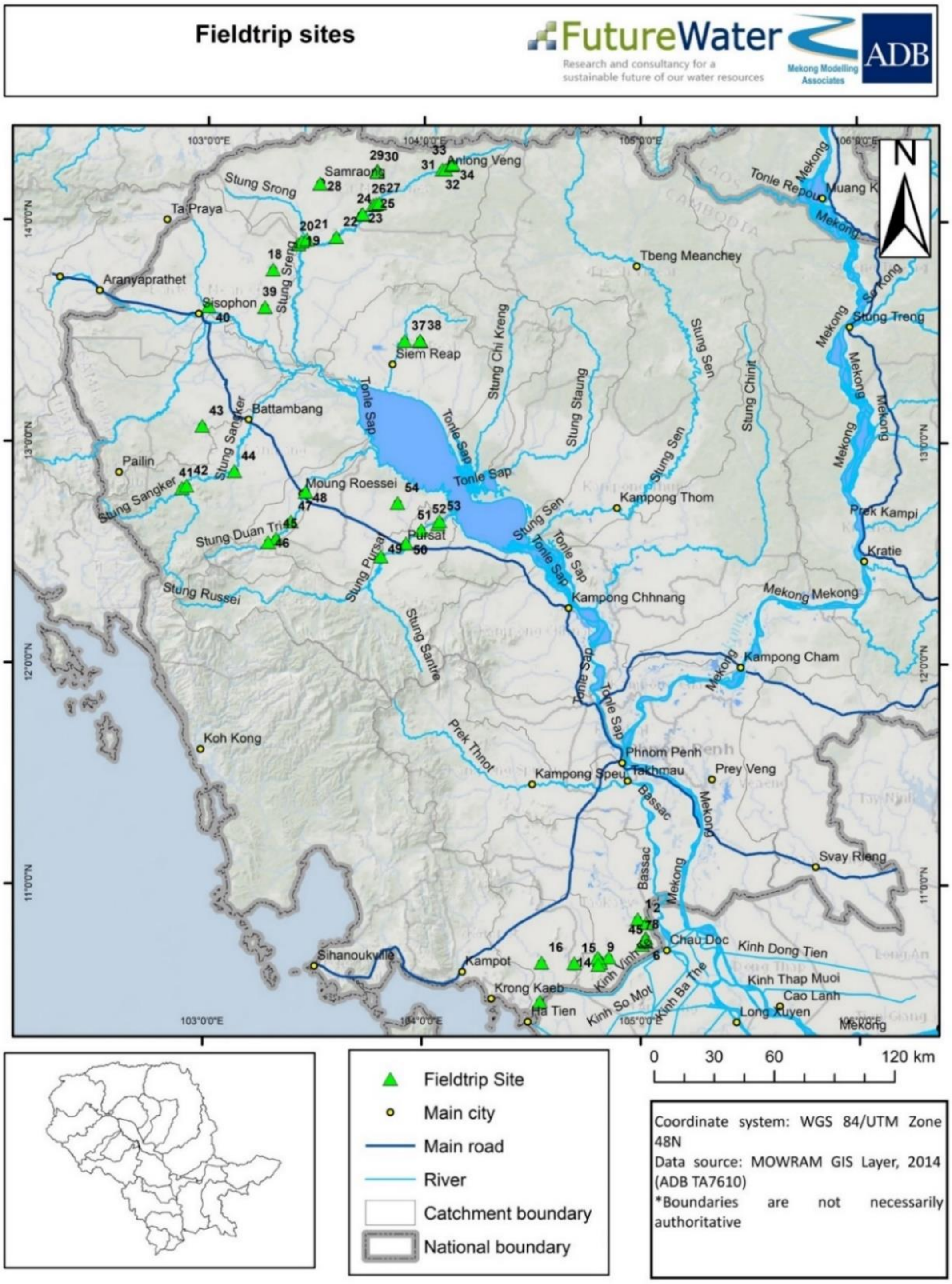

Figure 2-1: Field sites visited during the Phase 2 Eco-hydrological survey.

Important aspects of the hydrological regime for maintaining ecosystems in the Tonle Sap floodplain according to MRCS-WUP-FIN (2003):

- The **Maximum water level-** Flood provides the area with silt and nutrients and control habitat availability. Higher water levels make for more variety of habitats, higher primary production and therefore, higher herbivorous production, which leads to higher carnivorous production.
- **Minimum water level-** The relationship between minimum water level and the amount of flooded forest is unclear, the ecosystem would benefit from lower minimum levels due to decreased wave erosion. However, decreasing the minimum water level could lower sedimentation which would have a detrimental impact on flooded forest production and other ecosystems. Lower minimum water would also adversely affect fish since there would be less places for them to seek refuge in the dry season.
- **Water fluctuation range**- A high range leads to a higher variety of habitats, whereas, a lower water level range leads to more agricultural encroachment and less floodplain zonation.
- **Timing of the flood** – fish benefit from a fast-early rise in flood, whereas floating rice benefits from a late flood. Fast flood recession might negatively impact fish production as it limits the growing time for juveniles.
- **Duration** a longer duration flood will significantly affect zonation and generally promotes the growth of aquatic weeds like water hyacinth. Initially this could increase fish production but in the longer-term, ecosystem productivity as a whole would decrease as a result of decreased zonation.

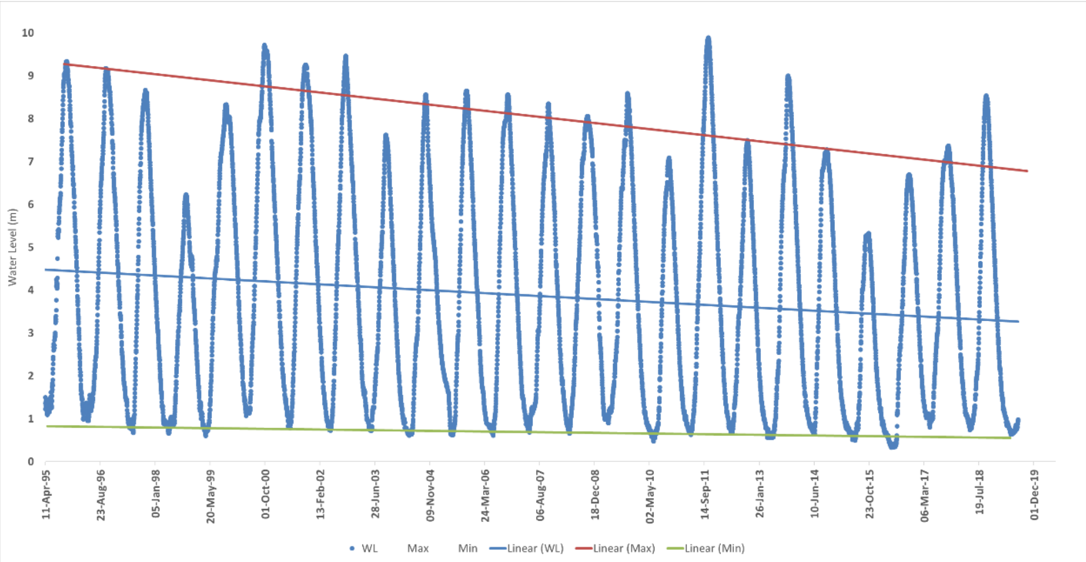

Figure 2-2: Tonle Sap Water Levels at Kampong Luong Station from 1995-2019. The annual maximum and minimum water levels are also shown.

Another aspect is the Tonle Sap Water Levels. Since 1995, the minimum Tonle Sap Water levels have reduced by a small but significant amount. The overall average has decreased by ~ 0.5m from 1995-2018. The most drastic change is the maximum water level, dropping on average nearly ~1m over the same period.

Figure 2-2 shows the Tonle Sap Water Levels at Kampong Luong Station from 1995-2019, including the trends in the annual maximum and minimum water levels. The increase of the minimum water level after 2016 can be attributed to the construction of dams on the Mekong. Furthermore, the average reduction in max water levels of 1m is and will be an issue for protected areas (link to figure of BPLs, IPLs, PAs) surrounding the Tonle Sap Lake. If the water level remains on this trajectory, there could be serious effects by 2030-2050.

2.1.2.2 General Eco-hydrological Impacts Development

- *Impacts on Seasonally Inundated Habitat:* Eco-hydrological development (e.g. water storage and diversion, esp. for irrigation) is likely to decrease the extent of flooded area and duration of floods, and hence have a direct impact on the floodplain habitats. The most pristine floodplain habitats are the flooded forests, which if partially cleared (by felling and burning) give way to flooded shrublands that are one of the most extensive habitats in the floodplains of both the Mekong Delta and Tonle Sap RBGs. Further burning and clearing results in flooded grasslands, which although largely a secondary habitat, are important for globally significant biodiversity such as Sarus Crane and Bengal Florican. Where the flooding regime allows, the floodplain habitat is converted into agriculture, especially rice fields, and it is therefore likely that further development of irrigation infrastructure will result in changes to the eco-hydrological environment, resulting in an increase in area of rice fields at the expense of flooded forest and flooded grassland.
- *General Impacts on Fish:* Irrigation development/rehabilitation causes changes in aquatic habitats and hydrology, especially if environmental flow has not been taken into consideration, and at least some components of aquatic biodiversity are negatively affected by development of irrigation. Improper design and insufficient water management can affect the fisheries productivity. A huge drawdown of reservoir levels for irrigation dramatically reduces fish production of those reservoirs. Improper design (e.g. no fish passes, which unfortunately seems standard) and operation of flood control and sluice gate structures will significantly reduce fisheries production. Additionally, farming practices (including use of banned fertilizers and pesticides and their excessive use) significantly impact on fisheries productivity, surface water quality, and possibly ground water quality, which drains from agricultural field to adjacent natural watercourses or the groundwater impacting long term drinking water sources located surrounding the agricultural areas. Any blockages such as dams, reservoirs and weirs obstruct both upstream and downstream migration paths for fish and other aquatic biota, especially if they are not equipped with properly designed and functioning fish passes. In Cambodia, most blockages have been constructed without fish passes, or have inadequately designed ones that do not function well or are simply used by fisherfolk to trap fish. Eco-hydrological development is also likely to result in a decrease in area and duration of flooding, which automatically translates into a decline in fisheries production as there is a close relationship with flooded area[1].
- *General Impacts on Birds:* Bird life is mainly affected by habitat loss and changes in seasonality, but also by agricultural intensification. As indicated above, habitats are directly affected by eco-hydrological changes as the extent of flooding will determine conversion of flooded forest and shrubland to grassland, and further to rice fields. Loss of flooded forest means a loss of forest birds, but also a loss of roosting and nesting areas for colonial water birds (e.g. cormorant, egret, herons). Seasonally flooded grasslands form an important habitat for globally significant bird species such as Sarus Crane *Antigone antigone* (IUCN

[1] In Cambodia, this relationship has been determined decades by Bardach (1959) and Welcomme (1979), and ranges from 25-78.5 kg/fish per ha of inundated area.

Red Data listed as Vulnerable) and Bengal Florican *Houbaropsis bengalensis* (IUCN Red Data listed as Critically Endangered), and eco-hydrological changes may result in a further conversion of such grasslands to rice fields. Timing and duration of floods are also important for many species, for example, certain diving duck require flooded areas for foraging, while Sarus Crane require soggy grasslands (e.g. to be able to feed on tubers of their preferred food *Eleocharis dulcis*). Eco-hydrological alterations may result in a shortening of the period during which grasslands remain inundated ('soggy') and can be utilized by wetland birds. Lastly, agricultural intensification is likely to result in an increase in the use of agrochemicals, which may result in increased impacts on birds (e.g. direct or indirect poisoning).

2.2 Data

2.2.1 *Data overview*

During Phase I, a large amount of data was collected. Table 2-1 provides an overview of all datasets used in the Rapid Assessment report, their sources, and the periods for which they are valid. In the Rapid Assessment report this data is represented and tables and maps for all River Basins.

Table 2-1: Overview of data sources used in this study.

Category	*Data layer*	*Data sources*	*Period*
General	Administrative maps	GADM v2.8[1], Open Development Cambodia, MRC	
	Terrain	MEKDAT (c-ctorg50) MRC (dem0603)	1950s & 1960s 2003
	River Map	MOWRAM GIS layer	2014
	Land Cover / Use	MRC BDPP GIS layers	2003, 2010
	Base map	Esri, GEBCO, NOAA, National Geography, Garmin	2019
Hydrology	Hydropower	ODC, MRC	2016, 2010
	Water Storage	CISIS Data	2017
	Irrigation	CISIS Data	2017
	Catchment boundaries	MOWRAM GIS layer DHWR's HEC-HMS model MRC GIS layer	2014 (ADB TA7610) - -
	Rainfall	ERA5, CHIRPS	2000-2014, 2018
	Evapotranspiration	IHE Water Accounting+	
	River Network	MOWRAM	2014
Environment	Paddy Area	MRC BDP GIS layers MRC Land Cover Mapping 2016 WISDOM GIS layer	2003, 2010 2016
	Protected Areas	UNEP-WCMC	2001
	Wetland Areas	MRC BDPP GIS layers	2003
	Soils	FAO	-

[1] http://www.gadm.org/

		MRC SWAT model	2012
	Geology	ODC	2006
	Important Bird Areas	Birdlife International	2013
	Key Biodiversity Areas	Birdlife International	2013
	Fish Resources	Fisheries Administration, Ministry of Agriculture, Forestry and Fisheries	
Social	Population	Commune Database	2016
		Center for International Earth Science Network	2016

During Phase II several additional data collection efforts were done. Several additional information, data, and reports were provided by PMU/MOWRAM:

1. Irrigation data from CISIS database on 8 river basins (October 30, 2019)
   a. Stung Sreng (RB: 21)
   b. Stung Sisophon (RB: 20)
   c. Stung Sangker (RB: 18)
   d. Stung Svay Don Keo (RB: 16)
   e. Stung Moung Russei (RB: 17)
   f. Stung Pursat (RB: 15)
   g. Stung Slakou (RB: 10)
   h. Stung Toan Han (RB: 09)
2. Report (hard copy) on the Korean project of Sala Ta Orn project (November 01, 2019)
3. Report (hard copy) on National Water Resources Management and Sustainable Irrigation Road Map and Investment Program 2019-2033
4. Report (hard copy) on Strategic Development Plan on Water Resources and Meteorology in 5 years 2019-2023

Additional data has been collected also on several other layers. The following paragraphs discuss these additional data sources.

2.2.2 *Climate*

For Phase I, the most state-of-the-art global weather dataset has been used: the reanalysis dataset ERA5. ERA5 is the latest climate reanalysis produced by ECMWF (European Centre for Medium-Range Weather Forecasts), providing daily data on many atmospheric, land-surface and sea-state parameters. Data is available at a spatial resolution of on a regular latitude-longitude grids at 0.25º x 0.25º resolution (~ 25 x 25 km), on a daily base over a period 1950 to the current day. For Phase II, this data has been substituted by the local observed data that was used for the detailed hydrological modeling (SWAT), for all basins in the Tonle Sap RBG. For the Mekong RBG, the ERA5 reanalysis dataset has been used, but covering the same period as was used in the Tonle Sap basins (20-year period between 1996-2015). Figure 2-1 presents the mean annual rainfall (mm/year) used for the Tonle Sap basins, averaged per catchment.

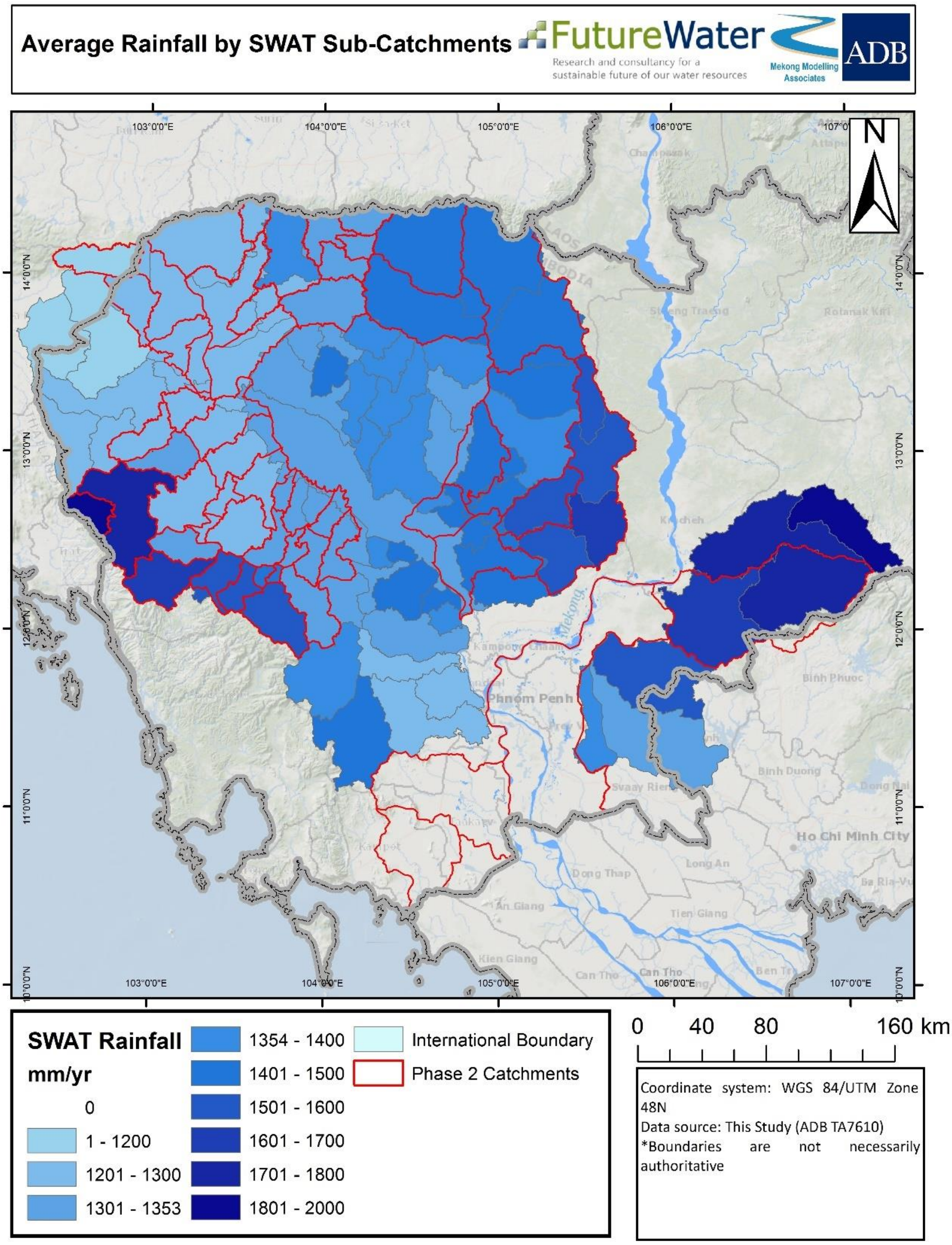

Figure 2-3: Mean annual rainfall as was used for the hydrological modeling in the detailed assessment.

For Phase II, a climate risk screening analysis was performed, presented in a parallel report. Main conclusions concerning the main targeted basin groups are summarized in this document in the respective sections.

2.2.3 *Gaging stations*

Figure 2-4 shows a map for all the basin groups in which the location of the gaging stations is shown. Within the Chhlong basin there are no gaging stations available so no map is presented.

Based on the station data available, Table 2-2 show the main flow statistics of the stations in the Tonle Sap basin.

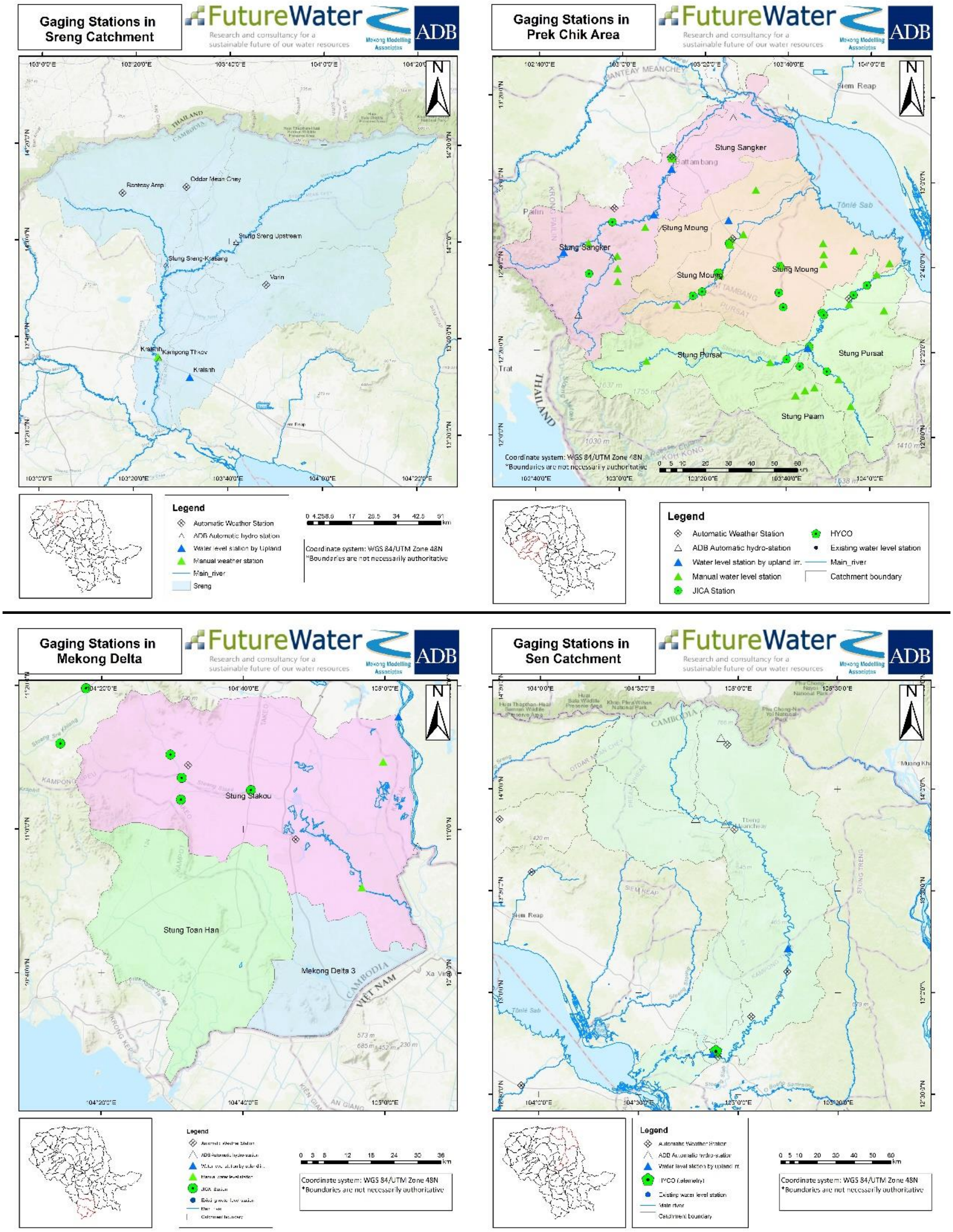

Figure 2-4: Map with the location of the gaging stations in the different basins studied.

Table 2-2: River flow in the 11 tributaries of Tonle Sap Lake Basin

N	*Tonle Sap Lake Rivers*	*Min Flow (m³/s)*	*Average Flow (m³/s)*	*Max Flow (m³/s)*	*STDV*
1	Stung Sen	0.01	245	1476	319
2	Stung Sreng	0.01	45	340	74
3	Stung Sangke	0.67	62	1020	98
4	Stung Dauntri	0.01	4	260	12
5	Stung Pursat	0.01	83	1264	121

The flow duration curve is a plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest. It characterizes the ability of the catchment to provide flows of various magnitudes. The Figure 2-5 below shows the flow duration curve of 5 tributaries of Tonle Sap Lake. Table 2-3 shows the statistics extracted from the flow duration curve.

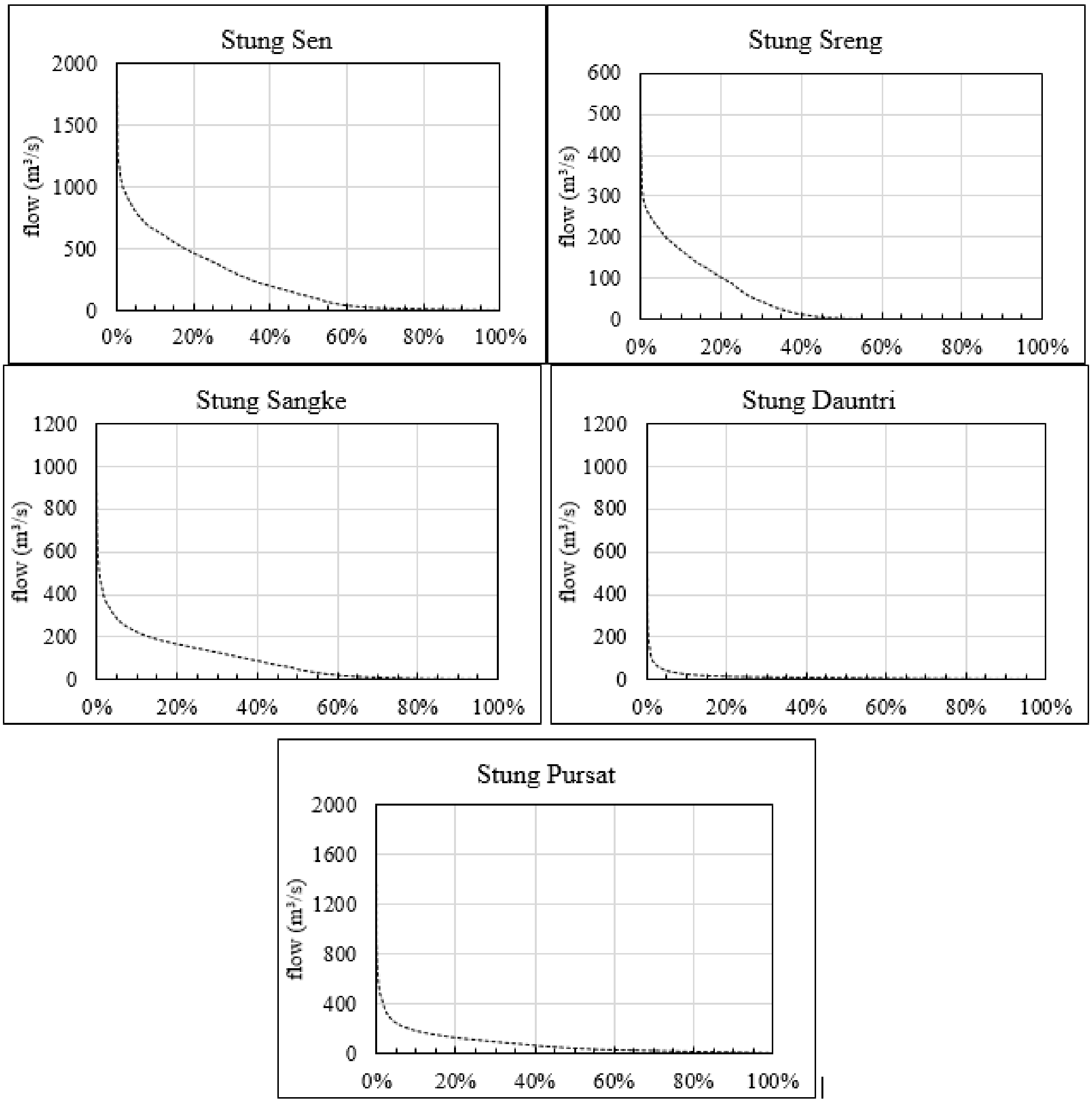

Figure 2-5: Flow duration curve of selected catchments

Table 2-3: Exceeding probability of river flow in 5 selected Tonle Sap catchments

Tonle Sap Lake tributaries	Flow at 5 % exceeding probability, Q_5 (m^3/s)	Flow at 25 % exceeding probability, Q_{25} (m^3/s)	Flow at 75 % exceeding probability, Q_{75} (m^3/s)	Flow at 95 % exceeding probability, Q_{95} (m^3/s)
Stung Sen	794.9	393.8	14.39	2.857
Stung Sreng	216.9	70.26	0	0
Stung Sangke	289.4	145.5	5.2	0.34
Stung Dauntri	39.92	11.95	2.94	1.07
Stung Pursat	252.9	116.1	23.61	12.14

2.2.4 *Crop production data*

The Ministry of Agriculture, Forestry, and Fisheries (MAFF) published provincial data outlining the annual production area for rice, maize, sugarcane and cassava both from rain-fed and irrigated crops. Tables 2-4 and 2-5 show that the annual production area of rice has increased both for wet season and dry season crops between 2013 and 2017 in both the Sreng-Sisophon and Sangker-Pursat regions. Rice production area is shown to be considerably smaller during the dry season in Otdar Meanchey than within other provinces which may be due to a lack of irrigation. Table 2-6 compares the production of different crop types within the two Basin Groups during 2017. It shows that rice production covers the largest area, followed by cassava, maize and finally sugarcane. Battambang has the largest total production area for rice and maize whilst Banteay Meanchey has the largest total production area for cassava and sugarcane.

Table 2-4: Annual production area for rice (dry season) (Source: MAFF, 2018)

MAFF Crop Data	Sreng-Sisophon Basin Group			Sangker-Pursat Basin Group		
	Banteay Meanchey	Otdar Meanchey	Siem Reap	Battambang	Pursat	*Total*
Year	Annual production area for rice *(dry season)* (ha)					
2017	22,336	47	21,740	19,281	16,186	79,590
2016	22,927	150	20,985	15,836	14,072	73,970
2015	14,903	449	17,775	11,738	11,686	56,551
2014	11,745	600	18,040	10,564	9,963	50,912
2013	12,400	600	18,000	10,600	10,000	51,600

Table 2-5: Annual production area for rice (wet season) (Source: MAFF, 2018)

MAFF Crop Data	Sreng-Sisophon Basin Group			Sangker-Pursat Basin Group		
	Banteay Meanchey	Otdar Meanchey	Siem Reap	Battambang	Pursat	*Total*
Year	Annual production area for rice *(wet season)* (ha)					
2017	240,411	82,415	186,520	324,624	116,757	950,727
2016	242,503	86,501	186,545	278,837	115,851	910,237
2015	235,222	72,000	185,220	279,123	105,593	877,158
2014	240,001	71,525	184,035	285,351	107,998	888,910
2013	206,998	63,921	179,065	270,070	104,453	824,507

Table 2-6: Annual production area for rice, maize, sugarcane and cassava from both rain-fed and irrigated crops (Source: MAFF, 2018)

MAFF Crop Data 2017	Sreng-Sisophon Basin Group			Sangker-Pursat Basin Group		
	Banteay Meanchey	Otdar Meanchey	Siem Reap	Battambang	Pursat	*Total*
Annual production area (ha) for rice *(wet season)*	240,411	82,415	186,520	324,624	116,757	950,727
Annual production area (ha) for rice *(dry season)*	22,336	47	21,740	19,281	16,186	79,590
Annual production area (ha) for maize *(wet season)*	13,869	*106*	*510*	124,647	4,281	143,413
Annual production area (ha) for maize *(dry season)*	407	3	445	439	239	1,533
Annual production area (ha) for sugarcane *(wet season)*	*449*	-	*400*	687	170	1,706
Annual production area (ha) for sugarcane *(dry season)*	*320*	-	*145*	72	93	630
Annual production area (ha) for cassava *(wet season)*	84,240	58,280	16,715	77,451	20,051	256,737
Annual production area (ha) for cassava *(dry season)*	24,379	-	3,315	1,037	6,134	34,865

Table 2-7: Irrigation data aggregated into sub-catchment groups (Source: CISIS, 2019)

Sub-catchment group	*Irrigation (dry season) (ha)*	*Irrigation (recession) (ha)*	*Irrigation (dry-in-wet) (ha)*	*Irrigation (wet season) (ha)*	*Total (ha)*
Sreng-Sisophon Basin Group					
Sisophon	0	5,202	5,192	8,837	19,231
Soay Chek	4	5,470	7,313	62,268	75,055
Sreng	0	510	1,006	34,046	35,562
Srong	0	0	498	8,954	9,452
Tanat	0	0	0	31,625	31,625
Total (ha)	4	11,182	14,009	145,730	170,925
% of irrigation area	0%	8%	10%	100%	117%
Sangker-Pursat Basin Group					
Moung Russei	360	0	0	10,939	11,299
Pursat	0	0	7,670	48,937	56,607
Sangker	339	0	0	72,377	72,716
Svay Don Keo	0	0	6,031	24,299	30,330
Total (ha)	699	0	13,701	156,552	170,952
% of irrigation area	0.45%	0%	9%	100%	109%
Slakou-Toan Han Basin Group					
Slakou	4,527	57,425	270	33,134	95,356
Toan Han	0	24,635	0	10,603	35,238
Mekong Delta	57,702	29,309	10,198	89,241	186,450
Total (ha)	62,229	111,369	10,468	132,978	317,044
% of irrigation area	36%	65%	6%	78%	185%

Table 2-7 shows the irrigated area for each season using data provided by CISIS, which is the data used in the modelling section of this report. The largest irrigation area across the four seasons was taken as the total crop area and used to show the percentage of irrigated area. Therefore, the percentage shown in orange represents the percentage area irrigated above the total crop area. A maximum of 400% could be achieved if the largest seasonal irrigation area was matched during the other three seasons. As MOWRAM aims to achieve a value of 215%, there is a need for improvements to irrigation within each region, in particular the Sreng-Sisophon and Sangker-Pursat Basin Groups.

Further analysis into land cover using the MRC Basin-Wide Flood Map dataset (MRC, 2010) was carried out. This dataset gives 3 major land cover types: annual crop, paddy field and orchard. This dataset was cross-referenced to irrigation polygons obtained from CISIS. It was found that between 22-26% of the *paddy field* land cover is within the CISIS polygons (Table 2-9). Therefore, it can be assumed that the remaining 74-78% of paddy fields are rain-fed, and hence, can be assumed to be only a single-use annual crop. For *orchard,* although the overall area is smaller compared to *paddy field class*, only 14% and 3% is found within the irrigation areas in the Sreng-Sisophon and Sangker-Pursat regions, respectively.

Concluding, specifically for Sangker-Pursat, as a large proportion of *orchards* are only rain-fed, and orchards generally have a high economic value, it should be considered as a key crop to irrigate. In addition, only a small amount of the total crop area is irrigated in both Basin Groups; suggesting a need for irrigation schemes.

Overall, within the Sreng-Sisophon (Figure 2-4) and Sangker-Pursat regions (Figure 2-5), the CISIS irrigation areas are mainly in the location of *paddy fields* (~20%, Table 2-9). There is a large scope in both of these Basin Groups for expansions of existing schemes to surrounding paddy fields. Annual crop often occurs in the higher elevations and upstream of the main tributaries. Thus, there is a potential for smaller schemes to pump water from the existing water network rather than constructing major canals.

Table 2-8: Land use in catchments and Irrigated Areas (Source: Basin Wide Flood Map, MRC 2010)

Basin Wide Flood Map	**Sreng-Sisophon Basin Group**			**Sangker-Pursat Basin Group**		
Land Use	**Total (ha)**	**Irrigated Areas (ha)**	**% of total**	**Total (ha)**	**Irrigated Areas (ha)**	**% of total**
Annual Crop	188,216	5,706	3%	218,170	8,009	3%
Paddy field	496,041	110,315	22%	527,313	140,440	26%
Orchard	848	121	14%	4,732	150	3%

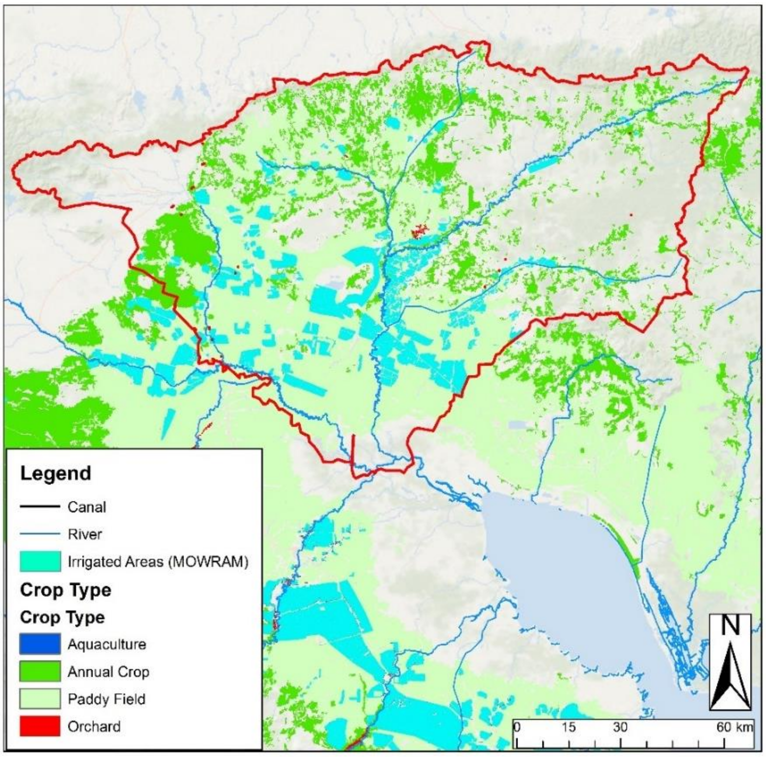

Figure 2-6: Crop Use within the Sreng-Sisophon Basin Group

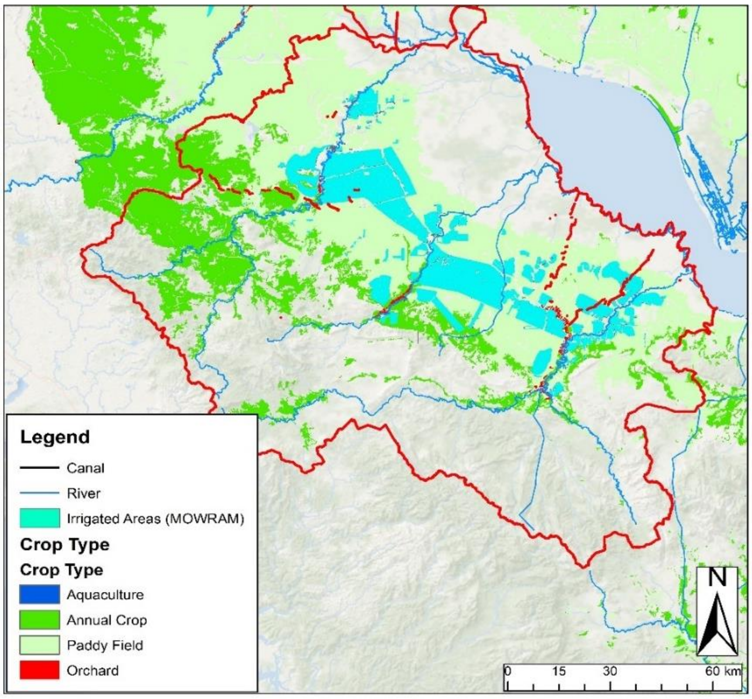

Figure 2-7: Crop Use within the Sangker-Pursat Basin Group

Similar to the annual crop as aforementioned, Figure 2-6 shows three areas where *orchard* crop type is close to either the existing irrigation areas or a river network. Therefore, for the future, it would only require either small extensions to existing projects, or individual pumping stations/low cost infrastructure to irrigate these areas.

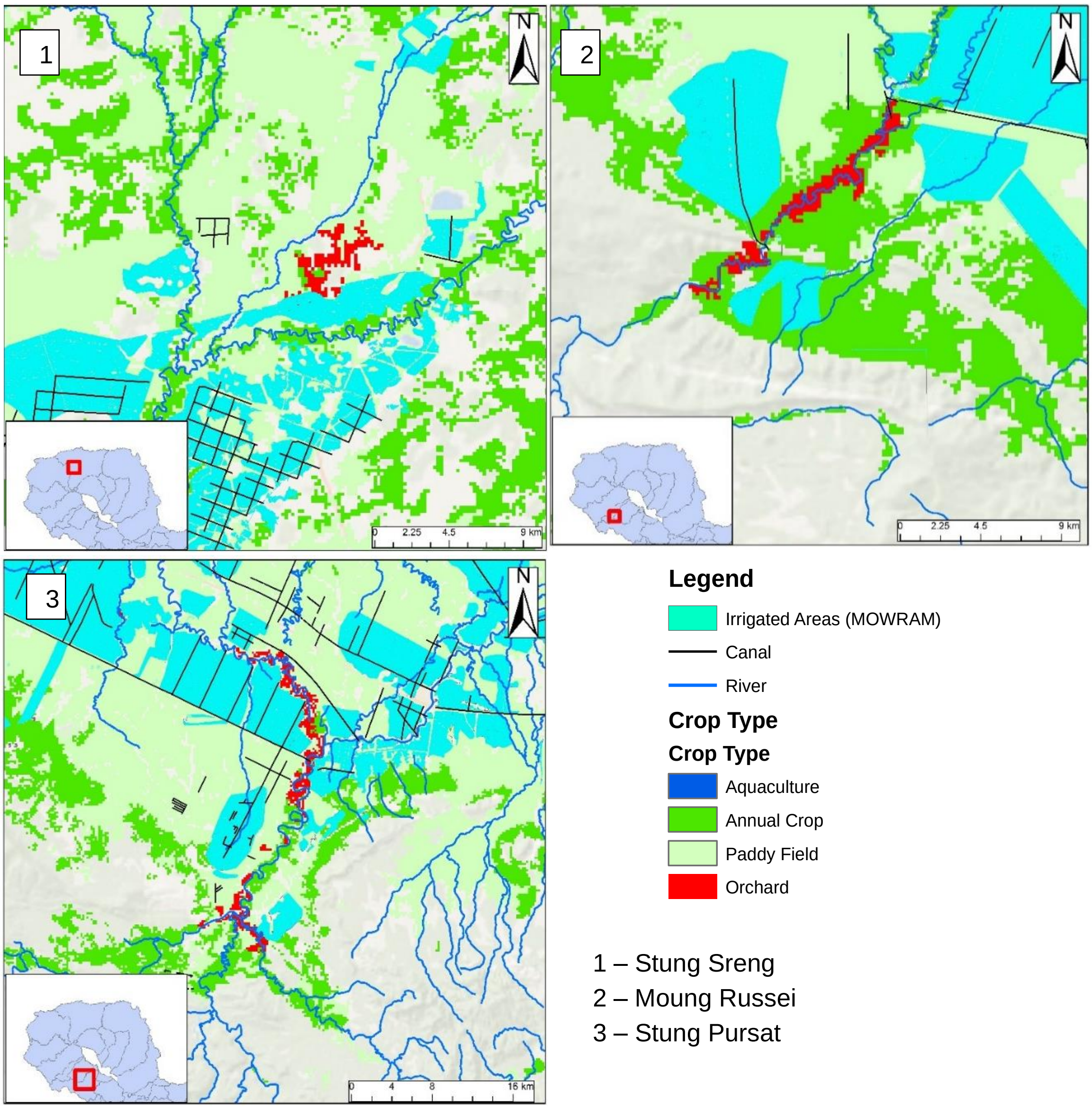

Figure 2-8: Locations of large unirrigated orchards

2.2.5 *Crop seasonal water demand*

As shown in the previous section, paddy rice cultivation is dominant in Cambodia. Actual water demand by the paddy cultivation is not well known and cannot be adequately measured in the field. Thus, for this assessment it is calculated using the Water Supply and Demand Framework (WSDF) as implemented in WEAP. Crop water requirements are calculated using the well-known Penman-Monteith equation, and with the FAO-56 crop coefficients. WEAP includes the advanced soil-moisture method to assess effective rainfall, and the soil water balance (drainage, surface runoff, deep percolation, open water evaporation, crop water transpiration), also considering flooding. Based on this balance (crop water requirements versus soil water available in the system), additional irrigation requirements are calculated. This irrigation water requirement is abstracted from the streams and rivers in the sub-catchment.

The different growing seasons have been implemented and used to actual calculate crop water requirements for each irrigation node or scheme in the system, based on data from the CISIS database (see previous section). Agricultural practices are quite diverse in Cambodia, and especially between the areas around Tonle Sap and in the Mekong Delta farmers there is clear distinction in dominant practices. In the Tonle Sap region only to a reduced extent so-called recession rice is cultivated (post-flood temporary ponding), while in the Mekong Delta this is actually a very common practice.

There are four main paddy growing practices in the area, see Figure 2-9:

- Wet Season
    - Land preparation: 1-Jun / 15 Jun
    - Planting: 15-Jun / 30-Jun
    - Harvesting: 1-Nov / 15 Nov
- Recession DS
    - Land preparation: 1-Nov / 15-Nov
    - Planting: 15-Nov / 31-Nov
    - Harvesting: 1-Mar / 15-Mar
- Dry in Wet (Early Dry Season Short Duration variety)
    - Land preparation: 15-Apr / 30-Apr
    - Planting: 1-May / 15-May
    - Harvesting: 15-Jul / 31-Jul
- Dry Season
    - Land preparation: 1-Dec / 15-Dec
    - Planting: 15-Dec / 30-Dec
    - Harvesting: 1-Mar / 15-Mar

For each of the irrigation demand nodes in the various, data of the irrigation database inventory have been used in the WSDF.

	01-Jan / 15-Jan	15-Jan / 01-Feb	01-Feb / 15-Feb	15-Feb / 01-Mar	01-Mar / 15-Mar	15-Mar / 01-Apr	01-Apr / 15-Apr	15-Apr / 01-May	01-May / 15-May	15-May / 01-Jun	01-Jun / 15-Jun	15-Jun / 01-Jul	01-Jul / 15-Jul	15-Jul / 01-Aug	01-Aug / 15-Aug	15-Aug / 01-Sep	01-Sep / 15-Sep	15-Sep / 01-Oct	01-Oct / 15-Oct	15-Oct / 01-Nov	01-Nov / 15-Nov	15-Nov / 01-Dec	01-Dec / 15-Dec	15-Dec / 31-Dec
Wet Season											1	2	3	3	3	3	3	3	3	3	4			
Recession	3	3	3	3	4																1	2	3	3
Dry in Wet								1	2	3	3	3	3	4										
Dry Season	3	3	3	3	4																		1	2

Figure 2-9. Cropping calendar for the four paddy seasons. 1 = land preparation, 2 = planting, 3 = growing, 4 = harvesting. Note: in reality some variation in paddy cultivation periods occur depending on local conditions

2.2.6 *Domestic and Industrial Water Consumption*

A range of per capita demands have been used in previous studies. There is evidence that as water becomes more available then the consumption increases and thus a review of recent data in Cambodia was carried out. Average water demand per day in Cambodia was previously estimated at around 90 litres per capita per day (lpcd) in 2007(Mekong River Commission, 2017) and used in various studies.

The actual measurements of water supply suggest this figure is too low. For Phnom Penh urban area actual water supply (including industrial) was estimated at 160 l/c/d in 2010. (PPWSA, 2010). In an ADB study in 2014, provincial towns' actual water demands were estimated; ranging between 120 l/c/d in Pursat and 187 l/c/d in Svay Rieng (ADB, 2014). These estimates are useful as the provinces have a range of urban and rural areas. Furthermore, as demonstrated in the Table below, once projects in the study had increased water supply in their service area, per capita consumption rates also increased. This indicates that greater water demands will occur when there is a reliable supply.

Table 2-9 Per capita Water Consumption in Provincial Towns at Project Completion and Evaluation, ADB (2014).

Waterworks	Battambang	Kampong Cham	Kampong Thom	Kampot	Pursat	Svay Rieng	Total
Per capita consumption (liters/day)							
At design	84	84	84	84	84	84	84
At completion	133	94	123	149	73	52	113
At evaluation	176	176	131	154	120	187	158

Source: Independent Evaluation Department computations based on data collected by the evaluation team from the waterworks.

Water supply capacity for urban centres within provinces aims to reach up to 120 l/c/d according to MOWRAMs 2014 report on national water status (MOWRAM, 2014). However, water consumption can range between 31 l/c/d in Stoung Saen to 215 l/c/d in Phnom Penh.

In keeping with the above data, it would therefore be appropriate to assume in the modelling higher figures than used previously and so for this project it is assumed that rural water supplies should meet an average demand of 90 l/c/d, and for urban supply to meet an average demand of around 140 l/c/d.

2.3 Models

2.3.1 *Water Supply and Demand Framework (WEAP)*

Successfully exploring and comparing the impact of various investment in the water and irrigation sector, requires a framework that can mimic reality. Such a scenario analysis should follow a clear future oriented focus. Such a future orientation requires data (past), investment ideas (scenarios) as well as models (future).

By combining local data sets and data obtained from remote sensing in hydrological models, information on crop transpiration, groundwater flows, recharge and runoff can be obtained. This results in a more complete knowledge base on the impact of various water allocation options and investments. Where data can provide information on historical and current water availability situations, water supply, demand and allocation models can provide future scenarios (both short term and long term) of water resources availability in a basin. These future scenarios contribute to the complex decision making process that policy makers face with regard to water allocation to competing sectors and multi-year strategic water resources planning (Figure 2-10).

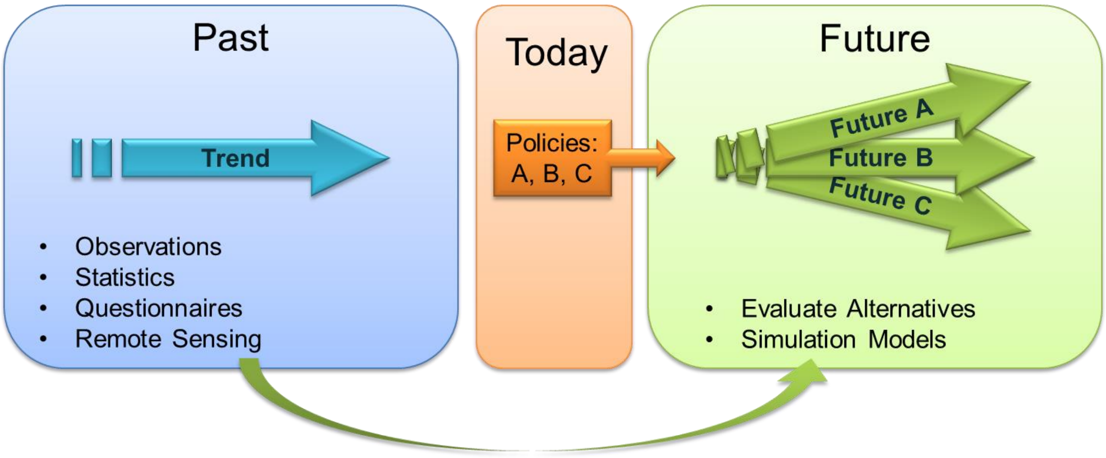

Figure 2-10: The need for water resources and demand assessments, and its linkages between data, models, past and future.

A broad range of water demand and allocation impact models is available to undertake scenario analysis. It is well accepted the best scenario model does not exist and that model selection depends mainly on the question to be answered:

- spatial domain (e.g. field, catchment, continent),
- temporal domain (single event, 30 years),
- main processes/topics (drought, flooding, water quality, erosion, crop growth, water allocation), amongst others.
- required accuracy (detailed design, scoping)
- amongst others

At the same, also practical considerations play a role while selection the appropriate modeling tool:

- existing models/tools in the area
- available resources
- familiarity with model/tool
- data availability
- amongst others

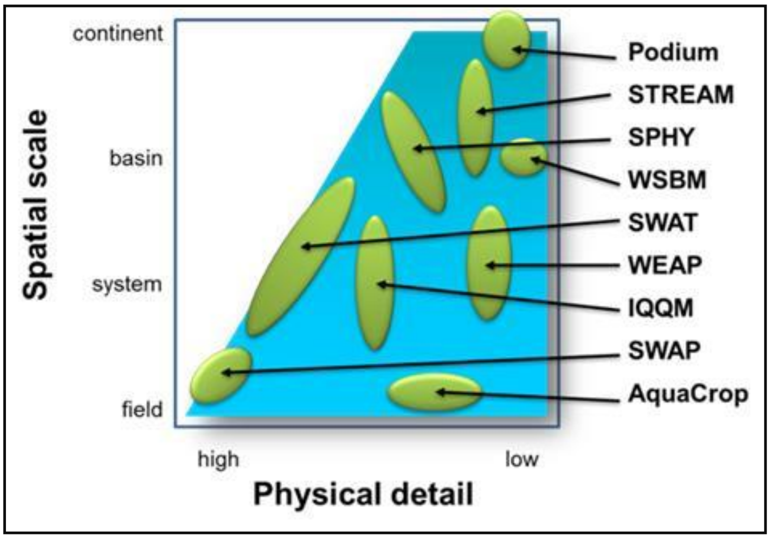

Figure 2-11: Relation between spatial scale and physical detail in water resources tools. The green ellipses show the key strength of some well-known models (Source: Droogers and Bouma, 2014).

	Drought	Floods	Allocation	Complexity	Scalable	Scenarios
HEC-HMS	2	3	1	3	3	3
HEC-RAS	1	5	2	4	2	2
SPHY	3	4	2	2	4	4
WEAP	5	4	5	1	5	5
SWAT	4	3	3	2	4	3
SOBEK	1	5	1	3	2	2
MIKE BASIN	4	3	4	2	4	4
MIKE SHE	3	3	3	5	2	1

Figure 2-12: Qualitative (expert based) assessment of some catchment scale models that might be used for the CRAs. Scores 1 (=limited) to 5 (=well suited). Note that the color scale for "Complexity" is reversed to maintain green for "better" and red for "worse".

Various scenario impact tools exist and appropriate selection of the most relevant is essential for the success of a project. Over the last decade, an integrated approach to water development has emerged which places water supply projects in the context of demand-side management, and water quality and ecosystem preservation and protection. Moreover, based on experiences from previous scenario assessment studies it is recommended to use a tool that can combine various strengths and is specifically geared towards scenario analysis. It was therefore selected to use the WEAP model. WEAP incorporates these values into a practical tool for water resources planning and policy analysis.

There are various reasons for choosing the WEAP as the most relevant one to implement the Water Supply and Demand Framework. Most important is that WEAP is completely focused towards scenario analysis in a user-friendly approach. Second, WEAP is very scalable and a first-order setup of a particular region can be easily expanded when more data/resources are available. Third, WEAP is commonly used world-wide for IWRM analyses. Finally, WEAP is freely available for organizations in developing countries.

A detailed discussion on WEAP can be found in the WEAP manual which can be freely downloaded from the WEAP website (http://www.weap21.org/). In summary WEAP have the following features:

- Integrated Approach: Unique approach for conducting integrated water resources planning and impact assessments.
- Stakeholder Process: Transparent structure facilitates engagement of diverse stakeholders in an open process.
- Water Balance: A database maintains water demand and supply information to drive mass balance model on a link-node architecture.
- Simulation Based: Calculates water demand, supply, runoff, flooding, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and in-stream water quality under varying hydrologic and policy scenarios.
- Hydrological Processes: Semi-distributed three-layer bucket approach (soil water, deep water, groundwater).
- Policy Scenarios: Evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.
- User-friendly Interface: Graphical drag-and-drop GIS-based interface with flexible model output as maps, charts and tables.

- Model Integration: Dynamic links to other models and software, such as QUAL2K, MODFLOW, MODPATH, PEST, Excel, HEC-RAS and GAMS. Links to all other models can be developed quite easily since WEAP can read and write plain text files similar as SWAT, SPHY, SWAP, Mike11, HEC-HMS, HEC-RAS and Geo-SFM.

The Water Supply and Demand Framework (WSDF) as implemented in WEAP requires data from various types. Required input data can be divided into the following main categories:

- Model building
  - Static data[1]
    - Digital Elevation Model
    - Soils
    - Land use, land cover
    - Population
    - Reservoir operational rules
  - Dynamic data
    - Climate (rainfall, temperature, reference evapotranspiration)
    - Evapotranspiration by crops and natural vegetation
    - Water demands by all sectors
    - Reservoir releases
- Model validation/calibration
  - Stream flow

Each of the above categories can be refined depending on availability and accessibility of data. The WEAP framework is flexible in level of details of data availability. A typical example is that water demands can be included as a total amount of water, but can be also estimated by WEAP using for example the population, their daily required intake and daily and/or monthly variation. Similarly, climate data can be entered at annual, monthly, 10-days or daily level. The more refined the input dataset is, the higher the accuracy of the WEAP model scenarios will be.

This feature is very useful in areas with low data availability or where more and better quality data will become gradually available as is the current study. The WEAP set-up gives the user the flexibility to add more detailed data when it becomes available, without having to start from scratch with every updated data set.

Some typical examples of how the WEAP Schematic input was created can be seen in the following Figures:

- River Nodes (Figure 2-14)
- Demand Nodes Irrigation (Figure 2-15)
- Demand Nodes Domestic (Figure 2-16)

Detailed description of model setup, data and scenarios is provided hereafter.

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[1] Nota that static data can still vary over longer time frames, but are fairly constant over days/weeks

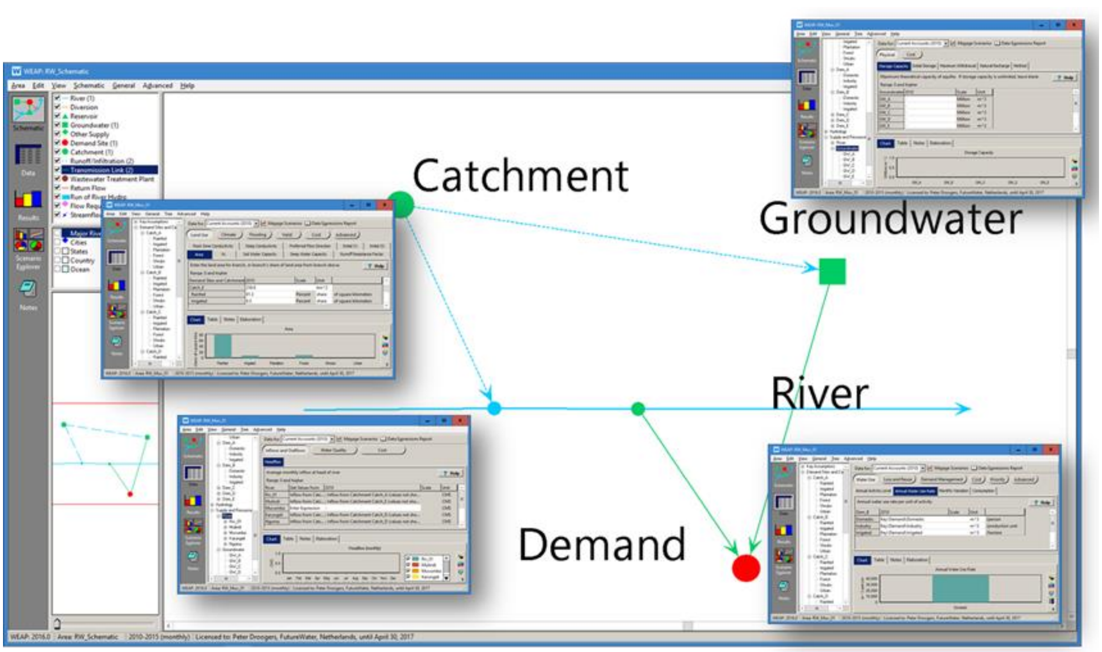


Figure 2-13: Schematization of one Sub-Catchment. Each demonstration catchment has been divided in five to six of these Sub-Catchments.

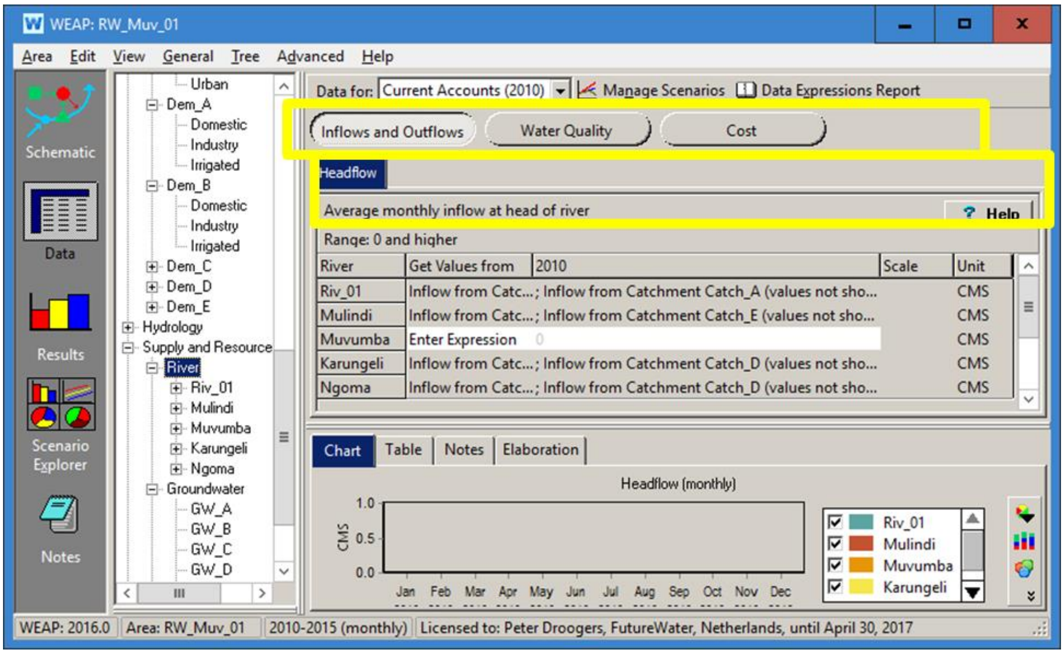


Figure 2-14: Most relevant input fields for the River Nodes in a Sub-Catchment.

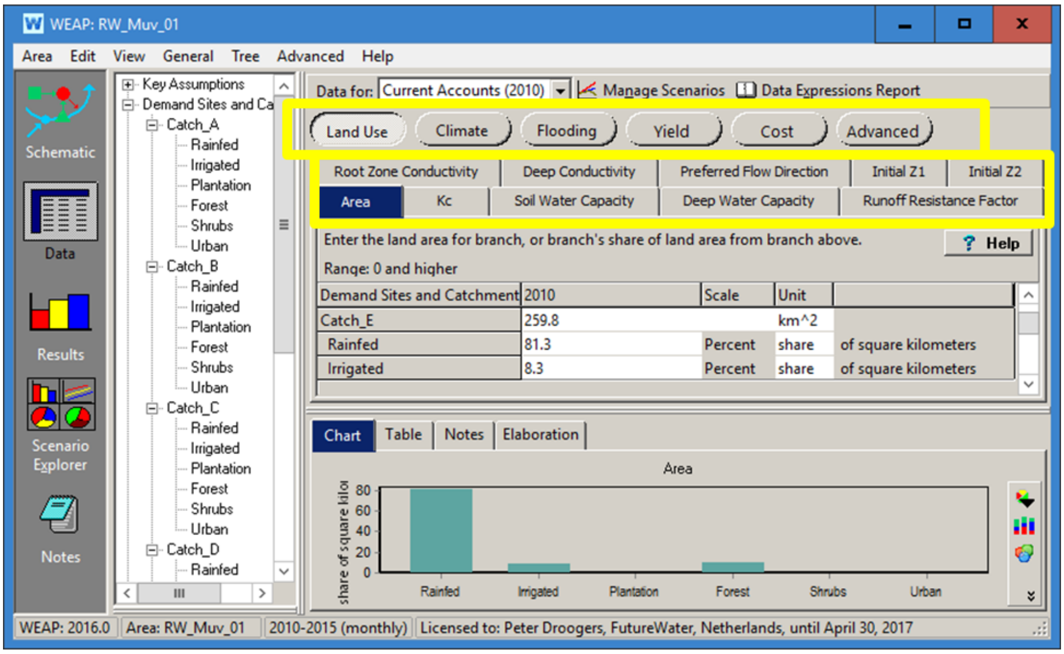


Figure 2-15: Most relevant input fields for the Catchment Nodes in a Sub-Catchment.

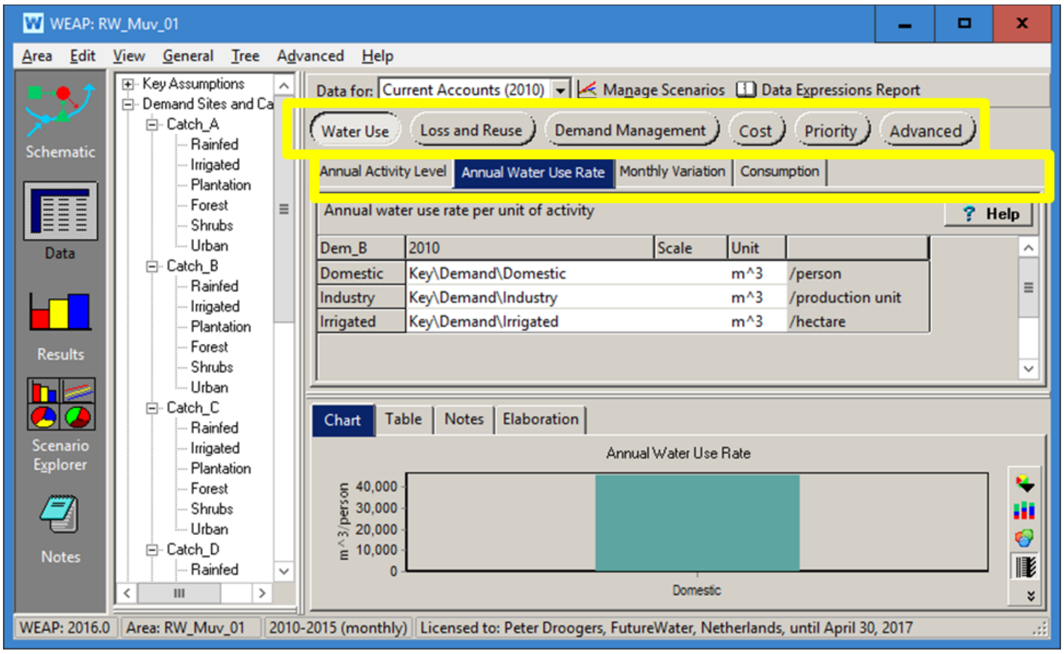


Figure 2-16: Most relevant input fields for the Demand Nodes in a Sub-Catchment.

2.3.2 *Hydrological model (SWAT)*

The SWAT (Soil and Water Assessment Tool) model is a semi-physically based model that is designed to simulate the impact of land management practices on the environmental–hydrological system in a watershed over long periods (years to decades). The SWAT model allows for a number of different physical processes to be simulated in a watershed, including water movement, sediment movement, crop growth, and nutrient cycling. SWAT can be used to analyze small or large catchments by discretising them into sub-basins, which are then further subdivided into hydrological response units (HRUs) with homogeneous land uses, soil types, and terrain slope class.

SWAT considers the watershed hydrology in two phases: the land phase and routing phase. The land phase is composed of the watershed land areas that simulate the water that is transported to the channels, together with sediment, nutrients and pesticides. The routing phase comprises of the behavior of the water in the channels, from the tributaries to the watershed outlet. The hydrology cycle that is simulated by the SWAT model is based on the water balance equation.

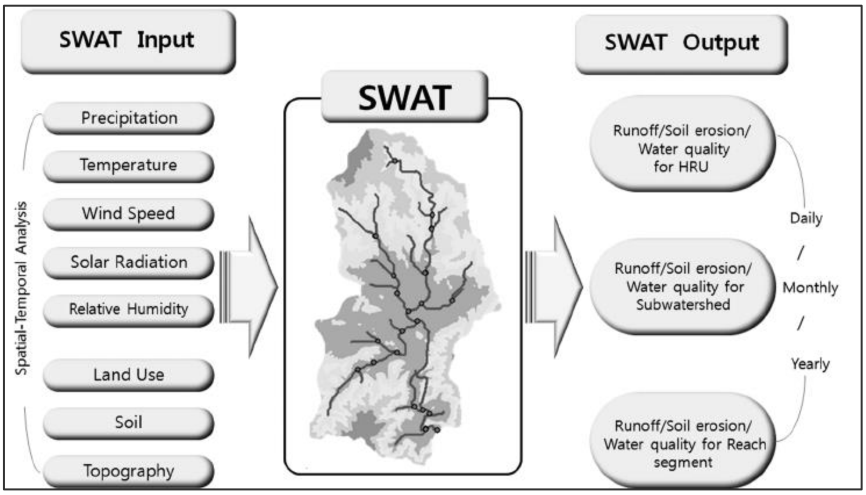


Figure 2-17: General overview of the SWAT model and its input and outputs.

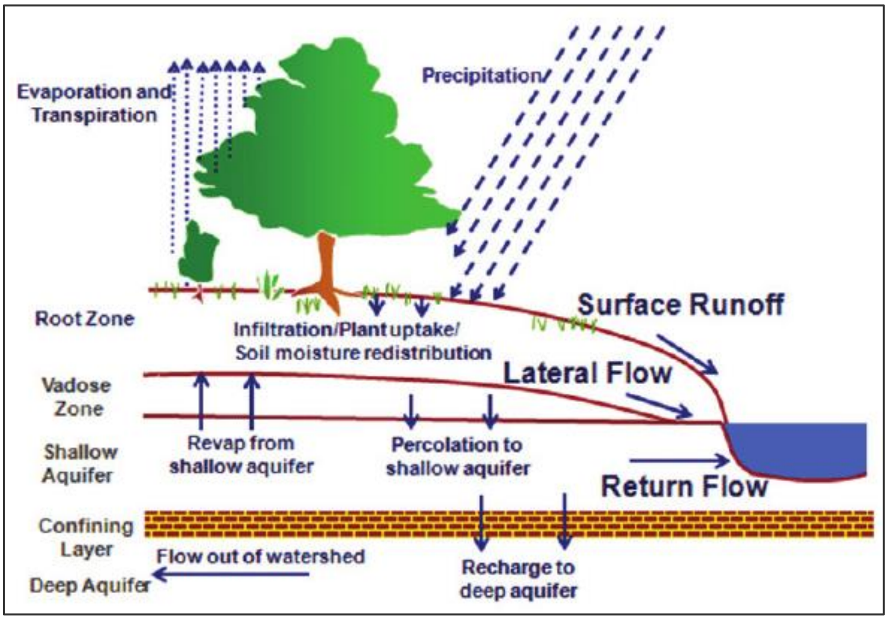


Figure 2-18: General overview of the main hydrological processes included in SWAT.

SWAT simulates runoff by using the SCS (Soil Conservation Service) curve number method and the Green–Ampt infiltration method. The peak runoff rate is estimated by using a modification of the Rational Method. Water is routed through the channel network by using the variable storage routing method, or the Muskingum routing method. The groundwater flow contribution to the total river flow is simulated by creating a shallow aquifer storage area, whereby percolation from the root zone is recharged to the shallow aquifer. Three methods for estimating potential evapotranspiration are used in SWAT: Priestley–Taylor, Penman–Monteith and ET–Hargreaves. A full explanation of the SWAT theories and structure are given in the SWAT theoretical documentation. In this study, the SCS curve number and Muskingum routing methods were used for surface runoff and flow computations while the Penman method was used to estimate potential evapotranspiration.

The SWAT model has been used to simulate river flows in the 11 sub-catchments of Tonle Sap Basin. The daily flows were calibrated (1997–2003) and validated (2004–2015) at 11 different river flow monitoring stations (Oeurng et al., 2019). The parameters for the flow simulations were fitted through an auto-calibration procedure, using SWAT-CUP for the 11 river flow stations. The daily flow calibration from 1997 to 2003 was also carried out using a sequential uncertainty fitting algorithm (SUFI-2) with SWAT-CUP (Oeurng et al., 2019). The model development has integrated Digital Elevation Model with a 50 m 50 m horizontal resolution for the lower Mekong, soils map developed by the MRC from base maps at 1: 250,000 scale, based on the FAO/UNESCO 1988 classification; up to three levels and 10 main soil types were included in the model. A land-use/land-cover (LULC) map developed by the MRC, based on satellite imagery from 1993–1997. LULC was characterized, and it included eight major LULC classes.

The SWAT model has been calibrated and validated for available streamflow records. Figure 2-19, Figure 2-20 and Figure 2-21 show for some selected stations the performance of the model. Overall, SWAT is very good in replicating the observed streamflow and is therefore considered to be of good quality to generate runoff for other ungauged rivers in the area. Details of SWAT and its performance can be found in Oeurng et al., 2019.

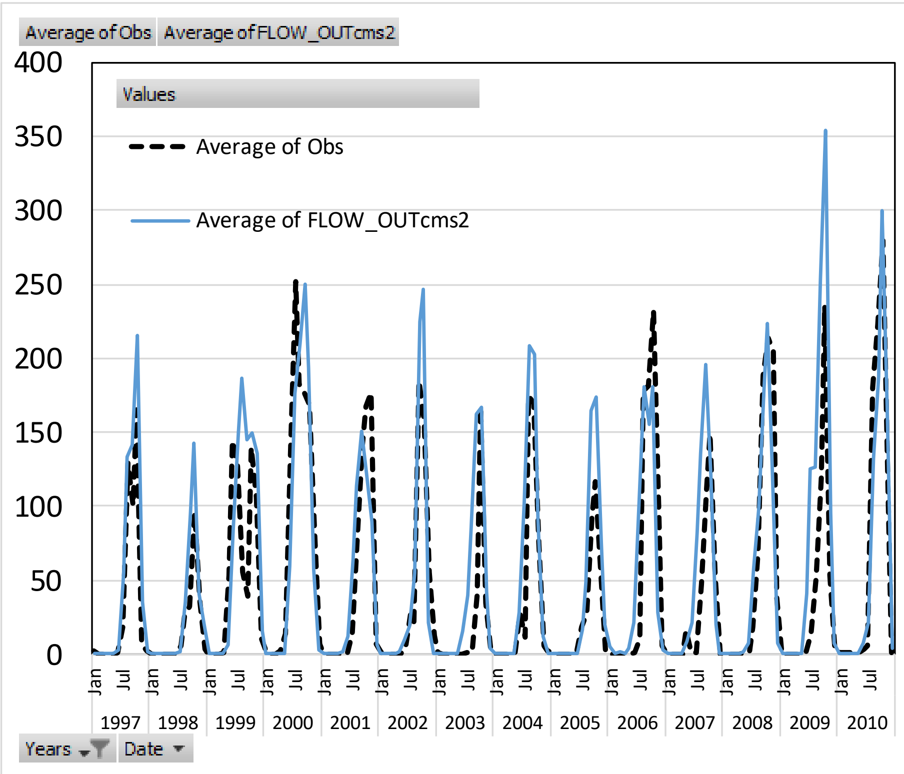


Figure 2-19: Performance of the SWAT model for Sreng River in m3 s-1. Source: Oeurng et al., 2019.

Figure 2-22 shows the overall mean annual flow for the entire Tonle Sap based on 31 years simulation. More refined maps for Sreng and Sangker River Basin Groups are presented in Figure 2-23 and Figure 2-24. The maps provide a summarizing overview of the results of the SWAT model as used as input for the Water Supply and Demand Framework as discussed in the previous section. The maps show that overall water resources are higher in Sangker compared to Sreng. The maps also indicate that dry years have a significant lower flow compared to an average year.

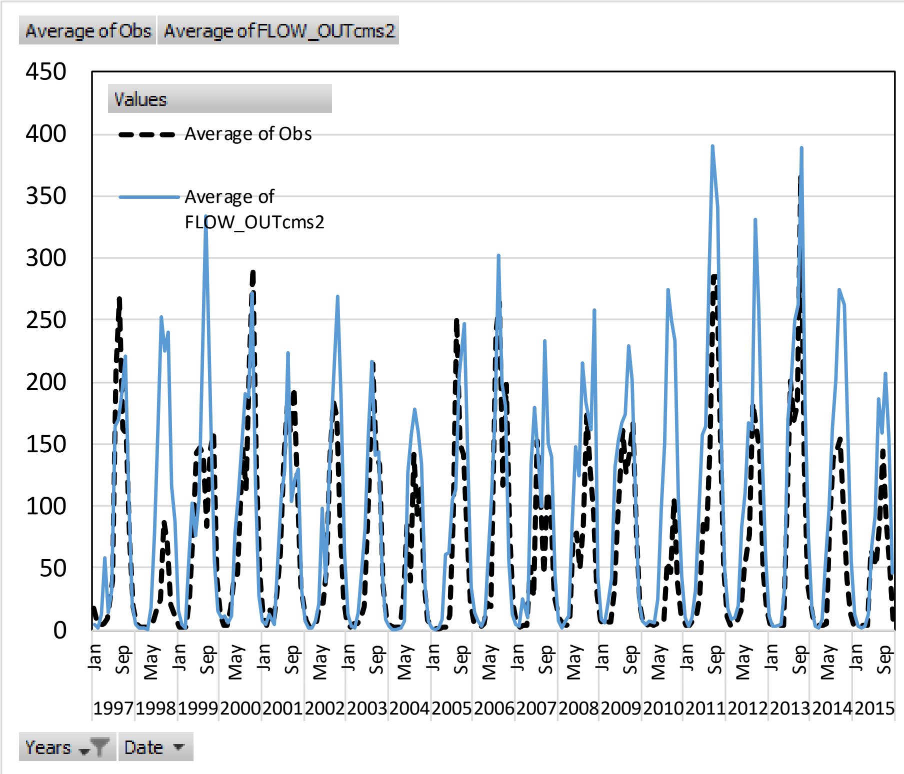


Figure 2-20: Performance of the SWAT model for Sangker River in m3 s-1. Source: Oeurng et al., 2019.

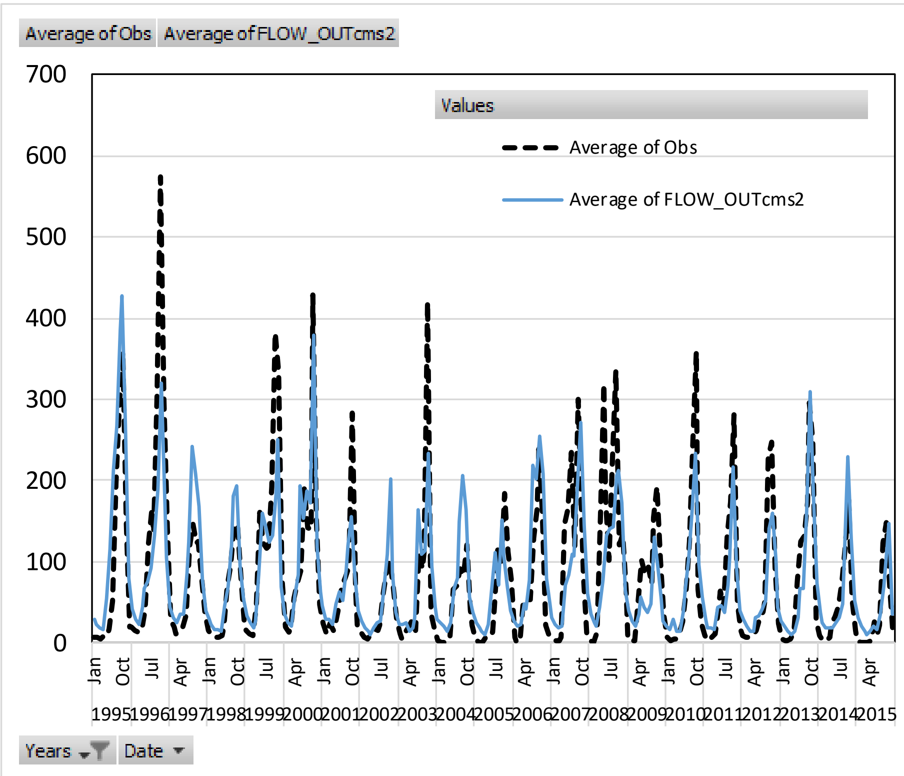


Figure 2-21: Performance of the SWAT model for Pursat River in m3 s-1. Source: Oeurng et al., 2019.

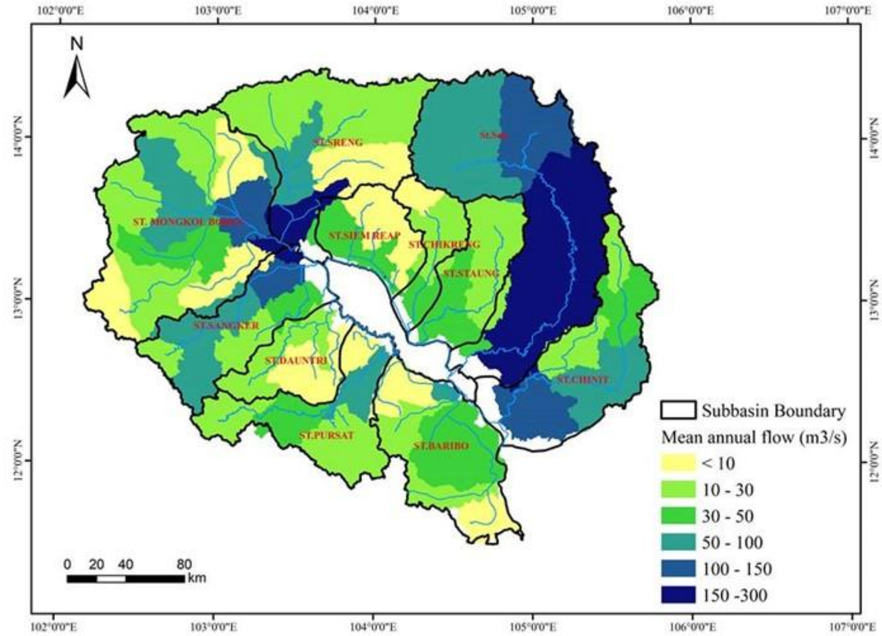


Figure 2-22: Spatial distribution of the (mean annual) river flow in each sub-basin, simulated from the Soil and Water Assessment Tool (SWAT) model (1985–2015). Source: Oeurng et al., 2019.

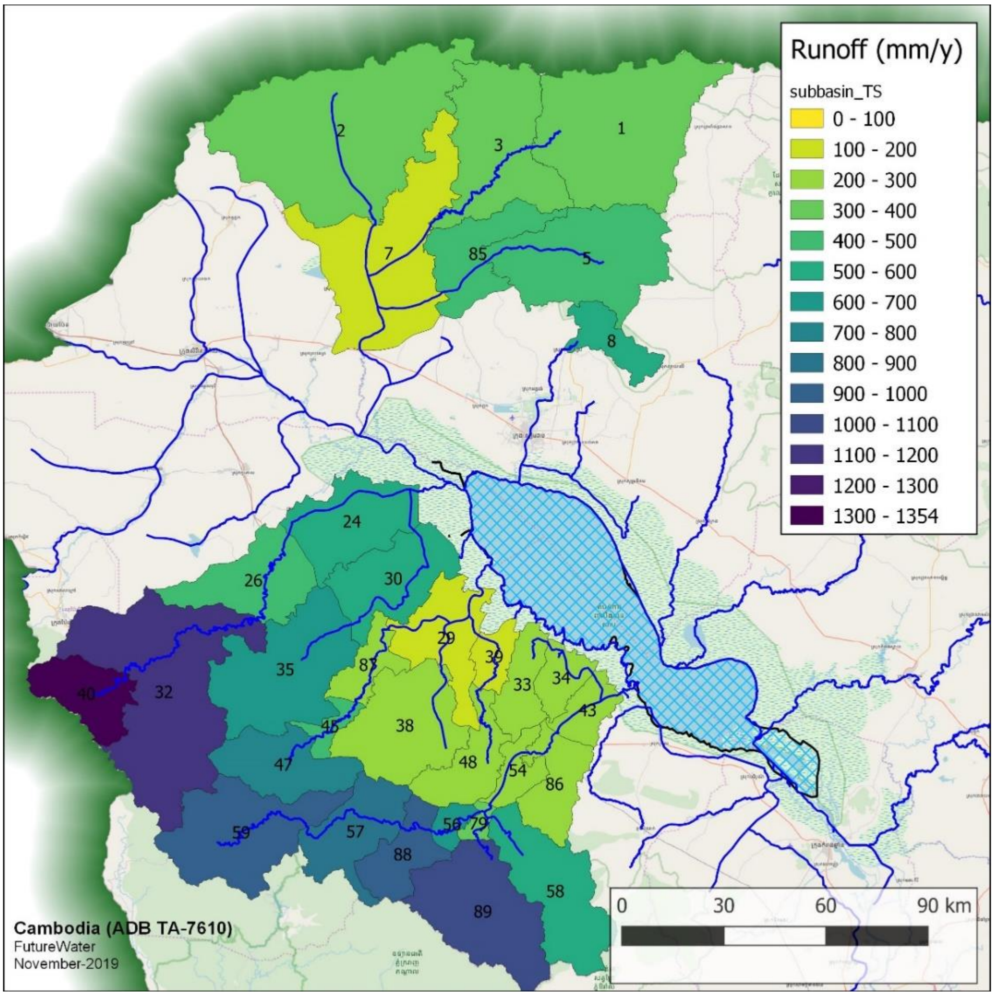


Figure 2-23: Mean annual runoff in mm/y for the River Basin Groups Sreng and Sangker as obtained from the (SWAT) model (1985–2015). Source: Oeurng et al., 2019.

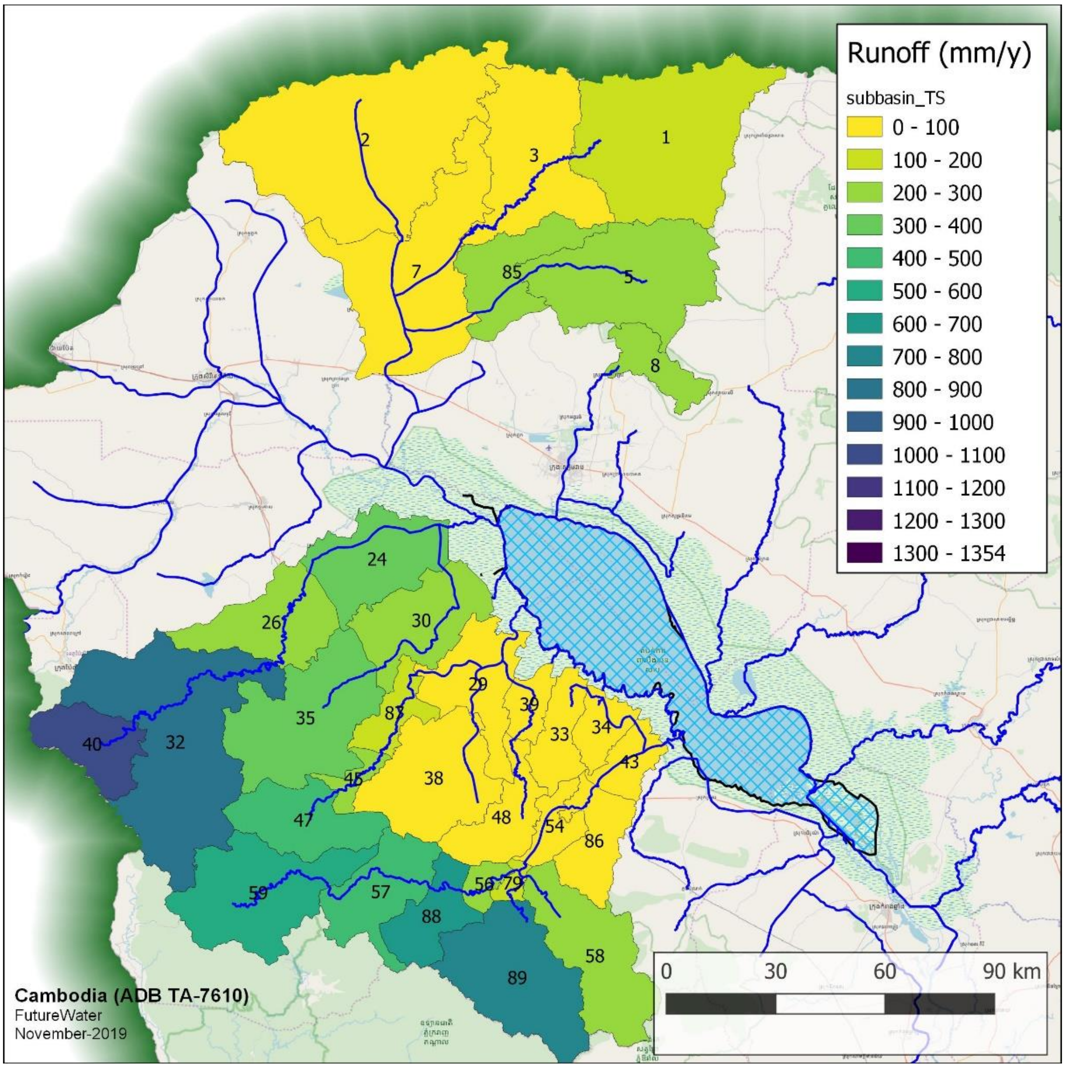


Figure 2-24: Same as Figure 2-22 but here for a dry year. Lowest annual runoff in mm/y for the River Basin Groups Sreng and Sangker as obtained from the (SWAT) model (1985–2015). Source: Oeurng et al., 2019.

2.3.3 *Flood routing model (ISIS)*

For the flood impact assessment in the Canal 98 area (Slakou-Toan Han basin group), a flood routing model is necessary. For this, the state-of-the-art ISIS model was used, applied in several occasions previously in the Mekong delta and in collaboration with MOWRAM.

The ISIS software developed by HR Wallingford and Halcrow is used to simulate the river system downstream of Kratie, including the Tonle Sap and the East Vaico in Vietnam where wet season flooding extends beyond the LMB boundary. The hydrodynamic model represents the complex interactions caused by tidal influences, flow reversal in the Tonle Sap River and over-bank flow in the flood season with the varying inflows from upstream. Typically, it generates hourly data for water levels and discharges throughout the main channels and distributaries in the delta. ISIS also has capability to simulate other water quality parameters, including sedimentation. The ‘model’ (referring to the input data for Mekong) has been continually developed in time since 2002. The most recent update was in 2014 to include the rapid development in both Cambodia and Vietnam. The extent is revealed in Figure 2-25.

For this report, the base model was manipulated from the original model (Figure 2-26) as it did not include either Canal 98 or the proposed link Canal.

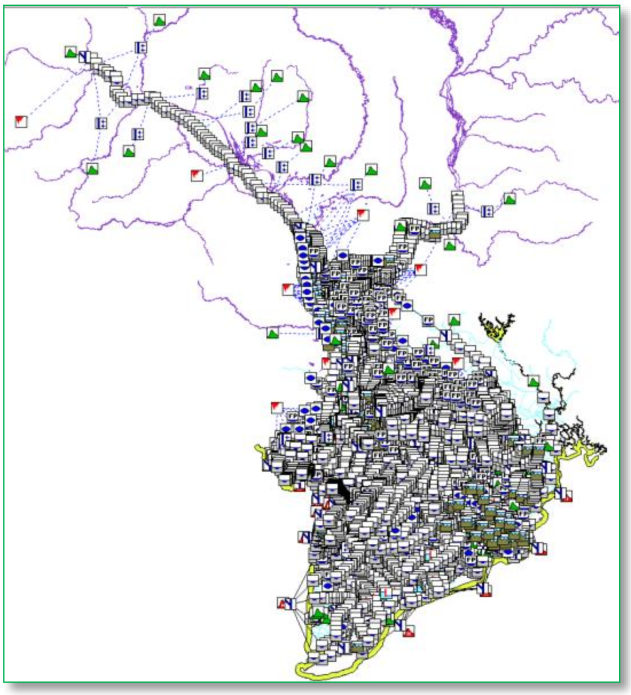


Figure 2-25: Extent of the ISIS model

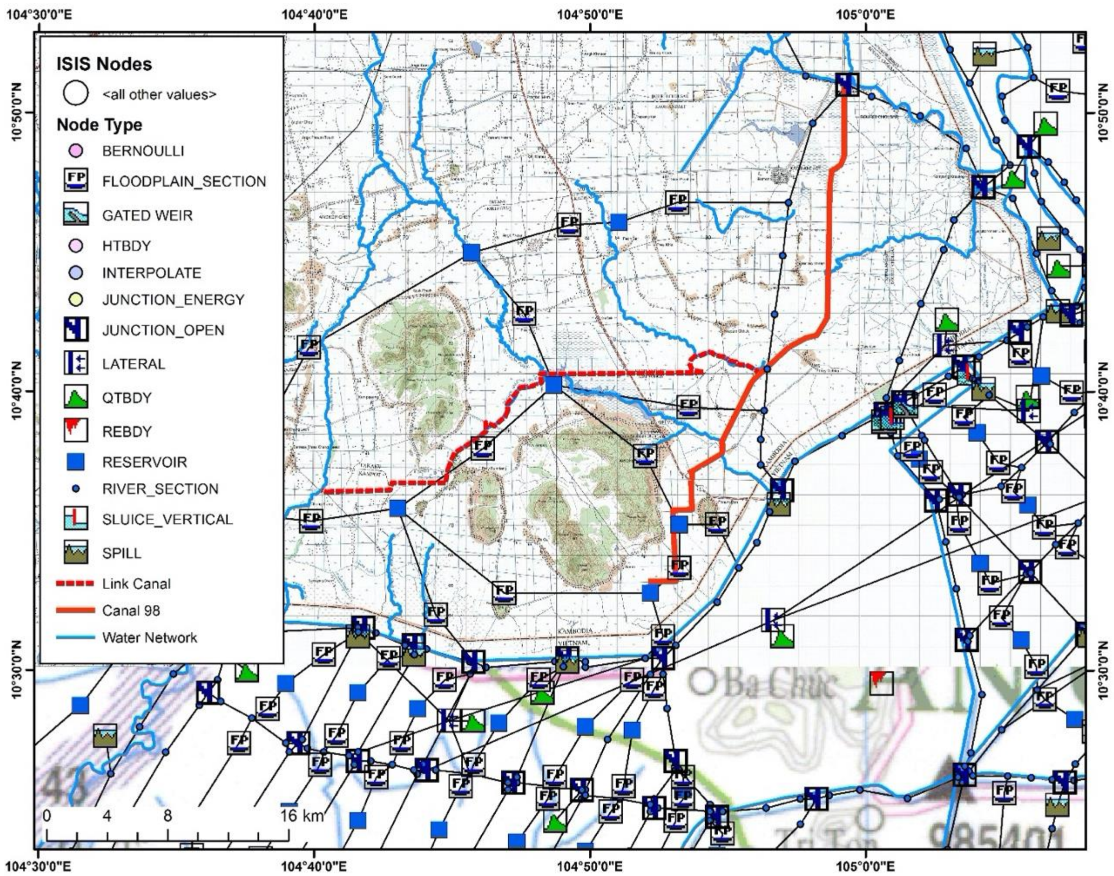


Figure 2-26: MRC ISIS Model

3 Sreng-Sisophon Basin Group: Surface Water Resources Assessment

3.1 Catchment characterization

The Sreng-Sisophon Basin Group lies predominantly within the provinces of Oddar Meanchey, Banteay Meanchey and Siem Reap but also lies within areas of Sa Keo and Battambang (Fig 3-1). The purpose of the study was to consider the whole of the Sreng and the part of the Sisopon that is adjacent to the Sreng and connects vis the reservoir Ang Trapeang Thmor. The area was divided into 15 sub-catchments, to obtain further spatial detail in the modelling assessment, which cover a total area of 14,006km^2. These sub catchments were named according to the main tributaries that flow through them: Sreng, Sisophon, Soay Chek, Srong and Tanat. The Stung Sreng is the largest tributary, in terms of discharge, to the Tonle Sap within this basin group. It has a maximum and minimum flow of 340 m^3/s and 45 m^3/s, respectively. The river flow typically increases from mid July and rises to over 120 m^3/s for its peak discharge in October.

The elevation within the region ranges from 637m to 2.5m and generally decreases from north to south, from the Dangrek mountains to the floodplain of the Tonle Sap (Fig 3-2). In terms of geology, old alluvium and young alluvium make up over 95% of the bedrock within the catchment representing 54% and 42% of the total area respectively (Fig 3-3). Alluvium is a deposit of clay, silt and sand left by flowing floodwater and typically produces fertile soil. Geology data for Thailand was not attained.

Acrisol soil covers 61% of the Sreng-Sisophon Basin Group whilst Cambisol represents 20% (Fig 3-4). Acrisol is a clay-rich subsoil that is associated with humid, tropical climates and often supports forested areas but low fertility and toxic amounts of aluminum pose limitations to its agricultural use. Cambisol soil can be exploited for agriculture due to its high mineral content.

Using the MRC and SERVIR landcover databases it can be found that the majority of land in the region is cropland and forest. Between 1987 and 2018, it was found that percentage of 'cropland' area increased from 47 to 62% whilst the area of 'forest' decreased from 24 to 13% (Fig 3-5, Fig 3-6). In addition, the 'mixed forest', 'evergreen broadleaf', and 'flooded forest' land cover classes also decreased in area. However, the 'orchard or plantation forest' increased in percentage area from 6 to 13%. CISIS irrigation statistics are summarised in Table 3-1, showing that wet season irrigated area makes up over 85% of the year-round total (Fig 3-7).

Figure 3-8 highlights that during a 1 in 100 year flood the southern part of the region would be largely inundated whilst the main tributaries such as the Sreng and Tanat would also burst their banks inundating the floodplain. Areas that lack in abundant water availability can be identified broadly using Figure 3-9 as the areas with low dry season actual evapotranspiration. This data was obtained by UNESCO-IHE in a water accounting assessment of Cambodia between 2000 and 2015, which was the aggregated and averaged for the dry season. The areas to the centre and west of the Basin Group are highlighted as those areas particularly lacking in abundant water. Figure 3-16 highlights the location of major infrastructure within the Sreng/ Sisophon RBG such as the Sreng 1 and Sreng 2 reservoirs which are considered in the modelled scenarios. These reservoirs provide valuable water storage, primarily for use in the dry season.

Finally, Figure 3-10 shows that within the Basin Group there are 10 protected areas, 19 river blockages and 40 CFRs. Further information on the protected environmental areas can be found in Table 3-2.

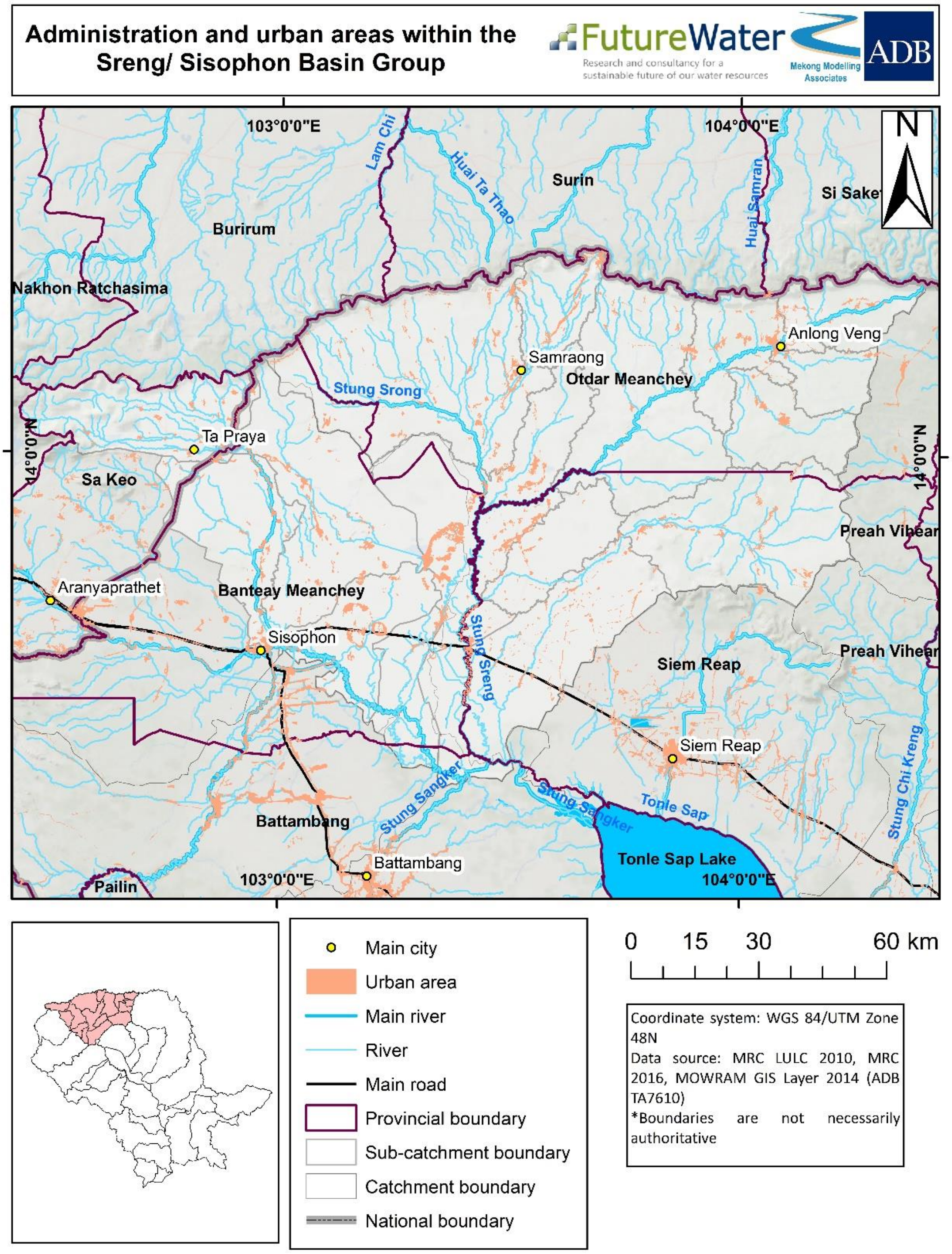


Figure 3-1: Administration and urban areas within the Sreng/ Sisophon Basin Group.

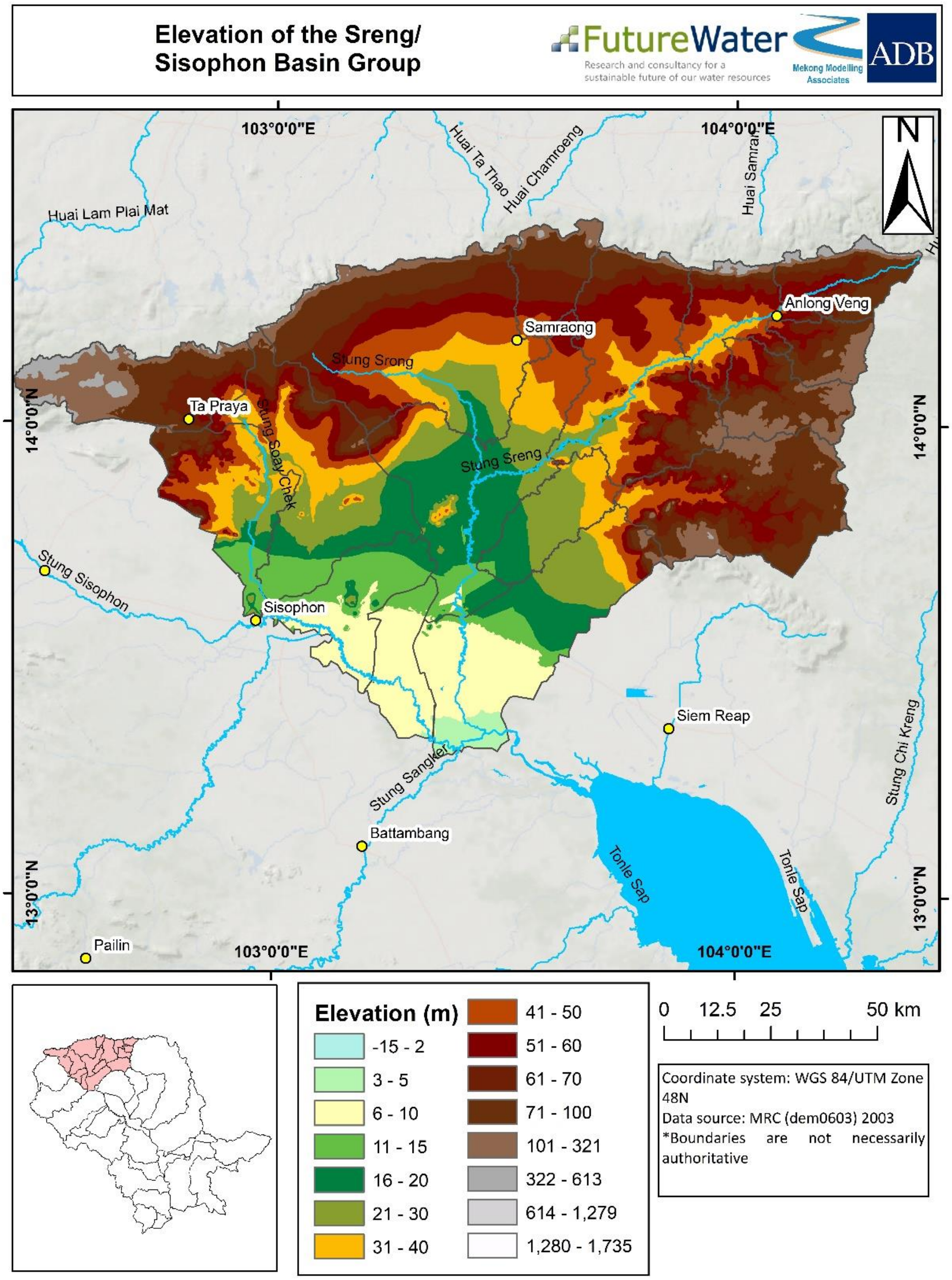


Figure 3-2: Elevation of the Sreng/ Sisophon Basin Group.

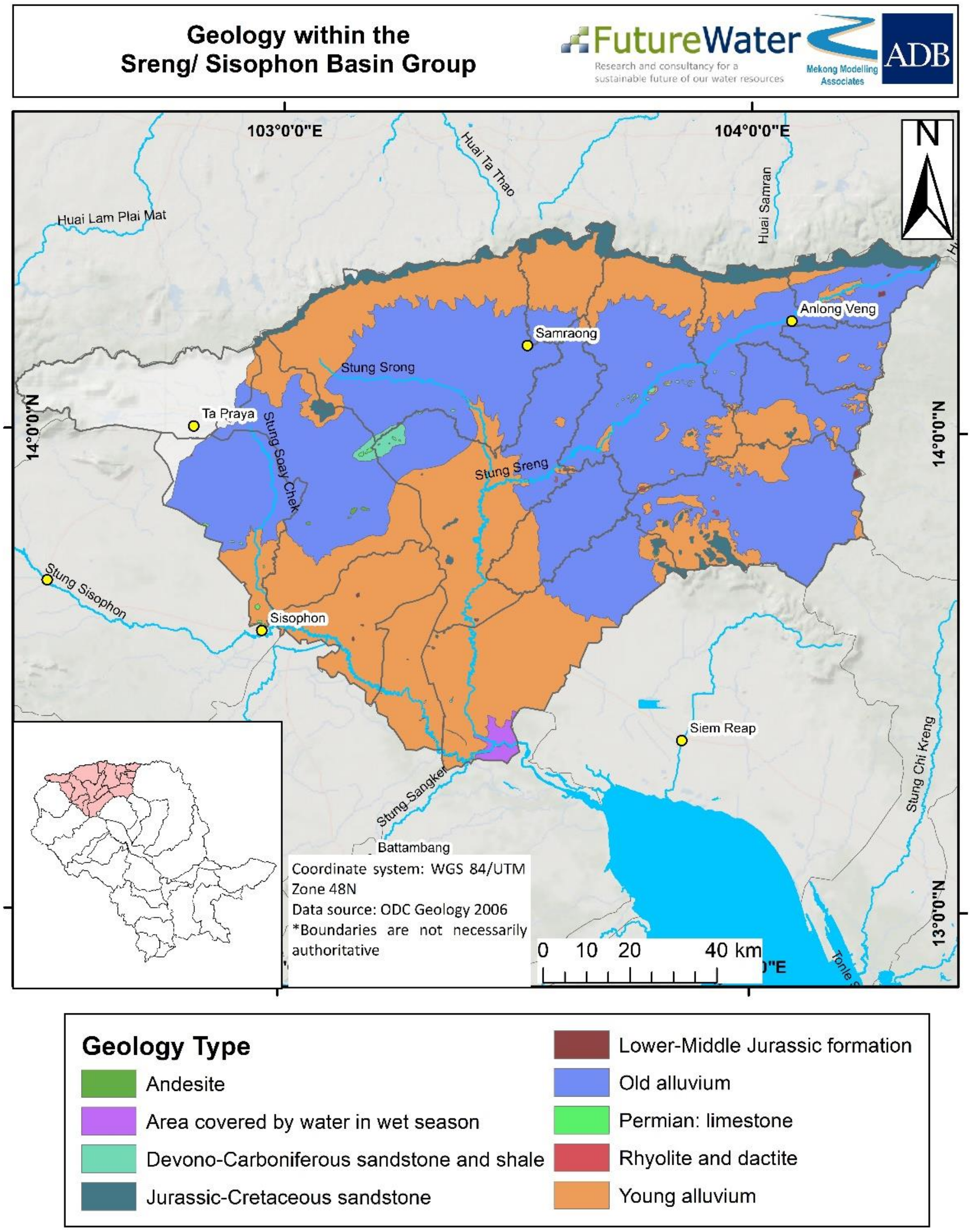


Figure 3-3: Geology within the Sreng/ Sisophon Basin Group.

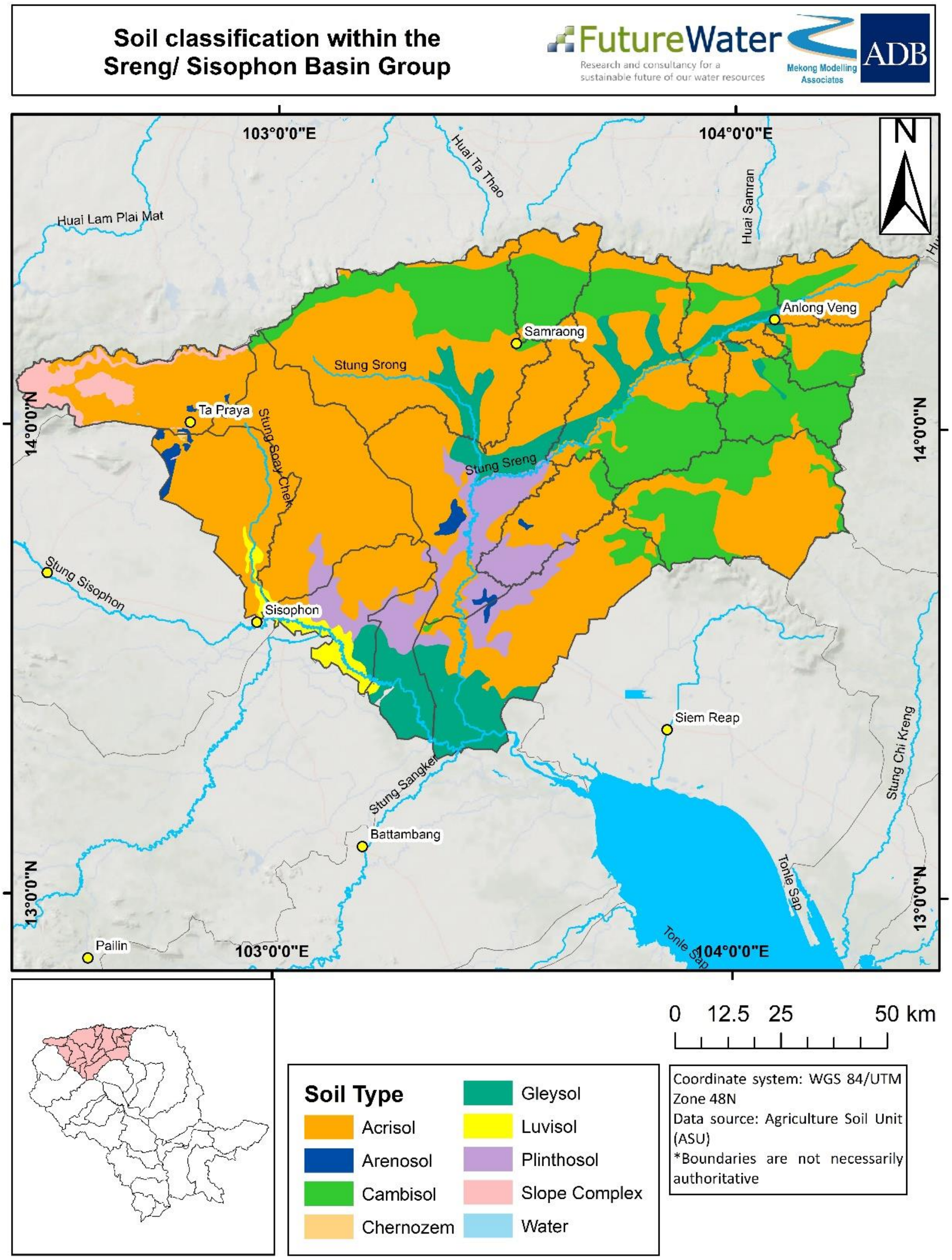


Figure 3-4: Soil Classification within the Sreng/ Sisophon Basin Group.

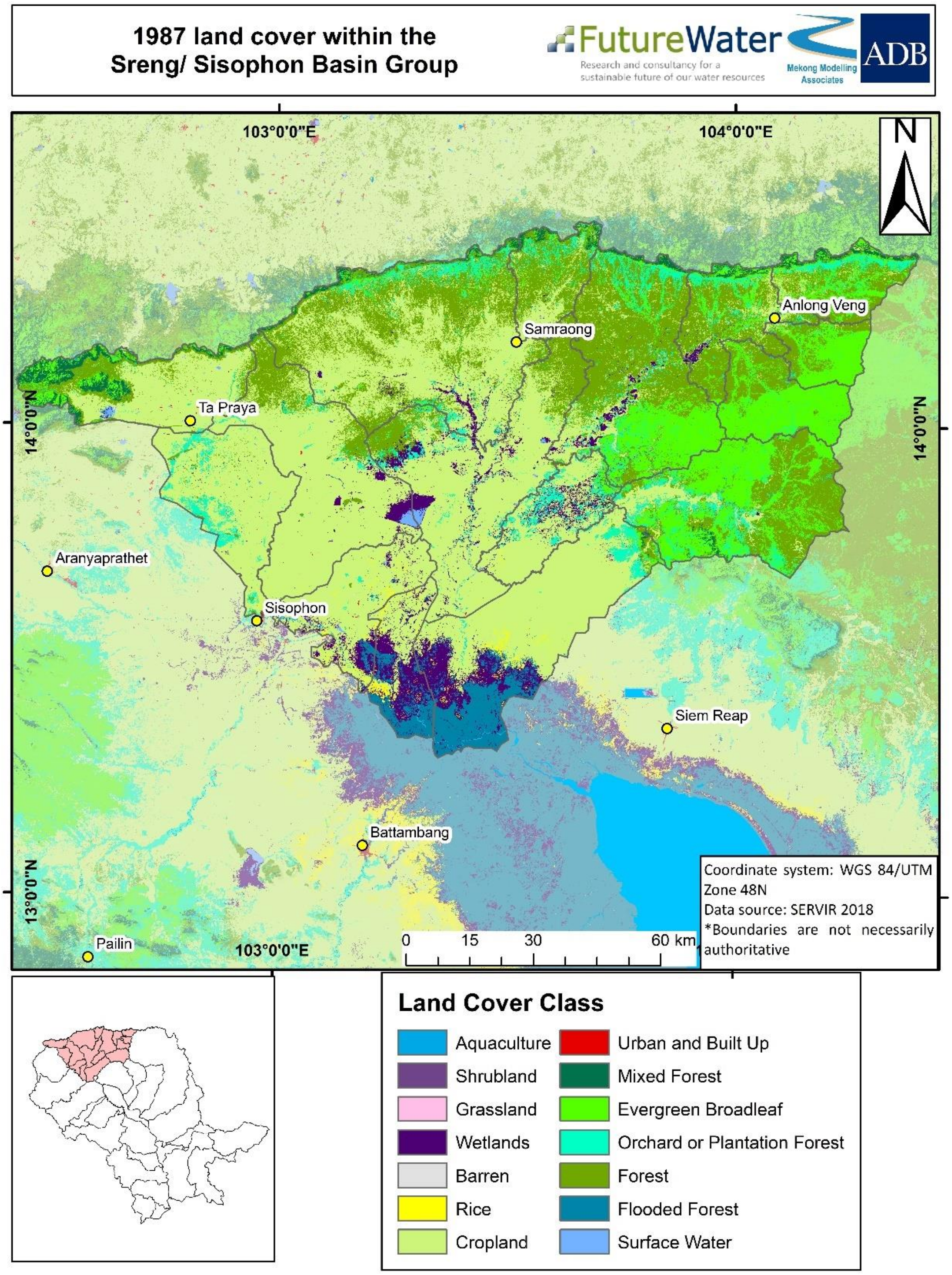


Figure 3-5: 1987 land cover within the Sreng/ Sisophon Basin Group.

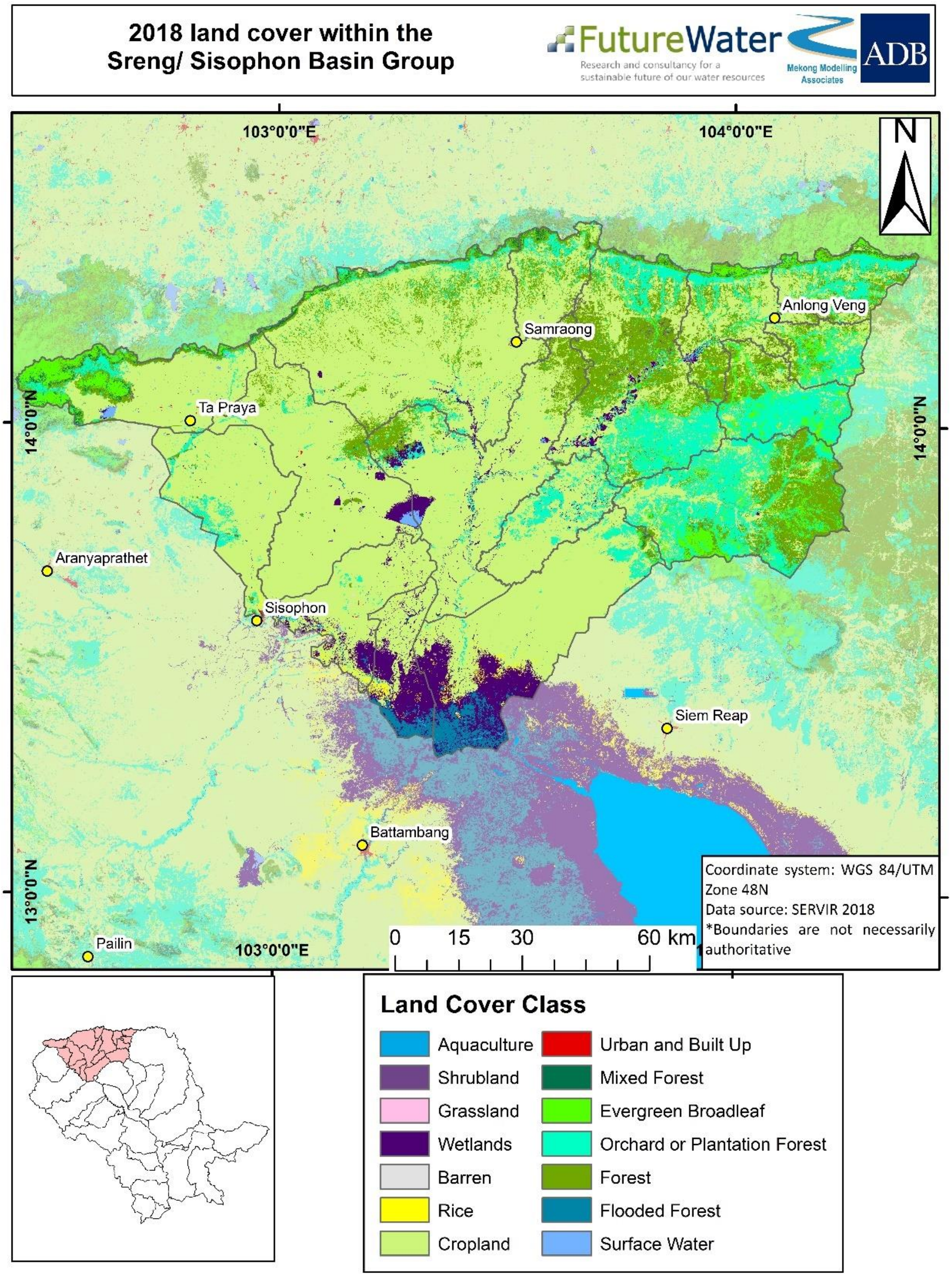


Figure 3-6: 2018 land cover within the Sreng/ Sisophon Basin Group.

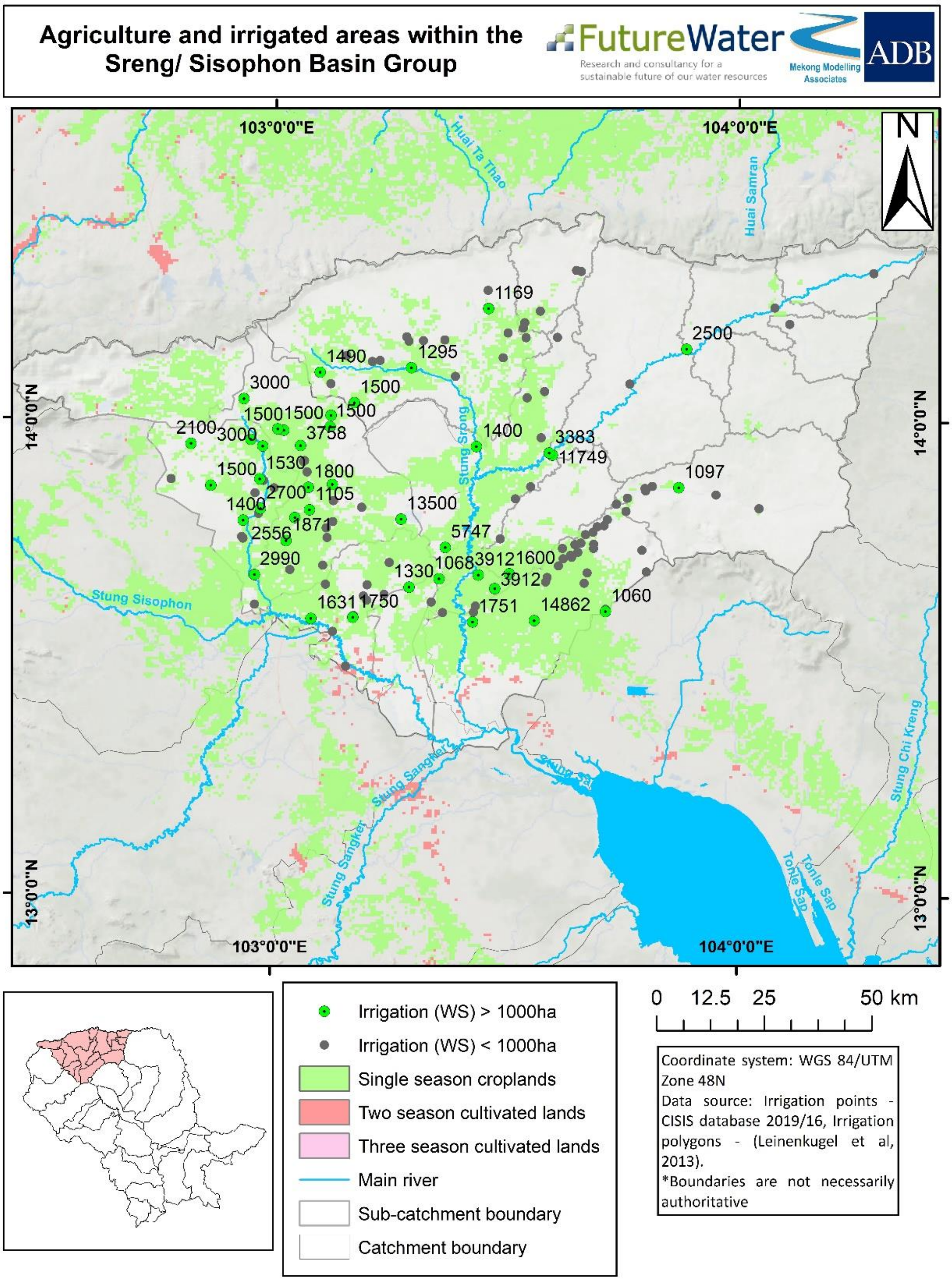


Figure 3-7: Agriculture and irrigated areas within the Sreng/ Sisophon Basin Group.

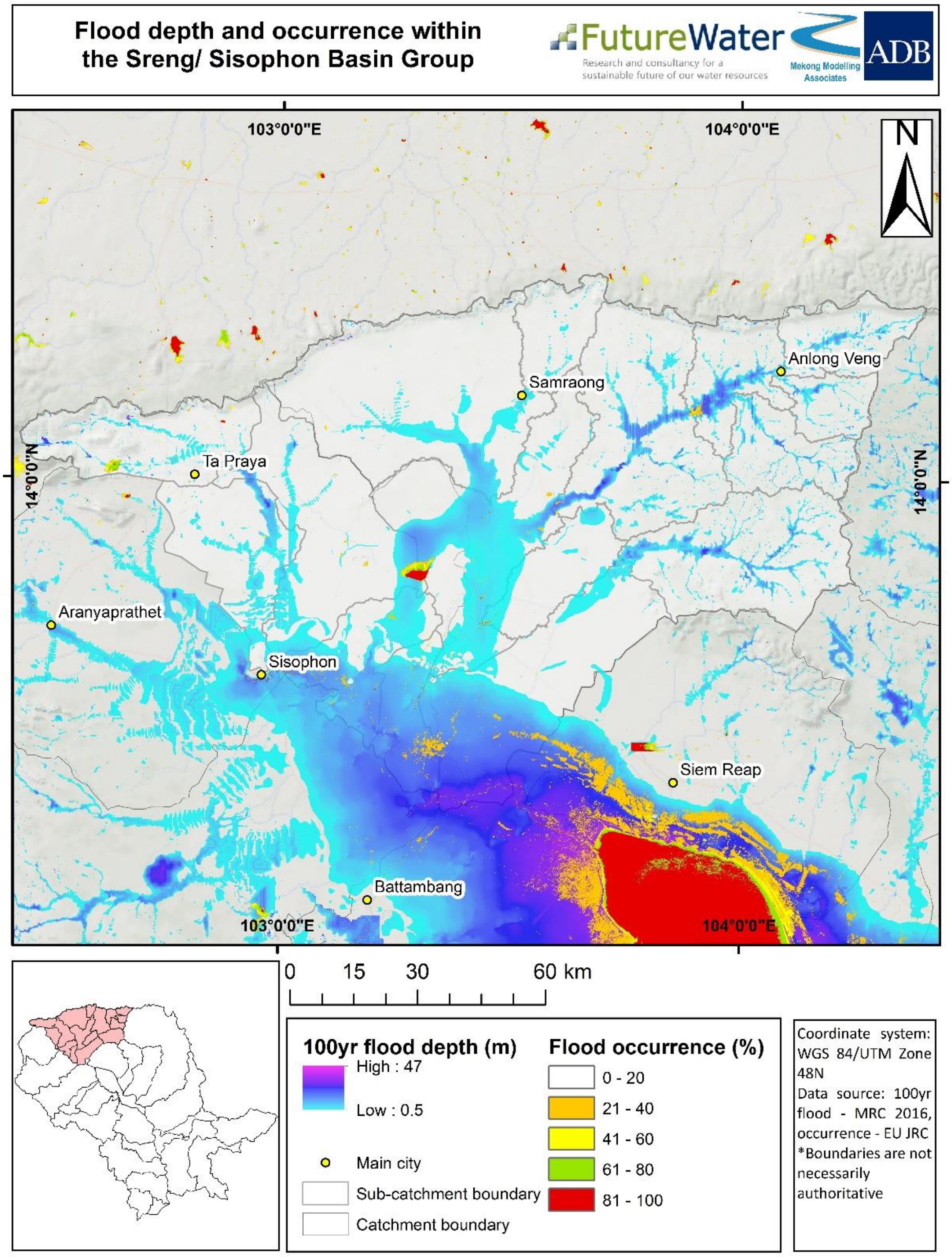


Figure 3-8: Flood frequency within the Sreng/ Sisophon Basin Group.

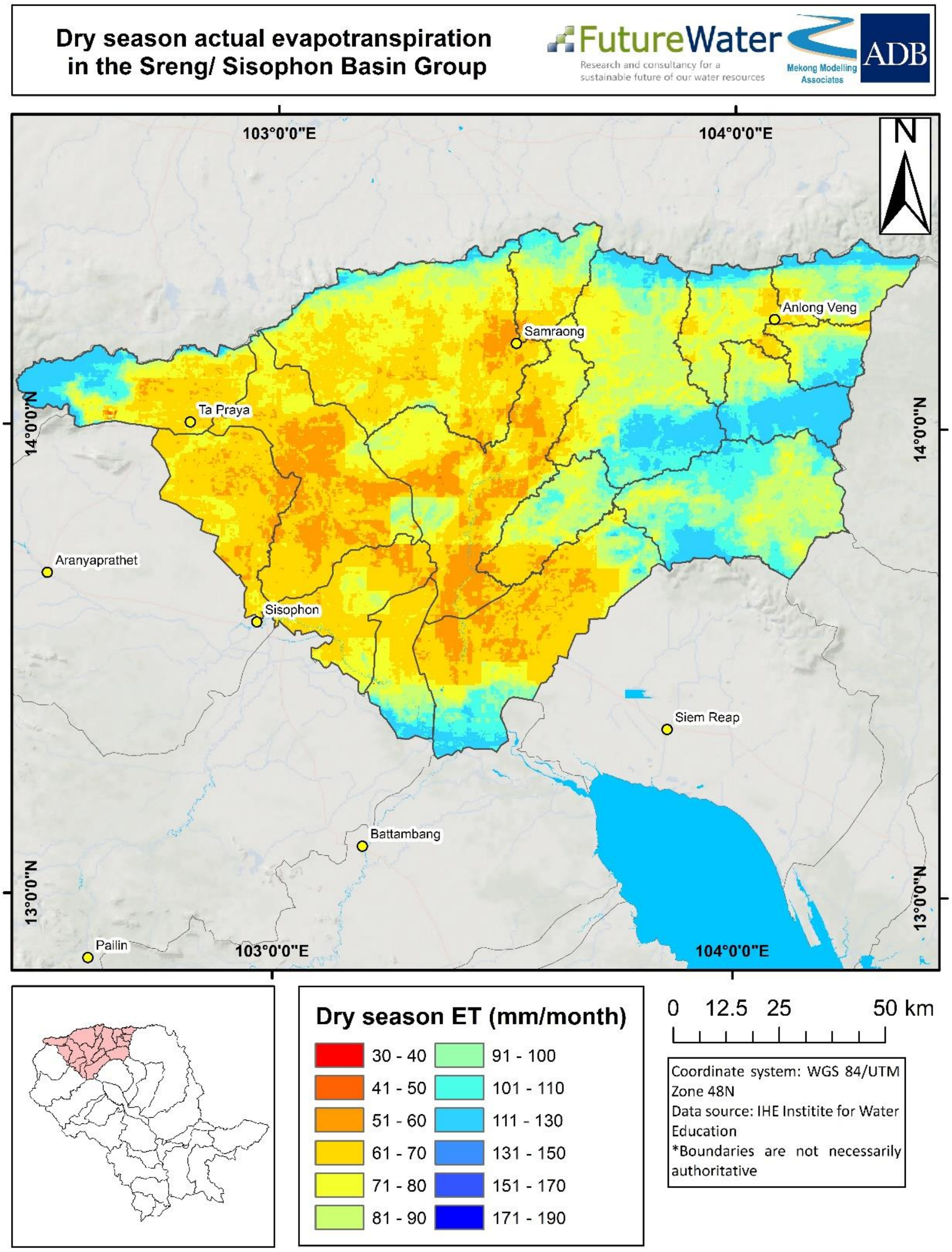


Figure 3-9: Dry season evapotranspiration in the Sreng/ Sisophon Basin Group.

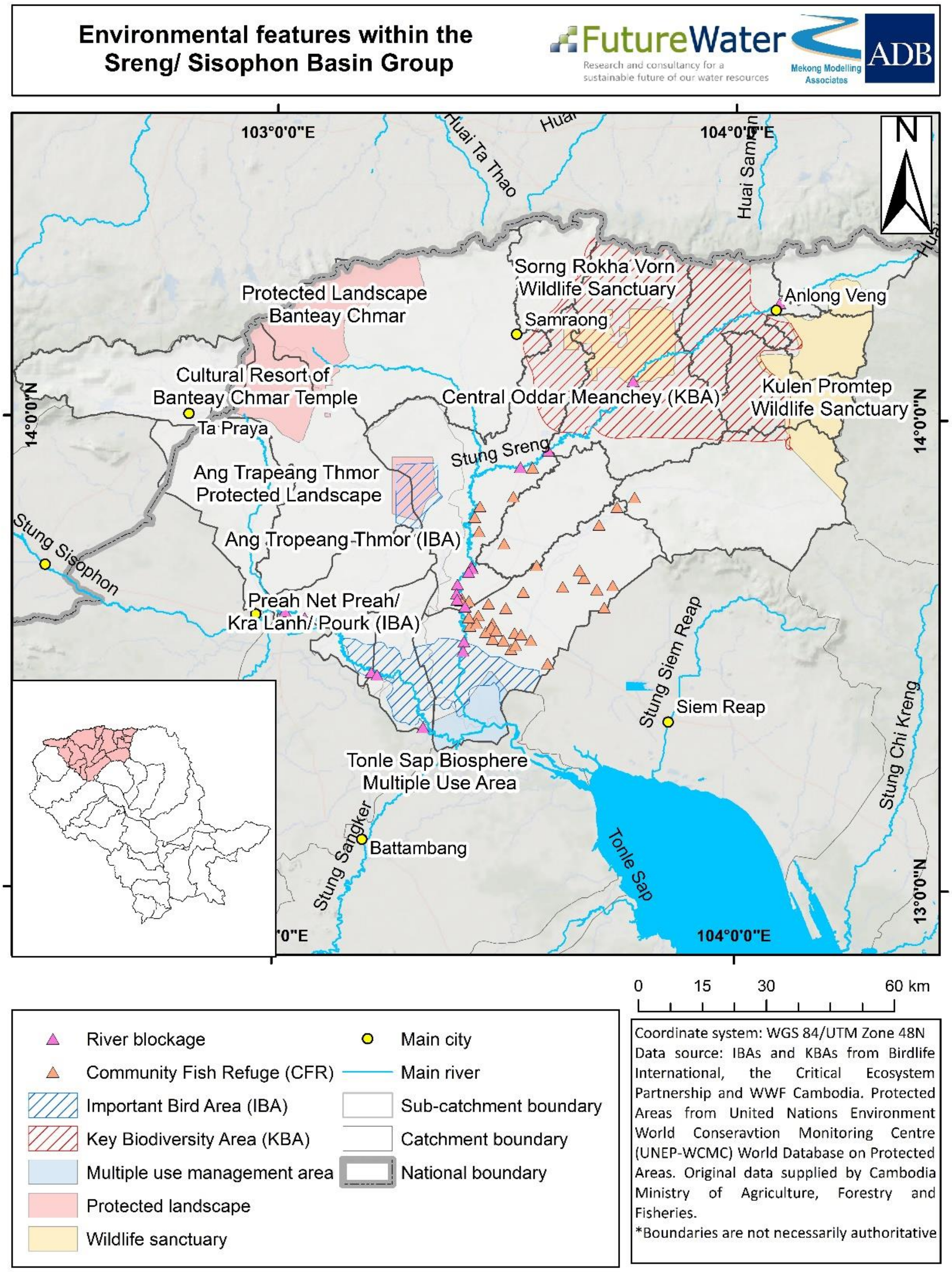


Figure 3-10: Environmental features within the Sreng/ Sisophon Basin Group.

3.2 Water uses

Principal water uses in this basin group are:

- Domestic
- Irrigation
- Environmental (including fisheries)

Recent data has been collected in Phase II on the irrigation areas from the most recent version of the CISIS database. Updated data per catchment in the basin group is presented in Table 3-1, also including population data for each basin. The catchment delineation is the one used in the detailed hydrological modeling (see section 3.6).

Table 3-1: Population and irrigated areas per catchment of the Sreng-Sisophon basin group.

	2016 population			Irrigated Area (ha)				Catchment Area (km^2)
Catchment	Rural	Urban	Total	Dry Season	Dry in Wet	Wet Season	Recession	
Sisophon 1	21,735	39,880	61,615	0	5,309	9,077	5,202	611
Sisophon 2	8,210	6,810	15,020	0	0	0	0	397
Soay Chek 1	696	1,077	1,773	0	0	0	0	830
Soay Chek 2	23,965	40,461	64,426	4	300	21,515	100	785
Soay Chek 3	34,287	52,569	86,856	0	7,013	40,753	5,370	1,299
Sreng 1	33,809	51,725	85,534	0	866	31,140	510	1,427
Sreng 2	36,427	5,207	41,634	0	0	3,383	0	1,435
Sreng 3	32,096	40,290	72,386	0	95	2,850	0	533
Sreng 4	17,646	6,762	24,408	0	0	0	0	496
Sreng 5	16,231	5,649	21,880	0	10	400	0	281
Sreng 6	38,153	17,027	55,180	0	35	185	0	427
Srong 1	55,798	41,475	97,273	0	468	7,940	0	1,958
Srong 2	9,983	24,643	34,626	0	30	1,014	0	399
Tanat 1	55,896	64,897	120,793	0	0	28,410	0	1,414
Tanat 2	16,052	8,561	24,613	0	0	2,052	0	487
Tanat 3	31,633	16,495	48,128	0	0	3,760	0	1,228
Total	432,617	423,528	856,145	4	14,126	152,479	11,182	14,006

Information on the environmental use of water is given in section 3.5.

These data have been used to estimate water demands in the Water Supply and Demand Framework and based on a number of data and assumptions listed in section 3.6. How that translates to water demands is presented in section 3.7.

3.3 Water availability

The source of Stung Sreng is in the Dangrek mountains at the Thai border although there is no significant transboundary area. It then traverses through Oddar Meanchey, Banteay Meanchey and Siem Reap Provinces, eventually joining with Stung Sangker and entering the Great lake. It is the second largest tributary of the Tonle Sap, with a drainage of approximately 9986 km^2. The river has four tributaries (Stung Srang, Stung Sreng, Stung Tanat and Stung Phlang. The Sreng has highly variable wet and dry seasons. Rainfall is temporally and spatially variable and flow is also variable between wet and dry season as well as years. The longer term record of hydrometric monitoring in the catchment and specifically the flow gauging is limited so various estimates of the water resource have been made.

This study uses a SWAT model that gives an annual average water resource that is similar to the Cambodian Water Resource Profile produced also under TA7610 but using other models and methodology. This seems to be significantly lower than the 1994 estimates of the Mekong Secretariat as shown in Table 3-2.

Table 3-2 Annual Yield Estimates for the Sreng basin

Date	Source	Q average	Q50 (m^3/s)	Estimated Annual Water Yield (MCM/y)
1994	Mekong Secretariat Irrigation Rehabilitation Study	145	42	4572
2014	ADB Cambodian Water Resources Profile TA7610			1720
2019	SWAT Model (this study)			1814

The variation in flow for the natural condition (ie not including the impact of existing reservoir storage) is illustrated below. It is noticeable how quickly the catchment responds to rainfall and the very low baseflow that results in negligible flows in the dry season.

Table 3-3 Monthly water availability in the Sreng catchment (1985-2015 average)

	Rainfall (mm)	Water yield (mm)	Water yield (MCM)	Water yield (m^3/s)
January	3	0	2	1
February	6	0	0	0
March	31	0	0	0
April	75	0	1	0
May	144	2	9	3
June	181	16	87	33
July	178	40	212	79
August	209	67	353	132
September	263	99	524	202
October	169	90	476	178
November	42	25	129	50
December	5	4	19	7
Annual total	**1306**	**344**	**1814**	

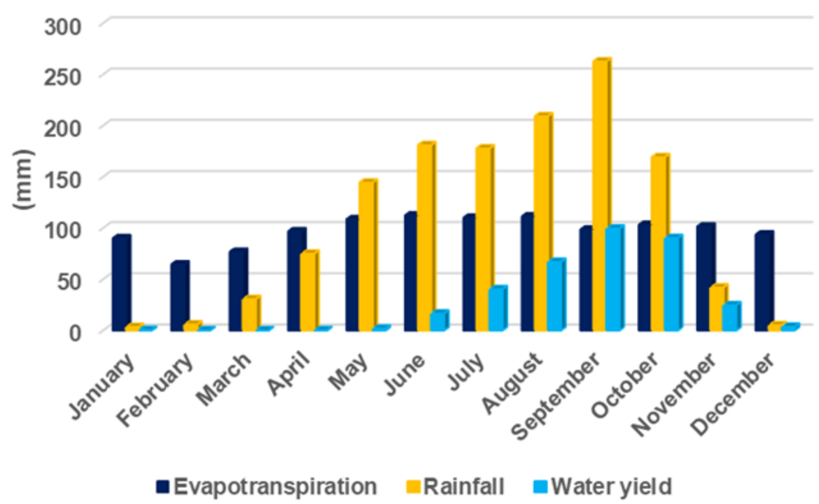


Figure 3-11 Rainfall, Evaporation and Water Yield in the Sreng Catchment

Only the part of the Sisophon that flows to Trapeang Thmar is included in the study. As discussed shown in the contributing catchment to Trapeang Thmar is different during flood and in dry conditions and significantly lower in the dry season than the full 'topographic' catchment. The available flow from the natural catchment into the Trapeang Thmar is thus highly uncertain but likely to be influenced by the other extractions that are included in the WEAP model. A dry season catchment of 656km^2 gave an estimated 430 MCM/y inflow in the Cambodia Surface water profile 2014. For comparison the options of 5m3/s from the existing secondary canal would yield an additional 160MCM/y and an enlarged canal with capacity of 50m3/s as considered in the options modelled would be able to supply 1580 MCM/y if the resource were available.

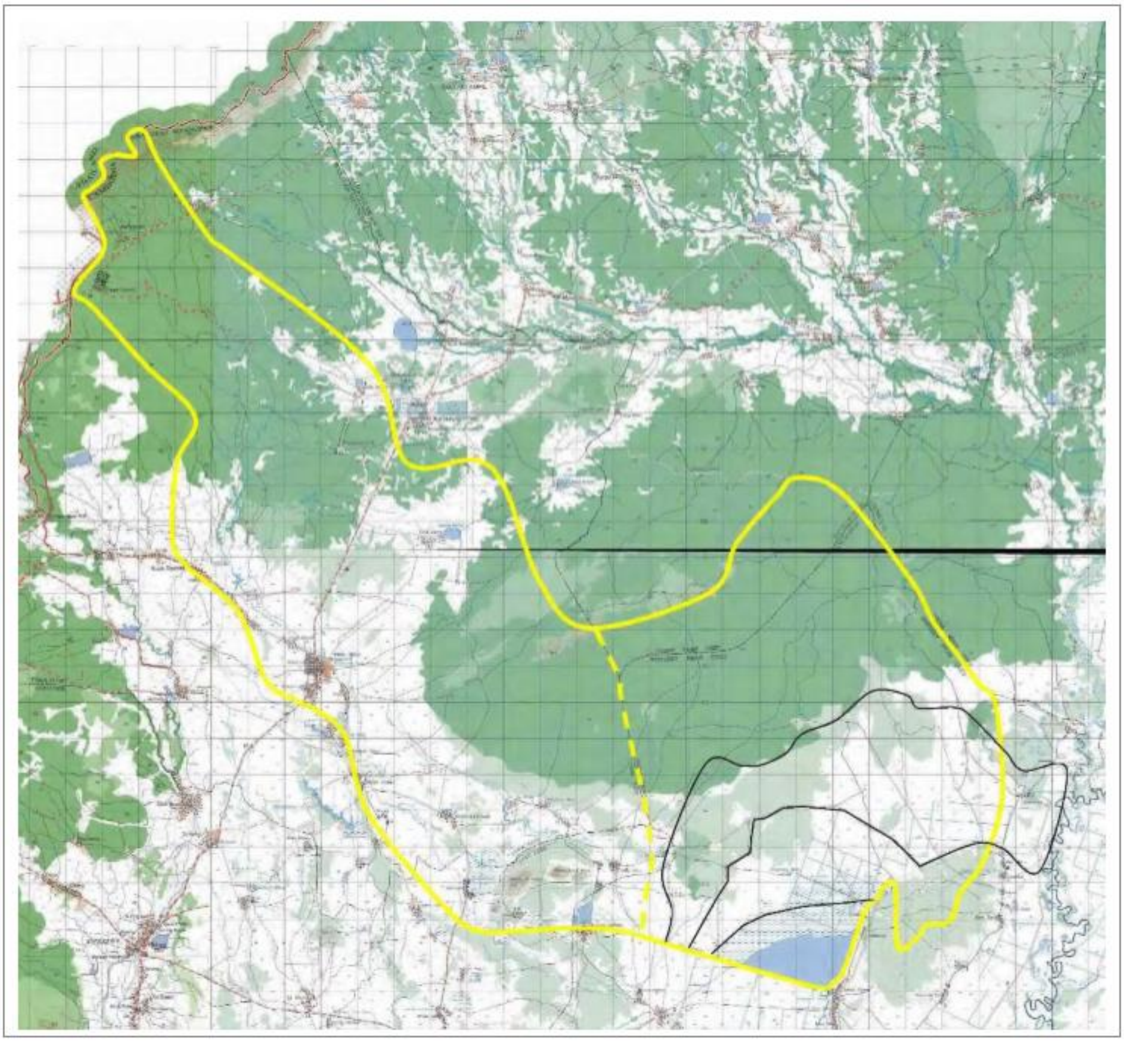


Figure 3-12 Suggested Dry Season Catchment relative to full catchment according to Trapeang Thmor Subproject Profile (ADB 3125-CAM(SF) 2014 Flood Reconstruction).

3.4 Climate risks

Notable climate sensitive developments in this basin group include:

- Irrigation modernization infrastructure
- Agricultural development plans leading to increased water demands
- Planned infrastructures related to the Trapaeng Thmar reservoir
- Any new upstream storage development

An ensemble of climate models was considered to assess of how shifting climate trends may affect future water related interventions. The climate screening analysis has been reported in a separate report. This section summarizes the main outcomes for this basin group.

3.4.1 *Climate projections*

In general, climate model outputs suggest an increase in both precipitation and temperature (Figure 3-13) notably for the further time horizon (2070-2099). These may be summarized as such:

- Increases in temperature range from 0.2 -2.2°C between the years 2020-2049, with little difference in predictions between the two respective RCPs.
- Increases in temperature between 2070-2099 have a much greater range (from 1 - 5.8°C), with greater increases in temperature anticipated by the climate model ensemble for RCP8.5.
- Predictions for changes in precipitation range between a 6% decrease and a 22% increase for the period 2020-2049, with most climate models predicting an increase.
- Increases in precipitation range from 1-24% for the period 2070-2099, with little difference between predictions for each respective RCP.

Overall, it is clear that the model ensemble anticipates a hotter climate in both the near and distant futures and under both RCP scenarios for this basin group. Predictions of precipitation changes are more uncertain, but overall suggest a wetter climate with higher annual precipitation in the future. Local experience however suggests a decline and unfortunately, the longer term hydrometric record in the catchment is not long enough to show which is the correct trend as discussed further below.

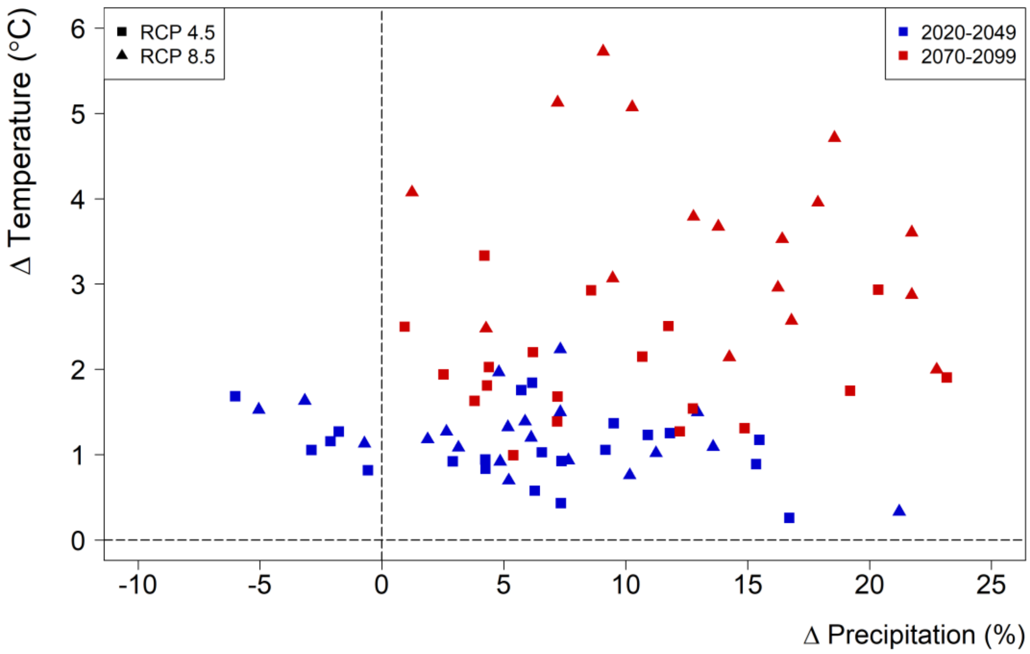


Figure 3-13 Average trends in temperature and precipitation for the Sreng-Sisophon basin group as predicted by the climate models considered in this study.

The indicator Annual Consecutive Dry Days (CDD) as predicted by the climate model ensemble is considered relevant to this water resources assessment as this indicator can be used as a proxy for assessing the impacts of climate change on drought events. Model outputs do not show a clear trend in CDD into the future in that there is a high range in predictions and a high level of overlap between historical and future scenarios for both RCPs (Figure 3-14). A larger range in predictions is evident at the higher RCP scenario and at the 2070-2099 horizon. When the ensemble mean is considered, however, a small increase is predicted in CDD for all RCPs and scenarios besides RCP45 at the 2070-2099 horizon.

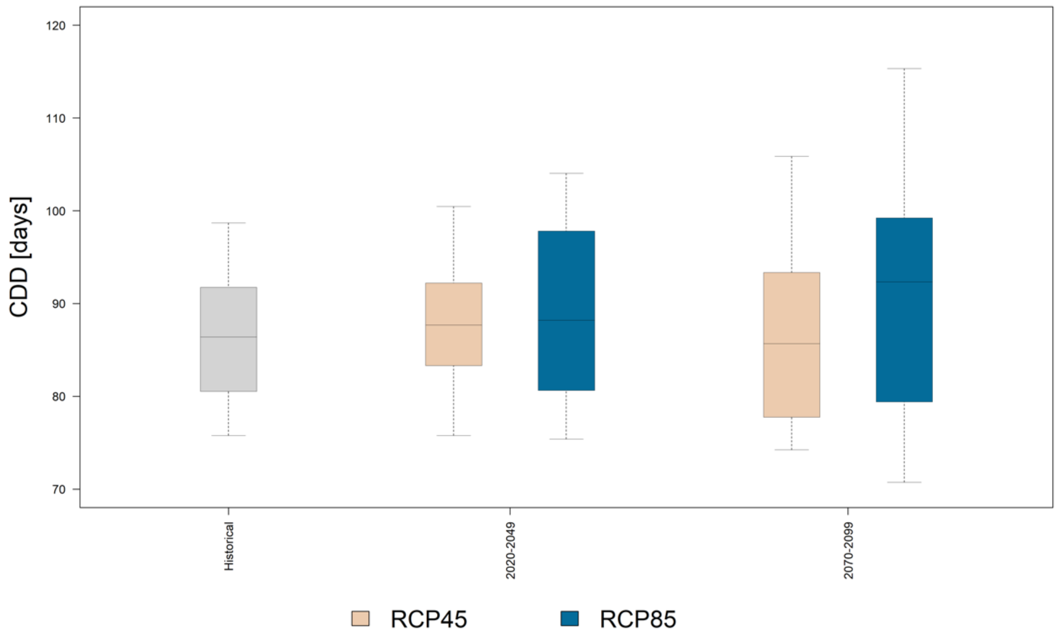


Figure 3-14. Trends in CDD in the Sreng-Sisophoon basin group at both RCP pathways and future time horizons. Variability in box plots indicates the range in predictions between climate models.

3.4.2 *Risks to water availability*

Based on annual rainfall and annual temperature changes, a first-order estimate can be made of how these changes influence annual flows through the basin group. This methodology relates changes in temperature to changes in evapotranspiration using a simple empirical formula (the Hargreaves equation for potential evapotranspiration) to predict future relative changes in evapotranspiration under increasing temperatures. Changes in mean annual flows can subsequently be approximated based on the difference between projected precipitation and evapotranspiration per basin group. These estimates are useful mainly for relative changes, and when comparing a large variety of climate model-outcomes. They allow for an approximation of how uncertainties in climate models regarding temperature and precipitation predictions relate to the uncertainties in water availability (expressed as annual flows).

These calculations indicate that the majority of models predict an increase in average annual flows through this basin group (Figure 3-15). The values related to this are such:

- Climate model ensemble returns a mean predicted increase in annual flow of 11% and 10% for the period 2020-2049 under respective RCP45 and RCP85 pathways
- Climate model ensemble returns a mean predicted increase in annual flow of 27% and 47% for the period 2070-2099 under respective RCP45 and RCP85 pathways

- Assuming variability between climate models and for different RCP pathways is representative of a range of likely future scenarios, the probability that annual flow will increase in this basin group is 63% and 83% for time horizons 2020-2049 and 2070-2099 respectively

Overall, therefore, the climate model ensemble suggests that mean flows are unlikely to be negatively affected by trends in temperature and precipitation induced by climate change, which is in line with other studies in the region. This is by no means certain, however, as other studies in the areas come to opposite conclusions. Indeed, Oeurng et al. (2019) predict decreases in average flows in the Tonle Sap Basin of up to 41% when a different model framework is considered and looking at specific scenarios instead of an ensemble. It is evident that a more detailed climate risk assessment is therefore necessary in this area.

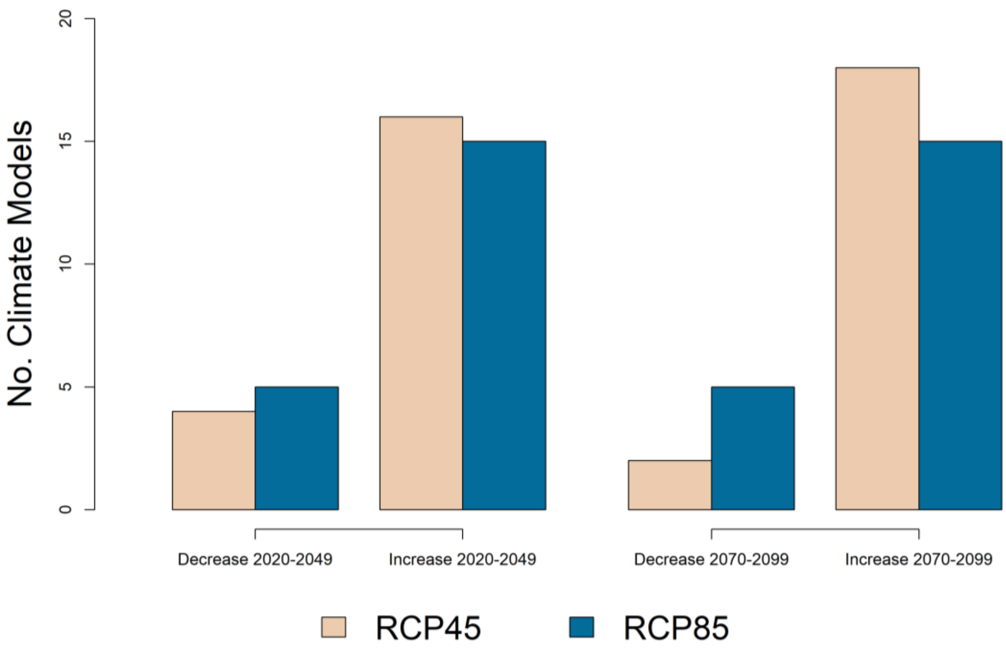


Figure 3-15. Number of models that predict a positive/negative relative changes in mean annual flows for the Sreng-Sisophoon basin group.

Alongside average changes in climate, seasonality should also be a consideration in relation to water availability. It is possible that annual flows may increase on average, but droughts in the dry season may remain a severe problem. To assess this, detailed hydrological modeling is required, which was out of scope of this study. However, the previously assessed indicator CDD gives an impression of changes in the lengths of drought periods (which can be assumed are related to dry season rainfall depths). Model outputs for CDD can be summarized as such:

- 12 out of 20 climate models predict an increase in CDD under the RCP45 scenario between 2020-2049, with 10 out of 20 models predicting an increase under the RCP85 scenario for the same time period
- 10 out of 20 climate models predict an increase in CDD under the RCP45 scenario between 2070-2099, with 12 out of 20 models predicting an increase under the RCP85 scenario for the same time period

- Assuming variability between climate models and for different RCP pathways is representative of a range of likely future scenarios, the probability that CDD will increase in this basin group is 55% for both time horizons (2020-2049 and 2070-2099)

Based on these results, future trends in CDD are clearly highly uncertain, with no clear consensus between models. Increases in the length and severity of drought events due to climate change should not, however, be discounted as this may represent a risk to future water availability. Proposed developments should therefore consider this eventuality.

3.4.3 *Other climate-related risks*

Besides risks to water availability, proposed projects in this basin group may also be affected by other climate-related risks. These include the following:

- Flooding – Longer and more intense periods of precipitation are likely to lead to higher flood risk into the future, especially in the south of the basin group close to the Tonle Sap lake
- Land degradation – Increased intensity of precipitation events is likely to lead to increases in soil erosion, related siltation of storage infra and canals, and may increase the probability of landslides in the basin group
- Extreme heat – maximum annual temperatures are likely to increase under a changing climate, leading to heatwaves and increasing the probability of wildfires

More detailed information on climate related vulnerabilities and risks in relation to this basin group can be found in the associated Climate Risk and Vulnerability study written to accompany this report (FutureWater, 2019).

3.5 Environmental risks identified

The interventions that have been short-listed by MOWRAM are mainly related to the Ang Trapaeng Thmar (ATT) dam. Figure 3-11 lists the protected areas in the catchment, along with land cover. These proposed interventions are likely influence the ATT area, which is also an IBA and an important reserve for Sarus Cranes.

The alignments of the canal(s) and existing reservoirs were investigated for potential impacts on wetlands, bird life and fisheries. However, apart from ATT, no additional wetlands of consequence appear to be affected, only ponds created along dikes (e.g. former borrow pits). The Stung Sreng II reservoir borders to the north on the 30,000 ha Sang Rukhavoan Wildlife Sanctuary that was gazetted in June 2018 (see Annex 1). This reserve, however, consists of mixed deciduous and non-deciduous forest, and secondary open woodland derived from these forests by cutting and clearing; no wetlands are included that could be affected by water resource activities along the Stung Sreng except for the potential for flow alterations to effect downstream habitats, including Prek Toal on the Sangker. The Sreng and Sisophon both join to the Sangker before it flows into Prek Toal and therefore development impacts from the Sreng and Sisophon catchments must also be considered.

Table 3-4: Protected Areas, Important Bird Areas (IBAs) and Key Biodiversity Areas (KBAs) in the Sreng and Sisophon sub-catchments.

Protected Area	Habitat	Area (ha)	Sub-catchment
Sorng Rokha Vorn Wildlife Sanctuary	Deciduous forest	30,254	Stung Sreng
Ang Trapaeng Thmar*	Grassland	12,659	Stung Sisophon
Kulen Promtep Wildlife Sanctuary	Lowland forest and swamp	406,825	Stung Sreng
Banteay Chhmar protected landscape	Forest	8,1897	Stung Sreng
Tonle Sap Man and Biosphere	Seasonally inundated grass/flooded forest/ open water etc.	322,270	All TLS*
IBAs & KBAs			
Central Oddar Meanchey KBA	Forest	N/A	Stung Sreng
Preah net Preah/ Kra Lanh/ Pourk IBA	Seasonally inundated lake side- grassland and flooded forest	69,570	Stung Sreng

* Protected areas are also IBAs

Lower parts of the catchment by the Tonle Sap lake are made up of seasonally inundated grassland and forest according to MRC 2010 landcover dataset. Seasonally inundated forest becomes grassland with distance from the lake. Heading north, landcover mostly consists of rice fields, interspersed with urban (built up) areas, patches of forest and other types of crops. To the north of the catchment, more extensive mixed forest areas exist, including Central Oddar Meanchey KBA and Sorng Rokha Vorn Wildlife Sanctuary, as well as in the east where there is the western edge of Kulen Promtep Wildlife Sanctuary. Much of the landscape is dominated by rice fields, as observed in the field visit.

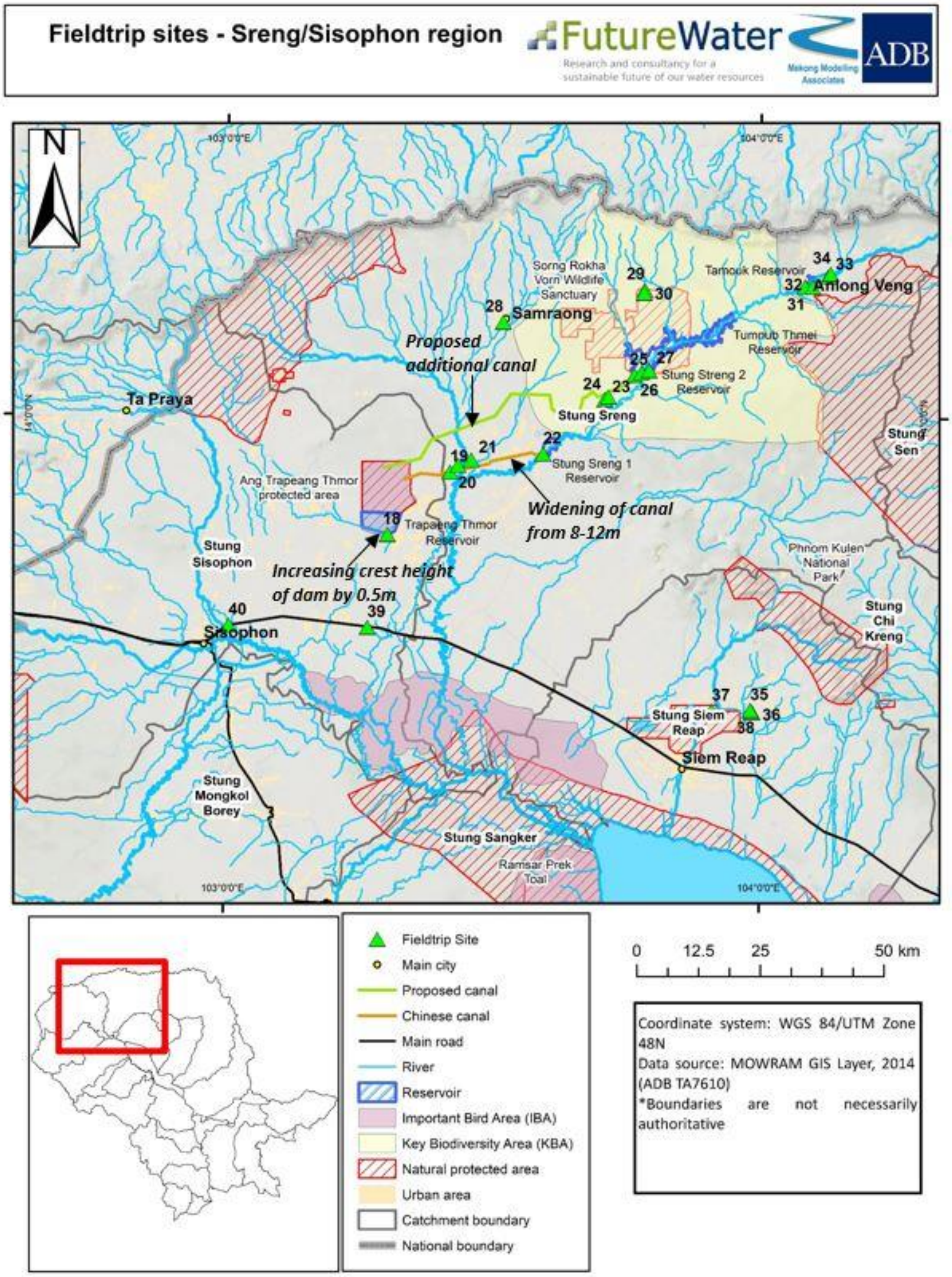


Figure 3-16: Field sites October 2019 - Sreng/ Sisophon region.

3.5.1 *Environmental constraints*

Ang Trapaeng Thmar (ATT) is a protected area and IBA (IBA 1) designated as the ATT Sarus Crane Conservation Area. Its total area is 12,659 ha and it consists of an artificial lake or shallow reservoir, located 70 km to the north-west of the Tonle Sap. Waters are shallow, and in the wet season water depth at the sluice gates is only about 1.5m, while the maximum water depth of the reservoir is only 3m. ATT largely consists of artificial habitats, including open waters/shallow lake, channels, pools and ponds that dot the landscape, often arising due to borrow pits for dike and road construction. In addition, there are vast grasslands with many true grasses but also various sedges, and large areas of rice fields. However, by far the largest part of the northern half has been converted to intensively managed rice fields that yield 2-3 crops per year.

The Sarus crane prefers soggy grasslands, and the main constraints appear to be the rapid drying out of the semi-natural wetlands (soggy grasslands and sedgelands) during March-May, the conversion of most semi-natural grassy wetlands to intensively cropped rice fields, and disturbance due to the intensity of agricultural development. Increasing the inundated area by raising the crest height of the dam will mean that a larger area is seasonally inundated; this may increase habitat for Sarus cranes, but this may be less beneficial if all additional inundated areas are intensively managed rice fields. In addition to lack of wet grass/sedgeland habitat, the avifauna is also potentially affected by the widespread use of herbicides and pesticides.

Neither of the reservoirs Stung Sreng I and II are equipped with fish passes, and while the spillways may at least allow fish to head downstream, a multitude of nets and traps need to be negotiated and this will reduce the likelihood of recruitment. The Stung Sreng II is nearing completion but has been allowed to fill without removal of the woody vegetation beforehand, which is SOP elsewhere as leaving the forest (remnants) leads to eutrophication issues and enhanced carbon emissions that could easily have been prevented.

3.5.2 *Potential impacts on birds*

The wet grasslands of Ang Trapaeng Thmar are important as foraging grounds for a large number of bird species, amongst which the Sarus Cranes, of which non-breeding flocks disperse from their breeding grounds in the north and north-east part of the country. In the southern parts of the Tonle Sap and Mekong river basins damp grassland habitat becomes increasingly fragmented and degraded, whilst numbers of cranes visiting these areas have been decreasing in recent years. This decrease is largely caused by human disturbance of the breeding population, but also the shortening of cranes' visits to these areas due to an earlier drying up of the damp grasslands show that the quality and extent of non-breeding habitat is important, in particular of the larger crane reserves such as ATT.

3.5.3 *Potential impacts on water quality*

As provided in the Rapid Assessment report on ecohydrology, water samples of a few important parameters (including pH, TSS, BOD_5, COD_{mn}, and Cr^{+6}) were collected by Ministry of Environment from the Tonle Sap's tributaries (Stung Sen, Stung Chinit, Stung Siem Reap, Stung Sangke, and Stung Pursat) (see Rapid Assessment report). The observed data indicated that the water quality concentrations for tested parameters in 2018 in the five catchments around the Tonle Sap River and Lake were still below the three thresholds of the MRC's Water Quality Guidelines and Cambodia's Water Quality Standards for public water areas and thus of acceptable or good quality. The COD concentration value (6.22 mg/L) in Stung Sangke, however, slightly exceeded the value of the MRC's Water Quality Guidelines for protection of human health. Based on the MRC's historic data (2000-2016), the high values of the Total Suspended Solids (TSS, ranged from 210 mg/L to 699 mg/L) downstream of Stung Sangke (Bacprea Station) were recorded during the period of 2005-2007, in which the highest one (699 mg/L) was in June 2006 (early wet season).

3.5.4 *Risk mitigation*

The interventions that MOWRAM is considering (see 3.1.2) for ATT will result in more water in the reservoir, increasing its area, but potentially also extending the period during which locations are inundated. From an ecological point of view, maintaining shallow ponds and inundated fields (rather than a deep reservoir) seems vital (e.g. for storks and cranes). Non-breeding Sarus Cranes visit the area outside their breeding period (July – September) during the dry season, when soggy grassland is needed for foraging.

Wet season demand: Less important, as this is when the area is used by waterfowl, but not by endangered and vulnerable species such as cranes and stork; vegetation does not include endangered species.

Dry season demand: To keep the area soggy, input must be > evapotranspiration rates, which hovers around 5-8 mm/day. This means that incoming waters need to be equal to evapotranspiration (5-8mm/day), which given the area (12,659 ha) means an inflow of 7.3-11.7 m^3/s. This may not be needed for the entire dry season but is likely to be more important towards the end of the dry season (March-April) when food becomes scarce. It is noted that the inundated area will increase in size due to raising of the crest from 1.0 to 1.5m. This means that a substantially larger area (than the 12,659ha) will be flooded at times, although most of the increase will be from flooding of additional rice fields.

3.6 Model setup

For the Sreng River Basin Group it was decided given the complexity in water supply and demand topics in Sreng to build the Water Supply and Demand Framework using WEAP (see previous Chapter for details regarding this approach). Some of the characteristics of the developed WSDF are:

- The inflow into the rivers and streams were obtained from the SWAT model. The simulated flows do not consider the influence of reservoirs, withdrawals and return flows.
- Irrigation demands have been calculated dynamically using the catchment nodes approach from WEAP combined with the advanced soil-moisture module. Withdrawals storage, and returnflows are calculated in WEAP.
- A timestep of one week (7 days) was used
- To introduce annual and weekly variation climate data from 20 years (1996-2015) have been used. For future scenarios the same climate variability was assumed, as the climate risk analysis showed that annual flows are likely to increase in this area, while there is not a clear trend in the drought (dry period) characteristic that was studied.
- A two years warming up period was used to ensure that the model was in equilibrium when starting the actual analysis.
- Input and output analysis were done by a combination of direct results from the model as well as using a set of excel VBA scripts.
- A total of 12 domestic water nodes were implemented and urban water requirements were set at 160 liters per person per capita (PPWSA, 2010). For rural water consumption 90 liter per person per capita was considered (Mekong River Commission, 2017).
- Irrigation demand areas were combined into 7 nodes. For each node four seasons were considered (see section 2.2.5 for details). The actual water demand is calculated by the WEAP model using the following principle. Crop water requirements are calculated by the Penman-Monteith approach considering climate data (e.g. temperature, windspeed, humidity, sun-shine hours). If sufficient water is ponded or available in the soil, actual water supply demand is zero. In case ponding is low and soil water is below a set

threshold value, water demand is calculated. This water demand is further refined by losses and reuse of water and the result is the so-called supply requirement. In case sufficient water is available in streams and reservoirs, this will be released and allocated.

- In case of shortages the water is rationed given a pre-defined priority. For the reference scenario, all sectoral demands (irrigation, domestic and environment) are given equal priority. For the future scenarios, a higher priority is given to domestic use.

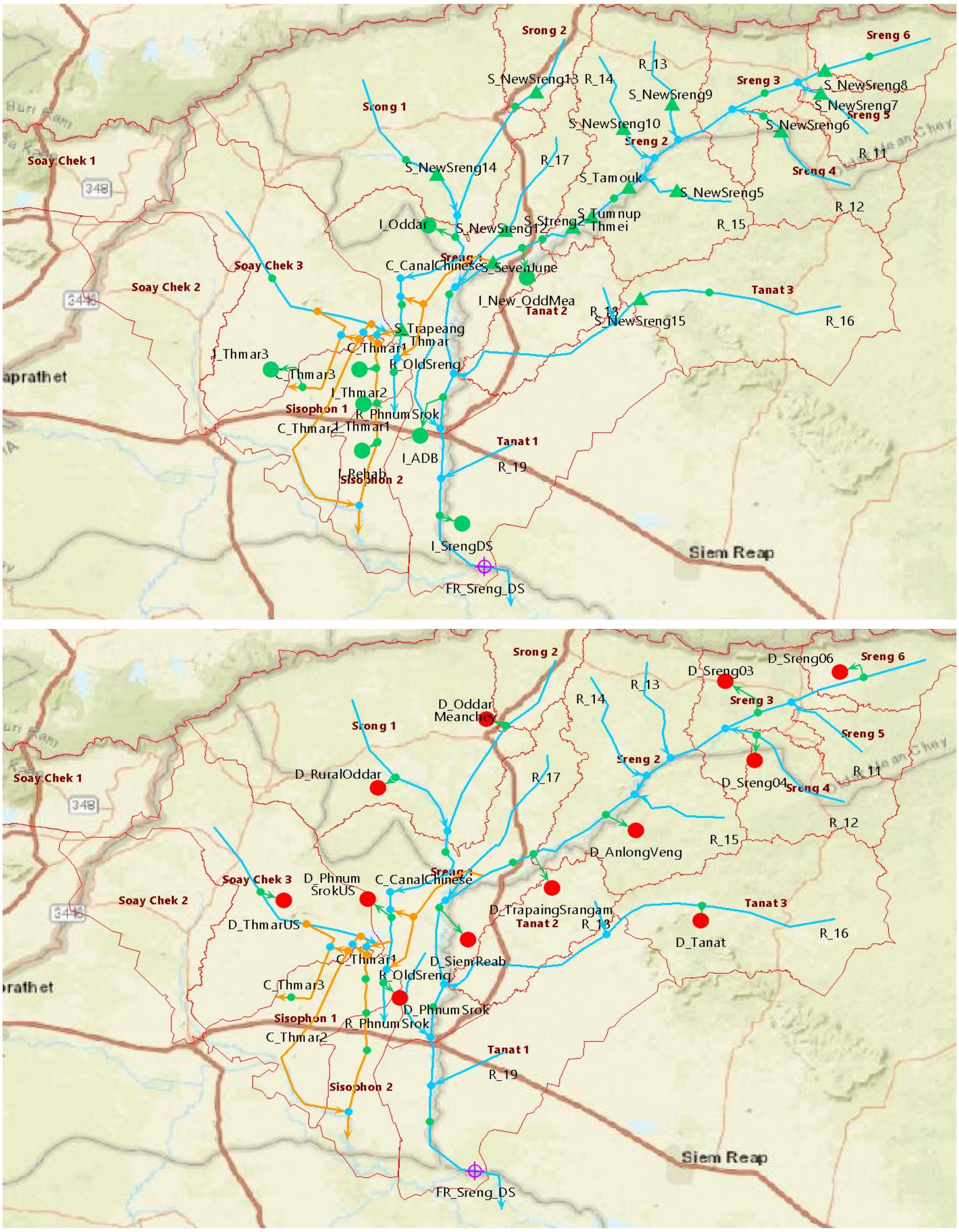


Figure 3-17: Schematic of the Water Supply and Demand Framework in WEAP for the Sreng Basin Group. Upper: all domestic demand nodes. Down: all irrigation demand nodes

3.7 Water balance evaluation

By using the Water Demand and Supply Framework as implemented in WEAP and discussed in the previous sections the current situation (reference, baseline) has been evaluated. Figure 3-18 shows the water balance for the Sreng Basin Group. Quite some variation exists between years with 2013 high rainfall and high water yields and 1998 and 2015 as very dry years. As keen been seen roughly 50% of the available water is used for crops (ETact) and 50% flows into the Tonle Sap. Domestic consumption is relatively small.

Table 3-5 shows for the irrigated areas the various components of the water demand, supply and coverage. The precipitation is the total rainfall that the irrigated areas receive: WEAP uses the soil moisture module to calculate the effective rainfall that is actually consumed by the crop. Crop water requirements and irrigation demands varies substantially between the irrigated areas mainly as a result of different areas cropped. Climate varies only to a smaller extent in the river basin group. The irrigation shortages and the coverage (expressed as water shortage over water demand) varies substantially between the different areas. Especially the more downstream areas have a much lower coverage and a larger water shortage.

Domestic demands, supplies and coverage are shown in Table 3-6. There is quite some variation between the domestic water demands as population differs between each area. Overall domestic coverage is around 69% so quite some of the population suffers from water shortages. Interesting is also to note that the entire water demand for domestic use of about 49 million cubic meter per year is an order of magnitude smaller compared to the water demand for irrigation (912 million cubic meter). For the reference scenario, presented here, all sectors are equally prioritized in case water shortages appear and water must be rationed across the various demand nodes. For future scenarios (see next section), priority is given to domestic. In the next section, also the seasonal coverage/shortage is presented, see Figure 3-18.

Environmental flows have been evaluated at the downstream point of Stung Sreng (Figure 3-19 and Figure 3-20). The figures indicate that the river falls completely dry in about 40% of the days. Flows below 1 $m^3 s^{-1}$ occurs in 52% of the days and flows below 2 $m^3 s^{-1}$ in 59% of the days. Section 3.5 has summarized the environmental risks related to these water shortages.

The Water Supply and Demand Framework provides a huge amount of supporting data. The model itself is attached to the report and can be used as reference in case additional output are needed to be analyzed. Figure 3-21 and Figure 3-22 provide examples of those detailed results from the WSDF.

In summary it can be concluded that for the Sreng River Basin Group in general water resources are sufficient over a full year, but at the same time water shortages are quite severe in the dry season. This means that by tailored investments improvements must be possible. The next sections will explore various of those investment options and the impact on water demand and supply.

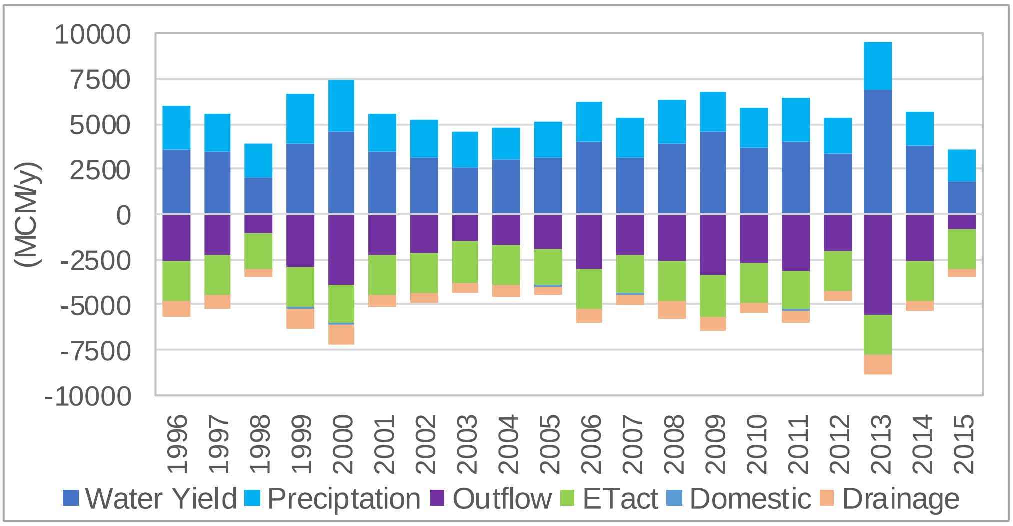


Figure 3-18: Overall water balance for Stung Sreng as evaluated using the combined SWAT-WEAP analysis. Water Yield is the runoff from the catchments in the rivers and streams; Precipitation is only the precipitation on the irrigated areas; Outflow is into Tonle Sap; ETact is water consumed by irrigated crops; Domestic is water consumed for the domestic sector; and Drainage is outflow from irrigated sector that are not further used.

Table 3-5: Results of the Water Supply and Demand Analysis for the irrigation schemes. Annual averages over a period of 20 years (1996-2015) are shown.

	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
I_ADB	472	574	486	196	178	18	91%
I_Oddar	112	154	119	59	37	21	64%
I_Rehab	248	310	200	74	41	33	55%
I_SrengDS	420	512	439	179	163	16	91%
I_Thmar1	138	180	142	67	41	26	62%
I_Thmar2	144	187	147	68	45	24	65%
I_Thmar3	692	870	640	268	158	110	59%
TOTAL	2491	2788	2,173	912	664	248	73%

Table 3-6: Results of the Water Supply and Demand Analysis for the domestic water requirements. Annual averages over a period of 20 years (1996-2015) are shown.

	Water Demand (MCM/y)	Supply Required (MCM/y)	Supply Delivered (MCM/y)	Coverage (%)
D_AnlongVeng	1.501	1.876	1.859	99%
D_OddarMeanchey	1.767	2.209	1.035	47%
D_PhnumSrok	3.710	4.638	4.618	100%
D_PhnumSrokUS	0.826	1.033	0.485	47%
D_RuralOddar	4.255	5.319	2.493	47%
D_SiemReab	8.931	11.164	11.113	100%
D_Sreng03	4.270	5.338	3.032	57%
D_Sreng04	0.975	1.218	0.762	63%
D_Sreng06	2.248	2.810	1.596	57%
D_Tanat	2.002	2.503	1.769	71%
D_ThmarUS	7.432	9.290	3.607	39%
D_TrapaingSrangam	1.027	1.284	1.278	100%
TOTAL	38.946	48.682	33.648	69%

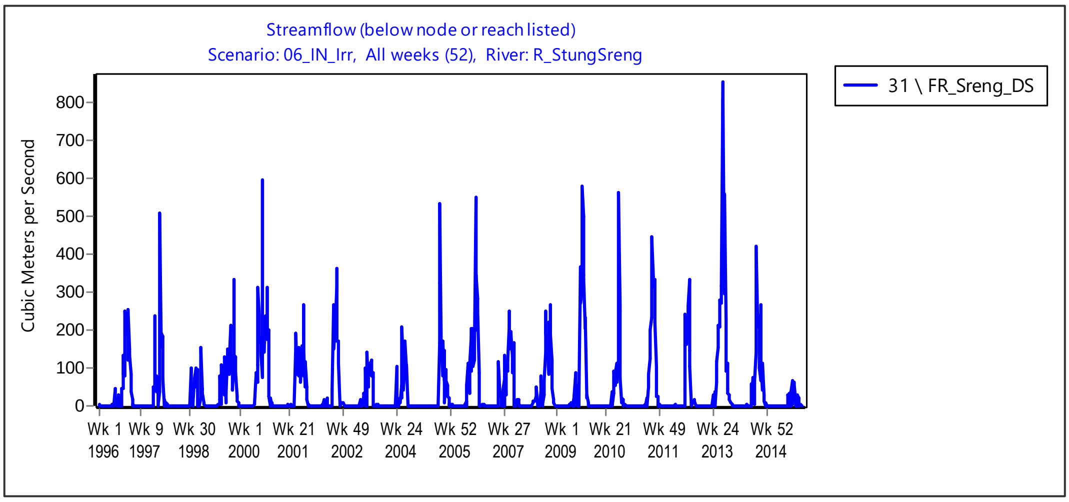


Figure 3-19: Environmental streamflow requirements presented as weekly flows over a period of 20 years downstream at Stung Sreng.

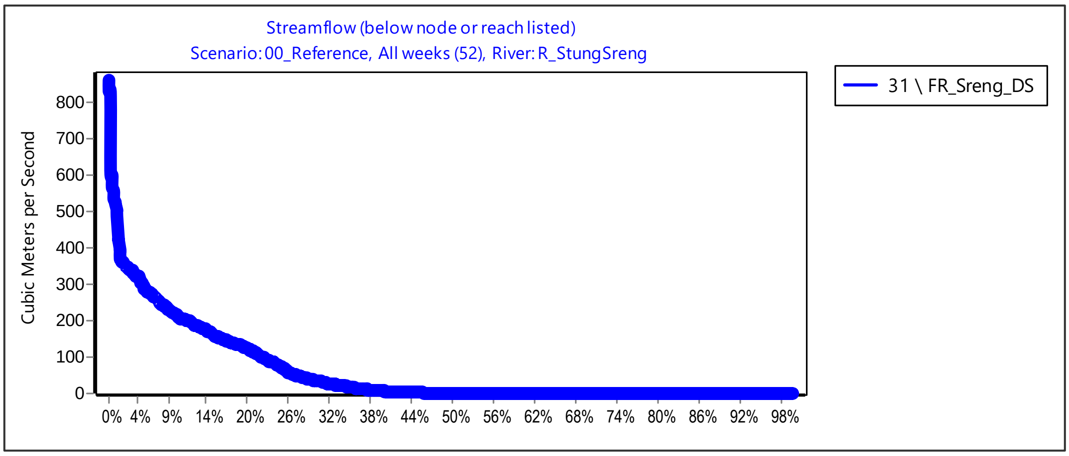
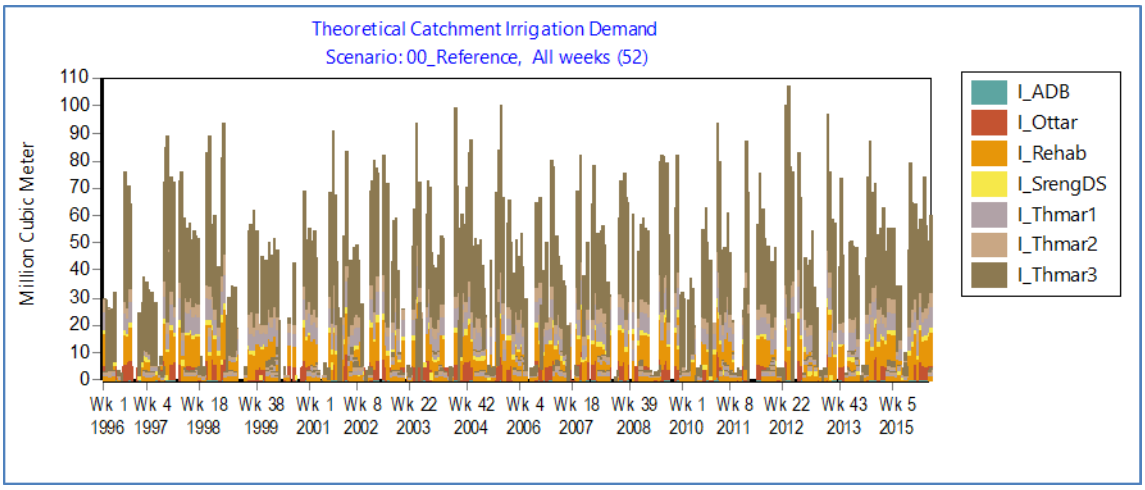


Figure 3-20: Environmental streamflow requirements presented as weekly exceedance levels based on a period of 20 years downstream at Stung Sreng.



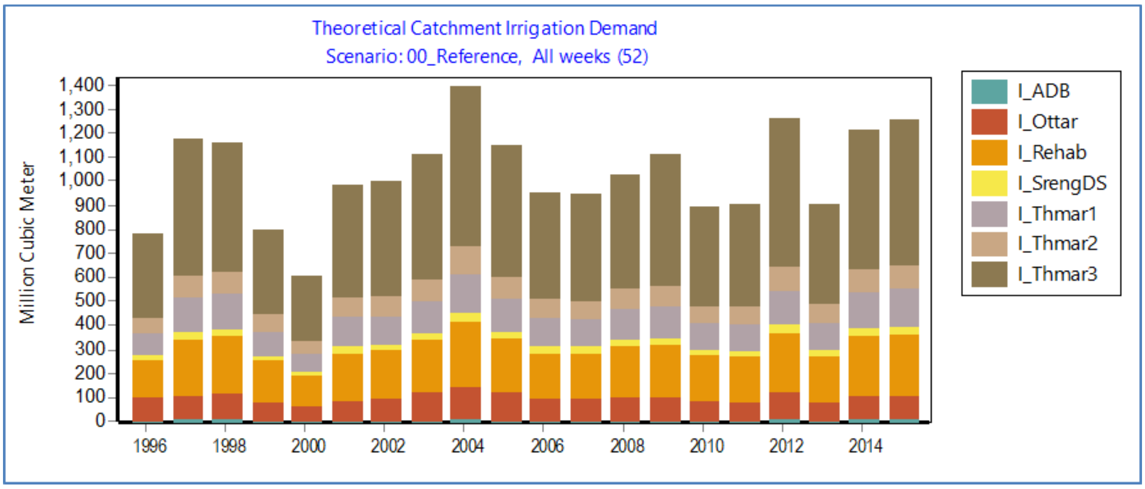


Figure 3-21: Example of output provided by the Water Supply and Demand Framework as implemented in WEAP: Irrigation Demand weekly (top) and annually (bottom).

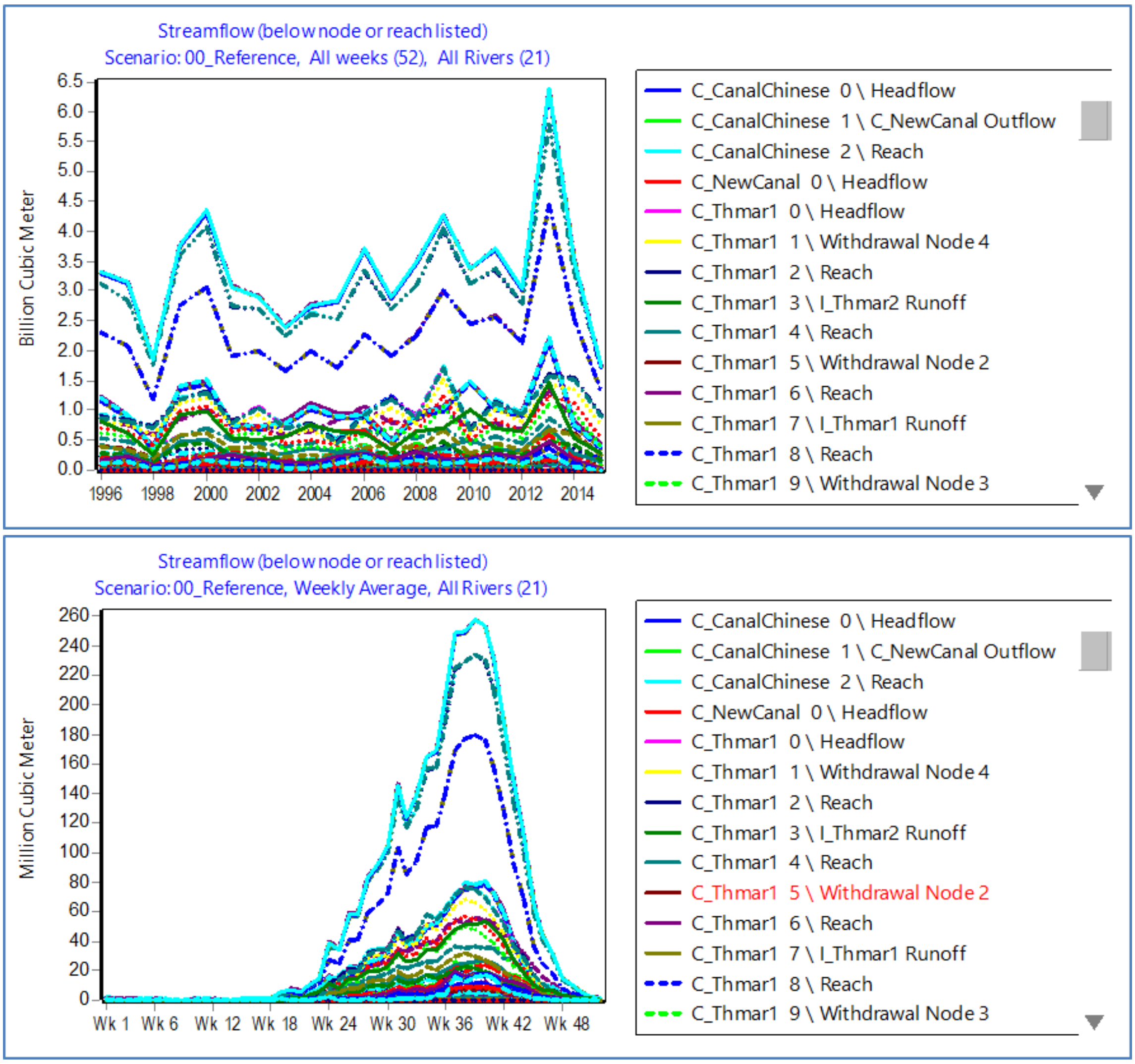


Figure 3-22: Example of output provided by the Water Supply and Demand Framework as implemented in WEAP: River flows annual (top) and monthly averages (bottom).

3.8 Scenario analysis

A set of potential investment scenarios to enhance crop production and to improve water security to all sectors have been explored. Those investment scenarios have been developed based on inputs received from MOWRAM during the field visits and meetings. It should be emphasized that the current study is an appraisal study and that based on these results more focused feasibility, pre-design and design evaluations are required.

For the Sreng River Basin Group a set of potential investment scenarios were explored using the Water Supply and Demand Framework as implemented using WEAP. Those scenarios exist of a combination of so-called water allocation options (A to D) and infrastructure investment options (E to L) as described below. Various combinations of those measures were integrated in the actual scenarios explored.

3.8.1 *Description of water allocation and irrigation system development options*

A: **Rational priorities during water shortage periods**
Highest priority 1 is given to domestic water use then priority 2 for environment and also priority 2 for irrigation

B: **Modernization of irrigation systems**
Losses in irrigation canals will be reduced from the currently assumed 25% to 10% and the reuse of runoff and drainage from irrigated areas will increase from 25% to 50%.

C: **Rice intensification**
An intensified cropping pattern, as proposed in the current National Irrigation Strategy. Double cropping is practiced assuming that 100% is cropped during wet season, 50% during the recession season, and 50% in the dry-wet (early wet) season. Thus, this aims for a cropping intensity of 200%.

D: **Diversification and intensification**
An intensified cropping pattern, as proposed in the current National Irrigation Strategy, but including also crop diversification. Same as previous scenario, but outside the wet season, the crop mix is 70% rice, and 30% vegetables.

3.8.2 *Description of infrastructure investment options*

For a map with current and planned infrastructure, please see Annex 5

E: **Sreng to Trapaeng Thmar current**
Infrastructure is implemented to enable the link from Sreng to Trapaeng Thmar through the existing Chinese canal, with its current capacity, approximately to be 5 $m^3 s^{-1}$ assumed in the dry season. If required to fill the reservoir capacity, 25 $m^3 s^{-1}$ is assumed in the wet season as the full main canal capacity may be utilized when demand is low elsewhere.

F: **Sreng to Trapaeng Thmar extended**
Capacity of the inter-basin transfer through a new Canal will be 50 $m^3 s^{-1}$.

G: **Irrigation expansion in Oddar Meanchey**
Irrigated area in the Oddar Meanchey province will be expanded, adding a total of 20,000 ha newly irrigated area. In the new areas, a crop mix is assumed, outside the wet season, that includes 30% vegetables.

H: **Increased reservoir capacity upstream**
To increase water availability in the dry season, new reservoirs will be developed upstream of the Tamouk reservoir, adding 250 MCM.

I: **Increased capacity Trapaeng Thmar**
Increased storage capacity of Trapaeng Thmar by 100% is evaluated

3.8.3 *Description of scenarios*

Table 3-7 presents the combination of the previously described investment options in a number of scenarios. The first set of scenarios (1-3) is based purely on the water allocation options. The second set of scenarios (4-6) is based on a combination of both water allocation as well as infrastructure investment options.

Table 3-7. The six scenarios explored for Sreng/Sisopon, and their associated water allocation and infrastructure investment options.

Scenarios	Water allocation options				Infrastructure investment options				
	A	B	C	D	E	F	G	H	I
00_Reference									
01_Priority Operations for domestic supply + Irrigation Modernisation	X	X							
02_Modernisation and Intensification to 200% for rice	X	X	X						
03_Priority, Modernisation+ Dry season Crop Diversification	X	X		X					
04_Trapeang Thmar Capacity Increase and Link canal to Sreng	X	X		X	X				X
05_As 4 with Irrigation Expansion in Oddar Meanchey	X	X		X		X	X		
06_As 5 with additional Sreng Reservoirs	X	X		X		X	X	X	X

The scenarios are briefly described here below.

01: **Modernization** (*01_Mod)*
This scenario explores the impact if losses in irrigation canals will be reduced from the currently assumed 25% to 10% and the reuse of runoff and drainage from irrigated areas will increase from 25% to 50%. Also, in case of water shortage, irrigation will get lower priority.

02: **Modernization combined with rice intensification** (*02_Mod_Int)*
Under this scenario also modernization and priority for allocation are the same as the previous scenario. On top of this a double cropping system is considered for rice.

03: **Modernization combined with rice intensification and diversification** (*03_Mod_Int_Div)*
Under this scenario also modernization and priority for allocation are the same as first scenario (*01_Mod*) the previous scenario. On top of this a double cropping system is considered but, in this case, this double cropping is not only rice, but in 30% of the area vegetable are assumed to grow.

04: **Additional infrastructure** (*04_Infr)*
The impact of doubling the capacity of Trapaeng Thmar and establishing the link from Sreng to Trapaeng Thmar are the options of this scenario.

05: **Irrigation expansion in Oddar Meanchey** (*05_Mea*)
Under this scenario it is assumed that the irrigated area in the Oddar Meanchey basin will be expanded to a total of 20,000 ha.

06: **Raising the capacity of Trapaeng Thmar** (*06_Mea_Infr*)

This scenario is based on the previous one (irrigation expansion in Oddar Meanchey) and includes as well additional reservoir capacity.

3.8.4 *Results: impacts on irrigation*

The six investment scenarios as described in the previous section were implemented in the Water Supply and Demand Framework as implemented in WEAP.

Table 3-8 provides a summary of the key results summarized for all irrigated areas in the river basin group. The table includes a summary of the

- Annual results
- Wet season results (week 24 – week 45)
- Dry season results (week 46 – week 23)

The most silent details are:

- **Precipitation** amount varies according to the cropped area of each of the scenarios. Obviously also quite some variation exists between years but here only averages are given.
- **Crop water requirements** (ET Potential) is the actual amount of water required by the crop, without considering any losses. Variation between the scenarios can be explained by the different irrigated areas considered and cropping patterns. Under all scenarios (except (*01_Mod*) crop water requirements are substantial higher because of the double cropping that was assumed. For two scenarios (*05_Mea* and *06_Mea_Infr*) it was assumed that an additional area of 20,000 ha will be irrigated. The difference between the Intensification (*02_Mod_Int*) and the combined intensification and diversification (*03_Mod_Int_Div*) shows that the crop water requirement is somewhat lower for the latter (less paddy rice). Also, the irrigation requirements are slightly lower in case of diversification.
- The amount of **actual crop water consumption** (ET Actual) shows quite some variation between the scenarios. Overall, whatever scenario will be selected more water is consumed by the crops compared to the baseline (*00_Reference*). This consumed water is considered as beneficial since it produces crop. As a very first rough estimate by using the water productivity of 0.72 kg m^{-3} as reported by (2019, Foley et al.) a rough estimate of crop production can be calculated. Looking at the individual scenarios, the following conclusions can be drawn:
    - *01_Mod*: The expected increase in crop water consumption (and therefore the amount of crop produced) is relatively small compared to the Reference. Although irrigation shortages decrease and coverage increase from 64% to 70% the overall benefits are relatively low. The main reason is that still most of the water consumed is coming from direct rainfall.
    - *02_Mod_Int*: Water demand and actual water consumption increases substantially by the expansion of the agricultural area (double cropping). Although the coverage is lower compared to the previous scenario and the irrigation shortages higher, total crop production (expressed as the ET Actual) can be expected to be higher. In other words, individual farmers will experience more water shortage, but production of the entire basin group will increase.
    - *03_Mod_Int_Dev*: Results for this scenario show the same trends as the previous one: water demand and actual water consumption increases substantially by the expansion of the agricultural area (double cropping).

Irrigation shortages decrease slightly compared to the previous scenario because consumptive use of water of vegetables is slightly lower than of rice.

- *04_Infr*: Increased storage and additional water for Trapaeng Thmar causes a slight increase in irrigation supply, crop water consumption, and thus a slightly increase in crop production. Irrigation shortage is only slightly lower though compared to the previous scenario.
- *05_Mea*: Expanding the in Oddar Meanchey area with 20,000 ha increases irrigation demand substantially. Potential crop production and the actual crops produced (ET Actual) increases by about 10%. Although additional water can flow to Trapaeng Thmar, irrigation shortage is high as storage capacity is not sufficient to supply the systems with sufficient water.
- *06_Mea_Infr*: The last scenario evaluated is based on the previous one, but additional reservoir storage capacity is considered as well. In this case, overall annual coverage goes up to values close to the reference scenario (59%), while sustaining considerably more crop production (crop water consumption is almost twice as high). For the dry season, this scenario shows the highest coverage of all scenarios including the reference scenario. This shows the effect of the storage infrastructure, buffering wet season-water for the dry season.

Irrigation shortage and **coverage** for this basin group is overall relatively low. Obviously, most of the water shortage occurs in the dry season. This becomes especially clear when looking at Figure 3-23 to Figure 3-25: these figures show the irrigation supplied and irrigation shortage together (note: the sum of both is equal to irrigation demand). It becomes clear from these figures that cropping intensification will lead to a drastic increase of irrigation shortage in the dry season. Clearly, the level of intensification as assessed here (leading to a doubling of irrigated area) is not feasible. However, part of this can be mitigated in the highest investment scenario with additional reservoir storage options (*06_Mea_Infr*) which is most effective in getting the highest coverage (water supplied over water demand).

Table 3-8. Results of the Water Supply and Demand Analysis for the six scenarios explored. Results reflect annual averages over a period of 20 years using climate conditions from 1996-2015.

Annual Scenario	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
00_Reference	2225	2788	2201	1091	696	395	64%
01_Mod	2225	2788	2234	1091	762	329	70%
02_Mod_Int	4124	5014	3609	2433	1108	1325	46%
03_Mod_Int_Div	4124	4752	3524	2254	1086	1168	48%
04_Infr	4124	4752	3586	2254	1167	1087	52%
05_Mea	4655	5346	3932	2399	1164	1235	49%
06_Mea_Infr	4655	5346	4124	2398	1416	982	59%

Wet Season Scenario	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
00_Reference	1505	1890	1645	905	647	258	72%
01_Mod	1505	1890	1664	904	704	201	78%
02_Mod_Int	2789	2571	2201	1108	754	355	68%
03_Mod_Int_Div	2789	2490	2152	1068	745	323	70%
04_Infr	2789	2490	2172	1067	798	270	75%
05_Mea	3146	2812	2426	1181	830	351	70%
06_Mea_Infr	3146	2812	2447	1181	885	296	75%

Dry Season Scenario	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
00_Reference	720	898	556	186	49	137	26%
01_Mod	720	898	571	186	58	128	31%
02_Mod_Int	1335	2443	1409	1324	354	970	27%
03_Mod_Int_Div	1335	2262	1372	1186	341	845	29%
04_Infr	1335	2262	1413	1186	369	817	31%
05_Mea	1509	2535	1506	1217	334	884	27%
06_Mea_Infr	1509	2535	1677	1217	531	686	44%

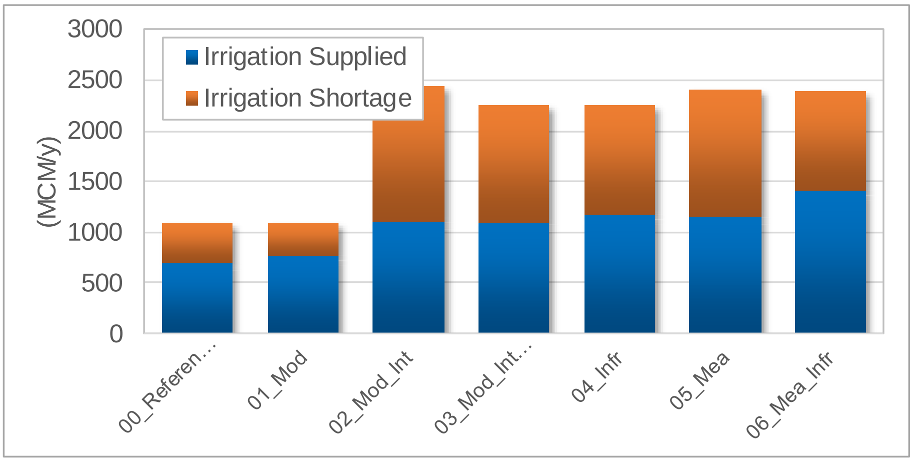


Figure 3-23: Irrigation supplied and irrigation shortages for the six investment scenarios (and reference). Note that total irrigation demand is just the total of supply and shortage. Results are based on 20 years averages.

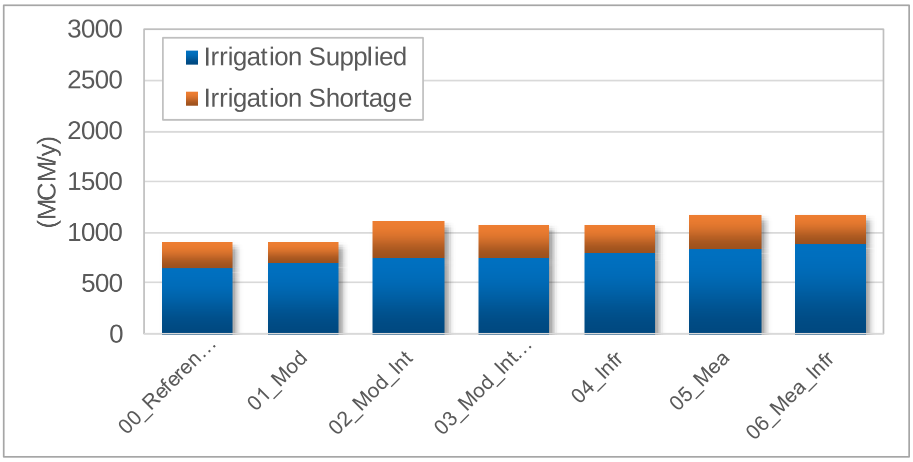


Figure 3-24: Same as above, but for wet season only.

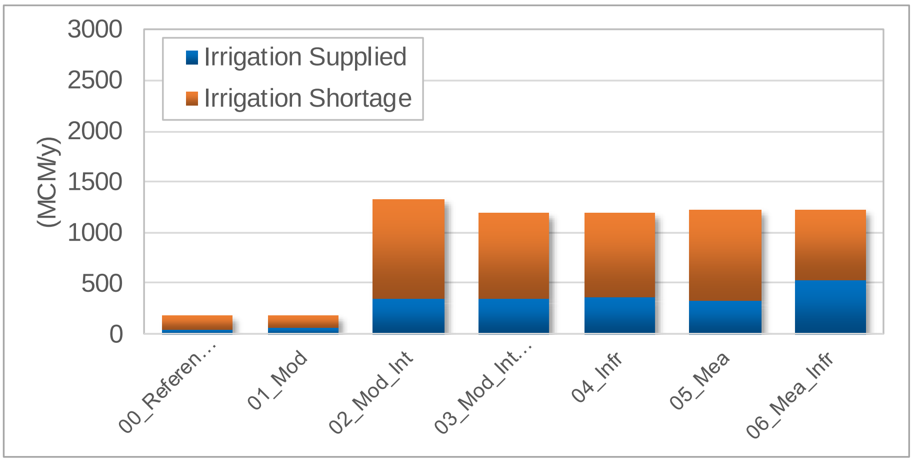


Figure 3-25: Same as above, but for dry season only.

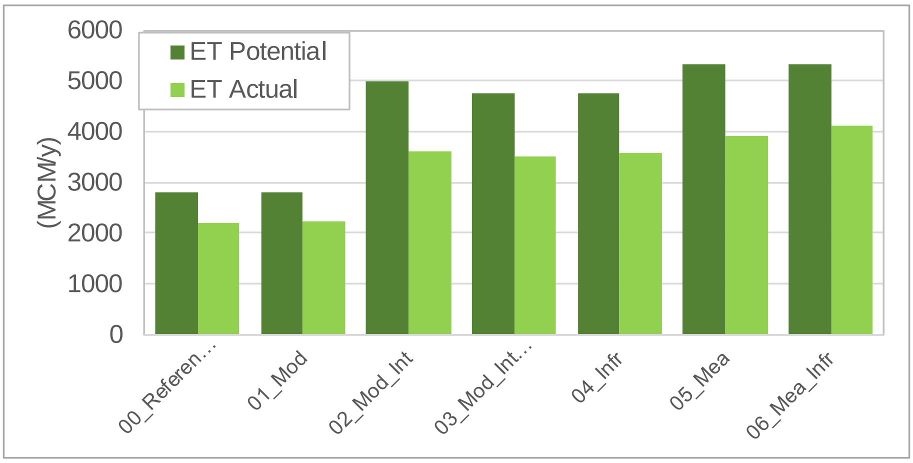


Figure 3-26: Potential crop water consumption and actual crop water use for the six investment scenarios (and reference). Results are based on 20 years averages.

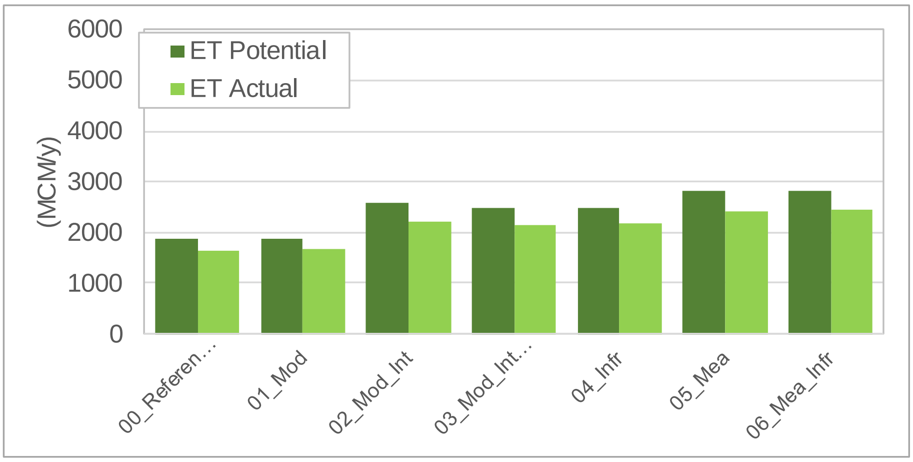


Figure 3-27: Same as above, but for wet season only.

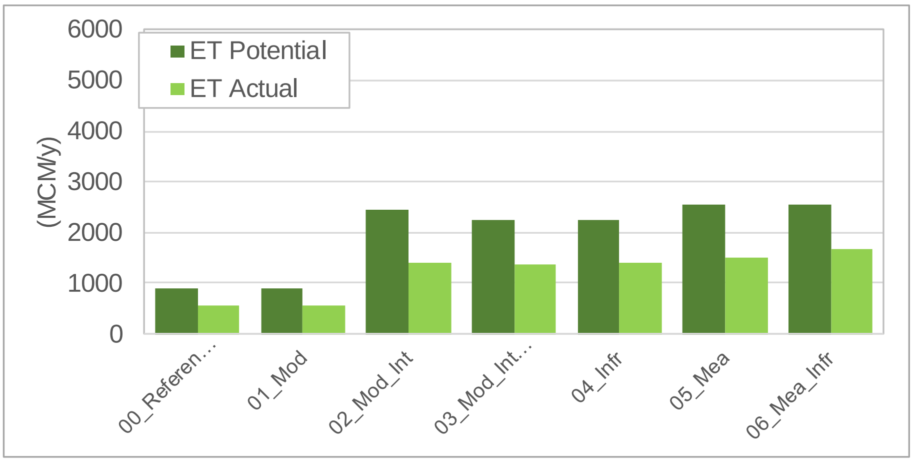


Figure 3-28: Same as above, but for dry season only.

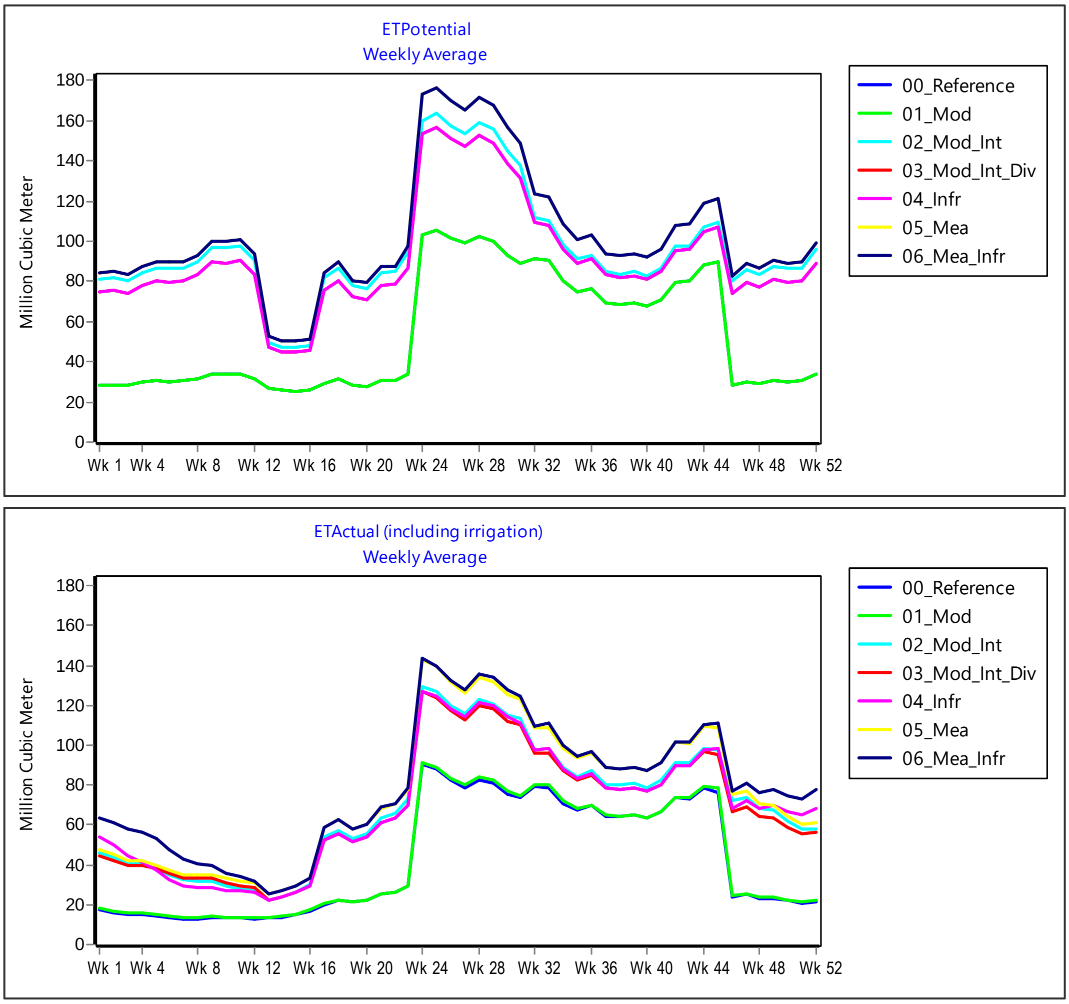


Figure 3-29: Average weekly crop water consumption (top) and crop water shortage for the six scenarios considered.

<u>Further exploring Diversification</u>

As discussed above, diversification as considered in the scenarios above causes a relatively small impact. Main reason is that only 30% of the area grown outside the wet season was considered to be vegetables. To explore a more drastic diversification strategy an additional scenario has been included assuming that 100% of the crops outside the wet season would be vegetables. Table 3-9 shows the impact of this additional scenario *(03b_Mod_Int_Div)*. In this case, irrigation shortage is decreased considerably, by more than half compared to intensification scenario with only rice.

Table 3-9. Results of an additional explorative scenario assessing impact of intensification and diversification to at 100% vegetables outside the wet season

Annual Scenario	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
00_Reference	2225	2788	2201	1091	696	395	64%
01_Mod	2225	2788	2234	1091	762	329	70%
02_Mod_Int	4124	5014	3609	2433	1108	1325	46%
03_Mod_Int_Div	4124	4752	3524	2254	1086	1168	48%
03b_Mod_Int_Div	4124	3968	3194	1682	1005	677	60%

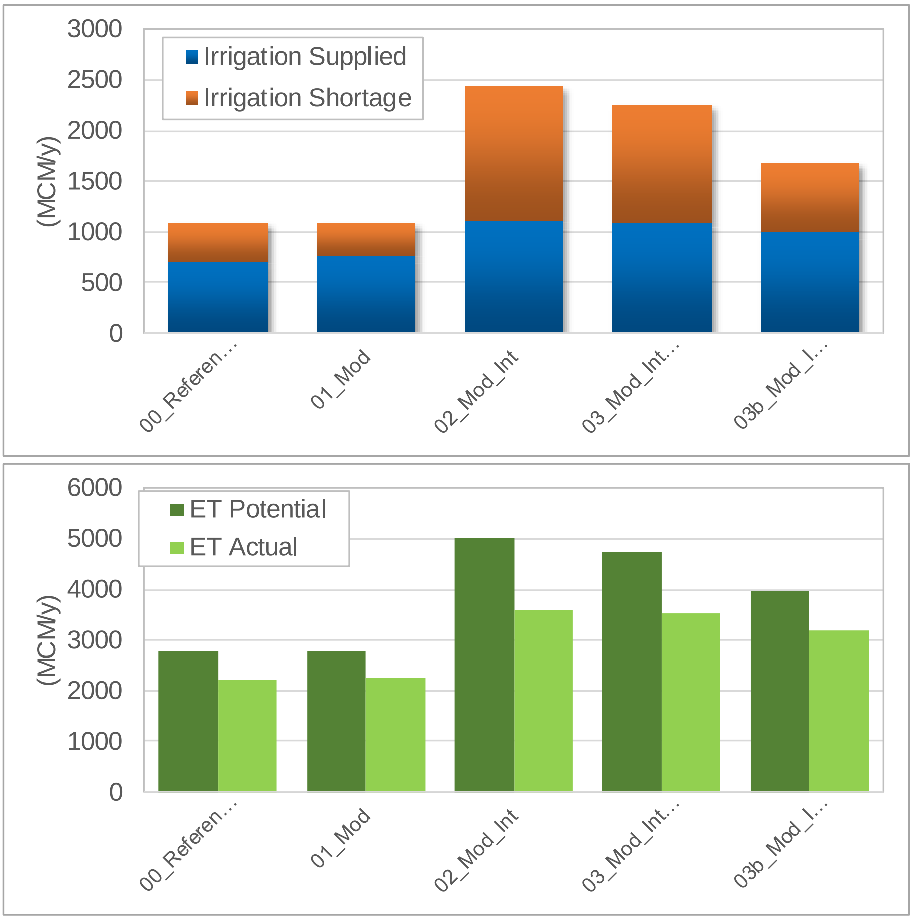


Figure 3-30. Above: irrigation supplied and shortage for the additional explorative scenario (last bar in the chart). Below: same with ET potential and ET Actual.

3.8.5 *Results: impacts on domestic use and environmental flows*

The water allocation options and investments related to irrigation and water resources development will likely also impact domestic water supply and environment flows. Table 3-10 shows water demands, supply required, supply delivered and the coverage for the domestic sector under the six investment scenarios. Please note that for this assessment it was assumed that all domestic water supplies are coming from surface water, and that the infrastructure is in place and operational.

Table 3-10 reflects that the domestic water demand and supply requirements do not change as it was assumed that everything will remain constant to ensure that only the impact of the investment scenarios will be reflected. As mentioned earlier the water demand and also the amount of water supplied to the domestic sector is an order of magnitude lower compared to the irrigation demands. All investment scenarios with additional irrigated areas have a small negative impact on domestic water supply and coverage will decrease. Main reason is that the double cropping with crops growing during the dry season. Under this scenario is so much water consumed by the crop, even while domestic gets higher priority, that domestic coverage is lower compared to the reference. Those results are somewhat surprising as in all scenarios domestic supply has a higher priority over the irrigation sector. Reason is that the priority is based on the actual moment water shortages occurs. In other words, reserving water in reservoirs for the dry season was not considered in the analysis as this requires adjusting reservoirs' operational rules. During the feasibility study and design phase those operational rules for the reservoirs must be further explored.

Impact of the various investment scenarios on environmental flows are assessed by looking at the flow downstream in Stung Sreng (Figure 3-31 and Table 3-11). As expected, mean annual flows will reduce under nearly all scenarios as more water will be consumed by the irrigation sector. For environmental flows the exceedance of certain threshold flows (e.g. 1, 5 or 10 $m^3 s^{-1}$) is relevant. The analysis shows that without taking any other measures also those low flows are expected to occur more frequent. The eco-hydrology sections provide more details and options to overcome those impacts.

Table 3-10: Impact of the six investment scenarios (and reference) on domestic water demand, supply and coverage expressed as water supplied over water demand. Results are based on 20 years averages.

Scenario	(MCM/y) Water Demand	(MCM/y) Supply Required	(MCM/y) Supply Delivered	(MCM/y) Shortage	(%) Coverage
00_Reference	38.9	48.7	32.9	15.8	68%
01_Mod	38.9	48.7	35.3	13.4	72%
02_Mod_Int	38.9	48.7	29.8	18.9	61%
03_Mod_Int_Div	38.9	48.7	30.1	18.6	62%
04_Infr	38.9	48.7	28.6	20.1	59%
05_Mea	38.9	48.7	29.8	18.9	61%
06_Mea_Infr	38.9	48.7	29.8	18.9	61%

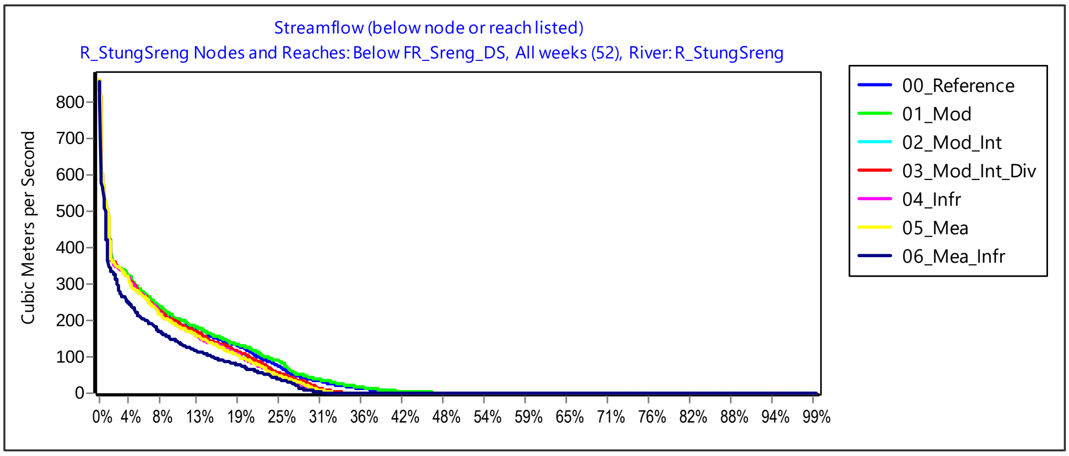


Figure 3-31: Impact of the six investment scenarios (and reference) on environmental streamflow requirements presented as weekly exceedance levels based on a period of 20 years downstream at Stung Sreng.

Table 3-11: Key threshold values for the environmental streamflow requirements. Avg is the mean flow over a period of 20 years. Other columns indicate the percentage of days where flow is zero, below 1 $m^3 s^{-1}$, 5 $m^3 s^{-1}$, and <= 25 $m^3 s^{-1}$.

	Flows (m3/s)				
Scenario	avg	=0	<=1	<=5	<=25
00_Reference	59.5	48%	52%	59%	67%
01_Mod	61.4	45%	51%	58%	66%
02_Mod_Int	54.2	65%	67%	68%	71%
03_Mod_Int_Div	54.6	65%	66%	68%	71%
04_Infr	52.2	67%	68%	69%	72%
05_Mea	52.3	66%	67%	68%	71%
06_Mea_Infr	41.5	68%	69%	70%	73%

4 Sangker-Pursat Basin Group: Surface Water Resources Assessment

4.1 Catchment characterization

The Sangker-Pursat Basin Group lies predominantly within the provinces of Pursat and Battambang but also lies within areas of Pailin (Figure 4-1). The area was divided into 27 sub-catchments, to allow for a more detailed assessment, which covered a total area of 17,767km^2. These sub-catchments were named according to the main tributaries which flow through them: Pursat, Svay Don Keo, Moung Russei, Sangker and Mongkol Borey. In terms of discharge, the Pursat and Sangker rivers are the largest within this basin group with maximum flows of 1264m^3/s and 1020m^3/s, respectively. The discharge within each of these rivers tends to peak in October which usually coincides with the highest Tonle Sap lake level.

The elevation within the region ranges from 1650m to -0.2m and generally decreases from west to east, from the Cardamom mountains towards the Tonle Sap (Figure 4-2). Young alluvium accounts for the majority of the bedrock in the region covering 40% of the total area. Jurassic-Cretaceous bedrock represents the second largest percentage area covering 15% (Figure 4-3).

Leptosol soil, which is typically shallow and susceptible to erosion, dominates the Sangker-Pursat Basin Group covering 32% of the total area. Acrisol, gleysol, luvisol and Cambisol also cover large areas within this region representing 24%, 15%, 13% and 12% of the total area respectively (Figure 4-4).

The SERVIR database classifies land cover into 17 different classes which are shown for the Sangker-Pursat Basin group in Figure 4-5 and Figure 4-6. Between 1987 and 2018 the largest reductions in percentage area were seen in the 'mixed forest' and 'flooded forest' classes with a 13% and 8% decrease, respectively. Percentage area increases of 7%, 6% and 5% can be seen in the 'cropland', 'wetlands' and 'orchard or plantation forest' classes, respectively. CISIS irrigation statistics, summarised in Table 4-1: Population and irrigated areas per catchment of the Sangker-Pursat basin group., give the wet season irrigation area as 93% of the year-round total. Furthermore, only 9% of the total irrigated area is in use outside of the wet season as shown in Figure 4-7.

Figure 4-8 highlights the vulnerability of the region surrounding the Tonle Sap to large flood events with areas neighbouring the lake experiencing a very high flood occurrence. Dry season actual evapotranspiration in this region exhibits a clear pattern with the west and east sides experiencing much higher rates than the centre (Figure 4-9). Therefore, the central region of the Basin Group can be assumed to be considerably lacking in abundant water during the dry season.

Finally, Figure 4-10 shows the 12 protected areas, 30 river blockages and 99 CFRs within the region. Further information on the protected environmental areas can be found in Table 4-4.

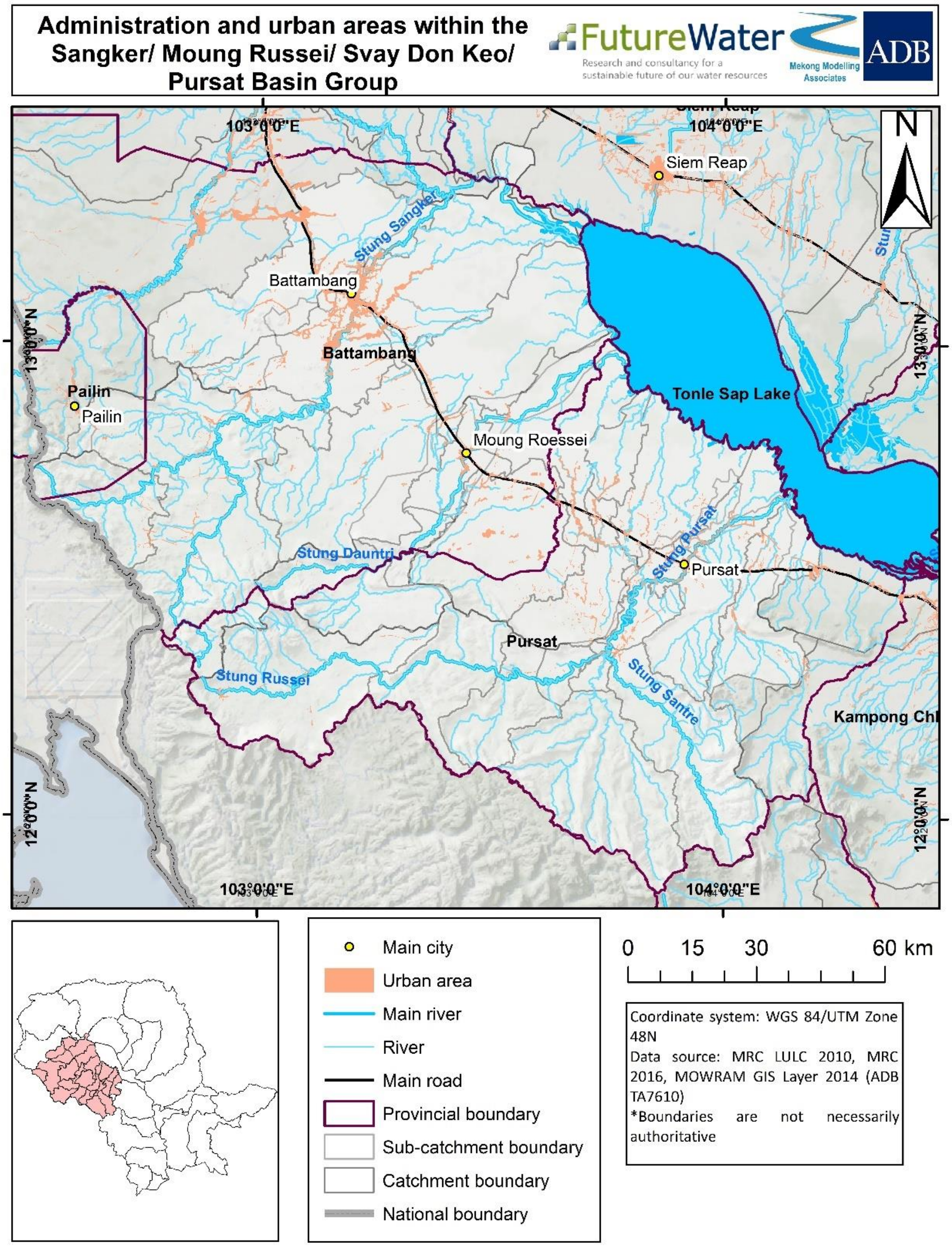


Figure 4-1: Administration and urban areas within the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group.

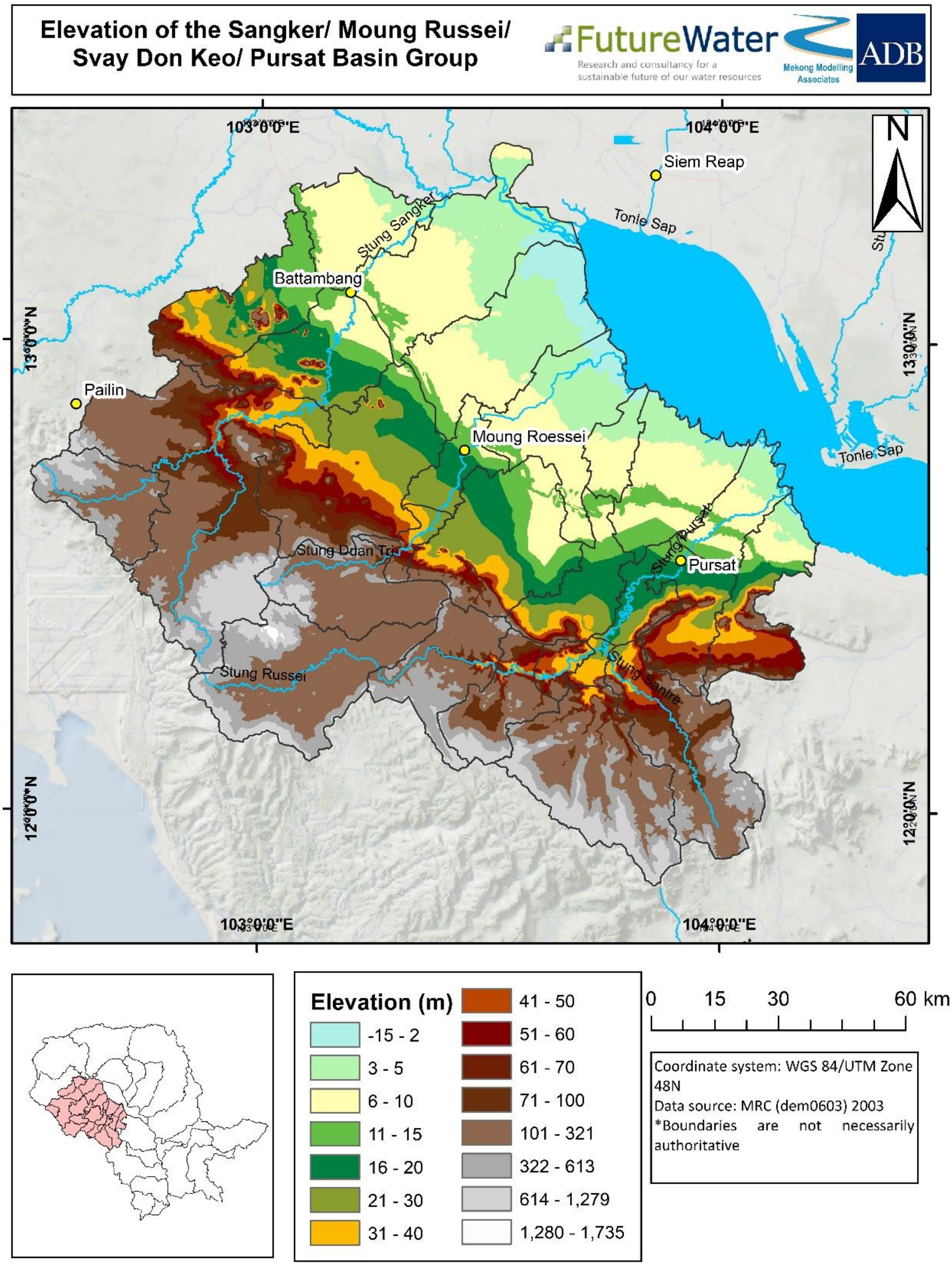


Figure 4-2: Elevation of the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group.

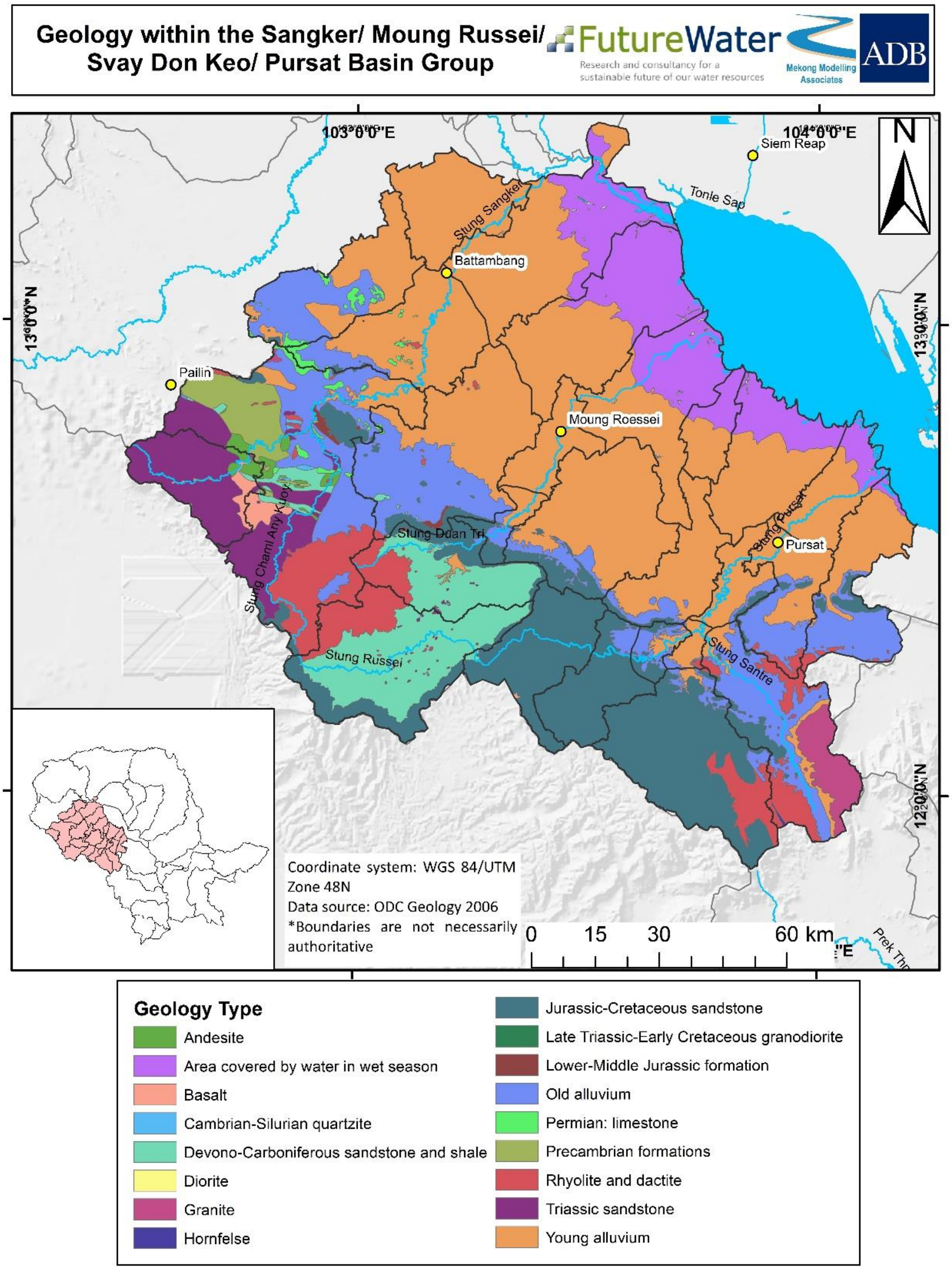


Figure 4-3: Geology within the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group.

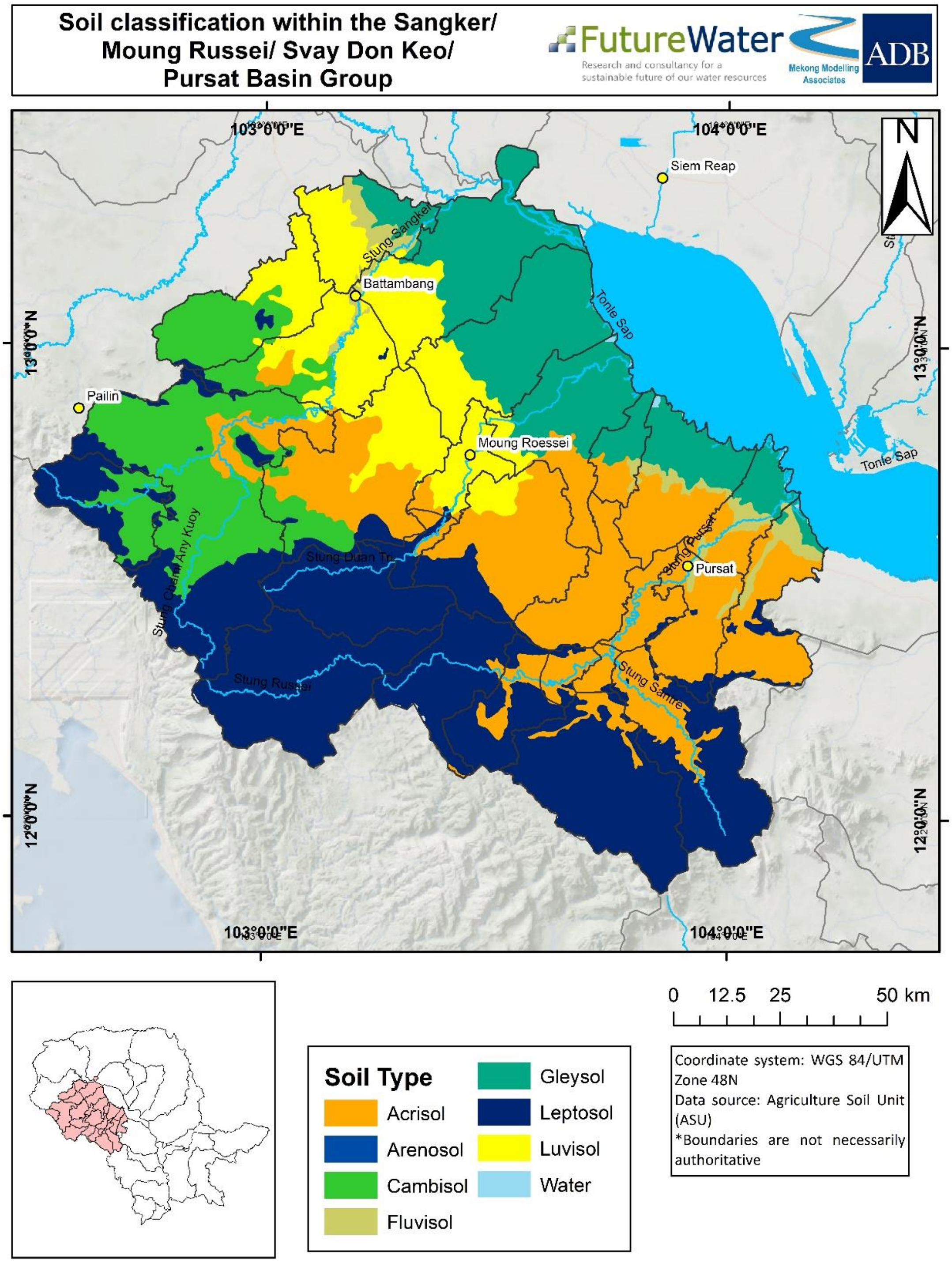


Figure 4-4: Soil classification within the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group.

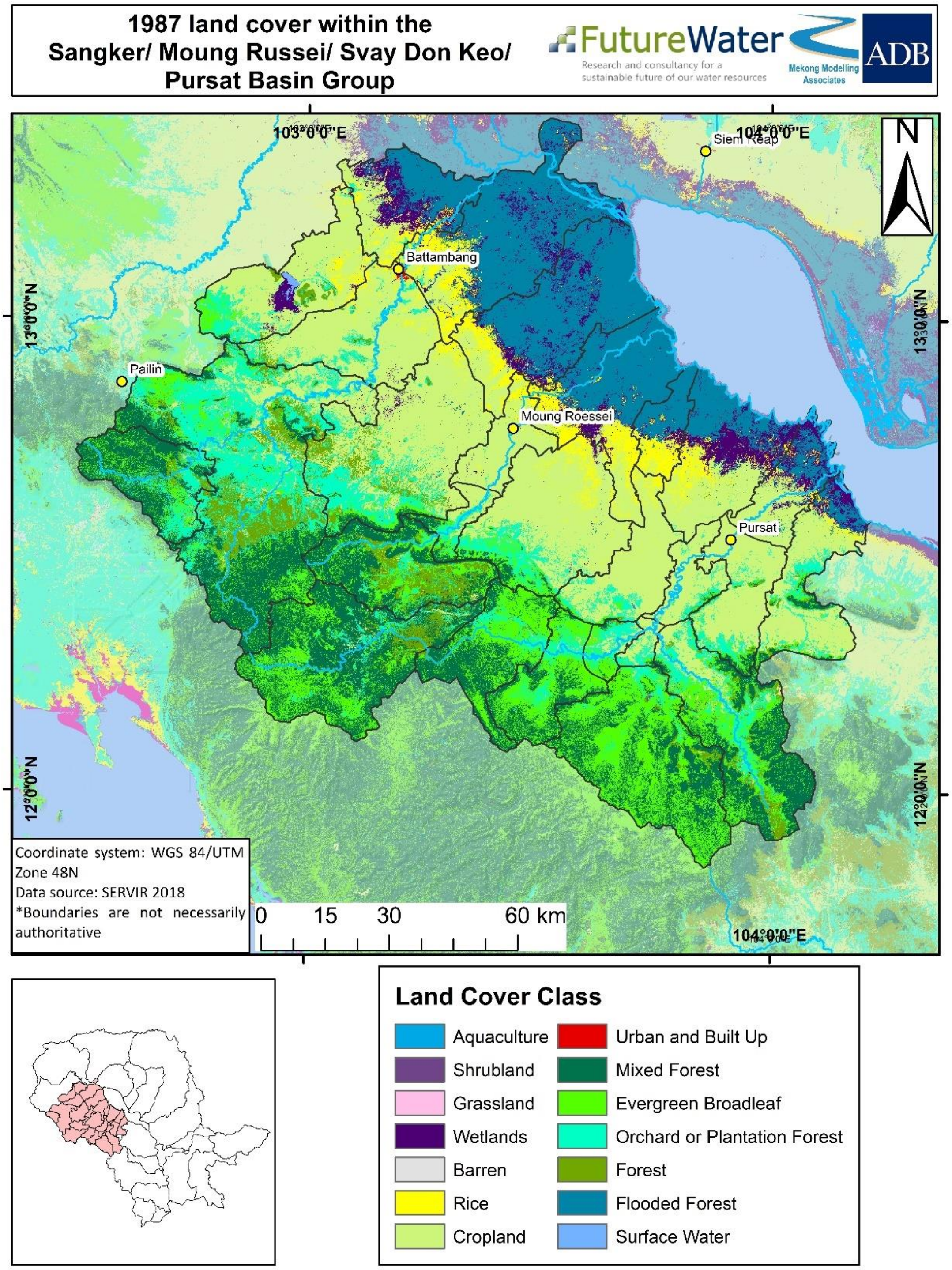


Figure 4-5: 1987 land cover within the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group.

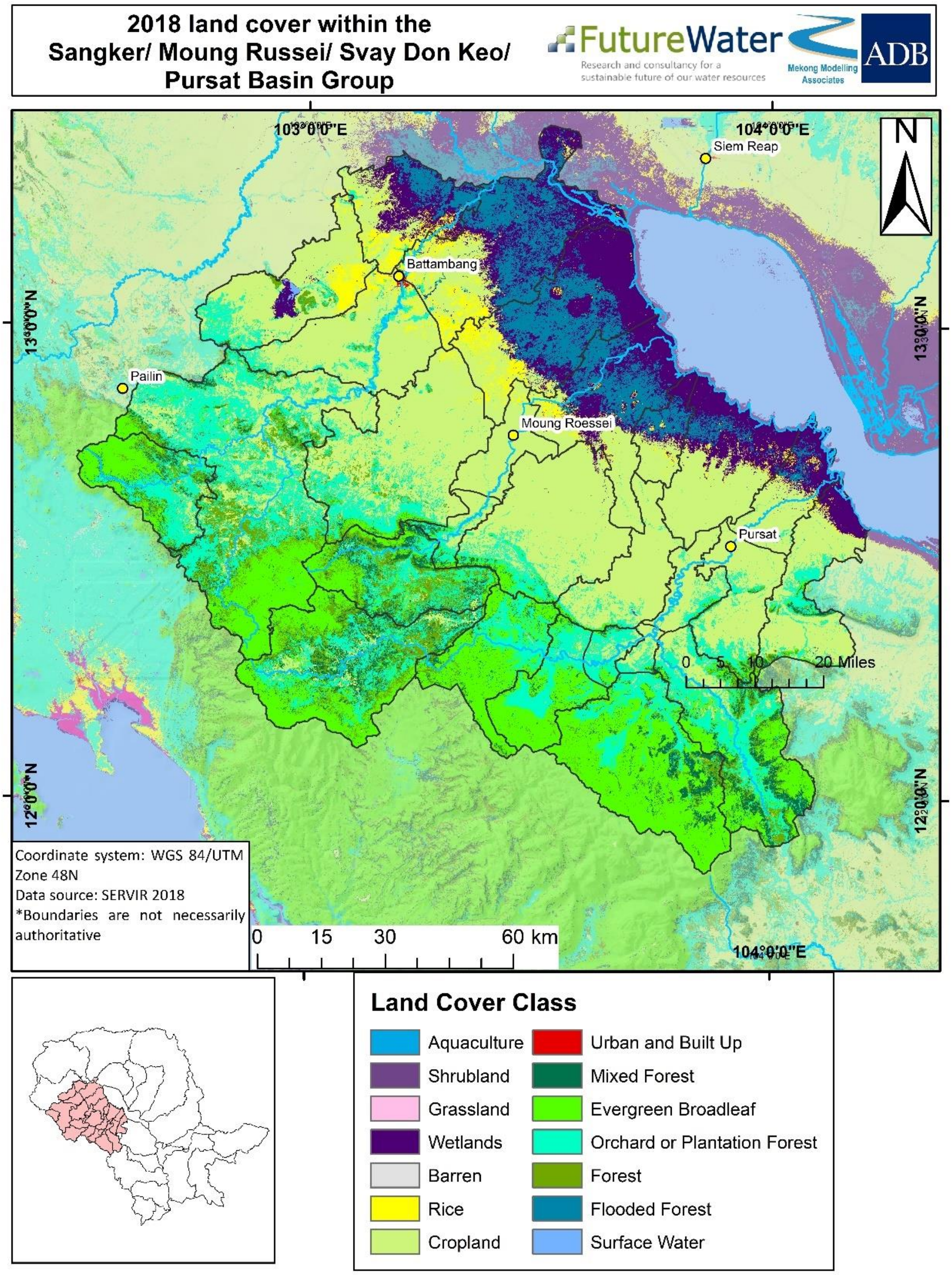


Figure 4-6: 2018 land cover within the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group.

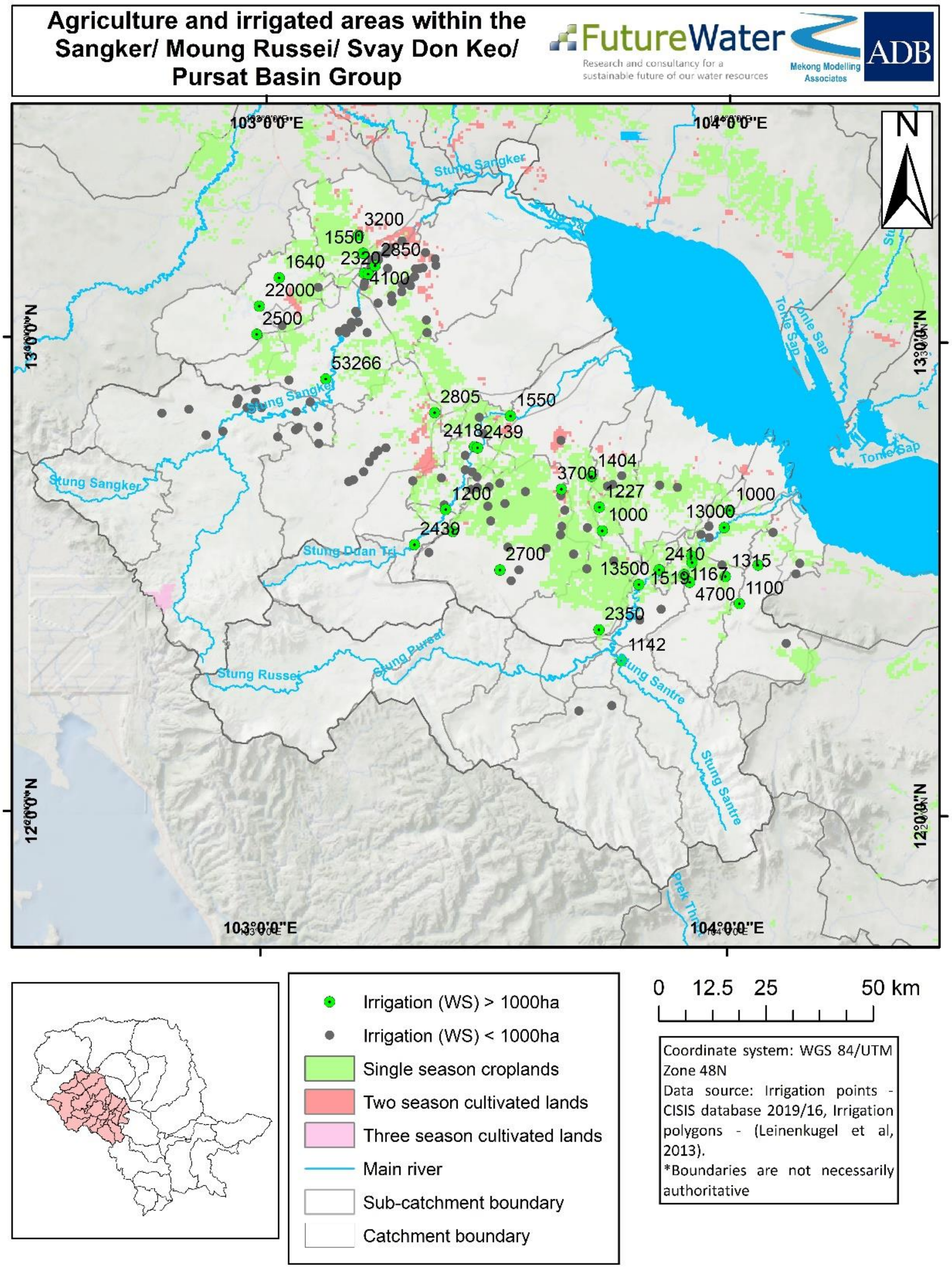


Figure 4-7: Agriculture and irrigated areas within the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group.

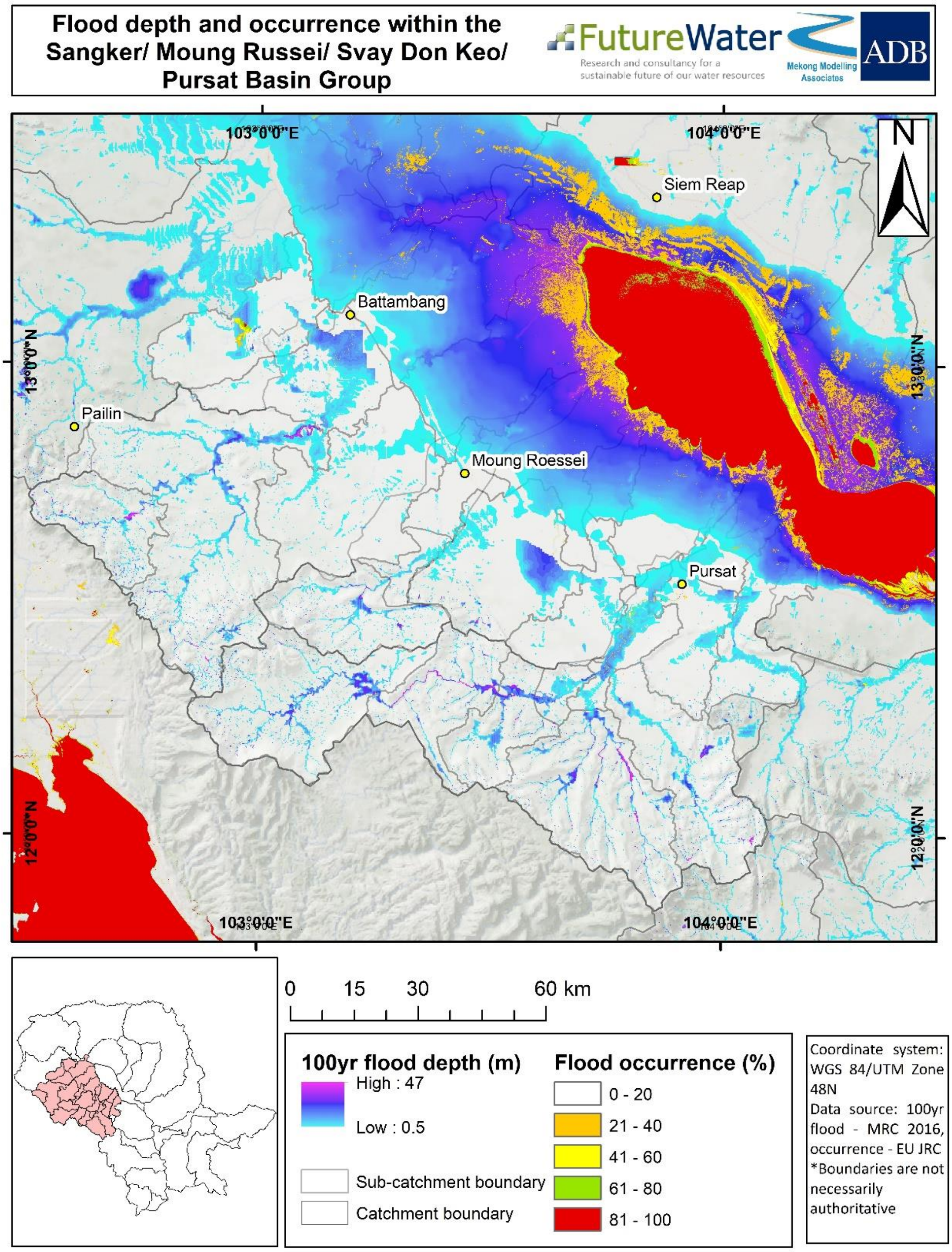


Figure 4-8: Flood frequency within the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group.

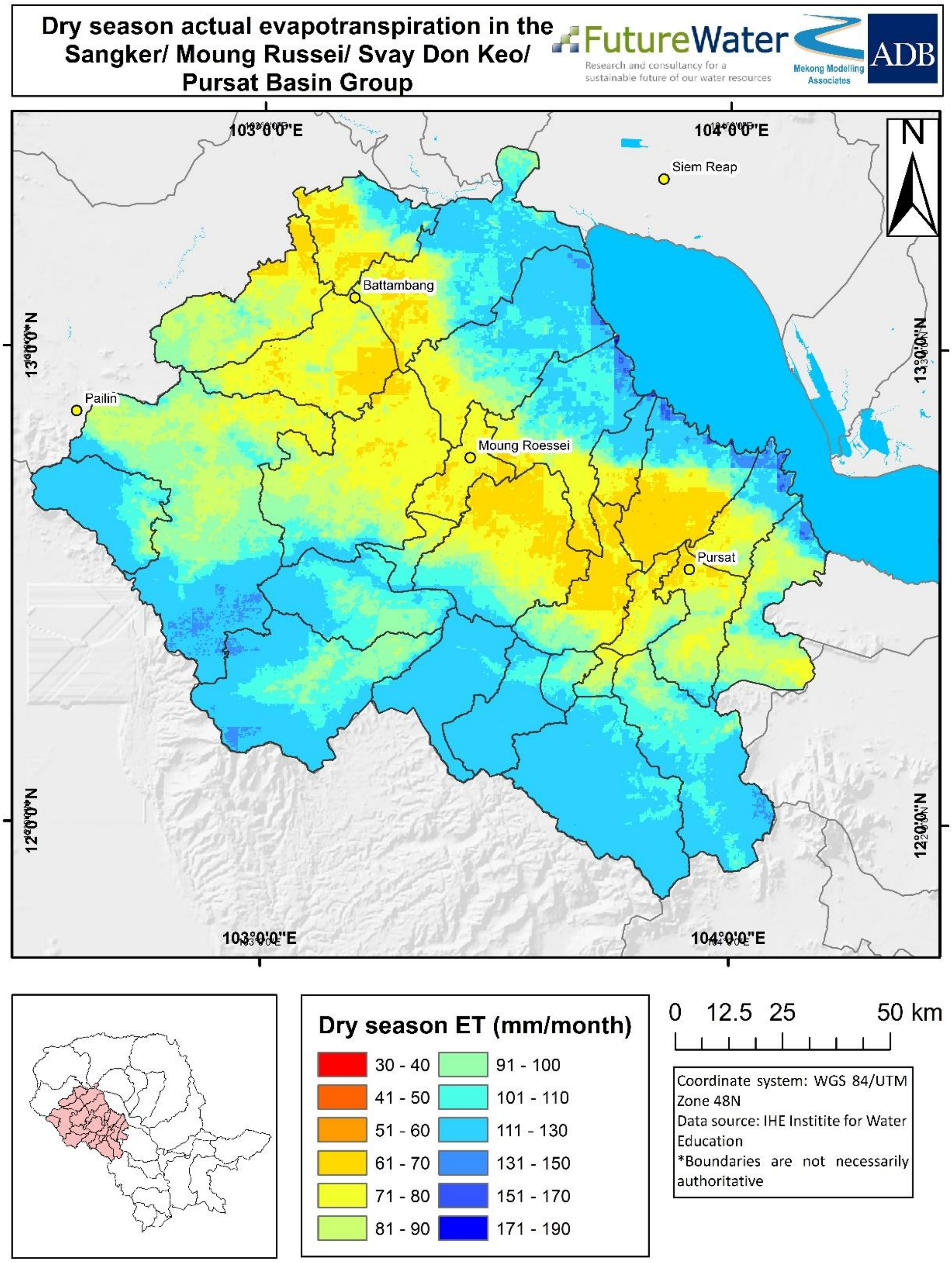


Figure 4-9: Dry season evapotranspiration in the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group.

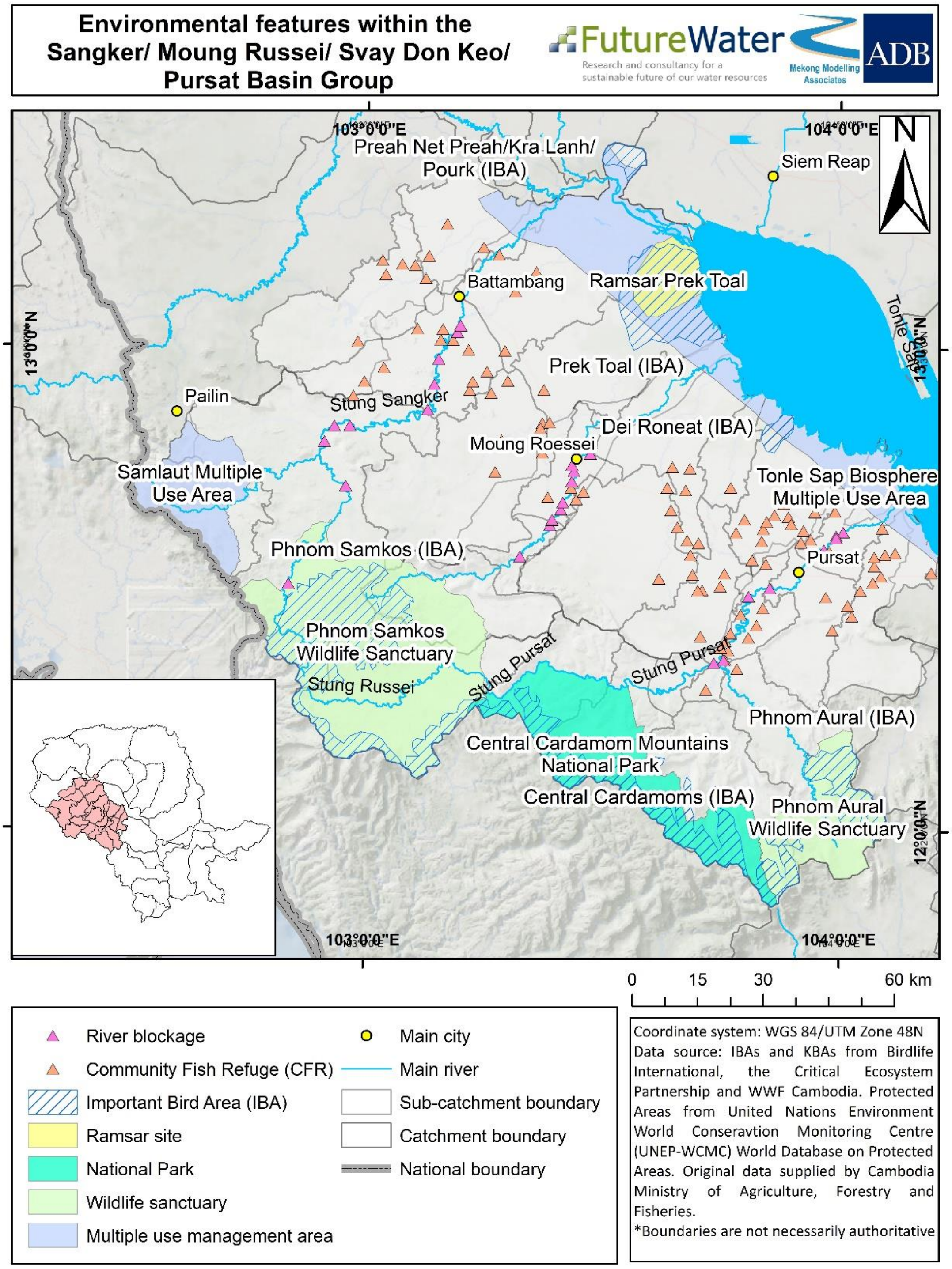


Figure 4-10: Environmental features within the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group.

4.2 Water uses

Principal water uses in this basin group are:

- Domestic
- Irrigation
- Environmental (including fisheries)

Recent data has been collected in Phase II on the irrigation areas from the most recent version of the CISIS database. Updated data per catchment in the basin group is presented in Table 4-1, also including population data for each basin. The catchment delineation is the one used in the detailed hydrological modeling (see section 4.6). Information on the environmental use of water is given in section 4.5.

Table 4-1: Population and irrigated areas per catchment of the Sangker-Pursat basin group.

	2016 population			Irrigation (ha)				Catchment Area (km²)
Catchment	Rural	Urban	Total	Dry Season	Dry in Wet	Wet Season	Recession	
Mongkol Borey 1	37,454	32,784	70,238	1,000	0	27,058	0	685
Mongkol Borey 2	10,883	32,650	43,533	80	0	4,915	0	524
Moung Russei 1	1,188	310	1,498	0	0	0	0	624
Moung Russei 2	14,423	12	14,435	180	0	2,439	0	135
Moung Russei 3	20,327	29,395	49,722	180	0	8,525	0	272
Pursat 1	4,547	1,465	6,012	0	0	0	0	1,087
Pursat 10	28,646	14,417	43,063	0	185	5,710	0	585
Pursat 11	17,377	17,005	34,382	0	2,910	14,462	0	358
Pursat 2	877	44	921	0	0	0	0	545
Pursat 3	4,087	785	4,872	0	0	0	0	428
Pursat 4	3,511	0	3,511	0	0	0	0	1,086
Pursat 5	3,795	220	4,015	0	0	0	0	121
Pursat 6	2,108	2,321	4,429	0	0	0	0	72
Pursat 7	8,930	1,600	10,530	0	50	1,142	0	916
Pursat 8	14,236	8,753	22,989	0	3,700	13,982	0	223
Pursat 9	23,412	25,473	48,885	0	1,010	19,351	0	448
Sangker 1	10,545	2,238	12,783	0	0	0	0	494
Sangker 2	77,494	31,149	108,643	50	0	713	0	2,065
Sangker 3	41,373	13,541	54,914	0	0	3,652	0	1,193
Sangker 4	49,862	157,529	207,391	110	0	54,903	0	712
Sangker 5	9,054	12,103	21,157	50	0		0	1,003
Sangker 6	24,960	104,046	129,006	129	0	13,039	0	1,095
Svay Don Keo 1	32,476	17,748	50,224	0	2,935	4,722	0	462
Svay Don Keo 2	71,711	29,494	101,205	0	1,990	14,336	0	955
Svay Don Keo 3	12,093	14,437	26,530	0	512	4,124	0	786
Svay Don Keo 4	5,452	7,005	12,457	0	350	1,077	0	221
Svay Don Keo 5	22,289	20,091	42,380	0	244	1,435	0	674
Total	553,110	576,615	1,129,725	1,779	13,886	195,585	0	17,767

These data have been used to estimate water demands in the Water Supply and Demand Framework and based on a number of data and assumptions listed in section 4.6. How that translates to water demands is presented in section 4.7.

4.3 Water availability

The water yield in each of the river basins is illustrated in Table 4-2 and Table 4-3 and illustrated as comparison of evapotranspiration, rainfall and yield in Figure 4-11 to Figure 4-14.

The flows in the smaller rivers are considerably lower in the dry season than the larger two rivers of Pursat and Sangker which also have the greater potential for storage to further increase dry season flows.

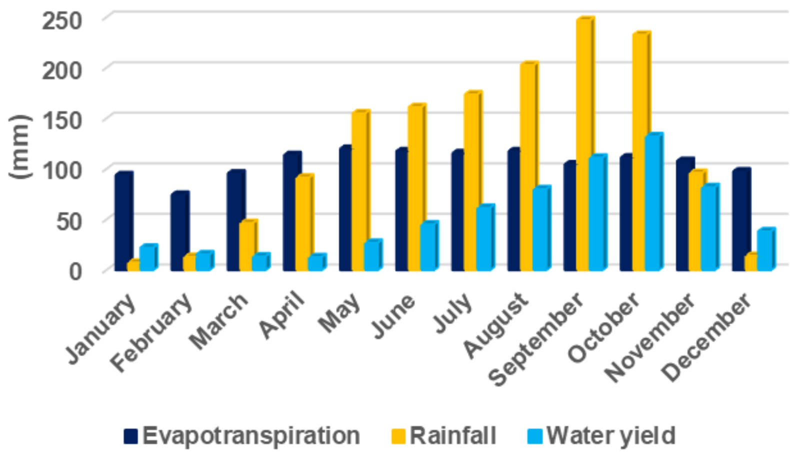


Figure 4-11 Rainfall Evaporation and water Yield Pursat River

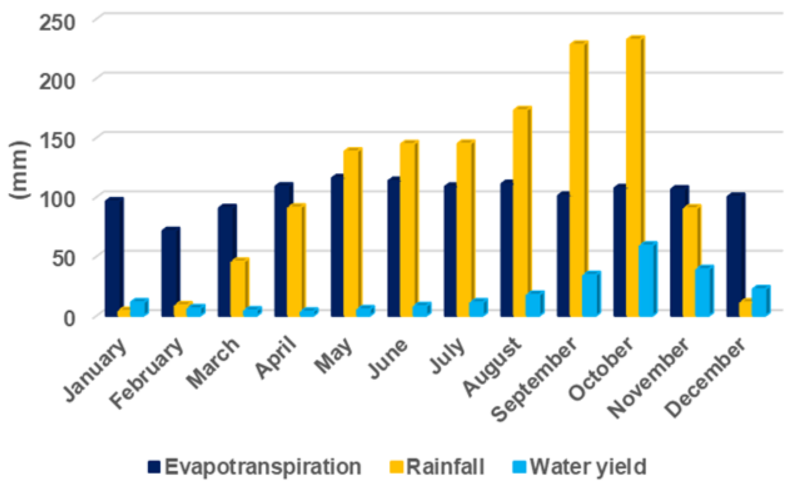


Figure 4-13 Rainfall Evaporation and water yield Svay Don Keo

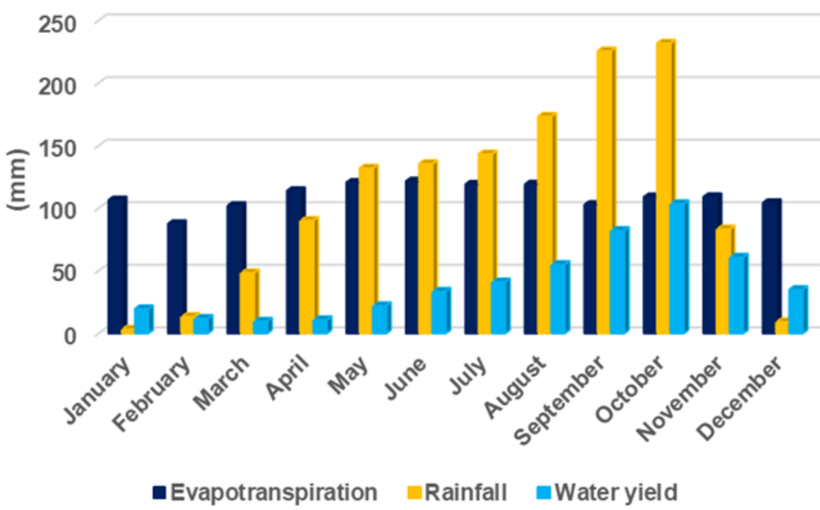


Figure 4-12 Rainfall Evaporation and water yield Moung Russei

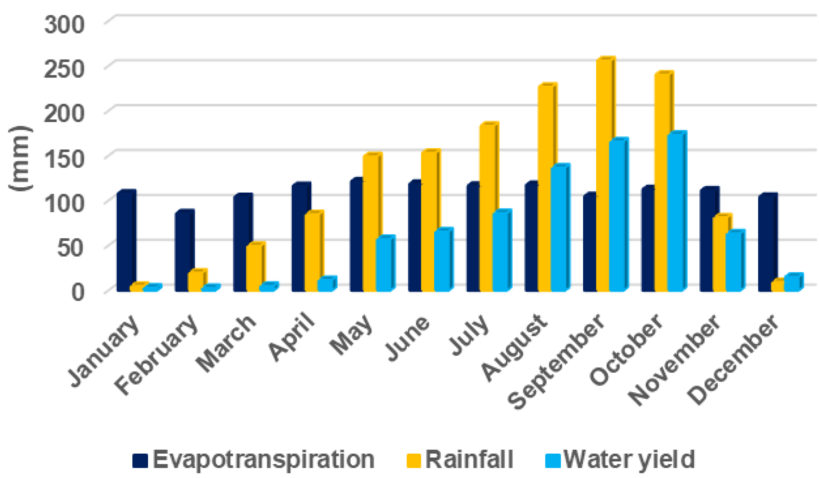


Figure 4-14 Evaporation, Rainfall and Water Yield Sangker

Table 4-2 Water Yield in Each Sub Catchment (mm)

	Pursat	Svay Don Keo	Moung Russei	Sangker
January	22	11	20	3
February	16	6	12	3
March	14	5	10	5
April	13	4	11	12
May	27	6	22	57
June	45	8	34	66
July	62	11	41	86
August	80	18	55	137
September	111	34	82	166
October	132	59	104	174
November	82	39	61	64
December	38	22	35	15
Annual total	**643**	**225**	**485**	**789**
Area (km^2)	**5269**	**2850**	**1031**	**5980**

Table 4-3 Water Yield Expressed as Volume of flow MCM monthly for each river basin

	Pursat	Svay Don Keo	Moung Russei	Sangker
January	117	60	103	18
February	83	34	63	15
March	71	24	51	28
April	68	19	57	62
May	143	29	116	302
June	239	43	177	347
July	325	60	216	455
August	422	94	290	722
September	586	182	433	875
October	697	312	546	915
November	432	207	320	336
December	202	118	184	81
Annual total	**3386**	**1183**	**2555**	**4155**

4.4 Climate Risk

Water use and water availability will be impacted by climate change. A climate risk screening analysis was performed which is reported in a parallel report. This section summarizes the main outcomes for this Sangker-Pursat basin group.

An ensemble of climate models was considered to assess how shifting climate averages may affect future water related interventions. Also drought period length, using the indicator Annual Consecutive Dry Days (CDD) as predicted by the climate model ensemble was considered. In this way both climate averages and extremes are considered in relation to water availability.

4.4.1 *Climate projections*

In general, model outputs suggest an increase in both precipitation and temperature (Figure 4-15), notably for the further time horizon (2070-2099). These may be summarized as such:

- Increases in temperature range from 0.2 -2.2°C between the years 2020-2049, with little difference in predictions between the two respective RCPs.
- Increases in temperature between 2070-2099 have a much greater range (from 1 - 5.6°C), with greater increases in temperature anticipated by the climate model ensemble for RCP8.5.
- Predictions for changes in precipitation range between a 6% decrease and a 21% increase for the period 2020-2049, with most climate models predicting an increase.
- Predictions for changes in precipitation range between a 4% decrease and a 24% increase for the period 2020-2049, with a large majority of climate models predicting an increase. A greater range in predictions is evident under RCP85.

Overall, it is clear that the model ensemble anticipates a hotter climate in both the near and distant futures and under both RCP scenarios for this basin group. Predictions of precipitation changes are more uncertain, but overall suggest a wetter climate with higher annual precipitation in the future.

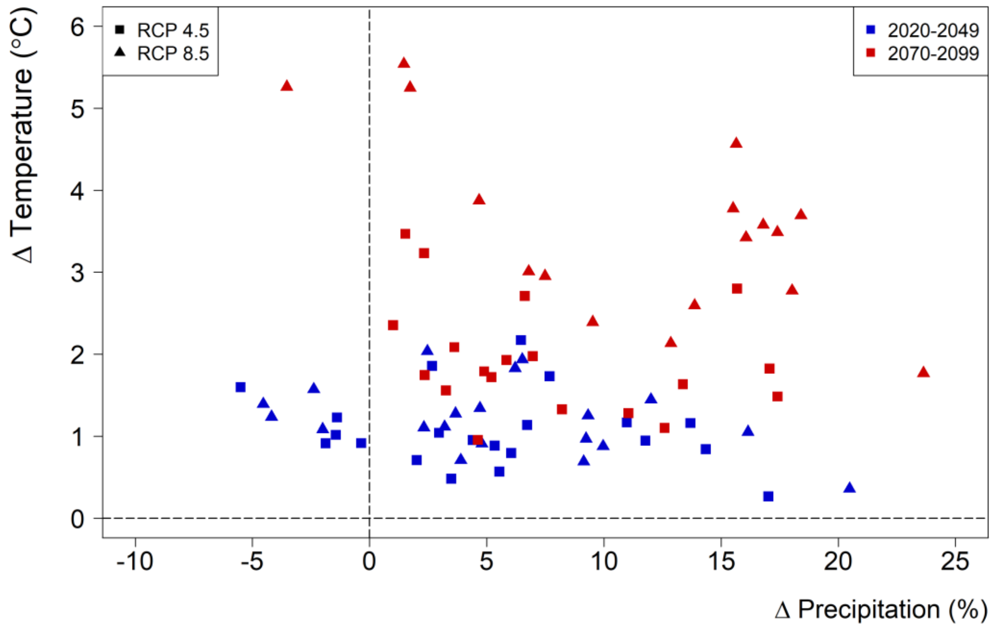


Figure 4-15. Average trends in temperature and precipitation for the Sangker-Pursat basin group as predicted by the climate models considered in this study.

Model outputs do not show a clear trend in drought period length (demonstrated by the proxy-indicator CDD) into the future in that there is a high range in predictions and a high level of overlap between historical and future scenarios for both RCPs (Figure 4-16). A larger range in predictions is evident at the higher RCP scenario and at the 2070-2099 time horizon. When the ensemble mean is considered, however, a small decrease is predicted in CDD the RCP45 pathway at both time horizons. For the RCP85 pathway, a small increase is predicted, with a larger increase for the 2070-2099 horizon.

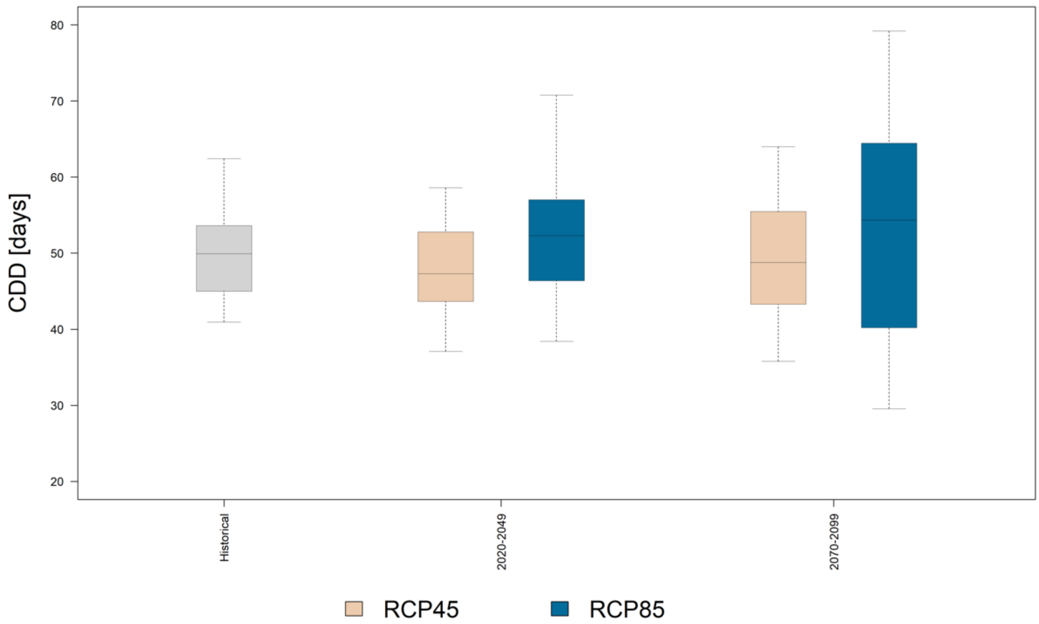


Figure 4-16. Trends in CDD in the Sangker-Pursat basin group at both RCP pathways and future time horizons. Variability in box plots indicates the range in predictions between climate models.

4.4.2 *Risks to water availability*

Based on annual rainfall and annual temperature changes, a first-order estimate can be made of how these changes influence annual flows through the basin group. This methodology relates changes in temperature to changes in evapotranspiration using a simple empirical formula (the Hargreaves equation for potential evapotranspiration) to predict future relative changes in evapotranspiration under increasing temperatures. Changes in mean annual flows can subsequently be approximated based on the difference between projected precipitation and evapotranspiration per basin group. These estimates are useful mainly for relative changes, and when comparing a large variety of climate model-outcomes. They allow for an approximation of how uncertainties in climate models regarding temperature and precipitation predictions relate to the uncertainties in water availability (expressed as annual flows).

These calculations indicate that the majority of models predict an increase in average annual flows through this basin group (Figure 4-17). The values related to this are such:

- Climate model ensemble returns a mean predicted increase in annual flow of 7% and 6% for the period 2020-2049 under respective RCP45 and RCP85 pathways
- Climate model ensemble returns a mean predicted increase in annual flow of 15% and 26% for the period 2070-2099 under respective RCP45 and RCP85 pathways
- Assuming variability between climate models and for different RCP pathways is representative of a range of likely future scenarios, the probability that annual flow will increase in this basin group is 75% and 73% for time horizons 2020-2049 and 2070-2099 respectively

Overall, therefore, the climate model ensemble suggests that water availability is unlikely (<25% probability) to be negatively affected by trends in temperature and precipitation induced by climate change, in line with other studies in the region. This is by no means certain, however, as other studies in the areas come to opposite conclusions. Indeed, Oeurng et al. (2019) predict decreases in average flows in the Tonle Sap Basin of up to 41% when a different model framework is considered and looking at a subset of climate models instead of an ensemble. It is clear that a more detailed climate risk assessment is therefore necessary in this area.

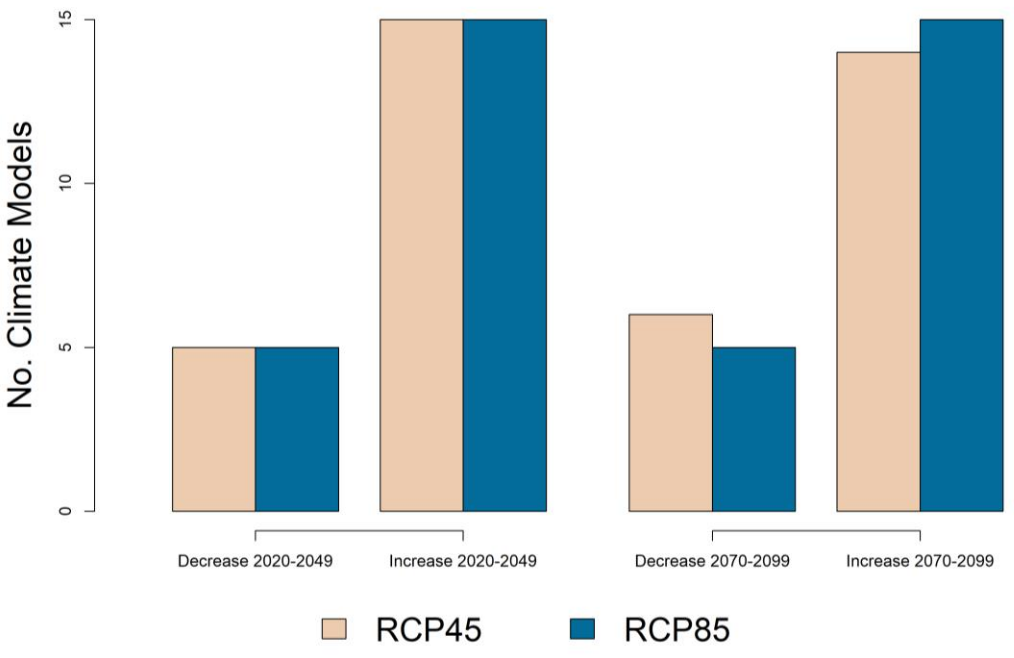


Figure 4-17. Number of models that predict a positive/negative relative changes in mean annual flows for the Sangker-Pursat basin group.

Alongside average changes in climate, seasonality should also be a consideration in relation to water availability. It is possible that annual flows may increase on average, but droughts in the dry season may remain a severe problem. To assess this, detailed hydrological modeling is required, which was out of scope of this study. However, the previously assessed indicator CDD gives an impression of changes in the lengths of drought periods (which can be assumed are related to dry season rainfall depths). Model outputs for CDD can be summarized as such:

- 5 out of 20 climate models predict an increase in CDD under the RCP45 scenario between 2020-2049, with 10 out of 20 models predicting an increase under the RCP85 scenario for the same time period
- 14 out of 20 climate models predict an increase in CDD under the RCP45 scenario between 2070-2099, with 12 out of 20 models predicting an increase under the RCP85 scenario for the same time period
- Assuming variability between climate models and for different RCP pathways is representative of a range of likely future scenarios, the probability that CDD will increase in this basin group is 48% and 55% for time horizons 2020-2049 and 2070-2099 respectively

Based on these results, future trends in CDD are clearly highly uncertain, with no clear consensus between models. Increases in the length and severity of drought events due to climate change should not, however, be discounted as this may represent a risk to future water availability. Proposed developments should therefore consider this eventuality.

4.4.3 *Other climate related risks*

Besides risks to water availability, proposed projects in this basin group may also be affected by other climate-related risks. These include the following:

- Flooding – Longer and more intense periods of precipitation are likely to lead to higher flood risk into the future, especially in the east of the basin group close to the Tonle Sap lake
- Land degradation – Increased intensity of precipitation events is likely to lead to increases in soil erosion and will increase the probability of landslides in the basin group (especially applicable in this basin group due to mountainous terrain in the west)
- Extreme heat – maximum annual temperatures are likely to increase under a changing climate, leading to heatwaves and increasing the probability of wildfires

More detailed information on climate related vulnerabilities and risks in relation to this basin group can be found in the associated Climate Risk and Vulnerability study written to accompany this report.

4.5 Environmental risks identified

At the moment various dams, reservoirs and weirs exist or are under construction along the Sangker, Pursat, Dauntri and Moung Russei rivers, see Figure 4-18. Table 4-4 lists the protected areas and IBAs in the catchment, along with their land cover/key habitats.

Table 4-4: Protected areas, Important Bird Areas (IBAs) and Key Biodiversity Areas (KBAs) in Sangker/Pursat/Moung Russei/Svay Don Keo sub-catchments.

Protected Area	Habitat	Area (Ha)	Sub-catchment
Prek Toal RAMSAR*	Seasonally inundated forest and shrubland	21,342	Stung Sangker
Samlaut Multiple Use Area	Forest	59,916	Stung Sangker
Phnom Samkos Wildlife Sanctuary*	Artificial landscapes (terrestrial); Forest; Rocky areas; Shrubland; Wetlands	330,756	Stung Sangker, Stung Pursat, Stung Moung Russei
Tonle Sap Man and Biosphere Reserve	Seasonally inundated grass/flooded forest/ open water etc.	322,270	All TLS*
Central Cardamom Mountains National Park*	Artificial landscapes (terrestrial); Forest; Grassland; Rocky areas; Shrubland; Wetlands	401,065	Stung Pursat
Phnom Aural Wildlife Sanctuary*	Artificial landscapes (terrestrial); Forest; Grassland; Shrubland; Wetlands	254,485	Stung Pursat
IBAs & KBAs			
Dei Roneat IBA	Wetland; swap forest and shrubland	7,251	Stung Pursat

* Protected Area is also an IBA

4.5.1 *Environmental constraints*

Hydrological interventions in the region priority aim at providing a more stable water supply to the Prek Chik irrigation system and secondly at other areas including Kamping Pouy service

areas – these interventions include dams and weirs, many of which are already present on these rivers, but with several more planned and/or underway (e.g. Dauntri reservoir).
These rivers feed into the northwestern and western part of Tonle Sap and increased utilization of their waters may impact habitats along the banks of the Tonle Sap, although to what degree remains uncertain. No wetlands of significance are known along the upper and middle courses of these rivers, except where they enter the Tonle Sap. The famous Prek Toal Ramsar site and bird sanctuary is located along the southern bank of the Sangker River, close to the shores of Tonle Sap about 2km from the dry season lake level. Important areas for bird conservation (e.g. Bakan grasslands, which supports Manchurian warbler, Chinese grassbird) and perhaps also for rare or uncommon plants also occur but are more confined to wetlands along the shores of the Tonle Sap than directly dependent on flow from these rivers. There is very little information available about heronries and other breeding colonies apart from the key large waterbirds of Prek Toal, unknown breeding colonies may still be found here (F. Goes pers. comm. July 2019).

Four of the weirs visited during the October surveys were equipped with fish passes, but three of these passes were unprotected and were simply used as ideal locations for catching fish (with suspended nets, dip nets). Only the Damnak Ampil headworks on the Pursat River had a fish pass that was protected with wire mesh to prevent fishing (see Annex 1). However, that fish pass and the two other recently constructed fish passes we inspected at Ream Kon and Lum Hach Dams were of a ‘half-cone’ design which is unsuitable and ineffective for passing Mekong system fishes. They are too steep (1:10 slope), too shallow, and highly sensitive to headwater fluctuations, so they either pass little or no water or else pass a high-velocity and extremely turbulent flow, making them impassable by most fish at most times including when visited. The design and performance of are half-cone fish pass design are unreported in any scientific or general literature to our knowledge, in contrast to several other types of fish pass which are well-documented.

The most suitable fish passes for low- to medium-height dams are likely to be vertical slot designs, like the fish pass which operates successfully for many years at Stung Chinit Weir, or other common and internationally documented types of fish pass. These include the cone fish pass at Kbal Hong Weir on the Pursat River, which is suitable for that low-head site, and passes many fish, according to monitoring data from IFReDI (Chann Aun Tob and Tim Marsden personal communications).

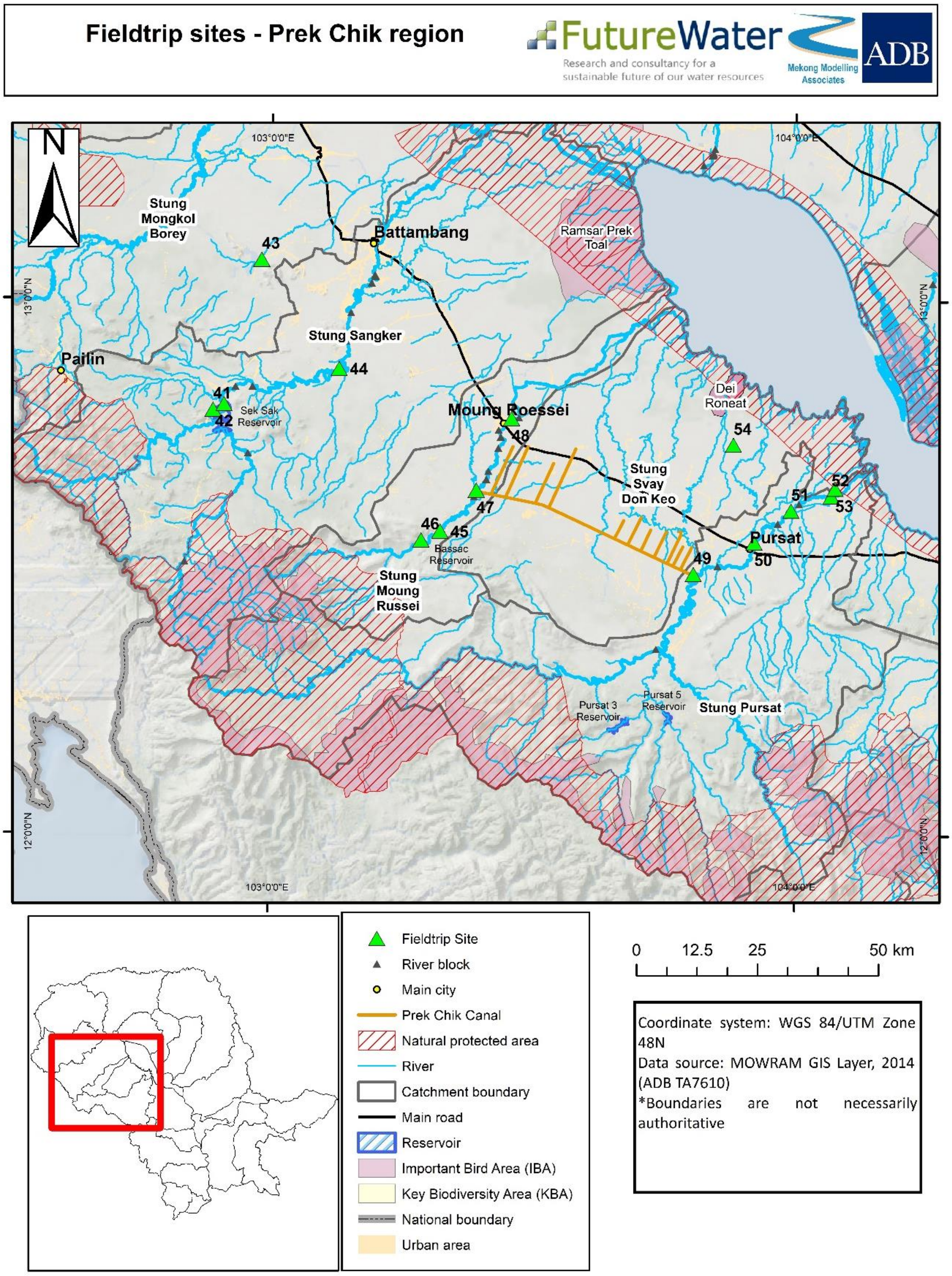


Figure 4-18: Environmental features in the basin group, indicating also field locations visited in October 2019.

Like on the Stung Sangker, dams in the area (e.g. Sek Sak, Dauntri) are (being) constructed without removal of the woody vegetation prior to inundation, which is normal procedure elsewhere as leaving the forest (remnants) leads to eutrophication issues and enhanced carbon emissions that could easily have been prevented.

4.5.2 *Potential impacts on birds*

Rice farming and cattle grazing form the main threats of this increasingly rare habitat, and any attempt to drain the grasslands for long periods or even permanently will invite more agricultural activities and encroachment on the remaining natural grasslands. Suitable habitat for the Chinese Grass-babbler, is exclusively formed by thick-stemmed reed-grass *Miscanthus* interspersed with shrubs, but this appears nowadays extremely scattered and degraded. Members of the babbler family are usually extremely sedentary and without doubt the present situation must hamper dispersal amongst the different fragments with disastrous consequences for the genetic health of the sub-populations.

4.5.3 *Potential impacts on water quality*

Historic data from MRC's database (2000-2016) shows that most water quality parameters in the Stung Pursat are well within the thresholds of MRC's Water Quality Guidelines and the Cambodian Water Quality Standard. Only the TSS concentration value at Stung Pursat is slightly high (97 mg/L), but still within acceptable levels. The DO values at Kampong Luong station, which is downstream of the Stung Pursat connecting to the Tonle Sap Lake in both dry and wet seasons during the period of 2000-2016, ranged from 2 mg/L (poor) to 10 mg/L (excellent). On the whole, water quality of the Stung Pursat was generally in a good condition for aquatic life. As most bottlenecks in water quality are in the dry season, hydrological interventions in these catchments may improve water quality in the drier months.

4.5.4 *Risk mitigation*

To ensure that water abstraction is within safe limits to maintain basic environmental functions in these river systems, the following environmental flows can be calculated for these river systems:

<u>Wet season e-flow demand</u>: The 30% of the mean annual flow may be sufficient, if this translates into several meters of flooding in the flooded forest areas in the periphery of Tonle Sap (bearing in mind that Mekong levels play an important role here, which makes it difficult to assess accurately).

<u>Dry season e-flow demand</u>: Using a standard indicative e-flow of 0.2 m^3/s per 100 km^2 of catchment area (combined = 15,712 km^2) one arrives at a dry season e-flow of 31.4m^3/s combined for these four catchments.

However, this is theoretical, as the natural dry season flow is very low (close to zero) for the smaller rivers. The Dauntri River, for example, is a medium-size river in its upper section (where a large dam is under construction, see Annex 1) but is reduced to a small channel in its lower section that peters out entirely before reaching the Tonle Sap. What is needed is flooding or waterlogging in these wetlands to extend for a sufficient number of months beyond the wet season (July-October), say until Jan-Feb, so that conversion of natural habitats such as inundated forest and inundated grasslands is discouraged. Supply of flow for this purpose would require control of water levels and the interactions with the lake level would need further study to come up with a practical management system.

The existing fish passes should be covered (e.g. with coarse wire mesh, like at the Kbal Hong headworks to prevent or at least discourage intensive fishing activities; like at Kbal Hong, the covering should extend well into the river to prevent the placing of nets at the beginning and end. Retrofitting of fish passes should be considered for those dams and weirs where they are currently lacking, while at the Dauntri (under construction) this can be incorporated into current design.

4.6 Model setup

For the Sangker River Basin Group (Sangker / Pursat / Moung Russei / Svay Don Keo) it was decided given the complexity in water supply and demand topics in Sangker to build the Water Supply and Demand Framework using WEAP (see previous Chapter for details regarding this approach). Some of the characteristics of the developed WSDF are:

- The inflow into the rivers and streams were obtained from the SWAT model. The simulated flows do not consider the influence of reservoirs, withdrawals and return flows.
- Irrigation demands have been calculated dynamically using the catchment nodes approach from WEAP combined with the advanced soil-moisture module. Withdrawals storage, and returnflows are calculated in WEAP.
- A timestep of one week (7 days) was used.
- To introduce annual and weekly variation climate data from 20 years (1996-2015) have been used. For future scenarios the same climate variability was assumed, as the climate risk analysis showed that annual flows are likely to increase in this area, while there is not a clear trend in the drought (dry period) characteristic that was studied.
- A two years warming up period was used to ensure that the model was in equilibrium when starting the actual analysis.
- Input and output analysis were done by a combination of direct results from the model as well as using a set of excel VBA scripts.
- A total of 25 domestic water nodes were implemented and urban water requirements were set at 160 liters per person per capita. For rural water consumption 90 liter per person per capita was considered.
- Irrigation demand areas were combined into 8 nodes. For each node four seasons were considered (see the Rapid Assessment report for details). The actual water demand is calculated by the WEAP model using the following principle. Crop water requirements are calculated by the Penman-Monteith approach considering climate data (e.g. temperature, windspeed, humidity, sun-shine hours). If sufficient water is ponded or available in the soil, actual water supply demand is zero. In case ponding is low and soil water is below a set threshold value, water demand is calculated. This water demand is further refined by losses and reuse of water and the result is the so-called supply requirement. In case sufficient water is available in streams and reservoirs, this will be released and allocated.
- In case of shortages the water is rationed given a pre-defined priority. For the reference scenario, all sectoral demands (irrigation, domestic and environment) are given equal priority. For the future scenarios, a higher priority is given to domestic use.

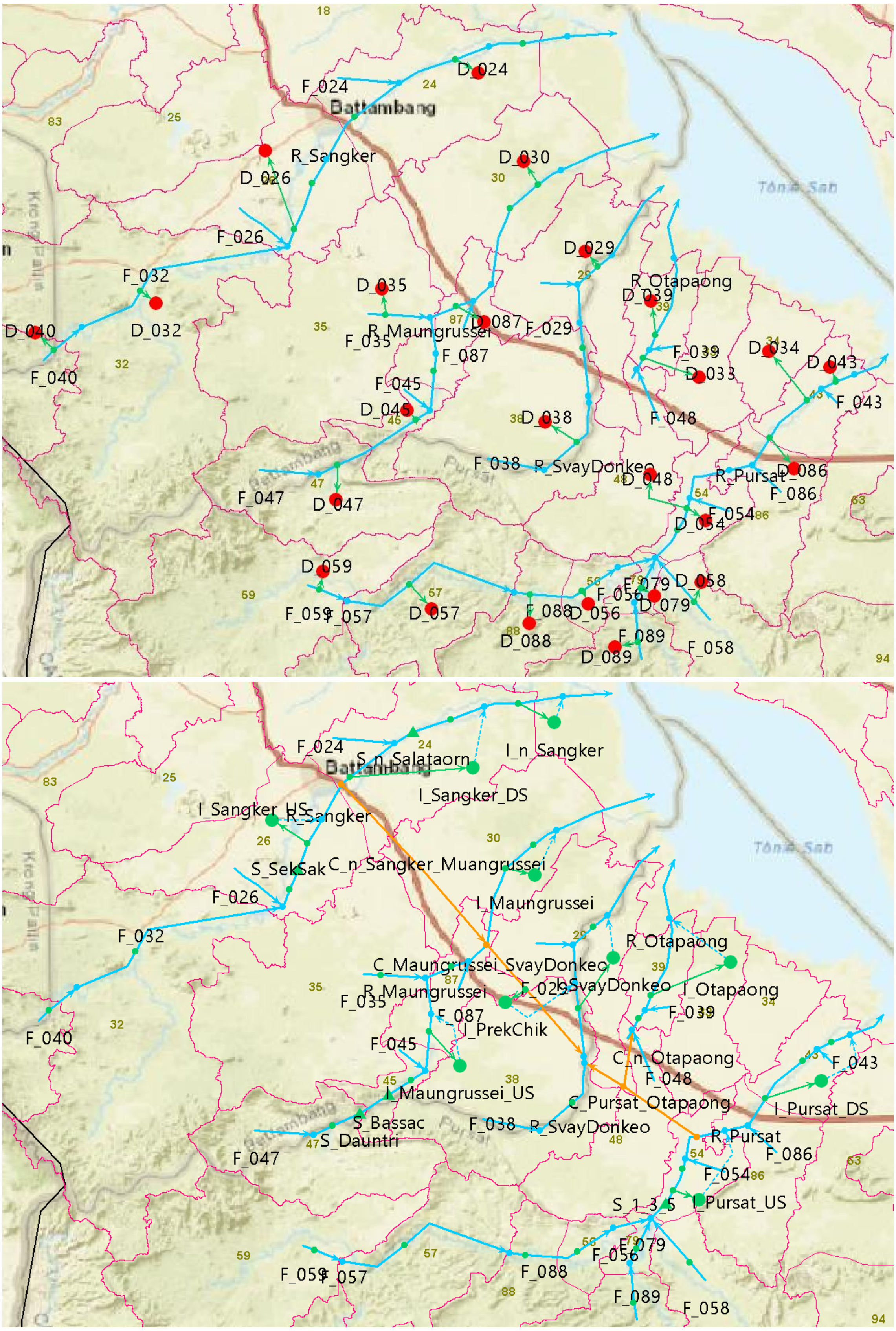


Figure 4-19: Schematic of the Water Supply and Demand Framework in WEAP for the Sangker River Basin Group. Upper: all domestic demand nodes. Down: all irrigation and environmental demand nodes and infrastructures.

4.7 Water balance evaluation

The Water Demand and Supply Framework as implemented in WEAP and discussed in the previous sections, was used to evaluate the current situation (reference, base-line). Table 4-5 shows for the irrigated areas the various components of the water demand, supply and coverage. The precipitation is the total rainfall that the irrigated areas receive: WEAP uses the soil moisture module to calculate the effective rainfall that is actually consumed by the crop. Crop water requirement and irrigation demands varies substantially between the irrigated areas mainly as a result of different areas cropped. Climate varies only to a smaller extent in the river basin group. The irrigation shortages and the coverage (expressed as water shortage over water demand) varies between the different areas. Overall is water shortage in the area not very severe as indicated by the numbers in the column “Coverage”. Obviously, variation between years and seasons is substantial and there might be periods where water is more stressed. Moreover, the analysis assumed that the irrigation infrastructure in in place and maintained.

Domestic demands, supplies and coverages are shown in Table 4-6. Results from the 25 domestic water nodes are aggregated here per basin. There is quite some variation between the various domestic water demands as population differs quite a lot in each area, which the analysis considered, including the proportion between rural and urban. Overall coverage is between 80% and 100%. This obviously depends on the season. Figure 4-31 in the next section shows weekly shortage, for the reference compared to the future scenarios. Interesting is that the entire water demand for domestic use of about 44 million cubic meter per year is an order of magnitude smaller compared to the water demand for irrigation (811 million cubic meter). For the reference scenario, presented here, all sectors are equally prioritized in case water shortages appear and water must be rationed across the various demand nodes. For future scenarios (see next section), priority is given to domestic.

Environmental flows have been evaluated at the downstream point of five main rivers in the Sangker River Basin Group (Figure 4-21 and Figure 4-22). The figures indicate that some rivers fall completely dry in 50% of the days, while others are able to maintain a certain baseflow. Section 4.5 has summarized the environmental risks related to these water shortages.

The Water Supply and Demand Framework provides a huge amount of supporting data. The model itself is attached to the report and can be used as reference in case more results are needed to be analyzed. Figure 4-23 provides examples of those detailed results from the analysis. In this particular figure, irrigation demand dominates the pattern, as domestic demand is relatively small compared to irrigation.

In summary it can be concluded for the Sangker River Basin Group that in general water resources are abundant, and that some water shortages occur in some areas and some periods of the year. This means that by improvements in water allocation and water use must be possible, possibly together with improvements in infrastructure if feasible. The next sections will explore various of those management and investment options and the impact on water demand and supply.

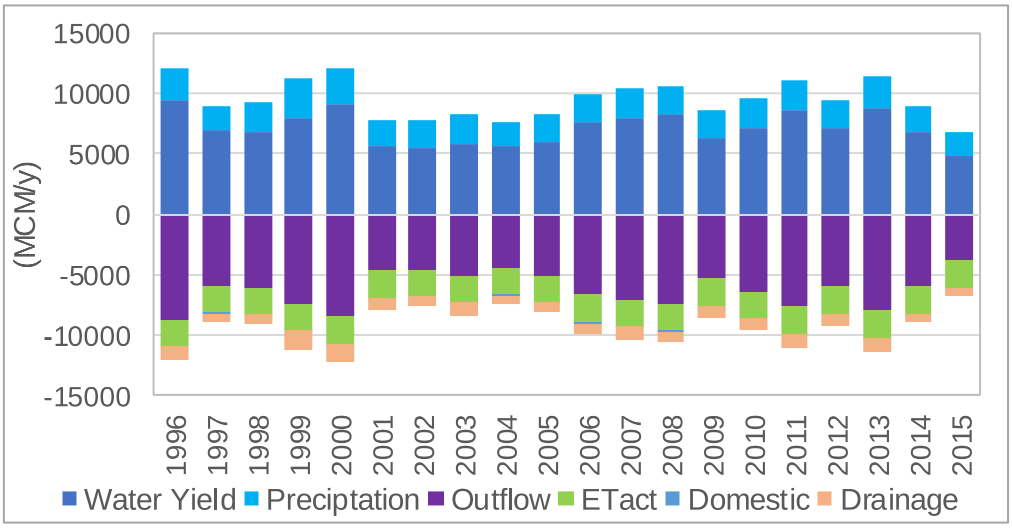


Figure 4-20: Overall water balance for Sangker-Pursat Basin Group as evaluated using the combined SWAT-WEAP analysis. Water Yield is the runoff from the catchments in the rivers and streams; Precipitation is only the precipitation on the irrigated areas; Outflow is into Tonle Sap; ETact is water consumed by irrigated crops; Domestic is water consumed for the domestic sector; and Drainage is outflow from irrigated sector that are not further used.

Table 4-5: Results of the Water Supply and Demand Analysis for the irrigation schemes. Annual averages over a period of 20 years (1996-2015) are shown.

	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
I_Maungrussei_US	204	345	255	169	97	72	57%
I_Otapaong	42	47	40	14	13	1	93%
I_PrekChik	139	157	127	54	26	28	48%
I_Pursat_DS	666	498	452	73	68	5	94%
I_Pursat_US	470	232	219	18	18	1	96%
I_Sangker_DS	181	208	182	70	64	6	92%
I_Sangker_US	708	908	802	361	330	31	91%
I_SvayDonkeo	168	182	145	52	29	23	56%
TOTAL	2,578	2,576	2,222	811	644	167	79%

Table 4-6: Results of the Water Supply and Demand Analysis for the domestic water requirements. Individual nodes are aggregated per basin. Annual averages over a period of 20 years (1996-2015) are shown.

	(MCM/y) Water Demand	(MCM/y) Supply Required	(MCM/y) Supply Delivered	(MCM/y) Shortage	(%) Coverage
D_Maungrussei	6.862	8.578	6.286	2	73%
D_Otapaong	5.157	6.446	6.439	0	100%
D_Pursat	11.176	13.970	13.957	0	100%
D_Sangker	19.201	24.001	23.665	0	99%
D_SvayDonkeo	1.729	2.161	2.057	0	95%
TOTAL	44.125	55.156	52.405	3	95%

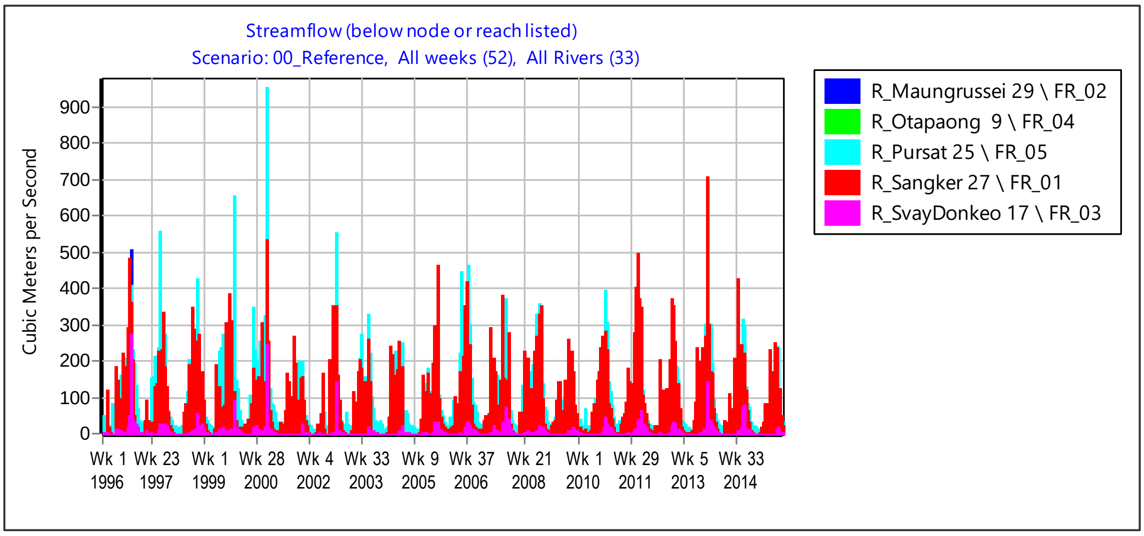


Figure 4-21: Environmental streamflow requirements presented as weekly flows over a period of 20 years downstream of the main rivers in the Sangker River Basin Group.

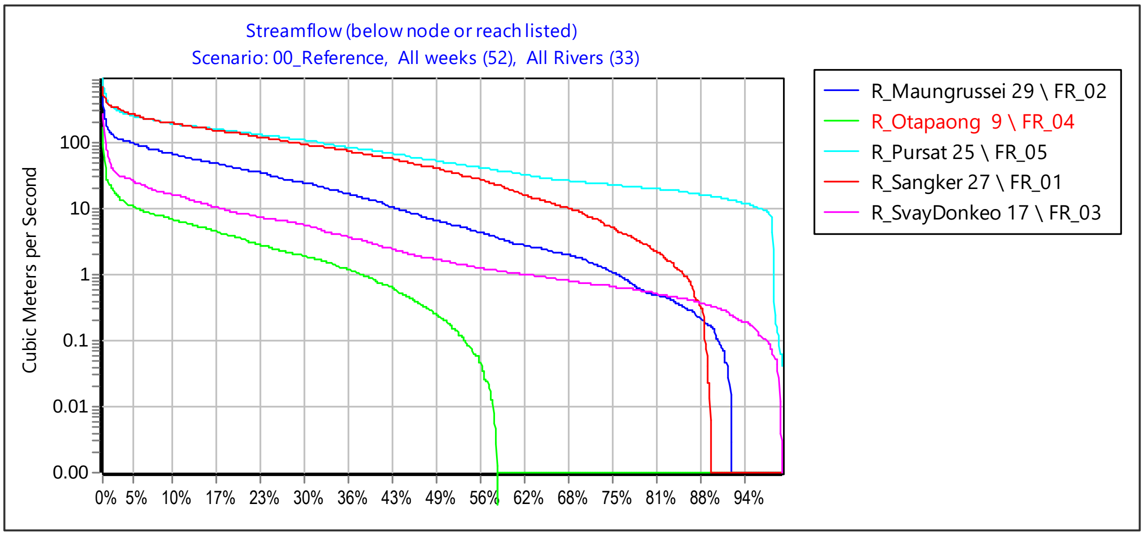
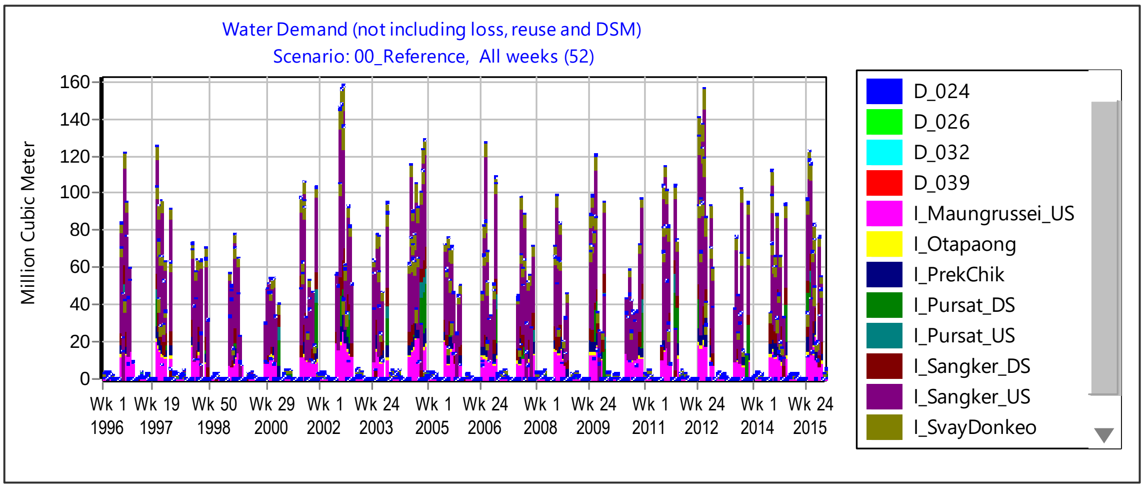


Figure 4-22: Environmental streamflow requirements presented as weekly exceedance levels based on a period of 20 years downstream of the main river in the Sangker River Basin Group.



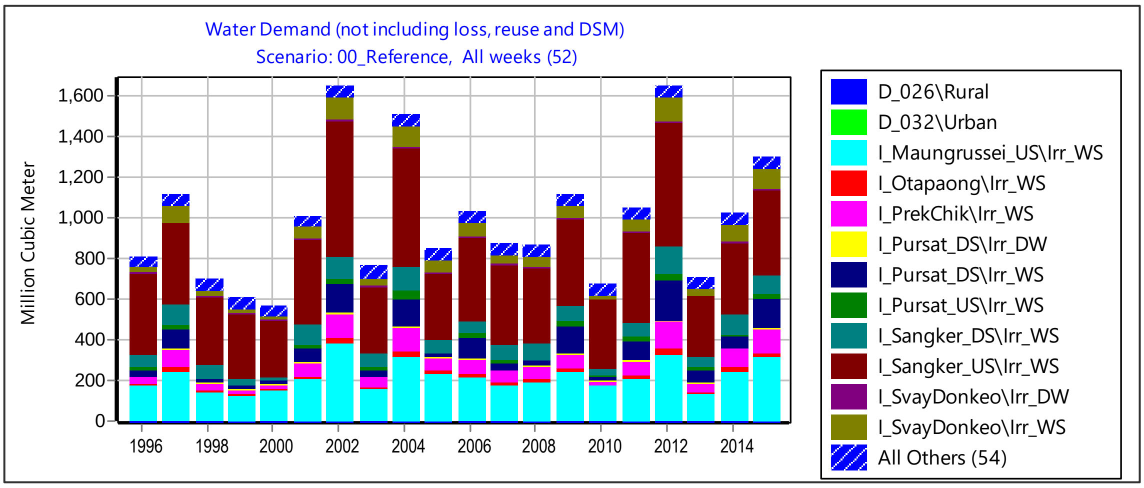


Figure 4-23: Example of output provided by the Water Supply and Demand Framework as implemented in WEAP: Water Demand weekly (top) and annually (bottom).

4.8 Scenario analysis

A set of potential investment scenarios to enhance crop production and to improve water security to all sectors have been explored. Those investment scenarios have been developed in consultation with MOWRAM. It should be emphasized that the current study is a pre-feasibility study and that based on those results more focused feasibility, pre-design and design evaluations are required.

For the Sangker River Basin Group a set of potential investment scenarios were explored using the Water Supply and Demand Framework as implemented using WEAP. Those scenarios exist of a combination of so-called water use options (A to D) and infrastructure investment options (E to L) as described below. Various combinations of those measures were integrated in the actual scenarios explored.

4.8.1 *Description of water allocation options*

A: **Rational priorities during water shortage periods**

Highest priority 1 is given to domestic water use then priority 2 for environment and also priority 2 for irrigation

B: **Modernization of irrigation systems**
Losses in irrigation canals will be reduced from the currently assumed 25% to 10% and the reuse of runoff and drainage from irrigated areas will increase from 25% to 50%.

C: **Rice intensification (rice only)**
An intensified cropping pattern, as proposed in the current National Irrigation Strategy. Double cropping is practiced assuming that 100% is cropped during wet season, 50% during the recession season, and 50% in the dry-wet (early wet) season. Thus, this aims for a cropping intensity of 200%.

D: **Diversification and intensification**
An intensified cropping pattern, as proposed in the current National Irrigation Strategy, but including also crop diversification. Same as previous scenario, but outside the wet season, the crop mix is 70% rice, and 30% vegetables.

4.8.2 *Description of infrastructure investment options*

For a map with current and planned infrastructure, please see Annex 5

E: **Prek Chik expansion**
Irrigated area in Prek Chik will be expanded with an additional 10,000 ha. In the new areas, a crop mix is assumed that includes besides rice also cassava, maize and vegetables

F: Link **Sangker to Moung Russei**
Canal that links Stung Sangker to Moung Russei is built and operational.

G: Link **Svay Don Keo to Moung Russei**
Additional water will come from (i) diversion canal from Svay Don Keo to Moung Russei (already existing but currently not active and needs to be dredged), (ii) when dredged, water can be brought from Svay Don Keo to Moung Russei and (iii) the transfer from Pursat to Svay Don Keo is already active. Thus, the dredging would allow water from Pursat to reach Moung Russei and allow additional water to reach the irrigation area Prek Chik.

H: **Increased reservoir capacity - Pursat**
Two new reservoirs in Pursat (referred to as S_1_2) with a capacity of 1040 + 295 MCM are assumed to be constructed.

I: **Increased reservoir capacity Sangker**
(referred to as Battambang, S_Bat1) with a capacity of 1040 MCM.

J: **Large irrigation expansion**
New irrigated areas in Kamping Pouy:18,000 ha, and Battambang: 10,000 ha.

K: **Diversion to Kamping Puoy**
A diversion canal to Kamping Pouy (in Stung Mongkol Borey) and Battambang

L: Dauntry reservoir completed
This infrastructure option includes the completion and full operation of the Dauntry reservoir.

4.8.3 *Description of scenarios*

Table 4-7 presents the combination of the previously described investment options in a number of scenarios. The first set of scenarios (1-3) is based purely on the water allocation options. The second set of scenarios (4-6) is based on a combination of both water allocation as well as infrastructure investment options.

Table 4-7. The six scenarios explored, and their associated water use and infrastructure investment options.

Scenarios	Water use options				Infrastructure investment options							
	A	B	C	D	E	F	G	H	I	J	K	L
00_Reference												X
01_Modernization	X	X										X
02_Mod_Intensive	X	X	X									X
03_Mod_Int_Crop Diversification	X	X		X								X
04_Pursat to Prek Chik canals. Additional Reservoir Sangker	X	X		X	X		X		X			X
05_Prek Chit Expansion, Reservoir in Pursat	X	X		X	X	X	X	X		X	X	X
06_Sangker and Pursat Reservoirs	X	X		X	X	X	X	X	X	X	X	X

The scenarios are briefly described here below.

01: **Modernization** (*01_Mod)*
This scenario explores the impact if losses in irrigation canals will be reduced from the currently assumed 25% to 10% and the reuse of runoff and drainage from irrigated areas will increase from 25% to 50%. Also, in case of water shortage, irrigation will get lower priority.

02: **Modernization combined with rice intensification** (*02_Mod_Int)*
Under this scenario also modernization and priority for allocation are the same as the previous scenario. On top of this a double cropping system is considered for rice.

03: **Modernization combined with rice intensification and diversification** (*03_Mod_Int_Div)*
Under this scenario also modernization and priority for allocation are the same as first scenario (*01_Mod*) the previous scenario. On top of this a double cropping system is considered but, in this case, this double cropping is not only rice, but in 30% of the area vegetable are assumed to grow.

04: **Enhanced irrigated area in Prek Chik option B** (*04_ Prek*)
Under this investment scenario it is explored what the impact will be if the irrigated area in Prek Chik will be expanded with an additional 10,000 ha. Additional water will come from (i) diversion

canal from Svay Don Keo to Moung Russei (already existing but currently not active and needs to be dredged), (ii) when dredged, water can be brought from Svay Don Keo to Moung Russei and (iii) the transfer from Pursat to Svay Don Keo is already active. Thus, the dredging would allow water from Pursat to reach Moung Russei and allow additional water to reach the irrigation area Prek Chik. Also increased reservoir capacity Sangker (referred to as Battambang, S_Bat1) with a capacity of 1040 MCM is assumed under this scenario.

05: **Large irrigation expansion** (*05_Prek_Bratt*)
Large scale irrigation expansion is evaluated under this particular investment scenario. A total of 38,000 ha expansion will be developed as follows: Prek Chik 10,000 ha, Kamping Pouy 18,000 ha, and Battambang 10,000 ha. In order to have additional water available a connection from Stung Sangker to Stung Moung Russei is needed. The link between Svay Don Keo to Moung Russei is also considered (G). In contrast to the previous scenario the increased reservoir capacity in Sangker (I) is not considered, but instead the increased reservoir capacity in Pursat (H) is assumed.

06: **Large irrigation expansion and infrastructure** (*06_Prek_Bratt_Infr*)
Same as previous scenario, but all proposed infrastructure is assumed to be constructed.

4.8.4 *Results: impacts on irrigation*

The six investment scenarios as described in the previous section were implemented in the Water Supply and Demand Framework as implemented in WEAP. Table 4-8 provides a summary of the key results summarized for all irrigated areas in the river basin group. The table includes a summary of the

- Annual results
- Wet season results (week 24 – week 45)
- Dry season results (week 46 – week 23)

The most silent details are:

- **Precipitation** amount varies according to the cropped area of each of the scenarios. Obviously also quite some variation exists between years but here only averages are given.
- **Crop water requirements** (ET Potential) is the actual amount of water required by the crop, without considering any losses. Variation between the scenarios can be explained by the different irrigated areas considered. For most scenarios, except *00_Reference* and *01_Mod*, double cropping was considered. For some other scenarios it was assumed that additional areas would be irrigated (*04_Prek, 05_Prek_Batt, 06_Prek_Batt_Infr):* expansion of 10,000 ha for Prek Chik and the additional development of Kamping Pouy (18,000 ha) and Battambang (10,000 ha). Those expansions result also in higher crop water requirements (ET Potential).
- The amount of **actual crop water consumption** (ET Actual) shows quite some variation between the scenarios. Overall, whatever scenario will be selected more water is consumed by the crops compared to the baseline (*00_Reference*). This consumed water is considered as beneficial since it produces crop. As a first estimate by using the water productivity of 0.72 kg m^{-3} as reported by (2019, Foley et al.) an indicative estimate of crop production can be calculated.
- Looking at the individual scenarios, the following can be commented and concluded:
    - *01_Mod*: The expected increase in crop water consumption (and therefore crop produced) is relatively small compared to the Reference. Although irrigation

shortages decrease and coverages increase from 77% to 87% the overall benefits are relatively low. The main reason is that still most of the crop water consumption is from rainfall.

- *02_Mod_Int*: Water demand and actual water consumption increases substantially by the expansion of the agricultural area (double cropping). Although the coverage is lower compared to the previous scenario and the irrigation shortages higher, total crop production (expressed as the ET Actual) can be expected to be higher. In other words, individual farmers will experience more water shortage, but production of the entire basin group will increase.
- *03_Mod_Int_Dev*: Results for this scenario show the same trends as the previous one: water demand and actual water consumption increases substantially by the expansion of the agricultural area (double cropping). Irrigation shortages are slightly lower compared to the previous scenario
- *04_Prek*: Water demand and water used to produce crop (ET Actual) increase quite a lot by the expansion of the Prek Chik area by 10,000 ha. The additional new link between Svay Don Keo and Moung Russei is quite effective and quite some additional water can be supplied to the systems.
- *05_Prek_Batt*: The expansion of the irrigated systems of Kamping Pouy (18,000 ha), and Battambang (10,000 ha) increases water demands and irrigation shortages increase substantially.
- 06_Prek_Batt_Infr: Same as previous scenario, but now considering additional reservoir capacity in Sangker (referred to as Battambang: S_n_Bat1) with a capacity of 1040 MCM. this additional storage capacity is quite effective in reducing the forecasted water shortage.

Table 4-8 presents the detailed numbers of the impact of the six investment scenarios for the entire river basin group. Figure 4-24 provides the same information but split out between the irrigated areas considered. From the figure it is again clear that the modernization scenario (*01_Mod)* is the most effective one in providing the highest coverage (water supplied over water demand).

The following Key Findings for Irrigation development can be extracted from the work presented here:

1. There is not sufficient water for the expansion of the irrigated areas of Kamping Pouy and Battambang unless new reservoir capacity will be developed in the Sangker (*06_Prek_Batt_Infr*).
2. Intensification to double cropping systems is possible in the river basin group only in combination with modernization and expansion of reservoir capacity and canals.

Table 4-8. Results of the Water Supply and Demand Analysis for the six potential investment scenarios. Results reflect annual averages over a period of 20 years using climate conditions from 1996-2015.

Annual Scenario	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
00_Reference	2578	2576	2227	840	648	192	77%
01_Mod	2578	2576	2278	840	734	106	87%
02_Mod_Int	4911	4743	3982	2026	1391	635	69%
03_Mod_Int_Div	4911	4509	3843	1868	1329	539	71%
04_Prek	5165	4804	4237	2443	1957	485	80%
05_Prek_Batt	5622	5334	4486	3483	2106	1377	60%
06_Prek_Batt_Infr	5622	5334	4667	3478	2590	888	74%

Wet Season Scenario	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
00_Reference	1617	1880	1667	812	624	188	77%
01_Mod	1617	1880	1713	811	706	106	87%
02_Mod_Int	3082	2580	2266	1021	719	302	70%
03_Mod_Int_Div	3082	2502	2213	986	710	276	72%
04_Prek	3239	2668	2384	1348	942	405	70%
05_Prek_Batt	3521	2967	2608	2000	1224	775	61%
06_Prek_Batt_Infr	3521	2967	2622	2000	1246	754	62%

Dry Season Scenario	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
00_Reference	961	697	560	28	24	4	86%
01_Mod	961	697	565	28	28	0	98%
02_Mod_Int	1829	2164	1716	1005	672	333	67%
03_Mod_Int_Div	1829	2007	1630	882	619	263	70%
04_Prek	1926	2136	1853	1095	1015	80	93%
05_Prek_Batt	2100	2367	1878	1483	882	601	59%
06_Prek_Batt_Infr	2100	2367	2045	1478	1344	134	91%

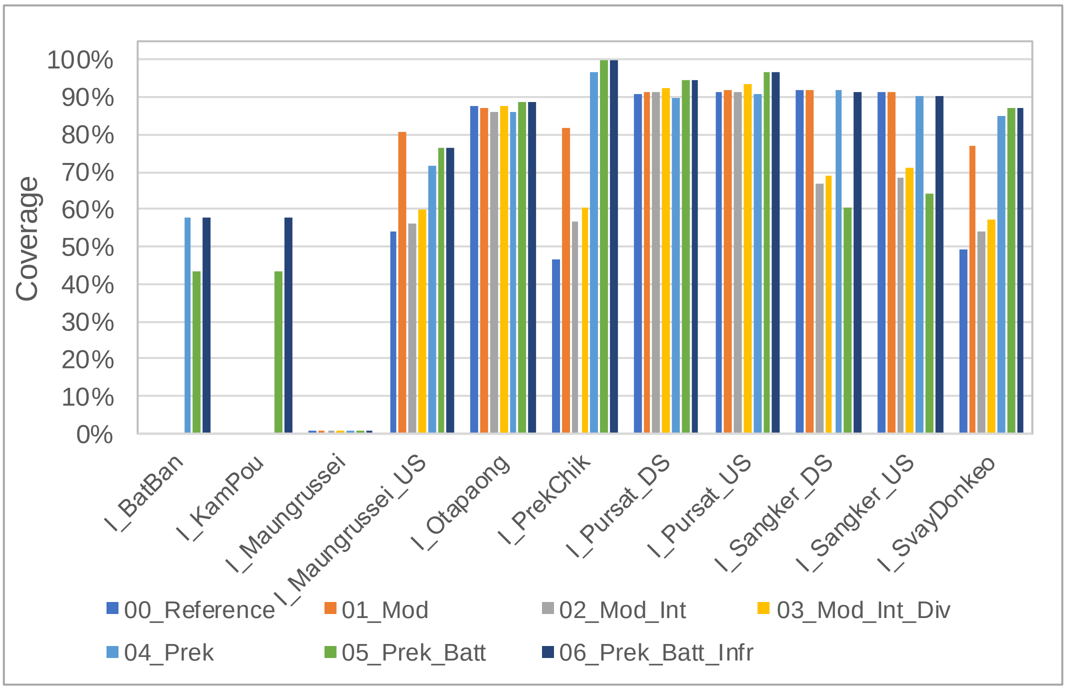


Figure 4-24: Impact of the six investment scenarios (and reference) on coverage expressed as water supplied over water demand. Results are based on 20 years averages.

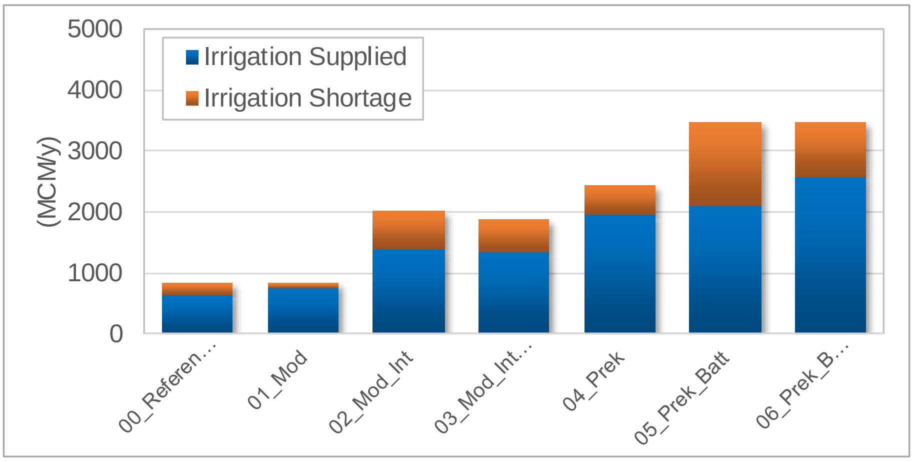


Figure 4-25: Irrigation supplied and irrigation shortages for the six investment scenarios (and reference). Note that total irrigation demand is just the total of supply and shortage. Results are based on 20 years averages.

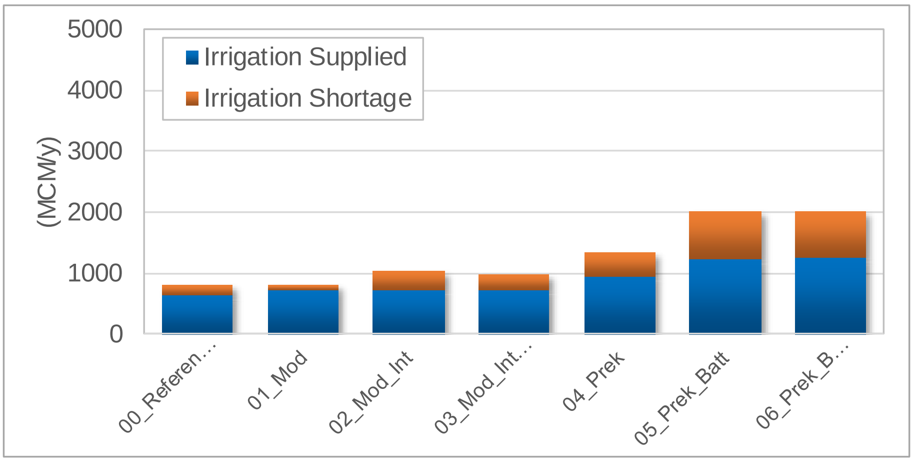


Figure 4-26: The same as above but for the wet season

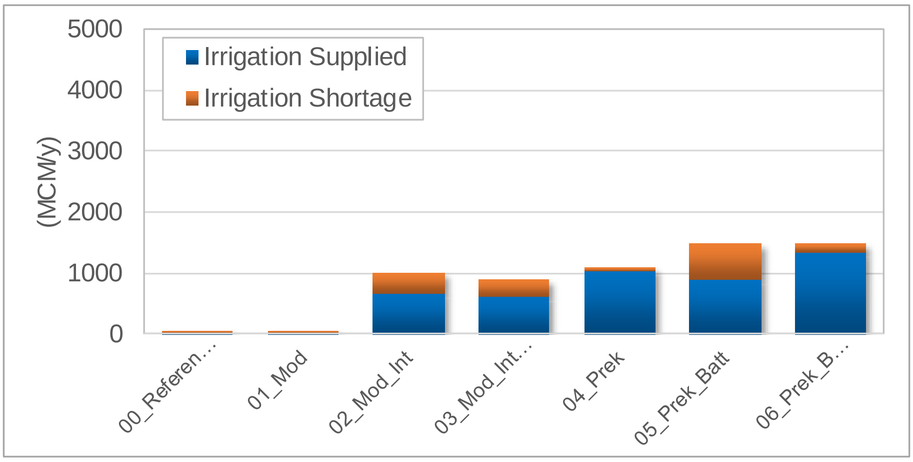


Figure 4-27: The same as above but for the dry season

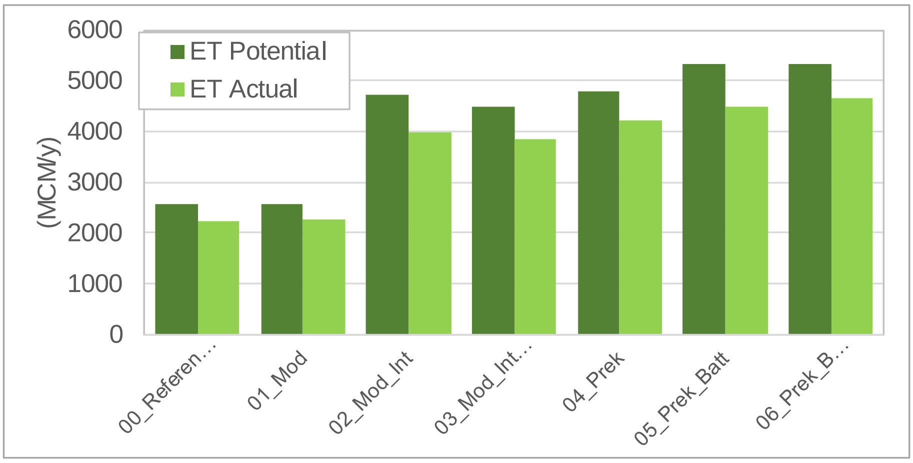


Figure 4-28: Potential crop water consumption and actual crop water use for the six investment scenarios (and reference). Results are based on 20 years averages.

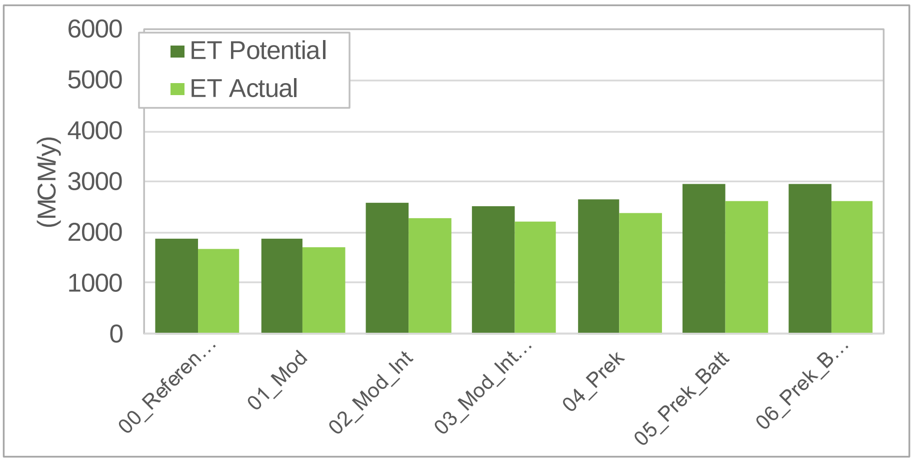


Figure 4-29: The same as above but for the wet season

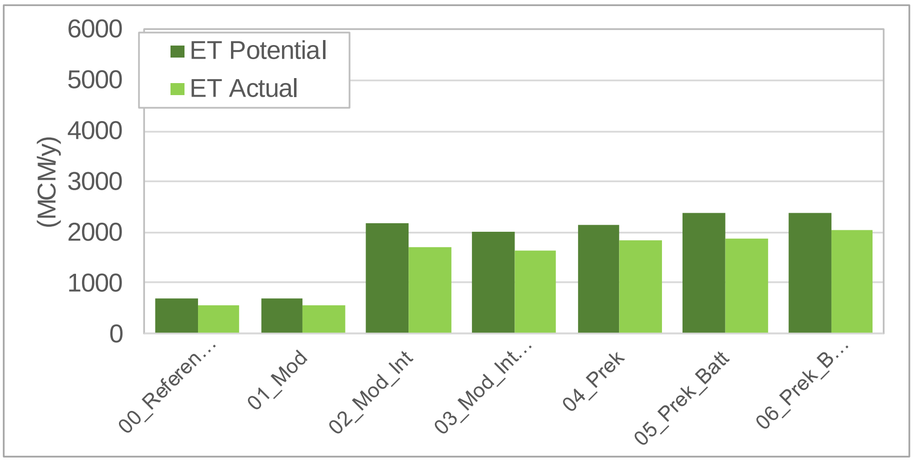
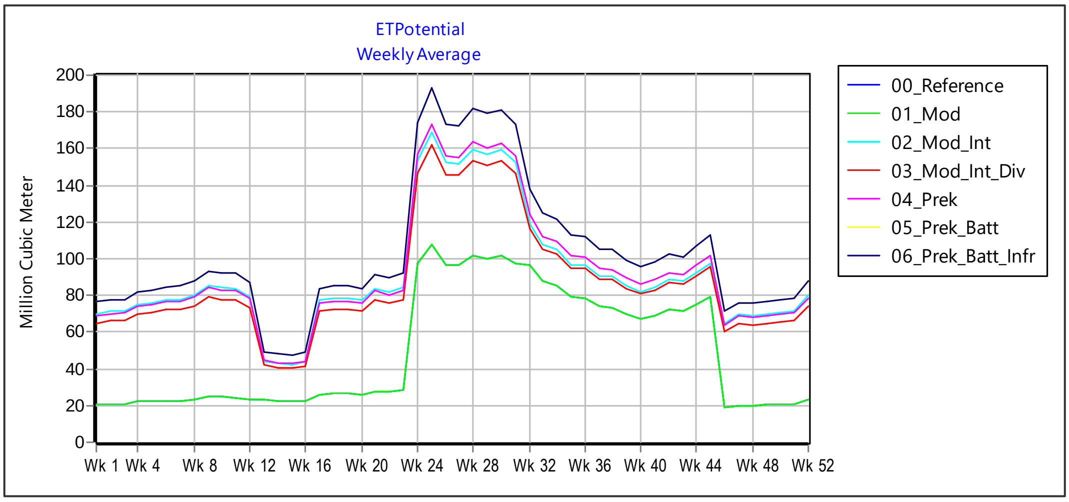


Figure 4-30: The same as above but for the dry season



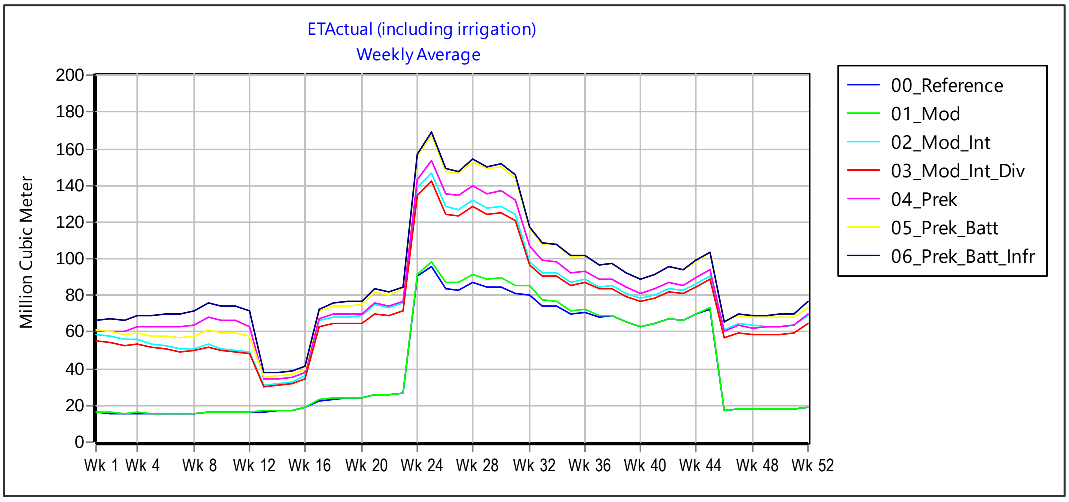


Figure 4-31: Average weekly crop water consumption (top) and crop water shortage for the six scenarios considered.

Further exploring Diversification

As discussed above, diversification as considered in the scenarios above causes a relatively small impact. Main reason is that only 30% of the area grown outside the wet season was considered to be vegetables. To explore a more drastic diversification strategy an additional scenario has been included assuming that 100% of the crops outside the wet season would be vegetables. Table 4-9 shows the impact of this additional scenario *(09_Mod_Int_Div)*. In this case, irrigation shortage is decreased considerably, by more than half compared to intensification scenario with only rice. Figure 4-32 shows similar figures for irrigation and ET as presented previously, but adding the additional scenario (last bar).

Table 4-9. Results of an additional explorative scenario assessing impact of intensification and diversification to at 100% vegetables outside the wet season

Annual Scenario	(MCM/y) Precipitation	(MCM/y) ET Potential	(MCM/y) ET Actual	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
00_Reference	2578	2576	2227	840	648	192	77%
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02_Mod_Int	4911	4743	3982	2026	1391	635	69%
03_Mod_Int_Div	4911	4509	3843	1868	1329	539	71%
09_Mod_int_Div	4911	3806	3370	1384	1117	267	81%

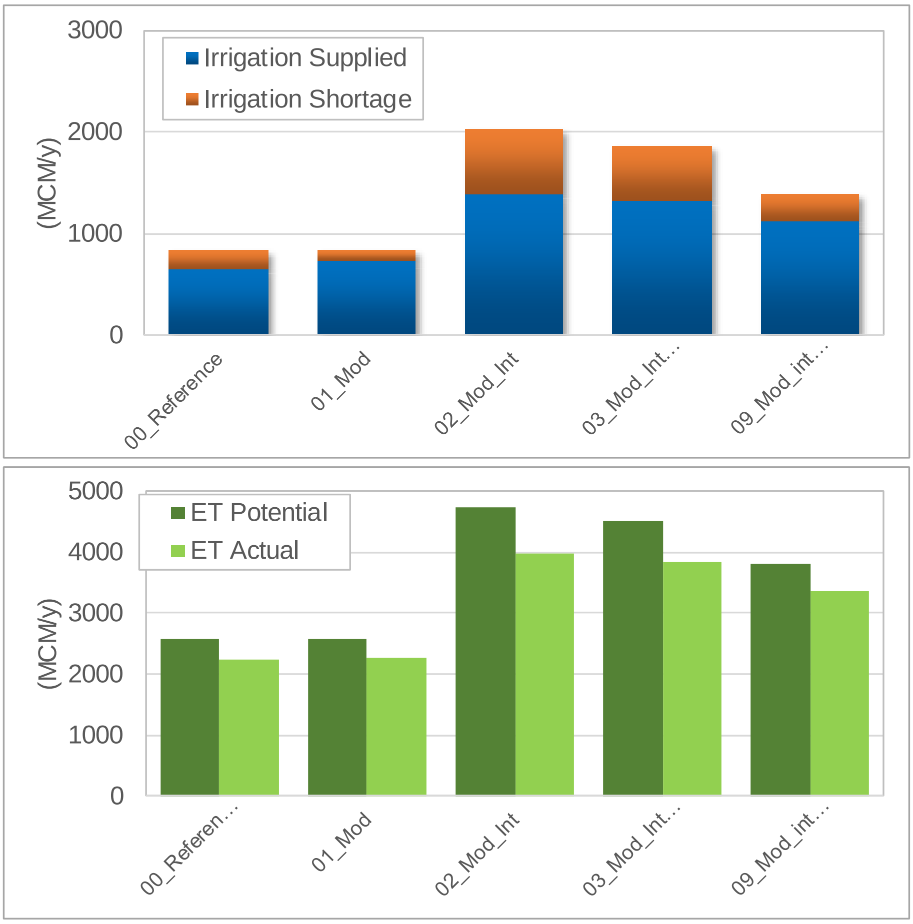


Figure 4-32. Above: irrigation supplied and shortage for the additional explorative scenario (last bar in the chart). Below: same with ET potential and ET Actual.

4.8.5 *Results: impacts on domestic use and environmental flows*

The water allocation options and investments related to irrigation and water resources development will likely also impact domestic water supply and environment flows. Table 4-10 shows water demands, supply required, supply delivered and the coverage for the domestic sector under the six investment scenarios. Please note that for this assessment it was assumed that all domestic water supplies are coming from surface water, and that the infrastructure is in place and operational.

Table 4-10 reflects that domestic water demands and supply requirements do not change as it was assumed that everything will remain constant to ensure that only the impact of the investment scenarios will be reflected. Please note that water demand and also the amount of water supplied to the domestic sector is an order of magnitude lower compared to the irrigation demands and supplies. Under the reference scenario domestic water supply and coverage are already quite high and are projected not to change under the other scenarios. It should be emphasized that coverages as presented in this study assume that the supply infrastructure is optimal. Any restrictions shown on water supply are because of water resources shortages; restrictions and failures in the domestic water supply infrastructure have not been considered.

Impact of the various investment scenarios on environmental flows are assessed by looking at flows downstream in the main rivers of Sangker River Basin Group (Figure 4-33 and Table 4-11). As expected, mean annual flows will reduce somewhat under all scenarios as more water will be consumed by the irrigation sector and for domestic water use. For environmental flows the exceedance of certain threshold flows (e.g. 1, 5 or 10 $m^3 s^{-1}$) is relevant. The analysis shows that overall no big changes can be expected in terms of low flows with the exception of the double cropping scenario (*06_IN_Irr*). The tables also show that there might be quite some variation between the different rivers.

Table 4-10: Impact of the six investment scenarios (and reference) on domestic water demand, supply and coverage expressed as water supplied over water demand. Results are based on 20 years averages.

Scenario	Water Demand (MCM/y)	Supply Required (MCM/y)	Supply Delivered (MCM/y)	Shortage (MCM/y)	Coverage (%)
00_Reference	44.1	55.2	52.2	3.0	95%
01_Mod	44.1	55.2	53.4	1.8	97%
02_Mod_Int	44.1	55.2	53.1	2.0	96%
03_Mod_Int_Div	44.1	55.2	53.1	2.0	96%
04_Prek	44.1	55.2	53.6	1.6	97%
05_Prek_Batt	44.1	55.2	53.1	2.0	96%
06_Prek_Batt_Infr	44.1	55.2	53.6	1.6	97%

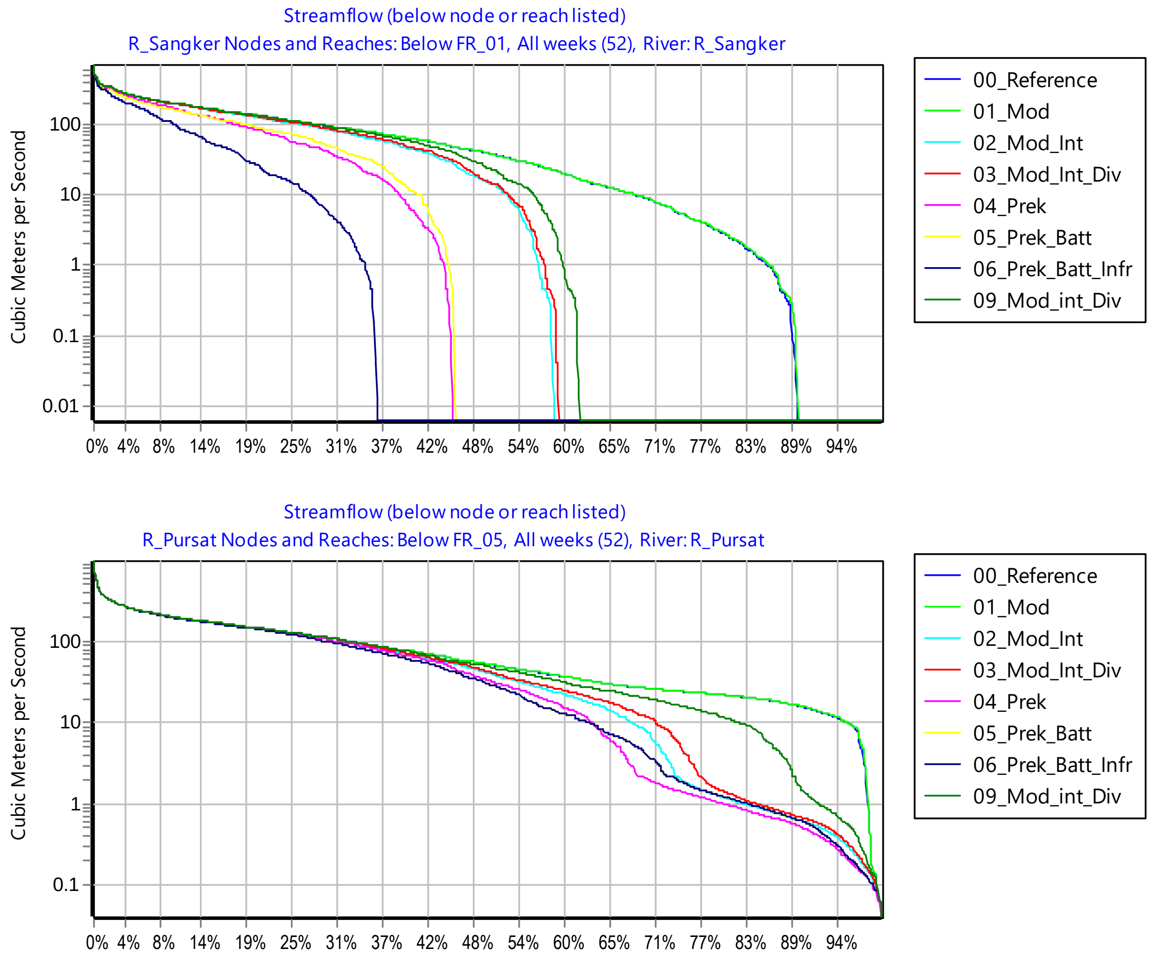


Figure 4-33: Impact of the six investment scenarios (and reference) on environmental streamflow requirements presented as weekly exceedance levels based on a period of 20 years downstream for Sangker (top) and Pursat (bottom).

Table 4-11: Key threshold values for the environmental streamflow requirements as extracted from Figure 4-33 for all scenarios and the total outlet of main rivers into Tonle Sap. Avg is the mean flow over a period of 20 years. Other columns indicate the percentage of days where flow is zero, below 1 $m^3 s^{-1}$, 5 $m^3 s^{-1}$, and <= 25 $m^3 s^{-1}$.

	Flows (m3/s)				
Scenario	avg	<=0	<=1	<=5	<=25
00_Reference	197.3	0%	1%	1%	11%
01_Mod	193.8	0%	1%	1%	13%
02_Mod_Int	171.7	0%	8%	24%	37%
03_Mod_Int_Div	174.1	0%	7%	22%	35%
04_Prek	151.6	0%	9%	29%	41%
05_Prek_Batt	150.7	0%	9%	27%	42%
06_Prek_Batt_Infr	130.9	0%	9%	27%	43%

5 Slakou-Toan Han Basin Group: Surface Water Resources Assessment

5.1 Catchment characterization

The Slakou-Toan Han Basin Group lies within the provinces of Kampot, Takeo, Kampong Speu and Kandal (Fig 3-37). The area was divided into 3 sub-catchments with a total area of 6,308km^2. The border with Vietnam makes up the southern edge of the Basin Group whilst the Bassac river runs parallel to eastern side.

The elevation within the region ranges from 776m in the north-eastern region towards the Cardamom mountains down to -1.6m in the south which is part of the low-lying Mekong Delta (Fig 3-38). In terms of geology within the region, young alluvium and old alluvium bedrock represent 72% and 22% of the percentage area, respectively (Fig 3-39).

Acrisol soil covers 73% of the Basin Group, which is a fertile top-soil. Plinthosol soil covers 10% of the region which is characterised by impenetrability (Fig 3-40).

The SERVIR database shows that the ‘rice’ and ‘cropland’ land cover classes make up over 80% of the total Basin Group area in both 1987 and 2018 (Fig 3-41, Fig 3-42). The percentage area of ‘rice’ increased by 7% over this period whilst the percentage area of ‘cropland’ decreased by 2%. The remainder of land cover classes did not increase or decrease in area significantly apart from ‘flooded forest’ which decreased in percentage area by 3%. CISIS irrigation statistics show that a large proportion of the total irrigated area occurs in the wet, recession and dry season with 42%, 35% and 20% of the total irrigated area, respectively (Fig 3-43).

Figure 3-44 exhibits a 1 in 100 year flood scenario and shows that the eastern and southern borders of the Basin Group would be inundated. Furthermore, a very high flood occurrence is also shown in these areas. From Figure 3-45, which shows the dry season actual evapotranspiration the central northern section of the region can be identified as the area most lacking in water, whereas the central eastern region exhibits high evapotranspiration indicating abundant water supply.

Finally, Figure 3-46 shows the location of the 2 protected areas in this Basin Group. Data showing the location of river blockages and CFRs was not available for this region. Further information about these environmental protected areas can be found in Table 3-19.

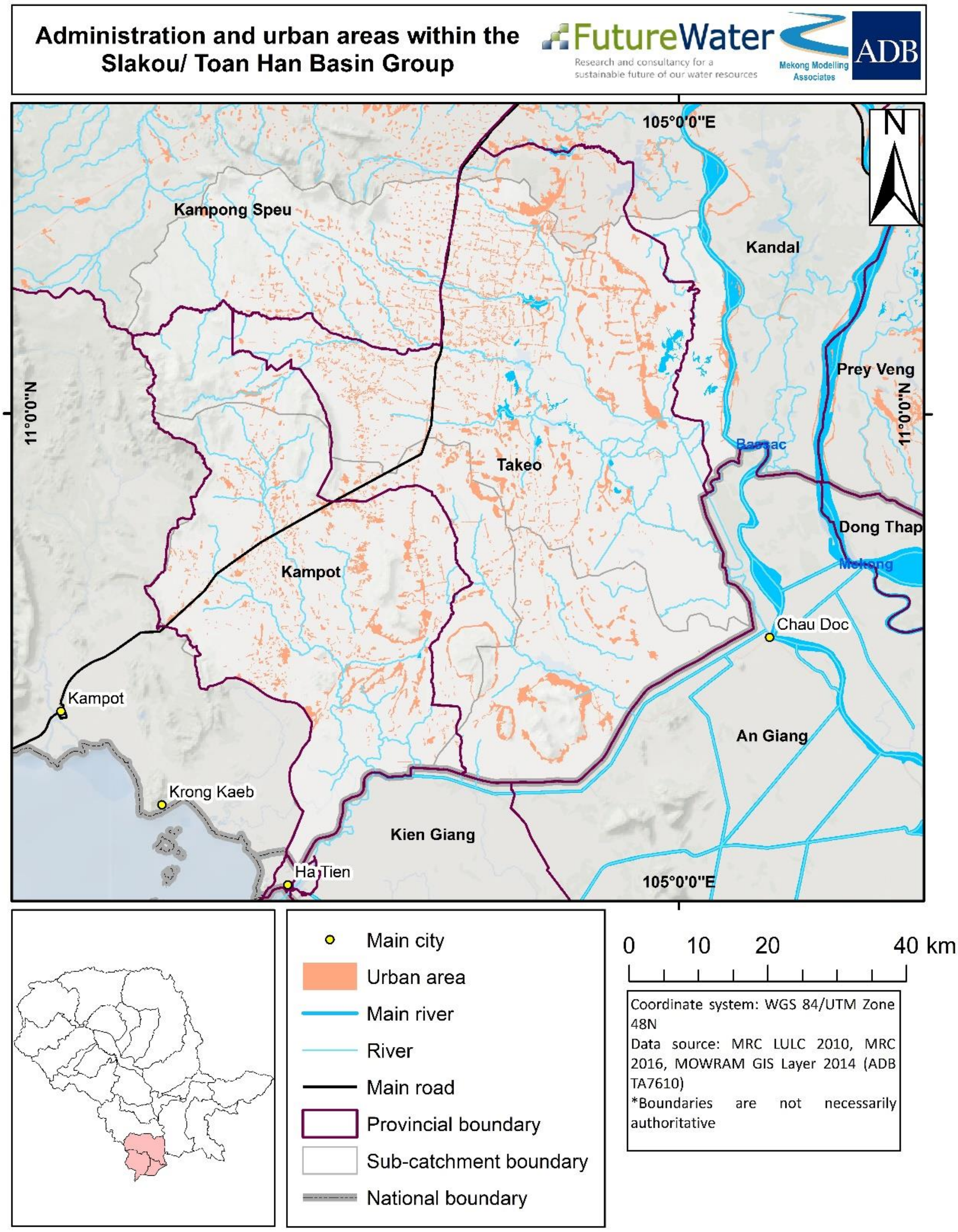


Figure 5-1: Administration and urban areas within the Slakou/ Toan Han Basin Group.

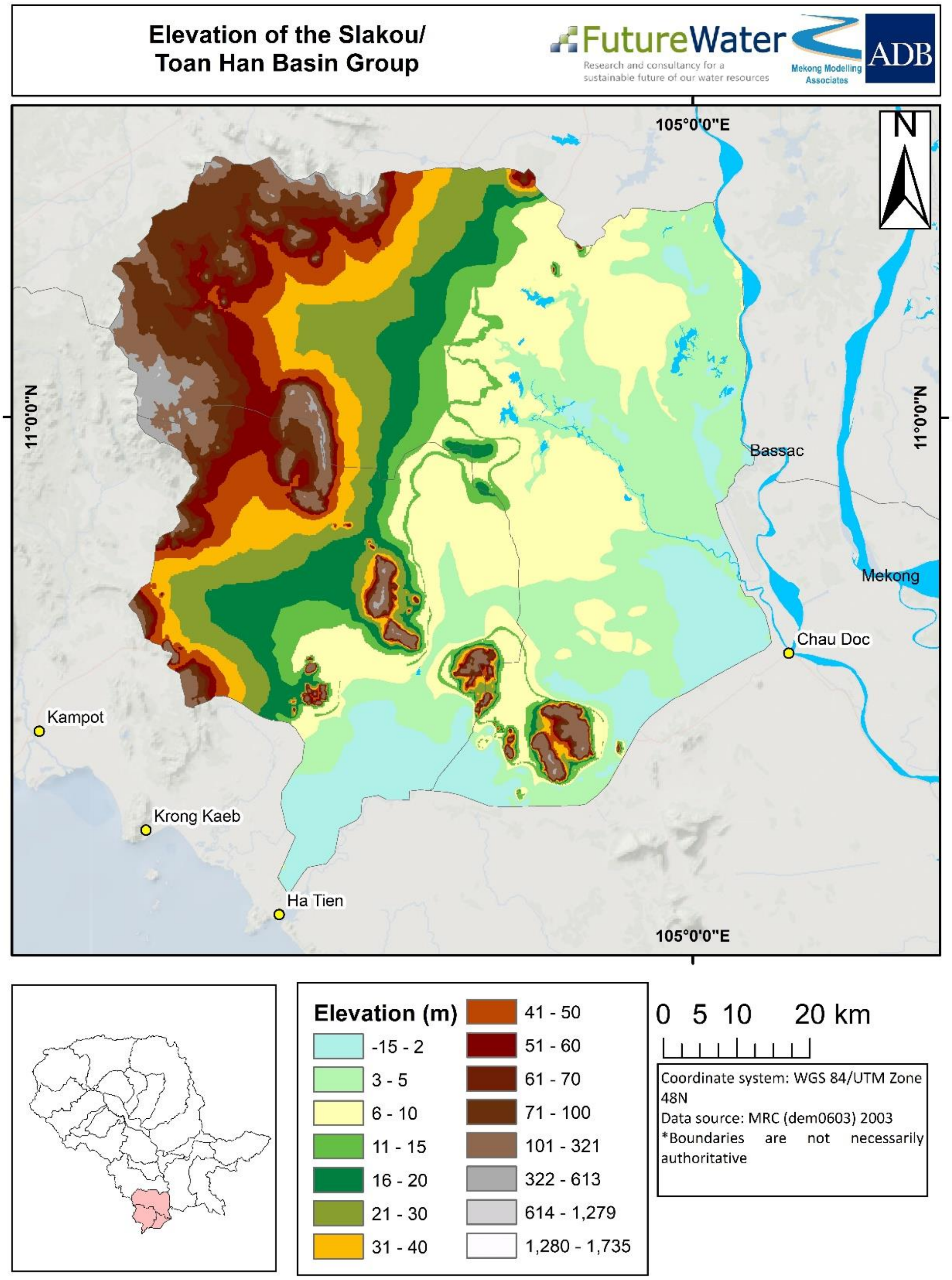


Figure 5-2: Elevation of the Slakou/ Toan Han Basin Group.

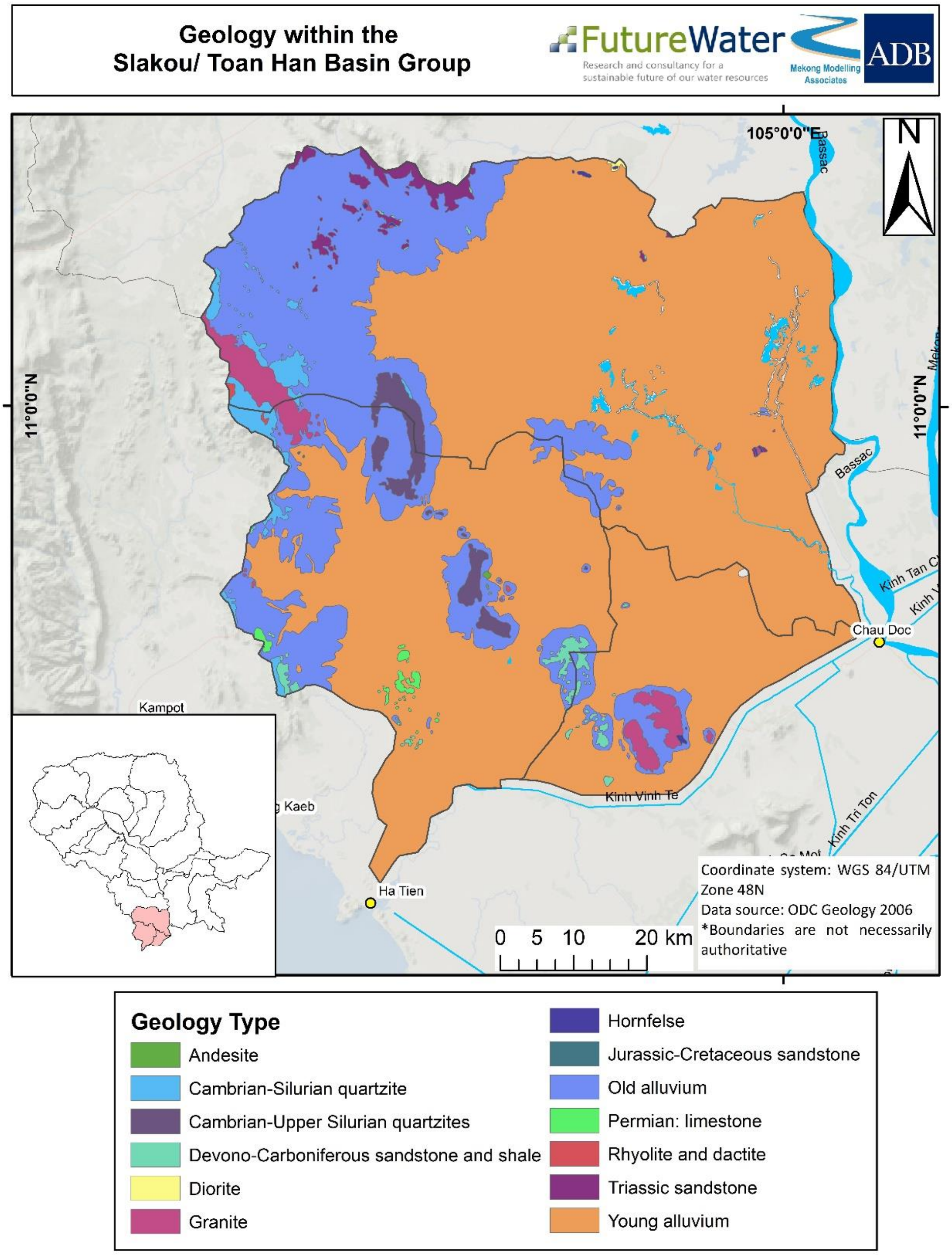


Figure 5-3: Geology within the Slakou/ Toan Han Basin Group.

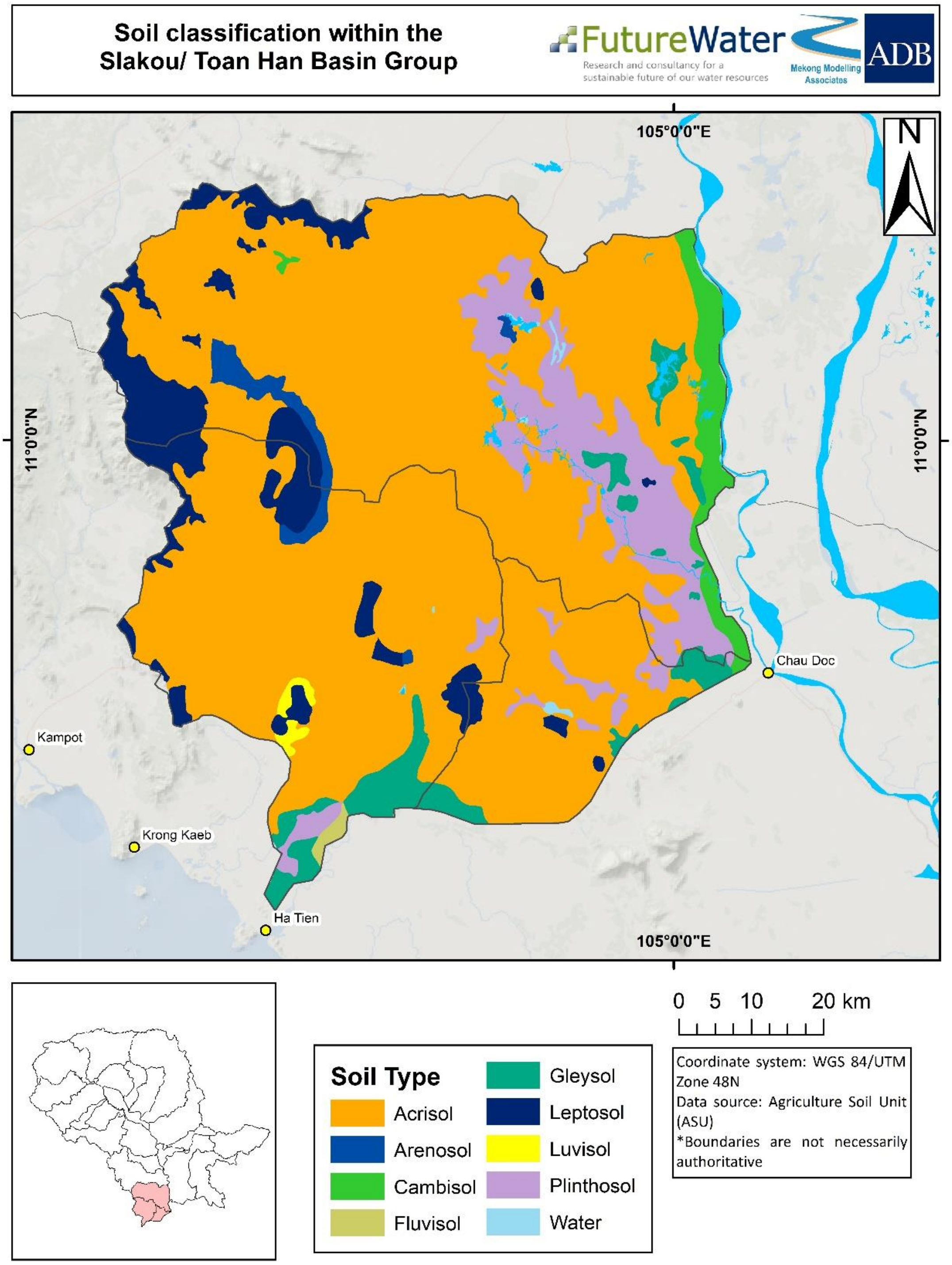


Figure 5-4: Soil classification within the Slakou/ Toan Han Basin Group.

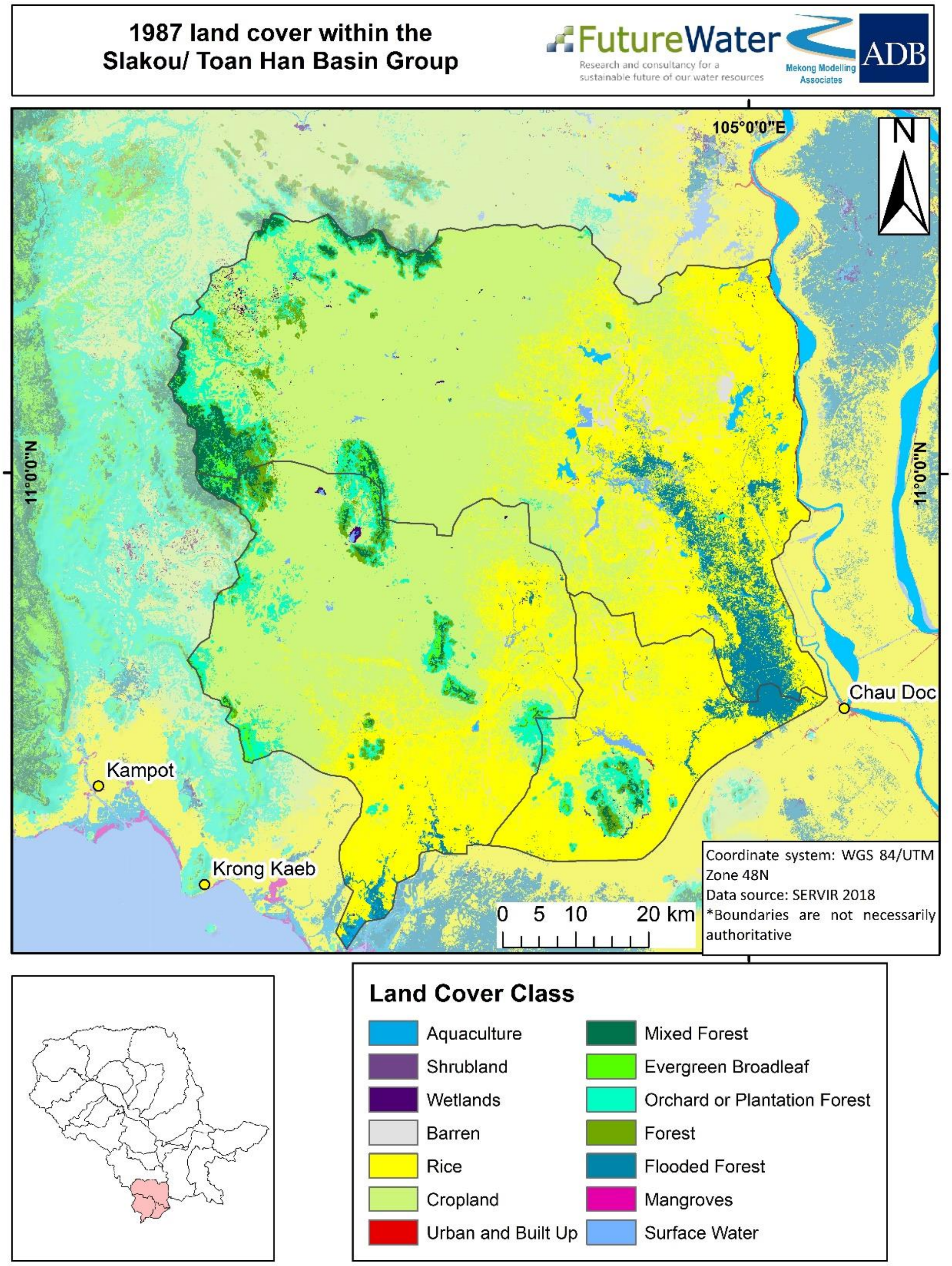


Figure 5-5: 1987 land cover within the Slakou/ Toan Han Basin Group.

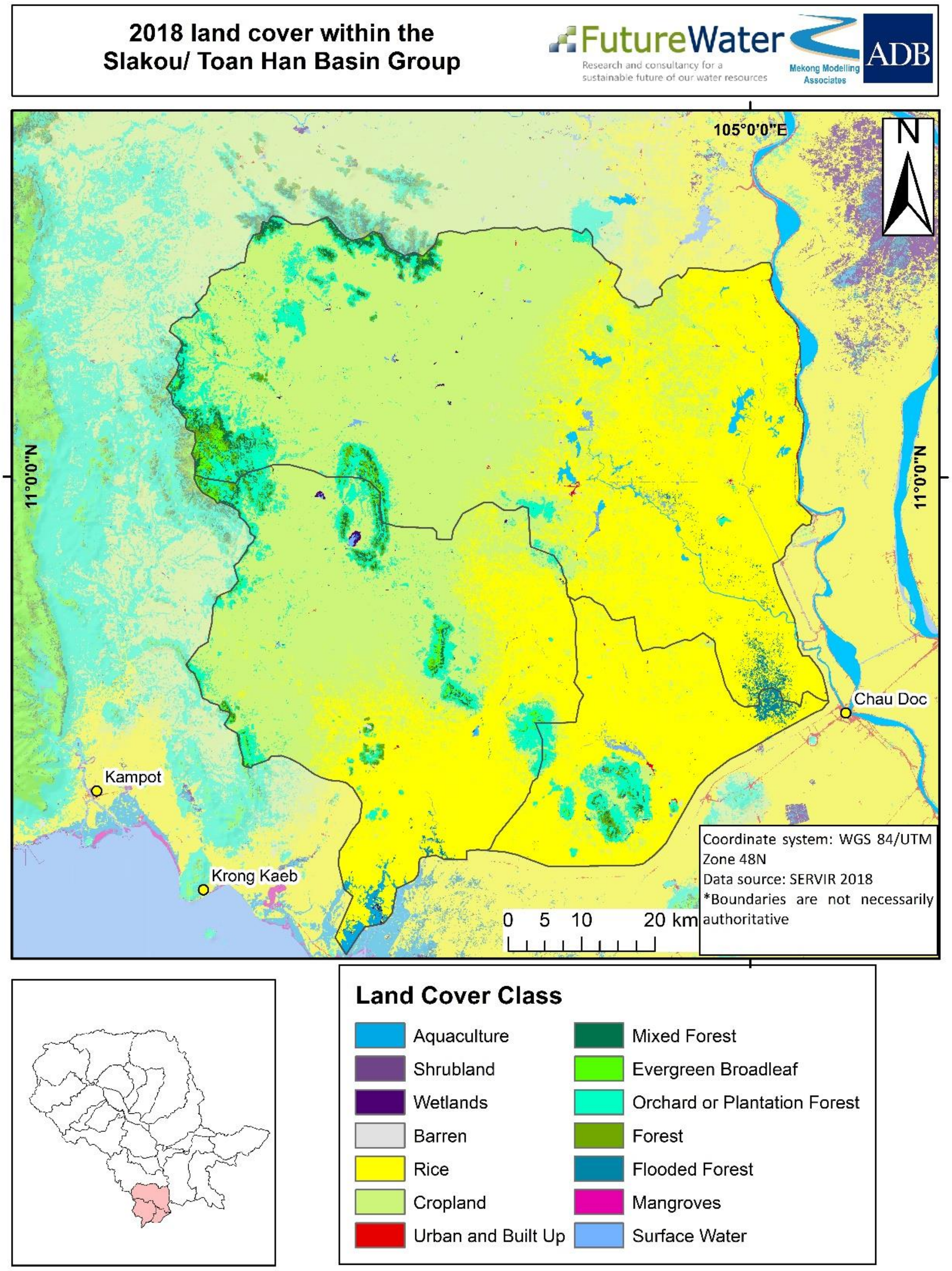


Figure 5-6: 2018 land cover within the Slakou/ Toan Han Basin Group.

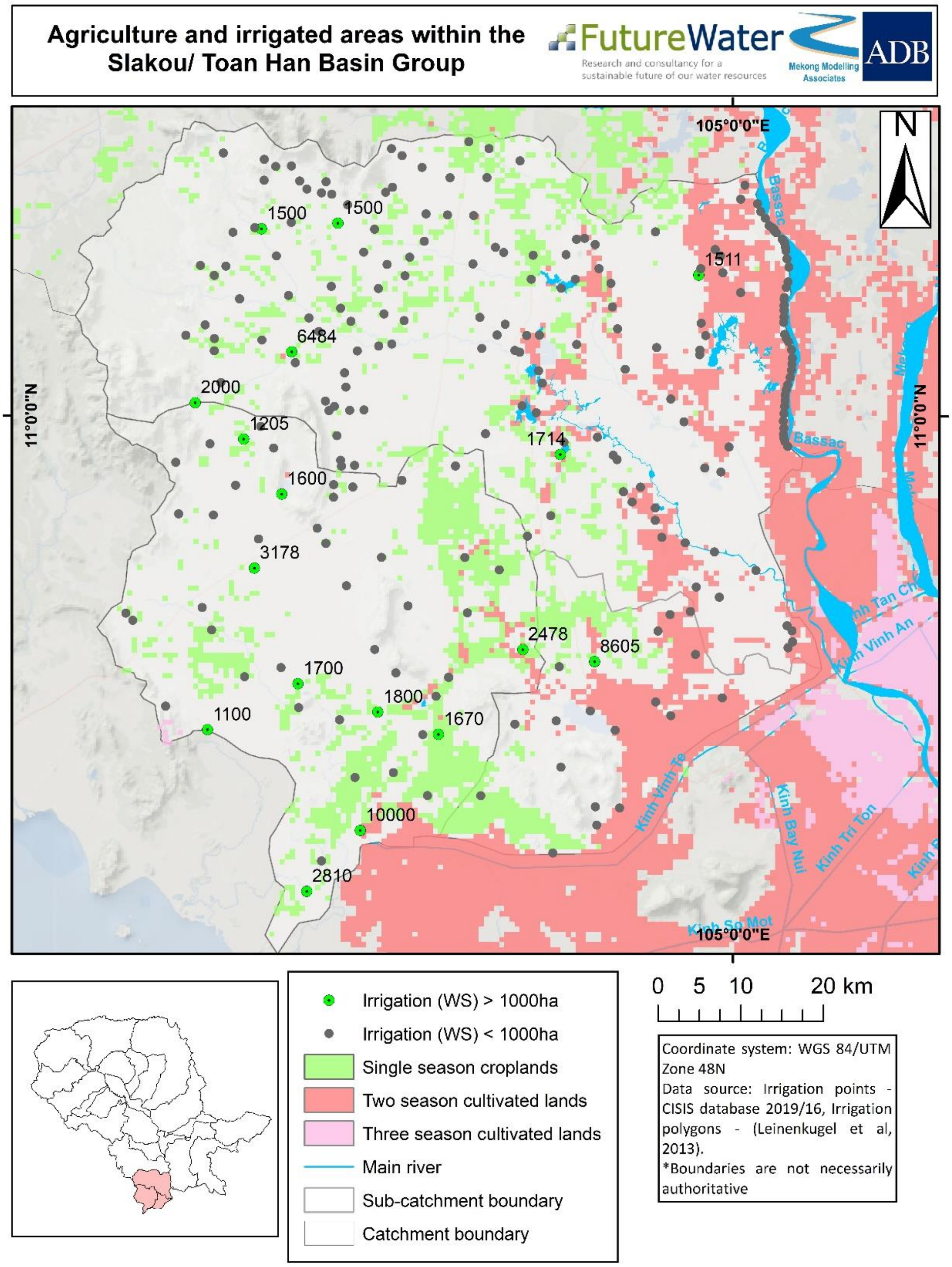


Figure 5-7: Agriculture and irrigated areas within the Slakou/ Toan Han Basin Group.

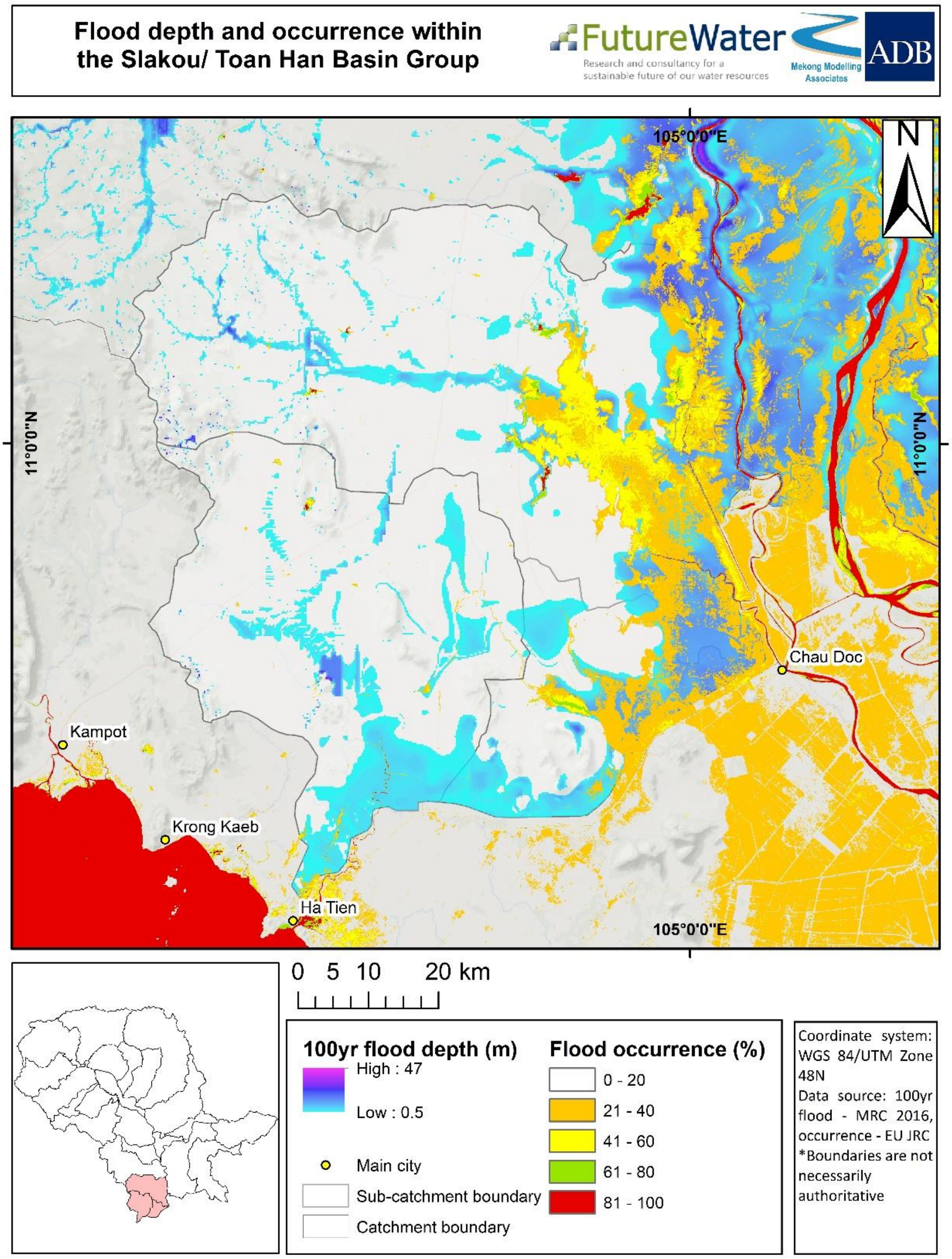


Figure 5-8: Flood frequency within the Slakou/ Toan Han Basin Group.

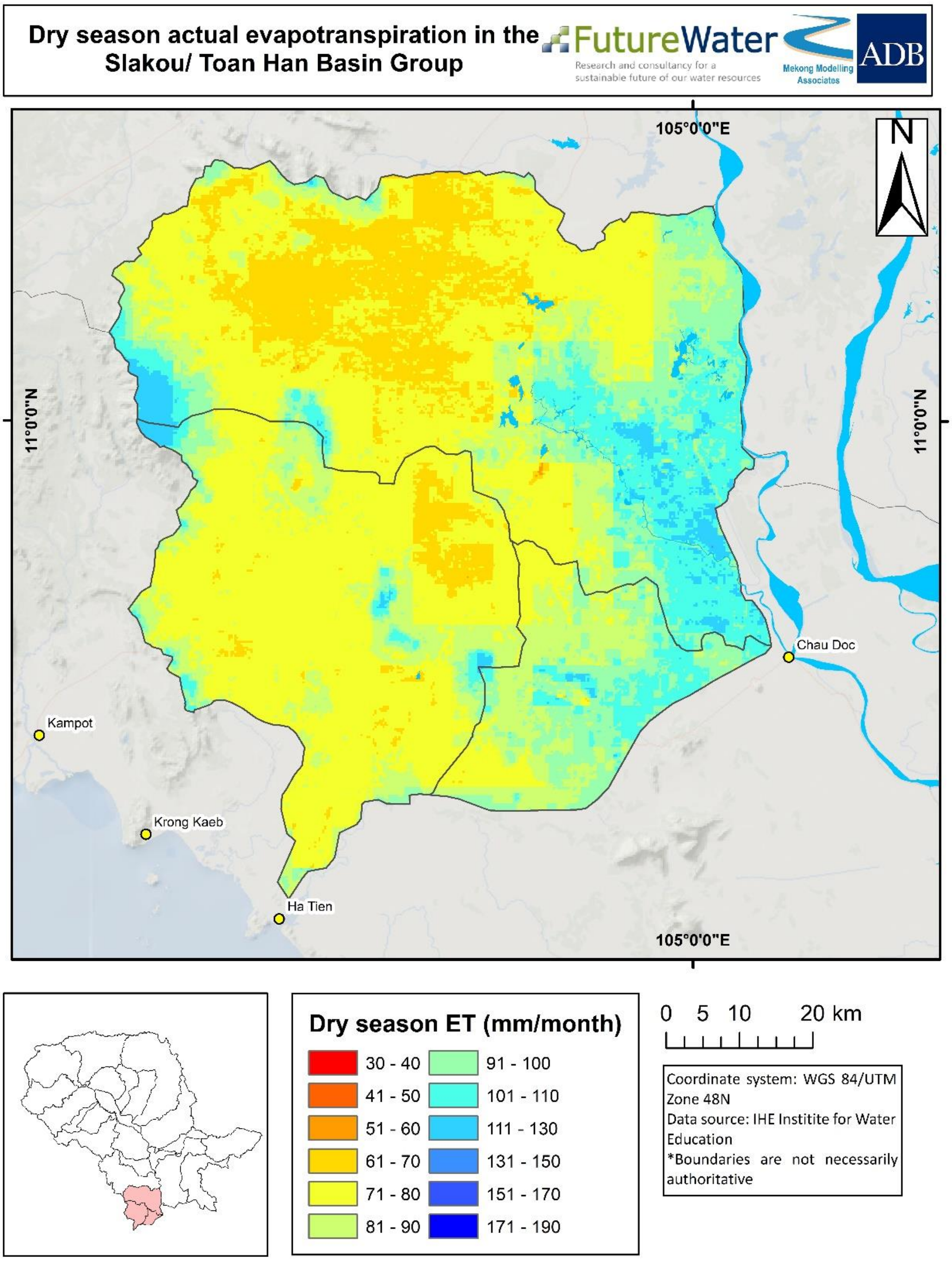


Figure 5-9: Dry season evapotranspiration in the Slakou/ Toan Han Basin Group.

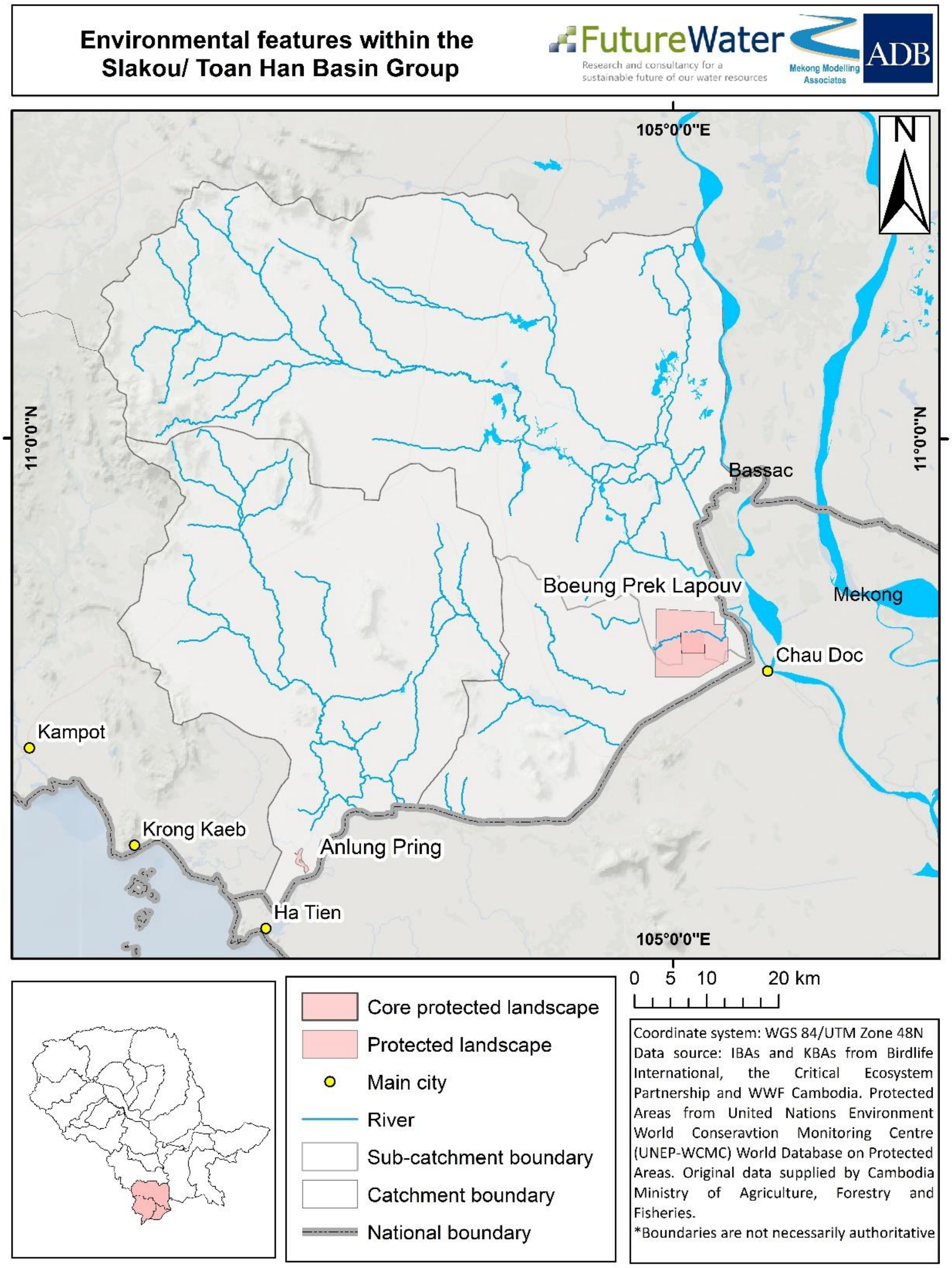


Figure 5-10: Environmental features within the Slakou/ Toan Han Basin Group.

5.2 Water uses

Principal water uses in this basin group are:

- Domestic
- Irrigation
- Environmental (including fisheries)

Recent data has been collected in Phase II on the irrigation areas from the most recent version of the CISIS database. Updated data per catchment in the basin group is presented in Table 5-1, also including population data for each basin. The catchment delineation is the one used in the detailed hydrological modeling (see section 5.6). Information on the environmental use of water is given in section 5.5.

Table 5-1: Population and irrigated areas per catchment of the Slakou-Toan Han basin group.

	2016 population			Irrigation (ha, CISIS Database 2018)				Catchment Area (km^2)
Catchment	Rural	Urban	Total	Real Dry Season	Dry in Wet	Wet Season	Recession	
Mekong Delta	278,383	130,520	1,942,425	57,702	10,198	89,241	29,309	2,056
Toan Han	251,031	126,953	377,984	0	0	10,603	24,635	774
Slakou	371,182	431,494	802,676	4,527	270	33,134	57,425	3,479
Total	900,596	688,967	3,123,085	62,229	10,468	132,978	111,369	6,308

These data have been used to estimate water demands in the Water Supply and Demand Framework and based on a number of data and assumptions listed in section 5.6. How that translates to water demands is presented in section 5.7.

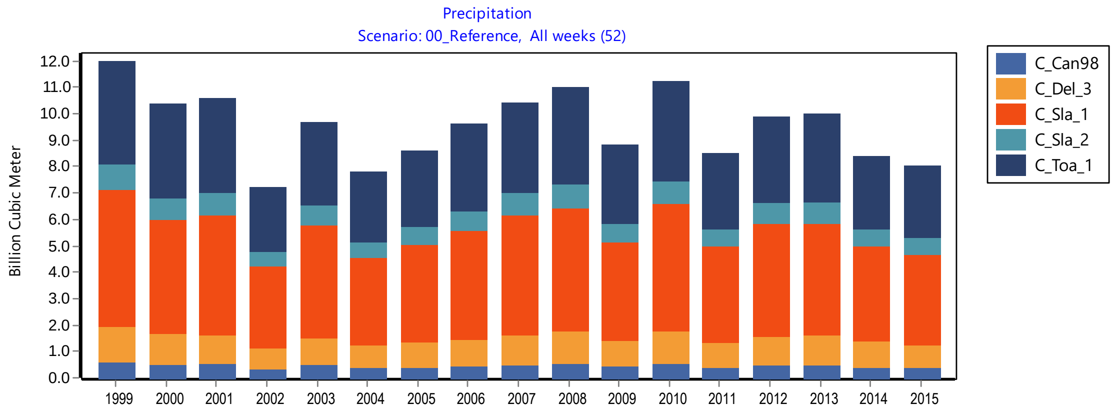
5.3 Water availability

Results of water resources availability for Results: impacts on domestic use and environmental flows, Stung Slakou, and area related to the Mekong delta which lies between these basins, were presented in the Phase I report, by various tables and graphs. Evaluations were based on available data, previous studies and the Water Supply and Demand Framework (WSDF) as implemented using the WEAP model. From this analysis,

Table 5-2. Water resources availability for the Slakou-Toan Han basin group

(MCM/y)	Stung Toan Ha	Stung Slakou	Mekong delta area	Total
Precipitation	3239	5252	1381	9872
Irrigation supply	82	206	48	337
Outflow to downstream	684	1511	545	2741
Actual evapotranspiration	2402	3830	854	7086
Groundwater recharge	240	472	110	821

Rainfall varies over the years and months. The annual and weekly variability is given in Figure 5-11.



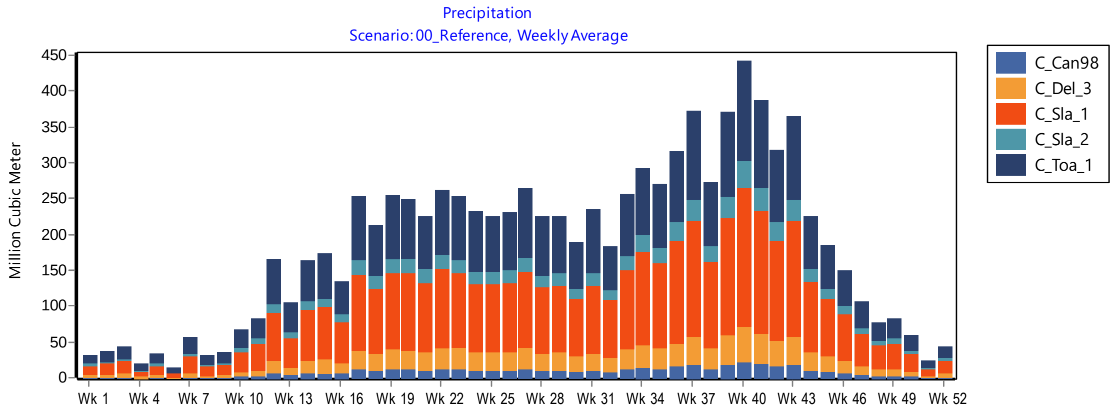


Figure 5-11. Annual (up) and weekly (below) variability of rainfall in the Slakou-Toan Han basin group

Another supply of water is the Mekong delta area, that brings flood waters to the area, which are used mainly for recession rice. No measurements are available on how much water is supplied from this source. For the analysis presented here, outputs from the ISIS models were used, and supplies from this source were dynamically modelled in the Water Supply and Demand Framework.

5.4 Climate risks

According to Sophanna et al. (2019) in their assessment of climate change vulnerability of BPL, climate change is expected to lead to an increase of maximum temperatures during both the dry and wet seasons. In addition, dry season precipitation is predicted to decrease, and wet season precipitation will increase. They consider that the duration of floods at BPL will increase by 3-7 days, while there may also be a minor increase in the period of drought, leading to prolonged and more severe water shortages. They consider that open water habitats containing aquatic plants are the most vulnerable ecosystems, while grasslands and shrubs and gallery forest are more resilient. However, as observed by local community members interviewed by Sophanna et al. (2019), "non-climate impacts such as land encroachment, shrub burning, agricultural runoff, bird poaching, and illegal fishing have impacted BPL far more than severe weather events thus far". Water related interventions led by MOWRAM are expected in the watershed in the near future, which can either further threaten BPL and its ecosystems (5.5.1–5.5.4) or provide an opportunity to install a greater resilience by creating water management infrastructure at BPL that enables reserve manages to assume control (5.5.5).

Similar climate change impacts (as outlined by Sophanna et al. 2019 for BPL) can also be expected at Preak Tonloab lake and the Anlung Pring crane reserve, i.e. greater floods and slightly longer and drier dry seasons. At Preak Tonloab increased floods may impact communities and their livelihoods adjacent the lake, although (minor) impacts on fisheries and bird life are not expected to be significant compared to other factors such as intensive fishing, use of agrochemicals and habitat conversion. At Anlung Pring the potential impact of climate change on bird life may be more significant, as during the dry season suitable habitat (for foraging) already appears limiting for species such as Sarus cranes and this may decline further unless mitigated.

Also, water allocation and water resources developments may be affected by climate change. For this study, an ensemble of climate models was therefore considered to assess how shifting climate averages may affect future water related interventions. Results of the climate risk screening analysis, reported in a separate report, are summarized here for this basin group.

5.4.1 *Climate projections*

In general, model outputs suggest an increase in both precipitation and temperature (Figure 5-12), notably for the further time horizon (2070-2099). These may be summarized as such:

- Increases in temperature range from 0.2 – 1.8°C between the years 2020-2049, with little difference in predictions between the two respective RCPs.
- Increases in temperature between 2070-2099 have a much greater range (from 0.9 – 4.5°C), with greater increases in temperature anticipated by the climate model ensemble for RCP8.5.
- Predictions for changes in precipitation range between an 8% decrease and a 22% increase for the period 2020-2049, with most climate models predicting an increase.
- Predictions for changes in precipitation range between an 8% decrease and a 24% increase for the period 2020-2049, with a large majority of climate models predicting an increase. A greater range in predictions is evident under RCP85.

Overall, it is clear that the model ensemble anticipates a hotter climate in both the near and distant futures and under both RCP scenarios for this basin group. Predictions of precipitation changes are more uncertain, but overall suggest a wetter climate with higher annual precipitation in the future.

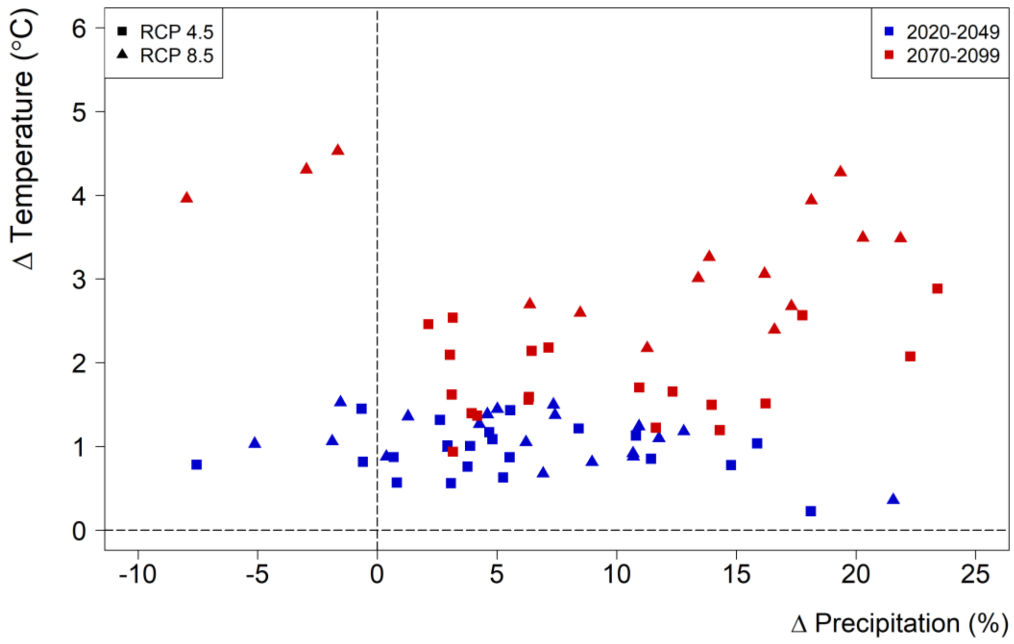


Figure 5-12. Average trends in temperature and precipitation for the Slakou-Toan basin group as predicted by the climate models considered in this study.

as predicted by the climate model ensemble are also considered relevant to this water resources assessment in that this indicator can be used as a proxy for assessing the impacts of climate change on drought events. In this way both climate averages and extremes are considered in relation to water availability.

Model outputs do not show a clear trend in drought period length, as demonstrated by the indicator Annual Consecutive Dry Days (CDD). The analysis shows that there is a high range in predictions and a high level of overlap between historical and future scenarios for both RCPs (Figure 5-13). A larger range in predictions is evident at the higher RCP scenario and at the 2070-2099 time horizon. When the ensemble mean is considered, however, a small increase is predicted in CDD for all RCPs and scenarios besides RCP45 at the 2020-2049 horizon.

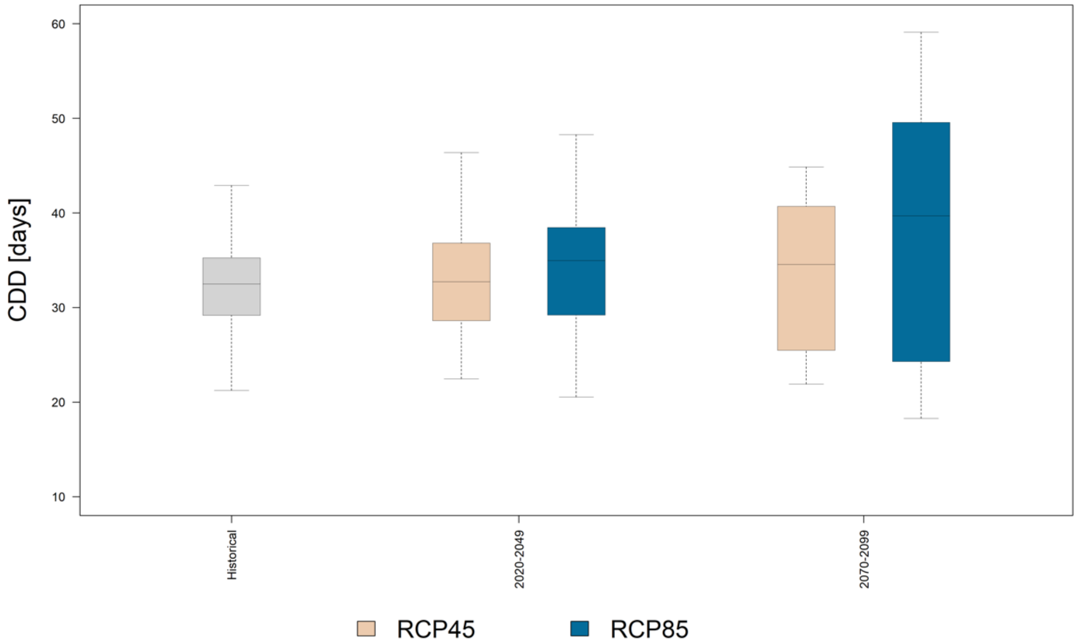


Figure 5-13. Trends in CDD in the Slakou-Toan basin group at both RCP pathways and future time horizons. Variability in box plots indicates the range in predictions between climate models.

5.4.2 *Risks to water availability*

Based on annual rainfall and annual temperature changes, a first-order estimate can be made of how these changes influence annual flows through the basin group. This methodology relates changes in temperature to changes in evapotranspiration using a simple empirical formula (the Hargreaves equation for potential evapotranspiration) to predict future relative changes in evapotranspiration under increasing temperatures. Changes in mean annual flows can subsequently be approximated based on the difference between projected precipitation and evapotranspiration per basin group. These estimates are useful mainly for relative changes, and when comparing a large variety of climate model-outcomes. They allow for an approximation of how uncertainties in climate models regarding temperature and precipitation predictions relate to the uncertainties in water availability (expressed as annual flows).

These calculations indicate that the majority of models predict an increase in average annual flows through this basin group (Figure 5-14). The values related to this are such:

- Climate model ensemble returns a mean predicted increase in annual flow of 7% and 8% for the period 2020-2049 under respective RCP45 and RCP85 pathways
- Climate model ensemble returns a mean predicted increase in annual flow of 17% and 33.5% for the period 2070-2099 under respective RCP45 and RCP85 pathways
- Assuming variability between climate models and for different RCP pathways is representative of a range of likely future scenarios, the probability that annual flow will increase in this basin group is 78% and 83% for time horizons 2020-2049 and 2070-2099 respectively

Overall, therefore, the climate model ensemble suggests that water availability is unlikely (less than 25%) to be negatively affected by trends in temperature and precipitation induced by climate change, in line with other studies. This is by no means certain, however, as other studies in the areas come to opposite conclusions. Indeed, Oeurng et al. (2019) predict decreases in average flows in the Tonle Sap Basin of up to 41% when a different model framework is considered. It is evident that a detailed climate risk assessment is therefore necessary in this area.

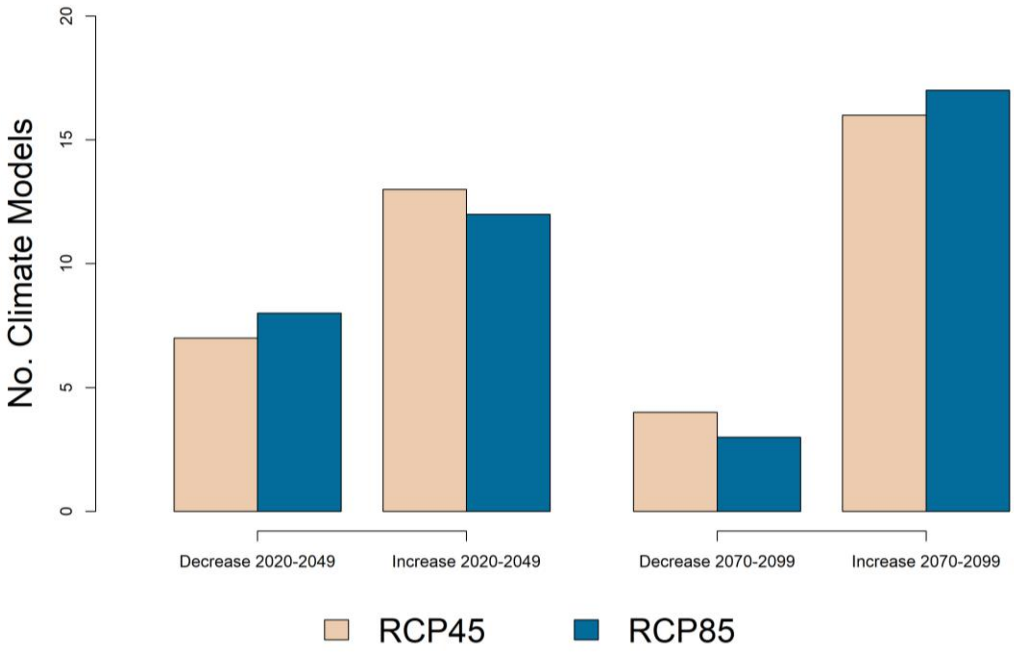


Figure 5-14. Number of models that predict a positive/negative relative changes in mean annual flows for the Slakou-Toan basin group.

Alongside average changes in climate, seasonality should also be a consideration in relation to water availability. It is possible that annual flows may increase on average, but droughts in the dry season may remain a severe problem. To assess this, detailed hydrological modeling is required, which was out of scope of this study. However, the previously assessed indicator CDD gives an impression of changes in the lengths of drought periods (which can be assumed are related to dry season rainfall depths). Model outputs for CDD can be summarized as such:

- 13 out of 20 climate models predict an increase in CDD under the RCP45 scenario between 2020-2049, with 5 out of 20 models predicting an increase under the RCP85 scenario for the same time period
- 15 out of 20 climate models predict an increase in CDD under the RCP45 scenario between 2070-2099, with 13 out of 20 models predicting an increase under the RCP85 scenario for the same time period
- Assuming variability between climate models and for different RCP pathways is representative of a range of likely future scenarios, the probability that CDD will increase in this basin group is 70% and 45% for time horizons 2020-2049 and 2070-2099 respectively

Based on these results, future trends in CDD are clearly highly uncertain, with no clear consensus between models. There is some indication, however, that this basin group may face increased prolonged periods of drought in the far future (2070-2099). Increases in the length and severity of drought events due to climate change should be considered in relation to proposed developments in the basin as this may represent a risk to future water availability.

5.4.3 *Other climate related risks*

Besides risks to water availability, proposed projects in this basin group may also be affected by other climate-related risks. These include the following:

- Flooding – Longer and more intense periods of precipitation are likely to lead to higher flood risk into the future, especially in the east of the basin group close to branches of the Mekong
- Land degradation – Increased intensity of precipitation events is likely to lead to increases in soil erosion and will increase the probability of landslides in the basin group
- Extreme heat – maximum annual temperatures are likely to increase under a changing climate, leading to heatwaves and increasing the probability of wildfires

More detailed information on climate related vulnerabilities and risks in relation to this basin group can be found in the associated Climate Risk and Vulnerability study written to accompany this report (FutureWater, 2019).

5.5 Environmental risks identified

There are three key wetlands located in this part of the Slakou/Toan Han that may be affected by additional water resources development, and these are:

- Boeng Prek Lapouv crane reserve
- Preak Tonloab lake
- Anlung Pring crane reserve.

Table 5-3: Protected areas, IBAs and KBAs in Stung Toan Han and Stung Slakou sub-catchments.

Protected Area	Habitat	Area (Ha)	Sub-catchment
Boeung Prek Lapouv*	Seasonally inundated grassland	9,276	Stung Slakou
Anlung Pring*	Seasonally inundated grassland	217	Stung Toan Han
IBAs and KBAs			
Kampong Trach IBA	Seasonally inundated grassland	1,108	Stung Toan Han

** Protected areas are also IBAs*

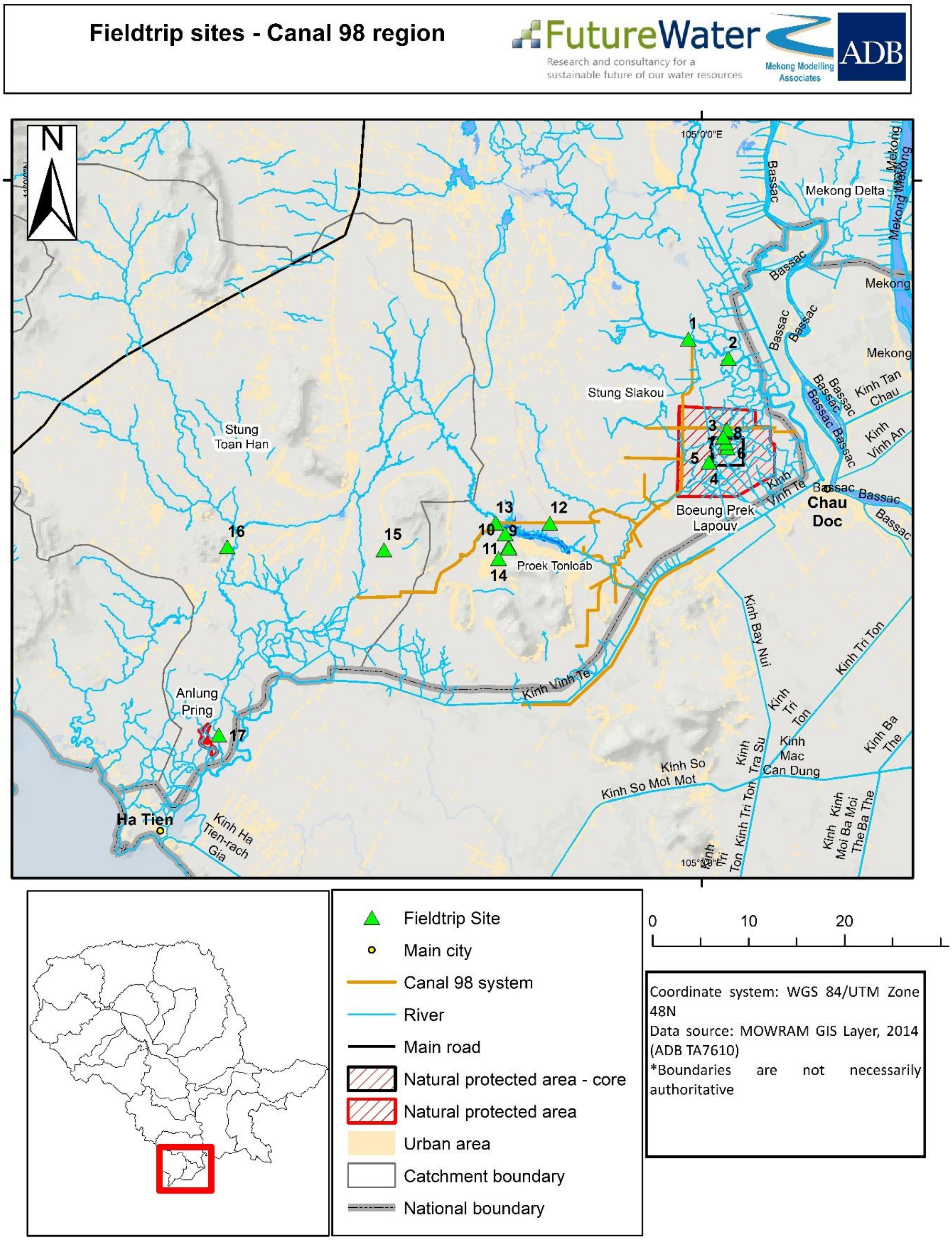


Figure 5-15: Environmental features and fieldtrip sites – Canal 98 region.

5.5.1 *Environmental constraints*

Boeng Prek Lapouv:

Officially, BPL consists of a 919ha central Core zone surrounded by a 3-4 km wide buffer zone (7,386 ha) consisting of a Conservation zone, Multiple use zone and a Community zone. In practice, though, only the core area is a protected area, the rest is all used for rice cultivation. The area was protected primarily because it supports a non-breeding Sarus Crane population outside of their breeding period (July – September). These birds visit BPL during the dry season, between December and March, when grassland is sufficiently wetted so that it is soft enough to forage for food sources such as water chestnut (*Eleocharis dulcis*) tubulars and insects.

BPL receives flow from Stung Takeo via irrigation canals and the Prek Lapouv from the north west. The area is inundated for 3-4 months per year. The reserve's hydrology has been altered by canal construction, both in the Pol Pot regime and later (1990s) by the EU-funded PRASAC project that resulted in the construction of Canal 98. Currently, the area in the south of the Canal 98 command area is not irrigated as the canal has silted up too much. The Core zone is slightly drained by Pol Pot era canals, but these are largely silted up. According to MOWRAM, desilting is to be carried out, along with concrete lining of sections of sandy soil where there is lots of infiltration. A section of a former river still remains as a 300 m long, 5m wide, 2-2.5 m deep body of water in the middle of the reserve area that serves as a source of fish stock.

The main issue at BPL is that the reserve area is drying out much sooner than in the past, and according to reserve management and BirdLife Cambodia (who have a conservation programme at BPL) this is largely due to increased water extraction (pumping) from the canals around the reserve (as silted-up main canals such as [parts of] Canal 98 do not provide enough water). Other issues include poaching/hunting (though, reportedly not much anymore), encroachment (on the northeast of the Core zone), pollution from pesticides and fertilizers from the adjacent rice paddies, noise and disturbance from ongoing mechanized farming practices and fires in 2018 and 2019 (not in 2016 and 2017).

Preak Tonloab:

The northern part of the proposed link canal alignment traverses a 400ha shallow lake, Preak Tonloab, which seems to have been created by the construction of the road that runs along the eastern end (Highway #3). Most of the area around the lake consists of rice paddies that are flooded in the wet season and are used for fishing. There is a very high density of fishing nets and traps, all with nets of very fine (and illegal) mesh size. These are illegal under Cambodian Fisheries Law, which prohibits use of any gear with mesh size less than 1.5 cm. In many cases the fine-mesh gears catch very small juvenile fish which are sold to feed to snakeheads (*Channa* spp.) raised in fish farms. The fine-mesh fishery thereby depletes the natural fishery. Given the presence of these gears without sanction at this location, it can be assumed that other illegal and destructive methods are also used, especially electrofishing and possibly explosives and poisons, which not only kill fish but also other aquatic animals and are hazardous for people. MAFF field staff arrest and prosecute many illegal fishers throughout the Cambodia each year, and these efforts need to be strongly supported if conservation areas are to meet their objectives. Community Fisheries Groups and the local members of Community Fish Refuges can be supported to work with MAFF staff to assist in these efforts. In the dry season water from lake is used to irrigate the rice fields. Duck rearing is common in the area, as is collecting of other products (e.g. stems of waterlilies and lotus seeds). Due to intensity of land use, the conservation value of this wetland seems limited, although it is clearly of local importance for fisheries, which are however likely to be highly impacted by use of illegal fishing methods.

Anlung Pring:

This small, 217 ha protected area lies in the far southwestern corner of the Mekong Delta RBG. The northern 33 ha is freshwater while the rest is brackish. The area is important for Sarus

Cranes that normally arrive in November and leave in May. They feed mainly in the brackish water zone (on *Eleocharis* [sedge] tubers), drink in freshwater zone, and roost in the *Melaleuca* trees along the river.

Environmental constraints include an enclave of 10 ha of rice paddies in the brackish water zone[1], declining volumes of freshwater entering the northern part of the reserve, and water quality issues in the southern, brackish part of the reserve where adjacent brackish-water fishponds discharge effluents (that include pesticides) into surface waters that enter Anlung Pring. Also, lowered water levels have at times led to oxidation of potential acid sulphate soils and temporary acidification.

5.5.2 *Potential Impacts on Fisheries*

The BPL wetland is also important in terms of its provision of fish. If the area dries out faster than normal, there could implications for fisheries.
Lower flood as a result of flood protection and diversion of water for other uses could also result in a (limited) decrease in fish production due to (limited) decreased sediment and nutrient transport. The rehabilitation of canal 98 would also affect sediment and nutrient transport, as well as increasing habitat fragmentation. Increased agricultural activity could increase the use of fertilisers and pesticides and significantly impact fish production. On the other hand, increased water availability and the possible creation of water infrastructure at BPL could improve fisheries.

The impact of upgrading Canal 98 [and a link canal] on fisheries at Preak Tonloab depends on the ultimate design of the canal, but any changes that decrease the area flooded and the duration of floods is likely to be detrimental to fisheries.

The impacts on fisheries at Anlung Pring could potentially be positive. Freshwater is a constraint in the northern part of the reserve in the dry months, and inflow of freshwater will potentially be increased via the proposed link canal. However, water quality could also be an issue, as effluents draining from agricultural fields will also contain agrochemicals, and high concentrations could be detrimental to fisheries.

5.5.3 *Potential Impacts on Birds*

Bird life at BPL is currently already affected by drying out of wetlands due to increased water usage by farmers. The potential impact of further water resource development (i.e. water diversion and flood protection) is likely to be significant and negative, unless water management infrastructure is installed at BPL (e.g. bunds and sluices) that allows reserve management to assume control of water and prevent rapid desiccation of the wetland.

The impact of upgrading Canal 98 [and a link canal] on bird life at Preak Tonloab depends on the ultimate design of the canal, but any changes that decrease the area flooded and the duration of floods locally is likely to be detrimental. However, the area does not appear to be of major importance to vulnerable bird species.

We were informed by the local WWT staff present at Anlung Pring that the sedge vegetation, especially in the periphery, was seasonally trampled by huge flocks of migratory birds, such as the Near-threatened Bar-tailed Godwit *Limosa limosa*. On the other hand, it was also said that

[1] These rice fields were present before the reserve was gazetted, and MoE have reached an agreement with farmers that this does not disturb the cranes – fields are cultivated after the cranes have left in May.

herds of water buffaloes ploughed through the mud and actually contributed to the fertility of the soil and its vegetation.

The presence of *Eleocharis* tubers as a seasonal staple food for Sarus cranes appears to be important as has been shown by a study by Yav Net (2014) who showed a positive correlation between the presence of *Eleocharis dulcis* and occurrence of Sarus cranes. *Eleocharis* has a narrow tolerance range to flood depth and duration (Meynell et al. 2012). For the tubers to form, ground water also needs to fall to between 30-40 cm below soil level (Van Ni et al. 2006). Moreover, the sogginess of the soil very likely determines the access to these tubers, which very likely cannot be extracted by foraging cranes if the soil is dried out too much; also, the living conditions of various prey animals (e.g. frogs, invertebrates) may not be met with if the soil is too dry.

5.5.4 *Potential Impacts on Water Quality*

No time series of water quality with importantly different parameters have been found during the study period. However, two parameters (pH and dissolved oxygen) were recorded at some points and times at BPL and ALP.

Based on Boeng Prek Lapouv's Management Plan (January 2014 – December 2018), the source of water in the BPL is mainly from the Prek Lapouv, Stung Takeo, and Bassac rivers. Water quality analysis was conducted in late February 2013 with samples taken from various canals, rivers and streams. Water was only slightly acidic to neutral with a pH level of 5 – 7. The dissolved oxygen (DO) levels in February ranged between 3.1 – 5.1 mg/L in canals and streams; however, the DO levels (5.1 – 7.1 mg/L) were high in November (during the peak flood period). According to the rapid assessment of ecohydrology, the DO values at stations along the Bassac River in both dry and wet seasons in 2017 were at the acceptable levels for biodiversity conservation in the rivers, which ranged from 11.09 mg/L to 11.80 mg/L in the wet season and from 4.68 mg/L to 9.83 mg/L in the dry season.

Water quality at BPL could be affected by the proposed upgrading of Canal 98 and the Link Canal. Soil acidification could occur as a result of oxidisation of acid-sulphate soils present in the catchment, releasing acid into surface water. This also results in high concentrations of iron and aluminium (the latter potentially toxic). Increased oxidation would occur if soils dry out too much during dry season. This would have a negative impact on ecosystems and humans alike.

Anlung Pring's Management Plan (January 2014 – December 2018) indicated that the reserve area is divided by a salinity barrier, which consists of different water quality. Surface water quality in the northern part (the non-tidal area north of salinity barrier) was generally more acidic (in which pH ranged between 3.7 – 5.7), whereas pH values in the tidal area south of the salinity barrier were between 4.7 – 7.1. During our October 2019 surveys we measured pH on both sides of the salinity barrier to be about 5, using universal pH paper. Salinity was considerably higher below the embankment where the water is brackish (salt content 2.2 – 3.4%). DO concentration of the surface water in the downstream part of Anlung Pring were at the acceptable levels for biodiversity conservation and aquatic life, which ranged from 4.2 – 5.6 mg/L, whereas that of the surface water (1.4 – 3.9 mg/L) in the northern part, where waters are stagnant, was considerably lower and less amenable for biodiversity conservation.

5.5.5 *Risk mitigation*

<u>*Boeng Prek Lapouv:*</u>

The potential investment scenario being considered by MOWRAM includes desilting and rehabilitation of Canal 98, and BPL reserve management (MoE) is generally positive about this as long as it provides more water in the drier months (Sarus cranes prefer soggy grasslands), preferably up to late April. However, the grasslands should not be too flooded at this time of year, nor should the dry season be too short. There are no structures (e.g. sluices) at all along primary, secondary or tertiary canals so there is little active water management other than pumping from the canals in the dry season. BirdLife Cambodia carried out a rewetting trial in 2016-2018 by constructing a 1.3m tall bund around a 16ha plot and managing water levels by means of four small sluice-gates. This had positive effects on numbers of birds and (according to BirdLife Cambodia and Wetland and Wildfowl Trust Cambodia) investments in water resources development could be mitigated by upscaling of this trial rewetting to include the entire 900 ha core area (and with sluice-gates), but with a bund of 2.3 m height as the trial bund was ultimately too low.

Tram Chim Integrated Fire and Water Management Strategy across the border in Viet Nam implemented sluice gates to maintain water levels at an optimum level to maintain vegetation. This set out guidelines for water levels in different management zones to guide sluice gate operation (Meynell et al., 2012), and could be useful in determining water levels for BPL.

Wet season e-flow demand: During this period there is a need to store water, to ensure that the area remains soggy until late April, and to refill the section of a former river that still remains as a 300m long, 5m wide, 2-2.5m deep body of water in the middle of the reserve that serves as a source of fish stock. Important is that water control structures are installed, i.e. a 2.3m tall bund around the core area, plus sluice-gates to allow control.

Dry season e-flow demand: To keep the area soggy, input must be > evapotranspiration rates, which hovers around 6 mm/day. This means that incoming waters need to be equal to evapotranspiration (6 mm/day), which given the area (919 ha) means an inflow of 0.6 m^3/s. Given the importance of the area, this should be provided during the entire dry season. Alternatively, water retained by the bund needs to be sufficient to keep the area soggy until late April; under this scenario, however, reserve management will have to prevent rice farmers from pumping water out of the reserve.

Preak Tonloab:

Preak Tonlaob (400ha), where is a natural shallow lake, is not designated as a protected area or landscape. During our survey, it is noticed that rice paddies during the wet season are cultivated around the lake; and lake are also used for fishing. Water from this lake is also used for cultivated rice fields during the dry season. Varieties of land use intensity have been found in these areas; consequently, this wetland is not been considered to be a conservation area. The mitigation options for this wetland area is therefore not strictly required as Anlung Pring and Boeng Prek Lapouv. Nevertheless, general mitigation measures in association with the fisheries sector need to be taken into account. As mentioned above, it is a very high density of fishing nets and traps, all with nets of very fine (and illegal) mesh size. Using all illegally fishing equipment and methods (including electrofishing, possibly explosives and poisons) can result in depletion of all kinds of fish, sanctions spelt out under the Fisheries Law should be enforced by the Provincial Department of Fisheries. Community Fisheries Groups and the local members of Community Fish Refuges can support the MAFF staff to assist in these efforts.

Anlung Pring:

Freshwater resources are declining at AP, so if more water could be channelled to this part of the Toan Han via the link canal, this could potentially be an improvement, provided that water quality is not compromised. As with BPL, a low bund and sluice gates could be an option to maintain wet conditions for a longer period, but this would require more investigation.
Repair and upgrading of the three existing sluice gates and flap-gates (separating the freshwater and brackish-water zones) could also be considered as these are poorly maintained and will not last much longer. Installation of extra flap gates at the site of the brackish-water fishponds could be considered to prevent effluents from the ponds entering Anlung Pring, i.e. allowing water to leave the ponds only when the flow is towards the coast (and not inland towards AP).

Mitigation for fisheries

The most important hydrological aspect for mitigating impact on fisheries is the maintaining of seasonal water levels and e-flows. At present this is already an issue as in the dry season flows are minimal to non-existent. A second hydrological aspect that affects fisheries is the maintaining of connectivity and migration routes for fish and other aquatic animals, upstream, downstream and laterally. During our surveys it was observed that most dams, weirs and reservoirs (even those currently under construction) are not equipped with fish passes, which effectively stops the migration of fish and other aquatic animals. Also, in the few instances where fish passes have been installed these are often poorly designed, either being poorly passable for fish or providing a fishing opportunity for local communities rather than a migration route for fish. Fishing pressures are already high, and where (new) structures are placed this can increase even further if not controlled. Water quality is also a major issue. Monitoring of fisheries and effectiveness of fish passes is required to ensure that this remains productive in the long-term.

In the dry season, stagnant waters have low DO levels that are highly detrimental to most fish species, while the (over-) use of pesticides and fertilizers can directly lead to fish kills or reduce water quality to the point that aquatic life is affected. Integrated pest management (IPM) training for farmers, which is a part of agricultural training, can help in reducing the dosage of chemical fertilizers and pesticides. Monitoring of water quality would be highly useful in ensuring that safe limits are adhered to, both for human usage and for fisheries.

5.6 Model setup

Given the questions related to water resources availability and allocation for the Slakou-Toan Han Basin Group, it was to build further on the Water Supply and Demand Framework using WEAP used in the Rapid Assessment phase. Some of the characteristics of the developed WSDF are:

- For the rainfall-runoff scheme, the same data and approach was used as in the Rapid Assessment phase: climate reanalysis data and the advanced soil-moisture module (similar to SWAT) implemented in WEAP.
- For the water availability in the Mekong-Basaac system, simulated outputs of the hydraulic model ISIS were used. Simulations were available for a ten-year period within the total 20-year period simulated in the WSDF.
- Irrigation demands have been calculated dynamically using the catchment nodes approach from WEAP combined with the soil-moisture option.
- A timestep of one week (7 days) was used.

- To introduce annual and weekly variation climate data from 20 years (1996-2015) have been used. For future scenarios the same climate variability was assumed, as the climate risk analysis showed that annual flows are likely to increase in this area, while there is not a clear trend in the drought (dry period) characteristic that was studied.
- A two years warming up period was used to ensure that the model was in equilibrium when starting the actual analysis.
- Input and output analysis were done by a combination of direct results from the model as well as using a set of excel VBA scripts.
- For each of the three basins, a domestic water node was implemented and urban water requirements were set at 160 liters per person per capita. For rural water consumption 90 liter per person per capita was considered.
- Irrigation demand areas were combined into five nodes. For each node four seasons were considered (see the Rapid Assessment report for details). The actual water demand is calculated by the WEAP model using the following principle. Crop water requirements are calculated by the Penman-Monteith approach considering climate data (e.g. temperature, windspeed, humidity, sun-shine hours). If sufficient water is ponded or available in the soil, actual water supply demand is zero. In case ponding is low and soil water is below a set threshold value, water demand is calculated. This water demand is further refined by losses and reuse of water and the result is the so-called supply requirement. In case sufficient water is available in streams and reservoirs, this will be released and allocated.
- Two environmental nodes were implemented, with the corresponding demand rates (see previous section 5.5.5):
    - Boeung Prek Lapouv reserve in the Stung Slakou basin (*Env_01*)
    - Kampong Trach IBA in the Stung Toan Han basin (*Env_02)*
- In case of shortages the water is rationed given a pre-defined priority. For the reference scenario, all sectoral demands (irrigation, domestic and environment) are given equal priority. For the future scenarios, a higher priority is given to domestic use.

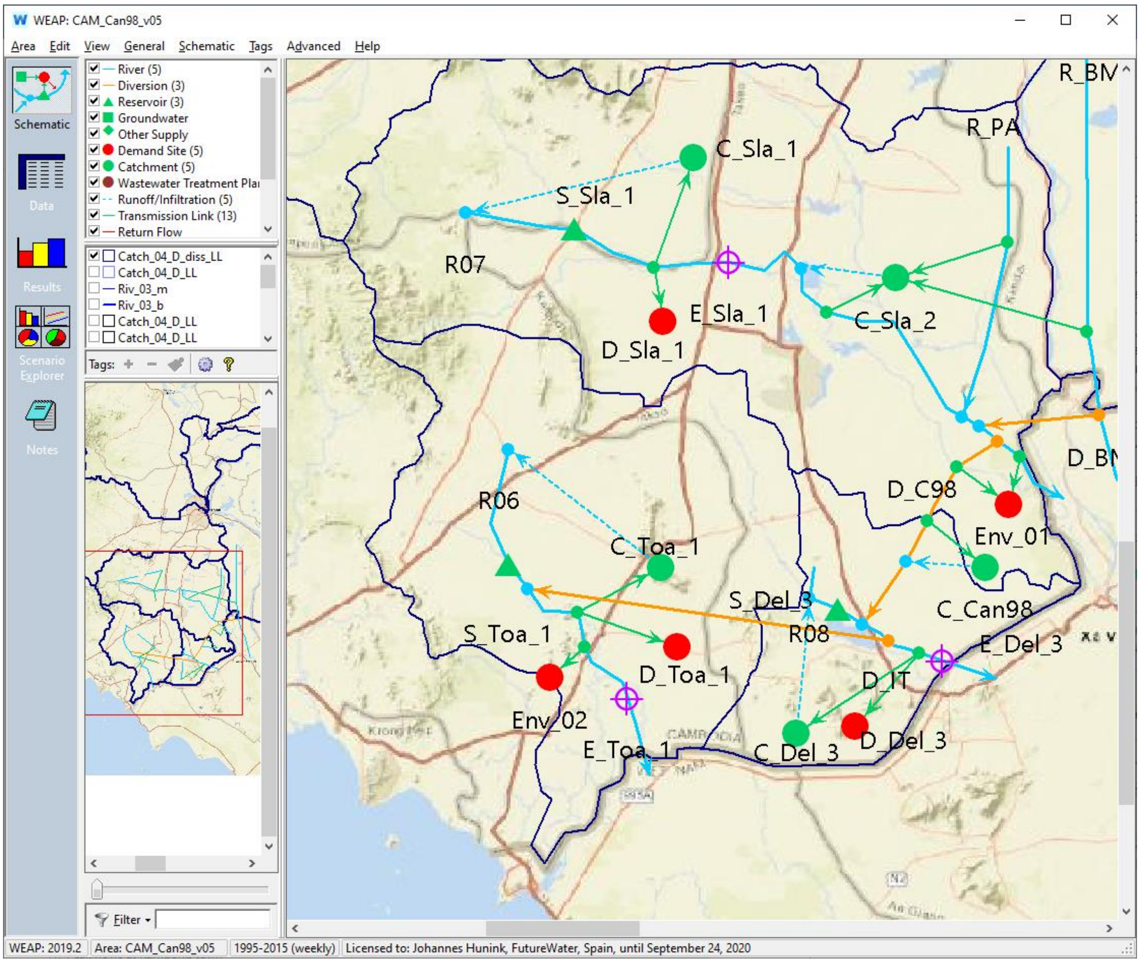


Figure 5-16: Schematic of the water supply and demand framework in WEAP for the Canal 98 Basin Group.

5.7 Water balance evaluation

The Water Demand and Supply Framework as implemented in WEAP and discussed in the previous sections, was used to evaluate the current situation (reference, or baseline). Table 5-4 shows for the irrigated areas the various components of the water balance: effective precipitation, water demand, supply and coverage. The irrigation demands vary substantially between the irrigated areas as a result of the different areas in the different cropping seasons. The irrigation shortages and the coverage (expressed as irrigation supplied over irrigation demand) varies between the different areas. For the Canal 98 command area, in the reference scenario it is assumed that Canal 98 is not rehabilitated yet, thus no water is supplied from this canal. Therefore, coverage is 0% in this scenario. For the other areas, coverage is between 50% and 80%. This is an average value over a 20-year period and varies among the years.

Domestic demands, supplies and coverages are shown in Table 5-6. There is quite some variation between the various domestic water demands as population differs quite a lot in each area. Overall coverage is between 73% and 100%. Important to note is that the entire water demand for domestic use and the two environmental demands of about 52 million cubic meter per year is an order of magnitude smaller compared to the water demand for irrigation (941 million cubic meter). In the reference scenario no specific priority has been given to any sector, so any water shortage will be allocated equally between and within sectors. For the future scenarios (next section) domestic water use has been given priority.

Table 5-6 shows also the water demands and water supplies for the two environmental demand nodes (Boeung Prek Lapouv reserve in the Stung Slakou basin and Kampong Trach IBA area in the Toan Han basin). As can be seen, the demand for the reserve in the Stung Slakou basin can be met under current water resources conditions. However, please note that this assumes that the connection with the Mekong river delta is in good condition to actively bring water to the reserve. For the smaller reserve in the Toan Han basin, deficits occur occasionally, obviously especially in the dry season, leading to a coverage of 86%.

The Water Supply and Demand Framework provides a huge amount of supporting data. The model itself is attached to the report and can be used as reference in case more results are needed to be analyzed. Figure 5-17 provides examples of those detailed results from the analysis.

In summary it can be concluded for the Slakou-Toan Han Basin Group that in general water resources are abundant, and that some water shortages occur in some areas and some periods of the year. This means that by tailored investments improvements must be possible. The next sections will explore various of those investment options and the impact on water demand and supply.

Table 5-4: Results of the Water Supply and Demand Analysis for the irrigation schemes. Annual averages over a period of 20 years (1996-2015) are shown.

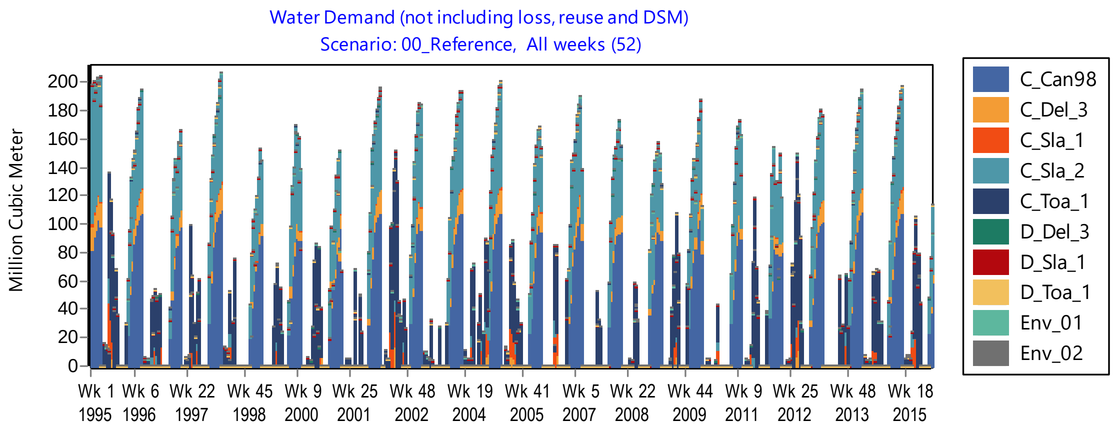
	Effective precipitation (MCM/y)	ET Potential (MCM/y)	ET Actual (MCM/y)	Irrigation Demand (MCM/y)	Irrigation Supplied (MCM/y)	Irrigation Shortage (MCM/y)	Coverage (%)
Canal 98	278	527	278	304	0	304	0%
Mekong Delta	190	261	226	69	36	32	53%
Slakou upstream	230	297	269	49	38	10	79%
Slakou floodplain	395	780	691	375	296	78	79%
Toan Han	572	743	646	145	74	71	51%
TOTAL	1666	2607	2,111	941	445	497	52%

Table 5-5: Results for the irrigation demand, supply, shortage and coverage, per irrigation season, based on averages over a period of 20 years (1996-2015).

	Dry	Dry-wet	Recession	Wet
Irrigation water demand	37	23	680	201
Irrigation supplied	28	17	278	122
Irrigation shortage	8	7	402	79
Coverage	77%	71%	41%	61%

Table 5-6: Results of the Water Supply and Demand Analysis for the domestic water requirements and two environmental demands (bird reserves). Annual averages over a period of 20 years (1996-2015) are shown.

	Water Demand (MCM/y)	Supply Required (MCM/y)	Supply Delivered (MCM/y)	Coverage (%)
Domestic Toan Han	11.3	14.2	12.1	86%
Domestic Stung Slakou	25.4	31.8	28.5	90%
Domestic Mekong delta	4.3	5.4	3.9	73%
Environmental Slakou	10.0	10.0	10.0	100%
Environmental Toan Han	1.1	1.1	0.9	86%
TOTAL	52.1	62.4	55.5	87%



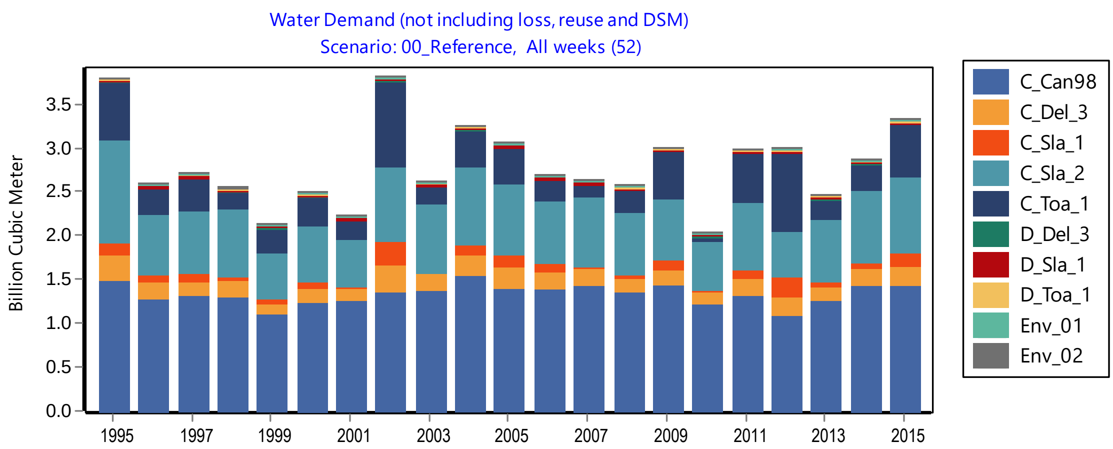


Figure 5-17: Example of output provided by the Water Supply and Demand Framework as implemented in WEAP: Water Demand average weekly (top) and annually (bottom).

5.8 Scenario analysis

A set of potential investment scenarios to enhance crop production and to improve water security to all sectors have been explored. Those investment scenarios have been developed in consultation with MOWRAM. It should be emphasized that the current study is a pre-feasibility study and that based on those results more focused feasibility, pre-design and design evaluations are required.

For the Slakou-Toan Han Basin Group a set of potential investment scenarios were explored using the Water Supply and Demand Framework as implemented using WEAP. Those scenarios exist of a combination of so-called water use options (A to D) and infrastructure investment options (E to I) as described below. Various combinations of those measures were integrated in the actual scenarios explored.

5.8.1 *Description of water allocation options*

A: **Rational priorities during water shortage periods**
Highest priority 1 is given to domestic water use then priority 2 for environment and 2 for irrigation

B: **Modernization of irrigation systems**
Losses in irrigation canals will be reduced from the currently assumed 25% to 10% and the reuse of runoff and drainage from irrigated areas will increase from 25% to 50%.

C: **Rice intensification (rice only)**
An intensified cropping pattern, as proposed in the current National Irrigation Strategy. Double cropping is practiced assuming that 100% is cropped during wet season, 50% during the recession season, and 50% in the dry-wet (early wet) season. Thus, this aims for a cropping intensity of 200%.

D: **Diversification and intensification**
An intensified cropping pattern, as proposed in the current National Irrigation Strategy, but including also crop diversification. Double cropping is practiced assuming that 100% is cropped during wet season (100% rice), 30% during the recession season, 35% in the dry-wet (early wet) season and 35% in the dry season (thus aiming for a cropping intensity of 200%). Outside the wet season, the crop mix is 70% rice, 30% vegetables.

5.8.2 *Description of infrastructure investment options*

For a map with the infrastructure in the Canal 98 command area, please see Annex 5.

E: **Water Control around the bird reserve Boeung Prek Lapouv**
Infrastructure is put into place so that the bird reserves are protected high water fluctuations (see section 5.5.5)

F: **Rehabilitation of Canal 98**
Canal 98 is rehabilitated, currently in a bad state, so it can provide water adequately to the Canal 98 command area.

G: **Connection to Toan Han basin**
Part of the water of Canal 98 is made available through a new connection (water transfer) to the Toan Han basin for domestic and irrigation purposes. It is assumed that the maximum capacity of both canals is 30 m^3/s.

H: **Low-flood protection**
Infrastructural measures are implemented that cause the area north of Canal 98 to be protected for the early flood season. This allows for another crop cycle in the early wet season: having reliable access to water for irrigating EWS rice allows farmers to start their crop earlier so that

the risk of crop damage due to the early flood will be reduced. Protected areas from early flood season are: 10,000 ha within the Canal 98 command area, in areas outside the protected area, and 10,000 ha in rest of the floodplain.

I: **High-flood protection**
As option H but assumes higher investments in flood protection, leading to full protection against floods, including during the high flood season. This allows for in total three crop cycles in the same areas as in scenario 02: (1) early wet season, (2) wet season and (3) flood recession season.

5.8.3 *Description of scenarios*

Table 5-7 presents the combination of the previously described investment options in a number of scenarios. The first set of scenarios (1-3) is based purely on the water allocation options. The second set of scenarios (4-6) is based on a combination of both water allocation as well as infrastructure investment options.

Table 5-7. The six scenarios explored, and their associated water use and infrastructure investment options.

Scenarios	Water use options				Infrastructure investment options				
	A	B	C	D	E	F	G	H	I
00_Reference									
01_ModOnly	X	X							
02_RiceInt	X	X	X						
03_Diversif	X	X		X					
04_Rehabilitation	X			X	X	X	X		
05_LowFloodProt	X			X	X	X	X	X	
06_FullFloodProt	X			X	X	X	X	X	X

The scenarios are briefly described here below.

01: **Modernization** (*01_ModOnly)*
This scenario explores the impact if losses in irrigation canals will be reduced from the currently assumed 25% to 10% and the reuse of runoff and drainage from irrigated areas will increase from 25% to 50%. Also, in case of water shortage, irrigation will get lower priority.

02: **Modernization combined with rice intensification** (*02_RiceInt)*
Under this scenario also modernization and priority for allocation are the same as the previous scenario. On top of this a double cropping system is considered for rice.

03: **Modernization combined with rice intensification and diversification** (*03_Diversif)*
Under this scenario also modernization and priority for allocation are the same as first scenario (*01_Mod*) the previous scenario. On top of this a double cropping system is considered but, in this case, this double cropping is not only rice, but in 30% of the area vegetable are assumed to grow.

04: **Canal 98 rehabilitated and Toan Han connection** (*04_Rehabilitation*)

Under this investment scenario the impact is explored of rehabilitating the Canal 98, currently in a bad state, so it can provide water adequately to the Canal 98 command area. Part of the water is also made available through a new connection (water transfer) to the Toan Han basin for domestic and irrigation purposes. It is assumed that the maximum capacity of both canals is 30 m^3/s. In this scenario, no flood protection measures are implemented. Also, a link is assumed between Canal 98 and the protected bird reserve in the area (*Env_01)*.

05: **Low-flood protection** (*05_LowFloodProt*)
Under this scenario, Canal 98 is rehabilitated, and the connection is made with the Toan Han basin, but also the area north the infrastructure of Canal 98 is protected for the lower flood season. This allows for another crop cycle in the early wet season. Additional areas that can be cropped in this season are:

- 10,000 ha in the Canal 98 command area (not including the protected area)
- 10,000 ha in rest of the floodplain

06: **Full flood protection** (*06_FullFloodProt*)
This scenario is as the previous scenario but assumes more investments in flood protection, leading to full protection against floods, including during the high flood season. This allows for in total three crop cycles in the same areas as in scenario 02: (1) early wet season, (2) wet season and (3) flood recession season.

5.8.4 *Results: impacts on irrigation*

The six investment scenarios as described in the previous section were implemented in the Water Supply and Demand Framework as implemented in WEAP. Table 5-8 provides a summary of the key results summarized for all irrigated areas in the river basin group. The table includes a summary of the

- Annual results
- Wet season results (week 24 – week 45)
- Dry season results (week 46 – week 23)

The most relevant outcomes are:

- **The effective precipitation** (amount of precipitation that is used by the crop) is dependent on the cropped area, and soil moisture conditions, and has thus also a relation with irrigation water supply. Averages are shown here, but obviously quite some variation exists between years and regions which are considered in the analysis.
- **Crop water requirements** (ET Potential) is the actual amount of water required by the crop, without considering any losses. Variation between the scenarios can be explained by the different irrigated areas, crop intensities and crop mix considered. As expected the values increase under the intensification scenarios 02 and 03, but also under the flood protection scenario, as more irrigated area becomes adequate for irrigation. Please note also, that compared to the other basin groups analyzed in the previous chapter, for this basin group the increase in crop water requirements for the intensification scenario is less substantial. This is because in this basin group already quite some cropping occurs outside of the wet season, nowadays. So, intensifying in the seasons outside the wet season (as analyzed here) has a smaller relative impact.
- The amount of **actual crop water consumption** (ET Actual) shows quite some variation between the scenarios. Overall, whatever scenario will be selected more water is consumed by the crops compared to the baseline (*00_Reference*). This consumed water is considered as beneficial since it produces crop. As a very first rough estimate

by using the water productivity of 0.72 kg m^{-3} as reported by (2019, Foley et al.) a rough estimate of crop production can be calculated. The particular reasons for higher crop water consumption (ET Actual) per scenario are:

- *01_ModOnly*: The expected increase in crop water consumption (and therefore crop produced) is relatively small compared to the Reference. Although irrigation shortages decrease, and coverages increase from 48% to 52% the overall benefits are relatively low. The main reason is that still most of the crop water consumption is from rainfall.
- *02_RiceInt:* Water demand and actual water consumption increases by the expansion of the agricultural area (double cropping). Although the coverage is lower compared to the previous scenario and the irrigation shortages higher, total crop production (expressed as the ET Actual) can be expected to be higher. In other words, individual farmers will experience more water shortage, but production of the entire basin group will increase.
- *03_Diversif:* Results for this scenario show the same trends as the previous scenario: water demand and actual water consumption increases substantially by the expansion of the agricultural area (double cropping). The main difference with the rice-only scenario is that shortage in this scenario is slightly lower, and coverage slightly higher.
- *04_Rehabilitation:* This scenario causes a substantial increase in beneficial crop water consumption (and thus crop production), while shortages decrease compared to the previous scenario. This suggests that rehabilitating the Canal 98 will have an overall beneficial impact on agricultural production
- *05_LowFloodProt*: approximately 20,000 ha can be cropped during the early wet season, as this area will be protected from the early floods. This leads to again substantial more beneficial crop water consumption then in the baseline and the previous scenario. Shortages do change significantly compared to the previous scenario. This indicates that the protection measures will have an overall beneficial impact on agricultural production.
- *06_FullFloodProt*: additional investments protect the same area also from higher floods, allowing another cropping cycle in the wet season, leading to an increase in crop water consumption (crop production) and irrigation supplied, a reduction in water shortage, and a minor increase in coverage.

- **Irrigation supplied**, **irrigation shortage**, and **coverage** reflect in an integrated way the impact of the various investment scenarios. In the current situation (*00_Reference*) coverage for all systems and all years is relatively low: 48% (please note that this includes the Canal 98 command area). Also please note that quite some variation exists between systems and years (see hereafter). Rehabilitating Canal 98 leads to an increase in coverage up to 80%. This number is even further increased when investing in flood protection and modernization, up to 83%.
- The coverage values are represented per irrigation demand node in Figure 5-18 which shows that all scenarios show some increase compared to the reference situation, but only a significant improvement can be expected under the investment for the Canal 98 area.

Table 5-8: Results of the Water Supply and Demand Analysis for the six potential investment scenarios. Results reflect annual averages over a period of 20 years using climate conditions from 1996-2015.

Annual	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)	(%)

Scenario	Precipitation	ET Potential	ET Actual	Irrigation Demand	Irrigation Supplied	Irrigation Shortage	Coverage
00_Reference	9524	11728	6961	937	448	490	48%
01_ModOnly	9524	11728	6989	937	487	450	52%
02_RiceInt	10535	12659	7745	1323	687	636	52%
03_Diversif	10587	12462	7653	1179	646	533	55%
04_Rehabilitation	10587	12462	7862	1178	946	233	80%
05_LowFloodProt	10883	12701	8084	1227	989	239	81%
06_HighFloodProt	11223	13048	8421	1294	1073	221	83%

Wet Season	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)	(%)
Scenario	Precipitation	ET Potential	ET Actual	Irrigation Demand	Irrigation Supplied	Irrigation Shortage	Coverage
00_Reference	6181	4733	3682	214	128	86	60%
01_ModOnly	6181	4733	3686	214	135	79	63%
02_RiceInt	6833	5029	3957	265	172	93	65%
03_Diversif	6867	4981	3918	253	163	89	65%
04_Rehabilitation	6867	4981	3944	252	212	40	84%
05_LowFloodProt	7061	5092	4048	275	230	45	84%
06_HighFloodProt	7283	5325	4268	322	271	51	84%

Dry Season	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)	(%)
Scenario	Precipitation	ET Potential	ET Actual	Irrigation Demand	Irrigation Supplied	Irrigation Shortage	Coverage
00_Reference	3343	6995	3279	723	320	404	44%
01_ModOnly	3343	6995	3303	723	352	371	49%
02_RiceInt	3702	7630	3789	1058	515	543	49%
03_Diversif	3720	7480	3735	927	482	444	52%
04_Rehabilitation	3720	7480	3918	927	733	193	79%
05_LowFloodProt	3822	7609	4036	953	759	194	80%
06_HighFloodProt	3940	7723	4153	972	802	170	83%

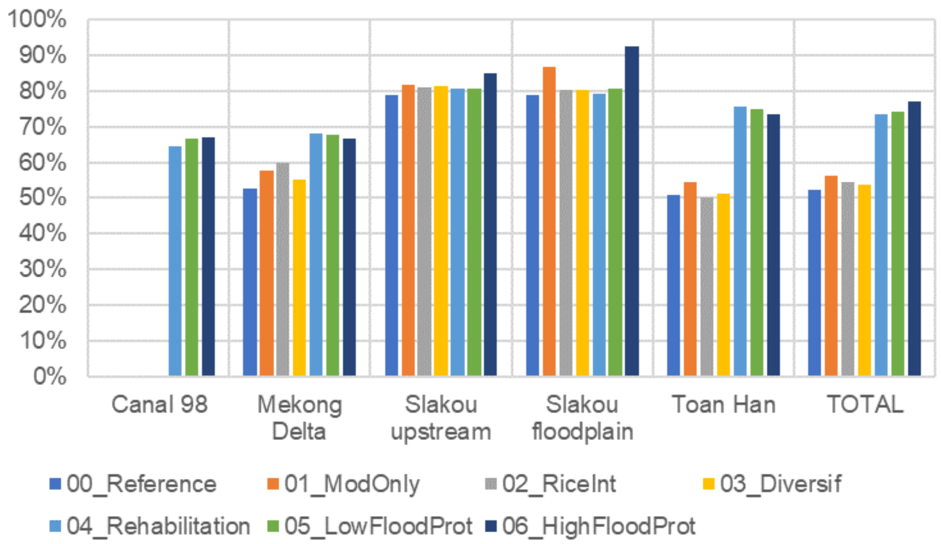


Figure 5-18: Impact of the six investment scenarios (and reference) on coverage expressed as water supplied over water demand. Results are based on 20 years averages.

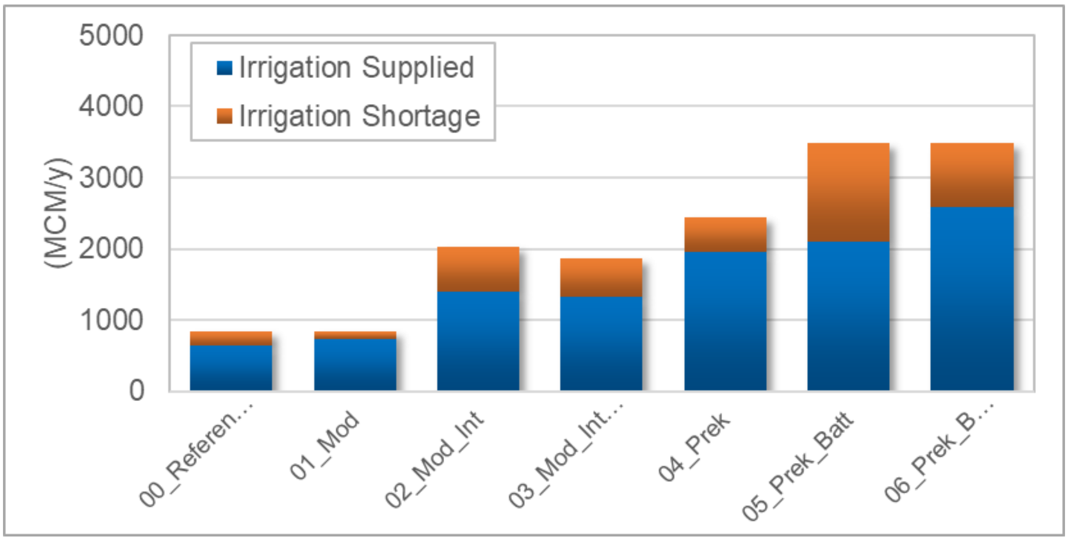


Figure 5-19: Irrigation supplied and irrigation shortages for the six investment scenarios (and reference). Note that total irrigation demand is just the total of supply and shortage. Results are based on 20 years averages.

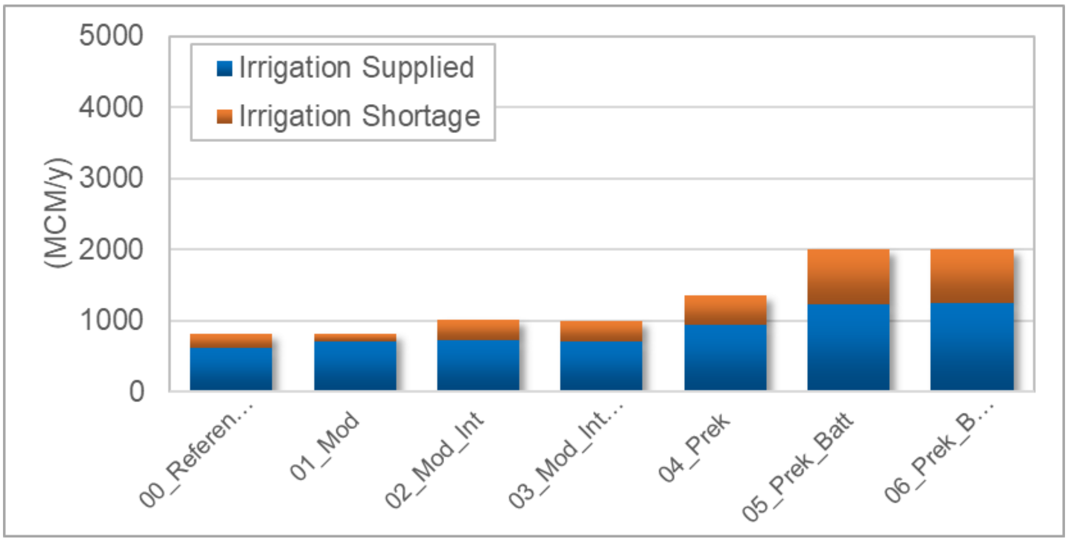


Figure 5-20: Same as above but for wet season only

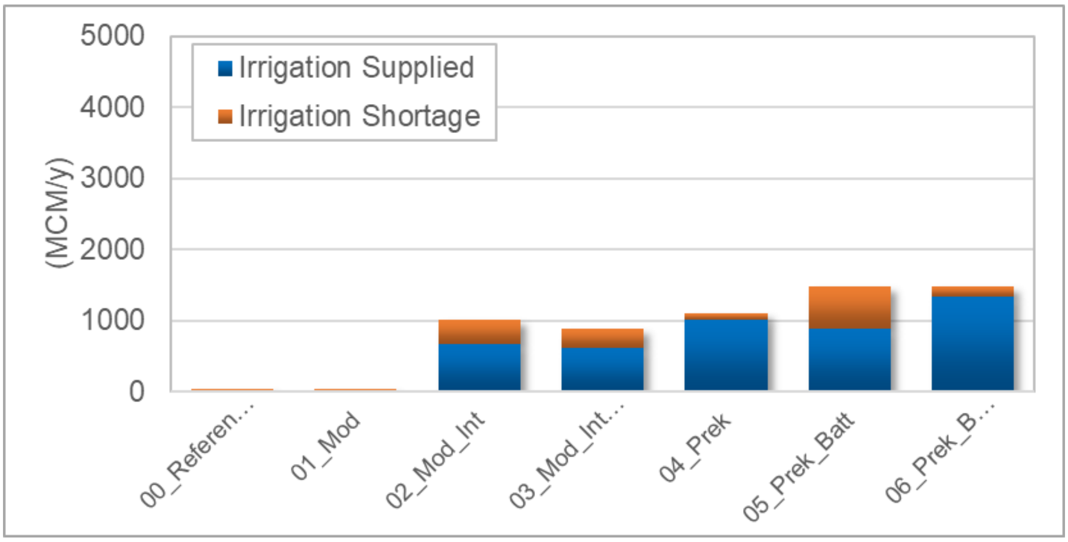


Figure 5-21: Same as above but for dry season only

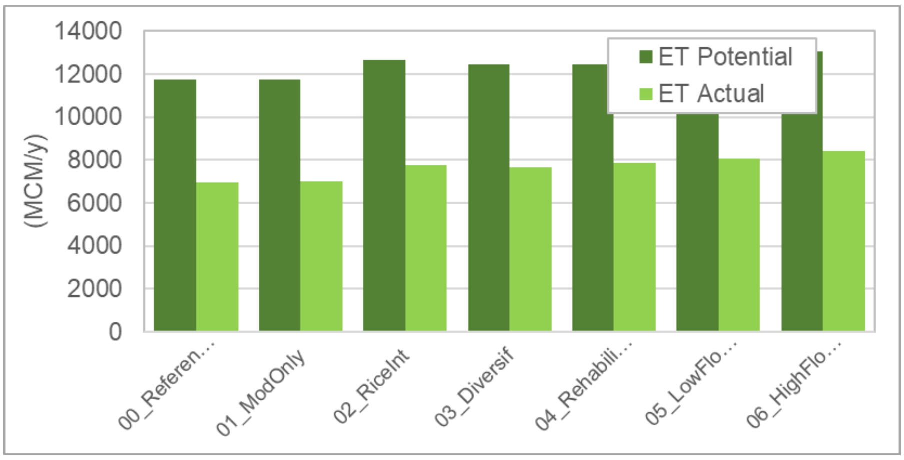


Figure 5-22: Potential crop water consumption and actual crop water use for the six investment scenarios (and reference). Results are based on 20 years averages.

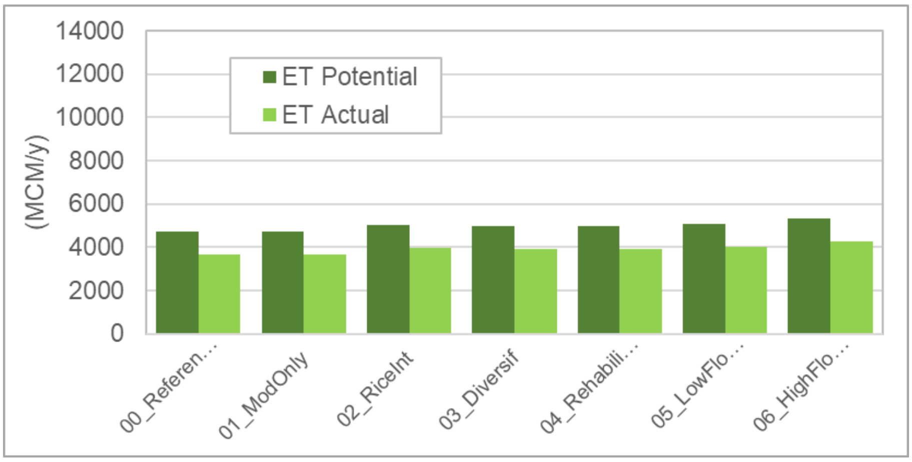


Figure 5-23: Same as above but for wet season only

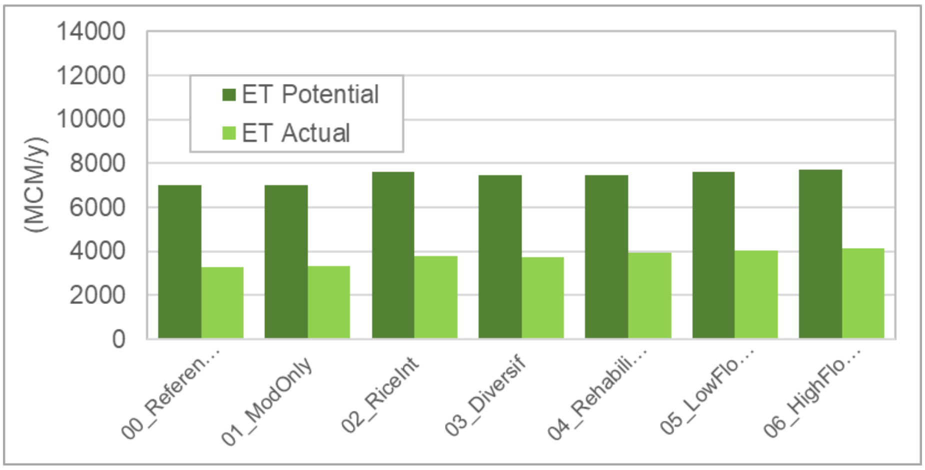
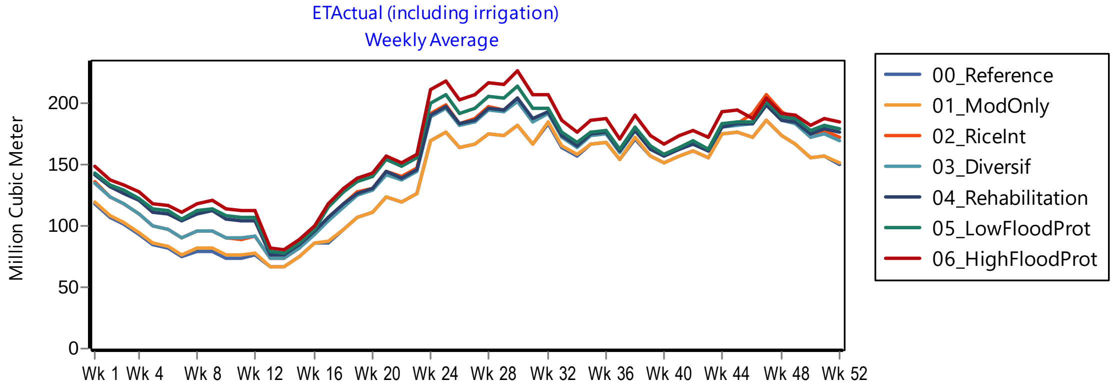


Figure 5-24: Same as above but for dry season only



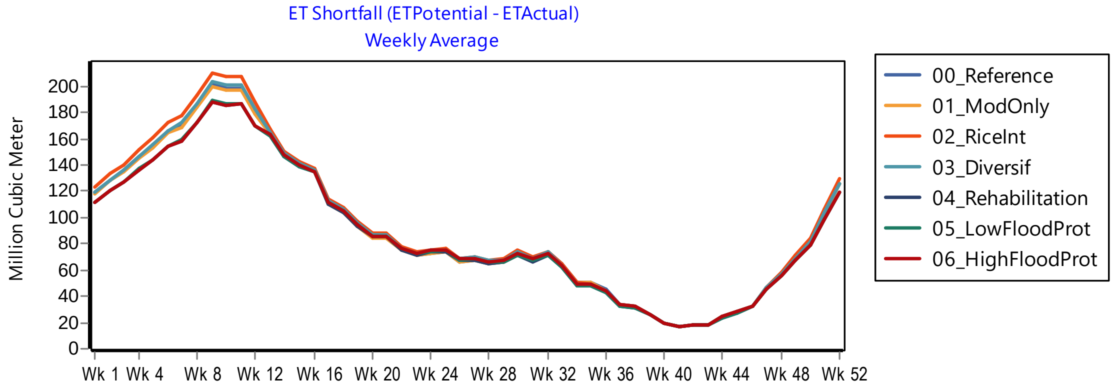


Figure 5-25: Average weekly crop water consumption (top) and crop water shortage for the six scenarios considered.

5.8.5 *Results: impacts on domestic and environmental use*

The goal of the connection with Toan Han should also benefit the domestic users in that basin, and not affect negative water use in the other areas. Table 5-9 shows water demands, supply required, supply delivered and the coverage for the domestic sector under the four investment scenarios. As expected, domestic water demands and supply requirements do not change as it was assumed that everything will remain constant to ensure that only the impact of the investment scenarios will be reflected.

As can be seen, domestic coverage goes up for all the future scenarios, mainly due to the prioritization of domestic supply (measure A in section 5.8.1)), to up to 99%. Table 5-10 then presents the same for the two environmental demand nodes. In this case, what is important to note, is that for the modernization scenario (01_ModOnly), no significant impact can be seen. However, when intensification is implemented (as for all the other future scenarios), environmental demand coverage will go down slightly. Although it is small, it clearly indicates that there will be an increasing pressure on water availability for environmental purposes, and water conflicts may arise. Thus, a key conclusion is here, that any future development in this basin should consider carefully the key two environmental features in this area (plus other risk factors as described in section 5.5)

Table 5-9: Impact of the six investment scenarios (and reference) on domestic water demand, supply and coverage expressed as water supplied over water demand. Results are based on 20 years averages.

Scenario	Water Demand (MCM/y)	Supply Required (MCM/y)	Supply Delivered (MCM/y)	Coverage (%)
00_Reference	41.1	51.3	44.6	87%
01_ModOnly	41.1	51.3	50.6	99%
02_RiceInt	41.1	51.3	50.6	99%
03_Diversif	41.1	51.3	50.6	99%
04_Rehabilitation	41.1	51.3	50.6	99%
05_LowFloodProt	41.1	51.3	50.6	99%
06_HighFloodProt	41.1	51.3	50.6	99%

Table 5-10: Impact of the six investment scenarios (and reference) on environmental water demand, supply and coverage expressed as water supplied over water demand. Results are based on 20 years averages.

Scenario	Water Demand (MCM/y)	Supply Required (MCM/y)	Supply Delivered (MCM/y)	Coverage (%)
00_Reference	11.1	11.1	10.9	99%
01_ModOnly	11.1	11.1	10.9	99%
02_RiceInt	11.1	11.1	10.7	96%
03_Diversif	11.1	11.1	10.7	96%
04_Rehabilitation	11.1	11.1	10.6	96%
05_LowFloodProt	11.1	11.1	10.6	96%
06_HighFloodProt	11.1	11.1	10.5	95%

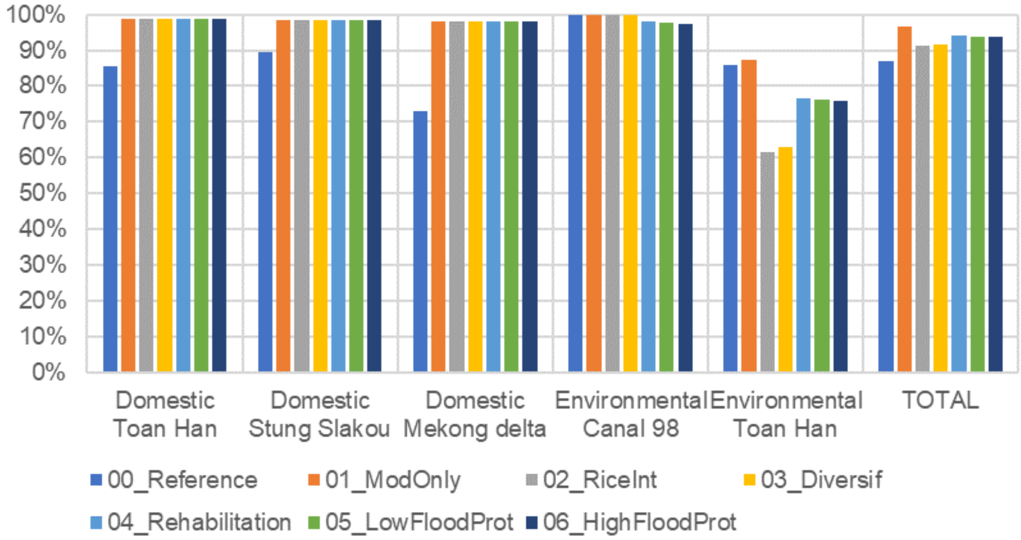


Figure 5-26: Impact of the four investment scenarios (and reference) on coverage expressed as water supplied over water demand. Results are based on 20 years averages.

6 Stung Slakou and Toan Han: Flood Impact Assessment

6.1 Model setup and performance

The regional ISIS model has been set up by the MRC and the latest version includes the key features of the Stung Slakou and Toan Han area.
The calibrated model set up and performance is described in MRC WUP, Council Study and Initial Studies Reports.

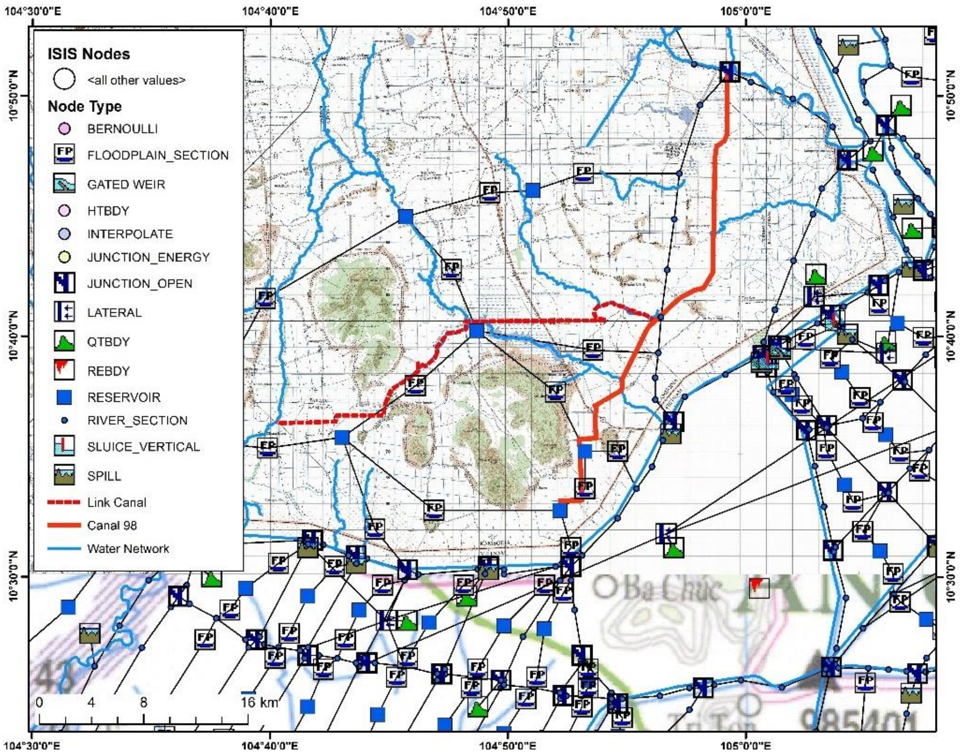


Figure 6-1: Regional ISIS Model Schematisation in area of Canal 98.

6.2 Current situation

On the Vietnamese side the Vin Te canal connects to the floodplain on the Cambodian side and flows pass through the viaduct over the floodplain near the Vietnam border post. Two rubber dams also allow floodwater into the poldered ricelands of An Giang province and are lowered from mid August giving farmers ‘Early flood protection’.

Currently much of the area floods each year and stays flooded until December or January.

Canal 98 becomes submerged during a flood as it has only low banks.

6.3 Impact of proposed investments

The new road linking road 2 to the Stung Takeo and the intake to Canal 95 and Canal 98 form a northern boundary to a potential flood scheme if canal 98 is built with a raised bank alongside. The bank could serve as a road as well as a flood control embankment and, could potentially 'shield' Canal 98 from siltation during the flood season as well as protecting a large area not only served by Canal 98 but by canal 95 and other areas as shown below. The area that could be protected from floods is shown by the yellow dashed lines, west of Canal 98 and south of the new road. The 100yr flood extent would impact this area considerably less.

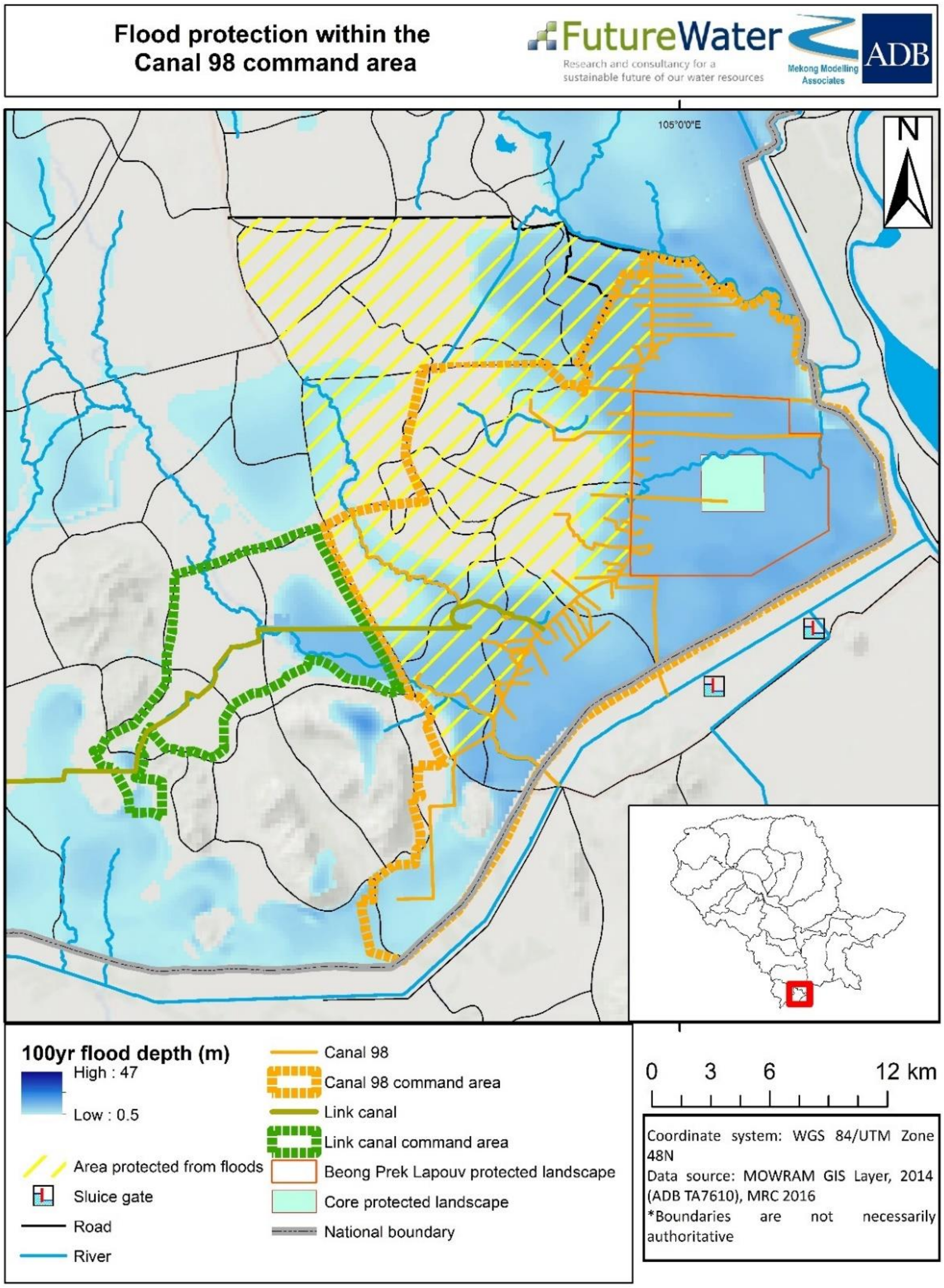


Figure 6-2: Flood protection within the Canal 98 command area.

6.4 Simulations and Options for mitigation measures

Simulations were carried out for a representative wet year (year 2000) and a dry year (Year 1998) so the current model and for the model with the protected area removed.

As shown in figure below the general features of the water levels in the area are for significant tidal variation during the dry season which gradually reduces as flood levels increase. Results are presented at Chau Doc on the Bassac near the border and at the Road 2 crossing in the Vin Te canal.

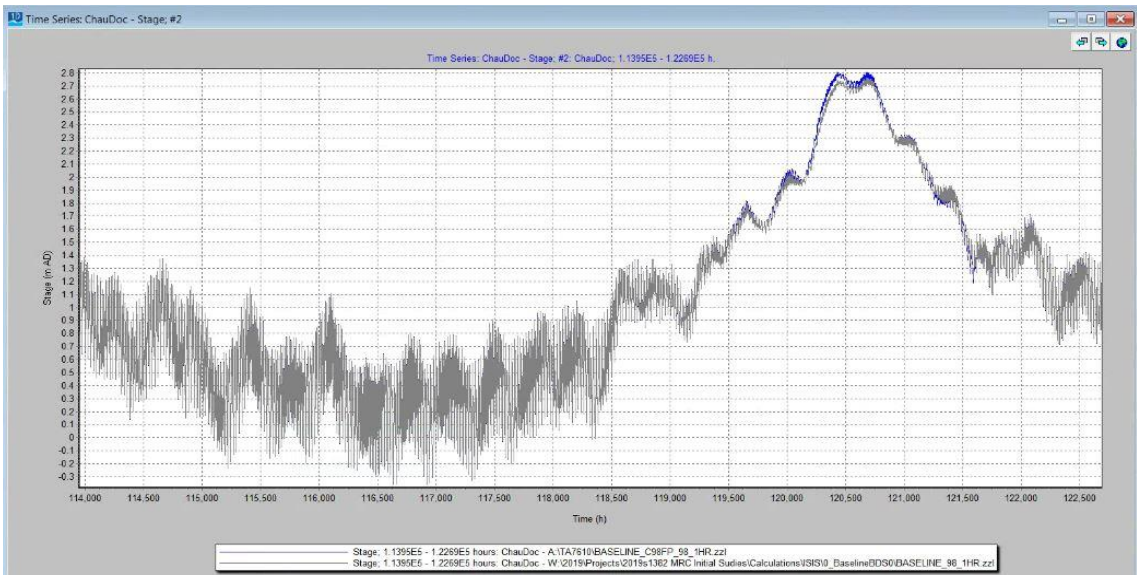
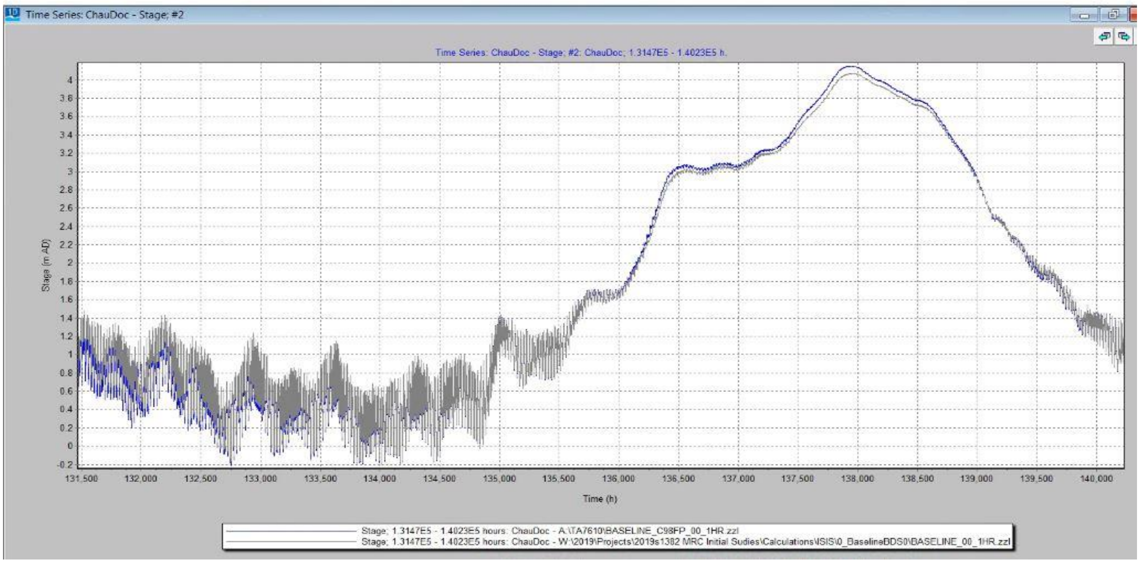


Figure 6-3: Water Level at Chau Doc with and without flood protection (1998 dry year)



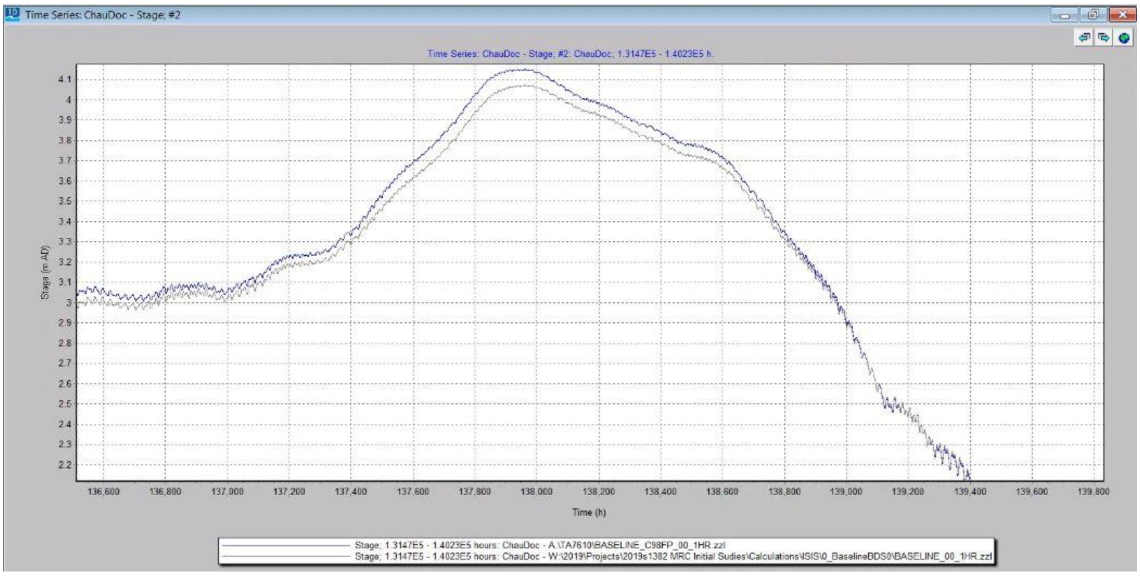


Figure 6-4: Water Level at Chau Doc with and without flood protection (2000 wet year,) full year above, peak only below.

Figure 6-5: Water Level at Road at border with and without flood protection (1998 dry year)

As the difference in water level is about 6cm increase at Chau Doc then it should be considered to allow the area to be subject to controlled flooding or early flood season protection early so that flood storage is available. This is practiced on the Vietnamese side so should be only subject to prior Notification under the MRC PNPCA process.

7 Stung Sen Basin: additional study

7.1 Key issues

The Rapid Assessment report provided quantitative numbers on the water balance of the Stung Sen and its sub-basins. Evaluations were based on available data, previous studies and the application of the Water Supply and Demand Framework (WSDF) as implemented using the WEAP model. The most significant conclusions regarding the state of the water resources for Results: impacts on domestic and environmental use can be summarized as:

- Results: impacts on domestic and environmental use is the largest catchment of the Tonle Sap river basin group with a size of about 16,000 km^2.
- Rainfall is about 1,650 mm per year and variation between the sub-catchments is relatively low.
- Demand for irrigation is low, as about only 5% of the total catchment area is currently under irrigation.
- Meeting environmental flow requirements can be achieved in about 64% of the time.

As this basin is relatively water abundant and current irrigated area is low, potentially there is room for expanding irrigation considerably. This irrigation potential however will likely be largely dependent on the expansion of storage capacity. Already some upstream reservoir developments are ongoing.

The objective of this additional study on the Stung Sen is

- Assess how the development of reservoirs in the Stung Sen basin could increase irrigation potential downstream in the Stung Sen and Stung Chinit, and thus whether there are sufficient water resources available for the desired service area
- Assess how a possible new transfer between Stung Sen and Stung Chinit via a canal in the area of a former branch of the Stung Sen could lower the flood risk in the main stem of the Stung Sen, near to Kampong town.

7.2 Catchment characterization

A wide range of data has been collected both during Phase I and Phase II of the study. Many data has been already reported in the two Rapid Assessment reports (Water Resources and Eco-hydrology) of Phase I. More recent data has been collected in Phase II on the irrigation areas from the most recent version of the CISIS database. Updated data per catchment in the basin group is presented in Table 7-1.

Table 7-1. Population and irrigated areas per catchment of the Stung Sen basin.

Catchment	2016 population			Irrigation (ha)				Catchment Area (km2)
	Rural	Urban	Total	Dry Season	Dry in Wet	Wet Season	Recession	
Sen 1	75,842	28,921	104,763	0	20	479	0	2,462
Sen 2	41,144	31,466	72,610	70	0	2211	0	4,608
Sen 3	58,795	16,592	75,387	0	0	334	0	2,497
Sen 4	22,456	20,865	43,321	0	35	7284	498	1,303
Sen 5	92,753	82,953	175,706	123	1591	26340	3706	4,266
Sen 6	14,273	12,749	27,022	0	0	310	3137	866
Chinnit 1	23,893	18,258	42,151	0	50	3212	0	1,193
Chinnit 2	111,088	95,299	206,387	463	1913	15406	0	4,496
Chinnit 3	65,821	81,537	147,358	55	572	8104	7059	1,845
Total	506,065	388,640	894,705	711	4,181	63,680	14,400	23,534

A large amount of spatial data has become available during the study. In the following maps, a selection of the most relevant spatial information is represented, in the following order:

1. Administrative boundaries
2. Digital Elevation Model
3. Geology
4. Soil
5. Land use classification in 1987
6. Land use classification in 2018
7. Irrigated areas
8. Flood frequency
9. Evapotranspiration (net water consumption)
10. Environmental features

The Sen-Chinit Basin Group lies within the provinces of Preah Vihear, Kampong Thom, Kampong Cham, Kampong Chhnang, Otdar Meanchey and Siem Reap (Fig 6-1). The area was divided into 9 sub-catchments covering a total area of 23,534km^2. The main tributaries that flow through the region are the Stung Sen and Stung Chinit. The Stung Sen has a total length of 508km and has a slope of around 0.01. The elevation within the region ranges from 760m to -0.6m and is generally lower towards the south and the banks of the Sen and Chinit (Fig 6-2). Geologically, this region is predominantly made up of old alluvium and young alluvium accounting for 47% and 24% of the total area, respectively (Fig 6-3). In addition, lower-middle Jurassic, andesite and basalt bedrock all represent over 5% of the total percentage area. Within the Sen-Chinit Basin Group, acrisol soil covers 73% of the total area whilst cambisol soil is the second most widely occurring, covering 12% of the total area (Fig 6-4). Furthermore, only gleysol, plinthosol and ferralsol soils also represent more than 1% of the total area. The SERVIR database shows that between 1987 and 2018 the percentage of ‘cropland’ increased by 11% from 14% of the total area to 25% (Fig 6-5, Fig 6-6). Other increases in area can be seen in ‘orchard or plantation forest’ from 12% to 30%, and ’wetlands’ from 4% to 8%. Decreases in percentage of the total area are exhibited in ‘evergreen broadleaf’ from 25% to 8%, ‘forest’ from 34% to 25%, and ‘flooded forest’ from 7% to 1%. CISIS irrigation statistics are summarised in Table 6-1, showing that wet season and recession irrigation make up 77% and 17% of year-round irrigated area, respectively (Fig 6-7). During a 1 in 100 year flood the south-west of the Basin Group would be majorly flooded whilst the areas adjacent to the large tributaries would also be subject to inundation (Fig 6-8). The areas with high flood occurrence occur predominantly in the south. The areas most lacking in abundant water can be found around and to the south-east of Kampong Thom (Fig 6-9). Most of the northern half of the region also lacks in dry season water availability. Finally, Figure 6-10 shows the location of the 16 protected areas, 11 river blockages and 34 CFRs within the Basin Group.

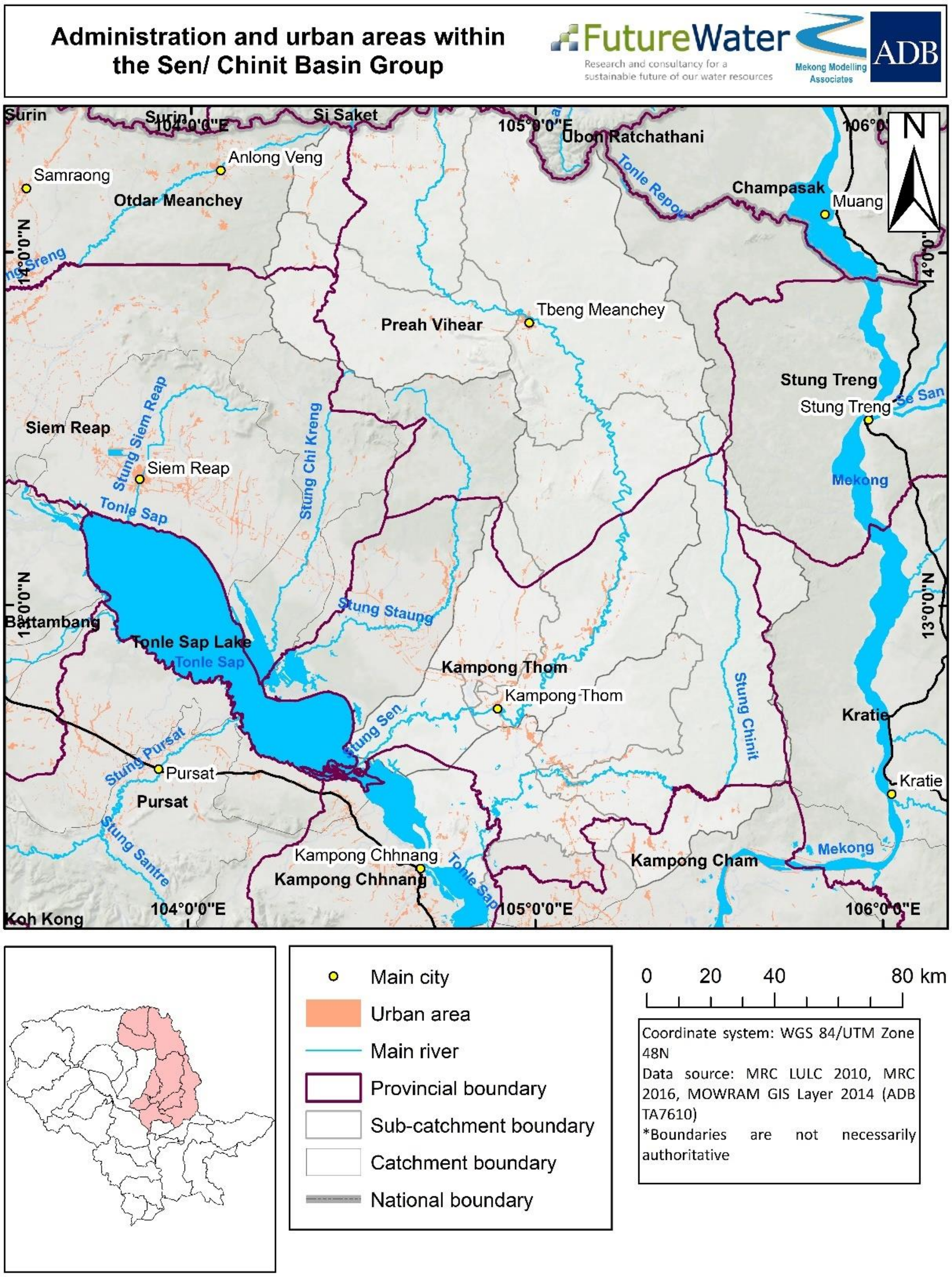


Figure 7-1: Administration and urban areas within the Sen/ Chinit Basin Group.

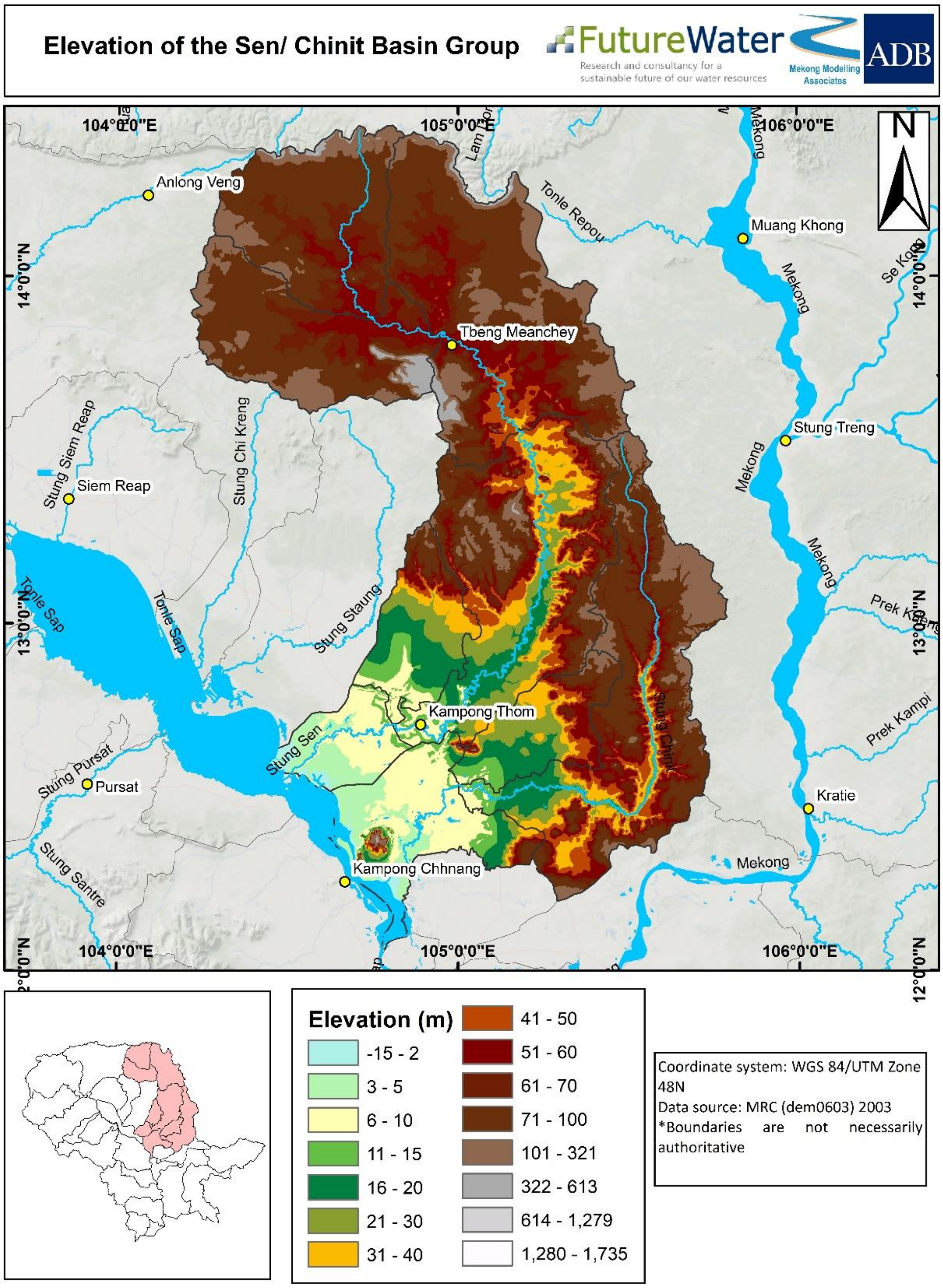


Figure 7-2: Elevation of the Sen/ Chinit Basin Group.

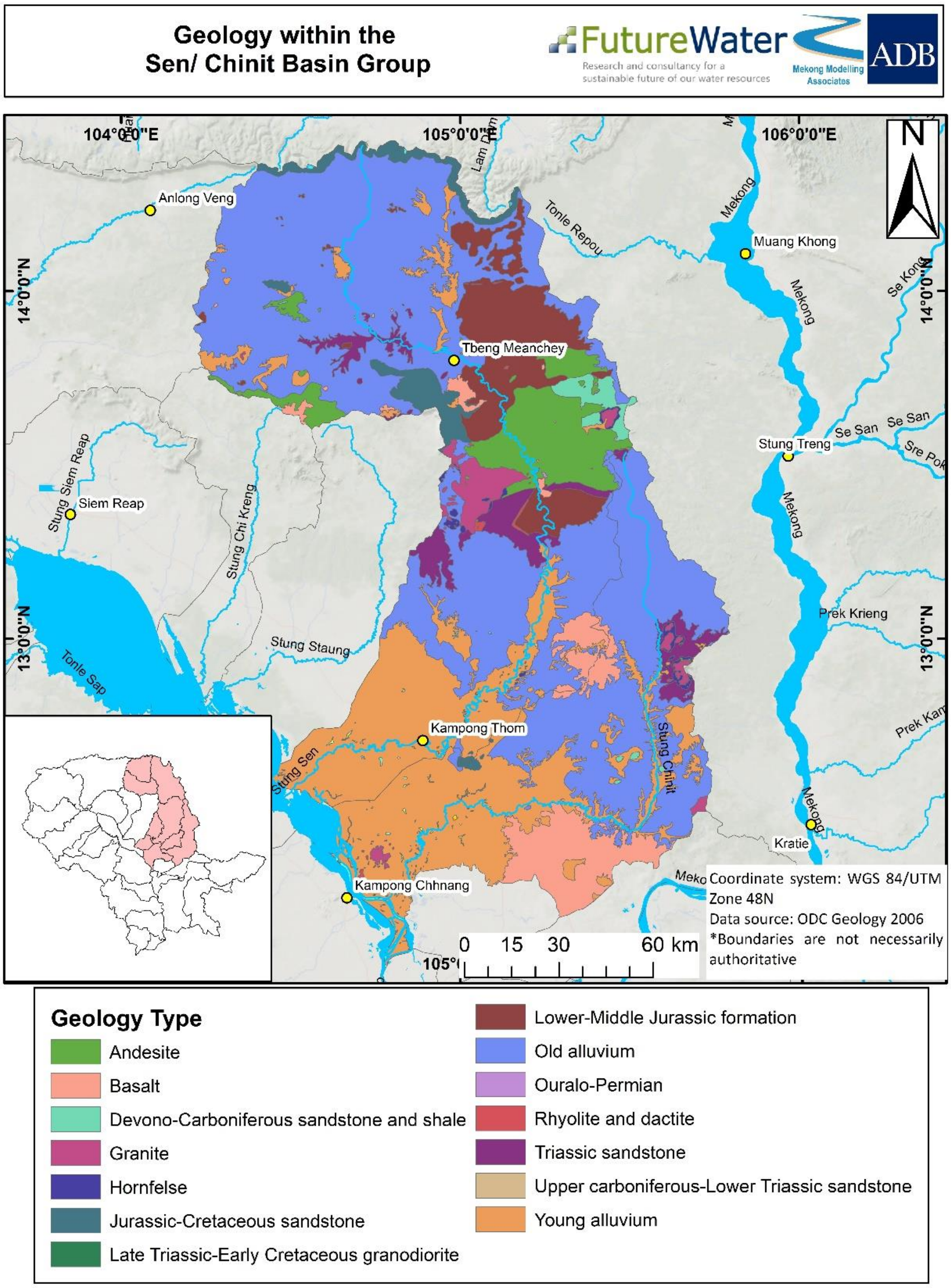


Figure 7-3: Geology within the Sen/ Chinit Basin Group.

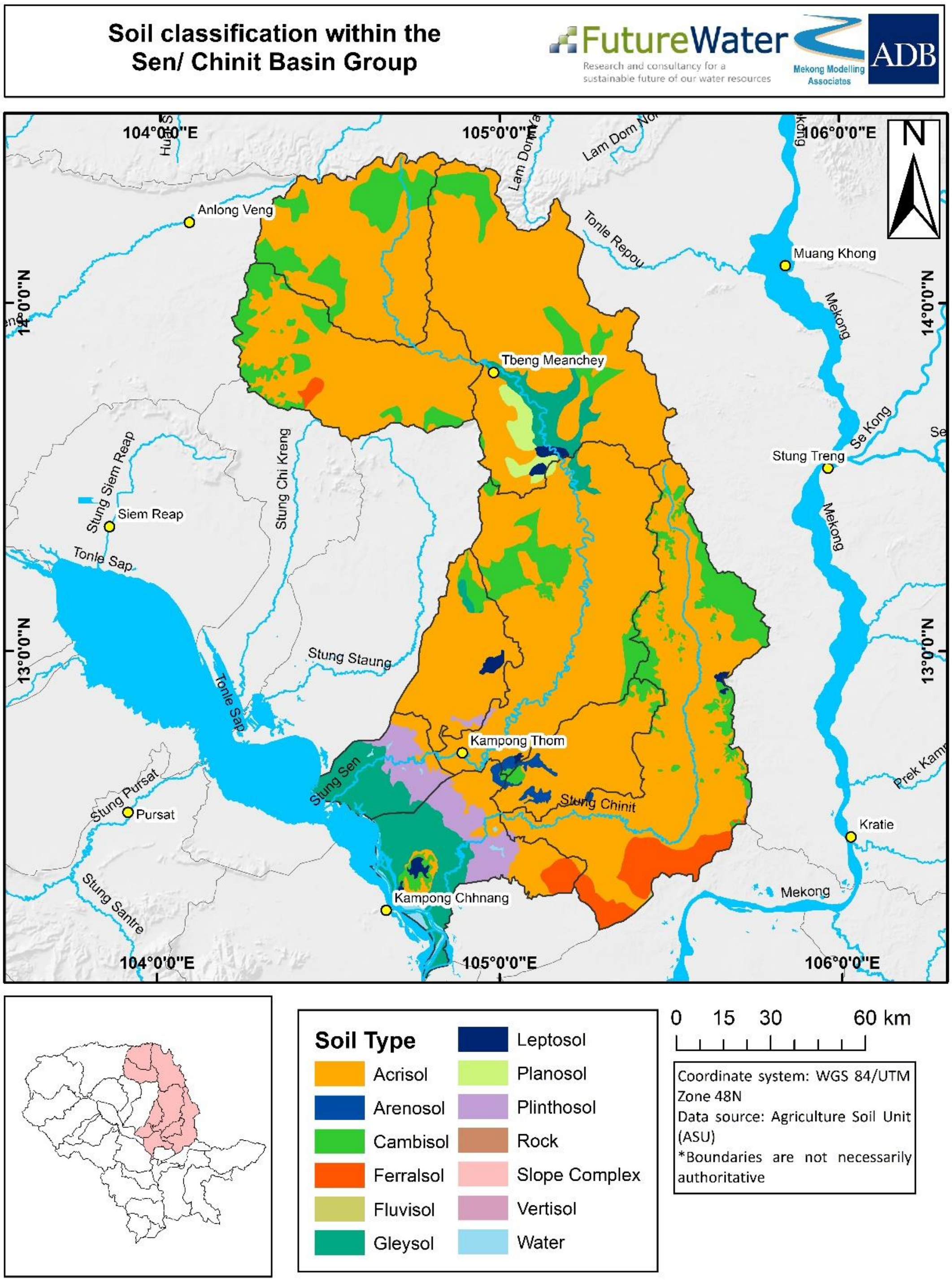


Figure 7-4: Soil classification within the Sen/ Chinit Basin Group.

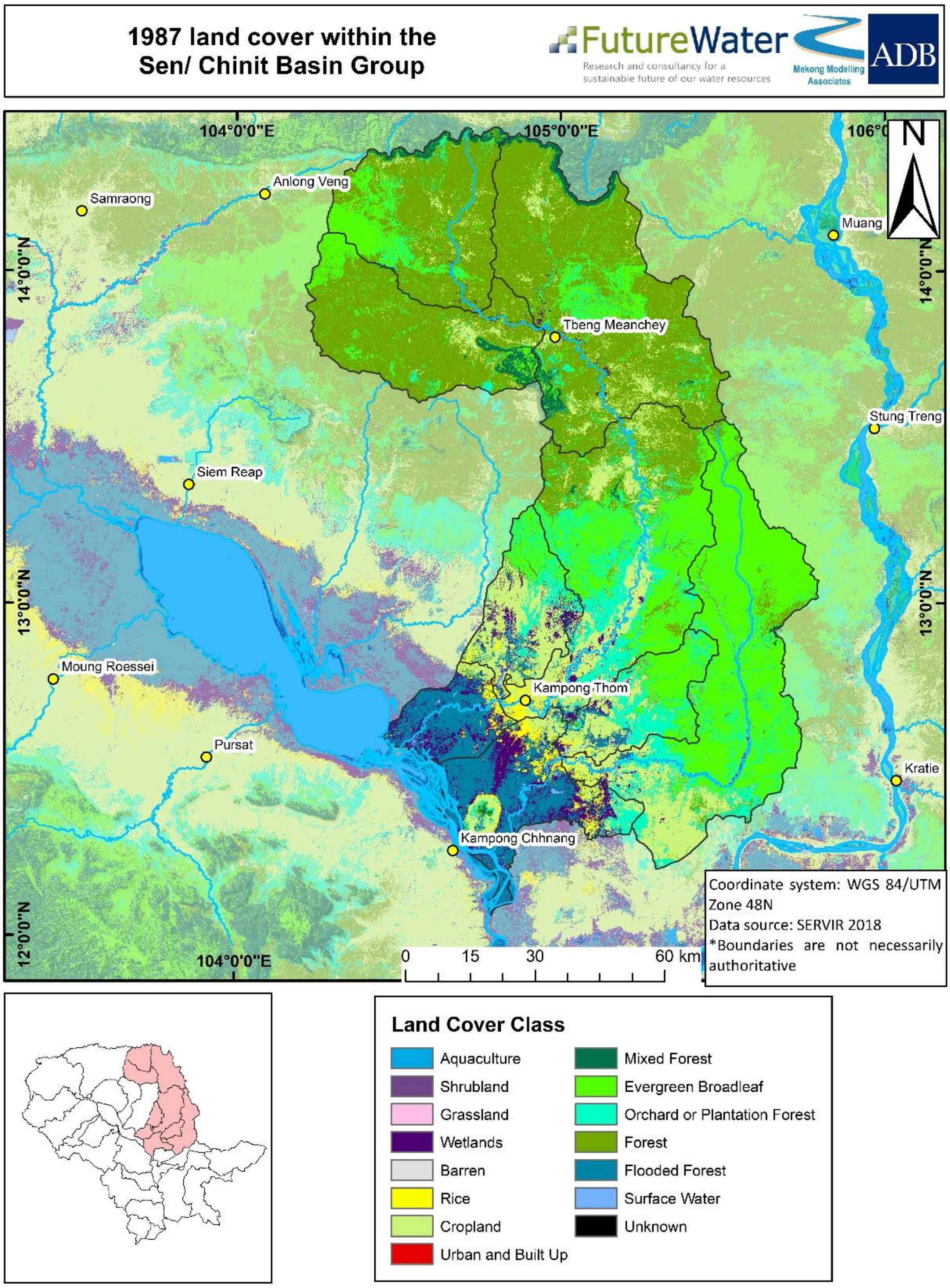


Figure 7-5: 1987 land cover within the Sen/ Chinit Basin Group.

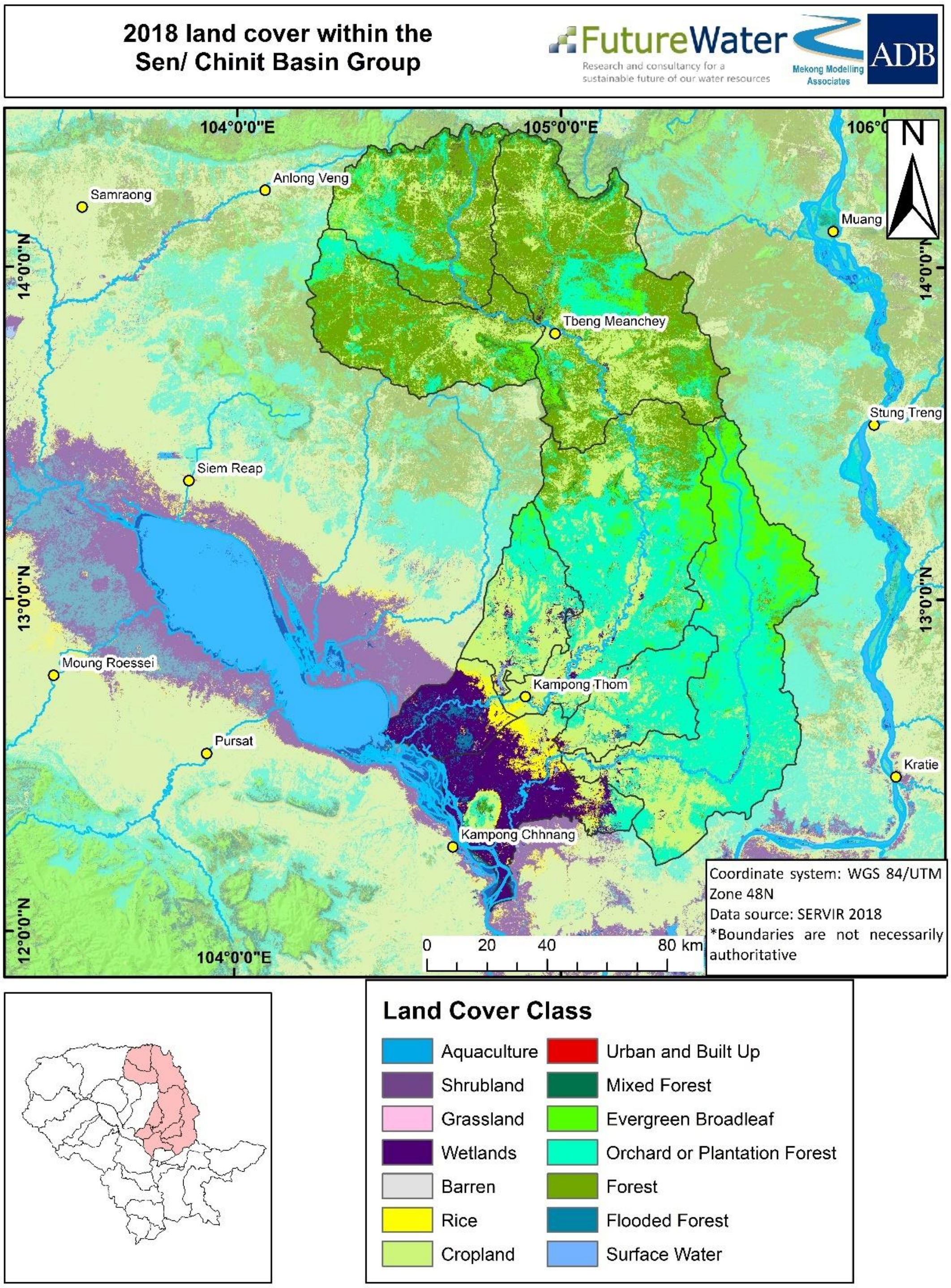


Figure 7-6: 2018 land cover within the Sen/ Chinit Basin Group.

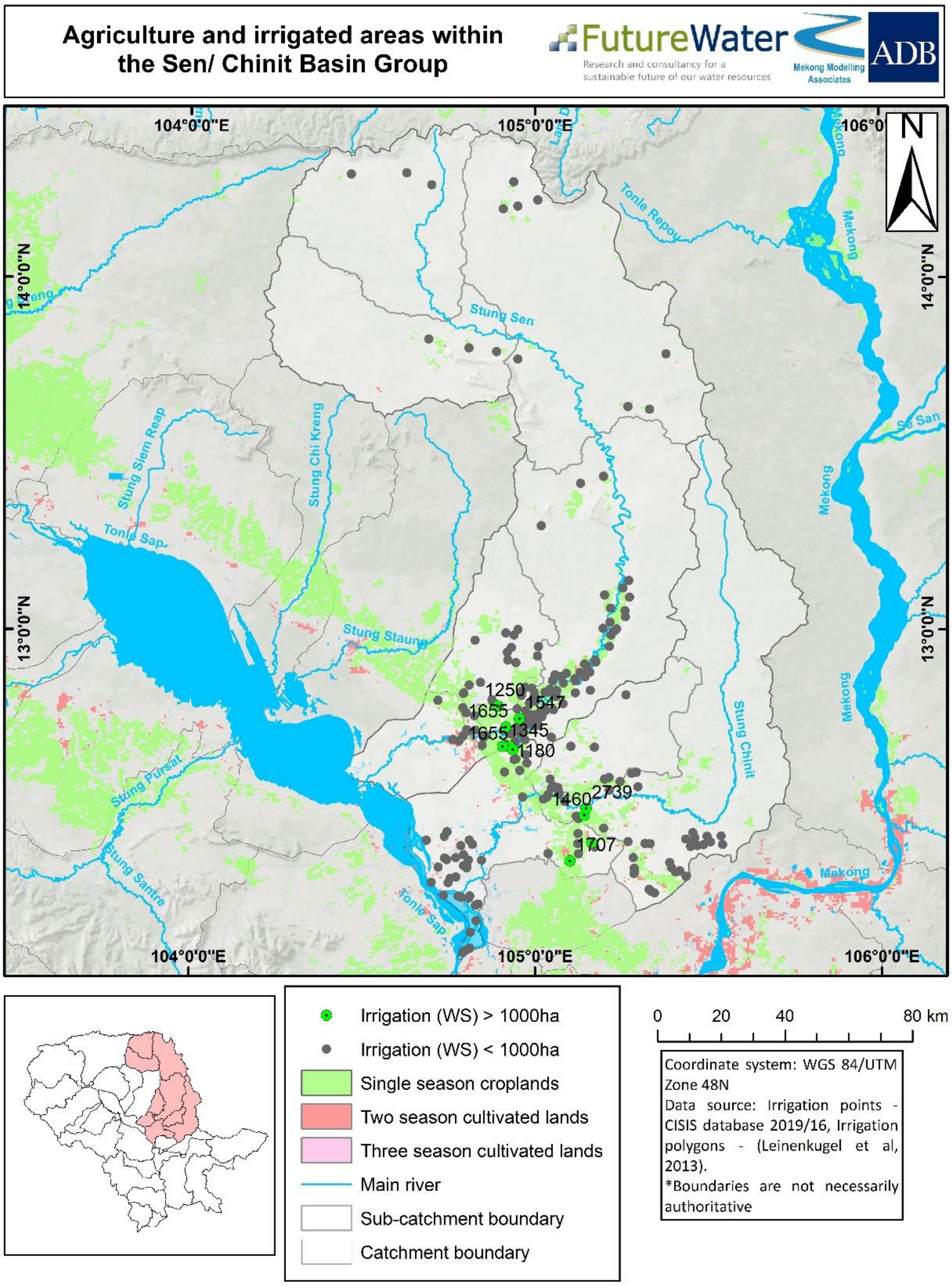


Figure 7-7: Agriculture and irrigated areas within the Sen/ Chinit Basin Group.

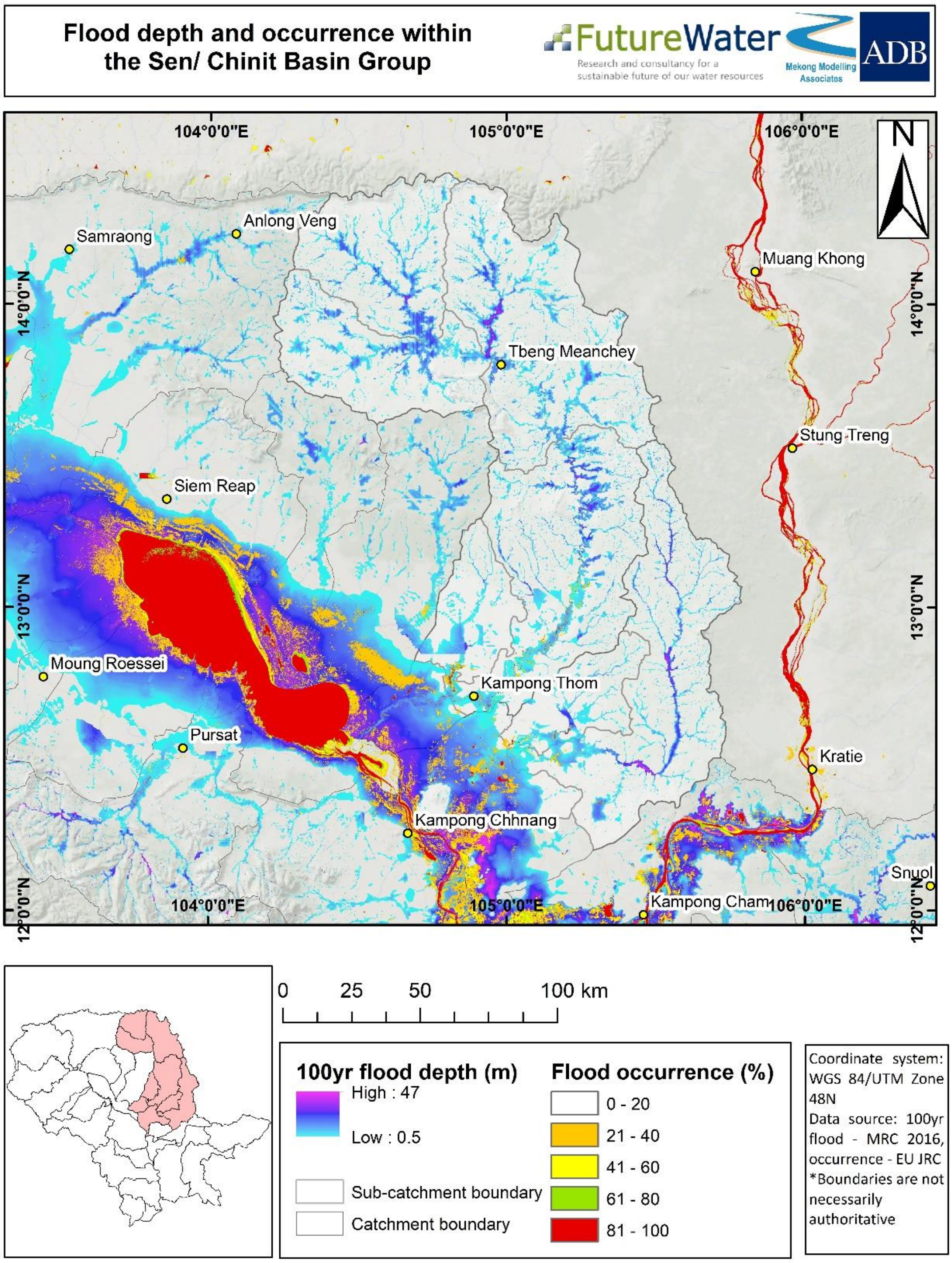


Figure 7-8: Flood frequency within the Sen/ Chinit Basin Group.

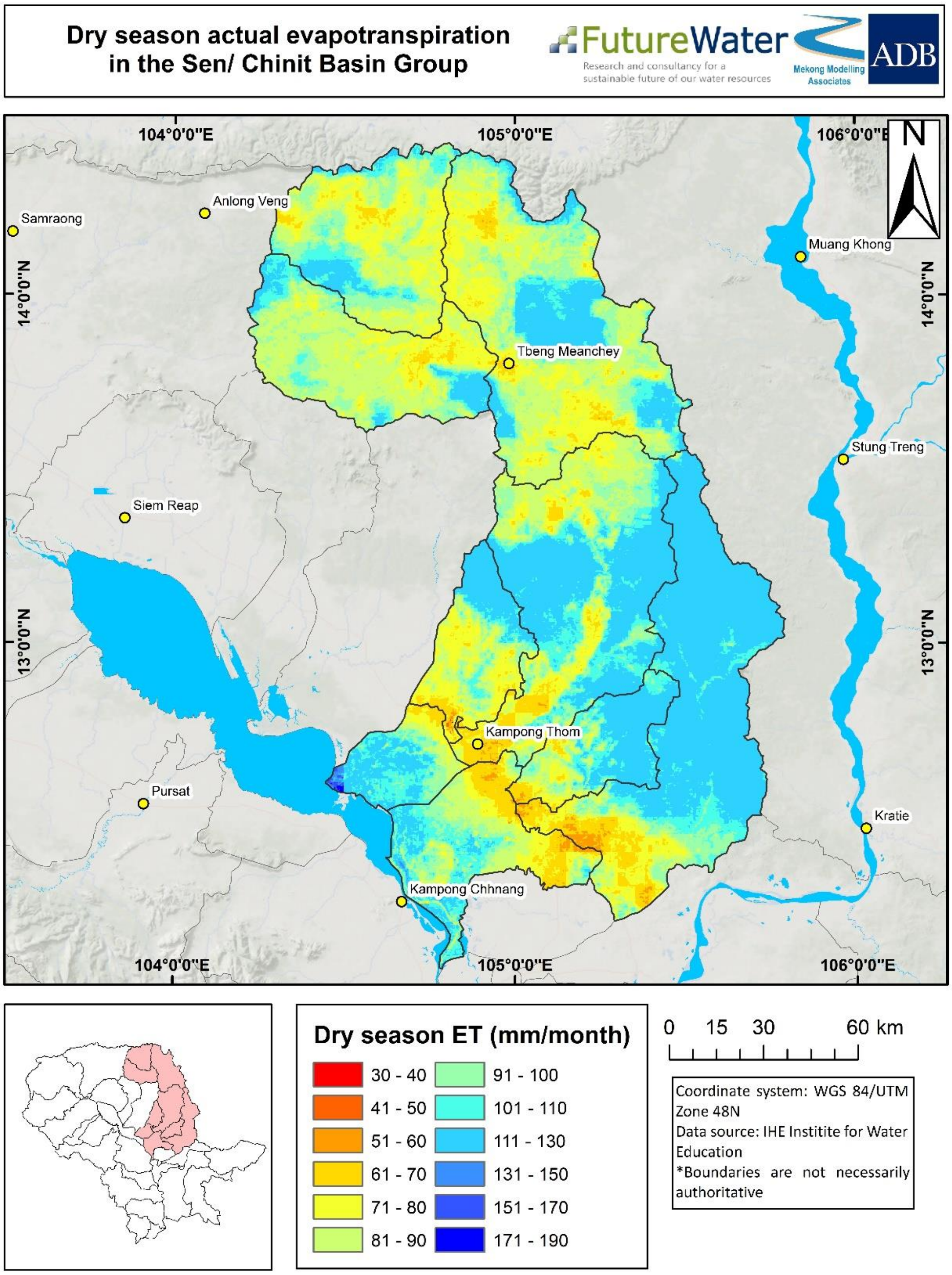


Figure 7-9: Dry season evapotranspiration in the Sen/ Chinit Basin Group.

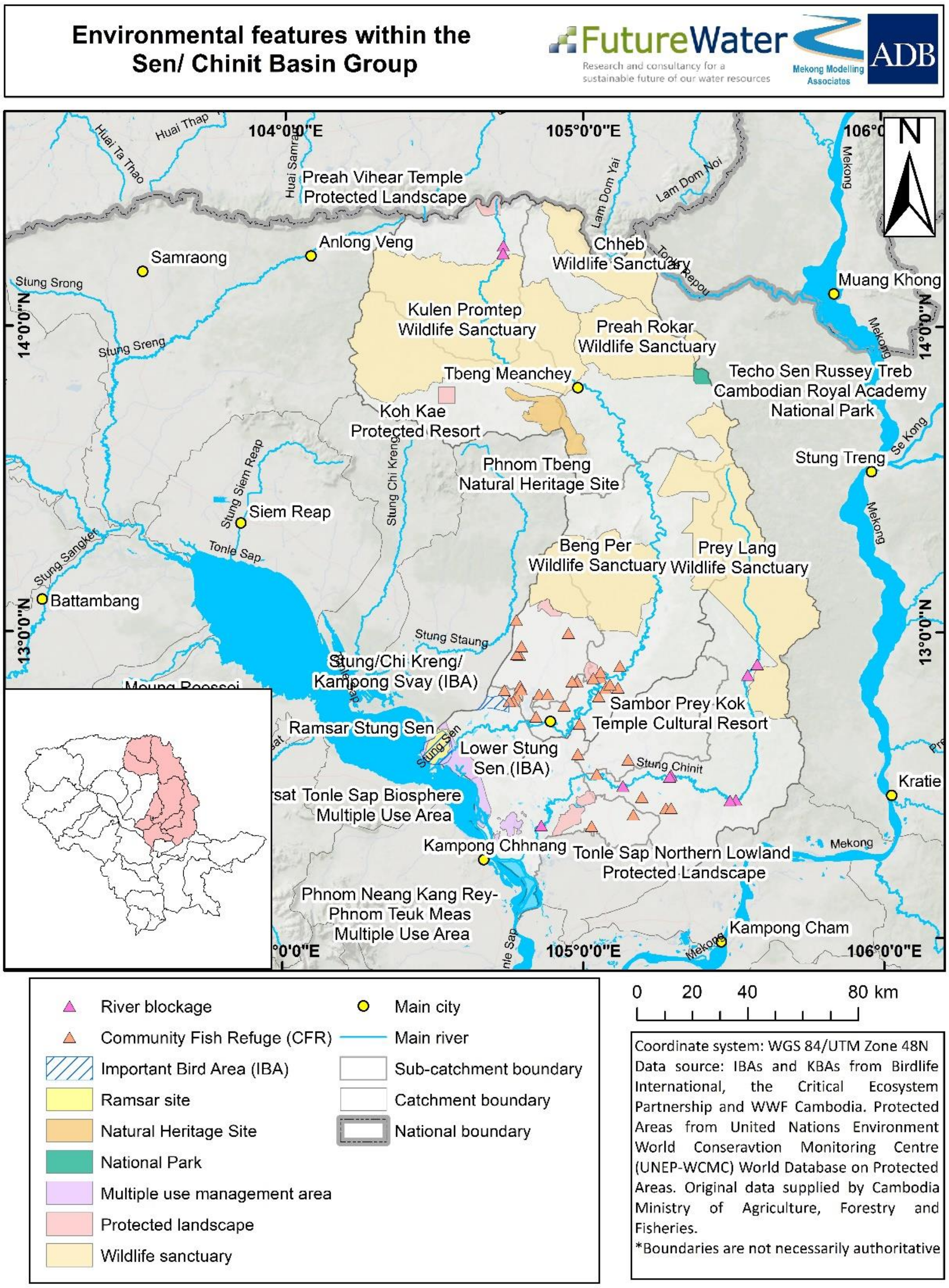


Figure 7-10: Environmental features within the Sen/ Chinit Basin Group.

7.3 Eco-hydrological considerations

The Eco-hydrological analysis performed on the Stung Sen has highlighted that the Lower Stung Sen is designated as a RAMSAR site in 2018 and supports many threatened bird species (see section 4 of the Ecohydrological report Phase I). The area is also thought to be crucial in retaining water in the wet season and preventing nearby settlements from flooding – something that could be further investigated in a hydraulic study. From the eco-hydrological assessment, it appears that the Lower Stung Sen Ramsar site is already nowadays under threat from agriculture, as protected wetland areas are converted into agriculture though irrigation development.

Currently this area is flooded annually, for several weeks or months. As discussed in the eco-hydrological report, whether such a flood is an ecological necessity can be debated, but it is known that flood pulses trigger flowering and fruiting and are certainly important for fish populations. Also, receding floodwaters form the basis for Cambodia’s very substantial inland fisheries, which may also be affected. Also they are important for sustaining extensive grasslands that support wildlife and key bird species (including endangered species such as the Sarus crane and Bengal florican) and livestock grazing.

Figure 7-11 shows the flows in the lower part of the Stung Sen, where it flows into the Lake, for the current situation (reference, in blue) and a scenario in which there is 3,000 MCM upstream storage, and a new irrigation of 300,000 hectares. As can be seen, in the current situation, low flows close to zero do not occur frequently (less than 1% of time). However, in analyzed scenario, flows close to zero would occur several weeks a year on average (about 15% of time on average). This will likely have considerable impacts on the eco-hydrological system.

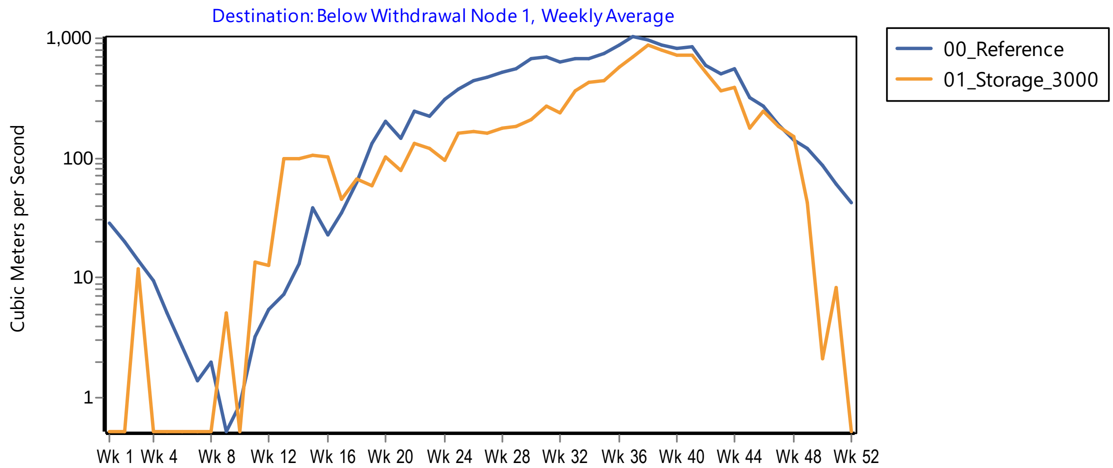
In terms of annual flood levels which are important for sustaining the previously mentioned ecohydrological functions, the analysis shows that these will be reduced by about 20% (the 5% exceedance level in the below figure of Figure 7-11). This is positive on one hand, as it will reduce annual floods that affect livelihoods negatively in this area. But reduced flood pulses in the Stung Sen floodplains will also affect fisheries production and cause less favourable conditions for wetland associated wildlife/birdlife and grazing lands.

Another factor is that more regulated flows typically encourage habitat conversion, also in areas where the most extreme floods (which are not reduced) still may have large impacts. Careful planning is thus necessary if part of the floodplain area will be converted, considering all these factors.

In summary, downstream impacts of upstream water storage developments and hydropower projects in the absence of mitigation include:

- regulation of seasonal flows, which *inter alia* will affect fish migration and spawning, and reproduction and growth on floodplains;
- reduction of downstream transport of nutrients and particulate matter, which are essential for aquatic productivity,
- poor water quality, with reduced oxygen concentrations, and elevated concentrations of toxicants including hydrogen sulphide, methane, manganese and iron, which may affect uses of the water;
- a positive impact are increased dry-season flows, which may support irrigation and E-flows, but in the scenario analysed this may be offset by increased water resources withdrawals of the new irrigation area.

It is thus important to consider the Integrated Water Resources Management principles to obtain a balance between the benefits of economic development (agriculture and hydropower) and maintaining ecosystem processes.



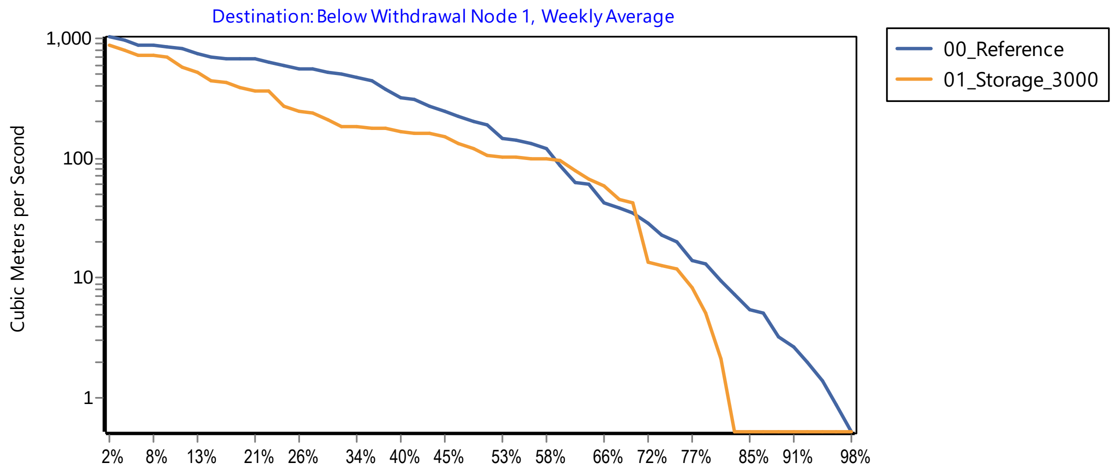


Figure 7-11. Outflow of the Stung Sen into the Tonle Sap lake. Above: mean weekly flow. Below: exceedance levels.

Table 7-2. Values for several exceedance levels as are shown in Figure 7-11 (m3/s).

Exceedance level	00_Reference	01_Storage_3000
1%	1713	1485
5%	1084	875
10%	850	681
50%	149	203
90%	3	101
95%	2	97
99%	1	95

7.4 Model setup

For the Stung Seng Basin it was decided, given the complexity in water supply and demand topics in this basin, to further build and improve on the Water Supply and Demand Framework, as implemented in WEAP and used for the Rapid Assessment report. The main characteristics and refinements that were done are:

- The inflow into the rivers and streams were obtained from the calibrated SWAT model, instead of the rainfall-runoff modeling done in the Rapid Assessment stage.

- Irrigation demands have been calculated dynamically using the catchment nodes approach from WEAP combined with the soil-moisture option.
- A timestep of one week (7 days) was used.
- To introduce annual and weekly variation climate data from 20 years (1996-2015) have been used.
- A two years warming up period was used to ensure that the model was in equilibrium when starting the actual analysis.
- Input and output analysis were done by a combination of direct results from the model as well as using a set of excel VBA scripts.
- The same domestic water nodes were implemented and urban water requirements were set at 160 liters per person per capita as in the Rapid Assessment phase (total six). For rural water consumption 90 liter per person per capita was considered.
- Irrigation demand areas were combined into six nodes. Besides a new irrigation node was added that represents the area where potentially irrigation can be further expanded. For the baseline scenario (current situation) this node is inactive.
- The actual water demand is calculated by the WEAP model using the following principle. Crop water requirements are calculated by the Penman-Monteith approach considering climate data (e.g. temperature, windspeed, humidity, sun-shine hours). If sufficient water is ponded or available in the soil, actual water supply demand is zero. In case ponding is low and soil water is below a set threshold value, water demand is calculated. This water demand is further refined by losses and reuse of water and the result is the so-called supply requirement. In case sufficient water is available in streams and reservoirs, this will be released and allocated. In case of shortages water will be rationed given a pre-defined priority (for the moment set at all equal).
- A raw estimate of the amount of crop that is produced has been calculated based on the water productivity of 0.72 kg m^{-3} as reported by (2019, Foley et al.). Such a crop production based on water productivity should be used with care, but as inter-comparison between various investment scenarios useful.
- A new reservoir node which is used to assess how increased reservoir storage upstream influences water availability downstream, just upstream of Rovieng town.

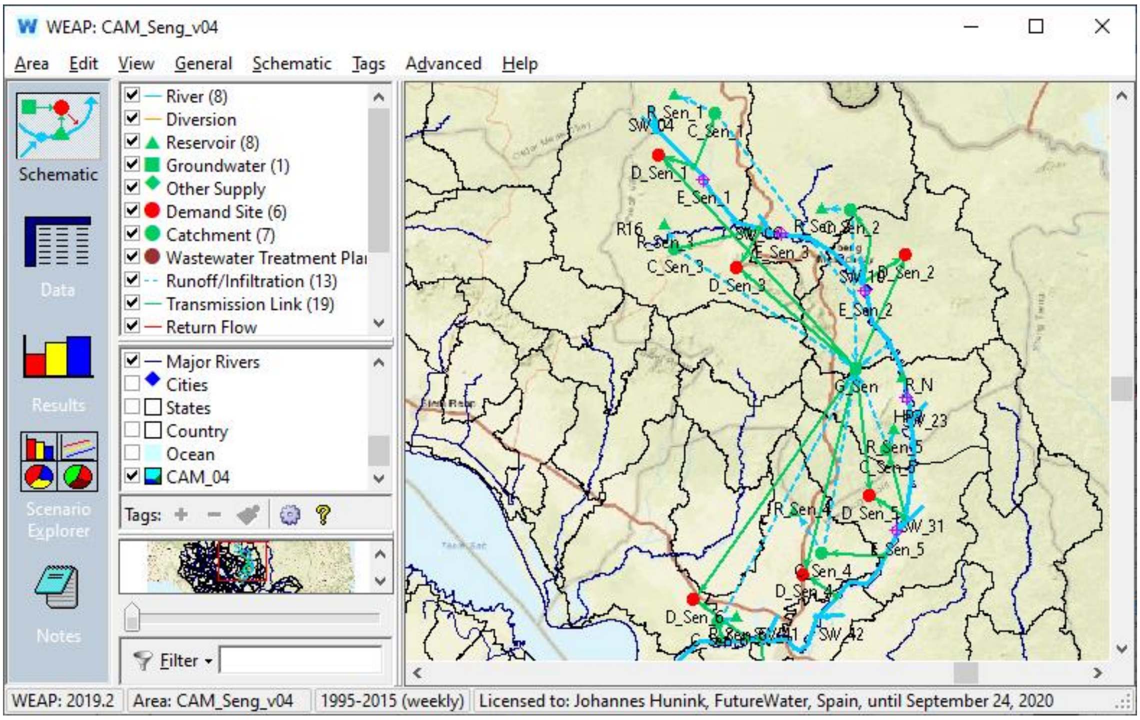


Figure 7-12: Schematic of the Water Supply and Demand Framework in WEAP for the Stung Sen Basin.

7.5 Water Demand and Supply Evaluation

The Water Demand and Supply Framework as implemented in WEAP and discussed in the previous section, was used to evaluate the current situation (reference, baseline). Table 7-3 shows for the irrigated areas the various components of the water demand, supply and coverage. Crop water requirement and irrigation demands varies substantially between the irrigated areas mainly as a result of different areas, depending on the cropping season. The irrigation shortages and the coverage (expressed as water supplied over water demand) varies slightly between the different areas. Overall is water shortage in the basin not severe as indicated by the numbers in the column “Coverage”. Obviously, variation between years and seasons is substantial and there might be periods where water is more stressed.

Domestic demands, supplies and coverages are shown in (Table 7-4). There is quite some variation between the various domestic water demands as population differs quite a lot in each area. Overall coverage is between 80% and 100%. Interesting is that the entire water demand for domestic use of about 18 million cubic meter per year is an order of magnitude smaller compared to the water demand for irrigation (772 million cubic meter). In the current analysis no specific priority has been given to any sector, so any water shortage will be allocated equally between and within sectors. The results presented also assume that the water supply infrastructure is in place and shortages presented here are only a consequence of water resources shortages.

Environmental flows have been evaluated at several points in the Stung Sen River Basin (Figure 7-13 and Figure 7-14). The figures indicate that the flow requirements are generally met, although in the dry season coverage goes down to 20%. This is on average, so some years coverage of environmental requirements may be even close to zero.

The Water Supply and Demand Framework provides a huge amount of supporting data. The model itself is attached to the report and can be used as reference in case more results are needed to be analyzed. Figure 7-15 provides an example of those detailed results from the analysis.

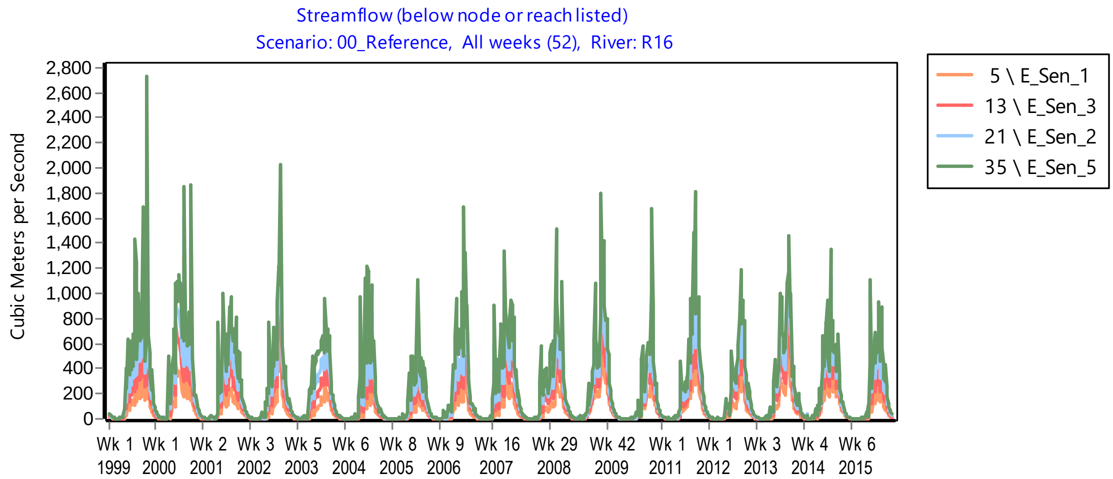
In summary it can be concluded for the Stung Sen Basin´s water resources are abundant, and that some water shortages occur in some areas and some periods of the year. This means that there may be potential to expand water resources usage in the basin, if planned carefully, considering impacts on other water use(r)s, including environment. The next section will explore how development of storage upstream and irrigation downstream relates to each other.

Table 7-3. Results of the Water Supply and Demand Analysis for the irrigation schemes. Annual averages over a period of 20 years (1996-2015) are shown.

	(MCM/y) Precipitation	(MCM/y) ET Potential	(tonnes/y) Crop Produced	(MCM/y) Irrigation Demand	(MCM/y) Irrigation Supplied	(MCM/y) Irrigation Shortage	(%) Coverage
C_Sen_1	8	6.4	4000	2.3	2.0	0.4	84%
C_Sen_2	39	28.4	18000	6.7	5.5	1.2	83%
C_Sen_3	6	4.2	3000	1.0	0.9	0.1	87%
C_Sen_4	133	99.4	65000	28.6	25.9	2.7	91%
C_Sen_5	533	400.1	258000	135.5	103.0	32.5	76%
C_Sen_6	52	45.5	30000	39.7	32.3	7.4	81%
TOTAL	772	584.0	378000	213.9	169.6	44.2	79%

Table 7-4. Results of the Water Supply and Demand Analysis for the domestic water requirements. Annual averages over a period of 20 years (1996-2015) are shown.

	(MCM/y) Water Demand	(MCM/y) Supply Required	(MCM/y) Supply Delivered	(%) Coverage
D_Sen_1	3.4	4.3	3.1	73%
D_Sen_2	3.0	3.7	2.8	76%
D_Sen_3	2.5	3.1	2.3	75%
D_Sen_4	1.3	1.7	1.7	99%
D_Sen_5	6.9	8.6	6.6	77%
D_Sen_6	0.9	1.2	1.2	100%
TOTAL	17.9	22.4	17.6	79%



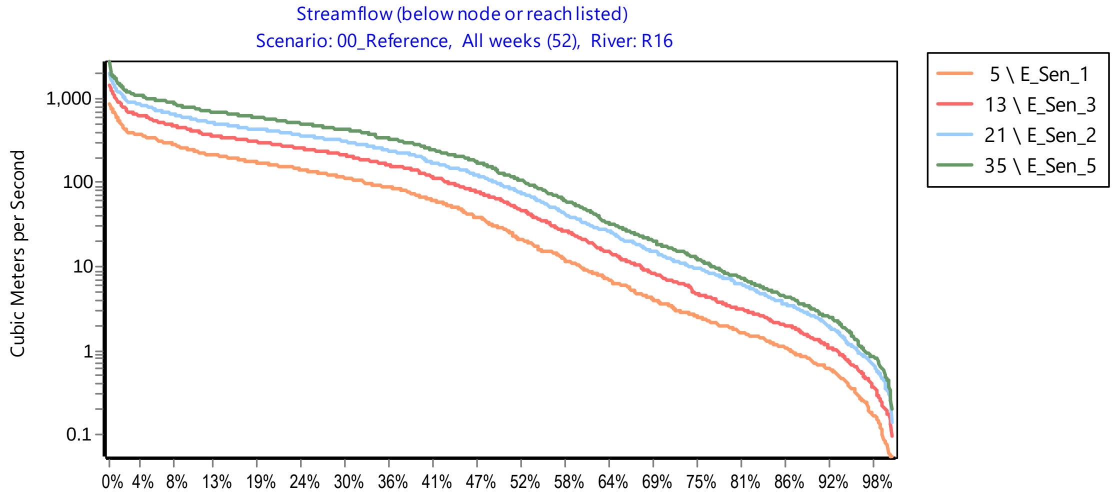


Figure 7-13. Streamflow at the four locations where environmental requirements are imposed in the Stung Sen basin. Above: presented as timeseries over a period of 20 years. Below: presented as weekly exceedance levels.

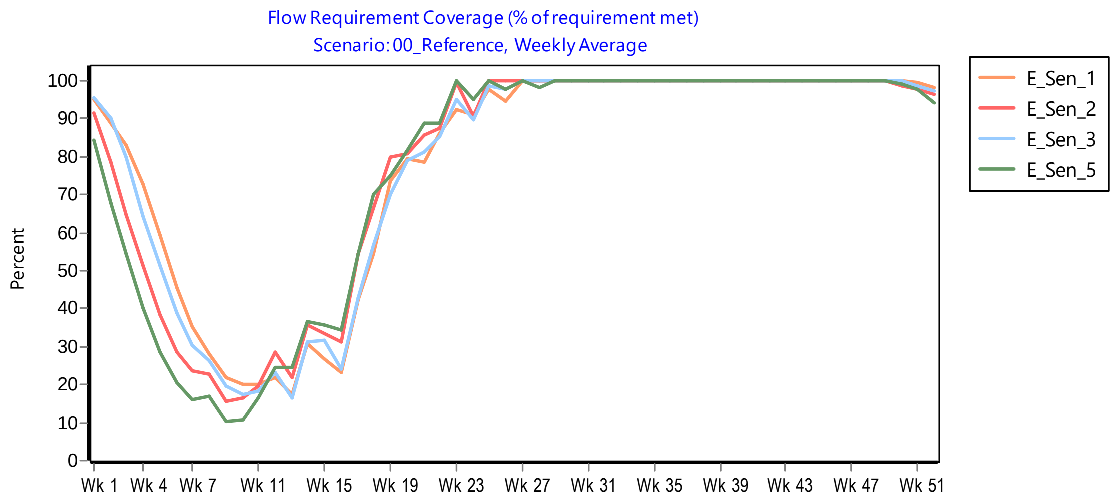


Figure 7-14. Coverage of streamflow requirements at the four locations in the Stung Sen basin (without reservoirs).

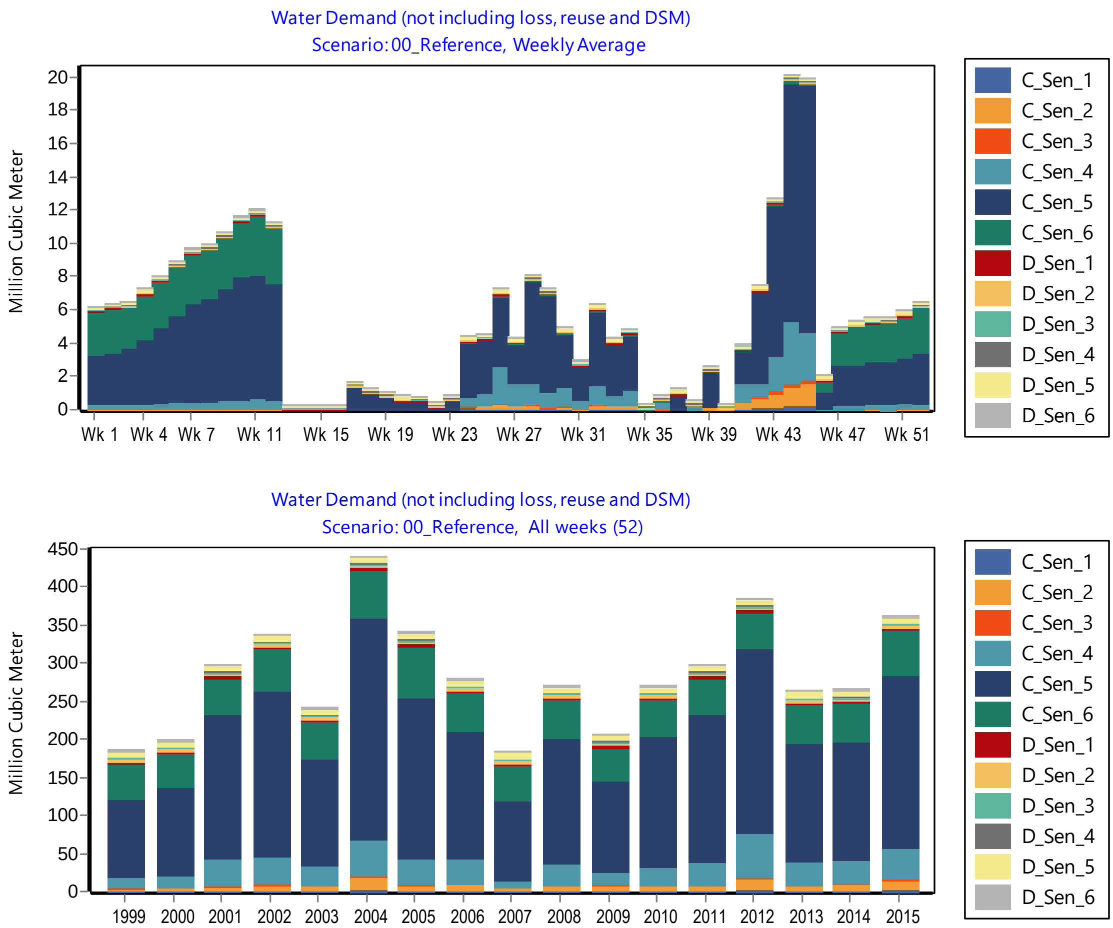


Figure 7-15. Example of output provided by the Water Supply and Demand Framework as implemented in WEAP: Water Demand average weekly (top) and annually (bottom).

7.6 Irrigation potential versus storage development

This section explores the scope in terms of water resources to expand irrigated area downstream of Stung Sen and possibly Stung Chinit (by means of a water transfer in the lower areas). The scenario explores:

- A potential newly irrigation area of 300,000 hectares. Double cropping is implemented:
  - 100% of the area is cropped in the wet season
  - 50% in the early wet season
  - 50% in the dry season
- The advantage of distributing the cropping between the early wet season and the dry season, instead of only one of these seasons, is that irrigation water demand is also more distributed along the year, which reduces the risk that conflicts arise with hydropower usage upstream, which typically needs to release water all-year-round.
- Additional storage capacity, up to 4,000 MCM upstream in the basin. Information available suggests the basin may have physical potential to increase reservoir storage to at least approximately that level:

  - One projected reservoir is currently already in an advanced phase of preparation and development financed by Chinese funds, with a total storage capacity of 256 MCM
  - A large hydropower reservoir is foreseen also, with 2890 MCM storage capacity
  - Preliminary analysis suggests that there may be scope for additional smaller reservoirs upstream.
- Two decision variables are assessed:
  - **Coverage** (total water supplied divided by the total irrigation demand) of the newly irrigated area
  - **Cropping intensity** (total irrigated area of all cropping seasons divided by the command area)

In Table 7-5 the main outputs of the water balance are shown for different upstream reservoir water storage capacities (from 0 to 4,000 MCM active storage). Effective precipitation and crop water requirements (ET potential) are the same for all scenarios, as well as net irrigation demand. The irrigation water supply though depends on the upstream water storage capacity. Shortage diminishes with increasing storage capacity. Coverage is calculated (irrigation supplied divided by irrigation demand) for the new irrigation area. This value ranges from 44% in case there is no upstream reservoir capacity regulating the flows (the current situation), up to 82% with maximum buildout of 4,000 MCM active storage.

Coverage versus upstream reservoir storage capacity is also shown in Figure 7-16. The figure shows clearly that coverage increases with increasing storage capacity. The figure shows also that for the higher capacities, less relative gain in coverage is obtained.

Besides the typical water balance items, also crop production is presented (a first-order approximation based on a typical Cambodian water productivity figure, explained previously). According to the analysis a total amount of rice of about 5 million tonnes per year can be produced in 300,000 hectares. This production is spread over the three cropping seasons. This is quite substantial as according to FAOstat in the entire country 10.4 million tonnes rice has been produced in 2017, which means that this new irrigation area alone could increase national production by approximately 50%.

The last column in Table 7-5 shows the cropping intensity that can be obtained, with the constraint imposed that crops need and receive their full crop water requirement. As can be seen, without upstream water storage, the 300,000 hectares area can be cropped a little bit more than once a year (113%). This number increases considerably with increasing storage, up to 163% with 4,000 MCM of active storage upstream. This is still however lower than the cropping intensity envisioned in the National Irrigation Strategy presented this year, targeting a cropping intensity of 200% - 215%.

Figure 7-17 shows this relationship between storage and cropping intensity. Also here it is obvious that for the higher capacities, the relative gain in cropping intensity is lower.

It is important to note that this analysis is done from a water resources perspective and has not investigated what the potential is in terms of land availability, considering different suitability aspects: biophysical ones as soil and slope, and socio-economic ones (accessibility, livelihood aspects). Also, environmental factors should be considered very carefully when planning the new irrigation area. The last section of this chapter presents several eco-hydrological considerations.

Table 7-5. Results of the Water Supply and Demand Analysis for scenarios of increasing upstream water storage capacity (left column). Annual averages over a period of 20 years (1996-2015) are shown.

Upstream storage capacity (MCM)	Effective precipitation (MCM/y)	ET Potential (MCM/y)	Crop Produced (tonnes/y)	Irrigation Demand (MCM/y)	Irrigation Supplied (MCM/y)	Irrigation Shortage (MCM/y)	Coverage (%)	Cropping intensity (%)
0	9857	7951	4759000	3559	1576	1982	44%	113%
250	9857	7951	4838000	3557	1767	1790	50%	122%
500	9857	7951	4911000	3557	1920	1637	54%	125%
1000	9857	7951	5034000	3556	2245	1311	63%	135%
2000	9857	7951	5146000	3556	2635	921	74%	148%
3000	9857	7951	5189000	3556	2832	724	80%	157%
4000	9857	7951	5208000	3556	2928	628	82%	163%

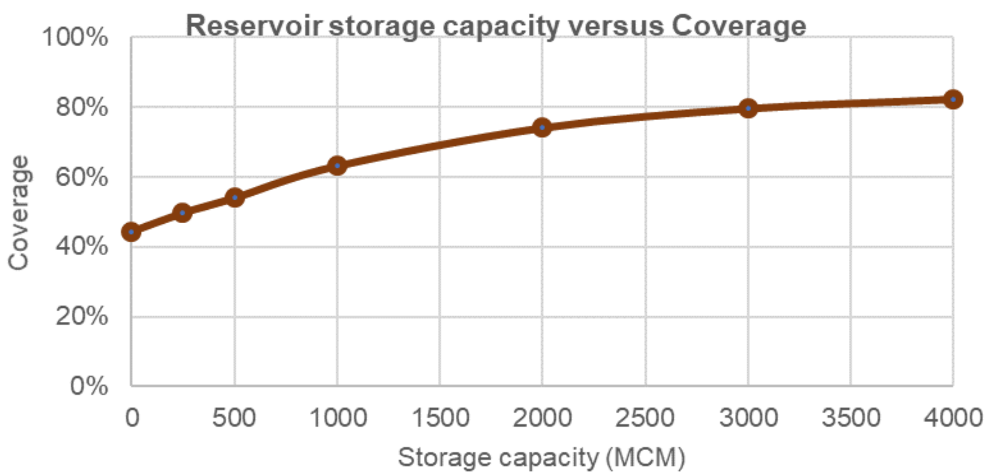


Figure 7-16. Increased reservoir storage capacity upstream in the Stung Sen basin versus coverage (supplied divided by demand) of the new irrigation area downstream

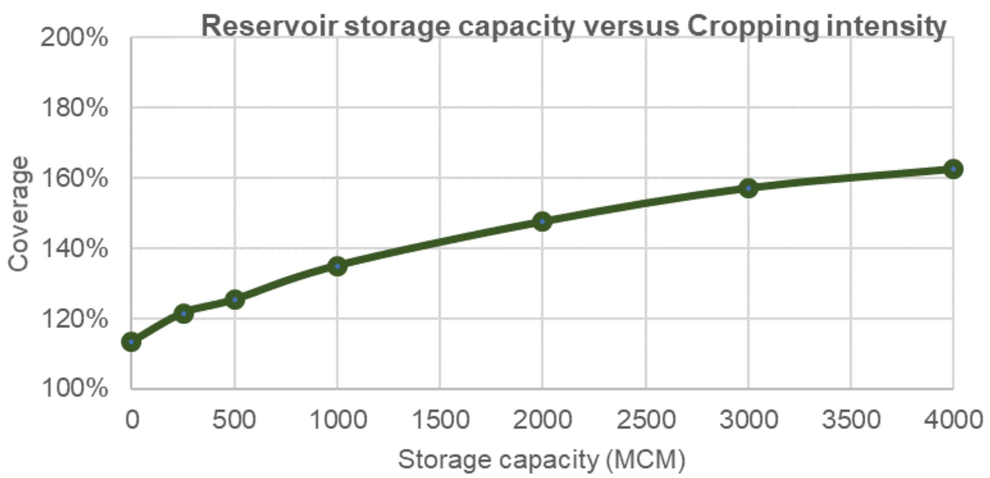


Figure 7-17. Increased reservoir storage capacity upstream in the Stung Sen basin versus cropping intensity (total irrigated area divided by command area) of the new irrigation area downstream

7.7 Peak flows at Kampong town

Peak flows in the flood season cause often problems in the downstream area of the Stung Sen, around the town of Kampong among others. Developing storage capacity upstream could regulate peak flows and conveying the water downstream to different areas in the floodplain could also reduce peak flows.

The modeling analysis was used to assess how the flow regime is altered when storage is developed upstream. Conveyance capacity downstream was assumed to be around 200 m^3/s in the wet season. As Figure 7-18 shows, during most of the year this capacity is fully used. Only during some short periods in between the cropping seasons, the conveyance system is unused.

Figure 7-19 shows how flows in the Stung Sen at Kampong Svay are influenced by upstream water storage developments. The upper figure shows clearly how flows are regulated, reducing low flows considerably. This is in fact even clearer in the lower figure which shows that low flows are much less frequent. Also the higher flows are reduced. Important though is that the most extreme high flows are not reduced: even with the 3,000 MCM capacity these flows cannot be regulated, also considering that normally when the high flows reach the reservoir, it is typically already partially full – something that this modelling assessment considers.

In conclusion: low flows will become considerably less frequent, as well as medium to medium-high flows. However, the extreme flows (this analysis suggests those above 1,700 m3/s) will not be regulated and may still cause considerable flooding of the areas.

This analysis is a first approximation and based on weekly data over a 20-year period, but should be further extended using an hydraulic model that considers the different infrastructures, and capacities.

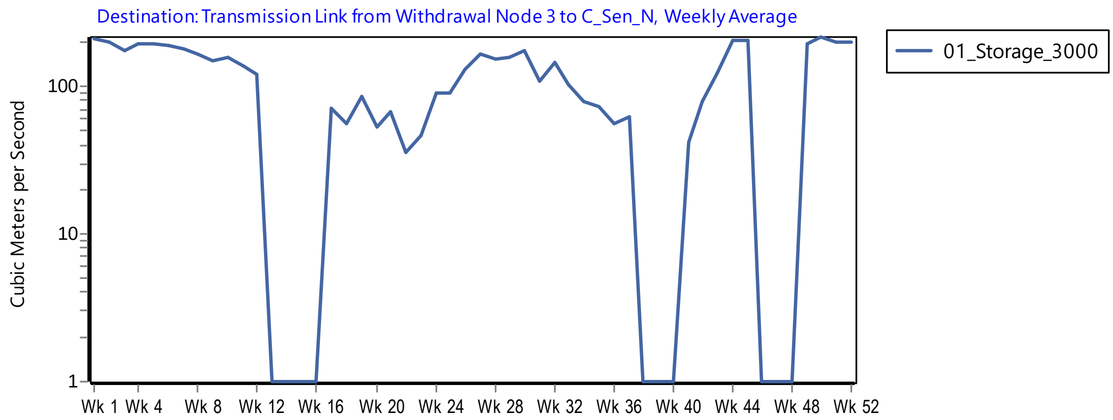


Figure 7-18. Mean weekly flow of the conveyance system of the new irrigation area downstream of Stung Sen and Stung Chinit, following the different cropping seasons, and for a scenario in which upstream storage capacity is 3,000 MCM, based on the 20-year simulation period.

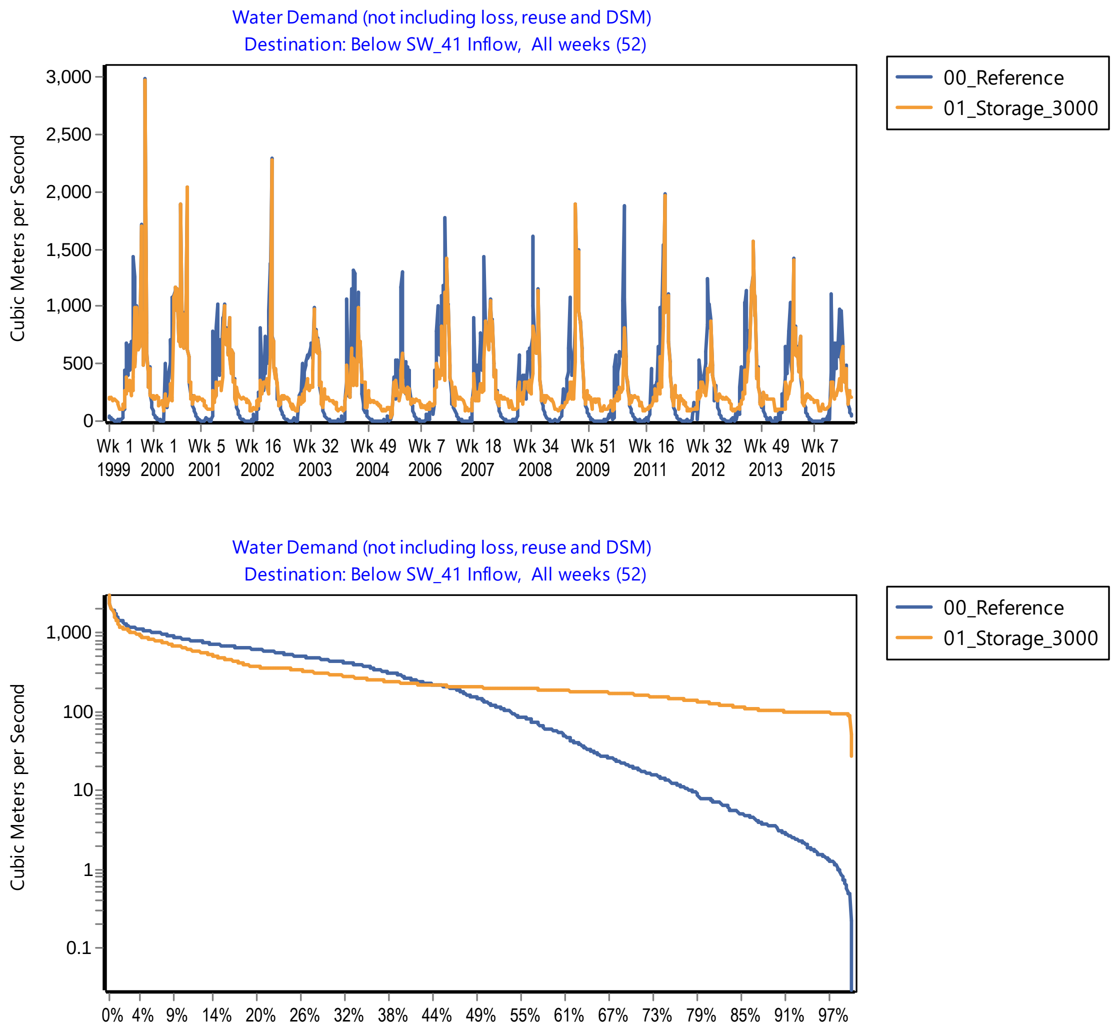


Figure 7-19. Weekly flows at Kampong town of the current situation (reference, blue) and a scenario of 3,000 MCM upstream storage (orange). Above: timeseries; below: exceedance levels.

8 Chhlong Basin: additional study

8.1 Prek Chhlong Link Canal Scheme Outline

8.1.1 *Introduction*

The Prek Chhlong lies at the far northeast of the Mekong Delta River Basin Group and flows to the Mekong ~5km downstream of Kratie. The catchment area (5,559km^2) is undulating and until recently was heavily forested but now contains a significant area of plantation and upland crops.

The primary purpose of this appraisal is firstly to examine rapidly if it is conceptually possible for the Prek Chhlong to provide an additional gravity water source to the extensive Prey Veng and Vaico Irrigation systems (2-300,000ha). They have been recently developed on the Mekong left bank but currently dependent on two major pumping stations each of 120m^3/s capacity. Electricity demands in Cambodia currently exceed supply and grid capacity and the system cannot be used to full capacity.

Therefore, the concept is to bring irrigation supply from the Prek Chhlong via a 100km gravity link canal to the head of the existing irrigation systems. The link canal potentially would have operational, cost and GHG emission benefits. In this section the basic demand and supply data are considered and then in the next section all available data is used to determine at a pre-feasibility technical level is such a scheme is possible.

8.1.2 *Prek Chhlong Water Resources*

The Prek Chhlong currently has no gauging site although a number of sample measurements have reportedly been made. A review of previous studies using hydrological models and regression techniques to estimate annual yield for ungauged catchments give a range of values as shown in Table 8-1. The 1994 Study and the 2014 Water Resources Profile give a higher estimated water yield than the MRC SWAT and FutureWater WEAP modelling assessments. The 1994 study potentially would be expected to give a higher yield than present as at that time the catchment was heavily forested, and/or the techniques used data from similar catchments. Conservatively, it is assumed that the available resource in the Chhlong is around 2,500MCM/yr and establishment of a gauge and rating is recommended.

Table 8-1: Rainfall and flows estimated in previous studies of Prek Chhlong.

Date	Source	Mean Rainfall (mm/y)	Q average	Q50 (m^3/s)	Estimated Annual Water Yield (MCM/y)
1994	Mekong Secretariat Irrigation Rehabilitation Study	1763/	156	24	4938
2014	ADB Cambodian Water Resources Profile TA7610	-	140		4401
2017	MRC SWAT Model (CS)	-	77		2431
2019	WEAP Model, Rapid Assessments TA7610	2040	86		2704

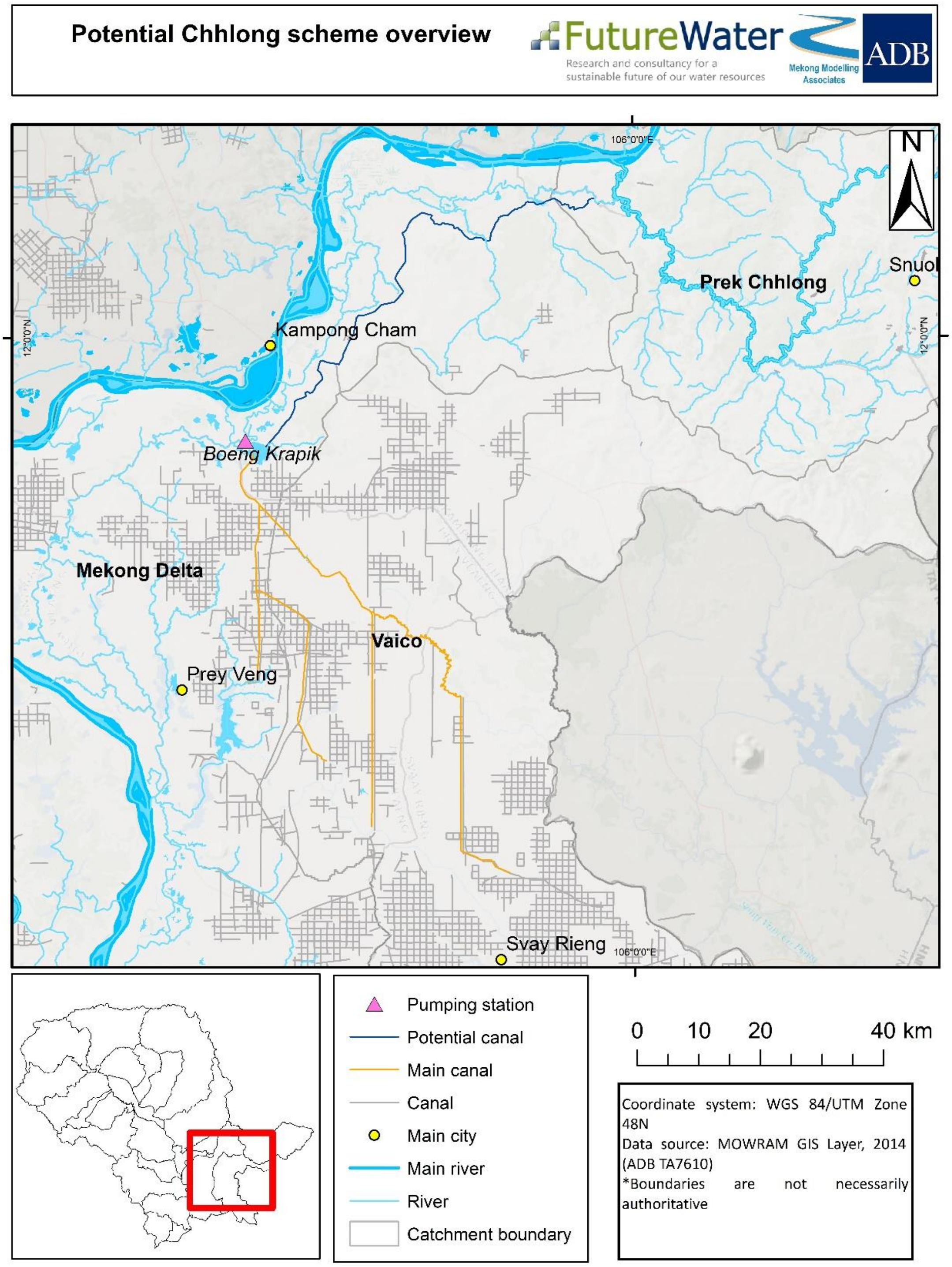


Figure 8-1. Map of the potential Chhlong link canal connection to the existing Vaico scheme main canal bypassing the pump station

8.1.3 *Prek Chhlong Water Demands*

The amount of local irrigation for the Chhlong is currently quite low and at the Rapid Appraisal stage this accounted for only 23.5 MCM or less than 1% of the available water resource. Even if this is doubled or more there will still be surplus water available which will flow to the Mekong.

8.1.4 *Mekong Delta and Vaico Water Demands*

The irrigation requirements for the Vaico and Prey Veng catchments is high as the areas of rice planted are currently 45,000 ha and 134,000 ha respectively. The total potential irrigation demand from such as areas is between 270 and 360m^3/s for dry season irrigation (1.5l/s-2.0l/s). Whilst in the wet season there is significant excess water available in the Mekong and on the floodplain It is understood that the system has not been able to supply sufficient supplies limited by the current pump stations and limited storage. More detail has been requested on the design capacity of the main canals but it is expected that these match the pump station capacity (120m3/s) which appears to be the case from field observation and examination of Google Earth imagery.

Figure 8-2. Photo of the Vaico main irrigation canals during the wet season

For an initial assessment it is calculated that a 2,500MCM water resource would be suitable for the supply to one crop in the delta/Vaico system assuming a demand of 8000M^3/crop/ha and 300,000ha to be irrigated or if storage is available then two crops for 150,000ha may be supplied using a canal of around 100-120m^3/s capacity. Such an option would fit better with the capacity of the recently developed Vaico/Prey Veng canals. It is concluded therefore that from this first pass, a link canal from the Chhlomg is worthy of further investigation using the available data as described below.

8.1.5 *Catchment characterization*

A wide range of data has been collected both during Phase I and Phase II of the study. Many data has been already reported in the two Rapid Assessment reports (Water Resources and

Eco-hydrology) of Phase I. More recent data has been collected in Phase II on the irrigation areas from the most recent version of the CISIS database. Updated data per catchment in the basin group is presented in Table 8-2.

Table 8-2: Population and irrigated areas per catchment of the Chhlong basin group.

	2016 population			Irrigation (ha)				
Catchment	Rural	Urban	Total	Dry Season	Dry in Wet	Wet Season	Recession	Catchment Area (km^2)
Mekong Delta 1	843,554	1,098,871	1,942,425	57,702	10,198	89,241	29,309	7,718
Chhlong 1	210,271	49,454	259,725	87	0	5,037	1,379	6,026
Vaico 1	564,392	5,198	569,590	2,686	6,308	89,239	9,434	6,349
Total	1,618,217	1,153,523	2,771,740	60,475	16,506	183,517	40,122	20,093

A large amount of spatial data has become available during the study. In the following maps, a selection of the most relevant spatial information is represented:

1. Administrative boundaries
2. Digital Elevation Model
3. Geology
4. Soil
5. Land use classification in 1987
6. Land use classification in 2018
7. Irrigated areas
8. Flood frequency
9. Evapotranspiration (net water consumption)
10. Environmental features

The Chhlong/ Vaico/ Mekong Delta Basin Group lies within the provinces of Kratie, Kampong Cham, Prey Veng, Kandal, Mondul Kiri, Binh Phuoc and Phnom Penh (Fig 7-3). The 3 catchments cover a total area of 20,093km^2. The Chhlong river flows for around 200km and is fed by a series of tributaries, some of which dry out completely in the dry season. The Chhlong river and its tributaries are linked to the floodplains of the Tonle Sap Great Lake and those of the Mekong River. The elevation within the Basin Group ranges from 720m to -12.9m (Fig 7-4). The mountainous areas to the north-east is where the highest elevations occur whilst the lowest occur to the south at the Mekong Delta. The topography in the north follows the path of the river to resembles a 'V' shaped valley. Young alluvium, old alluvium and basalt are the majority geology types within the Basin Group representing 59%, 25% and 14% of the total area, respectively (Fig 7-5). Geology data was not obtained for the southern part of the Chhlong catchment. Acrisol soils covers 45% of the total area within the region, a clay rich subsoil that is associated with humid, tropical climates and often supports forested areas (Fig 7-6). Acrisol is the most dominant soil type in Cambodia. Gleysol, cambisol and ferralsol soils also cover large areas representing 17%, 16% and 11% of the total area, respectively. However, no data on soil type could be obtained for the Vaico catchment and a portion of the Mekong Delta catchment. The SERVIR database shows that over 50% of the region is 'rice' and 'cropland' whilst a large portion is 'orchard or plantation forest' (Fig 7-7, Fig 7-8). During the 31-year period between 1987 and 2018, an increase in the percentage area of 10% and 9% were seen in the 'orchard or plantation forest' and 'cropland' land cover classes, respectively. 'Forest' and 'flooded forest' both exhibited around a 6% decrease in percentage area. The CISIS irrigation database, summarised in Table 7-2, shows that wet season irrigation area makes up 61% of the year-round total whilst dry season irrigated area makes up the second largest percentage with 20% (Fig 7-9). During a 1 in 100 year flood, the majority of the Mekong Delta catchment would be inundated whilst the Chhlong catchment would only be inundated along the riverbanks (Fig 7-

10). Large areas of yellow and orange within the Mekong Delta show that flooding is somewhat a regular occurrence. Figure 7-11 highlights that the area between Kampong Cham and Prey Veng suffers a lack of water during the dry season. In contrast, the eastern and western sides of the Chhlong catchment are shown to be abundant in water during this time. Finally, Figure 7-12 shows the location of the 6 protected areas and 16 river blockages within the Basin Group. No recorded CFRs were found in this region.

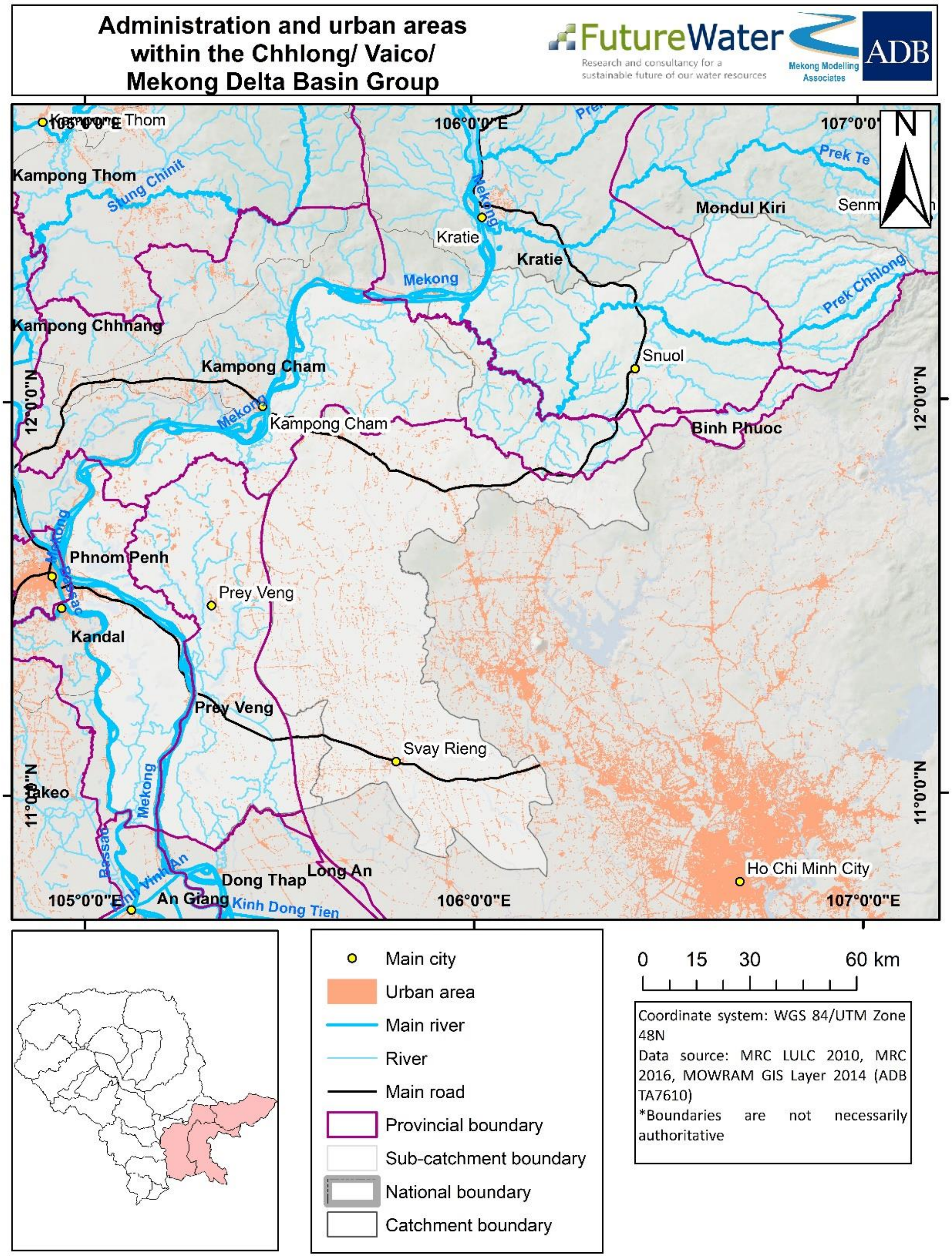


Figure 8-3: Administration and Urban Areas within the Chhlong/Vaico/Mekong Delta Basin Group.

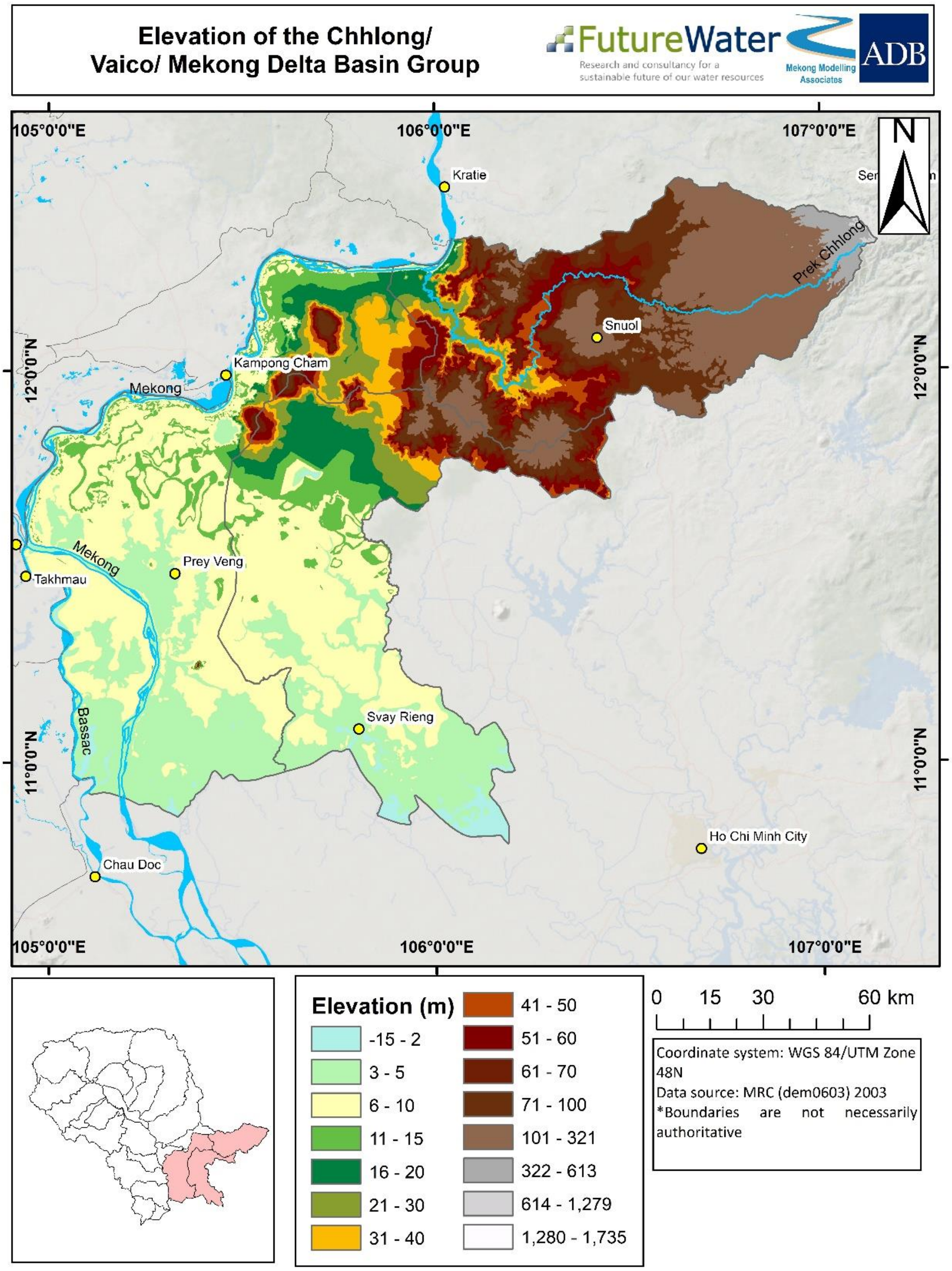


Figure 8-4: Elevation of the Chhlong/Vaico/Mekong Delta Basin Group.

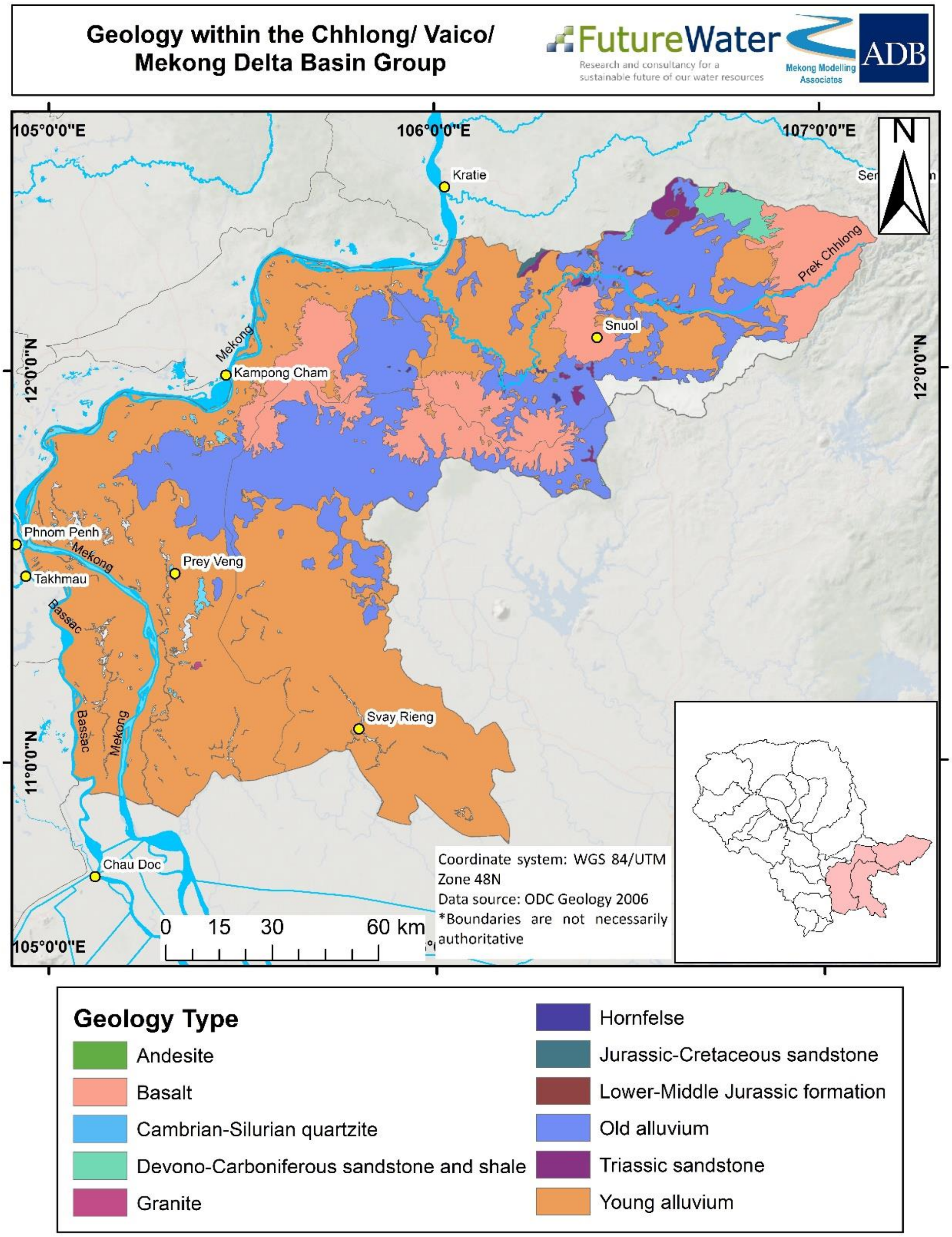


Figure 8-5: Geology within the Chhlong/Vaico/Mekong Delta Basin Group.

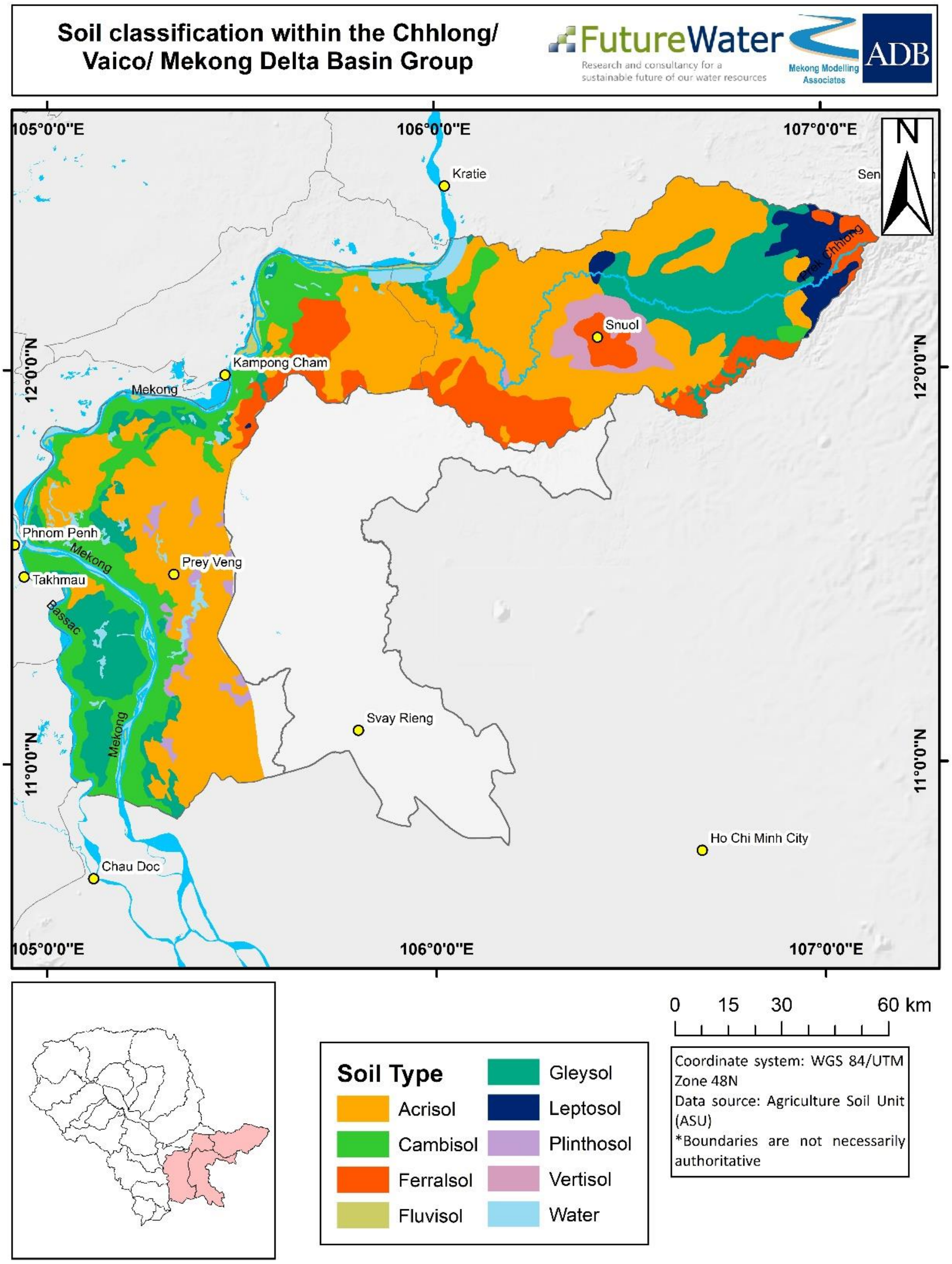


Figure 8-6: Soil Classification within the Chhlong and Mekong Delta Basins.

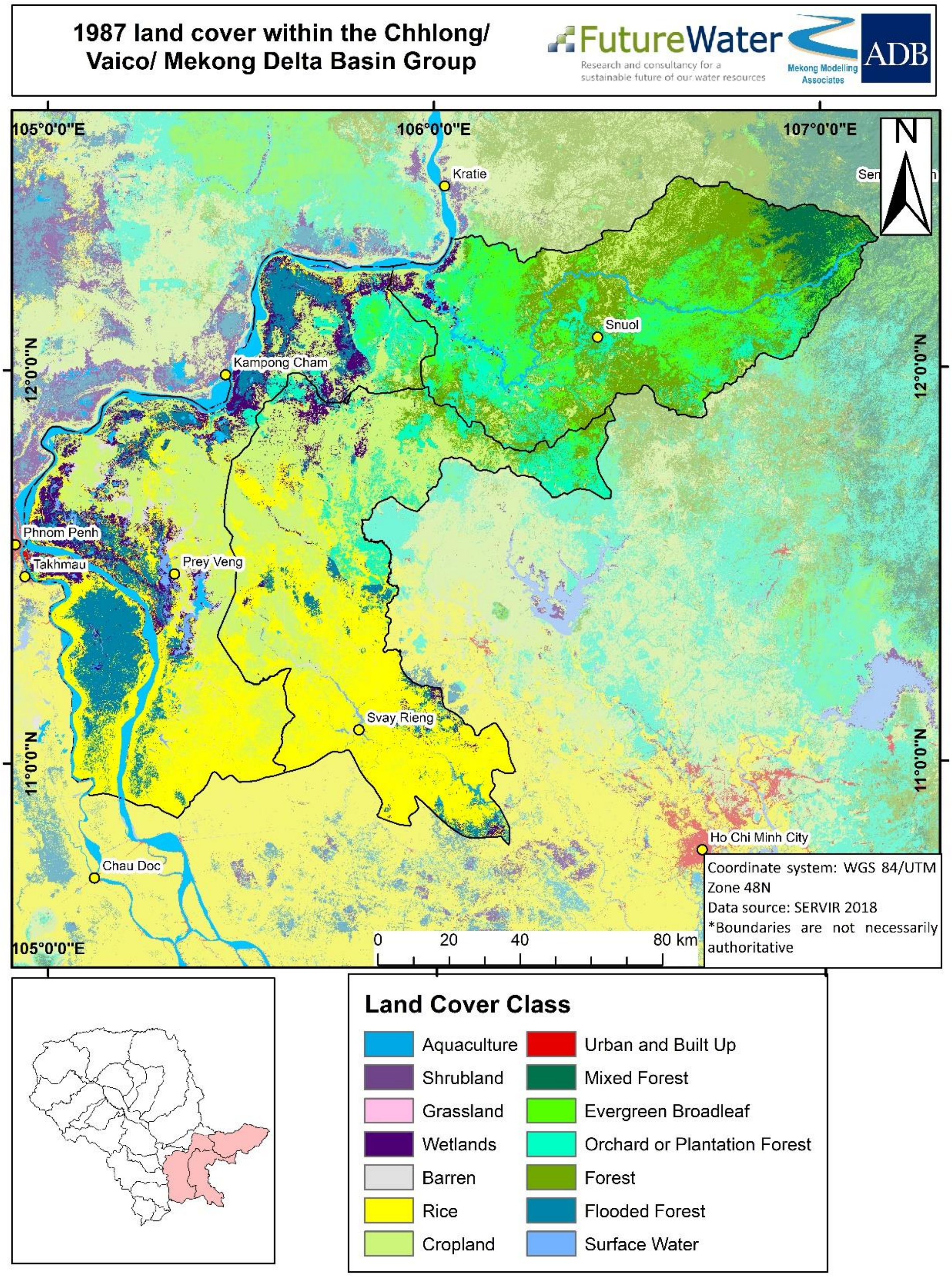


Figure 8-7: 1987 Land Cover within the Chhlong/Vaico/Mekong Delta Basin Group.

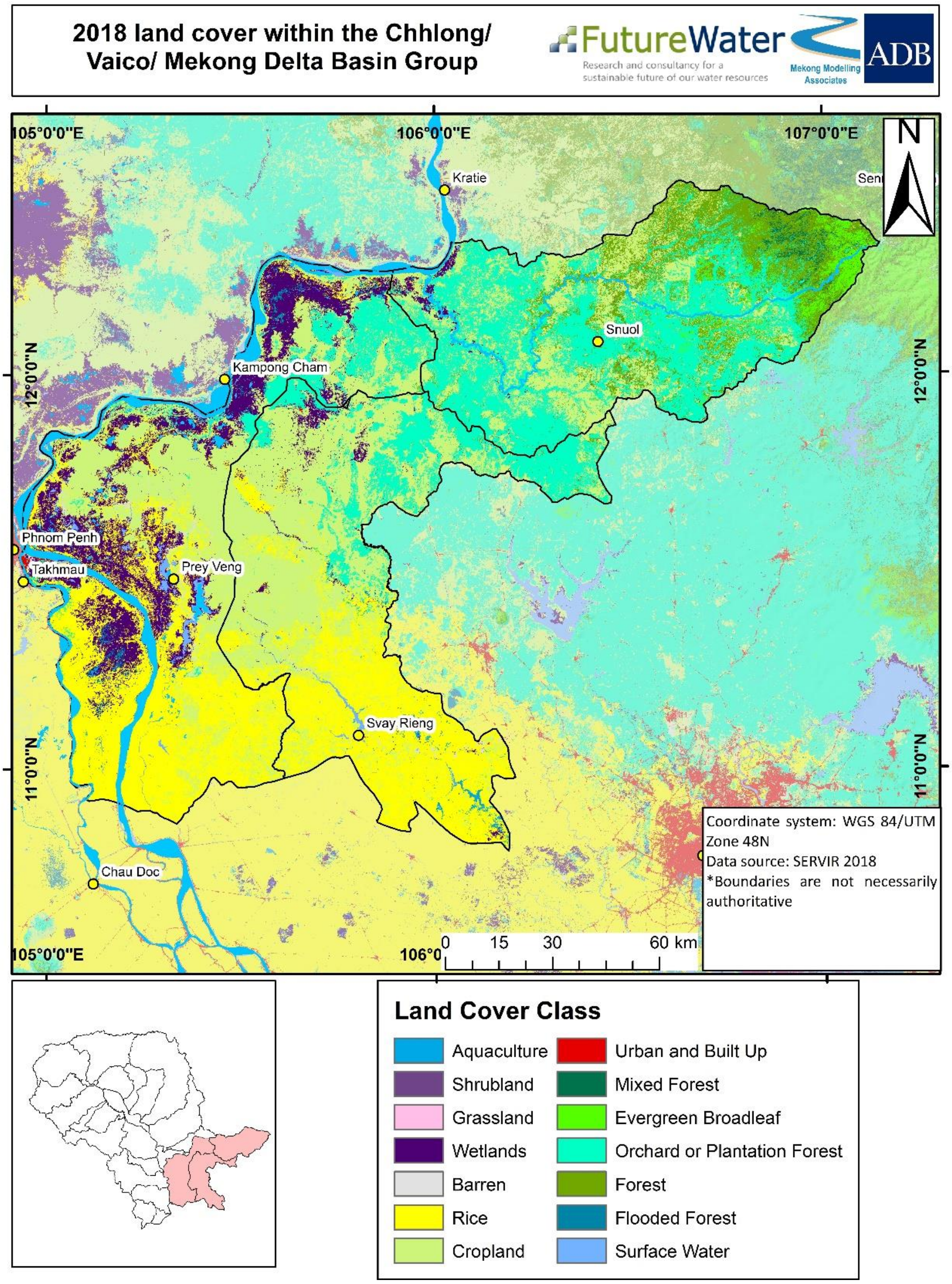


Figure 8-8: 2018 Land Cover within the Chhlong/Vaico/Mekong Delta Basin Group. Natural forest in the Chhlong catchment around Snoul is largely converted to plantation.

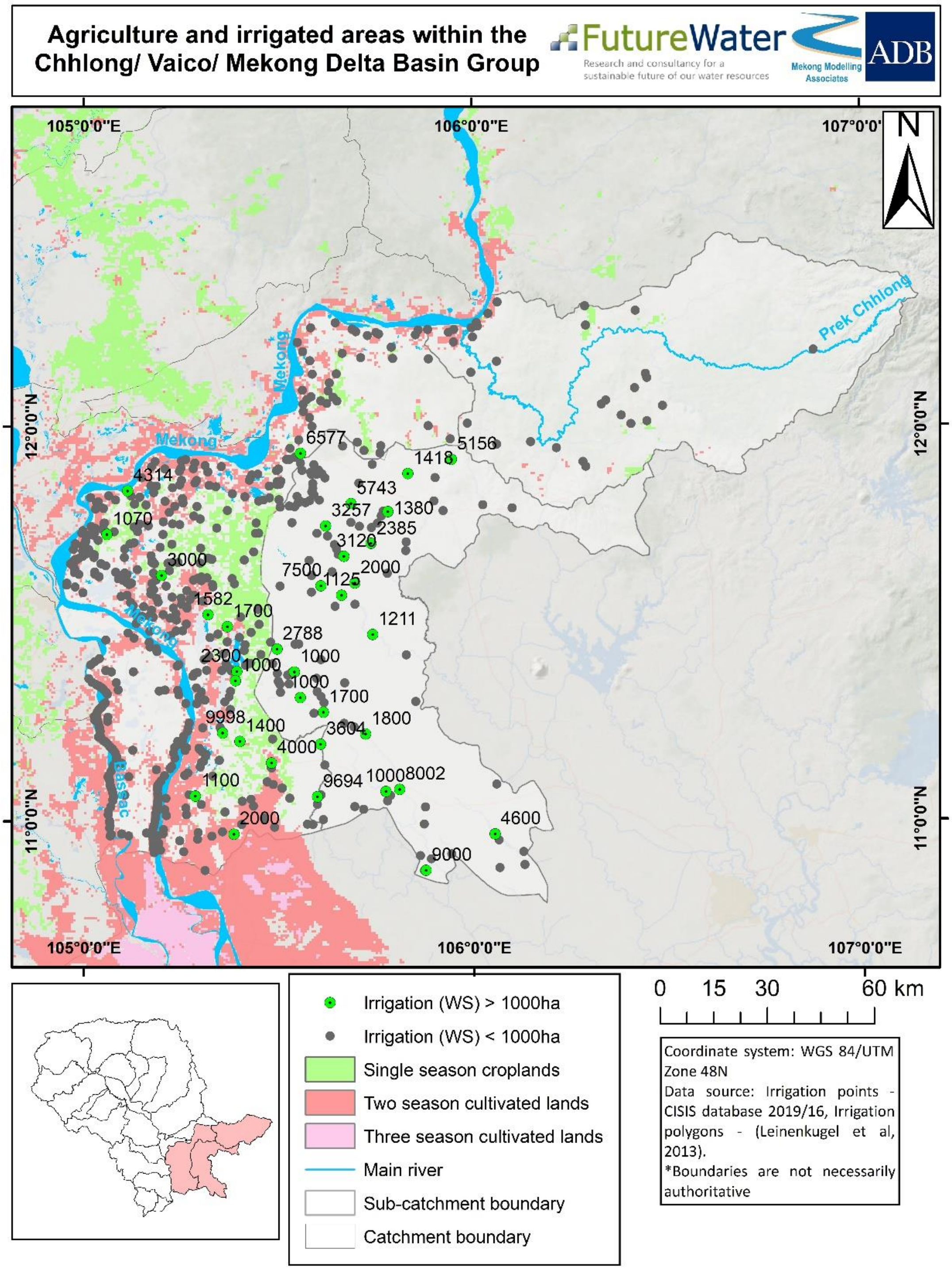


Figure 8-9: Agriculture and Irrigated Areas within the Chhlong/Vaico/Mekong Delta Basin Group.

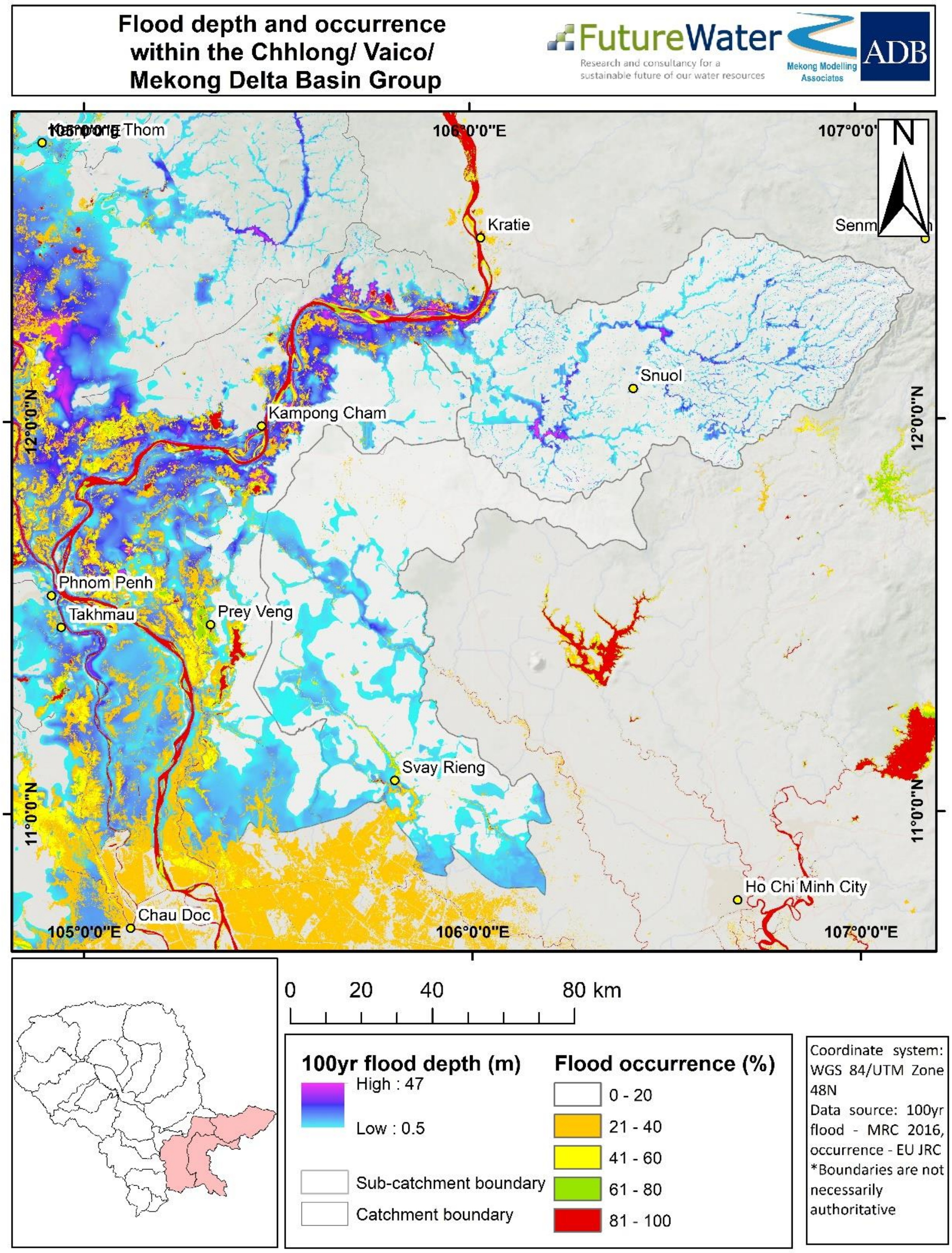


Figure 8-10: Flood Frequency within the Chhlong/Vaico/Mekong Delta Basin Group.

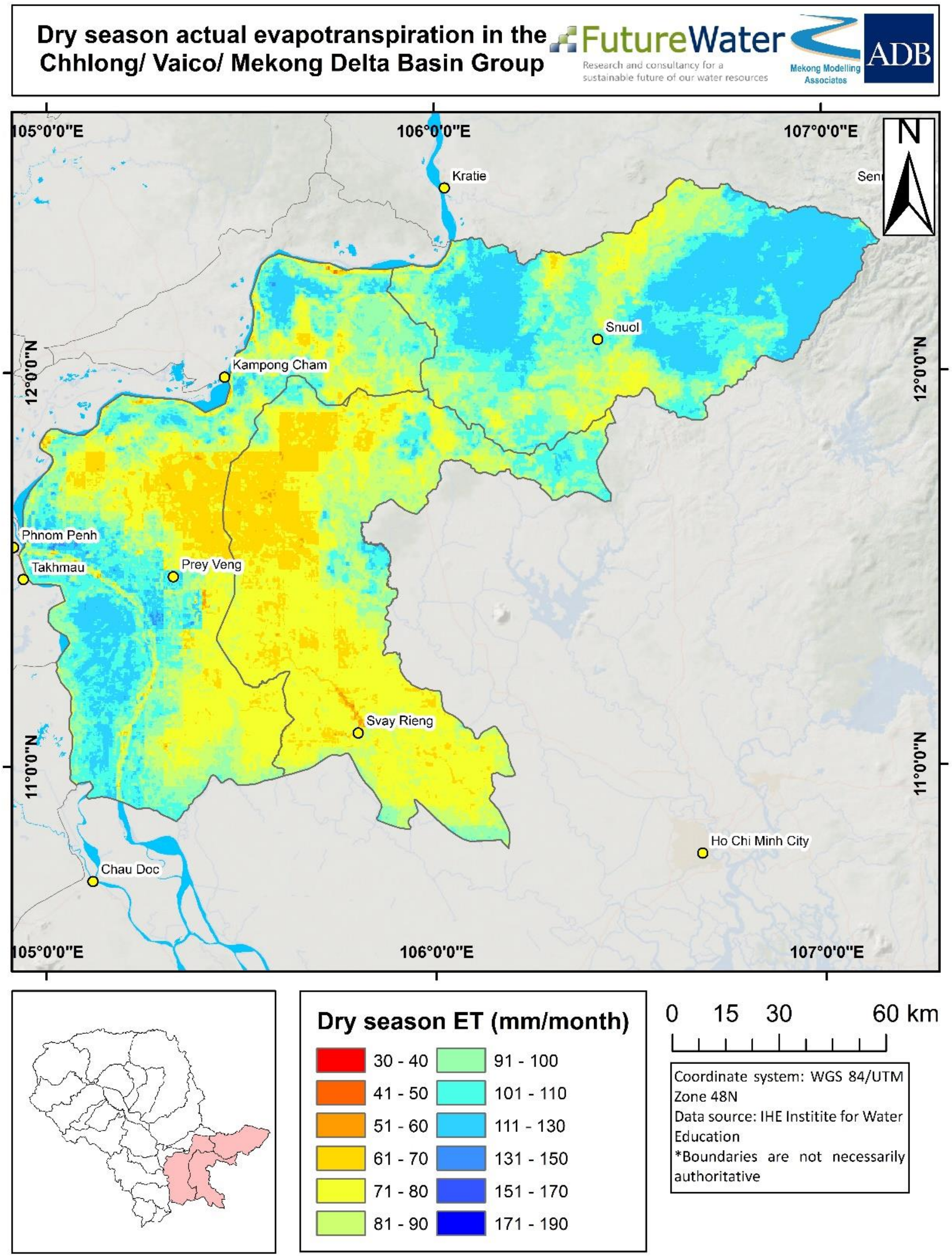


Figure 8-11: Dry Season Evapotranspiration in the Chhlong/Vaico/Mekong Delta Basin Group.

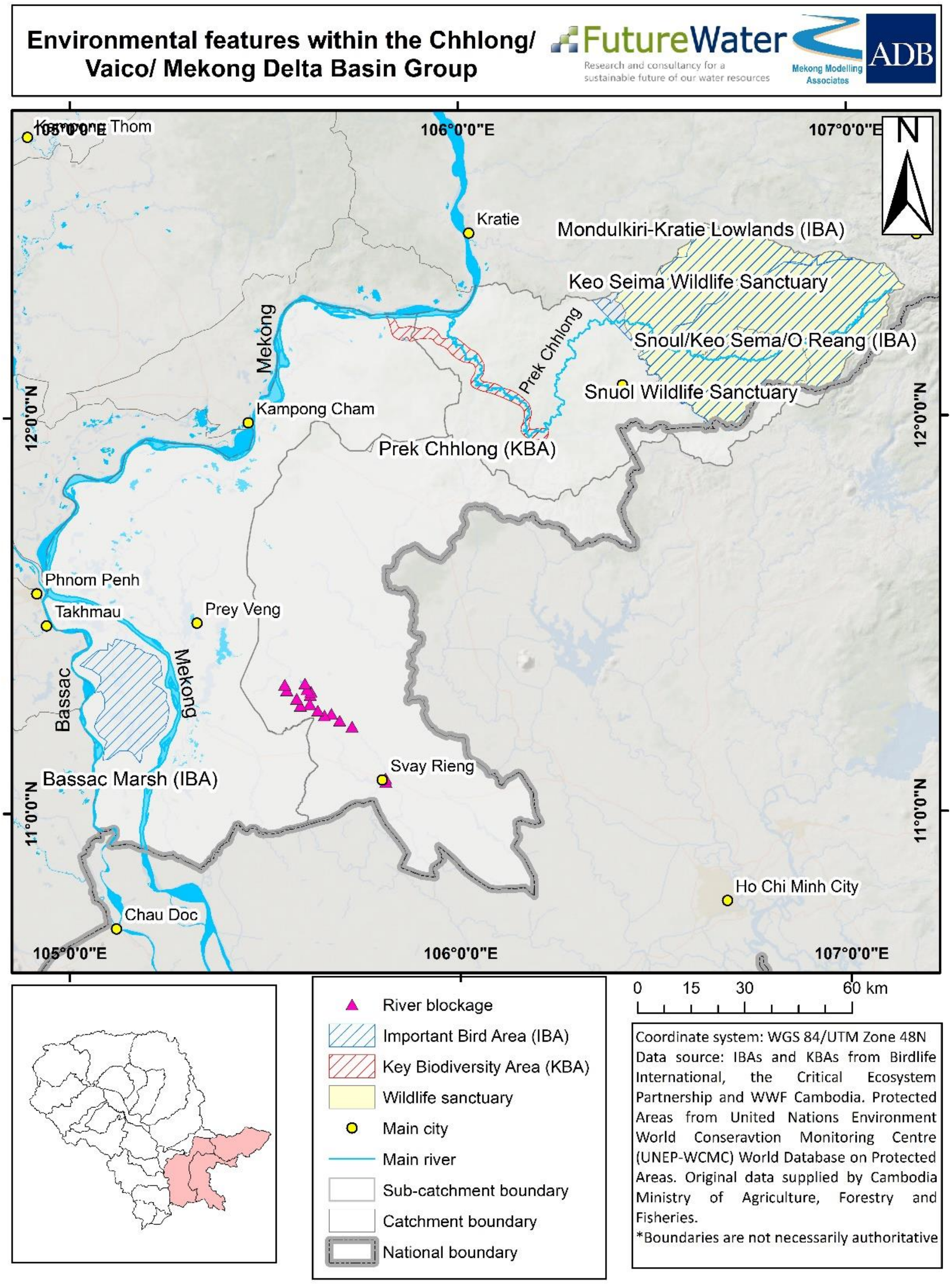


Figure 8-12: Environmental features within the Chhlong/Vaico/Mekong Delta Basin Group.

8.1.6 *Previous Studies of Potential Water Resource Development of the Chhlong*

MOWRAM have recently prepared preliminary investigations on the potential for storage and irrigation schemes on the Chhlong and the consultant team visited one of the potential development sites. Due to the undulating topography of the catchment, the areas of existing paddy and potential irrigation are relatively small but diversion or small pump schemes could be developed subject to more detailed topographic survey.

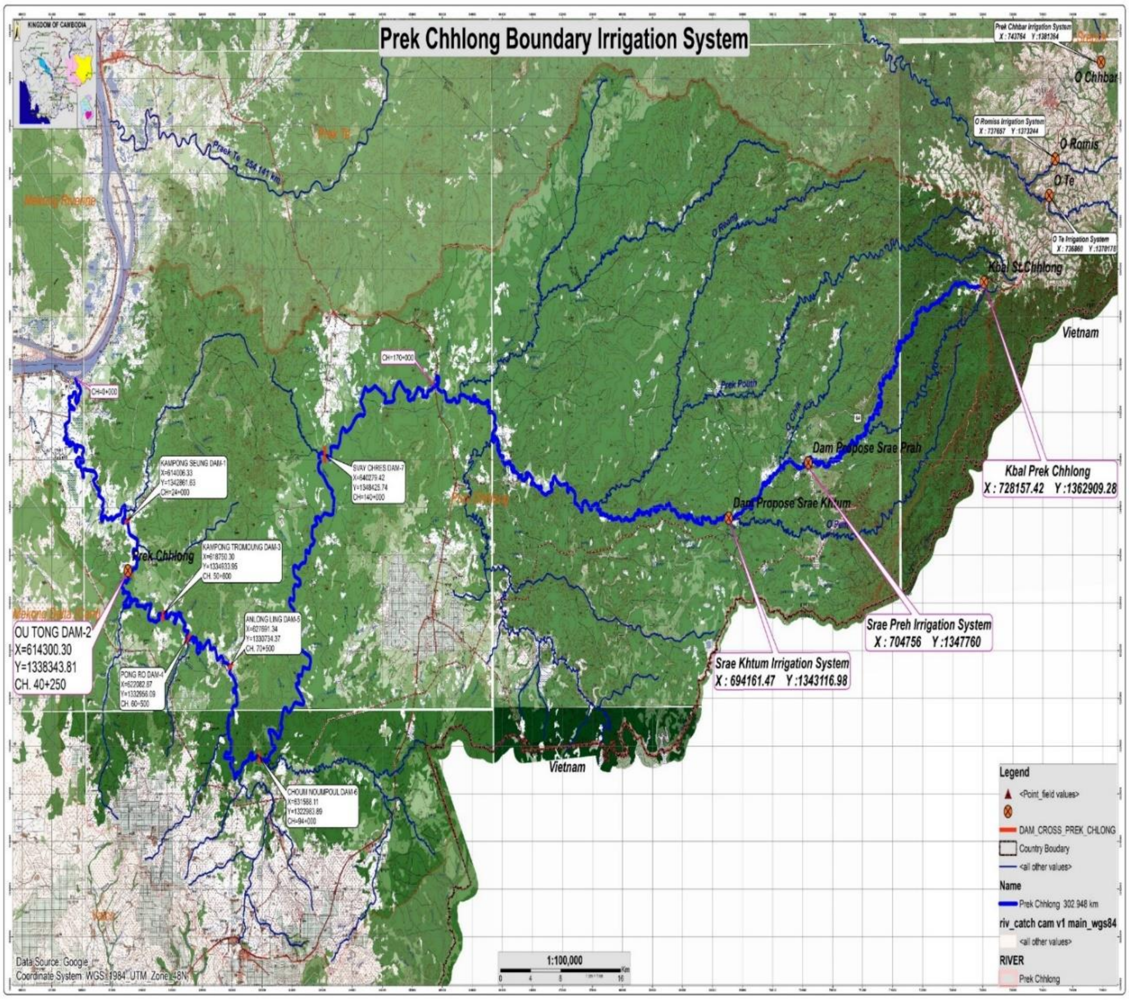


Figure 8-13: Prek Chhlong MOWRAM study sites.

We did not identify any previous studies that have been carried out for appraisal of a link canal from the Chhlong to the lower floodplain areas.

8.1.7 *Reservoir Developments on the Chhlong*

There are currently no diversion weirs or significant storage reservoirs on the Chhlong River. The Mekong Secretariat identified the Chhlong as having potential for hydropower development and the latest proposal included in the MRC Hydropower database is for an approximately 500 MCM storage scheme that would have characteristics and capacity as shown below. Such a reservoir would also have potential to provide the storage to improve the reliability of flow to a link canal.

Table 8-3: Prek Chhlong Proposed Hydropower Dam.

Project Name	Planned Gross Storage (MCM)	Live Storage (MCM)	Area (km2)	TWL (m AD)	Generation Capacity (MW)
Chhlong 2	520	515	81.0	63.0	16

8.2 Hydraulic Appraisal of Chhlong Link Canal

The appraisal comprised four components:

1. Assessment of water level and flow requirement for connection to the Vaico scheme
2. Assessment of the suitability of the topography
3. Estimation of the likely canal size
4. Options and Impact of Reservoir storage on the Chhlong

8.2.1 *Water Level for Supply to Vaico Scheme*

The Vaico scheme main canal takes off from the Boung Krapik Lake and then branches in to Vaico or directly south towards Prey Veng. The water level at the Boung Krapik Lake is now controlled by outlet structure and the inlet pump station. During the high flows in the Mekong, water may flow directly through the connection of the Tonle Toch into the Lake whereas in the dry season the water level in the Mekong drops and in the natural condition flow out back into the Tonle Toch as shown below.

The hydrodynamic model results for both the Lake and the Mekong were interrogated to examine the water levels to be expected during the flood and dry season. This shows that the water levels in the Mekong (and thus the Tonle Toch) drop significantly below the high ground level of around 10-12m and around 4m in the Lake itself. The highest water level in the Lake simulated was around 16m AD. This is also equivalent to the maximum land levels in the area. It may thus be assumed that the water level at the downstream end of the Chhlong Link canal should be around 14-16m AD given that the canals are not raised above the local landscape. That the Lake itself is below 4m suggests that it may be possible to lower this target water level following more detailed survey.

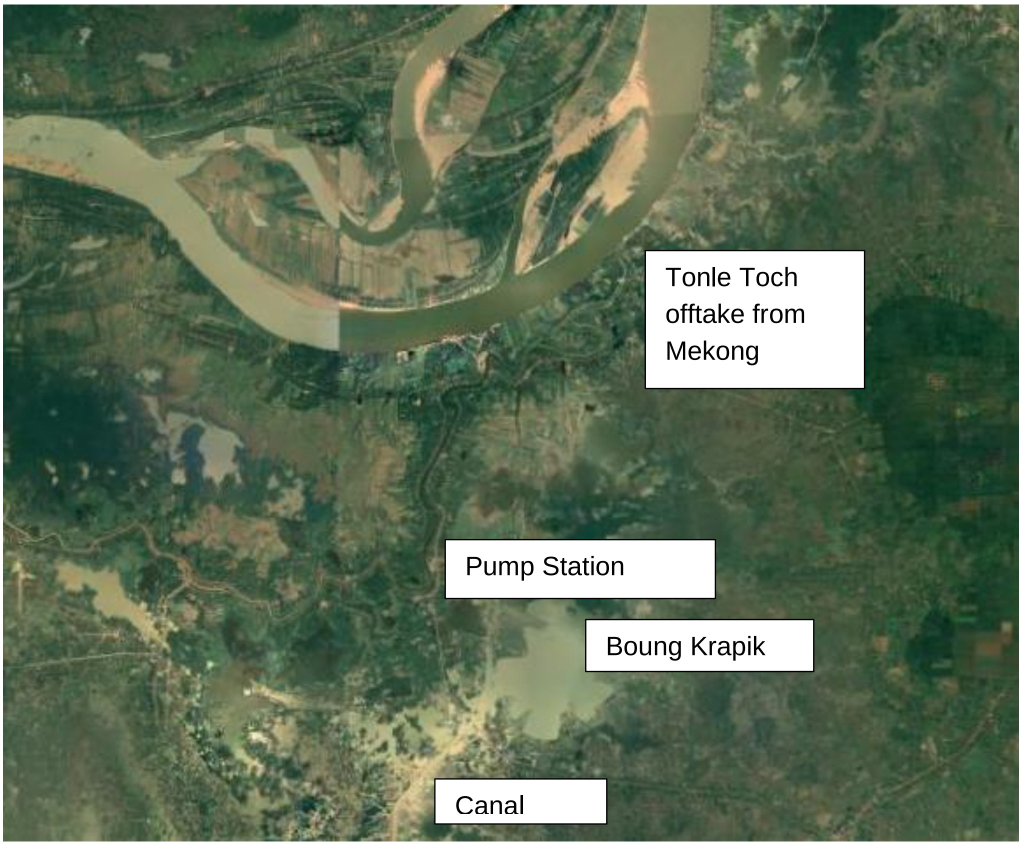


Figure 8-14: Vaico Scheme headworks to Boung Krapik.

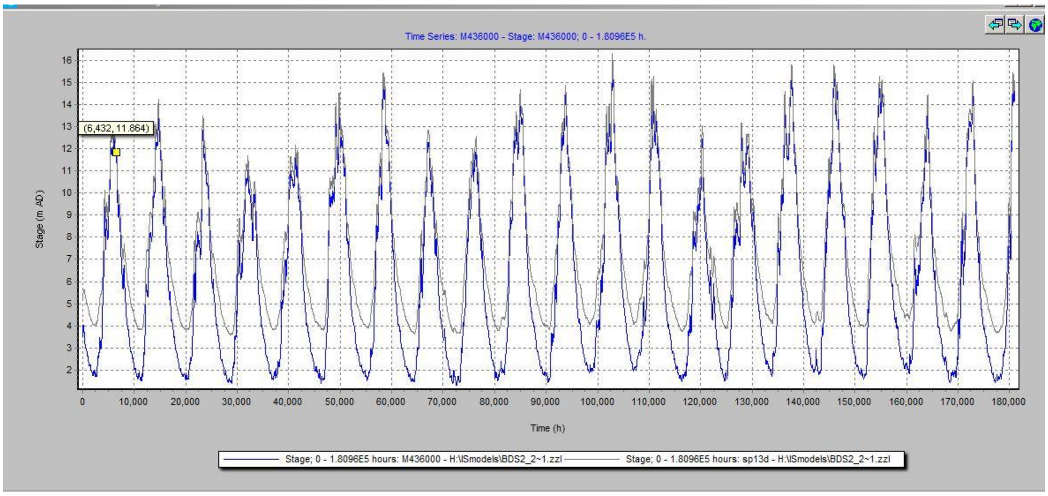


Figure 8-15: Model Results for Mekong (offtake of Tonle Toch) and Lake levels during 1985-2008.

8.2.2 *Long Profile of the Proposed Chhlong Link Canal*

The available ground DEM and contour maps were analysed and a potential canal route mapped out allowing for a suitable fall on the canal of 0.5m/10km or 1/20,000. The canal route would need to pass across a few valleys for which the route length can be minimized by building up the route into a reservoir or using a siphon. At the Chhlong end of the link canal there would seem to be an older river course that branches from the current outflow to the Mekong which has a local supply function. The canal would need a suitable barrage to secure head through the year.

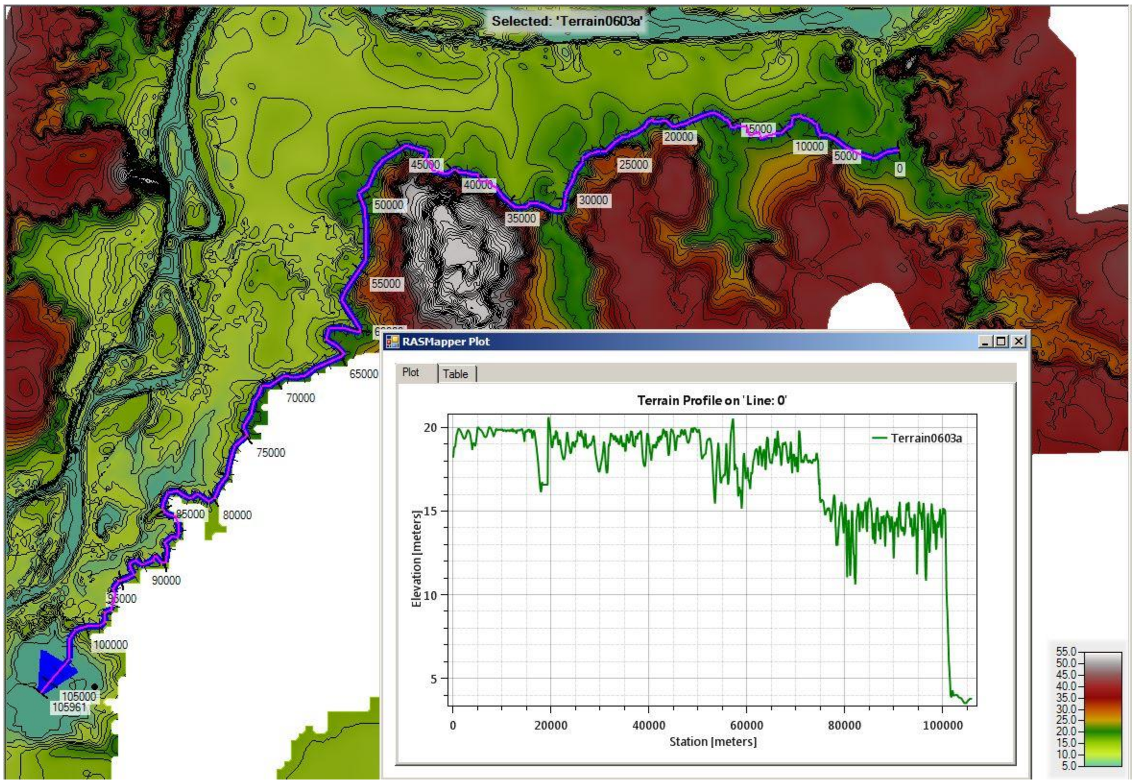


Figure 8-16: Long profile of land for selected initial route. Note at the end the canals discharge to the lake at 4m AD. It may be better to bypass the lake and connect directly to the Vaico irrigation canal.

An ISIS model of the canal was used to test the selected gradient and indicate the likely size of the canal. For 120m^3/s the canal should have a width of approximately 50m. For full supply to the area of 300,000ha the canal size would need to be approximately 100m.

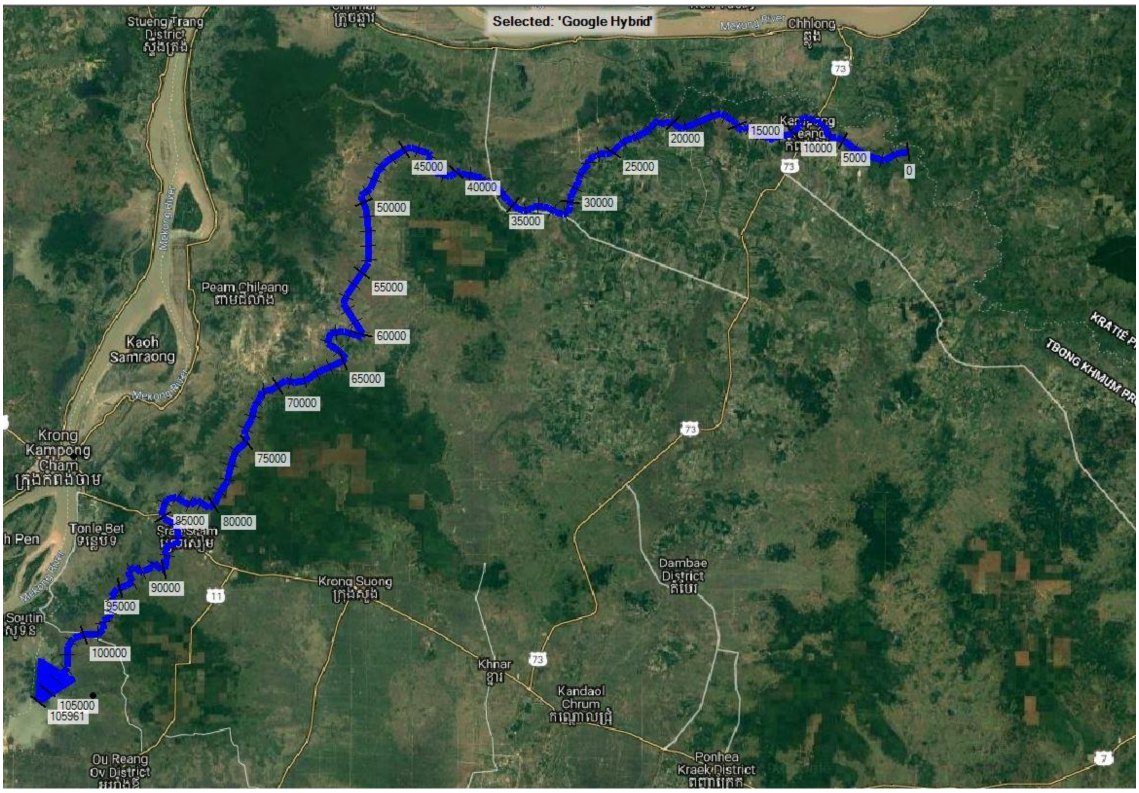


Figure 8-17: Potential route of link canal.

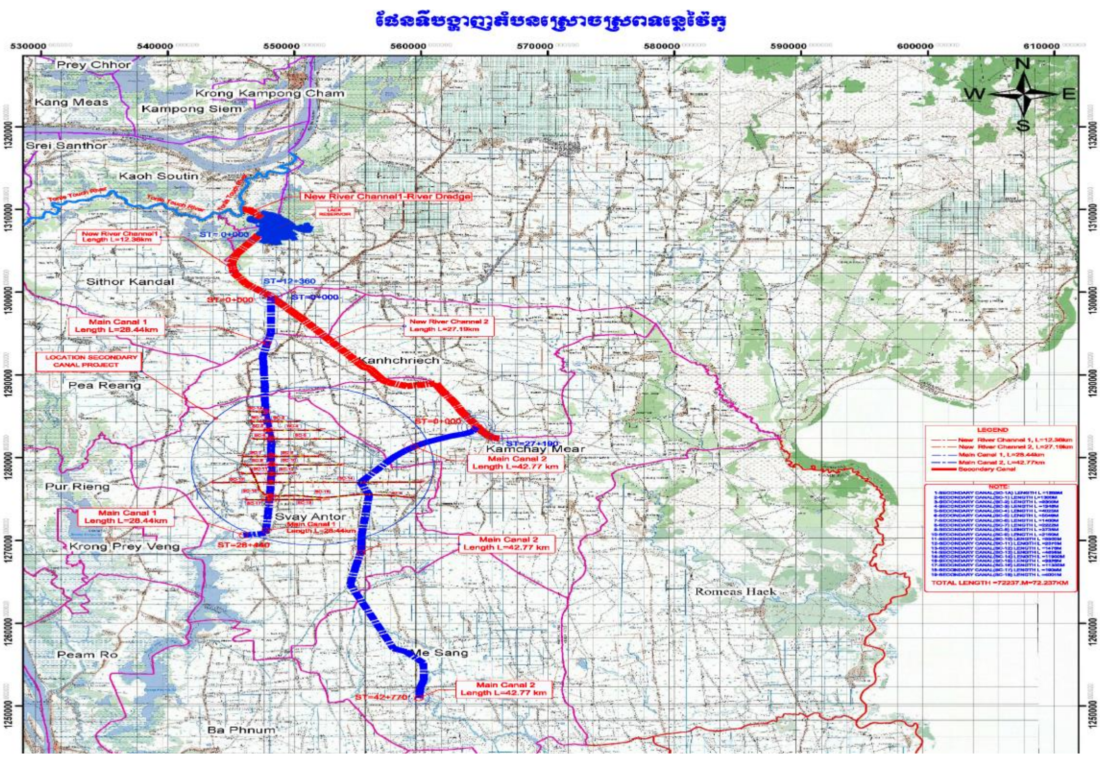


Figure 8-18: Vaico System Link Canals.

8.2.3 *Canal Flows and Storage*

The storage potential in the Chhlong is high and at least 500-1000MCM of storage could be developed. Without storage a supply of 120m^3/s could be diverted from May to October only supplying sufficient water for around 150,000ha. With a deployed storage of 500MCM in the dry season as proposed for hydropower, a further crop for 65,000ha in the dry season could be supplied by the link and potentially more if alternative crops and improved efficiencies can be attained.

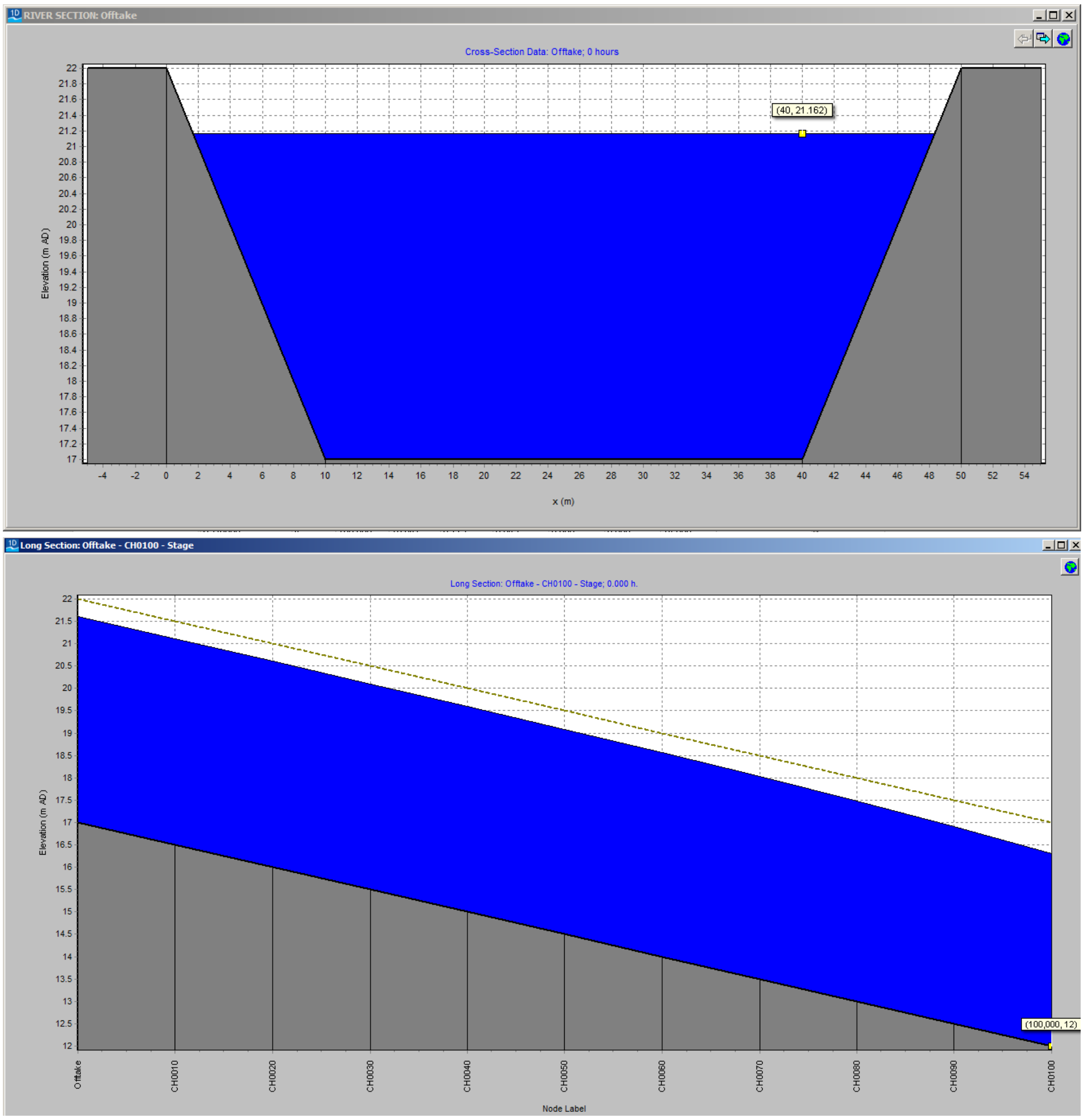


Figure 8-19: Long Section for 120m3/s flow and 50m wide channel.

8.2.4 *Conclusions for the Chhlong Link Canal*

From the analysis of water resource and potential route of a canal between the Chhlong and the Vaico canals indicates that this should be hydraulically feasible and could transform the availability of water in the Vaico and Prey Veng schemes without operation of pumping. If the canal is coupled with multipurpose storage then more area could be served in the dry season. It is concluded that further studies and survey are warranted.

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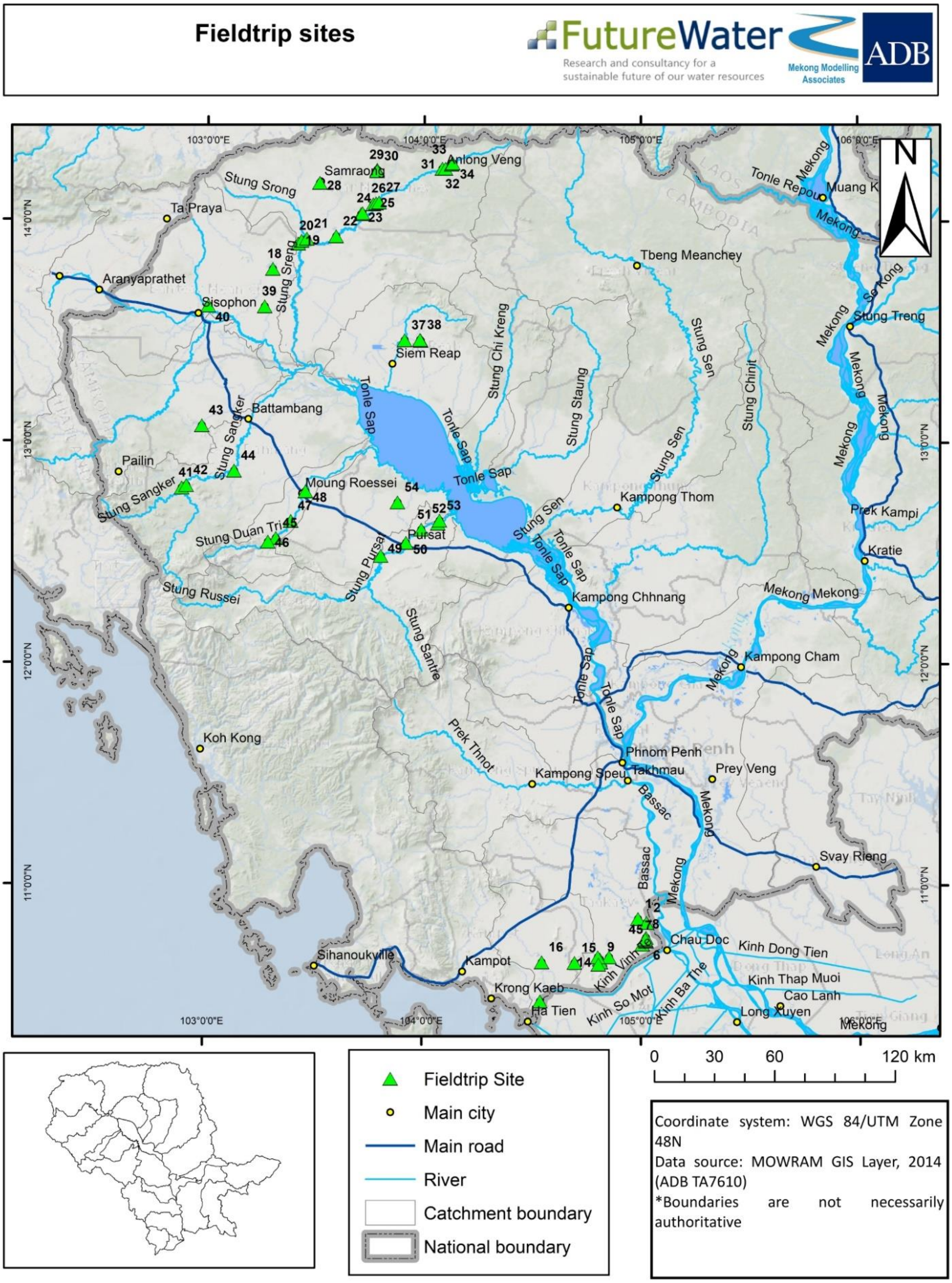
Appendix 1.Field notes of ecohydrological surveys

Surveys carried out during Phase 2

To supplement the field work carried out during Phase 1 for Rapid Assessments and Hydroecology further ecology work for the Surface Water Assessment River groups was completed in 14-24 October 2019. Landscape and Ornithological Surveys were carried out by a project team consisting of Dararath Yem, Juliet Mills, Bas van Balen and Wim Giesen, along with two counterparts from MOWRAM PMU (Visal Hon and Sovathepheap Keo) and counterparts from the various provincial PDWRAMs. The international fisheries expert, Kent Hortle, had visited various sites during a separate, earlier mission, and his record of reconnaissance is included as Appendix 4.
The record of wetland species is given in Appendix 2 and the record of Bird Species identified is given in Appendix 3.

The itinerary of the field reconnaissance trips is indicated below, while the map on the next page indicates locations visited during the surveys (numbers between brackets e.g. [14] correspond with the map numbers):

- 14 Oct.: Takeo/Tuan Lap, visit Boeng Prek Lapouv & environs [1-8]
- 15 Oct.: Survey of route of link canal, plus Anlung Pring [9-16]
- 16 Oct.: Kep, second visit Anlung Pring, plus travel to Phnom Penh [Ha Tien point]
- 17 Oct.: Travel from Phnom Penh to Siem Reap
- 18 Oct.: Survey of Ang Troepang Thmor [18], Stung Sangke reservoirs 1 & 2 [22-27]
- 19 Oct.: Visit Sang Rukhavoan wildlife sanctuary, borders on Stung Sangke 2 [29, 30]
- 20 Oct.: day off (Sunday)
- 21 Oct.: Survey of Stung Sangke from Battambang [41-44]
- 22 Oct.: Survey of Prek Chik area [45-48]
- 23 Oct.: Survey of Stung Pursat [49-53]
- 24 Oct.: morning survey of Bakan grassland [54], travel back to Phnom Penh


Fieldtrip sites
FutureWater
Research and consultancy for a sustainable future of our water resources
Mekong Modelling Associates
ADB
103°0'0"E
104°0'0"E
105°0'0"E
106°0'0"E
14°0'0"N
13°0'0"N
12°0'0"N
11°0'0"N
N
Samraong
Anlong Veng
Stung Srong
Ta Praya
Stung Sreng
Aranyaprathet
Sisophon
Tbeng Meanchey
Siem Reap
Stung Chi Kreng
Stung Sen
Stung Staung
Stung Chinit
Tonle Repou
Muang K
Mekong
Se Kong
Stung Treng
Tonle Sap
Battambang
Stung Sangker
Pailin
Moung Roessei
Kampong Thom
Prek Kampi
Stung Duan Tri
Pursat
Stung Pursat
Kratie
Stung Russei
Kampong Chhnang
Stung Santre
Kampong Cham
Koh Kong
Prek Thnot
Phnom Penh
Kampong Speu
Takhmau
Prey Veng
Bassac
Svay Rieng
Chau Doc
Kinh Dong Tien
Sihanoukville
Kampot
Kinh Vinh Te
Kinh Thap Muoi
Krong Kaeb
Cao Lanh
Ha Tien
Kinh So Mot
Kinh Ba The
Long Xuyen
0 30 60 120 km
Fieldtrip Site
Main city
Main road
River
Catchment boundary
National boundary
Coordinate system: WGS 84/UTM Zone 48N
Data source: MOWRAM GIS Layer, 2014 (ADB TA7610)
*Boundaries are not necessarily authoritative

1. Boeng Prek Lapouv (14 October 2019)

The Takeo crane reserve 'Boeng Prek Lapouv' (which means 'lake of pumpkin river' in Khmer) is located along the border with Vietnam and lies east of Canal 98. Officially, BPL consists of a 919ha central Core zone surrounded by a 3-4 km wide buffer zone (7,386 ha) consisting of a Conservation zone, Multiple use zone and a Community zone. The area was surveyed during Phase 1 (on 24 June 2019) and again during Phase 2 (14 October 2019) by a joint project team and MOWRAM staff.

According to the Boeng Prek Lapouv Management Plan (2014-2018), the area was originally largely forested and remained wet throughout much of the dry season. During 1975-79 small channels were excavated for drainage, the area was cleared and used for planting deep water rice. The first cranes were spotted only in 1986, after these changes had occurred. The EU irrigation project (PRASAC) from 1991-1998 provided for canal transport and more irrigation, and cultivation of rice in the dry season. As a result, the reserve becomes drier earlier and earlier in the dry season. During Important Bird Area (IBA no. 39) surveys by BirdLife in 2001-2004 the area was identified as one of Cambodia's 40 IBAs, and in 2007 the area was formally gazetted as a protected reserve. Until 2016 core zone management was handed over from MAFF (forestry) to MOE and it has been incorporated into the protected area system; hence it is no longer officially called the core zone, except for practical purposes.

In practice, however, intensively cultivated rice paddy fields are found all around right up to the canal that forms the outer perimeter of the Core zone, apparently handed out by MAFF before management was taken over by MoE. These are cultivated 2-3x per year and consist of fast-growing rice varieties that take only 75-85 days to mature. They are intensively sprayed with pesticides (given the number of bottles found around) and are preyed upon by rats (many traps and plastic sheeting present around the edges).

The reserve's hydrology has been altered by canal construction, both in the Pol Pot area and later by the EU-funded PRASAC project that resulted in the construction of Canal 98. Currently, the area in the south of the Canal 98 command area is not irrigated as the canal has silted up too much. The Core zone is slightly drained by Pol Pot era canals, but these are largely silted up. Desilting is to be carried out, along with concrete lining of sections of sandy soil where there is lots of infiltration. A section of a former river still remains as a 300 m long, 5m wide, 2-2.5 m deep body of water in the middle of the reserve that serves as a source of fish stock.

The reserve is affected by poaching/hunting (reportedly not much anymore), encroachment (on the northeast of the Core zone), pesticides and fertilizers from the adjacent rice paddies, noise and disturbance from ongoing mechanized farming practices, fires (in 2018 and 2019, not in 2016 and 2017) and drying out of the reserve from February-April.

BirdLife International Cambodia programme implemented a water management trial project at BPL from 2016-2018 (Bou et al. 2018[1]). In this, a 16 ha plot (400x400 m) just outside/adjacent to the 900 ha core area was encircled by a 1.3m high earthen bund, with a sluice-gate on each of the four sides. Water levels were managed so that water was retained longer, and the area was wetter than either the core area or the surrounding buffer zone (that has entirely been converted to rice fields). As a result, the number of bird species found in the trial plot area more than doubled, while the number of individuals of key species such as the Sarus Crane also doubled over a 2-year period. This contrasts with overall numbers that dropped over the same

[1] Bou, Vorsak, Ly Samphors, and Yav Net (2018) - Manage water for migratory Sarus Crane *Antigone antigone sharpii* in Cambodia Lower Mekong delta, BirdLife International Cambodia Programme, 27 pp.

period (e.g. of Sarus Crane, from 234 to 104). In terms of vegetation, which consisted of a mosaic of aquatic vegetation, shrubs and grassland, BirdLife removed the noxious shrub *Mimosa pigra* and assessed the impact of the water manipulation trials on vegetation density and height; only the 50-75% cover class increased significantly, while other classes remained the same. However, they unfortunately did not study impacts on plant species composition, as certain species are more favoured than others; for example, the tubers of the sedge *Eleocharis dulcis* are part of the diet of the Sarus Crane and may be the one of the main reasons for these birds to visit the protected areas or other areas unsuitable for agriculture (R. van Zalinge, pers. comm.) where the vegetation consists largely of sedges.

Photos 1a & 1b: water levels in the core zone are about 1 m deep at the time of the 14 Oct. survey (left); water levels are similar in the 16ha BirdLife pilot area (right)

BirdLife Cambodia and WWT would have liked to conduct the rewetting on a larger scale and with better bunds, but funds were lacking (Vorsak Bou & Saber Masoomi, pers. comm. 2019). The 1.3 m dike actually eroded rapidly as it was locally constructed, with local means, and from an initial 1.3 m it soon eroded to below 1m. The impact was also limited, as the period in which the area was still soggy was extended by only 10 days during the first season, and less than one month in the second season. WWT and BirdLife Cambodia calculated that in order to maintain waters/soggy conditions until April they would need a dike of 2.3 m height. The main problem remains extraction of water from the canals for irrigation of rice fields, as this has increased significantly over the past years, leading to a much more rapid drawdown.

Lots of issues remain regarding the buffer zone of 7200 ha, which has all been converted to rice paddies. Some (in government) are in favour of taking it back, others seek a compromise, and a buffer zone of 600 ha has been raised as a possibility, bringing the total area to 1500 ha. More recently there is also an issue with a human rights agency that is claiming 200 ha of land for the homeless. The claim appears baseless, as these are reportedly people that are not from the area but are returning after years in exile.

Vegetation in the reserve Core zone consists primarily of seasonally inundated grasslands with scattered shrubs and small trees. According to the BPL management plan, the grassland vegetation includes *Chloris barbata, Cynodon dactylon, Echinochloa stagnina, Eleusine indica, Ischaemum* sp., *Leersia hexandra, Phragmites vallatoria* and *Saccharum spontaneum* grasses, along with sedges such as *Eleocharis dulcis* and herbs such as *Persicaria hydropiper, Merremia umbelata* and *Ipomoea nil.* The few tree and shrub species include the exotic *Mimosa pigra, Morinda persicifolia* and *Phyllanthus reticulata*.

24 June 2019 observations along the dikes and areas directly around the BPL reserve Core Zone include a number of tree and shrub species such as *Acacia auriculiformis, Borassus flabellifer, Eucalyptus camaldulensis, Ficus* sp., *Mimosa pigra* and *Phyllanthus reticulatus.* Herbs and grasses include *Actinoscirpus grossus, Ceratopteris thalictroides, Echinochloa stagnina, Eichhornia crassipes, Fimbristylis miliacea, Grangea maderaspatana, Gymnopetalum chinense, Heliotropium indicum, Ipomoea aquatica, Ludwigia adscendans, Ludwigia hyssopifolia, Monochoria hastata, Morinda persicifolia, Passiflora foetida, Phragmites karka, Polygonum pulchrum* and *Saccharum spontaneum.*

14 October 2019 surveys in the core area confirm that there are very few trees in the area, those on the one island in the core zone are most dead (incl. *Dalbergia*), only the *Borassus flabellifer* palm is still alive. Some trees appear to be affected by fire. Shrubs such as *Gmelina asiatica* and *Sesbania javanica* are flowering, as are grasses (except reed), *Monochoria hastata, Ludwgia adscendans, Polygonum barbatum, Nymphaea nouchali, Nymphoides indica.* Species observed include *Brachiaria mutica* (dominant), *Convolvulaceae (non-flowering), Eichhornia crassipes, Eleocharis dulcis, Gmelina asiatica, Hymenachne acutigluma, Ipomoea aquatica, Ludwigia adscendans, Mimosa pigra, Monochoria hastata, Neptunia natans, Nymphaea nouchali, Nymphoides indica, Panicum paludosum* (dominant), *Phragmites karka (P. vallatorius* in BirdLife report, but this is asynonym)*, Phyllanthus reticulata, Polygonum barbatum,* and *Sesbania javanica.* On the whole there are no uncommon or rare plant species.


Photos 2a & 2b: the deep pool area in the core zone could not be reached as it was entirely covered with waterhyacinth (background, left); tall reeds Phragmites *on core zone, with* Mimosa pigra *and grasses (right)*

Water levels started rising on 2 September 2019, which is later than the usual mid-August. It reached a maximum mid-September 3.9 m asl but has now dropped to 2.8 m asl. The maximum is lower than last year (2018) when the floods reached a max. of 4.4 m asl, but it is as yet unclear how this will affect water levels in the core area in Q1 2020.

Potential acid sulphate soils possibly occur at BPL, judging from jarosite colouration observed in June. If these are exposed during dike construction this could lead to acidification and aluminium toxicity issues. It is recommended that a simple soil survey be carried out to assess the magnitude of the problem (concentrations of iron sulphide [FeS], depth). If FeS concentrations are low or very local, the problem may be non-existent and ignored. However, if higher concentrations occur, opportunities for flushing this with irrigation water need to be investigated, or dike construction reconsidered or adapted (e.g. shallower borrow pits).

The BPL management plan lists 110 bird species, while the local guards mentioned a number of 70+ species; the BirdLife IBA fact sheet gives the following IBA trigger species: Sarus Crane *Grus antigone*, Bengal Florican *Houbaropsis benghalensis*, Spot-billed Pelican *Pelecanus philippensis*, and Black-necked Starling *Sturnus nigricollis*. Our brief survey in June 2019 fell outside the breeding season of most of these species, and only a few Black-necked Starlings were seen. Altogether our survey in June yielded just 33 species, but certainly noteworthy were however a flock of 100+ of the globally near-threatened Painted Stork *Mycteria leucocephala* and a single male in breeding plumage of the Near-threatened Asian Golden Weaver *Ploceus hypoxanthus*. In October the resident avifauna appeared augmented by a number of migratory species, of which nine could be identified. The observation of a single female Streaked Weaver *Ploceus manyar*, nowadays becoming rare in SE Asia, was noteworthy as it showed that the area contains all the country's weaver species.

As described above, the BPL core area is entirely surrounded by intensively managed rice fields, where thousands of domestic ducks were kept along the canals to feed in separate groups of hundreds of ducks. Domestic ducks eat all kinds of fish and other aquatic animals, as well as aquatic plants, and are likely to be highly deleterious to fisheries in the canals, which are key dry-season refuges and dispersion pathways for fish and other aquatic animals. Intrusion of domestic ducks into any conservation areas should be restricted. The domestic ducks are likely to severely deplete the food supply for aquatic birds, and also to muddy the water and destroy plants.

BPL reserve management is generally positive about MOWRAM's plans for Canal 98 as long as it provides more water in the drier months (Sarus Cranes prefer soggy grasslands). However, the grasslands should not be too flooded, nor should the dry season be too short. At present there are no structures (e.g. sluices) at all along primary, secondary or tertiary canals so there is little active water management, and the latter will be required.

2. Link Canal and Anlung Pring (15 & 16 October 2019)

Interventions planned by MOWRAM in the Slakou/Toan Ha catchments include the desilting and rehabilitation of Canal 98 (which generally runs north-south), and the excavation of a Link Canal that links Canal 98/Slakou sub-basin with the Toan Han sub-basin to the west. In general, this will result in more water being available in the Toan Ha/western part of this area. The Link Canal will run east-west, and with a total length of about 37 km it passes between the two large hills (phnoms; actually, each consists of a cluster of hills) that form a natural boundary between the two sub-basins. The north-western of these consists of old alluvium and Devono-Carboniferous sandstone and shale and attain a height of 259 m, while the south-eastern one consists mainly of granite and old alluvium and attains a height of 457 m. Just one km north of the south-eastern phnom there is an extensive wetland (Preaek Tonloab) with an area of about 400 ha.

In its northern part, the link canal alignment traverses a large shallow lake, Preak Tonloab, which seems to have been created by the construction of the road that runs along the eastern end (Highway #3), which has very little (or no?) cross-drainage. Most of the area around the lake consists of rice paddies that are now flooded and are being used for fishing. There is a very high density of fishing nets and traps, all with nets of very fine (and illegal) mesh size. In the dry season, water from lake is used to irrigate the rice fields, and many pumps are already in place. Duck rearing is common in the area, as is collecting of other products (e.g. stems of waterlilies as vegetables).

Photos 3a & 3b: much of the area is flooded and rice fields are merged with the lake (left); duck keeping and fishing in the lake (right)

The Link Canal alignment as proposed by MOWRAM goes through the lake (mentioned above) then between the two hills (phnoms) to the west. Whether it will cut the lake in two is unclear, as the final design may involve culverts below the channel. The Link Canal alignment mostly follows existing canal alignments, and goes through rice fields, interspersed with groves of eucalypts and bamboo. Throughout much of the route, the alignment does not seem to pass by villages, just hamlets and isolated houses.

Anlung Pring (AP)

This small, 217 ha protected area lies in the far southwestern corner of the Mekong Delta RBG. The northern 33ha is freshwater while the rest is brackish. Three rangers from MOE are based at the site, and they receive support from WTT (funding) and from BirdLife Cambodia (training, monitoring, etc…). The Sarus Cranes normally arrive in November and leave in May. They feed mainly in brackish water zone (e.g., on *Eleocharis* tubers), drink in freshwater zone, and roost in the *Melaleuca* along the river (see map, below). The cranes breed in the wooded areas in the north and north-east of Cambodia, but when local conditions on the breeding grounds become too dry, most non-breeding birds come to the flood plains, where they move between suitable areas such as ATT, Anlung Pring and BPL. Reserve managers carried out trials with burning (first time in 2018) as this seems to encourage *Eleocharis,* which next to animal food such as crabs and insects a relatively important food source, although rice is also very much liked too (R. van Zalinge pers. comm.) . There is an enclave of 10 ha of rice paddies in the brackish water zone – these were present before the reserve was gazetted, and MoE have reached an agreement with farmers that this does not disturb the cranes – fields are cultivated after the cranes have left in May. Buffaloes also graze in AP, and the managers think this encourages *Eleocharis*, as the hooves of the buffaloes create good substrate (they work like ploughs); grazing pressures need to be kept at present low levels, though. [WG: buffaloes preferentially graze other species and hence promote *Eleocharis,* which is not that palatable]. Hunting reportedly does not occur anymore, and local villagers run a homestay for ecotourism. There is a visitor centre that doubles as a MoE office and lookout.

Photos 4a & 4b: view of southern, brackish part of Anlung Pring, from roof of visitor's centre (left), Sarus Crane monument near visitors' centre, looking towards freshwater part of reserve (right)

As mentioned, the northern part (33 ha according to MP) of the reserve is freshwater, and the southern part is brackish. We tested the pH, which appears to be about pH 5 on both sides. There are three sluice gates: two small ones (with a single gate) and one with double gates. These were installed in 2009 according to the previous operator (man from fishing camp nearby; according to Management Plan 2014-2018 these were installed in 2007), but seem poorly maintained (rusty, ladder missing [rusted away], no grease applied) and one would guess them to be at least twice as old. These also have flap-gates to keep out saline waters. The vertical sluice gates are normally raised in August (when floods normally occur) and lowered again by November, to prevent loss of freshwater.

Water quality is an issue, according to WWT staff (Holly, formerly with BirdLife), with pesticides from the rice paddies on the one hand, and especially effluents (with pesticides) from the brackish-water fishponds to the south. The effluents are released at high tide and then enter AP from the southern end via the river. According to WWT, these have affected the habitat and birds, and are the likely cause of recent in decline in numbers of Sarus Crane. These ponds (at Kampung Thach) were formerly owned by Vietnamese but have reportedly recently been taken over by Chinese investors. According to the 2014-2018 MP: "The floodplain contains acid sulphate soils … which need to be kept permanently moist to prevent leaching of acid into the water column. During the 2013 dry season, water levels dropped to such an extent that the ground became hard enough to walk across. This results in the formation of acidic compounds in the soil with acids leaching out when the soil is rewetted. To offset this and dilute acid leachate and/or maintain waterlogging in the soil column, water could be diverted from the Toan Han River, through the CAVAC channel near Kaoh Taa Kov, if it is of acceptable quality."

Water resource interventions: Freshwater resources seem to be declining at AP, so if more water could be channelled to this area via the link canal, this would always be an improvement, provided that water quality is not compromised. Repair and upgrading of the three existing sluice gates and flap-gates could also be considered as these re poorly maintained and will not last much longer. Perhaps some similar structures could be considered at the site of the brackish-water fishponds, to prevent effluents from the ponds entering the AP site. All sluice gates should be overshot or otherwise designed and operated to allow safe passage of fish and other aquatic animals and to allow floating aquatic plants and debris to pass.

Photos 5a & 5b: larger sluice gates, with gates raised to allow freshwater enter the brackish water zone in foreground (left); buffalo grazing in brackish water zone, with visitors centre in background (right)

For the area, a number of 57 bird species was reported according to a poster at the information centre, and local staff. Our survey yielded 51 species during two brief visits, adding 24 species to this list, amongst which a possible single Eastern Water Rail *Rallus indicus* which, if confirmed, is noteworthy, as only few records of this northern migrant are available for Cambodia. It was told by the local WWT staff that the sedge vegetation, especially in the periphery, was trampled seasonally by huge flocks of migratory birds, such as the Near-threatened Bar-tailed Godwit *Limosa limosa*. On the other hand, it was also said that herds of Water buffaloes ploughed through the mud and actually contributed to the fertility of the soil and its vegetation.

Map of Anlung Pring: the brackish zone is below/south of the east-west running road in the top end. Green is *Melaleuca,* used for roosting, and in the south are the brackish-water fishponds.

3. ATT and adjacent reservoirs (18 October 2019)

Ang Tropeang Thmor

Ang Tropeang Thmor (ATT) is an IBA (IBA 1) designated as the ATT Sarus Crane Conservation Area. Its total area is 12,659 ha and it consists of an artificial lake or shallow reservoir, located 70 km to the north-west of Tonle Sap Lake. Access is from Preah Net Preah, about 70km west of Siem Reap on Highway No. 6, and heading 16 km north on the road to Srah Chik.

Hydrology. During the Angkorian period, from the 10th to the 13th century AD, a major causeway was constructed through the area, which led to increased water accumulation to the north, mainly of surface runoff. In 1976, an 11 km stretch of this causeway was converted into a dam and a 9 km dyke constructed perpendicular to it. However, the planned irrigation reservoir was never completed, and until recently only the south-eastern corner of the reservoir remains inundated during the dry season, although, at the height of the wet season most of the area is inundated. In March-April 2019 the reservoir was almost completely dry, which has led to MOWRAM's concerns and the perception that an intervention may be required. From 2015-2018, ADB (loan 3125-CAM) and AusAID (grant 0281-CAM) financed the Tropaing-Thmor Irrigation System Construction out of MOWRAM's Flood Damage Emergency Reconstruction Project – additional funding. Under this project, new sluice gates and spillways were constructed, and the dike and dam received new embankment lining. In 2015, Chinese funding was provided to partly construct an 8m wide concrete-lined canal taking water from the existing large canals leading from the three reservoirs (153, 158 and 258 million m^3, respectively) on the Stung Serey river. However, this Chinese canal appears unfinished as it peters out in the northern part of the reserve. Recently, MOWRAM has undertaken excavation of an extension, but would prefer to re-do the whole canal, make this 12m wide and lead it right up to the reservoir area. During the dry season the reservoir holds 60 Mm^3 and plans are to raise this to 80 Mm^3; in the wet season it holds about 150-180 Mm^3.

On 18th October 2019, water depth at the sluice gates was 1.5 m, while the crest (or sill) is only 1.0 m deep. Reportedly, the maximum water depth of the reservoir is only 3 m. The dike along eastern side of the reservoir is only 1.5-2 m above present water level, and this freeboard tapers off to the north. MOWRAM plans to increase the crest height by 0.5 m which brings this to 1.5 m. They do not intend to increase this more than 0.5m because that would affect farmers to the north. The Chinese link canal has no flow at present as ATT is already full, and there is no need to overflow further.

Photos 6a & 6b: ATT sluice gates on 1st July 2019 (left) and 18th October 2019 (right)

The area largely consists of artificial habitats, including open waters/shallow lake, with submerged *Hydrilla verticillata* and submerged-floating *Nymphaea nouchali, Nymphoides indica* and *Nelumbo nucifera.* These species also occur in the channels, pools and ponds that dot the landscape, often arising due to borrow pits for dike and road construction. In addition, there are vast grasslands with many true grasses (*Echinochloa stagnina, Eragrostis uniloides*) but also various sedges (*Cyperus digitatus, C. imbricatus, Fimbristylis miliacea*), and large areas of rice fields. The description of the IBA states that the area has been ‘extensively converted to wet-rice agriculture, but this land has only been irregularly used for a number of years’. That no longer seems to be the case, and by far the largest part of the northern half has been converted to rice fields that yield 2-3 crops per year. The IBA description further mentions that in ‘the extreme north of the IBA, the habitat grades into open deciduous dipterocarp forest’ – this no longer can be regarded as forest, as only a scattered sprinkling of trees remain (local names: kokah, koko, sedal and toyung), with a total cover less than 1%. There were signs of continued pollarding of trees, but also ring-barking and charcoal making. Botanically the most interesting are the shrub habitats that line canals, as these are rich in species and include *Holarrhena curtisii, Leea indica Memecylon* sp. and *Olax obtusa*.


Photos 7a & 7b: grasslands largely dry and accessible on 1st July (left), but largely flooded on 18 October 2019 (right)

According to the BirdLife website (http://datazone.birdlife.org/site/results?cty=36), the IBA is the most important non-breeding site for Sarus Crane *Grus antigone* in Cambodia and regularly supports a significant proportion of the global population of the eastern subspecies *G. a. sharpii*. Non-breeding Sarus Cranes visit the area outside their breeding period (July – September) during the dry season, when soggy grassland is needed for foraging. In addition to Sarus Crane, the IBA regularly supports over 1% of the Asian biogeographic population of Lesser Whistling-duck *Dendrocygna javanica*, Comb Duck *Sarkidiornis melanotus*, Asian Openbill *Anastomus oscitans* and Black-necked Stork *Ephippiorhynchus asiaticus*. Furthermore, a large number of globally threatened and near-threatened species have been recorded at the IBA, including Bengal Florican *Houbaropsis bengalensis* (which probably breeds), White-shouldered Ibis *Pseudibis davisoni* and Greater Adjutant *Leptoptilos dubius*. Additionally, the globally threatened Pallas's Fish Eagle *Haliaeetus leucoryphus* has been recorded at the site as a vagrant.

During the 1st July 2019 survey 20 bird species were observed. We arrived at the south-eastern corner of the reservoir in the southern part of the IBA around midday; only very few water birds were seen (cormorants), and a few stilts along the margins; we followed the road along a canal. The whole area is marshy with low vegetation, and some sparsely distributed trees, grazed by water buffaloes. Several dozens of Asian Openbill stork were observed inside the area, but hundreds in the surrounding grasslands. The near-threatened Asian Pied Kingfisher *Ceryle rudis* was also observed.

In October 2019, a larger area was surveyed than in June 2019, i.e. following the Stung Sreng and its reservoirs. Water birds were even less numerous in October than in June, but overall a larger number of bird species was recorded (45, seven of which migratory), partly due to a brief survey of the forest remnants in the adjacent hills at the far end of the eastern sluices; here a relatively rich avifauna was suggested by the presence of Oriental Pied Hornbill *Anthracoceros albirostris*, and various other forest birds. The total number of bird species reported from the ATT area is 186 (BirdLife 2019), of which we managed to retrive 159 species from unpublished reports.

<u>Stung Sreng I Reservoir</u>

Stung Sreng I reservoir was accessed by road from northern ATT. These country roads traverse woodland areas with scattered (remnant) forest trees; conspicuous are the many dipterocarps that apparently have been left standing. In between these wooded areas are rice fields and there are no extensive wetlands, just village ponds with lotus and borrow pits with aquatic vegetation (lotus, water spinach, waterlily). At one point the survey team needed to cross the river by improvised ferry, as the condition of the road is too poor on this side. Some areas of higher ground also occur between ATT and Stung Sreng I; these are low, gently sloping hills with cassava and some scattered trees. At these points the canal is located up to 8-10 m below the surface.

Photos 8a & 8b: makeshift ferry crossing on route from ATT to Stung Sreng I (left); link canal is located 8-10m below surface at part of route with low hills (right)

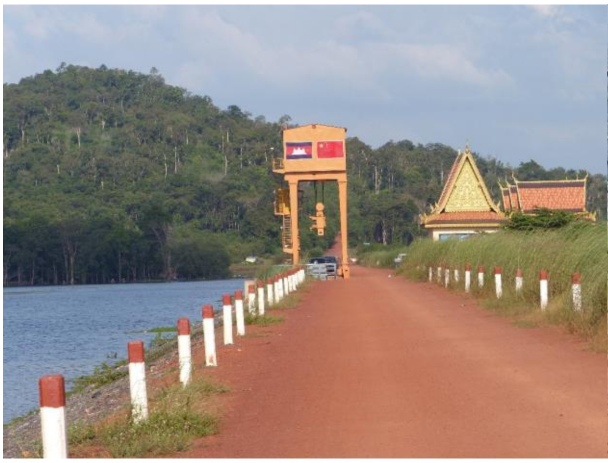
The Stung Sreng I reservoir is only 5-7 m deep. A first set of sluices control water flowing into the canal leading towards ATT, plus towards the Stung Sreng river; these are now closed as no water needed in the canal. The dam is full at present and water is flowing over the spillway into the river. At the far end of the dam wall there is a third set of sluices servicing the second primary canal that takes irrigation water in the direction of Siem Reap. Water levels are at 26-28 m asl, and the total capacity of the reservoir is reportedly 148 million m^3. There is no fish pass at this site, and it is likely that migratory fish have been seriously impacted by the dam.

Photos 9a & 9b: headworks with sluice gates for release into river, plus spillway in background (left); Stung Sreng river (not in flood) just downstream of headworks (right)

<u>Stung Sreng II reservoir</u>

According to signs at the reservoir, work started in June 2015 and was scheduled to be completed in 32 months, by the Chinese contractor Sinohydro. Water depth is max 10-12 m, mainly in the alignment of the river while the rest is (much) shallower. The area was previously forested and during construction timber/wood was not salvaged but just left *in situ*. As a result, there are now many dead trees at the northern end. Apparently, near the dam/sluices there were also many trees, but these were cut after construction as they were a nuisance in the sluice gates. The standing timber provides some benefits in providing habitat for fish and limiting the ability of people to catch them, but in general for reservoir management and for fisheries a small proportion of tree should be left in as cover (say 20%) in any reservoir. There are no fish passes, but along the spillway one can observe fish coming downstream via the overshot sluice gates, which are suitable for safe downstream passage of fish. However, a substantial portion of these fish are caught by the many nets draped in front of the spillway. Just downstream of the spillway there are also many fishermen with nets and traps. It is likely that they target upstream-migrating fish which accumulate downstream of the dam, and the lack of a fish pass at this site has likely caused serious losses of migratory fish, as is usual at such dams. There are no wetlands around the reservoir, just hills with both secondary, scrubby forest and tall primary forest. There are boats on the reservoir, and some tourism (e.g. there are food and drink stalls). Reportedly, some 300 families in two villages were resettled to make way for dam construction.

Photos 10a & 10b: dam spillway with many nets suspended (left); sluice gates at the far end (right)




Photos 11a & 11b: hills around and slopes around the reservoir are largely still forested (left); the forest was left standing in the inundated area, now a forest of dead trees (right) that are a source of eutrophication and carbon emissions.

4. Sang Rukhavoan Wildlife Sanctuary (19 October 2019)
(aka Sorng Roka Vorn) This Wildlife Sanctuary extends over 30,254 ha and was gazetted by sub-decree on 21st June 2018. It is located in Oddar Meanchey province and to the north it borders on the road linking Samraong and Anlong Veng, while to the south it borders on Stung Sreng II reservoir.

According to Terra Global Capital (2012)[1] the vegetation consists entirely of deciduous forests, which they describe as follows: "Mixed and deciduous forests are relatively open, and have low crown covers, only exhibiting a closed canopy structure during the wet season. The single-tree stratums of these forests generally feature tree diameters of less than 40 cm and are relatively species-poor, dominated by dipterocarps and a few gregarious species such as *Lagerstroemia* spp. and *Xylia xylocarpa (X. dolabriformis)* as well as numerous scattered associated species such as *Afzelia xylocarpa, Pterocarpus pedatus, Ceiba pentandra* and *Irvingia oliveri.* Important indigenous tree species include *Albizia lebbeck* (chres), *Fagraea fragrans* (ta trao), *Diospyros cuneata* (cheu kmao), *Gardenia angkorensis* (dai khala), *Dalbergia oliveri, Pterocarpus macrocarpus, Dipterocarpus turbinatus*, and *Afzelia xylocarpa* (beng), a high-value deciduous, broad-leaved tree. A number of bamboo species are also present in these forests. In the dry season, this forest type is subject to frequent fires. Although fire is a natural phenomenon in these systems, human intervention has exacerbated the incidence of fire due to the extremely dry conditions during the dry season. Due to fires, the understory is nearly always sparse and dominated by grasses."

During the survey the team came across several patches of fairly dense forest with a more-or-less closed canopy and including various large climbers. Much of the area, however, consists of a secondary open woodland, derived from the forest climax by tree felling and some burning. Dominants in this woodland are mainly dipterocarps, but also including *Diospyros, Dalbergia* and *Afzelia.* The ground cover of the woodland is dominated by a grass-like bamboo, with *Lees indica* and *Cycas siamensis* shrubs and a variety of herbs including *Amorphophallus* sp.*, Barleria strigosa, Lepidagathis incurva, Thunbergia fragrans.*

[1] Terra Global Capital (2012) – Reduced Emissions from Degradation and Deforestation in Community Forests – Oddar Meanchey, Cambodia Developed by Terra Global Capital for The Forestry Administration of the Royal Government of Cambodia. Project Design Document for validation under Climate, Community & Biodiversity Standard (Version 3-0). 198 pp.

Photos 12a & 12b: dense deciduous forest still occurs in patches (left), but open woodland tends to dominate, certainly closer to the road (right)

Photos 13a & 13b: Cycas siamensis *is uncommon and CITES listed (left), while* Barleria strigosa *is common from India to Southeast Asia and China (right)*

Land use in the area (apart from logging/wood collection) includes collecting dipterocarp resin (dammar), cattle grazing and cultivation of Zingiberaceae (ginger family) spices. A reforestation programme is underway by MoE, and a nursery facility is located along the main road, at the eastern end of the sanctuary.

Photos 14a & 14b: cattle grazing (left) and cultivation of ginger-like spices (right)

<u>Dam and riparian forest along Stung Sreng at Anlong Veng</u>

A small weir with spillway is located on the Stung Sreng in Anlong Veng town, close to the main road heading south towards Siem Reap. At the spillway water plummets about 2m and this attracts plenty of fisherfolk with a variety of nets (mostly fine-meshed). Just opposite from the weir is a small market where the fresh fish are sold – species observed include snakeheads, eels and carp, but also a variety of small juvenile fish and also an occasional snake (rainbow water snake *Enhydris enhydris*). There is no fish pass at the weir, which consequently blocks upstream fish migration for a significant period of the year. As in such barriers generally, the effects on fish and fisheries are likely to be highly significant.

Photos 15a & 15b: weir and spillway (left); fishing activity at the spillway (right)

Photos 16a & 16b: Variety of fish caught at spillway on the nearby market (left); small fry being cleaned and washed before being converted to prahok (right).

The Stung Sreng upstream of the reservoir at Anlong Veng was also briefly surveyed. The river is lined with riparian forest remnants and secondary scrub, with a variety of species including *Flacourtia rukam, Diospyros* sp. and *Afzelia lebbeck.* Other species include palms *Licuala paludosa* and *Caryota mitis,* river edge woody herbs such as *Donax canneformis,* and ferns such as *Lygodium flexuosum* and *Asplenium nidus.* There are many signs of ongoing logging of timber, as mainly large trees are targeted. The loss of forest in the catchment has multiple effects, causing erosion, poor water quality, and loss of important inputs of allochthonous organic material to the river.

Photos 17a & 17b: river lining riparian forest (left); Donax canniformis *a woody and versatile riparian herb (right)*

Brief surveys into the degraded forest of Sang Rukhavoan sanctuary along the main east-west road, the woods around the Ta Mok visitors' centre, and disturbed swampy forest in the far eastern part of the area showed a diverse bird fauna, amongst which a variety (8 species) of migratory species, e.g., five species of *Phylloscopus* leaf warblers. A family group of the globally vulnerable Great Slaty Woodpecker *Mulleripicus pulverulentus* was seen in the degraded forest.

5. Battambang, Stung Sangke River (21 October 2019)

Sek Sork (Parrot) Reservoir, (aka Battambang 1). Located on Stung Sangke, length of dam wall is 3.3 km. Maximum depth is 20-30 m, but most is 3-4 m only. Lots of trees/tree trunks remain standing in the waters and have not been salvaged; note that clearing of forest/woody vegetation is SOP for mitigating against both eutrophication and carbon emissions and to provide open areas for fishing. Construction started in 2010 and was completed in 2016. There are 3 turbines, two are 6.3 MW each, but these are not in use; a 3rd turbine of 0.5 MW is in use, but is operating below max capacity at only 20-30 KW. The project is used mainly for irrigation and flood protection. Max storage is 143 million m^3, now 121 million m^3, in dry season this declines to about 56 million m^3. Aquatic vegetation is not (yet) evident. There is some fishing with nets and fykes, as well as collecting of other aquatic animals, including snails *Pila ampullacea.* There is some ecotourism near the dam, with recreational housing and boating, but abundant driftwood is a problem. There is no fish pass at the weir, which consequently blocks upstream fish migration for a significant period of the year, which is likely to have caused serious impacts on fish and fisheries in the river.

Photos 18a & 18b: Sek Sork dam, with sluice gate buildings (left); flotsam consisting of decomposing wood from remaining dead trees in background (right).

<u>Komping Puoy (Kampingbuoy) reservoir</u>, is located on the Stung Bovil. It was constructed in the Pol Pot era for irrigation purposes, but has recently (2001) been rehabilitated with Japanese and Italian aid. It is a shallow dam with a maximum depth of only 3 m, with water levels at around 22-24 m asl, and it directs water into a primary irrigation canal at 22-24 m asl. A series of 10 sluices (that open directly into the primary canal) are currently closed as there is sufficient water in the canal. There is fishing activity including the harvesting of *Corbicula* bivalves. Water hyacinth *Eichhornia crassipes* and *Salvinia molesta* seem absent, and the shores are lined with lotus *Nelumbo nucifera* beds and wet grasslands. The small but steep hills that are close to the reservoir are densely forested. There is no fish pass at the weir, which consequently blocks upstream fish migration for a significant period of the year.

Photos 19a & 19b: Kompong Puoy reservoir sluice gate complex (left), and wet grasslands with well forested hills adjacent (right)

<u>Kanghort</u>. This is a low diversion weir which raises river water levels in the Sangke River for the primary irrigation canal without creating any significant storage. Managers open the gate when levels in the weir are at 21.5 m asl. Construction started in 2001 and it was completed in 2005, with Chinese assistance. There is no fish pass, and recreational fishing occurs with rods at the site of the sluice gates, while downstream subsistence fishing occurs, mainly with cast nets. The banks of the Sangke River downstream of the sluices are very steep and eroding. Scattered trees (*Acacia thailandica, Muntingia calabura*) line mainly the top of the banks, while on lower slopes there are clumps of reed *Phragmites karka* and reed-like *Saccharum spontaneum.*

Photos 20a & 20b: The four large Kanghort sluice gates (left); Stung Sangke just downstream of Kanghort (right).

Apart from numerous migrant Black Drongos *Dicrurus macrocercus*, a single Blue Rock Thrush *Monticola solitarius* roosting in the Kanghort sluice construction, and locally abundant Paddyfield Pipits *Anthus rufulus* foraging on the short-grazed grass strips along the dams, no noteworthy birds were observed.

6. Prek Chik (22 October 2019)

Bassac dam. This dam was constructed from 2000-2003, with a follow-up rehabilitation program from 2013-2015. Water is used for domestic purposes and irrigation. The reservoir is only 4 m deep max. and with a storage of only 500,000 m³. Expanding this reservoir is problematic as farmers have encroached on the banks with their fields of maize, cassava, pineapple and vegetables (beans). A Water User Association has been formed. Waterhyacinth occurs but does not appear to be problematic as it is only in low density. Shrubs and trees in places are found around the reservoir. The Bassac River downstream of the dam (and beyond the rock-lined section) seems fairly natural, with steep, eroding slopes lined with trees and shrubs (including *Acacia thailandica, Muntingia calabura, Vitex pinnata, Ziziphus cambodiana*) and beds of reed-like *Saccharum spontaneum*. However, water abstraction has depleted the flow and would have caused various effects on the aquatic and riparian ecosystems downstream. There is no fish pass at the dam which has blocked fish migrations and would have caused significant impacts on migrating fish.

Photos 21a & 21b: Bassac dam on downstream side (left), and vegetation along Bassac River just downstream of dam (right)

Dauntri Dam project. This project is under construction 5.2 km upstream of the Bassac Dam, along the upper Dauntri River. Construction has only just started by Kyeryong Construction Company in 2019 and is due to be completed in 2023. The project is a joint venture between K-Water (Korean Water Resources Corporation), Yooshin and Pyunghwa Construction. .

Mr Un Sokrit is the local PDWRAM engineer and team leader of the project. He explained that mean annual runoff is 333 million m^3 per year and the expected storage capacity of the reservoir is 163 million m^3, and the reservoir will cover approximately 60 km^2. The height of the main dam crest will be 96 m asl and the bed of the river at the dam wall is 48 m asl, hence the dam height will be about 48 m. The purpose of the project is to provide water for irrigation downstream and there is no provision for hydropower at the dam. The dam will be constructed using rock fill, with a clay core. The local rock is hard sandstone, and rock for dam construction will be excavated from bedrock within the reservoir footprint. A diversion tunnel is currently being built to allow dam construction. According to Mr Sokrit, there are many large fish in the vicinity of the dam site. The valley which will be flooded by the project is currently used mainly for farming with forest around the periphery. The forest above the dam will apparently remain intact. Resettlement has already taken place.

This dam project will allow for significant seasonal regulation of flows and facilitate increased diversion of water from the Pursat River, which will have flow-on effects on the aquatic and riparian communities downstream. There is no fish-pass or any other mitigating measures planned at the dam. Reservoir fisheries are likely to be significant for some period after impoundment, as up to about half of the indigenous species present are likely to survive in this relatively large reservoir, which has significant tributaries which are necessary for breeding of many species. Catches are likely to be increase for a few years and then decline over time, to an extent which will depend upon nutrient status and inflows from the catchment. Fisheries at the reservoir are likely to be accessed mainly by outsiders, who have the necessary experience and equipment to take advantage of the new source employment and income.

This project is designed to provide water to the Prek Chik scheme (via Bassac?). Vegetation in the area consists of scrubby, secondary woodland with patches of grass and tall weeds. Livestock grazing is still prevalent. Along the river scrubby vegetation includes species such as bamboo, *Ricinus communis, Chromolaena odorata, Mimosa pudica* and *Saccharum spontaneum.*

Photos 22a & 22b: Dauntri River lined with Saccharum, Chromolaena *and* Ricinus (left); *dam under construction in background, with access road in foreground (right)*

Prek Chik irrigation works. The storage dam and headworks were rehabilitated by ADB in 2016 under loan 3289-CAM (SF), titled Prek Chik Irrigation System Rehabilitation Works. The reservoir does not have much aquatic vegetation, although waterhyacinth *Eichhornia crassipes,* water lettuce *Pistia stratiotes* and water spinach *Ipomoea aquatica* are all present in low density. A Farmer User Cooperation (FUC) office is located at the site of the dam. The dam is used as a storage dam for Prek Chik farmers, and a cascade of water is supplied from Dauntri (planned) and Bassac dams. When the gates are open, water is supplied to farmers via the Prek Chik canal, otherwise it flows down the Stung Moung Russei River, especially if farmers along the Russei request this (they reportedly pump water from the Russei for irrigating rice fields. Water levels are low, and there was no water flowing over the spillway in spite of this being the end of the wet season. The Prek Chik Dam has allowed for significant diversion of water from the Dauntri River, and as a mitigating measure e-flows are required. At this dam there is no fish pass, which should be considered as part of the overall need to reinstate fish migrations along the Dauntri River for the benefit of riparian communities.

Photos 23a & 23b: Spillway of Prek Chik dam (foreground) with intake for primary irrigation canal in background (left); only standing water in the Stung Moung Russei river downstream of the Prek Chik dam (right).

Ream Kon Headworks. These headworks on the Dauntri River serve to raise water levels and directing water into irrigation canals. The main works have only just been completed (2019) and the last finishing touches are being applied by the contractor. The works also include a 'half-cone' fish pass; however, this was being used by local lads as an ideal location for trapping fish with their dipnets. The fish pass itself is small relative to the dam, it is too steep, and the 'half-cone' design is not likely to be successful for facilitating upstream fish passage, based on observations by the fisheries expert of the existing half-cone fish passes at Damnak Ampil and Wat Chre weirs. The whole works location was a scene of busy fishing activity, with lads catching small fish in front of the sluice gates, men with dipnets on long poles capturing fish in the pool between sluice gates and weir, gill nets suspended directly downstream of the works, and men with cast nets just further downstream. The fish pass obviously will not work under such intense fishing pressure, and the pass itself should be made inaccessible, e.g. with wire mesh or concrete slab covering.

Photos 24a & 24b: Ream Kon headworks, with irrigation canal intake to the right (left); boys with dipnets in the fish pass (right)

Dauntri River. In its upper course, the Dauntri River is being dammed to fill a large reservoir, while in the middle reaches it becomes gradually smaller, being tapped and siphoned off on all sides, while in its lower course it simply stops flowing and peters out altogether. This is probably not a recent occurrence as the channel also becomes smaller further downstream, i.e. there is no evidence of a wide, dry riverbed, just a gradually narrowing channel in which water is no longer flowing but stagnant. According to MOWRAM, before the Prek Chik irrigation works the Dauntri River was often completely dry towards its northern end, but now it often flows or at least contains water.

Photos 25a & 25b: Dauntri River upstream, just 500m downstream of the dam that is being built (left); Dauntri River between Prek Chik irrigation reservoir and the Ream Kon headworks (right)

The lowest number of birds of all sites visited during this survey was recorded here, with no noteworthy birds seen, except for perhaps a single Blue Rock Thrush foraging along the road or the stray Golden-fronted Leafbird *Chloropsis aurifrons*, a possible indication of a once rich woodland avifauna near the Dauntri dam under construction.

Photos 26a & 26b: Dauntri River several km downstream of Ream Kon headworks (left); further downstream it becomes stagnant and heavily polluted, but locals use pumps to divert this water to their rice fields (right).

7. Pursat River (23 October 2019)

Damnach Ampil. This headworks with seven large sluice gates serves to raise and maintain water levels in the Pursat River and lead water down the primary canal for irrigation works. Fine-meshed nets have been placed in front of the sluice gates, we were not in use at the time of the survey. A large fish pass has been installed it is coverted with coarse wire mesh to prevent people falling into it or trying to fish in it. Small, fine-meshed nets have been suspended in the fish-pass but these are not very effective. Also, the end of the pass with its wire mesh covering ends in the river, where it is not easy to place nets as currents are strong. This 'half-cone' fish pass is in many respects poorly designed, and is unlikely to be passing a significant number of fish. Flow in the lower section is highly turbulent, shallow and fast, which limits fish movement up it. Successful fish passes in the Mekong system include vertical slot (as at Stung Chinit), cone fish passes (as at Kbak Hong in Pursat and at some sites in Laos) and rock-ramp or nature-like fish passes as widely used elsewhere. The fish pass needs to be rebuilt to a design which can cope with varying headwater levels and varying fish accumulation zones downstream, and which provides a flow.

The river downstream of the headworks is lined with clumps of bamboo, various sedges *Cyperus* sp., *Calotropis gigantea, Cardiospermum halicacabum, Chromolaena odorata, Chrysophyllum cainito* (star apple), *Combretum trifoliatum, Mimosa pudica, Saccharum spontaneum, Sida rhombifolia* and grasses (grazed and non-flowering). Farmland along the river includes groves of *Borassus flabellifer* palms, *Bixa orellana,* bananas, cassava, mangos, coconut, papaya, lemons and *Canna* species*.* Local villagers collect various bivalves in the river, including small *Corbicula* and larger freshwater mussels *Physunio* species. The floodplains and associated water-bodies downstream of the dam are affected by the reduction in river flows caused by abstraction, with lateral flows being cut off by levees and farmland encroaching. The remnant floodplains along the whole length of the Pursat River should be the subject of a rehabilitation project as a mitigation measure for the ongoing impacts of water abstraction, given the importance of these wetlands for aquatic and riparian vegetation and fauna, and their significance for food and livelihoods for riparian communities.

Photos 27a & 27b: Damnach Ampil headworks (left); wire mesh covered fish pass (right), upper inlet section.

Photos 28a & 28b: Pursat River, with bamboo grove and grass (left); typical farmhouse in the Damnach Ampil area (right)

Pursat City. Within the city limits two weirs have been constructed to raise water levels in the Pursat River. Kbal Hong Weir is about 2 km downstream of the highway; it is about 100 m wide and was built to create a stable reservoir for aesthetics and recreational purposes and to divert water to a small irrigation offtake upstream of the dam on the west bank.

A ‘cone’ fish pass (with vertically placed cones not horizontally place ‘half cones’ as found at some sites) was built in 2018 on the western bank of the river below the dam. This fish-pass has been well-designed to cope with variation in flows, and is appropriate for the site and can pass more than 70 species of Mekong system fish over a range of sizes, based on prior field experiments in the Mekong basin and as shown by ongoing monitoring by IFReDI (personal communications from Chann Aun Tob and Dr Tim Marsden). The main limitation of the fish pass (as is a general issue for most fish passes) is its small size relative to the flow, which tends to limit the proportion of migrating fish which will be able to find its (downstream) entrance and pass through it. Added to this, there is no fish pass on the eastern side of the dam, so at higher flows fish tend to accumulate below the dam where they are caught before they can find the entrance to the fish pass. Various ‘technical’ measures can be applied to improve fish passage at the site, including enlargement of the fish pass or construction of additional passes. The ability to improve upstream fish passage is limited in this case only by the funds available.

While the design of the fish pass may be appropriate for this site, as at most locations in the Mekong basin, management of people is at least as important as technical issues related to water management. People fish all along the area downstream of the fish pass, and also within the fish pass itself, which creates an ideal fishing location for their dip and gill nets. Given the intensity of fishing relative to the size of the pass it is likely that many or most upstream-migrating fish are caught before they can pass. All fish caught at the time of the site visit appear to be juvenile and small, and they were mainly being processed to make prahoc. A sign has been erected nearby which reads “Fish need to move to survive” financed by USAID, who financed the fish pass.

MONRE should apply ‘no-fishing’ rules in the vicinity of dams and weirs, as is common practise, for fish conservation and for safety and operational reasons. MONRE should work with MAFF to engage the local CFRs and Community Fisheries groups to recognise weirs as important sites to create fish conservation zones (FCZs) which have been shown to be effective in maintaining fisheries in the Mekong basin. Generally, no-fishing zones are applied a fixed distance (e.g. 100 m) upstream and downstream of dams/weirs. ll fish passes need to be fenced and the ownership and management of each fish pass has to be clearly understood, while operators need to be paid or incentivised to ensure each fish pass is functioning as intended.

Photos 29a & 29b: fish pass at weir in Pursat municipality (left); fish caught here are all small and appear to be juveniles (right)

<u>Charek Weir.</u> The Charek headworks are located along the Pursat River about 12 km in a straight line from Pursat City in the direction of the Tonle Sap (the dam is about 20 km from the Tonle Sap). The dam is equipped with eight large (sluice-less) gates, but does not have a fish pass as the height difference is about 1.3 m. Nevertheless, the high turbulence and significant head-loss at the dam are likely create significant hydraulic barriers to upstream fish migration, especially for small fish which have limited swimming ability, and for large benthic fish, including most catfishes, which do not readily jump over barriers. Fishing activity was relatively intense at this site, compared with dams further upstream, which is consistent with reports that fish migrations now do not extend far up the river, ending at this most downstream dam, where the barrier itself combined with fish pressure tend prevent fish migrating further upstream. At the time of the site visit many people were fishing with fine-meshed nets suspended in front of the barrage and many fisherfolk operating dip and cast nets downstream of the barrage. Local fisherfolk complain that the average size of fish was decreasing, even in comparison to last year. The Pursat River and other large rivers around the Tonle Sap formerly supported significant migrations of fish from the Tonle Sap system, and these migrating fish have reportedly been largely eliminated by the many dams built along the tributary rivers since 2000.

Photos 30a & 30b: Suspended nets and cast nets at the Charek headworks (left); dip (foreground) and cast nets (background) are used intensively downstream of the barrage (right)

<u>Pursat River, mainly downstream of Charek Weir</u>. The road along the Pursat River peters out downstream of Charek about 6 km from the edge of Tonle Sap. During the survey we continued walking for 1.7 km along the river. Rice fields are main land use, along with cattle grazing, fodder collection and fishing in the river. Boats with drift nets were seen and again indicate that fishing is significant in the lower section of this river, but not further upstream, where fish migrations have been blocked by Charek Weir. Rice is irrigated via pumps, but at present not much pumping occurring as it is harvesting season for most. Vegetation along the Pursat River includes trees and shrubs: *Borassus flabellifer, Croton mekongensis, Mimosa pigra, Salix tetrasperma, Sesbania javanica* pus bamboo thickets; herbs and climbers: *Coccinia grandis, Gymnopetalum chinense, Heliotropium indicum, Oxystelmon esculentum,* and several sedges and grasses: *Fimbristylis milliaceum, Leptochloa chinensis,* and *Paspalum* species. A very tall grass occurs in large tussocks, but none were observed flowering; possibly *Miscanthus sinensis gigantea.*

Photos 31a & 31b: cattle-rearing and rice fields are common land use in the downstream Pursat area (left); fishing in the river includes the use of drift nets (right).

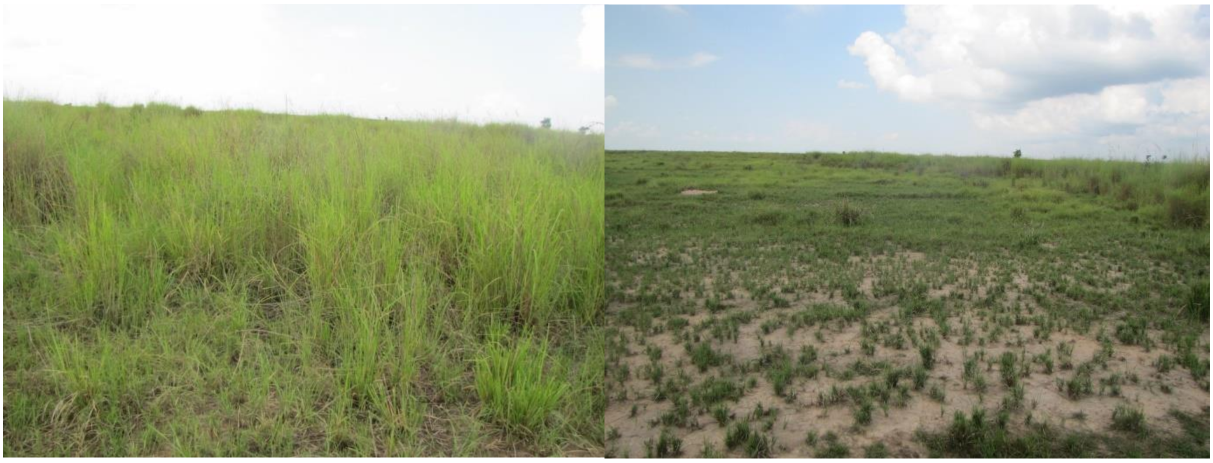
Photo 32a & 32b: Salix tetrasperma *willow trees (left);* Pentapetes phoenicea*, a widespread but uncommon Malvaceae species (right)*

A total of 41 bird species were recorded from the Pursat area. Especially in and above the wet-rice fields, largely harvested during our visit, large numbers of Whiskered Terns *Chlidonias hybridus* and Black-winged Stilts *Himantopus himantopus* were noticed.

8. Bakan grasslands (24 October 2019)

This is an important area at a about one hour drive from Pursat town, and within the Tonle Sap floodplain, featuring tall grass, dominated by thick-stemmed *Miscanthus* with many bushes, paddy fields and ponds with the only known site in Cambodia for globally Vulnerable Chinese Grass-babbler *Graminicola striatus* (Eaton et al. 2014), but more remnants of grassland may be important for these (and other grassland) species.

This 2100 ha large area is also habitat for a number of other scarce to rare birds, such as Bengal Florican, Manchurian Reed Warbler *Acrocephalus tangorum* and other migratory warblers. The brief visit yielded only 16 species of bird, the low number mainly caused by the timing of the visit later in the morning. Rice farming and cattle grazing form the main threats of this increasingly rare habitat.



Photos 33a & 33b. Bakan grasslands, left close-up of tall Miscanthus *reed grass, right the surrounding area.*

Appendix 2.List of wetland plant species

This list has been compiled on the basis of past plant records in Cambodian wetlands, notably by Rollet (1972), McDonald et al. (1997) and Giesen (1998), and augmented with records from the present study, based on brief surveys carried out in June-July and October 2019. Species names have been updated using the Plant List (www.theplantlist.org). A total of 280 plant species have been recorded to date, of which 26 species are introduced exotics.

#	Family	Species	local name	Exotic	Lifeform	Reference	2019 Surveys
1	Achariaceae	*Hydnocarpus anthelminthicus* Pierre ex Laness.	kiropau playtum; krabau phle thom		T	1,3	
2	Achariaceae	*Hydnocarpus saigonensis* Pierre ex Gagnep. *(unres)*	kirobau playtaug		T	1,3	
3	Alangiaceae	*Alangium ridleyi* King	Angkol, dok tua		S	1,3	
4	Alismataceae	*Sagittaria trifolia L. (sagittifolia* Lour.)			AH	1	
5	Amaranthaceae	*Alternanthera sessilis* (L.) R.Br. ex DC.	smau chang bangkang		H	1	+
6	Amaranthaceae	*Centrostachys aquatica* Wall. *(*syn. *Achyranthes aquatica RBr)*			H	1	
7	Annonaceae	*Dasymaschalon lomentaceum* Finet & Gagnep	chung jam		T	1	
8	Annonaceae	*Popowia diospyrifolia* Pierre ex Finet & Gagnep	kro vahn		T	1	
9	Annonaceae	*Uvaria pierrei* Finet & Gagnep.	tri:el sva ?		L	1,3	
10	Annonaceae	*Uvaria rufa* Blume			L		+
11	Annonaceae	*Xylopia* sp.	krai		T	3	
12	Apocynaceae	*Aganonerion polymorphum* Pierre ex Spire			S		+
13	Apocynaceae	*Calotropis gigantea* (L.) Dryand.			S		+
14	Apocynaceae	*Holarrhena curtisii* King & Gamble			S		+
15	Apocynaceae	*Parameria laevigata* (Juss.) Moldenke	vor chouy		L	3	
16	Apocynaceae	*Tabernaemontana divaricata* (L.) R.Br. Ex Roem. & Schult.			T		+
17	Apocynaceae	*Thevetia neriifolia* Juss. ex Steud.	kay yato *		T	1	
18	Araceae	*Amorphophallus* sp.			H		+
19	Araceae	*Colocasia esculenta* (L.) Schott.			H	2	+
20	Araceae	*Pistia stratiotes* L		+	AH	1,2	
21	Araliaceae	*Aralia* sp.			L		+
22	Arecaceae	*Borassus flabellifer* L. *	t'nau		T	2	+
23	Arecaceae	*Calamus godefroyi* Becc. (?)	phdau tuk		L	3	
24	Arecaceae	*Calamus palustris* Griff.	phdao shwaing		L	1,2	+
25	Arecaceae	*Calamus salicifolius* Becc.	rumpeah		L	1,2	+
26	Arecaceae	*Licuala paludosa* Griff.	Phao		S		+
27	Arecaceae	*Licuala spinosa* Wurmb	Phao		S		+
28	Asclepiadaceae	*Streptocaulon kleinii* Wight & Arn. (unresol).	voa tekdoh voa chuy		L	1	
29	Asclepiadaceae	?	voa chuy		H	1	
30	Asteraceae	*Ageratum conyzoides* (L.) L.		+	H		+
31	Asteraceae	*Eclipta prostrata* (L.) L. (syn. *E. alba* (L.) Hassk)			H	1	+
32	Asteraceae	*Grangea maderaspatana* (L.) Poir	smau chung toaki		H	1	+
33	Balsaminaceae	*Impatiens* sp			H	1	
34	Boraginaceae	*Coldenia procumbens* L.			H	1	
35	Boraginaceae	*Cordia* sp.	ao chrung		T	3	
36	Boraginaceae	*Heliotropium indicum* L.	promoi damray		H	1	+
37	Caesalpiniaceae	*Cassia javanica* L.			s/t		+
38	Caesalpiniaceae	*Crudia chrysantha* (P.) K. Schum.	sdai		T	1,3	
39	Caesalpiniaceae	*Cynometra dongnaiensis* Pierre *(?) (or C. ramiflora?)*	ampil tuk prey		T	3	
40	Caesalpiniaceae	*Cynometra inaequifolia* A.Gray (?)	chom prinh		T	3	

#	Family	Species	local name	Exotic	Lifeform	Reference	Surveys
41	Caesalpiniaceae	*Cynometra* sp.			T	1	
42	Caesalpiniaceae	*Peltophorum dasyrrhachis* (Miq.) Kurz (syn. var. *dasyrrachis*)	trah say		T	1	
43	Caesalpiniaceae	*Senna alata* (L.) Roxb. *(syn. Cassia alata* L.)		+	S	2	
44	Caesalpiniaceae	*Sindora siamensis* Miq. (syn. *Sindora cochinchinensis* Lam.)*			T	1	+
45	Caesalpiniaceae	*Tamarindus indica* L.*	ampel	+	T	1	+
46	Campanulaceae	*Sphenoclea zeylanica* Gaertn.			H	1	
47	Capparidaceae	*Capparis sepiaria* var. *fischeri* (Pax) DeWolf (syn. *C. micrantha* DC.)	kangce: ba:y da:c, kanchoeu bay dach		S	1,3	
48	Capparidaceae	*Crateva adansonii* subsp. *odora* (Buch.-Ham.) Jacobs *(syn. C. roxburghi* R. Br.)	thngan		S	1	
49	Capparidaceae	*Crateva nurvala* Buch.-Ham.	tonlea, knang, tonleap		S	1,2,3	+
50	Capparidaceae	*Maerua decandra* (Gagnep) Pax.	jaing		T	1	
51	Capparidaceae	*Stixis harmandiana* Pierre			L	3	
52	Celastraceae	*Lophopetalum fimbriatum* Wight (unres.)	sedar sar		T	3	
53	Celastraceae	*Lophopetalum wightianum* Arn.	sedar sar: pontaley; say doc		T	1	
54	Celastraceceae	*Salacia verrucosa* Wight	kandap changay		L	1	
55	Characeae	*Chara* sp.			AH	1,2	
56	Clusiaceae	*Calophyllum* sp	ankeur bos		T	1	
57	Clusiaceae	*Garcinia loureiroi* Pierre	sandan; sung dtun		T	1,3	
58	Clusiaceae	*Garcinia schomburgkiana* Pierre	tramoung		T	3	
59	Combretaceae	*Combretum indicum* (L.) DeFilipps (syn. *Quisqualis indica* L.)	voa domprea		L	1	
60	Combretaceae	*Combretum quadrangulare* Kurz.	sangkae		T	1	
61	Combretaceae	*Combretum trifoliatum* Vent.	trah, vor tras		L	1,3	+
62	Combretaceae	*Getonia floribunda* Roxb. *(syn. Calycopteris floribunda* Lam)	khsuch; voa so, vor khsuos		L	1,3	
63	Combretaceae	*Lumnitzera racemosa* Willd.	sogkul		T	1	
64	Combretaceae	*Quisqualis densiflora* Wall. ex Miq. (unres.)	vor preah		L	3	
65	Combretaceae	*Terminalia cambodiana* Gagnep (unres.)	tu-uhl, ta uah		T	1,3	+
66	Commelinaceae	*Commelina benghalensis* L.			H		+
67	Commelinaceae	*Commelina salicifolia* Roxb.	slop tia		H	1	
68	Commelinaceae	*Murdannia macrocarpa* D.Y.Hong			H		+
69	Connaraceae	*Connarus semidecandrus* Jack	am puah		L	1	+
70	Convolvulaceae	*Erycibe* sp.			L		+
71	Convolvulaceae	*Ipomoea aquatica* Forsk	traku: en; trakoun		AH	1,2	+
72	Convolvulaceae	*Ipomoea obscura* (L.) Ker-Gawl	voa ta-aut		L	1	+
73	Convolvulaceae	*Merremia hederacea* (Burm. f.) Hallier f. (syn. *Ipomoea chryseides* Ker Gawl.)	voa ta-euuk, thaek		L	1,2,3	+
74	Convolvulaceae	*Operculina petaloidea* (Choisy) Ooststr.			L		+
75	Cucurbitaceae	*Gymnopetalum chinense* (Lour.) Merr.			L		+
76	Cucurbitaceae	*Gymnopetalum scabrum* (Lour.) W.J.de Wilde & Duyfjes			L		+
77	Cucurbitaceae	*Trichosanthes* sp.	Tra sak-ay		L	1	
78	Cyperaceae	*Actinoscirpus grossus* (L.f.) Goetgh. & D.A.Simpson (syn. *Scirpus grossus* L. f.)	kok		H	1,2	+
79	Cyperaceae	*Cyperus cephalotes* Vahl			H		+
80	Cyperaceae	*Cyperus digitatus* Roxb.			H		+
81	Cyperaceae	*Cyperus haspan* L.			H	2	
82	Cyperaceae	*Cyperus imbricatus* Retz.			H		+
83	Cyperaceae	*Cyperus* cf. *pilosus* Vahl	kok konkaib		H	1	
84	Cyperaceae	*Cyperus procerus* Rottb.			H		+
85	Cyperaceae	*Cyperus sphacelatus* Rottb.			H		+
86	Cyperaceae	*Eleocharis dulcis* (Burm.f.) Trin. ex Hensch.			H		+
87	Cyperaceae	*Eleocharis ochrostachys* Steud.			H		+
88	Cyperaceae	*Eleocharis philippinensis* Svenson			H		+
89	Cyperaceae	*Eleocharis spiralis* (Rottb.) Roem. & Schult.			H		+
90	Cyperaceae	*Fimbristylis acuminata* Vahl.			H		+
91	Cyperaceae	*Fimbristylis dichotoma* (L.) Vahl			H		+
92	Cyperaceae	*Fimbristylis quinquangularis* (Vahl) Kunth *(F. miliacea)*			H		+
93	Cyperaceae	*Fimbristylis tomentosa* Vahl.			H		+
94	Cyperaceae	*Rhynchospora* sp	kakonkaib		H	1	
95	Cyperaceae	*Scleria* sp.			H	1,2	
96	Dilleniaceae	*Tetracera scandens* (L.) Merr.			S/L		+
97	Dilleniaceae	*Tetracera sarmentosa* (L.) Vahl	das kun, voa dakun		S/L	1	
98	Dipterocarpaceae	*Pentacme siamensis* (Miq.) Kurz (syn. *Shorea siamensis*)			T		+
99	Dipterocarpaceae	*Vatica* sp.	chramas		T	3	
100	Droseraceae	*Drosera burmannii* Vahl	sansaem duec		H	1	

#	Family	Species	local name	Exotic	Lifeform	Reference	Surveys
101	Droseraceae	*Drosera indica* L.			H	1	
102	Ebenaceae	*Diospyros cambodiana* Lecomte (*D. cf. bejaudii)*	ptul, phtuol		T	1,3	+
103	Ebenaceae	*Diospyros sylvatica* Roxb.	?kau-cha, maklua?, khchas		T	1,3	
104	Ebenaceae	*Diospyros* sp.	traulakh, kau kijau, dong-kau, tonlap		T	1,3	
105	Elaeaocarpaceae	*Elaeocarpus griffithii* (Wight) A.Gray	run dng plok / rom denh, romdenh phlouk		T	1,3	
106	Elaeaocarpaceae	*Elaeocarpus hygrophilus Kurz (E. madopetalus)*	run dng kaj, romdenh kaek		T	1,3	
107	Elaeaocarpaceae	*Elaeocarpus lacunosus* Wall. ex. Kurz.	cambak pra:ng		T	1	
108	Euphorbiaceae	*Croton caudatus* Geiseler	prabouy		S	3	+
109	Euphorbiaceae	*Croton krabas* Gagnep	pro buoymay		S	1,3	+
110	Euphorbiaceae	*Croton mekongensis* Gagnep	probouy chmoul		S	1	
111	Euphorbiaceae	*Homonoia riparia* Lour	rayi-tuk, rey tuk		S	1,3	+
112	Euphorbiaceae	*Jatropha curcas* L		+	S	1	
113	Euphorbiaceae	*Jatropha gossypiifolia* L.		+	S		+
114	Euphorbiaceae	*Mallotus paniculatus* (Lam.) Müll.Arg. *(syn. Mallotus cochinchinensis* Lour.)			T	1	
115	Euphorbiaceae	*Mallotus plicatus* (Müll.Arg.) Airy Shaw. *(syn. Coccoceras anisopodum)*	Chiro kaing, popleah		T	1,3	
116	Euphorbiaceae	*Melanolepis multiglandulosa* (Reinw. ex Blume) Rchb.f. & Zoll.	?		T		+
117	Euphorbiaceae	*Melanolepis vitifolia* (Kuntze) Gagnep.	samro		S/T	1	
118	Hydrocharitaceae	*Hydrocharis dubia* (Blume) Backer	saray		H	1	
119	Hydrocharitaceae	*Hydrilla verticillata* (L.f.) Royle			AH		+
120	Hydrocharitaceae	*Ottelia alismoides* (L) Pers.			AH	1	
121	Hypericaceae	*Cratoxylum formosum* (Jacq.) Benth. & Hook.f. ex Dyer (syn. *C. prunifolium Dyer, Cratoxylon prunifera*	longieng		T	1,3	
122	Lamiaceae	*Clerodendrum infortunatum* L.			S		+
123	Lamiaceae	*Glossocarya siamensis* Craib			L	3	
124	Lamiaceae	*Gmelina asiatica* L.	Aingchan; rumca:n, anchanh		T	1,3	+
125	Lamiaceae	*Vitex holoadenon* Dop	tien preyi		S	1,3	
126	Lamiaceae	*Vitex negundo* L.	troseat		S	1	
127	Lauraceae	*Cassytha filiformis* L.			L		+
128	Lauraceae	*Cryptocarya oblongifolia* Blume	sro da krohom, sedar kraham		T	1,3	
129	Lecythidaceae	*Barringtonia acutangula* (L.) Gaertn *(syn. Barringtonia micrantha)*	riang-tut; riang thom, reang-reang tuk		T	1,2,3	+
130	Lecythidaceae	*Careya arborea* Roxb.	reang phnum; kandol		T	1,3	
131	Leeaceae	*Leea indica* (Burm. f.) Merr.			S		+
132	Lemnaceae	*Lemna minor* L.	jo, chak		AH	1	
133	Lentibulariaceae	*Utricularia aurea* Lour	saray		AH	1,2	
134	Loganiaceae	*Strychnos* sp.	sleng		L	3	
135	Lythraceae	*Ammannia verticillata* (Ard.) Lam. *(syn. illeg. Ammannia baccifera* Pollini)			H	1	
136	Lythraceae	*Lagerstroemia calyculata* Kurz			T		+
137	Lythraceae	*Lagerstroemia thorelii* Gagnep.			T	1,2	
138	Malphigiaceae	*Hiptage triacantha* Pierre			L	1,3	
139	Malvaceae	*Abelmoschus esculentus* (L.) Moench.		+	S		+
140	Malvaceae	*Abelmoschus moschatus* Medik.			S		+
141	Malvaceae	*Brownlowia paludosa* (Kosterm.) Kosterm.	ronea		T	1	
142	Malvaceae	*Byttneria pilosa* Roxb. (miss-spelled as *Buettneria pilosa* Roxb.)			L	1,3	
143	Malvaceae	*Ceiba pentandra* Gaertn	*	+	T	1	
144	Malvaceae	*Corchorus cf. aestuans* L.			T		+
145	Malvaceae	*Decaschistia crotonifolia* Wight & Arn. *(D. parviflora)*			H		+
146	Malvaceae	*Gossypium herbaceum* L.		+	H/S		+
147	Malvaceae	*Grewia asiatica* L.			S		+
148	Malvaceae	*Grewia sinuata* Wall. ex Mast.	snai, snay tuk		S	1,3	
149	Malvaceae	*Helicteres hirsuta* Lour.			S		+
150	Malvaceae	*Melochia corchorifolia* L.	jitjau		H	1	+
151	Malvaceae	*Pentapetes phoenicea* L.	kachiep		H/S	3	+
152	Malvaceae	*Sicrea godefroyana* Hallier f. (syn. *Schoutenia godefroyana* Baill.)	?		S	1,3	
153	Malvaceae	*Urena lobata* L.			H		+
154	Marantaceae	*Schumannianthus dichotomus* (Roxb.) Gagnep.	run		H/S	1	
155	Marsileaceae	*Marsilea crenata* C. Presl	chantu: el phnum; thpa:uel trei		H	1	
156	Melastomataceae	*Melastoma malabathricum* L.	?		S	2	
157	Melastomataceae	*Melastoma malabathricum* L. subsp. *normale* (D. Don) K. Meyer			S		+
158	Melastomataceae	*Melastoma saigonense* (Kuntze) Merr.			S		+
159	Melastomataceae	*Memeclyon edule* Roxb. var. *ovata* C.B. Clarke			S/T		+
160	Melastomataceae	*Memeclyon edule* Roxb. var. *scutellata* (Lour.) C.B. Clarke			S/T		+

#	Family	Species	local name	Exotic	Lifeform	Reference	Surveys
161	Meliaceae	*Dysoxylum excelsum* Blume *(syn. D. procerum; illeg.)*	chey paur, bang keou kouk		T	1	
162	Menyanthaceae	*Nymphoides indica* (L.) Kuntze			AH	1,2	+
163	Mimosaceae	*Acacia auriculiformis* Benth.		+	T		+
164	Mimosaceae	*Acacia intsia* (L.) Willd. (typo A. intsii)	thmea		S/L	3	
165	Mimosaceae	*Acacia thailandica* I.C. Nielsen	banla bay kamnaub		S	1	
166	Mimosaceae	*Albizia lebbekoides (DC.) Benth.*	chum riek, kon tri		T	1,3	
167	Mimosaceae	*Albizia saman* (Jacq.) Merr. (syn. *Enterolobium saman* (Jacq.) Prain)*	chan rai	+	T	1	+
168	Mimosaceae	*Mimosa invisa* Colla		+	S/L	2	
169	Mimosaceae	*Mimosa pigra* L.	banlar yuon	+	S	1,2	+
170	Mimosaceae	*Mimosa pudica* L.		+	H	2	+
171	Mimosaceae	*Neptunia oleracea* Lour.	kancha: et, kanchait	+	AH/S	1,2	+
172	Mimosaceae	*Parkia sumatrana* Miq			T		+
173	Moraceae	*Cudrania cambodiana* Gagnep	Klley, khlé		L	1,3	
174	Moraceae	*Ficus heterophylla* L.f.	slot		S	1,2,3	
175	Moraceae	*Ficus* sp.	roleab		S	1	
176	Moraceae	*Ficus* sp.			T	1	
177	Muntingiaceae	*Muntingia calabura* L.		+	T		+
178	Myristicaceae	*Myristica* sp.			T		+
179	Myrtaceae	*Eucalyptus camaldulensis* Dehnh.		+	T		+
180	Myrtaceae	*Rhodomyrtus tomentosa* (Aiton) Hassk.			S		+
181	Myrtaceae	*Syzygium cinereum* (Kurz) Chantaran. & J.Parn.	pring bay		T	1	
182	Myrtaceae	*Syzygium sterrophyllum* Merr. & L.M.Perry (syn. *Eugenia)*	pring		T	1,3	
183	Nelumbonaceae	*Nelumbo nucifera* Gaertn.	chu		AH	1,2	+
184	Nymphaeaceae	*Nymphaea nouchali* Burm. f.	pralit		AH	1	+
185	Olacaceae	*Olax obtusa* Blume			T		+
186	Onagraceae	*Ludwigia adscendens* (L.) H.Hara	kampiu puey	+	H	1,2	+
187	Onagraceae	*Ludwigia hyssopifolia* (G.Don) Exell.	damrai	+	H	1	+
188	Onagraceae	*Ludwigia peruviana* (L.) H.Hara		+	H	2	
189	Pandanaceae	*Pandanus* sp.	?		S	2	
190	Papilionaceae	*Aeschynomene indica* L.	smau ombah		S	1	
191	Papilionaceae	*Butea monosperma* (Lam.) Taub. (syn. B. frondosa)	char		T	1,3	
192	Papilionaceae	*Crotalaria pallida* Aiton (C. striata)	changkrang svar		H/S		+
193	Papilionaceae	*Dalbergia cambodiana* Pierre	cranhung		T		+
194	Papilionaceae	*Dalbergia entadoides* Prain.	knai moen		L	1,3	+
195	Papilionaceae	*Dalbergia pinnata* (Lour.) Prain			T/L	1	
196	Papilionaceae	*Dendrolobium lanceolatum* (Dunn) Schindler	Tronombang keoury		S	1	
197	Papilionaceae	*Derris laotica* Gagnep			S/L	1	
198	Papilionaceae	*Desmodium cf. baccatum* (Schindl.) Schindl.			H		+
199	Papilionaceae	*Desmodium* sp.			H	3	+
200	Papilionaceae	*Sesbania javanica* Miq.	snau, senau		S	1,2	+
201	Passifloraceae	*Passiflora foetida* L.		+	L		+
202	Phyllanthaceae	*Antidesma ghaesembilla* Gaertn			T	1	+
203	Phyllanthaceae	*Antidesma montanum* Blume			T		+
204	Phyllanthaceae	*Aporosa octandra* (Buch.-Ham. ex D.Don) Vickery			T		+
205	Phyllanthaceae	*Breynia vitis-idaea* (Burm.f.) C.E.C.Fisch.*(syn. B. rhamnoides* Arg)	pnaik priep, phnek preap		S	1,3	
206	Phyllanthaceae	*Bridelia retusa* (L.) A.Juss. *(syn. Bridelia cambodiana* Gagnep)	tmegn trei		S/T	1	
207	Phyllanthaceae	*Glochidion obscurum* (Roxb. ex Willd.) Blume			T		+
208	Phyllanthaceae	*Hymenocardia punctata* Wall. ex Lindl. (syn. *H. wallichii* Tul.)	phnum phnaeng; kum pniang		S	1,3	+
209	Phyllanthaceae	*Phyllanthus reticulatus* Poir	tasieou		S	1,2	+
210	Phyllanthaceae	*Phyllanthus taxodiifolius* Beille	propain, prapenh nhi		S	1,3	+
211	Phyllanthaceae	*Phyllanthus* sp.	prophegn chmol		S	1,3	
212	Piperaceae	*Piper* sp.			L		+
213	Plantaginaceae	*Limnophila geoffrayi* Bonati (unresolved)			AH/H	1	
214	Plantaginaceae	*Limnophila repens* (Benth.) Benth.	maa:m		AH/H	1	
215	Plantaginaceae	*?Bacopa/Scoparia* sp.	pro matdai		H	1	
216	Poaceae	*Bambusa bambos* (L.) Voss (syn. *B. arundinacea)* *	russey prey		T	1,3	+
217	Poaceae	*Brachiaria mutica* (Forssk.) Stapf.	smau baramg	+	H	1	
218	Poaceae	*Chloris barbata* Sw.			H		+
219	Poaceae	*Echinochloa crus-galli* (L.) P. Beauv.			H		+
220	Poaceae	*Echinochloa stagnina* (Retz.) Beauv.		+	H	1	+

#	Family	Species	local name	Exotic	Lifeform	Reference	Surveys
221	Poaceae	*Eragrostis unioloides* (Retz.) Nees ex Steud.			H		+
222	Poaceae	*Eriochloa polystachya* H.B.K.			H		+
223	Poaceae	*Leersia hexandra* Sw.		+	H	1	+
224	Poaceae	*Leptochloa chinensis* (L.) Nees (miss-spelled as *Leptochloa sinensis* Nees.)			H	1	+
225	Poaceae	*Miscanthus fuscus* (Roxb.) Benth. *(syn. Sclerostachya fusca* A.C.)			H	1	+
226	Poaceae	*Miscanthus sinensis* Andersson			H		+
227	Poaceae	*Ophiuros exaltatus* (L.) Kuntze (*Rottboellia exaltatus)*			H		+
228	Poaceae	*Panicum repens* L.			H		+
229	Poaceae	*Paspalum scrobiculatum* L.			H	1	+
230	Poaceae	*Phacelurus cambogiensis* (Balansa) Clayton (syn. *Pseudovossia cambogensis* (Bal.) Camus)	smau sambuk kandoup		H	1	
231	Poaceae	*Phragmites karka* (Retz.) Trin. ex Steud.	traing, probos		H	1,2	+
232	Poaceae	*Polytrias amaura* (Buese) O.K.			H		+
233	Poaceae	*Pseudoraphis minuta* (Mez) Pilg. (*Chamaeraphis minuta* Mez.)			H	1	
234	Poaceae	*Saccharum spontaneum* L.	ampou		H	1,2	+
235	Poaceae	*Sacciolepis interrupta* (Willd.) Stapf			H	1	
236	Poaceae	*Sacciolepis myosuroides* (R.Br.) A.Camus			H	1,2	
237	Poaceae	*Setaria pumila* (Poir.) Roem. & Schult. (syn. *Setaria pallide-fusca)*	smau katooy shkai		H	1	+
238	Poaceae	*Vossia cuspidata* (Roxb.) Griff.			H	1	
239	Podostemonaceae	*Cussetia carinata* (Lecomte) M.Kato (syn. *Dalzellia carinata*)			H	1	
240	Polygalaceae	*Xanthophyllum glaucum* Wall. (unres.)	kansaeng, taseng.		T	1,3	
241	Polygonaceae	*Persicaria barbata* (L.) H.Hara (syn. *Polygonum barbatum* L.)	kontriang hai/kroting hai		H	1,2	+
242	Polygonaceae	*Persicaria pulchra* (Blume) Sojak (syn. Polygonum pulchrum)			H		+
243	Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	kampau	+	AH	1,2	+
244	Pontederiaceae	*Monochoria hastata* (L.) Solms			H	1,2	+
245	Pontederiaceae	*Monochoria vaginalis* (Burm.f.) C.Presl			H	1,2	
246	Potamogetonaceae	*Potamogeton* sp.			AH	1	
247	Pteridaceae	*Ceratopteris thalictroides* (L.) Brongn.	?		H	2	+
248	Putranjivaceae	*Drypetes thorelii* Gagnep.			T	3	
249	Rhamnaceae	*Ziziphus jujuba* Mill. *	pot trea, tronom arot	+	T	1,2	+
250	Rhizophoraceae	*Carallia brachiata* (Lour.) Merr. (syn. *Carallia lucida)*	trament		T	3	
251	Rubiaceae	*Adina* sp.	roleay		T	3	
252	Rubiaceae	*Gardenia cambodiana* Pitard	dongk dau, bay-remir, day khla		T	1,3	
253	Rubiaceae	*Ixora chinensis Lam.*			S		+
254	Rubiaceae	*Mitragyna diversifolia* (Wall. ex G.Don) Havil. (syn. Stephegyne)	khtoum tuk		T	3	+
255	Rubiaceae	*Mitragyna parvifolia* (Roxb.) Korth. (syn. Stephegyne)	khtoum		T	1,3	+
256	Rubiaceae	*Morinda persicifolia* Buch.-Ham.	nhor tuk		S	3	+
257	Rubiaceae	*Nauclea officinalis* (Pierre ex Pitard) Merr. & Chun	kau		T	1,2	+
258	Rubiaceae	*Randia longifolia* C. Gust. (?Benth. In McCarthy)	kmun kanjauh.		S	1	
259	Rubiaceae	*Randia* sp.			S	1	
260	Rubiaceae	*Uncaria homomalla* Miq.	sang khor		L	3	
261	Rubiaceae	*Uncaria* sp.			L	1	
262	Rutaceae	*Citrus lucida* (Scheff.) Mabb. (syn. *Feronia lucida* Tirjs. & Binn.; *Feroniella*)*	kro song		T	1	
263	Salicaceae	*Homalium brevidens* Gagnep (unres.)	rotiang-or-atiang		T	1,3	
264	Salicaceae	*Homalium dasyanthum* Warb. (unres.)	rotiang-or-atiang		T	1,3	
265	Salicaceae	*Salix tetrasperma* Roxb.	srol beng		T	1,2	+
266	Salviniaceae	*Azolla pinnata* R. Br.			H		+
267	Salviniaceae	*Salvinia cucullata* Roxb.	chou ankam		AH	1	
268	Sapindaceae	*Cardiospermum halicacabum* L.	pok om		L	1	+
269	Sapindaceae	*Schleichera oleosa* (Lour.) Merr. *(syn. S.oleosa* (Lour.) Oken) *	pung roa		T	1	
270	Sapotaceae	*Mimusops elengi* L. *	kdol, phkol		T	1,3	
271	Simaroubaceae	*Brucea javanica* (L.) Merr.			S/T		+
272	Simaroubaceae	*Quassia harmandiana* (Pierre) Nooteboom *(Samandura harmandii* Pierre)	kros, kras, plae kroh		T	1,3	+
273	Smilacaceae	*Smilax lanceifolia* Roxb.			L		+
274	Trapaceae	*Trapa natans* L. (syn. *Trapa bicornis* Osbeck)	krou chap		AH	1	
275	Vitaceae	*Cayratia trifolia* (L.) Domin.			L		+
276	Vitaceae	*Cissus hexangularis* Thorel ex Planch.	voa troduk		L	1	
277	Xyridaceae	*Xyris complanata* R. Br.	?		H	1	
278	Xyridaceae	*Xyris indica* L.	thnak twk		H	1	
279	Xyridaceae	*Xyris intersita* Malme	?		H	1	
280	Xyridaceae	*Xyris pauciflora Willd.*	?		H	1	
	* = cultivated						
	1 = McDonald *et al.* (1997); 2 = Giesen (1998); 3 = Rollet (1972)						

Appendix 3.Ornithology

1. **Introduction**

In June 2019 eight of the 12 areas that had been designated as Outstanding IBAs in the Tonle Sap and lower Mekong basin (BirdLife International 2013) were visited during a two-week survey. Because of extreme time constraints the surveys were brief, and often accessibility prevented us from going far inside the IBAs. Also, seasonality (outside breeding season with breeding population dispersed over a vast area; no congregations of migratory species, already on their northern breeding grounds or elsewhere) and time of the day (starting surveys late in the morning) were not favorable for an exhaustive bird survey, missing early songbirds and nightbirds. Nevertheless, a good idea was obtained of the general landscapes, and information on birdlife was collected from interviews with local villagers, officials etc. In October 2019 an Autumn survey of two weeks was undertaken to an additional set of areas in the Tonle Sap and lower Mekong regions, during which the same constraints and limitations had their impact on the results, except for the occurrence of migratory birds, which were often abundant and widespread.

Tables A1 and A2 give lists of all bird species reported and seen during the present and previous survey. Table A 3 gives a compilation of all bird data as were collected from (un)published bird reports, for which Goes (2013) has been consulted; listing of localities for most common species have not always been exhaustive in this publication, but major concentrations and all uncommon to rare species were mentioned per locality.

Table A1   Bird species reported and seen during the October and June 2019 surveys

APPENDIX 1 Bird species recorded in Jun and Oct 2019 Fr, occurrence in 12 (Jun) and 8 (Oct) sites; tot*, total number of abundance scores (see app 2)			migr status	survey Jun'19		survey Oct '19	BL Lapouv	Anglungpring	A T Thmor	Sang Rukhavoan	Stung Sangke	Preaek Chik	Pursat	Bakan
Species	Family	Common Name	M	tot*	Fr	Fr	1	2	3	4	5	6	7	8
Francolinus pintadeanus	Phasianidae	Chinese Francolin		-	-	0.125				1				
Coturnix chinensis	Phasianidae	Blue-breasted Quail		2	0.0833	-								
Dendrocygna javanica	Anatidae	Lesser whistlingduck		2	0.0833	-								
Nettapus coromandelianus	Anatidae	Cotton Pygmy-goose		3	0.0833	0.125		2						
Anas poecilorhyncha	Anatidae	Spot-billed Duck		5	0.1667	0.125	10							
Turnix suscitator	Turnicidae	Barred Buttonquail		-	-	0.25				1				1
Dendrocopos macei	Picidae	Fulvous-breasted Woodpecker		6	0.25	-								
Picus vittatus	Picidae	Laced Woodpecker		2	0.0833	0.125		1						
Dinopium javanense	Picidae	Common Flameback		-	-	0.25			1	1				
Mulleripicus pulverulentus	Picidae	Great Slaty Woodpecker		-	-	0.125				1				
Megalaima lineata	Megalaimidae	Lineated Barbet		2	0.0833	-								
Megalaima haemacephala	Megalaimidae	Coppersmith Barbet		-	-	0.25			1	1				
Anthracoceros albirostris	Bucerotidae	Oriental Pied Hornbill		-	-	0.125			1					
Upupa epops	Upupidae	Common Hoopoe		-	-	0.125					1			
Coracias benghalensis	Coraciidae	Indian Roller		10	0.3333	0.375		1	3				1	
Eurystomus orientalis	Coraciidae	Dollarbird		4	0.1667	-								
Alcedo atthis	Alcedinidae	Common Kingfisher	1	-	-	0.375	2	1	2					
Pelargopsis capensis	Alcedinidae	Stork-billed Kingfisher		5	0.1667	-								
Halcyon smyrnensis	Alcedinidae	White-throated Kingfisher		6	0.1667	0.375		1	1		1			
Halcyon pileata	Alcedinidae	Black-capped Kingfisher	1	-	-	0.125		1						
Ceryle rudis	Alcedinidae	Pied Kingfisher		4	0.1667	-								
Merops orientalis	Meropidae	Green Bee-eater		7	0.1667	0.625	4	5	4	2			1	
Merops philippinus	Meropidae	Blue-tailed Bee-eater		8	0.25	0.25	2	21						

Species	Family	Common Name	M	tot*	Fr	Fr	1	2	3	4	5	6	7	8
Merops leschenaulti	Meropidae	Chestnut-headed Bee-eater		8	0.1667	0.125				2				
Cacomantis merulinus	Cuculidae	Plaintive Cuckoo		6	0.1667	-								
Surniculus lugubris	Cuculidae	Drongo Cuckoo		2	0.0833	-								
Eudynamys scolopacea	Cuculidae	Asian Koel		2	0.0833	0.125		1						
Centropus sinensis	Cuculidae	Greater Coucal		23	0.6667	0.25						1		1
Centropus bengalensis	Cuculidae	Lesser Coucal		15	0.4167	-								
Loriculus vernalis	Psittacidae	Vernal Hanging Parrot		-	-	0.125				1				
Psittacula alexandri	Psittacidae	Red-breasted Parakeet		-	-	0.125			10					
Collocalia fuciphaga	Apodidae	Edible-nest Swiftlet		16	0.4167	0.25	10s		3				1	
Cypsiurus balasiensis	Apodidae	Asian Palm Swift		37	0.9167	0.875	10s	1	2	1	3	3	15	1
Apus affinis	Apodidae	House Swift		-	-	0.125					10			
Hemiprocne coronata	Hemiprocnidae	Crested Treeswift		2	0.0833	-								
Columba livia	Columbidae	Rock Pigeon		11	0.3333	0.125							45	
Spilopelia chinensis	Columbidae	Spotted Dove		29	0.75	0.75	3	2	7	3	1		2	
Streptopelia tranquebarica	Columbidae	Red Collared Dove		15	0.4167	0.375		25			50		6	
Geopelia striata	Columbidae	Peaceful Dove		20	0.5833	0.875		1	6	4	10	22	35	1
Treron vernans	Columbidae	Pink-necked Green Pigeon		3	0.0833	-								
Treron bicincta	Columbidae	Orange-breasted Green Pigeon		-	-	0.125			1					
Houbaropsis bengalensis	Otididae	Bengal Florican		3	0.0833	-								
Rallus indicus	Rallidae	Eastern Water Rail	1	-	-	0.125		?						
Amaurornis phoenicurus	Rallidae	White-breasted Waterhen		2	0.0833	0.125			1					
Gallicrex cinerea	Rallidae	Watercock		-	-	0.125		4						
Porpyrio porphyrio	Rallidae	Purple Swamphen		6	0.25	0.125		1						
Gallinula chloropus	Rallidae	Common Moorhen		-	-	0.125		6						
Gallinago stenura	Scolopacidae	Pintail Snipe	1	-	-	0.25							1	10
Gallinago gallinago	Scolopacidae	Common Snipe	1	-	-	0.125								10
Tringa nebularia	Scolopacidae	Common Greenshank	1	-	-	0.25		2					1	
Tringa glareola	Scolopacidae	Wood Sandpiper	1	-	-	0.125							1	

Species	Family	Common Name	M	tot*	Fr	Fr	1	2	3	4	5	6	7	8
Hydrophasianus chirurgus	Jacanidae	Pheasant-tailed Jacana	1	-	-	0.125	1							
Himantopus himantopus	Recurvirostridae	Black-winged Stilt		5	0.1667	0.25		28					200	
Pluvialis fulva	Charadriidae	Pacific Golden Plover	1	-	-	0.125							1	
Vanellus indicus	Charadriidae	Red-wattled Lapwing		8	0.25	-								
Glareola maldivarum	Glareolidae	Oriental Pratincole		20	0.5	-								
Chlidonias hybridus	Laridae	Whiskered Tern	1	-	-	0.375	17	25					800	
Elanus caeruleus	Accipitridae	Black-shouldered Kite		13	0.5	0.25	1	1						
Ichthyophaga ichthyaetus	Accipitridae	Grey-headed Fish Eagle		2	0.0833	-								
Spilornis cheela	Accipitridae	Crested Serpent Eagle		-		0.25				1				1
Circus spilonotus	Accipitridae	Eastern Marsh Harrier	1	-		0.25	1						1	
Butastur liventer	Accipitridae	Rufous-winged Buzzard		-		0.125			1					
Tachybaptus ruficollis	Podicipedidae	Little Grebe		2	0.0833	0.125	1							
Anhinga melanogaster	Anhingidae	Darter		3	0.0833	0.125	2							
Phalacrocorax niger	Phalacrocoracid	Little Cormorant		14	0.4167	0.25	1	1						
Phalacrocorax fuscicollis	Phalacrocoracid	Indian Cormorant		10	0.25	0.375	5	9	1					
Egretta garzetta	Ardeidae	Little Egret		6	0.1667	0.75	32	100s	25	7	500		50	1
Ardea purpurea	Ardeidae	Purple Heron		3	0.0833	0.375	10	2						1
Casmerodius [Ardea] alba	Ardeidae	Great Egret		6	0.1667	0.375	22	100			10s			1
Mesophoyx [Ardea] intermedia	Ardeidae	Intermediate Egret		-		0.125		1						
Bubulcus [ibis] coromandus	Ardeidae	Cattle Egret		5		0.5		12	5	11			30	
Ardeola bacchus	Ardeidae	Chinese Pond Heron	1	-		0.75	18	9	3	1	27		1	
Ixobrychus sinensis	Ardeidae	Yellow Bittern		6	0.1667	0.125	3							
Ixobrychus cinnamomeus	Ardeidae	Cinnamon Bittern		7	0.25	0.125		1						
Dupetor flavicollis	Ardeidae	Black Bittern		4	0.1667	-								
Pelecanus philippensis	Pelecanidae	Spot-billed Pelican		-	0	0.125	2							
Mycteria leucocephala	Ciconiidae	Painted Stork		4	0.0833	0.125			1					
Anastomus oscitans	Ciconiidae	Asian Openbill		14	0.3333	0.125			1		500+			
Leptoptilos javanicus	Ciconiidae	Lesser Adjutant		2	0.0833	-								

Species	Family	Common Name	M	tot*	Fr	Fr	1	2	3	4	5	6	7	8
Pitta moluccensis	Pittidae	Blue-winged Pitta		7	0.1667	-								
Gerygone sulphurea	Acanthizidae	Golden-bellied Gerygone		7	0.25	0.125		1						
Chloropsis aurifrons	Irenidae	Golden-fronted Leafbird		-		0.125						1		
Lanius cristatus	Laniidae	Brown Shrike	1	-		0.375		2	1				1	
Lanius collurioides	Laniidae	Burmese Shrike	1	-		0.25		1					1	
Crypsirhina temia	Corvidae	Racket-tailed Treepie		12	0.3333	0.125						1		
Corvus macrorhynchos	Corvidae	Large-billed Crow		21	0.5833	0.25				1			2	
Coracina macei	Corvidae	Large Cuckooshrike		-		0.125				1				
Pericrocotus divaricatus	Corvidae	Ashy Minivet	1	-		-								
Pericrocotus cinnamomeus	Corvidae	Small Minivet		-		0.125				6				
Pericrocotus [flammeus] specio	Corvidae	Scarlet Minivet		-		0.125				2				
Rhipidura aureola	Corvidae	White-browed Fantail		-		0.125				1				
Rhipidura javanica	Corvidae	Pied Fantail		13	0.3333	0.375		1	1	1				
Dicrurus macrocercus	Corvidae	Black Drongo	1	-		1	2	7	14	3	34	3	5	2
Dicrurus leucophaeus	Corvidae	Ashy Drongo	1	-		0.25				1		2		
Dicrurus hottentottus	Corvidae	Spangled Drongo		2	0.0833	0.125				1				
Dicrurus paradiseus	Corvidae	Greater Racket-tailed Drongo		4	0.1667	0.125						1		
Hypothymis azurea	Corvidae	Black-naped Monarch		2	0.0833	-								
Aegithina tiphia	Corvidae	Common Iora		17	0.5	0.125				1				
Tephrodornis gularis	Corvidae	Large Woodshrike		-		0.125				1				
Monticola [solitarius] philippensi	Muscicapidae	Blue Rock Thrush	1	-		0.125					1	1		
Muscicapa dauurica	Muscicapidae	Asian Brown Flycatcher	1	-		0.125		1						
Ficedula [parva] albicilla	Muscicapidae	Red-throated Flycatcher	1	-		0.5			5	9		1	5	
Cyanoptila cyanomelana	Muscicapidae	Blue-and-white Flycatcher	1	-		0.125				1				
Cyornis hainanus	Muscicapidae	Hainan Blue Flycatcher		-		-								
Cyornis tickelliae	Muscicapidae	Tickell's Blue Flycatcher		7	0.25	0.125				3				
Copsychus saularis	Muscicapidae	Oriental Magpie Robin		15	0.4167	0.25		1			1			
Copsychus malabaricus	Muscicapidae	White-rumped Shama		2	0.0833	-								

Species	Family	Common Name	M	tot*	Fr	Fr	1	2	3	4	5	6	7	8
Saxicola [torquata] stejnegeri	Muscicapidae	Common Stonechat	1	-		0.125								3
Saxicola caprata	Muscicapidae	Pied Bushchat		9	0.3333	0.75	2	4	1	1			1	2
Sturnus malabaricus	Sturnidae	Chestnut-tailed Starling		4	0.1667	-								
Sturnus sinensis	Sturnidae	White-shouldered Starling	1	-		0.125		50						
Sturnus nigricollis	Sturnidae	Black-collared Starling		6	0.25	0.125		2						
Acridotheres tristis	Sturnidae	Common Myna		33	0.8333	0.875	1	10s	2	5	6	1	16	1
Acridotheres grandis	Sturnidae	White-vented Myna		18	0.4167	0.375			2		25		2	
Gracula religiosa	Sturnidae	Hill Myna		2	0.0833	0.25			1	1				
Hirundo rustica	Hirundinidae	Barn Swallow	1	12	0.4167	0.75	2	2	200		3		25	3
Brachypodius atriceps	Pycnonotidae	Black-headed Bulbul		-		0.125			1					
Pycnonotus flaviventris	Pycnonotidae	Black-crested Bulbul		6	0.1667	-								
Pycnonotus aurigaster	Pycnonotidae	Sooty-headed Bulbul		2	0.0833	0.625			2	1	1	6	1	
Pycnonotus finlaysoni	Pycnonotidae	Stripe-throated Bulbul		2	0.0833	0.25			1	1				
Pycnonotus goiavier	Pycnonotidae	Yellow-vented Bulbul		21	0.5833	0.75	4		5	2	4	1	8	
Pycnonotus blanfordi	Pycnonotidae	Streak-eared Bulbul		13	0.4167	0.625	1	2	2	1		1		
Iole propinqua	Pycnonotidae	Grey-eyed Bulbul		3	0.0833	-								
Cisticola juncidis	Cisticolidae	Zitting Cisticola		14	0.3333	0.125				1				
Cisticola exilis	Cisticolidae	Bright-headed Cisticola		3	0.0833	0.125				1				
Prinia rufescens	Cisticolidae	Rufescent Prinia		-	-	0.125				3				
Prinia hodgsonii	Cisticolidae	Grey-breasted Prinia		-	-	0.25				2		1		
Prinia flaviventris	Cisticolidae	Yellow-bellied Prinia		19	0.5	0.375	2	1						1
Prinia inornata	Cisticolidae	Plain Prinia		16	0.5	0.75	6	2	1	1	1		1	
Locustella certhiola	Sylviidae	Rusty-rumped Warbler	1	-	-	0.125	1							
Acrocephalus tangorum	Sylviidae	Manchurian Reed Warbler	1	-	-	0.125		1						
Acrocephalus orientalis	Sylviidae	Oriental Reed warbler	1	-	-	0.375	4		4				2	
Arundinax aedon	Sylviidae	Thick-billed Warbler	1	-	-	0.125	1							
Orthotomus sutorius	Sylviidae	Common Tailorbird		14	0.4167	0.375			1			2	1	
Orthotomus atrogularis	Sylviidae	Dark-necked Tailorbird		12	0.3333	0.375			2	4			1	

Species	Family	Common Name	M	tot*	Fr	Fr	1	2	3	4	5	6	7	8
Orthotomus chaktomuk	Sylviidae	Cambodian Tailorbird		1	0.0833	-								
Phylloscopus fuscatus	Sylviidae	Dusky Warbler	1	-	-	0.25		1		1				
Phylloscopus inornatus	Sylviidae	Yellow-browed Warbler	1	-	-	0.125				2				
Phylloscopus borealis	Sylviidae	Arctic Warbler	1	-	-	0.125				1				
Phylloscopus plumbeitarsus	Sylviidae	Two-barred Warbler	1	-	-	0.125				7				
Phylloscopus tenellipes	Sylviidae	Pale-legged Leaf Warbler	1	-	-	0.125				3				
Megalurus palustris	Sylviidae	Striated Grassbird		9	0.3333	0.125								1
Garrulax leucolophus	Sylviidae	White-crested Laughingtrush		2	0.0833	0.25			1			1		
Pellorneum ruficeps	Sylviidae	Puff-throated Babbler		2	0.0833	-								
Mixornis gularis	Sylviidae	Striped Tit Babbler		10	0.25	0.125						5		
Timalia pileata	Sylviidae	Chestnut-capped Babbler		1	0.0833	-								
Mirafra javanica	Alaudidae	Australasian Bushlark		2	0.0833	0.25		1						2
Mirafra [marionae] erythrocephal	Alaudidae	Indochinese Bushlark		3	0.0833	0.25		1						4
Dicaeum cruentatum	Nectariniidae	Scarlet-backed Flowerpecker		7	0.25	0.375		2	1				1	
Anthreptes malacensis	Nectariniidae	Brown-throated Sunbird		7	0.1667	0.25						1	1	
Chalcoparia singalensis	Nectariniidae	Ruby-cheeked Sunbird		2	0.0833	-								
Nectarinia [sperata] brasiliana	Nectariniidae	Purple-throated Sunbird		2	0.0833	-								
Cinnyris [Nectarinia] jugularis	Nectariniidae	Olive-backed Sunbird		6	0.1667	0.5		1	1	2			1	
Passer domesticus	Passeridae	House Sparrow		10	0.25	0.5	1				16	1	1	
Passer flaveolus	Passeridae	Plain-backed Sparrow		6	0.1667	0.125		31						
Passer montanus	Passeridae	Eurasian Tree Sparrow		20	0.5	0.75	1		1	1	2	1	2	
Anthus richardi	Passeridae	Richard's Pipit	1	-	-	0.25		1						2
Anthus rufulus	Passeridae	Paddyfield Pipit		2	0.0833	0.625		10	2		11		3	8
Ploceus manyar	Passeridae	Streaked Weaver		-	-	0.125	1							
Ploceus philippinus	Passeridae	Baya Weaver		19	0.5	0.125	5							
Ploceus hypoxanthus	Passeridae	Asian Golden Weaver		2	0.0833	-								
Lonchura striata	Passeridae	White-rumped Munia		4	0.1667	0.125							1	
Lonchura punctulata	Passeridae	Scaly-breasted Munia		11	0.3333	0.375			2	1			1	
			34	98	98		33	51	45	48	21	20	41	20

Table A 2 Bird Species rarety

APPENDIX 2. Bird species recorded in June 2019 1, rare; 2, occasional; 3, frequent; 4, common; 5, very common			BL Lapouv	Bassac marshes	Prek Chhlong	Lower Stung Sen	Chhnok Tru	Boeung Chhmar	Ang Tropeang Thmor	Preah Net Preah	Stung Chi Kreng BFCA	Stung Prasat Balang	Veal Strongae	Stung Sen BFCA
Species	Family	Common Name	site 01	site 02	site 03	site 04	site 05	site 06	site 07	site 08	site 09	site 10	site 11	site 12
Coturnix chinensis	Phasianidae	Blue-breasted Quail												2
Dendrocygna javanica	Anatidae	Lesser whistlingduck							2					
Nettapus coromandelianus	Anatidae	Cotton Pygmy-goose												3
Anas poecilorhyncha	Anatidae	Spot-billed Duck	3					2						
Dendrocopos macei	Picidae	Fulvous-breasted Woodpecker			2							2	2	
Picus vittatus	Picidae	Laced Woodpecker											2	
Megalaima lineata	Megalaimidae	Lineated Barbet										2		
Coracias benghalensis	Coraciidae	Indian Roller		3		2						2		3
Eurystomus orientalis	Coraciidae	Dollarbird		2										2
Pelargopsis capensis	Alcedinidae	Stork-billed Kingfisher				2							3	
Halcyon smyrnensis	Alcedinidae	White-throated Kingfisher		2	4									
Ceryle rudis	Alcedinidae	Pied Kingfisher			2				2					
Merops orientalis	Meropidae	Green Bee-eater	4	3										
Merops philippinus	Meropidae	Blue-tailed Bee-eater					2			3			3	
Merops leschenaulti	Meropidae	Chestnut-headed Bee-eater			4	4								
Cacomantis merulinus	Cuculidae	Plaintive Cuckoo	3											3
Surniculus lugubris	Cuculidae	Drongo Cuckoo						2						
Eudynamys scolopacea	Cuculidae	Asian Koel		2										
Centropus sinensis	Cuculidae	Greater Coucal	3	2	4	3		2		2		3	4	
Centropus bengalensis	Cuculidae	Lesser Coucal	3	3	3		3						3	
Collocalia fuciphaga	Apodidae	Edible-nest Swiftlet	3	3		4	4	2						
Cypsiurus balasiensis	Apodidae	Asian Palm Swift	4	3	3		4	3	3	3	3	3	4	4
Hemiprocne coronata	Hemiprocnidae	Crested Treeswift			2									
Columba livia	Columbidae	Rock Pigeon		2	3				3	3				
Spilopelia chinensis	Columbidae	Spotted Dove	3	3	4	3				3	2	3	4	4
Streptopelia tranquebarica	Columbidae	Red Collared Dove	3		3					3			3	3

Species	Family	Common Name	site 01	site 02	site 03	site 04	site 05	site 06	site 07	site 08	site 09	site 10	site 11	site 12
Geopelia striata	Columbidae	Peaceful Dove	3	2	2	3				4		3		3
Treron vernans	Columbidae	Pink-necked Green Pigeon											3	
Houbaropsis bengalensis	Otididae	Bengal Florican									3			
Amaurornis phoenicurus	Rallidae	White-breasted Waterhen											2	
Porpyrio porphyrio	Rallidae	Purple Swamphen							2	2				2
Himantopus himantopus	Recurvirostridae	Black-winged Stilt							3	2				
Vanellus indicus	Charadriidae	Red-wattled Lapwing	3	3					2					
Glareola maldivarum	Glareolidae	Oriental Pratincole	4	3					3	2	4			4
Elanus caeruleus	Accipitridae	Black-shouldered Kite	2	3	2					2			2	2
Ichthyophaga ichthyaetus	Accipitridae	Grey-headed Fish Eagle				2								
Tachybaptus ruficollis	Podicipedidae	Little Grebe		2										
Anhinga melanogaster	Anhingidae	Darter						3						
Phalacrocorax niger	Phalacrocoracid	Little Cormorant		2				3	3				3	3
Phalacrocorax fuscicollis	Phalacrocoracid	Indian Cormorant	4					3	3					
Egretta garzetta	Ardeidae	Little Egret	3						3					
Ardea purpurea	Ardeidae	Purple Heron	3											
Casmerodius [Ardea] alba	Ardeidae	Great Egret						3	3					
Bubulcus [ibis] coromandu	Ardeidae	Cattle Egret		3					2					
Ixobrychus sinensis	Ardeidae	Yellow Bittern							2				4	
Ixobrychus cinnamomeus	Ardeidae	Cinnamon Bittern	3				2						2	
Dupetor flavicollis	Ardeidae	Black Bittern						2					2	
Mycteria leucocephala	Ciconiidae	Painted Stork	4											
Anastomus oscitans	Ciconiidae	Asian Openbill						4	3	4			3	
Leptoptilos javanicus	Ciconiidae	Lesser Adjutant											2	
Pitta moluccensis	Pittidae	Blue-winged Pitta			4								3	
Gerygone sulphurea	Acanthizidae	Golden-bellied Gerygone	2	3				2						
Crypsirhina temia	Corvidae	Racket-tailed Treepie		3		3						3	3	
Corvus macrorhynchos	Corvidae	Large-billed Crow				3	3	3	4		2		3	3
Rhipidura javanica	Corvidae	Pied Fantail	3	3	4								3	
Dicrurus hottentottus	Corvidae	Spangled Drongo			2									
Dicrurus paradiseus	Corvidae	Greater Racket-tailed Drongo			2							2		
Hypothymis azurea	Corvidae	Black-naped Monarch											2	

Species	Family	Common Name	site 01	site 02	site 03	site 04	site 05	site 06	site 07	site 08	site 09	site 10	site 11	site 12
Aegithina tiphia	Corvidae	Common Iora		3	4	2				3		2	3	
Cyornis tickelliae	Muscicapidae	Tickell's Blue Flycatcher			2			3					2	
Copsychus saularis	Muscicapidae	Oriental Magpie Robin		4	2	3	3						3	
Copsychus malabaricus	Muscicapidae	White-rumped Shama			2									
Saxicola caprata	Muscicapidae	Pied Bushchat	2	2							3			2
Sturnus malabaricus	Sturnidae	Chestnut-tailed Starling		2									2	
Sturnus nigricollis	Sturnidae	Black-collared Starling	2							2	2			
Acridotheres tristis	Sturnidae	Common Myna	3	4	3	3		3		4	3	3	3	4
Acridotheres grandis	Sturnidae	White-vented Myna		5				3	3	3			4	
Gracula religiosa	Sturnidae	Hill Myna										2		
Hirundo rustica	Hirundinidae	Barn Swallow	3	3			2	2					2	
Pycnonotus flaviventris	Pycnonotidae	Black-crested Bulbul						3				3		
Pycnonotus aurigaster	Pycnonotidae	Sooty-headed Bulbul			2									
Pycnonotus finlaysoni	Pycnonotidae	Stripe-throated Bulbul										2		
Pycnonotus goiavier	Pycnonotidae	Yellow-vented Bulbul		3	3	3			3		2	3	4	
Pycnonotus blanfordi	Pycnonotidae	Streak-eared Bulbul		2		3					2	3	3	
Iole propinqua	Pycnonotidae	Grey-eyed Bulbul			3									
Cisticola juncidis	Cisticolidae	Zitting Cisticola	4								4		3	3
Cisticola exilis	Cisticolidae	Bright-headed Cisticola											3	
Prinia flaviventris	Cisticolidae	Yellow-bellied Prinia	3	4	2	2		3					5	
Prinia inornata	Cisticolidae	Plain Prinia	3	3	2			2			3		3	
Orthotomus sutorius	Sylviidae	Common Tailorbird		3	3				2			3		3
Orthotomus atrogularis	Sylviidae	Dark-necked Tailorbird			4	2		2				4		
Orthotomus chaktomuk	Sylviidae	Cambodian Tailorbird			?									
Megalurus palustris	Sylviidae	Striated Grassbird	3	2							2			2
Garrulax leucolophus	Sylviidae	White-crested Laughingtrush										2		
Pellorneum ruficeps	Sylviidae	Puff-throated Babbler										2		
Mixornis gularis	Sylviidae	Striped Tit Babbler			4			3				3		
Timalia pileata	Sylviidae	Chestnut-capped Babbler			1									
Mirafra javanica	Alaudidae	Australasian Bushlark									2			
Mirafra [marionae] erythro	Alaudidae	Indochinese Bushlark									3			
Dicaeum cruentatum	Nectariniidae	Scarlet-backed Flowerpecker				2			2			3		

Species	Family	Common Name	site 01	site 02	site 03	site 04	site 05	site 06	site 07	site 08	site 09	site 10	site 11	site 12
Anthreptes malacensis	Nectariniidae	Brown-throated Sunbird			4							3		
Chalcoparia singalensis	Nectariniidae	Ruby-cheeked Sunbird										2		
Nectarinia [sperata] brasili	Nectariniidae	Purple-throated Sunbird			2									
Cinnyris [Nectarinia] jugula	Nectariniidae	Olive-backed Sunbird	2										4	
Passer domesticus	Passeridae	House Sparrow	4			3			3					
Passer flaveolus	Passeridae	Plain-backed Sparrow	3	3										
Passer montanus	Passeridae	Eurasian Tree Sparrow	4	4				3	3	3	3			
Anthus rufulus	Passeridae	Paddyfield Pipit	2											
Ploceus philippinus	Passeridae	Baya Weaver					3	4	3	3			3	3
Ploceus hypoxanthus	Passeridae	Asian Golden Weaver	2											
Lonchura striata	Passeridae	White-rumped Munia										2		2
Lonchura punctulata	Passeridae	Scaly-breasted Munia		3						3			2	3
			33	37	32	19	9	23	22	19	16	24	37	20

2. **Description of bird assemblages & species per habitat & habitat dependence**

Swamp forest
A total of 95 species are known to dwell the deciduous dipterocarp, or savannah forest, inundated during the wet season (see App 3). There is much overlap with the riparian assemblage, where refuge may be sought during the high water levels in the wet season. Woodpeckers, babblers, forest bulbuls are amongst the species not found commonly elsewhere. The large waterbird colonies are exclusively found in the swamp forest, mainly at high water levels.

Shrublands
A total of 41 species are known for shrublands, constituting a not very specialized assemblage, with birds also found in associated grasslands and remaining forest stands.

Marshes
A total of 131 species has been reported for marsh habitat, seasonally formed by inundated forest and grasslands that give refuge to a rich assemblage of waterbirds, notably rails and crakes, ducks (eight of which are winter visitors), and cormorants (3 species).

Grasslands
A total of 85 species has been reported for grassland habitat. During their flooding, species that are dependent on these grasslands for breeding, such as Bengal Floricans, seek refuge to the adjacent rice fields (Goes 2013, Mahood et al. 2019). Three species of lark are restricted to the grasslands.

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Riverine Channels, Riparian Assemblage
A total 93 species is reported to constitute the riparian forest bird assemblage which shows much overlap with that of dry deciduous forest, and the levees offer refuge to a number of species, especially ground-dwellers as Blue-winged Pittas *Pitta moluccensis*.

Freshwater Wetlands

Freshwater wetlands in the area include permanent open water bodies, inundated grasslands in the wet season (August-December). The duck family is well represented in the Tonle Sap biosphere with 12 species, eight of which are migrants from the northern hemisphere and absent during the time of survey, three were seen during our survey.

Open Countryside

Many of the 87 species of the open countryside assemblage are opportunists, found also found more natural open country, city parks, etc. such as Magpie Robins *Copsychus saularis*, Common Myna *Acridotheres tristis*, and three species of Sparrow.

Some species originate from coastal habitat e.g., Collared Kingfisher *Todiramphus chloris*, Pied Fantail *Rhipidura javanica*, and Golden-bellied Gerygone *Gerygone sulphurea*, the last-mentioned only recently expanding its range. Two nowadays abundant and widespread species, i.e., Peaceful Dove *Geopelia striata* and Indian House Sparrow *Passer domesticus*, have colonised Cambodia as recently as 1999 and 1995 respectively. Other species find suitable habitat in the vast rice fields, when their more natural habitat is temporarily not available, e.g., Bengal Florican, Blue-breasted Quail, or are here as non-breeding visitors from the northern hemisphere in their winter quarters, e.g., Brown Shrike *Lanius cristatus*, which is then common throughout, even in city parks, Black Drongo *Dicrurus macrocercus* outnumbering the resident population of the same species or the odd bird on passage, e.g., Eurasian Wryneck *Jynx torquilla*, with only a few records.

A number of bird species are strongly associated with elements in the open landscape, such as palm trees: the Indian Roller *Coracias benghalensis* and even more so, the Asian Palm Swift *Cypsiurus balasiensis*.

3.**Status and threats to bird assemblages per habitat:**

Lakes

The lake sides in the southern part of the Tonle Sap water body were visited, cormorants and Asian Openbills were seen in numbers. The large lake in the south of Ang Tropeang Thmor IBA was strikingly empty of birdlife. The entire area was busily visited by fishermen and disturbance may be considerable.

The newly established San Sang Rukhavoan Wild Sanctuary north-east of ATT offered good habitat for a large number of forest birds, but pressure from wood collecting, grazing etc appeared high.

Rivers and canals

Vegetation on the river banks was much affected, and only narrow fringes remained; a quick survey at Prek Chhlong showed a rich remnant bird but much encroachment more inland. River specialists as River Tern *Sterna aurantia*, River Lapwing *Vanellus duvaucelii*, and Mekong Wagtail *Motacilla samveasna* are naturally rare, or absent in our survey area. Masked Finfoot *Heliopais personata* may be threatened by the use of gill nets, and lines of fishing hooks along riverbank vegetation.

No riverine woodland habitat was surveyed in October, surveying was restricted to the banks of the Pursat river and canals linking the various reservoirs. Their open habitat offered habitat for mainly ground dwelling species, such as Paddyfield Pipit which was omnipresent, with reed bushes offering habitat for resident and migratory reed warblers.

Rice fields

The scarcity of birds, in particular the granivorous munias in the vast ricefields was striking; also Cattle Egrets *Bubulcus ibis*, pond herons *Ardeola* spp, etc were far less common than expected, especially considering old reports of the abundance of herons and storks throughout the country. The use of pesticides may be a cause for this, as poisoned Sarus Cranes, which are known to be fond of rice (R. van Zalinge, pers. comm.) have been recently reported (Bou et al. 2018) and direct evidence was most likely observed by us twice: two intoxicated immature Asian Openbills were seen at two sites during our survey. The Brahminy Kite, reportedly common throughout Cambodia (Goes 2013), was not seen a single time and its demise in other parts of SE Asia has been attributed to the use of pesticides amongst other causes (van Balen et al. 1993).

The inundated ricefields along the Pursat river towards southern Tonle Sap was habitat for Whiskered Tern in large numbers, attesting the importance of the region for the wintering population of this migratory tern.

Flooded forest

The large waterbird colony of Prek Toal are well protected nowadays and as a major tourist attraction its value is much appreciated. Where unmonitored and unprotected, breeding colonies are depleted by the collection of eggs and chicks, especially during the wet season when accessibility is greatly enhanced by the high water level.

Time constraints and timing (non-breeding season for most waterbirds) prevented us from visiting this important waterbird area.

Forest habitat is severely impacted by logging activities, either for opening up new agricultural lands (ricefields etc) as well as the collection of firewood.

Inundated grasslands.

The inundated Tonle Sap grasslands become marshes in the wet season, and form important wintering quarters for a large number of waterbirds (ducks, pelicans).

Loss of grassland to land reclamation for large-scale intensive agriculture, mainly through building dams for dry season rice cultivation (Goes 2013) is a major threat. An estimated 46% of grassland in the floodplain was lost between 1995 and 2005 (Packman et al., Eaton et al. 2014). For instance Bengal Florican needs vast grasslands, and when total grassland areas fall below a certain threshold, their population rapidly shrink to extinction (Mahood et al, 2019). Of Sarus Cranes a substantive portion of the non-breeding population congregates here, while the other birds remain in the breeding grounds in dry deciduous forest in the dry season (Bou Vorsak et al. 2019). A special case is the globally Near-threatened Rufous-rumped Grass Babbler *Graminicola bengalensis*, discovered in Cambodia as recently as 2013, found in Pursat, with suitable habitat remaining in the Bakan grasslands (Pursat) and possible suitable patches in the Kompong Thom area.

Whereas hunting and habitat disturbance form major threats for above-mentioned categories of bird, seven grassland passerine birds in particular are threatened in Cambodia by the merit-bird trade:

Streaked Weaver *Ploceus manyar* (Thr)
Baya Weaver *Ploceus philippinus* (NT)
Asian Golden Weaver *Ploceus hypox*anthus (Thr)
Red Avadavat *Amandava amandava* (Thr)
Chestnut Munia *Lonchura atricapilla* (Thr)
Chestnut-eared Bunting *Emberiza fucata* (NT)

Yellow-breasted Bunting *Emberiza aureola* (En)

Bird trapping has decimated wintering populations of Yellow-breasted Bunting and resident Chestnut Munias.

4. **Sensitive and rare/endangered bird species**

Appendix 4a and b lists all bird species hat received a global conservation status, based on actual declining numbers, or potential threats, e.g., small range, small population size (BirdLife International 2019c). Four Critically Endangered, three Endangered, and nine Vulnerable species are known from our survey sites, whereas 13 are known as Near-threatened species. Following are the species for which the Tonle Sap – Mekong deltas provide important habitat.

APPENDIX 3. Bird spp recorded in the survey areas, 1994-2019. Cr, Critically Endangered; En, Endangered; Vu, Vulnerable; NT, Near-threatened; DD, Data-deficient. Where two annotations are given divided by a slash, the first refers to the species' global status, the second to its local (Cambodian) status (following Goes 2013)		threatened status	migr status	BP Lapouv	Anglungpring	Bassac marshes	Prek Chhlong	Lower Stung Sen	Chhnok Tru	Boeung Chhmar	Ang Tropeang	Preah Net Preah	Stoung Chikreng	Stung Prasat	Veal Strongae	Stung Sen /Baray BFCA	Dey Roneath	Prek Toal	Swamp Forest	Marshes	Shrubland	Grasslands	Riverine channels	Open countryside
		Thr	M	1	AP	1	3	4	5	6	7	8	9	10	11	12	13	14	SF	Ma	SL	GL	RC	OC
Francolinus pintadeanus	Chinese Francolin												2								1	1		
Coturnix chinensis	Blue-breasted Quail	-/NT											4			2					1	1		1
Dendrocygna javanica	Lesser whistlingduck			1	1	2					5							2		1				
Sarkidiornis melanotus	Comb Duck	-/NT		2						1	4		1			2		3		1				
Nettapus coromandelianus	Cotton Pygmy-goose			1							4					3				1				
Anas penelope	Eurasian Wigeon		1								3									1				
Anas poecilorhyncha	Spot-billed Duck			3						2	3									1				
Anas clypeata	Northern Shoveler		1								2									1				
Anas acuta	Northern Pintail		1								3									1				
Anas querquedula	Garganey		1	1	1						4									1				
Anas crecca	Common Teal		1								2									1				
Aythya nyroca	Ferruginous Pochard	NT	1								2									1				
Aythya fuligula	Tufted duck		1								1									1				
Aythya marila	Greater Scaup		1								1									1				
Turnix sylvatica	Small Buttonquail	-/NT									3											1		
Turnix tanki	Yellow-legged Buttonquail	-/DD									1											1		
Turnix suscitator	Barred Buttonquail			1																		1		1
Jynx torquilla	Eurasian Wryneck		1								1		1											1
Dendrocopos macei	Fulvous-breasted Woodpecker						2				3			2	2				1				1	
Micropternus brachyurus	Rufous Woodpecker																	2	1					
Picus vittatus	Laced Woodpecker														2				1				1	
Picus xanthopygaeus	Streak-throated Woodpecker										1								1					
Picus erythropygius	Black-headed Woodpecker										3								1					
Megalaima lineata	Lineated Barbet													2					1					
Megalaima haemacephala	Coppersmith Barbet																		1					1
Coracias benghalensis	Indian Roller				1	3		2						2		3								1
Eurystomus orientalis	Dollarbird		1	2		2					2					2								1
Alcedo atthis	Common Kingfisher		1	1	1						2							2	1				1	
Pelargopsis capensis	Stork-billed Kingfisher			1				2							3			1		1			1	
Halcyon smyrnensis	White-throated Kingfisher			1	1	2	4				2							1		1				
Halcyon pileata	Black-capped Kingfisher		1	1	1						2							1		1			1	1
Todorhamphus chloris	Collared Kingfisher			1														2						1
Ceryle rudis	Pied Kingfisher	-/NT		3			2				3									1			1	
		Thr	M	1	AP	1	3	4	5	6	7	8	9	10	11	12	13	14	SF	Ma	SL	GL	RC	OC
Merops orientalis	Green Bee-eater			4	1	3																	1	1
Merops philippinus	Blue-tailed Bee-eater			1					2			3			3			1						1
Merops leschenaulti	Chestnut-headed Bee-eater						4	4											1				1	
Cacomantis merulinus	Plaintive Cuckoo			3							4					3			1					1
Surniculus lugubris	Drongo Cuckoo									2									1					
Eudynamys scolopacea	Asian Koel					2					2							2	1					1
Phaenicophaeus tristis	Green-billed Malkoha																	1	1					
Centropus sinensis	Greater Coucal			3		2	4	3		2		2		3	4						1			
Centropus bengalensis	Lesser Coucal			3		3	3		3		2				3			2			1	1		1
Psittacula finschii	Grey-headed Parakeet										1								1					
Collocalia fuciphaga	Edible-nest Swiftlet			3		3		4	4	2														1
Aerodramus germani	Germain's Swiftlet	-/DD									?													1
Cypsiurus balasiensis	Asian Palm Swift			4	1	3	3		4	3	3	3	3	3	4	4								1
Apus affinis	House Swift										2													1
Hemiprocne coronata	Crested Treeswift						2												1					
Tyto alba	Common Barn Owl					2					3		1											1
Tyto longimembris	Eastern Grass Owl												2									1		1
Otus lettia	Collared Scops Owl					2												2	1					1
Ketupa ketupu	Buffy Fish Owl																	2	1	1				
Strix seloputo	Spotted wood Owl																	3	1					
Caprimulgus affinis	Savanna Nightjar				1						1		1									1		1
Columba livia	Rock Pigeon					2	3				3	3												1
Spilopelia chinensis	Spotted Dove			3	1	3	4	3				3	2	3	4	4					1		1	1
Streptopelia tranquebarica	Red Collared Dove			3	1		3				2	3			3	3					1		1	1
Geopelia striata	Peaceful Dove			3		2	2	3			3	4		3		3					1		1	1
Treron vernans	Pink-necked Green Pigeon														3				1		1			
Houbaropsis bengalensis	Bengal Florican	Cr											3			1						1		1
Grus antigone	Sarus Crane	Vu		3							3		3			3		4	1	1				
Grus virgo	Demoiselle Crane		1										1									1		
Heliopais personata	Masked Finfoot	En/Cr								2								3	1	1				
Amaurornis phoenicurus	White-breasted Waterhen			1	1										2					1	1			1
Porzana pusilla	Baillon's Crake	-/DD	1															1		1				
Porzana fusca	Ruddy-breasted Crake			3	1						3									1				
Porzana cinerea	White-browed Crake										3									1				
Gallicrex cinerea	Watercock			1	1						3									1				
Porpyrio porphyrio	Purple Swamphen			1	1						4	2	4			2		4		1				
Gallinula chloropus	Common Moorhen			1	1						4							4		1				
Fulica atra	Common Coot					1				1	3									1				
Gallinago gallinago	Common Snipe		1	1	1															1				
		Thr	M	1	AP	1	3	4	5	6	7	8	9	10	11	12	13	14	SF	Ma	SL	GL	RC	OC
Limnocryptes minimus	Jack Snipe		1								?									1				
Limosa limosa	Black-tailed Godwit	NT	1	3	1	2					3							3		1				
Limosa lapponica	Bar-tailed Godwit		1						1											1				
Tringa erythropus	Spotted Redshank		1								2							2		1				
Tringa totanus	Common Redshank		1	1							1									1				
Tringa stagnatilis	Marsh Sandpiper		1	2																1				
Tringa nebularia	Common Greenshank		1	3	1						3									1				
Tringa ochropus	Green Sandpiper		1	1																1				
Tringa glareola	Wood Sandpiper		1	1																1				

Actitis hypoleucos	Common Sandpiper		1	1	1																		1	
Arenaria interpres	Ruddy Turnstone		1								1									1				
Calidris ruficollis	Red-necked Stint		1						2		2									1				
Calidris temminckii	Temminck's Stint		1								1									1				
Calidris subminuta	Long-toed Stint		1	1					1		1							1		1				
Calidris ferruginea	Curlew Sandpiper		1						?		1							?		1				
Philomachus pugnax	Ruff		1								3									1				
Phalaropus lobatus	Red-necked Phalarope		1	1														1		1			1	
Rostratula benghalensis	Greater Painted-snipe			2							3									1				
Hydrophasianus chirurgus	Pheasant-tailed Jacana		1	1		3					3									1				
Metopidius indicus	Bronze-winged Jacana			1							3							3		1				
Burhinus indicus	Indina Thick-knee	-/DD									2											1		1
Himantopus himantopus	Black-winged Stilt			1	1						3	2						3		1				
Pluvialis fulva	Pacific Golden Plover		1	1	1															1		1		
Charadrius dubius	Little Ringed Plover		1	2																1				
Charadrius mongolus	Lesser Sand Plover		1								2									1				
Charadrius leschenaulti	Greater Sand Plover		1								2									1				
Charadrius veredus	Oriental Plover		1								2		3			2						1		
Vanellus duvaucelii	River Lapwing	NT/En									1												1	
Vanellus cinereus	Grey-headed Lapwing		1	2							2									1				
Vanellus indicus	Red-wattled Lapwing			3	1	3					2									1				
Glareola maldivarum	Oriental Pratincole			4	1	3					3	2	4			4		4				1		
Chroicocephalus brunnicephalu	Brown-headed Gull		1								1							1		1			1	
Chroicocephalus ridibundus	Black-headed Gull		1			1														1			1	
Gelochelidon nilotica	Gull-billed Tern		1															?					1	
Hydroprogna caspia	Caspian Tern		1	1														1					1	
Sterna aurantia	River Tern	NT/Cr							1														1	
Chlidonias hybrida	Whsikered Tern		1	1		4			4		3							1		1			1	
Chlidonias leucopterus	White-winged Ten		1	1							1									1			1	
Pandion haliaetus	Osprey		1	1														1	1	1		1	1	
		Thr	M	1	AP	1	3	4	5	6	7	8	9	10	11	12	13	14	SF	Ma	SL	GL	RC	OC
Pernis ptilorhyncus	Oriental Honey-buzzard																	1	1					
Elanus caeruleus	Black-shouldered Kite			2	1	3	2					2			2	2					1	1		1
Milvus migrans	Black Kite	-/En									3									1				1
Milvus lineatus	Black-eared Kite		1								3							2		1				
Haliastur indus	Brahminy Kite									4	4							4		1			1	1
Haliaeetus leucoryphus	Pallas's Fish Eagle										1									1			1	
Ichthyophaga ichthyaetus	Grey-headed Fish Eagle	NT				1		2		4	2							4		1			1	
Gyps bengalensis	White-rumped Vulture	Cr							1										1				1	
Aegypius calvus	Red-headed Vulture	Cr									1								1				1	
Circaetus gallicus	Short-toed Eagle		1										1						1			1		1
Spilornis cheela	Crested Serpent-eagle					1												1	1					
Circus aeruginosus	Western Marsh Harrier		1		1						2		1			1		1		1		1		
Circus spilonotus	Eastern Marsh Harrier		1	1							2		3							1		1		
Circus melanoleucos	Pied Harrier		1	1																1		1		
Accipiter gularis	Japanese Sparrowhawk		1	1															1			1		1
Buteo burmanicus	Himalayan Buzzard		1								1								1					
Ictinaetus malayensis	Black Eagle										1								1					
Aquila clanga	Greater Spotted Eagle	Vu	1								1		1			1		1		1		1		1
Aquila pennata	Booted Eagle		1								1								1					1
Aquila heliaca	Eastern Imperial Eagle	Vu	1								2					1						1		
Polihierax insignis	White-rumped Pygmy Falco	NT									1								1					
Falco naumanni	Lesser Kestrel		1								2											1		1
Falco tinnunculus	Common Kestrel		1								1													1
Falco peregrinus	Peregrine Falcon		1								1													1
Tachybaptus ruficollis	Little Grebe			1	1	4					4									1				
Anhinga melanogaster	Darter	NT		1				3	3	3	3						4	4		1			1	
Phalacrocorax niger	Little Cormorant			1	1	2				4	3				3	3		4		1			1	
Phalacrocorax fuscicollis	Indian Cormorant			4						3	3							4		1			1	
Phalacrocorax carbo	Great Cormorant	-/NT		3	1	3					2							3		1			1	
Egretta garzetta	Little Egret			4	1						4					4		4		1			1	
Ardea cinerea	Grey Heron			4	1					4	4							4		1				
Ardea purpurea	Purple Heron			3	1	3					4							4		1		1	1	
Casmerodius [Ardea] alba	Great Egret			3	1					3	4							4		1		1	1	
Mesophoyx intermedia	Intermediate Egret			1	1	3					3					4		4		1			1	
Bubulcus ibis	Cattle Egret			1	1	3					2									1				1
Ardeola bacchus	Chinese Pond Heron		1	1		4					4							4		1				1
Ardeola speciosa	Javan Pond Heron			1	1													3		1				1
Butorides striatus	Little Heron		1	1	1													4		1			1	
Nycticorax nycticorax	Black-crowned Night Heron			1	1						4							4	1	1		1	1	
		Thr	M	1	AP	1	3	4	5	6	7	8	9	10	11	12	13	14	SF	Ma	SL	GL	RC	OC
Ixobrychus sinensis	Yellow Bittern			1	1	3					4		4		4			4		1		1		
Ixobrychus cinnamomeus	Cinnamon Bittern			3	1				2						2					1		1		
Dupetor flavicollis	Black Bittern									2					2			1		1				
Botaurus stellaris	Great Bittern		1								1		1							1				
Plegadis falcinellus	Glossy Ibis	-/DD		3	1				2	2								3		1				
Threskiornis melanocephalus	Black-headed Ibis	NT		3		2			3	3	4							3	1	1		1		1
Pseudibis davisoni	White-shouldered Ibis	Cr									1		1						1			1	1	
Platalea leucorodia	Eurasian Spoonbill										1							2		1				
Platalea minor	Black-faced Spoonbill	En	1	1																1				
Pelecanus onocrotalus	Great White Pelican										3							1		1				
Pelecanus philippensis	Spot-billed Pelican	NT		3	1	3				4	3		2					4		1				
Mycteria cinerea	Milky Stork	Vu/CR							1	1	3							3		1				
Mycteria leucocephala	Painted Stork	NT		4				2		3	4							4	1	1		1	1	
Anastomus oscitans	Asian Openbill			1						4	4	4			3		4	5	1	1		1	1	1
Ciconia episcopus	Woolly-necked Stork	-/NT			1						1		2					2	1			1		
Ephippiorhynchus asiaticus	Black-necked Stork	NT/Cr						2		2	3		1			2		2	1			1		
Leptoptilos javanicus	Lesser Adjutant	Vu/NT		2				3		3	3		2		2	2	4	4	1	1		1	1	1
Leptoptilos dubius	Greater Adjutant	En		3				3		3	3		1			1	1	3	1			1		
Pitta moluccensis	Blue-winged Pitta						4								3				1		1			
Cymbirhynchus macrorhynchos	Black-and-red Broadbill																	1	1				1	
Gerygone sulphurea	Golden-bellied Gerygone			2		3				2									1					
Lanius cristatus	Brown Shrike		1	1					1		1										1			1
Lanius schach	Long-tailed Shrike		1								1								1					
Lanius tephronotus	Grey-backed Shrike		1								1										1			1

Pachycephala cinerea	Mangrove Whistler	-/DD																2	1					
Crypsirhina temia	Racket-tailed Treepie					3		3						3	3				1	1		1	1	1
Corvus macrorhynchos	Large-billed Crow							3	3	3	4		2		3	3		4	1	1	1	1	1	1
Pericrocotus divaricatus	Ashy Minivet																	1	1				1	
Hemipus picatus	Bar-winged Flycatcher-shrike								1										1				1	
Rhipidura javanica	Pied Fantail			3		3	4				2				3				1				1	
Dicrurus macrocercus	Black Drongo			1	1						3							2	1		1	1	1	1
Dicrurus hottentottus	Spangled Drongo						2												1				1	
Dicrurus paradiseus	Greater Racket-tailed Drongo						2							2					1				1	
Hypothymis azurea	Black-naped Monarch														2			1	1		1		1	1
Aegithina tiphia	Common Iora					3	4	2				3		2	3				1				1	
Muscicapa sibirica	Dark-sided Flycatcher		1								1								1					
Ficedula zanthopygia	Yellow-rumped Flycatcher		1															1	1					
Ficedula albicilla	Taiga Flycatcher		1															1	1				1	
Cyornis tickelliae	Tickell's Blue Flycatcher						2			3					2				1				1	
		Thr	M	1	AP	1	3	4	5	6	7	8	9	10	11	12	13	14	SF	Ma	SL	GL	RC	OC
Luscinia svecica	Bluethroat		1	1							1							3			1	1		
Copsychus saularis	Oriental Magpie Robin			1	1	4	2	3	3						3				1	1	1	1	1	1
Copsychus malabaricus	White-rumped Shama						2												1					
Saxicola maurus	Eastern Stonechat		1	1	1						3								1		1	1	1	
Saxicola caprata	Pied Bushchat			2	1	2							3			2		1	1			1	1	1
Saxicola ferreus	Grey Bushchat		1								1								1		1			
Sturnus malabaricus	Chestnut-tailed Starling					2					3				2				1				1	1
Sturnus sturninus	Purple-backed Starling		1								1								1		1			
Sturnus sinensis	White-shouldered Starling		1								3								1	1	1	1		1
Sturnus roseus	Rosy Starling		1								2													1
Gracupica contra	Asian Pied Starling			1						1	3									1		1		1
Sturnus nigricollis	Black-collared Starling			2	1							2	2							1		1	1	1
Acridotheres tristis	Common Myna			3	1	4	3	3		3	4	4	3	3	3	4		1	1	1		1	1	1
Acridotheres grandis	White-vented Myna			1		5				3	3	3			4			1	1	1		1	1	1
Gracula religiosa	Hill Myna													2					1				1	
Riparia riparia	Sand Martin		1	1					2							2		1	1	1		1	1	1
Hirundo rustica	Barn Swallow		1	3	1	3			2	2	5				2			1		1	1	1	1	1
Cecropis striolata	Striated Swallow				1						1												1	1
Delichon dasypus	Asian House Martin		1															1		1		1		1
Pycnonotus flaviventris	Black-crested Bulbul									3				3					1				1	
Pycnonotus aurigaster	Sooty-headed Bulbul						2													1			1	1
Pycnonotus finlaysoni	Stripe-throated Bulbul													2									1	
Pycnonotus goiavier	Yellow-vented Bulbul			1		3	3	3			3		2	3	4				1	1		1	1	1
Pycnonotus blanfordi	Streak-eared Bulbul			1		2		3			2		2	3	3				1		1		1	1
Iole propinqua	Grey-eyed Bulbul						3																1	
Cisticola juncidis	Zitting Cisticola			4									4		3	3				1		1		1
Cisticola exilis	Bright-headed Cisticola														3				1			1		
Prinia hodgsonii	Grey-breasted Prinia			1																	1	1		
Prinia flaviventris	Yellow-bellied Prinia			3		4	2	2		3					5			1	1	1	1	1	1	
Prinia inornata	Plain Prinia			3		3	2			2	2		3		3					1		1	1	1
Zosterops palpebrosus	Oriental White-eye			1															1		1			
Locustella lanceolata	Lanceolated Warbler		1								1									1		1		
Locustella certhiola	Rusty-rumped Warbler		1	1		2					2							1						
Acrocephalus bistrigiceps	Black-browed Reed Warbler		1	1							1									1		1	1	1
Acrocephalus tangorum	Manchurian Reed Warbler	Vu	1								?		3									1		
Acrocephalus concinens	Blunt-winged Warbler		1								1		1								1	1		
Acrocephalus orientalis	Oriental Reed Warbler		1	1							1								1	1	1	1	1	1
Acrocephalus aedon	Thick-billed Warbler																							
Orthotomus sutorius	Common Tailorbird					3	3				2			3		3							1	1
		Thr	M	1	AP	1	3	4	5	6	7	8	9	10	11	12	13	14	SF	Ma	SL	GL	RC	OC
Orthotomus atrogularis	Dark-necked Tailorbird						4	2		2	1			4				1	1	1	1		1	
Orthotomus chaktomuk	Cambodian Tailorbird	NT					?									3					1			1
Phylloscopus fuscatus	Dusky Warbler		1								1							1	1	1	1	1	1	
Phyllocopus inornatus	Yellow-browed Warbler		1															1	1				1	
Phylloscous borealis	Arctic Warbler		1															1	1				1	
Megalurus palustris	Striated Grassbird			3	1	2					1		2			2			1	1	1	1	1	
Garrulax leucolophus	White-crested Laughingtrush													2				1	1				1	
Pellorneum ruficeps	Puff-throated Babbler													2					1					
Mixornis gularis	Striped Tit Babbler						4			3				3					1		1		1	
Timalia pileata	Chestnut-capped Babbler						1														1	1		
Mirafra javanica	Australasian Bushlark	-/NT			1						3		2									1		1
Mirafra marionae	Indochinese Bushlark												3								1	1		
Alauda gulgula	Oriental Skylark										3											1		1
Dicaeum cruentatum	Scarlet-backed Flowerpecker							2			2			3					1				1	1
Anthreptes malacensis	Brown-throated Sunbird						4							3					1	1			1	
Chalcoparia singalensis	Ruby-cheeked Sunbird													2				2	1				1	
Nectarinia sperata	Purple-throated Sunbird						2											3	1				1	
Nectarinia jugularis	Olive-backed Sunbird			2											4			3	1	1	1	1		1
Passer domesticus	House Sparrow			4				3			3													1
Passer flaveolus	Plain-backed Sparrow			3	1	3					3													1
Passer montanus	Eurasian Tree Sparrow			4	1	4				3	3	3	3					2						1
Motacilla alba	White Wagtail		1								1							2	1			1	1	1
Motacilla citreola	Citrine Wagtail		1										1									1		
Motacilla tschutschensis	Eastern Yellow Wagtail		1	1							1							1		1		1	1	
Anthus richardi	Richard's Pipit		1								3									1		1		1
Anthus rufulus	Paddyfield Pipit			2	1						2		2							1		1		1
Anthus cervinus	Red-throated Pipit		1								3		2									1	1	1
Ploceus manyar	Streaked Weaver	-/Thr		1							3		2							1	1	1		
Ploceus philippinus	Baya Weaver	-/NT		3		3			3	4	3	3			3	3		2	1			1	1	1
Ploceus hypoxanthus	Asian Golden Weaver	NT/Thr		4		4			2		3		2							1	1	1		
Amandava amandava	Red Avadavat	-/Thr									3		3									1		
Lonchura striata	White-rumped Munia													2		2				1	1	1	1	1
Lonchura punctulata	Scaly-breasted Munia					3					4	3			2	3			1	1	1	1	1	1
Lonchura atricapilla	Chestnut Munia	-/Thr		3									2							1		1	1	1
Emberiza fucata	Chestnut-eared Bunting	-/NT									1		3							1		1		
Emberiza aureola	Yellow-breasted Bunting	Vu/En	1	1	1						3		5			1				1		1		
			93	123	57	63	39	30	29	45	165	25	56	31	45	43	10	100	95	131	41	85	94	87

Appendix 4a. Globally Threatened Bird Species in the region Cr, Critically Endangered; En, Endangered; Vu, Vulnerable		DeyRoneath	Prek Chhlong	Prek Toal	Stung Sen	Chhnok Tru	Boeung Chhmar	IBA01-Ang T Thmor	IBA02 PNP/KL/Pourk	IBA16 St/Chik/K Svay	IBA17 Stung P Balang	IBA20 Veal Strongae	IBA21 SS/Santuk/Baray	BP Lapouv	Anglungpring	Bassac marshes	Sang Rukhavoan	Stung Sangke	Preaek Chik	Pursat	Bakan
Houbaropsis [Eupodotis] bengc	Bengal Florican									3			1								
Gyps bengalensis	White-rumped Vulture					1															
Sarcogyps [Aegypius] calvus	Red-headed Vulture							1													
Pseudibis davisoni	White-shouldered Ibis							1		1			3								
Heliopais personata	Masked Finfoot			3			2														
Platalea minor	Black-faced Spoonbill													1							
Leptoptilos dubius	Greater Adjutant	1		3	3		3	3		1			1	3							
Grus antigone	Sarus Crane			4				3		3			3	3							
Aquila clanga	Greater Spotted Eagle			1				1		1			1								
Aquila heliaca	Eastern Imperial Eagle							2					1								
Mycteria cinerea	Milky Stork			3		1	1	3													
Leptoptilos javanicus	Lesser Adjutant	4		4	3		3	3		2		2	2	2							
Mulleripicus pulverulentus	Great Slaty Woodpecker																1				
Graminicola striatus	Chinese Grass-babbler																				1
Acrocephalus tangorum	Manchurian Reed Warbler							?		3					1						1
Emberiza aureola	Yellow-breasted Bunting							3		5			1	1							
		2	0	6	2	2	4	9	0	8	0	1	8	5	1	0	1	0	0	0	2

Critically endangered

Bengal Florican *Houbaropsis bengalensis*
A survey in 2018 showed that the estimated number of displaying males in 2018 was 104 (89–117), down from 216 (156–275) in 2012, whereas the number of sites that supported displaying male Bengal Floricans was reduced from 10 to four between 2012 and 2018. The only site where numbers of birds are stable is Stoung-Chikraeng Bengal Florican Conservation Area, with 44 (25–63) displaying males in 2018. This is the only site that has an ongoing NGO-government conservation programme. Furthermore the recent data indicated that Bengal Floricans are lost from sites when the area of grassland falls below 25 km^2.
One or two birds were seen by us in June 2019 in the Stung Chi Kreng BFCA (=Bengal Florican Conservation Area.)

White-shouldered Ibis *Pseudibis davisoni*
Rare in Tonle Sap grassland in dry season; known to breed incidentally (?) in Baray BFCA, December – May.
Not seen during our surveys.

Yellow-breasted Bunting *Emberiza aureola*
Uncommon winter visitor, between November and April, mainly Tonle Sap floodplain, with huge concentrations of several thousands of birds in Stoung Chikreng and smaller numbers seen in both BFCAs and Ang Tropeang Thmor. Immediate threat from trapping for food and merit-bird release trade.
Not seen during our surveys.

Endangered

Masked Finfoot *Heliopais personata*
Known to breed in Prek Toal, breeding in wet season, September-November (Goes 2013).
Not seen during our surveys.

Greater Adjutant *Leptoptilos dubius*

Substantive part of Cambodian population in the Tonle Sap swamp forest, breeding from December – April in large waterbird colonies (Dey Roneat, Prek Toal); post-breeding congregations at Boeng Chhmar and scattered throughout the country (Goes 2013).
Not seen during our surveys.

Vulnerable

Sarus Crane *Grus antigone*
Breeding in wet season July – September, mainly in northern and north-eastern plains of Cambodia; because of water scarcity in these deciduous forests in the dry season, only small numbers can survive here and therefore most birds disperse across the Tonle Sap and Mekong flood plains; the largest post-breeding concentrations are then found at Ang Tropeang Thmor and Anglung Pring, with smaller ones scattered on the grasslands of the Tonle Sap floodplains. The excessive use of pesticides and hunting in the flood plains, deforestation and hunting on the breeding grounds are most likely the most important causes of the crane's sudden decline in recent years (R. van Zalinge pers. comm.).
Not seen during our surveys (R. van Zalinge pers. comm.).

Greater Spotted Eagle *Aquila clanga*
Uncommon winter visitor, having declined substantially since historical times, and only regularly seen at a few sites nowadays, with stronghold in the Tonle Sap grasslands.
Not seen during our surveys.

Milky Stork *Mycteria cinerea*
Small breeding population at Prek Toal and even smaller at Ang Tropeang Thmor, and dispersing in small numbers, pairs and singles associating with Painted Storks.
Not seen during our surveys.

Lesser Adjutant *Leptoptilos javanicus*
Fairly common and widespread, breeding December to June at Prek Toal and an unknown number of unmonitored colonies on the Tonle Sap floodplain.
Being considered globally Vulnerable, the population in Cambodia is relatively healthy and considered Near-threatened.
Single birds were seen in June 2019 in BP Lapouv and Veal Strongae.

Asian Woolly-necked Storkj *Ciconia episcopus*
The relatively healthy Cambodian population is considered Near-threatened (Goes 2013).
A flock of thirteen birds landing a huge dead tree was observed by us in the Angkor area, just outside our area of interest.

Great Slaty Woodpecker *Mulleripicus pulverulentus*
Elsewhere in SE Asia this large woodpecker is under serious threat of habitat destruction and therefore treated as Vulnerable (Lammertink et al. 2009). In Cambodia the species can still be found relatively widespread and is considered Near-threatened (Goes 2013). We saw a single group in the degraded forest in the northern part of our survey area.

Chinese Grass-babbler *Graminicola striatus*
This babbler is represented by only a few populations remaining, scattered over China, Myanmar and Cambodia, with a global population of less than 2500 individuals.

The Cambodian population may be not restricted to only the Bakan grasslands, as apparently suitable habitat is also found elsewhere in the region.

Manchurian Reed Warbler *Acrocephalus tangorum*
Uncommon winter visitor at low densities in Tonle Sap grasslands, from January to May, with an ability to use a variety of habitats, and therefore causes for decline since 2005 are unclear. Now only infrequently recorded in Stoung Chikreng BFCA (Goes 2013).
Near-theatened in Cambodia.

Near-threatened

Thirteen so-called Near-threatened bird species have been recorded in the region, six of which were seen during our surveys in June and October 2019.

Spot-billed Pelican *Pelecanus philippensis*
Two and singles seen in October in BP Lapouv and Anglungpring.

Oriental Darter *Anhinga melanogaster*
Common in the Boeung Chhmar IBA in June; singles in October at BP Lapouv.

River Lapwing *Vanellus duvaucelii*
Not seen during our surveys.

Bar-tailed Godwit *Limosa limosa*
In November-December large flocks are reportedly appearing in the Anglungpring reserve.
Not seen during our surveys.

Black-necked Stork *Ephippiorhynchus asiaticus*
Not seen during our surveys.

Painted Stork *Mycteria leucocephala*
Seen in small and larger numbers in the BP Lapouv Sarus Crane Reserve in June; a single bird soaring above Rohal along the road towards AT Thmor in October.

Black-headed Ibis *Threskiornis melanocephalus*
Not seen during our surveys.

Grey-headed Fish-eagle *Icthyophaga ichthyaetus*
Single bird seen and photographed in the Stung Sen IBA in June.

River Tern *Sterna aurantia*
Not seen during our surveys.

Cambodian Tailorbird *Orthotomus chaktomuk*
Not confirmed yet during our surveys, but may have been in some of the sites visited in June that lie within the species' range.

Migratory birds

About 93 (35%) out 265 spp that have been recorded in the survey areas (Appendix 3) are species with only migratory or vagrant populations in the survey areas, some species that have both resident and migratory have not been included. Table 1 shows the distribution of migratory species across the different habitat types in our survey area.

	Total # spp	# migratory spp
Swamp forest	95	20 (21%)
Swamps	131	58 (44 %)
Shrubland	41	11 (26 %)
Grassland	85	30 (35 %)
Riverine	94	26 (28 %)
Open country	87	23 (26 %)

Table 1. Distribution of migratory species over the various habitat types in the region.

Some of these species occur extremely seldomly in Cambodia, or are presumed to do so. However, the occurrence of huge numbers of Whiskered Terns *Chlidonias hybridus* in Bassac Marshes and Chhnuk Tru IBAs (BirdLife International 2004), and Yellow-eared Bunting in Stoung-Chikreng shows the importance of the swamps and grasslands as wintering quarters for a large number of migratory species.

The large numbers of migrating Oriental Praticoles *Glareola maldivarum* (30+ on 15 Oct at Preah Batchoanchum village, and 1000+ on 20 October in the Angkor region) suggest the importance of the open woodlands and grassland as passage areas on their way southwards as far as northern Australia, where it is very common in November and December (Pringle 1987), but during which time it is largely absent from Cambodia (Goes 2013).

During the second survey in November 2019, large numbers of migratory leaf-warblers and flycatchers were observed in the woodlands and degraded forests in the peripheries of the Tonle Sap region.

Black Drongos are represented by a migratory race, and presumably a resident race as well. Whereas not a single (resident) bird was seen in June, in October all sites had their Black Drongos, typically perched on powerlines.

Birds with local conservation status

There are 20 species which are more threatened in Cambodia than elsewhere in the world, amongst which locally critically endangered Masked Finfoot, River Tern, Milky Stork and Black-necked Stork (see Table 3). The following seven species were seen during our surveys (NT, Near-threatened; LC, Least Concern, and LK Little Known; Goes 2013, BirdLife 2019c).

Blue-breasted Quail *Coturnix chinensis* Globally LC, Cambodia NT

Pied Kingfisher *Ceryle rudis* Globally LC, Cambodia NT
Seen at two sites in June.

Germain's Swiftlet *Aerodramus [fuciphagus] germaini* Globally LC, Cambodia LK.
The taxonomic status of swiftlet remains to be solved, in the meantime so-called swiftlet houses are being built throughout, with non-native (sub)species introduced (Poole 2010).

Swiftlets of the Edible-nest Swiftlet type (habitus, vocalisation) were seen throughout the survey area.

Australasian Bushlark *Mirafra javanica* Globally LC, Cambodia NT.
The Tonly Sap grasslands are the most important habitat for this lark in Cambodia; the rapid conversion of this habitat in rice fields is an immediate threat.
Seen in small numbers at several sites.

Streaked Weaver *Ploceus manyar* Globally LC, Cambodia Threatened
Baya Weaver *Ploceus philippinus* Globally LC, Cambodia NT
Asian Golden Weaver *Ploceus hypoxanthus* Globally NT, Cambodia Threatened
Major threat for the survival of these three species in Cambodia is the merit-bird trade (Goes 2013). Streaked Weaver appears to be the most threatened of all three species in Cambodia (Mahood pers. comm. 2019).
All three weaver species were observed during the two surveys in June and October, though only Baya Weaver was also seen outside the BP Lapouv reserve. Two other grassland species threatened by the bird-trade, but not seen during our surveys are Red Avadavat *Amandava amandava* and Chestnut Munia *Lonchura malacca*.

Appendix 4.Fisheries

Fisheries field inspection 7-10/9/19

1. Introduction

Following submission of a Phase 1 report, this brief field visit (7-10/10/19) examined some dams and associated infrastructure so as to understand at first-hand their likely effects on fish and fisheries in their vicinity, and the possibility for improving mitigation measures for any negative impacts. Some community fish refuges (CFRs) were also inspected to examine how their operations had been affected by irrigation infrastructure, and what could be done to mitigate any negative impacts.

The project team consisted of Kent Hortle (Fisheries Specialist), Joshua Wilson and Juliet Mills (Interns) and Mong Marith (GIS Specialist), who met counterparts from the provincial PDWRAMs at the dam sites, and some local CFR members at the CFR sites. MOWRAM staff members were unavailable for the field visit because of the timing and short notice. See Appendix 1 for schedule.

Because of the short time available, a limited number of sites were visited, and only within some of the catchments on the south-west side of the Tonle Sap. Despite these limitations, the issues we encountered are as commonly observed at other sites in the Mekong basin, based on wide field experience by the Fisheries Specialist, and are similar to those seen at other sites by the aquatic ecologists during their field visits to a wider range of sites in late October, and

Some comments from this field visit have been incorporated into the Ecohydrology report, and this field trip report can be seen as an addendum, which could be combined with the Ecohydrology report later.

2. Background

As discussed in the Phase 1 Fisheries Report, irrigation can increase food production, but the losses from existing wild capture fisheries can be significant and decrease the overall benefits of irrigation schemes.

Various impacts on fisheries are caused by irrigation schemes, and among these the most significant are usually the creation of barriers to fish migration and abstraction/diversion of irrigation water, which reduces flows down the parent river. These impacts are the focus of this brief report and others are discussed in the Phase 1 report.

The Tonle Sap tributary rivers which were inspected all formerly supported significant fisheries, particularly for migratory fish, which are favoured in this environment because of the strong seasonal variation in flows, which exacerbate the separation of feeding, spawning and refuge habitats.

The tributary fisheries appear to have declined greatly since the 1990s, which is likely to be a result of dams blocking fish migrations and abstraction of water for irrigation, as well as other factors. Unfortunately there are however no systematic monitoring data of these fisheries over the last few decades and very limited survey information, so the conclusion of likely impacts and their causes is based only on general field observations and interviews with fishermen along some tributaries, as well as reasonable inference from studies elsewhere of similar projects.

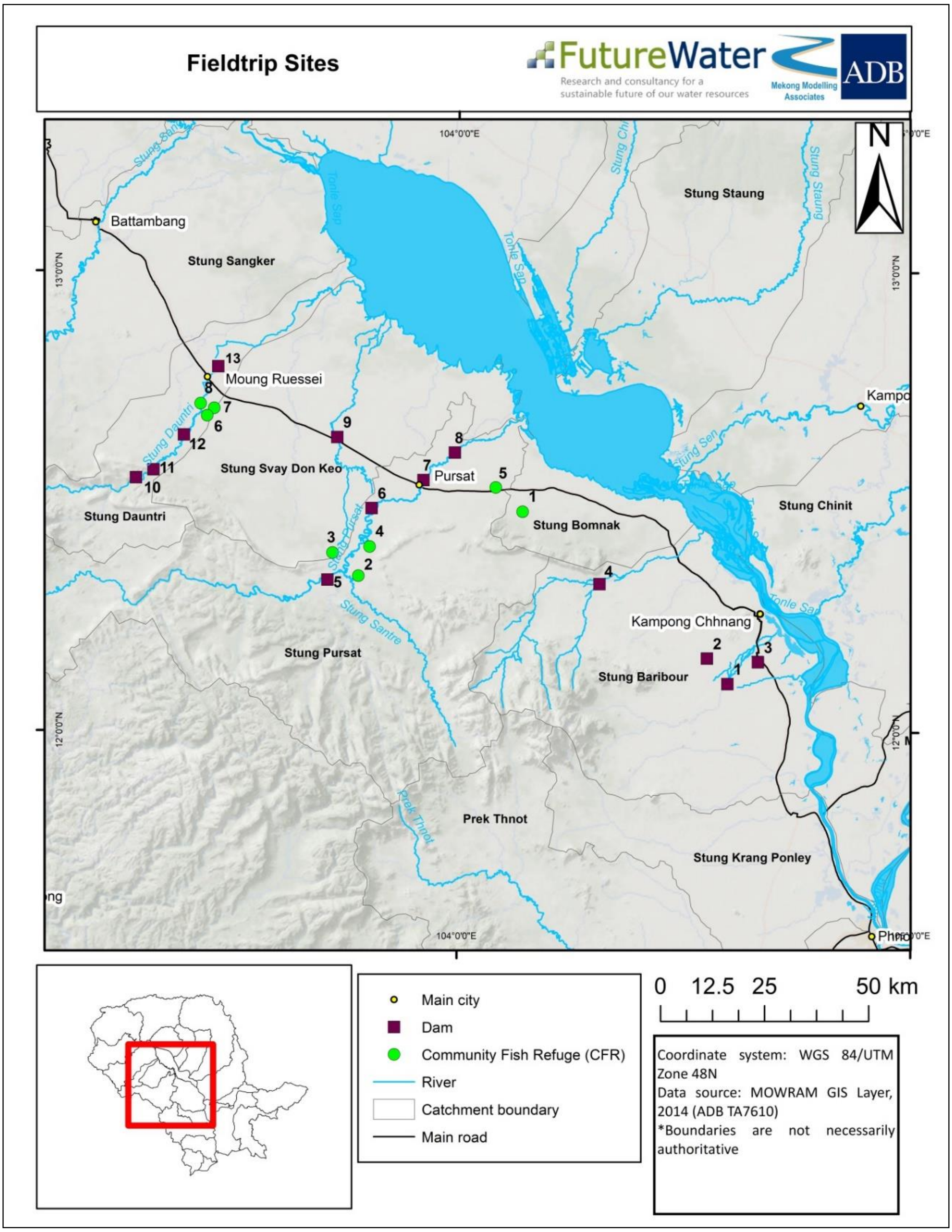

Figure 1: Dams and CFR sites visited 7-10 October 2019

See Table 1 for site names.

Table 1. Dam sites and community fish refuges (CFRs) visited during the field trip
See Figure 1 for locations

DAM SITES

Catchment	Name of Dam	No.	Fish-pass	Status	Water-gates at dam
Stung Baribour	Tang Krasaing	1	None		Undershot
	Achang	2	None		Undershot
	Chavaeng	3	None		Undershot
	Lum Hach Dam	4	Half-cone	Complete but not yet operational.	Overshot
Pursat	Damnak Choeur Krom	5	Vertical-slot	Under construction.	Overshot?
	Damnak Ampil	6	Half-cone	Operating but poor performance.	Overshot
	Kbal Houng	7	Cone design	Operating and good performance.	Overshot
	Charec	8	None		Overshot
Stung Svay Don Keo	Wat Chrey	9	Half-cone	Operating but poor performance.	Overshot
Stung Moung Russei	Dauntri Storage	10	None		Undershot
	Bassac	11	None		Undershot
	Prek Chik	12	None		Undershot
	Ream Kon	13	Half-cone	Operating but poor performance.	Undershot
	Bassac	11	None		Undershot
	Prek Chik	12	None		Undershot
	Ream Kon	13	Half-cone	Operating but poor performance.	Undershot

CFR SITES

Catchment	Name	No.
Stung Bomnak	Damnak Kranh CFR	1
Pursat	Boeng Chheutrav CFR	2
	Boeng Preah Ponley CFR	3
	Boeng Kampeng CFR	4
	Boeng Kantout CFR	5
Moung Russei	Ang Beng CFR	6
	Ang Ta Nak CFR	7
	Anlous Dong CFR	8

3 Field assessments of key issues

3.1 Fish passage

3.1.1 Upstream fish passage

Four of the new irrigation dams which we inspected include 'half-cone' fish-passes in their design, and of these one project (Lum Hach) was still under construction. These fish-passes were all built following the recommendation of (JICA and NKCL 2009), which did not explain why this particular design was recommended. The half-cone design is quite obscure; the only published reference we could find is to its use on an urban river in Tokyo, which however provided no data on hydraulic performance or the degree of success in facilitating fish passage fish upstream. By contrast, fish-passes of various other types are installed at many thousands of sites worldwide, with their hydraulic characteristics and fish passage performance well-documented in many publications which are readily available in the general and scientific literature (e.g. see (Baumgartner et al. 2018, Hortle and So 2017, Marsden et al. 2018, Schmutz and Mielach 2015).

The four 'half-cone' fish-passes which we inspected were are all non-functional for several reasons. They are quite steep (all are designed to 1:10 slope) and lack sufficient volume in their pools for energy dissipation, so the flow is extremely turbulent and too fast for fish to negotiate. The depth over the baffles and in their pools is too shallow for passage of large fish. They function over a very narrow headwater range, which would allow passage of only very small fish for limited periods when the upstream levels allow an optimal flow of water.

One of these fish-passes (Wat Chre) was dry because the head-water level was too low, apparently because a tree had jammed in the low-flow gate at the weir, preventing restriction of the flow which would have raised headwater levels.

Photo 1: Looking down Wat Chre fish-pass
Headwater levels are too low so there is no flow through it.
Note the unused slots for gates which could control inflows.

Photo 2: Wat Chre dam looking upstream
Fish-pass is on the left of the photo

The largest half-cone fish-pass (Damnak Ampil) had very fast and turbulent flow as a result of its poor design and high headwater levels; and it is highly unlikely that any fish could have made any headway to swim past the lower few pools. The Damnak Ampil fish-pass also had a fixed downstream entrance at right angles to the flow of the river, which provided a single entry point that would not be found by migrating fish at times when they accumulate upstream or downstream of it, as discharge varies.

Photo 3: Damnak Ampil Dam, Pursat River
The half-cone fish-pass is in the foreground, the irrigation offtake and canal are in the background.

Photo 4: Half-cone fish-pass at Damnak Ampil Weir, Pursat River
Plan view from drone video on 8 October 2019. Flow is from right to left.
Note the high turbulence in the pools and the length of the inlet section.

Photo 5: High turbulence and fast flow in the lower section of Damnak Ampil fish-pass on 8-10-19
The fish-pass is covered for safety reasons; despite that cover, local fishers managed to insert small nets to catch fish which attempt to leap at the baffle overflows. Fishing was only being carried out in the downstream section as fish could apparently go further than the first few baffles. The rounded design of the baffles leads to lateral rotation of the flow and high turbulence.

One half-cone fish-pass (Ream Kon) had some water passing down it, but it was being fished heavily by local people, so was simply functioning as a fish trap, to the extent that any fish were entering it.

Photo 6: Ream Kon half-cone fish-pass looking downstream
Note the very limited flow and shallow depth across the baffle and depth of only about 20 cm in the pools where the boys are standing. Photo by Wim Giesen.

For the existing half-cone fish-passes to be hydraulically functional at all, they would need careful monitoring on a daily basis, with headwater levels manually adjusted to control inflows. Their upstream inlets are protected by large concrete flumes, which have slots which may be intended to control water levels independently of operation of the dam's water-gates, however small gates would need to be fitted to the slots and adjusted daily. It is however considered unlikely that these fish-passes would ever be ecologically functional, i.e. they would never provide for significant upstream passage of a range of species and sizes of fish because of their poor designs.

The cone fish-pass which we inspected at Kbal Hong is designed to a 1:20 slope, (cf. 1:10 for the steeper half-cone fish-passes). It has adequate depth along its length for fish passage, and it provides relatively slow and non-turbulent flows through a range of headwater levels. It is suitable for Mekong basin species and it is ecologically functional, based on monitoring data from IFReDI, with about 70 species of fish in a range of sizes recorded swimming through it, and passage rates of up to 25 kg/hr of fish (Tim Marsden, pers. comm.). This design is generally suitable for low-level weirs. Its effectiveness in passing fish is only limited by its size relative to the dam (as is usual for fish-passes), and it is also affected by fishing activity in and near the fish-pass. These limitations are common and can be addressed by building larger or multiple passes, and by restricting access.

Photo 7: Cone fish-pass at Kbal Hong Irrigation Weir in Pursat in 2019 at low-moderate flow
Note the lack of turbulence in the fish-pass. Unfortunately there is full access to local people who catch or disturb fish. Photo by Dr Tim Marsden, Australasian Fish Passage Services.

Photo 8: Kbal Hong Weir at moderate-high flows on 8-10-2019
The cone fish-pass is ‘drowned out in the right foreground next to the wall. Fish can likely pass freely under these conditions.

Photo 9: Trap used to monitor fish passage in Kbal Hong fish-pass

Photos 10a & 10b: Fisher dip-netting along the wall downstream of Kbal Hong Weir
His catch included loaches, glass fish, cyprinids and shrimps

Damnak Choeur Krom Dam is under construction and will be the most upstream dam on the Pursat River when completed. A vertical slot fish-pass is to be installed at that site following the guidelines of (Marsden et al. 2018). It is likely that the vertical slot fish-pass will be hydraulically and ecologically functional at the site, based on the careful selection and design process, and on prior experience of the first vertical slot fish pass in Cambodia, which was built at Stung Chinit (in 2004). The Stung Chinit fish-pass performs well and as expected hydraulically, and passes many fish (Sok 2008). However, like many fish-passes, the Stung Chinit fish pass is not ideally located for approach by migrating fish, and it suffers from interference by fishers, as well as (reportedly) by the weir operators who use it as a fish trap, hence there is room for improvement.

Photos 11a & 11b: Damnak Choeur Krom dam site looking upstream (left) and downstream (right)

A vertical-slot fish-pass is reportedly included in the design

Photo 12: Tang Krasaing Dam, a typical small irrigation weir with no fish passage mitigation
Fish cannot ascend the steep drop across the spillway, and cannot pass safely through the top-down water-gates.

Photo 13: Achang Dam, Boribo R.
There is no fish-pass at this site. Note the undershot water gates and fast shallow flow over spillway

Photos 14 & 15: Bassac Dam, Dountri River
There is no fish-pass at this site. Note the undershot water gates and limited discharge to river downstream.

Photos 16 & 17: Prek Chik Dam, Dountri River
There is no fish-pas at this site. Note the undershot water gates and no flow to river downstream.
As shown in Table 1, seven other dam sites we inspected did not include fish-passes, as is usually the case in the Mekong basin and elsewhere; i.e. the vast majority of existing dams have no provision for fish passage. Fish passage and possible retrofit should be considered at all existing sites which do not have fish-passes, considering that maintenance of fish migrations and important fisheries is a basin-wide issue in any river system. The dams which are furthest down any river should receive priority attention, as they will limit the effectiveness of any fish passage measures at dams further upstream. This applies particularly to tributary rivers in which fish are migrating from and to a larger system, such as the Mekong River or Tonle Sap. A good example is the Charec Weir, the most downstream dam on the Pursat River. Despite this being a low-level weir, the gates create a significant hydraulic barrier, with a steep and fast drop over the gates at low flows, and severe turbulence downstream at high flows. A functional fish-pass at this site is urgently needed to improve the access by fish to the river and to reach the fish-passes at the three dams upstream.

Photo 18: Charec Weir, Pursat River, moderate discharge on 8-10-19
There is no fish pass at this site. Fish passage is inhibited by strong turbulence and fast flow, despite relatively little drop across the gates. Note the fishing nets used by people targeting fish which are obstructed at the barrier.

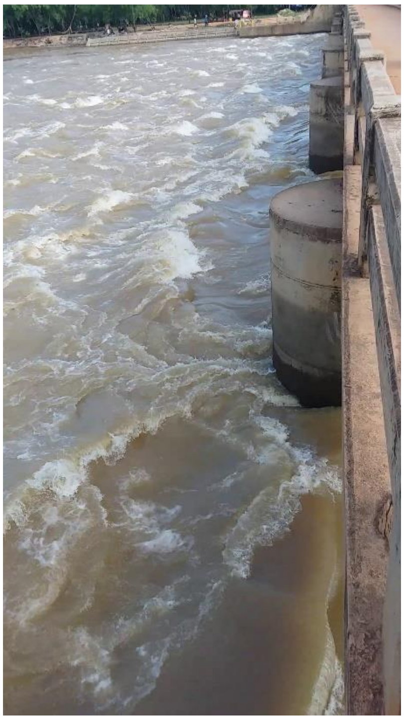

Photo 19: Charec Weir, Pursat River, moderate discharge on 8-10-19
Detail of high turbulence and fast flow downstream of the gates.

Photo 20: Charec Weir at a lower discharge than in previous photos
Note that despite less turbulence, there is a significant drop over the gates, which would be a hydraulic barrier to many fish, and the fishing activity which targets fish at the weir. Photo by Wim Giesen

Based on the above discussion the following measures are recommended to improve upstream fish passage.

- The half-cone fish-passes at four dam sites (and any others we did not inspect) should be rebuilt to designs which are suitable for passage of Mekong basin fish species and for each site's characteristics. The process for selection and design of replacement fish-passes has been well-documented and is explained by (Marsden et al. 2018).

- MOWRAM should work with IFReDI staff members who are receiving ongoing training with internationally recognised fish passage experts on fish passage to redesign and replace these non-functional half-cone fish-passes.

- MONRE should develop some standard criteria and design guidelines for fish passage at all dam sites, with some performance standards specified.

- MOWRAM should ensure that any fish passage designs proposed by developers are independently reviewed by fish passage experts. No more half-cone fish passes should be built.

- No-fishing zones need to be declared and policed at all dam sites to allow for fish passage.

- Migration of fish through all these passes should be monitored to judge their performance against standards, and the results should be published. IFReDI staff members and associated consultants are well-qualified and experienced for that function.

3.1.2 Downstream fish passage

As mentioned in the Phase 1 report, to complete their life cycles, most adult fish which swim up a Mekong or Tonle Sap tributary river in the early wet season must migrate back downstream, as must their larvae or fry which result from spawning in the tributary. Assuming that most fish migrate downstream during the mid to late wet season, the majority - roughly proportional to flow - are likely to pass downstream with the main river flow at most dams. Seven of the dams we inspected had undershot gates discharging downstream and six had overshot gates. The dams with overshot gates are likely to provide relatively hazard-free downstream passage for fish, whereas all the dams with undershot gates are likely to provide little or no safe downstream passage for fish, which are likely to be killed or injured by barotrauma, shear or strike when they pass below the gates, as discussed and illustrated in the Phase 1 report.

The fish-friendly overshot gates are operational on the larger and newer dams, whereas the undershot gates are in place generally on the older and/or smaller dams. As well as providing safe fish passage, the overshot gates allow for flow-through of plants and debris, so while they may be slightly more expensive, dam operation will be more efficient and will require less maintenance.

Based on the above discussion the following measures are recommended to improve downstream fish passage.

- MOWRAM should use overshot gates on all dams wherever possible.
- MOWRAM should examine and prioritise existing dams for retrofit of overshot gates, based on their likely significance for downstream fish migration.
- Overshot gates need to direct fish onto a safe entry, not onto exposed hard surfaces.

3.1.3 Lateral fish passage

All but one of the dams we visited are irrigation weirs (with limited storage), designed to raise upstream water levels so that water is diverted into canals. All of these canals had overshot gates, which may be fish friendly if fully opened, but may kill or injure any fish passing beneath them if water passes through a narrow gap with the gate shut down.

Photo 21: A typical top-down water-gate to irrigation canal from Tang Krasaing Reservoir
While fully open fish can pass, but when partly closed fish may be injured or killed by passage

It is possible that most fish passing through an irrigation weir might avoid irrigation off-takes if they are actively swimming upstream, of if they are migrating downstream during the mid- to late wet season when flow down the river is high relative to diverted flows. If only a small proportion of fish enter the canal(s) leading to an irrigation system, the impact may be acceptable, particularly if those fish enhance the rice-field fishery.

It is recommended that the impacts of diversion flows should be studied in depth at some representative sites, by documenting gate operations and relative flows, and the abundance of fish in the river system and canals. The resulting data would indicate the extent of the impact on fish populations in the river, and would provide some basis for developing guidance on assessing impacts and required mitigation measures.

Mitigation of diversion flow impacts could entail 1)) screening fish out of the off-takes, 2) management of the existing gates to protect fish, or 3) retrofitting overshot gates which would allow safe fish passage.

3.2 Downstream impacts of irrigation schemes

E-flows as discussed elsewhere are recommended as one way to mitigate impacts on the tributary rivers. All of the rivers we visited still have significant areas of remnant floodplains and floodplain water-bodies along the tributaries. These are critical for ecological functioning generally as well as fisheries, but are being progressively cut off by levees and modified by farming, processes which can be observed along all of the rivers we visited. One example is shown below.

These physical changes to floodplains need to be managed if e-flows are to be effective. Floodplains and their hydrology are complex, so each river system requires a systematic assessment and a program of works to maintain the connections of the flood plains and associated water-bodies to the rivers during flood levels, which will be predictably reduced as a result of irrigation abstractions.

Photo 22: Pursat River (right side) and floodplains downstream of Damnak Ampil Dam
On example showing how the floodplain is being cleared and intensively farmed, and waterbodies are being isolated from any flooding, preventing exchange with river flows and migration of fish.

3.3 Impacts of irrigation schemes on community fish refuges (CFRs)

As mentioned in the Phase 1 report, CFRs have been successful in increasing fish production from the rice-field landscape, but their function has at times been disrupted by blockage of fish migrations as well as lack of water caused by irrigation, road construction or farming activities. During the field visit we inspected 8 CFRs as listed in Table 1 and shown in Figure 1; with some issues summarised in Table 2 and illustrated in the figures below. The sites visited are a very limited group from within the hundreds of CFRs that are now registered (see Phase 1 report) but they exemplify the main issues mentioned, which are generally related to infrastructure cutting off water supply to CFRs, or blocking fish passage into and out of CFRs. These problems are generally technically simple and relatively inexpensive to resolve, and the CFRs generally do not require much water for their critical function of providing dry-season refuge habitat. Those who develop infrastructure should be aware of the CFRs needs and allow for their modest requirements within planning and budgeting.

Therefore it is recommended that MOWRAM improve dialogue with MAFF and with NGOs such as WorldFish to ensure that the CFRs which are affected by irrigation schemes are documented and taken into account at a local level to avoid disruption to drainage patterns and fisheries.

Table 2. CFRs which were visited and some issues with their management

Some images of the CFRs follow below in the same sequence as in the table.

Catchment	Name	No.	Main issues at the site
Stung Bomnak	Damnak Kranh CFR	1	Reservoir was constructed in ~2011 to provide for irrigation and fisheries. It leaked and a spillway and gate were constructed by MOWRAM. Other issues with inlet and outlet channels were fixed by the CFR members.
Pursat	Boeng Chheutrav CFR	2	This is a well-functioning CFR with obvious connections to surrounding rice-fields and fish visible.
	Boeng Preah Ponley CFR	3	Flow into this large (2.6 km2) wetland has been partly blocked by the main canal from Damnak Cher Krom Reservoir. This important wetland needs additional water and some excavation to improve its function both as a bird reserve and important fishery resource.
	Boeng Kampeng CFR	4	This small reservoir is a former floodplain water-body which has been choked by weeds for many years. The CFR members have cleared part of it to maintain a space for fish. Clearance of weeds and upgrade to overshot water-gates in off-takes would enhance its irrigation function as well as fisheries production.
	Boeng Kantout CFR	5	A small irrigation canal blocked flow and fish passage in 2012. The CFR members had to fix this problem themselves by installing small culverts.
Moung Russei	Ang Beng CFR	6	Flow to this CFR was cut off by a small road which was constructed as part of irrigation infrastructure. Watergates were installed later.
	Ang Ta Nak CFR	7	An irrigation canal blocked flow into this CFR for 6 months, culverts were installed later.
	Anlous Dong CFR	8	This CFR has a limited catchment, which needs some water supply for the dry season. It drains to a Stung Dauntri tributary which is highly incised, so fish cannot migrate into it. It is surrounded by trees but most are exotic and some are noxious, replanting with Cambodian species would enhance biodiversity and conservation value.

Photo 23: Damnak Kranh reservoir, new gate and spillway

Photo 24: Boeng Chheutrav CFR
This is an effective dry-season refuge for fish which is functioning well.

Photo 25: Boeng Preah Ponley, a 2600-ha natural wetland on 25/12/2018
The canal from Damnak Choeur Krom reportedly cut off some overland flow to the lake. The lake is shallow and overgrown by aquatic weeds. A dry season fish refuge of 1 ha was cleared of plants in the northern section in 2014, but the plants quickly regrew. A 1-ha fish refuge was excavated near the main wall in 2018.

Photos 26 & 27: Boeng Preah Ponley Bird Sanctuary and CFR near the irrigation canal offtake
The right photo shows the excavated 1-ha fish refuge. Further excavation and clearance of spoil are needed.

Photos 28 & 29: Boeng Kampeng CFR
The reservoir has been choked by aquatic weeds for many years. The water is 3-4 m deep in these pictures. Excessive plant growth amplifies water loss through evapotranspiration, as well as various negative ecological effects.

Photos 30 & 31: Boeng Kantout CFR
Note the typical riparian vegetation on the left and typical excessive aquatic plant growth on the right.

Photo 32: Boeng Kantout CFR concrete irrigation canal which cut off the flow to the CFR
The CFR members had to install culverts to provide flow under the canal, which is apparently not used.

Photo 33: Ang Beng CFR, deep pools provide dry-season fish refuge

Photo 34: Ang Beng CFR, showing road which cut flows, and culvert which was later installed

Photo 35: Ang Ta Nak CFR (ponds in right centre of photo)
Fish migrate between the CR (a refuge) and the inundated ricefields.

Photo 36: Ang Ta Nak CFR, opposite view
Road levees dam the drainage line and also off the CFR, culverts were installed later

Photo 37: Anlous Dong CFR next to main road which forms a dam

Photo 38: Anlous Dong CFR
Note the riparian vegetation, which could be enhanced by indigenous plantings.

3.4 Riparian vegetation cover

Near MOWRAM infrastructure and near many of the CFRs we observed significant cover of riparian and wetland vegetation, including some large trees. Most of the vegetation is however exotic, including some noxious species. Indigenous vegetation would benefit biodiversity including fish, so MOWRAM should consider a policy of planting indigenous Cambodian trees and other plants to help mitigate impacts of schemes on flora and fauna. A list of Cambodian trees is included in Annex 2.

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Appendix 1

Table 3: Field Trip Schedule

07-Oct-19	Mon	Departed Phnom Penh at 7 am. Visited Chavaeng and Tang Krasaing Reservoirs and canals. Then to Boribo River and Lum Hach weir and fish-pass; then Achang Dam and irrigation scheme. Met with IFReDI staff in the evening at Pursat as they were there to monitor the Kbal Hong fish-pass.
08-Oct-19	Tue	Pursat River - Charec Dam, Kbal Hong Dam and fish-pass, Damnak Ampil Dam and fish-pass, Damnak Choeur Krom dam site. CFRs visited: Boeng Chheutrav, Boeng Kampeng, Boeng Preah Ponley.
09-Oct-19	Wed	Dountri River: Wat Chre and fish-pass, Prek Chik Dam, Bassac Dam, Dountri River upstream storage reservoir construction site. CFRs visited: Ang Beng, Ang Ta Nak, and Anlous Dong.
10-Oct-19	Thu	CFRs: Boeng Kantout, Damnak Kranh, visited Kampong Luong fishing village on Tonle Sap. Returned to Phnom Penh.

Appendix 2

Table 4: Cambodian trees which are suitable for riparian planting

The list was compiled by Wim Giesen.

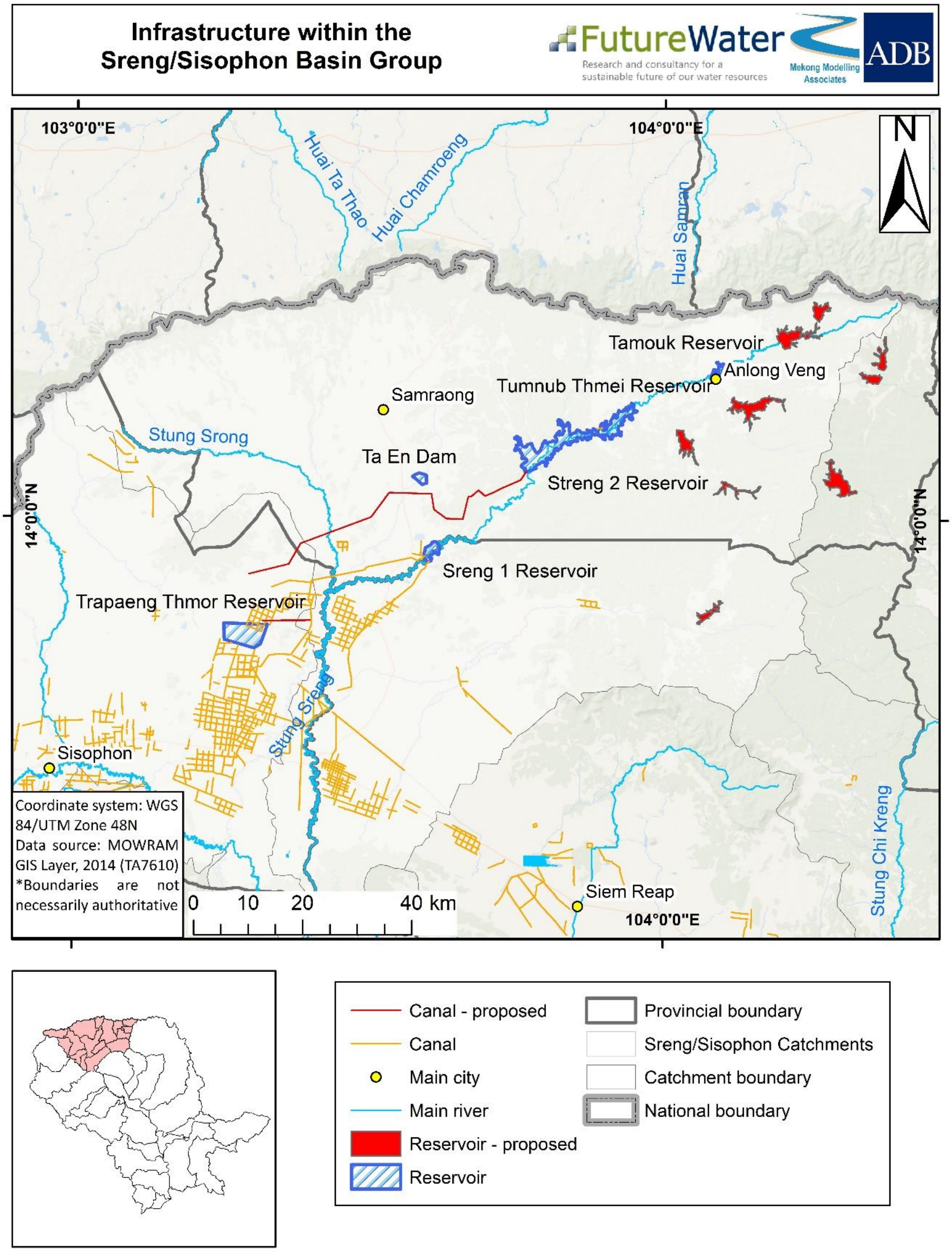
#	Family	Species	Local name
1	Achariaceae	*Hydnocarpus anthelminthicus* Pierre ex Laness.	kiropau playtum; krabau phle thom
2	Achariaceae	*Hydnocarpus saigonensis* Pierre ex Gagnep. *(unres)*	kirobau playtaug
3	Annonaceae	*Dasymaschalon lomentaceum* Finet & Gagnep	chung jam
4	Annonaceae	*Popowia diospyrifolia* Pierre ex Finet & Gagnep	kro vahn
5	Apocynaceae	*Tabernaemontana divaricata* (L.) R.Br. Ex Roem. & Schult.	
6	Apocynaceae	*Thevetia neriifolia* Juss. ex Steud.	kay yato *
8	Caesalpiniaceae	*Cassia javanica* L.	
9	Caesalpiniaceae	*Crudia chrysantha* (P.) K. Schum.	Sdai
10	Caesalpiniaceae	*Cynometra dongnaiensis* Pierre *(?) (or C. ramiflora?)*	ampil tuk prey
11	Caesalpiniaceae	*Cynometra inaequifolia* A.Gray (?)	chom prinh
12	Caesalpiniaceae	*Peltophorum dasyrrhachis* (Miq.) Kurz (syn. var. *dasyrrachis)*	trah say
13	Caesalpiniaceae	*Sindora siamensis* Miq. (syn. *Sindora cochinchinensis* Lam.)*	
14	Capparidaceae	*Maerua decandra* (Gagnep) Pax.	Jaing
15	Celastraceae	*Lophopetalum fimbriatum* Wight (unres.)	sedar sar
16	Celastraceae	*Lophopetalum wightianum* Arn.	sedar sar: pontaley; say dos
17	Clusiaceae	*Garcinia loureiroi* Pierre	sandan; sung dtun
18	Clusiaceae	*Garcinia schomburgkiana* Pierre	Tramoung
19	Combretaceae	*Combretum quadrangulare* Kurz.	Sangkae
20	Combretaceae	*Lumnitzera racemosa* Willd.	Sogkul
21	Combretaceae	*Terminalia cambodiana* Gagnep (unres.)	tu-uhl, ta uah
22	Ebenaceae	*Diospyros cambodiana* Lecomte (*D. cf. bejaudii; 3)*	ptul, phtuol
23	Ebenaceae	*Diospyros sylvatica* Roxb.	?kau-cha, maklua?, khchas
24	Elaeaocarpaceae	*Elaeocarpus griffithii* (Wight) A.Gray	run dng plok / rom denh, romdenh phlouk
25	Elaeaocarpaceae	*Elaeocarpus hygrophilus Kurz (E. madopetalus)*	run dng kaj, romdenh kaek
26	Elaeaocarpaceae	*Elaeocarpus lacunosus* Wall. ex. Kurz.	cambak pra:ng
27	Euphorbiaceae	*Mallotus paniculatus* (Lam.) Müll.Arg. *(syn. Mallotus cochinchinensis* Lour.)	
28	Euphorbiaceae	*Mallotus plicatus* (Müll.Arg.) Airy Shaw. *(syn. Coccoceras anisopodum)*	Chiro kaing, popleah
29	Euphorbiaceae	*Melanolepis vitifolia* (Kuntze) Gagnep.	Samro
30	Hypericaceae	*Cratoxylum formosum* (Jacq.) Benth. & Hook.f. ex Dyer (syn. *C. prunifolium Dyer, Cratoxylon prunifera*	Longieng
31	Lamiaceae	*Gmelina asiatica* L.	Aingchan; rumca:n, anchanh
32	Lauraceae	*Cryptocarya oblongifolia* Blume	sro da krohom, sedar kraham
33	Lecythidaceae	*Barringtonia acutangula* (L.) Gaertn *(syn. Barringtonia micrantha)*	riang-tut; riang thom, reang-reang tuk

34	Lecythidaceae	*Careya arborea* Roxb.	reang phnum; kandol
35	Lythraceae	*Lagerstroemia calyculata* Kurz	
36	Lythraceae	*Lagerstroemia thorelii* Gagnep.	
37	Malphigiaceae	*Hiptage triacantha* Pierre	
38	Malvaceae	*Brownlowia paludosa* (Kosterm.) Kosterm.	Ronea
39	Malvaceae	*Corchorus cf. aestuans* L.	
40	Melastomataceae	*Memeclyon edule* Roxb. var. *ovata* C.B. Clarke	
41	Melastomataceae	*Memeclyon edule* Roxb. var. *scutellata* (Lour.) C.B. Clarke	
42	Meliaceae	*Dysoxylum excelsum* Blume *(syn. D. procerum; illeg.)*	chey paur, bang keou kouk
43	Mimosaceae	*Albizia lebbekoides (DC.) Benth.*	chum riek, kon tri
44	Mimosaceae	*Parkia sumatrana* Miq	
45	Myrtaceae	*Syzygium cinereum* (Kurz) Chantaran. & J.Parn.	pring bay
46	Myrtaceae	*Syzygium sterrophyllum* Merr. & L.M.Perry (syn. *Eugenia)*	pring
47	Olacaceae	*Olax obtusa* Blume	
48	Papilionaceae	*Butea monosperma* (Lam.) Taub. (syn. B. frondosa)	Char
49	Papilionaceae	*Dalbergia cambodiana* Pierre	Cranhung
50	Papilionaceae	*Dalbergia pinnata* (Lour.) Prain	
51	Phyllanthaceae	*Antidesma ghaesembilla* Gaertn	
52	Phyllanthaceae	*Antidesma montanum* Blume	
53	Phyllanthaceae	*Aporosa octandra* (Buch.-Ham. ex D.Don) Vickery	
54	Phyllanthaceae	*Bridelia retusa* (L.) A.Juss. *(syn. Bridelia cambodiana* Gagnep)	tmegn trei
55	Phyllanthaceae	*Glochidion obscurum* (Roxb. ex Willd.) Blume	
56	Polygalaceae	*Xanthophyllum glaucum* Wall. (unres.)	kansaeng, taseng.
57	Putranjivaceae	*Drypetes thorelii* Gagnep.	
58	Rhamnaceae	*Ziziphus jujuba* Mill.	pot trea*
59	Rhizophoraceae	*Carallia brachiata* (Lour.) Merr. (syn. *Carallia lucida)*	Trament
60	Rubiaceae	*Gardenia cambodiana* Pitard	dongk dau, bay-remir, day khla
61	Rubiaceae	*Mitragyna diversifolia* (Wall. ex G.Don) Havil. (syn. Stephegyne)	khtoum tuk
62	Rubiaceae	*Mitragyna parvifolia* (Roxb.) Korth. (syn. Stephegyne)	Khtoum
63	Rubiaceae	*Nauclea officinalis* (Pierre ex Pitard) Merr. & Chun	Kau
64	Rutaceae	*Citrus lucida* (Scheff.) Mabb. (syn. *Feronia lucida* Tirjs. & Binn.; *Feroniella*)*	kro song
65	Salicaceae	*Homalium brevidens* Gagnep (unres.)	rotiang-or-atiang
66	Salicaceae	*Homalium dasyanthum* Warb. (unres.)	rotiang-or-atiang
67	Salicaceae	*Salix tetrasperma* Roxb.	srol beng
68	Sapindaceae	*Schleichera oleosa* (Lour.) Merr. *(syn. S.oleosa* (Lour.) Oken) *	pung roa
69	Sapotaceae	*Mimusops elengi* L. *	kdol, phkol
70	Simaroubaceae	*Quassia harmandiana* (Pierre) Nooteboom *(Samandura harmandii* Pierre)	kros, kras, plae kroh

Appendix 5.Infrastructure maps per basin group

5.1 Sreng/Sisophon Basin Group

Salient features – Location, coordinates, storage, length, etc.
E = Existing, UC = Under construction, P = Proposed
Tamouk Reservoir (E) – (400739, 1574299)
Tumnub Thmei Reservoir (E) – (379834, 1563847)
Sreng 2 Reservoir (E) – (368017, 1557266) – 258MCM max
Ta En Reservoir (E) – (347875, 1554597)
Sreng 1 Reservoir (E) – (348044, 1540764) – 87MCM max
Trapaeng Thmor Reservoir (E) – (317206, 1524704)
Proposed reservoirs in upper Sreng (P) – Total surface area 76.2 km^2
Streng 2 → Trapaeng Thmor canal (P) – 64.9km length


Infrastructure within the
Sreng/Sisophon Basin Group
FutureWater
Research and consultancy for a sustainable future of our water resources
Mekong Modelling Associates
ADB
103°0'0"E
104°0'0"E
14°0'0"N
N
Huai Ta Thao
Huai Chamroeng
Huai Samran
Tamouk Reservoir
Anlong Veng
Tumnub Thmei Reservoir
Samraong
Stung Srong
Ta En Dam
Streng 2 Reservoir
Sreng 1 Reservoir
Trapaeng Thmor Reservoir
Stung Sreng
Sisophon
Siem Reap
Stung Chi Kreng
Coordinate system: WGS 84/UTM Zone 48N
Data source: MOWRAM GIS Layer, 2014 (TA7610)
*Boundaries are not necessarily authoritative
0 10 20 40 km
Canal - proposed
Canal
Main city
Main river
Reservoir - proposed
Reservoir
Provincial boundary
Sreng/Sisophon Catchments
Catchment boundary
National boundary

5.2 Sangker-Pursat Basin Group

Salient features – Location, coordinates, storage, length, etc.

E = Existing, UC = Under construction, P = Proposed

Kamping Puoy Reservoir (E) – (279813, 1447309)

Sek Sak Reservoir (E) – (272981, 1416251) – 193MCM max

Kang Hot Diversion (E) – (296944, 1423654)

Bassac Reservoir (E) – (318124. 1389898) – 5MCM max

Prek Chik Village Scheme (E) – (325276, 1398348)

Pursat 3 Reservoir (E) – (356514, 1351072) – 25.5MCM max

Pursat 5 Reservoir (E) – (364871, 1352158) – 24.5MCM max

Damnak Ampil (E) – (370422, 1380621)

Damnak Choeur Krom (UC) – (359662, 1363694)

Sala Ta Orn Dam (UC) – (307131, 1453379) – 12MCM max

Dauntri Reservoir (UC) – (313921, 1387972) – 160MCM max

Tvark Dam (P) – (279160, 420037)

Pursat 1 Reservoir (P) – (312905, 1357447)

Pursat 2 Reservoir (P) – (330371, 1363101)

Prek Chik Canal (E) – 47.8km length

Infrastructure within the Sangker/ Moung Russei/ Svay Don Keo/ Pursat Basin Group

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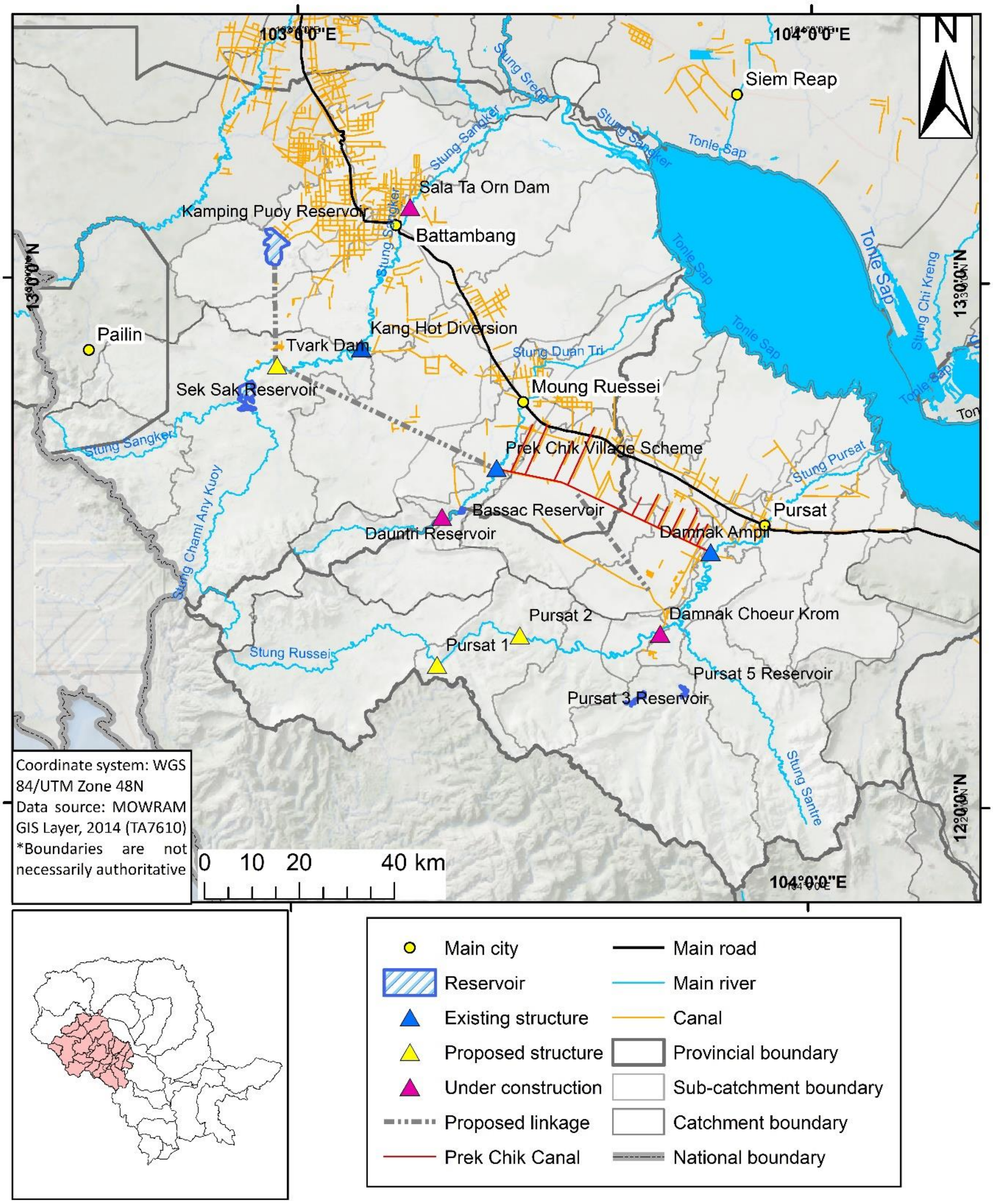
ADB



Pictures

Bassac dam:

Damnak Ampil:

Damnak Choeur Krom:

Dauntri dam:

Prek Chik Village Scheme:

Sek Sak:

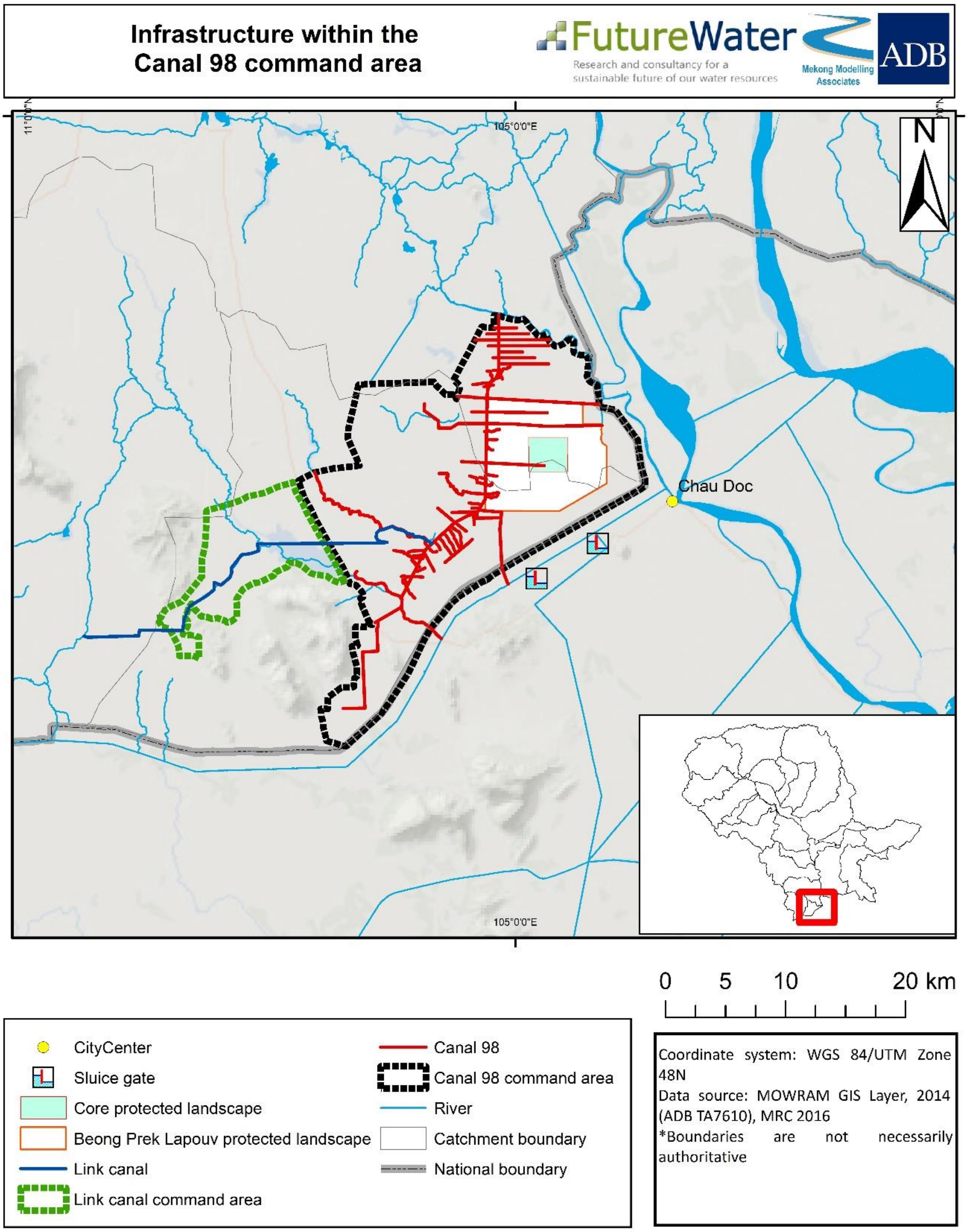
Kamping Puoy:

Kang Hot diversion:

5.3 Slakou/ Toan Han Basin Group

Salient features – Location, coordinates, storage, length, etc.
Canal 98 – 30.3km length
Canal 98 command area – 475.5km^2 total area
Link canal – 37.1km
Link canal command area - 85.2km^2 total area

Infrastructure within the Canal 98 command area



Coordinate system: WGS 84/UTM Zone 48N
Data source: MOWRAM GIS Layer, 2014 (ADB TA7610), MRC 2016
*Boundaries are not necessarily authoritative