THE KINGDOM OF CAMBODIA

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PROGRAM MANAGEMENT UNIT

Water Resource Management and Agro-Ecological Transition in Cambodia Program Phase-1.

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Better understanding of hydrological and hydraulic systems

Final Report

Component 3: Support to water resources monitoring and management (TA-IWRM)

Sub Component 3.1: Mekong Bassac Hydrological and Hydraulic Study

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Ministry of Water Resources and Meteorology (MOWRAM)

WAT4CAM:Component 3.1: Better Understanding of hydrological and hydraulic systems. Mekong Bassac Study

WAT4CAM – Component 3: Support to water resources monitoring and management

Final Report

FutureWater Report - WAT4CAM-CS/03-05
Joint Venture with Mekong Modelling Associates (Cambodia) & JBA Group (UK)

Client
Ministry of Water Resource and Meteorology (MOWRAM)

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V1.1
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Summary

The Mekong Bassac hydrological and hydraulic study is a sub component of WAT4CAM program under Integrated Water Resources Management (IWRM). The project informs and supports improvements to the system of Prek Irrigation from the Mekong and Bassac rivers between Phnom Penh and the Vietnam border. During the project a comprehensive dataset has been assembled including data from previous studies, analysis of hydrometric data, new modelling work and analysis of satellite imagery for floods and dry season period.

Key Messages from the study are:

- Changes in the Mekong flow upstream have resulted in significantly lower water levels from September to January. This lower water level can cut flow into the Prek channels to zero one or two months prior to previous conditions. This has severely exacerbated the decline of some channels and increases the importance of deriving a new strategy for rehabilitation.
- A much Improved understanding of the system has been achieved through development of a detailed HEC-RAS 2D which has been used in conjunction with analysis of ground and satellite data and this system is available for use for the Preks masterplanning or other projects.
- A database of each Prek channel has been assembled for future use.
- Some of the previous approaches such as gating of Prek inlets or using tail structures is questionable and should be re-examined.
- The simulation of Batch 1 Prek Cluster rehabilitation proposals does not indicate any severe impacts although flood levels may increase slightly more quickly. The use of a water supply from the tail Boueng area appears to be viable but the use of a tail structure with flapgate is questioned and it is suggested that more attention is paid to the rehabilitation requirements for the peripheral Toul Khtom channel which is key to the success of the work on the Preks.
- Satellite analysis of water requirements in the Preks has shown more clearly the water demand and this is needed over a wider area to consider all water users on the West Bassac floodplain.
- Up to date gauge information is essential for analysis of the system and older historic records may be misleading. The Ankor Borei gauge should be reinstated as soon as practical.
- Both 2019 and 2020 were exceptional years both in terms of very low dry season flows and 2020 in having a flood event at the very end of the rainy season and further analysis to examine the impact of climate change is recommended. .
- The dataset assembled is comprehensive and suitable for building new models and should help meet the needs of other components and the Prek Masterplanning.

- Under WAT4CAM 3.1 additional survey was completed for some key channels and structures to use in the modelling and analysis. One of the key surveys completed was for cross sections of the perennial Prek Ambel which is the key ‘spine’ of the conveyance southward on the West Bassac floodplain running parallel to the main river. The very shallow depth at the upstream connection to the Bassac is of concern for the water supply for a large area of irrigation and options to improve this part of the river should be considered in the Masterplan.
- The analysis indicates changes in the hydrology and change in the river bed level of the Bassac river. There is evidence that the sedimentation of land where the Prek channels meet the lower floodplain has, over the long term, has been successful at raising land over the past 60 years. Managing sedimentation at the mouth of the Preks has received little attention and there is scope to refine the knowledge on how best to approach this to minimise maintenance.

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Acronyms and Abbreviations

2D	2 Dimensional in plan
AFD	French Development Agency
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CNMC	Cambodian National Mekong Committee
CAVAC	Cambodia-Australia Agricultural Value Chain Program
DEM	Digital Elevation Model
GEE	Google Earth Engine. Cloud based Scripting facility for image processing
HEC	Hydrological Engineering Centre (US Corps of Engineers)
HEC RAS	HEC River Analsysis System
IFRM	Integrated Flood Risk Management
iSIS	Hydrodynamic model used by MRC
IWRM	Integrated Water Resources Management
JICA	Japanese International Cooperation Agency
KCC	Key Consultants (Cambodia)
LMB	Lower Mekong Basin
MRCS	Mekong River Commission Secretariat
MOWRAM	Ministry of Water Resource and Meterology
mpwt	Ministry of Public Works and Transport
Prek	A small river
Sentinel	European Space Agency System of Remote Sensing Satellites
Stung	Medium size River
TA-AGRI	WAT4CAM Component 4
TA-INFRA	WAT4CAM Component 1
TA-ISWM	WAT4CAM Component 2
TA-IWRM	WAT4CAM Component 3
Tonle	A large River
ToR	Terms of Reference for WAT4CAM 3.1
WAT4CAM	The Water Resources Management and Agro-ecological Transition for Cambodia “WAT4CAM” Program

1 Introduction

1.1 Background

The Water Resources Management and Agro-ecological Transition for Cambodia "WAT4CAM" Program aims to contribute to reduced poverty, economic development and reduced vulnerability of rural populations to climate change. The project is rehabilitating hydro-agricultural infrastructure, targeting the whole chain of water resources management, water services and agricultural production. The WAT4CAM Program Phase 1 consists of four key components, as outlined in the AFD project document:

- Component 1: Rehabilitation and completion of irrigation and drainage infrastructure: TA-INFRA
- Component 2: Improvement of irrigation management: TA-ISWM
- Component 3: Support to water resources monitoring and management: TA-IWRM
- Component 4: Support innovative farming practices and support to rice value chain: TA-AGRI

This report refers solely to Sub-Component 3.1.

<u>Sub-Component 3.1. Better understanding of hydrological and hydraulic systems</u>

Hydrological and hydraulic modelling are useful tools for (i) managing water resources, (ii) forecasting drought and flood, (iii) assessing impacts of new hydraulic infrastructures development.

The modelling and analysis needs to consider both larger scale regional issues such developments upstream and local effects. This includes aspects such as:

- Changes in the flow of the Mekong at Kratie due to hydropower dams and irrigation development in upstream countries
- Urbanisation and development around Phnom Penh
- Road construction and improvements that affect water flows
- Irrigation development outside of the preks area
- Infrastructure development in Vietnam close to the border affecting flood flows especially
- Climate change

A change in the flow split between the Mekong and the Bassac is influenced by changes in the river bed along the river as well as at the bifurcation at the Chaktomuk junction in Phnom Penh. The amount of water from the main rivers that can be diverted into prek channels depends critically on the relative bed levels and widths and, for dry season flows siltation in the prek channels has a strong influence. A combination of detailed and regional analysis is thus being completed (Figure 1-1). Critical for modelling is the data that is available to represent the water channels and physical system and well as the available hydrological data and observations for calibration. The report includes review of all data sources and the data obtained to date. Data gaps are identified and the methodology and survey described.

The task deepens knowledge of the extent of the flooded area, the duration of the flooded period as well as the inter-annual variation of flood periods, the results of this study should be used in the elaboration of a Preks Masterplan. At present a Concept Note on development options is prepared by WAT4CAM Component 1 which is the first step to define the scope of the Masterplan.

1.2 Overall Objectives

The objectives of this final report are to compile all the studies and previous reports of WAT4CAM 3.1. This study directly relates to preks downstream of Phnom Penh and along the Bassac and the right bank of the Mekong.

1.3 Programming

The study period was relatively short and occurred during the Covid pandemic, which increased challenges for collaborative working and capacity building for MOWRAM. Nevertheless, survey work was completed and used in the model development and successful liaison with other components was maintained. This included Component 1 TA_INFRA to support their analysis and feasibility studies of the Preks and preparation for a Preks Masterplan.

The environmental and social task within Component 3.1 was small in terms of resource and time available relative to the overall studies being conducted by others. The output depends on available data rather than new surveys.

1.4 Format of the Report

This report comprises nine chapters:

- Chapter 1: Introduction: Provides an overview of objectives, components, structure and work projections for the project.
- Chapter 2: Study Area Physical Characteristics and Hydrology: An overview of the key characteristics of the study area.
- Chapter 3: Modelling Conceptualisation and Design
- Chapter 4: Data Review
- Chapter 5: Model Setup and Development
- Chapter 6: Flood Mapping
- Chapter 7: Low flows analysis
- Chapter 8: Impact Analysis of Batch 1 Prek Rehabilitation proposals
- Chapter 9 Conclusions and Recommendations

The main text is supplemented by more detailed Appendices documenting the model and findings.

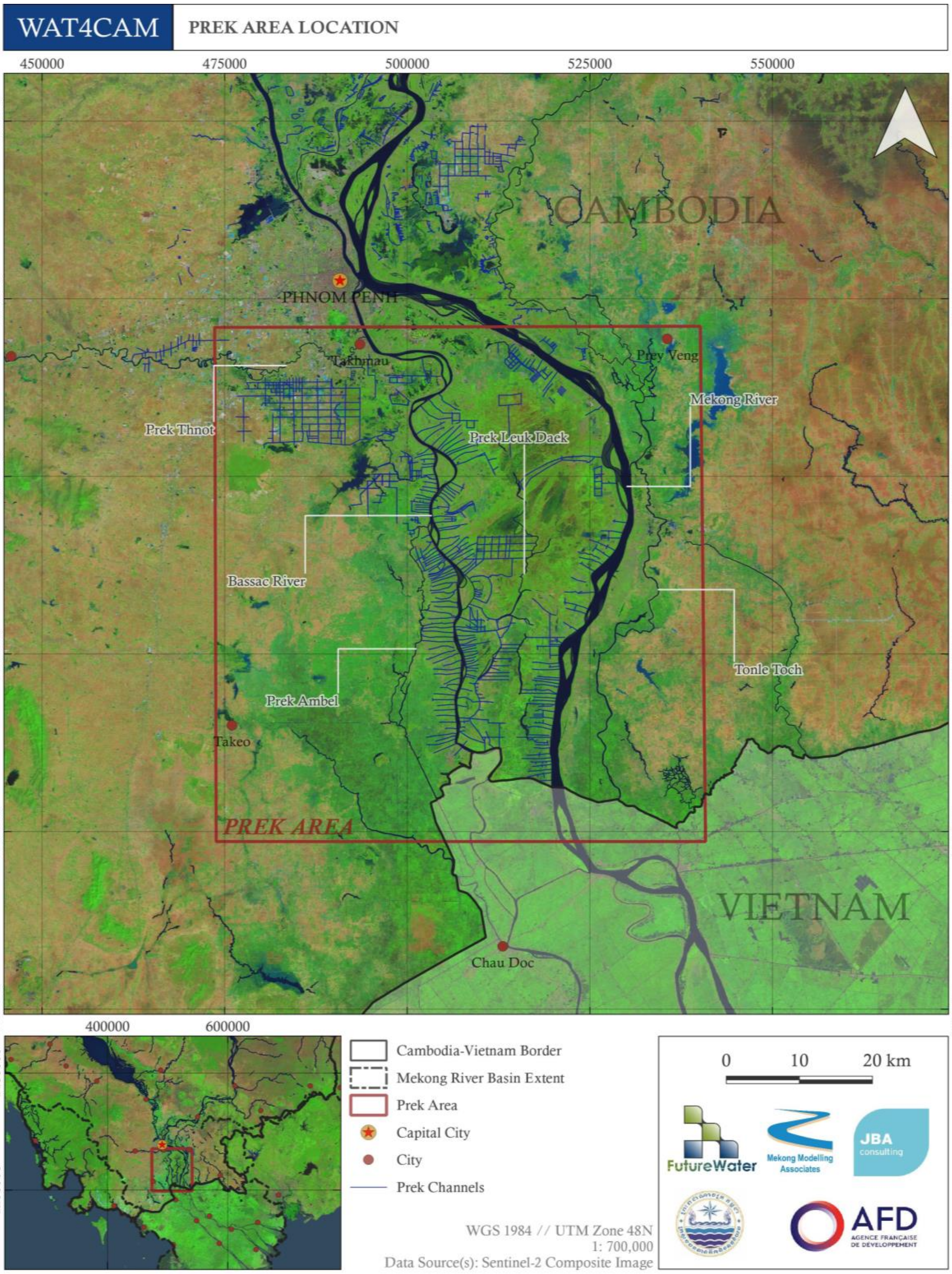

Figure 1-1 Study Area Location plan in the southern part of the Cambodian Mekong Delta

2 Study Area Physical Characteristics and Hydrology

The detailed study area extends from just downstream of the Bassac-Mekong bifurcation at Chaktomuk through the urban and urbanising areas of Phnom Penh to the more rural part at S'ang southward to the border of Vietnam, occupying the western floodplain of the Bassac river. The rehabilitation of preks is to the south of the urbanising part.

2.1 Upstream Main River System and the Prek Thnot

The Mekong rises over 5000km upstream of the study area on the Tibetan plain and flows through China, Lao PDR, and Thailand with increasing catchment inflows before reaching the border with Cambodia at the Khone Falls. Downstream of the falls the main river has further major inflows at Stung Treng, including the contribution from the Vietnam highlands in the SeSan and Sre Pok and from the Bolivan Plateau through the Xe Kong in Lao PDR. Downstream of Stung Treng the river flows through a rocky anastomosed reach before finally reaching the head of the Cambodia floodplain and delta at Kratie.

Below Kratie, the river meanders to Kampong Cham as it opens out onto the floodplain with spill rivers such as the Tonle Toch and Muk Kompul, on the left and right banks respectively. At Phnom Penh, the river confluences with the Tonle Sap and divides between the main Mekong and the Bassac at the Chaktomuk Junction. The Tonle Sap basin is unique in that the connection to the low lying Great Lake reverses on a rising flood in the Mekong with a peak flow approaching 10,000m^3/s significantly attenuating floods and sustaining the flow downstream at the end of the rainy season.

According to the Cambodia Water Resources Profile (ADB 2014) the river basins of Cambodia are classified into 5 groups:

Table 2.1 Catchment Areas of Basin Groups in Cambodia

	River Basin Group (RBG)	Catchment Area (km^2)
1	Coastal Zone	18046
2	3S Basin	25965
3	Upper Mekong	19522
4	Tonle Sap	81663
5	Mekong Delta	35839

Group 1 comprises the coastal rivers that discharge directly to the Gulf of Thailand whereas other groups are all directly in the Mekong system flowing towards the Vietnam part of the Mekong delta. The Prek system is part of the group 5 Mekong Delta RBG and influenced by the flow in the Mekong/Bassac, as well as local flows in the Prek Thnot which confluences with the Bassac at Takmau and Stung Slakou, which passes through Takeo and Ankor Borei.

Upstream across the National Road 3 there are two main sluice gates: (i) Tuk Thlar; (ii) 7 Makara and a weir. The new Phnom Penh airport in the Tonle Bati area south of Phnom Penh is scheduled to be completed by 2023 and will have full flood protection.

2020 Flood Event

In 2020 there was an exceptional flood on the Prek Thnot. The maximum recent discharge on the Prek Thnot in 2000 and 2020 at Peam Khley station north of Kampong Speu town was respectively: 2000, H=8.88m, Q=1,300 m^3/s; 2020, H=7.86m Q=950 m^3/s. Very high local rainfalls increased the severity of the flood event downstream, though this is not well recorded.

During the 2020 flood, the Tuk Thlar weir was damaged and the 7 Makara sluice gate was bypassed and limited by drowning conditions for several days. Consequently, there was severe flooding in newly developing areas of Phnom Penh. The high flood flows also passed downstream onto the Bassac floodplain and Preks area passing through the relief channel shown in Figure 2-1

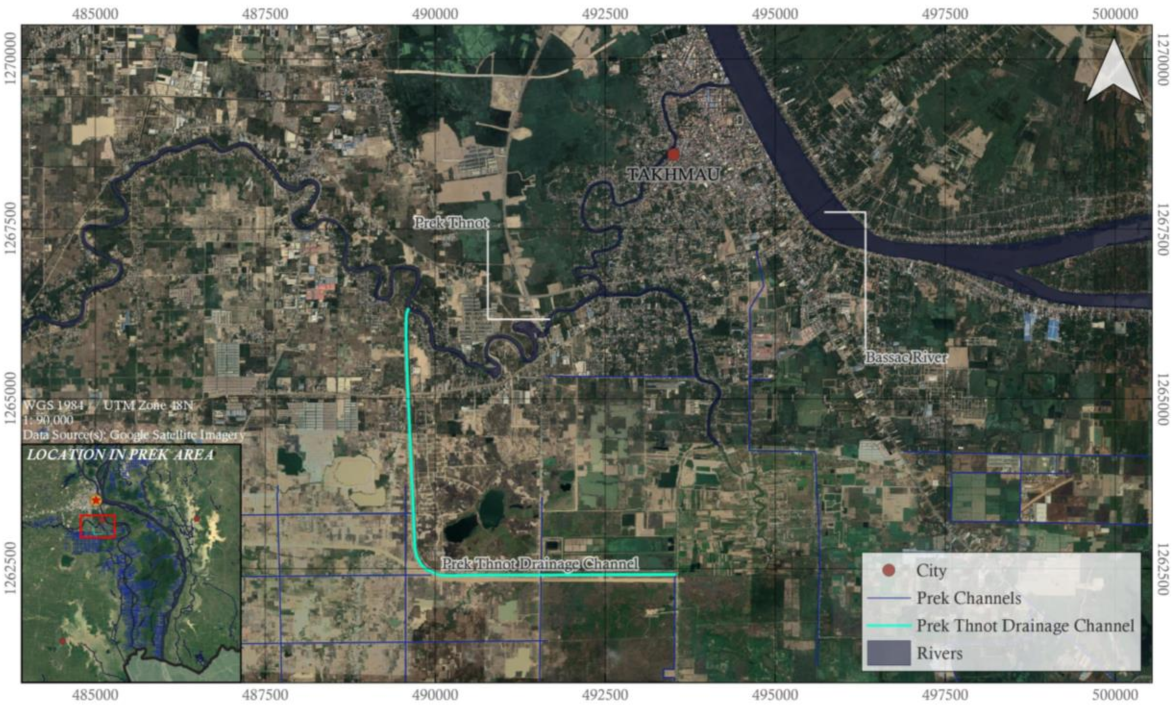

Figure 2-1 Prek Thnot Diversion Channel. Source: Imagery Google Satellite

2.2 Downstream Study Areas

This section is primarily comprised of low-lying floodplains bordered by the Bassac river to the east and higher terrain to the west. Elevation in the 'boeungs' remains below 4 m a.s.l, as seen in Figure 2-2, with natural higher elevation levees, produced by the deposition of silt, located alongside the natural river channels. Built up areas and perennial crops with lower water demands are typically found in these locations, in addition to the main transport routes. These levees also form a division between inundated floodplains and permanent channels during high flow. Often, the natural levees exhibit a migratory pattern away from the main channel as sedimentation increases along the banks of the Bassac and Mekong. Figure 2-4 shows an example of the Prek typical layout imposed onto imagery from Google Earth. Here, the sedimentation along the channels is evident, with flood water accumulating along the drainage lines, where elevation is lower, and moving through into the swamp/ marshland, or boeungs.

The crop areas are known as ‘chamkar’, and typically the main road passes along the chamkar resulting in built up areas for housing. This land use pattern can be seen in the 2010 MRC land cover map,(Figure 2-5), where annual crops and orchards found in proximity to the banks of the Bassac and Mekong rivers transition into rice paddies as distance from channel increases (MRC/Kityuttachai *et al*., 2016).

The border between Cambodia and Vietnam creates a hydraulic control that affects the flood behaviour in Cambodia and the downstream part of the West Bassac preks. The hydraulic controls include the effect of flood control structures that give an early flood control in Vietnam. This is achieved by a bank along the Vente Canal and opening controlled by sluices (formerly Rubber dams) that can be opened to allow flow. In the Trans-Bassac part there are also embankments near the border on the eastern side creating a polder with gated controls but the other part has openings through which floodwater flows. These controls will be included in the modelling.

2.3 Prek Irrigation

As identified in the Terms of Reference, according to the MOWRAM CISIS database there are around 2,500 hydraulic systems in Cambodia covering a potential irrigated area of around 1.18 million of hectares (out of a total of 3.05 million ha cultivated in the country). Among those irrigation systems, 1,200 are small scale of less than 200 ha, 1,250 are medium side of between 200 ha and 3 000 ha and 50 are large scale of more than 3,000 ha. Many of these systems are either dysfunctional or performing sub-optimally due to inconsistencies in maintenance. Among those irrigation schemes, 15% have never been rehabilitated since their construction during the Khmer Rouge regime and 22% haven't been rehabilitated since the 90's, indicating that the majority have already had some improvements, as identified in the terms of reference.

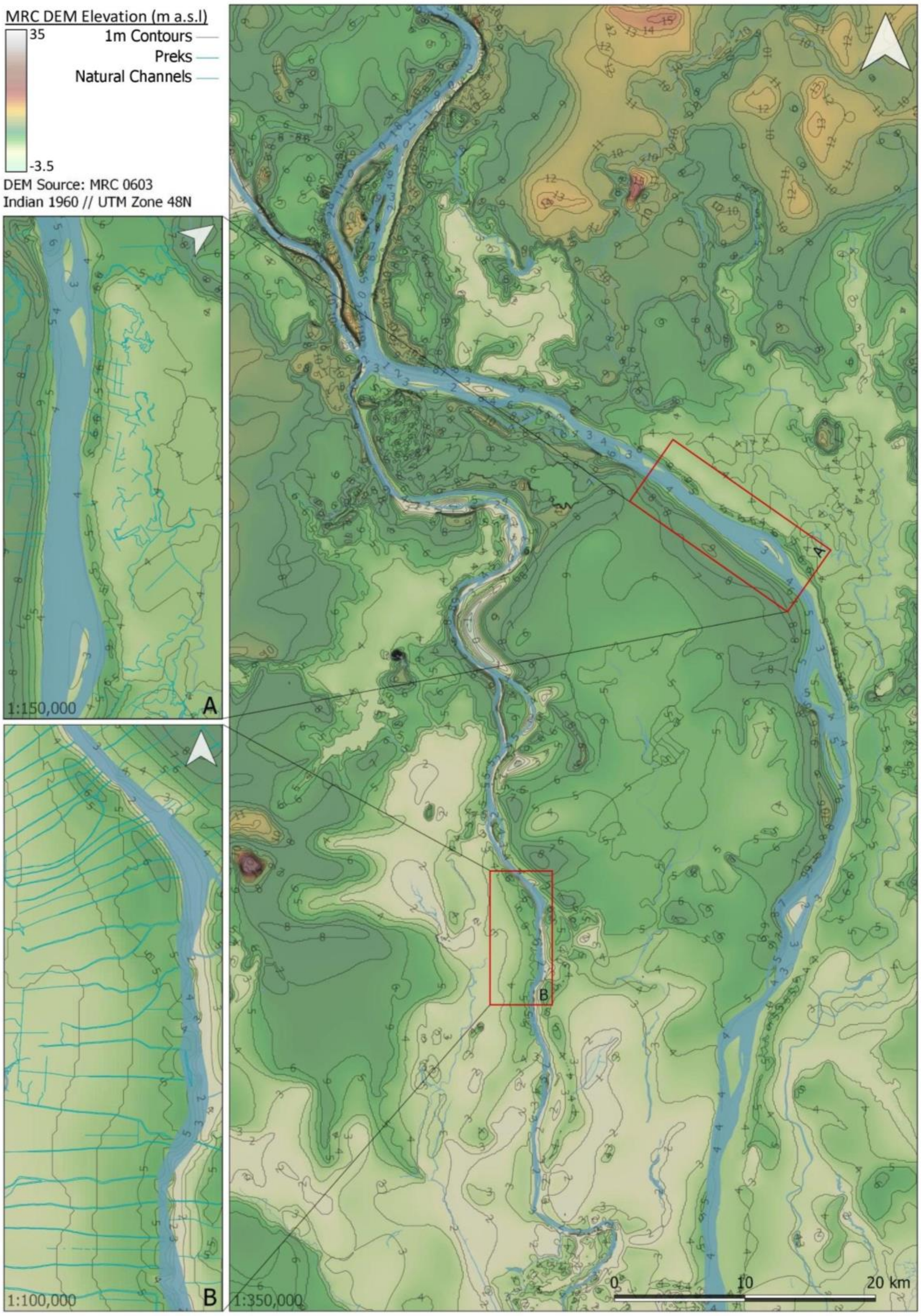

Figure 2-2 MRC DEM Elevation, with examples of natural levees on the banks of the Mekong (A) and the Bassac (B) rivers. (Data source as MRC 2003 using survey of 1960s)

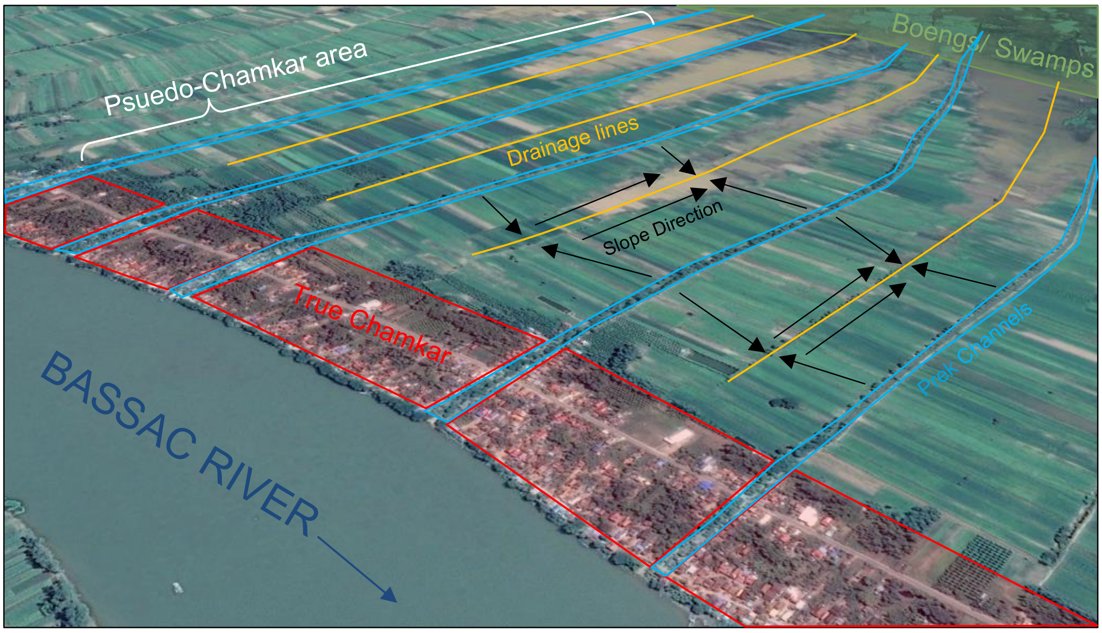

Figure 2-4 Example of Prek system layout. Source: Figure redrawn from ToR using Google Earth background imagery

When considering the hydrological component of prek restoration, bed level is the key feature. To increase flow duration throughout the year bed level should be as low as possible, such that a hydraulic gradient is maintained from the natural river channel into the preks regardless of seasonal water level changes. The main issue with this is that deep channels are costly and come with a high risk of bank collapse. The alternative is low-risk shallow channels, which typically only receive water during the monsoon season unless pumping stations are implemented. The difficulty of water diversion is exacerbated by the dredging witnessed along the Bassac and Mekong rivers south of Phnom Penh, but is also highly dependent on the Mekong flows from upstream.

Agriculture within the study region comprises rice, vegetables and fruit, commonly with irrigation by pumping post-wet season. There are typically 2 crop cycles extending from November to January, and February – April/May. During the wet season, agricultural output is limited by the floods. When sedimentation occurs along the preks and surrounding land, flood risk decreases and the potential for farmers to carry on higher value agricultural practices is improved, ultimately increasing annual returns for a given area of land.

<u>Land Cover</u>

Land cover plays a key role in understanding the processes occurring in the study area and is shown in Figure 2-5 (MRC 2016). This land cover dataset was developed by the MRCS from remote sensing images of 2010, updating an earlier 2003 version and validated by field surveys in 703 areas across the basin. There are also a number of global land cover datasets which use more up to date imagery but may use different classifiations and may not have verification for local conditions. In June 2021 ESRI released[1] a global land cover dataset for 2020 which is discussed further in Section 5.

As discussed above, areas lining the banks of both natural rivers and man-made Preks tend to be the most valuable land due to the increased elevations and better access. These elevated areas are also occupied by annual crops, a land cover type that has seen some expansion as a result of sedimentation along the Preks. The majority of the low-lying floodplain is used for the cultivation of rice, with some sparse areas of shrubland identified.

The Bassac marshes are located within the floodplain region between the Bassac and Mekong channels south of Phnom Penh. Vegetation in the marshes is dominated by seasonally inundated shrubs and savanna swamps, with agricultural land occupying the peripheral areas (BirdLife International, 2019). In the wet season these areas become inundated with vast sections of deep open water featuring areas of emergent, floating and submerged aquatic vegetation. Scott (1989) suggests that flood depths can range from 2.5 – 4.5 m, and last as long as 5 – 7 months annually. The soils of the marshes tend to be acidic and unsuited for cultivation.

In the drier months water levels drop close to sea level and become tide affected. The circulation of fresh water between the Mekong, Bassac and connecting channels provides a source of water for irrigation providing canals and channels are sufficiently deep. Where the land is above the dry season water level then it must be lifted and a number of schemes incorporate pumping, others require the farmers or cooperatives to lift the water.

The land further to the west is also developed for irrigation through pumping systems such as highlighted by the WAT4CAM Component 1 'Carte de Preks' shown in Figure 2-6. This shows 11 Pumping Stations including 8 developed under the CAVAC project and a number of privately operated ones to the west of Prek Ambel which forms the divide between Prek systems and other irrigations systems to the west.

In 2010 the MRC in conjunction with MOWRAM/CNMC published an indicative flood management plan for the Western Bassac area (Figure 2-7). This indicates a zoning of flood management allowing for a conveyance and storage route following the Prek Ambel but also proposed areas of flood protection. This is consistent with the planning of the area set out in the MRC/MOWRAM study for flood protection in the area which indicates a central flood zone and protection for the Preks and Western Irrigation Areas

[1] https://www.esri.com/about/newsroom/announcements/esri-releases-new-2020-global-land-cover-map/

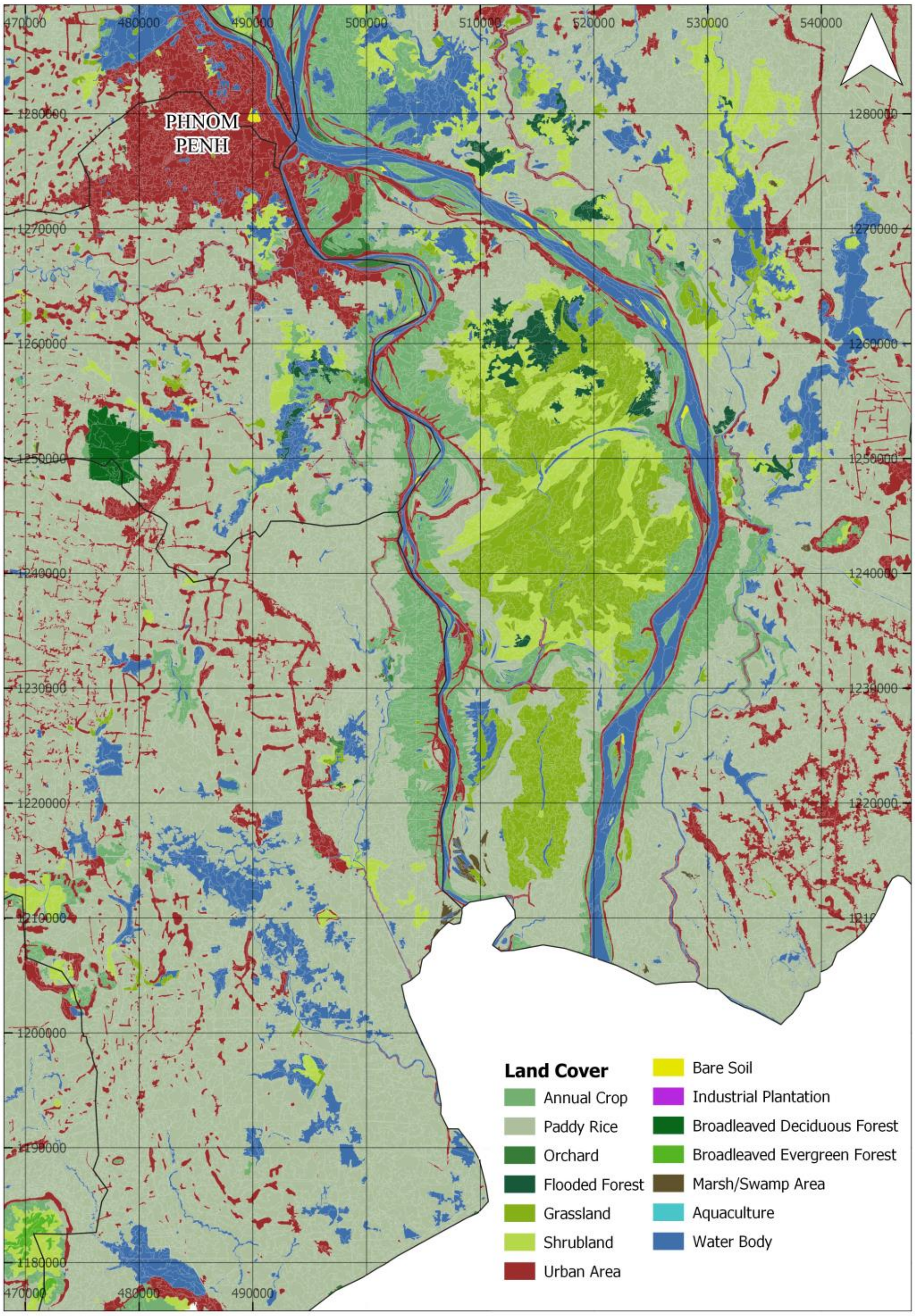

Figure 2-5 MRC Land Cover 2010 for Bassac and Lower Mekong Rivers. Source of data MRC 2016

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Figure 2-6 Carte de Preks (WAT4CAM Component 1) (above) and an example Pump Station to the west of Prek Ambel (below). Source: online resource made available by WAT4CAM Component 1

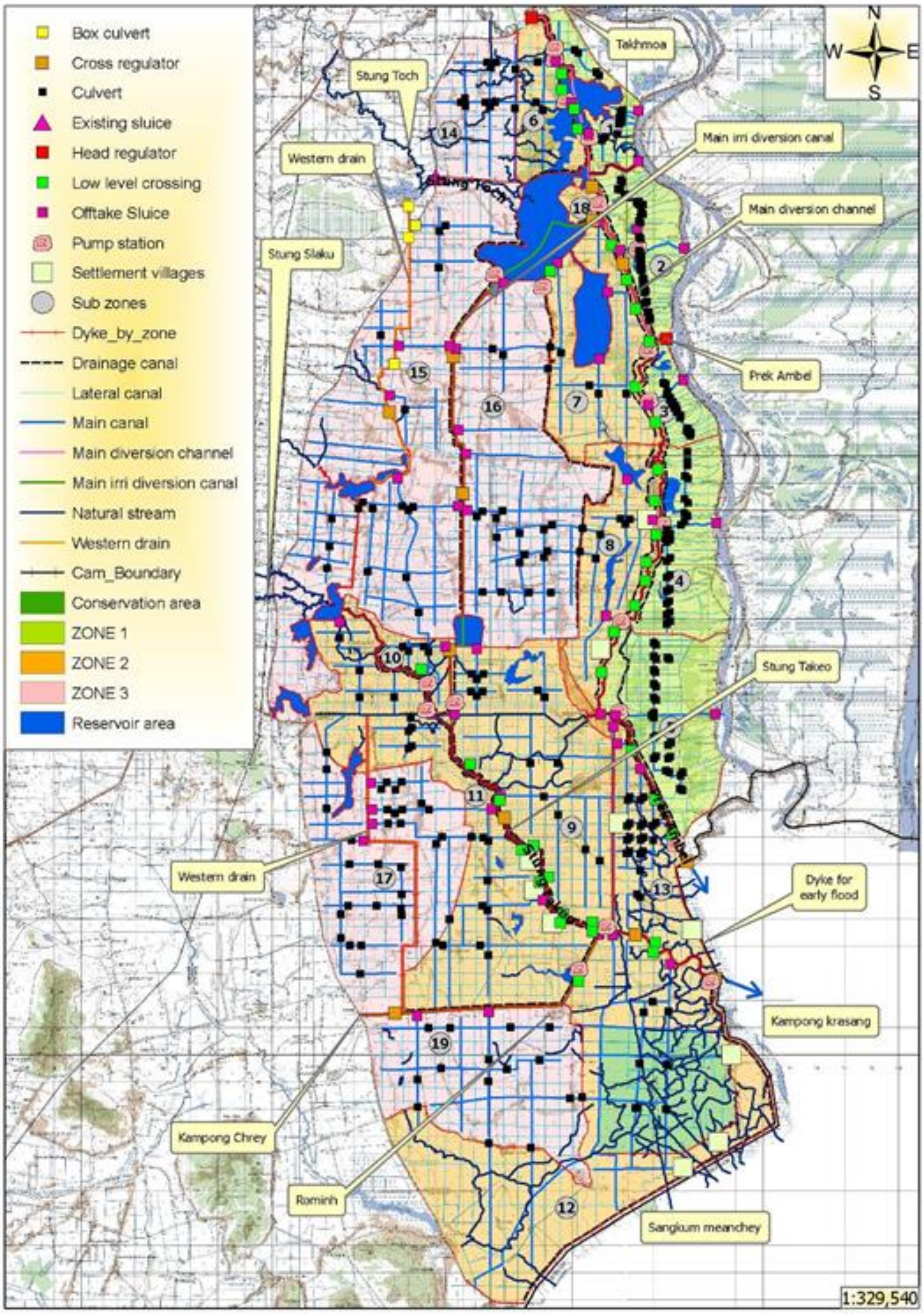
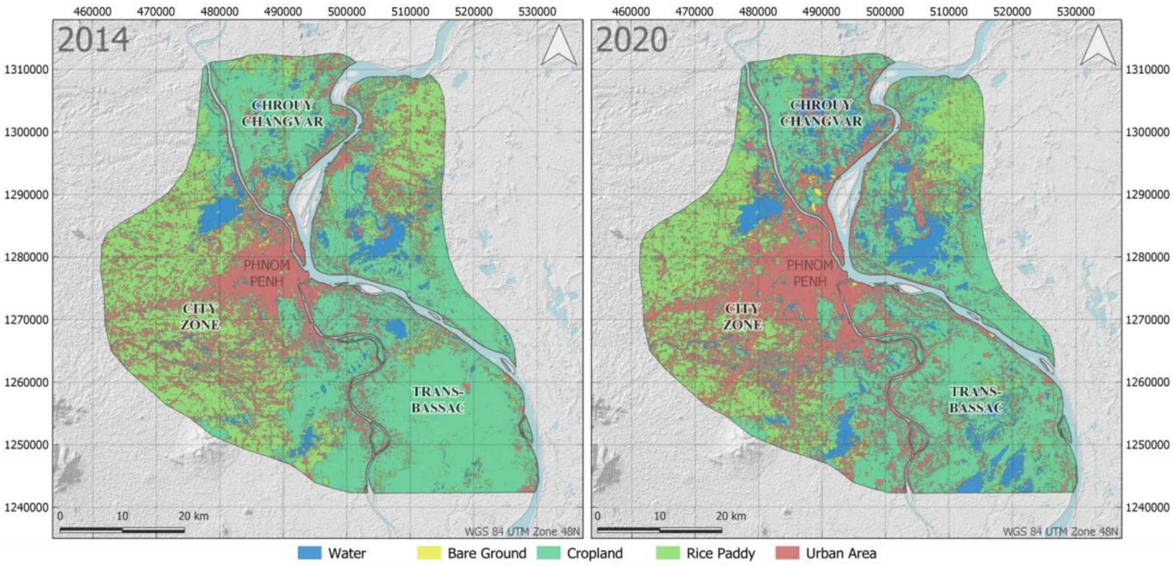


Figure 2-7 Flood Protection Strategy for the West Bassac according to MRC/MOWRAM Study 2010. If implemented the plan areas in green (Zone 1) would have early flood protection and pink full protection (Source: MRC, 2010).

In the upper areas for Preks near Tak Mau and Chbar Ampov, the urban area is developing quickly and the prek channels though no longer required for agriculture may form an important drainage function.

The change in Phnom Penh urban area between 2014 and 2020 is especially high near the Prek Thnot and the northern part of the Trans-Bassac (Chbar Ampov) as shown in Figure 2-8.



Land Cover	Chrouy Changvar				Trans-Bassac				Phnom Penh - City Zone				All Zones			
	2014		2020		2014		2020		2014		2020		2014		2020	
	% of Zone	km^2	% of Zone	km^2	% of Zone	km^2	% of Zone	km^2	% of Zone	km^2	% of Zone	km^2	% of Zone	km^2	% of Zone	km^2
Surface Water	6.2	23.9	13.4	52.0	2.0	14.5	8.3	60.0	4.2	59.8	5.9	83.2	4.8	153.8	9.0	288.0
Bare Ground	0.8	3.2	1.6	6.3	0.2	1.4	0.4	2.7	0.6	8.5	1.9	26.5	0.5	16.4	1.3	40.8
Crop/ Vegetation	77.7	301.6	62.4	242.6	87.5	634.8	73.7	532.2	64.7	914.3	52.0	734.2	73.8	2358.2	62.6	1996.3
Urban Area	15.3	59.4	22.5	87.0	10.3	74.5	17.6	126.9	30.5	430.3	40.2	567.2	20.9	668.8	27.1	863.6

Figure 2-8 Phnom Penh land cover change 2014 – 2020. Land cover was derived from Landsat Satellite imagery using Random Forest Classification (RFC) methods.

Geology

The Geology of Cambodia is dominated by young and old alluvial deposits in the lower elevations, with more variations seen as the elevation increases, generally towards the Cardamom mountain range and upstream of the Mekong catchment (Kubo, 2008). Here, typical geological formations include Jurassic-Cretaceous Sandstone, Devono-Carboniferous Sandstone and Shale, Basalt, Lower-Middle Jurassic Formations, Triassic Sandstone, Rhyolite and Dactite, and Precambrian Formations of Amphibolite, Quartzite and Gneiss (Figure 2-9). Within the study area the geology is almost exclusively composed of young alluvium.

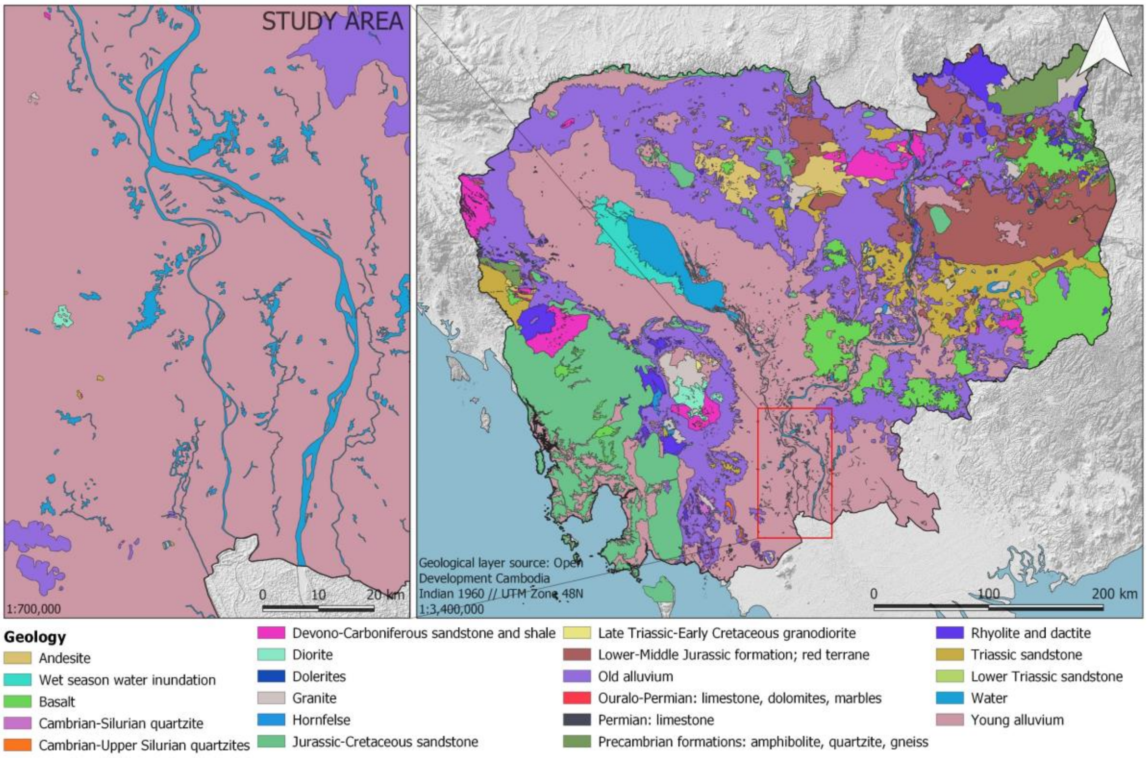


Figure 2-9 Geology of Cambodia (2006). Source of data https://opendevelopmentcambodia.net

<u>Soils</u>

Agriculture in the study area is strongly influenced by the variations in soil type shown in Figure 2-10. Across the majority of the floodplain soil type is dominated by Acrisol, characterized as a strongly weathered acid soil with low base saturation, formed by the process of acid rock weathering. Acrisol is considered a relatively unproductive soil due to aluminium toxicity, strong phosphorus sorption, slaking/crusting and a high susceptibility to erosion, although agricultural productivity increases when acid-tolerant, undemanding crops are grown (Buol, 2005).

Also found in these areas are sections of Plinthosol, Leptosol, Planosol and Gleysol. Plinthosol is an iron-rich clay soil containing plinthite (Blake *et al.,* 2008). Leptosol are very shallow soils located over hard rocks, common in mountainous regions. In the study region, Leptosol deposits are found in proximity to rocky outcrops, or 'phnoms'. Planosol can be identified by their coarser textures and are most often found in seasonally waterlogged regions mainly used for rice production.

Areas in proximity to the banks of the Bassac and Mekong primarily consist of Cambisol, a young, medium-fine textured soil derived from alluvial rocks. Considered a productive soil, Cambisol is used intensively for agricultural practices (Chesworth *et al.,* 2008). As identified above, deposition of this sediment along prek channels improves the agricultural productivity by elevating the land above high flow levels and replacing the relatively infertile Acrisol.

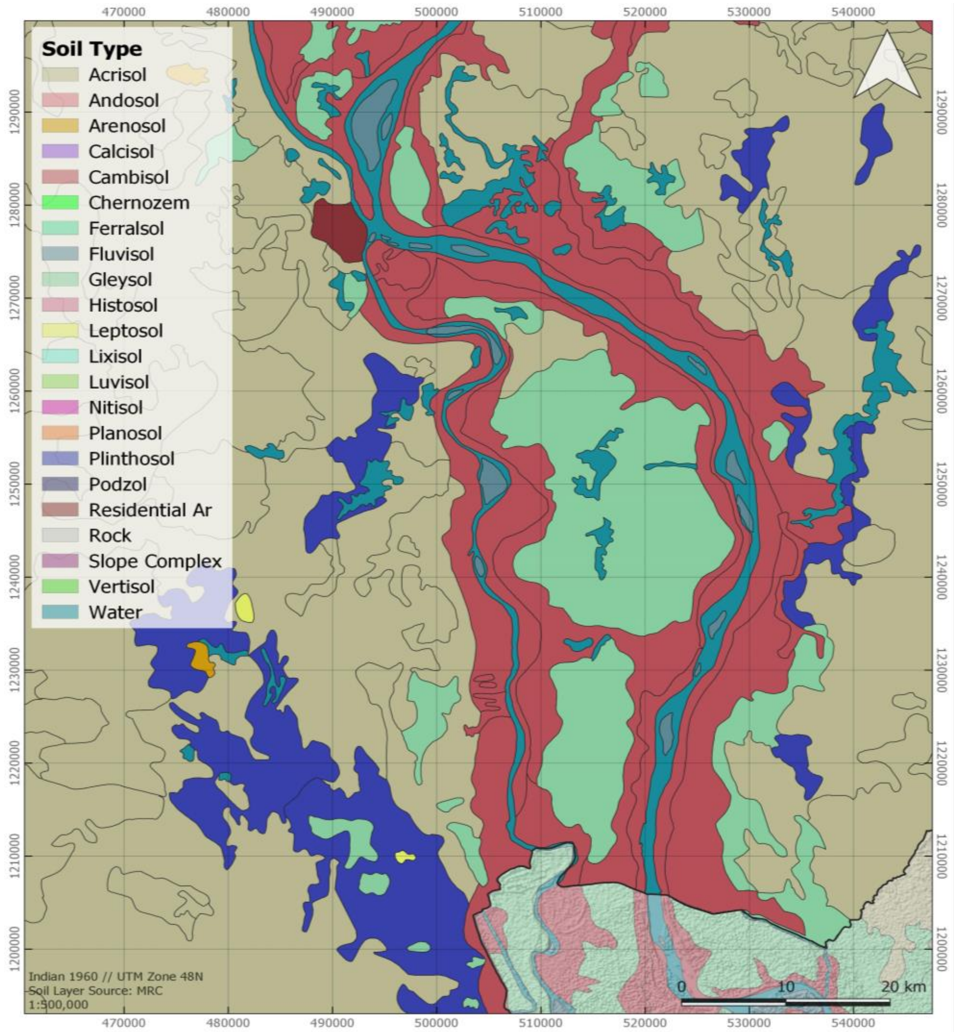


Figure 2-10 Soil types within the study area. Source of data : MRC

The Bassac marshes located between the Bassac and Mekong channels is made up of Gleysol, a wetland soil formed under waterlogged conditions typically used to cultivate rice. In the Bassac marshes, rice production tends to occur around the periphery, where water depth remains shallow annually (Sposito *et al*., 2016). Acid sulphate issues may become a problem if soils are drained.

Within the Bassac and Mekong channels, bars and islands are composed of Fluvisol, which develops in alluvial deposits near riverbeds (Jordanova, 2017). This soil is typically characterized by stratified layering of varied textures, resulting from the periodic depositional events occurring during periods of flooding. The surface primarily contains a sandy-clay loam and features high porosity (Belay *et al*., 2019).

Rainfall

Rainfall plays an important role in the provision of water to the vast low-lying floodplains, referring both to the localised rainfall within the area for immediate use or storage, and through increasing the water level within the main river systems to increase/ enable flow within the preks. In Cambodia, rainfall has significant seasonal variations with more than 80% falling in the rainy season, from July to December (MRC, 2005).

Figure 2-11 shows the mean annual rainfall from 2000 – 2019, derived from CHIRPS satellite data processed using Google Earth Engine. Rainfall exhibits a strong positive correlation with elevation with the lowest values occurring in the lower regions of the country, as low as 1250 mm to the north-west of Tonle Sap and south of Phnom Penh in the study area. The higher precipitation zones occur in the upper regions of the Mekong River catchment and along the Cardamom mountains to the south-west. Despite rainfall being lower in the Preks Study area, gauge records will be analysed and used in the modelling. Water levels in the channels are highly seasonal and tidal as will be discussed in Chapter 4.

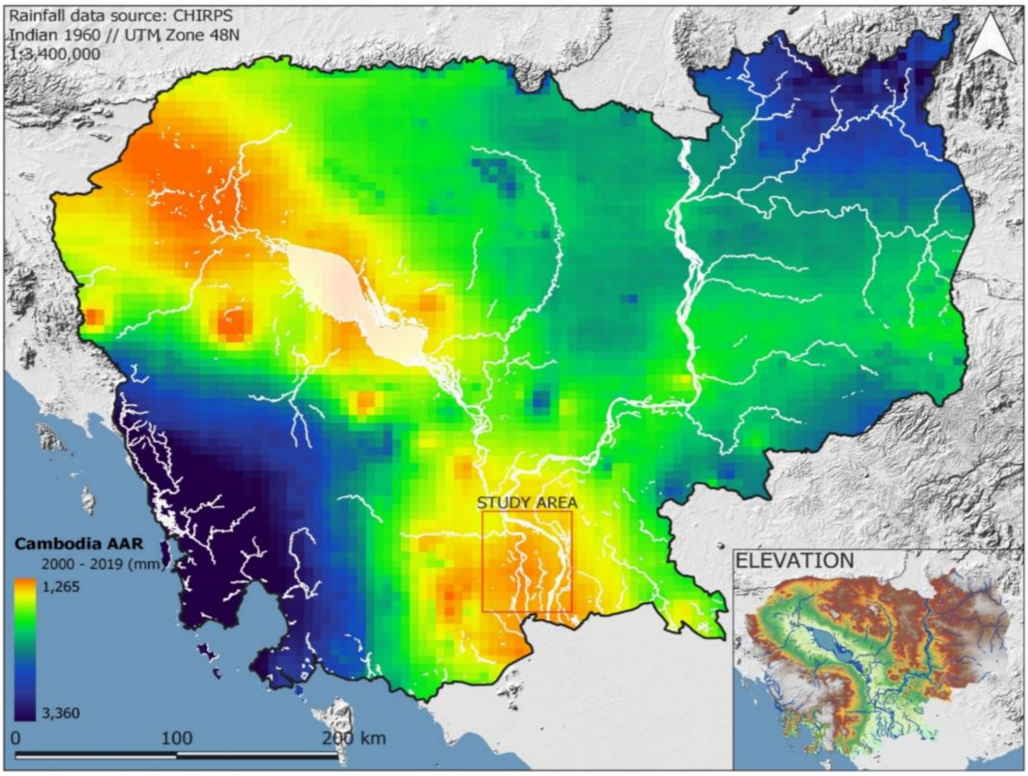


Figure 2-11 Average annual rainfall in Cambodia from 2000 – 2019, derived from CHIRPS data in GEE. Accessed December 2020

3 Conceptualisation & Design of the Modelling Framework

3.1 Scope and Aim of the Modeling Work

The requirement for increasing the understanding of the hydrological and hydraulic systems of the 'Mekong Bassac' reflects back on the needs for agricultural development in the prek areas, given increasing difficulty for farmers to access water from the channels which become disconnected from the Bassac longer during the dry season.

The aim of the work must be to describe and provide a better understanding of the dynamics of the hydraulic system affecting the floodplain areas of the Bassac and Mekong downstream of Phnom Penh, to provide information on the spatial and temporal dimension of the flood issue and, for low flow and drought conditions, to give a better understanding and assessment of the capacity and flows under different conditions in each prek channel. It is necessary to derive and prove the modelling against observations and satellite detected flood extents.

It was recommended in the terms of reference that a 2D hydraulic model of the area may be required to give sufficient detail and this aligns with the model set up as described in the next section.

The full Mekong Basin has a catchment of 760,000km^2 comprising territory in six countries resulting in a runoff on average of 475km^3. The floodplain area of the West Bassac in Cambodia is about 1,870km^2 and in the Trans-Bassac 980km^2. The irrigation service area of one of the larger individual Prek service area is around 500ha or 5km^2 and a typical farm unit 0.01km^2. At each scale there are thus multiple scales necessitating different analysis/approaches Table 3.1. Whilst the focus and the most detail and attention is focussed on the Preks area, factors affecting the local behaviour also need to be taken into account. For some of the upstream influences it is necessary to rely on previous studies such as the effect of climate change on flows.

The modelling is carried out within an overall framework of analysis including ii) extensive use of remote sensing and ii) analysis of the physical measurements of water levels and flow, survey and observations iii) modelling. Each aspect is complimentary and interpretation is made using all the available information.

Throughout the modelling exercise, close collaboration with the other components of the WAT4CAM project have been maintained to exchange knowledge and ensure that the model results are suitable to inform individual rehabilitation studies and an overall preks development plan.

Table 3.1 Scale of Hydrological Issues affecting flows down to a local scale

Scale	Location	Area (km2)	Proportion of Mekong
Basin	Total Mekong Catchment	760,000	100
National	Cambodia Mekong Basins	181,000	24%
Tributary	Prek Thnot	7,055	0.9%
Tributary	Stung Slakou	2,485	0.3%
Floodplain Zone	West Bassac Floodplain	1,870	0.2%
Floodplain Zone	Trans- Bassac Floodplain	980	0.1%
Preks Area	Total Prek Service area	120	0.02%
Prek Service Area	Larger Individual Prek	5	0.001%

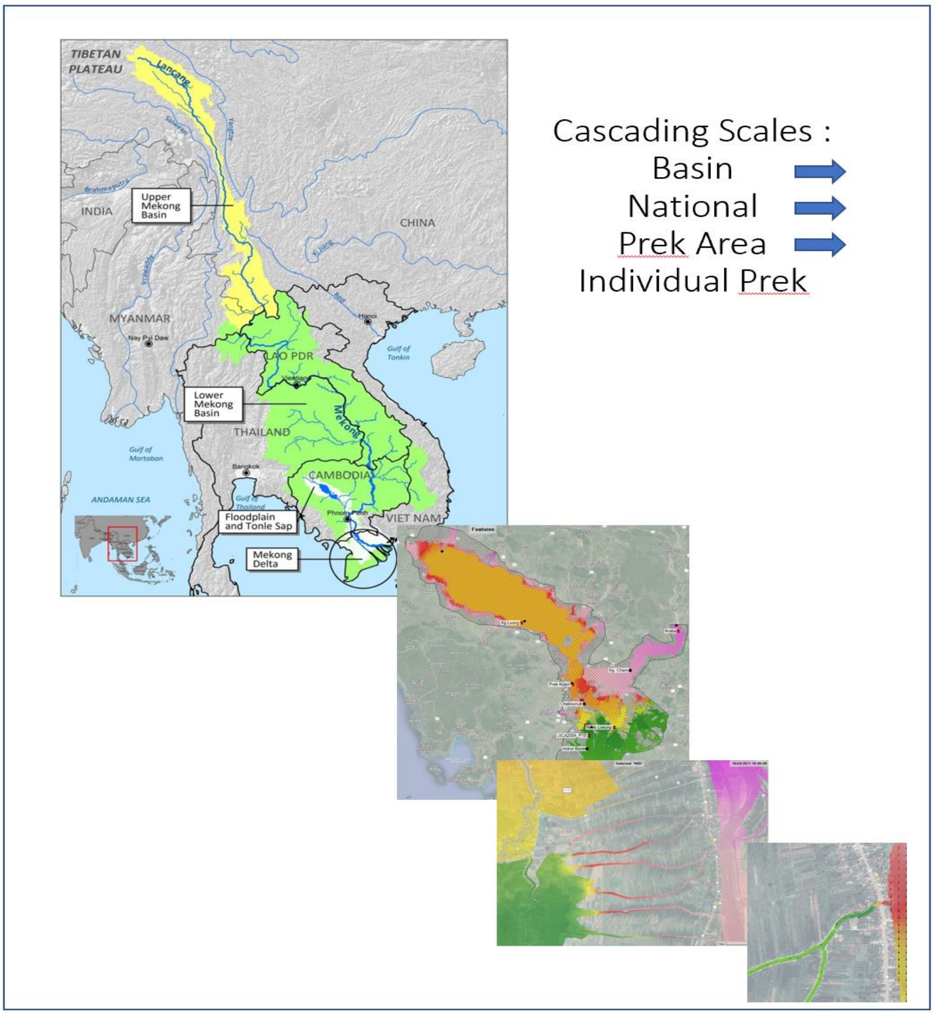


Figure 3-1 Cascading Scale of Issue affecting flows in a Prek (Basin Selection of suitable tools for modelling

3.2 Requirements of the Modeling Framework

3.2.1 Characteristics of the Hydrological System and Implications for Modeling

A number of researchers have developed models to represent parts of the Mekong River Basin such as MRCS[2], JICA[3] and academic studies such as cited by Johnston[4] have suggested that there may be a degree of 'over' modelling. However, in a large basin where rapid development is taking place the representation of land use, hydropower dams, irrigation and flood control quickly becomes out dated. Results obtained from models are then dependent on the assumptions made for hard to quantify aspects such as the reservoir operating rules. The hydraulic system in the area of the preks is affected by change occurring outside of the study area including outside of Cambodia both upstream in China, Thailand, Lao PDR and the Vietnam highlands and downstream in the Vietnam delta. Because the Mekong Bassac system is very flat below Phnom Penh, the downstream influences both flood and low flows. Other anthropogenic influences impact on water level such as the expansion of the urban area of Phnom Penh and development of infrastructure such as the new Phnom Penh International airport.

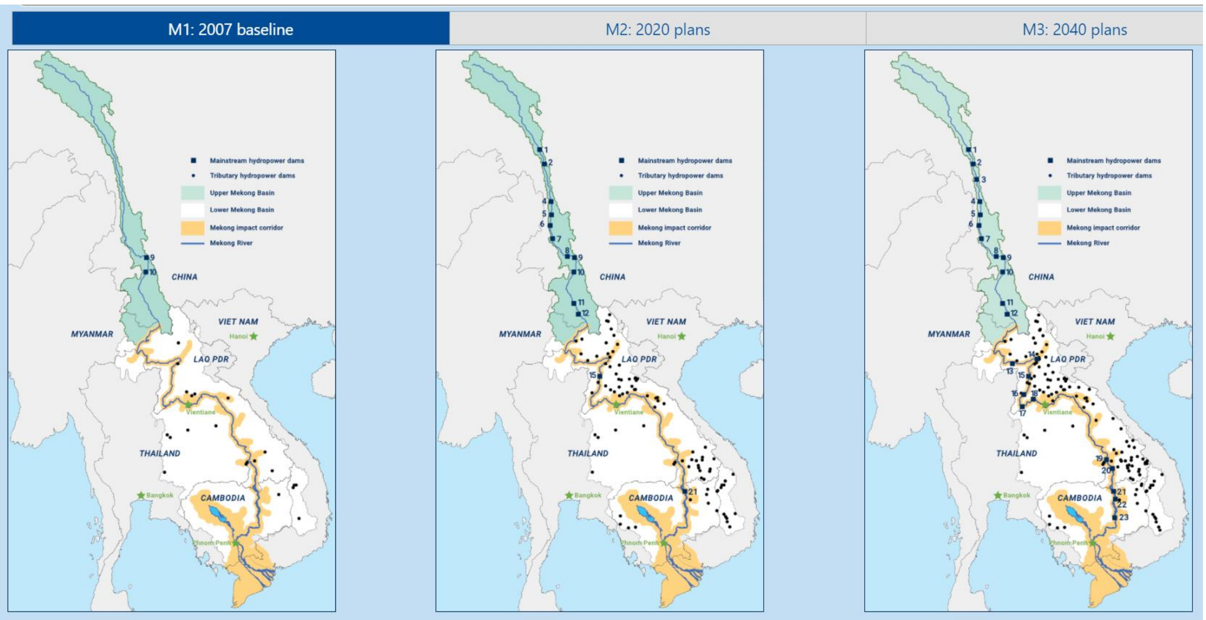


Figure 3-2 Changes in Upstream Conditions 2007/2020 and 2040 Future (MRC Council Study 2018[5])

This continually changing system can be represented through scenarios of flood and drought derived from analysis of a) **observed data** which already is showing change in

2 Mekong River Commission Decision Support Framework http://archive.iwlearn.net/mrcmekong.org/programmes/wup/DSF/DSF_Components.htm

3 JICA/CTi 2004 The Study on Hydro-Meteorology Monitoring for Water Quantity Rules in Mekong River Basin

4 Johnston R. & Smakhtin V..(2014) Hydrological Modelling of Large river Basins: How much is enough? Water Resource Management 28:2695-2739

5 Mekong River Commission Interactive Report on Council Study findings 2018 http://interactive.mrcmekong.org/council-study-findings/development-scenarios/ accessed July 2021)

recent years and b) the **previous modelling results** published by various organisations including the Mekong River Commission.

The component inputs used to determine suitable modelling conditions:

- Hydrological analysis of flow gauges, satellite remote sensing and previous studies to provide the scenarios of basin flow inputs for past, present and future events
- Hydrological modelling of tributaries where gauge or previous models are not available
- Tidal water levels in the Mekong and Bassac Rivers
- Local rainfall and evaporation

At a prek level the flows from the river or floodplain into a Prek channel were represented using:

- Detailed 2D modelling of the Cambodia Floodplain from Kratie to the Vietnam border with a level of detail sufficient to define individual preks

3.2.2 Requirements for Hydrological Scenarios

Chapter 4 elaborates on the previous hydrological studies that have been implemented in the study area. Building on the nature of previous model studies, the key new elements required for WAT4CAM study of the preks are:

1. Up to date inflows at Kratie and tributaries of the Tonle Sap and Mekong delta river basin groups including 2018-2020
2. Analysis of hydrological data to give probabilistic approach and define the scenario 'events' in past present and future.
3. Detection of past flood and drought characteristics from satellite-derived data
4. An Overall Model of floodplain areas of Cambodia including the Tonle Sap Lake
5. Detailed modelling down to the level of individual Preks
6. Simulation of tidal variation particularly in the dry season

3.2.3 Hydraulic Modelling

Recent experience in a wide range of river basins indicated that, for flood modelling and management it is highly beneficial to adopt a 2D modelling approach. The advantages over 1D modelling are many but include:

- Incorporation of model complex flow behaviour and especially flood paths
- Calculation of a range of parameters including flood hazard, flow paths that change depending on the state of flood levels
- Presentation of Outputs in a more graphical way illustrating flow paths using particle tracing etc.
- Faster production of flood maps
- Interaction with other non-specialists and stakeholders

Disadvantages, however, include:

- Much longer times for simulation which limit the cases that may be tested
- Need for more detailed input data and especially ground (DEM).
- Limited representation of crop demands

The advantages of 2D (or 1D/2D linked) models though are now well established, such that they are now standard for flood studies in places such as in UK, most parts of Europe and Australia and are becoming standardised in US. In Cambodia, 2D modelling has been more limited with MOWRAM trialling a HECRAS 2D and MRC also commissioning some 2D modelling. The additional detail and more meaningful output options are illustrated below in Figure 3-3 and Figure 3-4.

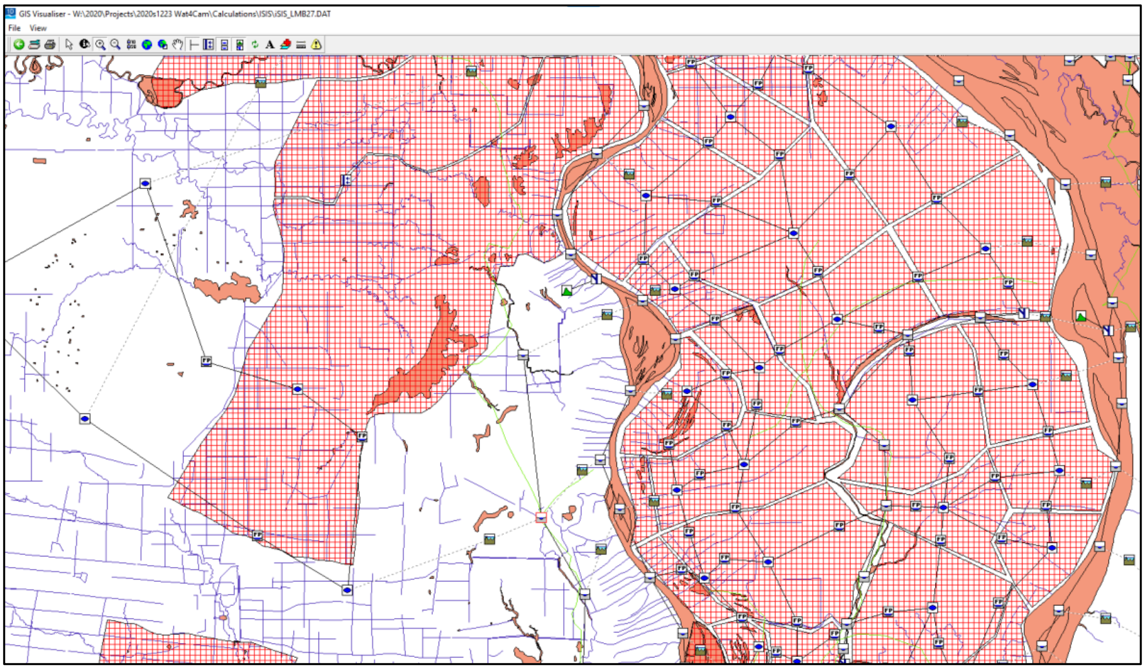


Figure 3-3 Representation of rivers and floodplain in a 1D model using cross sections, floodplain spills and storage units

Chapter 5 describes the model set-up that was developed to correspond with the requirements as stated in this chapter.

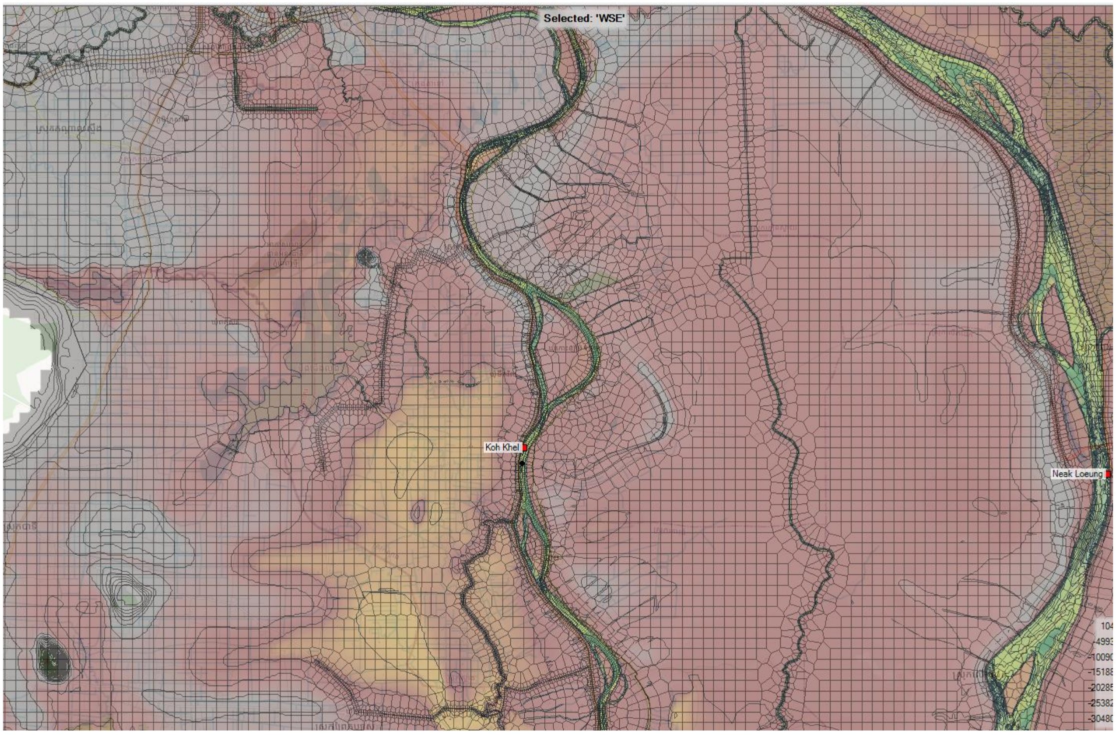


Figure 3-4 HECRAS 2D Model representation of the same area as above using orthogonal grid cells aligned with river features and rectangular grid cells in floodplain. HECRAS also captures sub grid features such as channels within the DEM not specifically defined for grid re-orientation

Key features of the HECRAS model formulation is the treatment of the grid and in the modelling full advantage is taken of the facility for:

a) Sub-grid Calculations;
b) Refinement Areas allowing more detailed grid areas to be combined in the same model with areas of higher detail;
c) Tools for rapid terrain modification – modification of a bare earth grid to include embankments (such as roads and canals) as well as river channels and canals.

The sub-grid facility is key to being able to develop a model that is both detailed enough to represent relatively small channels such as the preks whilst also representing the extensive floodplain areas of the Mekong and Tonle Sap.

4 Data Review

4.1 Approach

The data required for improving knowledge and understanding of the preks includes contextual information on the Lower Mekong river system reflecting the wider area influences on the preks study area. This includes the Tone Sap/Great Lake system and the irrigation and flood control in Vietnam. The flow in the main river is also influenced by the upstream developments and the changing climate in China, Lao PDR and Thailand, well beyond the study area.

There are significant changes occurring even within the study area including the urban growth of Phnom Penh and associated infrastructure and the changing river morphology, flow and sediment regime.

The approach adopted is to comprehensively assemble the latest available information making use of local knowledge, previous studies, models and remote sensing.

4.2 Data Requirements and Data Management

A number of types of data are needed and have been collected for the model building and analysis:

- Time Series Information (Rainfall, water levels, flows and sediment)
- River bathymetry
- Canal/prek dimensions and levels and structures
- Infrastructure such as flood banks/roads and pump stations
- Ground Level Survey and DEM
- Land Use and Agronomic Data including water uses, Irrigated Areas
- Environmental and social data
- Spatial data including base maps of rivers, canals, settlements and environmental areas
- Recorded flood levels and spatial extents
- Previous studies – including models, planning and climate change.

The spatial and temporal data are briefly reviewed in this report and their analysis and documented in the next chapter on model conceptualisation and setup.

4.3 Previous Studies and Data Collected

There are a large number of studies relevant to the water resources of the study area, some of which are specifically about Prek Irrigation Systems or the 'Colmatage' system and others concerning irrigation and water resources or floods and flood management. Other relevant studies concern the environment and social setting of the area. The transport infrastructure and urban development of Phnom Penh are also relevant as these affect the flows and floodplain management.

Information from the following were identified as key studies:

Modelling Studies

I. 1968 UNESCO Mekong River Delta Model Study. Sogreah
II. MRC 2004 Mekong Decision Support Framework Report DSF630 Development of ISIS Hydraulic Model. Halcrow
III. 2016 MRC Basinwide flood modelling
IV. 2018 MOWRAM Flood and Drought Management Study. Development of HECRAS flood model
V. 2020 MRC/FMMP Initial Studies Project Modelling Summary.

Irrigation:

I. 1994 Irrigation Rehabilitation Study UNDP 1994, Halcrow consultants
II. 1997 Agricultural Development Study of the Mekong Flooded Area JICA 1997 Sanyu Consultants
III. 1998 Project for the Improvement of the facilities of the Colmatage Systems in Kandal Province along the Mekong River JICA Sanyu Consultants
IV. 2011 CAVAC Water availability study and irrigation selection decision support system for Takeo Province. Updated Technical Report Halcrow April 2011
V. 2014 MOWRAM National Water Status Report. ADB/Egis
VI. 2018 WASP Package 2 Project Review Report 2018 AFD Sofreco
VII. 2019 ABD Rapid Assessment of Water Resources and Hydroecology. Futurewater.
VIII. 2020 WAT4CAM Component 1 Inception Report

Flood

I. 2003 MRC Consolidation of Hydro-Meteorological data and Multifunctional roles of Tonle Sap Lake and its Vicinities (Basinwide) JICA CTi/DHI
II. 2004 MRC The Study on Hydrometeorological monitoring for water quantity rules in Mekong River Basin. JICA/CTi
III. 2010 MRC FMMP Structural Measures and Flood Proofing in the Mekong Basin. Volume 6C Integrated Flood Risk Plan for the West Bassac Area in Cambodia. Haskoning.

4.4 Review of Previous Modelling Studies

4.4.1 Model Availability

As mentioned in the previous sections a number of models have been developed for the Lower Mekong. This section is focussed on the more recent modelling that is available to MOWRAM. This is primarily the 1D ISIS model from the MRC/CNMC (originally developed by Halcrow with some updating by JBA/MMA) and the 2D HECRAS model developed for the ADB flood forecasting centre project (developed by Eptisa for ADB/MOWRAM).

Through consultancy work for PIN the consultant also has access to a HECRAS2D model of the Mekong and Chbar Ampov area.

4.4.2 1-D/Pseudo 2D modelling

The 1D modelling of the Lower Mekong floodplains in ISIS for the MRCS is well documented and in active use for the studies for development and climate change. The results from this model can be analysed statistically to produce return period floods as well as for the change due to climate or upstream development. Although not adequately detailed enough for the requirements of WAT4CAM, the 1D approach gives a good understanding of the wider behaviour of the system including the tidal effects in the dry season and the operation of structures at the Vietnam border (Figure 4-1).

In the model the major channels are all represented, with the flood paths either as a series of cells and links (spill or floodplain) or as extended sections (for example Prek Ambel) where the main flood passages occur.

The large-scale nature of flood and drought behaviour is well represented in the model but details of specific areas are simplified. For example, the Preks below Phnom Penh (with the exception of Prek Ambel) are grouped and represented by spills from the Basaac to the floodplain.

The rainfall inputs and irrigation demands are included in the ISIS modelling and are suited for flood mapping and water quality simulations though it has not been used for sediment modelling. In the MRC Council Study sediment modelling was attempted using simple formulae on the deposition process.

The ISIS model is linked to a complex representation of the system of canals and banks in Vietnam which is all run on a 30 minute-1 hour timestep so as to represent the tides and is run with a 24-year hydrological timeseries (1985-2008 – period of available data).

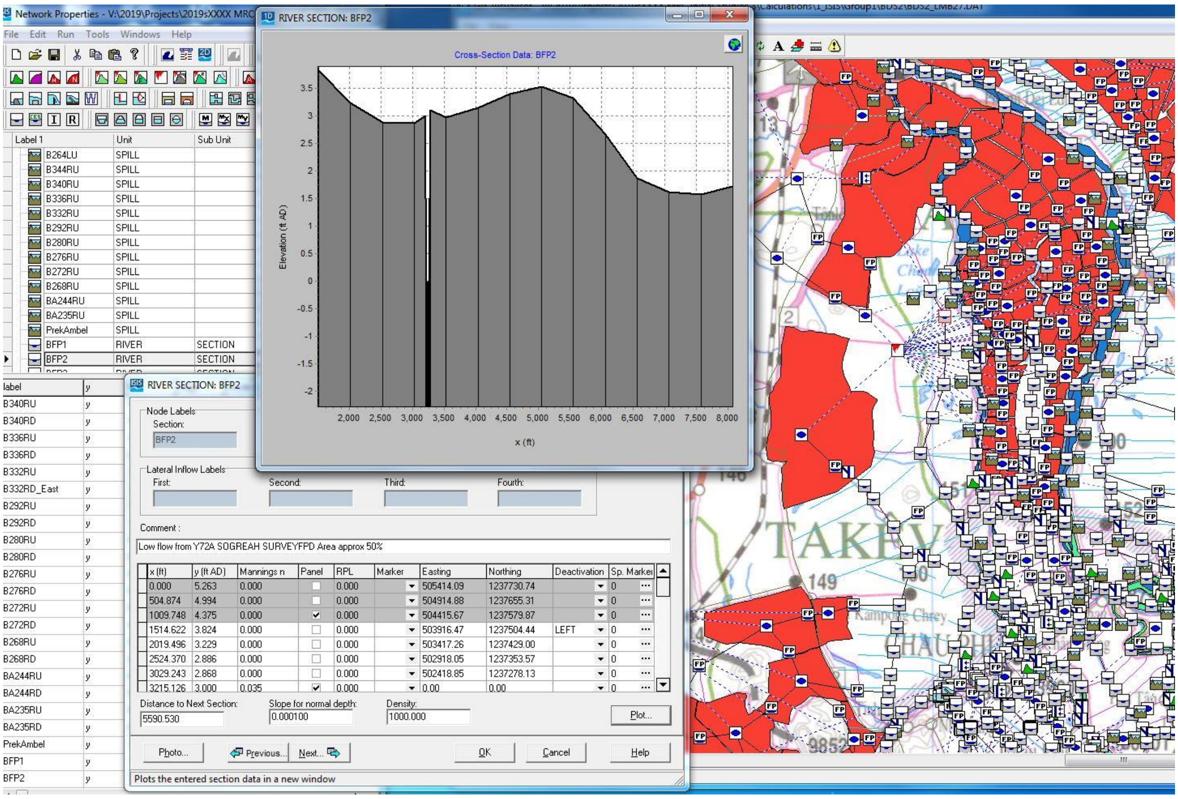


Figure 4-1 ISIS 1D Hydrodynamic Model Representation of the Preks Area (Source: MRC Model)

4.4.3 MOWRAM HECRAS 2D Model

As requested by MOWRAM, ADB supported a GMS project to establish a national flood forecasting centre for Cambodia and to improve hydraulic design standards (GMS-FDRMMP-CS 003). There were two modelling tools used in the context of flood forecasting – hydrological model and hydrodynamic model, using HEC-HMS and HEC-RAS. The data used to establish the model application were:

1. SRTM DEM 30X30 from USGS
2. DEM 200X200 from MRC
3. Land cover 2010 from MRC
4. Existing 1D hydrodynamic model river sections called iSIS from MRC
5. Infrastructures such as bridges, canals, storages …etc
6. Hydromet time series data
7. Discharge measurement on the test pilot tributary

The scope of 2D HEC-RAS covered the Mekong River, Bassac River, Tonle Sap River including Great Lake and the floodplain, Kratie where the start of lower Mekong delta for the Mekong River Basin was used as one of upstream boundaries as well as the tributaries around Great Lake (Figure 4-2). The downstream boundaries will take place at Tan Chau on Mekong River and Chau Doc on Bassac River where is the border between Cambodia and Vietnam.

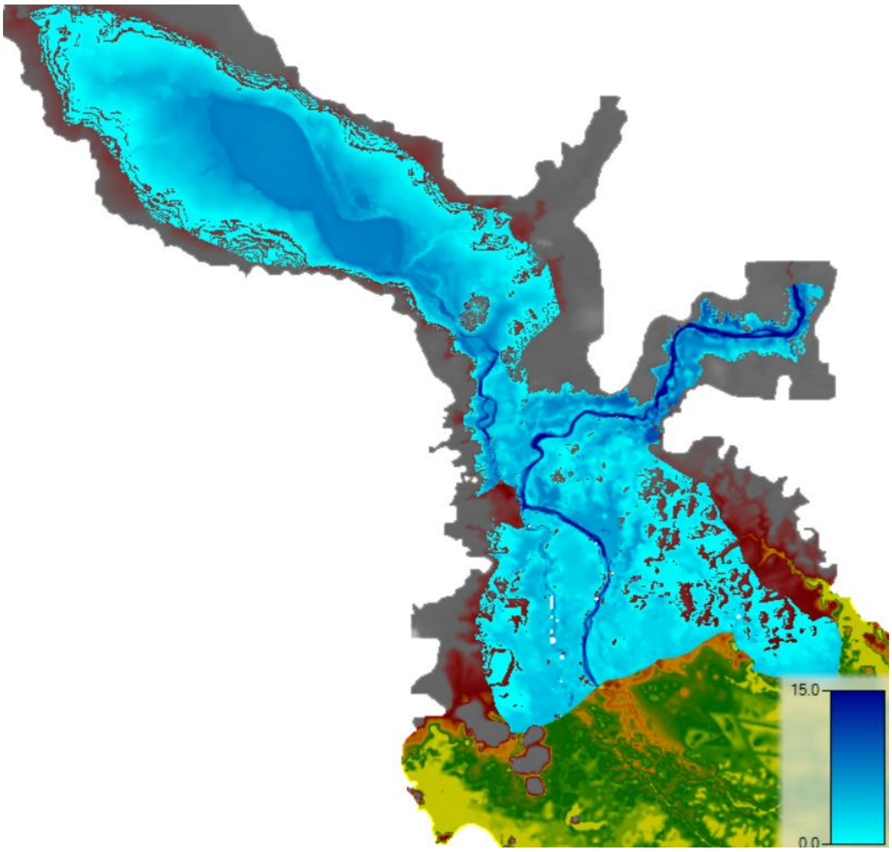


Figure 4-2 The simulation result of flood depth on 2D HEC-RAS. Source: Consultants rerun of MOWRAM model using HECRAS 5.06

4.4.4 Potential Improvements and lessons relevant for the WAT4CAM Project for the existing MOWRAM 2D model

There are a number of ways to improve the current MOWRAM model for the purposes of the WAT4CAM project for both dry season and for flood extent modelling. The detail in the model is not specific enough for the Preks study and no Preks are represented specifically. Priority details considered in the setup of the WAT4CAM model include:

- Downstream boundaries along the Vietnam border line should represent the floodplain flood routes
- Tides should be included and the model run in hydrodynamic mode
- More recent events such as 2011 and 2020 floods should be simulated for model testing and proving
- Other gauges should be used in the calibration
- Finer grid sizes should be considered in areas of study or hydraulic controls Model documentation needs to be improved

4.5 Irrigation/ Prek Development Studies

A number of studies and feasibility reports have been prepared for Irrigation development and rehabilitation in the area including the preks. This includes studies by JICA (1997) who looked at all of the flood area of Cambodia and collected a large amount of information on the preks in 1997. The number of preks in each district is given in Figure 4-3 which illustrates that Sa'aing and Kach Thum had the most preks recorded (74 and 103). For each prek an indicative channel size and depth is given which is a useful starting point for information. JICA then funded the rehabilitation of a number of preks for which more information is given in JICA(1998).

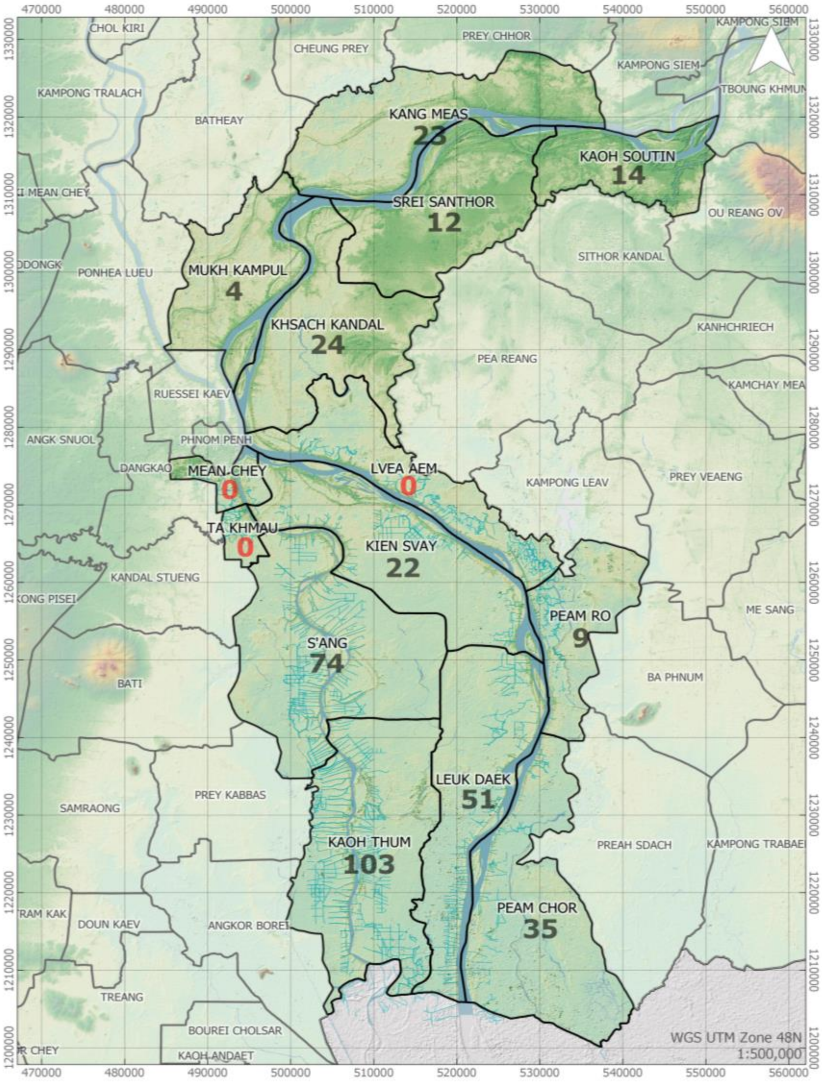


Figure 4-3 Number of prek channels in each district. Along the Mekong and Bassac Rivers. Data Source JICA (1997)

MOWRAM/Sofreco completed a review of the WASP package 2 (TA-Preks) in June 2018 and give information on 40 Preks mentioned in the ToR for WAT4CAM Component 3.1 including bed levels and length (Table 4.1 and Figure 4-4). The report also gives some information on bank collapses that occurred when rehabilitating in 2016-17 and gives a better appreciation of the problems to lower the bed levels of preks.

Table 4.1 Example of Indicative information given for 40 Preks in AFD/MOWRAM 2018/3.

No	Prek Name	Bridge Nr	Prek Length (m)	Bank Level (m asl)	Bed Level (m asl)			Prek Depth (m)
					Intake	Along	Tail	
A	TONLE BASSAC - RIGHT BANK							
1	Ta Chrouk	13	1,900	6.5-7.5	5.5	3.5-5.5	4.0	1.5-4.0
2	Ta Pem	15	2,100	6.0-7.0	4.0	3.0-5.0	5.5	1.2-3.2
3	Thmei Wat Kandal	19	2,150	6.0-7.0	4.7	3.5-5.0	3.0	2.0-3.0
4	Por	20	1,700	5.0-6.5	3.5	2.0-3.5	3.5	3.0-4.0
5	Ta Ouk	25	2,700	5.0-6.0	2.2	0.5-2.0	2.5	3.0-5.0
6	Kaev (Keo)	26	2,500	5.5-8.5	6.5	3.5-5.5	3.0	2.0-3.5

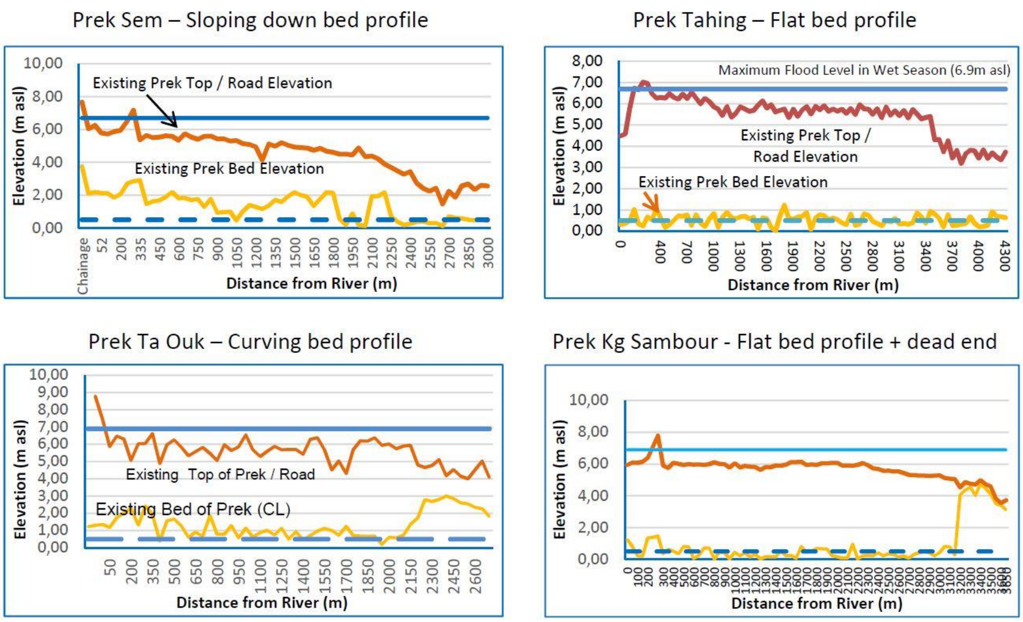


Figure 4-4 Illustrative Prek Long Profiles from Sofreco 2018 Review

AFD/MOWRAM (2018/2) completed both a Program Feasibility Study of WAT4CAM Phase 1 and a Pre-Feasibility Study for 'Batch 1' preks under WAT4CAM in July 2018 (Figure 4-6). In these reports the selection of 40 preks for further study (Figure 4-5) was made on the criteria:

- Step 1: global analysis was conducted on 78 preks. Three groups of preks were identified under the project area on right bank of Bassac River:
    1. Preks that link by Stung Thnot depression at their tail;
    2. Prek located between Bassac River and Prek Ambel;
    3. Prek located between Bassac River and Tlum Ktum canal.

All 40 were selected are in Kandal Province with most along the Basaac and some along the Mekong.

The hydraulic and hydrological modelling should thus enable a better understanding of the working of individual preks and should be able to analyse aspects such as (i) water demands and channel capacity, and (ii) the use of gates at the entrance to a prek. If these are closed at high river levels, then there are potential adverse effects given a) the role of preks in connecting the main river to the floodplain without which river levels will be higher and other channels are likely to erode; b) The tendency for siltation upstream of the gate c) fisheries d) navigation e) the role of Preks to supply water elsewhere than the immediate vicinity of the channel itself.

Comparison of total irrigation demand to the channel capacity will be helped by means of the data within the Cambodian Irrigation Information System (CISIS) on crop areas for different seasons (Figure 4-7).

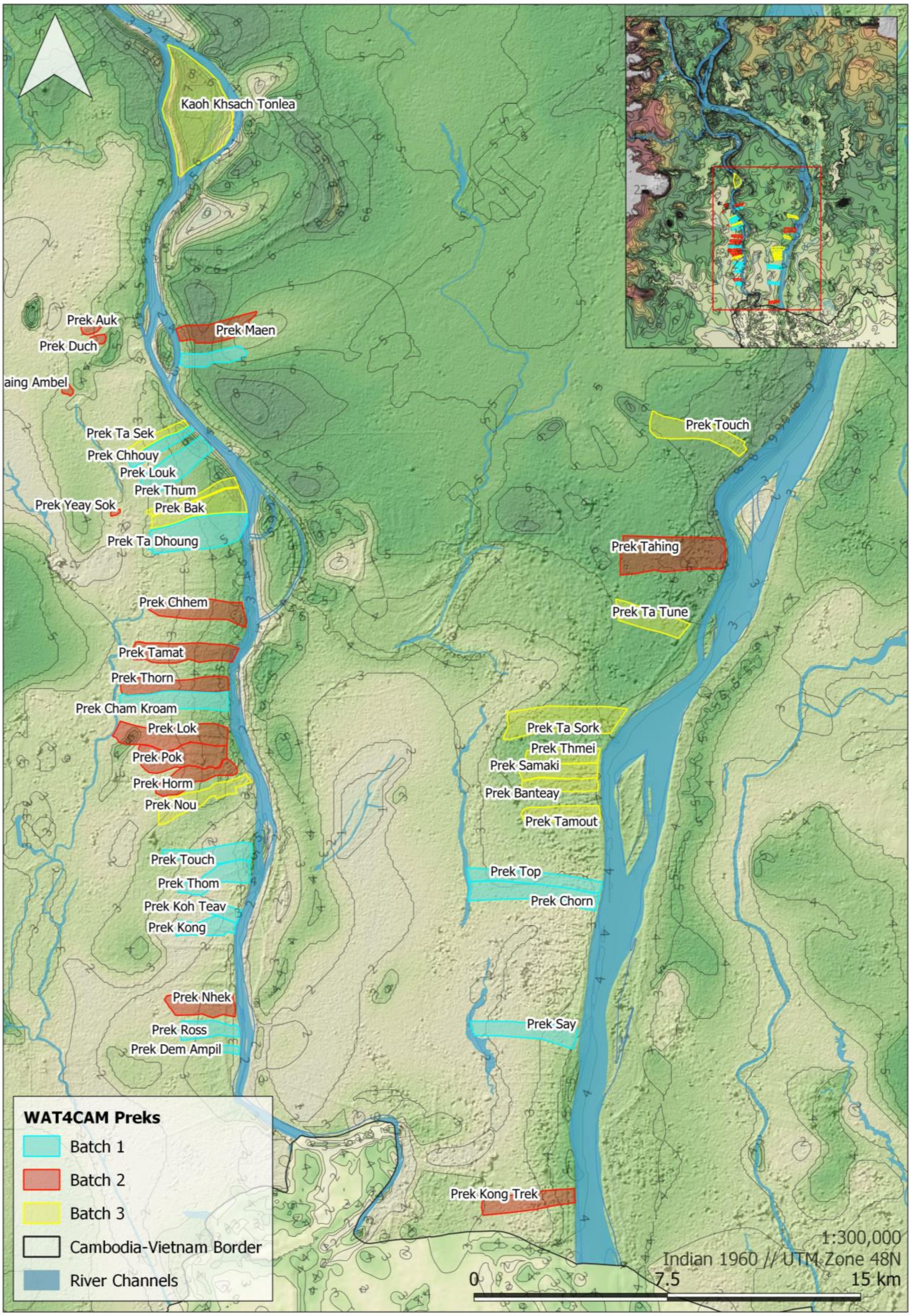


Figure 4-5 WAT4CAM Preks from batches 1, 2 and 3. Source: Consultants redrawing of figure in ToR

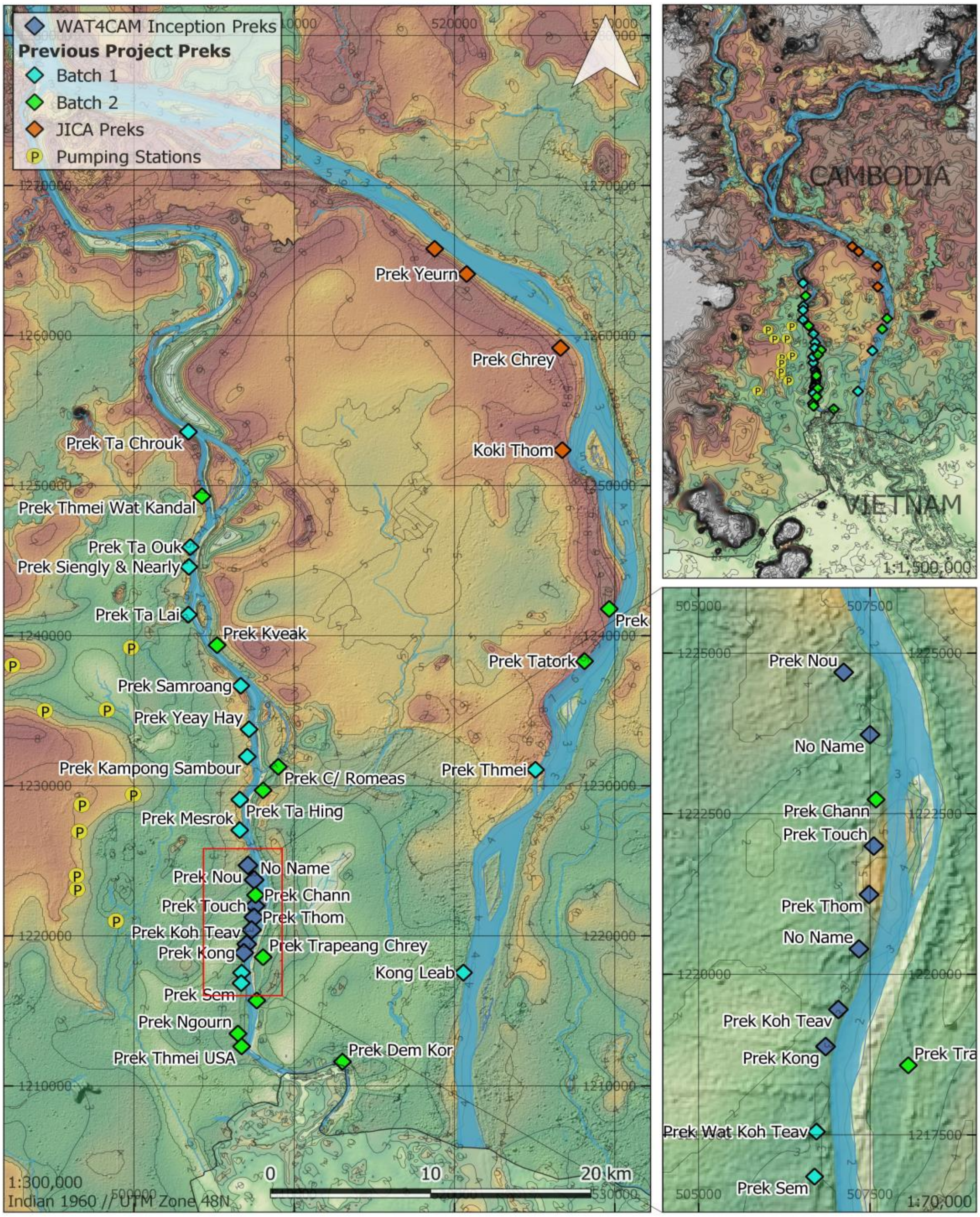


Figure 4-6 Location of Preks and Pumping Stations concerning previous projects (Left) and current project selected for Component 1 (Right). Source: Consultant processing of WAT4CAM Component 1 data

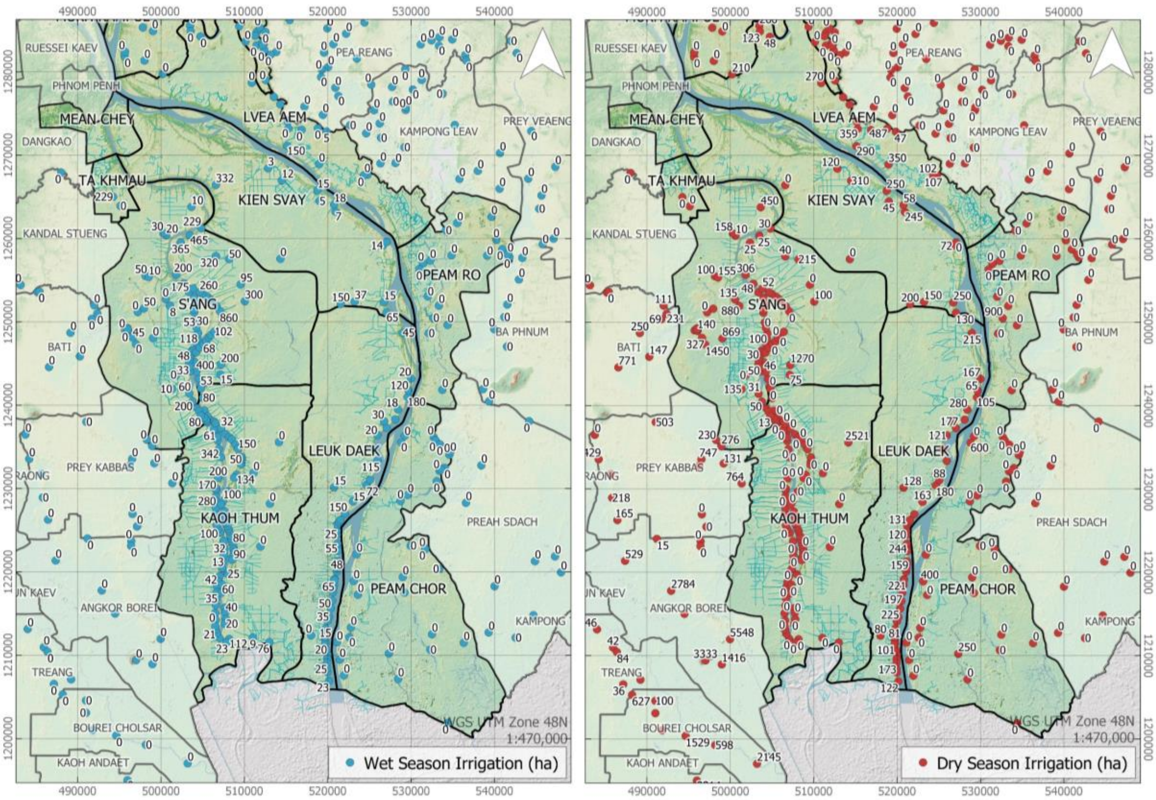


Figure 4-7 CISIS Areas of irrigation (ha) during the wet (left) and dry seasons (right) seasons. Source of data: MOWRAM CISIS database

4.6 Previous Flood Studies

Key Flood Studies listed above have defined issues for planning including:

1. Development on the floodplain resulting in higher river levels
2. Transboundary Impacts close to the Vietnam border
3. Upstream impacts including climate change

Recent MRC studies have defined the likely flood management of the West Bassac area. These areas are split into early flood protection zones and full flood protection zones, referring to the relative duration of protection per annum (Figure 4-8 and Figure 4-9). Early protection zones are only protected towards the beginning of the wet season to maximise rice production whilst river discharge remains relatively low.

As flow increases towards the middle and end of the wet season, these zones become inundated and protected extent is reduced to the ‘full flood protection zones’. These regions are slightly higher in elevation and contain urban areas, key transport routes and perennial crops in addition to rice paddies. The flood extent from September 2011, as seen in Figure 4-8, highlights that during high flow some of these full flood protection zones can also become inundated.

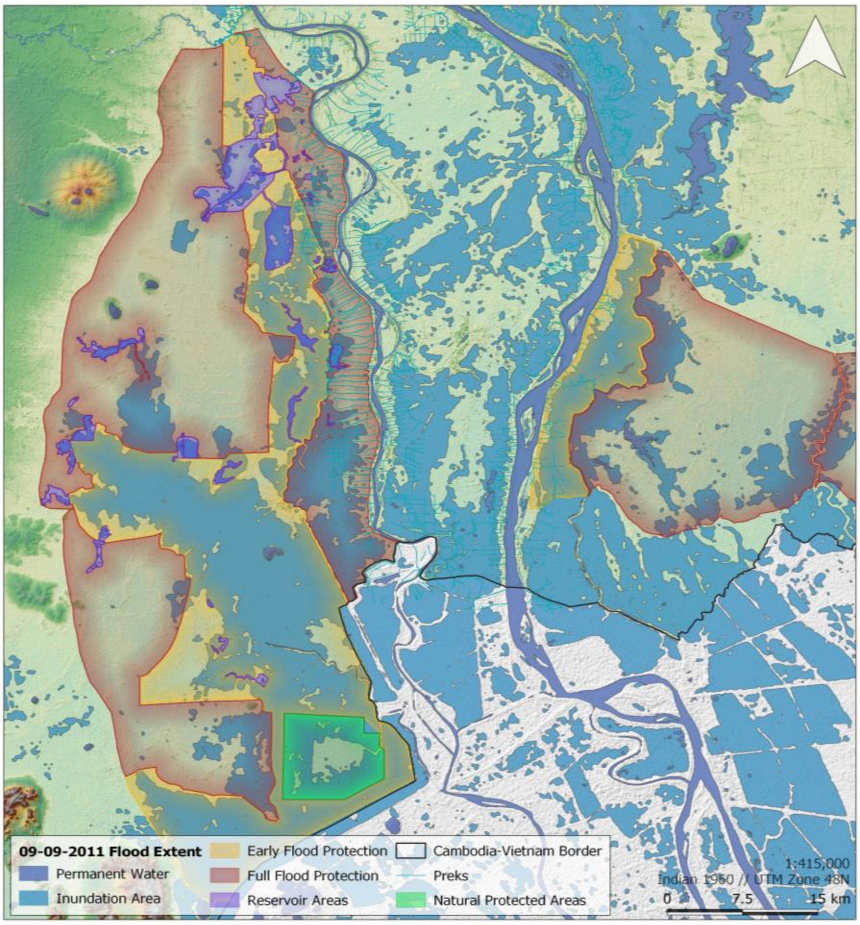


Figure 4-8 Ecological and flood protection planning zones within the study area. Source: Consultant redrawing of MRC figures, open development Cambodia GIS data for protected areas

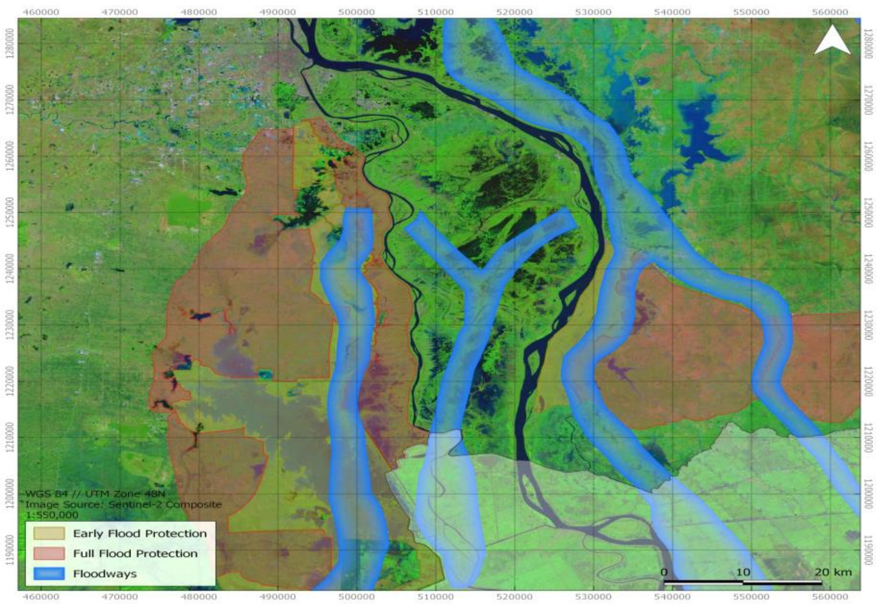


Figure 4-9 Flood Management suggested for the West Bassac Area in MRC Studies 2010 (shaded) and MRC Initial Studies Project (2020). Potential floodways in blue (Source Consultant redrawing of MRC FMMP 2020)

4.7 Time Series Availability and Assessment

4.7.1 Review of Data Availability

Extensive data is available for both time series and spatial data to use in the modelling. Primary sources of data to be used in modelling are listed in Table 4.2

Table 4.2 Primary Data Sources for Hydraulic Modelling

Data Type	Location	Source	Acquisition Year(s)
Bathymetric Surveys	Bassac River	Ministry of Public Works and Transport Department of Highways (MPWT)	2001
			2020
	Prek Selection along Bassac	WAT4CAM Component 1/KCC	2019
Daily Water Level & Discharge Gauge Data	Bassac River: Koh Khel	MOWRAM	1991 - Present
	Bassac River: Bassac Chaktomuk		1980 - Present
	Mekong River: Neak Luong		
Rainfall Gauge Data	Kandal and Takeo	MOWRAM	Daily
	Chaktomuk Tan Chau	MRC	15 Minute rain gauge at WL station
	Chaktomuk	MRC	01/01/2010 - Present
Tidal Water Level (15 minute)	Chau Doc	MRC/MOWRAM	16/08/2010 - Present
	Tan Chau		16/08/2010 - Present
	Study Area Extent		1963-2003
Digital Elevation Model (100m)	Floodplain below Kratie	MRC Sogreah survey digitised MRC 2003 combined with Columbo and Philippine survey and Vietnam gridpoints 1980	Compiled by MRC in 2003 from surveys in 1960s.

Channel flow within the study area is dictated by the seasonal variations in rainfall and snowmelt in the catchments of the Upper and Lower Mekong, a river basin of 790,000km^2. Due to the location of the Bassac-Mekong bifurcation, just downstream of the Tonle Sap-Mekong confluence, this also strongly associates with the unique flow regime of the Tonle Sap. As the dry season begins and water level in the Mekong and Bassac decreases in November/ December flow is reversed and travels back towards the Mekong. The system has strong seasonality with a flood pulse in the wet season, during which discharge in the Mekong averages 9,540 m^3/s higher than that of the dry season at Phnom Penh (see also Table 7.4).

4.7.2 River Discharge and Water Level

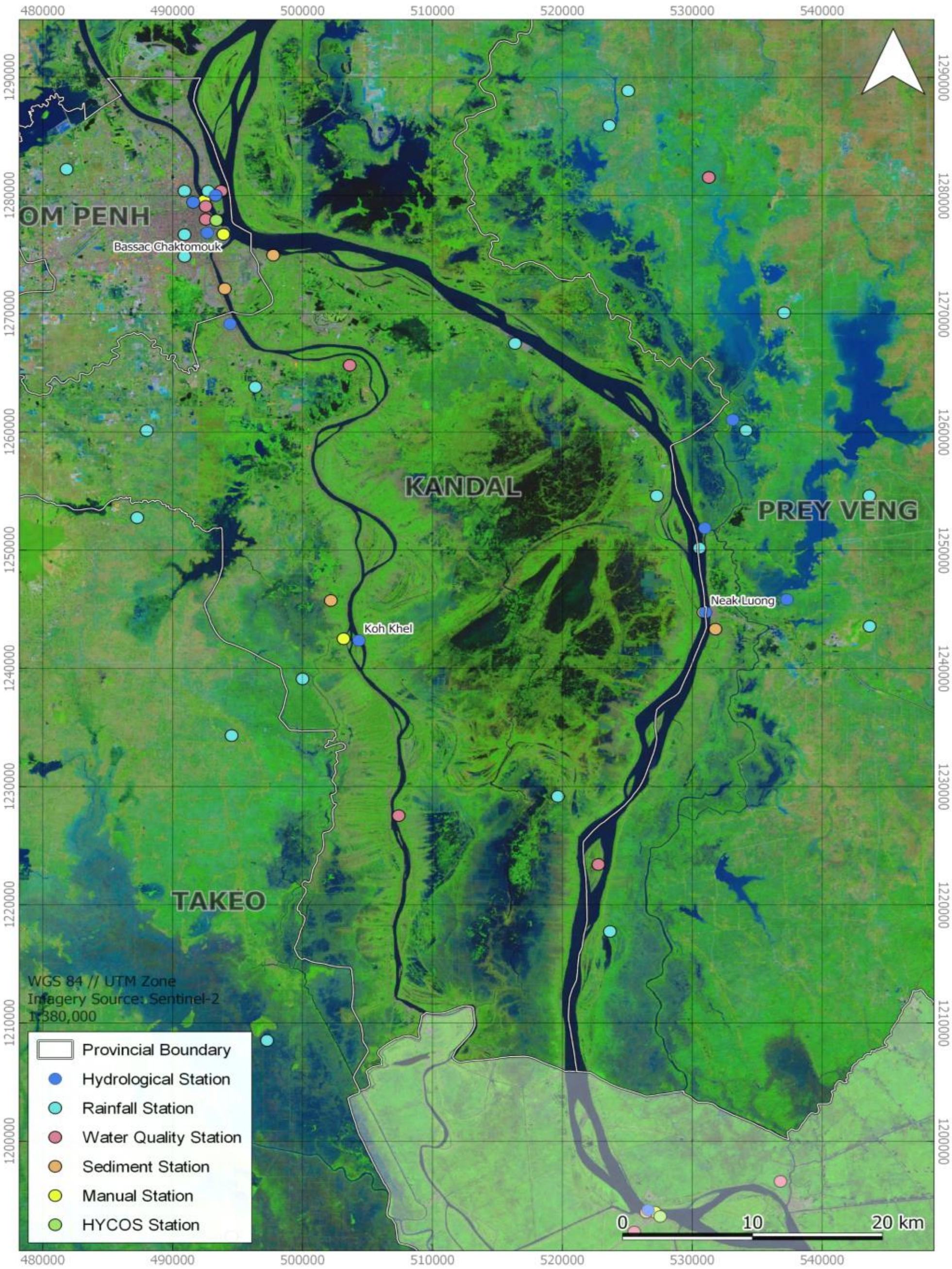


Figure 4-10 Hydrological & Meteorological Station locations within the study area. Key stations are labelled. Source of data MRC station locations GIS 2010 with corrections

Figure 4-10 shows the location of all monitoring stations, with the key hydrological stations labelled. Stations at Chaktomuk and Neak Luong have daily discharge and water level records from 1980 to present, whereas the Koh Khel station data starts from 1991 to present. The daily discharge and water level records can be seen below in Figure 4-11 and Figure 4-12 respectively.

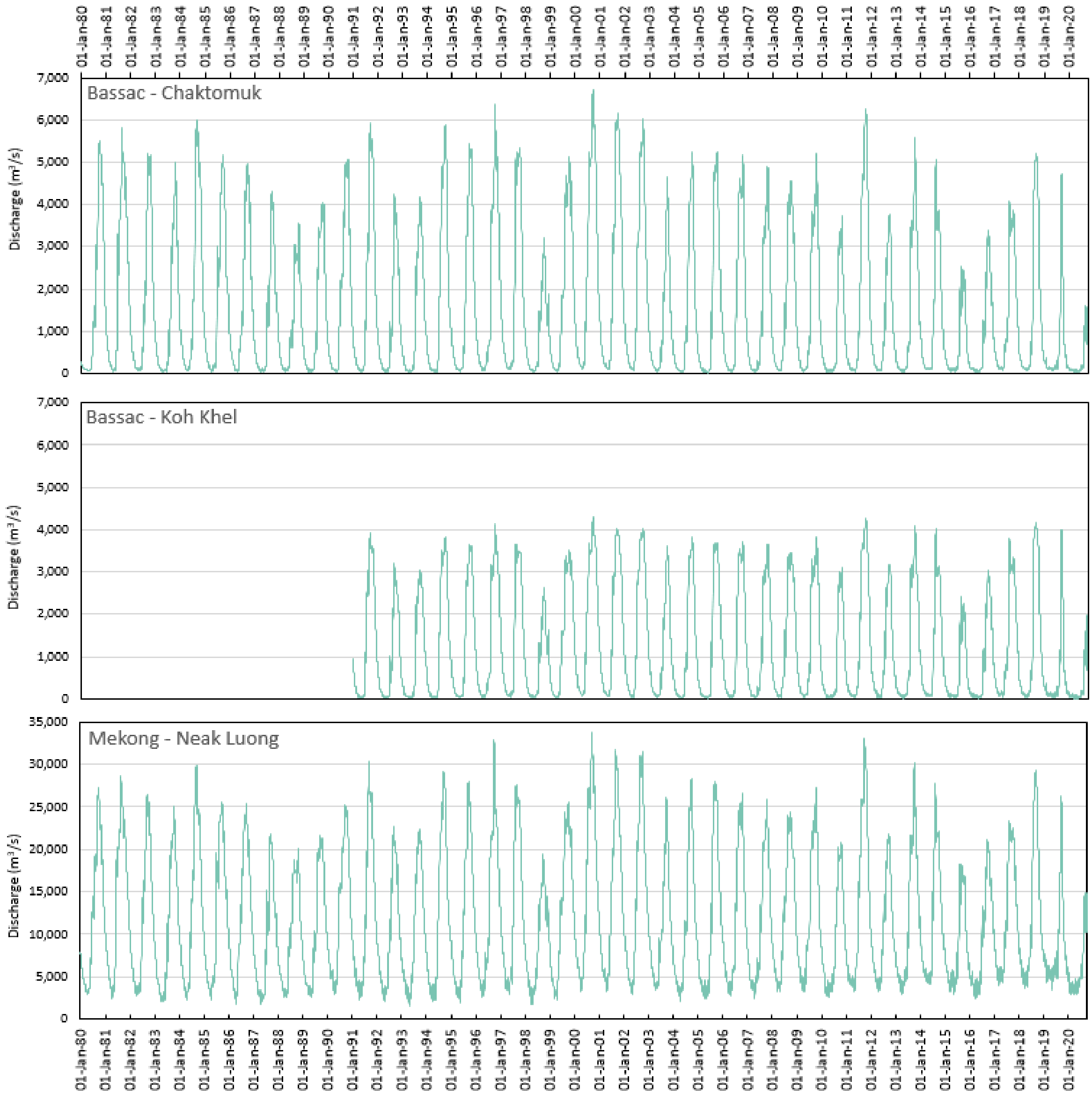


Figure 4-11 Daily discharge data at the 3 main hydrological stations. Source of data MRC water levels consultant analysis of rating curves

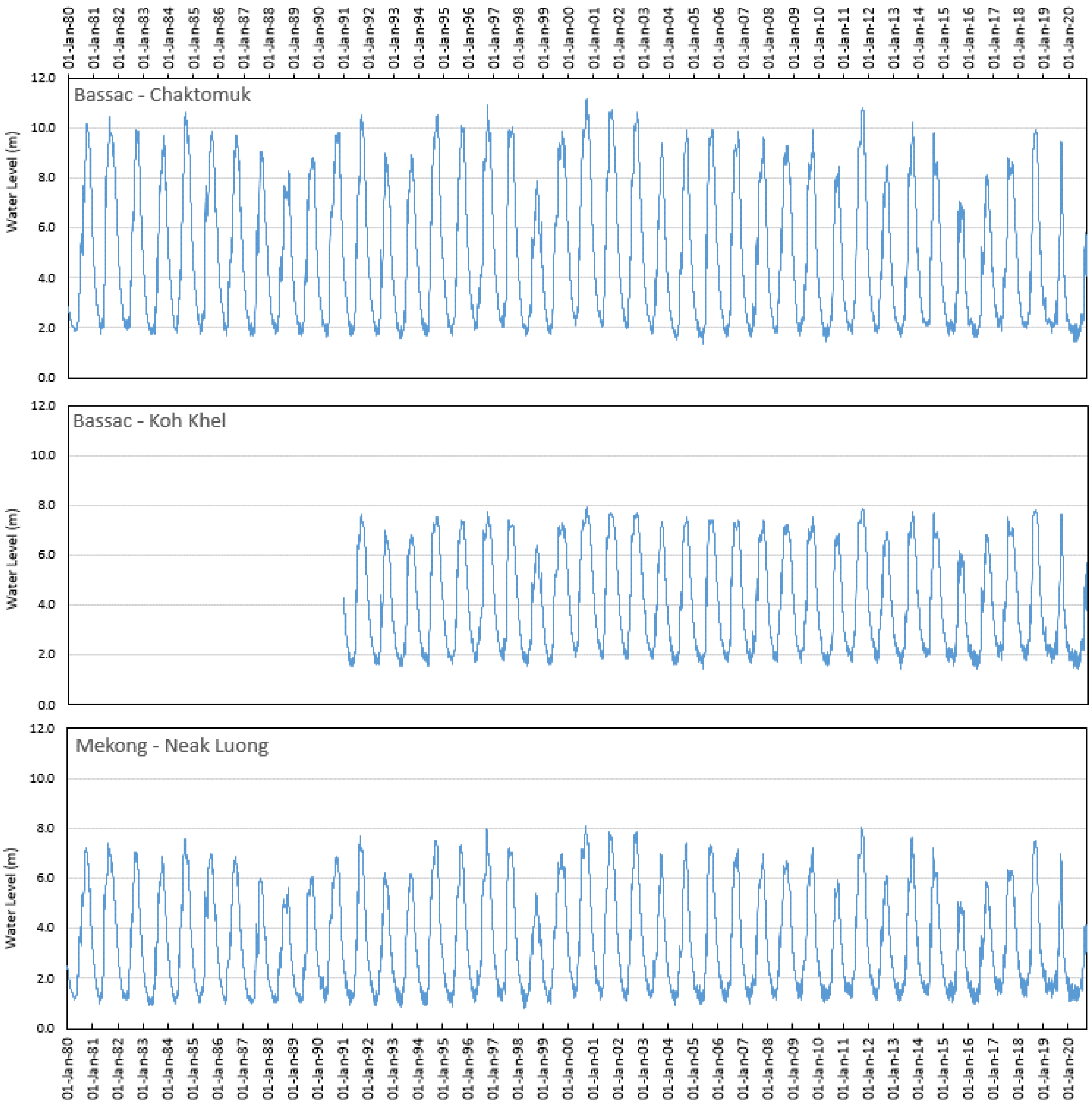


Figure 4-12 Daily (gauge) water level data at the 3 main hydrological stations. Source of data MRC

4.7.3 Water Level Preliminary Analysis

Gauge levels for Kratie, Chaktomuk, Neak Loung and Koh Khel, the main stations in the Preks area were plotted seasonally for wet and dry seasons as shown Figure 4-13 and Figure 4-14. This highlighted a concern that recent years are significantly different to the longer-term average which makes a quantitative analysis of the current situation more difficult. Data was then plotted as monthly frequencies violin plot and the same plot with the last five years plotted separately as shown in Figure 4-15 and Figure 4-16. The recent years shown deviate significantly especially for the wet season and early dry.

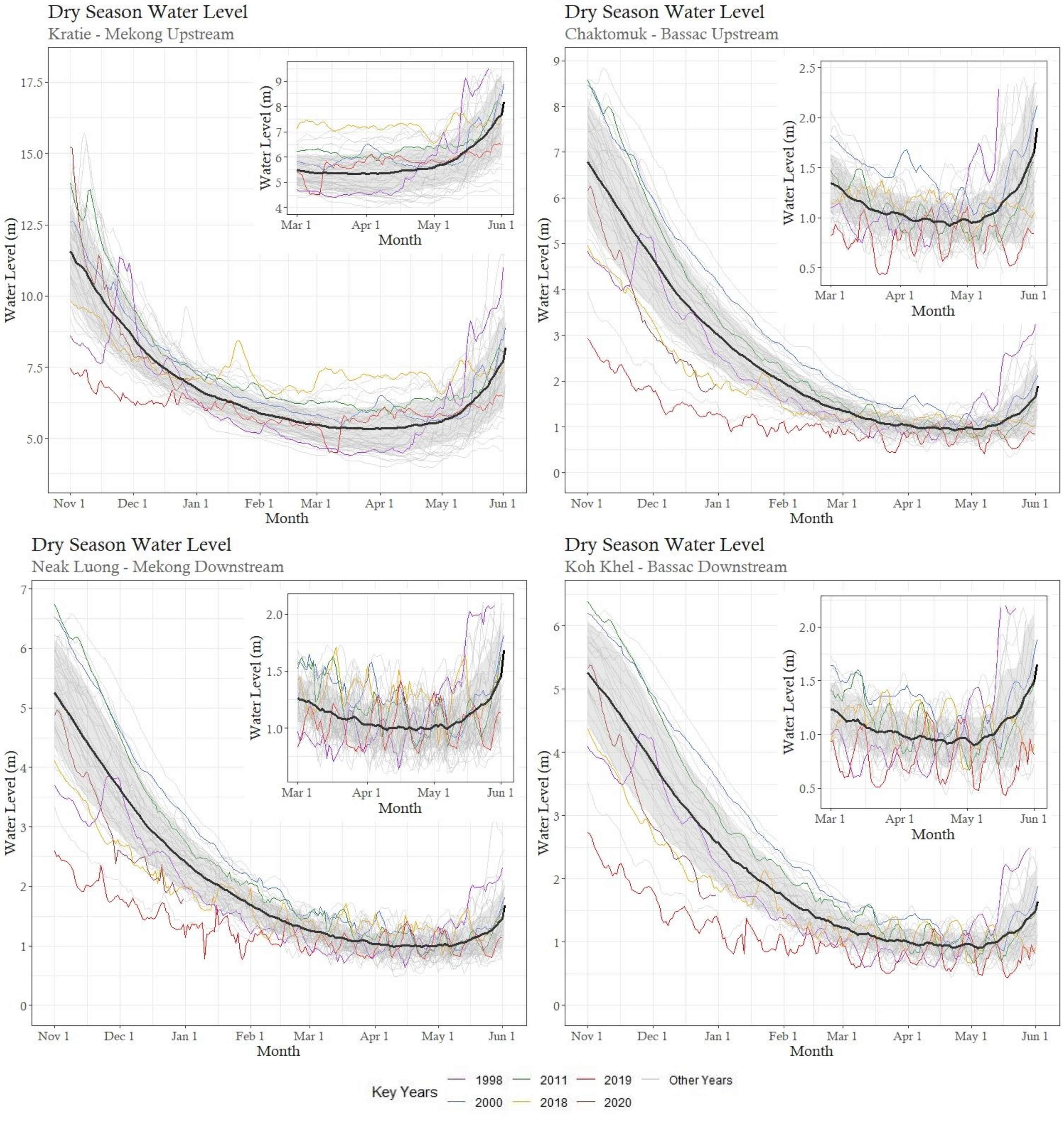


Figure 4-13 Dry Season daily water level at the Kratie, Chaktomuk, Neak Luong and Koh Khel gauges. Mean water level is shown in black, with 1 standard deviation bounds shaded in grey. Coloured lines represent the key high and low flow years identified.

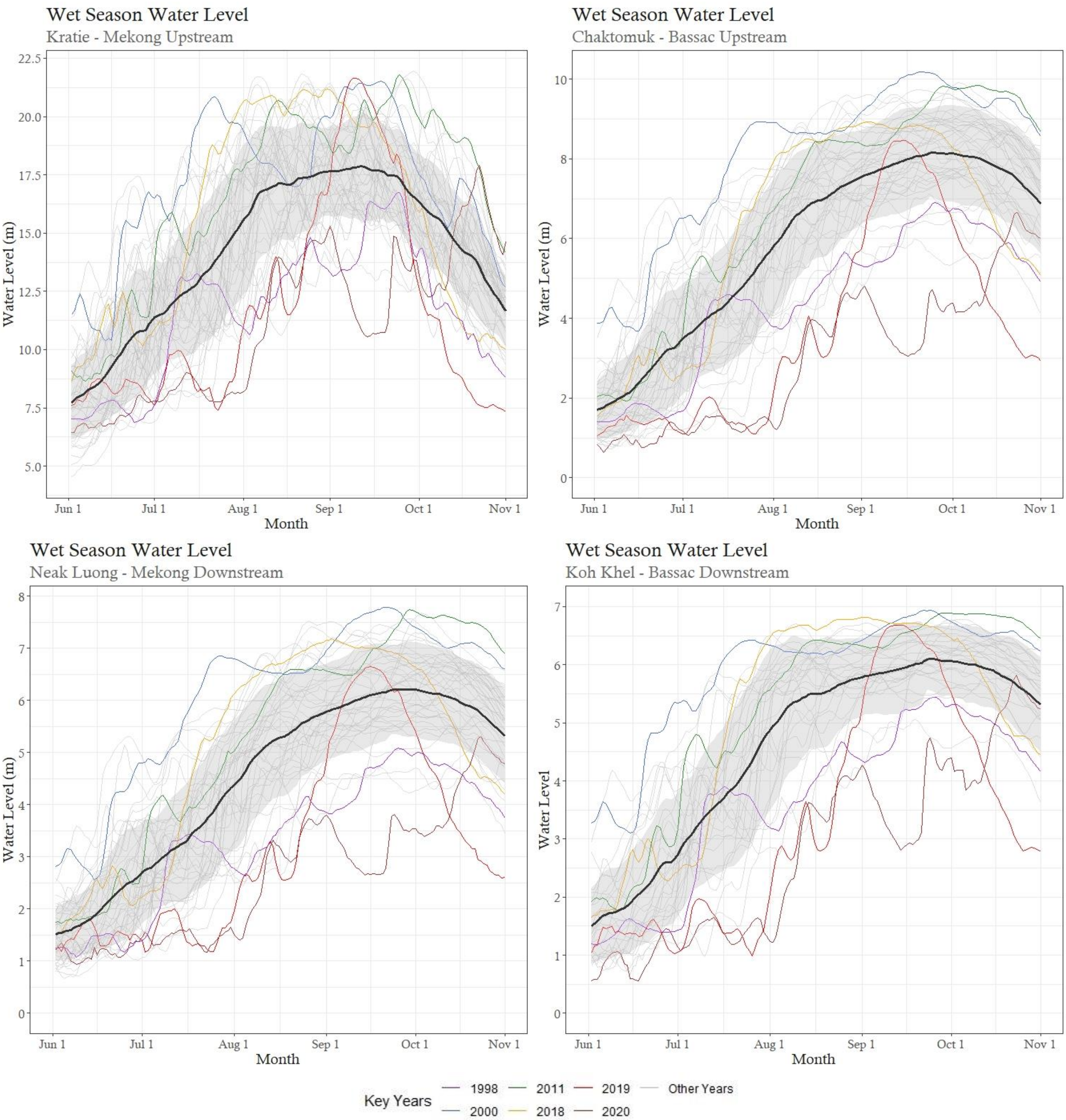


Figure 4-14 Wet Season daily water level at the Kratie, Chaktomuk, Neak Luong and Koh Khel gauges. Mean water level is shown in black, with 1 standard deviation bounds shaded in grey. Coloured lines represent the key high and low flow years identified.

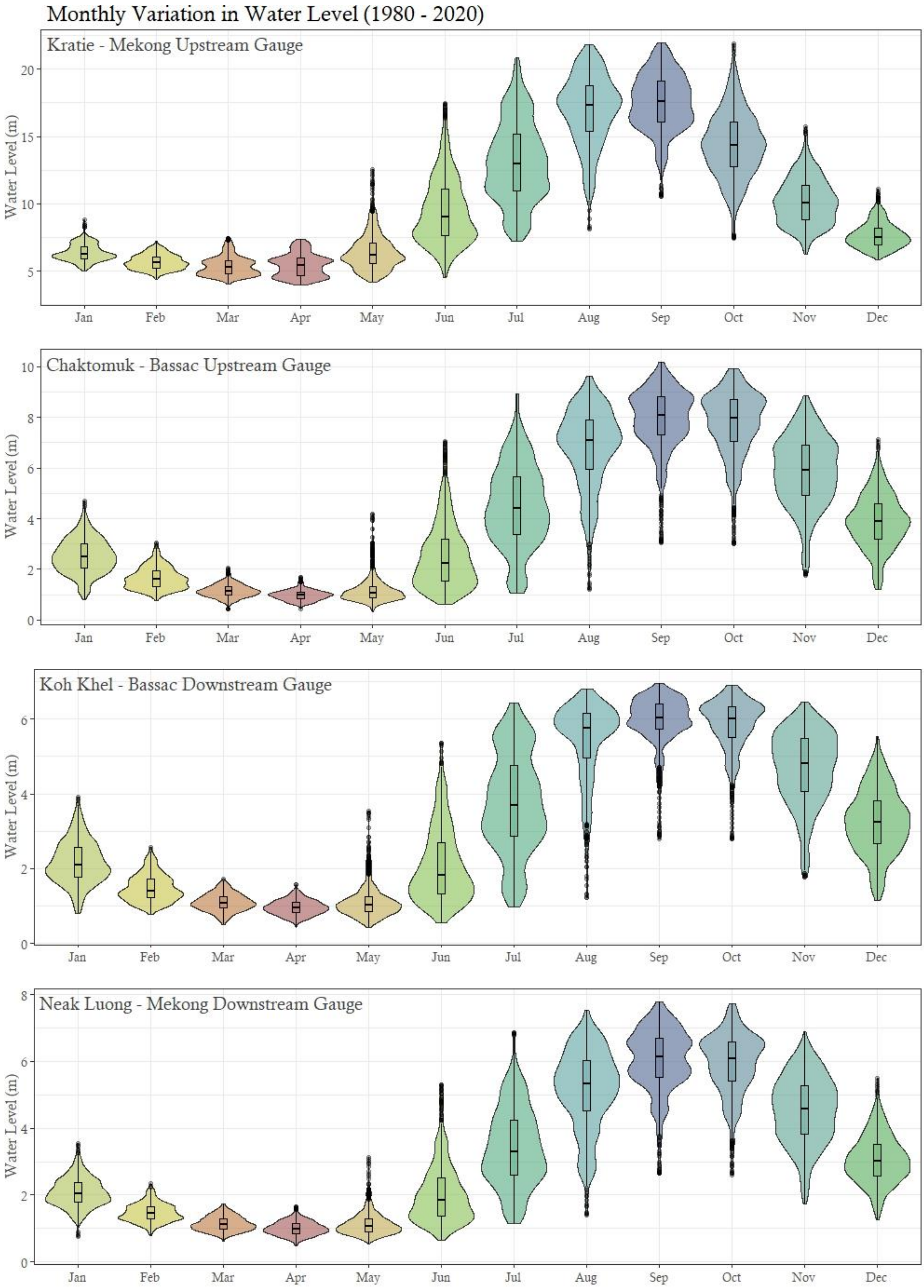


Figure 4-15 Monthly variation in daily water level frequency at the Kratie, Chaktomuk, Koh Khel and Neak Luong gauges. Data period extends from 1980 – 2020 (and 1991 – 2020 for Koh Khel).

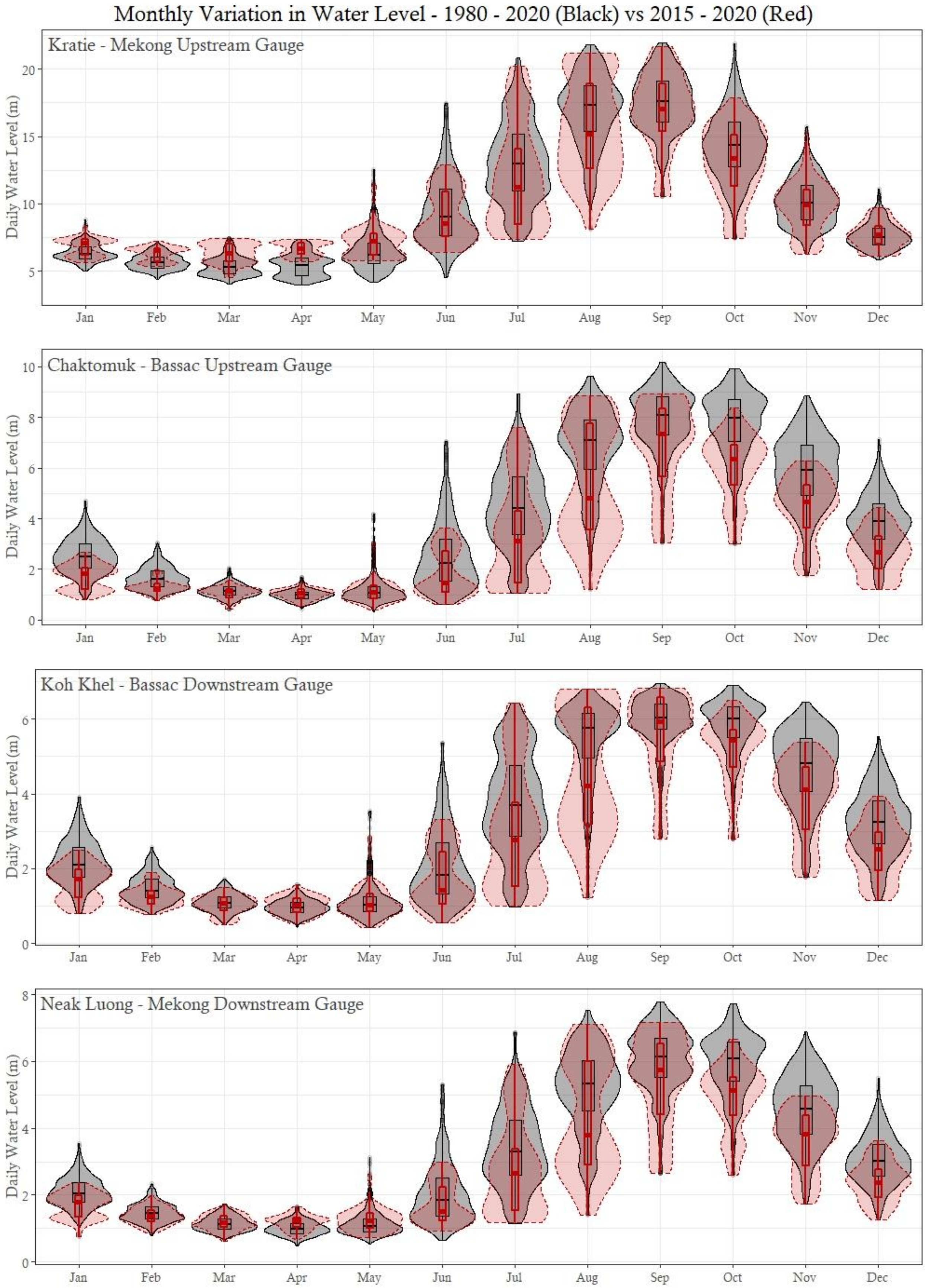


Figure 4-16 Monthly variation in daily water level frequency at the Kratie, Chaktomuk, Koh Khel and Neak Luong gauges. Data in grey represents the full data series (1980 – 2020) and data in red represents the last 5 years (2015 – 2020).

4.7.4 Discharge Data Preliminary Analysis

The dry and wet season daily discharge from 1980 – 2019 at the Kratie, Chaktomuk, Neak Luong and Koh Khel gauges respectively. The dry season here extends from November 1st to May 31st, while the wet season occurs between June 1st and October 31st. In the following sections, season year refers to the year in which a season begins, such that a dry season occurring from November 1st 2000 to May 31st 2001 would be the 2000 dry season.

The discharge in the dry season period is typically characterised by a steep falling limb from November to January followed by a relatively level period until May, when discharge starts to increase. On the Mekong, mean daily discharge ranges from 2,600 m^3/s to 12,500 m^3/s at Kratie and 3,900 m^3/s to 18,000 m^3/s at Neak Luong. Record minimum and maximum flows during the dry season are 1,000 m^3/s and 25,000 m^3/s at the Kratie gauge, and 2,000 m^3/s and 24,900 m^3/s at Neak Luong.

Huge inter-annual variability can be seen in the flow dataset, with notable high and low years identified in colour (Figure 4-17 and Figure 4-18). This variability refers to a) absolute discharge at a given time, b) changes in flow dynamics through the season, and c) spatial variation in relative discharge between years.

An example of variability (a) can be seen in discharges in May across all gauges, where flow during the driest part of the season varies from 200% (Koh Khel) to 500% (Kratie). An example of variability (b) can be seen at the Neak Luong gauge, comparing the falling and rising limbs of 2011 flow with 1998 flow. 1998 discharge begins low in November at 13,000 m^3/s with a shallow falling limb, while 2011 starts at 24,900 m^3/s and features a much steeper falling limb. As the dry season ends, 1998 flow increases relatively quickly to 9,000 m^3/s by June 1st while 2011 flow increases at a much slower rate, reaching 7,000 m^3/s by the same time. Variability (c) is most notable when comparing Kratie with the other gauges, with a clear example being the 2020 flow in November, which is the highest at the beginning of the month at Kratie (25,000 m^3/s) but below the mean daily discharge for the same period at all other gauges. This type of variability has natural sources but has been increasingly affected by dam development and regulation in recent years.

Wet Season flow also shows inter-annual variability, with the most notable variations being absolute peak discharge and hydrograph wavelength. These variations can range significantly, as seen when comparing 1998 and 2000 flow. A good example of hydrograph variation can be seen between 2018 and 2019 flow where, despite similar peak discharges, the duration of high flow in 2018 is much longer than 2019 (approximately 3 months to 1 month).

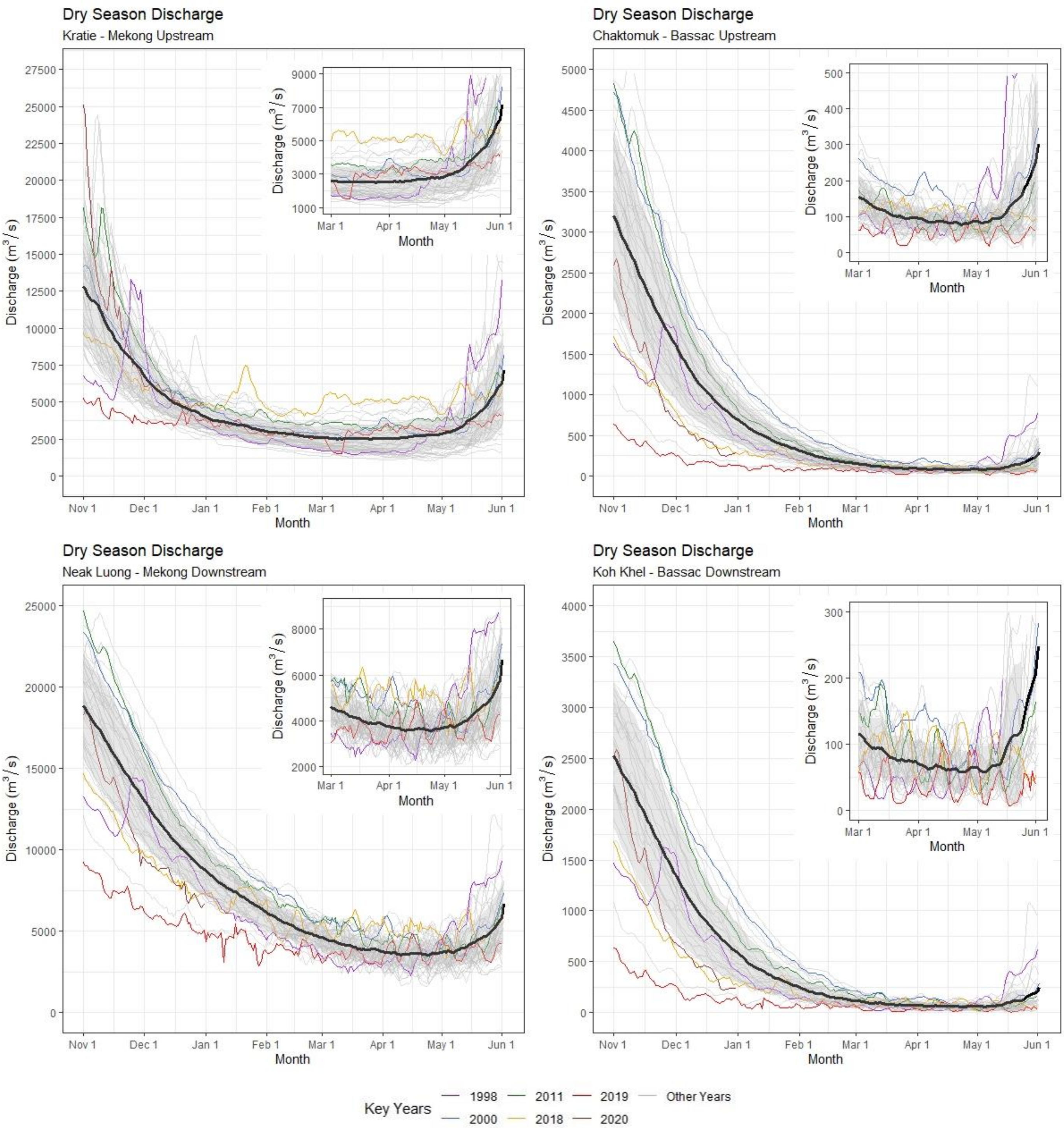


Figure 4-17 Dry Season daily discharge at the Kratie, Chaktomuk, Neak Luong and Koh Khel gauges. Mean discharge is shown in black, with 1 standard deviation bounds shaded in grey. Coloured lines represent the key high and low flow years identified.

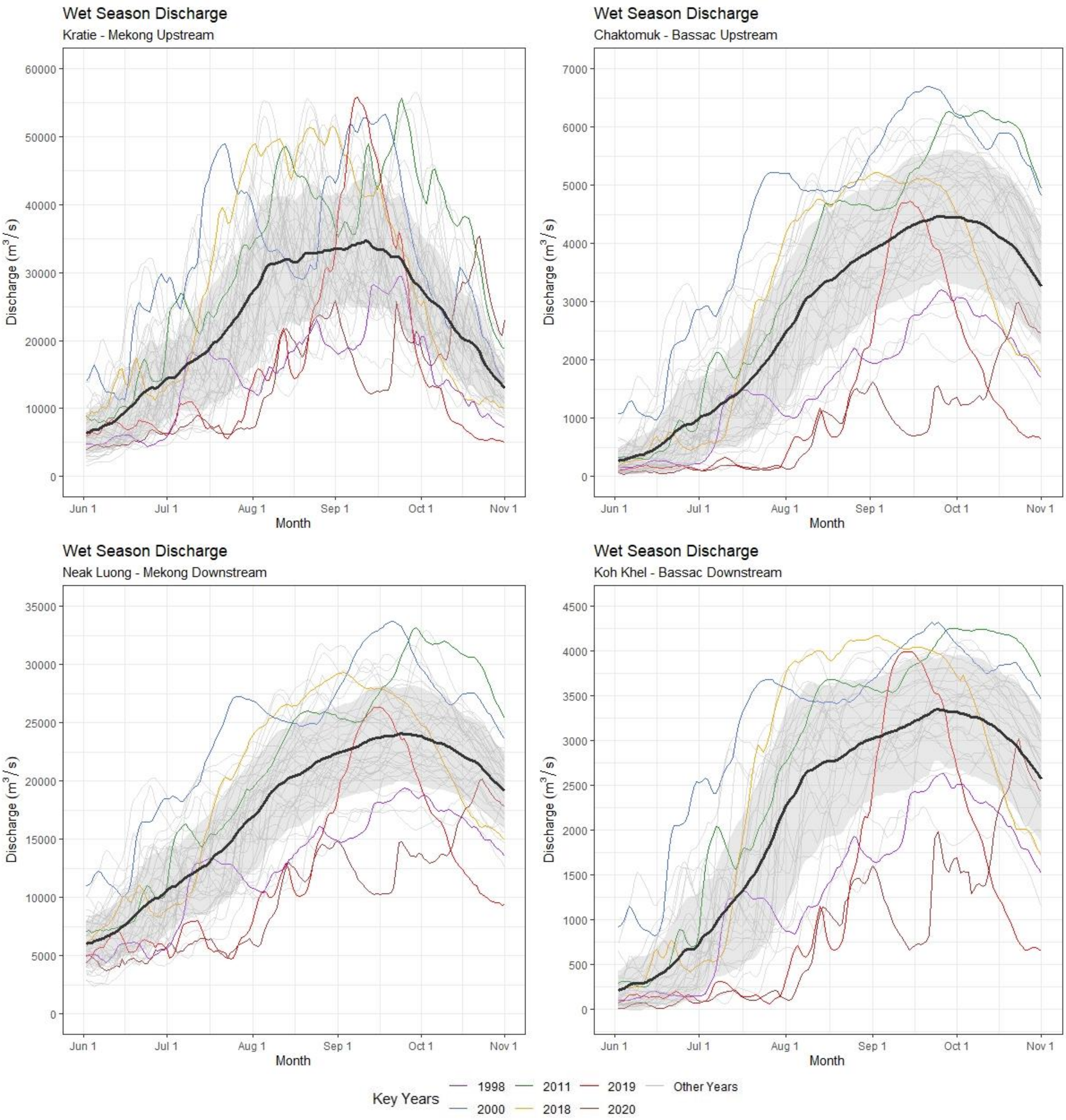


Figure 4-18 Wet Season daily discharge at the Kratie, Chaktomuk, Neak Luong and Koh Khel gauges. Mean discharge is shown in black, with 1 standard deviation bounds shaded in grey. Coloured lines represent the key high and low flow years identified.

These variations in the duration of high flow events are important in understanding flood dynamics and can be evaluated further by assessing the frequency of different discharge values across years. This also has importance in understand low flow dynamics and is shown here as violin plots.

Figure 4-20 and Figure 4-19 show discharge frequency at the Chaktomuk gauge for annual flow as well as for dry and wet season periods. Key years are highlighted in colour, with the colour assignment matching those of the discharge dry and wet season graphs above.

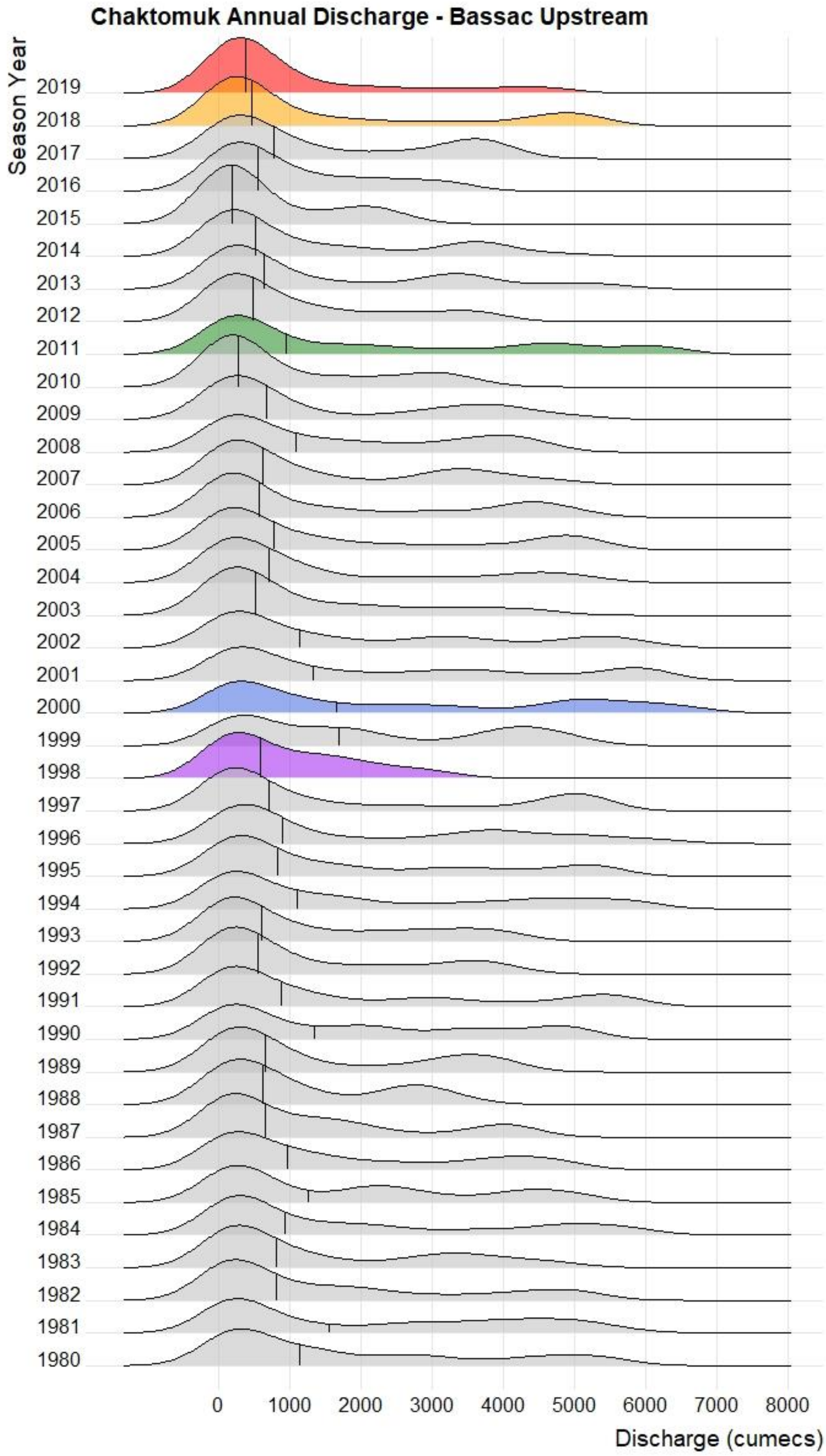


Figure 4-19 Ridgeline plots representing annual daily discharge frequency in each measured year at Chaktomuk. Median values are represented with a vertical black line, with key years highlighted in colour.

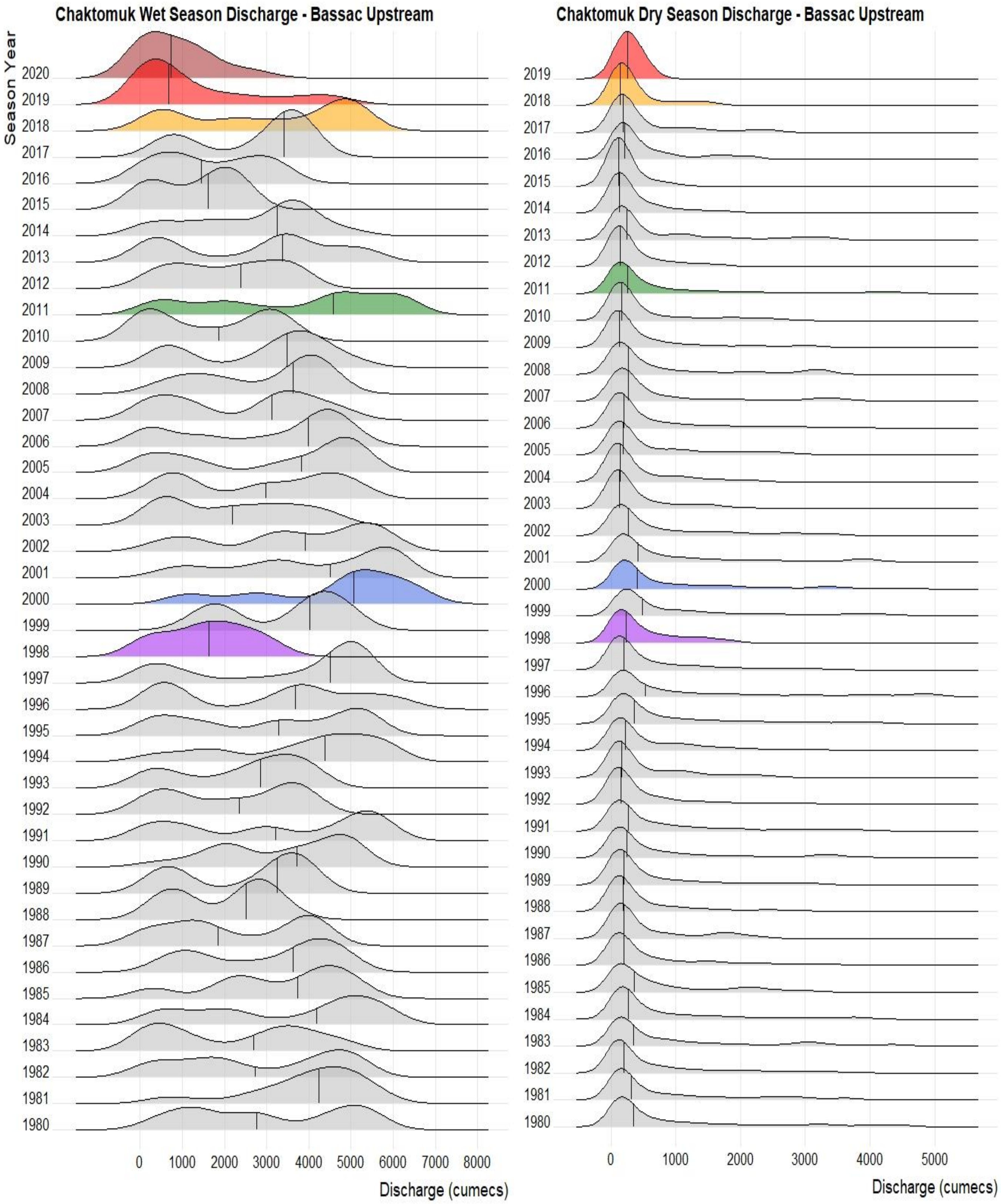


Figure 4-20 Ridgeline plots representing dry and wet season daily discharge frequency in each measured year at Chaktomuk. Median values are represented with a vertical black line, with key years highlighted in colour.

The difference between the Mekong at the Kratie gauge and the Mekong discharge downstream of Phnom Penh is marked as shown in Figure 4-21.

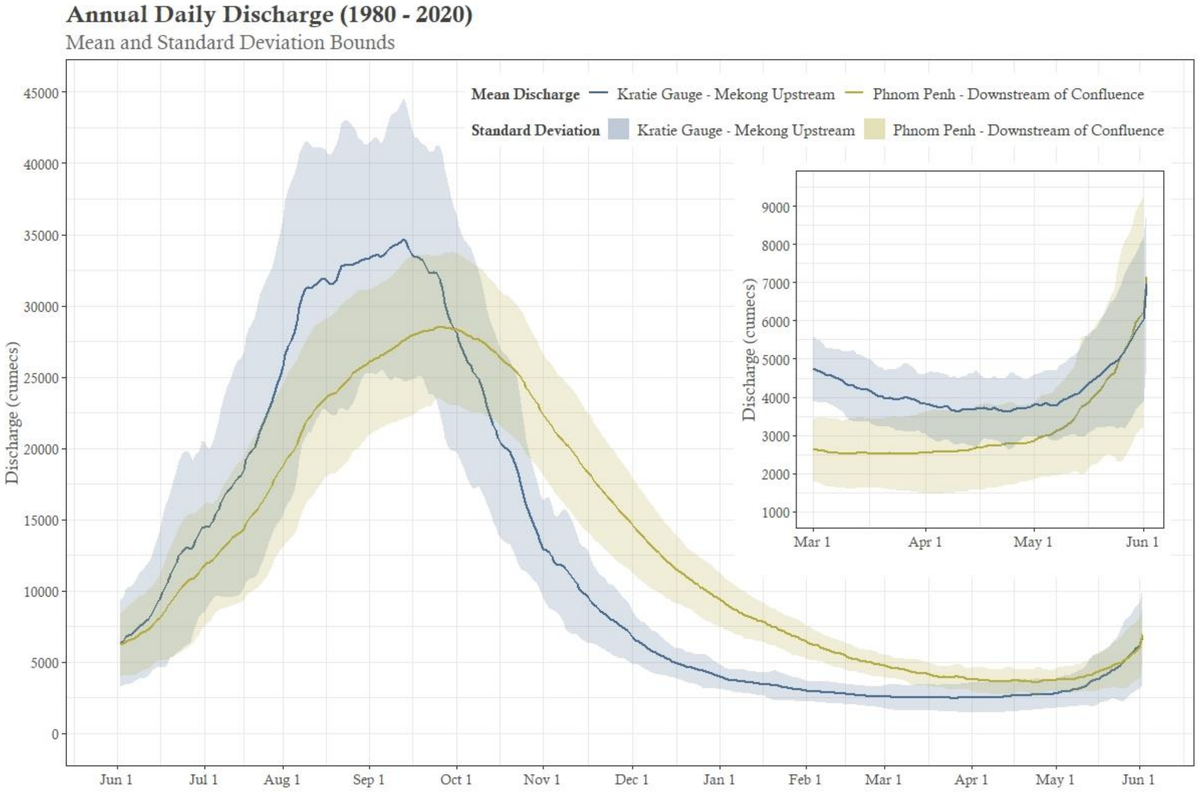


Figure 4-21 Average annual daily discharge of the Mekong and 1 standard deviation bounds for the period 1980-2020. Upstream flow is derived from the Kratie gauge, and downstream flow is a sum of flow at Chaktomuk (Bassac River) and Neak Luong (Mekong River). The storage effect of the Cambodia floodplain and Tonle Sap Lake is clearly seen in both the wet season when downstream flows are attenuated and in the dry season when flows are raised through to May.

4.7.5 Rainfall Data

Data for nine rainfall stations with a near complete record 1985-2018 (Kratie, Kampong Thom, Kampong Chhnang, Prey Veng, Svay Rieng, Kampong Speu, Phnom Penh, Kandal and Takeo) were assembled for model input. Graphs of daily rainfall for each station are included in Annex 1.

The daily rainfall were processed to give the annual maximum rainfall for these locations and is presented in and in Appendix 1. A maximum value of 268mm in one day was observed at Kratie in 1988 but though there is a potential trend up or down at most stations, no evidence was found for increasing severity of local rainfall as generally assumed will occur with climate change.

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For modelling we want to identify suitable simulation events and it is clear that heavy rainfall at a single station does not necessarily coincide with river flooding. The dry and wet year has been assessed further based on the average rainfall amount at a number of key stations and compared with ‘wet years’ for river discharge as shown in Table 4.3. If an annual rainfall is below the total average rainfall, it is considered as “Dry Year” and if an annual rainfall is above the total average rainfall, it is considered as “Wet Year” as shown in Table 4.4.

Table 4.3 Daily maximum rainfall recorded from 1985 to 2018 for Kratie, Kampong Thom, Kampong Chhnang, Prey Veng, Svay Rieng, Kampong Speu, Phnom Penh, Kandal and Takeo

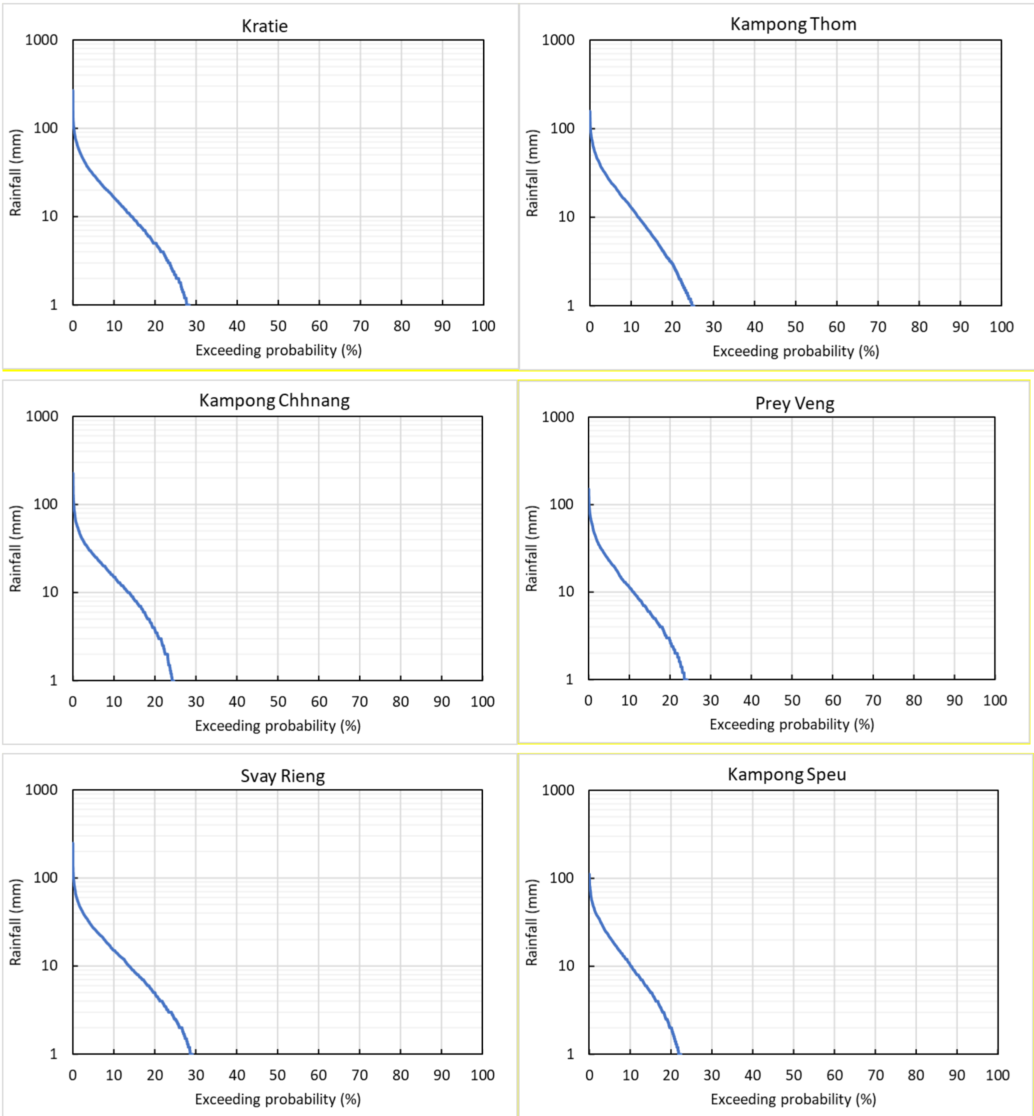
Year	Kratie	Kampong Thom	Kampong Chhnang	Prey Veng	Svay Rieng	Kampong Speu	Phnom Penh	Kandal	Takeo
1985	87	75	88	100	156	95	79	72	60
1986	96	77	105	85	78	72	113	72	60
1987	143	81	96	70	89	60	146	72	75
1988	268	106	112	108	104	53	74	70	58
1989	179	67	103	86	124	71	85	92	81
1990	179	72	128	80	131	71	61	98	100
1991	107	80	151	67	131	48	75	89	74
1992	121	84	226	96	75	98	130	94	118
1993	111	100	54	83	69	42	83	115	88
1994	73	107	110	81	113	80	113	133	94
1995	117	91	107	132	132	73	133	41	82
1996	80	115	84	87	248	84	101	68	82
1997	96	69	64	49	194	59	103	49	57
1998	90	97	130	84	115	81	83	54	82
1999	110	86	130	52	58	64	74	63	121
2000	95	80	60	127	106	110	98	59	90
2001	47	91	72	93	97	83	61	60	89
2002	73	99	61	51	126	112	73	68	64
2003	103	79	65	70	77	76	73	72	48
2004	105	90	83	89	56	95	66	70	95
2005	82	101	99	70	39	82	74	47	55
2006	87	120	174	60	98	73	91	66	73
2007	117	157	85	60	70	82	94	120	122
2008	64	136	58	101	88	100	153	85	110
2009	153	131	76	64	87	75	75	87	41
2010	77	81	103	150	91	103	99	63	97
2011	121	140	118	82	94	105	83	62	85
2012	103	82	74	93	96	79	95	65	75
2013	99	81	79	124	96	62		58	51
2014	69	106	84	106	92	51		67	114
2015	99	59	72	88	65	68		83	82
2016	67	76	56	77	92	68		95	67
2017	105	70	63	69	75	48			82
2018		105	46			42			96
Min	268	157	226	150	248	112	153	133	122
Max	47	59	54	49	39	42	61	41	41

Table 4.4 Dry and wet year for Kratie, Kampong Thom, Kampong Chhnang, Prey Veng, Svay Rieng, Kampong Speu, Phnom Penh, Kandal and Takeo

Year	Kratie (mm)	Dry/ Wet	Kampong Thom (mm)	Dry/ Wet	Kampong Chhnang (mm)	Dry/ Wet	Prey Veng (mm)	Dry/ Wet	Svay Rieng (mm)	Dry/ Wet	Kampong Speu (mm)	Dry/ Wet	Phnom Penh (mm)	Dry/ Wet	Kandal (mm)	Dry/ Wet	Takeo (mm)	Dry/ Wet	Wet Stations	Kratie Flow Volume (km^3)	Dry/ Wet
1985	1099	D	1606	W	1733	W	1249	D	1899	W	1479	W	1388	W	1251	D	1165	D	6	371.5	D
1986	1672	D	1822	W	1401	D	1348	W	1869	W	1124	D	1311	D	1291	W	602	D	5	350.8	D
1987	1331	D	1227	D	1669	W	1140	D	1676	W	946	D	1291	D	1013	D	509	D	3	290.2	D
1988	1712	D	1606	W	1587	W	1688	W	1623	D	1111	D	1362	W	1364	W	566	D	5	251.5	D
1989	2149	W	1573	W	1773	W	947	D	1718	W	997	D	1299	D	1557	W	1223	W	7	314.9	D
1990	1493	D	984	D	2040	W	1255	D	1672	W	795	D	1277	D	978	D	643	D	3	427.3	W
1991	1881	W	1413	D	2853	W	918	D	1347	D	1044	D	1163	D	979	D	1045	D	2	397.0	W
1992	2402	W	1254	D	2482	W	947	D	1384	D	934	D	1033	D	840	D	1088	D	2	307.2	D
1993	1692	D	2070	W	1027	D	1486	W	1784	W	950	D	1402	W	928	D	1369	W	6	317.7	D
1994	1634	D	1864	W	1974	W	1269	D	1674	W	1061	D	1154	D	1518	W	1142	D	5	430.7	W
1995	2538	W	1656	W	1314	D	1854	W	1854	W	1203	W	1209	D	976	D	1203	W	7	381.5	D
1996	1389	D	1780	W	1602	W	1117	D	1511	D	1418	W	1579	W	1208	D	1401	W	5	426.4	W
1997	1804	W	1013	D	1326	D	682	D	1337	D	1329	W	1350	W	1046	D	946	D	3	404.0	W
1998	1869	W	1321	D	1581	W	1195	D	1541	D	1490	W	1399	W	1537	W	1221	W	6	261.2	D
1999	2404	W	1776	W	1839	W	1010	D	1489	D	1423	W	1580	W	1685	W	1540	W	7	418.8	W
2000	1535	D	1665	W	1463	D	1186	D	2194	W	1699	W	1321	D	1907	W	1559	W	6	525.0	W
2001	1636	D	1588	W	1255	D	901	D	1629	D	1768	W	1096	D	1430	W	1625	W	4	495.1	W
2002	1909	W	1425	D	1160	D	1273	D	1521	D	937	D	896	D	1253	D	1292	W	2	485.8	W
2003	1668	D	1386	D	1119	D	1619	W	1603	D	1049	D	1074	D	1249	D	1384	W	2	340.5	D
2004	2250	W	1213	D	1249	D	1181	D	1244	D	949	D	1111	D	1200	D	1108	D	1	382.5	D
2005	1468	D	1276	D	1349	D	1259	D	1712	W	1114	D	1469	W	1092	D	1245	W	4	425.4	W
2006	1705	D	1237	D	1315	D	1188	D	1616	D	1178	W	1405	W	1150	D	1241	W	3	406.9	W
2007	1633	D	1442	W	1724	W	1163	D	1695	W	1111	D	2051	W	1075	D	1211	W	6	384.4	W
2008	2595	W	1395	D	1420	D	1723	W	2164	W	1188	W	1639	W	1373	W	1640	W	8	430.6	W
2009	1849	W	1490	W	1635	W	1178	D	1540	D	1340	W	1158	D	1091	D	1017	D	4	408.8	W
2010	1495	D	1391	D	1220	D	1887	W	1984	W	1220	W	1712	W	1133	D	1570	W	6	308.9	D
2011	1986	W	1658	W	1922	W	1370	W	1841	W	1378	W	1168	D	1248	D	1487	W	8	515.2	W
2012	2221	W	1317	D	1830	W	1784	W	1704	W	1444	W	1593	W	1464	W	1379	W	9	348.4	D
2013	1662	D	1512	W	1369	D	1297	D	1467	D	1298	W			1307	W	981	D	3	418.8	W
2014	1697	D	1173	D	1421	D	1678	W	1430	D	932	D			1198	D	1298	W	2	409.0	W
2015	1185	D	899	D	1209	D	1281	D	1370	D	868	D			1168	D	1077	D	0	296.7	D
2016	1880	W	1471	W	1383	D	2136	W	2148	W	1430	W			1593	W	1329	W	8	345.1	D
2017	2075	W	1468	W	1617	W	1473	W	1816	W	1137	D					1494	W	7	454.6	W
2018			948	D	998	D					518	D					809	D	0	479.3	W
2019																				311.5	D
2020																				277.5	D
Min	1099		899		998		682		1244		518		896		840		509			251.5	
Average	1804		1439		1555		1324		1668		1172		1339		1253		1188			383.4	
Max	2595		2070		2853		2136		2194		1768		2051		1907		1640			525.0	

4.7.6 Rainfall frequency distribution

The rainfall exceedance distribution curve was plotted based on the data from 1985 to 2018 for the same stations Figure 4-22 and it can be seen that in the lower part of the basin there are fewer days when rainfall exceeds a threshold such as 1 mm/day and only on around 20% of the days does precipitation exceed the evapotranspiration of 4-5 mm/day at Takeo, for example.



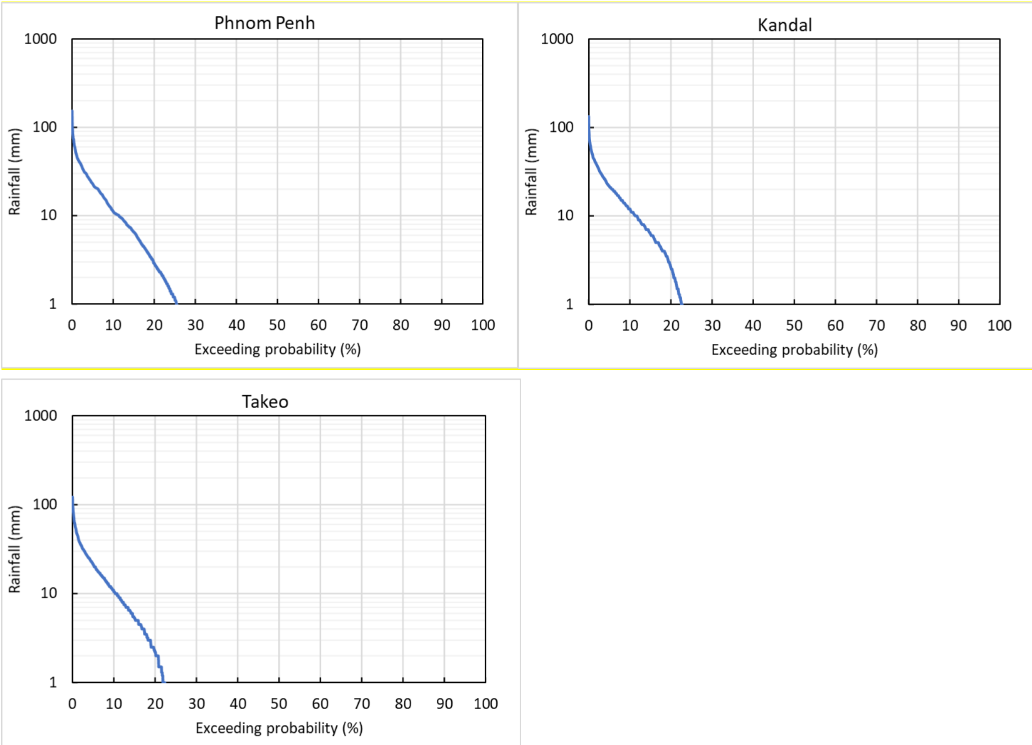


Figure 4-22 Daily Peak Daily Rainfall Exceedence Curves from 1985 to 2018 for Kratie, Kampong Thom, Kampong Chhnang, Prey Veng, Svay Rieng, Kampong Speu, Phnom Penh, Kandal and Takeo

4.7.7 Tidal water level fluctuations

15-minute water level gauge data is available from 3 MOWRAM/MRC gauges located at Chaktomuk, Chau Doc and Tan Chau. This data helps identify the tidal effects on intra-daily water level fluctuations that can play a crucial role when modelling flow regimes. Figure 4-24 shows the acquisition range, beginning in January 2010 at Chaktomuk and mid-August 2010 at Chau Doc and Tan Chau, extending to September 2020. The tidal influence increases during the dry season as discharge decreases and water level recedes, evident in Figure 4-24 by the consistent increases in amplitude in the troughs throughout the time series. This is most apparent at Chau

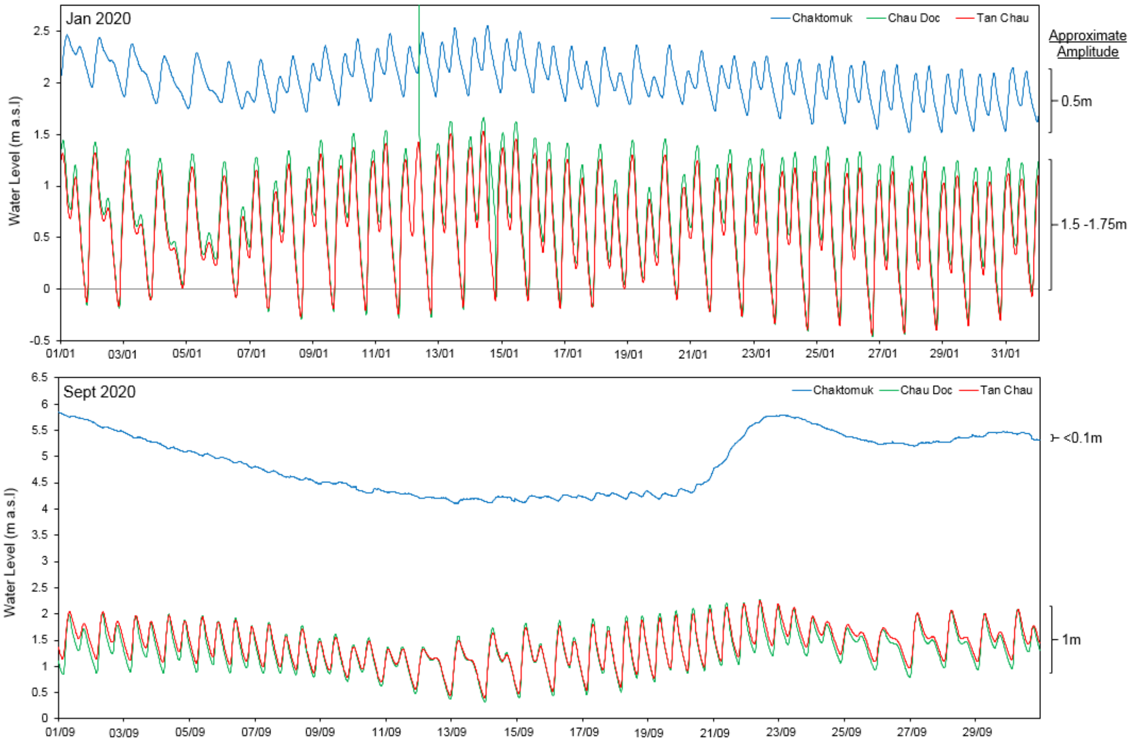


Figure 4-23 15-minute interval water level data for January (above) and September (below) 2020. Source of data MRC

Doc and Tan Chau, which reside approximately 100km downstream of Chaktomuk on the Bassac and Mekong Rivers respectively.

Figure 4-23 shows the same water level data for January and September 2020 as examples of the recent dry and wet season respectively. At Chaktomuk, dry season intra-daily fluctuations show an amplitude of ~0.5m. This reduces to ~<0.1m during the wet season as water level and discharge increases and flow regimes become dictated by Tonle Sap outflow and increased rainfall. During this period in this location, the negligible fluctuations in water level suggest it has little influence on flow regime during the wet season. As such, tidal influences will have a greater consideration when modelling the dry season, as its influence increases at lower levels.

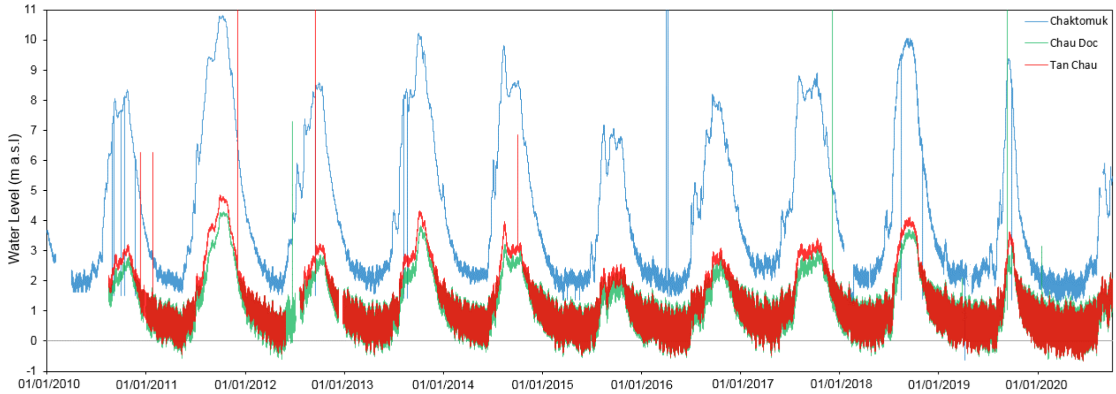


Figure 4-24 15-minute interval water level data from January 2010 (start of acquisition) to September 2020 at 3 gauges. (Source of data MRC)

At Chau Doc and Tan Chau the intra-daily water level fluctuations are much greater in the dry season, ranging by ~1.5 – 1.75m. The unusual nature of the 2020 hydrology highlighted in previous sections can also be seen in the wet season intra-daily water level fluctuations, which are much higher than usual at ~1m. This can be seen by the increased amplitude of the 2020 wet season at Chau Doc and Tan Chau relative to all previous years in Figure 4-24.

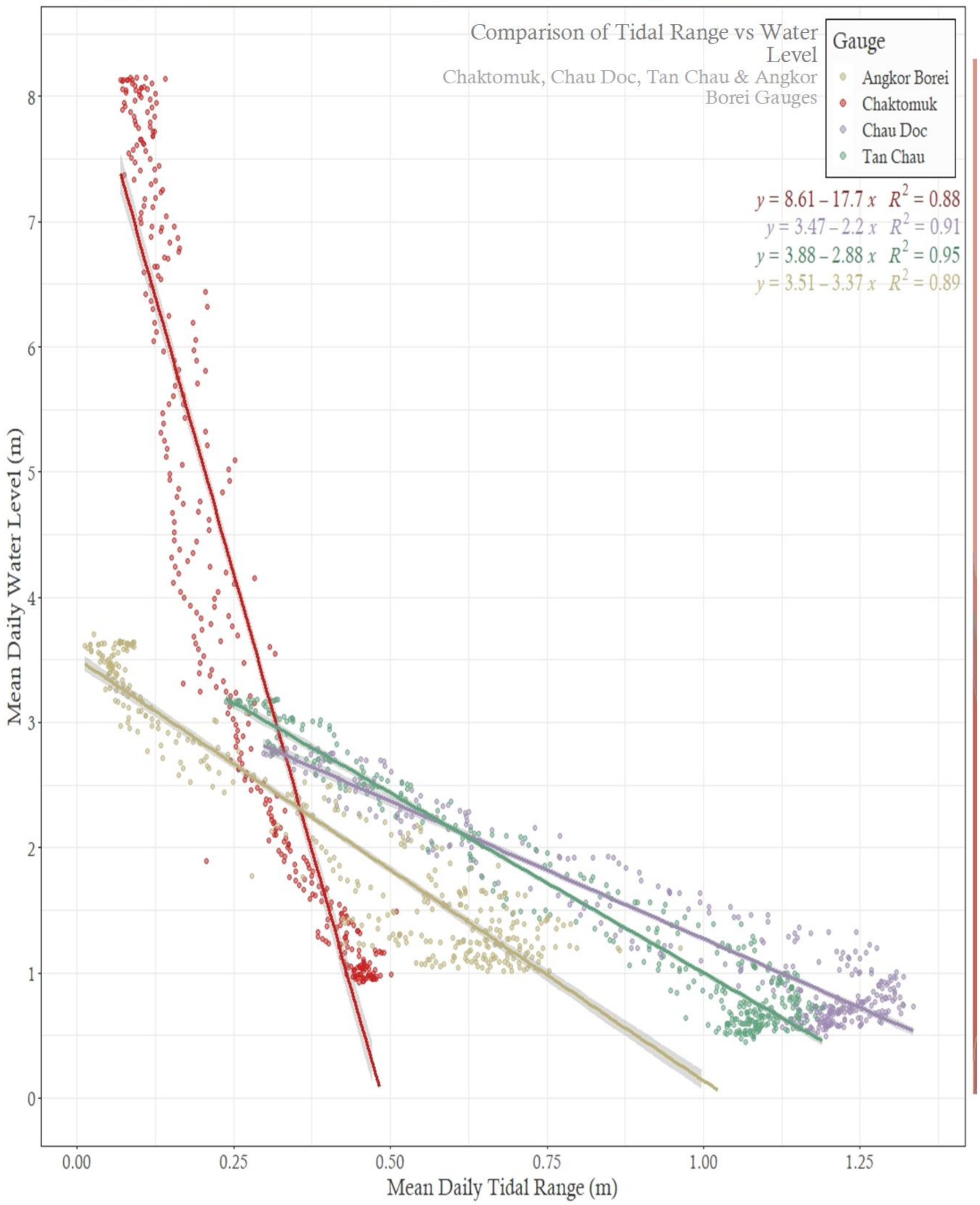


Figure 4-25 Change in tide range with water level at Chaktomuk, Angkor Borei, Tan Chau and Chau Doc gauges

4.8 Inundation Areas

There are a number of flood years for which the outline of the flood at specific dates or for the maximum extent has been processed. These include 1998, 2000, 2001, 2002, 2004, 2006. In recent years more detailed information can be obtained by downloading and processing satellite images either in the visible spectrum (Sentinel

2 or Landsat 7/8) or as radar which is less susceptible to clouds (Sentinel-1). These are presented and analysed in Section 6.

4.9 Topographic Survey

In Figure 4-26, a recent 2020 survey for WAT4CAM Component 1 (point elevations) is compared with a DEM derived from a 1963 UNESCO topographic survey (contours) to assess the limitations of the original DEM for model implementation. The 2020 survey was completed by Key Consultants Cambodia (KCC) as part of the WAT4CAM Component 1 study. Flood extent from the 9th of October 2011 extracted from Radar-Sat2 SAR imagery is also shown for reference. Despite the 57-year difference in data acquisition and the frequent changes witnessed across the floodplain area, much of the surveyed elevation remains very similar, although there are some regions of change.

The most significant regions of aggradation are located close to the Bassac channel along the prek channels. Slight decreases in elevation can be seen further onto the floodplain away from the Bassac. These differences indicate sediment deposition and land build up in the vicinity of the Preks since the 1960s survey but some land subsidence in the low lying Boeung area.

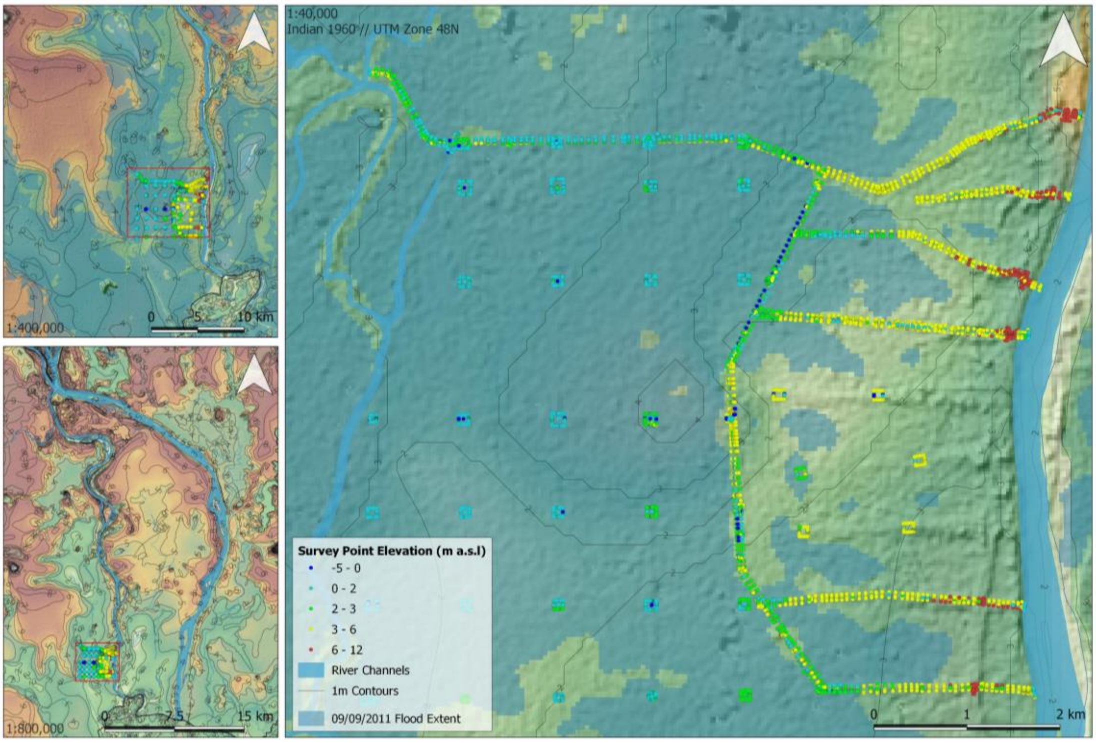


Figure 4-26 Field Survey elevation comparison with DEM and October 2011 flooding. Source: Field data from WAT4CAM Component 1. 2011 flood outline from Radarsat 2

4.10 Review of Remotely Sensed Information Available

Satellite remote sensing offers a means to monitor water resources and their change in time across large areas. Monitoring these variations is critical in monsoonal regions, such as Southeast Asia, where annual variation in rainfall results in hydrologic extremes that affect local communities. A tremendous catalyst for these developments has been the rise of cloud-based data providers and computational resources such as Google Earth Engine (GEE), which offer a means to address computational challenges in enabling satellite image processes to be scaled up in time and space. One of such methods, produced from Landsat imagery (courtesy of the United States Geological Study (USGS) and NASA) has resulted in The JRC Monthly Water History v1.2 (1984-2019) water occurrence dataset developed by the European Commission Joint Research Center (JRC) as part of the Copernicus Program (see Figure 4-27). The dataset (which is updated annually) shows the location and temporal distribution of water surfaces at the global scale over the past 35 years and provides statistics on the extent and change of those water surfaces. It supports applications including water resource management, climate modelling, biodiversity conservation and food security. The method is based on the optical, near infrared and shortwave infrared information provided over the full-time span of the Landsat data catalog.

In this project, four key applications of remote sensing technology are foreseen:

- Flood frequency mapping
- Mapping of trends in land use and irrigation development
- Analyzing local impacts of drought in the study area due to insufficient water delivery from the preks
- Supporting hydraulic modelling efforts by providing validation data

An overview of collected remote sensing data for implementing these activities is provided in Table 4.5.

Table 4.5. Overview of available satellite remote sensing data used in the project.

Description	Source	Spatial resolution	Period
Optical, (near-)infrared and thermal data	Landsat 5-8	30m	1984 - present
Optical and (near-)infrared data	Sentinel 2	10m-20m	2017 - present
SAR data	Sentinel 1	10m-40m	2014 - present
Optical, (near-)infrared data	MODIS	250m-500m	2000 - present
Precipitation	CHIRPS	5km	1981 - present

Actual Evapotranspiration	IHE, Water Accounting+	250m	2003 - 2014
Land cover	SERVIR-Mekong	30m	1987 - 2018
Digital Elevation Model	SRTM	30m-90m	
Surface water occurrence	JRC	30m	1984 - present

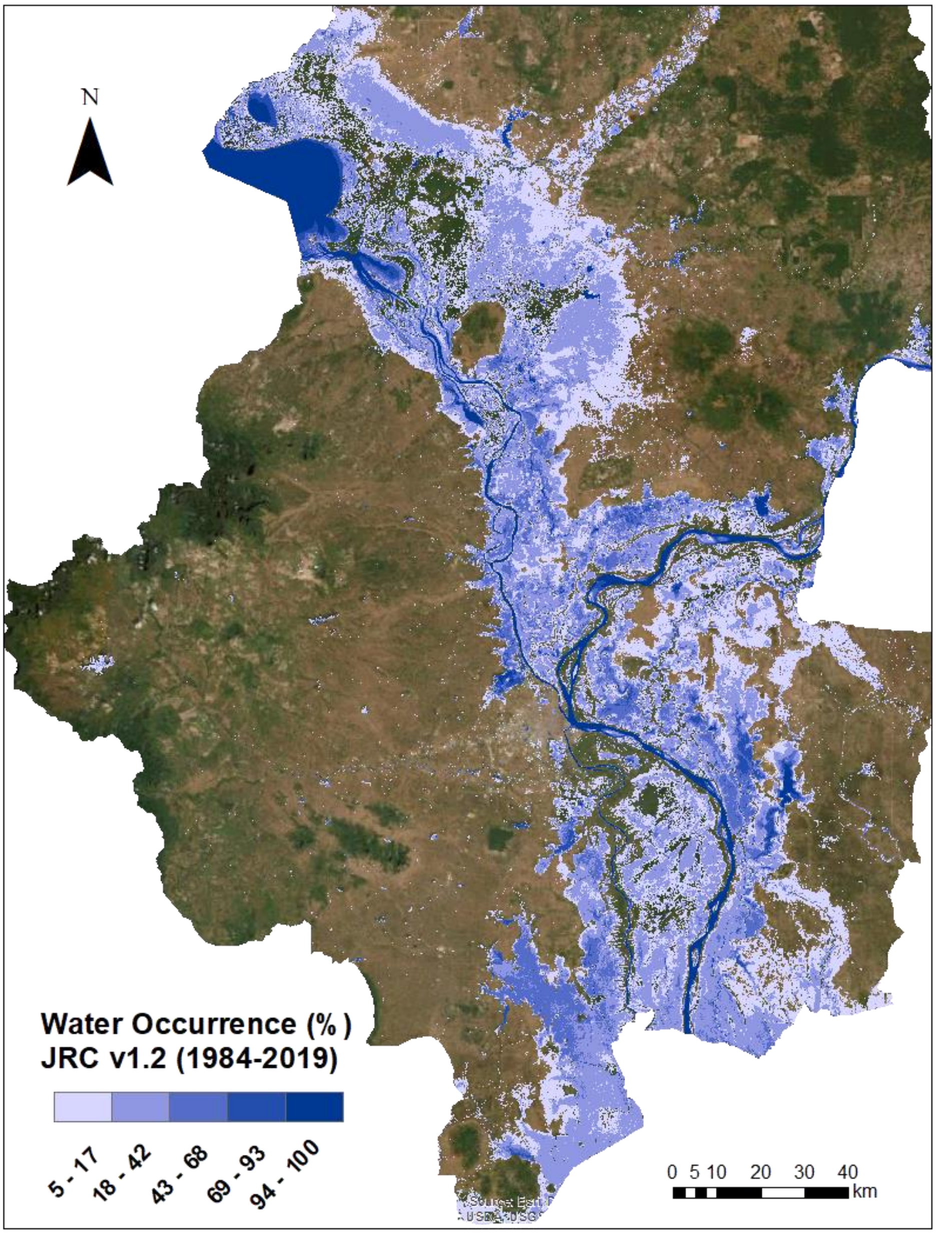


Figure 4-27 Water Occurrence (%) for the study area based on JRC dataset v1.2 (1984-2019).

Flood frequency mapping based on Remote Sensing

Many satellite remote sensing surface water mapping studies and applications focus on the use of optical sensors. These optical water mapping methods typically include historical time-series analysis using spectral information and thresholds, sometimes combined with decision tree and machine learning approaches. However, even with well-defined methods and readily available data for surface water mapping applications, optical sensors can only be used during the day and are hindered by clouds that obscure surface observations, especially in monsoon-driven environments. Often, peak surface water extent during flood events occur when there is cloud cover, resulting in data gaps limiting the use of optical sensors for flood monitoring applications. To address the issue of cloud cover, Synthetic Aperture Radar (SAR) has increasingly been employed as the sensor signals penetrate clouds, this can be used in all weather conditions and during day or night. In fact, the application of SAR data for surface water mapping is nowadays considered to be the most useful space-based remote sensing technology for detecting surface water in the presence of clouds. With the 2014 launch of the Copernicus Sentinel-1 satellite by the European Space Agency (ESA), consistent data acquisition with free, publicly accessible data, has enabled SAR to be applied more frequently to a variety of research areas such as providing data about the extent and depth of water bodies.

Using Sentinel-1 SAR and leveraging the data archive and computing power of Google Earth Engine, an automated and systematic approach will be applied to rapidly produce robust maps of the spatial extent of the most significant rivers and lakes across the entire territory. While SAR imagery provides unobstructed views of the Earth, it is susceptible to image artifacts caused by radio frequency interference, terrain effects, heavy precipitation, and speckle noise. Therefore, careful consideration is needed in pre-processing SAR imagery and in the application of automated surface water mapping methods due to these challenges.

Mapping of trends in land use and irrigation development

Regarding land use mapping for agriculture & irrigation monitoring, an approach will be adopted that utilizes cross correlation between rainfall and vegetation greenness using EVI MODIS products (MOD13Q1 and MYD13Q1) and the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) rainfall product. In contrast with natural areas, agricultural fields are often supplemented with irrigation water to ensure crop growth and optimize yields. Irrigation practices occur throughout the year but are most important during the dry season. Intensive agricultural systems, that produce two or three crops a year, can be found throughout the Mekong region depending on water availability. Areas that remain wet in the dry season are generally greener than the surrounding natural areas. For natural areas, a high cross-correlation can be expected between rainfall and greenness. For irrigated agricultural areas this correlation is expected to be less pronounced as these areas remain green with no rainfall. The cross correlation between (detrended) EVI and CHIRPS is calculated using lag of 30 days to account for the delayed response of vegetation to rainfall.

Analysis of drought impacts

FutureWater has developed a standardized methodology for analyzing impact of droughts on agriculture, which was previously successfully applied in Cambodia. By making use of long archives of high-resolution satellite imagery such as Landsat data, anomalies in vegetation cover (crop growth) can be identified and integrated with other hydro-climatological indicators. The purpose of this analysis is the identification of sections in the study area which perform relatively weak in terms of crop production during the dry season, which can be seen as an indication that water delivery to these areas is insufficient and rehabilitation of these preks may be warranted.

Validation data for hydraulic modelling activities

The same systematic SAR-based approach as applied for flood frequency mapping will be utilized to monitor and map dry or flooded areas during a short-period drought or flood crisis (10 days) and for preparing flood extent maps of specific events for hydraulic model validation. These events will be identified by the hydraulic modelling team.

<u>Sediment mobility from Sentinel-2 imagery</u>

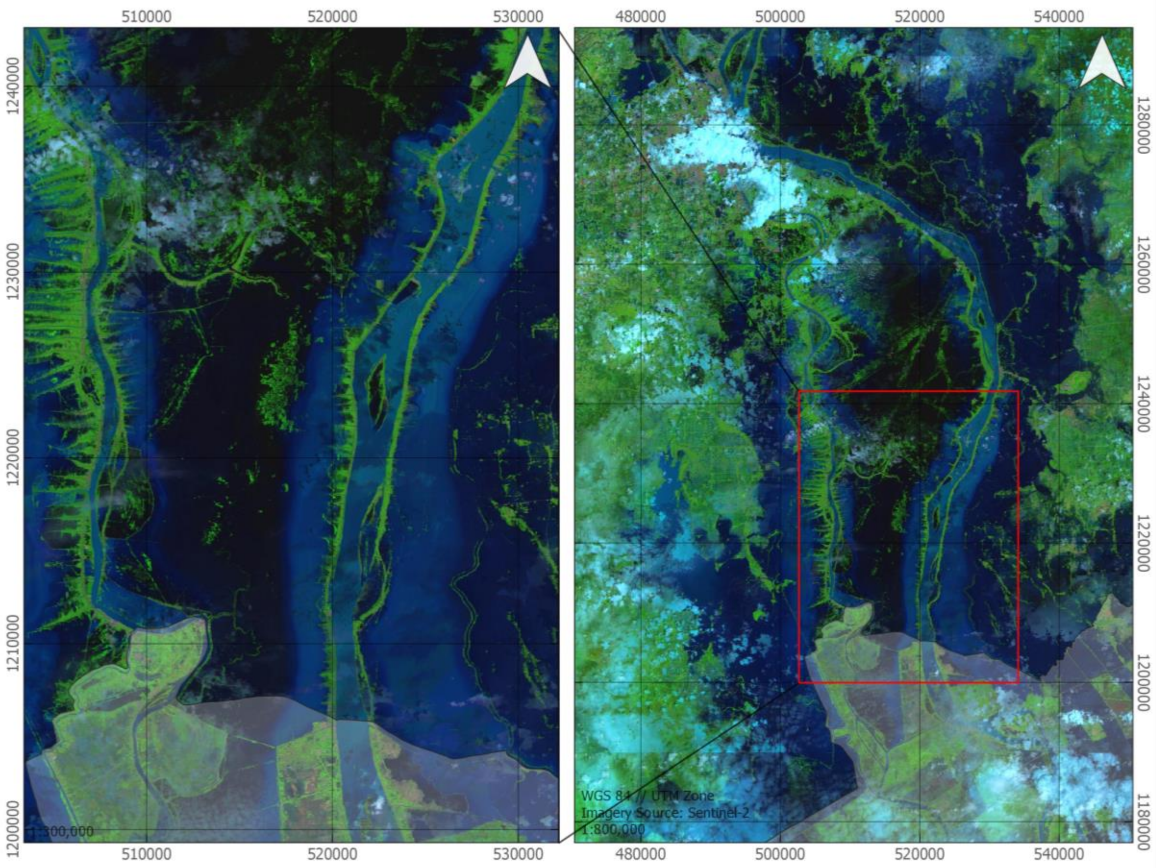


Figure 4-28 Evidence of sediment mobility from Sentinel-2 satellite imagery (Sep 28th 2018). Blue areas indicate inundation extent, with lighter blue representing higher suspended sediment load.

4.10.1 Environmental Data and Issues

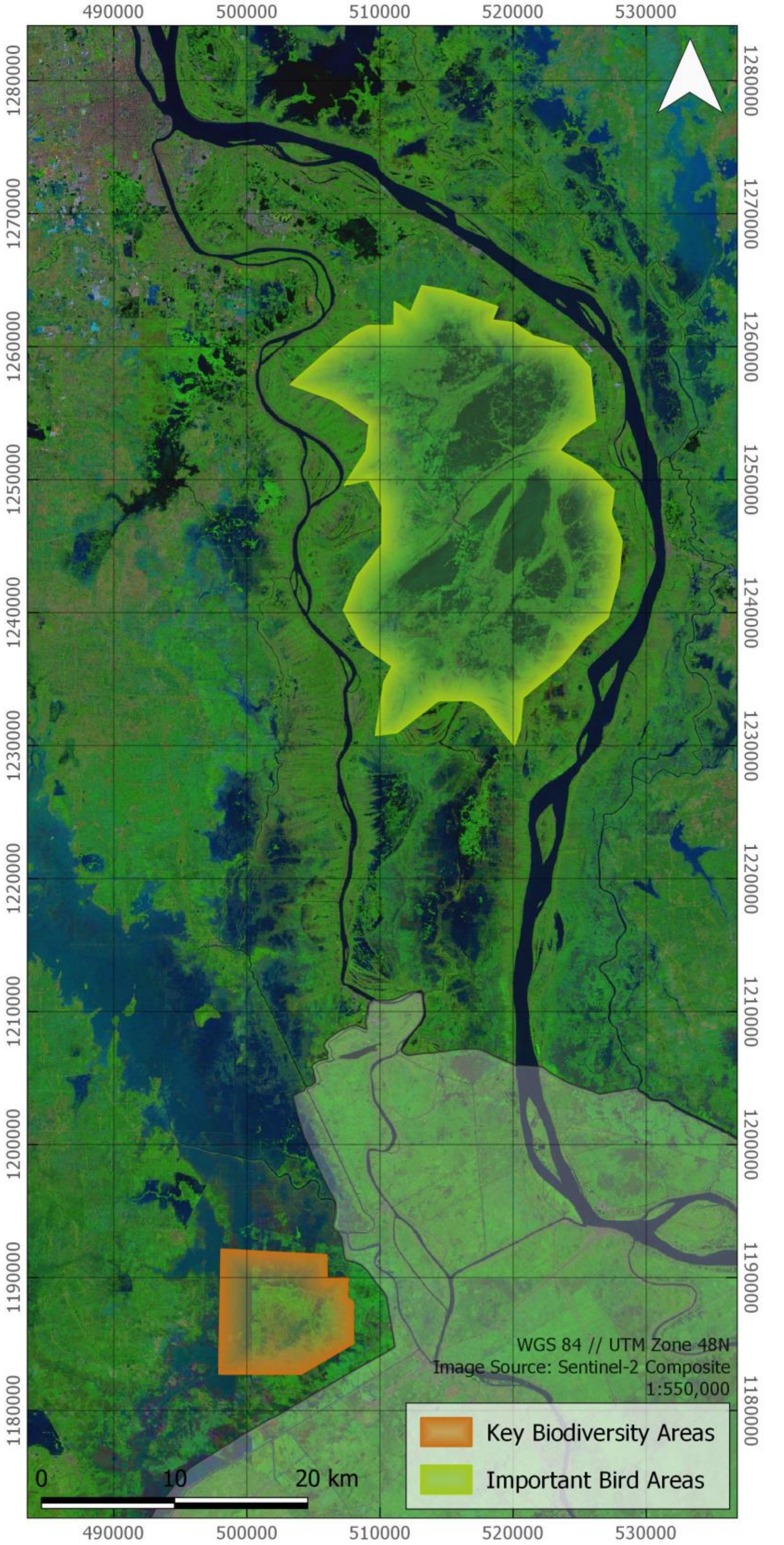


Figure 4-29 Environmentally designated areas

Within the West Bassac area the primary protected area is the downstream nearer the Vietnam border and outside of the immediate Preks area as shown in Figure 4-29. In the Trans-Bassac area the Bassac marshes are designated as IBA or important bird areas with high diversity. This may be of significance when studying the Preks in the vicinity particularly in ensuring that sufficient water is available to maintain the marsh habitat.

Also of concern in the area is the water quality which has been deteriorating due to the development of the city and the lower dilution in the Bassac. This will be looked into further during the study.

4.10.2 Social Data and Issues

Social data such as population and poverty will be mapped and related to the priority development.

Figure 4-30 shows the extents of the Community Fisheries which superseded the Cambodian fishing lots located along the Tonle Sap, Mekong, and Bassac rivers, as identified by the MRC (Jensen, 2002). west of the Bassac river.

The fisheries provide an important source of protein and income in the area both from wild fish as well as farmed fisheries. The Bassac Marsh especially is an important fishing area.

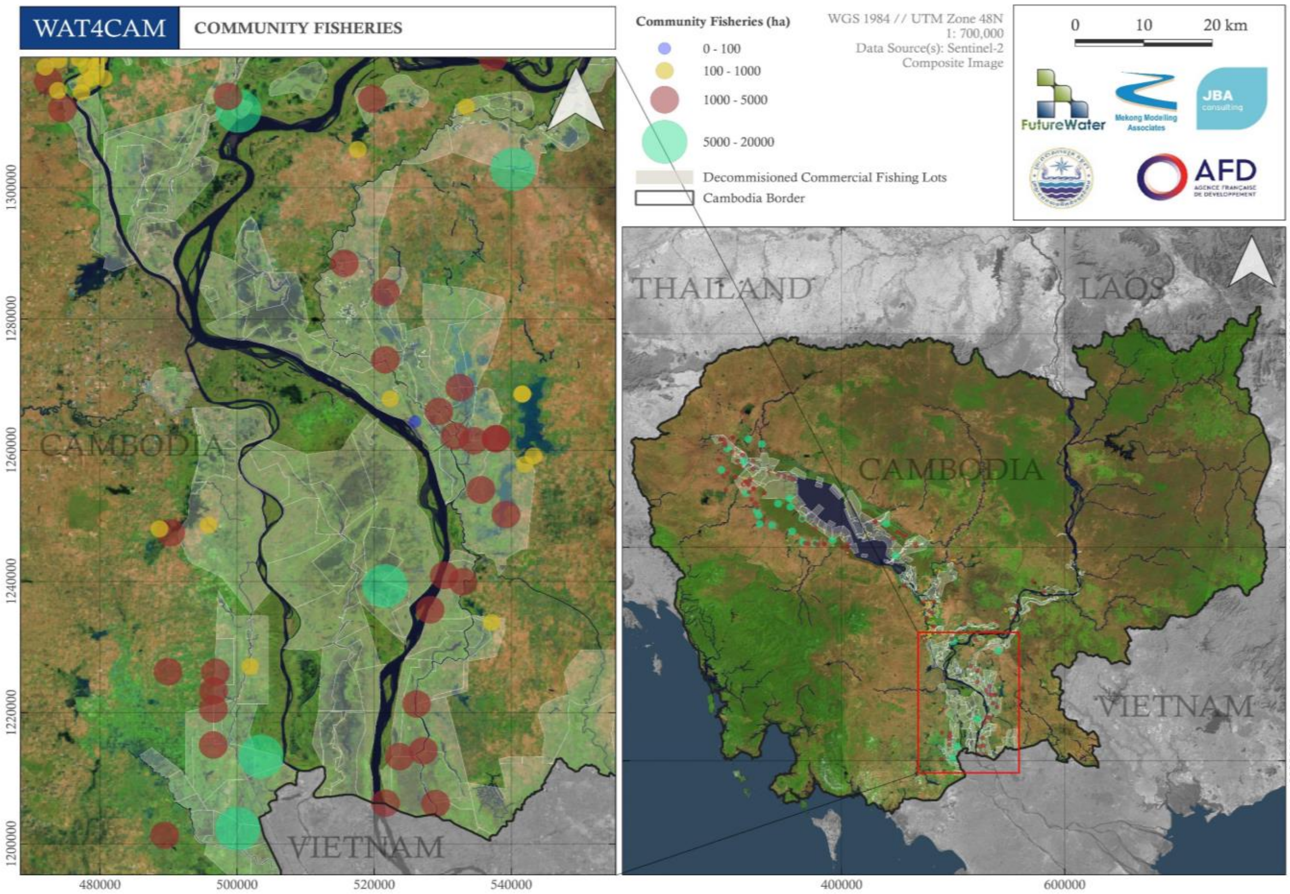


Figure 4-30 Cambodian community fisheries and former fishing lots. Source of raw data MRC, compilation by Consultant and ADB (2020)

4.11 Bassac River Bathymetric Changes

Previous models have been based on river bathymetry surveys that are over 20 years old. For the Bassac, the condition at the Chaktomuk junction has changed over that period and it would appear that the river has been in decline. To ensure flood modelling accuracy representative bathymetric data of the river is needed. In the case of the Bassac which is critical for the study, a new survey is available and this was compared with the older data used in existing models.

For the Bassac, two bathymetric surveys provided by the Ministry of Public Works and Transport Department of Highways (MPWT are available for implementation:

- one from 2001,) and;
- a more recent survey from 2019,

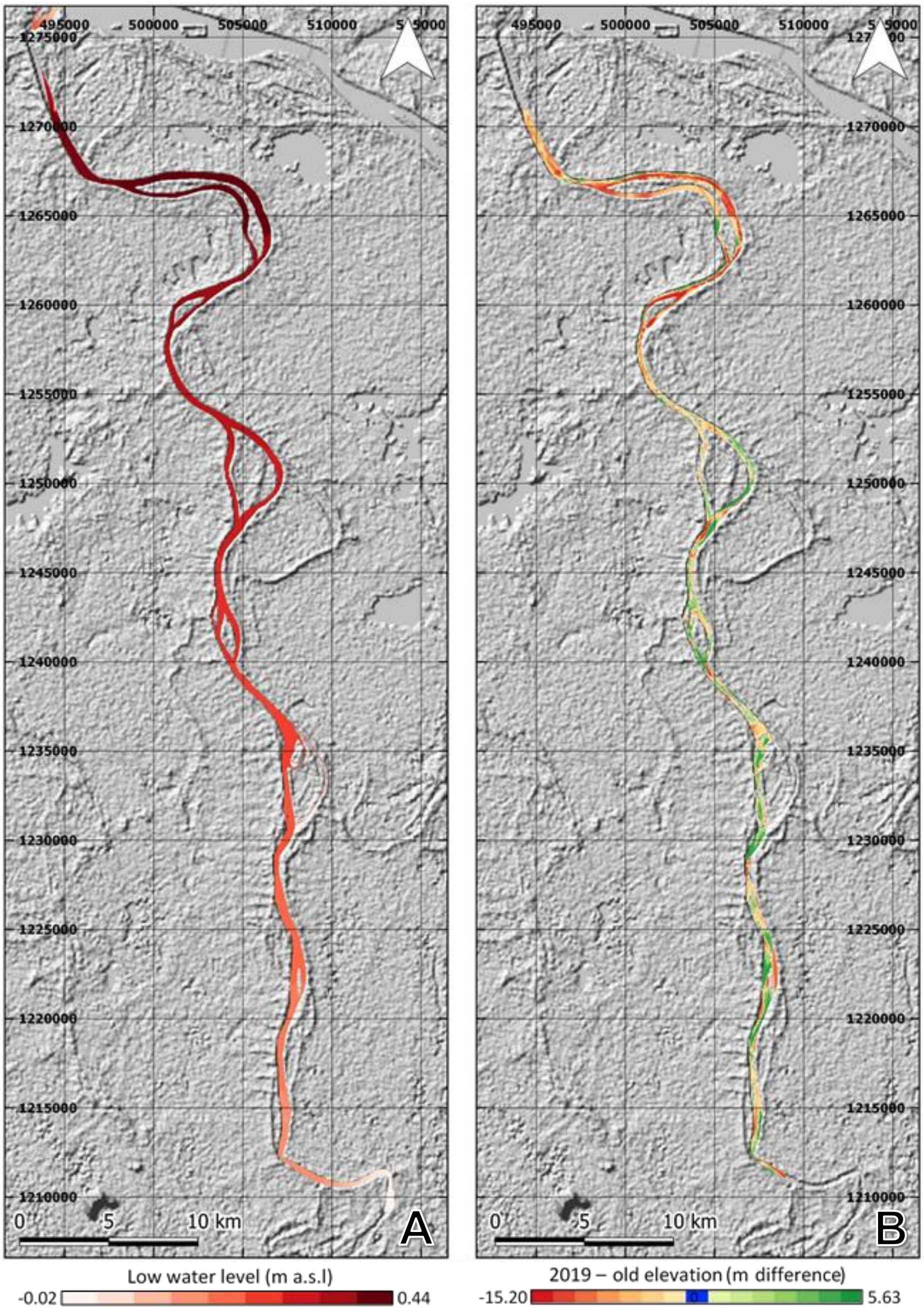


Figure 4-31 Change in sub-reach low water level (A) and bathymetry from the 2001 and 2019 surveys (B).

Presently, a DEM with the 2001 bathymetry is in use for flood modelling, so this section analyses the degree of change in bathymetry between the two available surveys, and therefore whether an update to the 2001 DEM would be necessary.

Survey data is provided in depth measurements, so to convert this to bed elevation the depth was subtracted from low water level, as published for the Hydrographic Atlas 2001 by the Mekong River Commission (Figure 4-31A). These levels were calculated on a sub-reach basis, ranging from -0.02 m a.s.l in the south to 0.44 m a.s.l in the north near Phnom Penh. Once bathymetric elevation was calculated for each set of survey points, DEMs were then created by linearly interpolating within the Bassac Channel banks. The 2001 DEM was then subtracted from that of 2019, as seen in Figure 4-31B. Changes in bed elevation ranged from -19.50 m to 9.00 m reflecting the presence and movement of bars and pools. However there is also an average change of -1.31 m for the reach (Figure 4-31).

This analysis shows a significant change in bathymetry caused by a combination of both natural and artificial processes. The most extensive areas of change are found directly downstream of Phnom Penh, and just north of the Vietnam border. The most contributing instigator of change here is likely dredging of the bed for materials as well as to maintain navigation. The effect of these changes will mean a decrease in water surface elevation in the Bassac for a given discharge, increasing the difficulty to divert the same volumes of water into a Prek. For the WAT4CAM modelling of the Bassac a new bathymetric DEM is implemented using the most recent survey data.

4.12 Additional Topographic Survey

From the analysis two areas stood out as being critical to the modelling for improvement of knowledge in the Preks area: Survey was arranged and completed in January 2021 covering survey of each point shown in Figure 4-32:

1. Prek Ambel is a key river that the Preks connect to or link with during flood that has very little bathymetric data for use in existing models. Cross sections were therefore surveyed, the first survey data since 1965 for the Prek Ambel.
2. A number of key Preks being considered by TA-INFRA, Prek Kampong Sambour, Ta Hing, Mesrok and Nou.
3. The level of the road embankment and the openings on the left bank of the Bassac and the right bank of the Mekong are undefined in the older survey. The road levels and opening dimensions are needed.
4. There was little information on the current state of the Preks at a larger scale. As it is frequently the Prek inlet close to the road that is the control, one section at each and every Prek was surveyed at the road crossing and documented in photographs. This provides a ‘Prek Database’ used for modelling and future use in the Masterplan.

The Survey Report is provided in Appendix 2 and the Preks Database in Appendix 3.

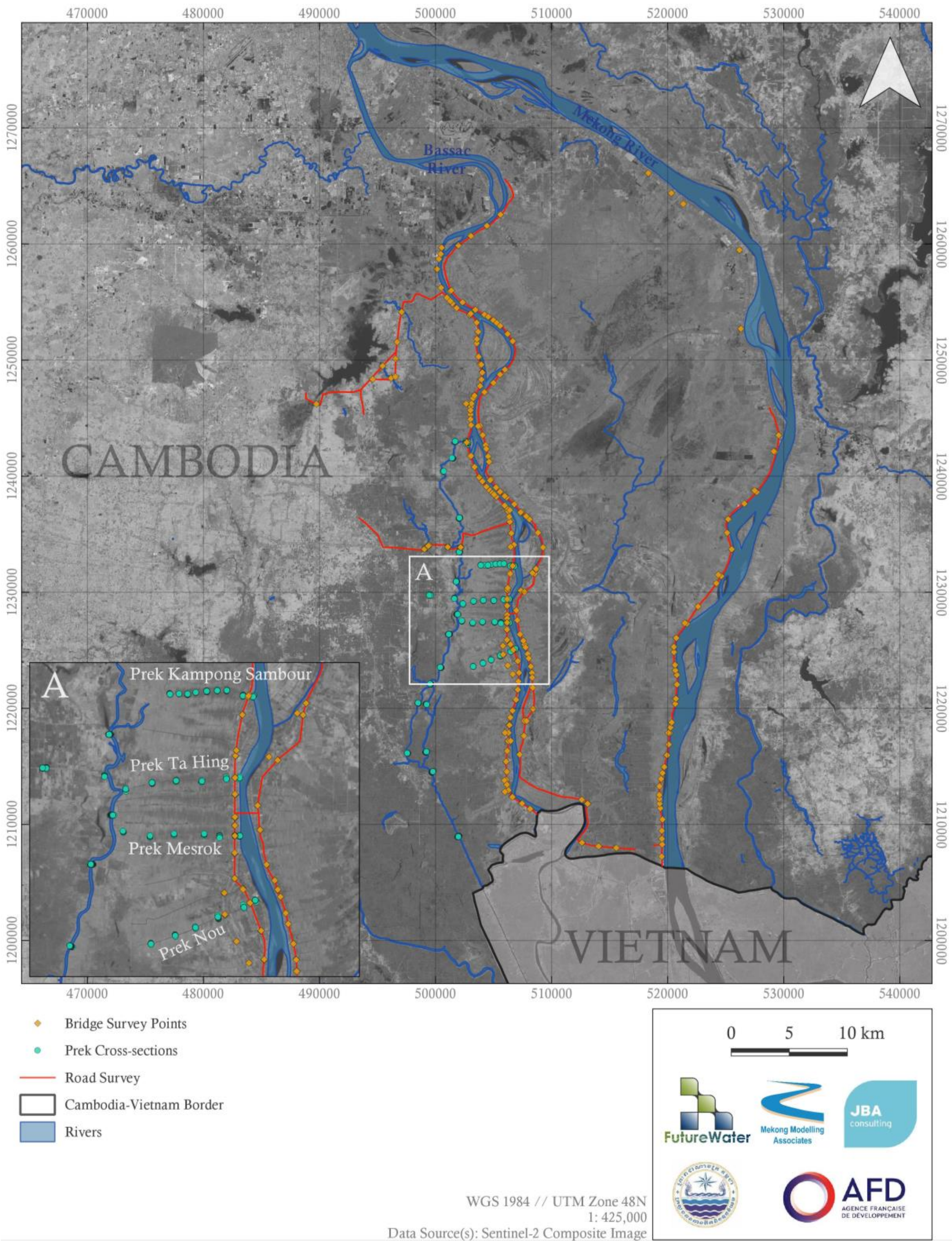


Figure 4-32 Location of Cross section and level surveys completed by WAT4CAM 3.1 for Prek Ambel and road levels and openings of each Prek within the study area along the Bassac and Mekong (shown as orange dot)

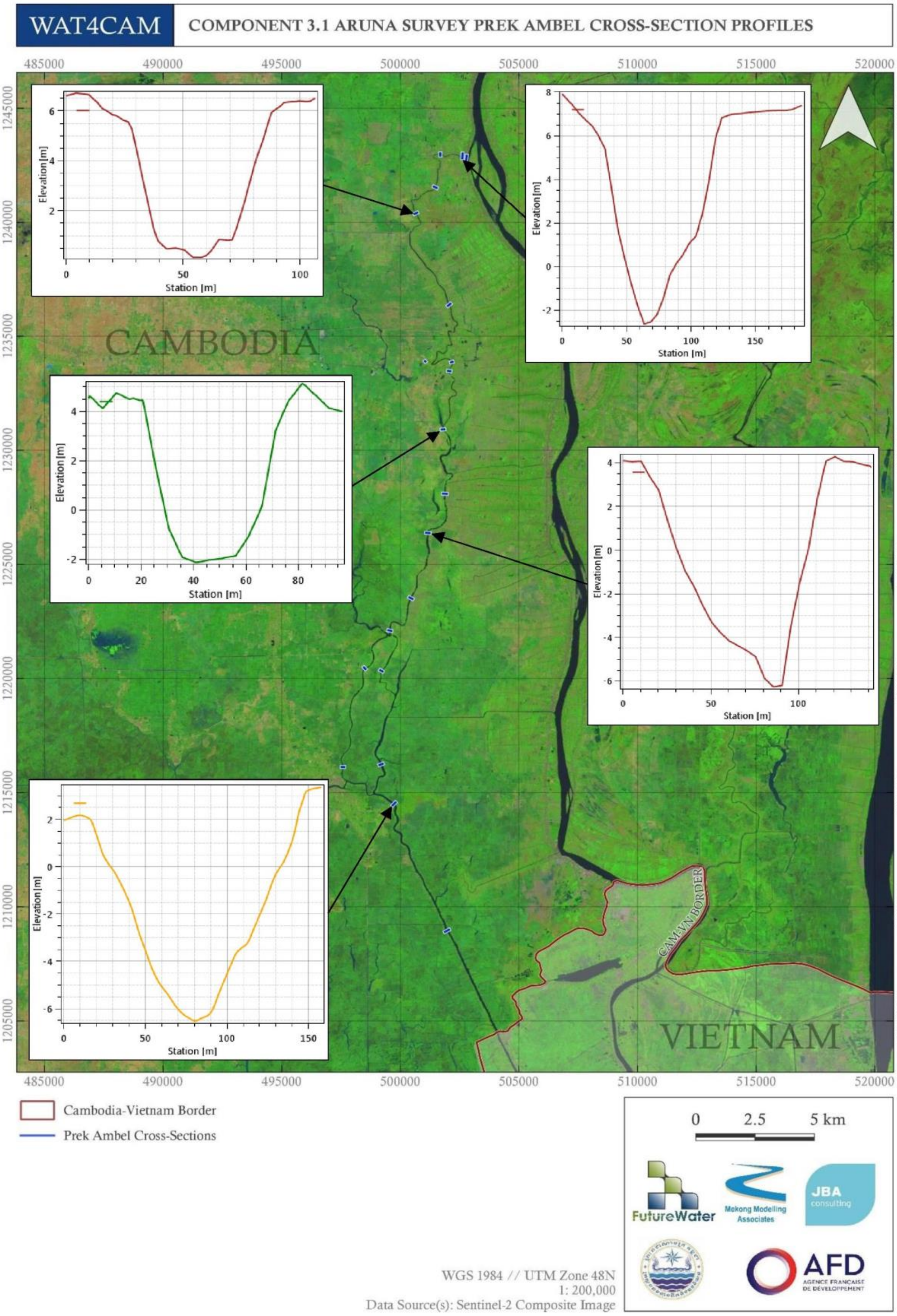


Figure 4-33 New Section Survey for Prek Ambel, near offtake level is +1m so very shallow in the dry season whereas the tide dominated part nearer the border is below -6m.

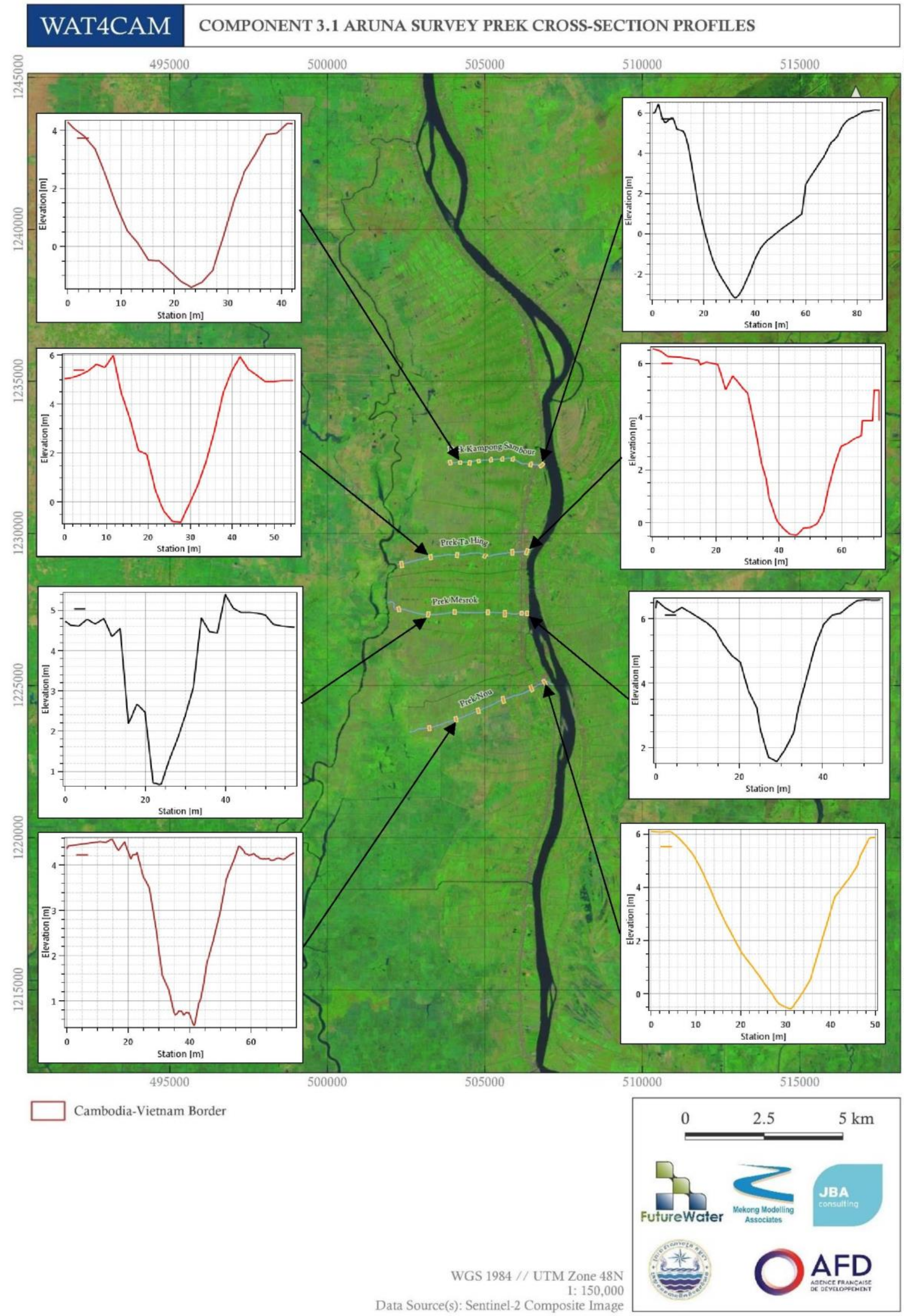


Figure 4-34 Survey X Sections for Prek Kampong Sambour, Ta Hing, Mesrok and Nou. Mesrok has the highest bed

Table 4.6 Prek Database Assembled for Batch 1 Wat4Cam Preks as defined in SCP (2018) using survey data collected for modelling. Note uneven distribution of River Preks

	Prek Identification			Channel Dimensions			Key Features			Flow
	Prek	ARUNA Prek Code	CISIS Reference Number	Channel Length (km)	Mean Channel Width (m)	Inlet Bed Elevation (m)	Classification	Province	CISIS Prek Area (ha)	Gated (Y/N)
West Bassac	Prek Ta Sek	WB37	08101532	2.93	10	4.439	Agri Prek	Kandal	85.5	N
	Prek Chhouy	WB38	08101531	3.03	11	4.085	Agri Prek	Kandal	97.1	N
	Prek Louk	WB40	08041475	6.19	11	4.066	Agri Prek	Kandal	172.9	N
	Prek Thum	WB44	08041514	3.71	12	4.49	Agri Prek	Kandal	109.1	N
	Prek Bak	WB45	08041513	4.69	17	4.166	Agri Prek	Kandal	162	N
	Prek Ta Dhoung	WB46	08041512	4.12	16	1.637	Agri Prek	Kandal	262.8	N
	Prek Chhem	WB49	08041509	6.24	15	2.675	Agri Prek	Kandal	341.2	N
	Prek Tamat	WB51	08041507	4.82	14	3.797	Agri Prek	Kandal	222.8	N
	Prek Thon	WB53	08041505	4.46	18	0.431	River Prek	Kandal	200.4	N
	Prek Cham Kroum	WB54	08041504	4.68	16	0.393	River Prek	Kandal	357.2	N
	Prek Lok	WB57	08041502	4.59	15	1.724	Agri Prek	Kandal	331.7	N
	Prek Pok	WB58	08041501	6.10	15	0.267	River Prek	Kandal	434.7	N
	Prek Horm	WB59	08041500	6.03	18	0.427	River Prek	Kandal	325.5	N
	Prek Nou	WB60	08041499	4.95	22	0.253	River Prek	Kandal	454.1	N
	Prek Touch	WB63	08041496	4.42	16	2.594	Agri Prek	Kandal	296.5	N
	Prek Thom	WB64	08041495	8.38	18	3.29	Agri Prek	Kandal	216.1	N
	Prek Koh Teav	WB66	08041487	2.82	17	3.41	Agri Prek	Kandal	175.2	N
	Prek Kong	WB67	08041489	2.97	16	1.143	Agri Prek	Kandal	228.9	N
	Prek Nhek	WB71	08041588	7.48	16	1.242	Agri Prek	Kandal	214.1	N
	Prek Ross	WB72	08041485	7.76	12	0.673	River Prek	Kandal	244.7	N
	Prek Dem Ampil	WB79	08041484	3.16	10	1.242	Agri Prek	Kandal	371.3	N
East	Prek Maen	EB22	08041600	2.95	14	3.818	Agri Prek	Kandal	180.6	N
West Mekong	Prek Tasork	WM10	08052330	5.50	10	-0.009	River Prek	Kandal	526.60	N
	Prek Thmei	WM11	08052331	2.44	15	0.199	River Prek	Kandal	175.80	N
	Prek Samaki	WM12	08052323	3.34	16	-0.33	River Prek	Kandal	0.00	N
	Prek Banteay	WM13	08051448	3.84	14	0.272	River Prek	Kandal	46.30	N
	Prek Tamout	WM14	08052329	5.27	16	-0.56	River Prek	Kandal	299.30	N
	Prek Top	WM18	08052333	4.50	15	0.56	River Prek	Kandal	264.90	N
	Prek Chorn	WM19	08052311	4.71	14	0.58	River Prek	Kandal	207.20	N
	Prek Say	WM25	08051461	2.62	14	0.614	River Prek	Kandal	176.30	N
	Prek Kong Treuk	WM35	08052317	3.19	12	3.405	Agri Prek	Kandal	190.50	N
	Prek Touch	WM36	08051455	3.92	9	3.489	Agri Prek	Kandal	506.00	N
	Prek Tahing	WM6	08051457	11.52	16	1.163	Agri Prek	Kandal	412.50	N
	Prek Ta Tune	WM8	08051458	3.15	10	1.129	Agri Prek	Kandal	251.10	N
Water Gate	Prek Haong	WG24	08041581	6.38	10	3.909	Agri Prek	Kandal	327.5	N

Table 4.7 Other Preks in Wat4Cam Comp3.1 Prek Database, detailed in Appendix 2

West Bassac

Prek Identification				Channel Dimensions			Key Features			Flow
Prek		Survey Prek Code	CISIS Reference Number	Channel Length (km)	Mean Channel Width (m)	Inlet Bed Elevation (m)	Classification	Province	CISIS Prek Area (ha)	Gated (Y/N)
Teuk Chor Reservoir	2	WB01	08100989	4.33	18	1.593	Agri Prek	Kandal	966.03	N
Prek Roka Kpous	2	WB02	N/A	2.15	10	5.515	Agri Prek	Kandal	0	N
Prek Spean Lak 6	2	WB03	N/A	2.26	10	5.746	Agri Prek	Kandal	0	N
Prek Spean Lake 7	2	WB04	N/A	1.78	8	5.66	Agri Prek	Kandal	0	N
Prek Spean Lak 8	2	WB06	N/A	3.42	10	6.434	Agri Prek	Kandal	0	N
Prek Spean Lak 9	2	WB09	N/A	3.12	16	5.522	Agri Prek	Kandal	19.83	N
Prek Spean Lak 10	2	WB11	N/A	2.09	9	6.182	Agri Prek	Kandal	0	N
Prek Spean Lak 11	2	WB12	N/A	2.18	9	5.416	Agri Prek	Kandal	0	N
Prek Spean Lak 12	2	WB13	N/A	1.93	9	5.97	Agri Prek	Kandal	0	N
Prek Chhrouk	2	WB14	08101465	2.19	10	3.695	Agri Prek	Kandal	82.98	N
Prek Thmei Teuk	2	WB15	08101466	2.98	8	5.131	Agri Prek	Kandal	120.86	N
Prek Ta Bem	2	WB16	08101464	2.26	9	3.968	Agri Prek	Kandal	164.99	N
Prek Ta Va	2	WB17	08101463	1.99	10	5.076	Agri Prek	Kandal	146.33	N
Prek Wat Kbal Koh	2	WB18	08101462	1.93	9	5.117	Agri Prek	Kandal	111.28	N
Prek Ong Pang	2	WB19	08100055	4.57	9	4.314	Agri Prek	Kandal	186.01	Y
Prek Okgna Yeuk	2	WB20	08101544	2.07	10	3.705	Agri Prek	Kandal	146.39	N
Prek Po	2	WB21	08101542	1.80	10	3.019	Agri Prek	Kandal	102.6	N
Prek Wat Chong Hoh	2	WB22	08101541	2.45	9	2.373	Agri Prek	Kandal	171.01	N
Prek Mao	2	WB23	08101467	2.85	11	3.829	Agri Prek	Kandal	189.46	N
Prek Chin	2	WB24	08101468	2.48	13	1.554	Agri Prek	Kandal	43.92	N
Prek Maen	2	WB25	08101469	2.35	9	3.966	Agri Prek	Kandal	59.61	N
Prek Ta Ouk	2	WB26	08101470	3.25	10	0.932	**River Prek**	Kandal	112.19	N
Prek Keo	2	WB27	08101471	1.99	8	4.26	Agri Prek	Kandal	77.88	N
Prek Wat Koh Khel	2	WB28	08101536	2.41	11	5.485	Agri Prek	Kandal	67.23	N
Prek Ta Ang	2	WB29	08101538	1.95	10	3.946	Agri Prek	Kandal	83.48	N
Prek Seang Ly	2	WB30	08101540	2.44	11	3.443	Agri Prek	Kandal	92.36	N
Prek Ta Pang	2	WB31	08101539	3.03	8	4.302	Agri Prek	Kandal	140.8	N
Prek Ta Lai	2	WB32	08101535	1.33	8	3.621	Agri Prek	Kandal	99.22	N
Prek Thmei Prek Ambil	2	WB33	08101534	2.38	9	4.132	Agri Prek	Kandal	132.08	N
Prek Ta Roat	2	WB34	08100756	3.40	11	2.987	Agri Prek	Kandal	121.19	N
Prek Ta Ong	2	WB35	08100757	2.34	11	3.707	Agri Prek	Kandal	114.4	N
Prek Teav Prek Ambil	2	WB36	08101533	2.79	9	4.105	Agri Prek	Kandal	92.6	N
Prek Thom Prek Ambil	2	WB39	08101530	3.84	12	4.287	Agri Prek	Kandal	103.7	N
Prek Ta Ke	2	WB41	08041474	3.57	7	4.792	Agri Prek	Kandal	61.19	N
Prek Thou	2	WB42	08041473	3.70	12	4.213	Agri Prek	Kandal	88.6	N
Prek Samroung	2	WB43	08041472	3.61	11	3.945	Agri Prek	Kandal	102.41	N
Prek Yeay Hay	2	WB47	08041511	6.78	14	1.044	Agri Prek	Kandal	571.96	N
Prek Kampong Sambour	2	WB48	08041510	3.19	21	0.766	**River Prek**	Kandal	258.83	N
Prek Thmei Prek Thmei	2	WB50	08041508	4.38	14	1.237	Agri Prek	Kandal	617.4	N
Prek Ta Hing Prek Thmei	2	WB52	08041491	4.28	15	0.265	**River Prek**	Kandal	253.41	N
Prek Chong	2	WB55	08041503	3.82	9	4.266	Agri Prek	Kandal	278.54	N
Prek Me Srok	2	WB56	08041503	4.71	10	0.248	**River Prek**	Kandal	278.54	N
Prek Put	2	WB61	08041498	3.07	6	3.9	Agri Prek	Kandal	236.01	N
Prek Chann	2	WB62	08041497	4.15	12	0.253	**River Prek**	Kandal	247.35	N
Prek Bro Theat	2	WB65	08041494	1.67	8	2.834	Agri Prek	Kandal	131.42	N
Prek Teav Sampov Poun	2	WB68	08041488	7.20	33	-0.606	**River Prek**	Kandal	192.23	N
Prek Wat Koh Teav	2	WB69	08041506	2.38	13	0.506	**River Prek**	Kandal	131.08	N
Prek Sem	2	WB70	08041486	3.04	12	0.479	**River Prek**	Kandal	140.66	N
Prek Ngoun	2	WB73	08041587	6.81	10	0.673	**River Prek**	Kandal	238.93	N
Prek Thon Sampov Poun	2	WB74	08041586	6.60	13	2.446	Agri Prek	Kandal	160.64	N
Prek Thmei USA	2	WB75	08041585	4.15	10	0.729	**River Prek**	Kandal	226.57	N
Prek Seing	2	WB76	08041584	7.19	20	-0.402	**River Prek**	Kandal	230.45	N
Prek Chhin	2	WB77	08041583	5.07	8	3.822	Agri Prek	Kandal	123.45	N
Prek Spean Lak 77	2	WB78	N/A	2.77	18	3.538	Agri Prek	Kandal	0	N

East Bassac

Prek Identification			Channel Dimensions			Key Features			Flow
Prek	Survey Prek Code	CISIS Reference Number	Channel Length (km)	Mean Channel Width (m)	Inlet Bed Elevation (m)	Classification	Province	CISIS Prek Area (ha)	Gated (Y/N)
Prek Yaey Keam	EA1	08041594	5.22	6	3.629	Agri Prek	Kandal	343.68	N
Prek Dem Chrey	EA2	08041561	2.24	9	3.145	Agri Prek	Kandal	86.86	N
Prek Ta Eang	EA3	08041566	3.03	5	2.713	Agri Prek	Kandal	281.88	N
Prek Ta Nob	EB1	N/A	4.41	16	2.248	Agri Prek	Kandal	0	N
Prek Thmei Traeuy Sla	EB10	08101522	3.51	9	3.906	Agri Prek	Kandal	283.23	N
Prek Phum Prek	EB11	08101521	4.18	12	4.222	Agri Prek	Kandal	196.79	N
Prek Pan	EB12	08101520	4.05	11	3.484	Agri Prek	Kandal	207.64	N
Prek Balat Chheung	EB13	08101519	4.45	12	3.23	Agri Prek	Kandal	315.63	N
Prek Khlok	EB14	08101518	7.16	19	3.552	Agri Prek	Kandal	388.82	N
Prek Thmei Ta Lun	EB15	08101517	1.98	10	2.281	Agri Prek	Kandal	196.83	N
Prek Pe	EB16	08101516	3.99	16	4.181	Agri Prek	Kandal	804.15	N
Prek Wat Talun	EB17	08101481	2.54	8	4.289	Agri Prek	Kandal	789.59	N
Prek Russei Srok	EB18	08101479	2.81	8	4.938	Agri Prek	Kandal	801.73	N
Prek Wat Khpob	EB19	08101483	6.46	8	4.24	Agri Prek	Kandal	422.97	N
Prek Ta Tin	EB2	08101529	3.90	10	4.967	Agri Prek	Kandal	459.15	N
Prek Thmei Khpob	EB20	08101476	4.40	12	3.795	Agri Prek	Kandal	267.33	N
Prek Duy	EB21	08041582	4.57	9	4.3	Agri Prek	Kandal	205.31	N
Prek Kdey Talang	EB23	N/A	3.13	10	3.634	Agri Prek	Kandal	0	N
Prek Khveak	EB25	08041515	3.66	12	1.282	Agri Prek	Kandal	225.35	N
Prek Val	EB27	08041579	5.25	7	3.144	Agri Prek	Kandal	204.04	N
Prek Ta Inn	EB28	08041601	5.07	12	1.57	Agri Prek	Kandal	206.13	N
Prek Svay	EB29	08041602	5.38	11	4.545	Agri Prek	Kandal	138.95	N
Prek Ta Chor	EB3	08101528	7.90	13	2.867	Agri Prek	Kandal	1284.96	N
Prek Ta Dol	EB30	08041545	11.44	11	3.944	Agri Prek	Kandal	42.15	N
Prek Ta Rot	EB31	08041546	12.88	10	3.818	Agri Prek	Kandal	3641.73	N
Prek Dem Sdei	EB32	08041547	3.03	7	3.602	Agri Prek	Kandal	158.97	N
Prek Ta Kol	EB33	08041548	3.42	7	3.857	Agri Prek	Kandal	224.61	N
Prek Kong Sroy	EB34	08041556	2.06	7	5.007	Agri Prek	Kandal	104.82	N
Prek Thmei 2 Kampong Kong	EB35	08041557	1.03	8	3.801	Agri Prek	Kandal	76.69	N
Prek Kuth	EB36	08041551	6.61	8	2.305	Prek	Kandal	0	N
Prek Chrong Romeas	EB37	08041552	5.18	11	3.005	Agri Prek	Kandal	626.67	N
Prek Hang Kampong Kong	EB38	08041553	2.74	13	3.379	Agri Prek	Kandal	239.27	N
Prek Thmei Chrouy Ta Kaev	EB39	08041599	10.66	13	3.515	Agri Prek	Kandal	5323.68	N
Prek Ta Sao	EB4	08101527	5.73	15	0.607	**River Prek**	Kandal	593.3	N
Prek Lach	EB40	08041598	3.81	8	1.843	Agri Prek	Kandal	154.67	N
Prek Kong Ros	EB41	08041595	5.79	9	3.912	Agri Prek	Kandal	450.9	N
Prek Ta Khin	EB43	08041593	3.92	10	4.393	Agri Prek	Kandal	212.1	N
Prek Ta Teing	EB44	08041592	2.19	8	3.747	Agri Prek	Kandal	159.51	N
Prek Kampong Dor Chas	EB45	08041591	2.84	10	3.582	Agri Prek	Kandal	442	N
Prek Ta Sek Chrouy Ta Kaev	EB46	08041590	2.52	8	3.557	Agri Prek	Kandal	148.15	N
Prek Wat Dem Po	EB47	08041578	2.27	7	3.139	Agri Prek	Kandal	185.19	N
Prek Phum Thmei	EB48	08041560	4.89	8	3.364	Agri Prek	Kandal	276.77	N
Prek Wat Chheu Khmao	EB49	08041563	8.37	8	3.079	Agri Prek	Kandal	4971.36	N
Prek Ta Khut	EB5	08100063	5.42	9	4.288	Agri Prek	Kandal	959.81	N
Prek Thmei Chheu Khmao	EB50	08041564	2.01	6	2.469	Agri Prek	Kandal	195.84	N
Prek Hom Chheu Khmao	EB52	08041567	10.27	12	0.909	**River Prek**	Kandal	4935.04	N
Prek Dem Kor	EB54	08041576	3.38	14	-0.817	**River Prek**	Kandal	5322.89	N
Prek Ta Chi	EB6	08101526	5.36	10	4.641	Agri Prek	Kandal	359.73	N
Prek Por	EB7	08101525	4.53	11	3.121	Agri Prek	Kandal	332.76	N
Prek You Heung	EB8	08101524	5.18	9	2.711	Agri Prek	Kandal	294.85	N
Prek Ta Eak	EB9	08101523	1.31	12	4.035	Agri Prek	Kandal	214.41	N

West Mekong

Prek Identification			Channel Dimensions			Key Features			Flow
Prek	ARUNA Prek Code	CISIS Reference Number	Channel Length (km)	Mean Channel Width (m)	Inlet Bed Elevation (m)	Classification	Province	CISIS Prek Area (ha)	Gated (Y/N)
Prek Koki Thom	WM0	08021864	6.43	8	2.453	Agri Prek	Kandal	139.88	N
Prek Spean Dek	WM1	08051450	4.82	10	3.586	Agri Prek	Kandal	186.96	N
Prek Chin Sok	WM15	08051445	3.77	9	0.37	**River Prek**	Kandal	315.31	N
Prek Bakk Touk	WM16	08052306	3.79	11	0.268	**River Prek**	Kandal	272.58	N
Prek Yeay Kam	WM17	08052334	3.60	10	0.524	**River Prek**	Kandal	241.94	N
Prek Bakk	WM2	08052307	3.20	10	3.274	Agri Prek	Kandal	169.54	N
Prek Banh Chhaev	WM20	08052309	3.53	12	0.399	**River Prek**	Kandal	157.34	N
Prek Pak	WM21	08052320	3.13	12	0.631	**River Prek**	Kandal	135.20	N
Prek Koh Roka	WM22	N/A	3.01	10	2.494	Agri Prek	Kandal	0.00	N
Prek Noy	WM23	08051452	2.49	10	0.121	**River Prek**	Kandal	147.92	N
Prek Chrov	WM24	08052312	1.80	10	0.523	**River Prek**	Kandal	146.28	N
Prek Hon	WM26	08052315	3.25	12	-0.098	**River Prek**	Kandal	280.27	N
Prek Ta Chheang	WM27	08052324	3.64	11	0.639	**River Prek**	Kandal	442.84	N
Prek Ta Soum	WM28	08051453	4.67	13	-0.459	**River Prek**	Kandal	279.37	N
Ta Vann Canal	WM29	08052346	3.18	10	3.112	Agri Prek	Kandal	148.32	N
Prek Ta Tork	WM3	08051449	5.75	11	2.674	Agri Prek	Kandal	184.81	N
Prek Samaki	WM30	08052322	3.03	9	2.336	Agri Prek	Kandal	95.51	N
Prek Ta Nhor	WM31	08052327	3.10	8	3.054	Agri Prek	Kandal	114.47	N
Prek Ta Mean	WM33	08051456	4.05	9	3.715	Agri Prek	Kandal	216.59	N
Prek Ta Chuop	WM34	08052325	3.23	10	3.027	Agri Prek	Kandal	198.33	N
Prek Bun Kry	WM36	08052310	4.78	9	3.489	Agri Prek	Kandal	215.36	N
Prek Apech	WM37	08052305	4.39	8	1.66	Agri Prek	Kandal	156.05	N
Prek Chrey	WM39	08021867	2.97	13	2.963	Agri Prek	Kandal	96.72	Y
Prek Spean Lak 5	WM4	N/A	7.85	16	-0.689	**River Prek**	Kandal	0.00	N
Prek Yuon	WM40	08022335	12.18	14	3.255	Agri Prek	Kandal	380.65	Y
Prek Pol	WM41	08021812	2.21	12	3.305	Agri Prek	Kandal	298.23	N
Prek Dach	WM5	08052313	3.65	8	4.567	Agri Prek	Kandal	113.30	N
Prek Thmei Leuk Dek	WM7	08051460	3.61	11	-0.141	**River Prek**	Kandal	295.35	N
Prek Wat	WM9	08051459	1.58	8	1.525	Agri Prek	Kandal	177.37	N

Water Gate

Prek Identification			Channel Dimensions			Key Features			Flow
Prek	ARUNA Prek Code	CISIS Reference Number	Channel Length (km)	Mean Channel Width (m)	Inlet Bed Elevation (m)	Classification	Province	CISIS Prek Area (ha)	Gated (Y/N)
Prek Leab	WG22	08051451	2.55	12	2.727	River Prek	Kandal	203.09	N
Prek Soum	WG26	08041580	13.53	12	3.508	River Prek	Kandal	222.8	N
Prek Trapeang Chrey	WG51	08041565	5.25	13	0.712	River Prek	Kandal	373.66	N

5 Model Set Up and Development

5.1 Model set up

5.1.1 Components

The model is developed using the HECRAS 6.0/6.1 software which is available freely from the US Corps of Engineers website[1]. No other software is necessary for setting up or running the model, although access to GIS and Satellite processing as described in the previous chapter can be used for data analysis and presentation.

The components necessary for any hydraulic model are similar although the 2D modelling environment is particularly intuitive and graphic:

i) Upstream and Downstream Boundaries – flows at tributaries and water level at the downstream
ii) Model Grid Data including grid extent and alignment and the data for river channels, floodplain topography, roughness, structures (weirs/gates) at each grid cell. Grids are shaped using breaklines and refinement areas.
iii) Internal boundaries including rainfall/evaporation irrigation pumping and demands and bridges.
iv) Run parameters used, dates, timestep, solution method

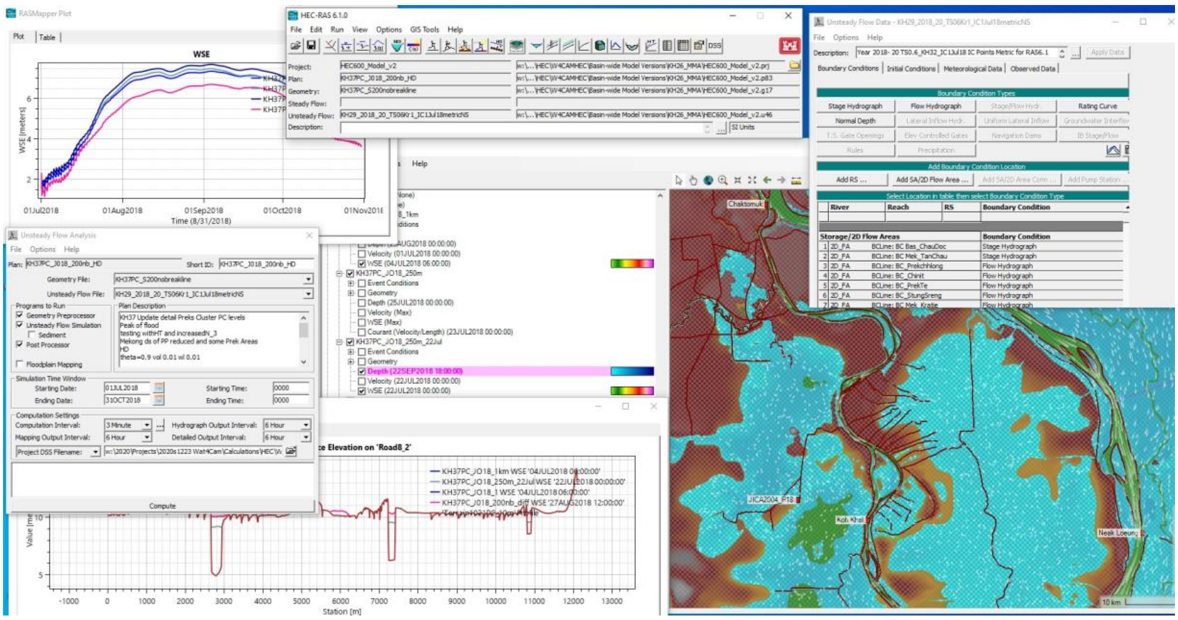


Figure 5-1 HECRAS Interface screens showing GIS mapper, time series and long section plots, run control

[1] *https://www.hec.usace.army.mil/software/hec-ras/download.aspx*

5.1.2 Grid extent

The extent of the model domain is the whole Cambodia floodplain downstream of Kratie including the Tonle Sap Lake which strongly influences flows in the area.

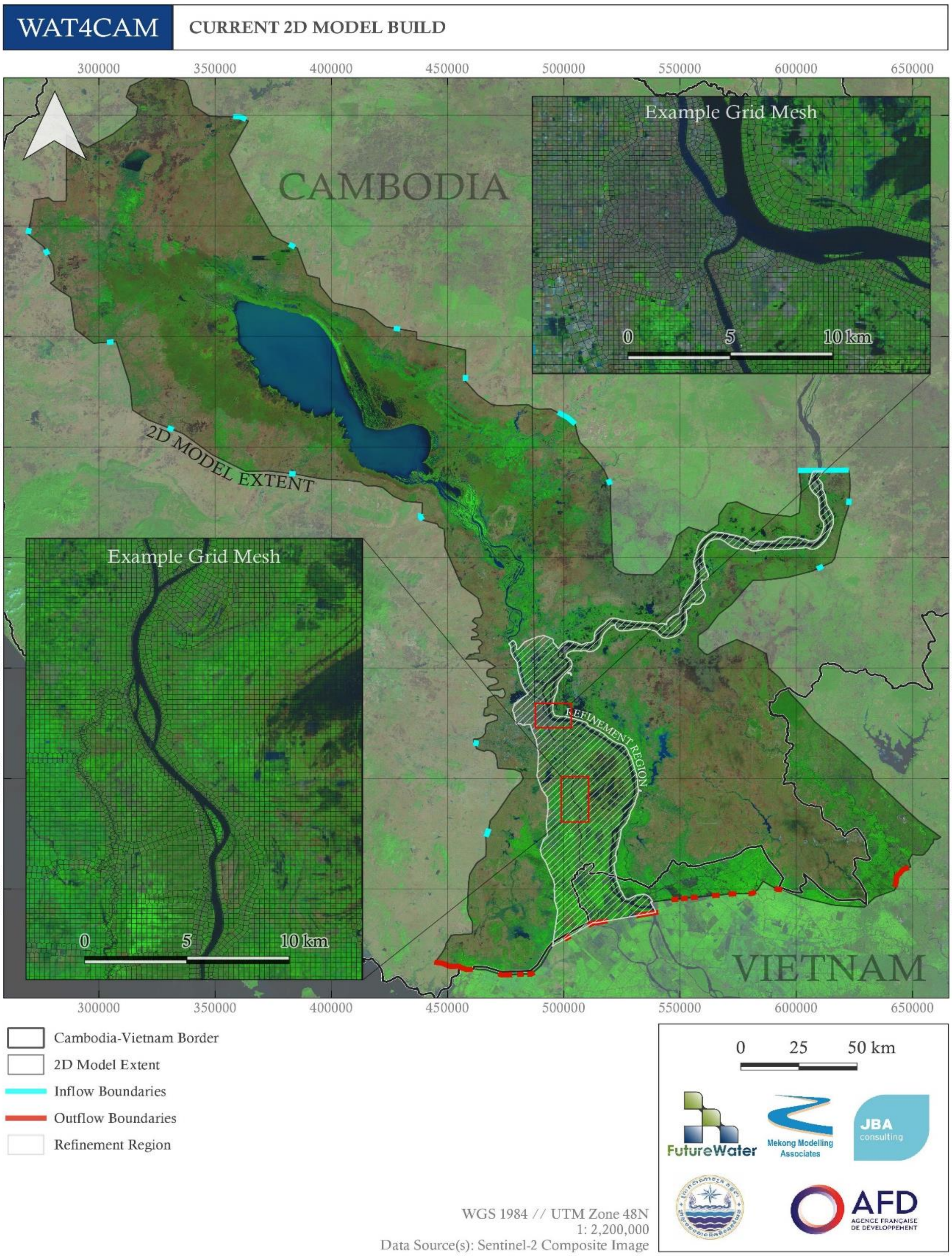


Figure 5-2 2D Model grid extent with refinement region and inflow/ outflow boundaries highlighted. Examples of the grid mesh are also shown

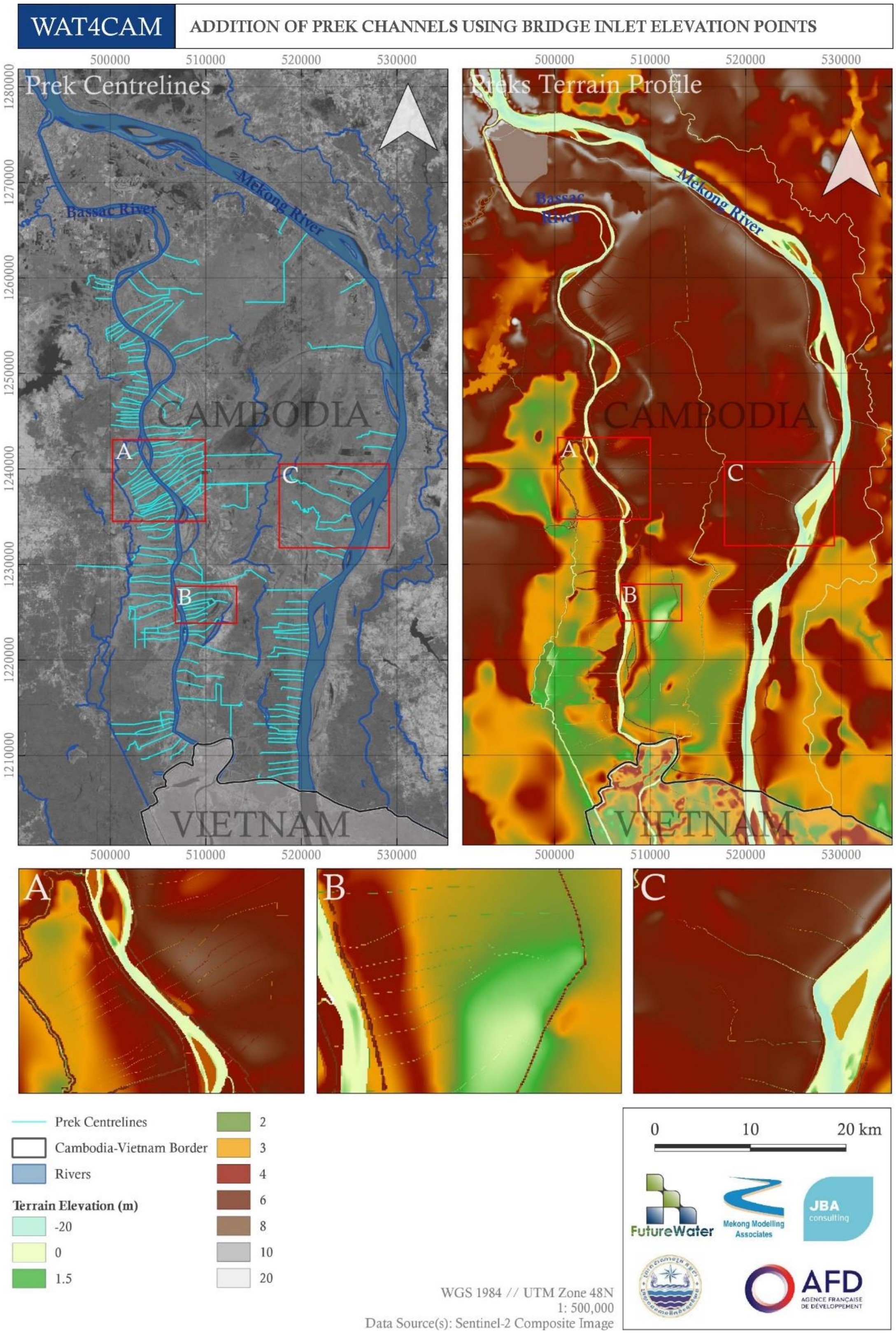


Figure 5-3 Implementation of Prek inlet survey points into the terrain as Prek channels

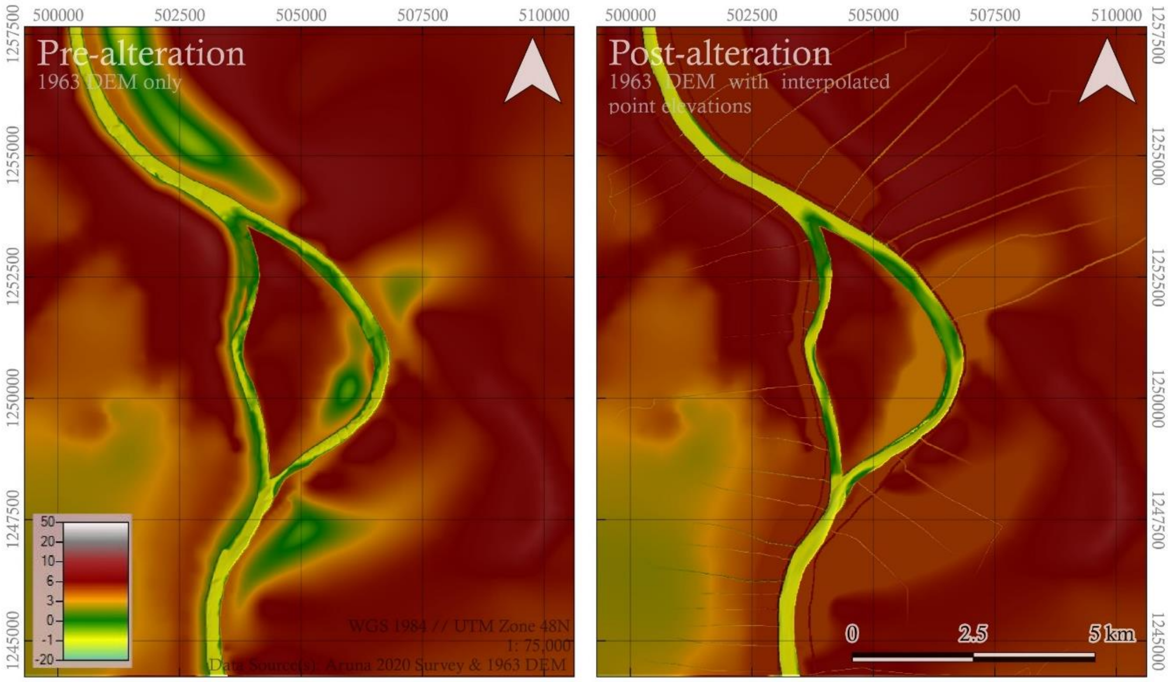


Figure 5-4 Comparison of pre- and post- terrain editing in example Prek location.

Figure 5-4 shows the comparison of the terrain pre- and post- editing in another example Prek area along the Bassac River. Preks in this area were among those with single bed elevation points at the inlets.

For the surveyed road embankments, the same terrain modification tool was used again with average road width extracted from Google Satellite Imagery, determined as 10 m, and bank slope set to 2. Centreline and bank levels available from the Aruna survey were used to input this feature into the terrain. Figure 5-5 shows an example of a small section of this road survey, with reference to a Google Satellite Image of the same area.

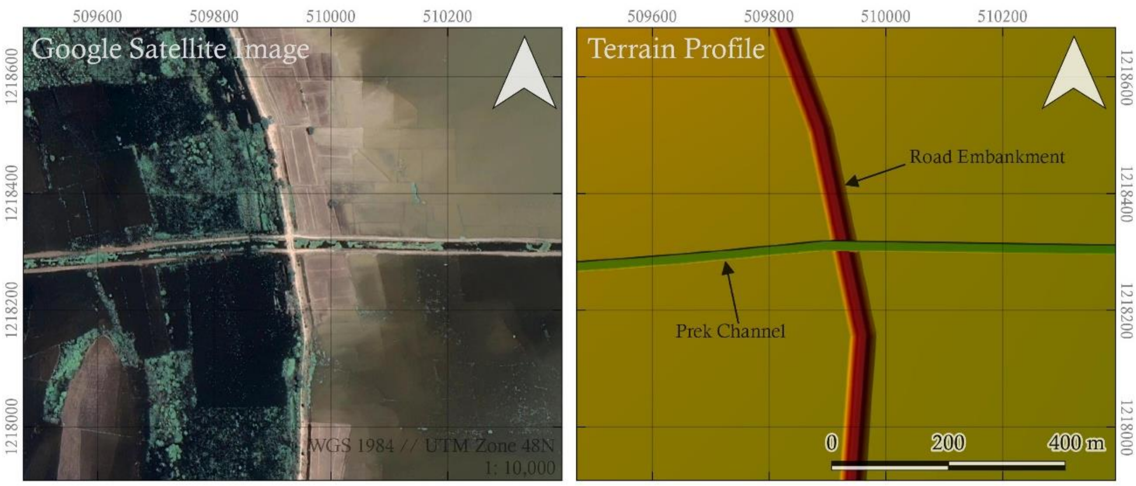


Figure 5-5 Example of road survey data in terrain.

5.1.3 Additional Bathymetric Surveys/ Data

This section describes the additional bathymetric surveys completed outside the WAT4CAM project that were made available by MOWRAM.

Mekong, Bassac & Tonle Sap Rivers

Bathymetric data for the Mekong, Bassac, and Tonle Sap rivers were collected by MOWRAM in 2018/19 surveys. Elevation points were interpolated in HECRAS to produce the bathymetric DEM which was then added to the terrain layer. Figure 5-6 shows an example of the survey data points and final interpolated bathymetry.

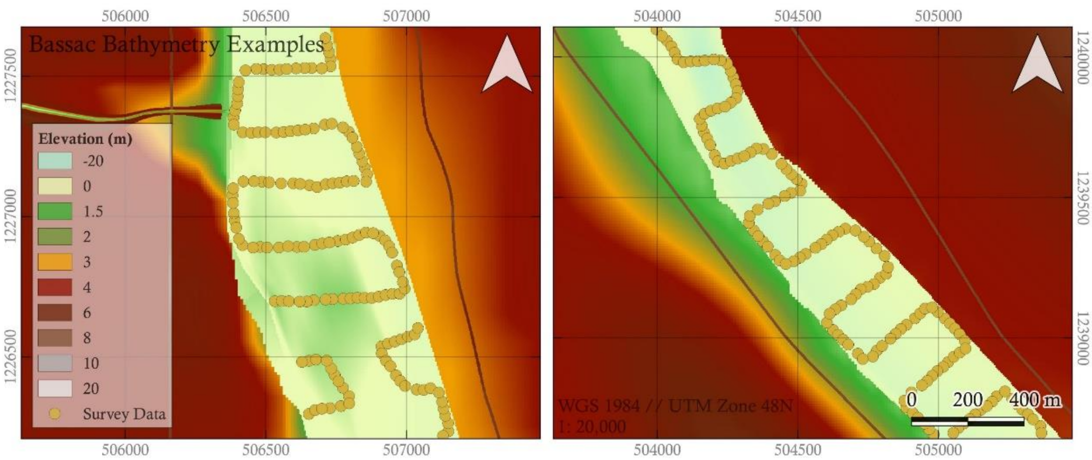


Figure 5-6 Example of survey data points and profile in terrain.

Pursat River

In a previous ADB 2017 study, the Department of Hydrology at MOWRAM completed a cross-sectional survey of the Pursat River and developed a bathymetric DEM. For use in this project, this processed DEM was added directly to the terrain. Figure 5-7 shows the location of the Pursat and the addition of the channel to the DEM.

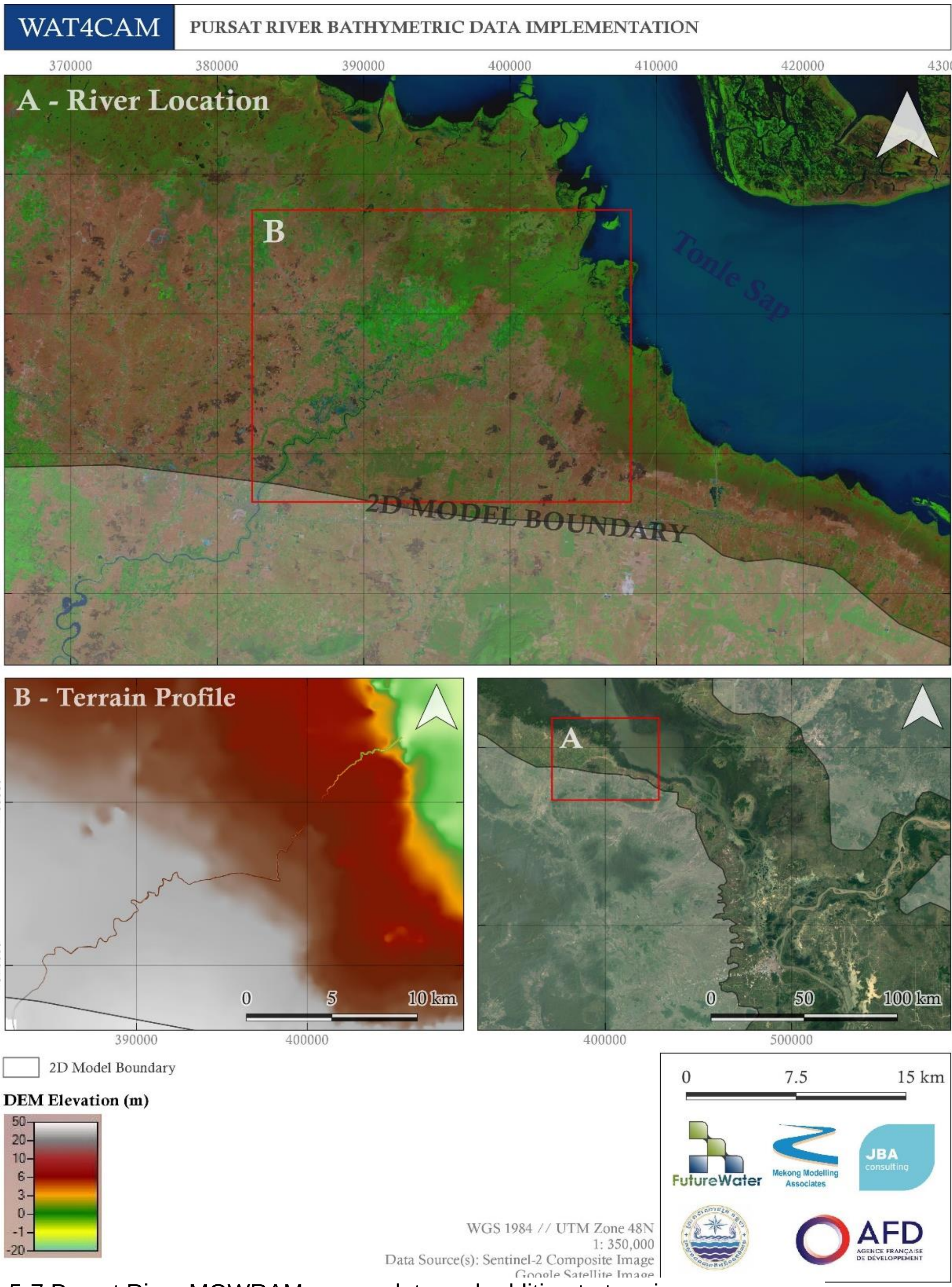


Figure 5-7 Pursat River MOWRAM survey data and addition to terrain.

5.1.4 Other Surveys

Border Canals

The So Ha – Cai Co and Vinh Te Canals are important features at the border of the study area, dictating flow along and across the Cambodia-Vietnam border by their channels, adjacent embankments, and bridge inlets.

The So Ha – Cai Co Canal extends eastward away from Bassac along the Cambodia-Vietnam border, with a combined channel length of 56.41 km. The So Ha Canal is the section of channel connecting to the Bassac, with a width of 32.79 km, with the Cai Co Canal connecting to the east and running another 23.62 km eastward. From 2002 – 2005, the So Ha – Cai Co Canal was dredged as part of an improvement project completed by the Ministry of Agriculture and Rural Development of Vietnam, aiming to:

- Improve drainage capacity of the canal for quicker drainage off the flood over-flowed from Cambodia via Dong Thap Muoi area to Mekong River, and;
- Supply water for irrigation of 19,000 ha and domestic use.

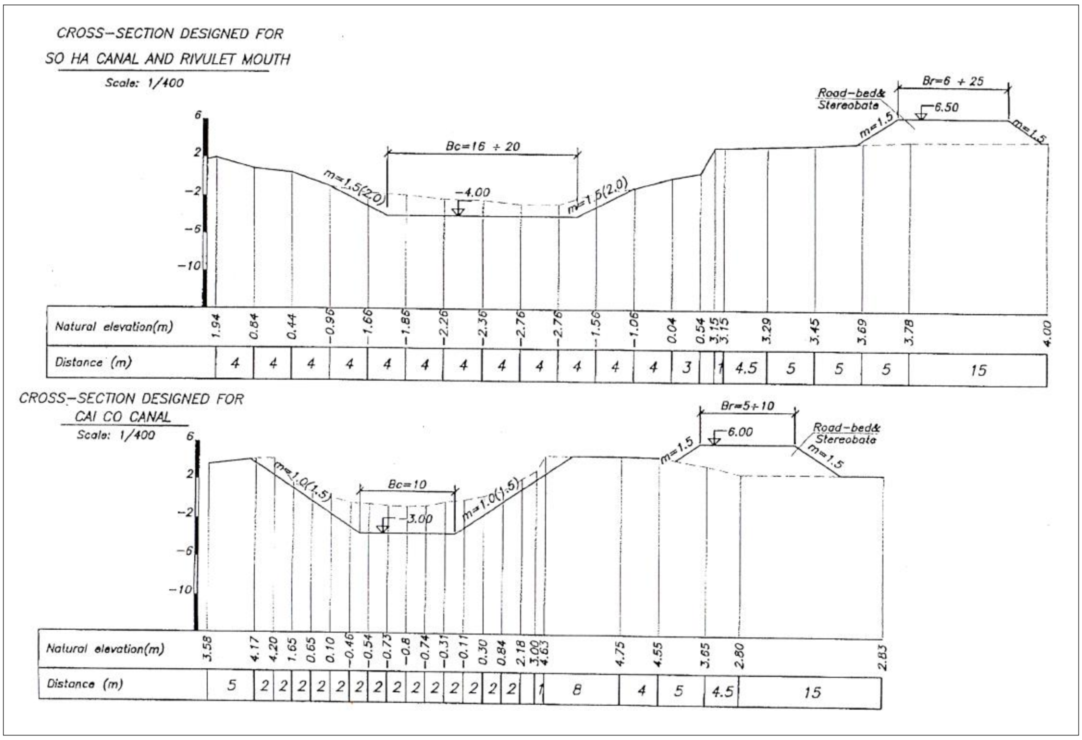


Figure 5-8 Cross-section profiles of the So Ha – Cai Co Canal post-dredging.

Figure 5-8 shows the cross-section profiles for the new channel and embankments which were used for terrain alteration of the DEM.

The Vinh Te canal is located on the west of the Bassac and runs 87 km westward along the Cambodia-Vietnam border towards the coast, delivering water from the Bassac River to Ha Tien on the Gulf of Thailand. To add this channel to the terrain, average width was extracted from Google Satellite imagery, determined as 50m, and depth levels were replicated from the rehabilitated So Ha – Cai Co Canals.

The location and terrain profile for both border canals can be seen in Figure 5-9.

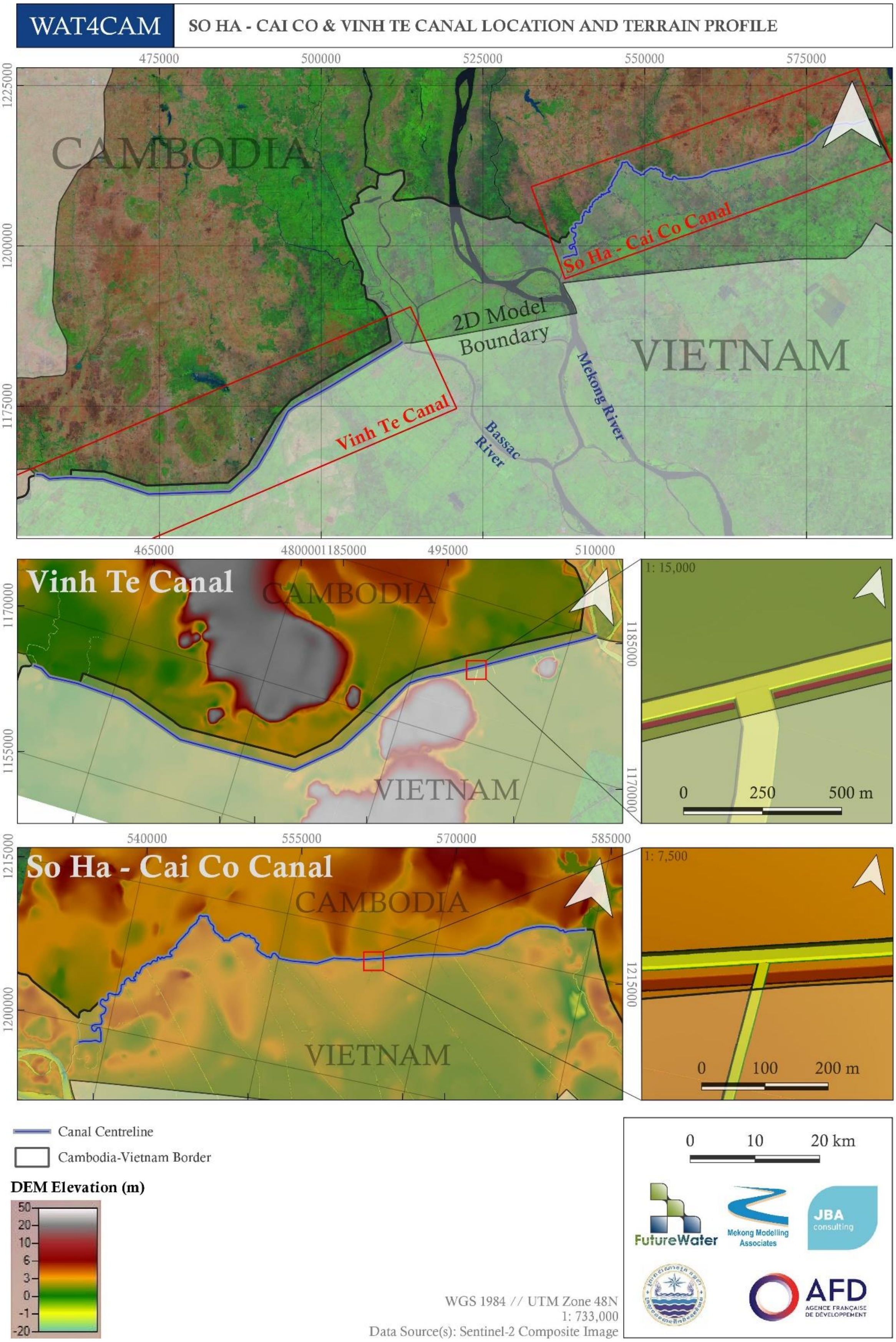


Figure 5-9 Border Canal location and terrain profile.

Road Surveys

Figure 5-10 shows other road surveys from the MRC that have been added to the terrain, including sections of National Roads 1, 5, 6 & 8 and some smaller roads around Phnom Penh such as Street 598. In addition to these features, the National Road 6 section extending North from the National Road 5 junction was added as, despite the lack of survey data here, the road and its bridge inlets play a crucial role in the flow dynamics between the Mekong River and Tonle Sap. As no survey data was available, elevation was approximated from the other surveyed sections and road width was measured from Google satellite imagery.

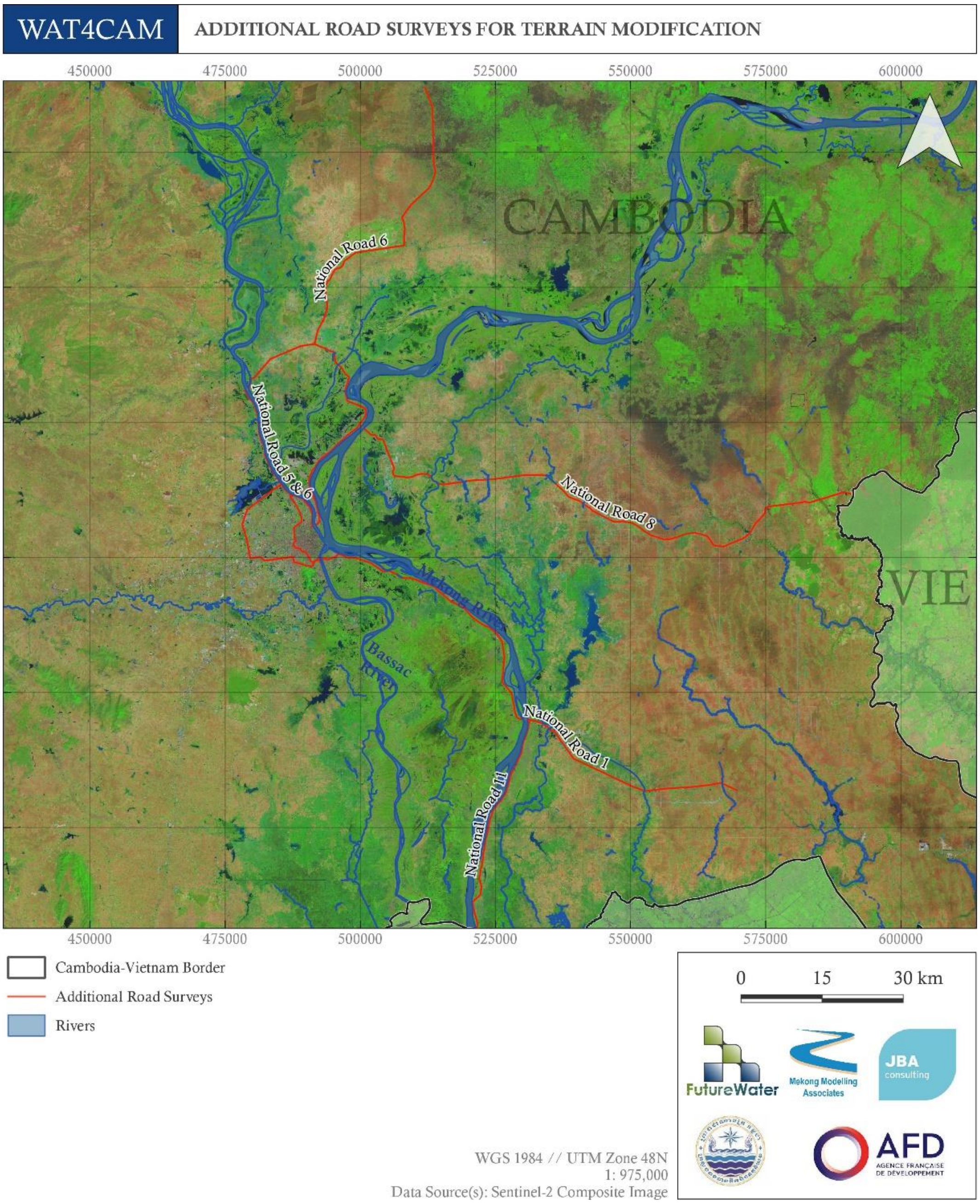


Figure 5-10 Additional road surveys (2014) from CNMC added to terrain.

Bridge inlet elevations were not provided in these surveys, so inlets not measured in the Aruna Dec 20 – Jan 2021 survey used width derived from Google Satellite imagery, and bed elevation was reduced to ground level.

Additional channels added from estimated width-depth data

In 2013, Andreadis *et al.* provided an estimation of channel widths and depths that cover the Cambodia region, using hydraulic geometry equations in conjunction with HydroSHEDS hydrographic data. The bank-full width values were estimated from width measurements of nine major rivers, extracted from Landsat imagery. As high-resolution Google Satellite imagery was available, channel widths were derived from this source and, being more accurate than estimated widths from the Andreadis *et al.* dataset, were used instead.

Therefore, for important channels located in the study area that lacked survey data, channel depths from this dataset and Google Satellite derived channel widths were used for inputting these channels into the terrain. It should be noted however that channel depth estimations are based on flow accumulation, a function of catchment area, and thus does not consider artificial channel alteration or water diversion. Consequently, this data should not be considered a viable replacement for survey data, although in this instance it was decided that to maximise terrain accuracy, using this data would be preferred over the original unaltered 1963 DEM.

The channels added using this method can be seen in Figure 5-11. This primarily includes Tonle Sap and Mekong tributaries and Prek Thnot which are used as inflow boundaries in the 2D model geometry. More channels are located to the east of the Mekong, and in the south west of the 2D model extent at the Cambodia-Vietnam border. These channels function to improve flow dynamics near and across the outflow boundaries of the model.

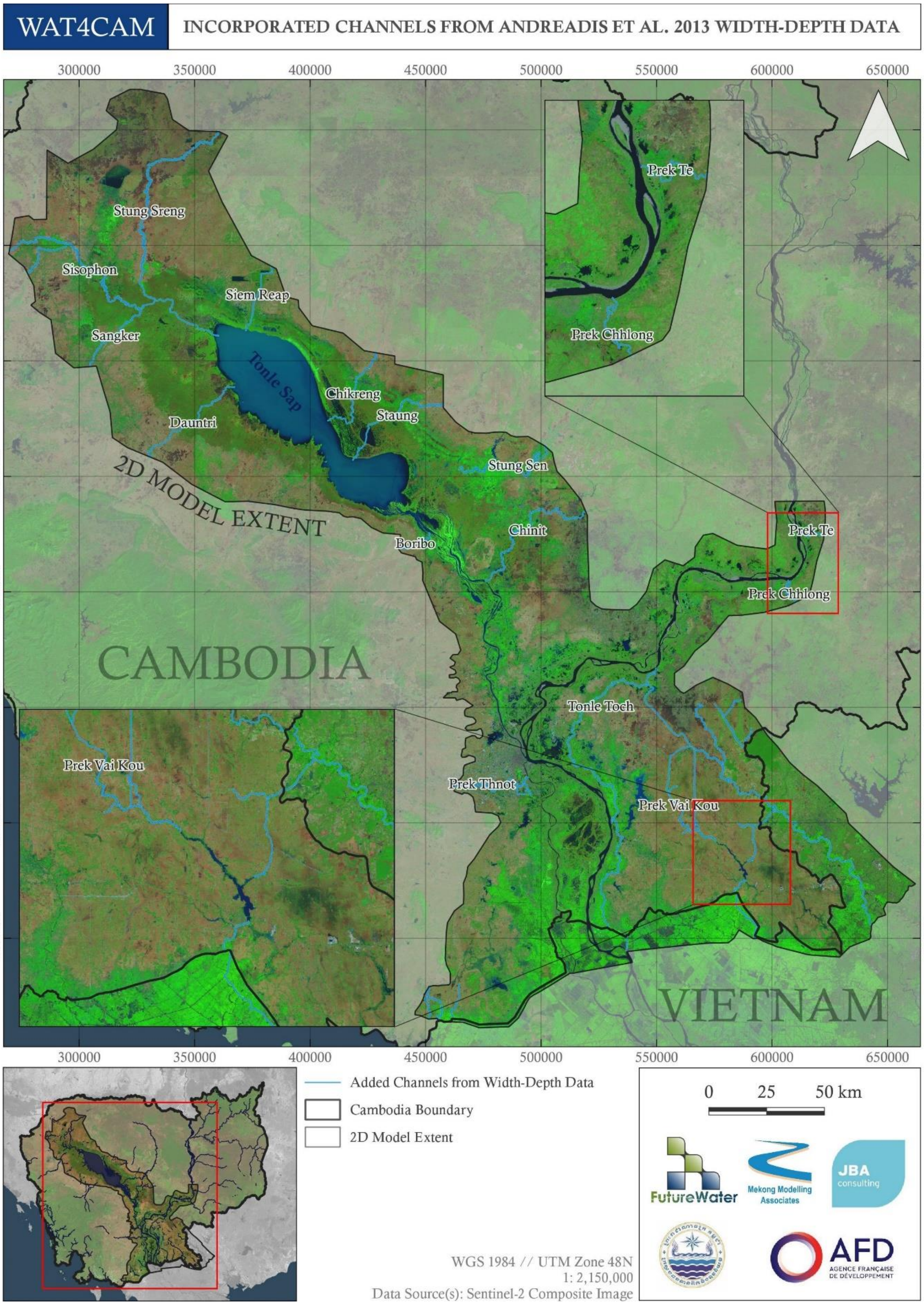


Figure 5-11 Channels added to the terrain from estimated width-depth data.

Manning's N

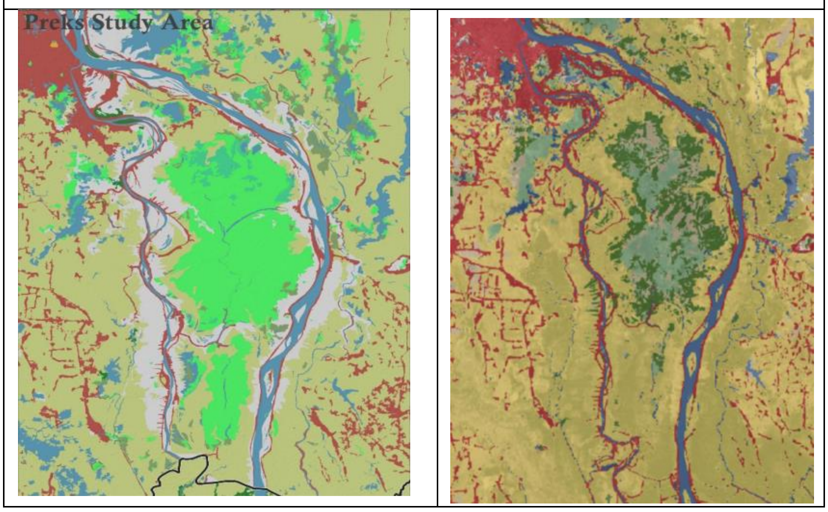
In HECRAS, the roughness of channels and floodplain can be set directly or by using land cover polygons and assigning a roughness to each Land Cover class. Overides can also be used for setting roughness of specific elements, for example rivers or reaches of different characteristics. All of these were used for the WAT4CAM model.

Initial input values for Manning's N were assigned from standard texts and past experience for the 2010 MRC land cover dataset classes. (Table 5.1). The extent of this land cover shapefile only includes the Mekong catchment area, whereas the initial extents of the 2D flood model extend beyond this, particularly in the south-east area of Cambodia. Therefore, to improve the land cover extent, sections of the 2003 MRC land cover dataset were combined to the periphery of the 2010 layer.(Figure 5-12). The ESRI 2020 Land Cover dataset is slightly more up to date and of high 10m resolution which is particularly useful for the definition of urban areas so at the suggestion of MOWRAM this was also downloaded. The classes available unfortunately do not match well for the Preks area, in particular for distinguishing orchard areas, paddy fields and the high vegetation of the Bassac marshes. The MRC dataset was thus used in the calibration work though future updating should consider the new datasets which are being improved continuously using AI technology.

Table 5.1 Initial Manning's N values assigned to land cover classes.

Land Cover	Mannings N value
Water Body	0.025
Paddy Field	0.04
Crop	0.05
Grass/ Shrubland	0.08
Bare Ground	0.03
Urban Area	0.1
Orchard/ Forest	0.12
Marshes/ Swamp	0.04
Mangroove/ Flooded	0.04
Aquaculture	0.05
Other	0.03

Comparison of MRC (left) and ESRI (2020) Land Cover datasets



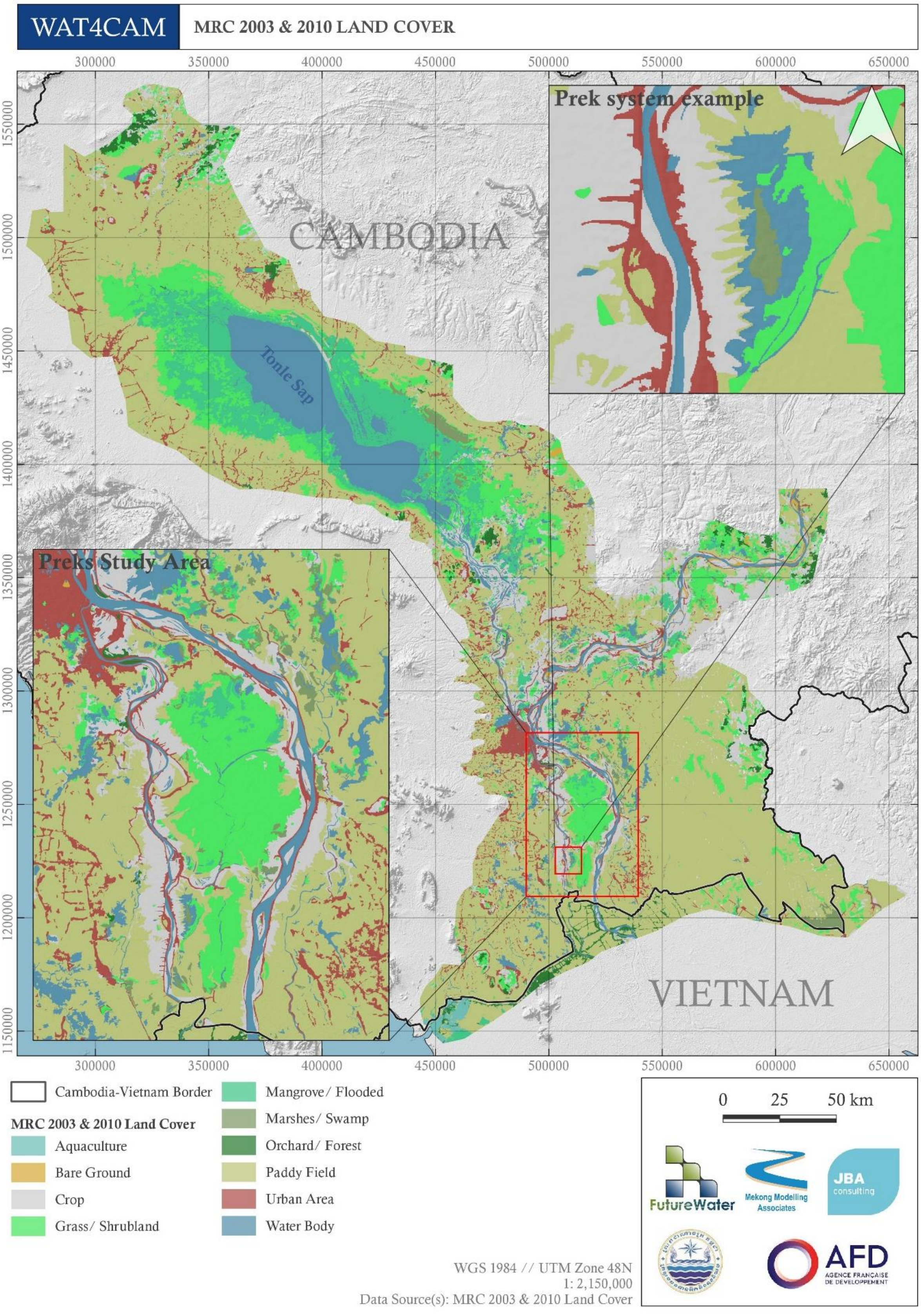


Figure 5-12 MRC 2003 & 2010 land cover used for Manning's N values in 2D flood model.

5.2 HECRAS Model Run Parameters

5.2.1 Grid Sensitivity Tests

The grid used is an important aspect of 2D modelling. Too fine a grid will make simulations very lengthy, too coarse a grid will be inaccurate or unstable. Modelling for the Preks project is particularly challenging as the channels of interest are very small relative (5-10m wide) to the full extent of the system that needs to be included in the model (400kmx275km). Within HEC-RAS the grid size may be varied using a finer grid along breaklines or through defining a local refinement zone. Small cells in one area though may determine the time step in a simulation that in turn controls how long the simulation may take.

The different options presented are: –

1. 200m grid size (no refinement: existing MOWRAM model)
2. 250m grid size with breaklines
3. 500m grid size with breaklines
4. 1000m gridsize

These different grids options in the vicinity of the Preks area are shown in Figure 5-13 to Figure 5-15.

The resulting number of grid points and simulation times for a typical one season simulation (July-October 2018) are shown in the table below:

Grid Size (m)	Breakline min grid (m)	No of Cells	Simulation of 4 months (Hours)
1000	10	57,602	10.5
500	10	174,403	41.1
250	10	654,450	120.5
200 (MOWRAM FF model)	200	820,287	*not run in hydrodynamic mode.

It can be seen that there is a big difference in simulation times and even though these are carried out on a fast i7 desktop computer, the simulation times are significant for a modelling study even for a 1km grid. The MOWRAM model does not run in a hydrodynamic mode but with simplified equation mode and a large timestep which keep the simulations times in around 1.5 hours but greater than the 250m grid if run fully hydrodynamic.

Each of the model configurations were run on a fast i7 desktop computer for the July-October 2018 event. The water levels at Chaktomuk, Koh Khal and Neak Luong are shown in Figure 5-16. There is a variation in the results from one site to another. The 250m and 500m results are reasonably consistent at each site though the diffusive wave 200m grid is consistently different and the 1km grid deviates.

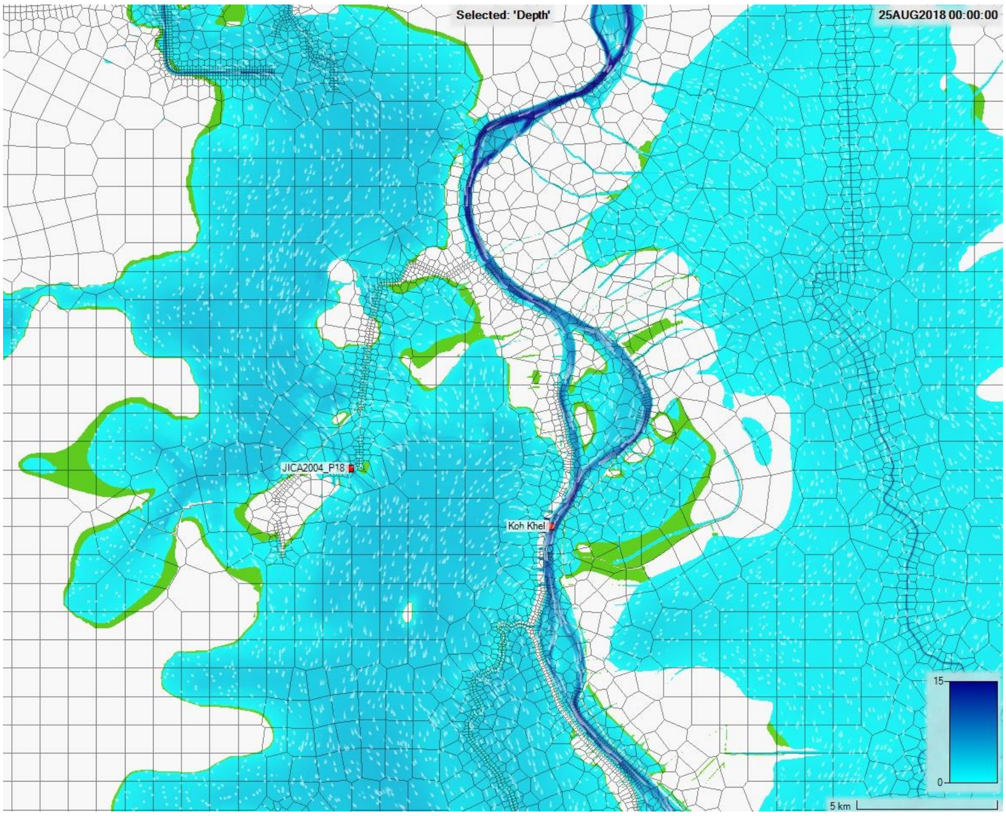


Figure 5-13 Grid Sensitivity tests - 1km grid with enhancements at breaklines

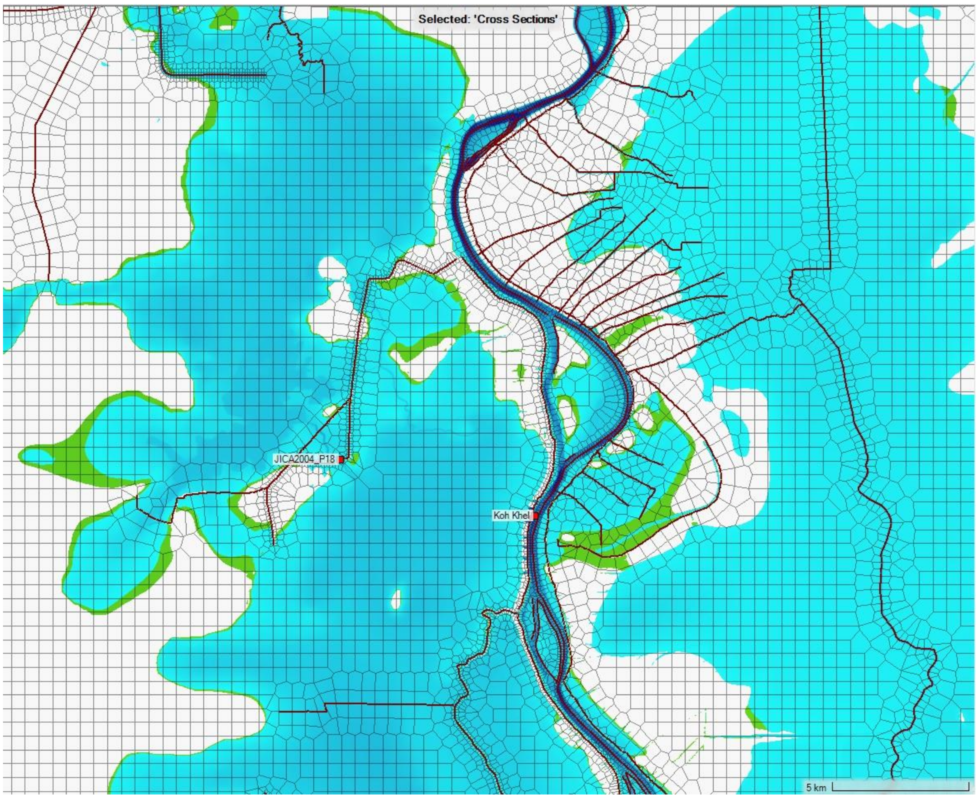


Figure 5-14 Grid Sensitivity 500m grid with breakline enhancements

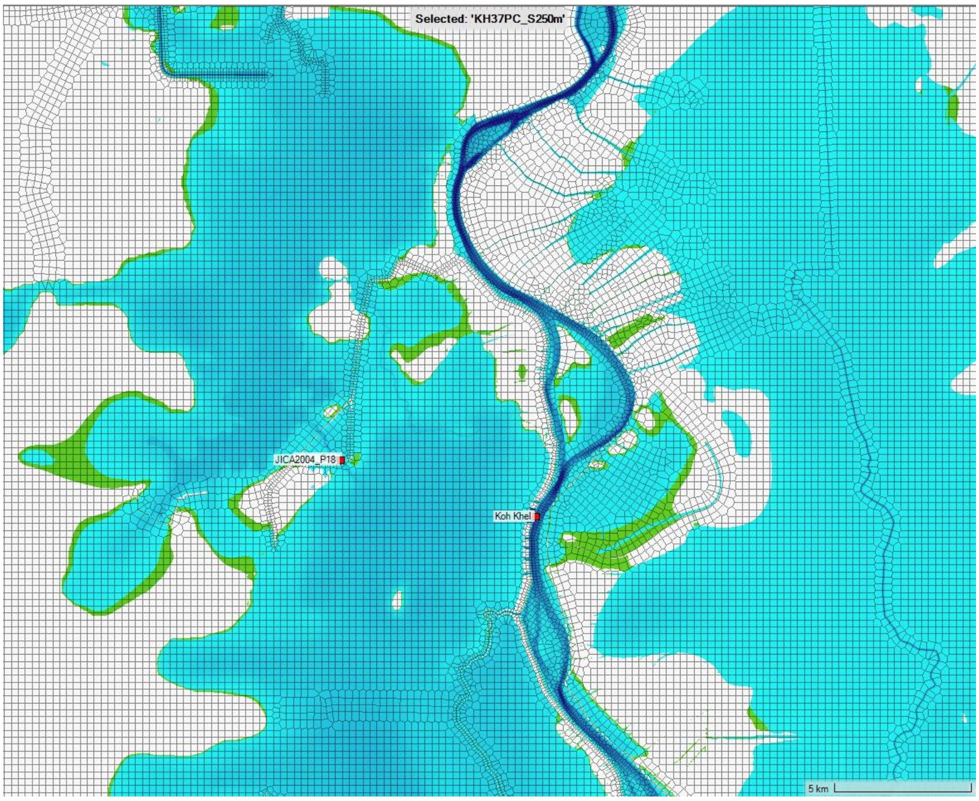


Figure 5-15 Grid Sensitivity - 250m grid

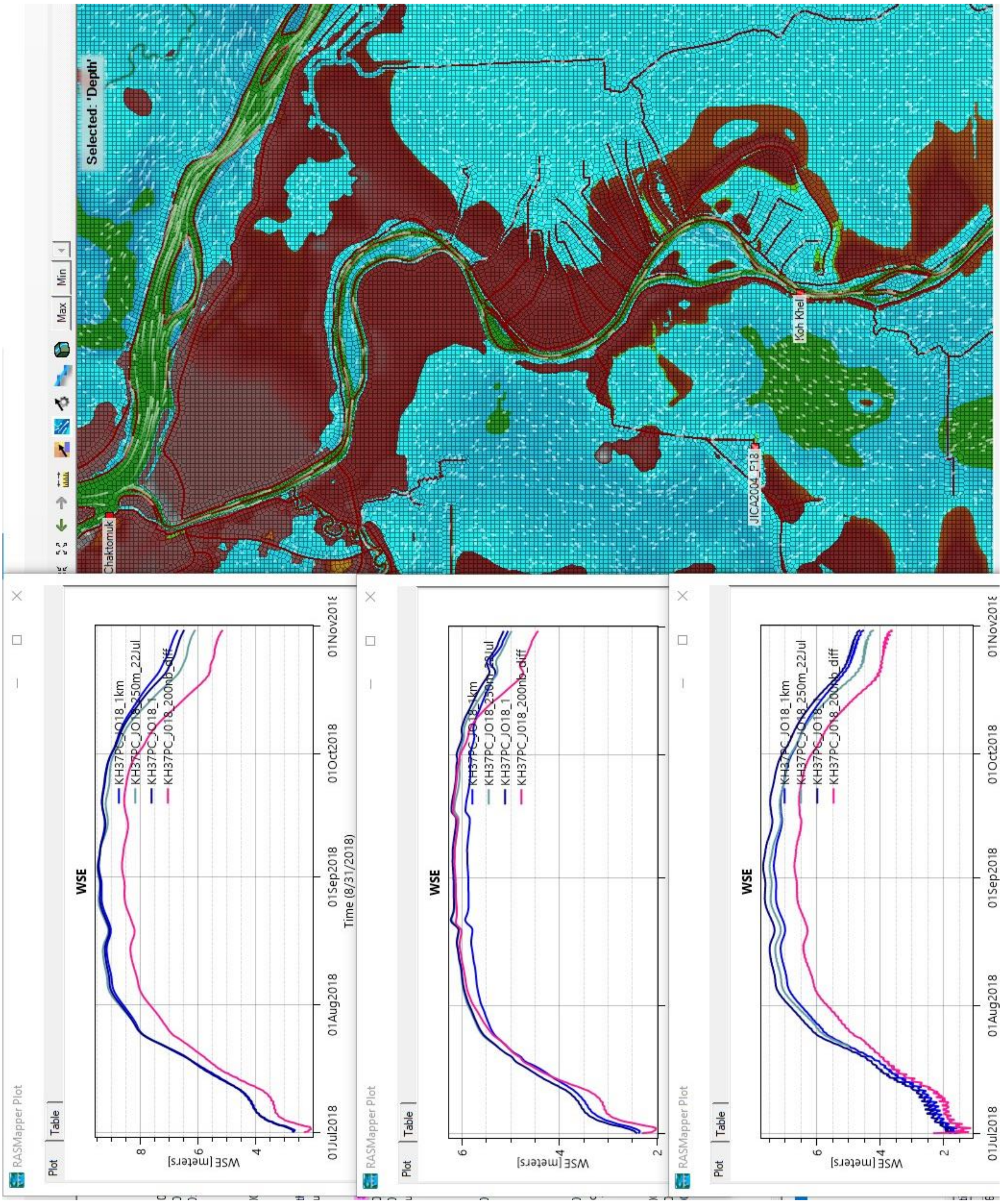


Figure 5-16 Grid Sensitivity - Simulation results (top to bottom) at PP Chaktomuk, Koh Khal and Neak Luong

To test and demonstrate the impact of different grid sizes on breaklines, further tests were carried out for an example single prek, Prek Thom using 50m – 5m grid size as shown in Figure 5-17.

WAT4CAM	GRID Sensitivity testing. Prek Thom

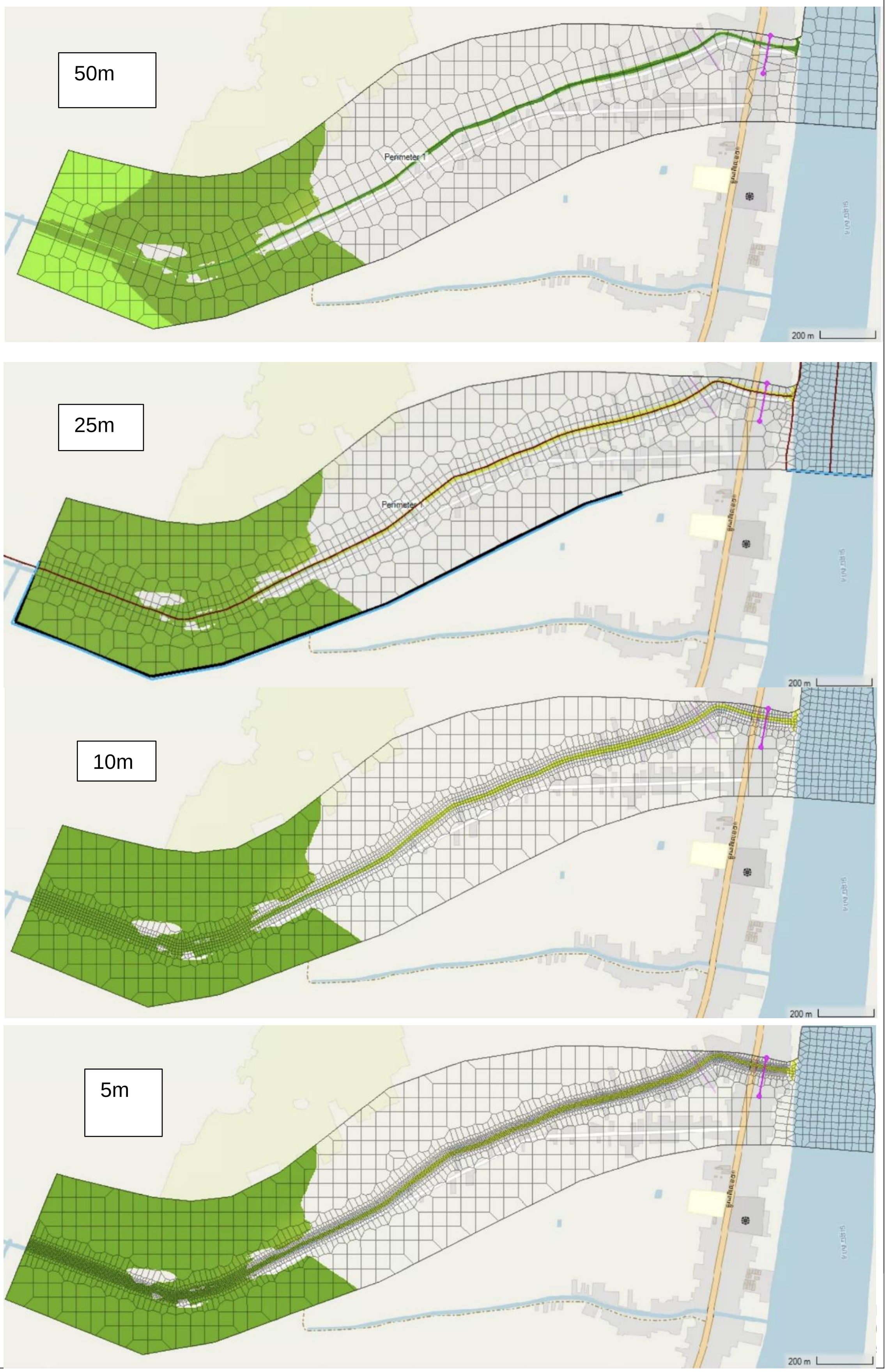


Figure 5-17 Grids of 5m, 10m, 25m and 50m used for Prek Thom

The submodels were run again for the 2018 event with the result as shown in Figure 5-18. It can be seen that the variation between results at 50m and 10m grid size vary by 20%. 5m, 10m and 25m results are within a closer band of less than than 10% thus the 10m sub grid size is taken to be adequate for the current purpose as more detail should be considered to evaluate the peak flows into a Prek at the design phase.

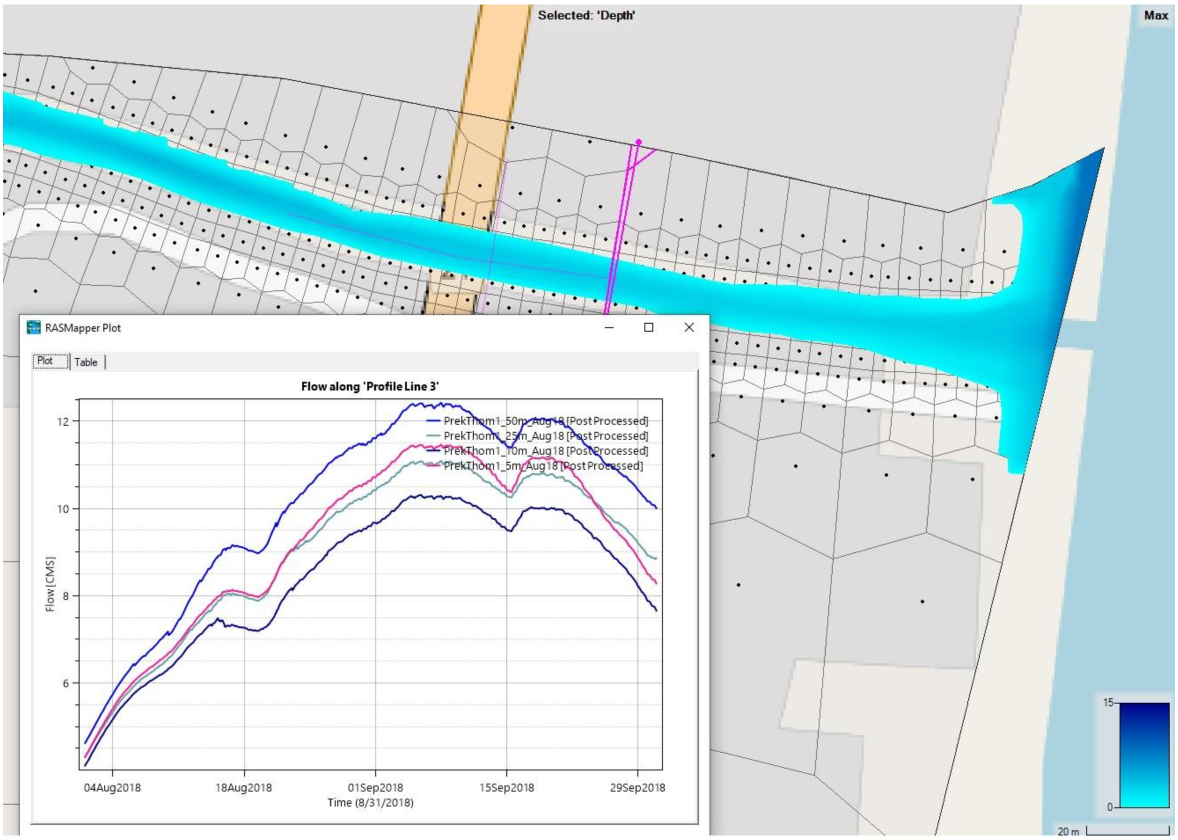


Figure 5-18 Flows in Prek Thom Sub model for grid sizes 5-50m

5.2.2 HEC-RAS Versions

During the project HEC released versions of the software 5.07, 6.0 Beta v1, 6.0 Beta v2, 6.0 and 6.1. At each release there is some change in results and hence a consistent version 6.0 has been used for calibration and the runs presented.

5.2.3 Hydrodynamic and Diffiusion Wave Options

From section 5.2, it can be seen there is a considerable difference between hydrodynamic runs and for a tidal situation it is essential to use fully hydrodynamic mode. In a tidal situation especially, the diffusion approach to simplifying the equations of fluid motion do not capture the momentum effects that are important in the mainstream Mekong and hence lower water levels are obtained even during floods.

5.3 Model Calibration and Verification

5.3.1 Model Calibration 2018-2020

The model was run for the period July 2018 to October 2020 for calibration and the 2000 flood used as a verification. Due to the length of time of simulations, the model was run season by season and then the record joined.

The standard gauge stations on the mainstream where data could be obtained were used for the calibration and verification work. The results for 1-D modelling are well established for the period 1985-2008 but for the recent years, the data is not so well established and flow inputs have a significant effect on the 2D simulation. Thus where there are deficiencies in calibration this may not be due to the representation in the 2D domain but errors in the accuracy of net inflows.

The stations assessed are illustrated for the 2018 flood and for the period 2018-2020 in Table 5.2.

The statistics of fit between the model and the observed data for the 8 stations within the 2D domain were calculated for each wet season as presented in :Figure 5-19 and Figure 5-20:

1. Difference in flood peak level (m)
2. Coefficient of Regression (R^2)
3. Nash Sutcliffe Coefficient of Efficiency

The fit is within expected ranges though improvements ought to be possible with further refinement of demands and inflows.

Table 5.2 Statistics of Calibration Fit 2018-2020

Parameter/m	Kratie	KampongCham	Chaktomuk	NeakLeung	KohKhel	Ankor Borei	KampongLoung	PrekKdam
Model Peak 2018	20.96	14.76	9.14	7.36	6.27	4.61	9.41	9.39
Observed Peak 2018	21.20	14.63	8.93	7.18	6.82	4.29	9.18	9.11
Difference 2018	-0.24	0.13	0.22	0.18	-0.55	0.33	0.23	0.28
r2 2018 wet	0.99	0.99	0.98	0.98	0.95	0.94	0.95	0.87
ns 2018	0.98	0.94	0.95	0.97	0.88	0.71	0.91	0.75
Model Peak 2019	21.36	15.06	9.05	7.31	6.32	4.48	7.20	8.30
Observed Peak 2019	21.65	14.82	8.47	6.65	6.68	3.88	7.20	8.06
Difference 2019	-0.29	0.24	0.58	0.67	-0.36	0.61	0.00	0.25
r2 2019 wet	0.99	0.98	0.98	0.95	0.97	0.96	0.92	0.96
ns 2019	0.96	0.91	0.92	0.95	0.92	0.75	0.83	0.88
Model Peak 2020	18.36	12.69	7.02	5.20	5.37	3.68	6.38	6.76
Observed Peak 2020	17.91	11.56	6.66	5.30	5.82	3.40	6.60	6.62
Difference 2020	0.45	1.13	0.36	-0.10	-0.45	0.28	-0.22	0.14
r2 2020 wet	0.96	0.94	0.94	0.90	0.92	0.90	0.78	0.94
ns 2020	0.90	0.59	0.79	0.90	0.87	0.47	0.63	0.87
Overall Min Model	5.73	1.13	0.78	0.60	0.66	0.33	1.31	0.93
Overall Min Data	4.51	1.32	0.42	0.77	0.43	0.29	1.02	0.70

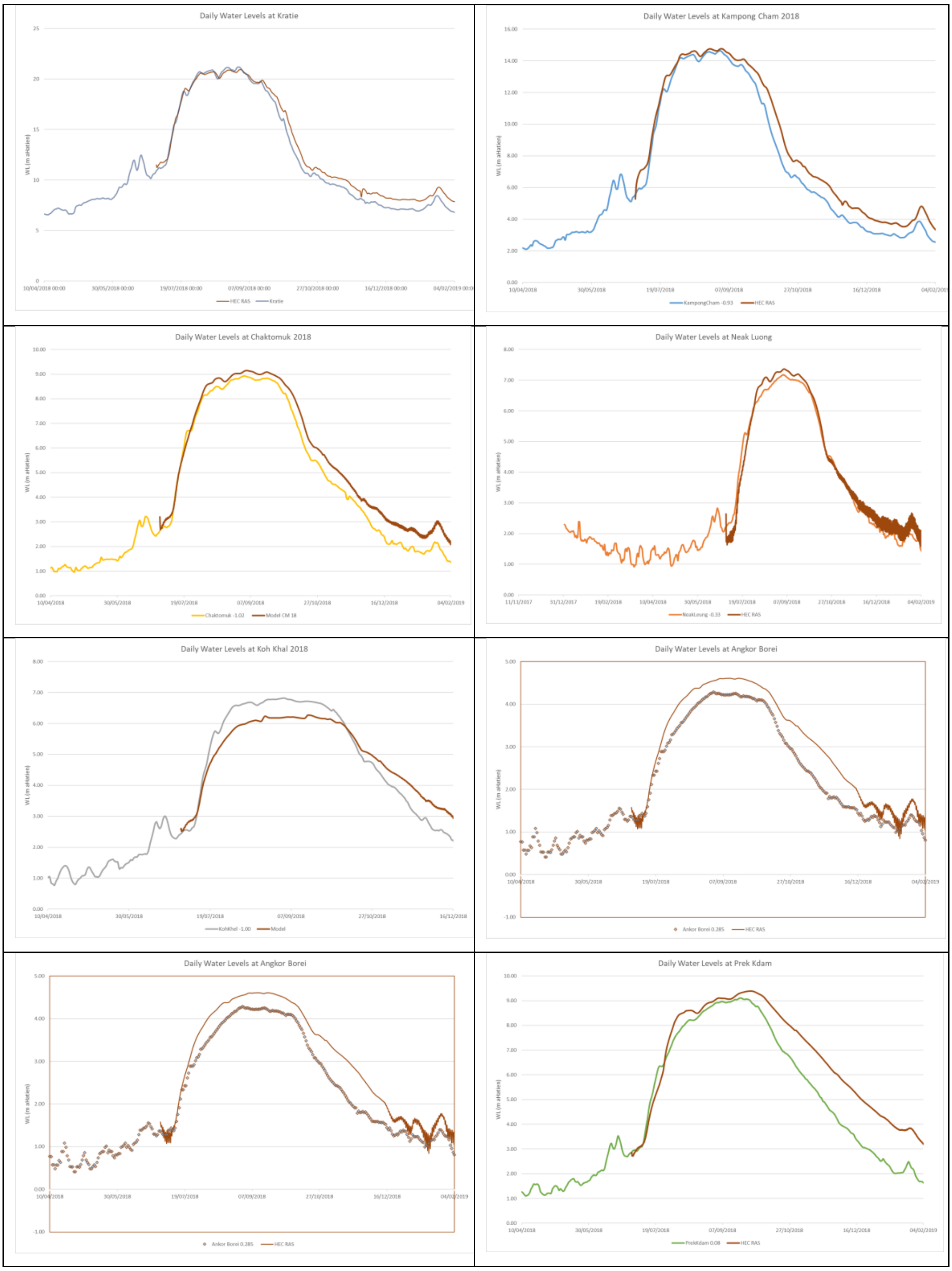


Figure 5-19 Comparison of Model and Observed data during wet season 2018 for Kratie, Kampong Cham, Chaktomuk (PP), Neak Luong, Koh Khal, Kampong Luong and Prek Kdam

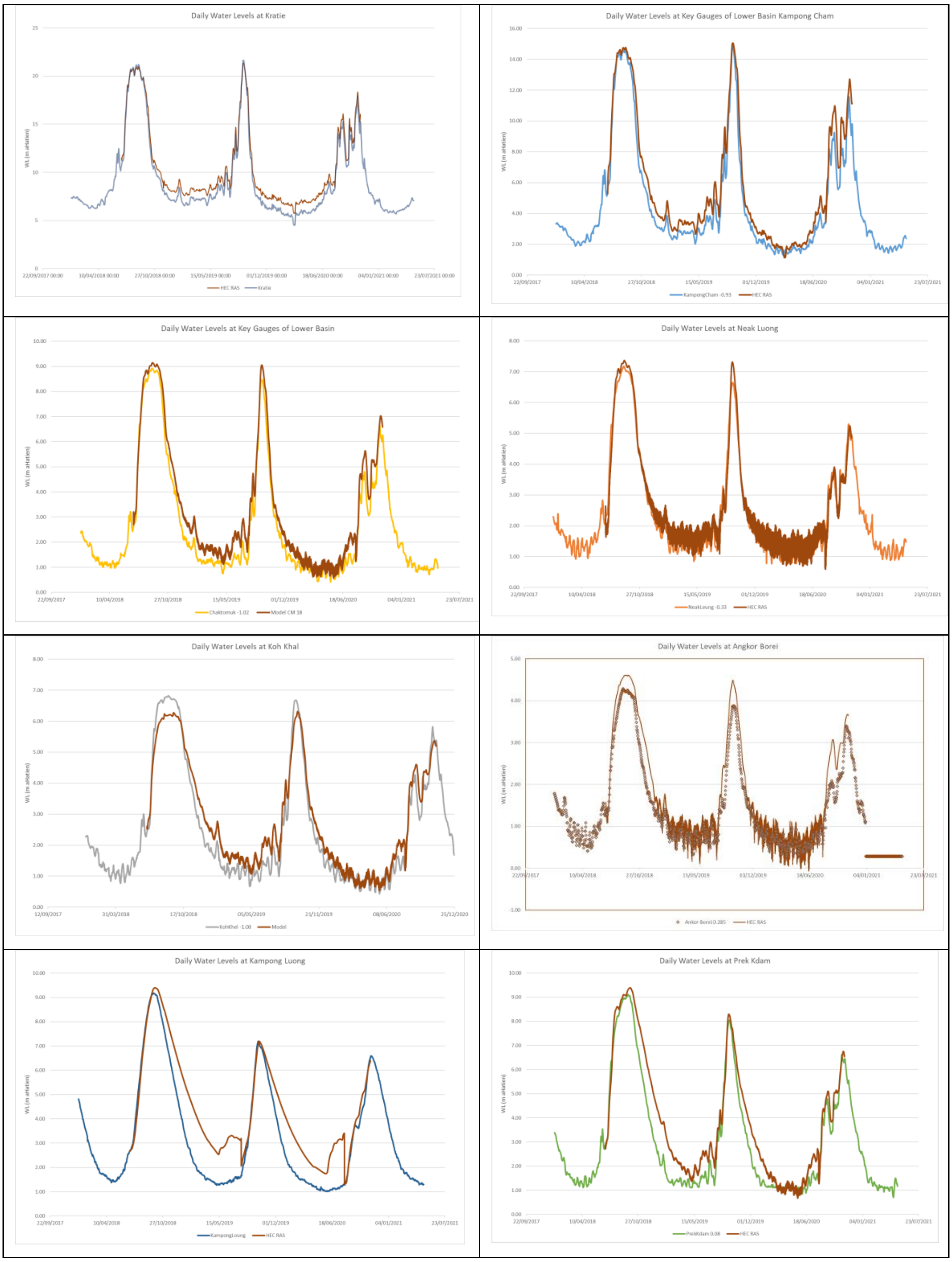


Figure 5-20 Comparison of Model and Observed data during 2018-2020 for Kratie, Kampong Cham, Chaktomuk (PP), Neak Luong, Koh Khal, Kampong Luong and Prek Kdam

5.3.2 Verification 2000

The verification simulation for year 2000 produced good results without further adjustment as shown in Figure 5-21.

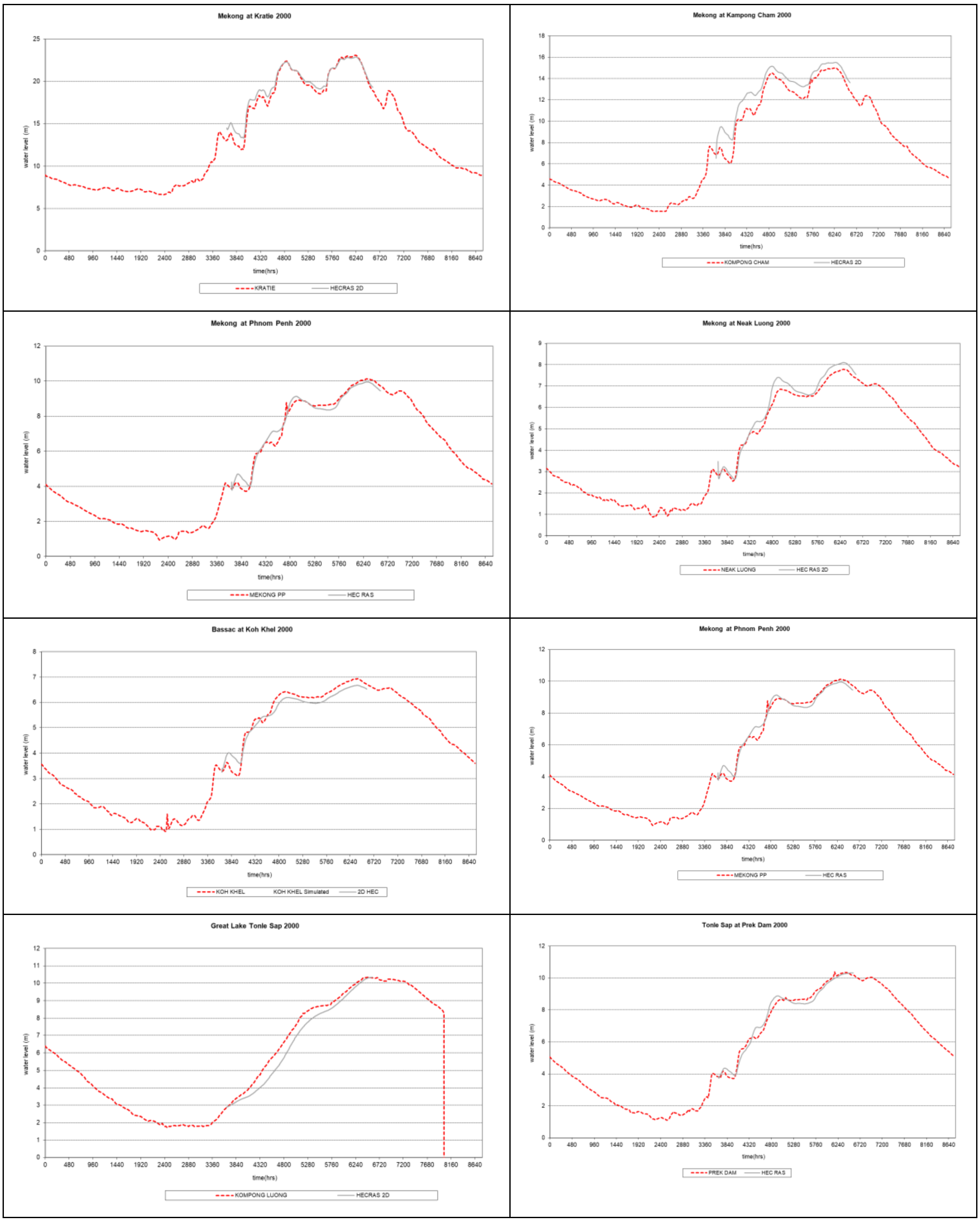


Figure 5-21 Comparison of Model and Observed data during 2000 flood for Kratie, Kampong Cham, Chaktomuk (PP), Phnom Penh Port, Neak Luong, Koh Khal, Kampong Luong and Prek Kdam

5.4 Climate Change

5.4.1 Implementation for WAT4CAM Modelling

The floods and droughts of the Preks area are largely determined by the influence of large-scale changes at the level of the Mekong basin. Reliance is thus placed on the extensive studies carried out by the Mekong River Commission.

Whilst the changing temperature in the region can be documented from analysis of gauge record, for the hydrological domain, the much larger variation makes the detection and projection of change more difficult and fort he purposes of WAT4CAM a pragmatic approach based on the more detailed is needed to define:

a. Changing flood peaks
b. Sea Level Rise
c. Local Rainfall and change in water demand
d. Change in dry season flow

Simulations were carried out perturbing the main inflow to the system by fixed proportions and through a sea level rise routed through the 1D ISIS model. The basis and theoretical background is explained in the next section as a summary of the relevant MRC documents from which they are drawn.

5.4.2 Theoretical Basis of Climate Scenarios Used

Unlike some basins of the world there are no simple guidelines to apply a change to the flow regime for testing the possible impact of climate change. The closest is the result of the MRC studies between 2013 and 2020. In these, firstly the effect of atmospheric forcing scenarios was examined in various climate models and the performance of these models assessed for performance in the Mekong Basin. It was found that different climate models indicated different levels of change important for hydrology. After a screening process and processing of models to indicate change, a number of well performing climate models were selected and hydrological simulations carried out using the changes indicated.

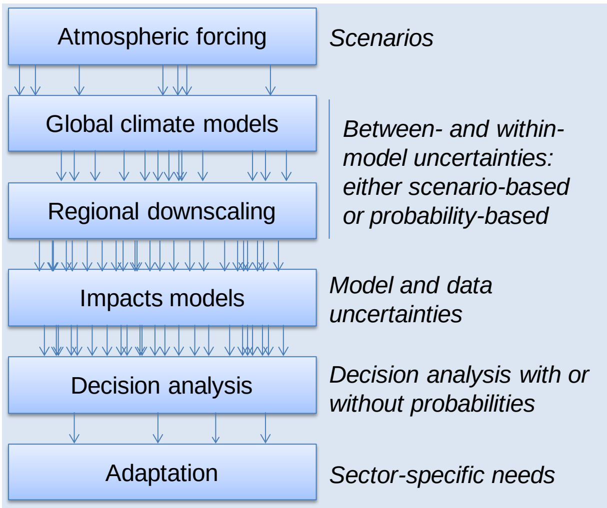


Figure 5-22 Climate Change Assessment Chain of Modelling and Analysis (Source MRC 2014)

The MRC decision support system uses meteorological data to drive a model chain of SWAT (runoff) - IQQM (routing, reservoirs and demands) – Hydraulic model of the Cambodia floodplains including the Tonle Sap and Mekong Delta. The final part of the chain can be replaced by the WAT4CAM model for Cambodia if suitable boundaries at the Vietnam border are used.

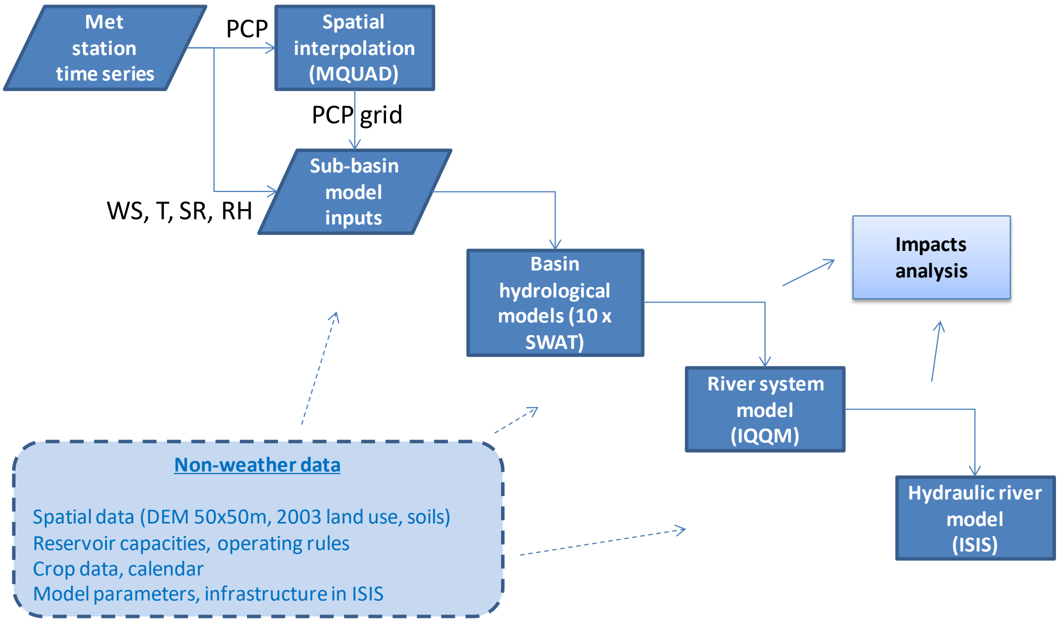


Figure 5-23 Chain of Models used in teh MRC Decision Support System(Source MRC 2014)

Selection of Climate Models

The Climate models selected for analysis should firstly be able to reproduce the main aspects of the climate of the Mekong basin as change of a poorly performing model is likely to be a poor basis on which to predict hydrological change.

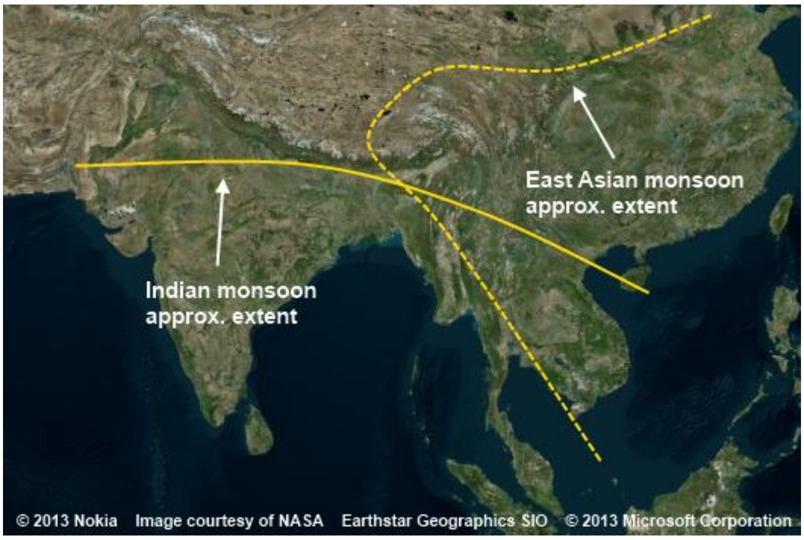


Figure 5-24 Climate Features influencing Mekong Hydrology(Source MRC 2014)

Many of the climate models perform badly when assessed and the list of possible models is as shown in Table 5.3.

Table 5.3 The better performing GCM models of CMIP3 and CMIP5 assessed against parameters driving hydrological change (Source MRC 2014)

GCM	Pattern correlation* – precipitation	Pattern correlation* – 850 hPa wind	Pattern correlation* – monsoon onset	Pattern correlation* – monsoon peak	Pattern correlation* – monsoon duration
CanESM2	0.815	0.951	0.298	0.451	0.164
CCSM4	0.849	0.952	0.581	0.717	0.570
CNRM-CM5	0.852	0.974	0.674	0.638	0.656
gfdl_cm2_0	0.826	0.954	0.715	0.540	0.495
gfdl_cm2_1	0.843	0.957	0.453	0.662	0.485
GFDL-CM3	0.844	0.941	0.458	0.407	0.406
GFDL-ESM2M	0.828	0.958	0.490	0.714	0.383
ingv-sxg	0.814	0.950	0.277	0.575	0.417
MIROC5	0.842	0.940	0.362	0.778	0.652
NorESM1-M	0.848	0.913	0.558	0.723	0.565

Further analysis of the better performing GCMs in term of the change in precipitation yearly or seasonally was then carried out so that the likely range of change could be captured from a limited number of scenarios and GCM projections of change. This is shown below in Table 5.4.

Thus three GCM models were selected to represent a) Overall wetter climate b) Seasonal Changing climate c) Less change and drier conditions:

a. GFDL-CM3
b. IPSL-CM5A-MR
c. GISS-E2-R-CC

These have subsequently been run through the MRC Model Chain for a variety of emission scenarios and epochs of 2030 – 2040 – 2060 and 2090.

Table 5.4 Change in precipitation over the Mekong basin for better performing GCM (Source MRC 2014)

Rank	Overall (all 3 seasons and all 3 locations)	Wet (May-Oct)	Dry (Nov-Apr)	Annual (Jan-Dec)
1	MIROC5 (39.9%)	NorESM1-M (25.6%)	MIROC5 (68.3%)	MIROC5 (28.8%)
2	MPI-ESM-LR (32.1%)	GFDL-ESM2M (25.3%)	MPI-ESM-LR (61.6%)	NorESM1-M (25.8%)
3	NorESM1-M (26.5%)	MIROC5 (22.6%)	NorESM1-M (28.2%)	MPI-ESM-LR (20.3%)
4	GFDL-CM3 (25.2%)	GFDL-CM3 (23.8%)	ACCESS1.0 (41.0%)	GFDL-CM3 (24.4%)
5	GFDL-ESM2M (8.2%)	IPSL-CM5A-MR (19.1%)	CNRM-CM5 (30.7%)	GFDL-ESM2M (19.5%)
6	CanESM2 (12.9%)	CMCC-CM (17.9%)	GFDL-CM3 (27.5%)	CMCC-CM (14.8%)
7	CNRM-CM5 (17.9%)	MPI-ESM-LR (14.4%)	CanESM2 (7.7%)	CNRM-CM5 (12.9%)
8	IPSL-CM5A-MR (2.2%)	CanESM2 (16.0%)	IPSL-CM5A-LR (-4.5%)	IPSL-CM5A-MR (14.1%)
9	CMCC-CM (9.2%)	*GFDLCM21 (12.5%)*	GISS-E2-R-CC (-3.5%)	CanESM2 (14.8%)
10	IPSL-CM5A-LR (7.8%)	IPSL-CM5A-LR (15.1%)	CMCC-CM (-5.2%)	IPSL-CM5A-LR (13.0%)
11	ACCESS1.0 (17.9%)	CCSM4 (10.7%)	*GFDLCM20 (-5.7%)*	CCSM4 (8.7%)
12	CCSM4 (4.6%)	CNRM-CM5 (10.1%)	CCSM4 (-5.7%)	*GFDLCM21 (8.6%)*
13	*GFDLCM21 (0.9%)*	*GFDLCM20 (8.5%)*	GFDL-ESM2M (-20.2%)	ACCESS1.0 (8.5%)
14	*GFDLCM20 (3.2%)*	ACCESS1.0 (4.3%)	*GFDLCM21 (-18.4%)*	*GFDLCM20 (6.7%)*
15	GISS-E2-R-CC (-13.8%)	GISS-E2-R-CC (-20.1%)	IPSL-CM5A-MR (-26.6%)	GISS-E2-R-CC (-17.7%)

In MRC Basin Flood Analysis (MRC 2017) change is presented for using these climate models with RCP scenarios/model combinations for 2030 and 2060. The higher range of these were selected for sensitivity testing in WAT4CAM of 20% and 30% increase in flood peaks relating to high and extreme change expected.

Table 5.5 Flow Change at Kratie for different scenarios resulting from MRC analysis of various climate change models and emmission scenarios (Source MRC/JBA 2017)

Model	RCP/Epoch	Change/Event
GFDL	4.5/2060	20%/5yr
IPSL	4.5/2060	18%/5yr
GFDL	8.5/2060	29%/5yr
GFDL	8.5/2060	25%/100yr

The scenarios for sea level rise vary little. At the sea a rise of 0.3m is applied that translates to a lower rise at the Cambodia/Vietnam border during floods due to attenuation of tidal peaks in the large floodplains

5.5 Initial Modelling Results & Illustrative Outputs

5.5.1 Large Scale

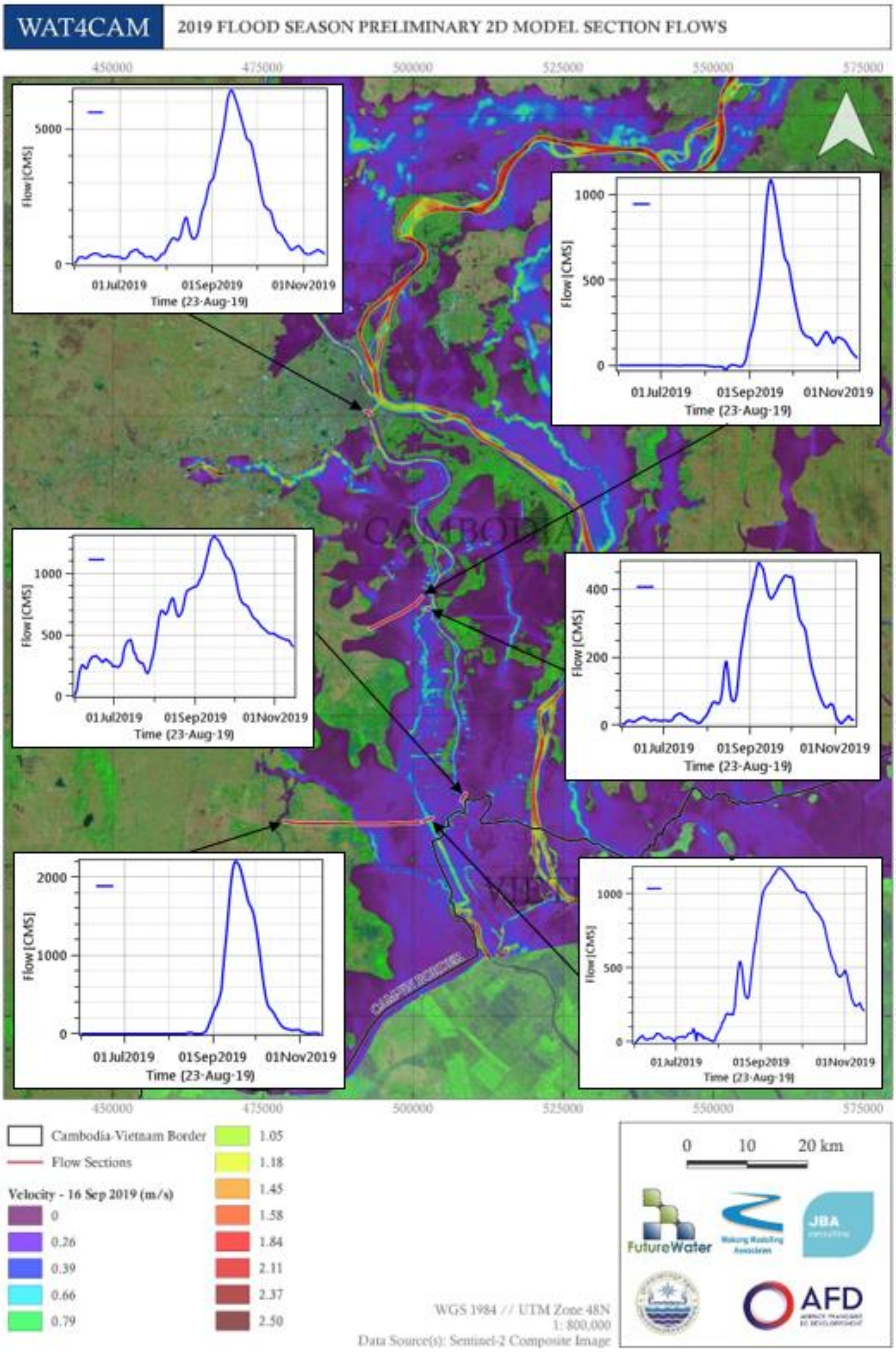


Figure 5-25 2D Modelled velocity and discharge profile 23rd August 2019 at different river sections.

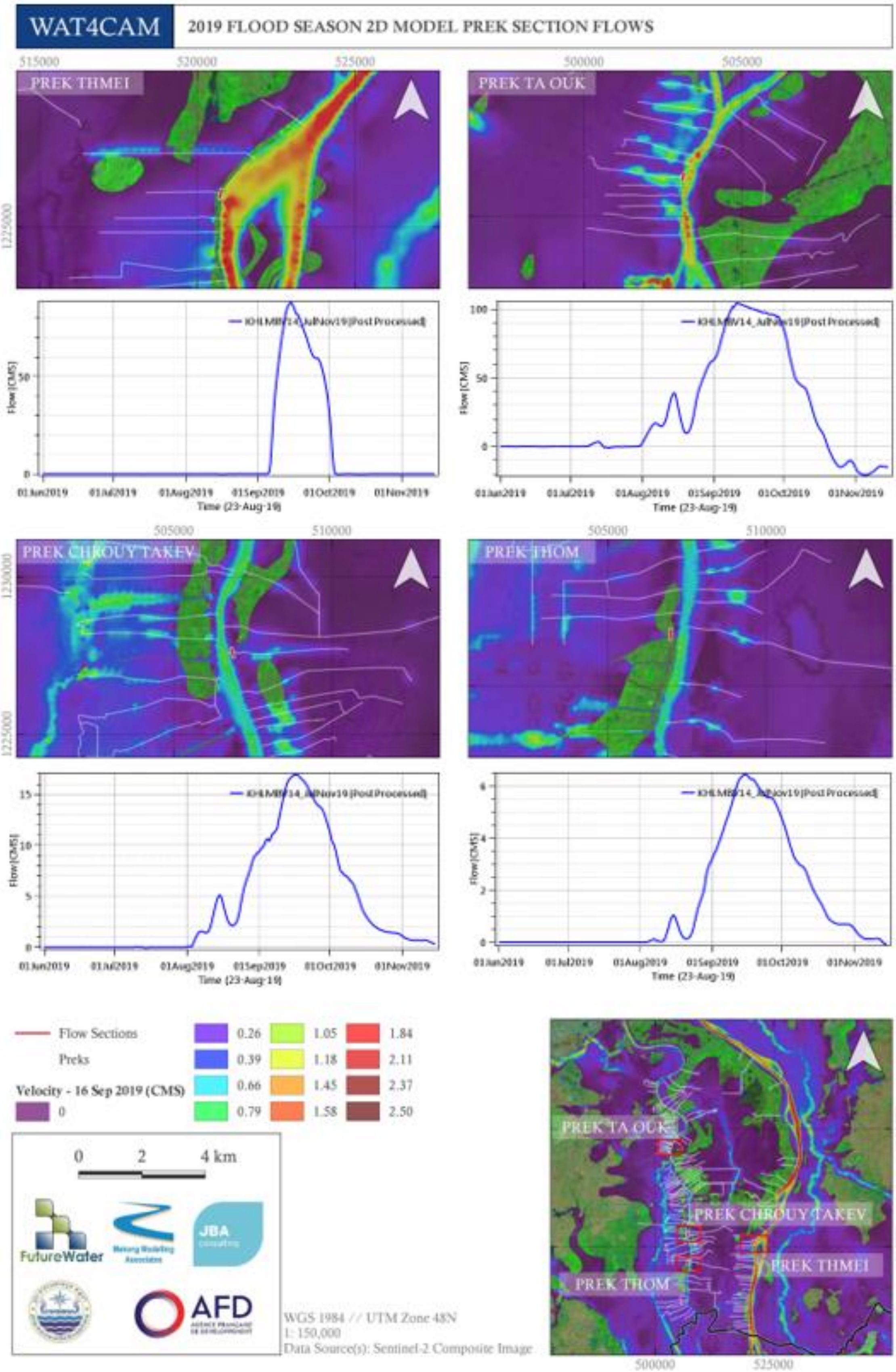


Figure 5-26 Modelled velocity and discharge profile 23rd August 2019 at different prek sections.

5.5.2 Local Scale

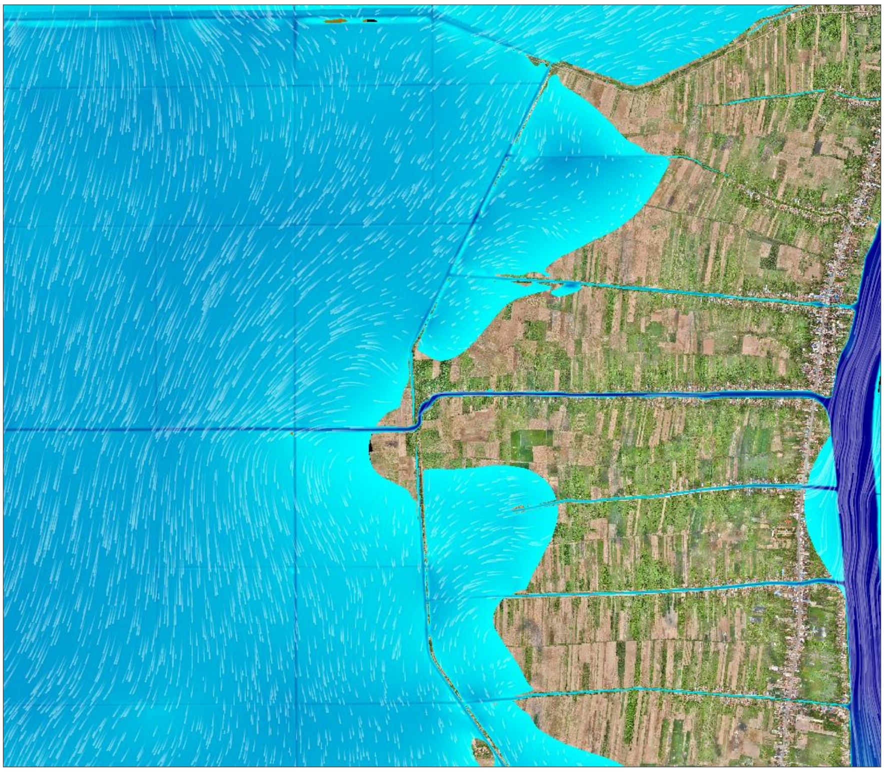


Figure 5-27 Localised Prek Cluster example model depth output with particle tracing arrows (Peak depth).

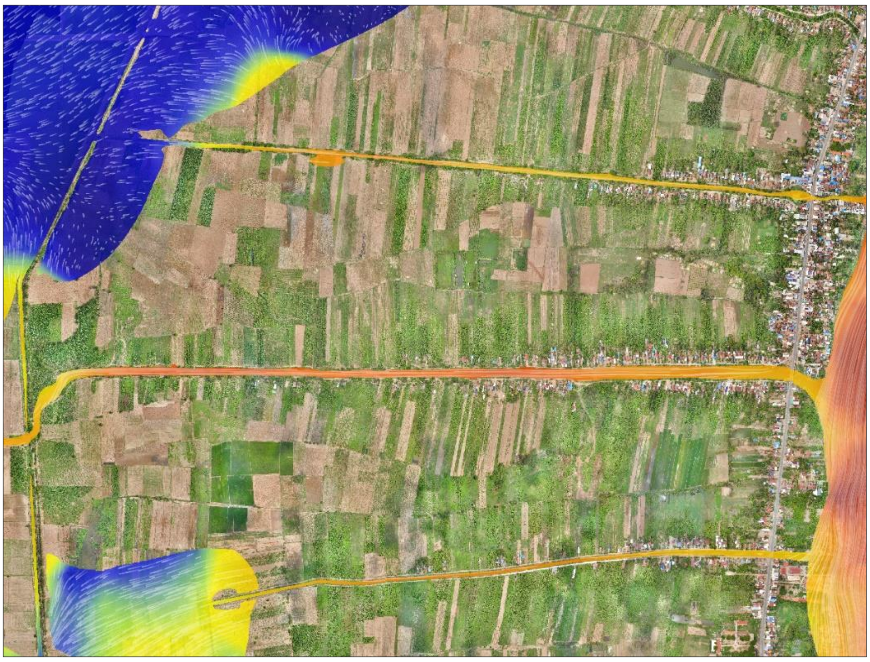


Figure 5-28 Localised Prek Cluster example model velocity output with particle tracing arrows.

6 Flood Mapping

6.1 Methodology – Conjunctive Use of Remote Sensing and Modelling

In a data-scarce environment such as Cambodia, it is essential to integrate various types of data sources to obtain a picture of the hydrological system that is as comprehensive as possible. River flow records are a typical example of important locally sourced data. A national hydrological station database is managed by the MOWRAM Department of Hydrology and River Works (DHRW), with a total of 31 stations operational for daily water level measurement and 17 automatic stations. Although maximum use needs to be made of locally available data, good quality long-term records of flow and rainfall suffer from gaps and short record length.

Over recent years, the quality and accessibility of satellite-derived data has greatly increased, and thereby also its suitability for performing eco-hydrological assessments. Its spatially distributed nature makes remote sensing data ideal for assessing vegetation dynamics, evapotranspiration, inundated areas and rainfall, as well as intercomparing different areas and evaluating temporal trends. This chapter describes the data and methods used:

a) Occurrence and seasonality of floods based on **remote sensing,**
b) Analysis of gauges and use of the **HEC-RAS model** to generate existing and future flood mapping for expected return periods.

6.2 Analysis of Satelite Imagery for flooding

Imagery is first presented to show visually the flood spatial development and location qualitatively observing optical imagery of flooding. However, to characterise inundation dynamics in the study area, a more quantitative approach is also followed. through applying image classification techniques to extract water masks from radar and optical images. The allows for the calculation of inundation extents, allowing for a more quantitative assessment of flooding dynamics with reference to time and space.

This analysis focuses on the following inundation characteristics:

- Flood events – Identifying the extents of notable flood events which have caused significant economic damage and displacement / death of people (specifically flooding in October/November 2020)
- Flood occurrence – The regularity of inundation of different areas over time
- Flood seasonality – The recurrence of inundation during different seasons

The following products are used in this exercise:

- Radarsat – Available radarsat imagery for historic flood events going back to the 1990s. These are relatively poor resolution but the best available record of key events such as the floods of 2000, 2001, 2002 and 2011.
- Sentinel 1 – Radar imagery at ~25m resolution running from 2005-present day
- Sentinel 2 – Optical imagery at ~25m resolution running from 2005-present day
- Landsat 7 and 8 – Optical imagery at ~30m resolution running from 2000-present day but often severely limited in the wet season due to clouds
- Landsat 5 – Optical imagery at ~30m resolution running from 1988-2011

6.3 2011 Flood

Flooding of the area of Kandal in which the Preks are located is common and a normal part of the flood pulse cycle of the Lower Mekong that people have adapted to through raised communication and living areas and by adopting suitable agricultural practises. More extreme floods, however can be very damaging and the last such large flood occurred in 2011 resulting in extensive damages.

The progression of the 2011 flood was tracked by Radarsat images as shown in Figure 6-1.

During the wet season much of the floodplain areas provide natural floodways, along which discharge exceeding in-channel capacity can flow. Within the study area most floodplain inundation occurs adjacent to the Mekong and Bassac channels, although once spilt from the main numerous floodways may continue independently combining again with the main channel at hydraulic controls or possibly taking a separate path to the sea such as via the route of the Ven Te canal along the Cambodia Vietnam border.

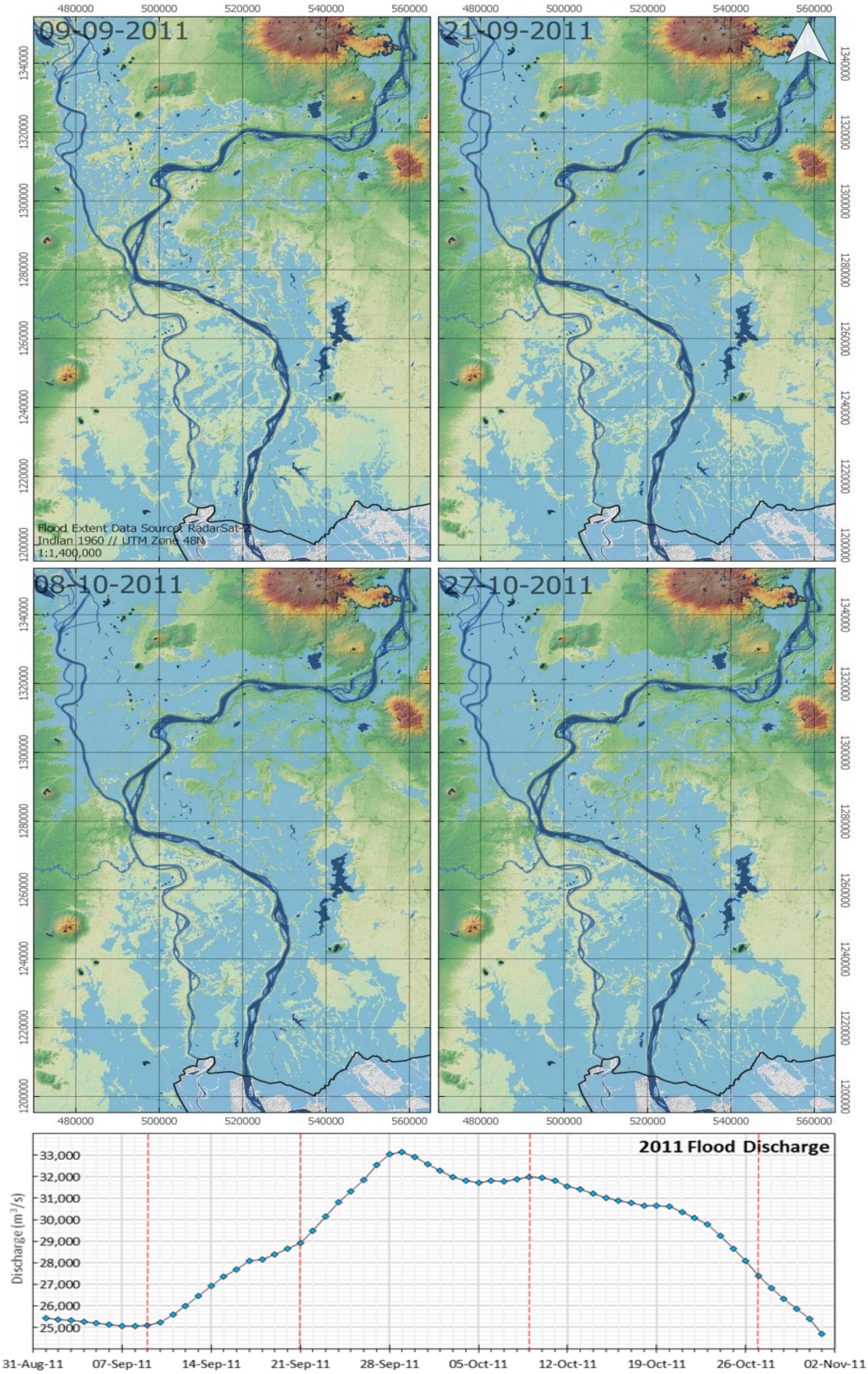


Figure 6-1 Inundation extent for 2011 September – October flood event, derived from RadarSat-2 SAR imagery. Dark blue indicates permanent water bodies, light blue indicates flood area.

6.4 2020 Wet Season Inundation

As seen in the data presented from the hydrological stations in the Mekong and Bassac Rivers, the 2020 wet season was one of the driest on record. Despite the varying cloud coverage, Sentinel-2 satellite imagery offers a useful way to visualise the effect of this unusually dry wet season on water inundation.

Late in the season after the normal wet season withdrawal heavy rainfall occurred in Lao and a number of Cambodia catchments including Sisopon, Mongol Borei and the Prek Thnot. Thus, high inflows occurred on the southern perithery of Phnon Penh and rapid rise in the Bassac and on the west Basaac floodplain. This can be seen in Figure 6-2 which shows the extent of flooding during November 2020 as seen from Sentinel-2 imagery. Despite the high cloud cover percentage many areas of flooding can be seen clearly. On the left, the view focusses on a tight cluster of preks from batches 1, 2 and 3. From this view the drainage lines and Boeng areas are clearly identified by the inundation extent, with the chamkars elevated between the prek and drainage channels.

Figure 6-3 shows the inundation at different times throughout the season 2020, from July 14th, August 18th, September 12th and November 16th. These dates were largely selected based on available image acquisition dates and minimum cloud cover, however despite this they represent the season’s progression well.

Figure 6-4 to Figure 6-7 compare the wet season inundation extent for the same month in multiple years for July, August, September and November. In each image, dark blue represents inundated area. Imagery from October was too sparse and contained too much cloud cover, so was excluded in the comparisons. The images though highlight the remarkable difference between recent years for the same month of the year.

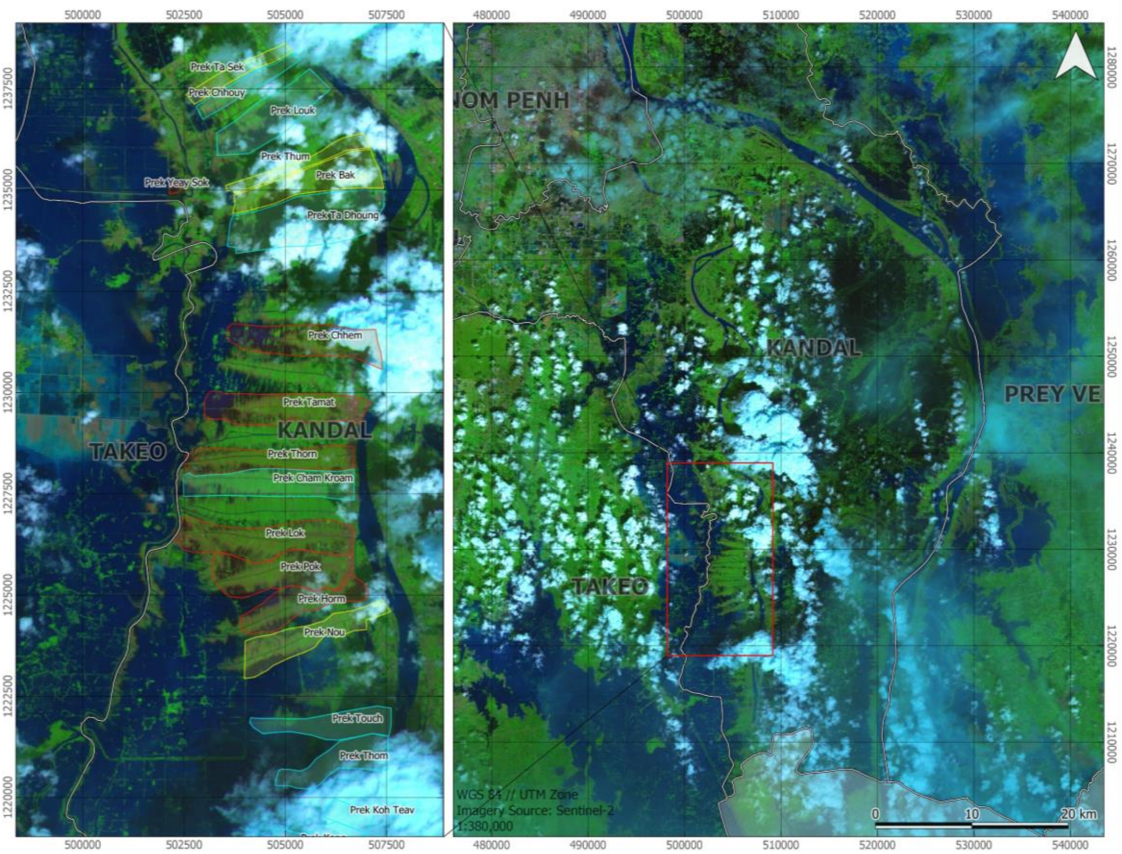


Figure 6-2 Nov 2020 flooding seen from Sentinel-2 composite image (6th Nov). Dark blue areas represent flood inundation extent, with WAT4CAM prek cluster boundary outlines

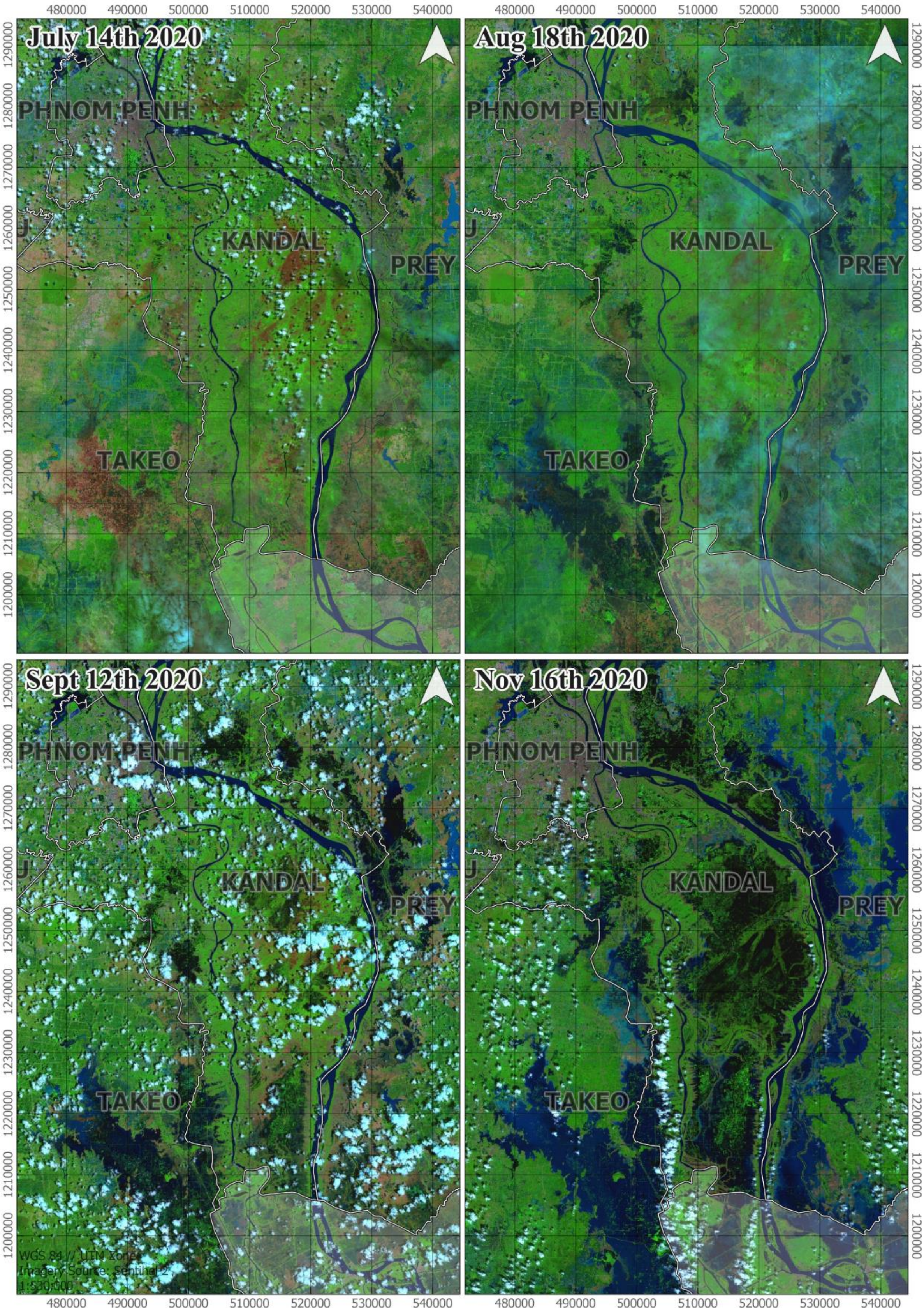


Figure 6-3 2020 wet season inundation extent as seen from Sentinel-2 satellite imagery.

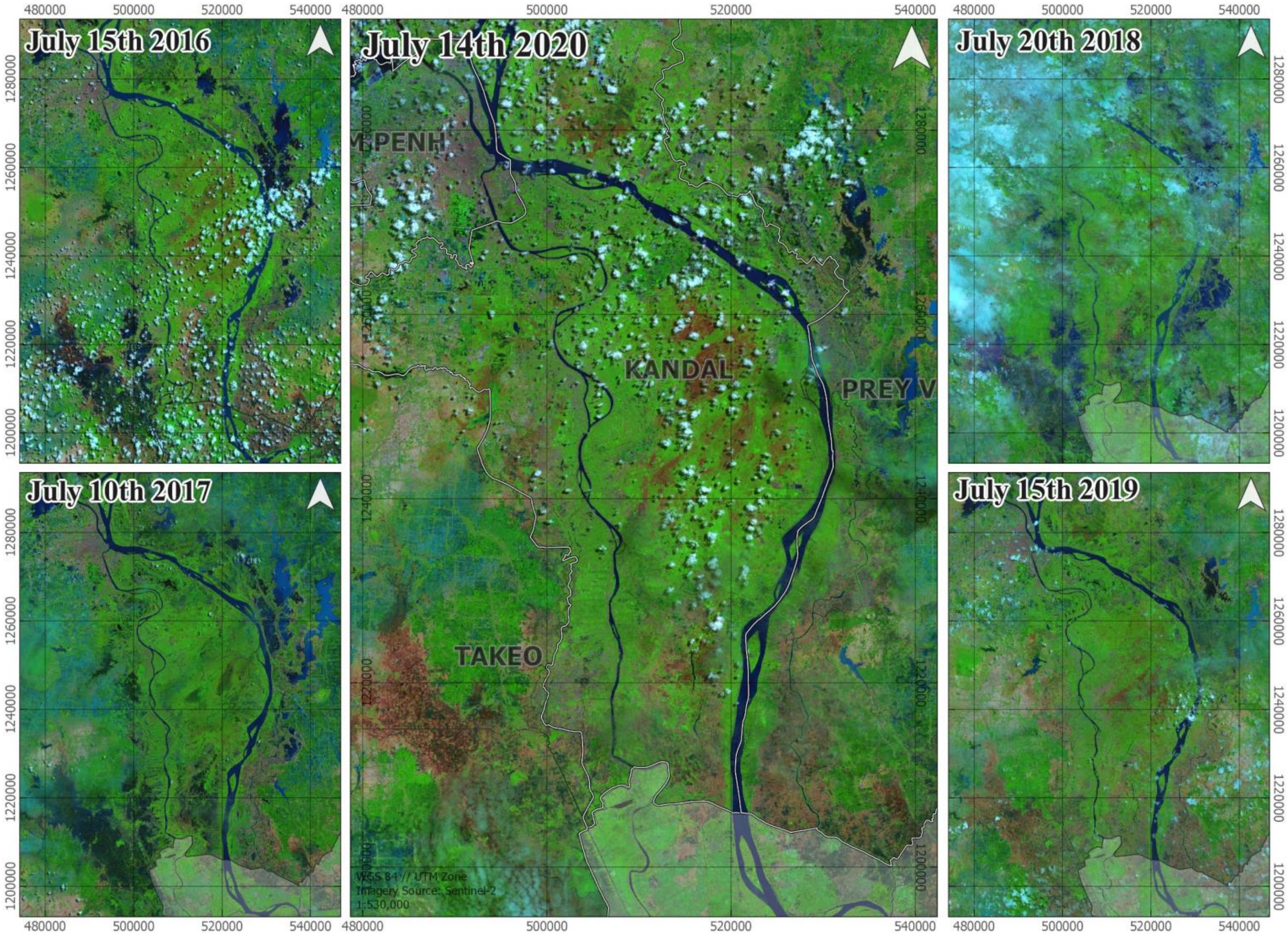


Figure 6-4 *July* Bassac/Mekong water inundation from 2016 – 2020, as seen from Sentinel-2 satellite.

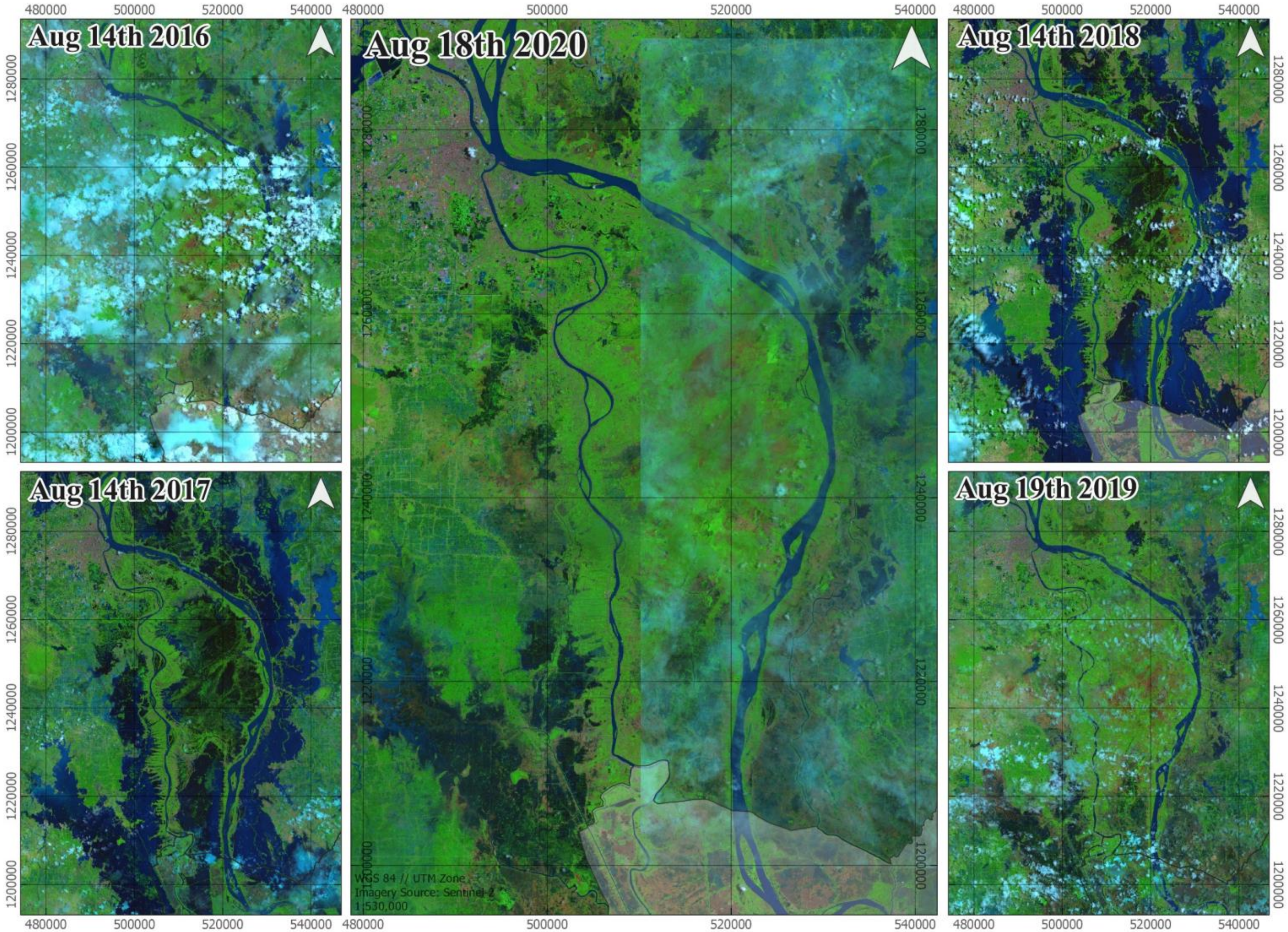


Figure 6-5 *August* Bassac/Mekong water inundation from 2016 – 2020, as seen from Sentinel-2 satellite.

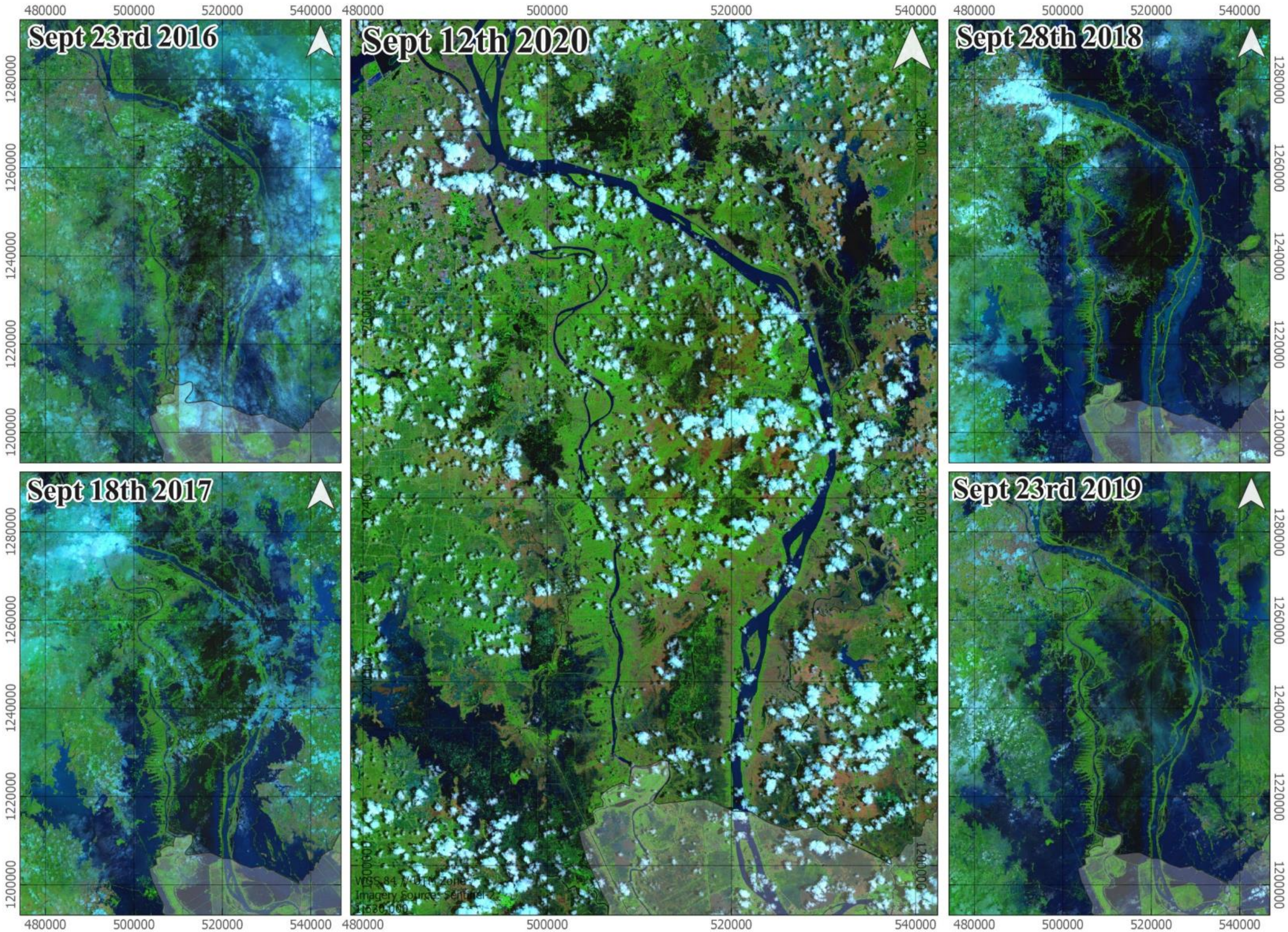


Figure 6-6 September Bassac/Mekong water inundation from 2016 – 2020, as seen from Sentinel-2 satellite.

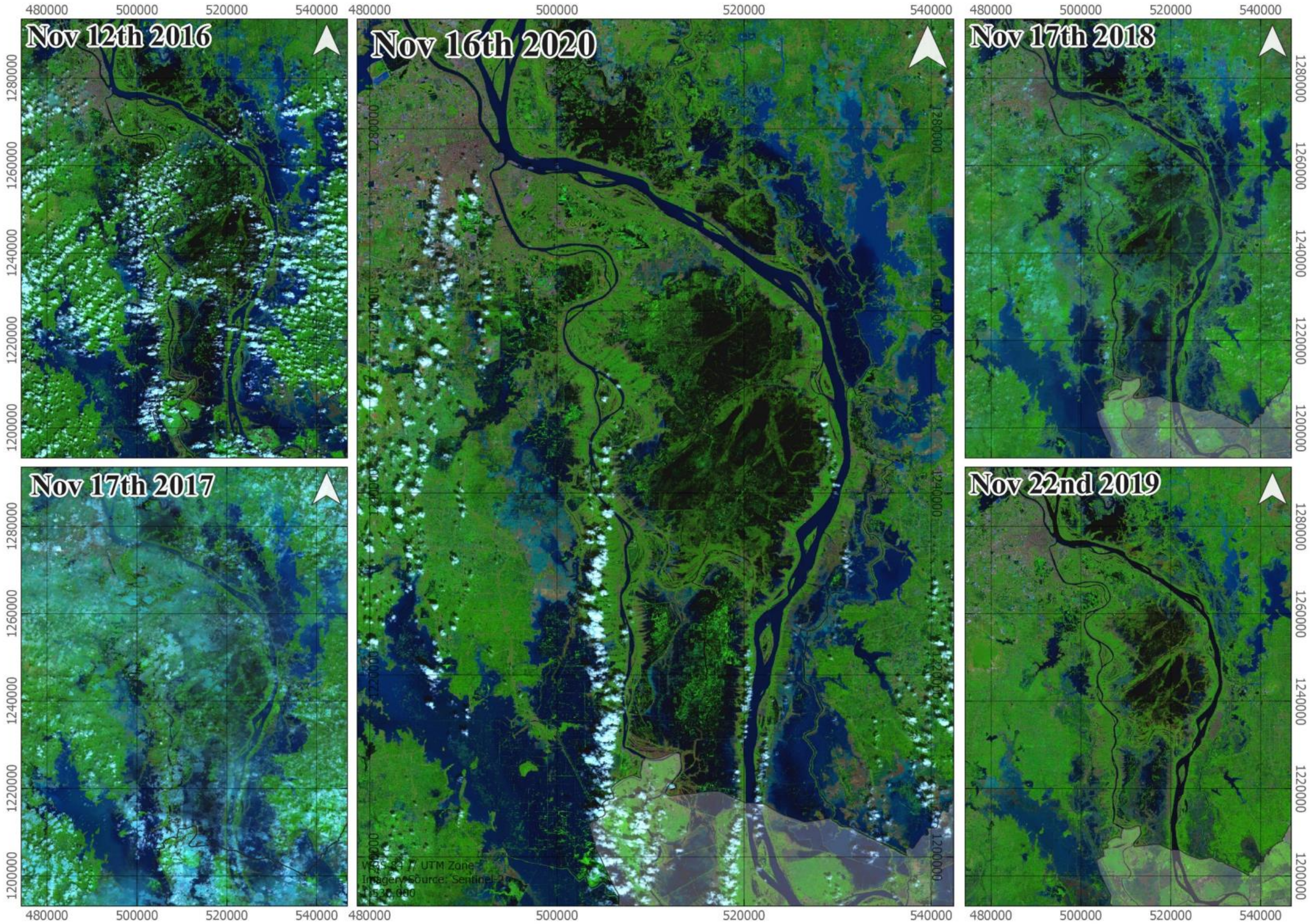


Figure 6-7 *November* Bassac/Mekong water inundation from 2016 – 2020, as seen from Sentinel-2 satellite.

6.5 Quantitative Analysis of Flood Areas

For calculation of flood areas it is necessary to differentiate between flood and non flood areas in the imagery. This is done by creating a ‘mask’ of the area that appears flooded.

To extract a water mask from optical imagery, the following methodology is used:

1. Calculate MNWDI from an image with the following equation:
   MNDWI = (Green-MIR) / (Green+MIR)
2. Define a threshold parameter at which all pixels higher than this in MNDWI image are classified as water - this threshold is defined via a tuning process in which true colour (RGB) imagery is compared with extracted water extents

To extract a water mask from radar imagery (Sentinel-1), the following process is used:

1. Subset “VH” polarized bands from imagery (recognised as best identifying water bodies)
3. Define a threshold parameter at which all pixels higher than this are classified as water - this threshold is defined via a tuning process in which true colour (RGB) imagery is compared with extracted water extents
4. For optical imagery, cloud cover in images is often problematic whereas radar imagery does not encounter these issues. To deal with cloud cover, images are filtered by cloud percentage – in this case set as 20%. Following filtering, clouds are also masked from optical images using a cloud masking algorithm in Google Earth Engine.

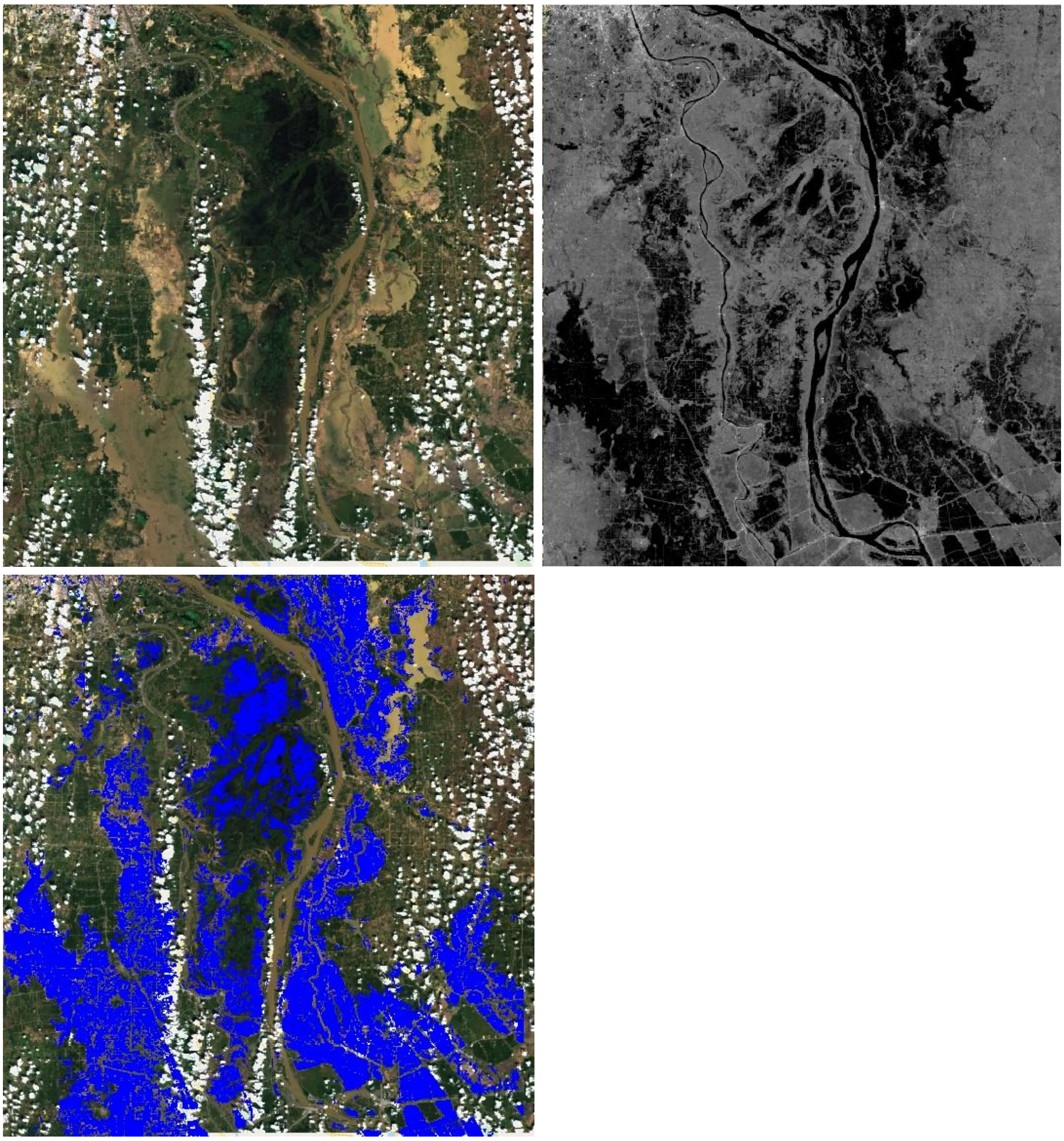


Figure 6-8 Parameter tuning procedure example for flood extent on 17/11/2020. Clockwise from top left: Sentinel-2 optical imagery, Sentinel-1 radar imagery, Sentinel-2 overlain with extracted flood extent based on best-fit tuned parameter in Google Earth Engine.

6.5.1 2020 flood season

Sentinel-1 was used to derive flood extents for October/November flooding events of 2020 as the most recent flood event in Cambodia. These events led to significant loss of life and displacement of people in the Tonle Sap basin and damages and displacement along the Prek Thnot and upper part of the West Bassac. This flood could be classified as a high tributary flood but of average to low severity in the main River Mekong and Bassac. The most recent significant event in the main rivers in Cambodia was in 2011 which was unfortunately prior to the availability of data from the Sentinel satellites though some imagery from Radasat and visible spectrum satellites like Landsat are available.

A number of aerial images were available covering the October/November 2020 period from both Sentinel-2 and Landsat 7/8 (Figure 6-9 and Figure 6-10), showing evidence of widespread flooding in the project area. When this flooding is considered in relation to the Prek systems, the following observations can be made:

- On Preks coming from the Mekong. flooding affects the Preks themselves but less in the areas towards which they drain. Of particular interest is the strip of flooded area located in the centre of the Mekong Preks running in a North-South direction.
- On Preks coming from the Bassac, this pattern reversed, with the Prek areas themselves clear of flood water but the areas they drain flooded
- Flood water is high in sediment to the East and West of the two main channels, but seems less turbid in areas between the two channels

Water masks were extracted from Sentinel-1 imagery during the flood event, allowing an inundation extent series to be constructed (Figure 6-11). When compared with discharge records from the stations shown in Figure 6-11, this shows a very good level of agreement. This shows the following:

- Flood extent increased over the period 10th September – 22nd October and decreased (for the most part) between 22nd October and 1st December
- Spikes in discharge are mirrored by large increases in flood extent
- Flood extents suggest two peaks in flooding, with a main peak around 22nd October followed by a smaller peak around 2nd November (mirrored in discharge record)

Water masks were extracted for these events to give an idea of the spatial patterns of flooding (Figure 6-12 & Figure 6-13). This confirms observations already made, showing that the Preks on the Mekong largely become flooded, whereas for Preks on the Bassac only the areas they drain to are flooded, even at maximum flood extent (22nd October).

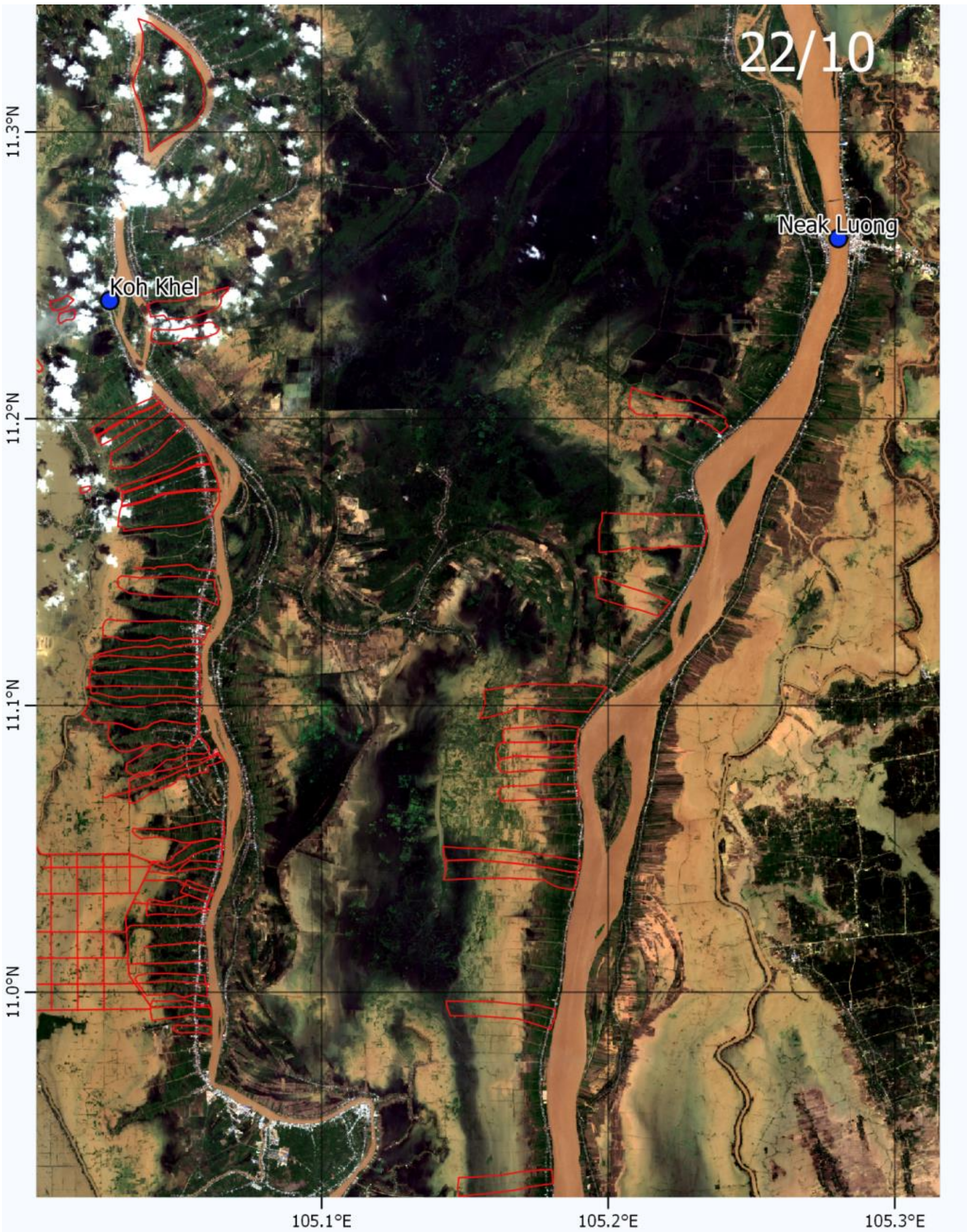


Figure 6-9 Sentinel-2 High resolution imagery of flooding on 22nd October, 2020. Locations of gauging stations also shown.

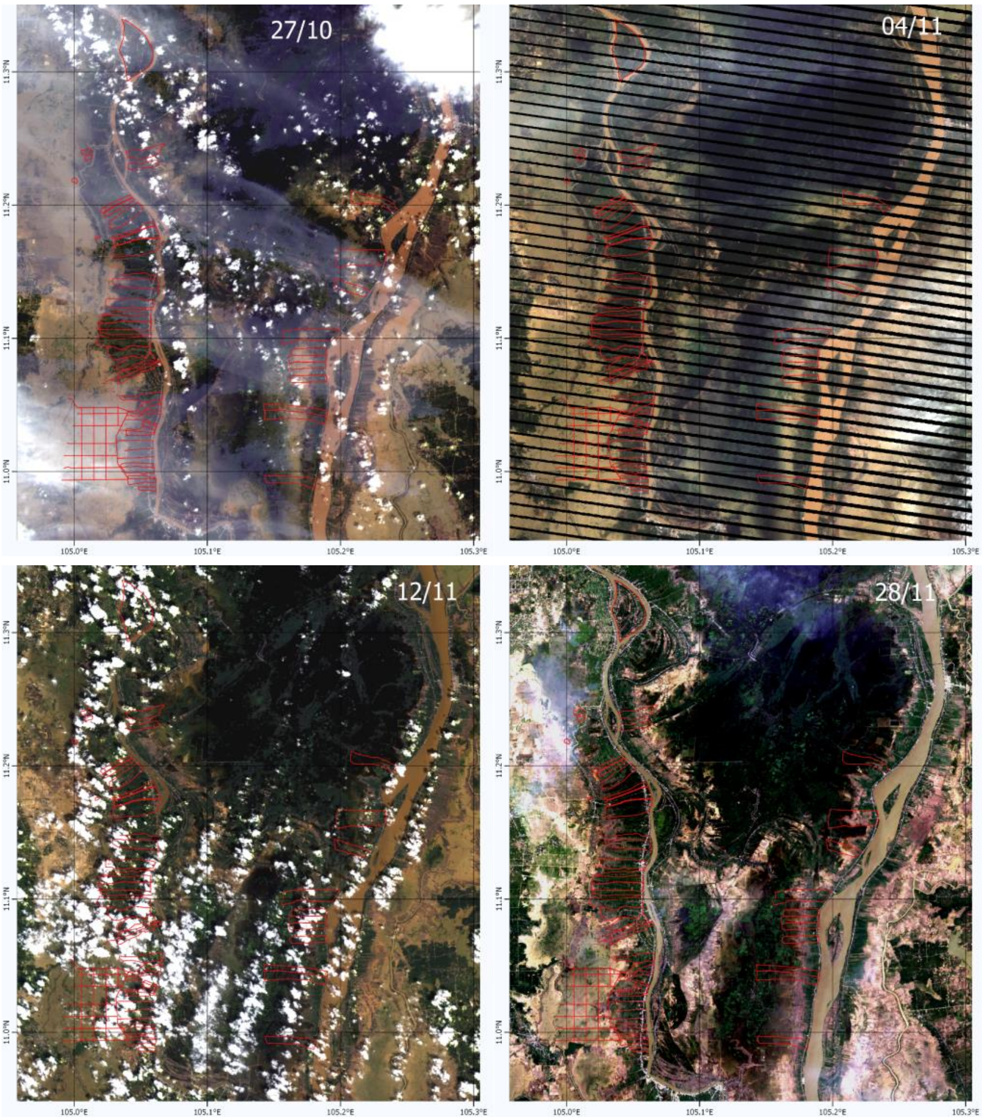


Figure 6-10 Landsat imagery series of flood event 2020. Striped image is Landsat 7.

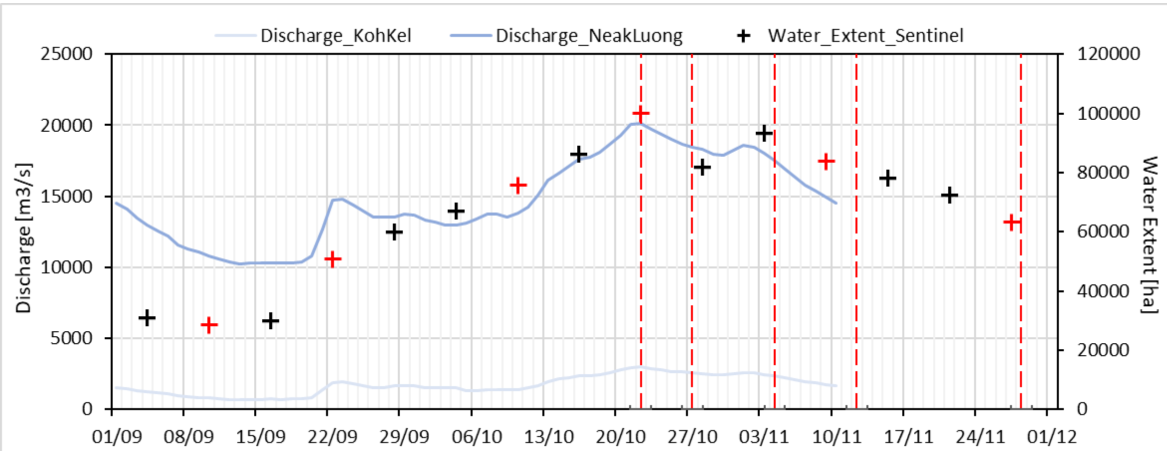


Figure 6-11 Flood extent and discharge series. Red dashed lines indicate images shown in Figure 6-9 and Figure 6-10, red crosses indicate water extents shown in Figure 6-12.

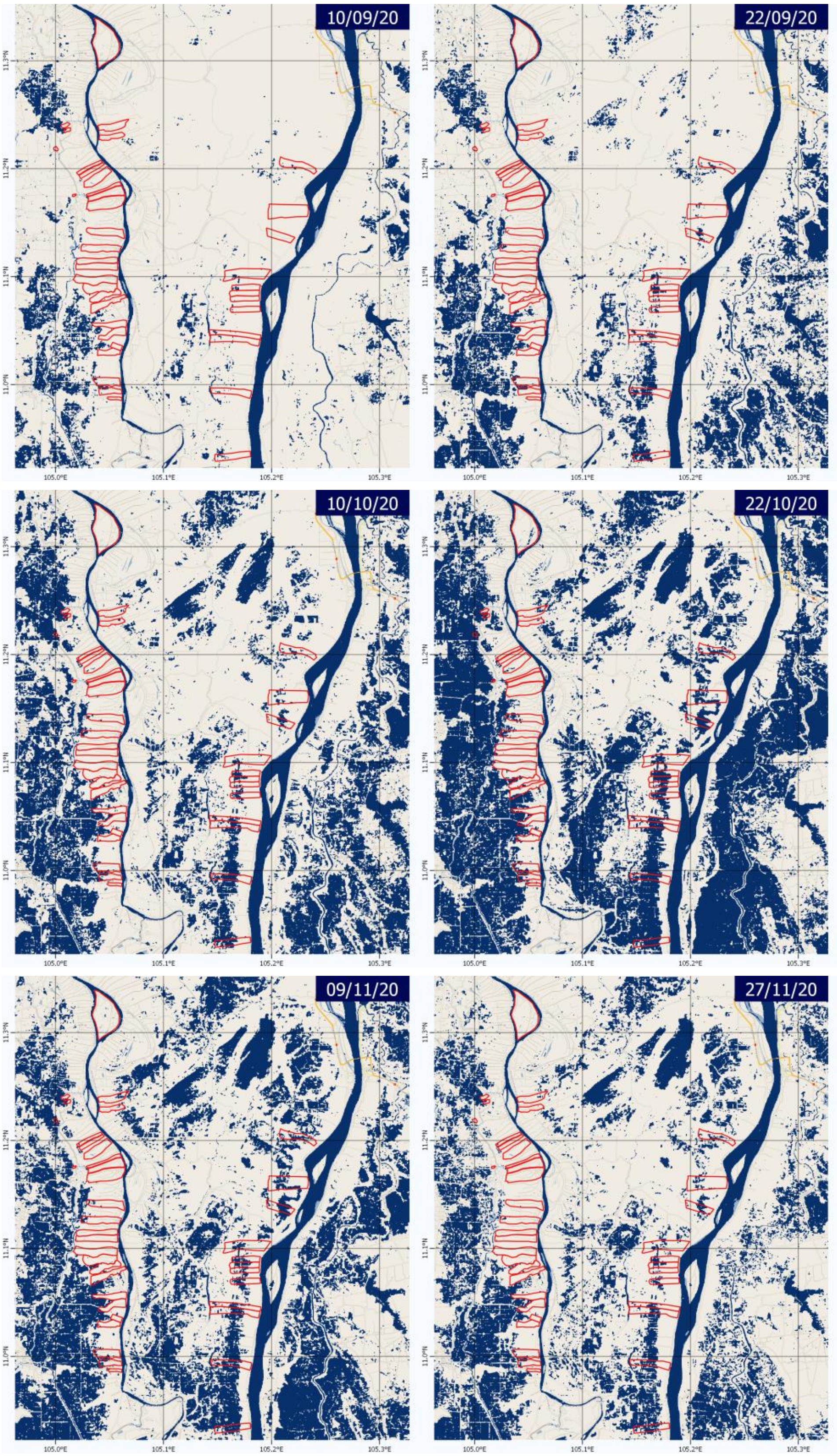


Figure 6-12 Water extent series based on water masks extracted from Sentinel-1 radar imagery in 2020.

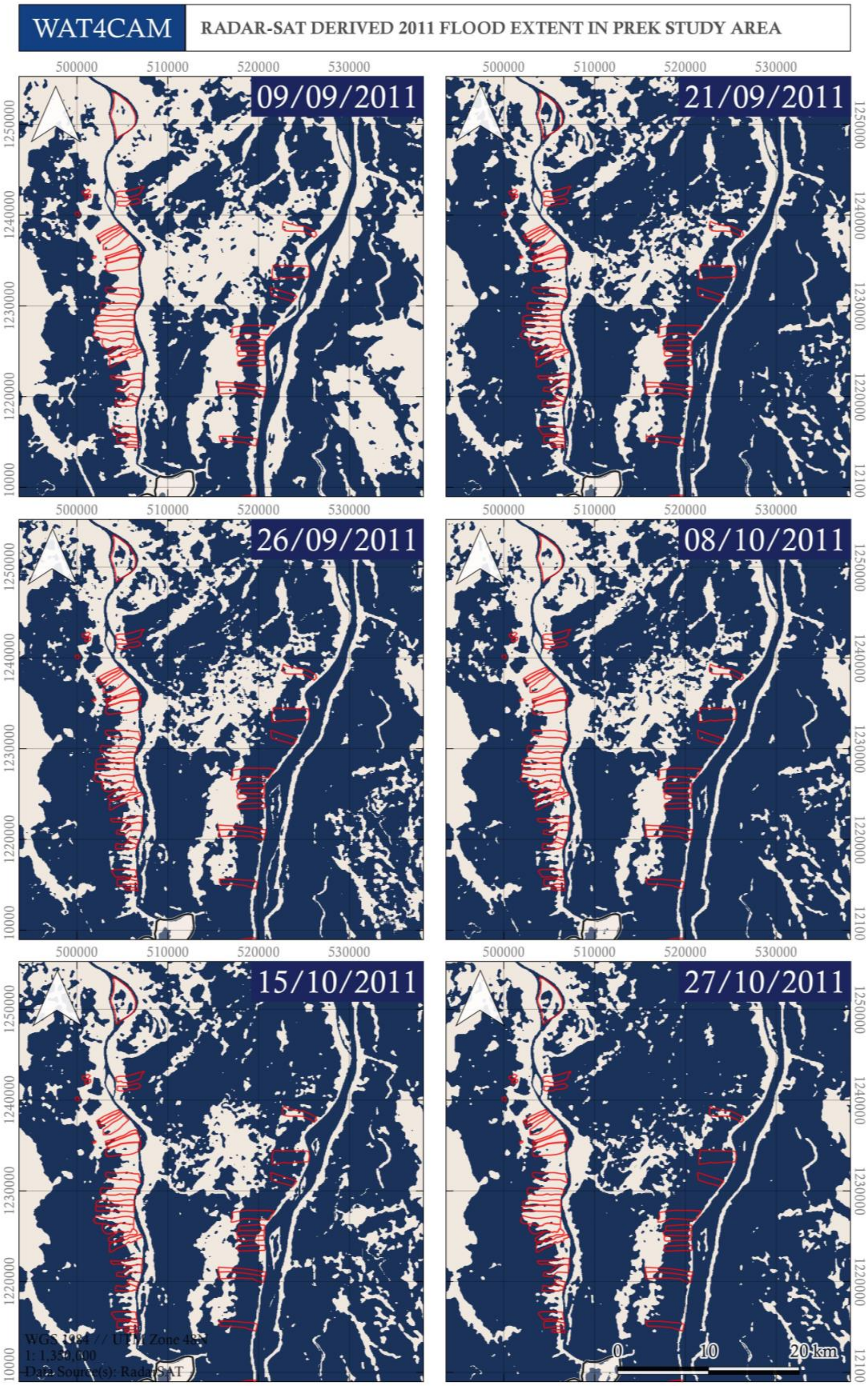


Figure 6-13 Water extent series based on water masks extracted from Radarsat imagery for 2011 at similar times up to the end of October, as shown opposite for the 2020 flood in Figure 6-12.

6.5.2 Flooding Occurrence

Flood water occurrence maps (Figure 6-14 and Figure 6-15) indicate the frequency of inundation spatially. This was generated for Sentinel-1 through extracting water masks from the full series (2016-2021), then averaging these binary water masks to yield a percentage of time in which each pixel is inundated (0% = never inundated, 100% = permanent water body). Landsat water occurrences were not generated for this report, but rather taken from the JRC developed Global Surface Water Explorer; this uses Landsat imagery from 1988-present to visualize changes in surface water over time. Important to note is that Landsat-JRC water occurrences are constructed during cloud-free periods, whereas Sentinel-1 water occurrences use all images in the series (radar is cloud-piercing), therefore Sentinel may give a better overall picture of where is inundated during extreme flooding events.

The following conclusions can be drawn:

- Preks themselves are rarely inundated on the western bank of the Bassac, but areas outside them are inundated for at least half of the time in the average year (50%)
- Preks on the Mekong are regularly inundated, with a strip of regular (>50%) inundation again evident running North-South

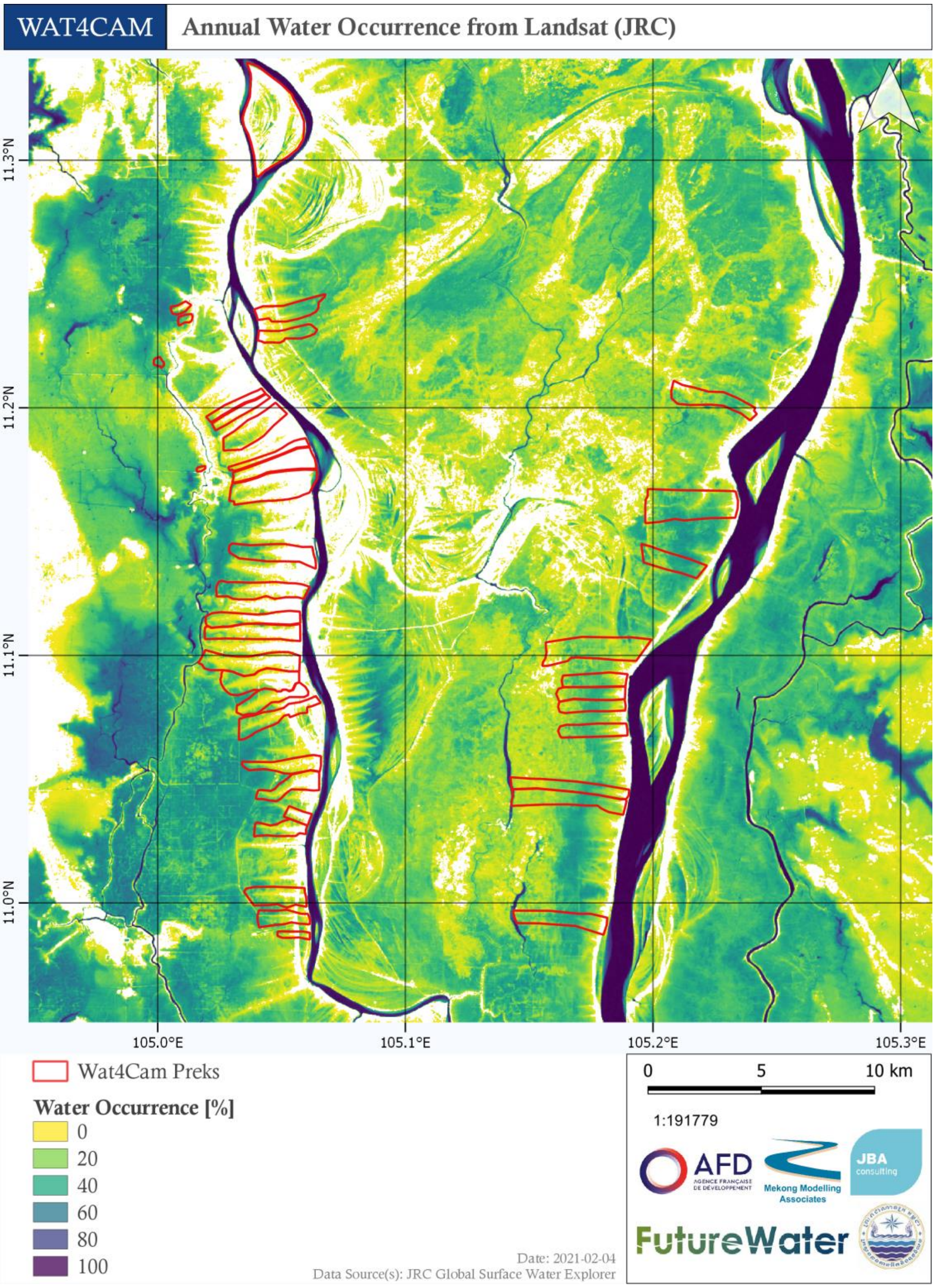


Figure 6-14 Water occurrence calculated from Landsat imagery by JRC (using full 1988-2020 series).

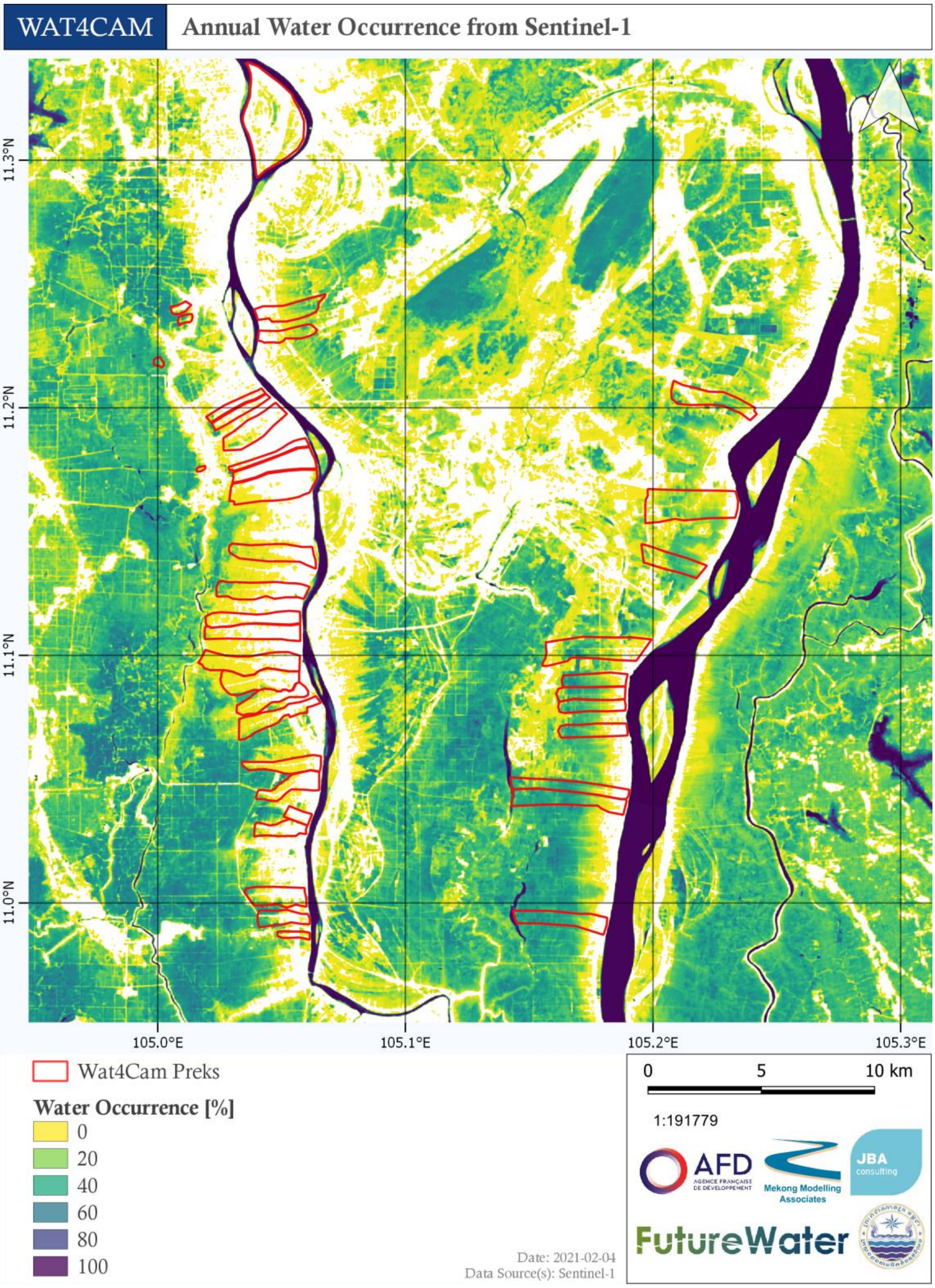


Figure 6-15 Water occurrence calculated from Sentinel-1 imagery (using full 2016-2020 series).

6.5.3 Seasonality of Flooding

To better understand the seasonality of inundation, water extents are extracted from the full series of Sentinel-1 and combined Landsat 5, 7 and 8 imagery. When compared with discharge records (Figure 6-16 and Figure 6-17), this shows a very similar pattern, with extreme variation throughout the year and clear peaks around September/October. A clear decrease in maximum inundation extents throughout the year is evident in the last decades, with especially low inundation extents recorded for 2020 – this is perhaps somewhat contradictory as localized flooding was severe in 2020 but in the Preks area as a whole it was very much less than ‘average’ as can be seen from the longer term record of Landsat..

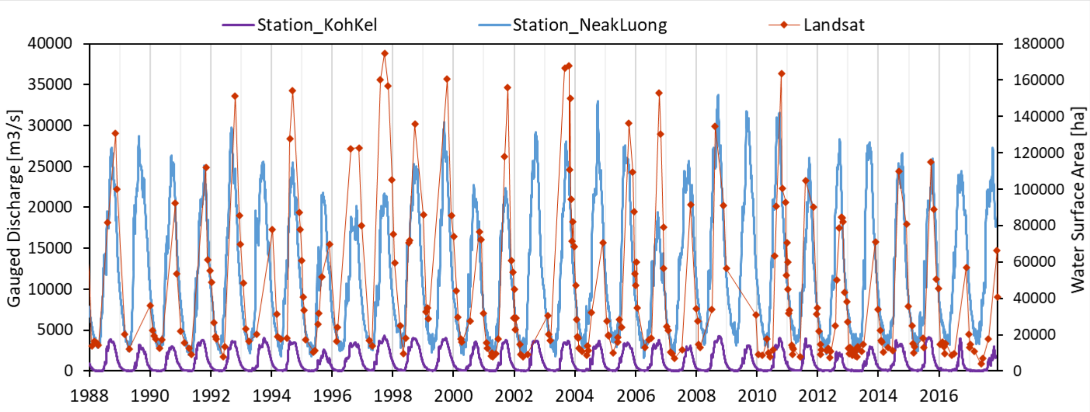


Figure 6-16 Landsat series compared with discharge measurements (based on <20% cloud cover images in the period 2001-2021).

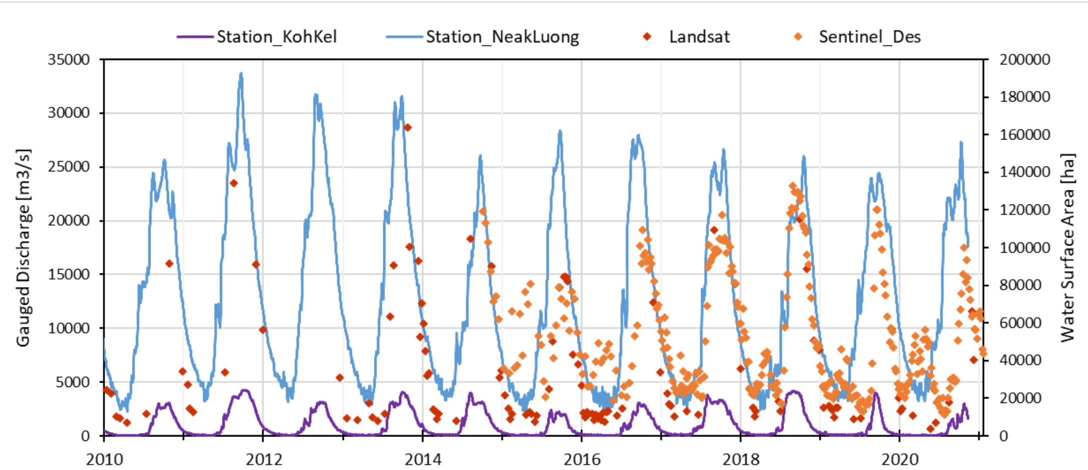


Figure 6-17 Landsat and Sentinel series compared with discharge measurements (based on <20% cloud cover images in the period 2001-2021).

Figure 6-18 shows water occurrences as calculated from Sentinel-1 imagery for the wet season (August-November). This, intuitively, shows higher water occurrences in most areas, with especially high (>80%) occurrences notable in the areas attached to the Prek systems to the west of the Bassac.

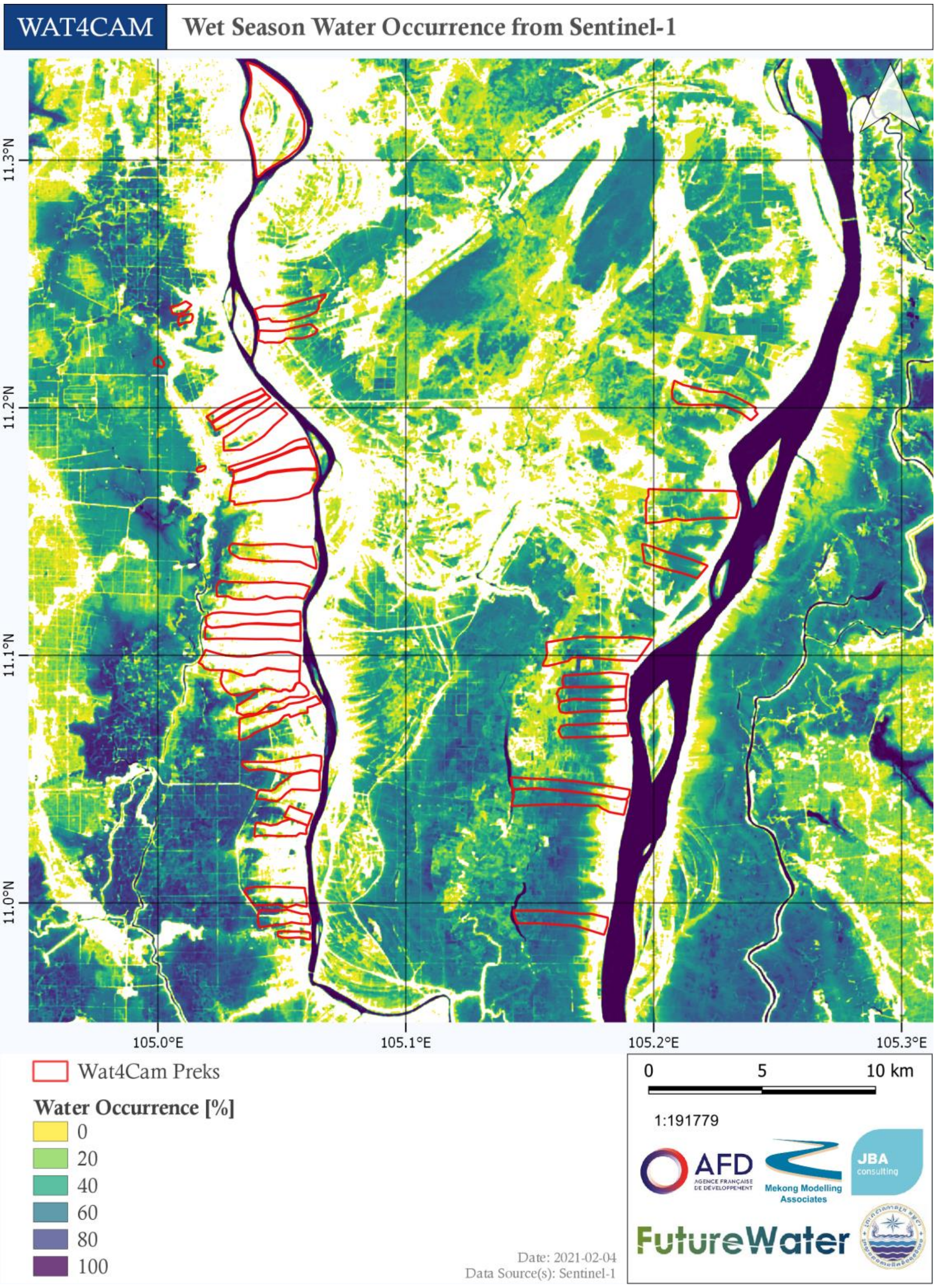


Figure 6-18 Water occurrences calculated for the wet season (August-November)

6.5.4 Flood Extent Trend identification

Trend analysis was performed on flood extents to determine if a change in flooding dynamics has occurred over the monitored period.

Landsat imagery is used to explore longer term trends in inundation as it has a longer record (1988-2020), with Sentinel-1 used to characterize rends in recent years. Sentinel is more useful for this exercise as it has many more images for the time period 2016-2020 due to its overpass time and the fact that it is cloud penetrating. Landsat has a longer record but has less density of images when filtered by cloud cover (20% used as a threshold in this case).

Landsat (1986-2020)

Table 6.1 shows average inundation extents for 5-year periods when imagery is aggregated into 3-month periods. This shows a clear picture of reducing inundation extents year-on year, with the period 2015-2020 showing the lowest inundation extents for the period monitored. This trend is also shown when 3-month averages of water extent for each year are considered (Figure 6-19), with a clear decreasing trend shown for all 3-month periods, but the most extreme decrease shown in the September October November series (indicating the wettest part of the year).

Table 6.1 Average inundation extent per 3-month aggregate for 5 year intervals.

	DJF	MAM	JJA	SON
1985-1990	30,944	15,433	32,080	84,486
1991-1995	34,902	14,804	42,215	107,525
1996-2000	50,163	16,701	45,163	136,876
2001-2005	54,396	13,553	78,315	130,884
2006-2010	42,572	11,895	20,651	135,773
2011-2015	32,038	10,426	41,837	110,704
2015-2020	24,856	11,313	20,653	81,068

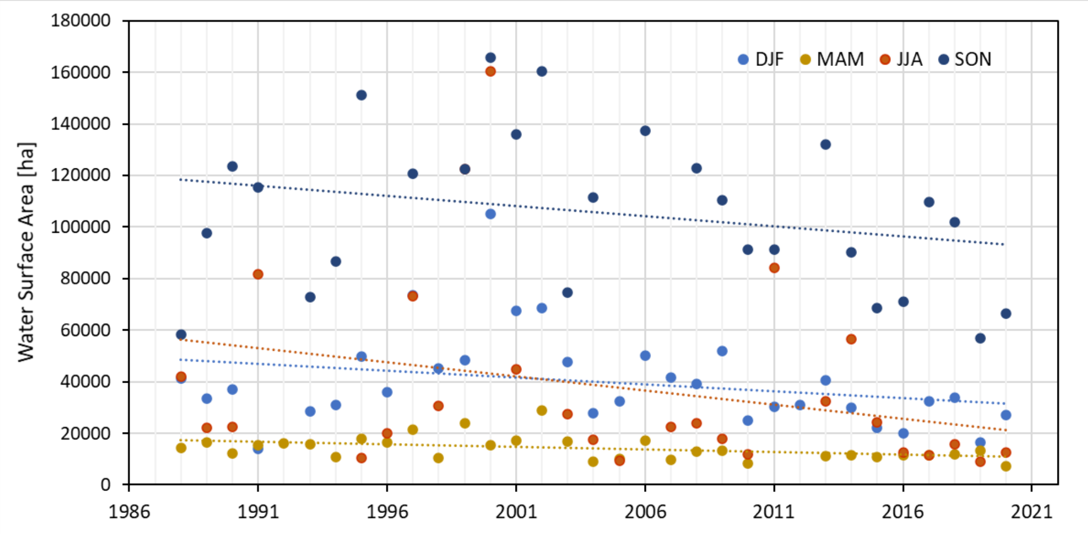


Figure 6-19. Average water surface area for 3-month aggregated images per year, with linear trendlines.

Figure 6-20 shows the change in seasonality between the 1988-2010 and 2010-2020 period. This shows a clear reduce in inundation extents for all months, but with the most severe decreases evident in October, where a reduction of over 40,000 ha flooded area is shown on average.

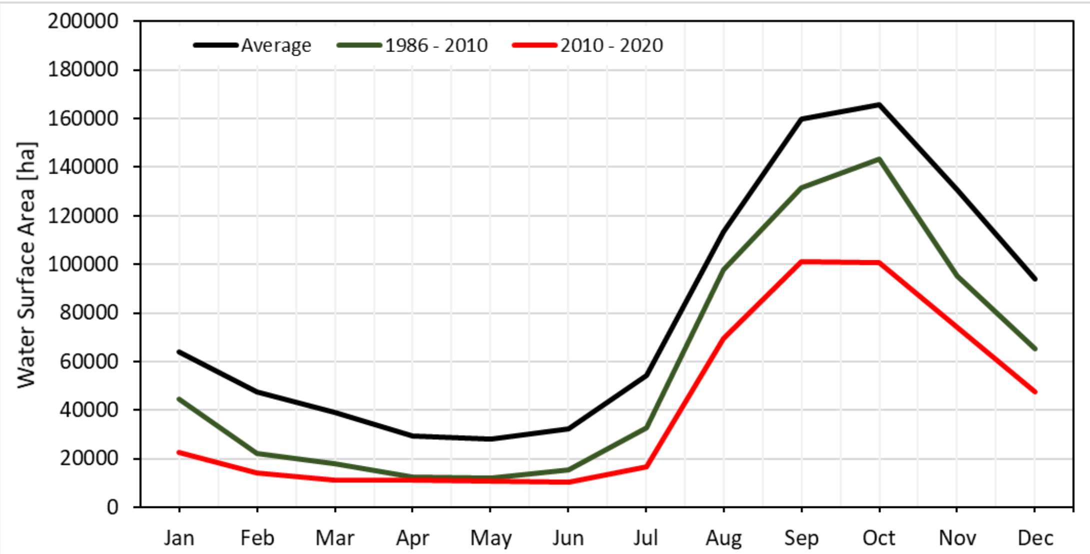


Figure 6-20 Average inundation per month for entire time period, 1986-2010 aggregated and 2010-2020 aggregated.

Figure 6-21 and Figure 6-22 show the changes in inundation extent spatially between 1988-2010 and 2010-2020 in terms of annual average extents and wet season extents respectively. The following observations can be made:

- Prek systems and surrounding areas appear to be less frequently inundated in the last decade when compared to 1988-2010, with the exception of systems to the South of the Mekong
- This trend is accentuated during the wet season, where reductions of over 40% inundation occurrence are shown to have occurred in some areas on the Bassac and increases of around 40% shown in the system to the south of the Mekong

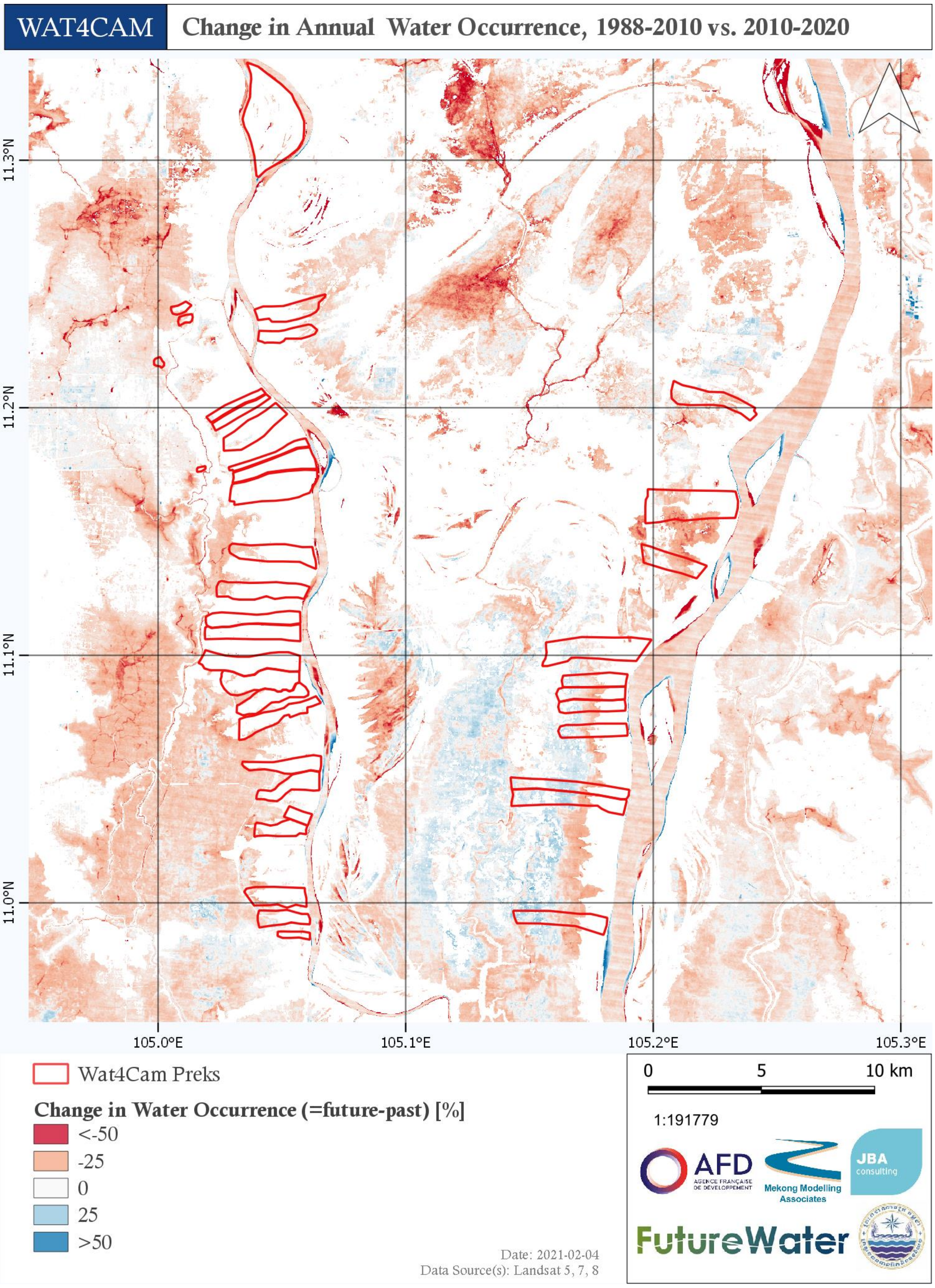


Figure 6-21 Changes in annual water occurrence between 1988-2010 and 2010-2021. Striping pattern is an artefact of Landsat-7 imagery.

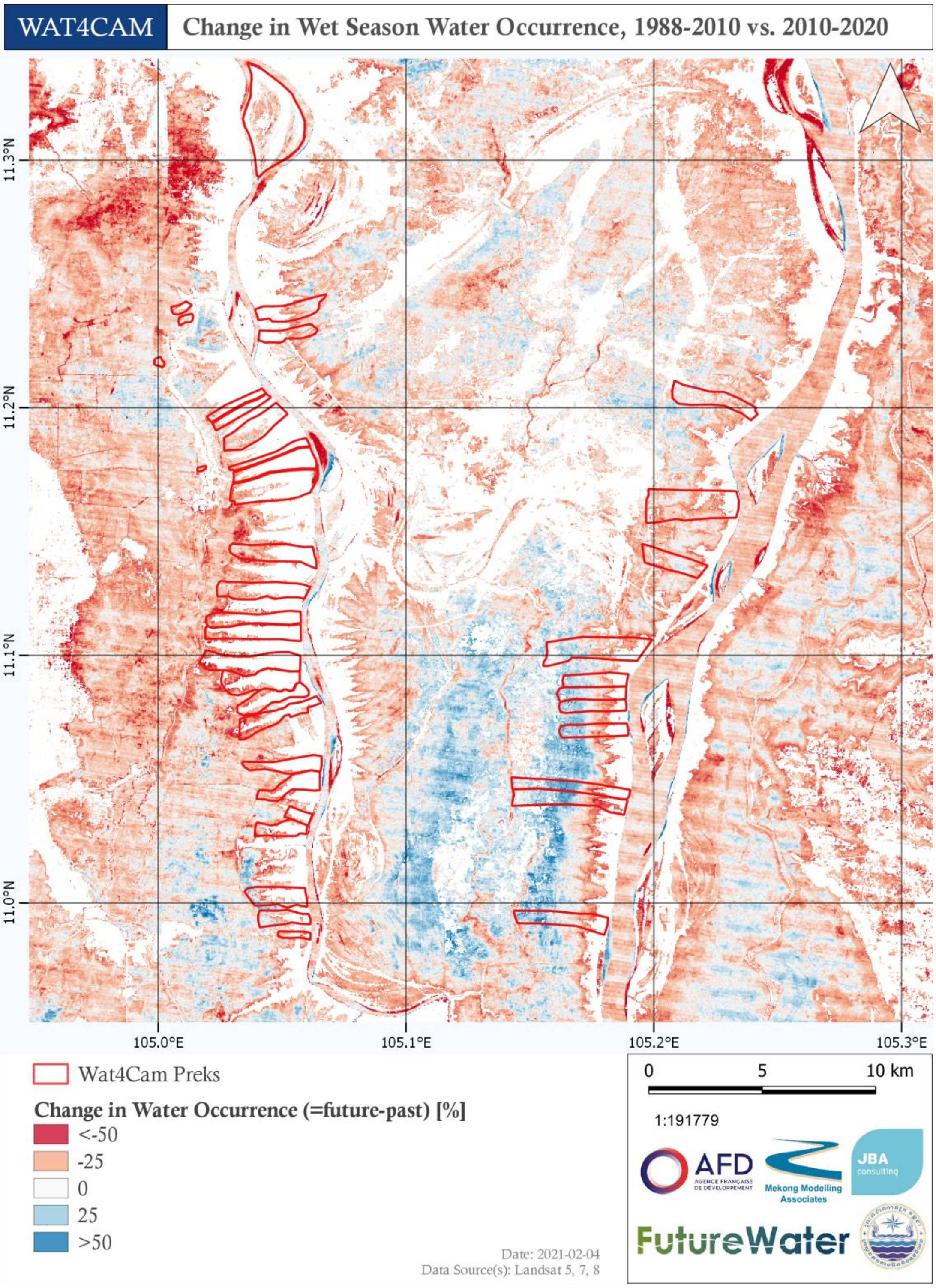


Figure 6-22 Changes in wet season (August-November) water occurrence between 1988-2010 and 2010-2021. Striping pattern is an artefact of Landsat-7 imagery.

Sentinel (2014-2020)

Sentinel imagery from 2016-2020 was analysed to take a closer look at recent years, in which irregular patterns in flooding have been noticed by local partners. The increased density of images allows individual months to be analysed.
Figure 6-23 and Figure 6-24 show deviations from average water extent (for the period 2016-2020) and changes in seasonality for the last 5 years. These show the following:

- From 2017-2019, the onset of the flood season became earlier year-on-year, with a higher peak in average monthly flood extent (highest in 2019)
- 2020 was an anomalous year, with a much sharper peak in inundation extent and a later onset of flooding than average
- 2016 is anomalous in terms of having a large peak much earlier in the year (May) in terms of inundation extent, and a much smaller peak in the usual flood season.

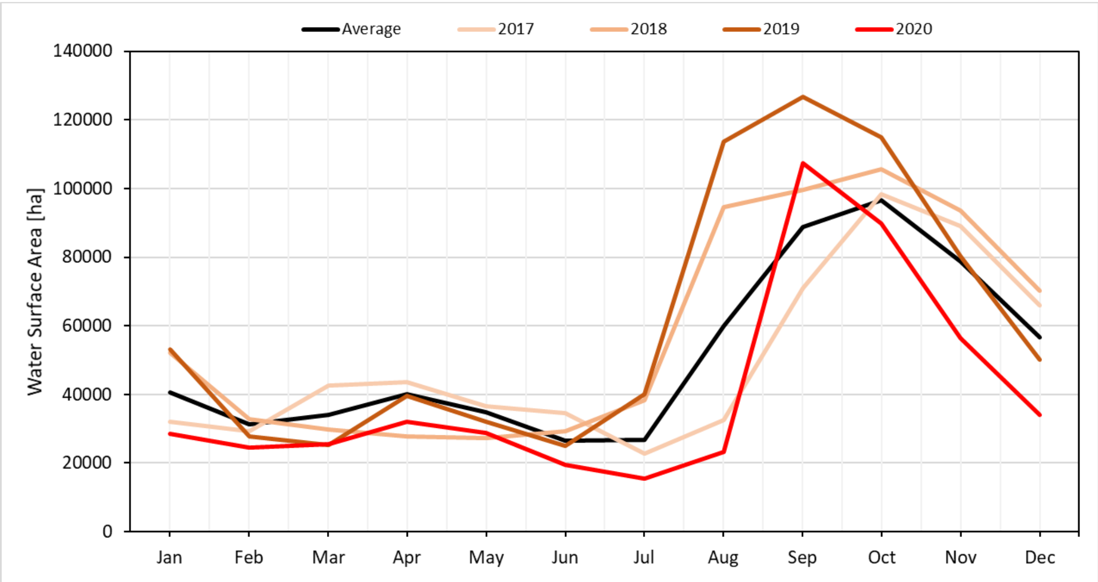


Figure 6-23 Seasonal trends in monthly average water extents for 2015-2020 derived from Sentinel-1 imagery

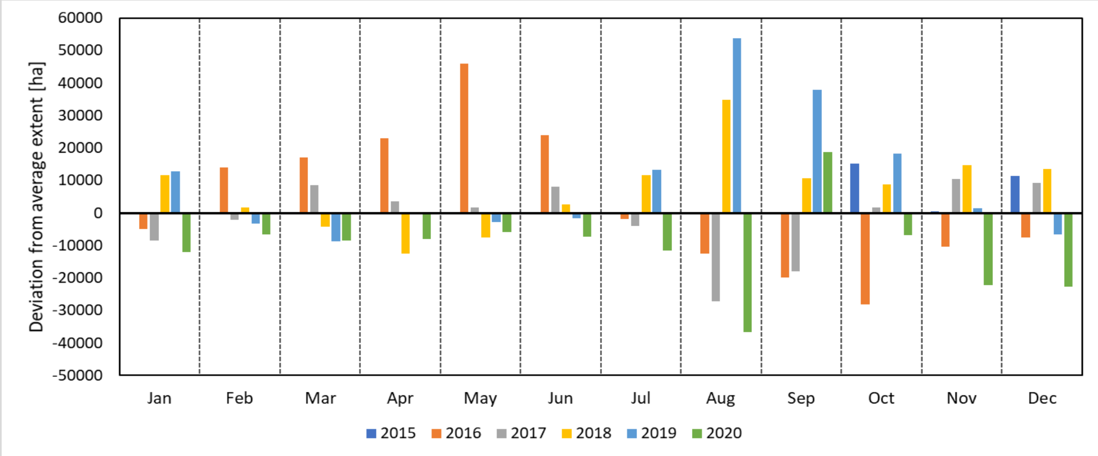


Figure 6-24 Deviation from mean monthly water extents per month for 2015-2020 derived from Sentinel-1 imagery

6.6 Flood Mapping of Current Day and Future Conditions from Modelling

6.6.1 Requirements

The WAT4CAM 3.1 Terms of reference specify a requirement for flood hazard maps for present and future scenarios covering (1) flood extent for selected annual exceedance probabilities (2) Inundation depth and extent per selected annual exceedance probability. (3) Animation and video as data visualisation for hydrodynamics of the study area.

6.6.2 Approach taken

The assessment of the remotely sensed flooding has already identified a number of key issues including the significant change that is occurring in the flood regime of the area. This is complemented by the detailed modelling undertaken using the 2D package HEC-RAS described in Chapter 5. Due to the level of complexity and the large area extent, simulations are relatively time consuming and can only be undertaken for particular seasons. Once run though outputs of maximum depths, durations, hazard etc are easily obtained. Animations and video are also readily prepared.

To obtain a probabilistic approach to flood mapping, within the Mekong floodplains it is difficult to get a single map representing say a 1:20 year flood using deterministic approaches. Analysis of flow or water level tends to show a variation in event severity that varies spatially. The solution to this issue is either to carry out long term simulations and then analyse the results statistically as has been done using 1D models in the past or to look only at local areas and tie in the specific simulation with analysis of the gauge record. In this case the later approach has been taken.

Future scenarios can then be assessed using a perturbation of the present-day system as described in Chapter 4. The high level of uncertainty of the impact of climate change indicates that any one 'scenario' linking atmospheric forcing to hydrological change can only be illustrative rather than a prediction of the future. Adopting a high degree of change gives an indication of the robustness of the system or a 'stress test' which is the approach adopted here.

6.6.3 Probabalistic Analysis of Gauge Data

The return period of a particular flood event simulation and its resulting flood event can be determined through the analysis of gauges. Chaktomuk, Koh Khal and Neak Luong were all analysed, and can be used to locally determine the right flood level to use for mapping locally.

Chaktomuk Gauge Phnom Penh

The analysis was carried out using the gauge data from 1980-2020. The gauge zero of -1.02m needs to be accounted for when translating to water level. It can be seen that a downward trend in the peak is apparent and a statistical Man-Kendall test signifies this change is not yet proven to be significant. If the trend was correct this means that the 2000 flood, judged as a 20-50 year event at the time may now be a rarer occurrence.

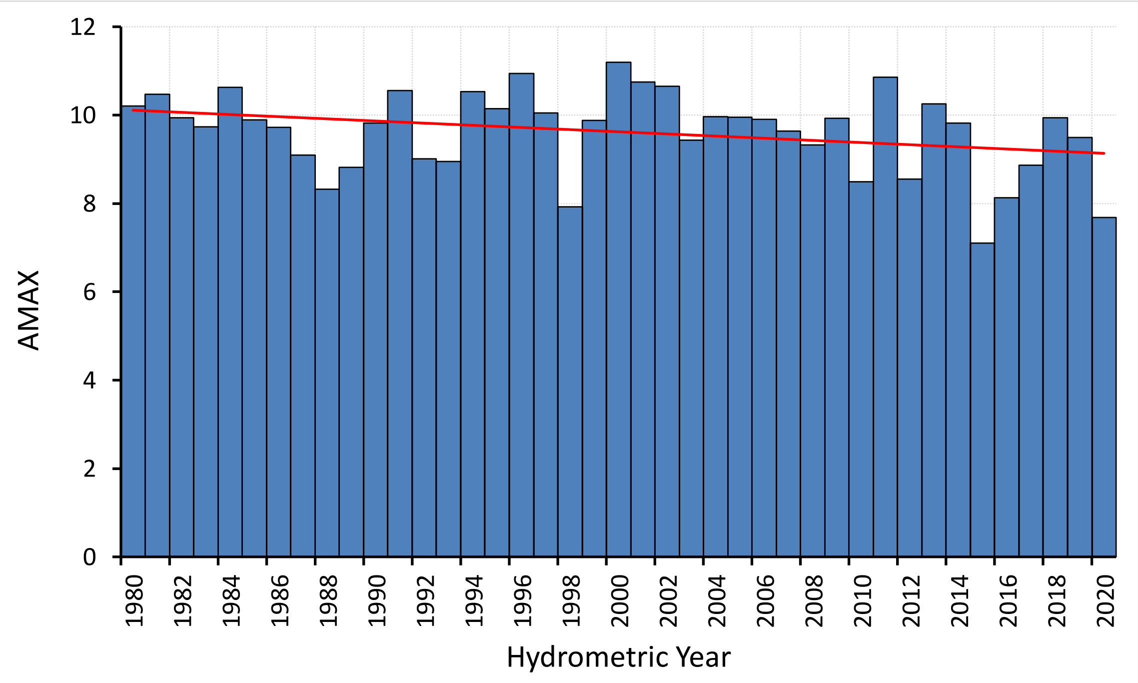


Figure 6-25 Annual Maximum Gauge Level at Chaktomuk 1980-2020

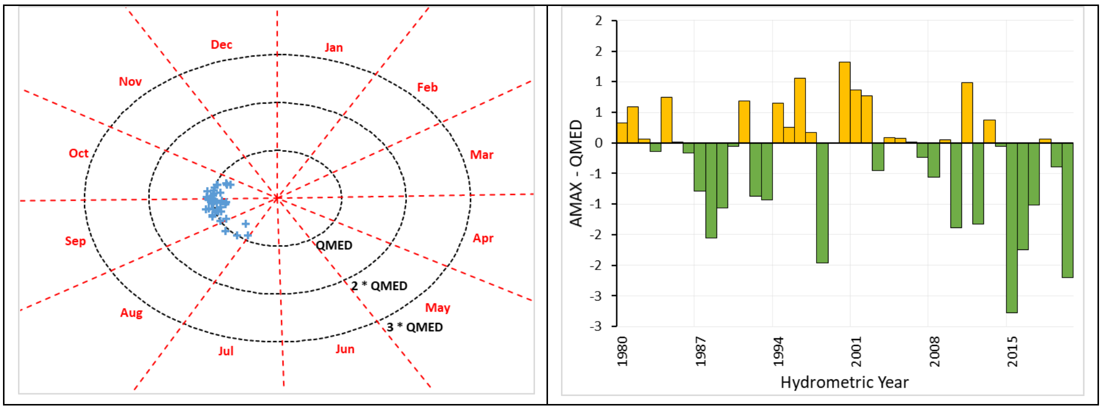


Figure 6-26 Seasonality and deviation from median

Frequencies are estimated by fitting extreme value distributions such as GEV, Pearson Type III, Log Normal, Log Pearson III etc and examining the fit.

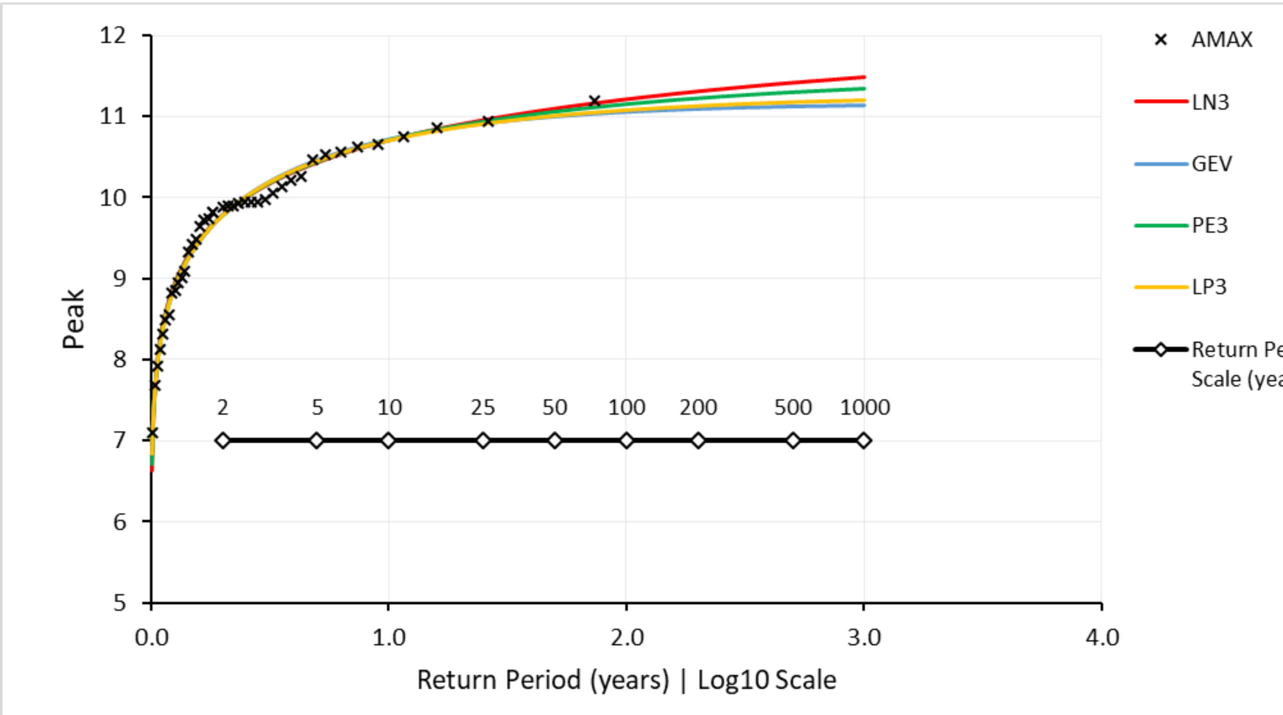


Figure 6-27 Plotting of frequency distributions for Chaktomuk gauge levels

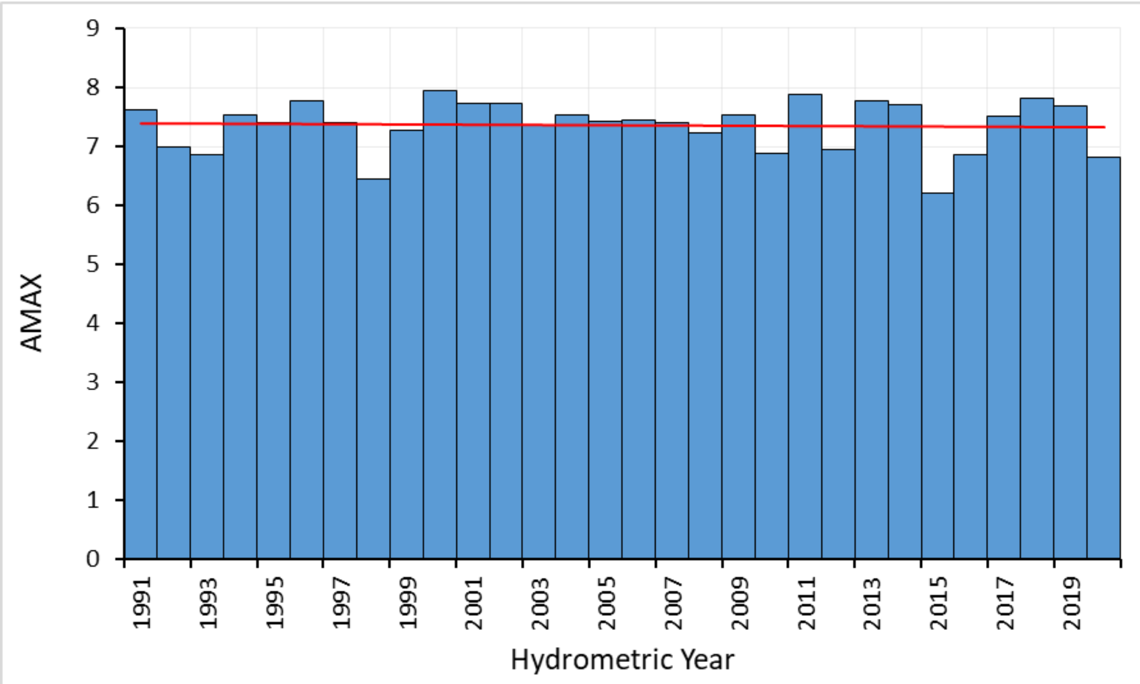
The difference in levels is not highly dependent on the distribution used but LN3 appears to be appropriate. Projected levels are listed below.

Selected frequency models	Peaks for the following return periods (years). Changing the white cell							
	2	5	10	25	50	75	100	200
Log-Normal (3-parameter)	9.78	10.43	10.70	10.95	11.10	11.17	11.21	11.31
Generalised Extreme Value	9.78	10.47	10.72	10.92	11.00	11.04	11.06	11.10
Pearson Type III	9.78	10.44	10.71	10.94	11.06	11.12	11.15	11.23
Log-Pearson Type III	9.79	10.46	10.71	10.92	11.02	11.06	11.09	11.14

Note Gauge datum -1.05m must be added to get to water levels. A 5 year level is +9.38m and 100 year 10.16m to Hatien datum.

Koh Khal (Bassac)

Similar to Chaktomuk, there is a slight declining trend in the annual maxima:



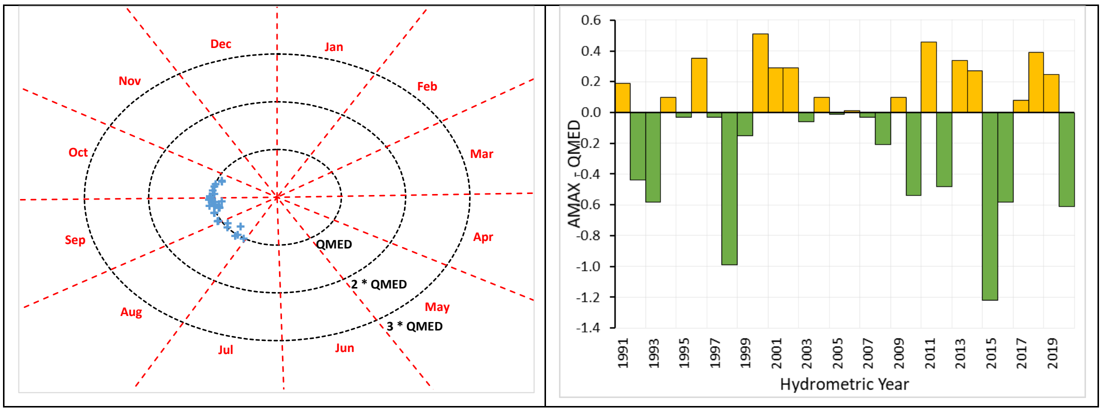


Figure 6-28 Seasonality and deviation from median

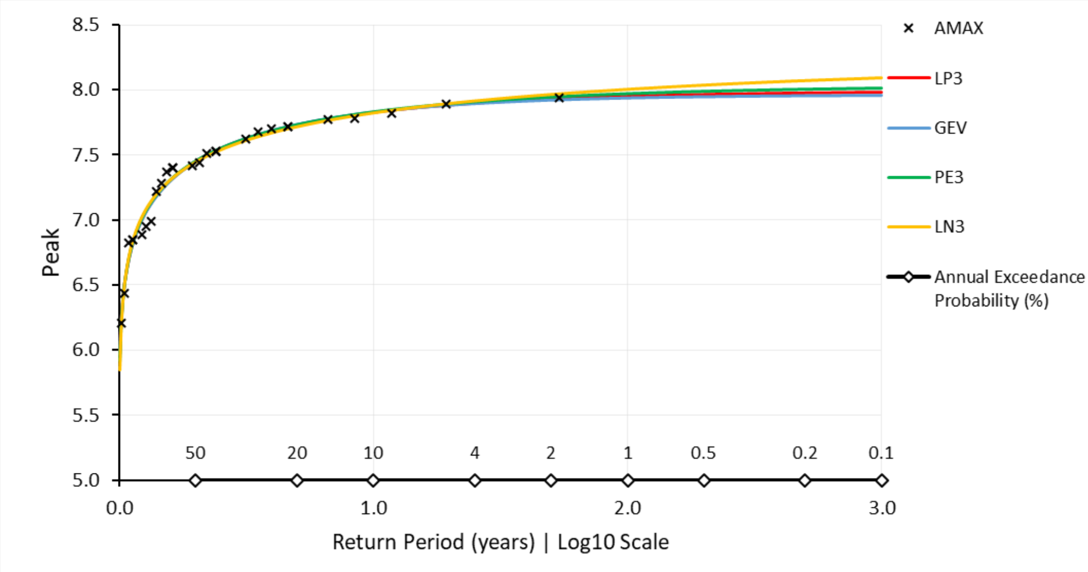


Figure 6-29 Frequency Fitting for Koh Khal Gauge Level

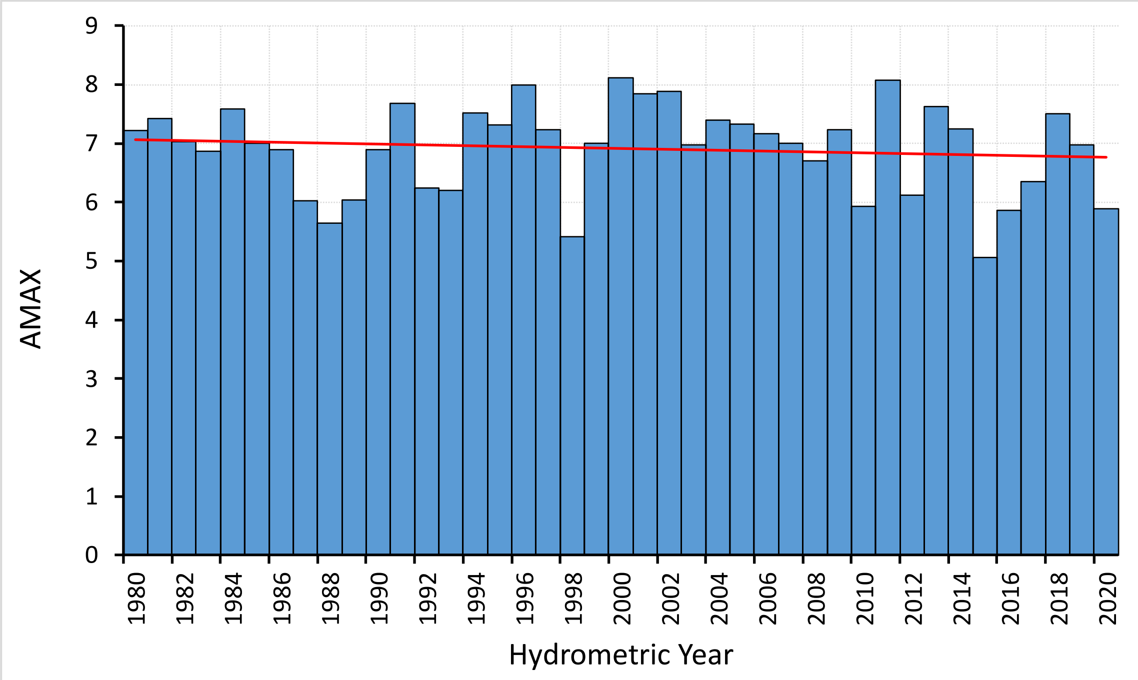
The difference in levels is not highly dependent on the distribution used but GEV appears to be appropriate. Projected levels are listed below.

	2	5	10	25	50	75	100	200
Log-Pearson Type III	7.45	7.73	7.83	7.90	7.93	7.95	7.95	7.97
Generalised Extreme Value	7.45	7.74	7.83	7.90	7.93	7.94	7.94	7.95
Pearson Type III	7.45	7.73	7.83	7.91	7.94	7.96	7.97	7.99
Log-Normal (3-parameter)	7.45	7.72	7.83	7.92	7.97	7.99	8.01	8.04

Note Gauge datum -1.0m must be added to get to water levels. A 5 year (20% AEP) level is +6.74m and 100 year 6.94m.

Neak Luong

Presenting results similarly to Chaktomuk and Koh Khal, there is a slight declining trend in the annual maxima:



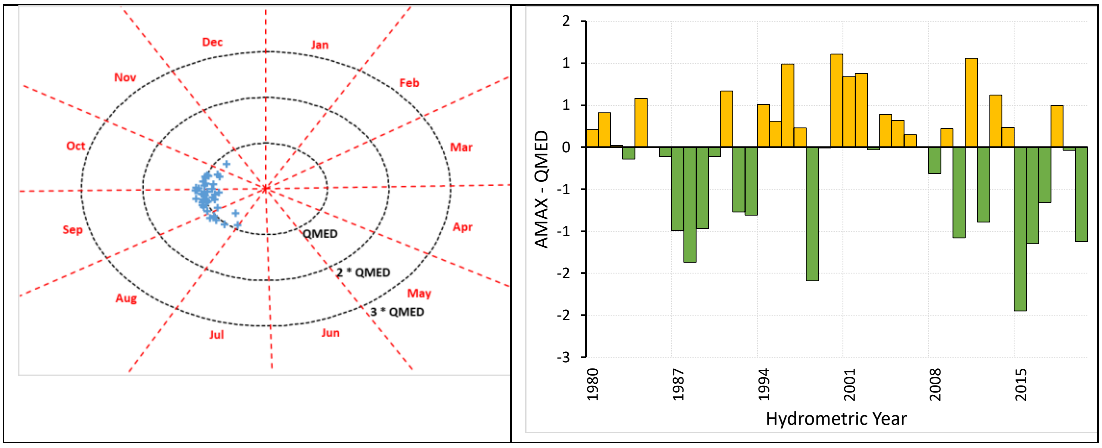


Figure 6-30 Seasonality and deviation from median

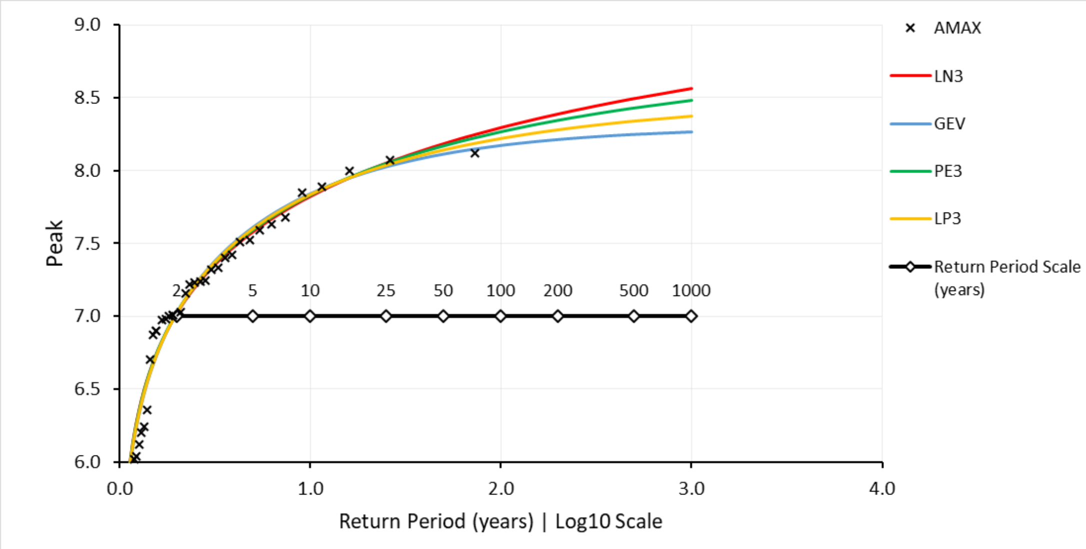


Figure 6-31 Frequency Fitting for Neak Luong Gauge Level

The difference in levels for a specific frequency event is not highly dependent on the distribution used but GEV appears to be appropriate. Projected levels are listed below.

	2	5	10	25	50	75	100	200
Log-Normal (3-parameter)	7.02	7.58	7.82	8.05	8.19	8.25	8.30	8.39
Generalised Extreme Value	7.02	7.61	7.84	8.03	8.11	8.15	8.17	8.21
Pearson Type III	7.02	7.59	7.83	8.05	8.17	8.23	8.26	8.34
Log-Pearson Type III	7.02	7.60	7.84	8.04	8.14	8.19	8.22	8.28

Note Gauge datum -0.33m must be added to get to water levels. A 5 year (20% AEP) level is +7.28m and 100year 7.82m using GEV. Small rises of this magnitude generally do not affect the local flood extents greatly but can significantly impact durations and flood flows that could increase scouring and structural damage to banks etc.

6.7 Results from HEC-RAS Model

6.7.1 Current Day

The HEC-RAS Model was run for a full range of flood seasons including 2000, 2011, 2018, 2019, 2020.

Considering peak levels attained at Chaktomuk model peak levels and estimated return periods are as follows

Year	Peak Level Recorded (mAD)	Peak Level Model (m AD)	Estimated Return period of flood at Chaktomuk
2000	10.15	9.96	40
2011	9.81	10.12	75
2018	8.90	9.14	3
2019	8.45	9.05	3
2020	6.63	7.03	Lowest on record

We have a range of flood return period events available as well as the build up and recession to each.

If we overlay a 3 year event on top of the 75 year, it becomes apparent that there is not very much difference in extent when looking at a macro scale as shown in Figure 6-32

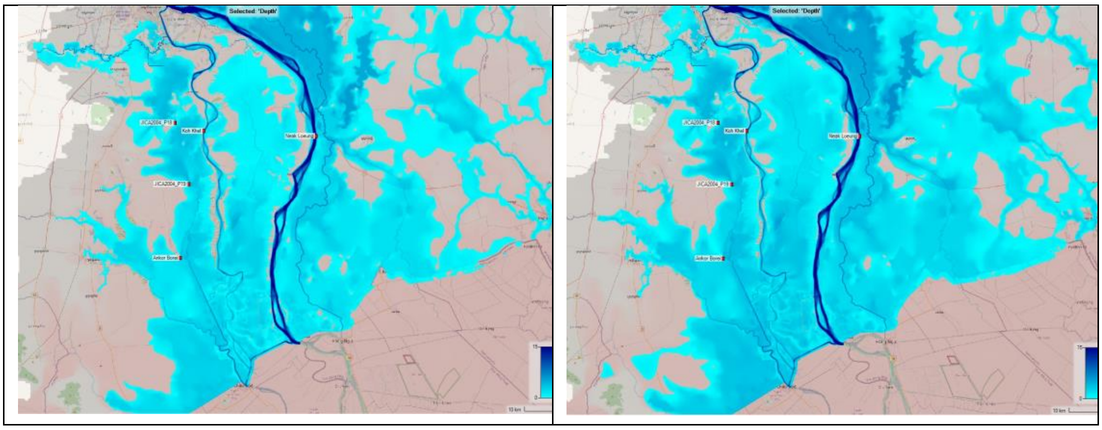


Figure 6-32 2018 (left) and 2011(right) peak modelled depths. Whilst there are differences between the estimated 3 year return period and 75 year return period events, they are not large at a macro scale.

We may also consider the changes not only of maximum flood extent but also velocity, hazard, duration and other derived parameters. Looking at a specific area also allows us to consider more changes that occur with increased flood severity.

A number of examples are thus included and presented in the report but also the GIS files of flood extent, depth are being provided in a soft copy form for more easy access and study. This is linked with the capacity building and model data handover for MOWRAM. The model also has the advantage over satellite analysis of being able to study the progression of a flood and easily animate the results. Such animations are also being provided together with the outline extents and depth rasters.

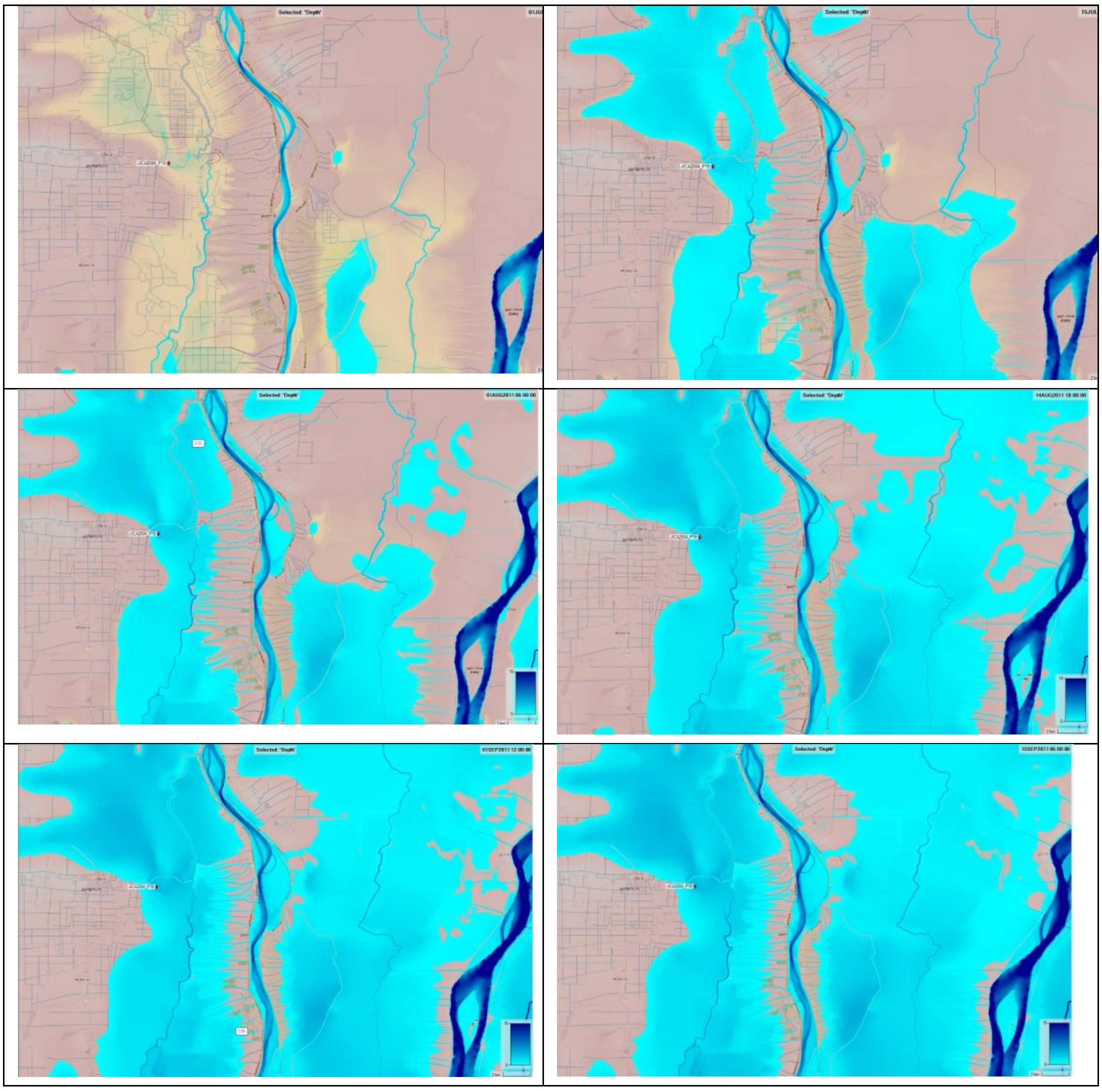


Figure 6-33 2011 Flood Depth progression for area from Prek Ambel to Prek Cluster. July 1(left) July 15 (right), Aug 1 (left) Aug 15 (right), Sep 1 (left), Sep 15 (right). This long flood continues to rise peaking at the beginning of October. The progression Continues in next figure.

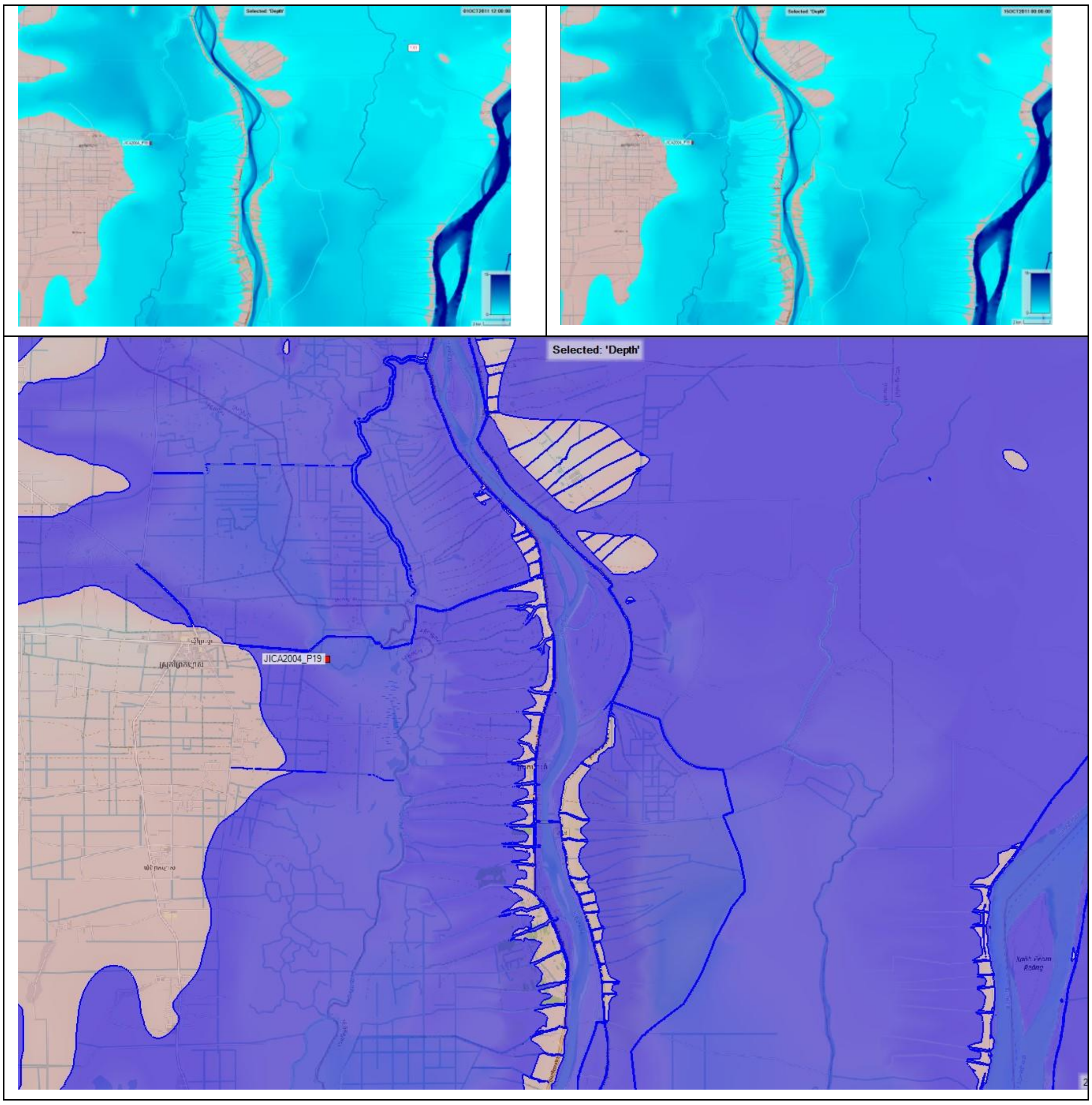


Figure 6-34 Flood Depth 1 October and 15 October (start of recession) and inundation boundary below. Note how the Preks form an important connection between the main rivers and floodplain enabling balancing of levels, fish passage etc that would be disrupted if the channel was closed.

Other output examples are given for the same area and flood event.

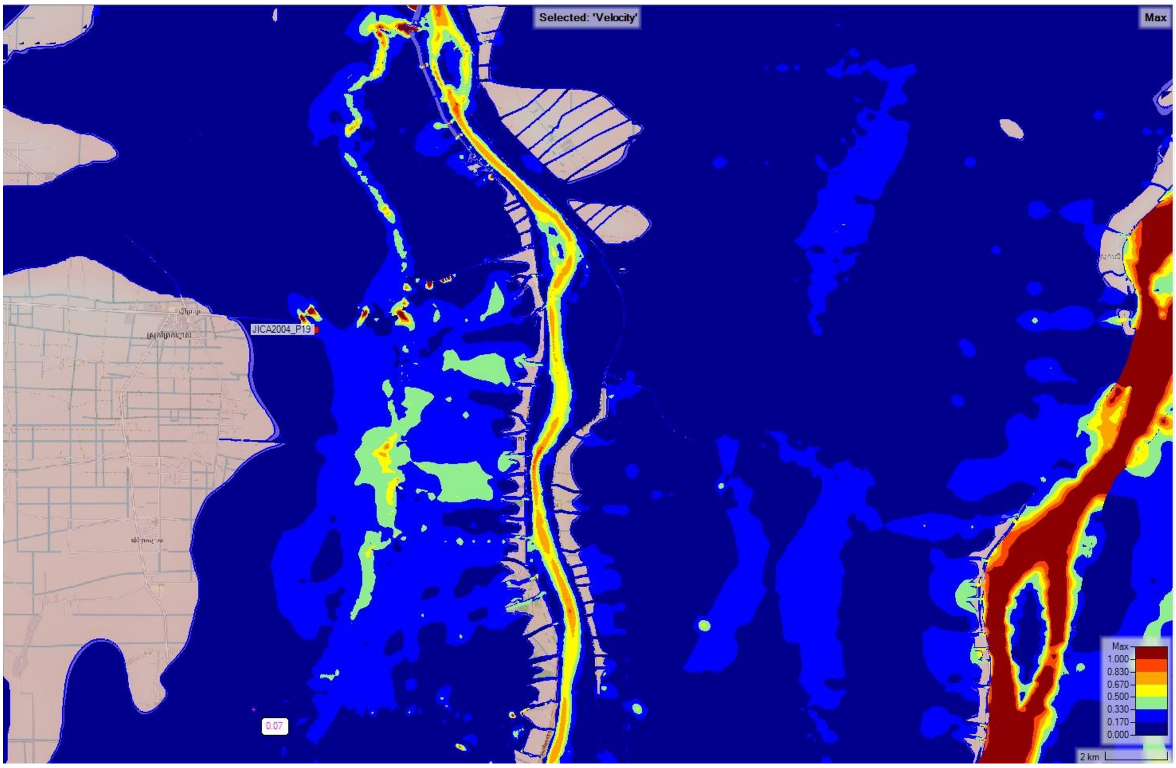


Figure 6-35 Peak Velocity in 2011 Flood, floodplain velocities are generally low, enhancing sedimentation but at certain restrictions are much higher

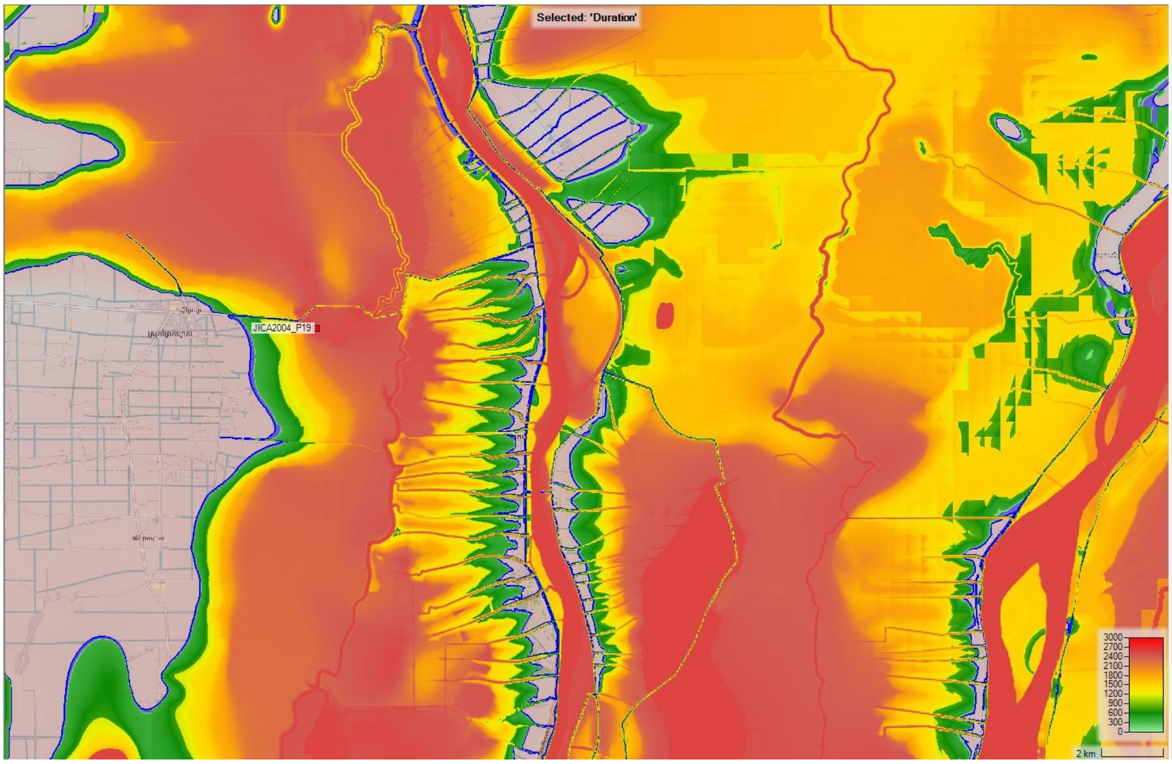


Figure 6-36 The Duration of flood between 1 July and 31 October 2011. Scale up to 3000 hours (125 days)

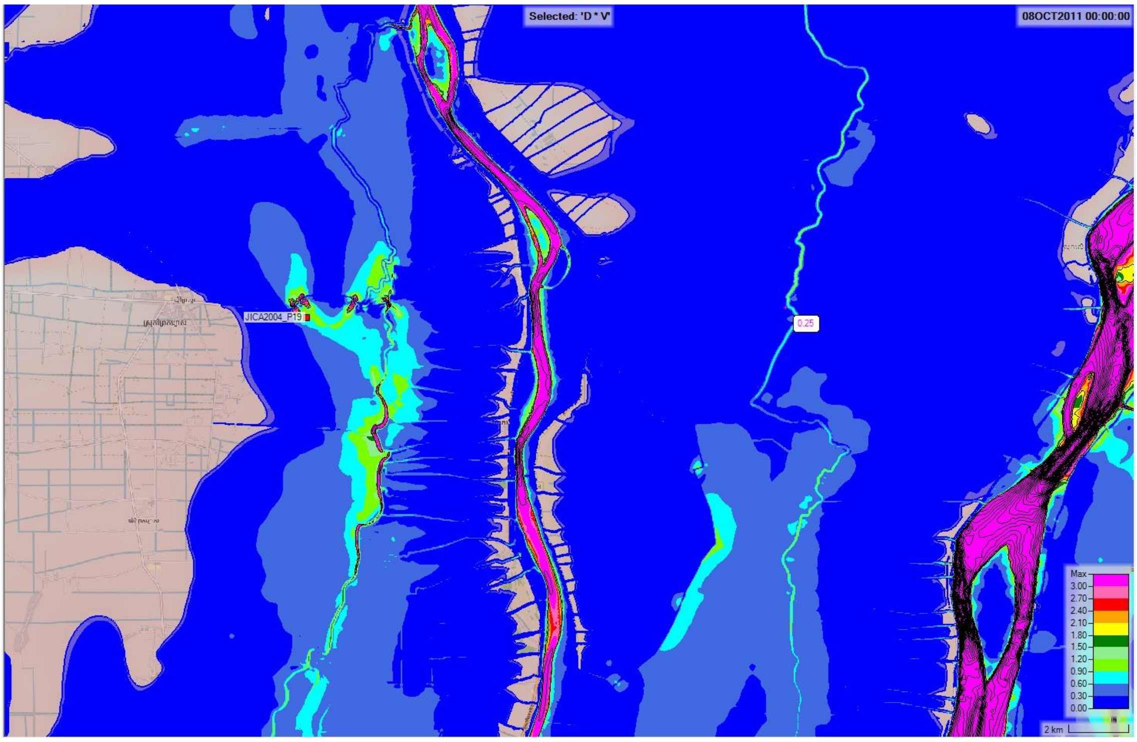


Figure 6-37 Depth Velocity Product as an indicator of Hazard to life. Other standard Hazard formulations can be calculated in HEC-RAS mapper.

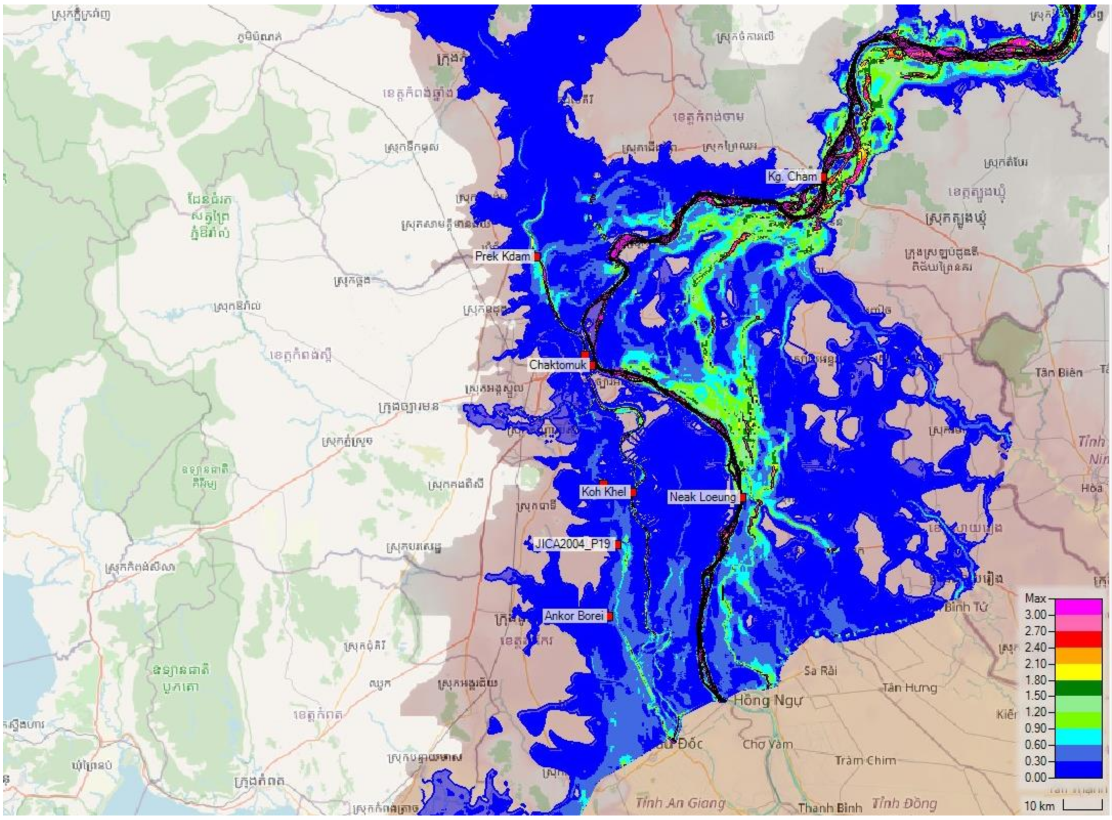


Figure 6-38 Depth-Velocity product for upstream floodplain showing higher hazards on Mekong left bank and upstream of Kampong Cham

6.7.2 Future Conditions

Approach

As described in chapter 5 climate change sensitivity has been assessed using 20% and 30% flow increases and consideration of sea level rise impact. Simulations were carried in the HEC-RAS 2D model for 2018 and 2019 events and assessed using depth, inundation extent and durations. For sea level rise, the change must be imposed at the coast, which is at the downstream part of the delta in Vietnam outside of the 2D model domain. To assess the effect in Cambodia, the 1D ISIS model was used to indicate the amount of change transferred up into Cambodia.

Impact of Upstream change

Although currently there appears to be a downward trend in peak gauge levels, this is most likely due to upstream development as demonstrated in various modelling studies previously (MRC 2020). The effect of the sensitivity scenario values of 20% and 30% Increase in upstream levels are noticeable on the peak flood extent as highlighted below. Within the prek cluster, for example the peak flood envelope would inundate an extra 110-120m (for 20% scenario), and 200m (30% scenario) depending on the local land slope. Other places where the gradient is greater show less change and some more change where it is very flat. At Koh Khal the increase in water level is 0.19m and 0.28m at the flood peak for 20% and 30% increases respectively.

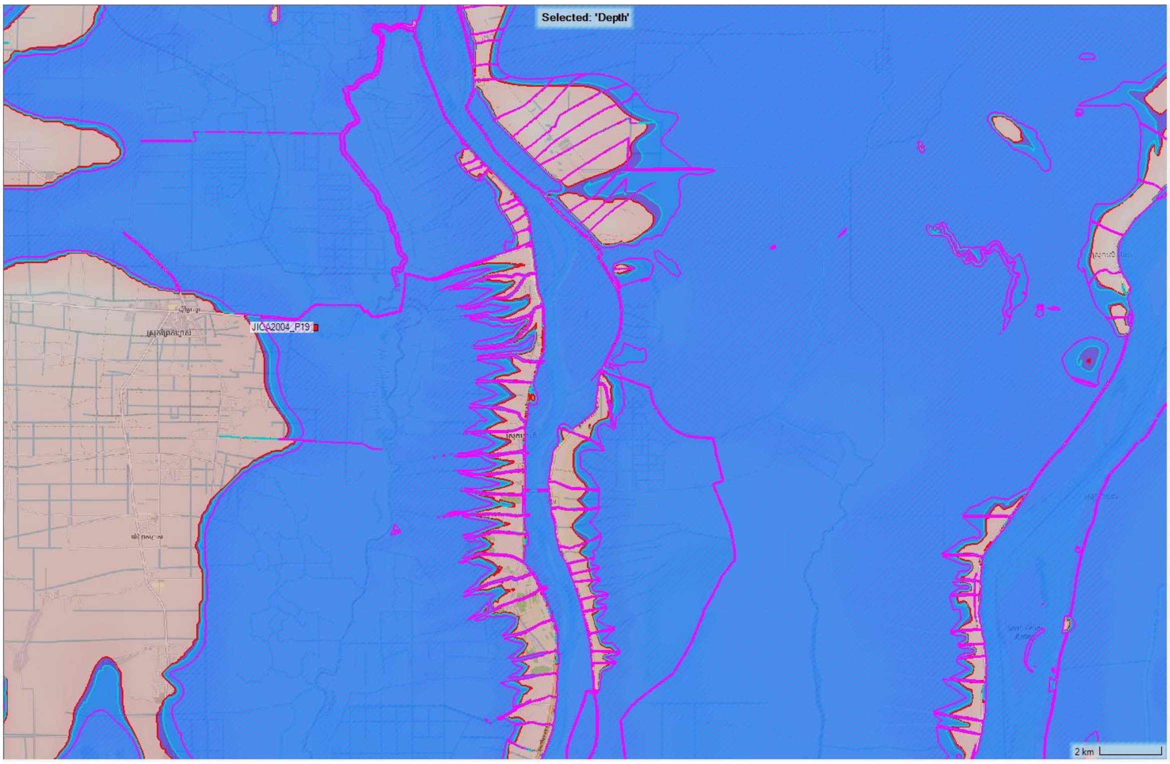


Figure 6-39 Change in flood extent for Climate change Scenarios 20% and 30% flow increase

Impact of Sea Level Rise

The impact of a 0.3m sea level rise at the Vietnam coast was simulated in the 1D model to ascertain the change in the Mekong and Bassac channels. At the near border monitoring stations of Tan Chau and Chau the change was found to vary significantly depending on the state of the flood as shown in Figure 6-40 and Figure 6-40. For flood periods the change in water level is below 0.05m at Tan Chau on the Mekong and below 0.1m at Chau Doc. At Phnom Penh this translates to a change in peak flood level increase of only 2mm so a very much reduced effect for floods than the increase in fluvial flows.

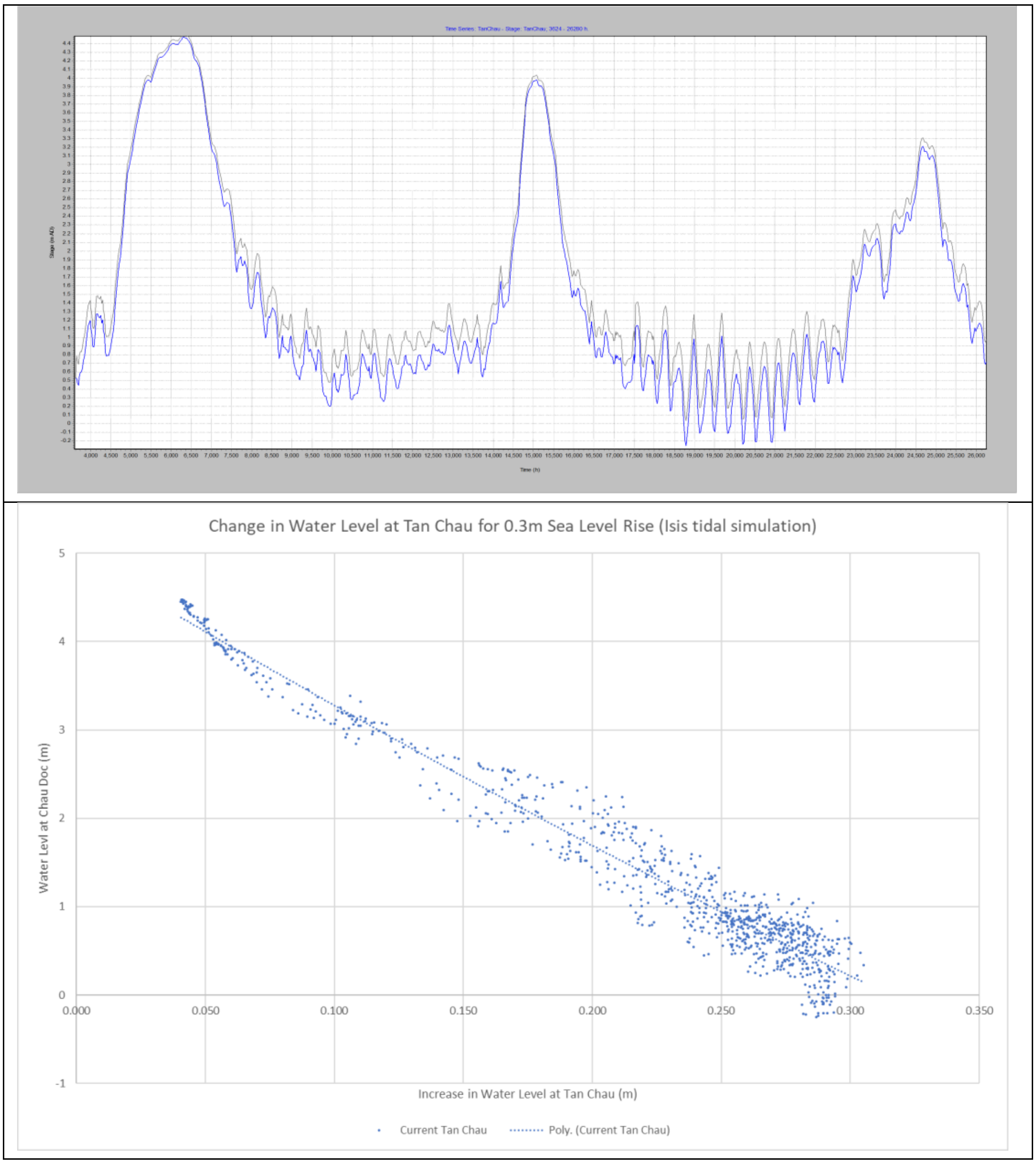


Figure 6-40 Simulated Water levels (above) and Change in Water Level at Tan Chau for a 0.3m increase in sea level at the coast. Simulations for 2018-2020

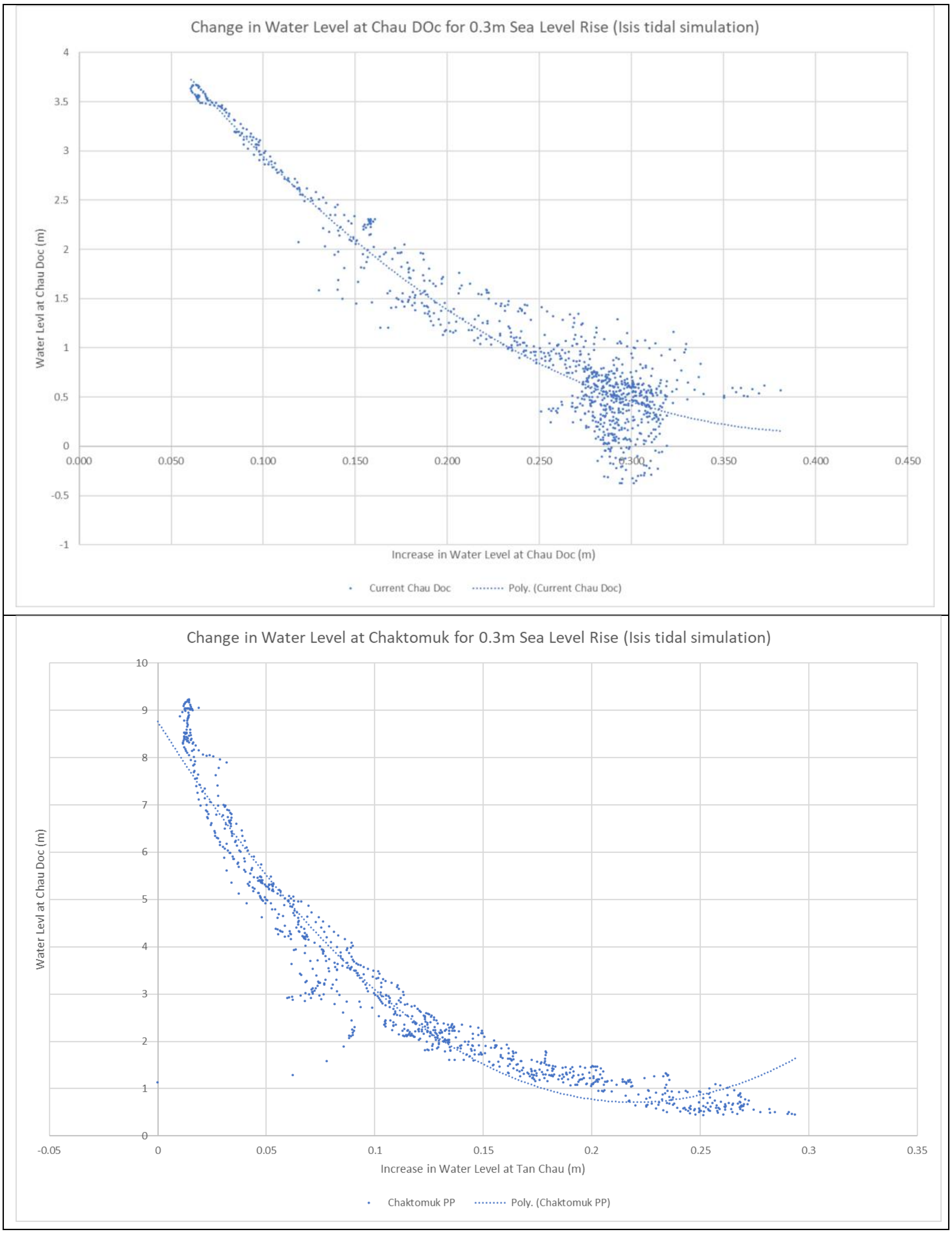


Figure 6-41 Change in water level at Chau Doc and Chaktomuk for 0.3m coast sea level rise 2018-2020 simulation result from 1D modelling

7 Low-flow Assessment, cropping patterns, water availability and use

7.1 Methodology

As completed for the flood season, a combination of analysis of 2D modelling, remote sensing analysis, and analysis of gauge records and is utilised for the low flow assessment. Specifically, the model is used to inform about the flows, levels and distribution within the system, analysis of remotely sensed data is used to detail the changing cropping within preks and estimation of water demands. Analysis of gauges is used together with data surveyed for the preks to give the requested water levels.

The chamkar areas of the preks are typically cultivated with annual crops. The variety of crops in these areas is quite large, including for example sugarcane, various vegetables, and fruit trees (in particular mango). The low-lying boeung areas typically consist of rice paddies that are planted after the flood recedes and typically is served by an irrigation system.

7.2 Modelling

The model was used for giving an overall picture and understanding of the water distribution downstream of Kratie and some of the constraints on supply for the prek systems.

The overall change in water stored on the floodplain and Great Lake is shown at the beginning of each month in Figure 7-1 which shows the simulated changes November 2018 to April 2019. There is a small issue with the model in that evaporation of flooded areas is not included in the calculation, thus some of the water bodies remain for longer than they do in practice. The symbiosis of the Mekong and Tonle Sap is then highlighted in Figure 7-2, which shows the distribution of flows in the wet and dry season for each of the four branches of the Chaktomuk. The Tonle Sap reverses in the wet season, filling the Lake, but then gradually discharges from October through to April. On December 1, for example over 5000m^3/s is discharging from the Tonle Sap to the Mekong, well over half of the total flow. Most of this flow goes across the border to Vietnam as flows into the preks and other channels totals only a few 10s of m3/s as shown in Figure 7-3. This figure illustrates the flow in nine locations or series of offtakes.

On the West Bassac, upstream of the Prek Ambel the flows summed for preks peaks at around 500m3/s but is disturbed when the Prek Thnot flows increase and there is a short period of outflow. The Prek Ambel peaks at around 400m^3/s, limited possibly by the road bridge that constrict the channel. Flows tail off to low values by February and the water demands downstream are mostly satisfied by reversal and tidal circulations.

For the Trans-Bassac flows are presented for the sum of Bassac left bank preks which are simulated to peak at 800m3/s inflow during the wet season and a recession through to late December. On the Mekong side, the preks upstream of Neak Luong bridge are relatively few and the offtake is limited to only 200m3/s in the wet season and a rapid decline even by the start of November. Downstream of Neak Luong crossing there are more prek channels and inflow of the wet season peaks at 1300m3/s with a period of outflow in November. Ultimately though there is little flow after 1 February.

The flows in the rivers Prek Ambel, Mekong downstream of Chaktomuk and the Bassac at the border show the dominance of the Mekong as a source of water with continued tidal flows with a net outflow to Vietnam of over 2500m3/s. The Bassac maintains a limited flow and becomes more tidal though not reversing at the border.

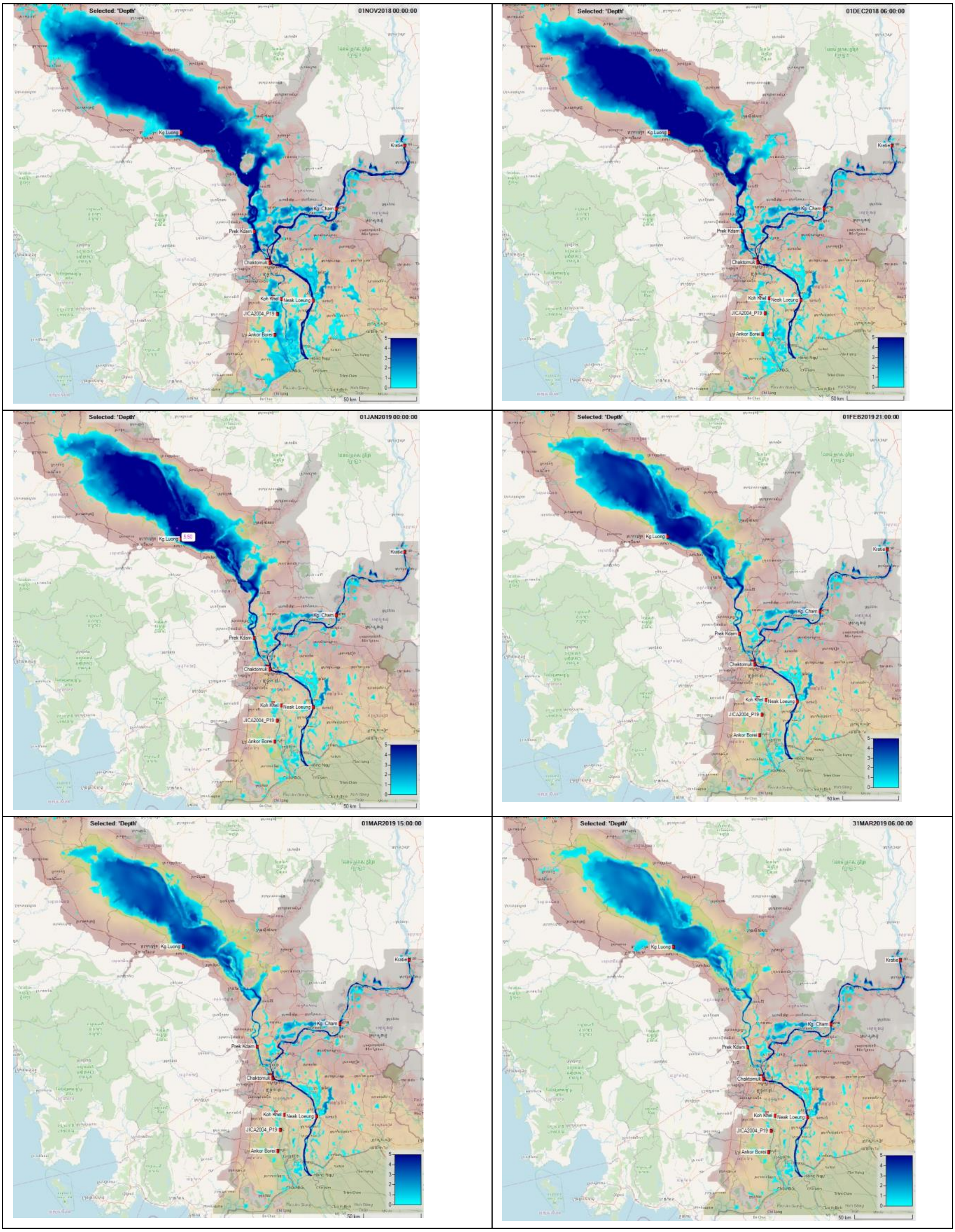


Figure 7-1 Great Lake and Floodplain simulated drawdown 1 November 2018 to 1 April 2019

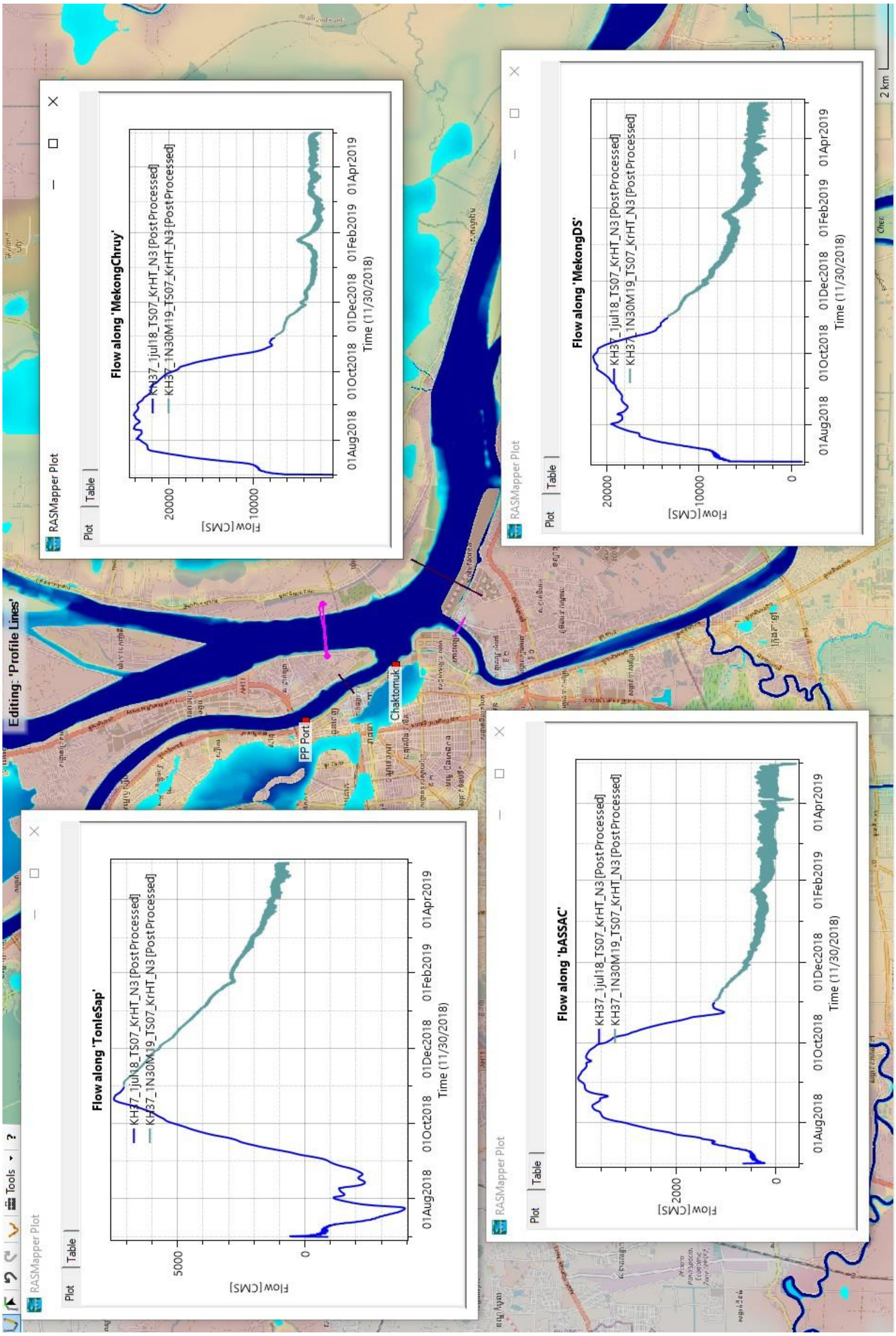


Figure 7-2 Modelled Distribution of flow at the Chaktomuk Junction July 2018 to April 2019. Note the reversal of the Tonle Sap and the subsequent significant contribution to Mekong flows. Bassac flows tend to low tidal values in February and even have periods of reversal.

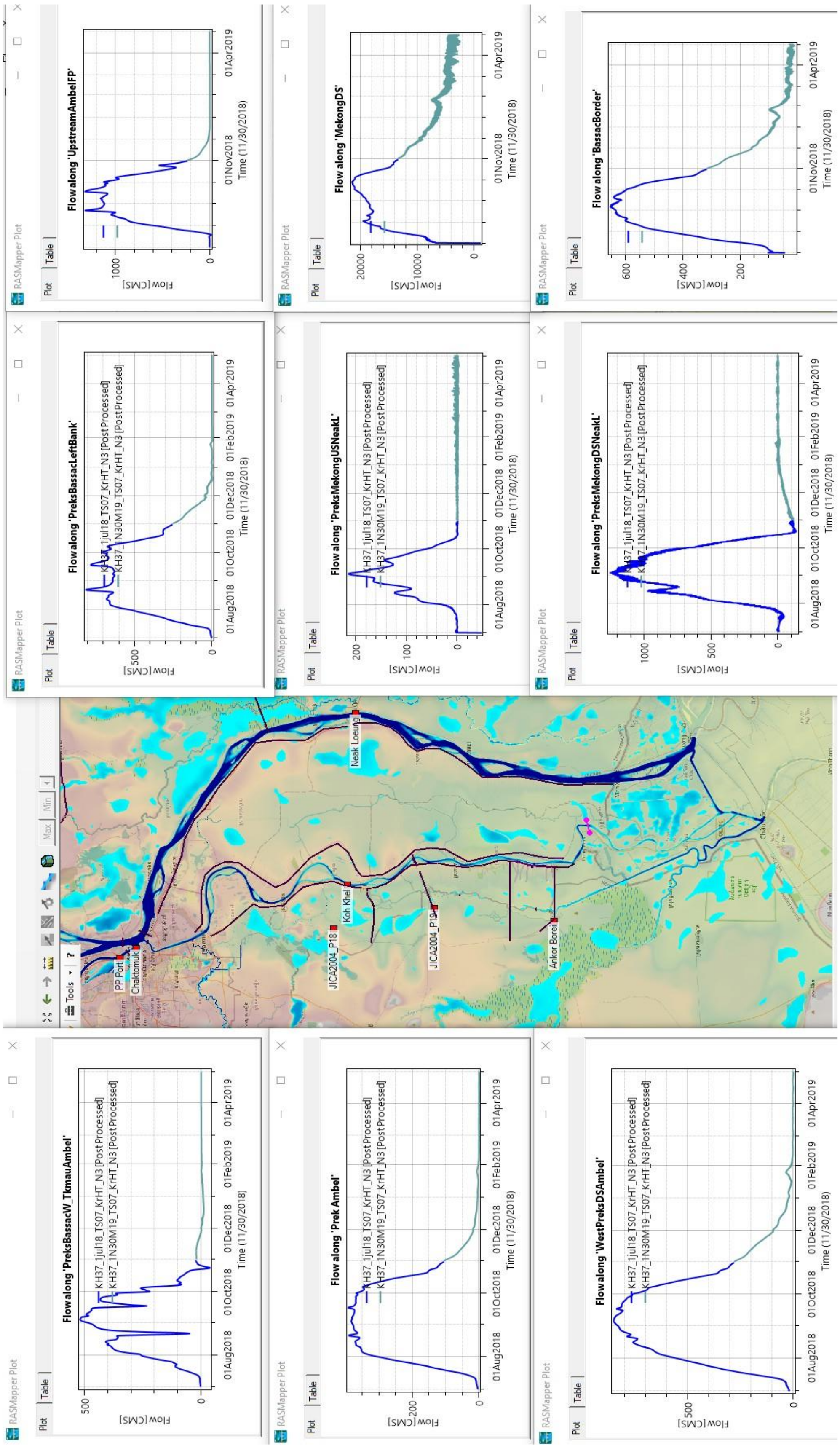


Figure 7-3 Flows into Preks of the West Bassac, east Bassac and Mekong left bank

7.3 Satellite Analysis

In the dry season, irrigation water is supplied from the prek canals by pumping, as well as from several shallow reservoirs developed in the region. The WAT4CAM Prefeasibility Study report (2018) describes how several preks suffer from inadequate water supply in the dry season, due to deterioration of the system. These include Preks Chhouy, Louk, Ta Dhoung, Thom, Koh Teav, Kong, and Top. For some of these preks, alternative large-scale pumping is possible from the main river (Bassac in these cases), to mitigate part of the supply deficiency. Some farmers also have access to groundwater. Overall, particularly irrigation water supply and crop conditions in the dry season (several months after the rainy season) can be assumed indicative of a prek's functioning in terms of irrigation. It is relevant to focus on the Chamkar areas when assessing Prek condition as they depend directly on one prek, whereas the boeung areas are typically supplied by a network of different canal.

Actual evapotranspiration (ET_{act}) was used to calculate the water demands in the pre systems using available data UNESCO-IHE (2017), UNSECO-IHE performed a water accounting assessment for Cambodia, of which the ET_{act} data (2003 – 2014) have been made available for this study. This dataset consists of monthly map layers with a 250m spatial resolution. ET_{act} is informative to understand the amount of water consumed by the system in the dry season, and is a direct consequence of the volume of irrigation water supplied.

7.3.1 Cropping patterns

Spatial patterns and temporal trends for the different crop types were calculated based on Sentinel-2 satellite data (10m resolution), which is available from 2015 – present. Normalized Difference Vegetation Index (NDVI) was calculated as an indicator of crop health and density in the agricultural system. NDVI is a useful indicator of cropping areas and density in agricultural areas. It serves two purposes in this analysis: performing a preliminary distinction between fruit trees and vegetables in Chamkar areas, and the temporal trends.

Figure 7-4 shows the NDVI value in January computed from Sentinel-2 imagery for the years 2016 to 2020. The map was calculated based on median reflectance values recorded by the satellite sensor and is thus representative of typical spatial patterns in January over the past 5 years. When comparing with land cover, clearly both the Chamkar cropland and the boeung rice fields directly west from the Bassac preks are still green in this month, benefitting from high flows in the preceding wet season. Riceland further west typically lies fallow in January. In March (Figure 7-5), the boeung areas are typically not cropped as no more flood water is available to supply to the fields, while sections of the Chamkar areas supplied by the main canal remain relatively green.

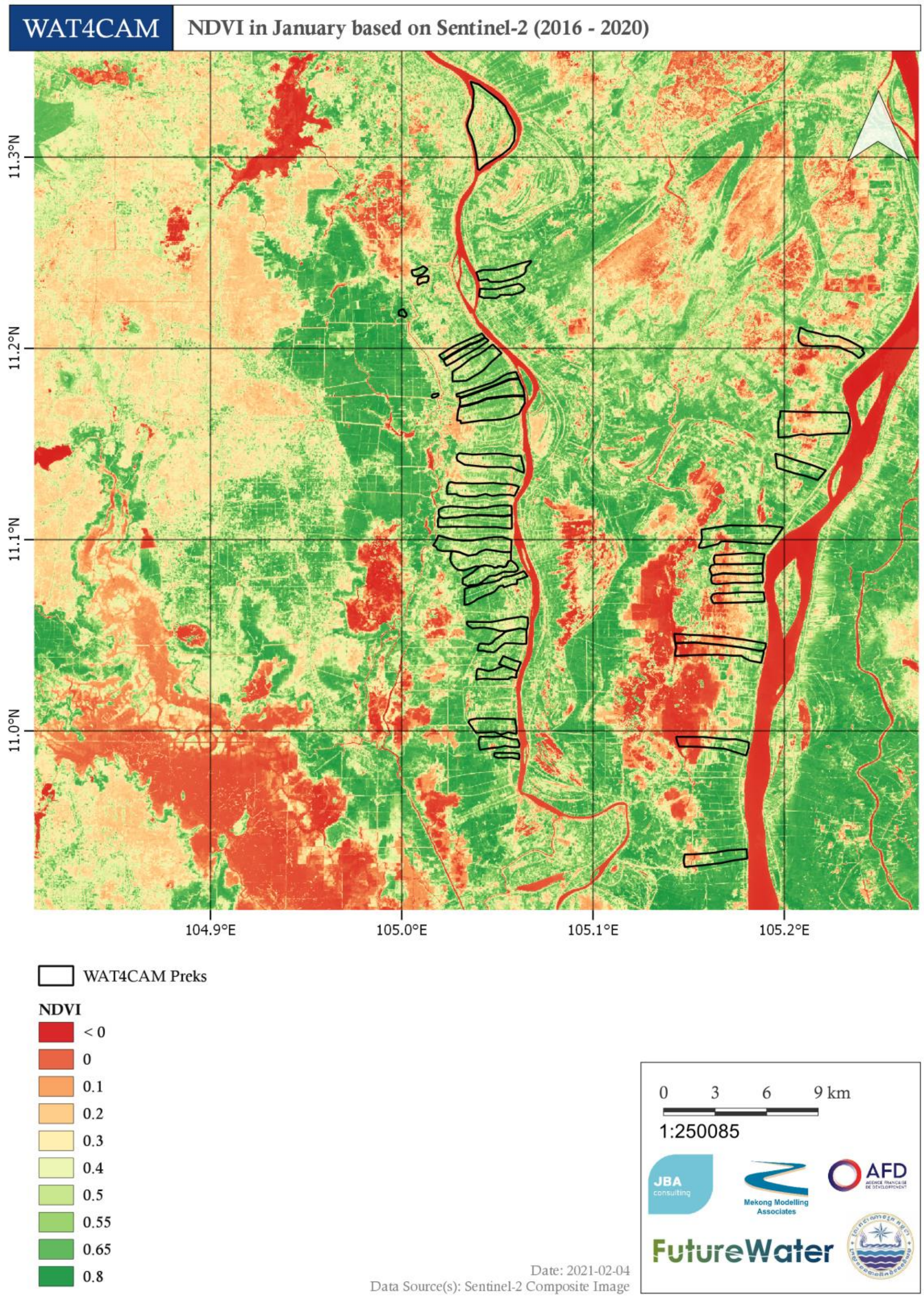


Figure 7-4 NDVI in January, based on median red and near-infrared reflectance values for the full Sentinel-2 time series, filtered for cloud cover (2016-2020).

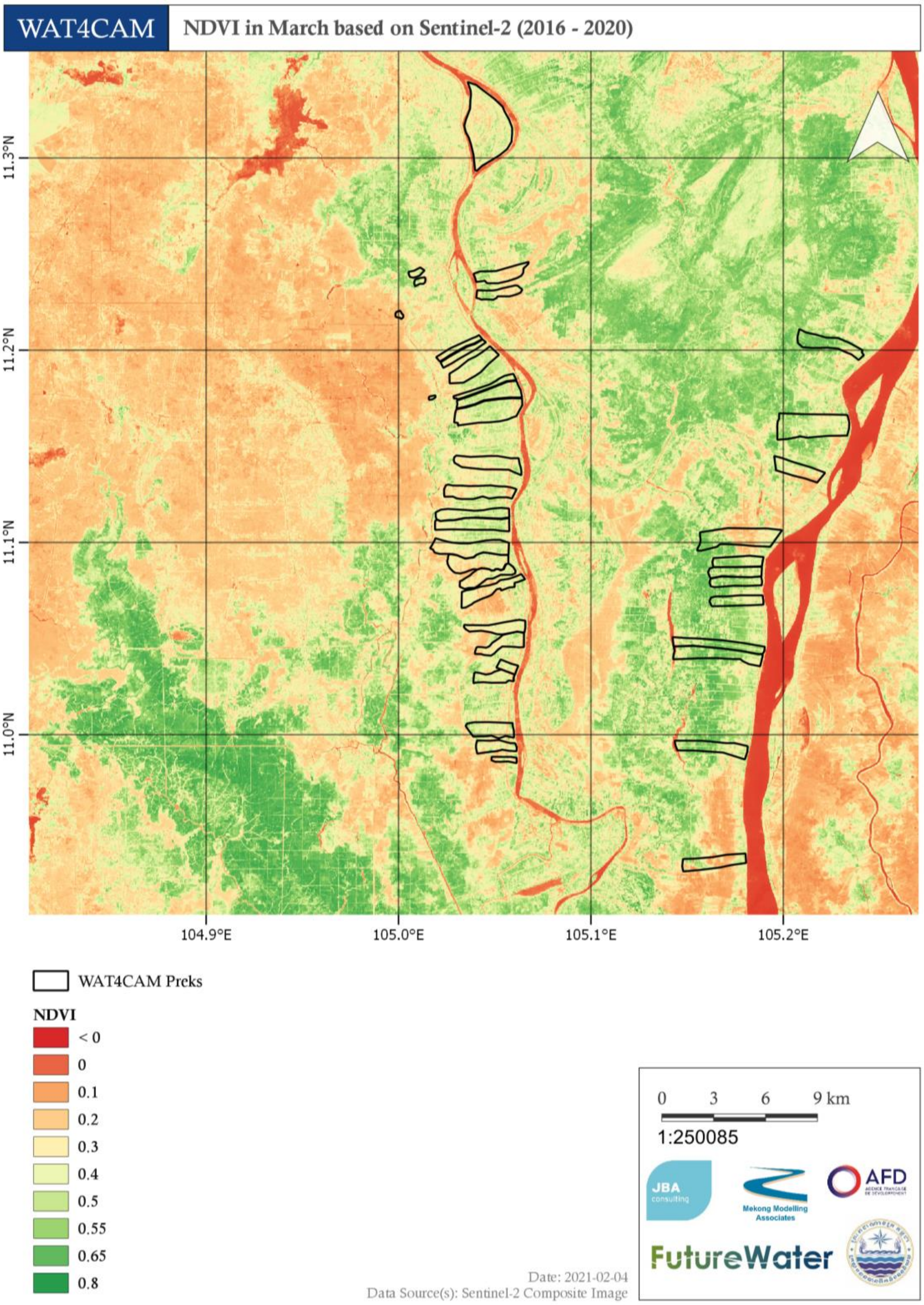


Figure 7-5 NDVI in March, based on median red and near-infrared reflectance values for the full Sentinel-2 time series, filtered for cloud cover (2016-2020).

For evaluation of the prek systems, it is especially important to focus on the chamkar areas supplied by individual preks. A preliminary land cover map of the preks was produced largely based on Sentinel-2-derived NDVI time series, as a foundation for analyses of cropping patterns. The classes were defined as follows:

- **Fruit trees**: all land with an NDVI of >0.43 in the months of March-April 2020, validated based on visual interpretation of high-resolution Google Earth imagery. Erroneously classified natural vegetation areas in the western sections of the Mekong Preks, were omitted based on ESA Climate Change Initiative (CCI) land cover data1;
- **Natural vegetation**: all pixels filtered out in the second step of above procedure;
- **Open water**: all pixels with an NDVI value of <0.1 based on median red and near-infrared reflectance values for the full Sentinel-2 time series. This resulted in some urban area being classified as water, which was corrected based on the ESA-CCI urban class;
- **Urban / built-up area**: all land with an NDVI value of <0.21 and > 0.1, based on median red and near-infrared reflectance values for the full Sentinel-2 time series. This resulted in some flooded vegetation area being classified as urban/built-up, which was corrected based on the ESA-CCI flooded vegetation class;
- **Cropland (vegetables and rice)**: all land not classified under the above categories.

It is out of scope of this assignment to perform an in-depth land use / land cover classification with corresponding validation efforts. However, visual interpretation of the resulting map (10m resolution) shows that it is of sufficient quality for the objective of this study. Impressions of the land cover classification are provided in Figure 7-6-Figure 7-8.

1 https://maps.elie.ucl.ac.be/CCI/viewer

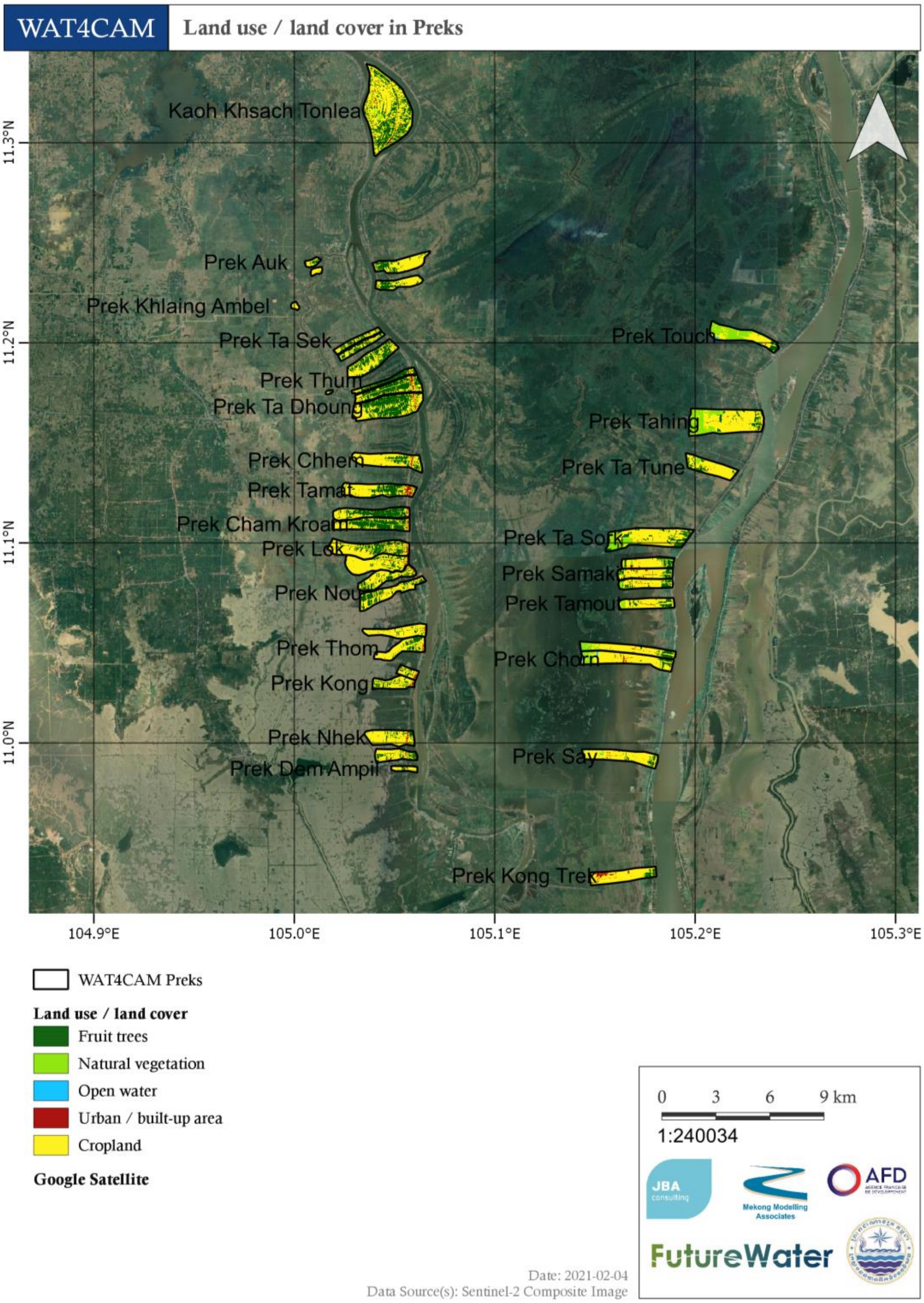


Figure 7-6 Land use / land cover classification (2020) of Prek systems included in WAT4CAM.

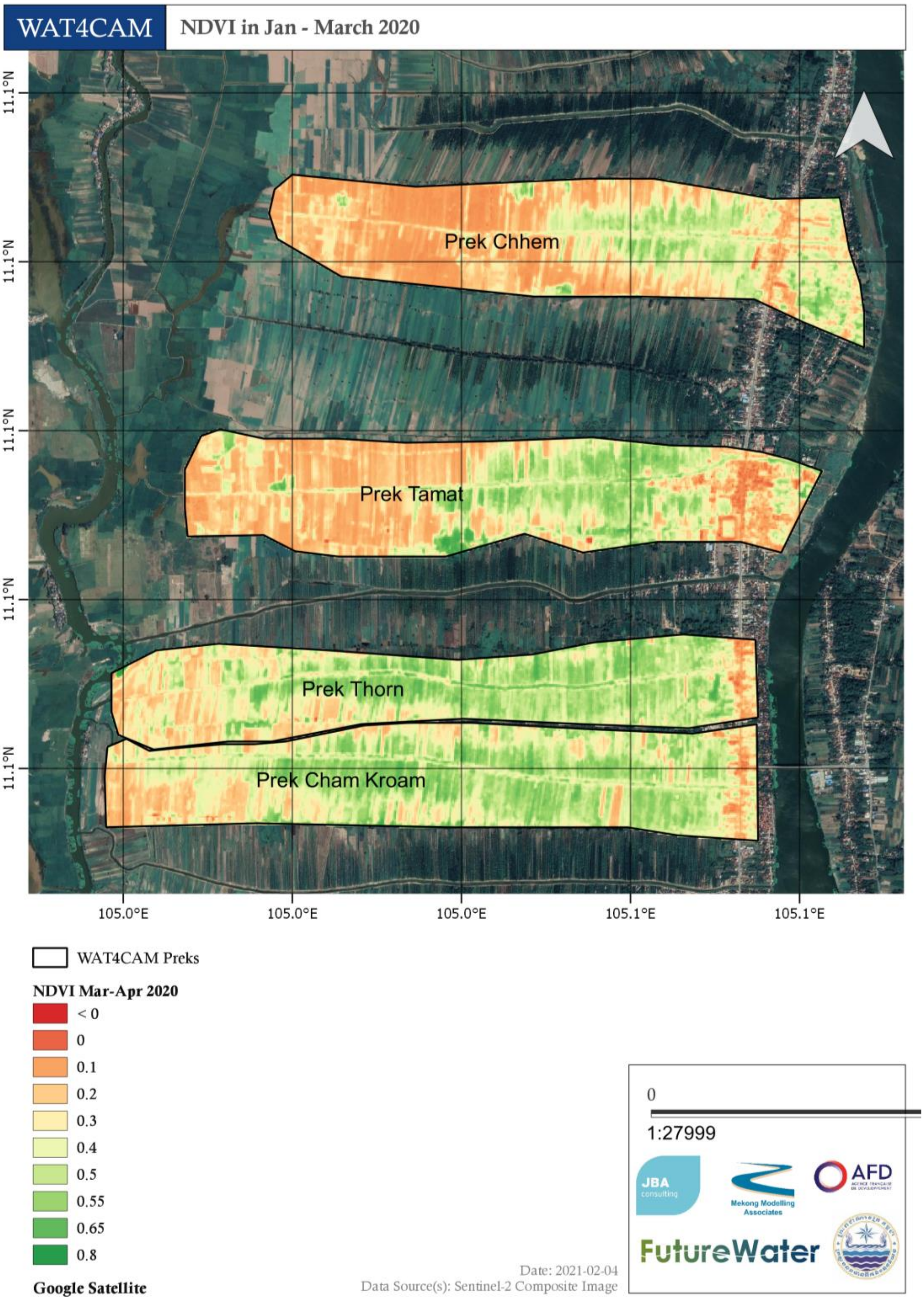


Figure 7-7 NDVI in March-April 2020 for selected Prek systems on the western bank of Bassac River.

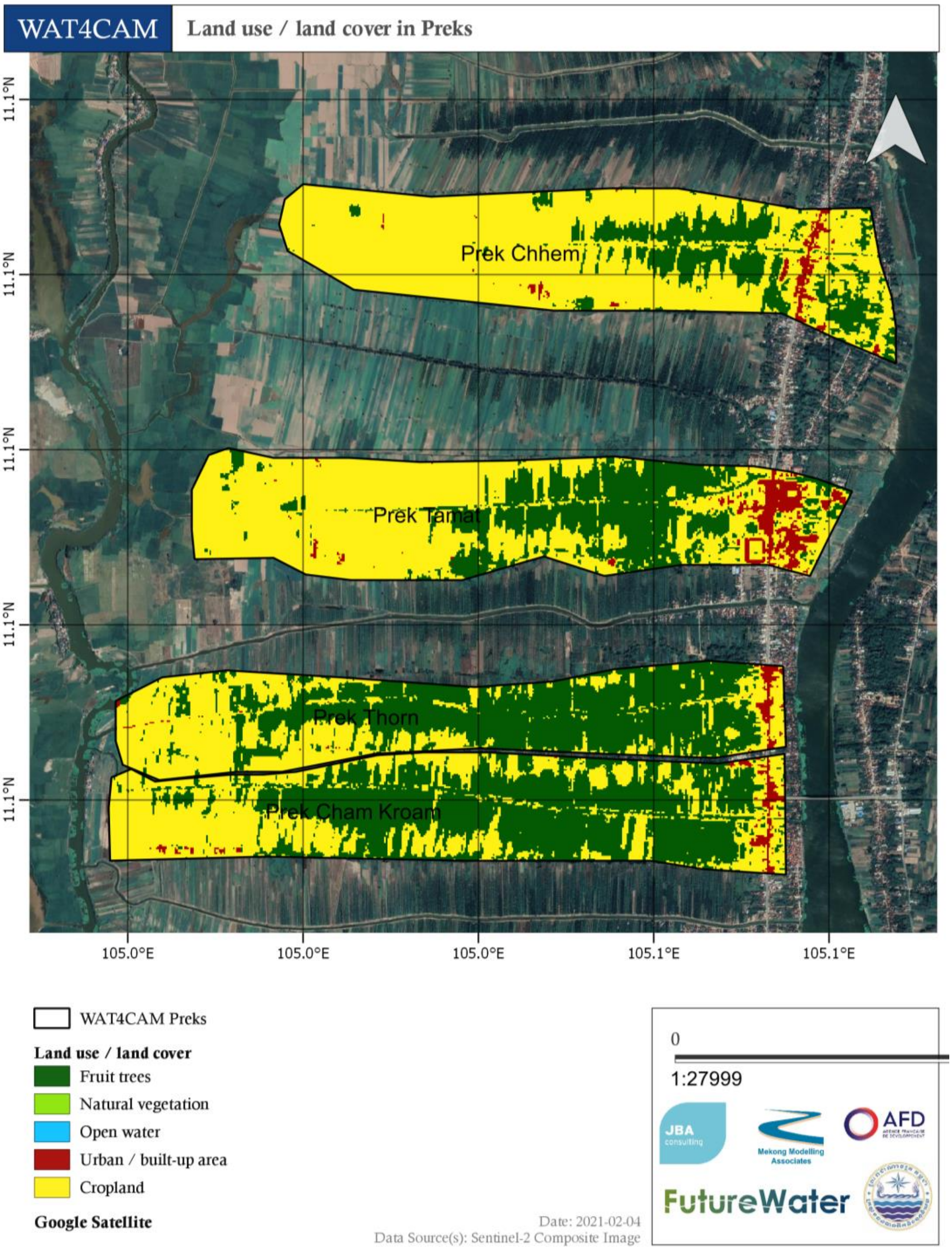


Figure 7-8 Land use / land cover classification (2020) of selected Prek systems on the western bank of Bassac River.

Table 7.1 and Figure 7-9 give an overview of land use / land cover in 2020 in the WAT4CAM prek systems. Overall, approximately two-thirds of the Chamkar areas are covered with vegetables or rice, with 26% of the surface area occupied by fruit trees. There is, however, quite some variability among the individual preks. Interestingly, fruit tree (mostly mango) cultivation has overtaken other crops in terms of surface area particularly in the middle-section preks of the Bassac. In the Mekong preks, other crops prevail and sections of natural vegetation are located at the western ends of the defined areas. In addition, some minor-scale water storage sites are present in several of the Mekong Preks, whereas these are negligible in the Bassac.

Table 7.1 Land use / land cover for each Prek, listed in upstream-downstream order.

Prek Name	*Area (ha)*										Total	River
	Fruit trees		**Natural vegetation**		**Open water**		**Urban / built-up**		**Cropland**			
Kaoh Khsach Tonlea	316	36%	9	1%	0	0%	27	3%	515	59%	867	Bassac
Prek Maen	52	26%	0	0%	0	0%	2	1%	146	73%	200	Bassac
Prek Haong	38	30%	0	0%	0	0%	1	1%	88	69%	127	Bassac
Prek Auk	11	36%	0	0%	0	0%	0	0%	20	64%	31	Bassac
Prek Duch	2	8%	0	0%	0	0%	0	1%	20	92%	22	Bassac
Prek Khlaing Ambel	0	0%	0	0%	0	0%	0	2%	14	98%	15	Bassac
Prek Ta Sek	32	37%	0	0%	0	0%	1	1%	53	62%	86	Bassac
Prek Chhouy	41	42%	0	0%	0	0%	1	1%	57	57%	99	Bassac
Prek Louk	114	44%	0	0%	0	0%	3	1%	139	54%	256	Bassac
Prek Yeay Sok	1	17%	0	0%	0	0%	0	5%	5	77%	7	Bassac
Prek Thum	62	66%	0	0%	0	0%	2	3%	29	31%	94	Bassac
Prek Bak	140	57%	0	0%	0	0%	9	4%	97	39%	246	Bassac
Prek Ta Dhoung	223	53%	0	0%	0	0%	12	3%	190	45%	424	Bassac
Prek Chhem	51	19%	0	0%	0	0%	6	2%	216	79%	273	Bassac
Prek Tamat	83	30%	0	0%	0	0%	15	5%	181	65%	279	Bassac
Prek Thorn	126	56%	0	0%	0	0%	4	2%	96	43%	226	Bassac
Prek Cham Kroam	147	55%	0	0%	0	0%	5	2%	117	44%	268	Bassac
Prek Lok	95	28%	0	0%	0	0%	5	1%	240	71%	339	Bassac
Prek Pok	39	13%	0	0%	0	0%	6	2%	251	85%	297	Bassac
Prek Horm	55	29%	0	0%	0	0%	5	3%	131	69%	191	Bassac
Prek Nou	70	31%	0	0%	0	0%	4	2%	150	67%	224	Bassac
Prek Touch	12	7%	0	0%	0	0%	3	2%	166	91%	181	Bassac
Prek Thom	38	21%	0	0%	0	0%	5	3%	140	76%	183	Bassac
Prek Koh Teav	13	21%	0	0%	0	0%	3	5%	43	73%	59	Bassac
Prek Kong	33	25%	0	0%	0	0%	3	3%	97	73%	133	Bassac
Prek Nhek	27	13%	0	0%	0	0%	5	2%	181	85%	213	Bassac
Prek Ross	34	25%	0	0%	0	0%	5	4%	98	72%	137	Bassac
Prek Dem Ampil	5	13%	0	0%	0	0%	1	2%	35	85%	41	Bassac
Prek Touch	18	7%	126	49%	5	2%	1	0%	107	42%	258	Mekong
Prek Tahing	46	9%	153	28%	0	0%	4	1%	337	62%	541	Mekong
Prek Ta Tune	29	14%	9	4%	0	0%	2	1%	166	81%	206	Mekong
Prek Ta Sork	87	20%	67	15%	1	0%	2	0%	284	64%	441	Mekong
Prek Thmei	37	22%	3	2%	0	0%	5	3%	123	74%	168	Mekong
Prek Samaki	35	20%	0	0%	0	0%	9	5%	129	75%	173	Mekong
Prek Banteay	34	22%	12	8%	0	0%	2	1%	109	70%	156	Mekong
Prek Tamout	31	18%	13	8%	0	0%	3	2%	125	73%	172	Mekong
Prek Top	29	12%	33	13%	5	2%	4	2%	177	72%	247	Mekong
Prek Chorn	24	7%	35	11%	10	3%	8	2%	249	76%	326	Mekong
Prek Say	21	8%	6	2%	5	2%	4	2%	221	86%	256	Mekong
Prek Kong Trek	18	8%	2	1%	0	0%	19	8%	200	84%	239	Mekong
Total	**2268**	**26%**	**467**	**5%**	**26**	**0%**	**196**	**2%**	**5743**	**66%**	**8701**	

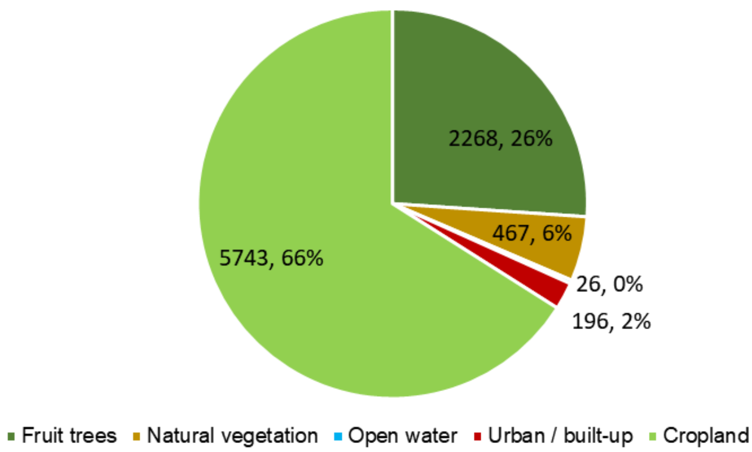


Figure 7-9 Portion of total land surface area covered by each land use / land cover class, in hectares and % of overall area.

To support identification of preks in need of rehabilitation, the agricultural area left fallow in the latter part of the dry season is an important indicator of water supply. Figure 7-10 and Figure 7-11 show the extents of fallow agricultural land to total cropland, respectively for Preks along the Bassac and Mekong Rivers. Both in terms of absolute (187 ha) and relative (36%) portions of cropland left fallow, Kaoh Khsach Tonlea ranks highest among the Bassac Preks. Other preks with substantial fallow acreages are Preks Pok (95 ha), Ta Dhoung (54 ha), Chhem (47 ha), Nou (45 ha), and Lok (44 ha). In terms of percentages, Prek Khlaing Ambel ranks highes with over half (53%) of its cropland left fallow in recent dry seasons. In the Mekong preks (Figure 7-11), relative portions of fallow agricultural land are overall lower than in the Bassac systems. However, especially Prek Ta Sork ranks high in terms of both absolute and relative area of non-cultivated land in the dry season.

It should be noted that water deficiencies experienced in the preks are not just a consequence of conditions of the main canal, as they also reflect farmers' access to alternative water sources (e.g. groundwater and pumping from the main river).

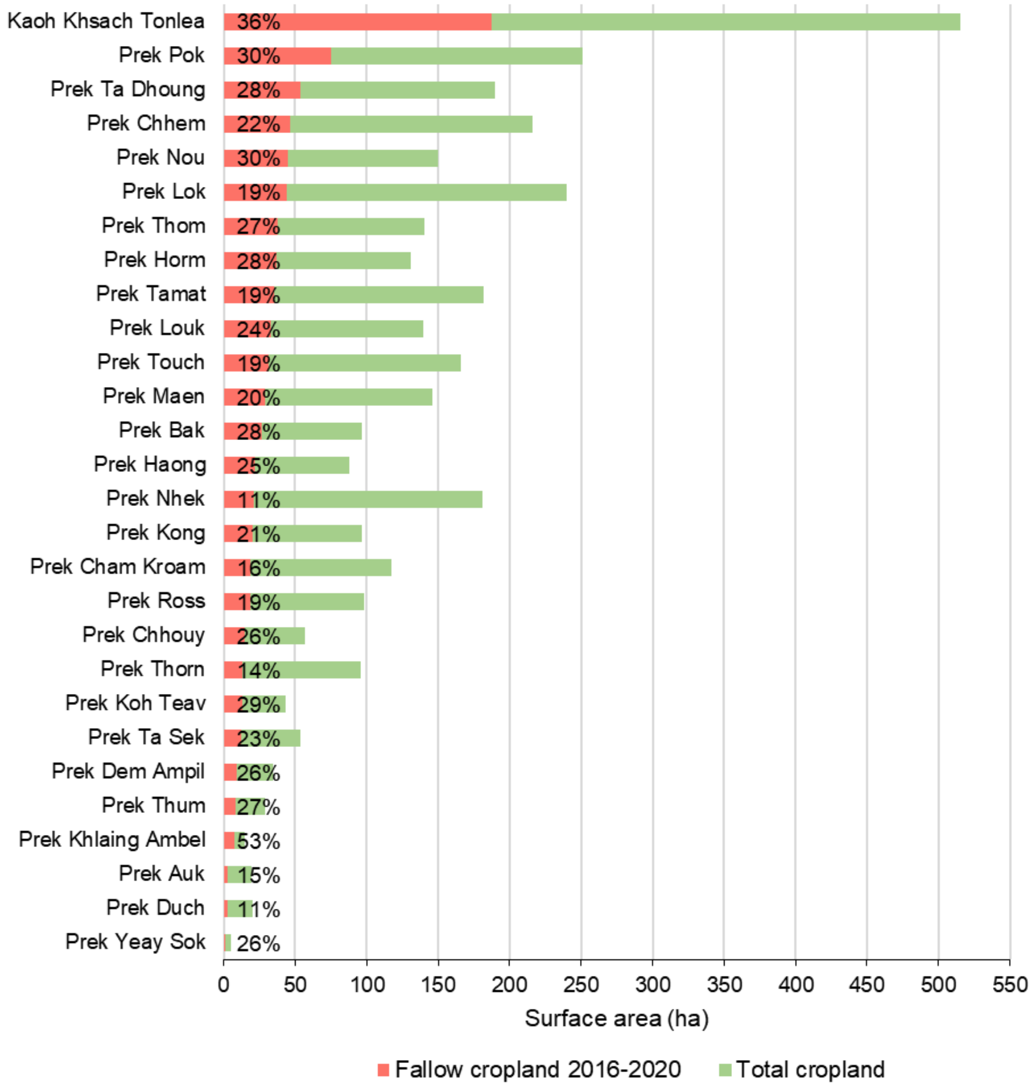


Figure 7-10 Area of cropland left fallow in the months February – April on average in years 2016 – 2020 (Bassac River). Preks are ranked based on absolute surface area left fallow. Percentages indicate fallow area relative to total cropland.

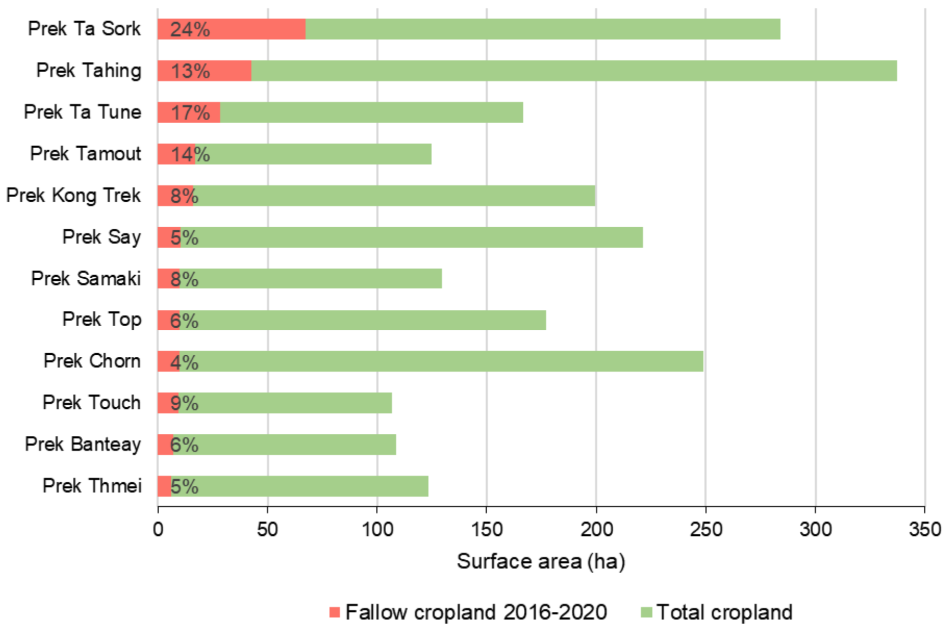


Figure 7-11 Area of cropland left fallow in the months February – April on average in years 2016 – 2020 (Mekong River). Preks are ranked based on absolute surface area left fallow. Percentages indicate fallow area relative to total cropland.

7.3.2 Water use

To provide an overview of consumptive water use in the vicinity of the preks during the low-flow season, the available ET_{act} map series was aggregated for the February-April months for each of the years 2003 – 2014 and averaged (Figure 7-12). A similar spatial pattern as Figure 7-5 can be observed, with evapotranspiration within the Preks being higher than in the western paddy areas, which lie fallow during this period.

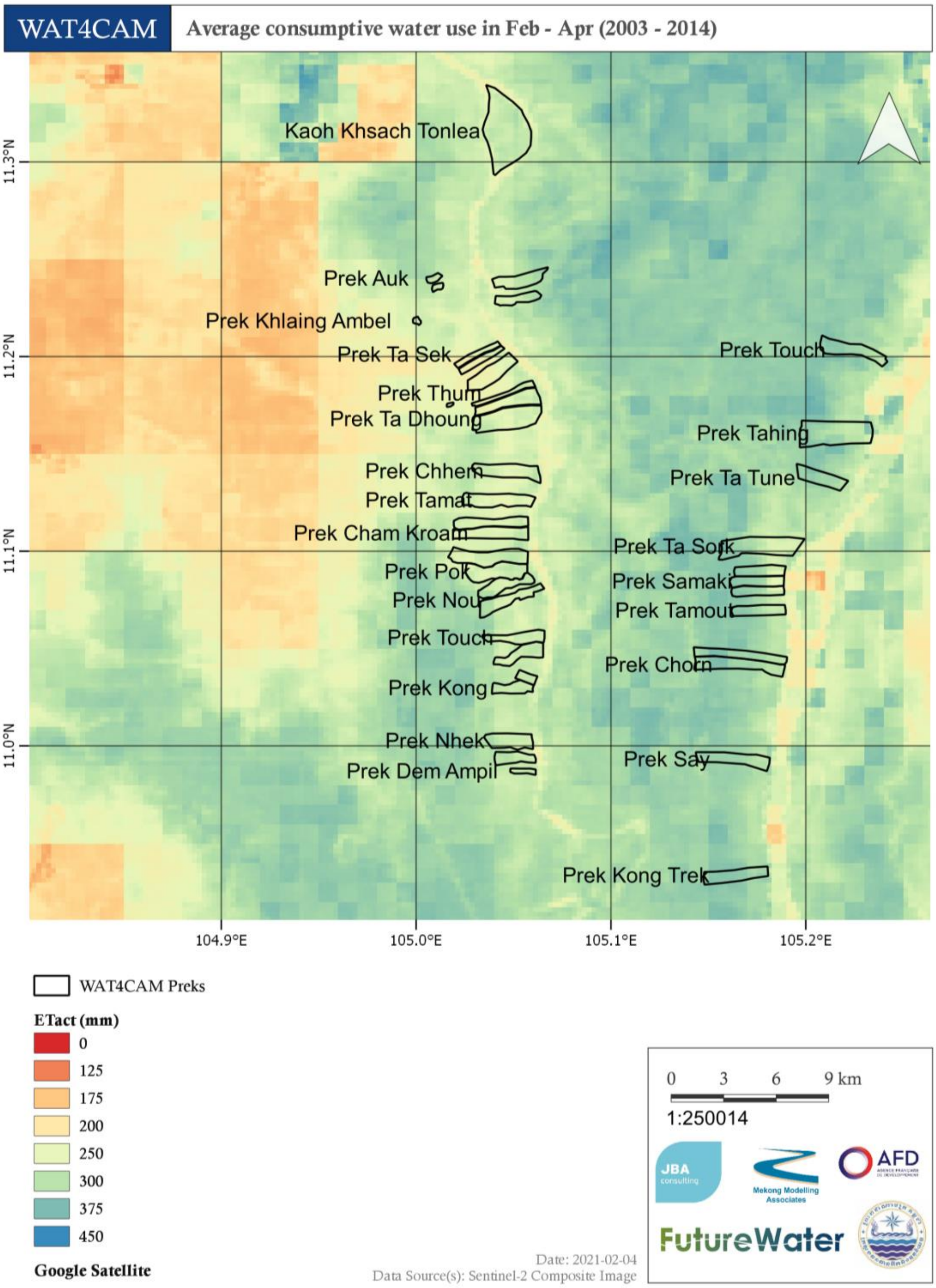


Figure 7-12 Actual evapotranspiration in the months February – April, averaged for the 2003 – 2014 period.

Figure 7-13 presents ET_{act} totals for the WAT4CAM preks in the dry season months, for each of the years 2003 – 2014. Interestingly, an upwards trend seems to be present over this period, which could be explained by shifts in timing of the preceding wet season as well as (related) changes in land use and cropping patterns. Ongoing siltation due to fertile sediments provided from the preks can also lead to a long-term increase of cropped area during the dry season, due to increased elevation of the land. However, this can only be possible if sufficient water for irrigation is available.

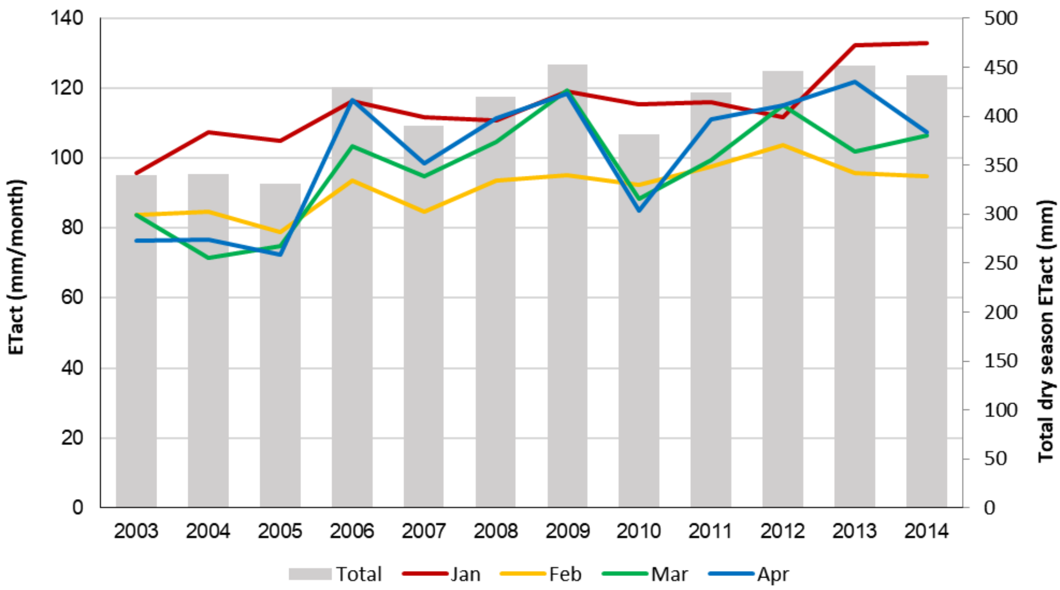


Figure 7-13 Average water consumption (ET_{act}) per month, as well as dry season totals, in the WAT4CAM preks during 2003 – 2014.

In the prek systems of Cambodia, dry-season water availability and water consumption by crops on the long term are closely interrelated, as crop type and cropping calendar choices are restricted by water availability. It is therefore assumed that preks with relatively low ET_{act} in the dry season during the 12-year period of analysis are structurally deprived of water, compared to areas with higher consumptive water use. Average monthly ET_{act} is listed for each of the preks in Table 7.2. Generally, the lowest values are found in the upper and particularly middle preks along Bassac River. Water consumption in preks further downstream is at the high end of the range of ET_{act} values, not only in January but also in later months as the impact of relatively high-water supply directly after the flood season carries on into the drier months. In the Mekong preks, water use (and thus water availability) is clearly higher than in the Bassac preks during the driest months of the year.

Table 7.2 Average water consumption (ETact) during the dry season, for each Prek (2003 – 2014). Colour scales are defined per month, with red indicating Preks with the lowest water use and blue the highest water use. Preks are listed in upstream-downstream sequence per river system.

River	Prek	Area	ETact							
			Jan		Feb		Mar		Apr	
		ha	MCM	mm	MCM	mm	MCM	mm	MCM	mm
Bassac	Kaoh Khsach Tonlea	867	0.91	104.6	0.70	80.3	0.81	93.4	0.95	109.9
	Prek Maen	200	0.23	113.5	0.19	94.6	0.19	96.7	0.20	100.7
	Prek Haong	127	0.15	114.6	0.11	90.5	0.12	94.2	0.13	102.4
	Prek Auk	31	0.03	108.7	0.03	94.2	0.03	100.6	0.03	99.6
	Prek Duch	22	0.02	103.0	0.02	89.5	0.02	94.0	0.02	100.1
	Prek Khlaing Ambel	15	0.02	125.4	0.01	94.7	0.01	83.9	0.01	87.3
	Prek Ta Sek	86	0.09	102.9	0.07	76.7	0.07	80.2	0.08	87.8
	Prek Chhouy	99	0.10	103.9	0.08	77.3	0.08	79.0	0.08	84.7
	Prek Louk	256	0.27	106.4	0.21	81.8	0.21	80.3	0.21	80.0
	Prek Yeay Sok	7	0.01	110.6	0.01	85.8	0.01	81.4	0.01	81.1
	Prek Thum	94	0.10	107.1	0.08	81.6	0.08	82.4	0.09	91.8
	Prek Bak	246	0.26	104.4	0.20	81.0	0.21	85.3	0.23	92.7
	Prek Ta Dhoung	424	0.42	99.2	0.36	84.2	0.39	91.1	0.39	91.5
	Prek Chhem	273	0.29	107.5	0.24	87.7	0.24	88.5	0.25	92.7
	Prek Tamat	279	0.31	110.3	0.25	88.1	0.23	84.1	0.24	87.3
	Prek Thorn	226	0.26	117.3	0.20	90.2	0.20	87.9	0.20	87.2
	Prek Cham Kroam	268	0.31	117.2	0.24	90.1	0.23	87.2	0.24	88.6
	Prek Lok	339	0.41	120.7	0.31	92.4	0.31	90.1	0.31	92.3
	Prek Pok	297	0.36	120.2	0.27	90.1	0.27	89.7	0.28	93.4
	Prek Horm	191	0.24	123.7	0.17	91.1	0.18	93.2	0.18	96.0
	Prek Nou	224	0.28	124.4	0.21	92.4	0.21	95.6	0.22	96.8
	Prek Touch	181	0.23	124.9	0.17	95.4	0.17	93.2	0.16	89.1
	Prek Thom	183	0.22	122.3	0.17	94.2	0.17	92.3	0.17	95.1
	Prek Koh Teav	59	0.07	120.5	0.05	90.5	0.05	93.3	0.06	101.2
	Prek Kong	133	0.17	125.8	0.13	94.7	0.13	94.4	0.13	97.2
	Prek Nhek	213	0.26	123.5	0.20	94.3	0.20	92.1	0.21	97.5
	Prek Ross	137	0.16	120.1	0.13	96.7	0.14	99.9	0.13	94.2
	Prek Dem Ampil	41	0.05	121.1	0.04	91.5	0.04	94.0	0.04	98.0
	Total (Bassac)	**5519**	**6.23**	**112.9**	**4.84**	**87.8**	**4.98**	**90.3**	**5.25**	**95.1**
Mekong	Prek Touch	258	0.3	117.5	0.25	97.6	0.3	113.8	0.3	116.8
	Prek Tahing	541	0.6	113.0	0.53	97.4	0.6	105.8	0.6	113.7
	Prek Ta Tune	206	0.2	115.5	0.21	101.3	0.2	115.3	0.2	110.6
	Prek Ta Sork	441	0.5	123.4	0.41	93.2	0.4	99.1	0.5	105.2
	Prek Thmei	168	0.2	109.9	0.16	96.7	0.2	104.2	0.2	107.3
	Prek Samaki	173	0.2	105.7	0.17	98.4	0.2	103.2	0.2	108.5
	Prek Banteay	156	0.2	113.3	0.15	99.2	0.2	106.3	0.2	107.4
	Prek Tamout	172	0.2	116.9	0.17	96.5	0.2	108.1	0.2	108.1
	Prek Top	247	0.3	123.0	0.24	99.0	0.3	112.2	0.3	115.9
	Prek Chorn	326	0.4	121.6	0.32	99.0	0.4	110.6	0.4	114.5
	Prek Say	256	0.3	117.8	0.24	95.4	0.3	112.6	0.3	110.5
	Prek Kong Trek	239	0.3	122.2	0.26	110.7	0.3	117.1	0.3	111.6
	Total (Mekong)	**3182**	**3.73**	**117.4**	**3.13**	**98.3**	**3.45**	**108.4**	**3.54**	**111.2**

7.4 Modelling the Tidal Condition

Appreciating the importance of tidal flows and water level variation in the dry season, The modelling has been carried out using a fullly hydrodynamic approach. The boundaries were set at the tidal recording stations of Tan Chau and Chau Doc close to the border with Cambodia but within Vietnam recorded every 15 minutes and available through the MRC/CNMC.

Within the study area only the gauges at Chaktomuk, Ankor Borei and Koh Khel provide a high frequency record sufficient to determine tidal levels and unfotunately the Ankor Borei gauge has been unserviceable since a new bridge was built in its location. The model thus provides a means to supplement the gauging records as shown in Figure 7-14.

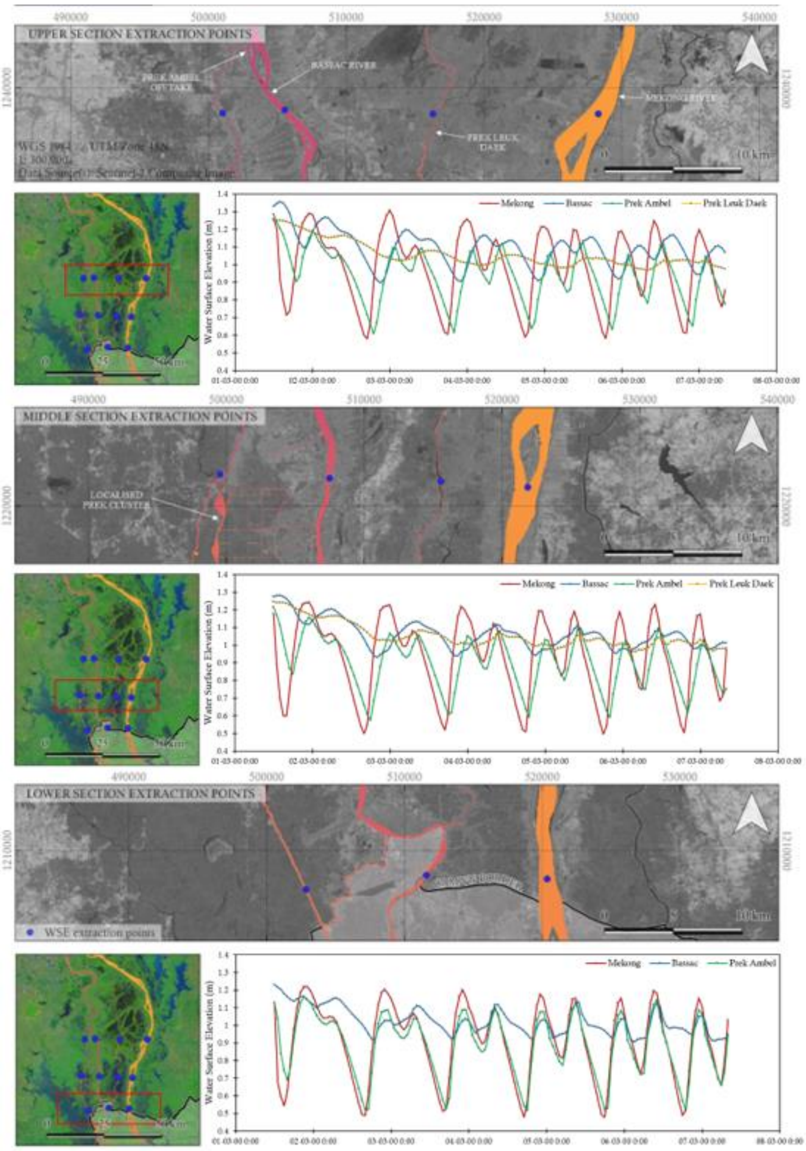


Figure 7-14 Tidal effects on water level seen on different channels at different locations upstream.

7.5 Analysis of Dry Season Water Levels and Flows

Figure 7-15 and Table 7.4 shows the daily discharge and water level of the Mekong at Neak Luong, with 5-year averages for the wet and dry seasons, classified here as June – October and November – May respectively, presented. Although the dry season witnesses some fluctuations in average the wet season is where most disparity is noticed, with changes in consecutive 5-year average discharge ranging from +17.0% to -12.6%, not taking into consideration the 2020 data.

Some indication of upstream dam and climate change impacts can also be seen from the 5-year averages. Since 2000, 5-year averages have consistently decreased in both the dry and wet season, ranging from -2.4% to -12.6%. Although the 2020+ year bracket is limited in data, the wet season flow of the Mekong for 2020 has been the lowest on record with an average of just 8,650 m^3/s. In 2020 the dry season flow was significantly lower than the previous 5-year average at -41.3%.
The interactions of tide and fluvial flow varies with flows such that a mean/median water level has with it a particular tidal range on average. This is illustrated below for the Mekong

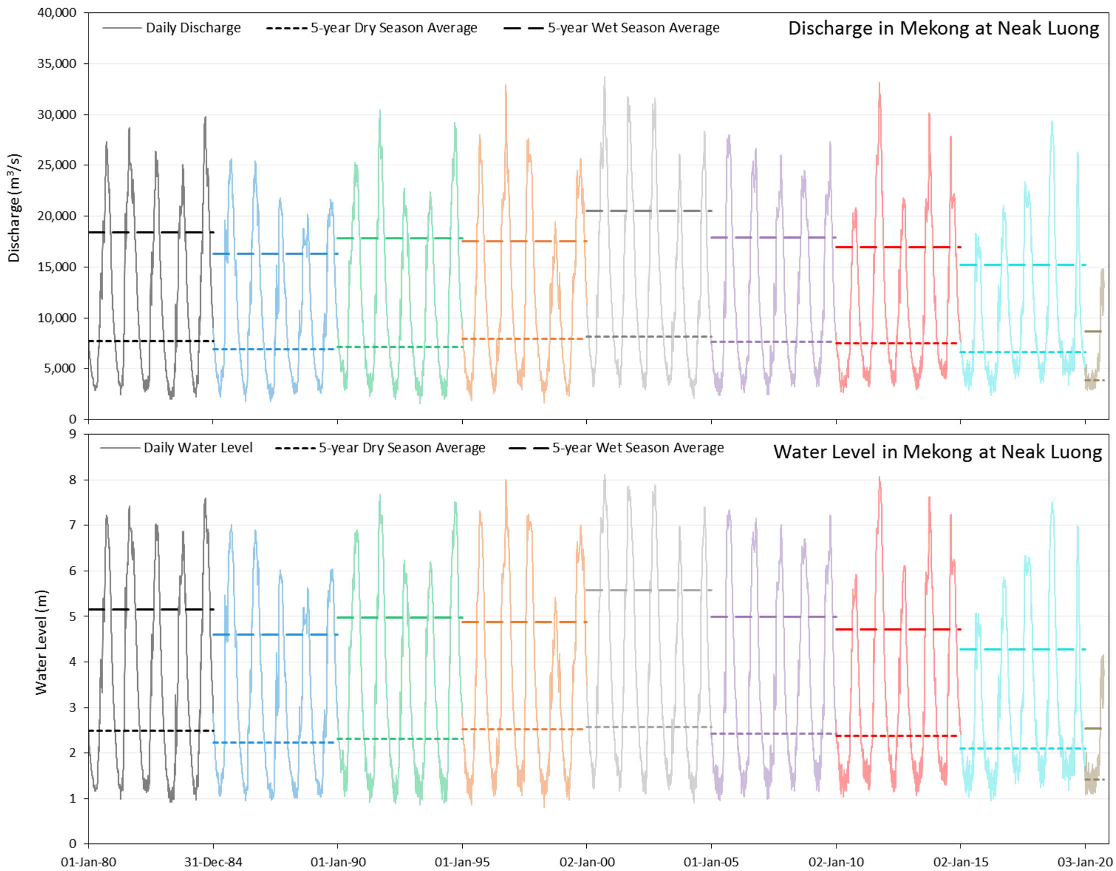


Figure 7-15 Daily discharge and gauged level at Neak Luong from 1980 – Present. 5-year averages for the wet season (June – October) and dry season (November – May) are calculated. Source of raw data MRC, Consultant analysis.

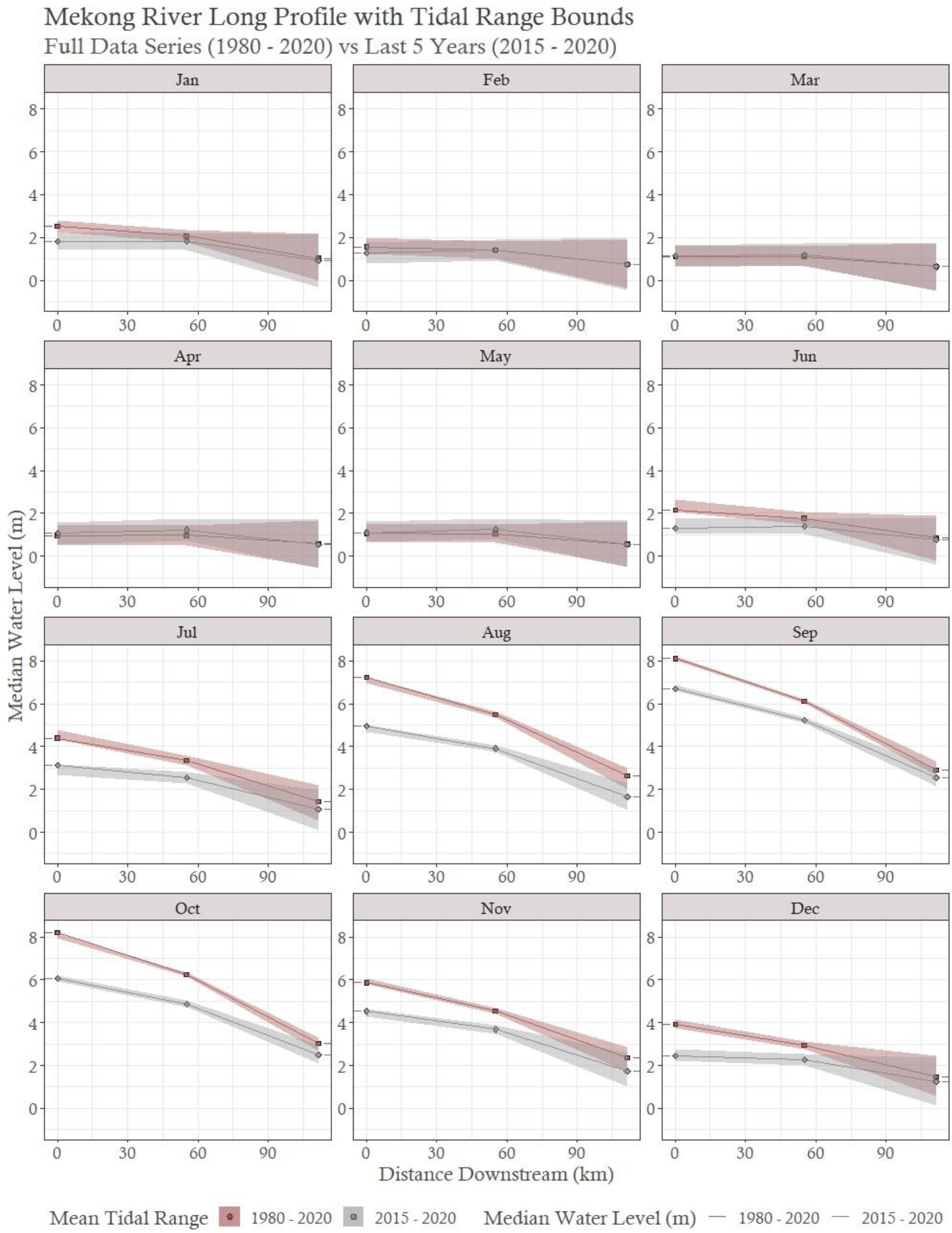


Figure 7-16 Changes in median water level and tidal range for the Mekong.

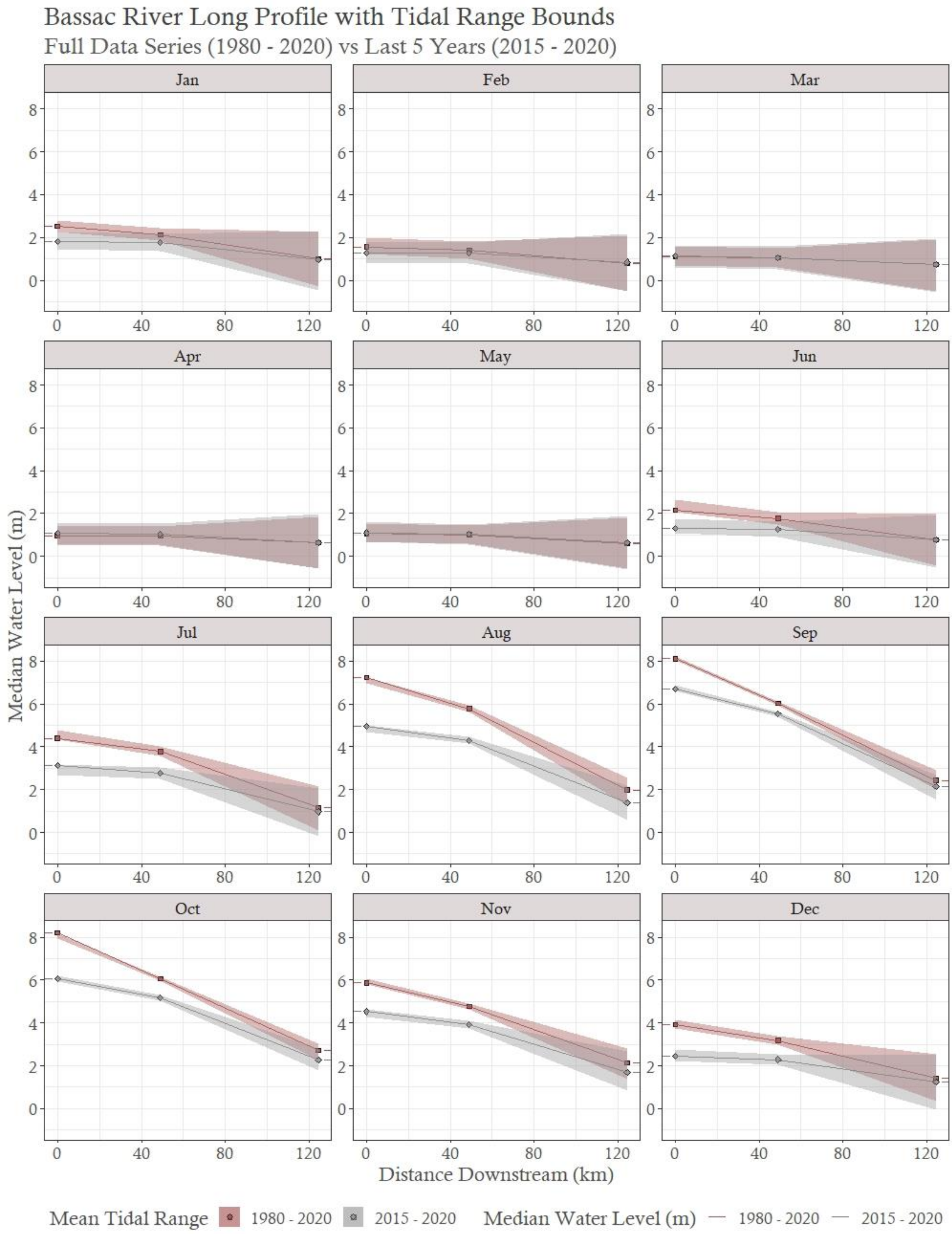


Figure 7-17 Changes in median water level and tidal range for the Bassac

As it was outside the normal range, the 2020 dry season average flow may be understated due to the difficulty of estimating the low flows using rating curves. However, even when discounting the 2020+ data the next lowest average discharge and water level occurred in the 5-year period prior, from 2015 – 2020. It therefore seems certain that the future regime will be different to the past and this must be taken account of in the analysis.

During the observation period from 1980 to 2020, the flow at Bassac Chaktomuk varied between 3.3 m^3/s in low flow period to 6692m^3/s in high flow period with average of 1528 m^3/s. The long-term trend showed that the magnitude of river flow is decreasing (Figure 7-18). It was observed that the flow in 2020 is the lowest during the whole observation period.

Based on the long-term observation of peak flow in Bassac River at Chaktomuk from 1980 to 2020, the minimum peak flow is accounted for 1615 m^3/s in 2020 while the maximum peak flow reached 6692 m^3/s in 2000. The average peak flow for Bassac is accounted for 4890 m^3/s (Table 7.3).

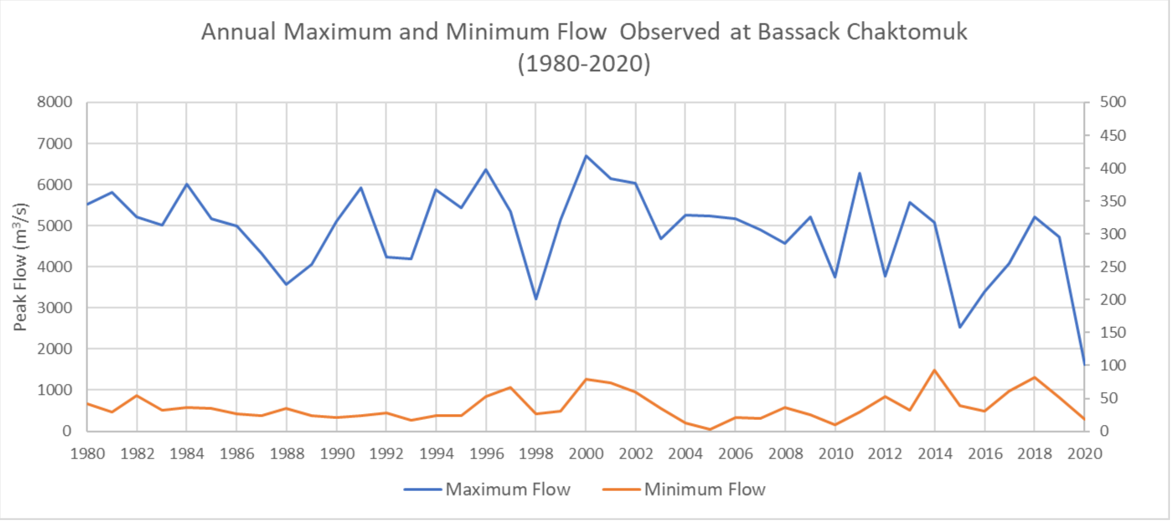


Figure 7-18 Annual maximum and minimum flow of Bassac River at Bassac-Chaktomuk observed from 1982 to 2020. (Note 2020 record incomplete at time of analysis and figure will be updated in final report)

The Flow duration curve for Bassac at Chaktomuk was developed (Figure 7-19). It showed that about 10% of flow are higher than 4000 m^3/s but for over 50% of the time flows are below 100m^3/s and likely to be a constraint on diversion of flow from the Bassac compared with the Mekong which has over 1000m^3/s reliably in the dry season.

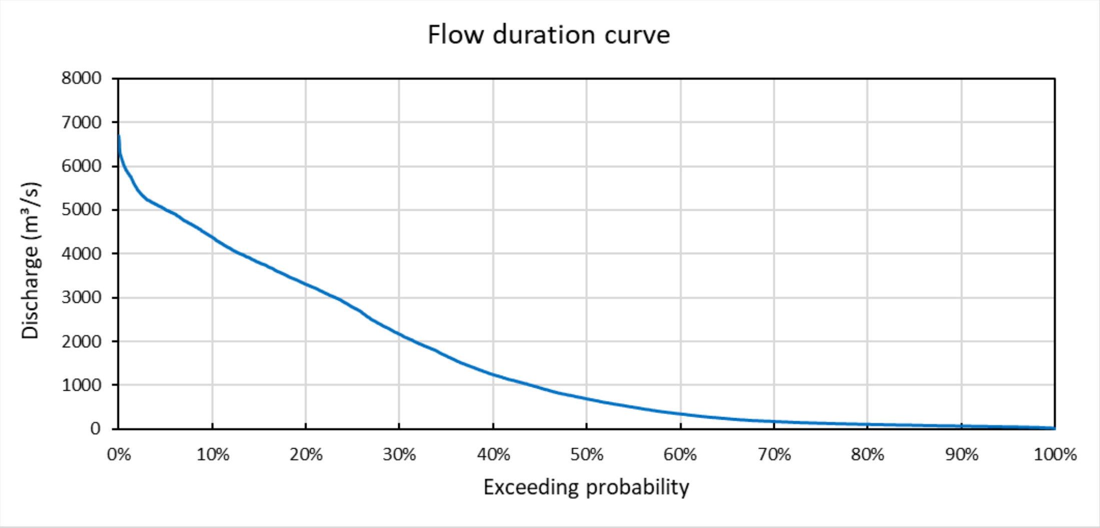


Figure 7-19 Flow duration curve of Bassac River at Bassac-Chaktomuk observed from 1982 to 2020

Table 7.3 Annual maximum and minimum river flow at Bassac-Chaktomuk observed from 1982 to 2020 (Source of raw data MRC, Consultant analysis of rating curves and statistics)

Year	Maximum Flow (m3/s)	Minimum Flow (m3/s)
1980	5524	42
1981	5821	30
1982	5224	54
1983	5006	32
1984	6007	36
1985	5169	34
1986	4984	27
1987	4328	23
1988	3583	34
1989	4059	23
1990	5092	20
1991	5925	24
1992	4247	28
1993	4187	17
1994	5891	24
1995	5446	23
1996	6376	53
1997	5345	67
1998	3221	27
1999	5158	31
2000	6692	79
2001	6149	73
2002	6031	59
2003	4677	34
2004	5257	13
2005	5235	3

Year	Maximum Flow (m3/s)	Minimum Flow (m3/s)
2006	5180	21
2007	4899	20
2008	4562	36
2009	5213	25
2010	3742	9
2011	6280	29
2012	3779	52
2013	5572	32
2014	5079	93
2015	2520	38
2016	3390	31
2017	4080	61
2018	5217	81
2019	4724	51
2020	1615*	18
Min	1615	3
Mean	4890	37
Max	6692	93

*from data up to October

Table 7.4 5-year average calculations for dry and wet season discharges at Neak Luong, Mekong River, with seasonal variations represented. Source Consultant analysis of MRC data

Year Bracket	Dry Season Average Discharge (m^3/s)	Wet Season Average Discharge (m^3/s)	Wet and Dry Season Difference (m^3/s)	% decrease since previous 5-year avg (Dry)	% decrease since previous 5-year avg (Wet)
1980 - 1985	7,708	18,422	10,714	-	-
1985 - 1990	6,876	16,260	9,384	-10.80	-11.74
1990 - 1995	7,112	17,806	10,694	3.43	9.51
1995 - 2000	7,910	17,502	9,592	11.23	-1.70
2000 - 2005	8,138	20,480	12,342	2.88	17.01
2005 - 2010	7,636	17,902	10,266	-6.17	-12.59
2010 - 2015	7,457	16,972	9,516	-2.35	-5.20
2015 - 2020	6,591	15,171	8,579	-11.61	-10.61
2020+	3,866	8,647	4,781	-41.34	-43.00
Average	7,033	16,574	9,541	-	-

In reality, the flows in the main Mekong river far exceeds the requirement for diversion in Cambodia (see section 7.3.2) and the main issue is the water level. Flow rates in the Bassac are more limited but through the network of interconnected tidal channels, water can be obtained at a low level limited by the channel bed and the demands of other users.

7.6 Estimation of expected water levels

The scope of the project calls for a tabulation of expected water levels at each Prek, throughout the year. Water levels, as has been highlighted earlier depend on a rapidly changing flow regime from upstream and the changing tidal regime from downstream.

The tidal range varies with distance along the river and with the fluvial flow, but the minimum level expected can be defined through analysis of the data and intelligent interpolation between gauge sites for the Mekong and the Bassac as tabulated below for median values and 20th percentile (Table 7.5). The tables show the expected water levels using the full record and analysis of the most recent 5 years only which would be recommended for future use.

The lower water levels in the Mekong and Bassac in the past five years exhibit severe change from September to January (-2.27m in September, -1.2m in December) which severely restricts the ability of the Preks to divert water. The rehabilitation work must take this loss of level/flow into account even if the absolute minima of the year in April and May do not decrease, as many of the Preks are already dry in December.

Month	Median Water Level (m)								
	Chaktomuk			*Koh Khel*			*Neak Luong*		
	1980 - 2020	*2015 - 2020*	*Change*	*1991 - 2020*	*2015 - 2020*	*Change*	*1980 - 2020*	*2015 - 2020*	*Change*
Jan	2.49	1.83	↓-0.67	2.09	1.74	↓-0.36	2.05	1.79	↓-0.26
Feb	1.60	1.27	↓-0.34	1.40	1.24	↓-0.16	1.45	1.36	↓-0.09
Mar	1.13	1.12	↓-0.01	1.08	1.07	↓-0.01	1.12	1.18	↑0.06
Apr	0.98	1.07	↑0.09	0.96	1.04	↑0.08	0.99	1.23	↑0.24
May	1.08	1.10	↑0.02	1.03	1.03	↑0.00	1.07	1.25	↑0.18
Jun	2.25	1.45	↓-0.80	1.82	1.43	↓-0.39	1.85	1.51	↓-0.34
Jul	4.40	3.13	↓-1.27	3.69	2.77	↓-0.92	3.29	2.65	↓-0.64
Aug	7.07	4.80	↓-2.27	5.76	4.21	↓-1.55	5.32	3.81	↓-1.51
Sep	8.08	7.33	↓-0.75	6.04	5.94	↓-0.10	6.13	5.75	↓-0.38
Oct	7.96	6.34	↓-1.63	6.00	5.44	↓-0.57	6.08	5.14	↓-0.94
Nov	5.92	4.66	↓-1.26	4.82	4.11	↓-0.71	4.59	3.82	↓-0.77
Dec	3.88	2.68	↓-1.20	3.25	2.51	↓-0.74	3.01	2.39	↓-0.62

The application of this is tabulated in Appendix 3.

Table 7.5 Water Levels along Mekong and Bassac for different months

Month	Median Water Level (m)														
	Chaktomuk			*Koh Khel*			*Neak Luong*			*Chau Doc*			*Tan Chau*		
	1980 - 2020	*2015 - 2020*	*Change*	*1991 - 2020*	*2015 - 2020*	*Change*	*1980 - 2020*	*2015 - 2020*	*Change*	*2007 - 2020*	*2015 - 2020*	*Change*	*2007 - 2020*	*2015 - 2020*	*Change*
Jan	2.49	1.83	↓ -0.67	2.09	1.74	↓ -0.36	2.05	1.79	↓ -0.26	1.01	0.96	↓ -0.05	1.05	0.94	↓ -0.12
Feb	1.60	1.27	↓ -0.34	1.40	1.24	↓ -0.16	1.45	1.36	↓ -0.09	0.77	0.86	↑ 0.09	0.75	0.76	↑ 0.01
Mar	1.13	1.12	↓ -0.01	1.08	1.07	↓ -0.01	1.12	1.18	↑ 0.06	0.70	0.73	↑ 0.04	0.64	0.62	↓ -0.02
Apr	0.98	1.07	↑ 0.09	0.96	1.04	↑ 0.08	0.99	1.23	↑ 0.24	0.62	0.70	↑ 0.07	0.57	0.60	↑ 0.03
May	1.08	1.10	↑ 0.02	1.03	1.03	↑ 0.00	1.07	1.25	↑ 0.18	0.57	0.64	↑ 0.07	0.56	0.55	↓ 0.00
Jun	2.25	1.45	↓ -0.80	1.82	1.43	↓ -0.39	1.85	1.51	↓ -0.34	0.73	0.73	↑ 0.00	0.82	0.75	↓ -0.08
Jul	4.40	3.13	↓ -1.27	3.69	2.77	↓ -0.92	3.29	2.65	↓ -0.64	1.08	0.96	↓ -0.12	1.28	1.00	↓ -0.28
Aug	7.07	4.80	↓ -2.27	5.76	4.21	↓ -1.55	5.32	3.81	↓ -1.51	1.91	1.44	↓ -0.47	2.52	1.68	↓ -0.84
Sep	8.08	7.33	↓ -0.75	6.04	5.94	↓ -0.10	6.13	5.75	↓ -0.38	2.46	2.09	↓ -0.36	2.96	2.64	↓ -0.32
Oct	7.96	6.34	↓ -1.63	6.00	5.44	↓ -0.57	6.08	5.14	↓ -0.94	2.67	2.28	↓ -0.39	3.07	2.51	↓ -0.55
Nov	5.92	4.66	↓ -1.26	4.82	4.11	↓ -0.71	4.59	3.82	↓ -0.77	2.08	1.72	↓ -0.36	2.28	1.80	↓ -0.49
Dec	3.88	2.68	↓ -1.20	3.25	2.51	↓ -0.74	3.01	2.39	↓ -0.62	1.42	1.29	↓ -0.13	1.47	1.27	↓ -0.20

Month	20th Percentile Water Level (m)														
	Chaktomuk			*Koh Khel*			*Neak Luong*			*Chau Doc*			*Tan Chau*		
	1980 - 2020	*2015 - 2020*	*Change*	*1991- 2020*	*2015 - 2020*	*Change*	*1980 - 2020*	*2015 - 2020*	*Change*	*2007- 2020*	*2015 - 2020*	*Change*	*2007 - 2020*	*2015 - 2020*	*Change*
Jan	1.94	1.18	↓ -0.76	1.70	1.13	↓ -0.57	1.74	1.32	↓ -0.42	0.67	0.56	↓ -0.11	0.74	0.57	↓ -0.17
Feb	1.27	1.08	↓ -0.19	1.15	1.01	↓ -0.14	1.25	1.15	↓ -0.10	0.40	0.36	↓ -0.04	0.44	0.31	↓ -0.13
Mar	0.94	0.83	↓ -0.12	0.90	0.79	↓ -0.11	0.95	0.99	↑ 0.04	0.33	0.31	↓ -0.02	0.33	0.25	↓ -0.08
Apr	0.80	0.86	↑ 0.06	0.79	0.78	↓ -0.01	0.83	0.99	↑ 0.16	0.31	0.29	↓ -0.02	0.30	0.28	↓ -0.02
May	0.84	0.81	↓ -0.03	0.81	0.75	↓ -0.06	0.87	0.98	↑ 0.11	0.26	0.25	↓ -0.01	0.27	0.22	↓ -0.05
Jun	1.42	1.06	↓ -0.36	1.24	1.03	↓ -0.21	1.29	1.18	↓ -0.11	0.37	0.25	↓ -0.13	0.40	0.26	↓ -0.14
Jul	3.18	1.37	↓ -1.81	2.66	1.41	↓ -1.25	2.44	1.48	↓ -0.96	0.66	0.40	↓ -0.26	0.76	0.48	↓ -0.27
Aug	5.51	3.21	↓ -2.29	4.58	2.88	↓ -1.70	4.13	2.68	↓ -1.45	1.27	1.00	↓ -0.27	1.48	1.10	↓ -0.38
Sep	7.13	5.31	↓ -1.83	5.61	4.68	↓ -0.93	5.42	4.20	↓ -1.22	1.95	1.53	↓ -0.42	2.35	1.80	↓ -0.55
Oct	6.74	4.63	↓ -2.11	5.32	4.38	↓ -0.95	5.22	3.83	↓ -1.39	2.19	1.82	↓ -0.37	2.39	2.01	↓ -0.38
Nov	4.70	3.16	↓ -1.54	3.89	2.86	↓ -1.03	3.67	2.68	↓ -0.99	1.61	1.29	↓ -0.32	1.64	1.25	↓ -0.39
Dec	3.03	1.79	↓ -1.24	2.53	1.73	↓ -0.80	2.47	1.85	↓ -0.62	1.01	0.83	↓ -0.18	1.09	0.84	↓ -0.25

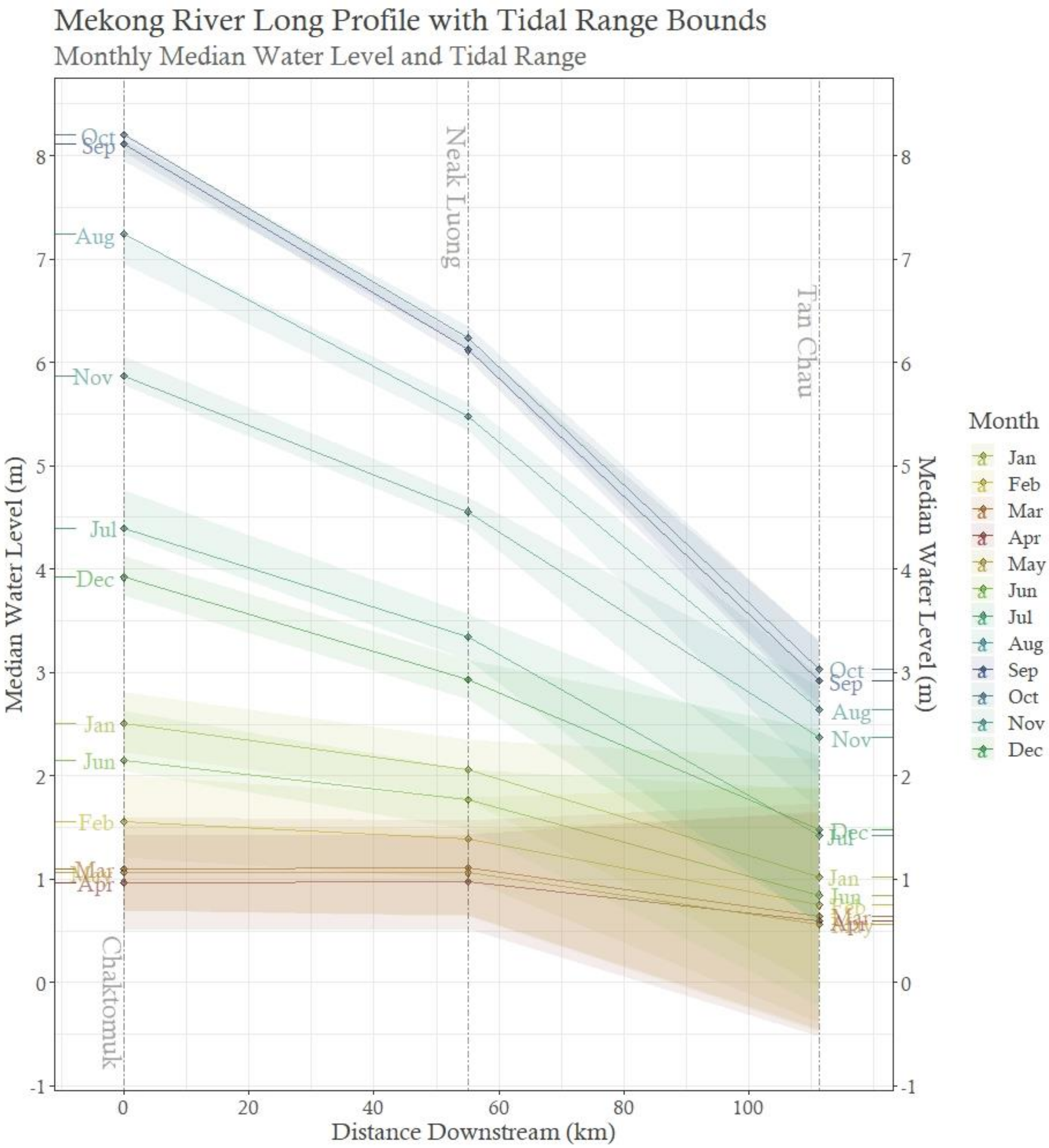


Figure 7-20 Monthly Water Levels in the Mekong from Phnom Penh to the Vietnam Border also showing expected tidal range

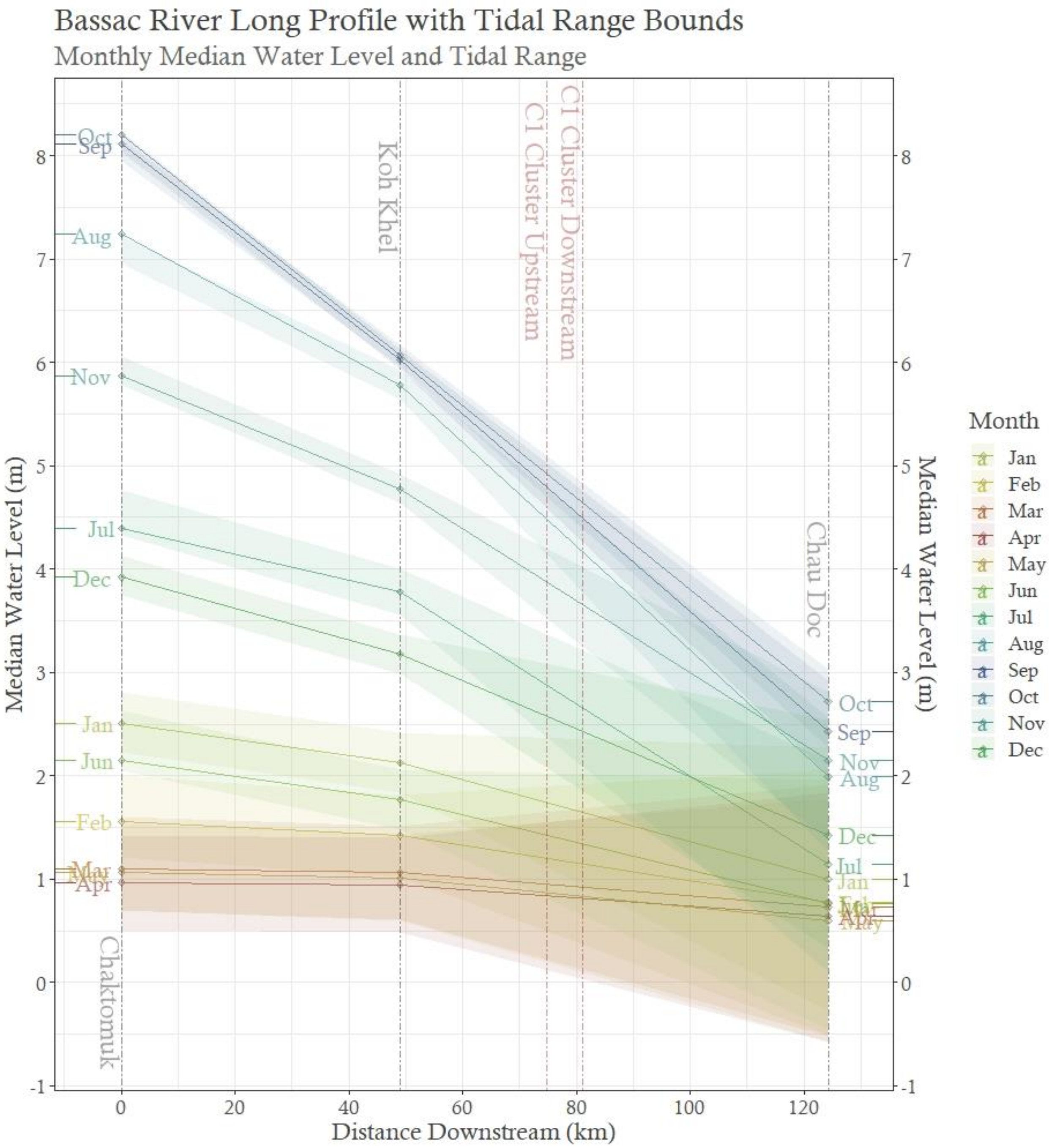


Figure 7-21 Monthly Water Levels in the Mekong from Phnom Penh to the Vietnam Border also showing expected tidal range

8 Impact Analysis of the Preks selected in WAT4CAM Program Phase 1

8.1 WAT4CAM Phase 1 Preks

Six Preks have been selected by WAT4CAM TA-INFRA to assess possible interventions and rehabilitation options. The following preks were selected for study, ordered from north to south of the Prek Çluster:

- Prek Thom
- Prek Pra Theat
- Prek Koh Teav
- Prek Kong
- Prek Nhek
- Prek Ros

The Preks are presented below in Figure 8-1. The full length of Prek Thom is 8352m although only around 4km is envisaged for rehabilitation. Prek Tiev is not part of the rehabilitation work but potentially is critical for the dry season functioning. Under the classification adopted for the Prek Masterplan study, the Prek Tiev would be classified as a River Prek that gives a year-round hydraulic connection between the Bassac and the Prek Ambel. The Prek Thom channel although shown on the map as extending the whole way does not form such a year-round connection due to limited depth especially across the Boeung and a silted length near the Bassac. 'The Toul Kthum canal links the tail end of Preks Thom, Kong, Tiev, Nhek and Ros.

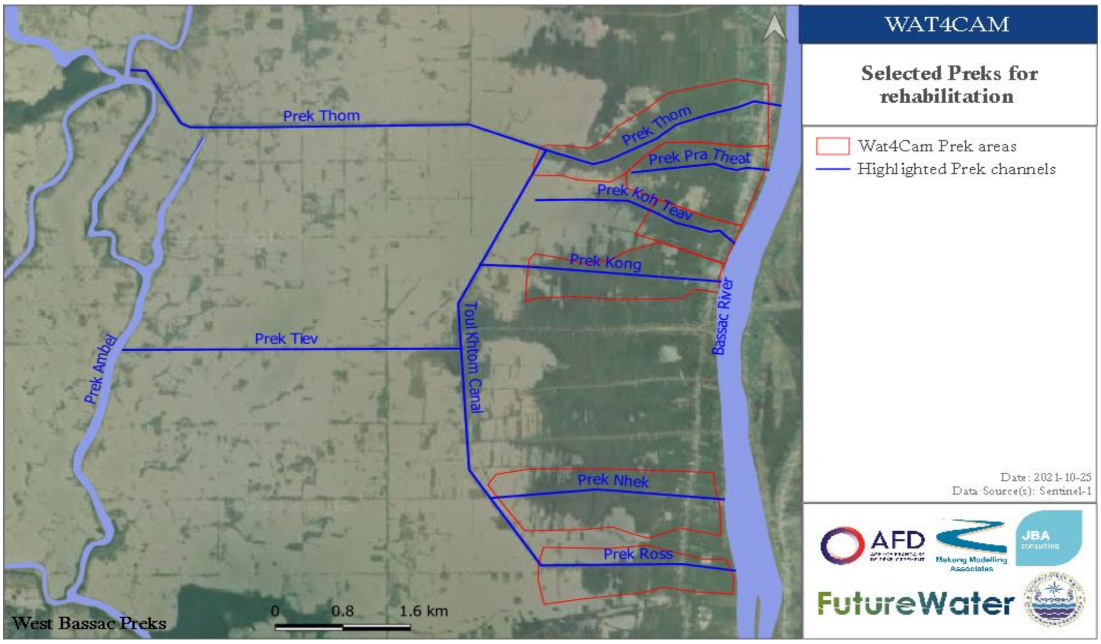


Figure 8-1. Selected Preks for rehabilitation

8.2 Overview of Phase 1 Cluster Preks

The main channels of the ‘’Prek Cluster” link to the Bassac river and extend towards the Prek Ambel through the lower lying Boeung area that forms the main rice land. The cluster has nine Prek channels, two of which were already rehabilitated under previous programs (Prek Wat Koh Tiev and Prek Sem) and the Prek Tiev that forms a year-round linkage between the Bassac and Prek Ambel, central to the cluster. At the extremity of the main Chamkar area there is a bank which has a further channel on the west side named the Toul Kthum canal.

The Prek Cluster is unusual in having a bank around the main Chamkar and some lower land. It is not clear why the bank was built as it is not effective in reducing floods or storing water though this may have been the intention. It also does not seem to have been successful in generating more sedimentation locally (Colmatage). It does, however provide an additional access route and potential sites for back pumping.

The Prek Tiev performs an important navigation function so has a clear passage through the embankment (Figure 8-2) and thus there can be no control on floods. The navigation role may be greater importance than flood control or sedimentation and hence a continuous bank around the Prek Cluster has not been completed.

Figure 8-2 Prek Tiev junction with Toul Kthum canal and bank with road access. Prek Tiev has year-round flow so is not included for rehabilitation work and would be defined as a ‘River Prek’. Note that Toul Kthum canal is, in contrast dry at this location.

8.2.1 Prek Thom

Prek Thom connects to the Bassac through the urbanised area with around 130m upstream of the road bridge. This part of the channel is significantly silted up.

Figure 8-3 Prek Thom Offtake from Bassac (Background imagery from Bing)

The survey carried out for TA-INFRA indicated a maximum to the bed of +4.2m and 3.8m in front of the bridge as shown on KCC Survey in April 2020.

As part of WAT4CAM 3.1 survey of all bridge openings to preks, the river section below the bridge section for Road 22 at Prek Thom had a lowest level of 3.29m and obvious signs of trash and siltation in the channel (Figure 8-4). Flow into the Prek at the current time is potentially even more restricted than the April 2020 survey indicated.

Prek Thom feasibility study indicated the presence of farmer operated pumps at the junction of Prek Thom and Toul Khtom though no physical connection. There is a track running along the northern side of Prek Thom from the Toul Kthum junction until confluence with a branch of the Prek Ampul that appears to carry much of the flood discharge

Figure 8-4 Prek Thom condition when surveyed by Component 3.1 in January 2021

Figure 8-5 Prek Thom junction with Toul Kthom canal

Figure 8-6 Prek Thom connection to Prek Ambel branch channel in dry and flood season (Source Google Earth Imagery 2019 and 2020). The direct connection to Prek Ambel is lost but the branch is wider than the main Prek channel

8.2.2 Prek Pra Theat

Prek Pra Theat is a smaller Prek which originates with around 190m of channel from the Bassac to the Road 22 Bridge. This part of the channel is severely silted up and has a surveyed bed of +3.19m at the bridge according to the April 2020 survey.

When visited in January 2021 there was a significant blockage of the channel as shown in Figure 8-7 . It is not clear if the 'dam' across the Prek was for pumping purposes or remaining after bridge replacement work.

Figure 8-7 Prek Pra Teat at Road Bridge (January 2021)

The Prek runs through to lower ground but does not connect to another canal or Prek.

8.2.3 Prek Koh Tiev

Prek Koh Tiev has approximately 200m of channel on the Bassac side of the road bridge that runs through both urban and agricultural land. The actual offtake is poorly defined and in recent years has only operated at higher main river flows, hence the more widespread use of tubewells on this prek.

The channel at the bridge is, however in a better condition than Pra Theat but also with a high bed level of about 4.4m similar to Pra Theat. The channel extends to the Toul Khtom canal.

Figure 8-8 Offtake of Prek Koh Teav

8.2.4 Prek Kong

Prek Kong is a larger channel than the previous preks and is in a better condition. There is about 210m of intake channel from the Bassac with a maximum bed level of about 2.4m with some urban development for most of the banks Figure 8-9. It is also apparent that high flows have caused an area of erosion on the landward side of the bridge. At the time of the model survey the prek had a water flow as seen in Figure 8-10. Prek Kong connects to the Toul Khtom canal. The adjacent prek to the south, Prek Tiev is central to the Prek cluster and has an even larger channel with a year-round flow.

Figure 8-9 Prek Kong intake from Bassac (left) and Prek Tiev (right)

Figure 8-10 Prek Kong in January 2021

8.2.5 Prek Nhek

Prek Nhek has a long channel between the Bassac and Road 22 of 440m and the prek has a further bridge close to the river as shown in Figure 8-11.

The highway bridge crossing is relatively small with a hard bed. From the April 2020 survey the bed level has a peak of around 2m and then a relatively stable profile with a bed around 1.7m. The prek extends to the Toul Khtom canal.

Figure 8-11 Prek Nheak intake from the Bassac

Figure 8-12 Prek Nheak Highway Bridge in January 2021

8.2.6 Prek Ros

Prek Ros is similar to Prek Nhek but has a longer intake between the Bassac and highway of 630m running through agricultutal land. The profile peaks at around 3m near the entrance to the Prek and around 2.3m at the highway bridge.

Figure 8-13 Connection of Prek Ros to Bassac

Figure 8-14 Prek Ros at Highway 21 crossing

8.3 Survey results

The detailed survey of TA-INFRA from March 2020 provides a strong basis to define the channel profiles for all the preks in the Cluster as well as covering key parts of the irrigation channels in the Boeung area. The features of the channels have been checked at each of the highway crossings and photos taken that record the issues faced.

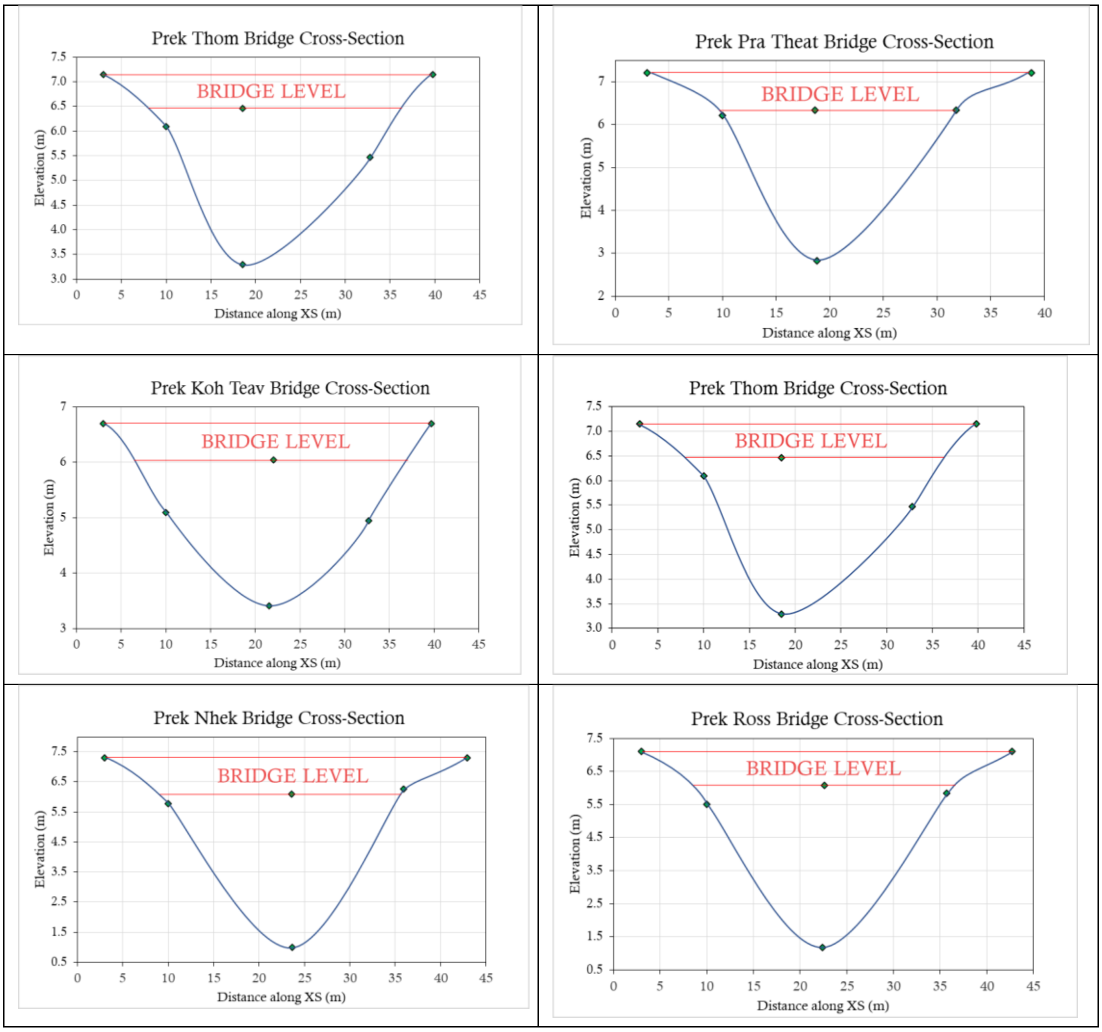


Figure 8-15 Prek Cross Section Measured at Highway Crossing January 2021

The Prek Ambel is also a key waterway and river sections have been taken along the Prek Ambel as part of Component 3.1 surveys.

The Bassac bathymetry is available from navigation survey and some updates from the Ministry of Public works. As described in Volume 2, Model Conceptualisation this data has been combined and used in the modelling.

8.4 Baseline Prek Inflows

Prek functionality for irrigation is dependent on the frequency at which water is available in the prek for farmers to extract. Using gauged water levels at Koh Khal with adjustment to the Prek Cluster and using the bed elevation near the prek inlet, derived from the TA-INFRA prek survey this may be calculated. Assuming a water depth of 1 m would be sufficient for pump extraction by farmers. The number of days in each year and each season could be calculated, as shown in Figure 8-16.

Across the data series, ranges of up to 100 days can be seen at each prek. When applying a linear regression, the number of annual flow days consistently decreases across preks. It should be noted however that due to restrictions in data, Prek bed levels were assumed constant throughout the time period, using data from the 2020 KCC survey. In reality however, it is understood that these prek systems have witnessed varying degrees of both artificial and natural aggradation and/or erosion.

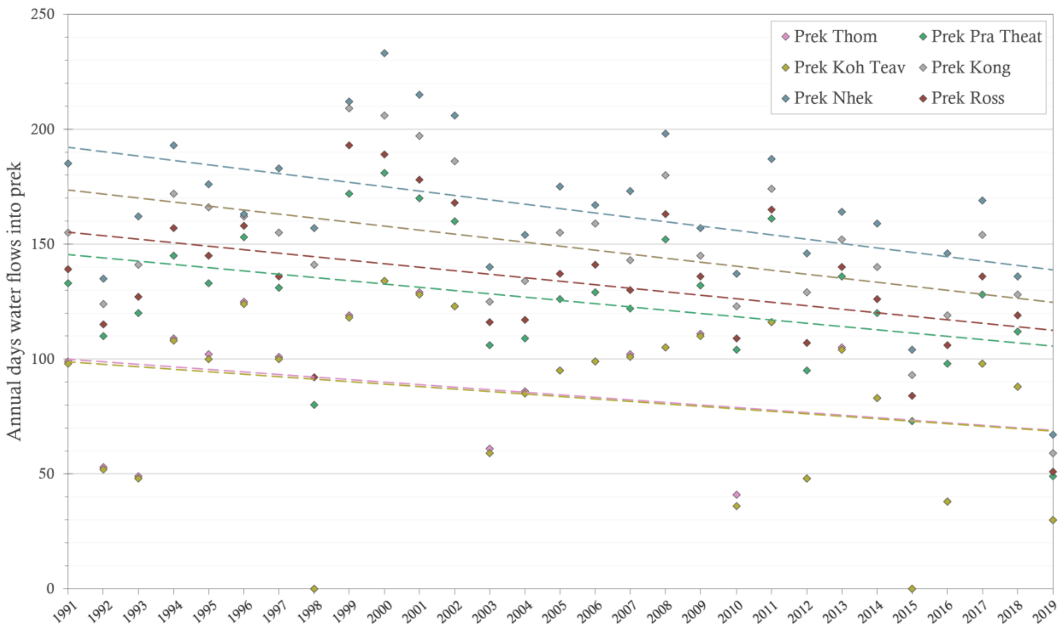


Figure 8-16 Annual days of >1 m flow depth in each Prek of the localised Prek cluster.

It is apparent that Prek Nhek, Prek Kong, Prek Ross and Prek Pra Theat tend to have a high number of days annually where flow is >1 m, ranging from 80 – 230 days. In contrast, Prek Koh Teav and Prek Thom typically saw a lower amount of flow days, ranging from 0 – 125 days.

Although the annual frequency of flow is very important in determining Prek functionality, analysing this data further can enable us to understand the seasonal variations in flow frequency, which can help identify poor performing Preks during certain key periods. Figure 8-17 shows the seasonal frequency of flow >1 m in each of the Preks in the localised Prek cluster. Each datum point indicates the days of flow per year for the given season, with the mean value shown in red. For reference, the total number of dry season days is 212, and wet season days is 153. As expected, dry season flow frequency is consistently lower than that of the wet season, although seasonal variability changes significantly between the Preks. In particular, Prek Koh Teav and Prek Thom rarely have any flow in the dry season and the lowest frequency of flow annually (Figure 8-16), mean dry season flow days is 8 but medians are almost zero. Considering the dry season is 212 days long, this means that a flow depth of >1 m is seen on just 3.8% of days on average.

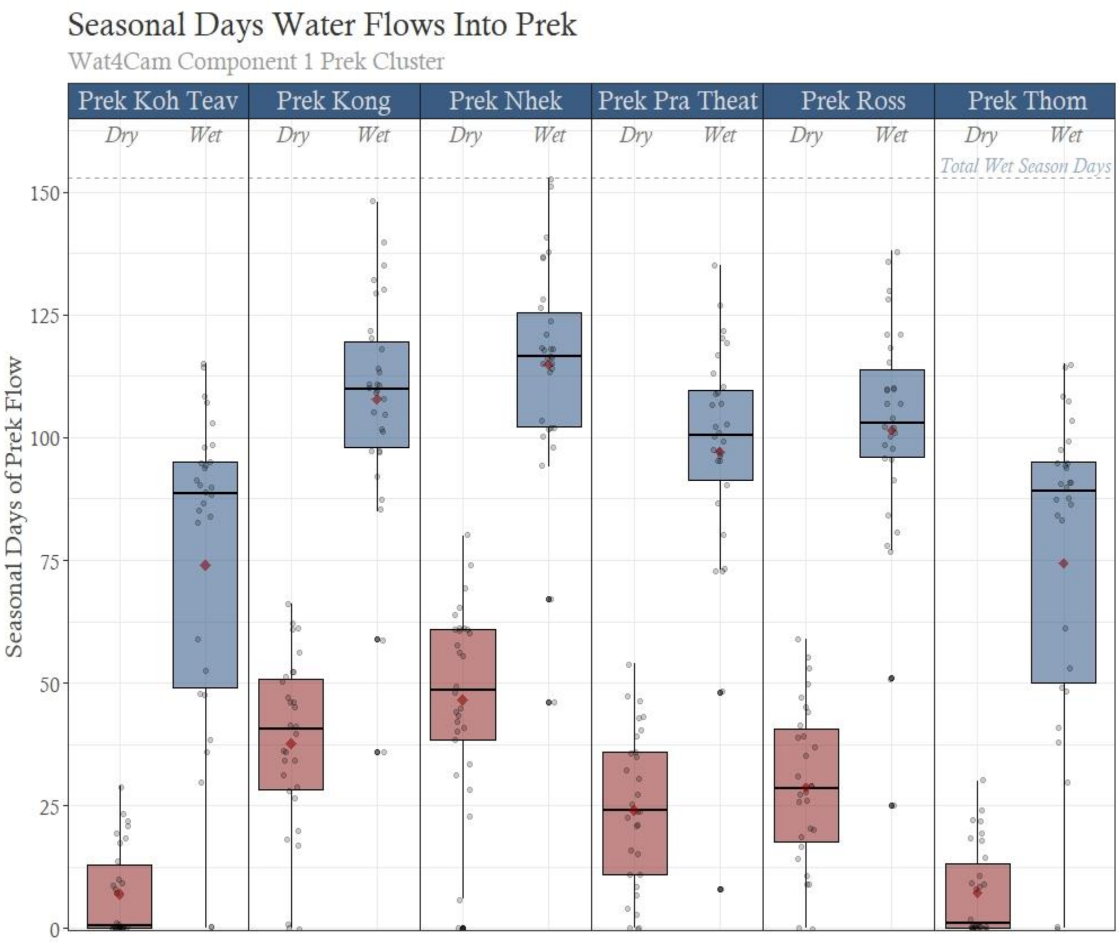


Figure 8-17 Seasonal days water flows into Preks from field assessment, using a 1m depth threshold. ‘Dry’ refers to the dry season period and ‘Wet’ refers to the wet season.

8.5 Key constraints for Prek functioning

The multi-functional nature of the Prek channels clearly relates to a number of aspects in both flood and dry season that go beyond a simple irrigation channel. Prek functions include:

a) Irrigation supply
b) Floodplain management
c) Navigation
d) Drainage and water quality
e) Accumulation of silt for land building and fertilisation
f) Fish passage

Proper hydrological functioning for these purposes requires:

1. Bed levels compatible with water level in the main channel for seasonal or year-round flows
2. Capacity sufficient to pass flood flow between the river and the floodplain
3. A maintenance regime to sustain the bed levels as a degree of sedimentation is to be expected. Channels with longer intakes will be more susceptible to adverse effects of siltation rather than in the tail area where it is more desirable.

The rehabilitation proposal addresses these key hydraulic requirements and learns from some of the earlier prek rehabilitation works. For example expensive gated structures at the prek entrance are avoided – these both limited functioning of the prek for flood as well as environmental impact such as barriers to fish movement or land building.

The changing regime of the Mekong is resulting in lower river levels early in the dry season (November/December/January), significantly reducing the ability of some of the smaller preks to support agriculture. The somewhat higher dry season flows in March/April/May do not reach the required threshold levels to allow for crop cultivation. Climate change impacts are important as it is likely that higher flood flows will more likely cause erosion damage as well as increased rate of siltation at the inlet.

8.6 TA-INFRA proposals for Rehabilitation works in Prek Thom

The feasibility report of Prek Thom indicates different rehabilitation options for improved development of Prek Thom. Improvements/interventions not only focus on infrastructural works, but also on socio-economic interventions.

Some of the interventions that are proposed and affect water availability and water use are:

- Development of a Farmer Water Use Community (FWUC) for management of the water resources in a collective way;
- To connect the Toul Khtom canal to the Prek Thom and construct a new head regulator structure at the junction for improved water management;
- Increase the conveyance and storage capacity of the Prek in order to harvest river water and more efficient pumping to the fields;
- To re-establish the connection with the Prek Ambel through the Prek Thom channel improvements;
- Drainage improvements;
- Development of an urban sewage system.

To improve access to water, three alternative options for intervention have been identified. These options for Prek Thom, as an example, are:

1. Deep excavation of Prek Thom.
2. Shallow excavation of Prek Thom without rehabilitation of the first 880 m of the Prek to prevent 5 houses from being affected (these 5 houses otherwise need to be removed/replaced)
3. Shallow excavation of Prek Thom of the entire prek including the first 880 m.

All options will yield benefits in terms of increased agricultural production, better infrastructure, formation of institutional structures and capacity building of farmers. The following benefits are identified related to water resources management:

- Flood mitigation;
- Year-round access to water for crop production yielding reduced risks of crop losses from floods and droughts;
- Increased knowledge of famers to improve agricultural practices as farmers would learn more on agro-ecological technologies, market linkages and water management practices to boost crop productivity leading to better livelihood outcomes for the household
- Increased social capital; farmers could learn how to work together as groups to handle their production issues, manage the use of water and maintain the Prek;
- Improved access to water for dry season will increase cropping intensity.

8.7 Initial Environmental Examination

Although WAT4CAM TA-INFRA includes the execution of feasibility and safeguard studies relating to the prek rehabilitation, comment on the social and environmental impact of these developments as a function of hydraulic impacts in the scope for Component 3.1.

There is clearly commonality with the safeguard studies of TA_INFRA but consideration was given within the framework of an Initial Environmental Examination (IEE). The impact assessment and mitigating measures cover the whole cycle of the project activities, from pre-construction to construction and operation and maintenance, including as follows aspects that the model can be used to inform:

A. Design phase/pre-construction phase:
   Whilst the design is intended to make more water accessible within preks consideration should be given to the impact on the water availability elsewhere. Comments will be made on the likely impact of design
B. Construction phase:
   Immediately after construction the rehabilitated channels will be sensitive to high velocities so flood conditions may be simulated
C. Operation phase:

Continuing impacts such as higher flood levels, lack of water elsewhere, fisheries or navigation impacts are considered as well as benefits.

The main results of a general IEE are presented in Table 8.1. This table indicates the different potential negative impacts that were identified, possible mitigation measures, the institutional responsibility and the monitoring indication for every phase. The full IEE is presented in Annex 1.

Likely hydraulic changes that can be studied using modelling are:

1. Change in dry season flow in the Prek and any impact elsewhere
2. Change in flood flow into the Prek during the rainy season
3. Change in the water level on the floodplain due to a better connection with the man river
4. Change in silt conveyance and potential for land raising
5. Impact and necessary capacity of structures (not yet defined for feasibility level)

Table 8.1 Overview of the components of an Initial Environmental Examination (IEE) of Prek Kong, Prek Nhek, Prek Ross, and Prek Thom.

No.	Potentially Negative Impacts	Mitigation Measures	Institutional Responsibility	Monitoring Indication
A. Design Phase				
A.1	Incorporation of EMP into detailed designed and update of EMP	• Incorporate EMP into the detailed design • Review, revise, and update IEE and EMP to minimize adversely negative environmental impacts	Contractor or Designer	Approval of updated IEE & EMP following the detailed design
A.2	Public Consultation	Conduct public consultation with targeted famers/groups within subproject areas of Prek Kong, Prek Nhek, Prek Ros, and Prek Thom	Consultants Subproject Implementor Contractor	Public Consultation Reports
A.3	Water Availability and Balance	• Detailed water sources • Required volume of water use • Estimate of water availability	Study Team Consultants	Water sources Volume of water use required Water availability
A.4	Land Acquisition and Compensation	• Land details and requirement to complete land agreements with negotiated settlement or voluntary donation as specified in tender and contract documents. • Sign land agreements prior to construction activities commencing on the plot	Contractor or Designer	Resettlement checklist and safeguard due diligence report

No.	Potentially Negative Impacts	Mitigation Measures	Institutional Responsibility	Monitoring Indication
A.5	Protected Areas and Cultural Heritages	Cultural heritages should be taken into account during the design phase	Contractor or Designer	Approval of updated IEE & EMP following the detailed design
A.6	Grievance Redress Mechanism	Prepare grievance redress mechanism report	Contractor or Designer	Approval of updated IEE & EMP following the detailed design
A.7	Potential Climate Change Impacts	Incorporating in detailed design adequate considerations and conditions relative to climate change using recommended climate adaptation measures and good engineering designed practices	Contractor or Designer	Approval of updated IEE & EMP following the detailed design
B. Construction Phase				
B.1	Soil Erosion	• Minimize unneeded encroachment onto adjacent lands • Use surplus topsoil for earth filling work at approved location • Reduce extra spoil generation by minimizing width and depth of canal excavation • Install intercepting ditches and drains to prevent runoff entering construction site	Contractor	Visual Inspection
B.2	Soil Contamination	• Safely store petroleum products, hazardous materials, and wastes from rainwater • Install fuel tanks on an impermeable ground in a bunded area • Avoid soil contamination with petroleum products, lubricants, or hazardous materials during equipment maintenance and repair, field refueling, and hazardous material handling • Organize spill response kit at each construction site for collection and storage of contaminated soil and provide training for workers on use of spill response kit	Contractor	Visual Inspection
B.3	Noise Quality and Vibration	• Locate sites for concrete concrete-mixing and similar activities at least 300 m away from sensitive areas • Operate between 8am-6pm only and reach an agreement with nearby residents regarding the timing of heavy machinery work, to avoid any unnecessary disturbances • Provide advance warning to the community, including residents, school, temple and hospital on timing of noisy activities • Construction workers to use appropriate personal protective equipment for high noise or lengthy exposure	Contractor	Visual Inspection Monitoring Report
B.4	Air Quality	• Managed stockpiles to reduce dust emissions. The location of the stockpiles must be downwind of sensitive receptors. The stockpiles must be sprayed with water before material is moved • Spray water on construction sites and material handling routes where fugitive dust is generated • Cover with tarpaulins or other suitable materials for trucks carrying earth, sand or stone • Maintained to a high standard for construction vehicles and machinery to minimize high emissions	Contractor	People Complaints Visual Inspection and Monitoring Report

No.	Potentially Negative Impacts	Mitigation Measures	Institutional Responsibility	Monitoring Indication
B.5	Water Quality	• Do not wash equipment in any surface water bodies throughout the project implementation period • Dump wastewater into any ditches or streams • Dispose wastewater from labor camps and construction sites into septic tanks without contacting ground • Station fuel storage, equipment maintenance, and repair workshops, and vehicle washing areas at least 300 m away from any water body	Contractor	People Complaints Visual Inspection and Monitoring Report
B.6	Waste Disposal and Management	• Collect and keep construction camp and site wastes into confined waste containers equipped with covers installed away from sensitive areas • Dispose construction wastes and demolition debris at authorized locations • Do not burn wastes throughout the project implementation period	Contractor	People Complaints Visual Inspection and Monitoring Report
B.7	Impact on fish and other aquatic ecosystems	• Increase turbidity and erosion of backfill material into the river can possibly affecting aquatic organisms. Limit traffic on the embankments and compact the embankments can minimize the impacts • Construction noise and vibrations may temporarily disturb fishes and birds. Implement the noise standard as required by Sub-decree on Noise Quality can reduce the affects	Contractor	Embankment compacted Heavy traffic on the embankments reduced Noise quality standard implemented
B.8	Flora and Fauna	• Acquire tree cutting permit from local forestry and wildlife department for any trees to be cut under the project • Replant trees or re-vegetate areas at other approved locations by using only native plants • Identify, demarcate and protect sites where small animals, reptiles, and birds of common species live, such as vegetated roadside areas, tree belts, inner areas of bridges, river riparian zones, etc. • Strictly prohibit poaching of wildlife and damaging plants during the implementation period	Contractor	People Complaints Visual Inspection and Monitoring Report
B.9	Incidence of Unexploded Ordnance	Workers, bystanders and equipment can be exposed to UXO risks. Review Cambodia Mine Action Center's map to understand whether the subproject areas are marked with unexploded ordnance	Contractor	Unexploded Ordnance Map reviewed
B.10	Occupational Health and Safety	• Allocate budget for occupational health and safety measures • Contract with Health and Safety Specialist to develop, implement, and supervise Health and Safety Management Plan • Conduct initial and regular refresher training for all workers on labor rights, occupational health and safety matters, ensure provision and distribution of personal protective equipment, and keep record and report any H&S incidents	Contractor or Health and Safety Specialist	People Complaints Visual Inspection and Monitoring Report
B.11	Community Safety	• Take into account temporary traffic management and road safety awareness measures to ensure safety of nearby residents, community and visitors • Install clear signs of accidence warning people of potential dangers, such as moving vehicles, hazardous materials, etc.	Contractor	People Complaints Visual Inspection and Monitoring Report

No.	Potentially Negative Impacts	Mitigation Measures	Institutional Responsibility	Monitoring Indication
B.12	Grievance Redress Mechanism	Implement grievance redress mechanism	Contractor	Grievance Redress Mechanism Report
C. Operation Phase				
C.1	Drainage	Monitor changes in waterlogging due to potential waterlogging at downstream areas can be occurred	Implementing Agencies	Changes in waterlogging downstream areas
C.2	Canal Sedimentation	• Develop an operations and maintenance plan by including regular maintenance and removal of deposited sediment • The plan has to eb taken into consideration disposal sites for the removed sediment	Implementing Agencies	Operations and maintenance plan established and implemented Disposal sites built Sedimentation removed as planned
C.3	Pesticide Usage	Overuse of pesticides causing land and water degradation. To avoid the said problem farmers should receive integrated pest management training which is part of agriculture component training.	Implementing Agencies	Monitoring amounts used and purchase records
C.4	Chemical Fertilizer Usage	Overuse of pesticides causing land and water degradation. To avoid the said problem farmers should receive integrated pest management training which is part of agriculture component training.	Implementing Agencies	Monitoring amounts used and purchase records
C.5	Agricultural Solid Wastes	• Do not throw, bury or burn pesticide wastes at any place without any permission from an Agricultural entity or competent authority • Do not re-use a pesticide container to pack any product that is not a pesticide, especially food and feed	Implementing Agencies	People Complaints Visual Inspection and Monitoring Report
C.6	Impact on fish and other aquatic ecosystems	Abstract water may have adverse environmental consequences, which impact on fisheries and other aquatic ecosystems, especially during the dry season (low flow regime). A proper water management plan can reduce these impacts	Implementing Agencies	A proper water management plan developed and implemented
C.7	Flooding and Natural Disaster	Increased flooding and natural disasters can cause potential impacts on farming system, economic and social life. Well maintenance of irrigation system can give right to well operation capacity and less cost for repairing. Develop clear operating rules for reservoirs can minimize flooding risk.	Implementing Agencies	Operation maintenance recorded Reservoir recorded data Operation rules established

8.8 Impact Analysis Model setup

The full Cambodia floodplain model was used and modified for the prek improvements proposed by TA-INFRA. In addition, a sub model of the Prek Cluster area only was developed so that more detail could be represented in the simulation using a finer mesh size and small timestep. The overall model was used primarily to study flow in the monsoon season and the detail cluster model to examine low flow water distribution and to give indications of sediment movement.

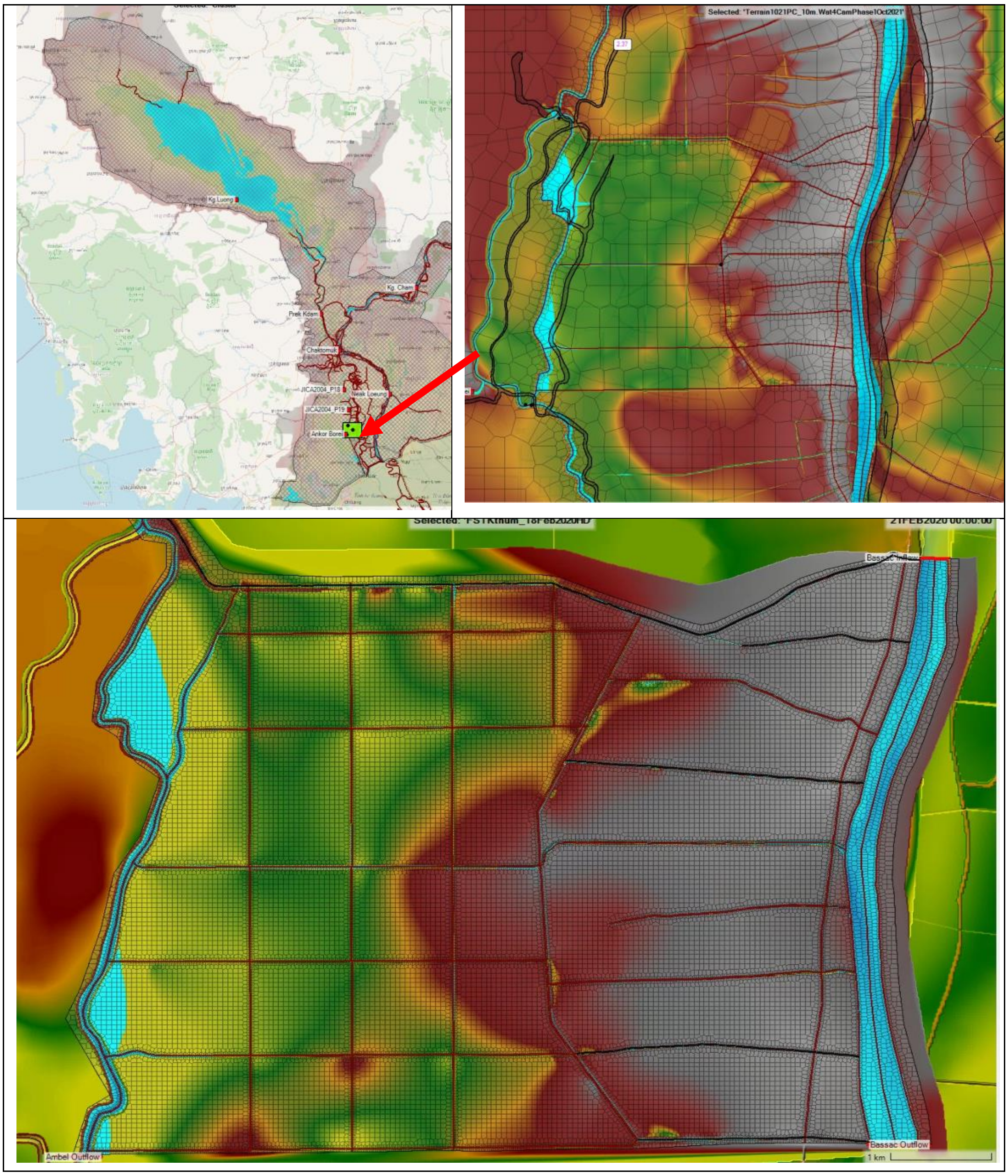


Figure 8-18 Extent of Full 2D Model and Grid size in full model and Local Prek Cluster Model (below)

A preliminary sediment model was also set up to help investigate the influence of certain prek features.

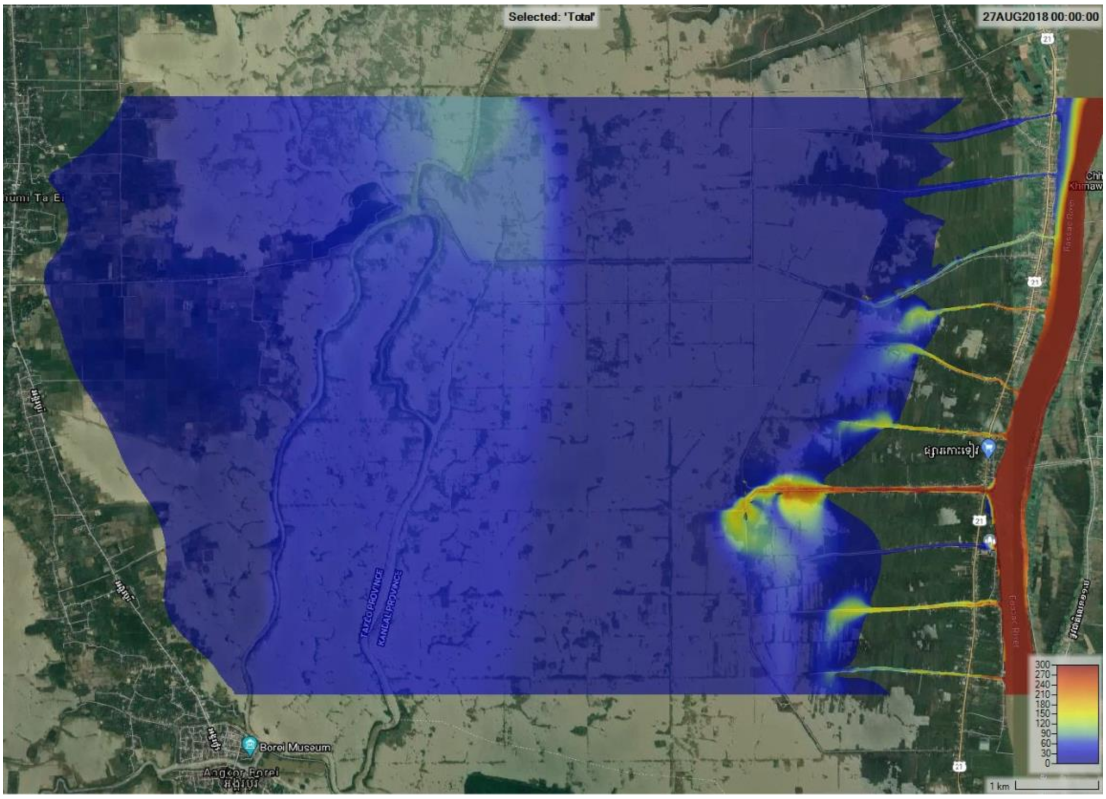


Figure 8-19 Preliminary Sediment Model. Sediment Concentration near the peak of the 2018 flood

8.9 Scenario development

8.9.1 Prek feasibility studies

The analyses show that water availability is limited in all preks during the dry season, while other parts get flooded during the wet season. Farmers do not have access to water year-round, except for the farmers with a tube well installed, or those at the tail end of preks, where the tidal effect in the system maintains a minimum level and where connected to a larger tidal channel, farmers can access water using pumps.

From the TA-INFRA Phase 1 feasibility report, it is suggested that the main issues in most of the preks are:

- Poor water management: collective water management is not present; water management is entirely up to the individual farmers.
- Erosion of the embankments and sedimentation and vegetation in the prek bed that block the water flow;
- Pollution and reduced water quality: dwellings and households' waste (water), pesticides and other chemicals, hydrocarbon products (diesel etc.) from pumps.
- Labour constraints: there is a high demand for workers in construction or for garment factories.

- Cash flow constraints: Farmers may need to borrow money but fluctuating crop prices result in high risk in repaying the debts.
- Poor application of soil fertilizers:
- Overuse of pesticides;
- Fluctuating prices and lack of access to market information.

8.9.2 Interventions Considered in TA-INFRA Draft Feasibility (October 2021) and Selected Optimal

A package of interventions at each of the preks are considered in the feasibility study and the most effective selected. The proposed works related to the physical intervention and the most economically effective proposed is summarised in Table 8.2.

Table 8.2 Options for physical intervention works on the prek channel considered in feasibility (other interventions such as FWUC strengthening, agriculture extension work, access bridges not shown)

Option	Prek Thom	Prek Pra Theat	Prek Koh Teav	Prek Kong	Prek Nhek	Prek Ros
Deep excavation						
Shallow excavation (without rehabilitation in the urban areas (houses not affected)						
Shallow excavation (with rehabilitation in the urban areas (houses affected)						
Pumped irrigation system						
Extension of Prek						
Terminal Structure with gate and flap gate						
Terminal Structure with gate						
Extension						
Selection of Options		Preferred			Assessed	

8.9.3 Model parameterization and scenarios

The models were run for pre-rehabilitation and post-rehabilitation considering both wet season changes and dry season. The setup of the model for post rehabilitation was simply to lower the bed to that specified for the preferred rehabilitation option selected by TA-INFRA. The bed change was made using the available HECRAS routine for modification of geometry and the model grid was kept unchanged. When further information becomes available on the proposed tail structure then a more detailed modelling could be completed to aid design.

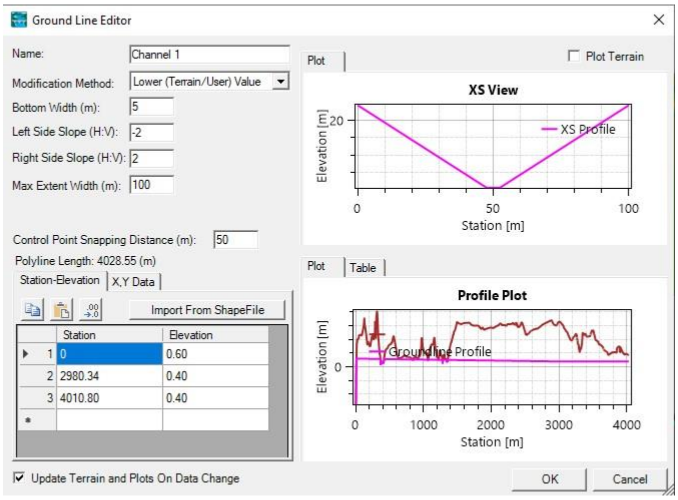


Figure 8-20 Terrain Modification in HECRAS 6.1

Scenarios simulated were selected to give indications of baseline çonditions and for the preferred option of the Feasibility Study. The TA-Infra survey was used to define the baseline condition including all channels of the Prek Cluster between the Bassac and the Prek Ambel and boundary conditions for the flow and water levels at the upstream and downstream of the Bassac and Prek Ambel were taken from the larger model. The long section drawing presented in the feasibility study were used to define the ‘with project’ geometry an example of which is given in Figure 8-22:

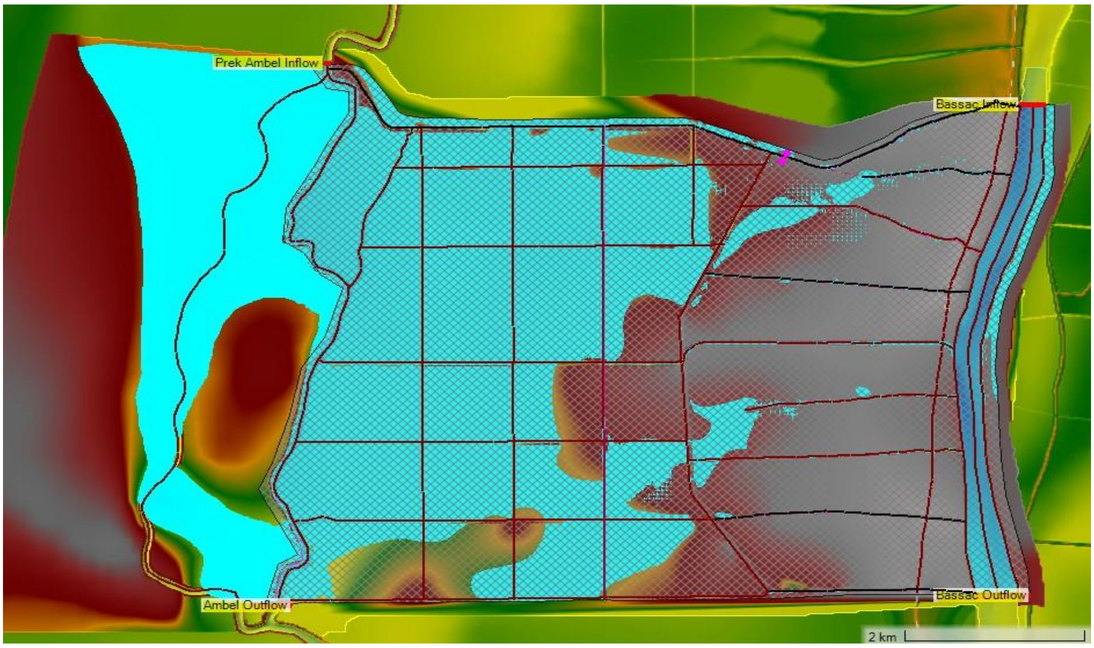


Figure 8-21 Prek Cluster Sub Model Boundary Conditions and channels ‘burned into ground DEM

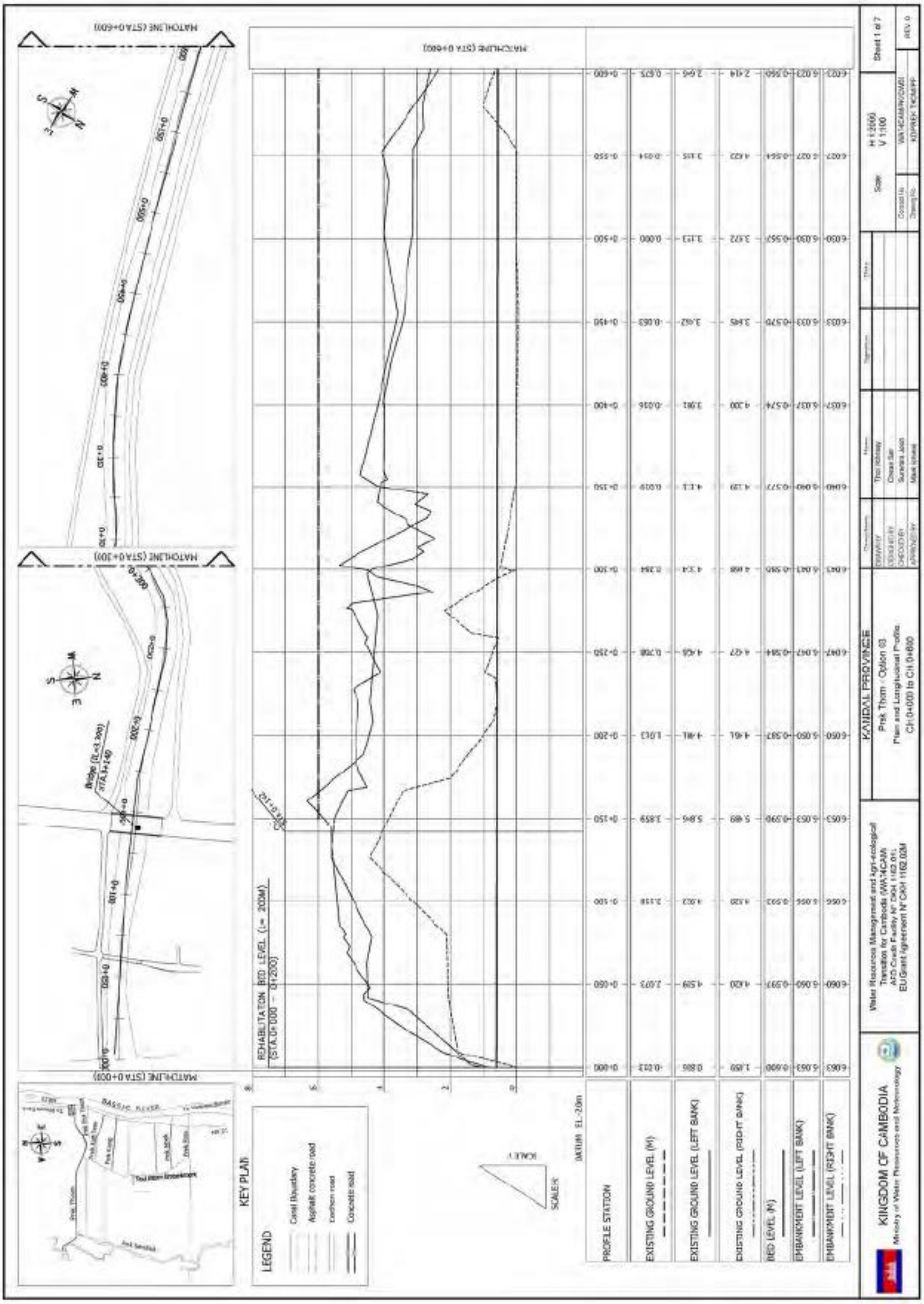


Figure 8-22 Prek Thom Long Section showing proposed bed level and survey results. This is one of 7 sheets for Prek Thom (Egis Eau Feasibility Study of Prek Thom October 2021

8.10 Results of Modelling and Analysis of Remote Sensing fort he Prek Cluster Area

The work for rehabilitation of 6 Preks within a ‘Prek Cluster’ is all within a close geographic area so for practical purposes, changes in water level are very similar especially at the downstream (boeung) side of the prek.

The hydrology of the area has been analysed and reported in the Feasibility studies and in Report 3 of Component 3.1 ‘Flood Mapping and Low flow analysis’ so given there is no additional data available, this is not repeated here. However, one feature of the analysis is the significant change that has occurred within the last 5-10 years that makes it particularly difficult to estimate the statistics of low flow and flood levels. For design purposes, thus a certain caution is needed given the higher than usual uncertainties and assuming the historical pattern will apply in the future is most unlikely (see Figure 8-23).

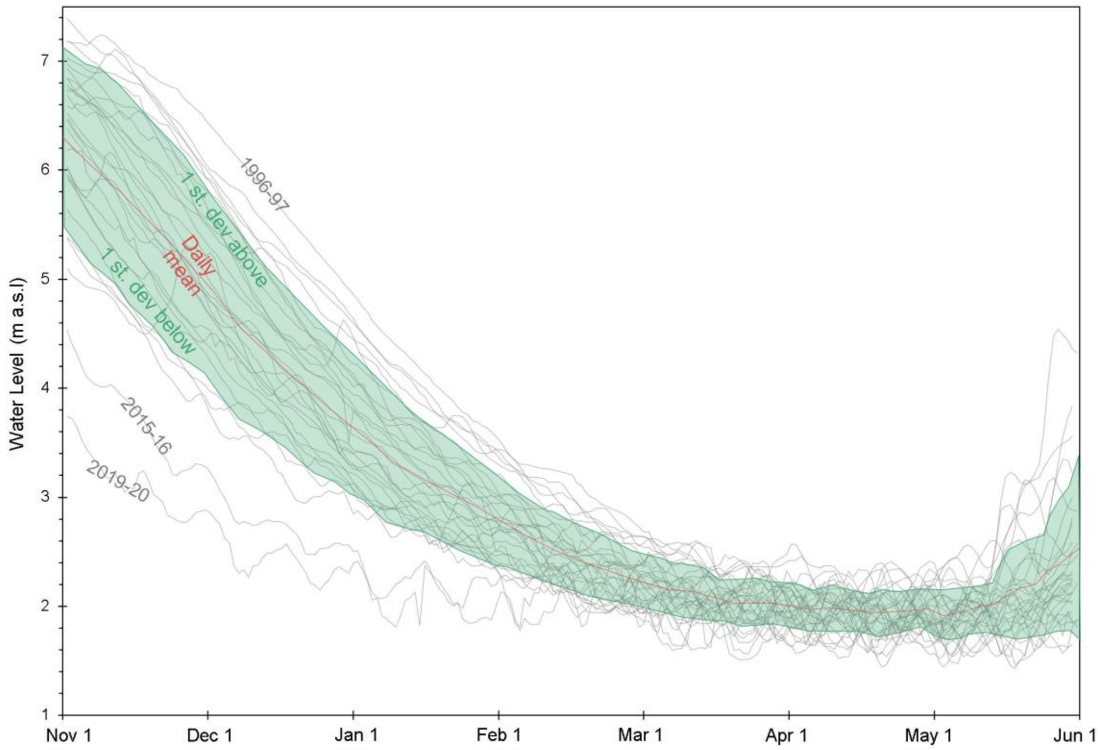


Figure 8-23 Observed Water levels (gauge) at Koh Khal during the dry season (1980-2020) compared with mean and standard deviation (**Subtract 1m to get to datum msl**)

8.10.1 Prek Cluster Baseline

More detailed modelling has been carried out specifically for the Phase 1 Preks which will be described for each prek in the next section and after as a whole. Simulations for the whole region (full model) indicate high flows in flood but constraints during the dry season can be better defined with a finer grid so the local model is used. As would be expected from the survey levels at the mouth of each of the feasibility study preks, the model indicates long periods of no flow but spill into the prek during flood such as shown in Table 8.15 and Figure 8-75.

8.11 Prek Thom

Prek Thom is located north end of the Prek Cluster at bridge N62 along the western embankment of the Bassac River. It has a gross command area of 302 ha, though only 90ha is Chamkar. The prek has a length of 4,000m to the boeung area and over 8km at the connection to Prek Ambel.

The main water sources of flow in Prek Thom are the Bassac River during high flows in the Bassac river and from the Prek Ambel in the lower parts. Water may also be lifted by farmers indirectly through pumping from the Toul Khtom channel which links through the Boueng to the Prek Ambel. It is important to note that there is no direct connection between Prek Thom and the Toul Khtom channel, water can only be pumped from there when the water level is sufficiently high and may be influenced by the tidal effect in the system.

8.11.1 Baseline situation

Flows in the Prek

As discussed in the previous chapter, the current bed of the Prek Thom precludes inflow from the Bassac river at times between November and June depending on the year.

Land use

According to the feasibility study of Prek Thom, landuse in Prek Thom consists of the following characteristics, presented in Table 8.3

Table 8.3. Landuse classification in Prek Thom.

Land use	Area (ha)	Percentage of Prek area (%)
Chamkar area	90	30
Cash crops / Annual crops	36	12
Rice area in Prek area	148	49
Rice area in Boeung	190	-
Colmatage area (Prek channel)	6	2
Residential area	22	7
Total Prek area	302	
Total Prek area + Boeung area	492	

Typical crops grown in the command area of Prek Thom are mango, maize and mung/soya (in the Chamkar area) and cash crops / annual crops such as vegetables (cucumber 10%, long bean 5%, bottle gourd 5%, pumpkin 4%, okra 3% and bitter gourd 3%). The remaining agricultural land in used to produce rice (Figure 8-24).

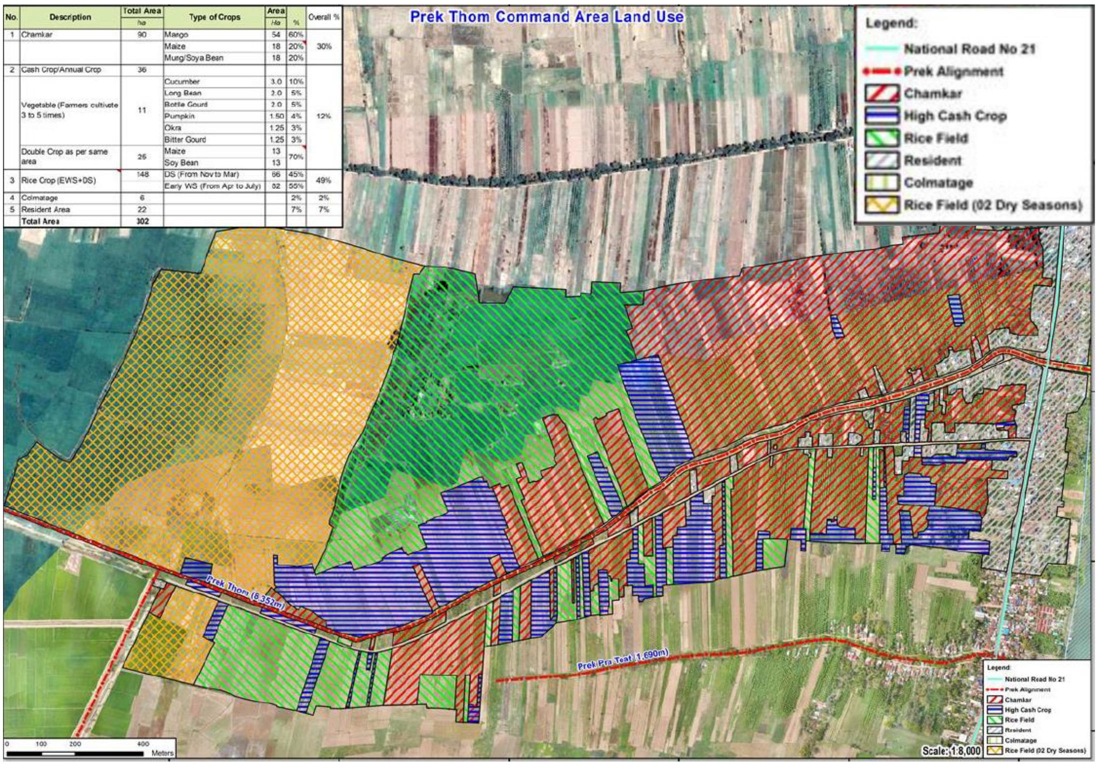


Figure 8-24. Landuse classification in Prek Thom.

8.11.2 Rehabilitation Options

The feasibility report of Prek Thom indicates different rehabilitation options for improved development of Prek Thom. Improvements/interventions not only focus on infrastructural works, but also on more socio-economic interventions.

Some of the interventions that are proposed and affect water availability and water use are:

- Development of a Farmer Water Use Community (FWUC) for management of the water resources in a collective way;
- To connect the Toul Khtom canal to the Prek Thom and construct a new head regulator structure at the junction for improved water management;
- Increase the conveyance and storage capacity of the Prek in order to harvest river water and more efficient pumping to the fields;
- To re-establish the connection with the Prek Ambel through the Prek Thom channel improvements;
- Drainage improvements;
- Development of an urban sewage system.

To improve access to water, three interventions have been identified. These options are:

1. Deep excavation of Prek Thom.
2. Shallow excavation of Prek Thom without rehabilitation of the first 880 m of the Prek to prevent 5 houses from being affected (these 5 houses otherwise need to be removed/replaced)
3. Shallow excavation of Prek Thom of the entire prek including the first 880 m.

All options will yield benefits in terms of increased agricultural production, better infrastructure, formation of institutional structures and capacity building of farmers, however the feasibility study found Option 1 to be the most beneficial.

8.11.3 Flood season Analysis

The flood peaks passing through the road bridge to Prek Thom were extracted from the full model for different simulation years as shown in Table 8.4. It can be seen that there is a significant increase in peak flood flows, rising from 7.3m3/s to 23.5m3/s for a 2018 flood magnitude.

Table 8.4 Simulated Flood Season Peak Water levels and flows Prek Thom

Scenario Year	Simulated Peak Water Level Bassac (m AHT)	Simulated Peak Water Level Floodplain (m AHT)	Simulated Peak Flow into Prek (m3/s) existing condition	Simulated Peak Flow into Prek (m3/s) after rehabilitation
2000	5.75	5.53	3.1	
2011	5.63	5.35	2.7	
2018	5.1	4.83 4.83	7.3	23.5
2019	5.11	4.74 4.75	1.5	7.0
2020	4.18	3.7	1.2	

Sentinel-1 imagery (2016-2021) was used to analyse analysis water occurrence during the wet season (Figure 8-25). The command area remains almost completely dry in the wet season, with small areas having a water occurrence of about 20%. This means that these areas are flooded during the wet season in 1 out of the 5 years.

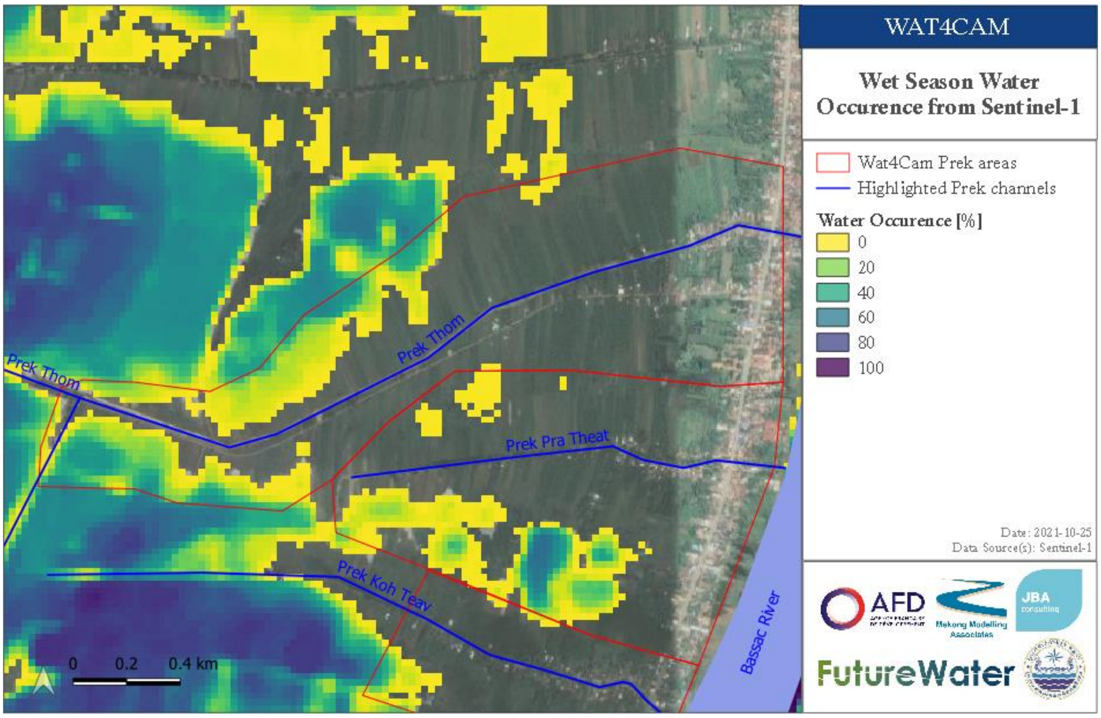


Figure 8-25. Water occurrences calculated for the wet season from Sentinel-1 imagery (August-November) using the full 2016-2020 series.

The trend shows that the water occurrence in the recent past (2010-2020) has been lower compared to the more distant past (1988-2010) in the prek area (Figure 8-26). Water occurrence in the wet season has reduced with about 25%.

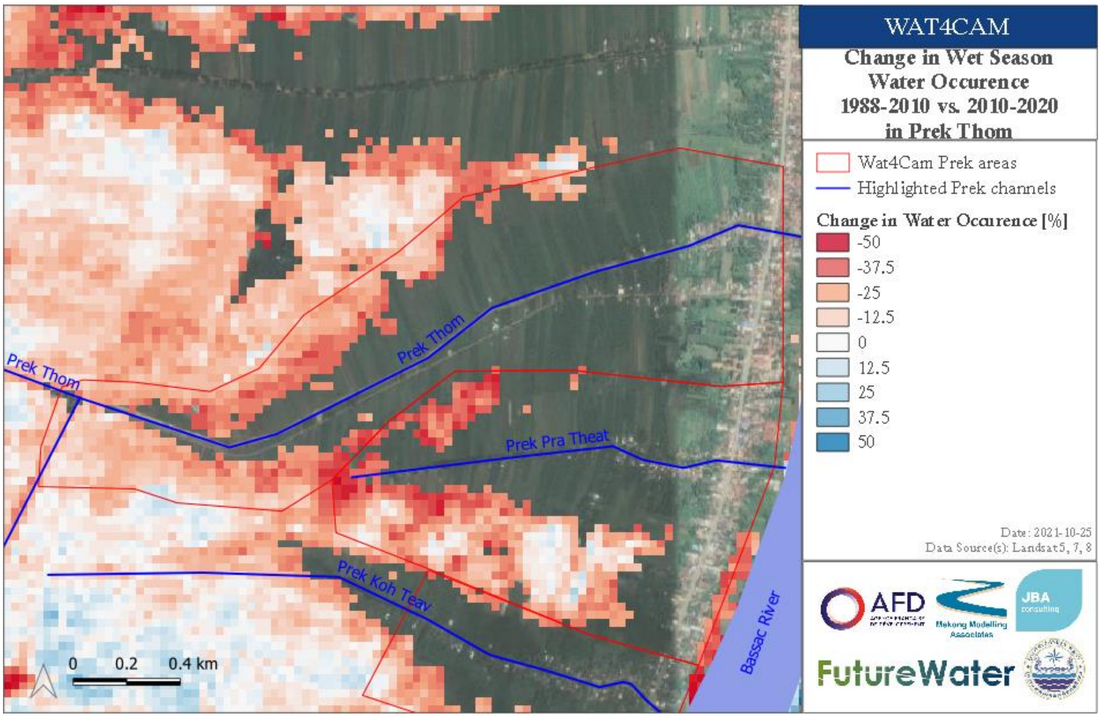


Figure 8-26. Change in Water occurrences calculated for the wet season from Landsat 5, 7 and 8 imagery (August-November) using the full 1988-2020 series.

8.11.4 Dry Season Analysis

As mentioned above during the dry season, water availability is limited. Using Sentinel-2 satellite data derived NDVI values, the percentage of agricultural land that lies fallow in the dry season was calculated for all the preks. The analysis shows that for Prek Thom, 14% of the agricultural land lies fallow in the dry season which ranks it among the Preks with smallest areas with fallow land along the Bassac river (Figure 8-27).

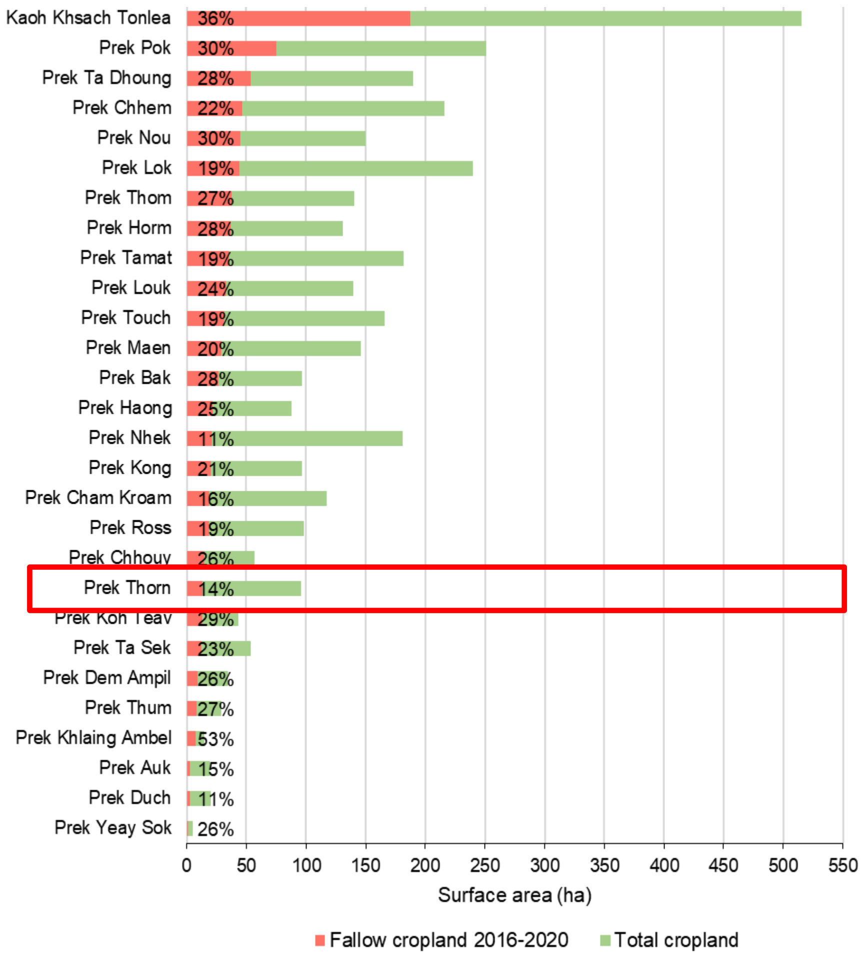


Figure 8-27. Area of cropland left fallow in the months February – April on average in years 2016 – 2020 (Bassac River).

The main water user in Prek Thom is agriculture through irrigation. Figure 8-28 presents actual evapotranspiration (ET_{act}) totals for Prek Thom in the dry season months, for each of the years 2003 – 2014. This ET_{act} provide valuable insights in water availability and water use in the dry season. Interestingly, an upwards trend seems to be present over this period, which could be explained by natural/climate related phenomena such as shifts in timing of the preceding wet season or ongoing siltation due to fertile sediments from the prek resulting in increased elevation of the land and with that, increased agricultural area. It could also be the result of manmade interventions such as changes in land use and cropping patterns or increased water supply from an increasing number of tube wells.

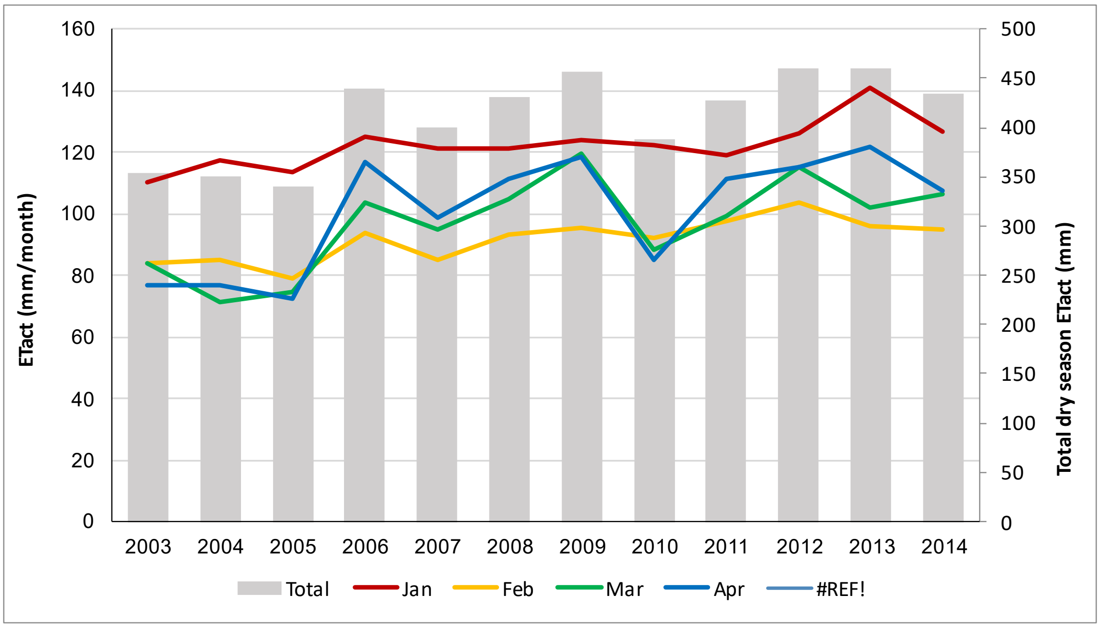


Figure 8-28. Average water consumption (ET_{act}) per month, as well as dry season totals, in Prek Thom during 2003 – 2014.

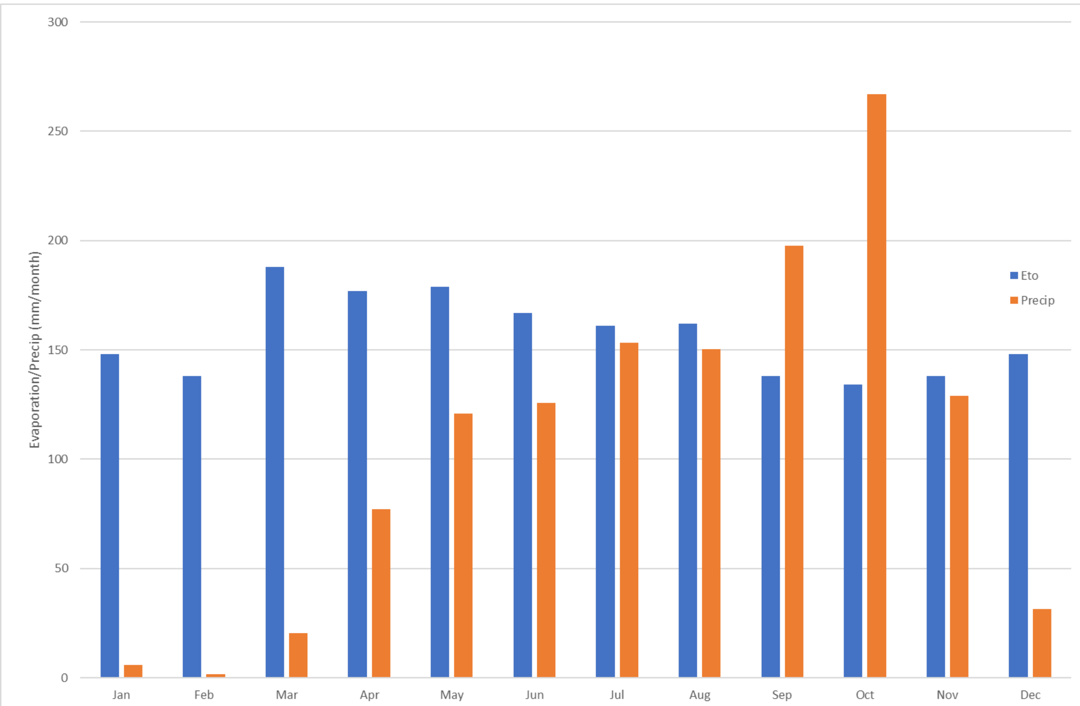


Figure 8-29 Reference Potential Evapotranspiration (ETo/month) and average rainfall (Takeo)

Comparing the prek-averaged actual evapotranspiration ET_{act} with potential evapotranspiration, the effect of water shortage in March may be postulated. Rainfall is also limited compared to evaporative demands in December- March.

Figure 8-30 shows the spatially the consumptive water use of vegetation (agriculture) in the dry season (February – April) in Prek Thom calculated from the Sentinel-2 imagery between 2003-2014. It shows that Prek Thom consumes on average between 250-375 mm/dry season which compares well to the numbers presented in Figure 8-28.

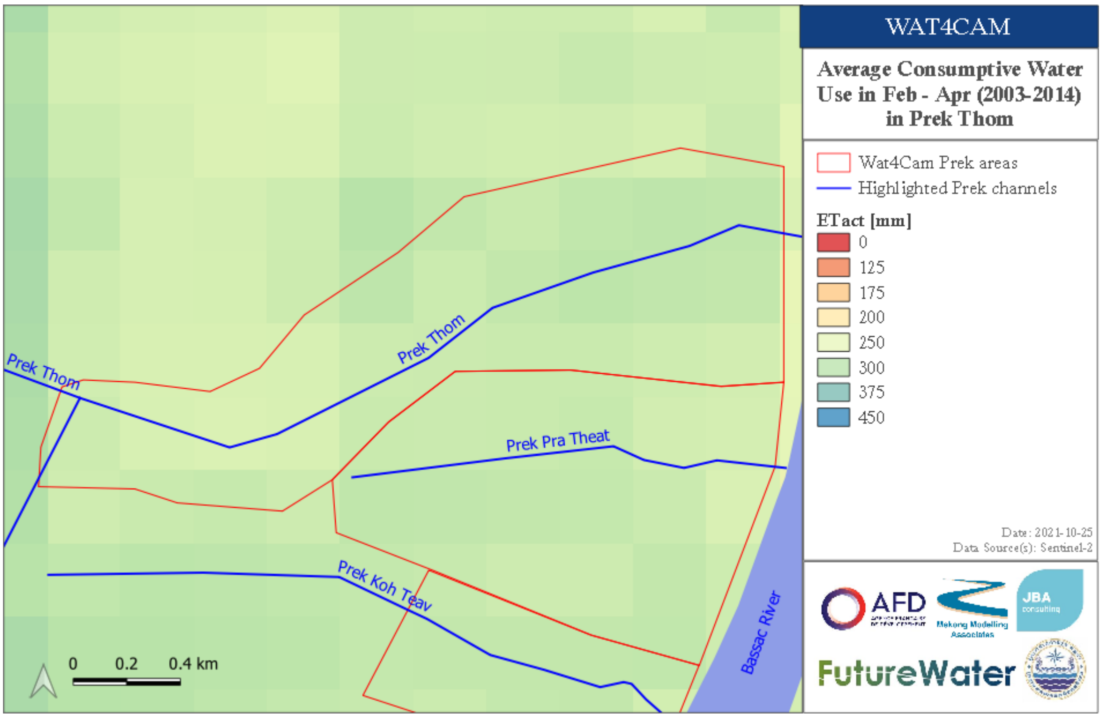


Figure 8-30. Actual evapotranspiration in the months February – April, averaged for the 2003 – 2014 period.

The main water user in Prek Thom is agriculture through irrigation. Figure 8-31 presents the monthly (l/s) and total (MCM) dry season water demand for Prek Thom, for each of the years 2003 – 2014. During this period there was supply from the Bassac either by gravity or a private pumping machine that is no longer operational. The calculation, however provides valuable insights in water availability and water use in the dry season. Expressing actual evapotranspiration as a flow indicates the likely requirements that must be provided to the crop from a combination of pumping from the prek by farmers and from rainfall and soil moisture storage and shallow groundwater.

Effective rainfall in the dry season is highly variable so pumping capacity should be capable to supply at least 80-90l/s in January and February and allowing for a less than perfect efficiency at least 100l/s should be available in the prek. Pumps that work only for a number of hours in day time may extract up to three times this amount for an 8-hour duration/day. The lower demand in March may have been due to the cropping pattern at the time. Interestingly, an upwards trend seems to be present over this period, which could be explained by natural/climate related phenomena such as shifts in timing of the preceding wet season or increased agricultural intensification.

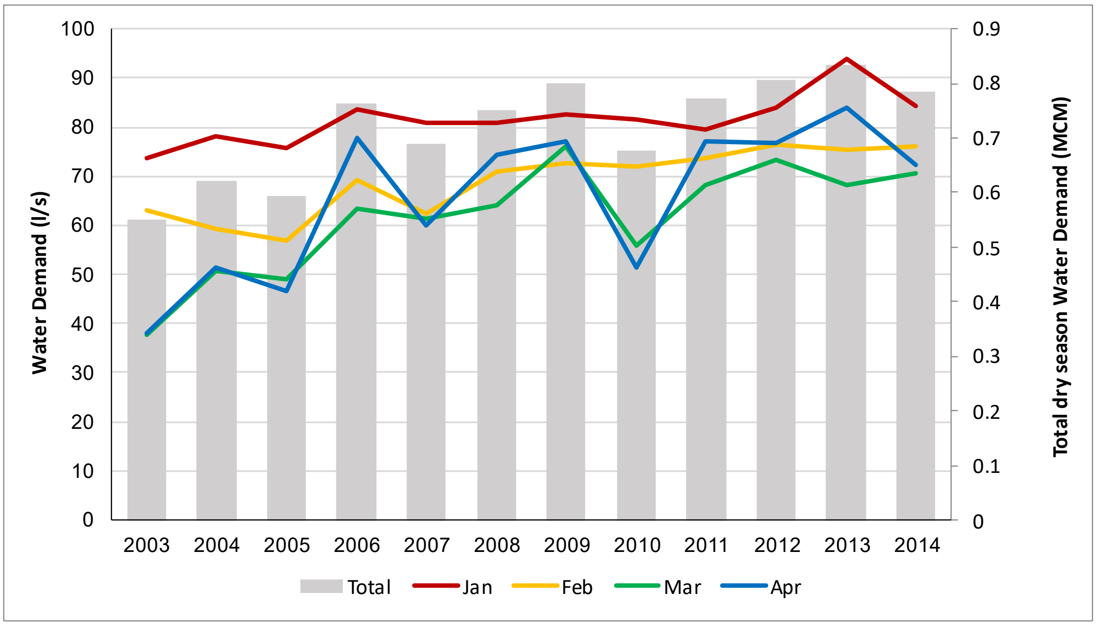


Figure 8-31. Average water demand (l/s) per month, as well as dry season totals (MCM), in Prek Thom during 2003 – 2014.

Other Water uses

Water from Prek Thom is used by different stakeholders and for different purposes. Apart from irrigation, water is used for domestic purposes (cooking, washing, house fixing etc.), livestock (drinking and cleaning), fishing (only during the wet season) and for access to fields and for crop transportation. A private water company provides households in the village with a domestic water supply line.

8.11.5 Tidal Levels

The tidal behaviour of the Prek Ambel differs to the Bassac which in turn differs to the Mekong which is a deeper channel and the tidal wave travels faster giving greater amplitude and giving rise to circulation between larger and more constrained channels.

Results were extracted from the Prek Cluster model to illustrate the differences as shown in Figure 8-32. It can be seen that it is expected that the level in the Bassac is predicted to be higher than in the Prek Ambel by around 0.2m but tidal fluctuation may only be around 0.15m. These results are with rehabilitation as most of the channel stays dry otherwise during this month. If the Prek Thom mouth becomes silted preventing inflow from the Bassac then the water level at the prek connection to Toul Khtom would be lower.

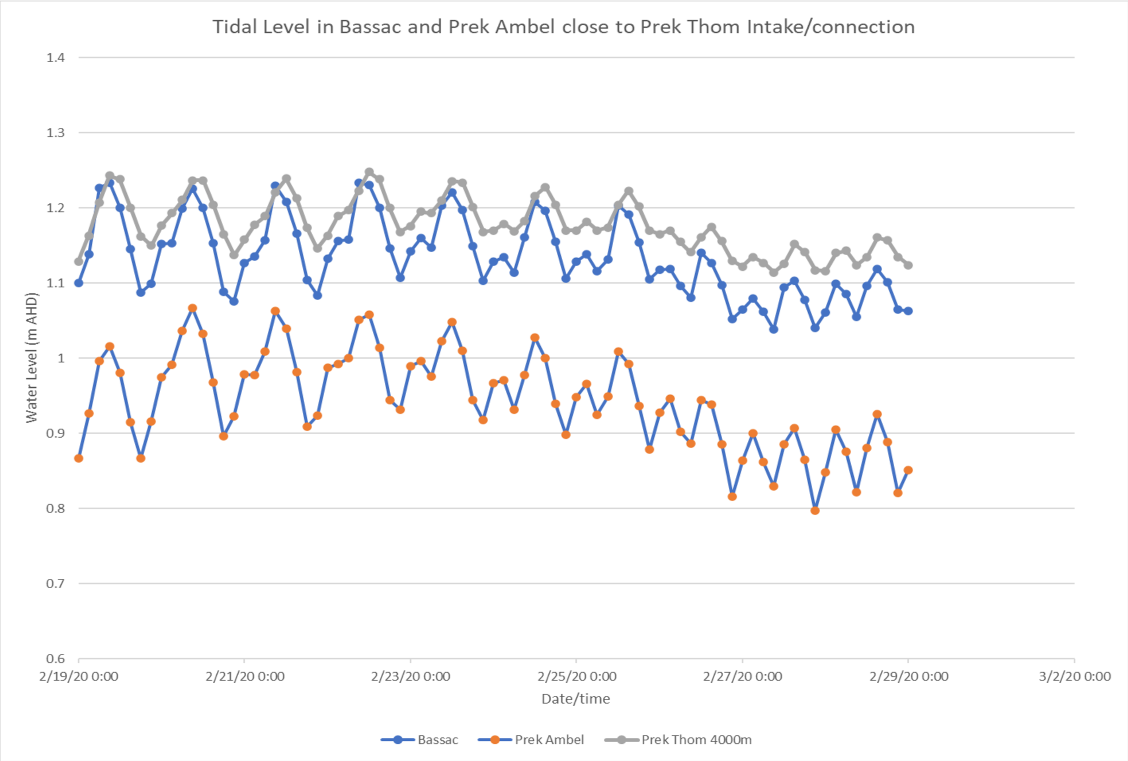


Figure 8-32 Simulated tidal levels in Prek Cluster model for Bassac, Prek Ambel and Prek Thom Ch4000 for rehabilitated channel

8.11.6 Tidal Flows

The flows driven by the tide vary with the upstream condition but also with the natural spring neap cycle. Without rehabilitation there is no connection through Prek Thom in the dry season but with rehabilitation there is a small net flow from the Bassac to the Prek Ambel but some reversal also as shown in Figure 8-33. The connection to the Ambel which serves part of the Boeung channel and land has a higher tidal activity that is enhanced by the Bassac connection. The tidal flux helps to reduce siltation in the channels though some parts of the existing channels are shallow. Even the Prek Thom near the Toul Khtom has a bed of 0.4m so a depth of around 1.1m.

8.12 **Prek Pra Theat**

8.12.1 Existing Situation

Prek Pra Theat is located south of Prek Thom and north of Prek Koh Teav at bridge N63 along the western embankment of the Bassac River. It’s a rather small Prek with a gross command area of 92 ha. The Prek has a length of 1,690 m. Interestingly, Prek

Pra Theat is not connected directly to the Toul Khtom Canal like most of its neighbours. The main water source of Prek Pra Theat is the Bassac River.

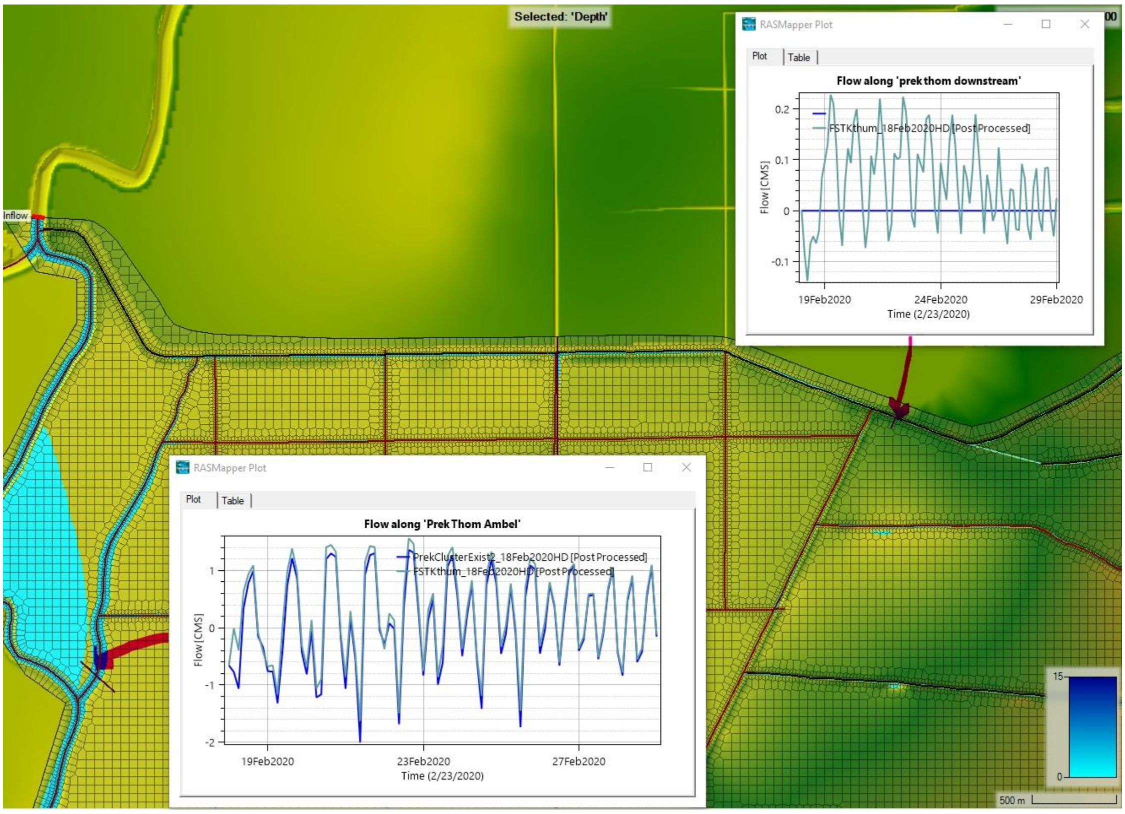


Figure 8-33 Modelled Tidal flows in Prek Thom after rehabilitation

Currently the bed level of Prek Pra Theat is 3 m higher than the lowest average monthly water levels in the Bassac River leaving the Prek without inflow of fresh water for 9 months a year (January – September). The result is a dry prek for 4 months a year, when all surface water has evaporated.

Since there is no connecting to the Toul Khtom canal it is not possible to use the tidal effect of the system to pump water during the dry season directly from surface water

According to the feasibility study of Prek Pra Theat, land use consists of the following characteristics, presented in Table 8.5

Table 8.5. Landuse classification in Prek Pra Theat.

Land use	Area (ha)	Percentage of Prek area (%)
Chamkar area	28	30
Cash crops / Annual crops	20	22
Rice area in Prek area	24	26
Rice area in Boeung	61	-
Colmatage area (Prek channel)	3	4

Residential area	17	18
Total Prek area	92	
Total Prek area + Boeung area	153	

Typical crops grown in the command area of Prek Pra Theat are mango and banana (in the Chamkar) and cash crops / annual crops such as maize and vegetables. The remaining agricultural land in used to produce rice (Figure 8-34).

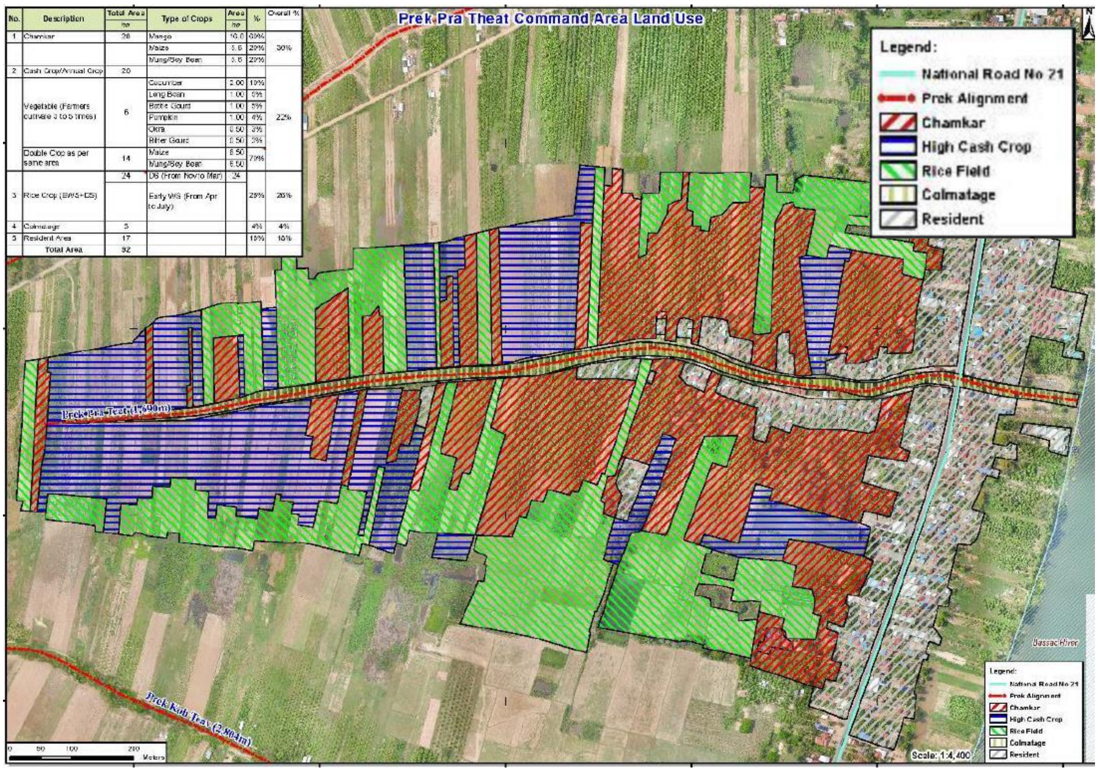


Figure 8-34. Landuse classification in Prek Pra Theat.

8.12.2 Rehabilitation otions

The feasibility report of Prek Pra Theat indicates different rehabilitation options for improved development of Prek Pra Theat. Improvements/interventions not only focus on infrastructural works, but also on more socio-economic interventions.

Some of the interventions that are proposed and affect water availability and water use are:

- Development of a Farmer Water Use Community (FWUC) for management of the water resources in a collective way;
- To construct a new connecting pipe and junction structure to connect Prek Thom with Prek Pra Theat for intake of water for irrigation when flow from the Bassac is not possible.
- Increase the storage capacity of the prek in order to harvest river water and more efficient pumping to the fields;

- Drainage improvements;
- Development of an urban sewage system.

To improve access to water, four alternative interventions have been identified. These options are:

1. Deep excavation of Prek Pra Theat.
2. Constructing of a junction structure connecting Prek Thom with Prek Pra Theat (pipeline) without rehabilitation of the first 750 m of the prek to prevent 25 houses from being affected (these 25 houses otherwise need to be removed/replaced)
3. Shallow excavation from the head and deep excavation from the tail of Prek Pra Theat with a junction structure connecting Prek Thom with Prek Pra Theat (pipeline).
4. Pumped irrigation system: construction of two concrete ponds that are filled with water from Bassac River (by gravity).

All options will yield benefits in terms of increased agricultural production, better infrastructure, formation of institutional structures and capacity building of farmers.

Option 2 is preferred in the feasibility study.

8.12.3 Flood season Analysis

The improvements in the Prek Pra Theat channel including connection to the Prek Thom were put in the model and the change in peak flows and water level were examined as shown in Table 8.6. There is a significant increase in the flow peak.

Table 8.6 Simulated Wet Season Flows and Water Levels Prek Pra Theat

Scenario Year	Simulated Peak Water Level (m AHT)	Simulated Peak Flow into Prek (m3/s) Existing Situatio	Simulated Peak Flow into Prek (m3/s) Option 3
2000	5.72	3.11	
2011	5.61	2.8	
2018	5.09	1.9	9.5
2019	5.0	1.7	9.0
2020	4.13	1.2	

Sentinel-1 imagery (2016-2021) was used to analyse analysis water occurrence during the wet season (Figure 8-35). The command area remains almost completely dry in the wet season, with a maximum water occurrence of 40% in a very small area in the southern part of the command area. This means that this small area is flooded during the wet season in 2 out of the 5 years.

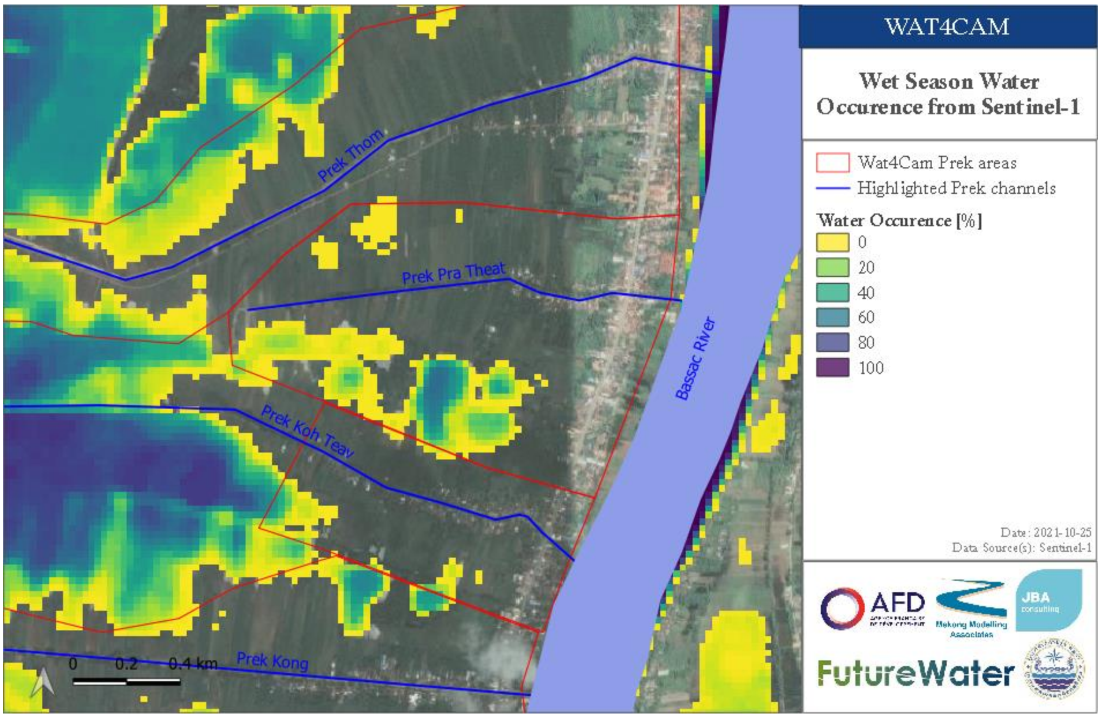


Figure 8-35. Water occurrences calculated for the wet season from Sentinel-1 imagery (August-November) using the full 2016-2020 series.

The trend shows that the water occurrence in the recent past (2010-2020) has been lower compared to the more distant past (1988-2010) in the prek area (Figure 8-36 and Figure 8-42). Water occurrence in the wet season has reduced by up to 50%.

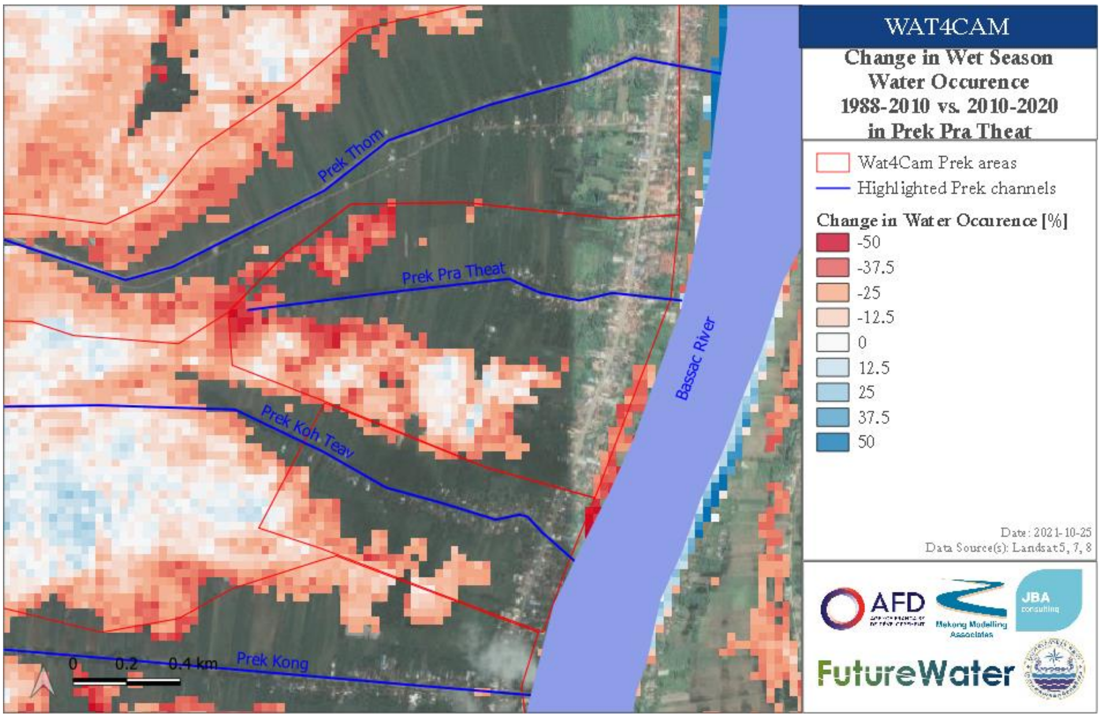


Figure 8-36. Change in Water occurrences calculated for the wet season from Landsat 5, 7 and 8 imagery (August-November) using the full 1988-2020 series.

8.12.4 Dry Season Analysis

As mentioned above during the dry season, water availability is limited. The main water user in Prek Pra Theat is agriculture through irrigation. Figure 8-37 presents ET_{act} totals for Prek Pra Theat in the dry season months, for each of the years 2003 – 2014.

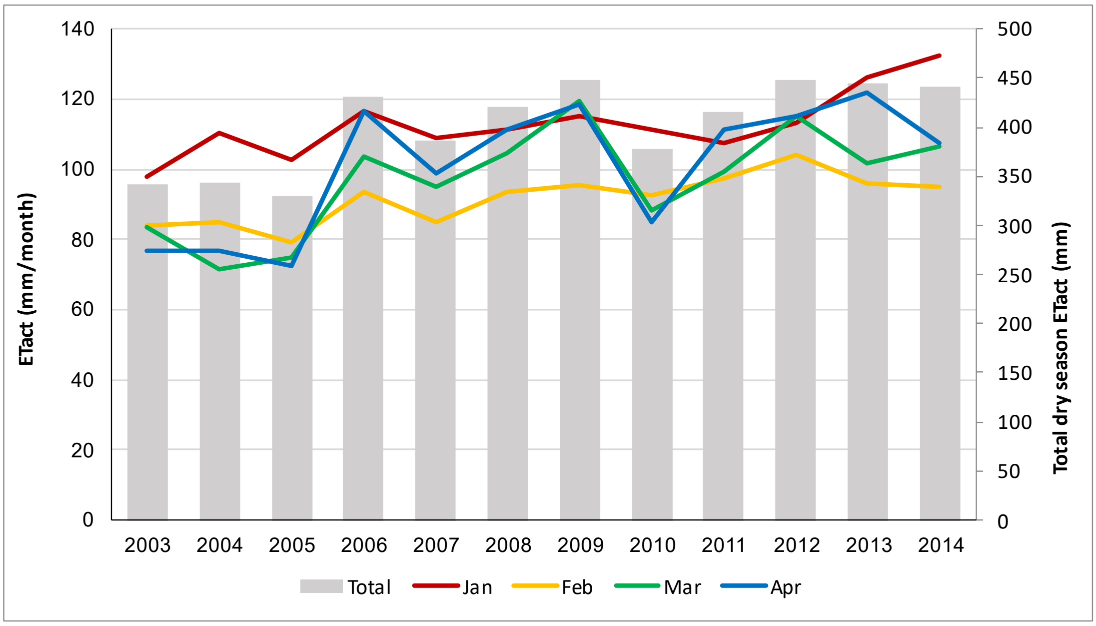


Figure 8-37. Average water consumption (ETact) per month, as well as dry season totals, in Prek Pra Theat during 2003 – 2014.

Figure 8-38 shows the consumptive water use of vegetation (agriculture) in the dry season (February – April) in Prek Pra Theat calculated from the Sentinel-2 imagery between 2003-2014. It shows that Prek Pra Theat consumes on average between 250 and 300 mm/dry season which compares well to the numbers presented in Figure 8-37.

Figure 8-39 presents the monthly (l/s) and total (MCM) dry season water demand for Prek Pra Theat, for each of the years 2003 – 2014. These numbers provide valuable insights in water availability and water use in the dry season. Interestingly, an upwards trend seems to be present over this period, which could be explained by natural/climate related phenomena such as shifts in timing of the preceding wet season or ongoing siltation due to fertile sediments from the prek resulting in increased elevation of the land and with that, increased agricultural area. It could also be the result of manmade interventions such as changes in land use and cropping patterns or increased water supply from an increasing number of tube wells. Per unit of land, the evaporation is lower than Prek Thom, indicating a more severe shortage of water, consistent with farmers needing to develop an alternative to the prek water by using tubewells.

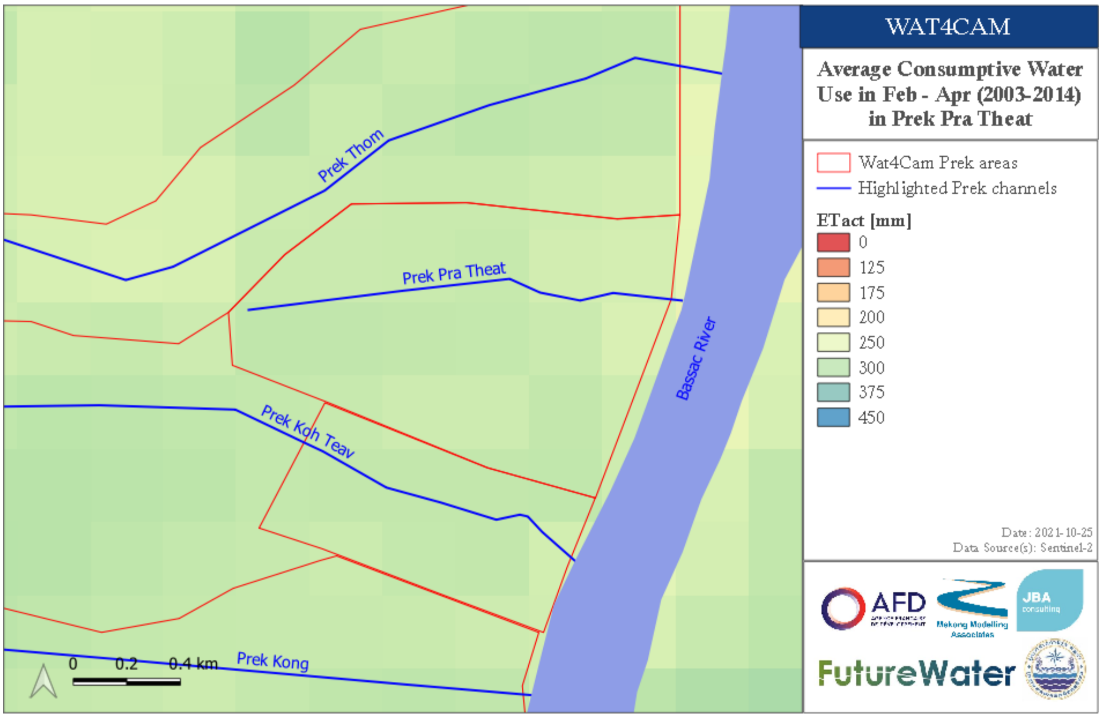


Figure 8-38. Actual evapotranspiration in the months February – April, averaged for the 2003 – 2014 period.

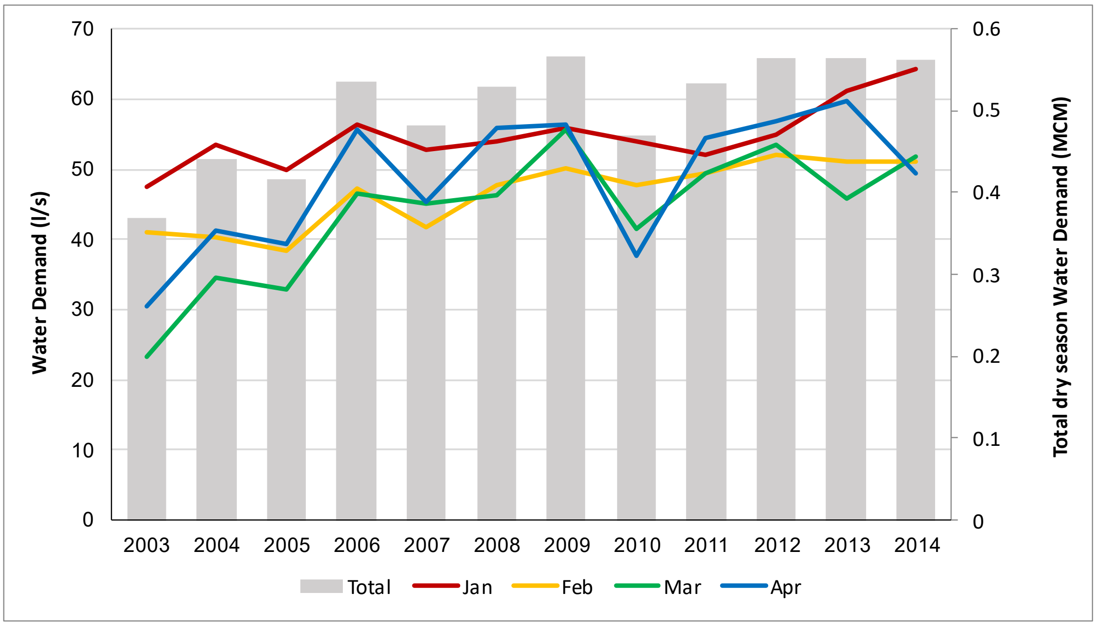


Figure 8-39. Average water demand (l/s) per month, as well as dry season totals (MCM), in Prek Pra Theat during 2003 – 2014.

<u>Other Water uses</u>

Water from Prek Pra Theat is used by different stakeholders and for different purposes. Apart from irrigation, water is used for domestic purposes (cooking, washing, house fixing etc.), livestock (drinking and cleaning), fishing (only during the wet season) and for access to fields and for crop transportation. A private water company provides households in the village with a domestic water supply line.

8.12.5 Tidal Flow and Level

As it is proposed that Prek Pra Theat will be connected to Prek Thom, the situation will be similar to that described in section 8.11.5.

8.13 Prek Koh Teav

Prek Koh Teav is located south of Prek Pra Theat and north of Prek Kong at bridge 64 along the western embankment of the Bassac River. It's a Prek with a gross command area of 171 ha. The Prek has a length of 2,804 m. Interestingly, Prek Koh Teav is not connected directly to the Toul Khtom Canal like most of its neighbours.
The main water sources of Prek Koh Teav are the Bassac River during high flows in the Bassac river and indirectly from the larger Prek Ambel through the downstream located Prek Tiev and small drainage channels during the dry months.

8.13.1 Baseline situation

Currently the bed level of Prek Koh Teav is 5 m higher than the lowest average monthly water levels in the Bassac River leaving the prek without inflow of fresh water for almost 7 months a year (December – June). The result is a dry prek for 5 months a year, when all surface water has evaporated.

Due to the tidal effect in the system, at the tail ends of the Prek farmers are able to access water in the Toul Khtom Canal when the tide is high. Using pumps, they can irrigate their crops during limited periods of time. Next to these pumps, several farmers in the Prek have installed tube wells (23 wells in total), for irrigating crops with ground water.
According to the feasibility study of Prek Koh Teav, landuse in Prek Koh Teav consists of the following characteristics, presented in Table 8.7.

Table 8.7. Landuse classification in Prek Koh Teav.

Land use	Area (ha)	Percentage of Prek area (%)
Chamkar area	29	17
Cash crops / Annual crops	36	21
Rice area in Prek area	88	51
Rice area in Boeung	132	-
Colmatage area (Prek channel)	4	2

Residential area	14	8
Total Prek area	171	
Total Prek area + Boeung area	303	

Typical crops grown in the command area of Prek Koh Teav are Mango and Banana (in the Chamkar) and cash crops / annual crops such as maize and vegetables. The remaining agricultural land in used to produce rice (Figure 8-40).

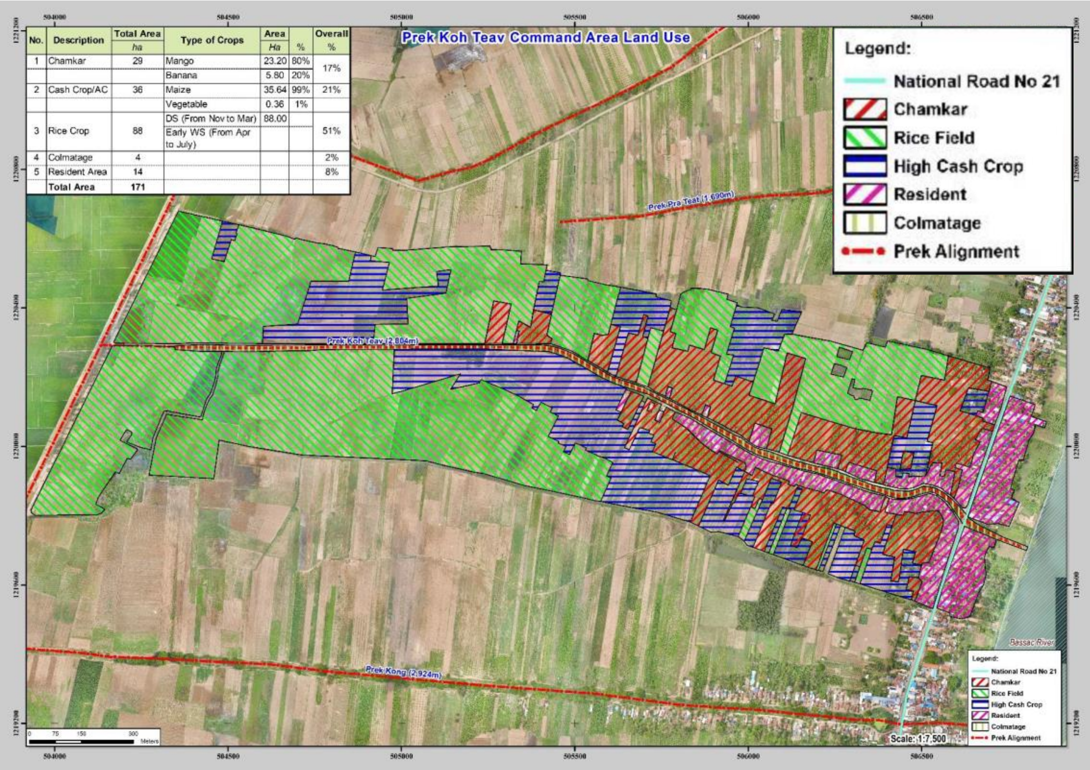


Figure 8-40. Landuse classification in Prek Koh Teav.

8.13.2 Rehabilitation Options

The feasibility report of Prek Koh Teav indicates different rehabilitation options for improved development of Prek Koh Teav. Improvements/interventions not only focus on infrastructural works, but also on more socio-economic interventions.

Some of the interventions that are proposed and affect water availability and water use are:

- Development of a Farmer Water Use Community (FWUC) for management of the water resources in a collective way;
- To construct a new tail end and connect Prek Koh Teav with the Toul Khtom Canal directly;
- Increase the storage capacity of the prek in order to harvest river water and more efficient pumping to the fields;
- Drainage improvements;

- Development of an urban sewage system.

To improve access to water, three interventions have been identified (called alternatives). These options are:

1. Deep excavation of Prek Koh Teav.
2. Shallow excavation of Prek Koh Teav without rehabilitation of the first 700 m of the Prek to prevent 2 houses from being affected (these 2 houses otherwise need to be removed/replaced)
3. Shallow excavation of Prek Koh Teav of the entire Prek including the first 700 m.

All options will yield benefits in terms of increased agricultural production, better infrastructure, formation of institutional structures and capacity building of farmers.

Option 3 is preferred in the feasibility study.

8.13.3 Flood season Analysis

The improvements in the Prek Koh Teav channel were put in the model and the change in peak flows and water level were examined as shown in Table 8.8. There is a significant increase in the flow peak.

Table 8.8 Simulated Peak Food flows in Prek Koh Teav existing and rehabilitation option

Scenario Year	Simulated Peak Water Level (m AHT)	Simulated Peak Flow into Prek (m3/s)	Simulated Peak Flow into Prek (m3/s) Option 2
2000	5.71		
2011	5.58		
2018	5.06	2.8	15.4
2019	4.96	2.3	14.6
2020	4.08	1.2	

Sentinel-1 imagery (2016-2021) was used to analyse analysis water occurrence during the wet season (Figure 8-41). The Chamkar area remains almost completely dry in the wet season, however, the occurrence of water is much higher at the tail end of Prek Koh Teav in the rice fields. This means that these areas are flooded during the wet season in 4 out of the 5 years.

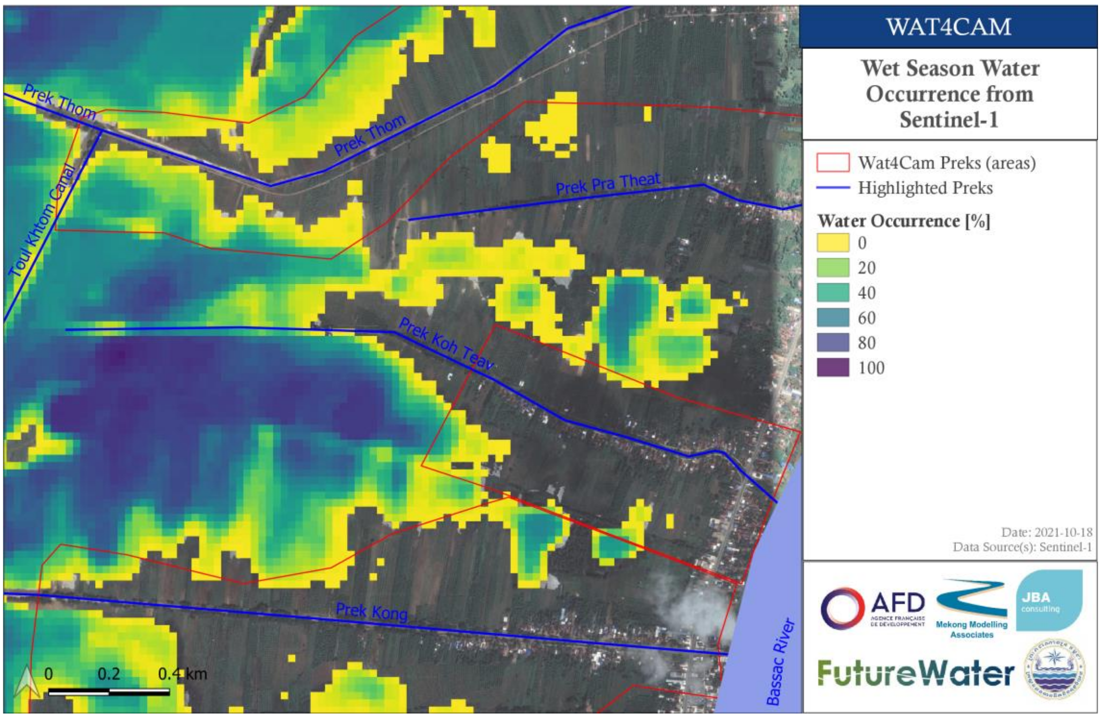


Figure 8-41. Water occurrences calculated for the wet season from Sentinel-1 imagery (August-November) using the full 2016-2020 series.

The trend shows that the water occurrence in the recent past (2010-2020) has been lower compared to the more distant past (1988-2010) in the prek area (Figure 8-42). Water occurrence in the wet season has reduced with about 25%. At the tail ends of Prek Koh Teav interestingly, water occurrence has also increased with up to 25%. This could be the result of irrigating through pumping from the Toul Khtom Canal when possible or from the tube wells that have been installed in the more recent past.

8.13.4 Dry Season

As mentioned above during the dry season, water availability is limited. Using Sentinel-2 satellite data derived NDVI values, the percentage of agricultural land that lies fallow in the dry season was calculated for all the preks. The analysis shows that for Prek Koh Teav, 29% of the agricultural land lies fallow in the dry season which ranks it 5th highest of all Preks along the Bassac river (Figure 8-43).

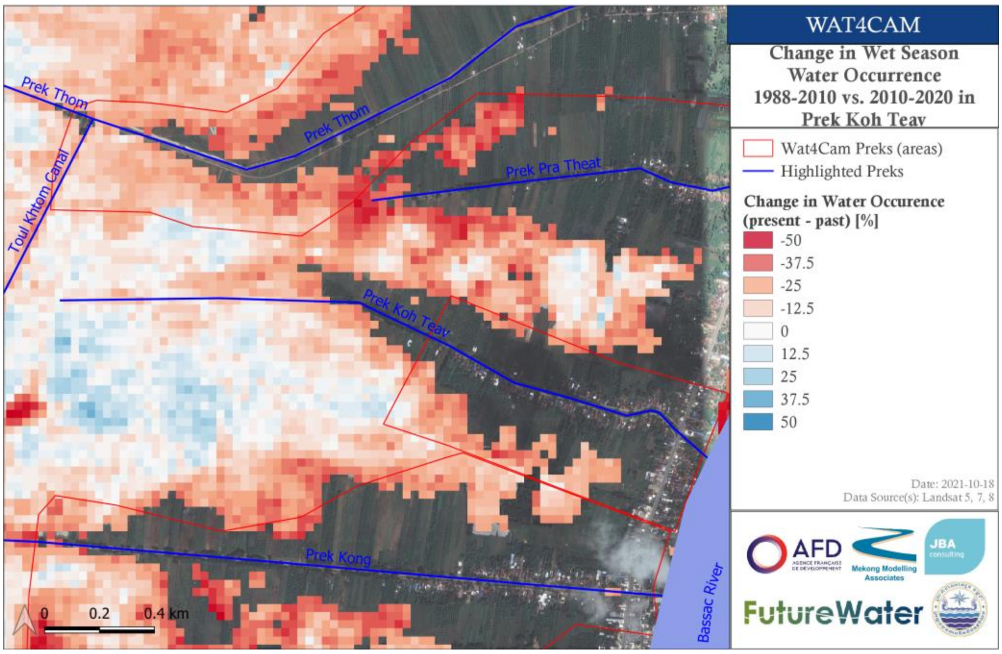


Figure 8-42. Change in Water occurrences calculated for the wet season from Landsat 5, 7 and 8 imagery (August-November) using the full 1988-2020 series.

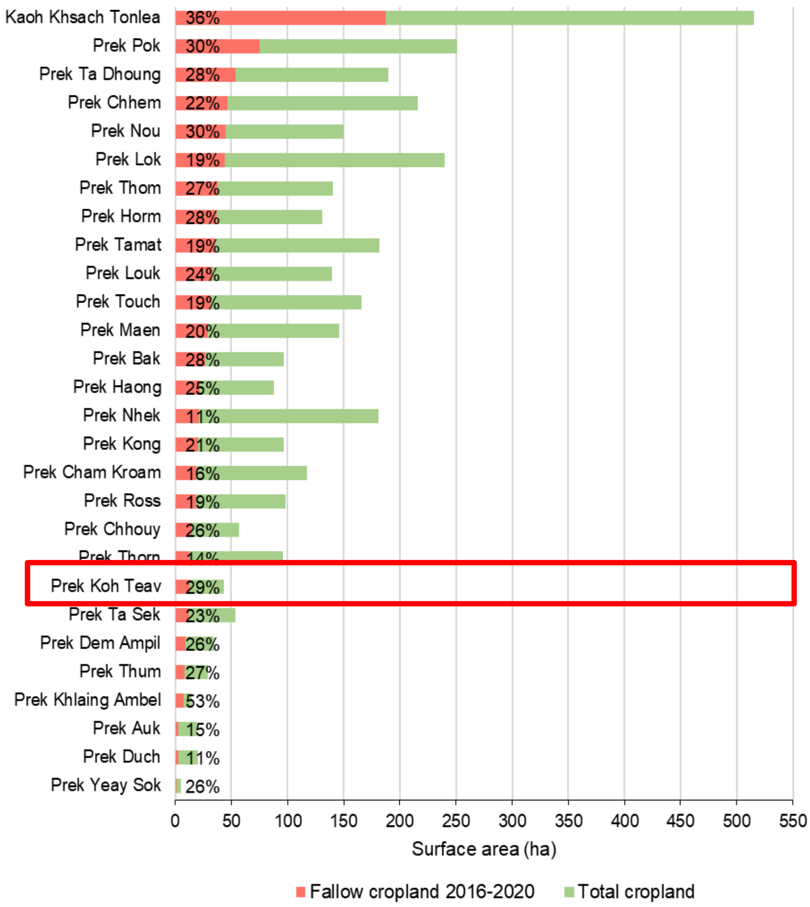


Figure 8-43. Area of cropland left fallow in the months February – April on average in years 2016 – 2020 (Bassac River).

The main water user in Prek Koh Teav is agriculture through irrigation. Figure 8-44 presents ET_{act} totals for Prek Koh Teav in the dry season months, for each of the years 2003 – 2014. This ET_{act} provide valuable insights in water availability and water use in the dry season. Interestingly, an upwards trend seems to be present over this period, which could be explained by natural/climate related phenomena such as shifts in timing of the preceding wet season or ongoing siltation due to fertile sediments from the prek resulting in increased elevation of the land and with that, increased agricultural area. It could also be the result of manmade interventions such as changes in land use and cropping patterns or increased water supply from an increasing number of tube wells.

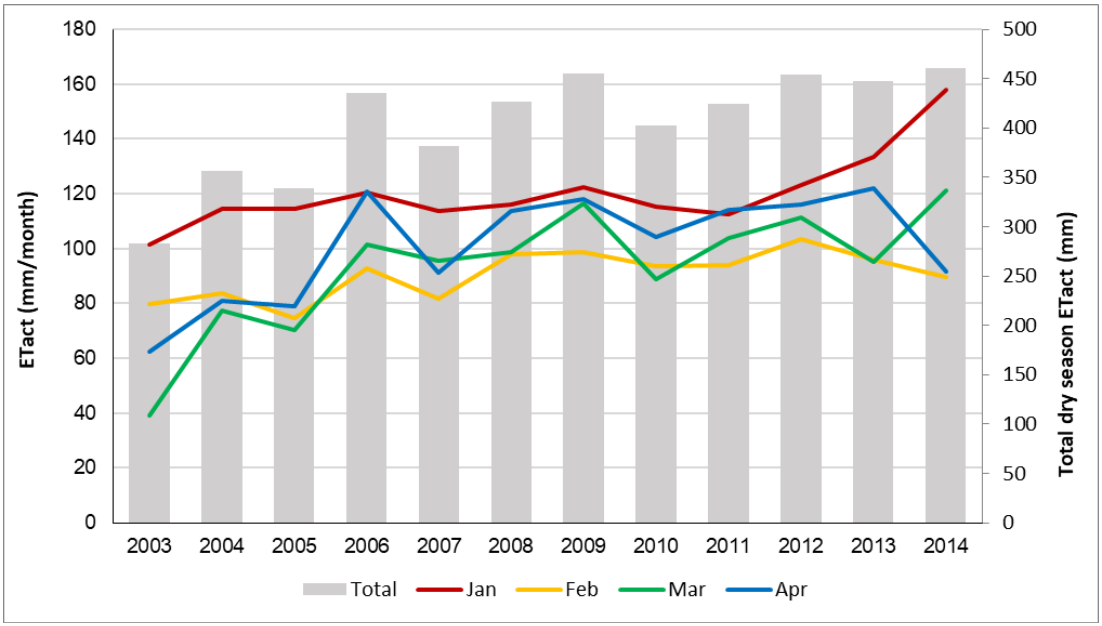


Figure 8-44. Average water consumption (ETact) per month, as well as dry season totals, in Prek Koh Teav during 2003 – 2014.

Figure 8-45 shows the consumptive water use of vegetation (agriculture) in the dry season (February – April) in Prek Koh Teav calculated from the Sentinel-2 imagery between 2003-2014. It shows that Prek Koh Teav consumes on average between 300-375 mm/dry season which compares well to the numbers presented in Figure 8-44.

The main water user in Prek Koh Teav is agriculture through irrigation. Figure 8-44 presents the monthly (l/s) and total (MCM) dry season water demand for Prek Koh Teav, for each of the years 2003 – 2014. These numbers provide valuable insights in water availability and water use in the dry season. Interestingly, an upwards trend seems to be present over this period, which could be explained by natural/climate related phenomena such as shifts in timing of the preceding wet season or ongoing siltation due to fertile sediments from the prek resulting in increased elevation of the land and with that, increased agricultural area. It could also be the result of manmade interventions such as changes in land use and cropping patterns or increased water supply from an increasing number of tube wells.

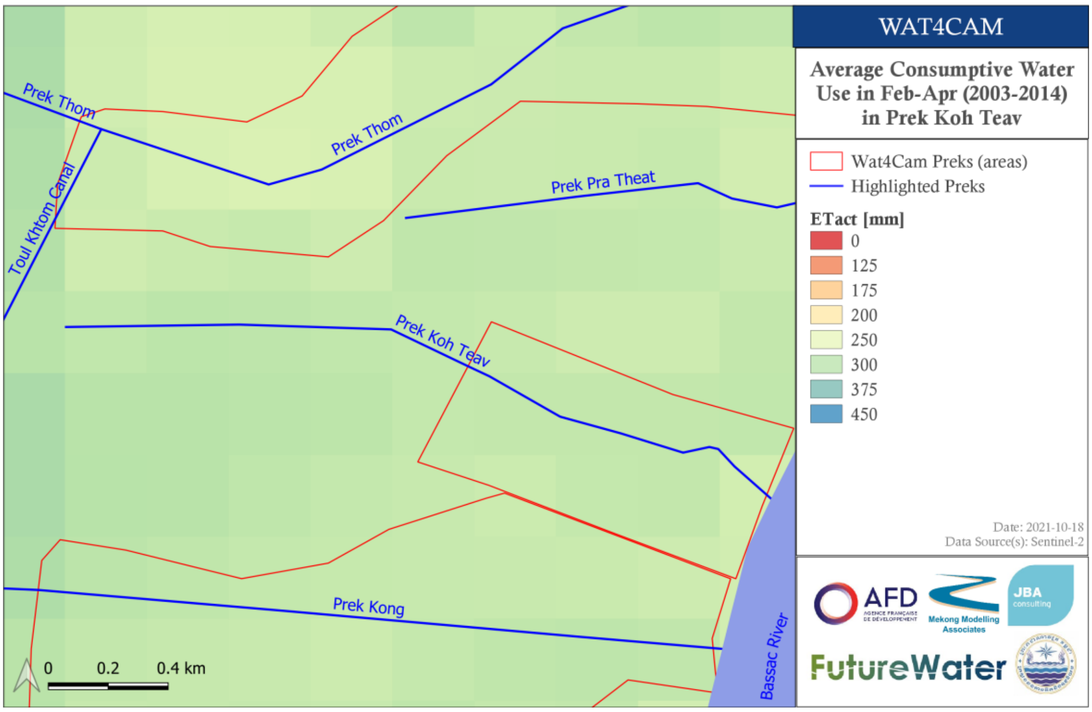


Figure 8-45. Actual evapotranspiration in the months February – April, averaged for the 2003 – 2014 period.

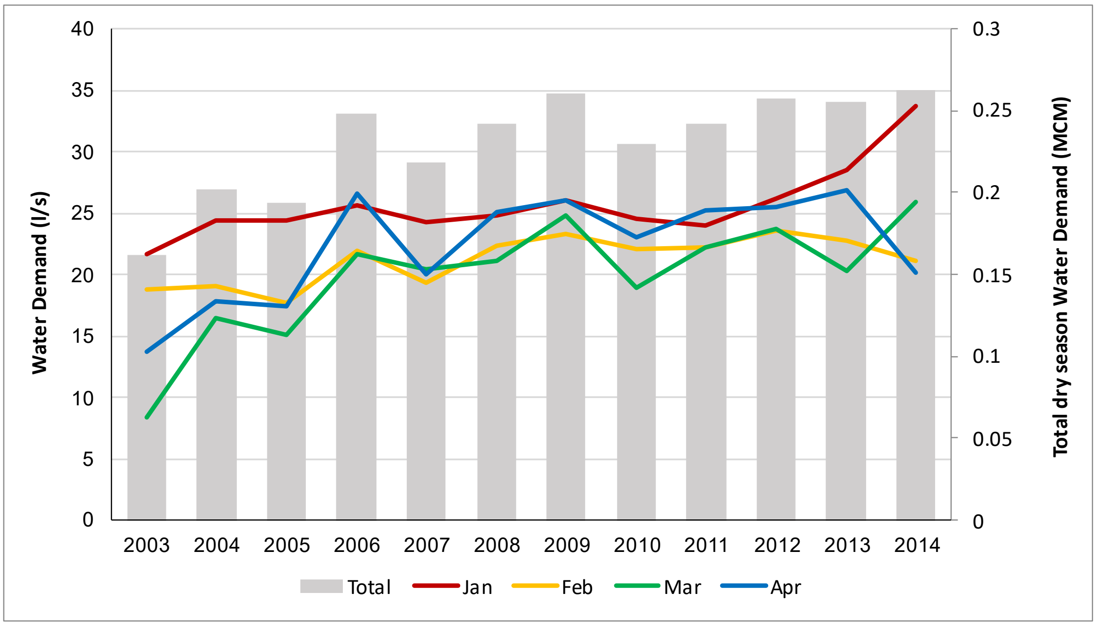


Figure 8-46. Average water demand (l/s) per month, as well as dry season totals (MCM), in Prek Koh Teav during 2003 – 2014.

<u>Other Water uses</u>

Water from Prek Koh Teav is used by different stakeholders and for different purposes. Apart from irrigation, water is used for domestic purposes (cooking, washing, house fixing etc.), livestock (drinking and cleaning), fishing (only during the wet season) and for access to fields and for crop transportation. A private water company provides households in the village with a domestic water supply line.

8.13.5 Tidal Levels and Flows

During periods of low water level there is no flow from the Bassac into Prek Koh Teav and it is expected that tidal flows and a flapped structure at the tail would be able to ‘pump’ sufficient water back up the prek for irrigation requirements. The initial modelling had no flow in the area prior to lowering of the bed of Toul Khtom to an assumed -0.5m near to the central River Prek, Prek Teav. With this work it was then possible to get a backflow up tp Prek Koh Teav and flows as shown in were simulated without a flap gate. The water level at the proposed location of a flap gate is similar to that in Prek Thom.

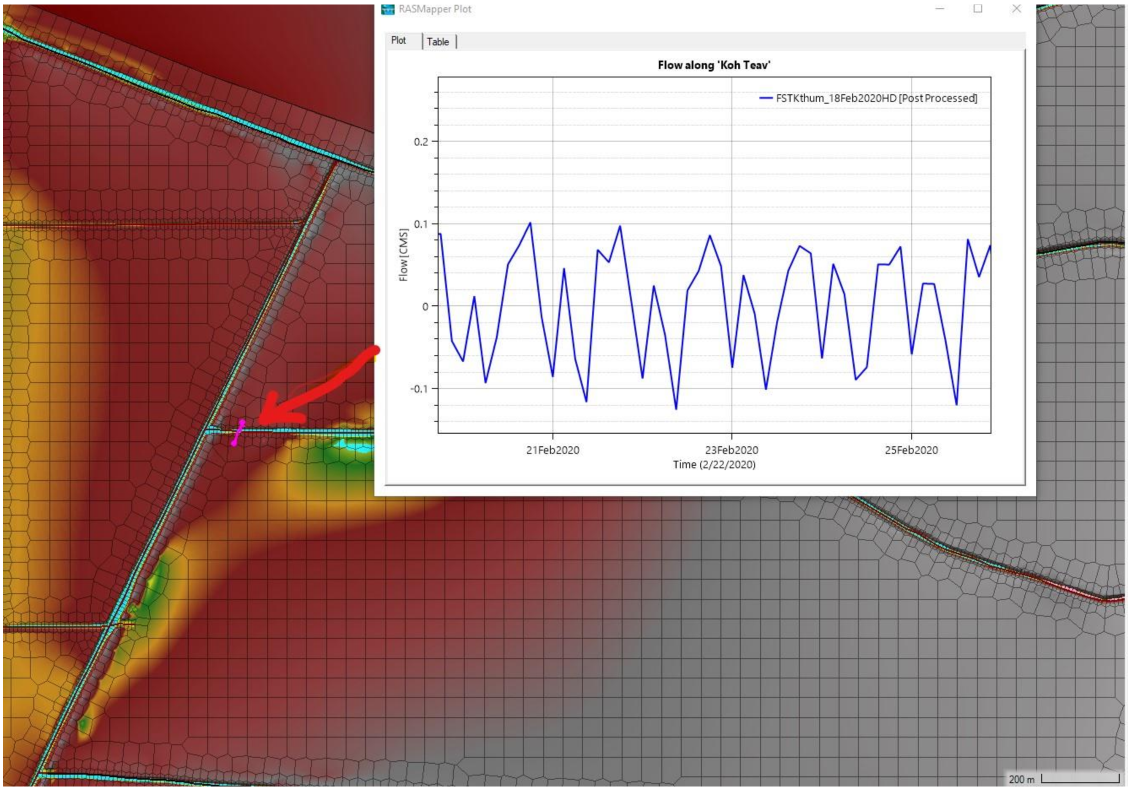


Figure 8-47 Modelled Flow at the outfall of Prek Koh Teav simulated during dry season

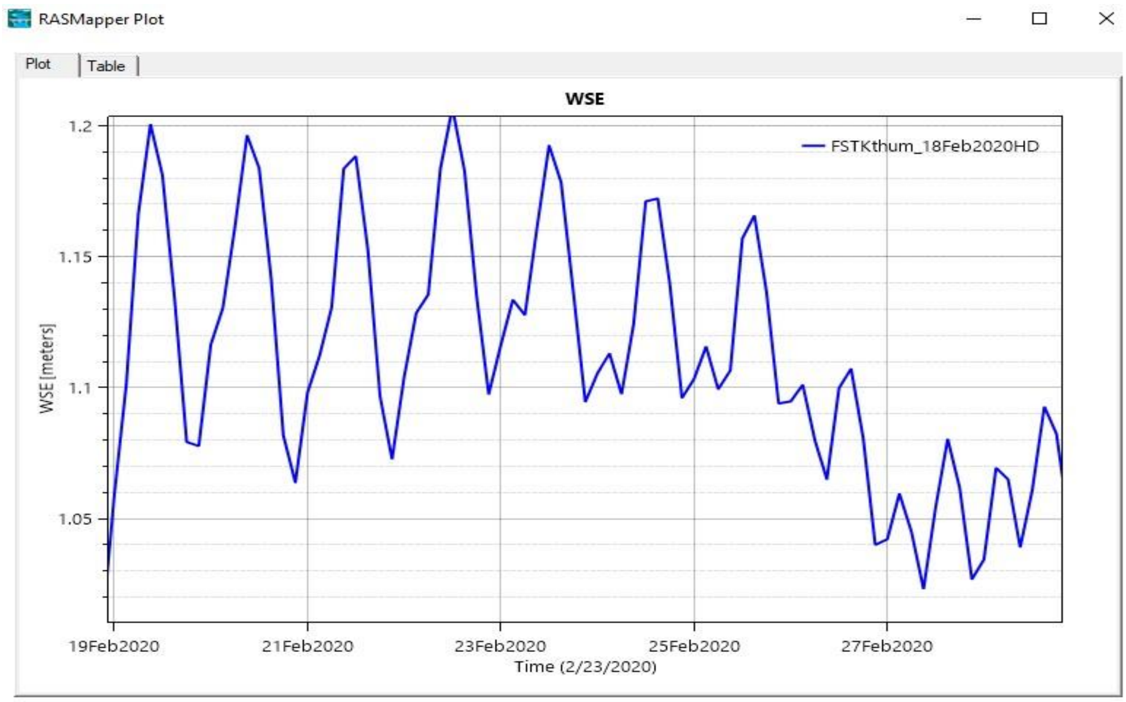


Figure 8-48 Water Level at Junction of Prek Koh Teav with Toul Khtom

It is suggested that with the relatively low tidal variation, the use of a flap gate that inevitably introduces further head losses and maintenance issues would not be worthwhile and would have issues to pass the high flood flows.

8.14 Prek Kong

Prek Kong is located south of Prek Koh Teav and north of Prek Tiev at bridge N65 along the western embankment of the Bassac River. It is a prek with a gross command area of 227 ha. The main water sources of Prek Kong are the Bassac River during high flows in the Bassac river and the Toul Khtom canal during the dry months at the tail ends of the prek.

8.14.1 Baseline situation

Currently the bed level of Prek Kong is 3 m higher than the lowest average monthly water levels in the Bassac River leaving the prek without inflow of fresh water for at least 6 months a year (January – June). Since no pumps are installed, the result is a dry Prek for 6 months a year, when all surface water has evaporated.

Due to the tidal effect in the system, at the tail ends of the prek farmers are able to access water in the Toul Khtom Canal when the tide is high. Using pumps, they can irrigate their crops during limited periods of time. Next to these pumps, several farmers in the Prek have installed tube wells (13 wells in total), for irrigating crops with ground water.

According to the feasibility study of Prek Kong, landuse in Prek Kong consists of the following characteristics, presented Table 8.9.

Table 8.9. Landuse classification in Prek Kong.

Land use	Area (ha)	Percentage of Prek area (%)
Chamkar area	35	15
Cash crops / Annual crops	84	35
Rice area in Prek area	85	35
Rice area in Boeung	123	-
Colmatage area (Prek channel)	6	2
Residential area	30	12
Total Prek area	240	
Total Prek area + Boeung area	363	

Typical crops grown in the command area of Prek Kong are predominantly Mango but also Banana and Melaleuca are grown closer to the drains or lower areas with better access to the groundwater table (in the chamkar). Cash crops / annual crops that are grown are maize (70%), bottle gourd (10%), pumpkin (8%), eggplant (7%) and papaya (5%). The remaining agricultural land in used to produce rice (Figure 8-49).

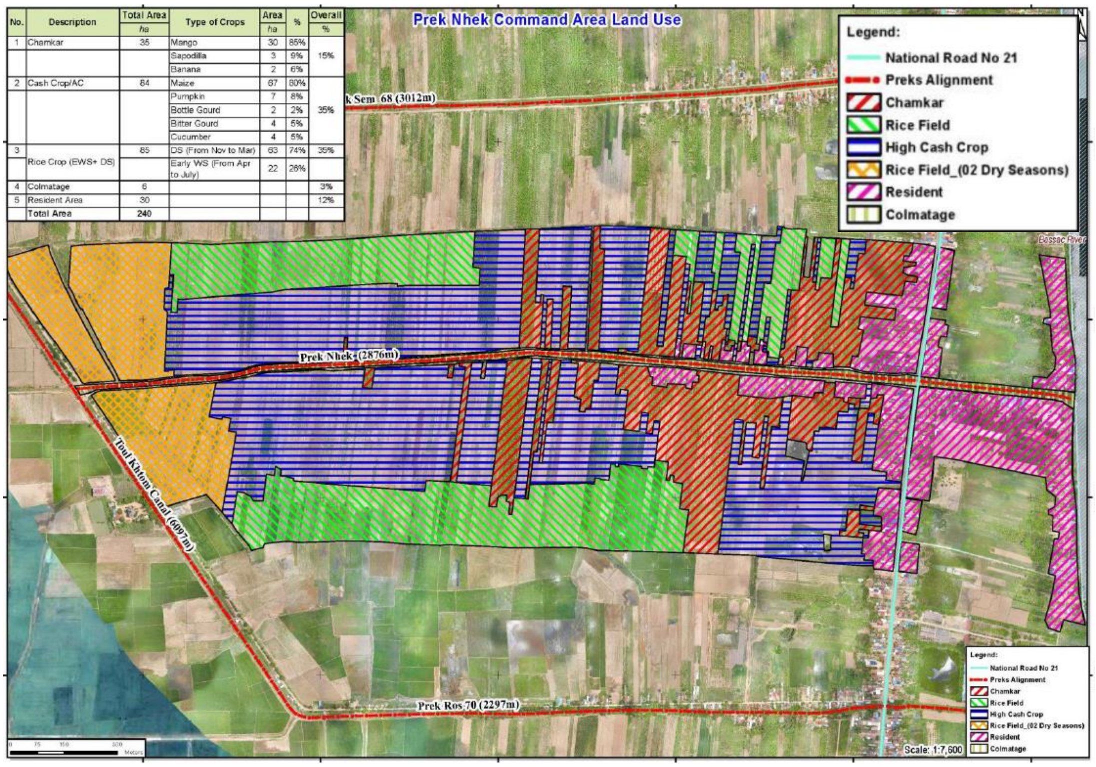


Figure 8-49. Landuse classification in Prek Kong.

8.14.2 Rehabilitation Options

The feasibility report of Prek Kong indicates different rehabilitation options for improved development of Prek Kong. Improvements/interventions not only focus on infrastructural works, but also on more socio-economic interventions.

Some of the interventions that are proposed and affect water availability and water use are:

- Development of a Farmer Water Use Community (FWUC) for management of the water resources in a collective way;
- To construct a new tail structure at the junction of the Toul Khtom canal;
- Increase the storage capacity of the prek in order to harvest river water and more efficient pumping to the fields;
- Drainage improvements;
- Development of an urban sewage system.

To improve access to water, three interventions have been identified (called alternatives). These options are:

1. Deep excavation of Prek Kong.
2. Shallow excavation of Prek Kong without rehabilitation of the first 800 m of the Prek to prevent 28 houses from being affected (these 28 houses otherwise need to be removed/replaced)
3. Shallow excavation of Prek Kong of the entire prek including the first 800 m.

All options will yield benefits in terms of increased agricultural production, better infrastructure, formation of institutional structures and capacity building of farmers. Option 3 is the preferred option according to the feasibility study.

8.14.3 Flood season Analysis

The improvements in the Prek Kong channel were put in the model and the change in peak flows and water level were examined as shown in Table 8.10. There is a marginal increase in the flow peak to 14m^3/s in a flood of 2018 magnitude.

Table 8.10 Simulated peak flows and levels in Prek Kong

Scenario Year	Simulated Peak Water Level (m AHT)	Simulated Peak Flow into Prek (m^3/s)	Simulated Peak Flow into Prek (m^3/s) Option 2
2000	5.68	7.6	
2011	5.57	7.2	
2018	5.04	13.0	14.0

Scenario Year	Simulated Peak Water Level (m AHT)	Simulated Peak Flow into Prek (m^3/s)	Simulated Peak Flow into Prek (m^3/s) Option 2
2019	4.95	12.0	13.2
2020	4.05	0.2	

Sentinel-1 imagery (2016-2021) was used to analyse analysis water occurrence during the wet season (Figure 8-50). The command area remains almost completely dry in the wet season; however, the occurrence of water is significant (40%) at the tail end (south) of Prek Kong in the rice fields. This means that these areas are flooded during the wet season in 2 out of the 5 years.

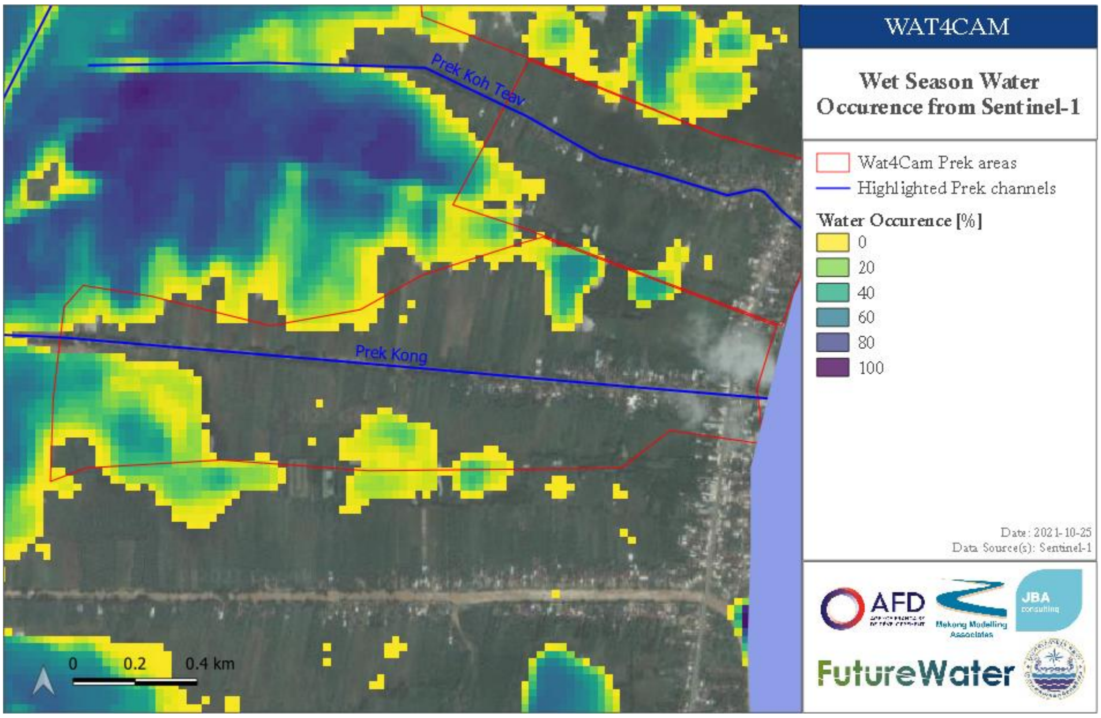


Figure 8-50. Water occurrences calculated for the wet season from Sentinel-1 imagery (August-November) using the full 2016-2020 series.

The trend shows that the water occurrence in the recent past (2010-2020) has been lower compared to the more distant past (1988-2010) in the Prek area (Figure 8-51). Water occurrence in the wet season has reduced with about 0% to 50%. There are some pixels that show an increase in wet water occurrence. This could be the result of irrigating through pumping from the Toul Khtom Canal when possible or from the tube wells that have been installed in the more recent past.

8.14.4 Dry Season Analysis

As mentioned above during the dry season, water availability is limited. Using Sentinel-2 satellite data derived NDVI values, the percentage of agricultural land that lies fallow in the dry season was calculated for all the Preks. The analysis shows that for Prek Kong, 21% of the agricultural land lies fallow in the dry season. This is a low to average percentage of fallow land compared to other Preks (Figure 8-52).

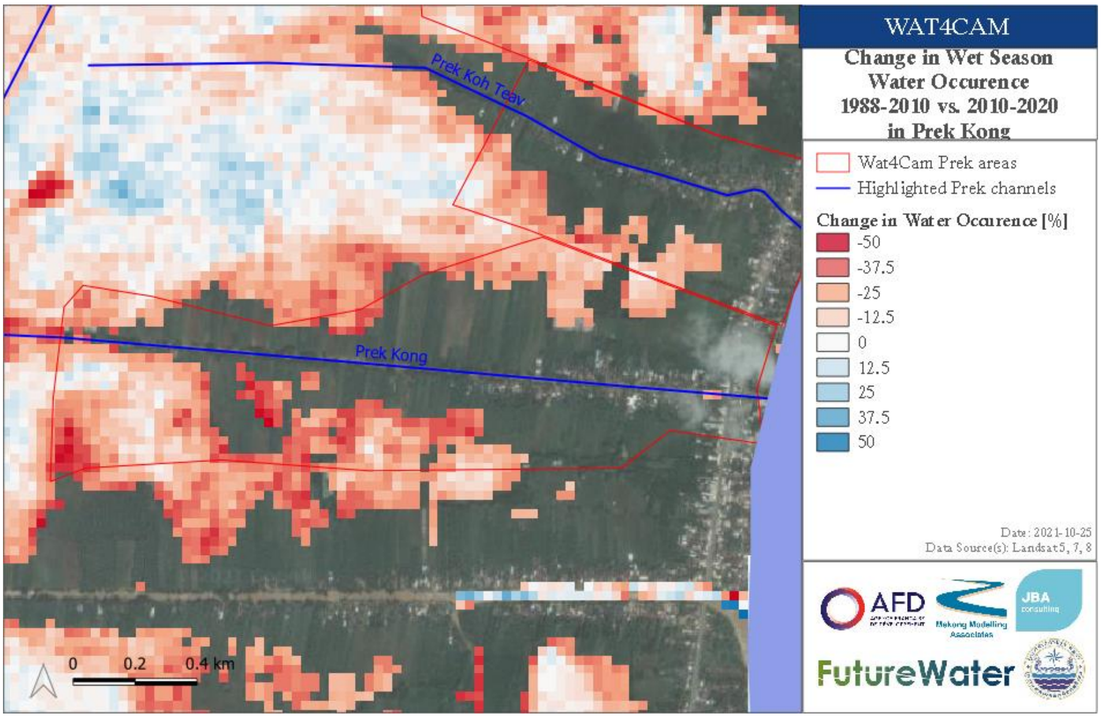


Figure 8-51. Change in Water occurrences calculated for the wet season from Landsat 5, 7 and 8 imagery (August-November) using the full 1988-2020 series.

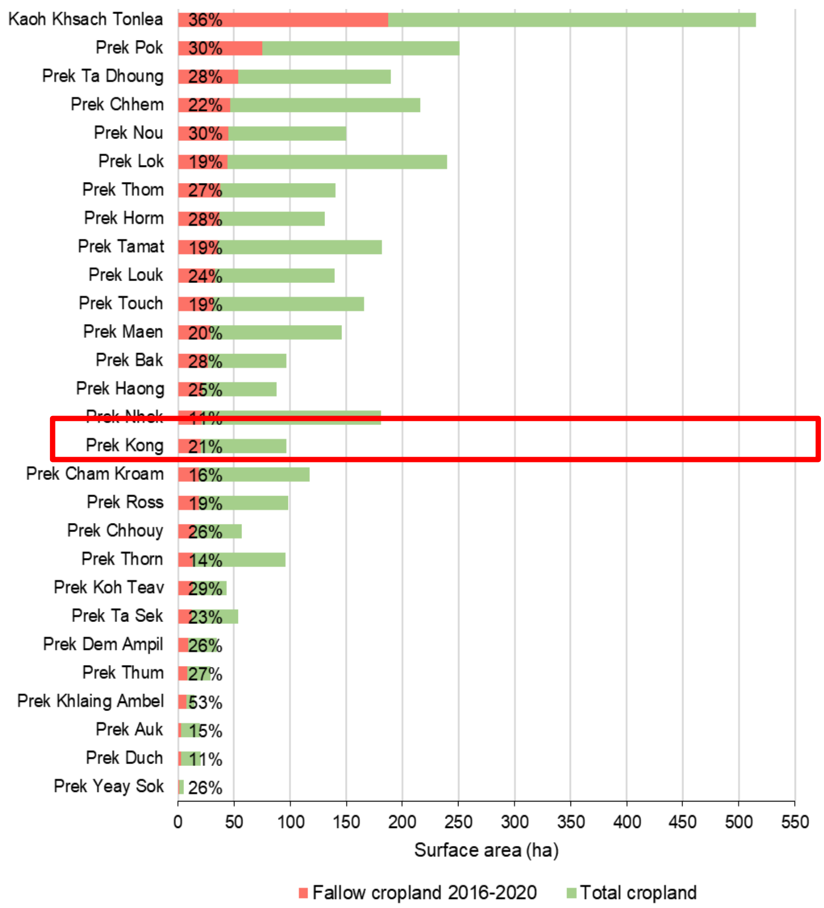


Figure 8-52. Area of cropland left fallow in the months February – April on average in years 2016 – 2020 (Bassac River).

The main water user in Prek Kong is agriculture through irrigation. Figure 8-53 presents ET_{act} totals for Prek Kong in the dry season months, for each of the years 2003 – 2014. It shows that Prek Kong consumes on average around 300 mm/dry season.

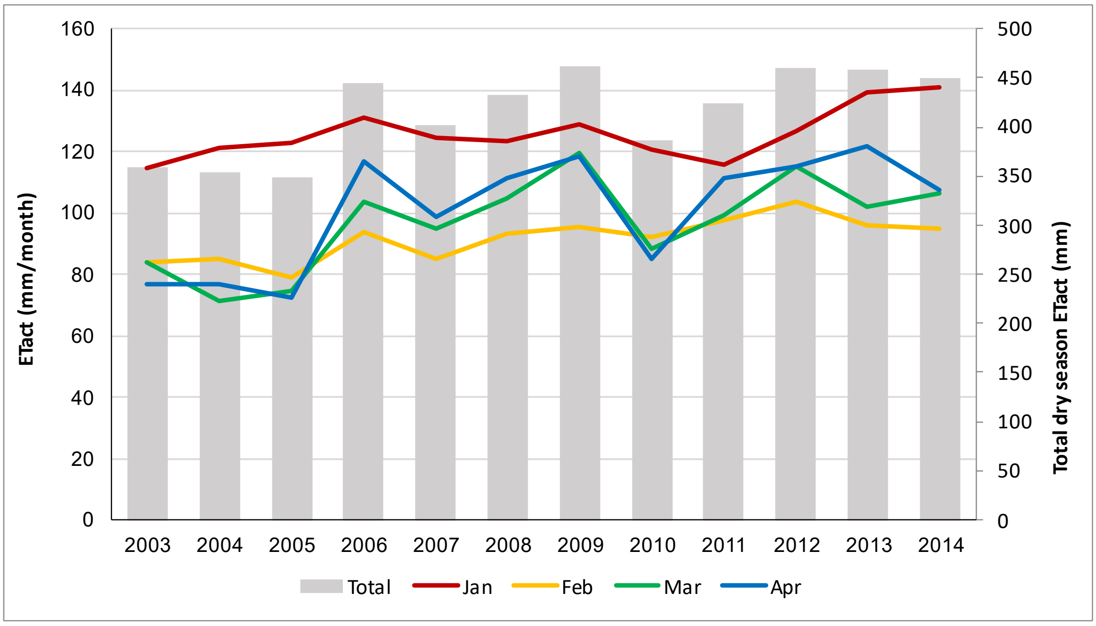


Figure 8-53. Average water consumption (ETact) per month, as well as dry season totals, in Prek Kong during 2003 – 2014.

Figure 8-54 shows the consumptive water use of vegetation (agriculture) in the dry season (February – April) in Prek Kong calculated from the Sentinel-2 imagery between 2003-2014. It shows that Prek Kong consumes on average around 300 mm/dry season which compares well to the numbers presented in Figure 8-53.

The main water user in Prek Kong is agriculture through irrigation. Figure 8-53 presents the monthly (l/s) and total (MCM) dry season water demand for Prek Kong, for each of the years 2003 – 2014. These numbers provide valuable insights in water availability and water use in the dry season. Interestingly, an upwards trend seems to be present over this period, which could be explained by natural/climate related phenomena such as shifts in timing of the preceding wet season or ongoing siltation due to fertile sediments from the Prek resulting in increased elevation of the land and with that, increased agricultural area. It could also be the result of manmade interventions such as changes in land use and cropping patterns or increased water supply from an increasing number of tube wells.

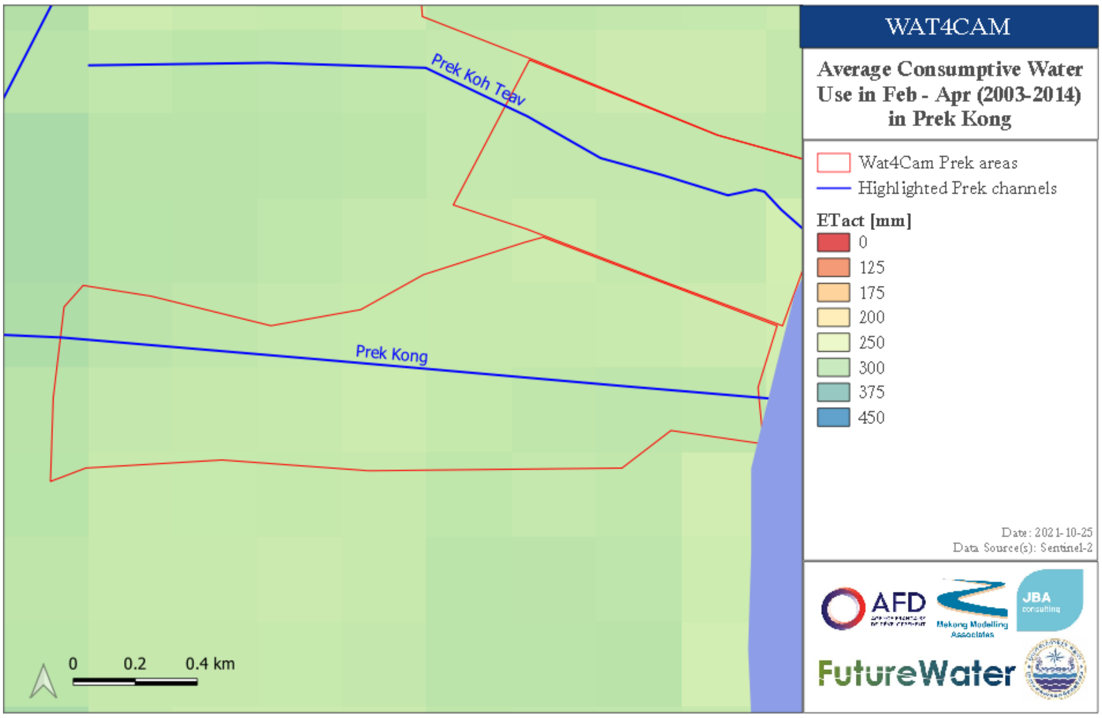


Figure 8-54. Actual evapotranspiration in the months February – April, averaged for the 2003 – 2014 period.

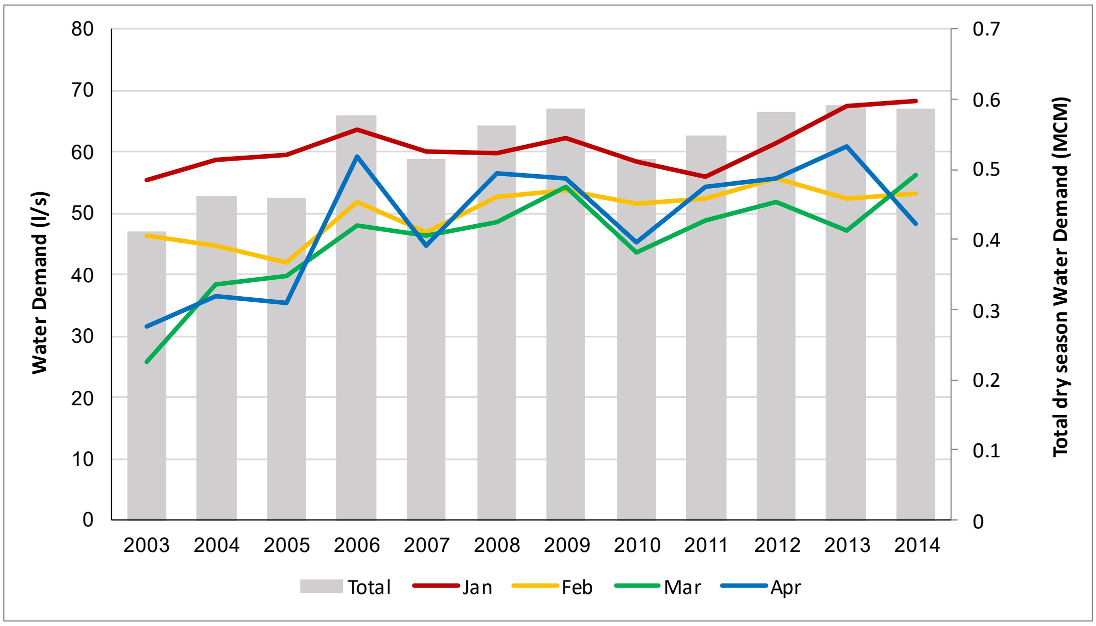


Figure 8-55. Average water demand (l/s) per month, as well as dry season totals (MCM), in Prek Kong during 2003 – 2014.

Other Water uses

Water from Prek Kong is used by different stakeholders and for different purposes. Apart from irrigation, water is used for access to fields and for crop transportation, for domestic purposes (cooking, washing, household etc.), for colmatage and for fields or for re-sale, fishing (only during the wet season). A private water company provides households in the village with a domestic water supply line.

8.14.5 Tidal Water Levels and Flows

Prek Kong is in a stronger position close to the stronger link of River Prek Teav than the more northern Prek and thus there is a slightly greater tidal flow and water level variation at the junction to Toul Khtom. Nevertheless it is suggested that the prek may be directly connected without the need for a flap gate.

There is little net flow down Prek Kong and a weak tidal flux in the Toul Khtom to the north from Prek Tiev.

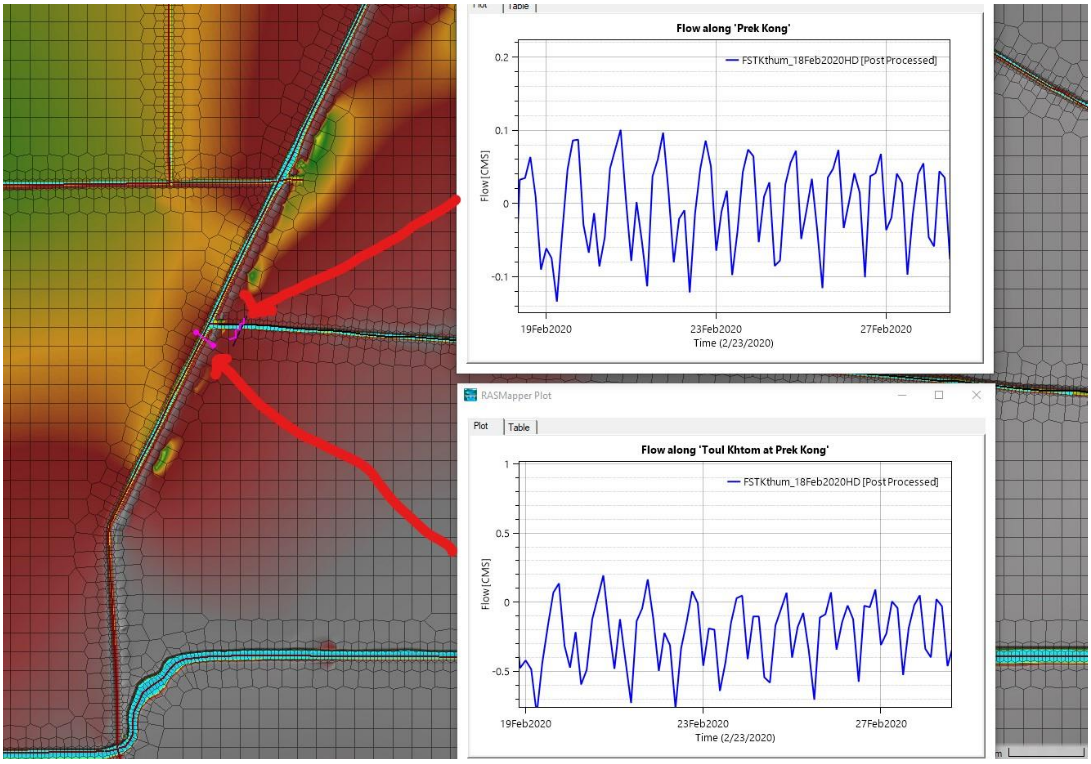


Figure 8-56 Simulated Flow in Prek Kong and Toul Khtom in dry season

8.15 **Prek Nhek**

8.15.1 Baseline situation

Prek Nhek is located south of Prek Sem and north of Prek Ros at bridge N69 along the western embankment of the Bassac River. It's a Prek with a gross command area of 240 ha. The Prek has a length of 2,876 m.

The main water sources of Prek Nhek are the Bassac River during high flows in the Bassac river and the Toul Khtom canal during the dry months at the tail ends of the Prek.

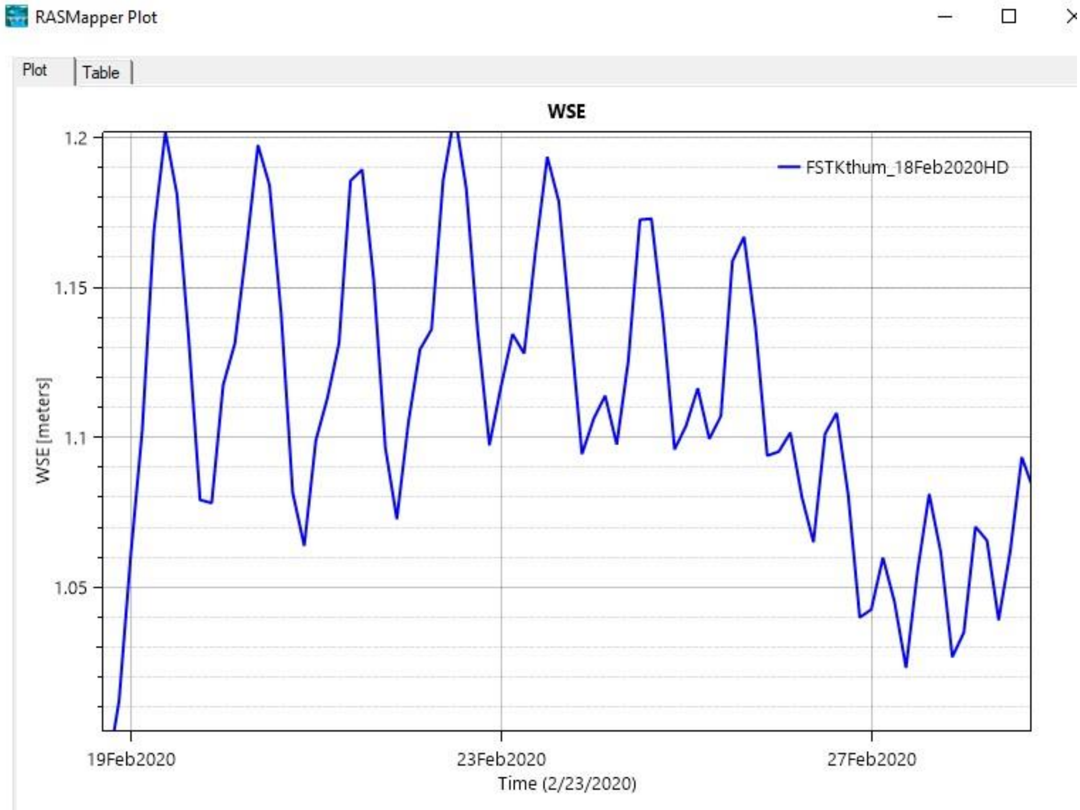


Figure 8-57 Simulated Water level at Prek Kong terminal structure in dry season

Currently the bed level of Prek Nhek is lower than most of the average monthly water levels in the Bassac River allowing water to flow into the Prek by gravity for at least 8 months a year. Only in the months March – June, no inflow from the Bassac River is observed.

Due to the tidal effect in the system, at the tail ends of the prek farmers are able to access water in the Toul Khtom Canal when the tide is high. Using pumps, they can irrigate their crops during limited periods of time. Next to these pumps, several farmers in the Prek have installed tube wells (10 wells in total), for irrigating crops with ground water.

Land use

According to the feasibility study of Prek Nhek, landuse in Prek Nhek consists of the following characteristics, presented in Table 8.11.

Table 8.11. Land use classification in Prek Nhek.

Land use	Area (ha)	Percentage of Prek area (%)
Chamkar area	29	17
Cash crops / Annual crops	36	21
Rice area in Prek area	88	51
Rice area in Boeung	132	-

Land use	Area (ha)	Percentage of Prek area (%)
Colmatage area (Prek channel)	4	2
Residential area	14	8
Total Prek area	171	
Total Prek area + Boeung area	303	

Typical crops grown in Prek Nhek are Mango and Banana (in the Chamkar) and cash crops / annual crops such as maize and vegetables. The remaining agricultural land in used to produce rice (Figure 8-58).

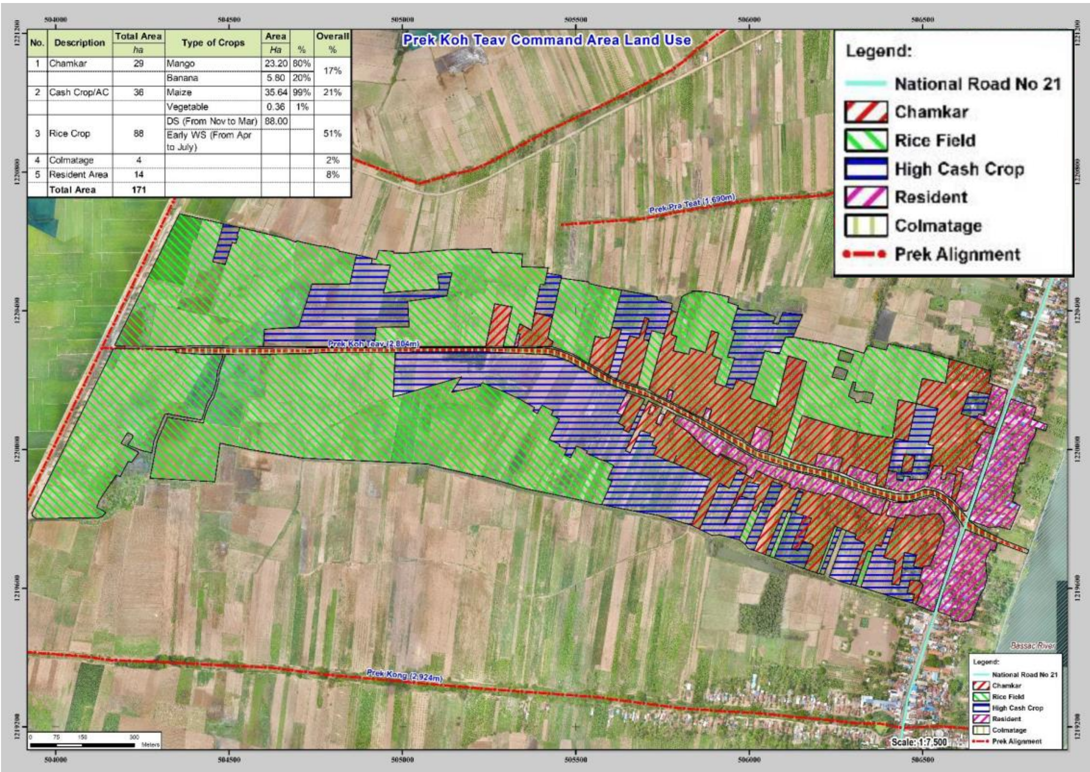


Figure 8-58. Land use classification in Prek Nhek.

8.15.2 Rehabilitation Options

The feasibility report of Prek Nhek indicates different rehabilitation options for improved development of Prek Nhek. Improvements/interventions not only focus on infrastructural works, but also on more socio-economic interventions.

Some of the interventions that are proposed and affect water availability and water use are:

- Development of a Farmer Water Use Community (FWUC) for management of the water resources in a collective way;
- To construct a new tail structure at the junction of the Toul Khtom canal;
- Increase the storage capacity of the Prek in order to harvest river water and more efficient pumping to the fields;

- Drainage improvements;
- Development of an urban sewage system.

To improve access to water, three interventions have been identified (called alternatives). These options are:

1. Deep excavation of Prek Nhek.
2. Shallow excavation of Prek Nhek without rehabilitation of the first 850 m of the Prek to prevent 10 houses from being affected (these 10 houses otherwise need to be removed/replaced)
3. Shallow excavation of Prek Nhek of the entire prek including the first 850 m.

All options will yield benefits in terms of increased agricultural production, better infrastructure, formation of institutional structures and capacity building of farmers.

Option 3 is the preferred option selected in the Feasibility Study.

8.15.3 Flood season Analysis

The improvements in the Prek Nhek channel were put in the model and the change in peak flows and water level were examined as shown in Table 8.12. There is a marginal increase in the flow peak to 15.4m3/s in a flood of 2018 magnitude.

Table 8.12 Simulated Peak Food flows in Prek Koh Nhek existing and rehabilitation option

Scenario Year	Simulated Peak Water Level (m AHT)	Simulated Peak Flow into Prek (m3/s)	Simulated Peak Flow into Prek (m3/s) Option 2
2000	5.71	7.6	
2011	5.58	7.3	
2018	4.97	9.8	15.4
2019	4.84	2.3	14.6
2020	3.88		

Sentinel-1 imagery (2016-2021) was used to analyse analysis water occurrence during the wet season (Figure 8-59). The command area remains for the most part during the wet season, however, the occurrence of water is high at the tail end of Prek Nhek in the rice fields with a water occurrence of up to 60%. This means that these areas are flooded during the wet season in 3 out of the 5 years.

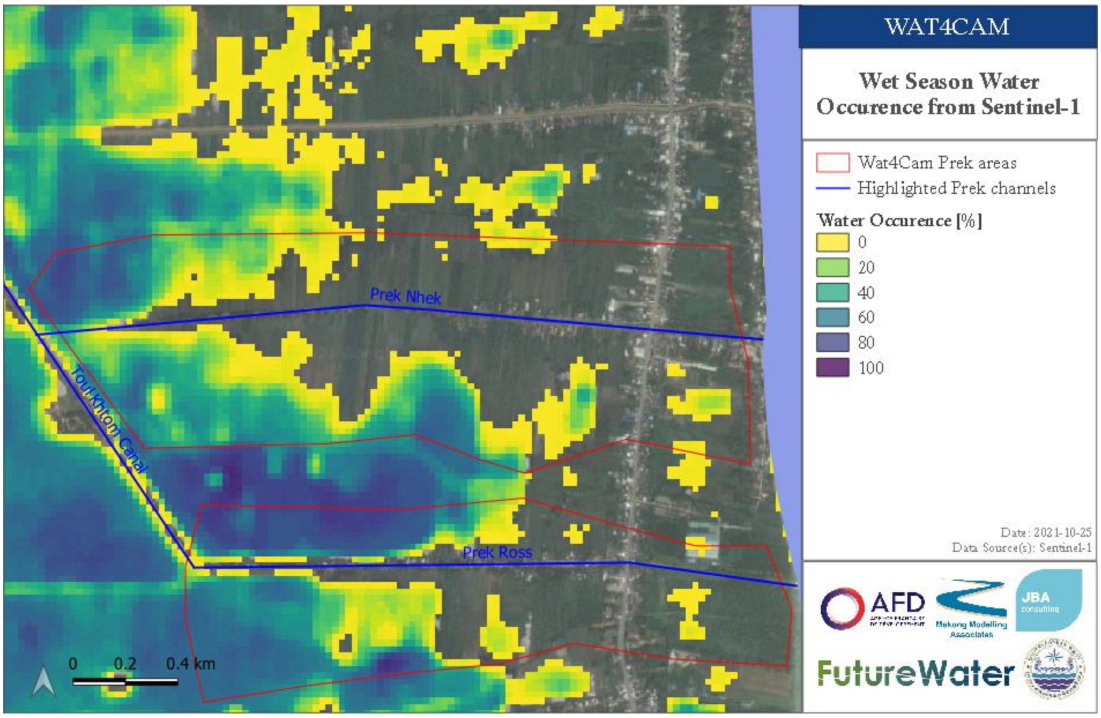


Figure 8-59. Water occurrences calculated for the wet season from Sentinel-1 imagery (August-November) using the full 2016-2020 series.

The trend shows that the water occurrence in the recent past (2010-2020) has been lower compared to the more distant past (1988-2010) in the prek area (Figure 8-60). Water occurrence in the wet season has reduced with about 25% to 50% in some parts. However, closer to the tail ends of Prek Nhek interestingly, water occurrence has also increased with up to 40%. This could be the result of irrigating through pumping from the Toul Khtom Canal when possible or from the tube wells that have been installed in the more recent past.

8.15.4 Dry Season Analysis

As mentioned above during the dry season, water availability is limited. Using Sentinel-2 satellite data derived NDVI values, the percentage of agricultural land that lies fallow in the dry season was calculated for all preks. The analysis shows that for Prek Nhek, only 11% of the agricultural land lies fallow in the dry season which ranks it among the lowest of all preks along the Bassac river (Figure 8-61).

The main water user in Prek Nhek is agriculture through irrigation. Figure 8-62 presents ET_{act} totals for Prek Nhek in the dry season months, for each of the years 2003 – 2014. It shows that Prek Nhek consumes on average between 300-375 mm/dry season.

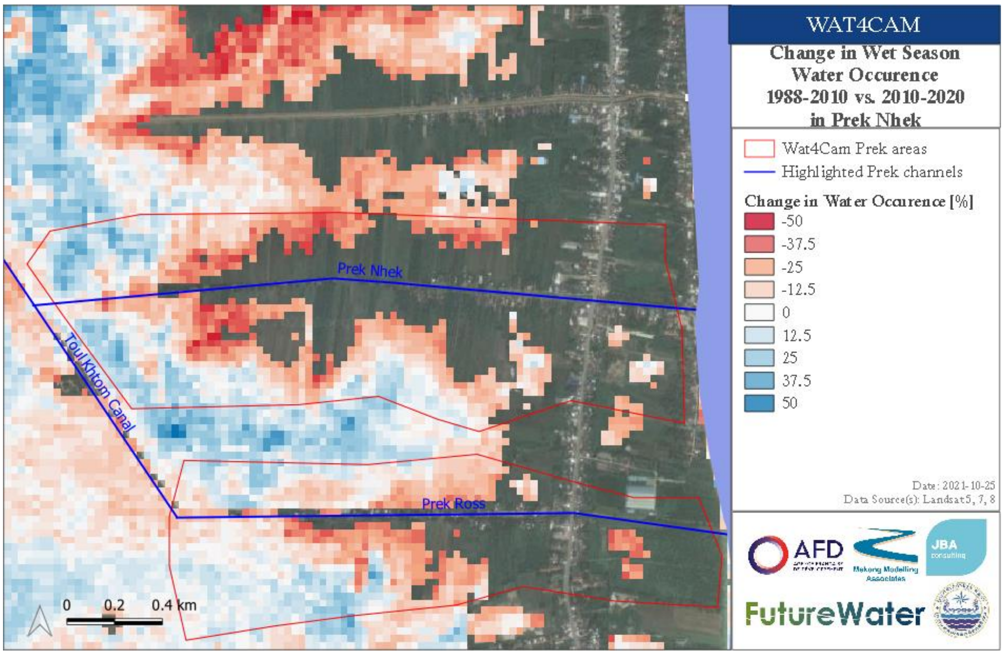


Figure 8-60. Change in Water occurrences calculated for the wet season from Landsat 5, 7 and 8 imagery (August-November) using the full 1988-2020 series.

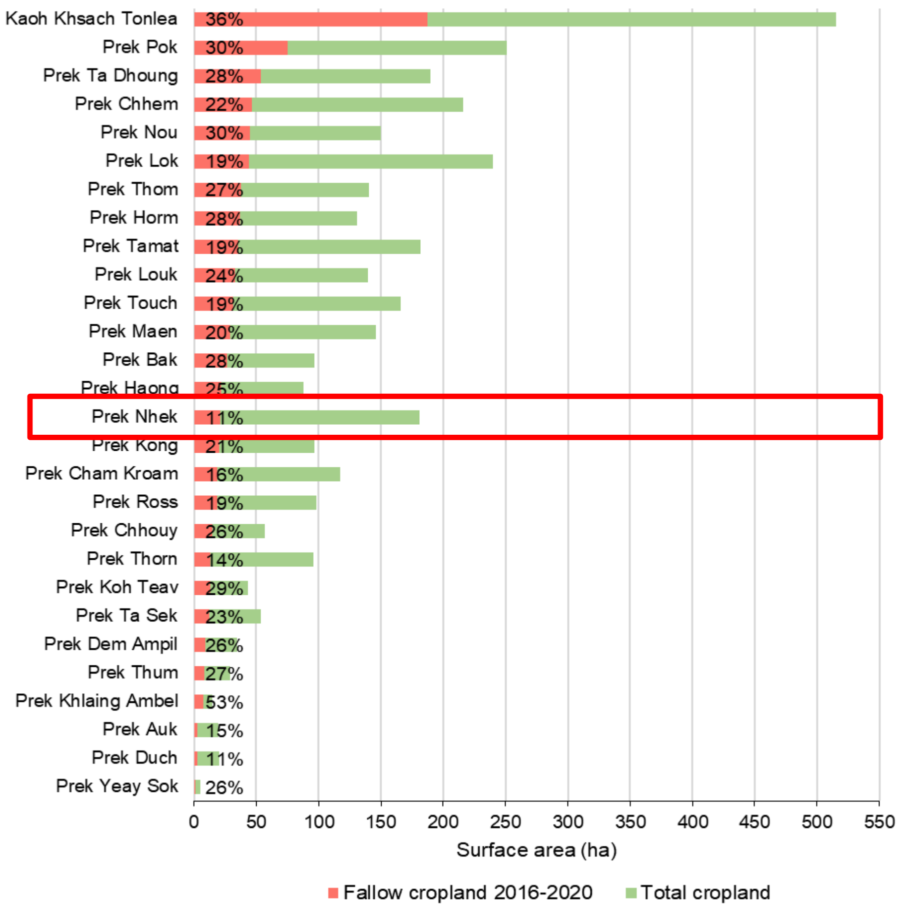


Figure 8-61. Area of cropland left fallow in the months February – April on average in years 2016 – 2020 (Bassac River).

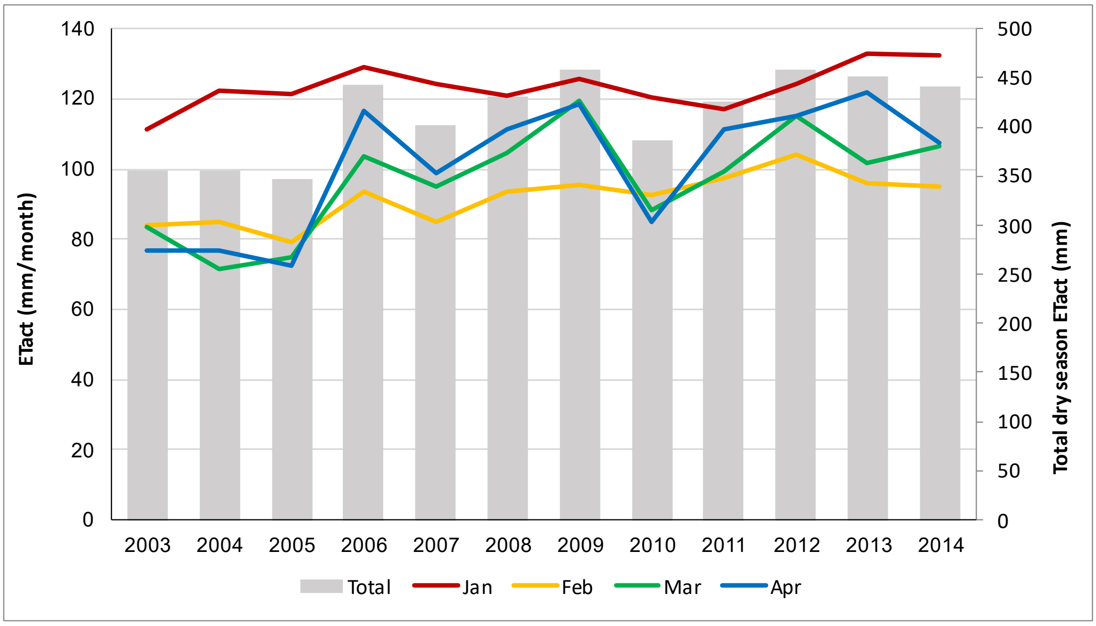


Figure 8-62. Average water consumption (ETact) per month, as well as dry season totals, in Prek Nhek during 2003 – 2014.

Figure 8-63 shows the consumptive water use of vegetation (agriculture) in the dry season (February – April) in Prek Nhek calculated from the Sentinel-2 imagery between 2003-2014. It shows that Prek Nhek consumes on average between 300-375 mm/dry season which compares well to the numbers presented in Figure 8-62.

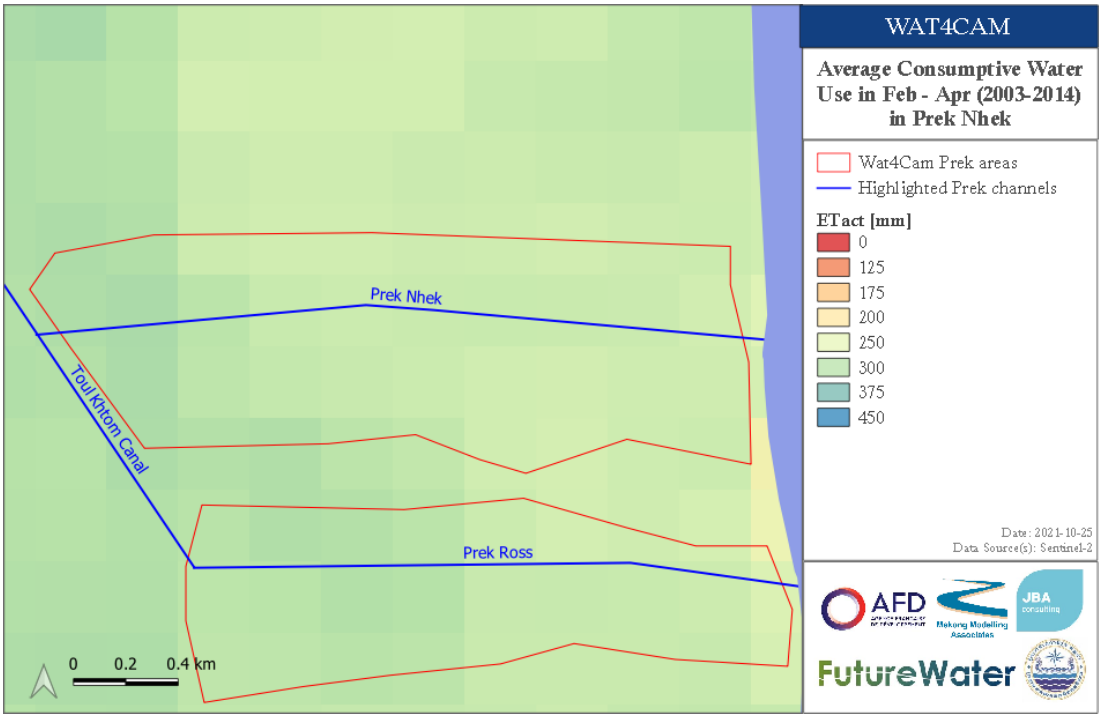


Figure 8-63. Actual evapotranspiration in the months February – April, averaged for the 2003 – 2014 period.

Figure 8-62 presents the monthly (l/s) and total (MCM) dry season water demand for Prek Nhek, for each of the years 2003 – 2014. These numbers are somewhat lower than other preks in February/March time even though the amount of fallow land is low. Demand is highest in January. Interestingly, only a very slight upwards trend seems to be present over this period, which could be explained by natural/climate related phenomena such as shifts in timing of the preceding wet season or ongoing siltation due to fertile sediments from the prek, resulting in increased elevation of the land and with that, increased agricultural area.

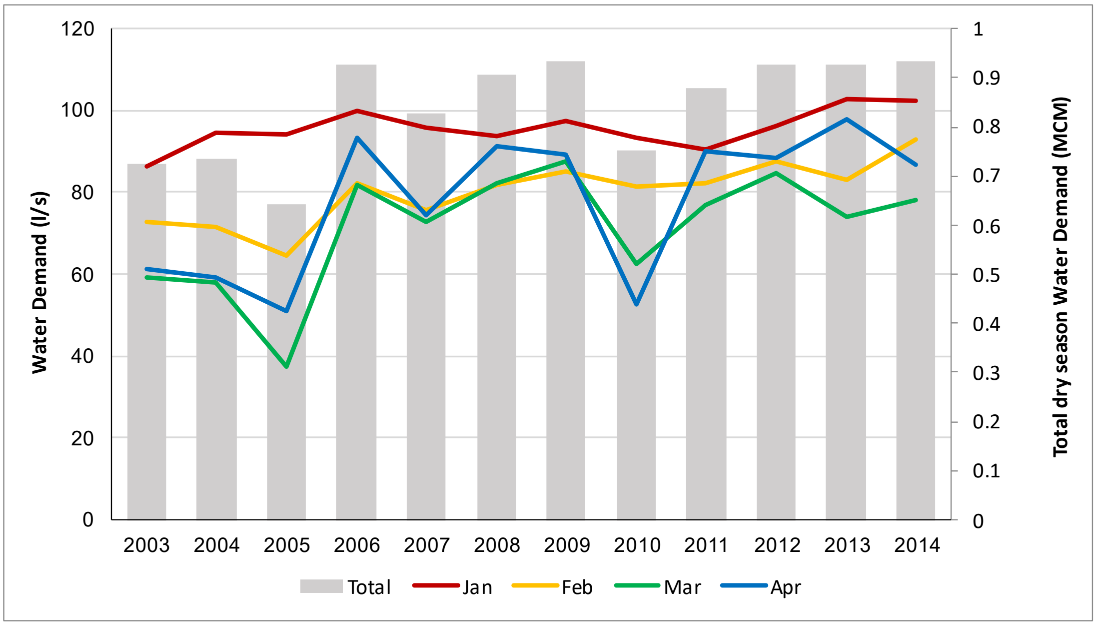


Figure 8-64. Average evaporative water demand (l/s) per month, as well as dry season totals (MCM), in Prek Nhek during 2003 – 2014.

<u>Other Water uses</u>

Water from Prek Nhek is used by different stakeholders and for different purposes. Apart from irrigation, water is used for access to fields and for crop transportation, for domestic purposes (cooking, washing, household etc.), for colmatage and for fields or for re-sale, fishing (only during the wet season). A private water company provides households in the village with a domestic water supply line.

8.15.5 Tidal Water Levels and Flows

Prek Nhek is in a stronger position close to the link of River Prek Teav and better channels across the Boueng to Prek Ambel than the more northern Prek and thus there is a slightly greater tidal flow and water level variation at the junction to Toul Khtom. Nevertheless, it is suggested that the prek may be directly connected without the need for a flap gate.

There is little net flow down Prek Kong and a weak tidal flux in the Toul Khtom to the north from Prek Tiev.

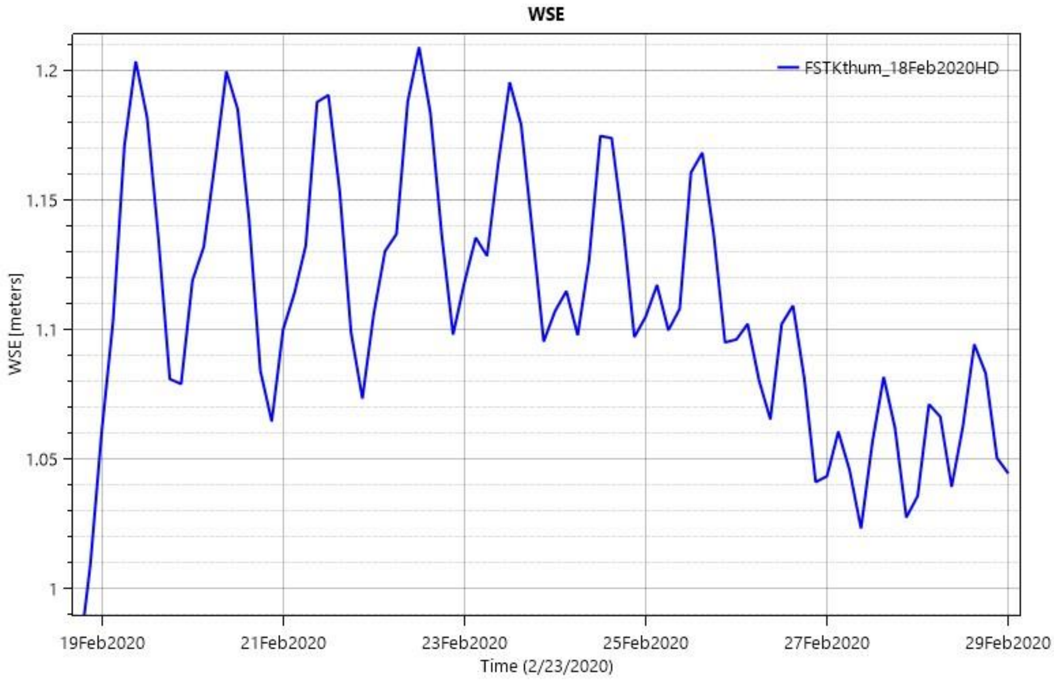


Figure 8-65 Water level variation in Prek Nhek during dry season (February 2020.

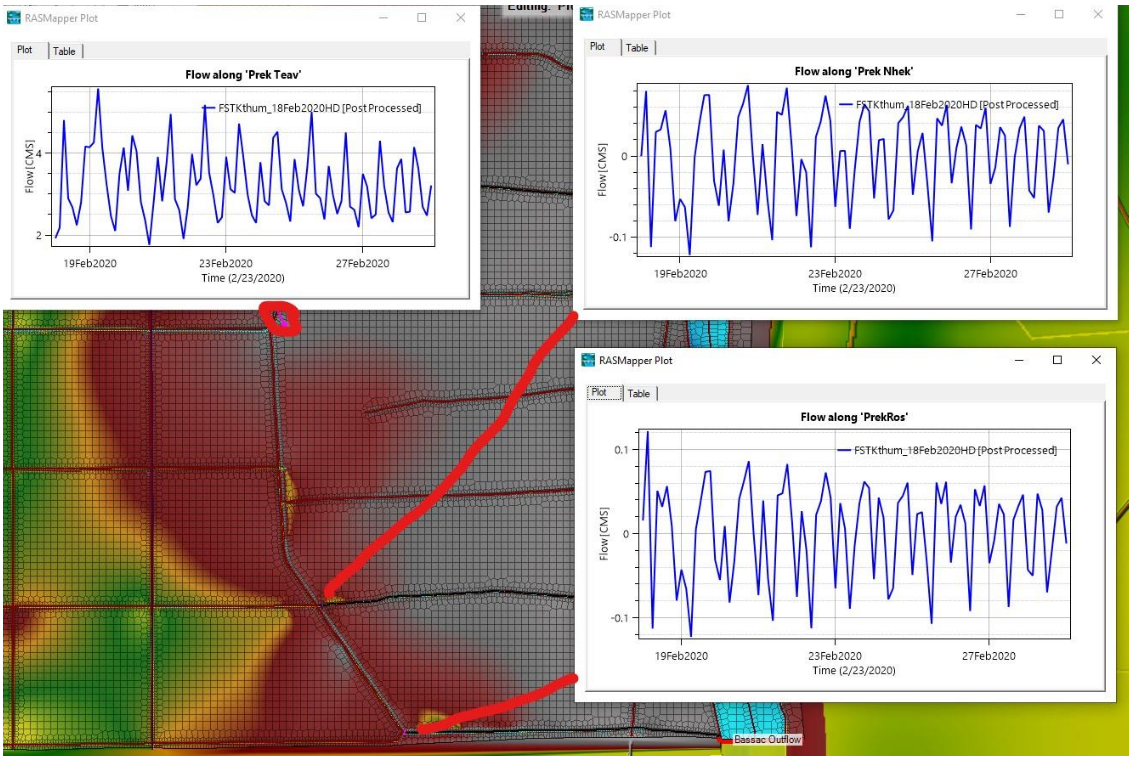


Figure 8-66 Flow in Prek Nhek, Ros and Tiev

8.16 Prek Ros

Prek Ros is located south of Prek Nhek at bridge N70 along the western embankment of the Bassac River. It's a Prek with a gross command area of 213 ha. The Prek has a length of 2,297 m.
The main water sources of Prek Ros are the Bassac River during high flows in the Bassac river and indirectly from the grid network of channels in the boeung area that can supply Prek Ros for the whole year from January to December.

8.16.1 Baseline situation

Currently the bed level of Prek Ros is higher than the lowest average monthly water levels in the Bassac River leaving the prek without inflow of fresh water for 6 months a year (January – June). The result is a dry prek for 6 months a year, when all surface water has evaporated.

Due to the tidal effect in the system farmers are able to access water from the Toul Khtom Canal when the tide is high. Using pumps, they can irrigate their crops during limited periods of time. A lot of farmers have also excavated ponds for their irrigation during the dry season. Several farmers in the prek have installed tube wells (9 wells in total), for irrigating crops with ground water.

Land use

According to the feasibility study of Prek Ros, landuse in Prek Ross consists of the following characteristics, presented in Table 8.13.

Table 8.13. Landuse classification in Prek Ros.

Land use	Area (ha)	Percentage of Prek area (%)
Chamkar area	17	8
Cash crops / Annual crops	14	7
Rice area in Prek area	157	74
Rice area in Boeung	66	-
Colmatage area (Prek channel)	5	2
Residential area	20	9
Total Prek area	213	
Total Prek area + Boeung area	279	

Typical crops grown in the command area of Prek Ros are mango (in the Chamkar) and cash crops / annual crops such as maize. The remaining agricultural land in used to produce rice (Figure 8-67).

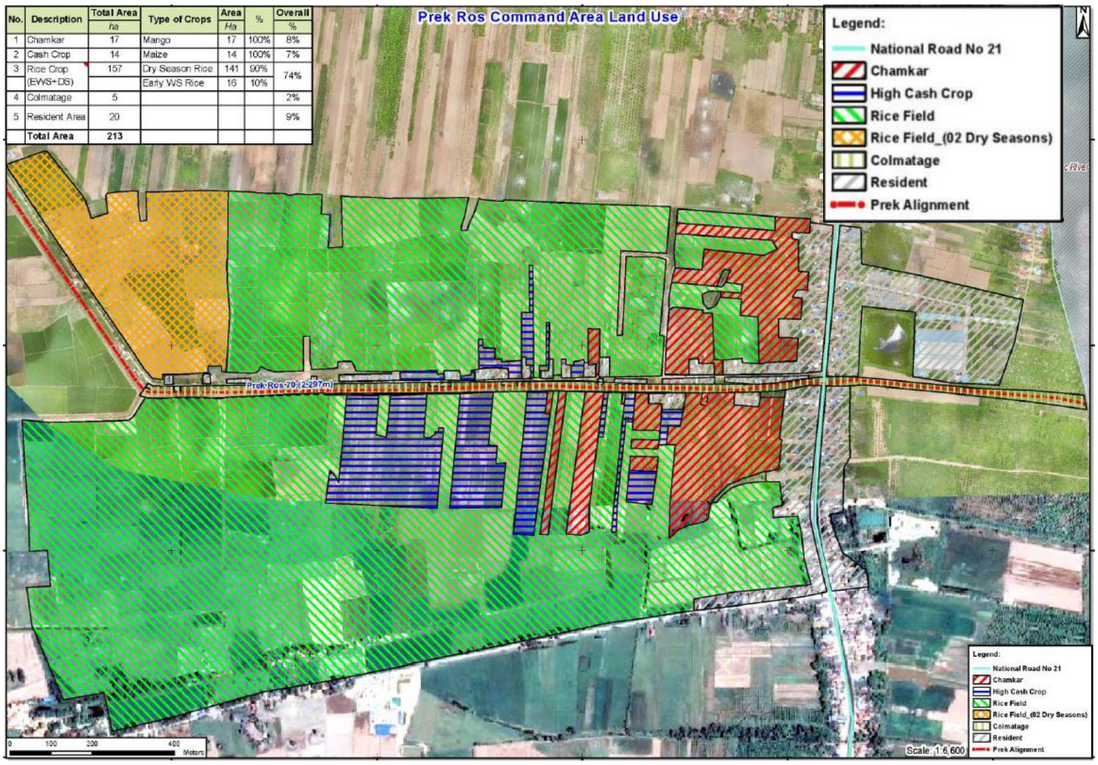


Figure 8-67. Land use classification in Prek Ross.

8.16.2 Rehabilitation Options

The feasibility report of Prek Ros indicates different rehabilitation options for improved development of Prek Ros. Improvements/interventions not only focus on infrastructural works, but also on more socio-economic interventions.

Some of the interventions that are proposed affect water availability and water use are:

- Development of a Farmer Water Use Community (FWUC) for management of the water resources in a collective way;
- To construct a new head regulator on the right embankment of Prek Ros for better water management and irrigation purposes;
- Increase the storage capacity of the prek in order to harvest river water and more efficient pumping to the fields;
- Drainage improvements;
- Development of an urban sewage system.

To improve access to water, three interventions have been identified (called alternatives). These options are:

1. Deep excavation of Prek Ros.
2. Shallow excavation of Prek Ros without rehabilitation of the first 750 m of the prek to prevent 54 houses from being affected (these 54 houses otherwise need to be removed/replaced)

3. Shallow excavation of Prek Ros of the entire prek including the first 750 m.

All options will yield benefits in terms of increased agricultural production, better infrastructure, formation of institutional structures and capacity building of farmers.

Option 3 is shown to be best and selected in the Feasibility Study**.**

8.16.3 Flood season Analysis

The improvements in the Prek Ros channel were put in the model and the change in peak flows and water level were examined as shown in Table 8.14. There is a marginal increase in the flow peak to 24m3/s in a flood of 2018 magnitude.

Table 8.14 Simulated Peak Food flows in Prek Ros existing and rehabilitation option

Scenario Year	Simulated Peak Water Level (m AHT)	Simulated Peak Flow into Prek (m^3/s)	Simulated Peak Flow into Prek (m^3/s) Option 3
2000	5.65		
2011	5.5		
2018	4.95	10.6	24.2
2019	4.82	8.1	20.4
2020	3.84		

Sentinel-1 imagery (2016-2021) was used to analyse analysis water occurrence during the wet season (Figure 8-68). A significant part of the command area has a water occurrence of 60%-80% water is much higher at the tail end of Prek Ros in the rice fields. This means that these areas are flooded during the wet season in 3-4 out of the 5 years.

The trend shows that the water occurrence in the recent past (2010-2020) has been lower compared to the more distant past (1988-2010) in the prek area (Figure 8-69). Water occurrence in the wet season has reduced with about 25%. Interestingly, water occurrence has also increased with up to 25% in some parts of the command area. This could be the result of irrigating through pumping from the Toul Khtom Canal when possible or from the tube wells that have been installed in the more recent past.

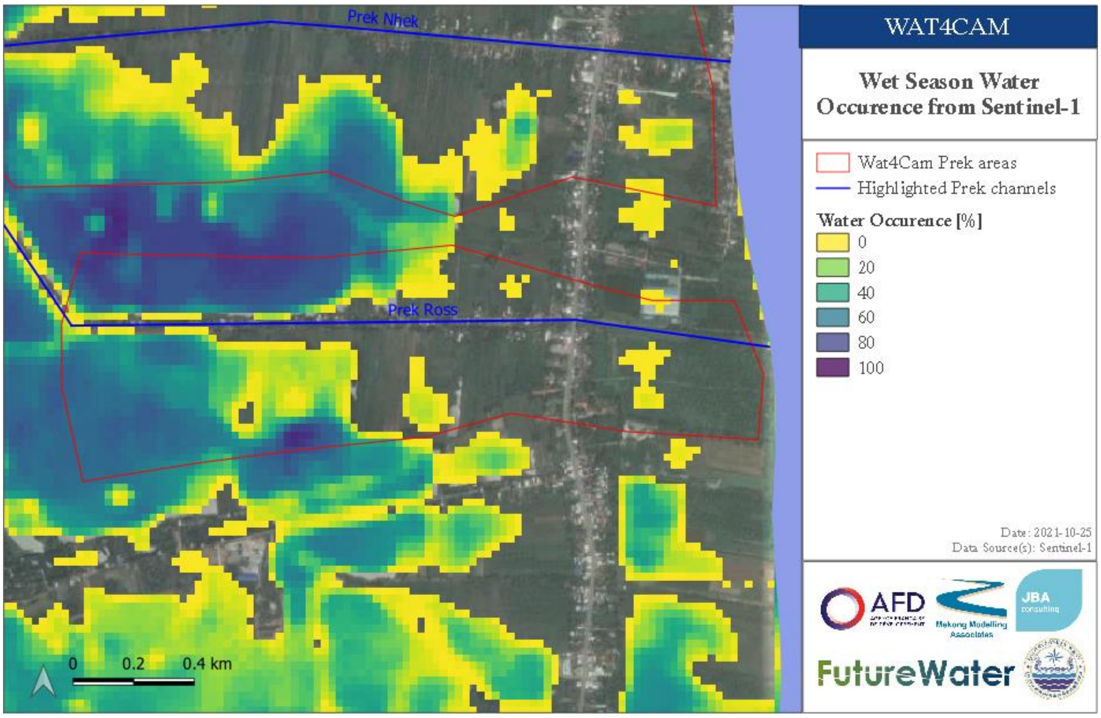


Figure 8-68. Water occurrences calculated for the wet season from Sentinel-1 imagery (August-November) using the full 2016-2020 series.

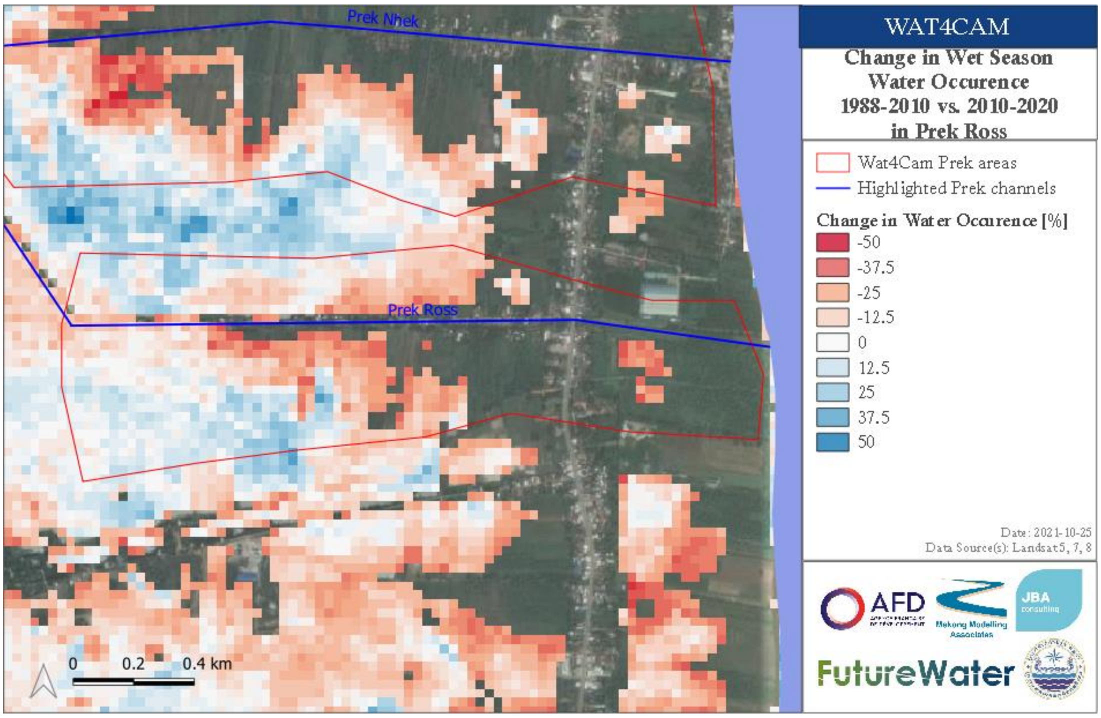


Figure 8-69. Change in Water occurrences calculated for the wet season from Landsat 5, 7 and 8 imagery (August-November) using the full 1988-2020 series.

8.16.4 Dry Season Analysis

As mentioned above during the dry season, water availability is limited. Using Sentinel-2 satellite data derived NDVI values, the percentage of agricultural land that lies fallow in the dry season was calculated for all preks. The analysis shows that for Prek Ros, 19% of the agricultural land lies fallow in the dry season which is more or less the average percentage of all the preks near the Bassac river (Figure 8-70Figure 8-43).

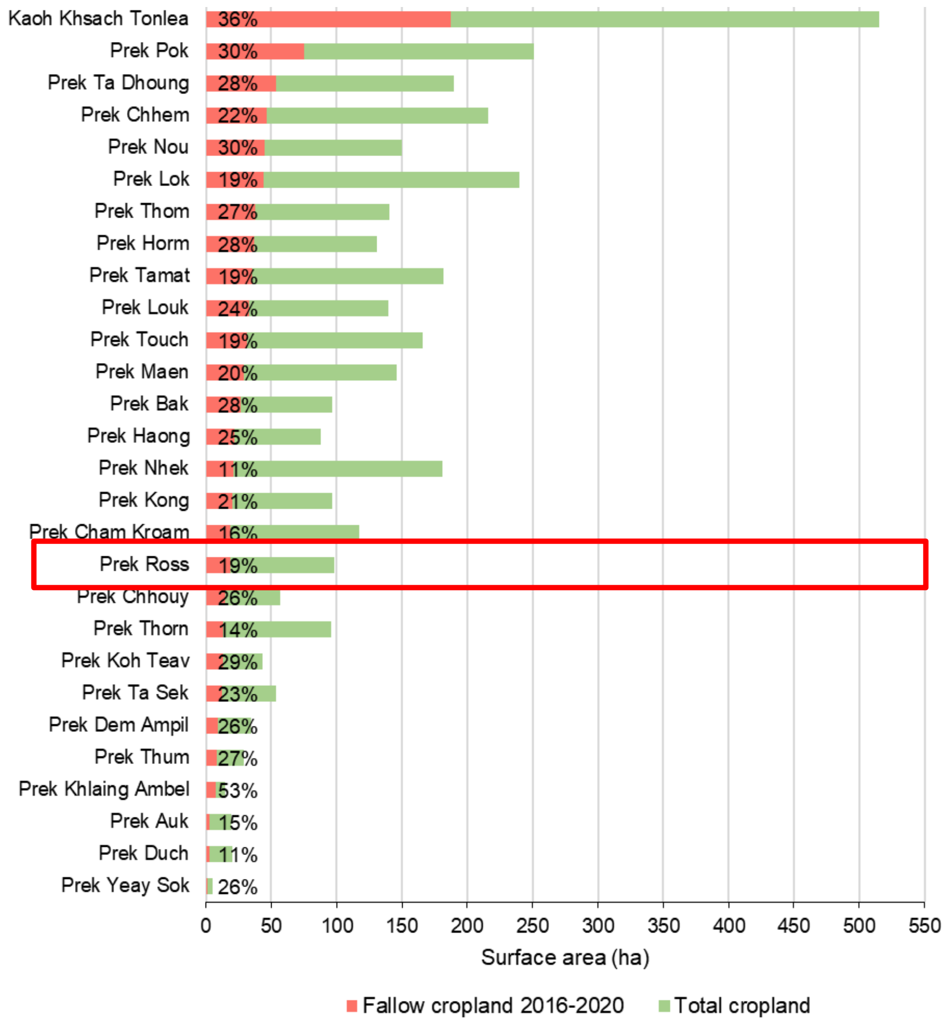


Figure 8-70. Area of cropland left fallow in the months February – April on average in years 2016 – 2020 (Bassac River).

The main water user in Prek Ross is agriculture through irrigation. Figure 8-71 presents ET_{act} totals for Prek Ross in the dry season months, for each of the years 2003 – 2014. This ET_{act} provide valuable insights in water availability and water use in the dry season. Interestingly, an upwards trend seems to be present over this period, which could be explained by natural/climate related phenomena such as shifts in timing of the preceding wet season or ongoing siltation due to fertile sediments from the prek resulting in increased elevation of the land and with that, increased agricultural area. It could also be the result of manmade interventions such as changes in land use and cropping patterns or increased water supply from an increasing number of tube wells.

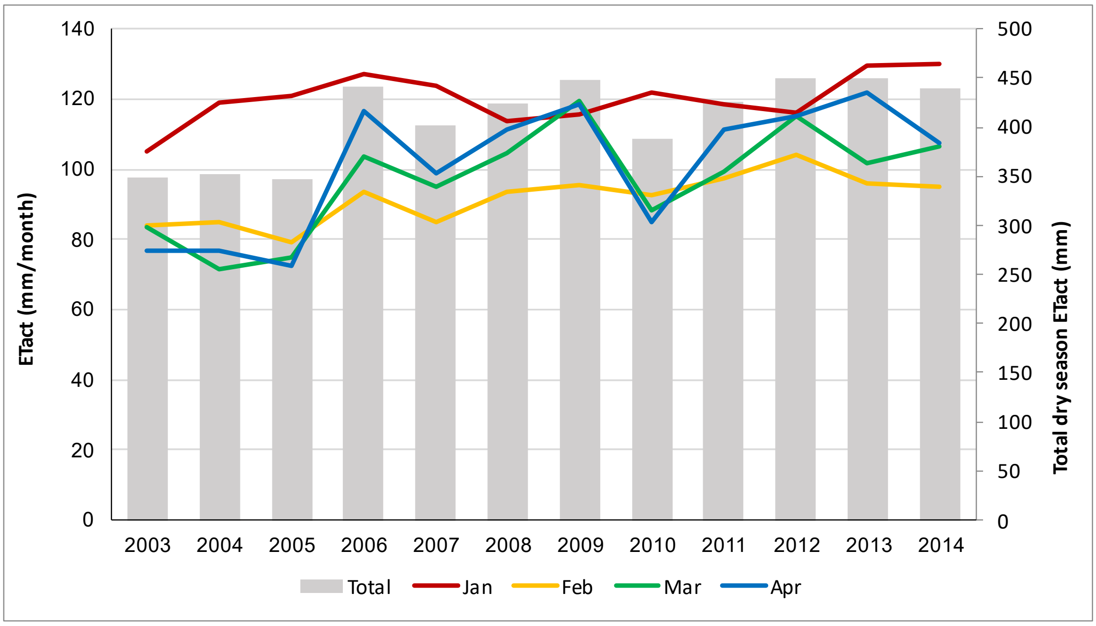


Figure 8-71. Average water consumption (ETact) per month, as well as dry season totals, in Prek Ross during 2003 – 2014.

Figure 8-71 shows the consumptive water use of vegetation (agriculture) in the dry season (February – April) in Prek Ros calculated from the Sentinel-2 imagery between 2003-2014. It shows that Prek Ros consumes on average between 300-375 mm/dry season which compares well to the numbers presented in Figure 8-72.

The main water user in Prek Ros is agriculture through irrigation. Figure 8-71 presents the monthly (l/s) and total (MCM) dry season evaporative water demand for Prek Ros, for each of the years 2003 – 2014. These numbers provide valuable insights in water availability and water use in the dry season. Interestingly, an upwards trend seems to be present over this period, which could be explained by natural/climate related phenomena such as shifts in timing of the preceding wet season or ongoing siltation due to fertile sediments from the Prek resulting in increased elevation of the land and with that, increased agricultural area. It could also be the result of manmade interventions such as changes in land use and cropping patterns or increased water supply from an increasing number of tube wells.

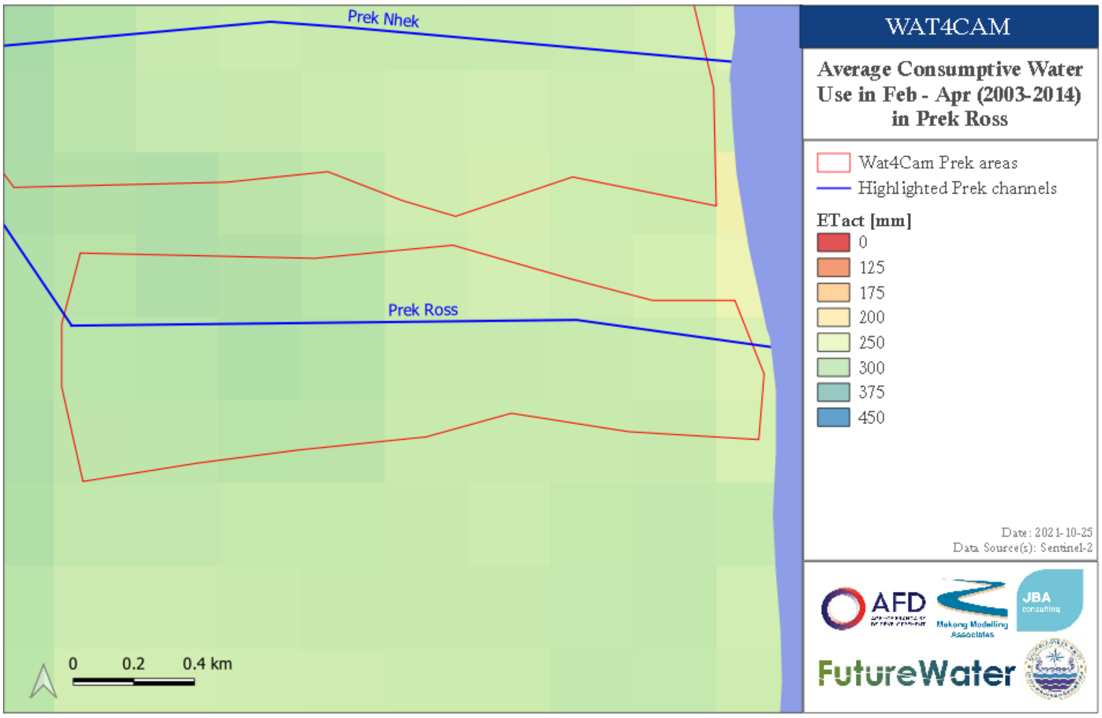


Figure 8-72. Actual evapotranspiration in the months February – April, averaged for the 2003 – 2014 period.

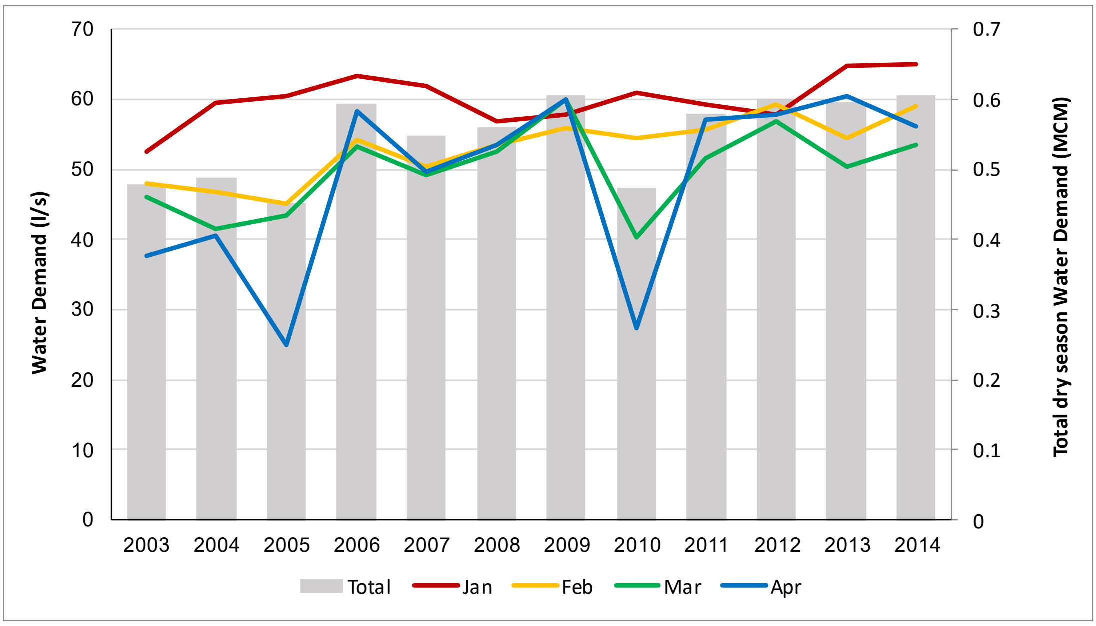


Figure 8-73. Average water demand (l/s) per month, as well as dry season totals (MCM), in Prek Ros during 2003 – 2014.

Other Water uses

Water from Prek Ros is used by different stakeholders and for different purposes. Apart from irrigation, water is used for domestic purposes (cooking, washing, house fixing etc.), livestock (drinking and cleaning), fishing (only during the wet season) and for access to fields and for crop transportation. A private water company provides households in the village with a domestic water supply line.

8.16.5 Tidal Water Levels and Flows

The variation in water level at the tail of Prek Ros is similar the previous preks showing a weak tidal variation of around 0.1m or less depending on the spring/neap cycle of the moon. Tidal flows are similar to Prek Nhek as shown in Figure 8-74 and flows in Figure 8-66.

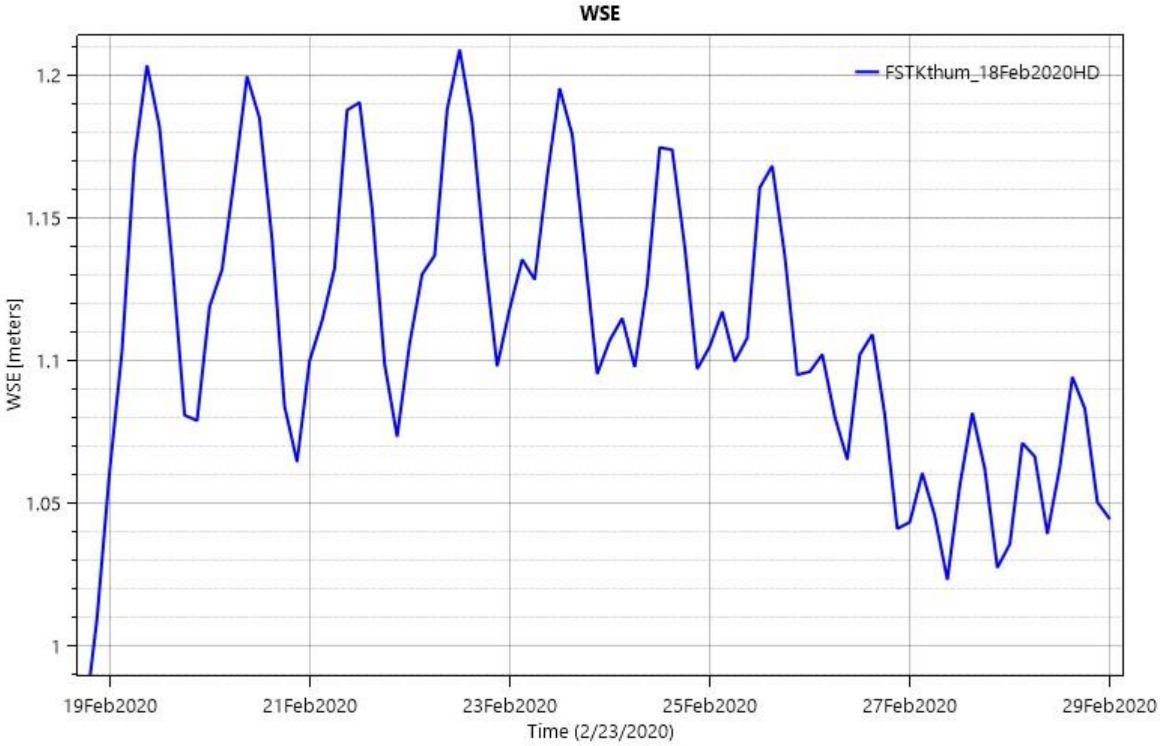


Figure 8-74 Water level variation in Prek Ros during dry season

8.17 Cumulative Impacts of Prek Cluster Rehabiltation

8.17.1 General

The hydraulic effect of the rehabilitation of six preks within the Preks Cluster will be in three areas which will be described in separately sections:

1. Increased Flows in Dry and Wet Season and thus increased availability of water in both chamkar and boeung areas
2. Small Increase in peak flood level on the flood floodplain
3. Increased sediment fluxes

8.17.2 Change in Flood Flows

Whilst the primary purpose of the rehabilitation works is for improving the availability of water during the dry season, which in turn gives the positive effects on agriculture and socio-economic situation of the beneficiaries, changes will also occur in the wet season. The most noticeable impact in the wet season will be the increase in flows, far exceeding the possible demands for irrigation near the peak of a flood. From a flood management perspective this is highly desirable as without (or with a continuing decline in the Prek condition) restoration of the link between the main river and the floodplain the main Bassac and Mekong rivers will be forced to carry higher flows with resulting increases in flood level and erosive power of the main river. Other preks that are still active have small decreases in peak flood flows with the rehabiltation.

Table 8.15 15 Indicative Peak Flood Flows(m3/s) in Prek Cluster channels (2018 flood event)

Ref	Prek	Peak Flow Simulated for 2018 flood (m^3/s) Existing	Peak Flow Simulated for 2018 flood (m^3/s) - Rehabilitated
1	Thom	7.3	23.5
2	Pra Theat	4.0	10.5
3	Koh Tiev	2.8	15.4
4	Kong	12	12.5
	Teav	64	62
	Wat Koh Tiev	0.45	0.4
	Sem	13.3	13.0
5	Nhek	9.8	15.4
6	Ros	10.6	24.2
	Total	124	177

For comparison the peak flow in the Bassac is estimated as 1535m^3/s at the Prek Cluster during this event and the total West Bassac floodplain flow at the cluster peaks at around 2675m^3/s nearly twice that carried in the river itself. Flows into preks from the Prek Ambel downstream to the cluster peak at 937m^3/s with the remainder being from the upstream part (Prek Thnot and other local inflows).

During a more extreme event such as Year 2000 these flows will be higher but it can be seen that the prek connection to the main river plays an important role in the flood behaviour. If these preks were either closed off due to siltation or by intervention then it is likely to have adverse effects on the river and any remaining connection channels. Historically, prior to the improvement of the main highways in Cambodia, roads such as National Highway 21 would have been overtopped during extreme events but the improvement of the road, bridges and raising of land related to urbanisation cut off this route for flood relief so there is more reliance on the remaining prek channels.

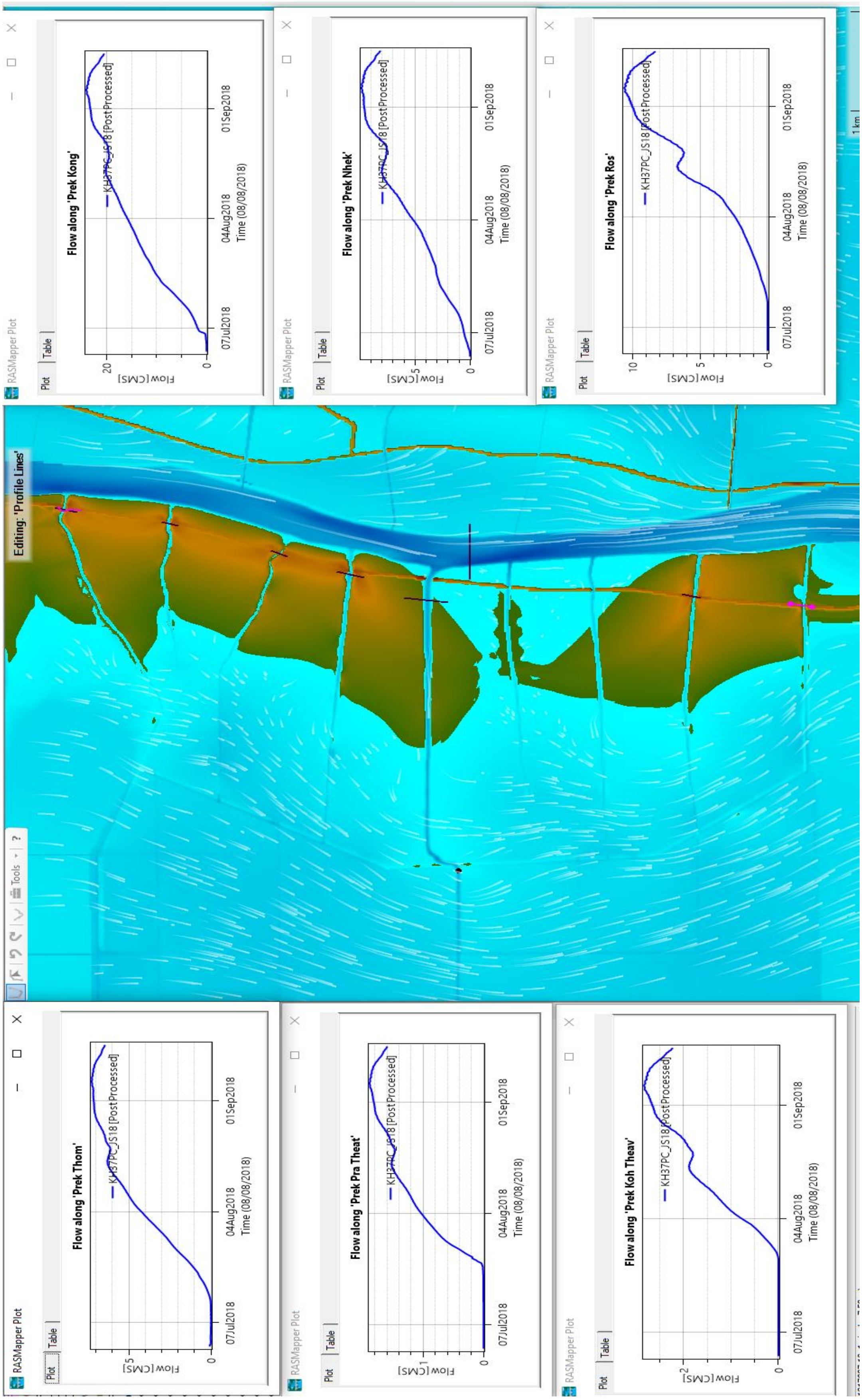

RASMapper Plot
Plot
Table
Flow along 'Prek Kong'
KH37PC_JS18 [PostProcessed]
Flow [CMS]
Time (08/08/2018)
07Jul2018
04Aug2018
01Sep2018
Flow along 'Prek Nhek'
Flow along 'Prek Ros'
Editing: 'Profile Lines'
Tools
1 km
Flow along 'Prek Thom'
Flow along 'Prek Pra Theat'
Flow along 'Prek Koh Theav'

Figure 8-75 Prek Cluster Area Depths, Flow into each Prek and flood plain flow directions during flood (2018)

8.17.3 Flood Water Levels

The behaviour of the floodplain water levels change very slightly with and without the prek channel improvements as shown in Figure 8-1. The flood rises slightly more quickly with the increased capacity of the rehabiltated preks but the peak is almost indistinguishable and without 1cm difference. The maximum extent of the flood would not be expected to change. The peak level in the Bassac near Prek Thom is reduced by about 1cm only. It is therefore concluded that the rehabilitation works will not have an adverse effect of increasing levels elsewhere but has a small effect of decreasing the Bassac level.

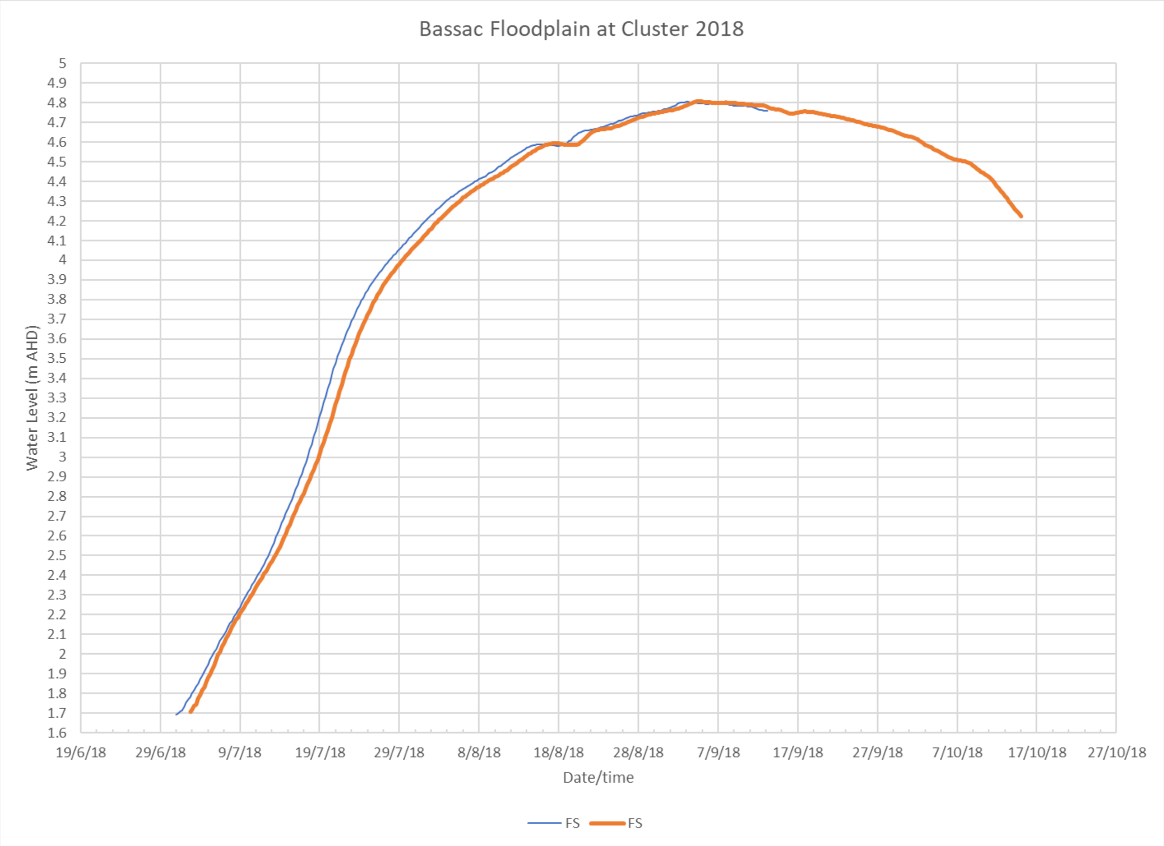


Figure 8-76 DIfference in flood levels simulated with and without prek cluster rehabilitation.

8.17.4 Dry season water levels

The increased size of channels connecting with the Boeung area and ultimately the Prek Ambel might be expected to impact on the tidal behaviour in the Prek Ambel. This does not occur in the model and no change was found.

Within the Boeung area and especially along the Toul Khtom chanel there is an increase in the tidal peak levels due to the better penetration of the high tide wave after rehabilitation of the Toul Khtom as shown in Figure 8-77. The increase in tide amplitude is greatest near the Prek Teav as changes attenuate further towards Prek Thom or Prek Ros.

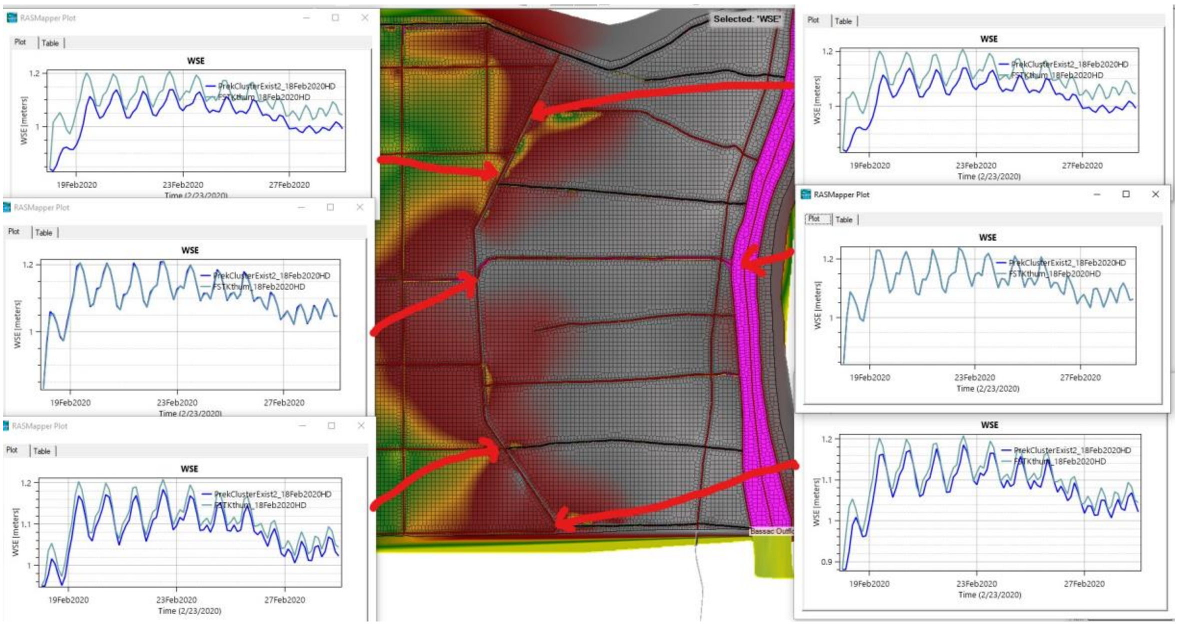


Figure 8-77 Increases in Water Level at Prek Outfalls during dry season. Feasibility studies in light blue, existing in dark blue. Results given for (top right clockwise) Prek Koh teav, Bassac River, Prek Ros, Preak Nhek, Prek Teav, Prek Kong

8.17.5 Siltation

The feasibility study illustrates the significant change in topography and development in the area since the 1960s surveys including a lake area indicated within the northern part of the embanked area and this is reproduced below as Figure 8-78. It is interesting that Prek Tiev was connected to the lake and was one of the larger preks even in the 1960s. There is also very little higher elevation 'Chamkar' shown.

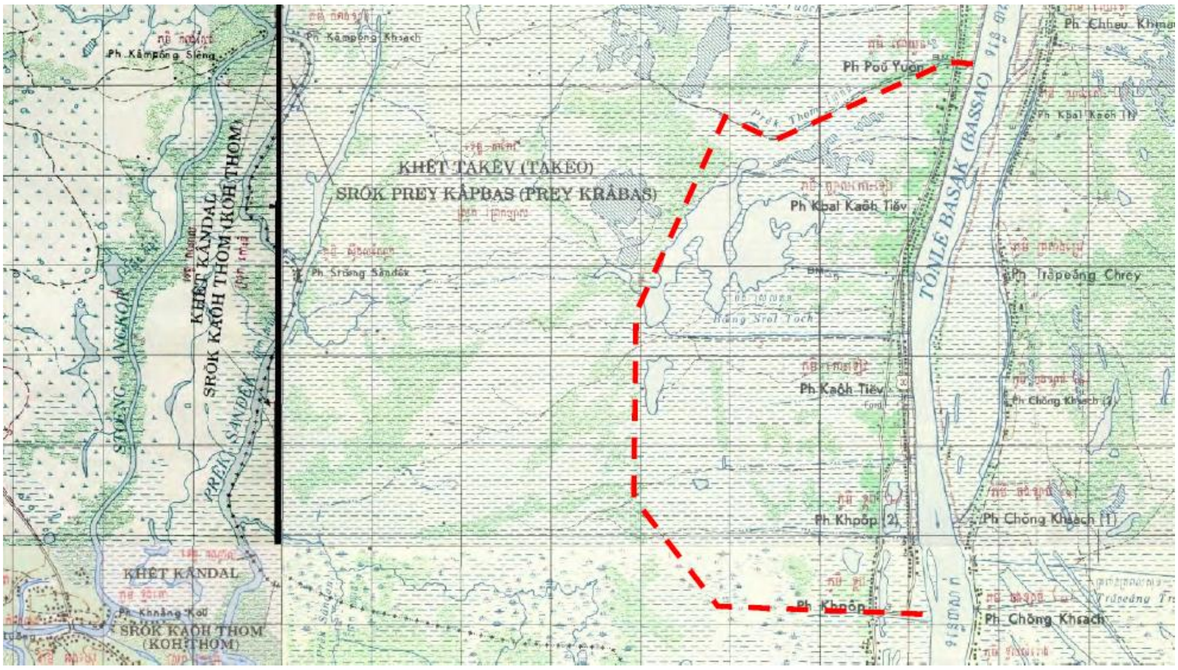


Figure 8-78 Topographic map of 1971 presented in feasibility study (EGIS Eau 2021)

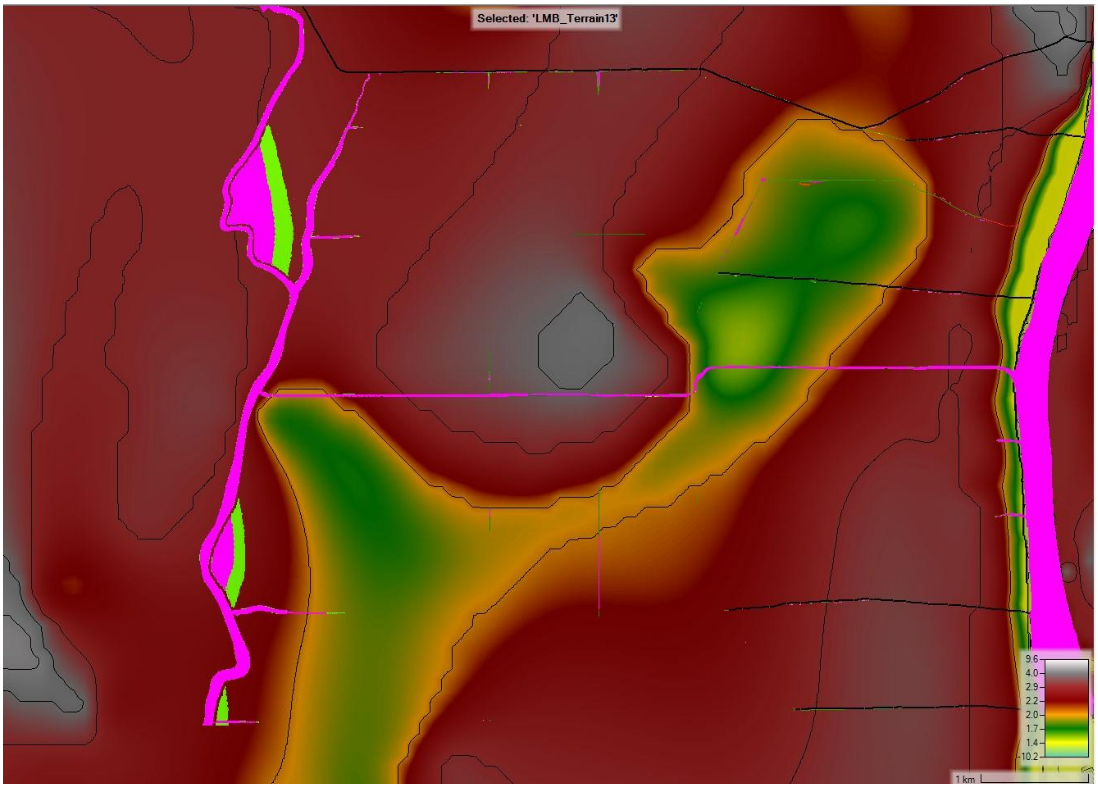


Figure 8-79 DEM based on 1960s survey showing low lying lake and limited elevation of the bank along the main river

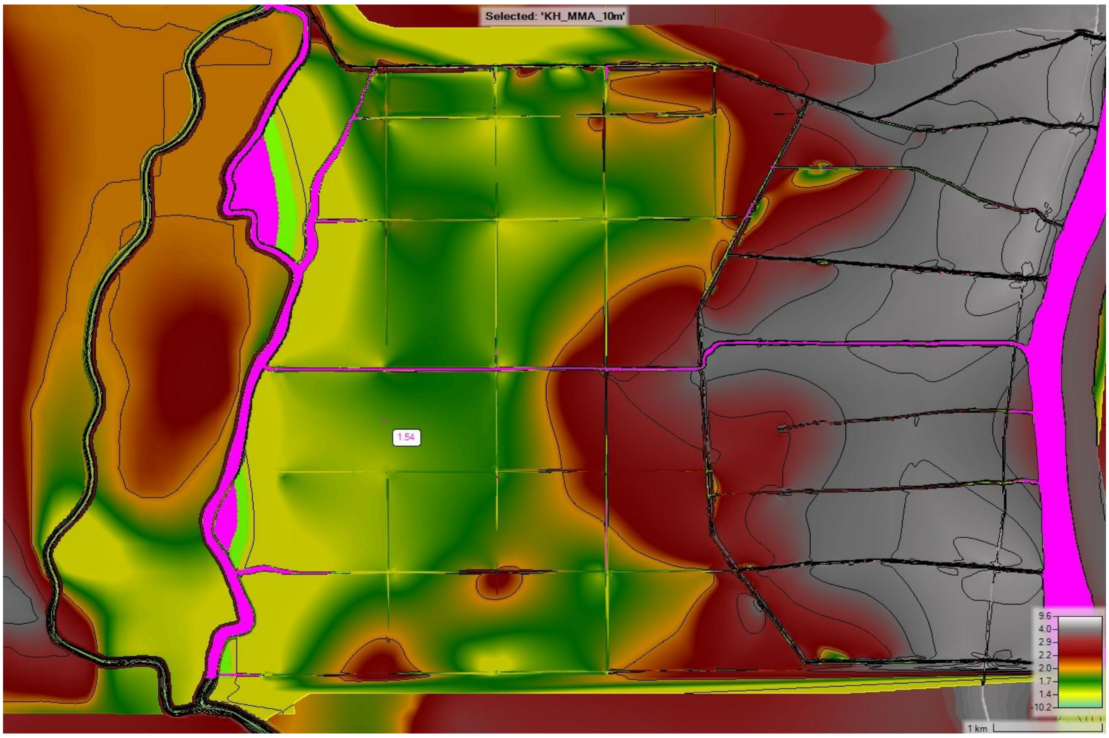


Figure 8-80 DEM based on the 2021 WAT4CAM Survey by TA-INFRA. The Lake feature within the Prek Cluster has largely disappeared and banks along the Bassac River are much higher in the area of urban development. The Boeung area seems to be lower

The DEM based on 1960s topographic survey also shows this low lying lake area and as shown in Figure 8-79 and Figure 8-80. Although there is an increased land elevation near the Bassac river and the immediate Chamkar in the 1960s DEM, by 2021 the Boeung area and Prek Ambel are generally lower and the Chamkar higher and larger. It is not clear if this change will have been part of a natural geomorphic process, inaccuracy of the 1960s DEM or was a deliberate movement of material by the farmers. It seems likely though that at least some of the change was due to the natural siltation process intended with the 'çolmatage' system of preks.

A model was therefore set up to include the sediment movement in the HECRAS software to give some comparison and more insights into the processes. Note that at the present time there is insufficient information on sediment sizes and concentration/deposition etc to develop a fully calibrated 2D sediment model so the results are intended to be illustrative and qualitative rather than definitive. Analysis therefore needs a geomorphic interpretation. It has only been possible to achieve such 2D sediment modelling in HECRAS since the release of HECRAS version 6.1 in September 2021 although a test version was available in version 6.0. A model was set up on the based of the measurement of MRC Sediment and discharge project[1] 2009-2013 in the Bassac and estimated grain size composition. Figure 8-81 shows the sediment concentration on August 13 in the flood season 2018.

[1] MRC (2015) Discharge Sediment Monitoring Project (DSMP) 2009 2013 Summary & Analysis of Results

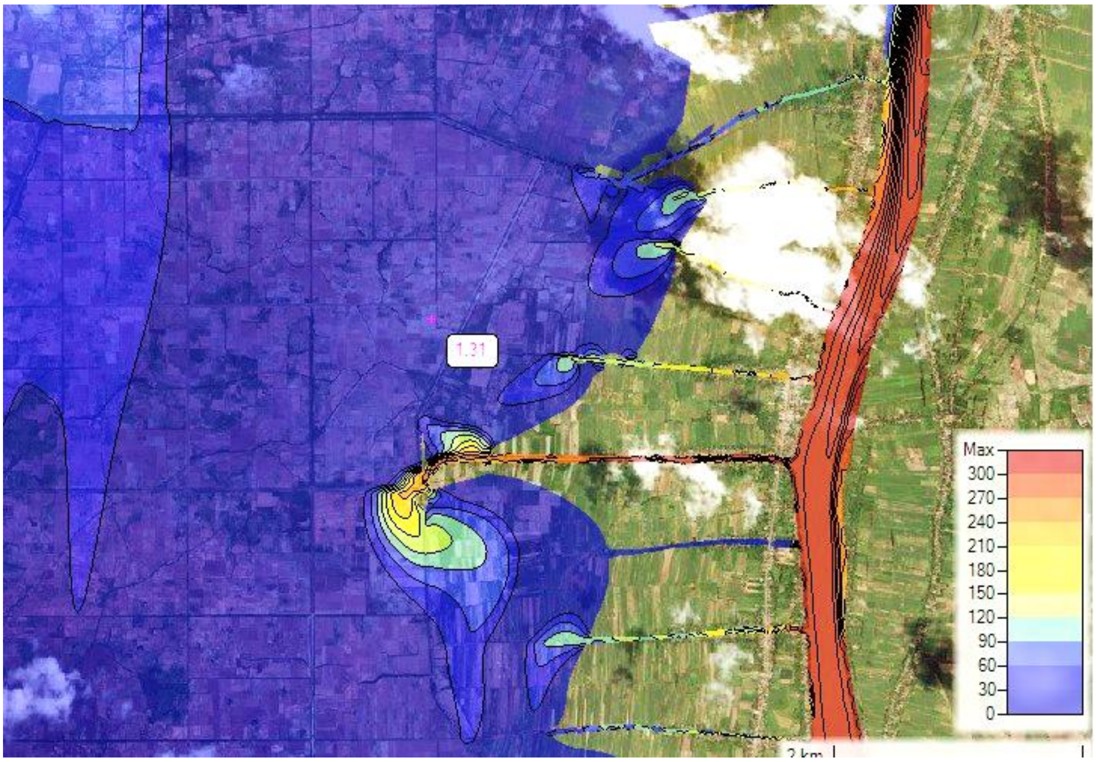


Figure 8-81 HECRAS 2D Simulated sediment concentrations during flood season 2018. Sediment Concentrations in the rehabilitated Preks reduce rapidly as flow merges with the flooded area and velocities reduce.

The area where deposits would be expected will vary with the position of the flood extent (Figure 8-82) and for Prek Koh Teav and Prek Kong the embankment along Toul Khtom does seem to contain the area of deposition. The Prek Teav area of deposition includes the Toul Khtom near the bank and this is in keeping with the higher bed level in the Toul Khtom canal in this area.

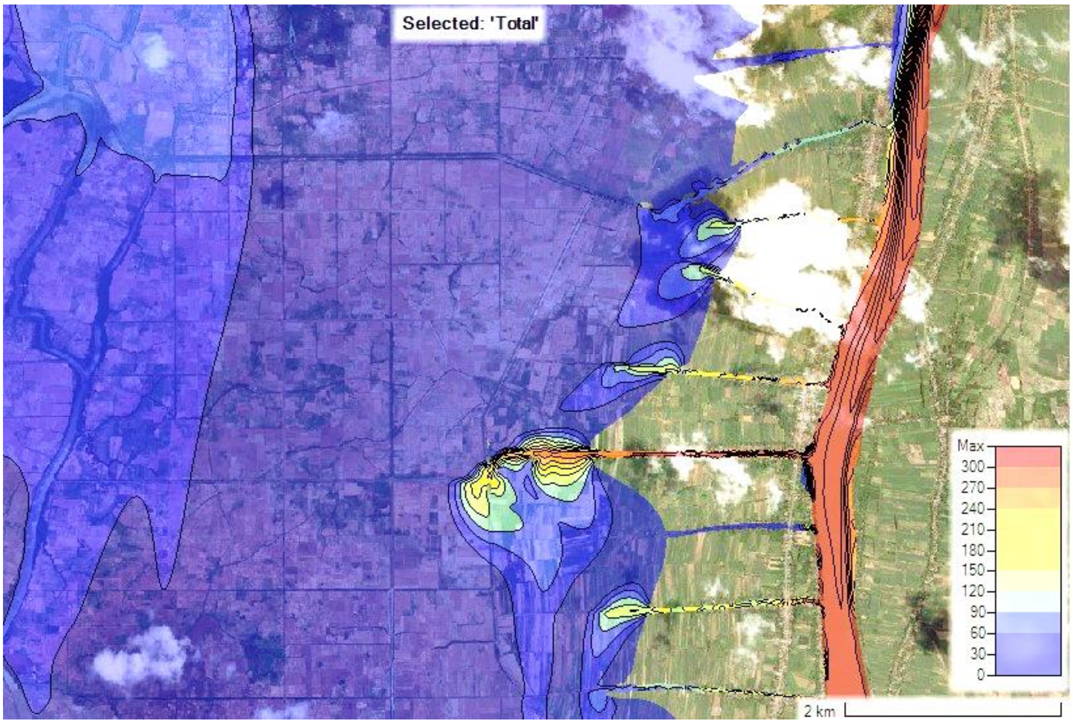


Figure 8-82 Sediment concentrations simulated near the peak of the flood 2018 (August 26). Note that the flood extent is slightly higher than the previous figure so deposition moves to the east at the end of the prek

Another feature that is notable is at the connection to the Bassac there is a significant reduction in sediment concentration implying that deposition is occurring. This is likely to be influenced by the main river alignment at the offtake and the length of connection where velocities may be quite low due to slow flow along the banks of the main river during flood. Although not yet definitive the conditions that are favourable for formation of a ‘river prek ‘with a self-sustaining bed level will be relevant for the Prek Masterplan and further work on this elsewhere may yield further insight

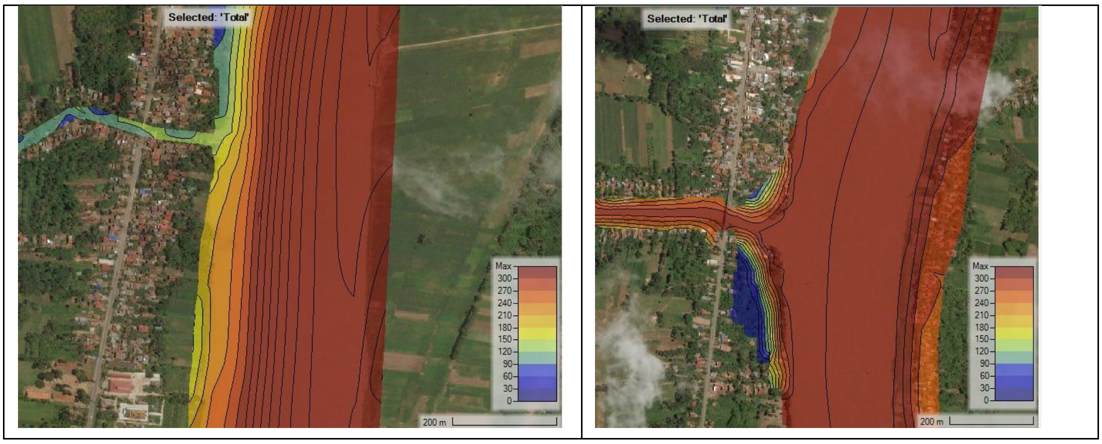


Figure 8-83 Comparison of simulated sediment concentration at offtake of Prek Thom and Prek Tiev. In Prek Thom the concentration is halved before the road bridge, thus deposition in this upstream part of the prek may be expected.

To determine the impact of the sediment rehabilitation, rather than to rely on the sediment modelling it is suggested that a useful result could be obtained simply by comparing the volume of flood flows that are carried down each Prek before and after rehabilitation, in that once the sediment is on the floodplain then it will deposit in areas of low velocity.

All rehabilitated Preks are expected to carry more flow and thus volume of sediment, typical increases are as shown below. For example, Prek Thom carries around 4 times the current amount of water volume and thus sediment flux than the current situation. This should benefit the fertility of the lower land as well as providing material for land raising.

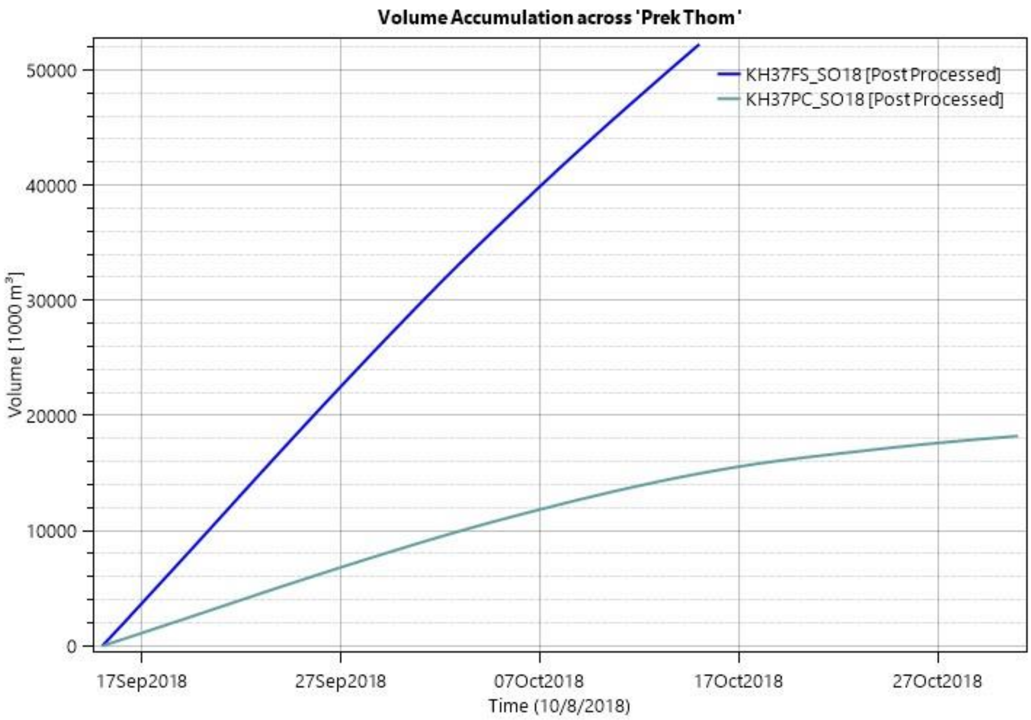


Figure 8-84 Example volume accumulation for flow into Prek Thom with and prior to rehabilitation during the peak of the wet season 2018.

8.17.6 Environment and Social Impact

The cumulative impact on the environmental and socio-economic condition of the Cluster area is already shown to be positive in the feasibility study but the analysis has identified a number of extra aspects:

The flood impacts are for slightly reduced levels in the Bassac River but a slightly increased rate of rise on the floodplain. There is no increase in the peak on the floodplain though. The more rapid rise on the floodplain is of marginal benefit for fisheries and positive for mainstream flood management. Although there is no environmental listing of the immediate Boeung area, the wetland provides habitat for fish and other species and will help the wetland reserve downstream at Boueng Prek Lapouv.

The increased availability of irrigation supply in the prek during dry season should reduce the dependence of some farmers on groundwater, safeguarding the use of shallow groundwater for other purposes and potentially giving a less contaminated crop.

Pollution of the prek by domestic waste is intended to be prevented through a new sewer line, but in any case, with increased flow the effect will be mitigated somewhat and in the case of the Prek Thom, dilution should be possible at any time of year.

The Preks that are not functioning at present seem to attract significant solid waste at the road crossings. Rehabilitation of the area and a local campaign to limit disposal into the prek should help reduce the health hazard.

The increased sediment flux will have a positive benefit for land management and fertility.

8.18 Synthesis of results

8.18.1 Inflow from Bassac

The rehabilitation of the preks will increase both dry season and wet season flows from the Bassac to the tail. The selection of a bed level of +0.6m at the head of Prek Thom (Table 8.16) can be expected to have some limitations at low tides during the dry season as illustrated in Table 8.17 on the basis of gauge analysis. The yellow shaded cells indicate that the rehabilitated Prek Thom would have periods of no flow from the Bassac at low tides during the months of February to June. The table also illustrates the difference in recent years to the longer term 30-year averages which had higher water levels especially in all months June to January.

For other rehabilitated preks with a bed level of 1.5m AD, all day flows would only occur July to September from the Bassac.

To ensure flow into the Prek Thom 'year round' it would be desirable to adopt a lower bed level than 0.6m. We note that the survey of Prek Thiet (a perennial prek) indicates a bed level of -0.6m AD, ie 0.6m below sea level whereas Prek Thom will be 1.2m higher bed.
For the rehabilitated bed level of 1.5m for Preks, flow from the Bassac may be expected only in July-December. The minimum

Table 8.16 Summary of Rehabiltated Prek Bed levels

Prek	Bed at Sta 0+000 (m AD)	Transition to lower bed (if any)	Bed level at outfall (m AD)	Length of Rehabiltation (km)	Comment
Thom	0.6	none	0.336	4+000	River Prek
Pra Theat	1.5	0+750	0.488	1+681	To be joined with Thom
Koh Teav	1.5	0+700	0.44	2+400	
Kong	1.5	0+800	0.4	2+974	
Nheak	1.5	0+850	0.408	2+876	
Ros	1.5	0+750	0.447	2+297	
Toul Khtom	-	-	-	Link canal, rehabilitation work expected but not yet defined	

Table 8.17 Summary of monthly Median Water Level and Tidal Ranges (Prek Thom)

PREK THOM						25.85km
Month	Median Water Level (m)		Median - tide	Median +tide	Median - tide	Change in Minimum
	1991 - 2020	*2015 - 2020*	*1991 - 2020*	*2015 - 2020*	*2015 - 2020*	
Jan	1.74	1.47	1.11	2.21	0.73	-0.38
Feb	1.20	1.11	0.49	1.90	0.33	-0.17
Mar	0.95	0.94	0.23	1.71	0.17	-0.06
Apr	0.84	0.90	0.13	1.67	0.14	0.01
May	0.87	0.90	0.19	1.64	0.16	-0.03
Jun	1.42	1.10	0.82	1.75	0.44	-0.38
Jul	2.87	2.14	2.38	2.70	1.59	-0.79
Aug	4.48	3.30	4.16	3.68	2.92	-1.25
Sep	4.79	4.37	4.57	4.65	4.08	-0.49
Oct	4.91	4.17	4.71	4.44	3.90	-0.81
Nov	3.87	3.16	3.53	3.60	2.72	-0.81
Dec	2.58	1.93	2.07	2.54	1.32	-0.75

8.18.2 Water Levels in Toul Khtom and at the Outfall of Preks Pra Theat, Koh Teav, Kong, Nhek and Ros

The median water levels in the Toul Khtom can be expected to be similar to those in the Bassac during the dry season but the tidal ranges will be different. In the feasibility study it seems to be assumed that the tide will be similar to that measured at the nearest gauge at Ankor Borei. This is likely to be a significant overestimate of tidal range as the tide ‘wave’ is significantly dampened as it enters the smaller channel network of the Prek Ambel and Boueng channels.

The tidal range at the outfall of the rehabilitated preks will depend on the connection of Toul Khtom to the central Prek Teav. At present the channel of the Toul Khtom is dry when levels are low as the bed is around +1m near to the Teav so it is assumed that the Toul Khtom would be excavated to around -0.5m consistent with other parts of the channel. In this case the model indicates a tidal range of only around 0.2m. With a minimum mean level of around 0.9m then there should be a depth of water at the tail of the rehabilitated preks of around 0.5m (Bed level 0.4m) which is likely the minimum for pumping out by the farmers. The flap gates being proposed as part of the Prek rehabilitation at outfall structures to help sustain water levels in the rehabilitated Preks are likely to introduce headlosses of around 0.1m and thus it is suggested that these should be reconsidered.

The rehabilitation of Prek Thom to only 4km out of its total length to the Prek Ambel should be checked if there are any blockages or shallow points of the unrehabilitated channel and the bank separating the Prek Thom from the Toul Khtom canal should be removed or the channels reconnected so that there is a strong supply 'ring' around the boeung area connecting the Prek Ambel with the Prek Thom, Toul Khtom and outfalls of Prek Koh Teav, Kong and Prek Teav for the northern side and Toul Khtom to Prek Nhek and Prek Ros to the south.

8.19 Flood control and siltation

The flood impact of the works is shown not to be deleterious in terms of higher water levels on the floodplain but has benefit in terms of some lowering of the upstream level. The flow in the rehabilitated preks does increase in flood and indicative changes have been given. For further study of the high flow in a particular prek, the rehabilitated cross sections must be defined as well as the bed levels.

The transport of sediment in rehabilitated Preks will increase and may be considered as proportional to the volume of flow conveyed in the flood season. Modelling of the areas of sediment deposition indicate a relatively limited area located close to where the prek meets the flooded area of the Boeung. Sedimentation at the inlet channels is also to be expected and maintenance regime should take this into account or else the prek inlet channel bed levels will rise again and flow in the dry season will be affected.

8.20 Practical Considerations

The prek rehabilitation proposals strike a balance between the cost of construction and the benefits and social impacts. Key design features proposed are the lowering of the Prek Thom at the inlet to give a year-round capacity for flow, whereas the other 5 Preks to be rehabilitated avoid significant bed lowering in the upstream and urban part of the Prek and rely on a backflow from the downstream boeung area.

There is obviously a limit to the lowering of the bed of a prek before there are impacts on the side bank stability and a slippage or widening of the channel occurs. Experience of previous prek rehabilitations has shown how this can happen and how expensive it is to come up with a stable solution. We would question whether +0.6m is the best choice of level given potential for lower tidal levels in the Bassac and the expected sedimentation that will be revealed at the start of the dry season.

The reliance of the design for water to backflow into the prek in the dry season is high however and the proposed outfall with flap gate to enhance the water available in the prek, we would question. What is critical is to ensure a strong connection of channels to the Prek Ambel, this could be through the improvement of the Toul Khtom particularly where it connects to the Prek Teav on both the south and north side where the bed is currently high.

The ’without project’ situation would be for continuing decline of the prek system with adverse effect not only on irrigation but flood management particularly given climate change impacts as well as likely encroachment on the channels through the urban part in the future making rehabilitation more difficult,

The solid waste in the channels must also be a threat to health locally and disposal should be facilitated to reduce this in future. The removal of spoil during the rehabilitation works should allow for the proper disposal of this waste.

Improving Water Use Efficiency depends on having a reliable water supply. The analysis of water usage using remote sensing indicated a rising demand though areas of fallow land remained.

9 Conclusions and Recommendations

9.1 Achievement of the Outputs Required

The purpose and scope of this WAT4CAM component is to build understanding of the hydrological and hydraulic systems of the prek irrigation systems downstream of Phnom Penh. This has been achieved through a combination of data collection and analysis, processing and interpretation of remote sensing, and construction and use of an extensive 2D model using the software HEC-RAS, which is freely available but of the highest capacity. In addition, projections of mean water levels at each offtake and the likely future tidal range have been provided. Overall, a significant dataset for model building and analysis of the Preks downstream of Phnom Penh was assembled.

Innovative use of satellite image processing has been able to show the trends in flood extent and duration, changes in cropping area and use of water for each studied prek system specified.

The HEC_RAS 2D model developed is based on the representation of each and every prek and river channel between Phnom Penh and the border with Vietnam and includes representation of the Tonle Sap and Great Lake as well as the Mekong left bank.

A local model of the TA-INFRA proposals for rehabilitation of systems within a cluster of preks on the West Basaac floodplain has also been completed including hydraulic and sediment simulations to assess impact.

9.2 Flood Season: General Findings and Implications

Hydrological and hydraulic functioning of the prek systems was evaluated by integrating gauge data analyses, satellite-based assessment of flood extent and frequency, and 2D modelling of the including 2000, 2011, 2018, 2019, and 2020 flood events. The following main conclusions can be drawn from this study regarding the flood season:

- Prek systems appear to operate very differently in the two regions (Mekong and Bassac). The satellite-based analysis showed that prek command areas on the western bank of the Bassac are rarely inundated, whereas regular flooding occurs of prek areas along the Mekong. This has implications for prek rehabilitation efforts. If better drainage and control of flooding is more important, Mekong system should be prioritized for rehabilitation
- The analyses suggest declining trends in annual peak flows, and prek systems and inundation frequencies in general seem to be decreasing in the last decade when compared to 1988-2010. The regularity of inundation in the area

appears to be reducing over time. This has implications for Prek rehabilitation and maintenance.

- Although 2018 floods were larger than average, 2020 floods were severe only within local areas such as the Prek Thnot, but the year in general had much reduced flood water extents compared to average between June and September. This may be an artifact of upstream dam regulation and climate change in which extremes and averages are less coupled. Prek rehabilitation should take the changing situation into account in the rehabilitation.

9.3 Low Flows: General Findings and Implications

To understand the functioning of the hydrological and hydraulic system during the dry season, a combination of analysis of 2D modelling, remote sensing analyses, and assessment of gauge records was implemented. The following main conclusions can be drawn from this study regarding the flood season:

- The model was used for giving an overall picture and understanding of the water distribution downstream of Kratie and some of the constraints on supply for the Prek systems. Results show how water availability for offtake to preks rapidly declines during the low-flow season, where little flow is left in the West Bassac and Mekong systems in February. Based on gauging data, a tabulation of expected water levels at each prek throughout the year was constructed, to promote understanding of hydrological dynamics across the study area.
- At Neak Luong (Mekong), since 2000, 5-year averages of gauge data have consistently decreased in the dry season.
- Remote sensing analysis shows that, in the Mekong Preks, water availability and use are clearly higher than in the Bassac Preks during the driest months of the year. This is reflected in the agricultural area left fallow in the respective systems. Individual prek systems were ranked according to observed fallow cropland in the dry season, which can indicate shortage of water from the preks.

Overall, the water level changes in the main Bassac river in the last five years have been significant and these changes have made it more difficult to access water in the preks. This may be caused by a combination of climate change and the development of dams upstream which are also a climate change mitigation measure. The impact of these is being paid for by the farmers though the rehabilitation costs will offset this. The financing of the rehabilitation it could be argued should therefore partly be from climate funds and dam developers.

9.4 Climate Change

Climate change could affect the flood and drought situation significantly. For floods, a 30% increase in flows will results in depths increasing around 0.25m and the extent by over 100m additional land. Sea level rise is mostly confined within Vietnam with an increase of around 0.05m in Cambodia during flood, but a full 0.3m in the dry season which may be of benefit.

During the dry season there is already a drastic reduction in water levels from upstream development. Previous analysis in the Mekong suggests a higher demand for water by 8-12% (Kitamura 2014). A change in flow due to climate change due to an increase in evaporation and evaporative demand can be expected but the practical implications are much more dependent on the change in net evaporative demand after taking account of changing precipitation.

Sea level rise, whilst having a significant impact in Vietnam due to increased salinity intrusion, is most unlikely to extend as far as the Cambodia border so the higher water levels in the dry season would have a positive effect for flow to the Preks though could make some areas more prone to tidal inundation on a spring tide.

9.5 WAT4CAM Batch 1 Prek Cluster Rehabilitation

9.5.1 Functioning of the Prek Irrigation Systems

A better understanding of the functioning of Prek Irrigation systems is emerging which has implications for better design in the future. Key design aspects such as use of gates at the head of the system, other weirs and outlet structures especially need careful consideration of the local condition, as does the practical limits of any proposed bed lowering.

1. The concept of and distinguishing aspects of ‘River Preks’ and ‘Agri Preks’ is useful and turning an ‘agri’ prek into a year-round ‘River Prek’ is unlikely to be feasible in the majority of cases. Reasons for this are both capital cost and sedimentation giving an unbearable maintenance requirement.
2. The role of preks in flood management has been overlooked in the past and constrictions and costly gates have only made sedimentation and maintenance worse with few (if any) benefits.
3. The prek channels serve as a key access route either by vehicle or by boat ad this access role is an important part of the functioning.
4. Water levels will be lower than in the past for much of the year (even if the minima does not change greatly) so the new regime may need adaptation for many Prek systems

5. Colmatage or sedimentation is definitely occurring as can clearly be seen in the difference in land surveys of the 1960s with present day and in the pattern of flooding. This sedimentation, which mostly occurs at the interface of the prek channel and the flooded area, should still be considered in rehabilitation proposals.
6. Without maintenance, the prek waterways attract garbage that further reduces cross section. Where there is pollution passing into the prek due to lack of any sewerage system this is a public health hazard so a longer-term solution must be to restore a working Prek or provide an alternative system.

9.5.2 Proposed Rehabilitation Options

The modeling performed in this study demonstrates that hydraulic effect of the rehabilitation of six preks within the Preks Cluster is expected in three areas:

1. Increased flows in dry and wet seasons, and thus increased availability of water in both chamkar and boeung areas
2. Small Increase in peak flood level on the flood floodplain
3. Increased sediment fluxes

We would support the idea for better utilising water from the boeung system to supply Prek areas in the dry season but caution that the analysis of the capacity of channels has not been detailed so far. The use of a terminal structure with flap gate could be detrimental to water passage both in the wet season and if the flap gate reduces reverse flows.

The chosen bed level for Prek Thom of +0.6m AD will constrain flow capacity and does not allow for any sedimentation. We estimate minimum water level to be +0.9m with not much difference from February to May.

9.6 Constraints and Issues

When interpreting the results of this study, some limitations need to be taken into account. Most notably, the following issues need to be considered:

a) Covid-19 has, unfortunately, limited the amount of capacity building possible for MOWRAM and travel for some of the team members.
b) The scale of the Mekong river system, including upstream dams, is large and data from other countries on future plans and operation is sparse. Other parties are drawing benefit from development upstream that is impacting downstream use. MOWRAM has little control of this, but the Prek irrigation systems are being impacted by low water early in the dry season.
c) Synthetic hydrographs as called for in the terms of reference would not capture the issues of variability and change in the Mekong. The very latest data from 2018-2020 has been used, but some gap filling was needed in time series of tributary flows and demands.

d) For detailed analysis, channel surveying and a better ground DEM are critical.
e) Long seasonal floods and tide-dominated dry seasons are challenging for fine scale modelling due to the high levels of computation needed and long run times.
f) Operation of gates and pumps could be included in the model, but details are currently unknown.
g) A study of the overall demands in the whole West Bassac floodplain area is needed, but was beyond the scope of the study.
h) The HEC-RAS Software is very capable but has some limitations, including evaporation from flooded areas thus slowing down the recession and drying up of ponded areas.

9.7 Recommendations

9.7.1 Recommendations on Data and Models

Readily accessible good quality data is needed for planning engineering works such as WAT4CAM rehabiliation of the Prek Irrigation Systems. Mowram's Hydrometric network is a key part of this information system and a key gauge fort his study is Ankor Borei which is currently not functioning as the gauge housing was damaged during bridge construction.

Recommendation 1: Re-Install Ankor Borei Gauge to a working condition

Recommendation 2: Up to date data (up to 2020 at least) is essential on river levels and flow should be available and used by all parts of WAT4CAM. Currently it is very hard to access such data and the current efforts to support a National Water Resources Information System that should be supported.

Recommendation 3: The HEC-RAS Model developed should be maintained and updated for use in future

Recommendations on Model Use

The model can be used for flood and drought studies should be adopted by MOWRAM in conjunction with the existing HECRAS model of the flood centre, and be maintained and improved. To ensure sustainable uptake of the results of this study, the hand over and training / capacity building should be well documented and support should continue beyond the end of the current study.

9.7.2 Prek Masterplan

Recommendation 4: The Model should be used in the development of the Prek Masterplan including an extension of the work of Component 3.1 to support TA-INFRA.

The application of remote sensing, analysis of water gauges and modelling to improve the understanding of the complex hydraulics of the prek system has been proven by WAT4CAM Component 3.1 for the Batch 1 works for the Preks Cluster.

The Preks Masterplan similarly faces a complex situation, with significant change going on in the main rivers and continuing development and urbanisation on the floodplain.

Working with the Preks Working group, component 3.1 has proposed aggregating a number of Prek into hydraulic units that could be studied so that a better understanding is obtained of the specific conditions which vary across the region as shown in Figure 9-1. Further use and improvement of the Preks database in combination with other data could also aid in the prioritisation for rehabilitation works.

Specifically, some of the issues for further input could be regarding:

- Implications of the changing flood regime for crop patterns
- Actual water use cumulatively in the whole area and how this could be improved, for example through the Prek Ambel and other ‘river prek’ connections
- Use of storage areas in the Trans-Bassac part
- Spills from the Prek Thnot and Bati Lakes system
- Effect of roads across the Trans-Bassac floodplain
- Effect on the IBA of the Trans-Bassac marshes
- Use of gates and terminal structures.
- Sedimentation in canals, upstream channel and on the floodplain
- Water use and efficiency
- Fisheries and navigation

9.7.3 Recommendations for Future Studies

WAT4CAM 3.1 have developed a large-scale model attuned to studies in the area of the Preks downstream of Phnom Penh. The model is suited for use elsewhere and, for example could be extended to support other studies including those of WAT4CAM in the Tonle Sap and a proposed flood channel or other works in the Mekong floodplain area.

Future Studies could include:

a) Study and inclusion of major water consumers such as pumped schemes in the west Bassac that are not part of the prek system

b) New communication infrastructure such as roads, rail and air should be studied explicitly.
c) Potential for improving flow in the Bassac and to the Boeungs by, for example, improving Prek Ambel.
d) Additional remote sensing analyses of water use would help to enhance understanding of crop water requirements and water shortages across specific prek command areas. The current study has made use of readily available evapotranspiration data, spanning the entire study area though extracted only for the part defining the tentative list of Preks for rehabilitation. Dedicated high-resolution analyses of water consumption using high-resolution satellite data would provide insight into prek-specific water use patterns especially during the dry season, and help to calibrate models for running scenarios reflecting water management and climate change pathways for the whole areas, accepting that the water source is shared also with other irrigation systems and water users in the West Bassac floodplain.
e) The effect of climate change on water demands should be included above taking account otheeh latest scenarios and data available.
f) Capacity Building in the processing of remote sensing products for studies of longer-term change
g) Monitoring of the role of sediment processes in the Preks
h) Development of sediment models to aid sediment management in the Prek systems.

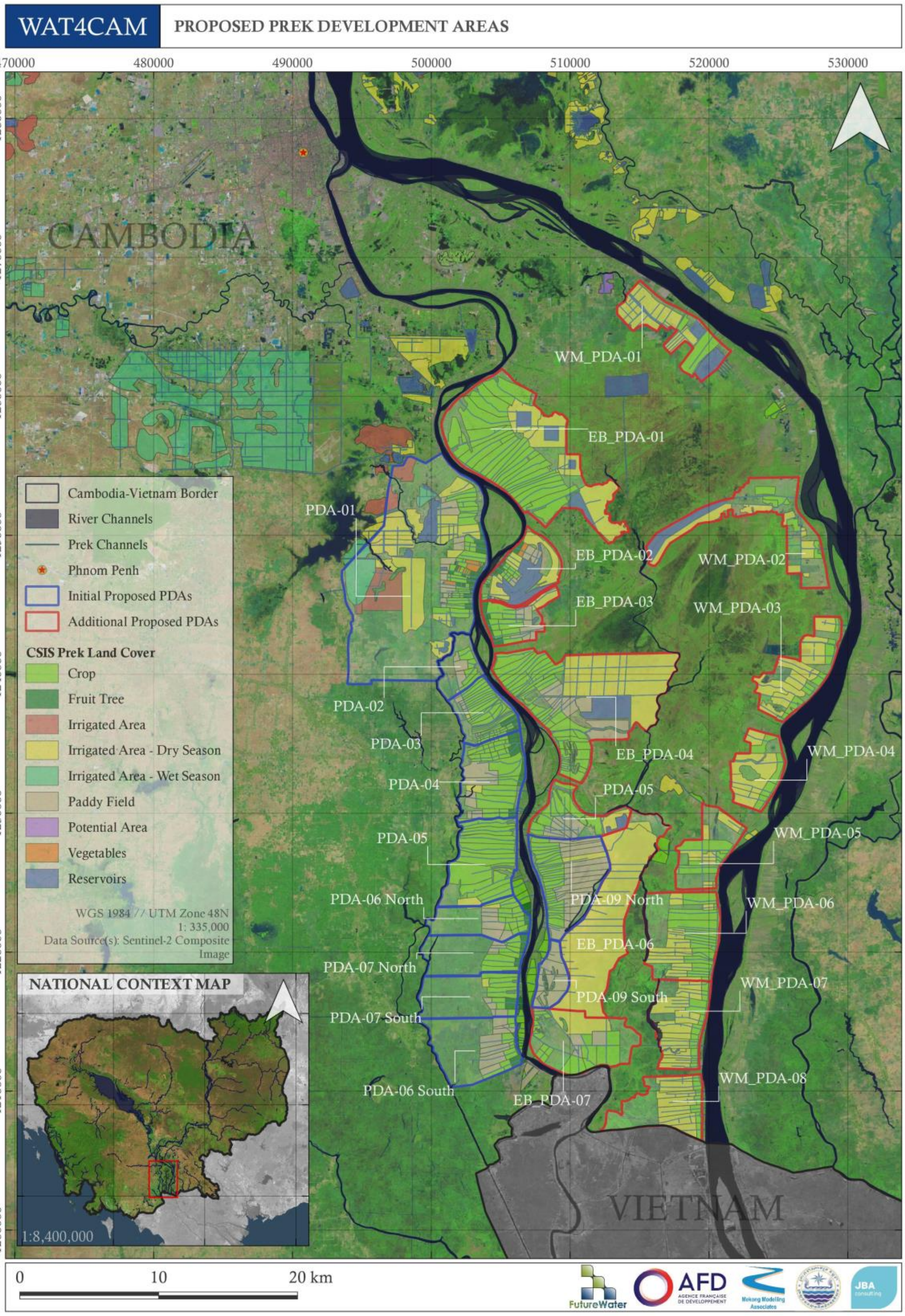


Figure 9-1 Potential Grouping of Preks for study in Prek Masterplanning

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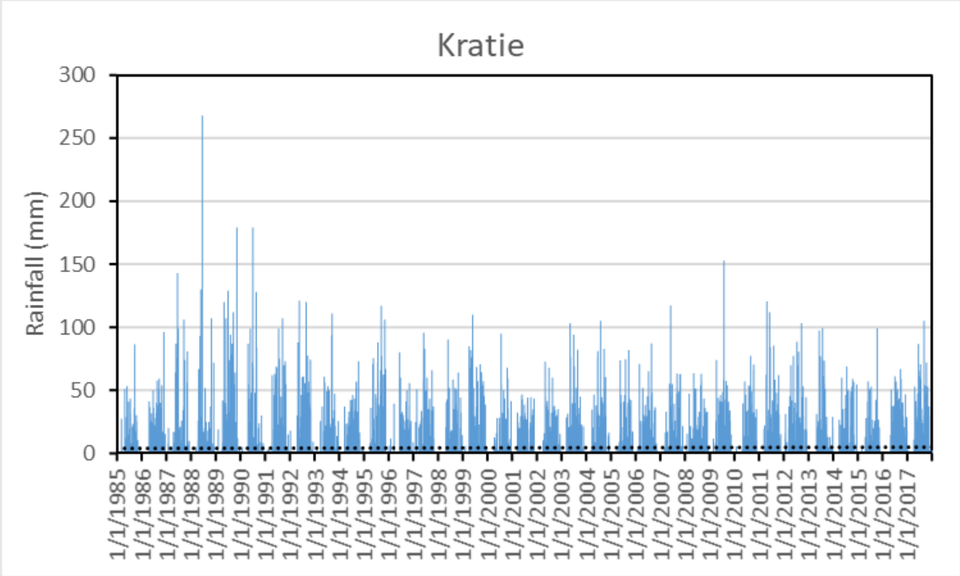
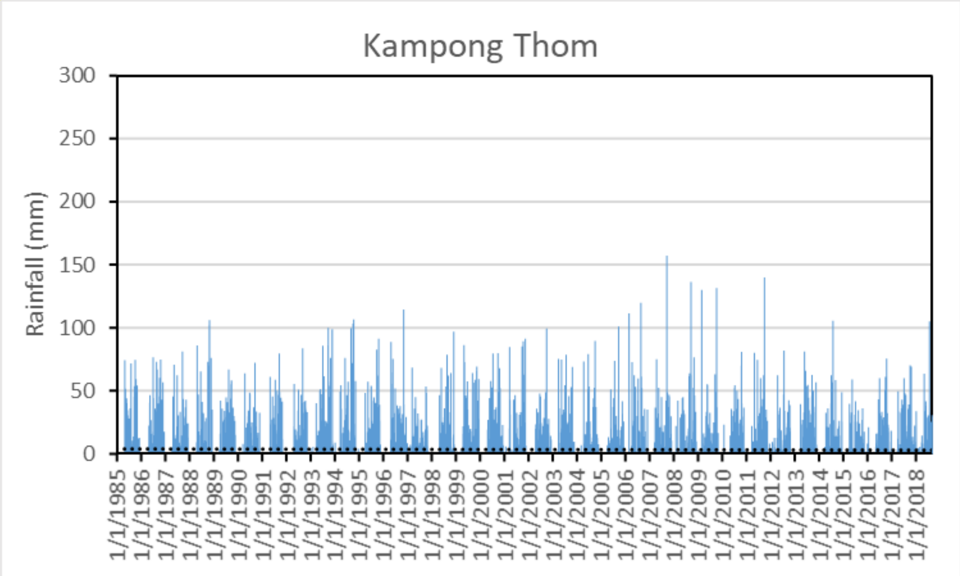
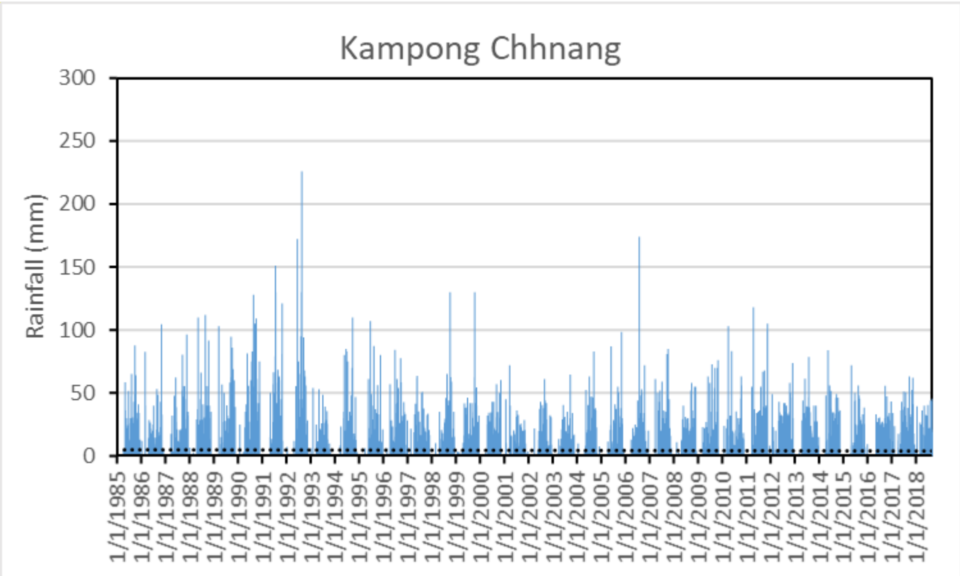
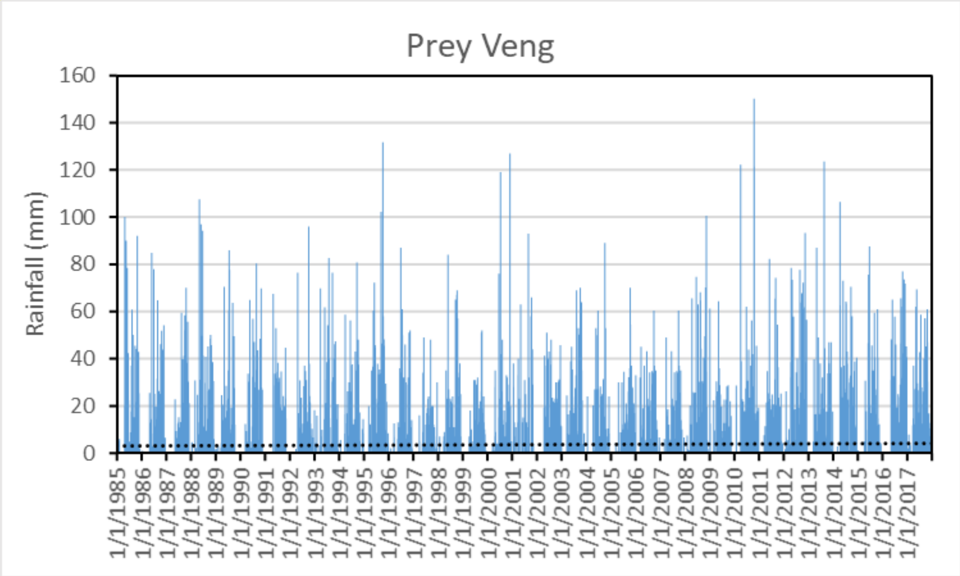
11 APPENDIX 1 DAILY RAINFALL DATA

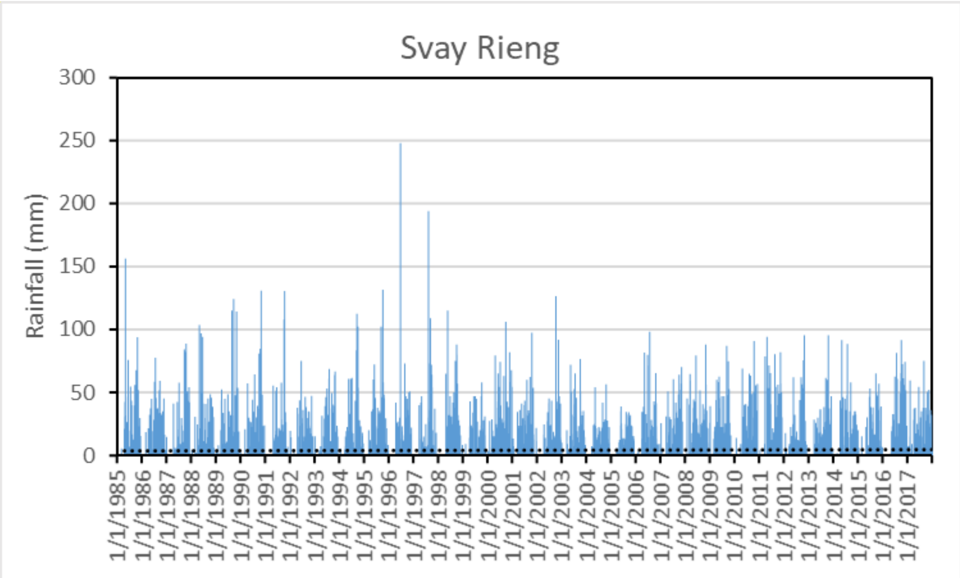
Daily rainfall for each station

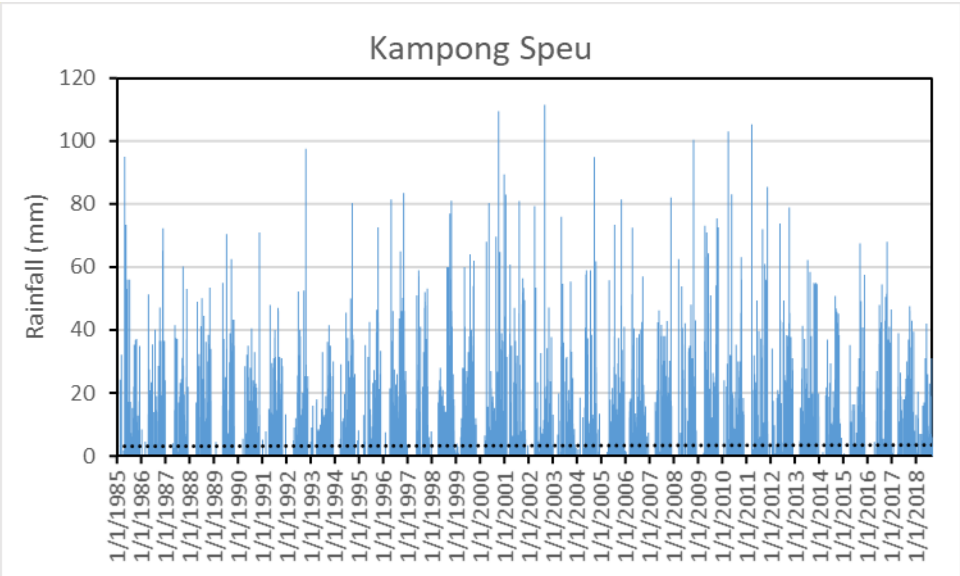


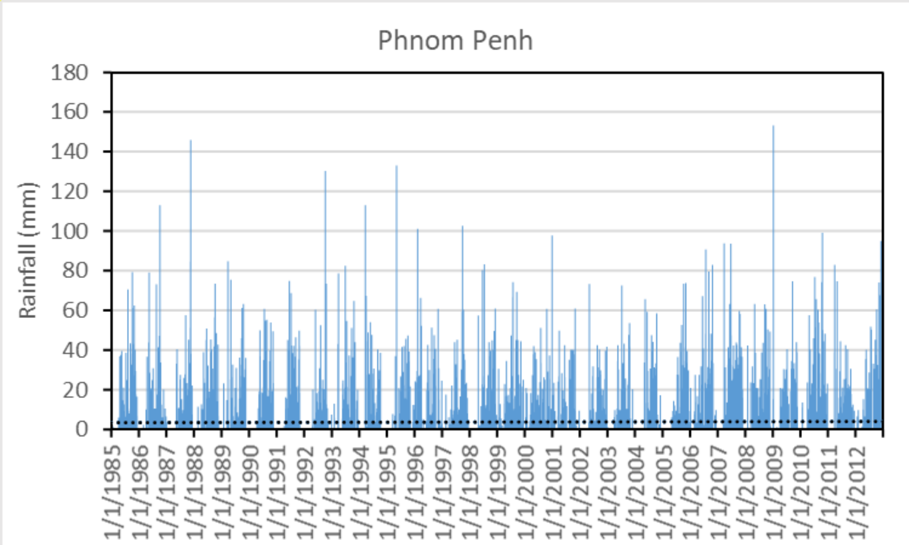





Prey Veng
Rainfall (mm)


Svay Rieng
Rainfall (mm)


Kampong Speu
Rainfall (mm)


Phnom Penh
Rainfall (mm)
180
160
140
120
100
80
60
40
20
0
1/1/1985
1/1/1986
1/1/1987
1/1/1988
1/1/1989
1/1/1990
1/1/1991
1/1/1992
1/1/1993
1/1/1994
1/1/1995
1/1/1996
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1/1/2002
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1/1/2004
1/1/2005
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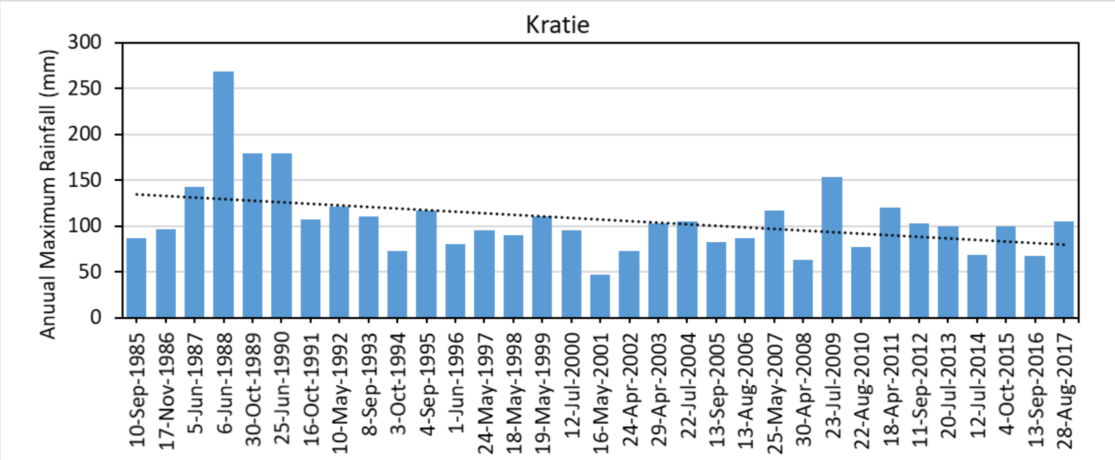
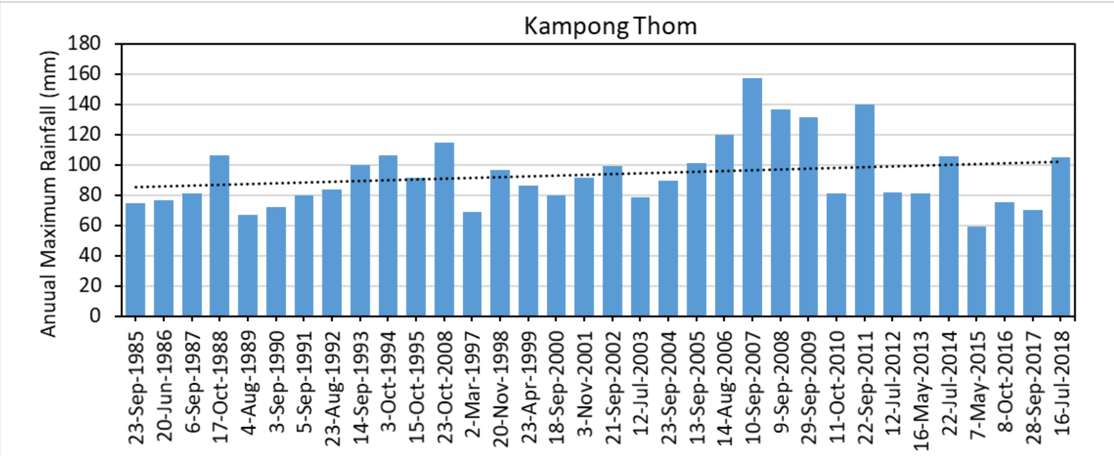
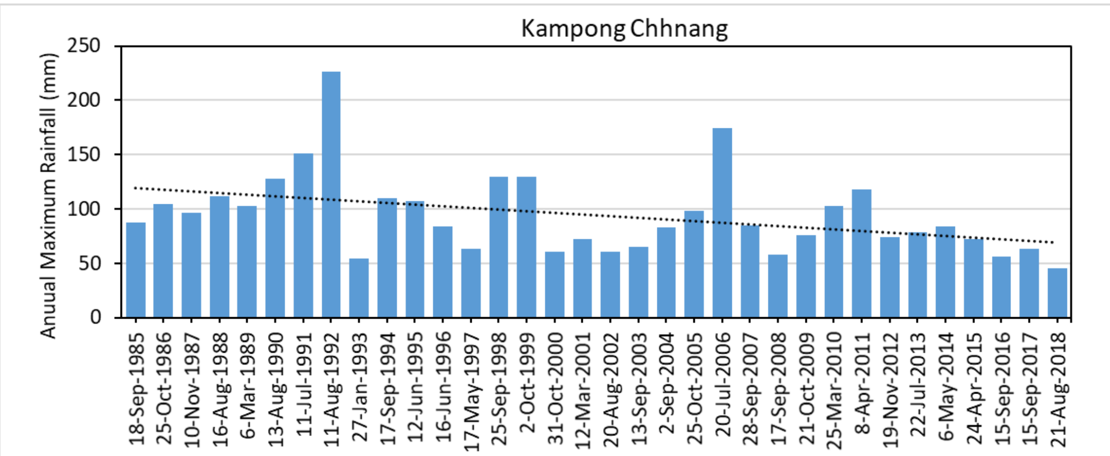
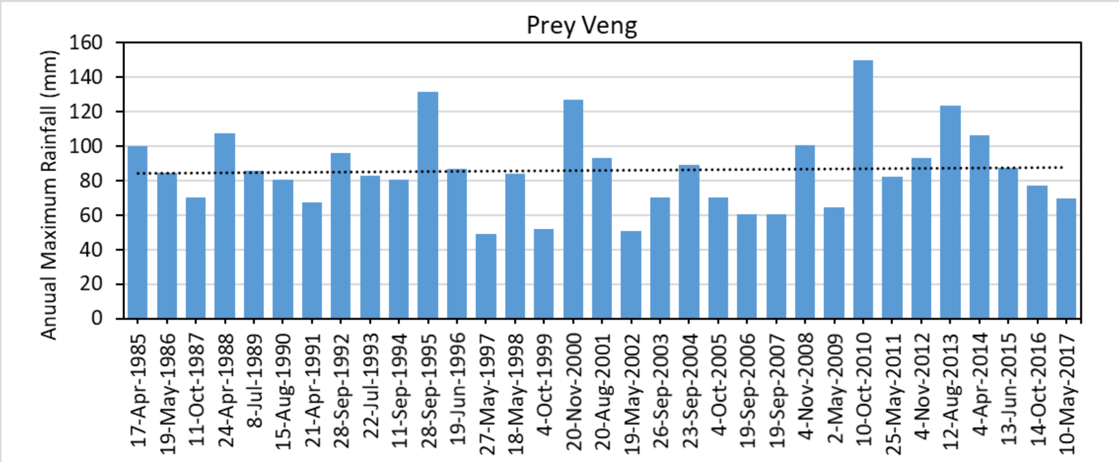
1/1/2009
1/1/2010
1/1/2011
1/1/2012

Annual maximum daily rainfall for each station








Prey Veng
Anuual Maximum Rainfall (mm)
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20
40
60
80
100
120
140
160
17-Apr-1985
19-May-1986
11-Oct-1987
24-Apr-1988
8-Jul-1989
15-Aug-1990
21-Apr-1991
28-Sep-1992
22-Jul-1993
11-Sep-1994
28-Sep-1995
19-Jun-1996
27-May-1997
18-May-1998
4-Oct-1999
20-Nov-2000
20-Aug-2001
19-May-2002
26-Sep-2003
23-Sep-2004
4-Oct-2005
19-Sep-2006
19-Sep-2007
4-Nov-2008
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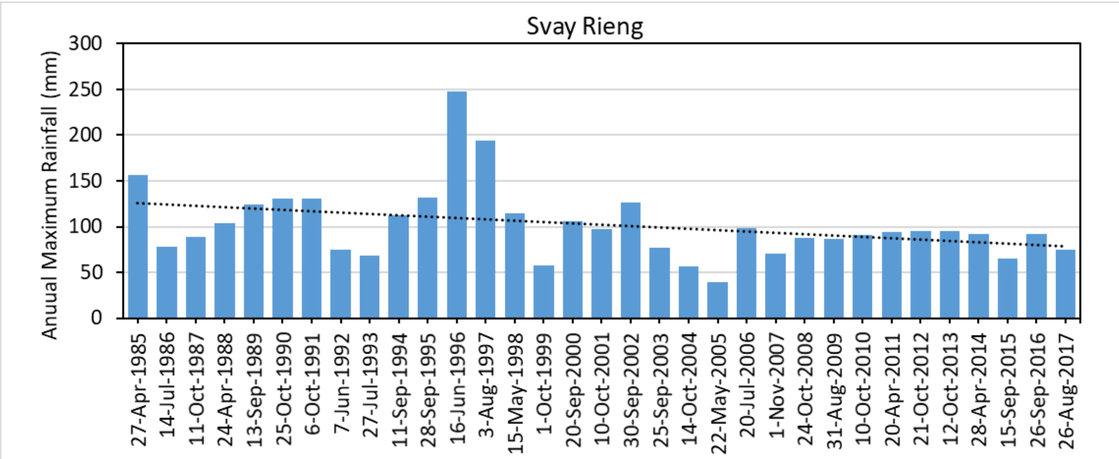
14-Oct-2016
10-May-2017


Svay Rieng
Anuual Maximum Rainfall (mm)
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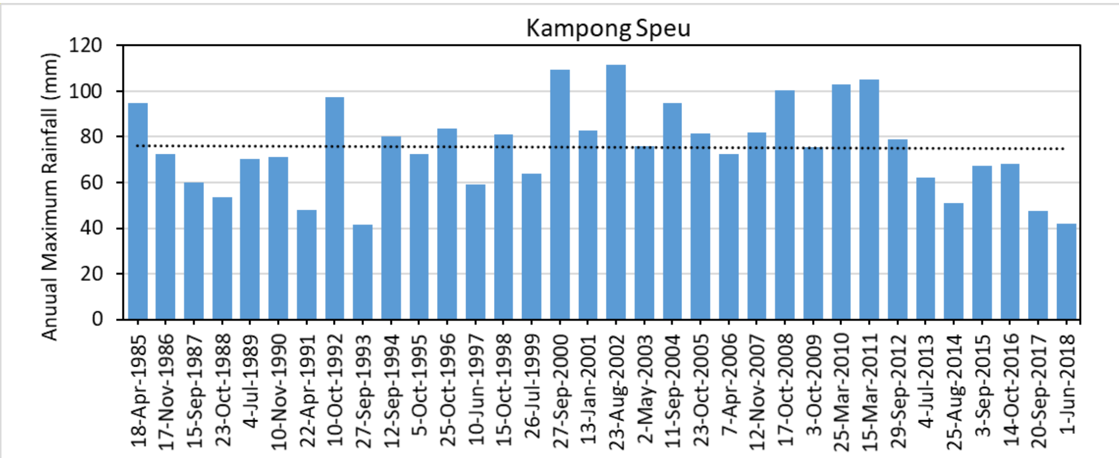
50
100
150
200
250
300
27-Apr-1985
14-Jul-1986
11-Oct-1987
24-Apr-1988
13-Sep-1989
25-Oct-1990
6-Oct-1991
7-Jun-1992
27-Jul-1993
11-Sep-1994
28-Sep-1995
16-Jun-1996
3-Aug-1997
15-May-1998
1-Oct-1999
20-Sep-2000
10-Oct-2001
30-Sep-2002
25-Sep-2003
14-Oct-2004
22-May-2005
20-Jul-2006
1-Nov-2007
24-Oct-2008
31-Aug-2009
10-Oct-2010
20-Apr-2011
21-Oct-2012
12-Oct-2013
28-Apr-2014
15-Sep-2015
26-Sep-2016
26-Aug-2017


Kampong Speu
Anuual Maximum Rainfall (mm)
0
20
40
60
80
100
120
18-Apr-1985
17-Nov-1986
15-Sep-1987
23-Oct-1988
4-Jul-1989
10-Nov-1990
22-Apr-1991
10-Oct-1992
27-Sep-1993
12-Sep-1994
5-Oct-1995
25-Oct-1996
10-Jun-1997
15-Oct-1998
26-Jul-1999
27-Sep-2000
13-Jan-2001
23-Aug-2002
2-May-2003
11-Sep-2004
23-Oct-2005
7-Apr-2006
12-Nov-2007
17-Oct-2008
3-Oct-2009
25-Mar-2010
15-Mar-2011
29-Sep-2012
4-Jul-2013
25-Aug-2014
3-Sep-2015
14-Oct-2016
20-Sep-2017
1-Jun-2018

12 APPENDIX 2 SURVEY REPORT

TOPOGRAPHIC SURVEY WORK

WAT4CAM
COMPONENT3

Support to
Water Resources Monitoring and Management

Under

WAT4CAM-CS/03-01
Funded by AFD and EU

Survey Report

January 2021

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HISTORY REVISION:

Name	Author	Revision	Date
EGI002 Survey Report 08-Feb-2021.pdf	Sami Sivuth	Original Submission	08-Feb-2021
EGI002 Survey Report_V1_19-Feb-2021.pdf	Sami Sivuth	Changed attend person and client firm	19-Feb-2021

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Contents

I, Introduction

I-1, Executive Summary

This report details the results of topographic survey conducted by Aruna Technology for Water Resources Monitoring and Management Project. The survey work was carried out on December 07th 2020 to January 14th 2021.

This report covers the survey undertaken in two adjoining provinces Kandal and Prey Veng in Cambodia.

Topographic Survey:

A. **Level Road Survey: 231km**
   - Road West Mekong: 43km
   - Road West Bassac: 69km
   - Road East Bassac: 80km
   - Road 21 East Bassac: 39km

B. **Prek Cross-Section Survey: 45 Sections**
   - Prek Ambel (Prek Kbal Khmaoch): 18 Sections
   - Prek Kampong Sambuor: 6 Sections
   - Prek Ta Hing: 6 Sections
   - Prek Mesrok: 6 Sections
   - Prek Nou: 6 Sections
   - Canal CAVAC: 3 Sections

C. **Bridge Survey: 191**

D. **Water Gate Survey: 19**

E. **Water Gauge Survey: 3**

Output of Survey Points and digital maps:

- The survey points coordinate list level roads, Prek cross-sections, bridges and water gauge survey

- Map layouts (of level roads, Prek cross-sections, bridges and water gauge) were designed on A3 size paper with scale of 1:160 000

I-2, General Condition

The topographic survey works were undertaken from December 07th 2020 to January 14th 2021. The objective of the work was to provide 16 benchmark points connected national network, topographic survey of level roads, Prek cross-sections, bridges and water gauge in order to collecting 3D points for determine water resources monitoring and management.

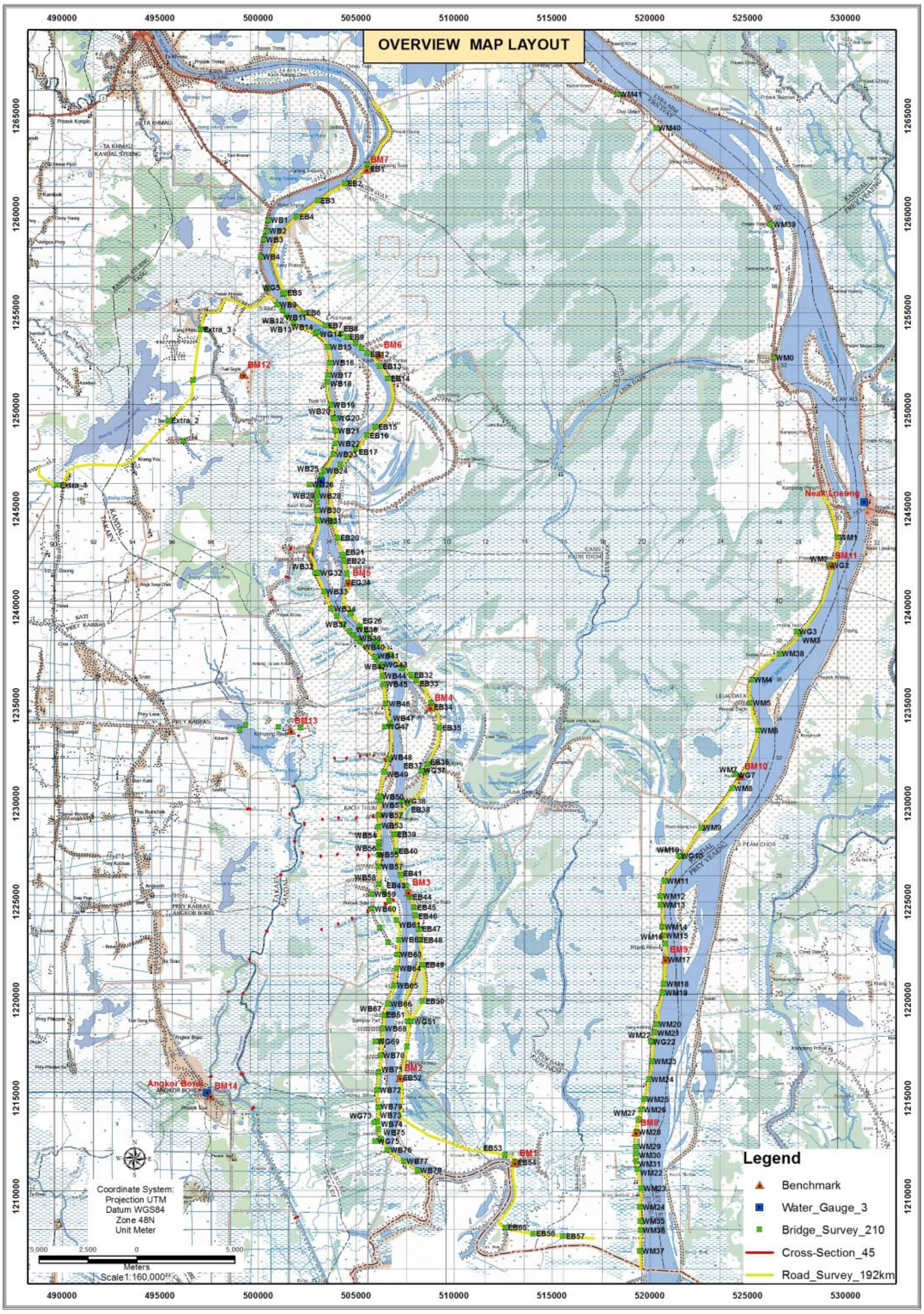


Figure 1: Topographic Map Showing Project Site Location

I-3, Scope of Work

Land survey works were carried out with the following items and quantities:

1. Level Road Survey: 231km
    a. Road West Mekong: 43km
    b. Road West Bassac: 69km
    c. Road East Bassac: 80km
    d. Road 21 East Bassac: 39km
2. Prek Cross-Section Survey: 45 Sections
    a. Prek Ambel (Prek Kbal Khmaoch): 18 Sections
    b. Prek Kampong Sambuor: 6 Sections
    c. Prek Ta Hing: 6 Sections
    d. Prek Mesrok: 6 Sections
    e. Prek Nou: 6 Sections
    f. Canal CAVAC: 3 Sections
3. Bridge Survey: 191
4. Water Gate Survey: 19
5. Water Gauge Survey: 3
6. Map layouts
7. Survey report

II, Survey Equipment

Four sets of GPS Receiver (Trimble R4 and R6) and one set of Eco-Sounder Sonarmite were applied for benchmark, topographic survey of level roads, Prek cross-sections, bridges and water gauge survey.

Figure 2: GPS Static Survey for Benchmark Control Points

Figure 3: RTK Survey Base Station with Radio Link (left) and Rover (right)

Figure 4: Surveyor was operating Eco-sounder on boat (right) and Eco-sounder system (left)

III, Bench Mark Establishment and Description Card

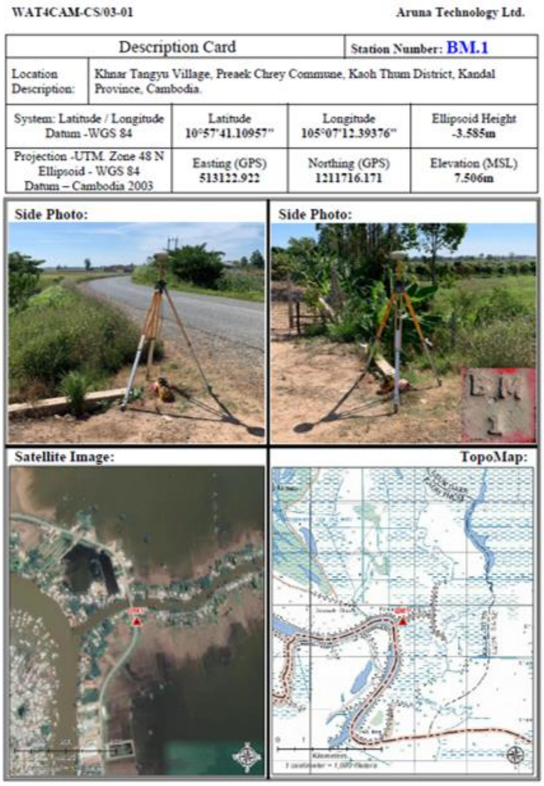
III-1, Benchmark Establishment

The concrete pillar 20cm x 20cm x 50cm were constructed as control point. Control point locations were selected disturbance or damage was unlikely and in an open area for GPS observation works. The 14 concrete monument benchmark constructed on site.

Figure 5: Picture of BM1 (left) & BM4 (right) benchmark GPS control point

III-2, Description Card for Benchmark Point

The 14 Description cards have been prepared for each GPS benchmark points including site photos, satellite image and description. Benchmarks were numbered BM1 to BM14. There are two description cards TBM1 and TBM19 from previous survey KCC were prepared as well. For more detail please see Annex 1 description cards.

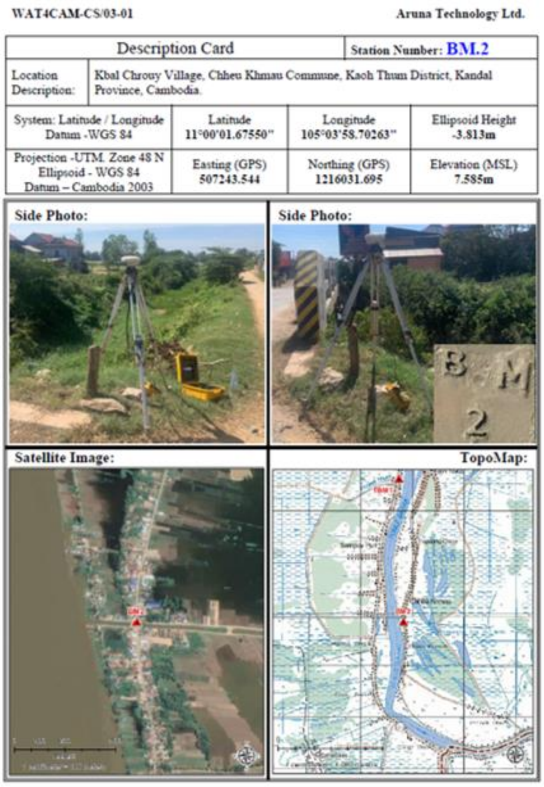


WAT4CAM-CS/03-01 Aruna Technology Ltd.

Description Card			Station Number: BM.1
Location Description:	Khnar Tangyu Village, Preaek Chrey Commune, Kaoh Thum District, Kandal Province, Cambodia.		
System: Latitude / Longitude Datum -WGS 84	Latitude 10°57'41.10957"	Longitude 105°07'12.39376"	Ellipsoid Height -3.585m
Projection -UTM. Zone 48 N Ellipsoid - WGS 84 Datum – Cambodia 2003	Easting (GPS) 513122.922	Northing (GPS) 1211716.171	Elevation (MSL) 7.506m

Side Photo: Side Photo:

Satellite Image: TopoMap:



WAT4CAM-CS/03-01 Aruna Technology Ltd.

Description Card			Station Number: BM.2
Location Description:	Kbal Chrouy Village, Chheu Khmau Commune, Kaoh Thum District, Kandal Province, Cambodia.		
System: Latitude / Longitude Datum -WGS 84	Latitude 11°00'01.67550"	Longitude 105°03'58.70263"	Ellipsoid Height -3.813m
Projection -UTM. Zone 48 N Ellipsoid - WGS 84 Datum – Cambodia 2003	Easting (GPS) 507243.544	Northing (GPS) 1216031.695	Elevation (MSL) 7.585m

Side Photo: Side Photo:

Satellite Image: TopoMap:

Figure 6: Sample Description card of bench mark

IV, GPS Static Survey for Control Point, Trimble R6s Receiver

Four sets of Trimble GPS receiver were used for static survey to create site control points. One set of GPS receiver was setup on vertical known point ***ARUN*** (fixed it as vertical reference point) and one receiver was setup on horizontal known point ***GPS 1*** (fixed it as horizontal reference point) and two or one set were setup on new points. Two known points were kept each observation and move two points (BM1-BM14 and some check points). Please see description card of base station ***ARUN*** and ***GPS1*** in Annex 5.

A one second interval static survey method was applied for GPS static survey. One observations was applied for observed for static survey with the observation time about 2 hours except the longer observation was extend to reach accuracy tolerance about 3 or 4 hours. The GPS baseline was about 3km to 30km. See Figure 7 GPS point network and baseline.

The GPS static horizontal accuracy is 11mm and vertical accuracy is 57mm before network adjustment. Please see GPS static output report in Annex 2.

Table 1: The table of GPS static maximum accuracy

				H	V			
TBM1 --- BM2 (B41)	TBM1	BM2	Fixed	0.004	0.015	178°14'41"	5548.388	0.395
ARUNA --- GPS1 (B6)	ARUNA	GPS1	Fixed	0.011	0.057	158°44'08"	30261.323	-13.440
ARUNA --- BM12 (B1)	ARUNA	BM12	Fixed	0.006	0.038	166°17'59"	26911.239	-15.667

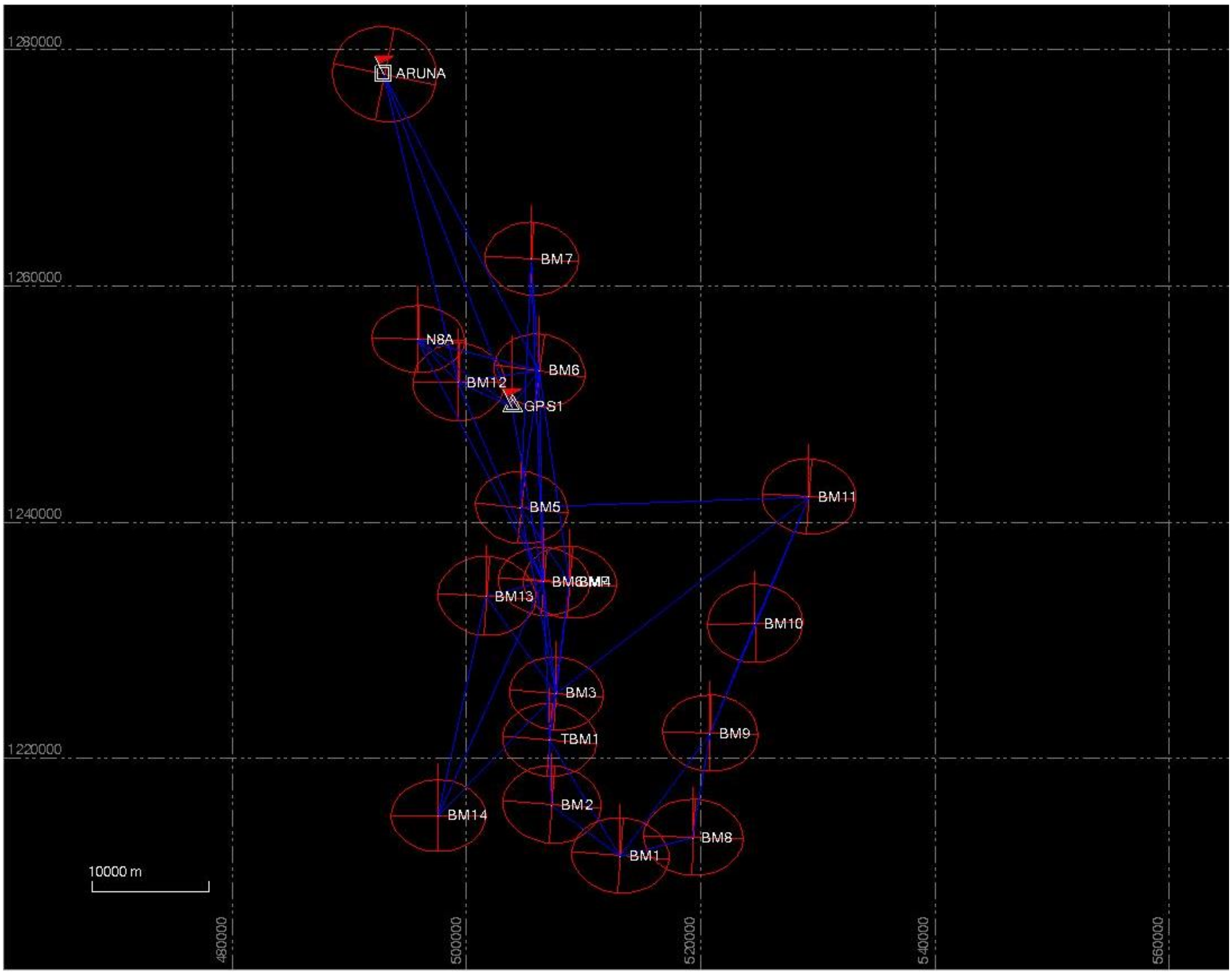


Figure 7: GPS observation points network and point accuracy

ARUN benchmark point was constructed and survey on roof top of ARUNA office. See Figure 8. It is our primary control point connected both vertical and national datum network in Cambodia. This reference point was connected to zero-order Cambodia horizontal national benchmark in 2004 and connected Cambodia vertical national benchmark BM16 near Chrouy Changva bridge. See Figure 10.

GPS1 is our secondary benchmark point was constructed and survey previous survey 2013 for Cambodia Floodplain for Improvement of the MRC Toolbox project. It connected both vertical and horizontal datum network in Cambodia. See Figure 6.

Horizontal (X, Y) datum was connected to national coordinate system benchmark (**Datum WGS84, Zone 48N**).

Vertical (Z) datum was connected to national vertical datum **Ha Tien Mean Sea Level**.

The elevation (Z) was transferred by using GPS Static survey and transformed height from ellipsoidal height to orthometric height (MSL) through Geoid Model EGM2008. For more detail please see Annex 2 Trimble Business Center software output GPS report.

Figure 8: GPS Base Station ***ARUN***, horizontal national benchmark network

Figure 9: GPS Base Station ***GPS1***, vertical & horizontal national benchmark network

Figure 10: Cambodia vertical national benchmark BM16:11.481m

V, Topographic Survey

V-1, Level Road Survey

Three sets of GPS receiver with PPK continues survey method (every 7m was applied for level road survey). Two sets of GPS receiver were setup on two known points and one set of GPS receiver was set up as rover on car roof for measure road level.

Figure 11: The photo of PPK rover was setup on the car

About 10km distance from one base station to another was designed by surveyor in order to conduce road level. Rover on the car can reach about 20km per session (1 base point about 10km) and each road section was surveyed double run (go-trajectory and back-trajectory) to ensure that the survey data is correct. Surveyor was kept same way and moved to the next session until completed each lite route.

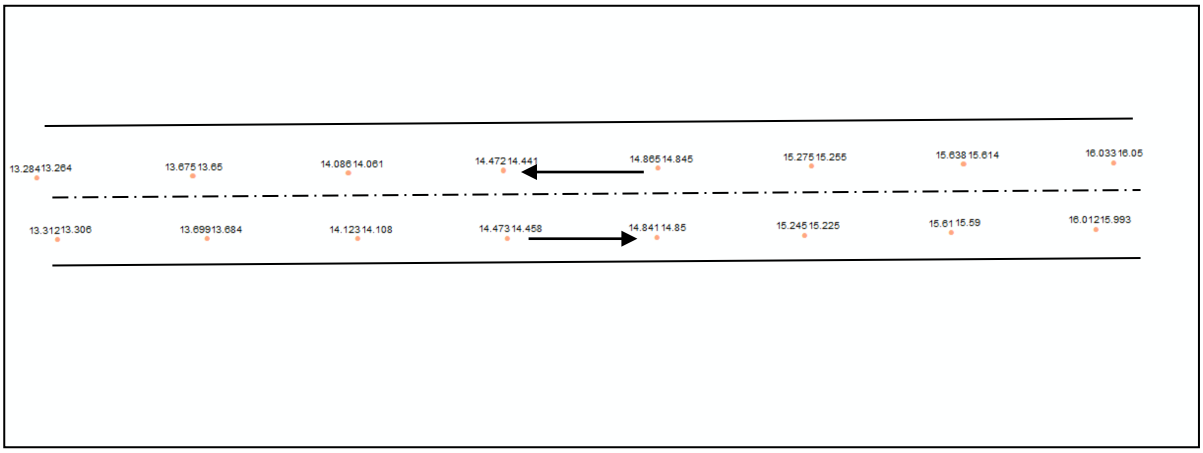


Figure 12: Points road level survey go-trajectory and back-trajectory

Four roads with total length 231km were survey (Road West Mekong: 43km, Road West Bassac: 69km, Road East Bassac: 80km and Road 21 East Bassac: 39km).

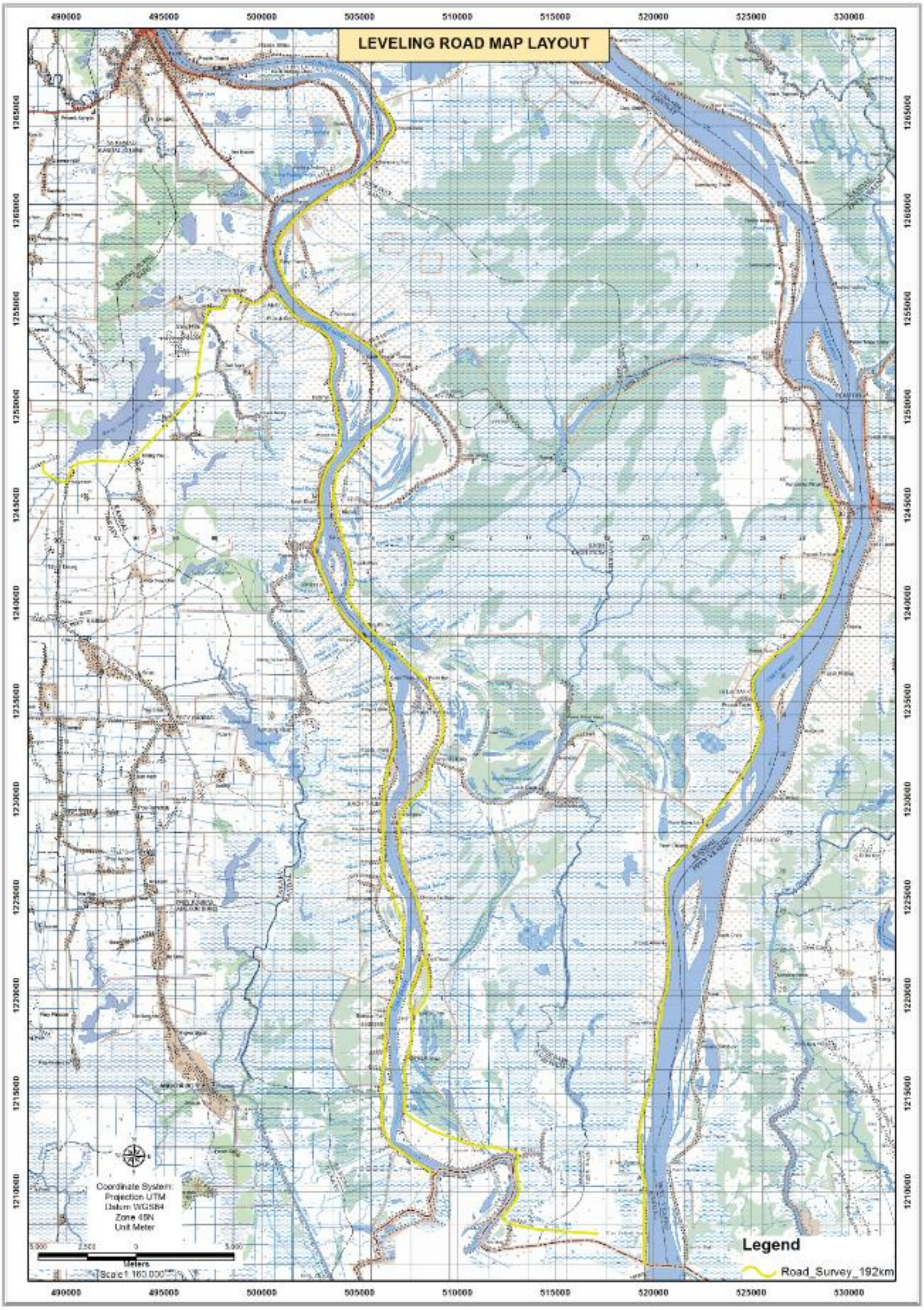


Figure 13: Sample map showing the road level survey (yellow lines)

V-2, Prek Cross-Section Survey

Three sets of GPS receiver with RTK and one set of Eco-Sounder Sonarmite survey method were applied for cross-section survey. One RTK base station with radio link was running whole day and one rover survey on Prek banks and another rover was connected to Eco-sound system in order to measure part of cross-section in the big Prek (Prek Kbal Khmaoch).

The whole cross-section was combination between points on ground (slop points to river, water level, river bank and natural ground level) and points in the river were survey as cross points.

Figure 14: RTK base station with radio link (left) and surveyor was operating RTK rover on ground (right)

Figure 15: Surveyors operating RTK rover in the water

The Eco-Sounder survey work is the combination two systems GPS RTK (Base and Rover) system and Eco-Sounder system.

Surveyor was checked water level, GPS antenna height, and transducer height and test points before survey Eco-sounder make sure system working correctly.

The Easting, Northing, Elevation and Depth were stored straight way from survey points Eco-sounder and GPS to controller.

Figure 16: Surveyors operating Echo-sounder on boat (left) and surveyor checked water level and transducer height (right) before start survey

Table 2: List of Cross-Section Survey

No	Name	Cross-Section
1	Prek Ambel (Prek Kbal Khmaoch)	18
2	Prek Kampong Sambuor	6
3	Prek Ta Hing	6
4	Prek Mesrok	6
5	Prek Nou	6
6	Canal CAVAC	3
	Total	45

V-3, Bridge Survey

The RTK and PPK survey were applied for bridge survey. The bridge points such as invert level, span and top level were surveyed and record in order to determine discharge of water flow. Surveyor not only survey the bridges along the road 21 but also the water gates downstream were surveyed similar to bridge. There were 191 bridges and 19 water gates in total were surveyed.

Figure 17: Surveyor was operating RTK rover to measured bridge points

Figure 18: Some of the water gate photos west side of the bridges along road 21

V-4, Water Gauge Survey

GPS RTK was applied for survey three gauges (Koh Khel, Neak Leoung and Angkor Borey). Surveyor measure the appropriate height on gauge then he determines level zero according to the actual survey points. Please see description card of water gauge in Annex 3.

Table 3: List of Water Gauges

Gauge ID	Easting	Northing	Elevation	Level on Gauge	Level: 0m on Gauge (based on survey datum Ha Tien)	Water Level	Date
Koh Khal	503221.719	1246401.349	1.937m	3.000m	**-1.063m**	1.743m	6-Dec-20
Neak Loeung	530948.607	1245344.626	2.494m	3.000m	**-0.506m**	1.733m	9-Jan-21
Angkor Borei	497414.667	1215293.244	2.285m	2.000m	**0.285m**	1.534m	10-Jan-21

Figure 19: Surveyor was operating RTK rover to measure Neak Loeung gauge

VI, Data Processing

VI-1, GPS Computation

GPS processing and adjustment were done by Trimble Business Center software. There are 19 points in total on site (14 new benchmark and 3 check reference points, one horizontal control point ***GPS1*** and one vertical control point) were processing. For more information about GPS computation please see attach report and digital data in Annex 2. Initially, ellipsoidal height was defined for all points by using GPS. The ellipsoidal heights were transformed to orthometric height by using EGM08 (Earth Gravity Model 2008) geoid model.

The GPS static horizontal accuracy is 11mm and vertical accuracy is 57mm before network adjustment

Table 4: All Static Control Point Coordinate List

Coordinate System: Projection UTM, Zone 48N, Datum WGS 84 Unit Meter

Point ID	Easting	Northing	Elevation	Remark
ARUN	492899.772	1277978.157	23.265	Aruna
BM1	513122.922	1211716.171	7.506	Aruna
BM2	507243.544	1216031.695	7.585	Aruna
BM3	507662.479	1225478.381	8.102	Aruna
BM4	508792.576	1234891.866	5.634	Aruna
BM5	504609.488	1241239.921	7.887	Aruna
BM6	506204.443	1252841.590	6.413	Aruna
BM6-MF	506560.781	1234935.034	6.882	MRC/FINNMAP
BM7	505529.188	1262270.613	7.641	Aruna
BM8	519291.407	1213266.322	7.402	Aruna
BM9	520800.054	1222064.301	7.919	Aruna
BM10	524631.463	1231403.961	8.369	Aruna
BM11	529242.318	1242117.557	7.913	Aruna
BM12	499265.037	1251841.604	7.016	Aruna
BM13	501672.156	1233706.735	6.500	Aruna
BM14	497575.966	1215126.178	5.488	Aruna
GPS1	503863.945	1249785.924	9.071	Aruna
N8A	495800.204	1255466.713	42.344	National BM
TBM1	507072.451	1221575.229	7.261	KCC
TBM19	506173.261	1216342.529	7.308	KCC

Coordinate System: Geographic Coordinate System

Point ID	Latitude	Longitude	Ellip. Height	Remark
ARUN	11°33'38.51655"	104°56'05.56633"	10.607	Aruna
BM1	10°57'41.10957"	105°07'12.39376"	-3.585	Aruna
BM2	11°00'01.67550"	105°03'58.70263"	-3.813	Aruna
BM3	11°05'09.24051"	105°04'12.58116"	-3.382	Aruna

BM4	11°10'15.71654"	105°04'49.91715"	-5.884	Aruna
BM5	11°13'42.42464"	105°02'32.01840"	-3.853	Aruna
BM6	11°20'00.14072"	105°03'24.69341"	-5.373	Aruna
BM6-MF	11°10'17.13925"	105°03'36.32860"	-4.729	MRC/FINNMAP
BM7	11°25'07.13105"	105°03'02.47007"	-4.282	Aruna
BM8	10°58'31.48102"	105°10'35.67166"	-3.446	Aruna
BM9	11°03'17.89751"	105°11'25.56703"	-2.983	Aruna
BM10	11°08'21.89097"	105°13'32.08242"	-2.475	Aruna
BM11	11°14'10.57572"	105°16'04.41851"	-2.852	Aruna
BM12	11°19'27.60287"	104°59'35.75327"	-5.055	Aruna
BM13	11°09'37.16851"	105°00'55.13390"	-5.303	Aruna
BM14	10°59'32.21644"	104°58'40.12095"	-6.282	Aruna
GPS1	11°18'20.66724"	105°02'07.46484"	-2.781	Aruna
N8A	11°21'25.61927"	104°57'41.43130"	30.080	National BM
TBM1	11°03'02.16502"	105°03'53.10395"	-4.209	KCC
TBM19	11°00'11.80290"	105°03'23.43463"	-4.138	KCC

VI-2, PPK Processing

The Trimble Business Center (TBC) software was applied to processing PPK baseline for road level survey (there were two base stations and one rover every session). That mean most of the PPK points had two baselines except the baseline is too long or bad satellite signal from another benchmark point.

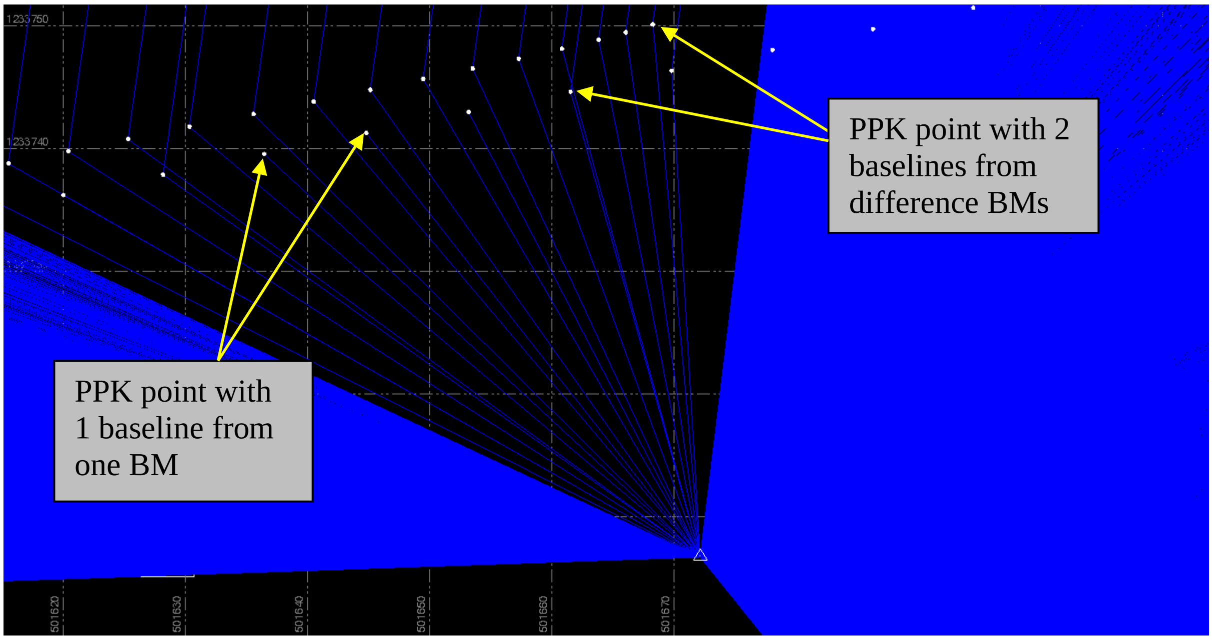


Figure 20: PPK points survey with one baseline and two baselines

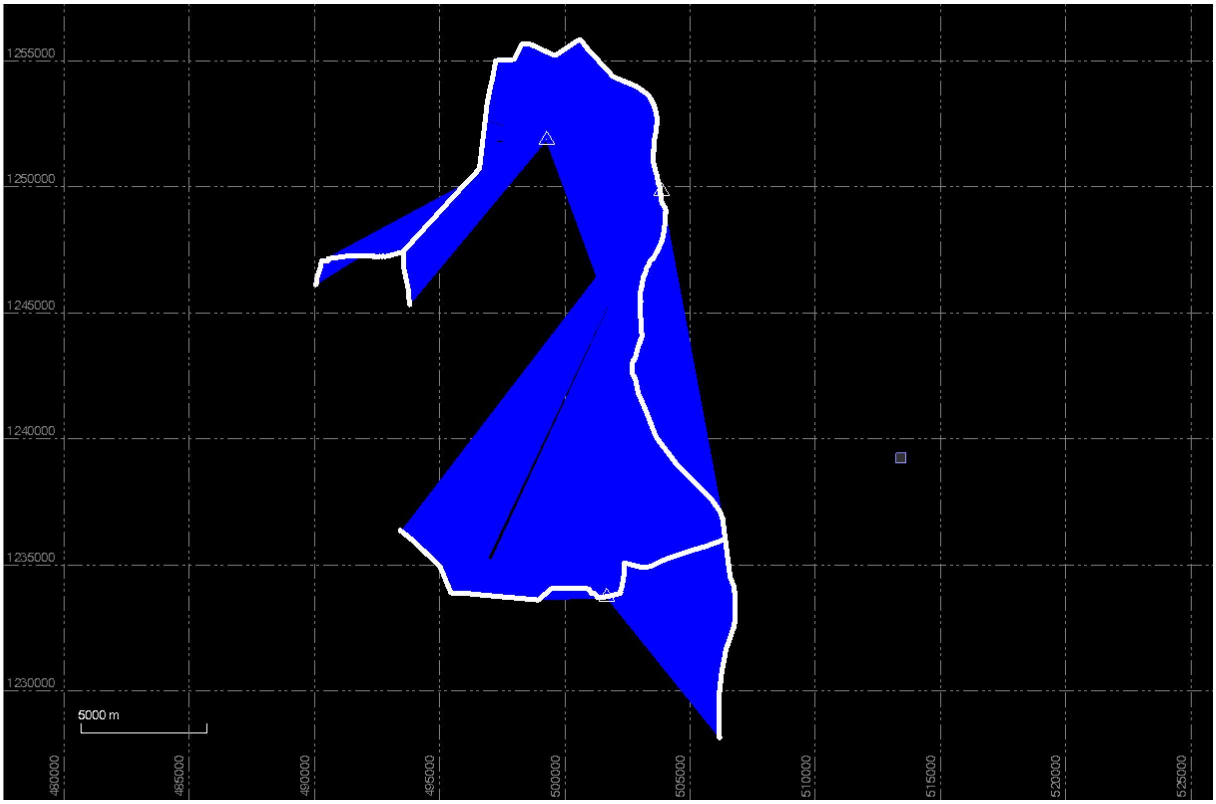


Figure 21: The combination sessions of PPK data processing on 15-Dec-2020

VII, Quality Control

VII-1, Control Points Quality Check

VII-1-1, Checking of horizontal control point, the TBC software was applied static computation by fixed the known point ***GPS1*** then determine ***ARUN*** and ***N-8A*** then we get result as below.

Table 5: Comparison Control Point Done by ARUNA and Original Coordinates

Static Survey on December 2020					Original Coordinates			Diff. Easting and Northing	
Point ID	Easting	Northing	Elevation	Remark	Point ID	Easting	Northing	Diff. Easting	Diff. Northing
GPS1	*503863.945*	*1249785.924*	*9.071*	*Fixed; National BM Datum 2003*					
ARUNA	492899.772	1277978.157	23.265	Determine	ARUNA	492899.774	1277978.157	**-0.002**	**0.000**
N-8A	495800.204	1255466.713	42.344	Determine; National BM Datum 2003	N-8A	495800.240	1255466.770	**-0.036**	**-0.057**

VII-1-2, Checking of horizontal control point, the TBC software was applied static computation by fixed the known point ***GPS1*** then determine ***TBM1*** and ***TBM19*** then we get result as below.

Table 6: Comparison Control Point Done by ARUNA and KCC Original Coordinates

Aruna Benchmark Coordinates List				KCC Benchmark Coordinates List				Diff. Easting and Northing	
Point ID	Easting	Northing		Point ID	Easting	Northing		Diff. Easting	Diff. Northing
TBM1	507072.451	1221575.229		TBM-1	507072.714	1221575		-0.263	0.268
TBM19	506173.261	1216342.529		TBM-19	506173.515	1216342		-0.254	0.245

We noted that the results (Easting and Northing) are quite big difference. It's because we (Aruna and KCC) were used difference horizontal datum.

Note: Cambodia government has two horizontal datums, one is datum 2004 done by Cambodian Geography Department and another one is datum 2009 done by Cambodian Geography Department and KOICA. This two datums is difference position about 25cm to 30cm.

VII-1-3, Checking of Vertical control point, the TBC software was applied static computation by fixed the known point ***ARUN*** then determine ***GPS1*** and ***Koh Khel Zero Meter on gauge (equal – 1m Ha Tien Datum)*** then we get result as below.

Table 7: Comparison Control Point Done by ARUNA and Original Coordinates

Static Survey on December 2020						Original Elevation					Diff. Elevation
Point ID	Easting	Northing	Elevation	Remark		Point ID	Easting	Northing	Elevation		
ARUN	492899.772	1277978.157	23.265	Aruna							
GPS1	503863.945	1249785.924	9.071	Aruna		GPS1	503863.945	1249785.924	9.082		-0.011
Koh Khal	503221.719	1246401.349	-1.063	Elevation at gaue zero meter		Koh Khal	503221.72	1246401.35	-1.000		-0.063

VII-1-4, Checking of Vertical control point, the TBC software was applied static computation by fixed the known point ***ARUN*** then determine ***BM6-MF (MRC) -TMB1*** and ***TBM19*** then we get result as below.

Table 8: Comparison Control Point Done by ARUNA and KCC Original Coordinates

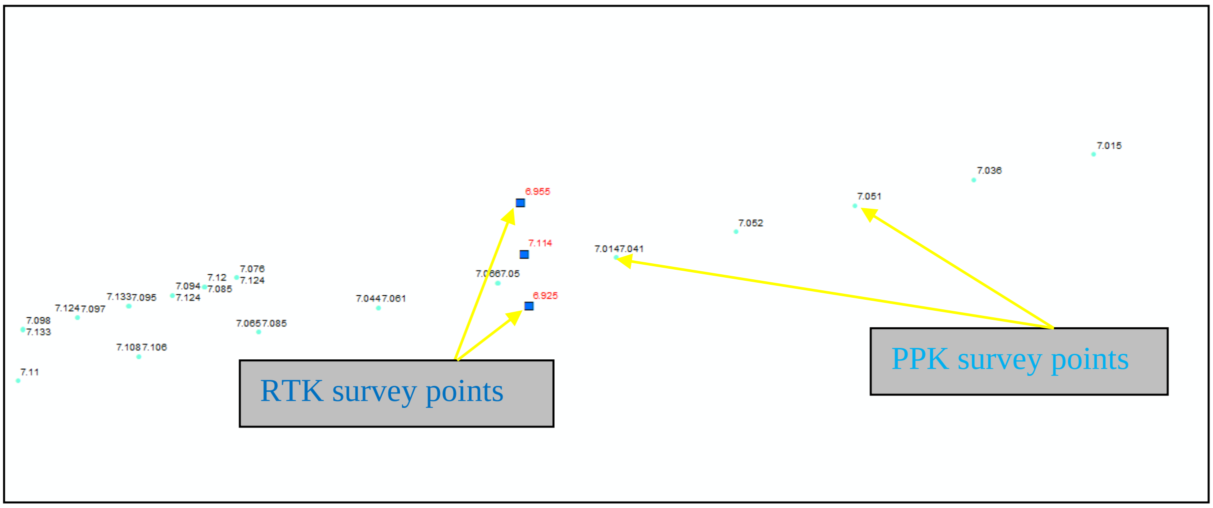
Static Survey on December 2020						Original Elevation					Diff. Elevation
Point ID	Easting	Northing	Elevation	Remark		Point ID	Easting	Northing	Elevation		
BM6-MF	506560.781	1234935.034	6.882	MRC/FINNMAP		BM6-MF	506560.78	1234935.03	6.7601		0.1219
TBM1	507072.451	1221575.229	7.261	KCC		TBM1	507072.714	1221574.961	7.537		-0.276
TBM19	506173.261	1216342.529	7.308	KCC		TBM19	506173.52	1216342.28	7.584		-0.276

VII-2, RTK and PPK Quality Check

- **Checking RTK**, the surveyor was checking RTK point on a known after setup base station and before start work. The accuracy RTK points +/- few cm.

- **Checking PPK**, the surveyor was checking PPK point two time and two difference ways. Checking with PPK themselves by running two ways go and back and check the difference elevation (the difference is less than 5cm). See Figure 12 above.

- The RTK points were survey some road sections to the elevation between PPK and RTK points accuracy about +/-4cm.



VIII, Final Data and Output for Delivery

The final data has been prepared as follows:

- Description cards of benchmarks, one (1) set of hard and soft copy.

- Description cards of water gauges, one (1) set of hard and soft copy.

- Map layouts (of level roads, Prek cross-sections, bridges and water gauge) were designed on A3 size paper with scale of 1:160 000, one (1) set of hard and soft copy.

Please refer to the following Annexes for further details and reference.

- Annex 1: Description cards of benchmarks
- Annex 2: Trimble Business Center output static report
- Annex 3: Description cards of water gauges
- Annex 4: Map layouts
- Annex5: Reference document

Phnom Penh, February 08th, 2021

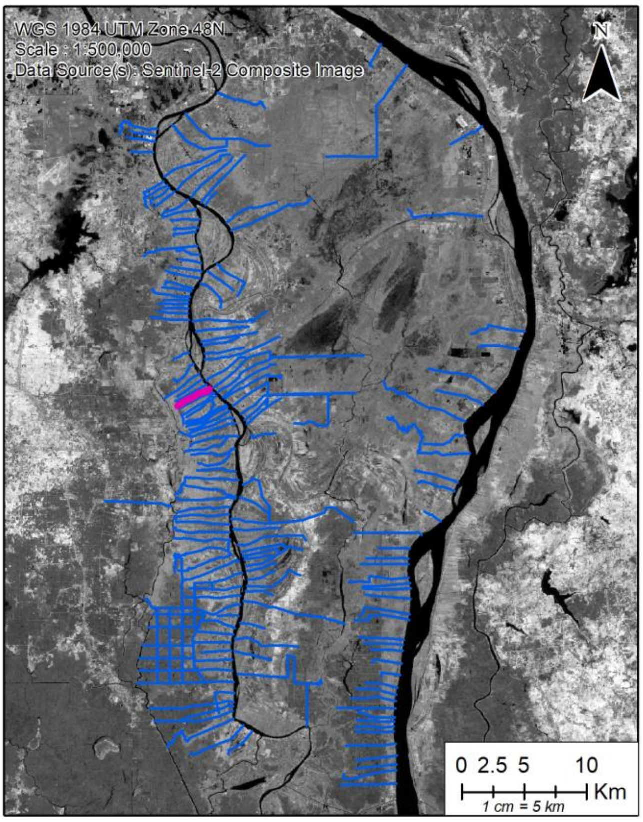
Aruna Technology Ltd.
Authorized Signature:

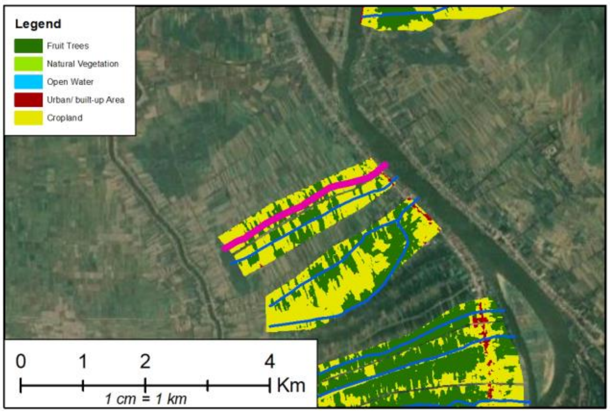
Sami Sivuth
Senior Survey
Tel: 012 620 969
Email: sami.sivuth@arunatechnology.com

13 APPENDIX 3 PREKS DATABASE

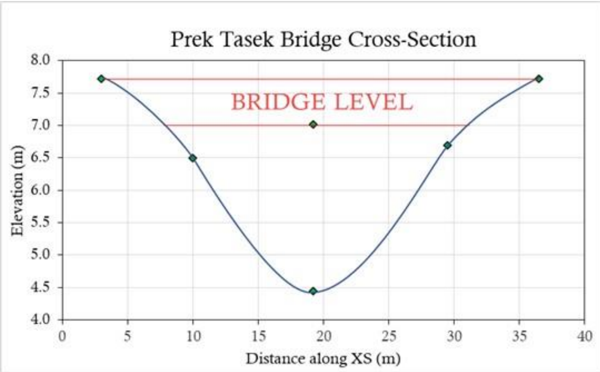
West Bassac Phase 1

WAT4CAM	PREK TA SEK	WB37/08101532



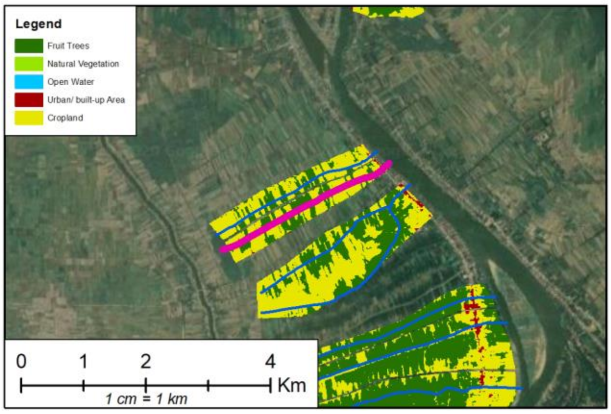


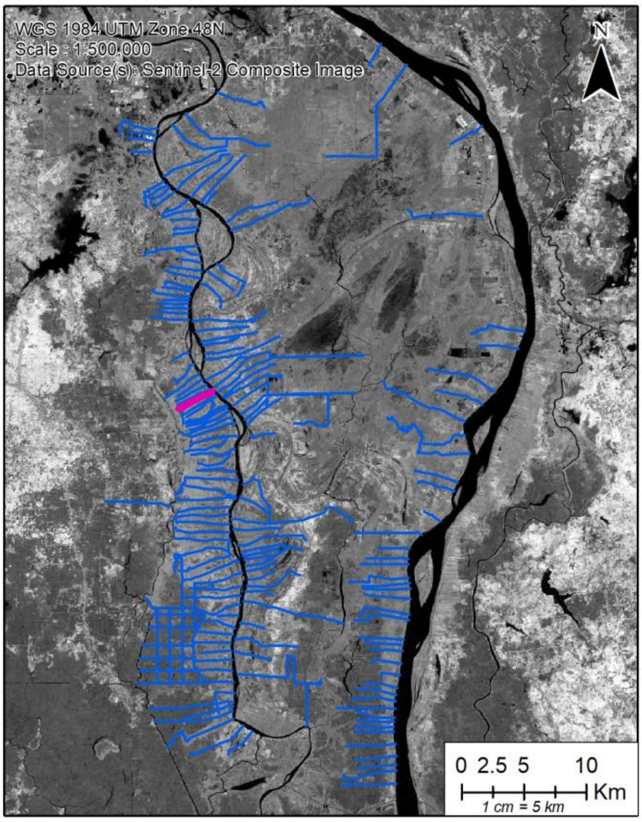
PREK TA SEK	WB37
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101532
CISIS Area (ha)	85.5
Total Area (CISIS GIS)	85.7
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	4.0
Orchard Area (Ha)	31.5
Field Crop Area	53.2
Natural (Ha)	0.0
Area of Water (Ha)	4.9
Average Field Crop Harvest (Ha)	41.0
Fallow Area (2020) Ha	12.9
Fallow Area (2019) Ha	11.8
Fallow Area (2018) Ha	8.4
Fallow Area (2017) Ha	11.8
Fallow Area (2017) Ha	16.2
Average Fallow (Ha)	12.2

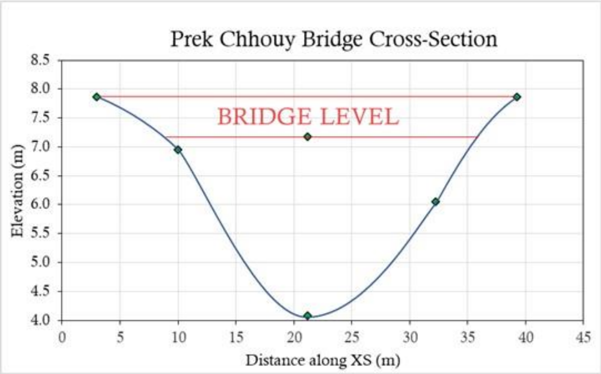


CHANNEL DIMENSIONS	
Channel Length	2.9 km
Channel Width	10 m
Inlet Bed Level	4.44 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	0.1 (m^3/s)
Av ETA(mm) in January (m3/s)	102.9 mm (0.033 m^3/s)
ETA (Feb)	76.7 mm (0.025 m^3/s)
ETA (March)	80.2 mm (0.026 m^3/s
ETA (April)	87.8 mm (0.028 m^3/s)

WAT4CAM	PREK CHHOUY	WB38/08101531



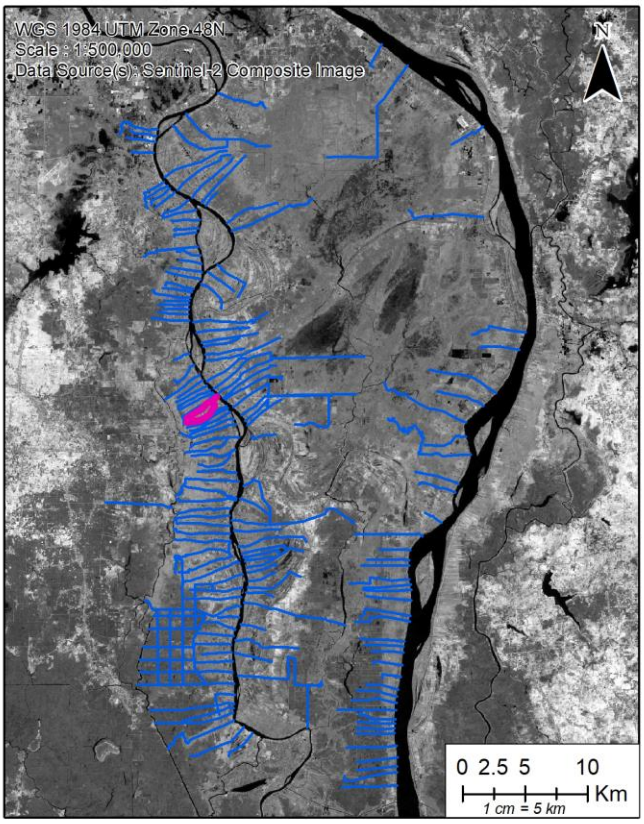


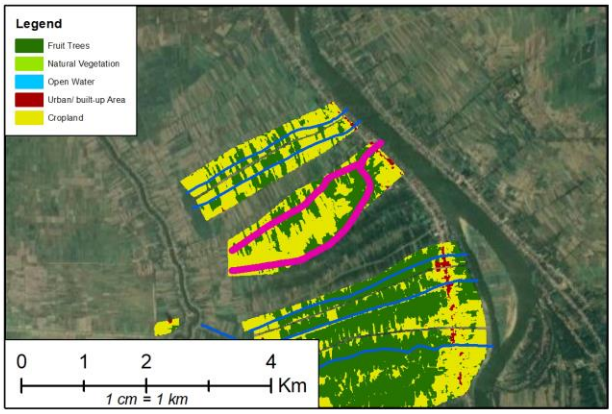


PREK CHHOUY	WB38
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101531
CISIS Area (ha)	97.1
Total Area (CISIS GIS)	99.5
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	4.7
Orchard Area (Ha)	41.5
Field Crop Area	57.0
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	42.4
Fallow Area (2020) Ha	13.6
Fallow Area (2019) Ha	12.9
Fallow Area (2018) Ha	11.6
Fallow Area (2017) Ha	15.9
Fallow Area (2017) Ha	19.1
Average Fallow (Ha)	14.6

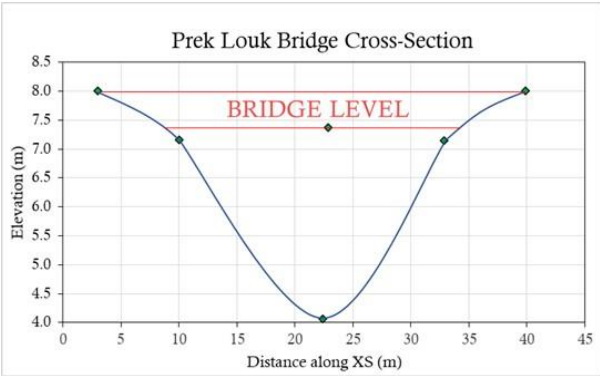
CHANNEL DIMENSIONS	
Channel Length	3.0 km
Channel Width	11 m
Inlet Bed Level	4.09 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	3.8 (m^3/s)
Av ETA(mm) in January (m3/s)	103.9 mm (0.039 m^3/s)
ETA (Feb)	77.3 mm (0.029 m^3/s)
ETA (March)	79.0 mm (0.029 m^3/s
ETA (April)	84.7 mm (0.031 m^3/s)

WAT4CAM	PREK LOUK	WB40/08041475



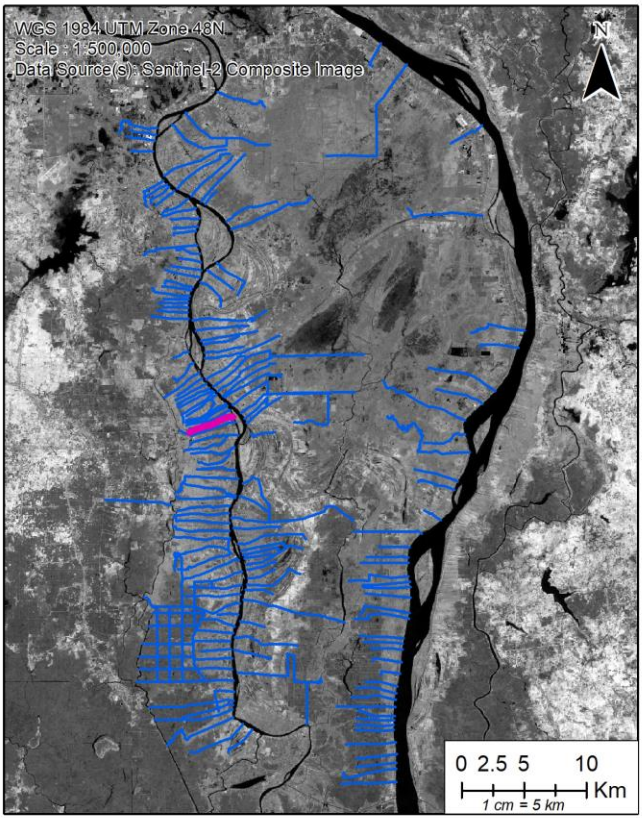


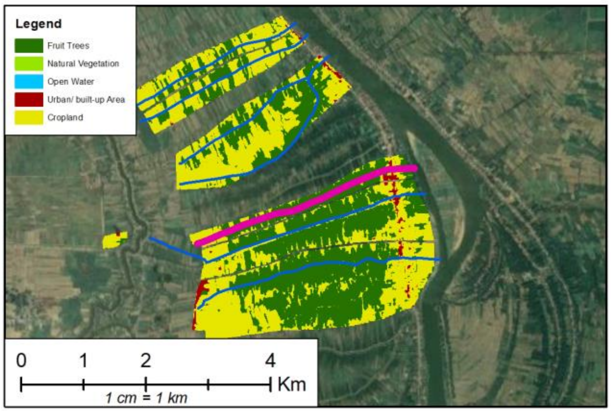
PREK LOUK	WB40
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041475
CISIS Area (ha)	172.9
Total Area (CISIS GIS)	256.3
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	18.9
Orchard Area (Ha)	113.6
Field Crop Area	139.5
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	106.6
Fallow Area (2020) Ha	22.1
Fallow Area (2019) Ha	43.7
Fallow Area (2018) Ha	12.4
Fallow Area (2017) Ha	31.9
Fallow Area (2017) Ha	54.4
Average Fallow (Ha)	32.9



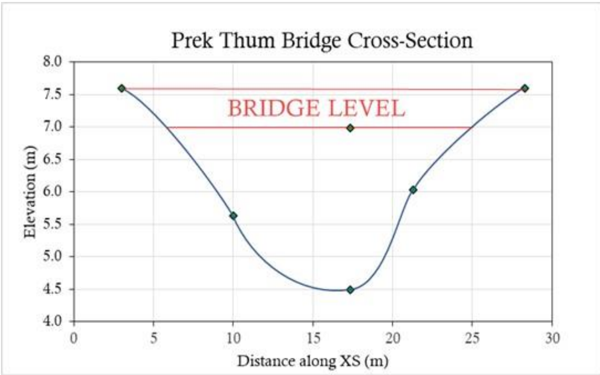
CHANNEL DIMENSIONS	
Channel Length	6.2 km
Channel Width	11 m
Inlet Bed Level	4.07 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	0.9 (m^3/s)
Av ETA(mm) in January (m3/s)	106.4 mm (0.102 m^3/s)
ETA (Feb)	81.8 mm (0.078 m^3/s)
ETA (March)	80.3 mm (0.077 m^3/s
ETA (April)	80.0 mm (0.077 m^3/s)

WAT4CAM	PREK THUM	WB44/08041514



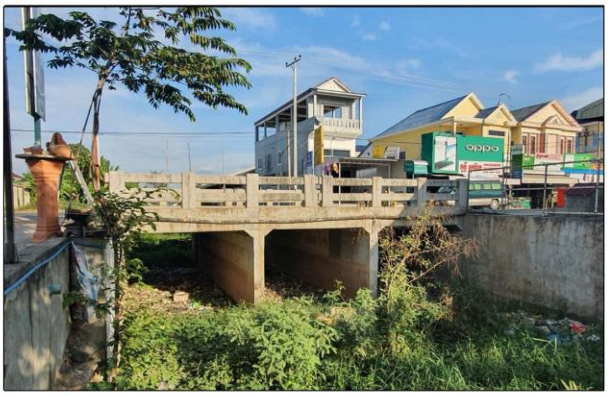


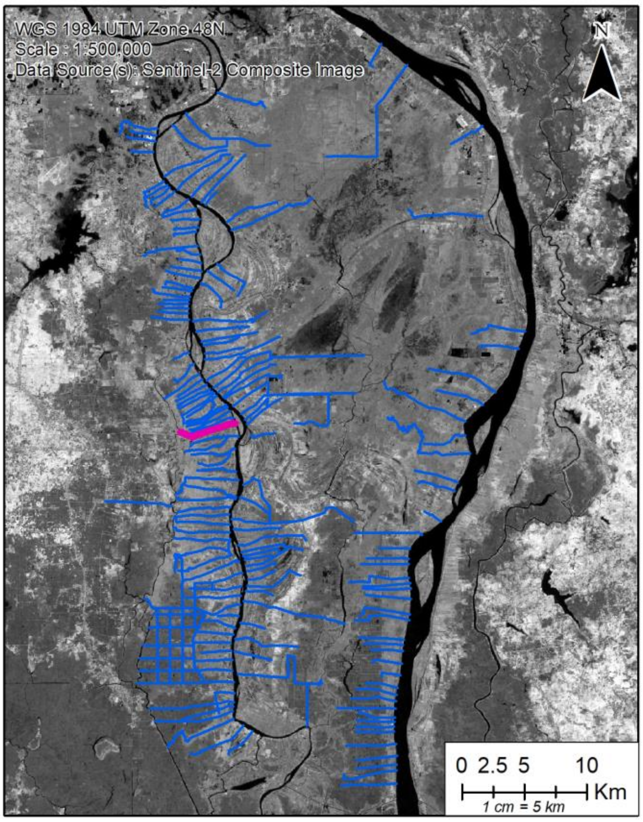
PREK THUM	WB44
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041514
CISIS Area (ha)	109.1
Total Area (CISIS GIS)	93.9
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	5.0
Orchard Area (Ha)	62.2
Field Crop Area	29.3
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	21.3
Fallow Area (2020) Ha	6.2
Fallow Area (2019) Ha	8.5
Fallow Area (2018) Ha	5.5
Fallow Area (2017) Ha	6.4
Fallow Area (2017) Ha	13.5
Average Fallow (Ha)	8.0

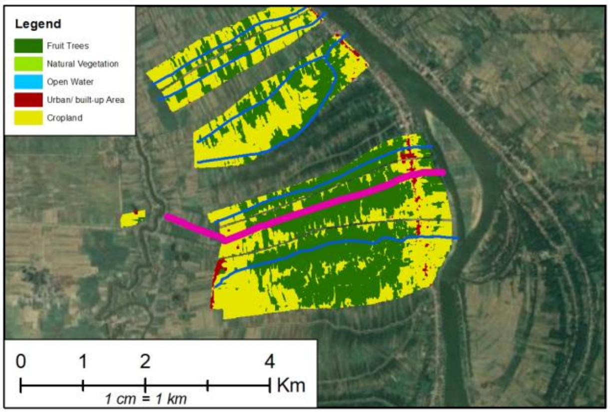


CHANNEL DIMENSIONS	
Channel Length	3.7 km
Channel Width	12 m
Inlet Bed Level	4.49 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	0.5 (m^3/s)
Av ETA(mm) in January (m3/s)	107.1 mm (0.038 m^3/s)
ETA (Feb)	81.6 mm (0.029 m^3/s)
ETA (March)	82.4 mm (0.029 m^3/s
ETA (April)	91.8 mm (0.032 m^3/s)

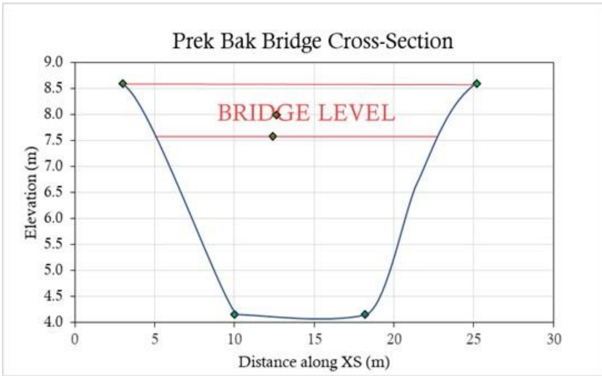
WAT4CAM	PREK BAK	WB45/08041513





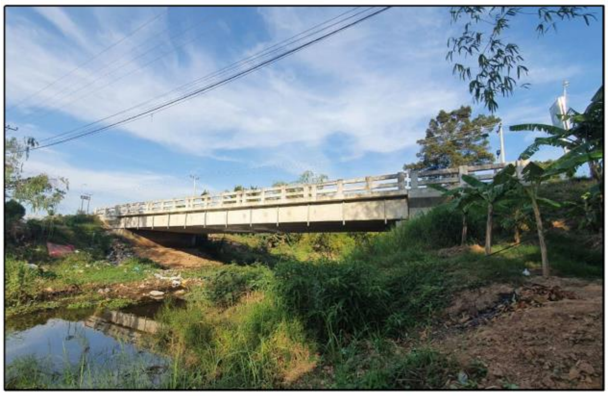


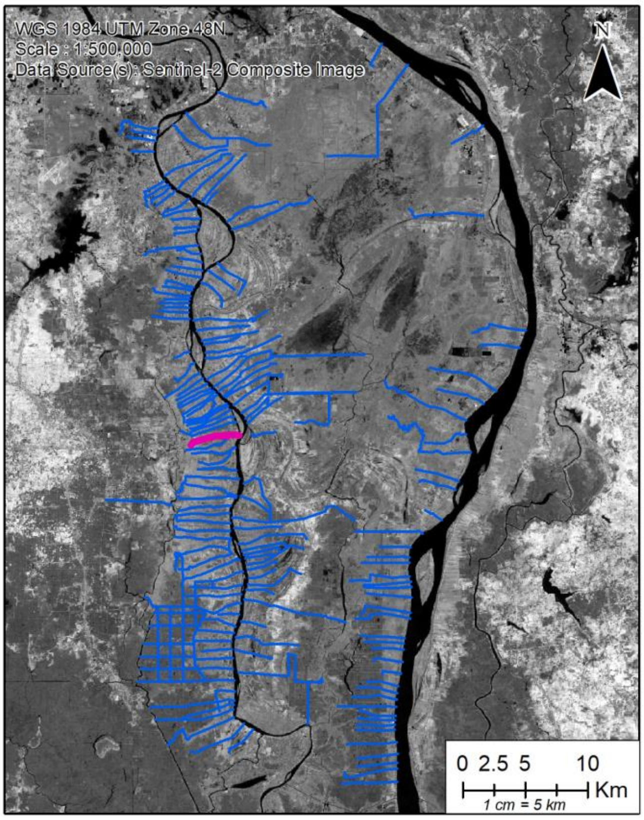
PREK BAK	WB45
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041513
CISIS Area (ha)	162.0
Total Area (CISIS GIS)	246.3
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	26.8
Orchard Area (Ha)	140.1
Field Crop Area	96.8
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	69.9
Fallow Area (2020) Ha	25.0
Fallow Area (2019) Ha	27.1
Fallow Area (2018) Ha	14.0
Fallow Area (2017) Ha	26.7
Fallow Area (2017) Ha	41.5
Average Fallow (Ha)	26.9

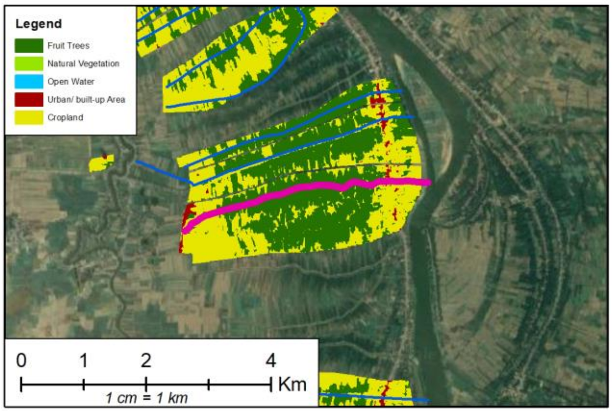


CHANNEL DIMENSIONS	
Channel Length	4.7 km
Channel Width	17 m
Inlet Bed Level	4.17 (m AHD)
FLOW	
Dry Season Min (m3/s)	-0.8 (m^3/s)
Flood peak	1.0 (m^3/s)
Av ETA(mm) in January (m3/s)	104.4 mm (0.096 m^3/s)
ETA (Feb)	81.0 mm (0.075 m^3/s)
ETA (March)	85.3 mm (0.078 m^3/s
ETA (April)	92.7 mm (0.085 m^3/s)

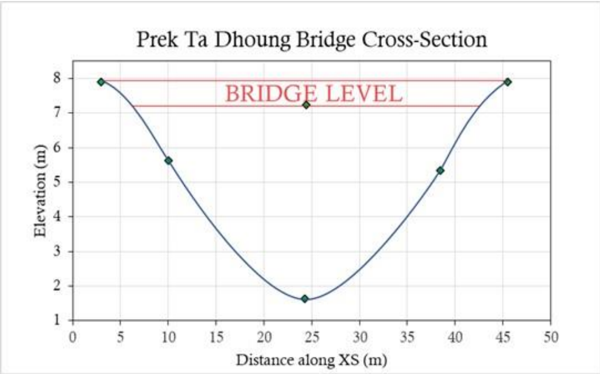
WAT4CAM	PREK TA DHOUNG	WB46/08041512





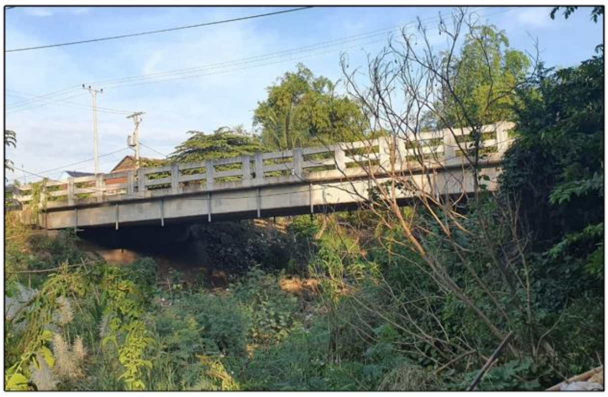


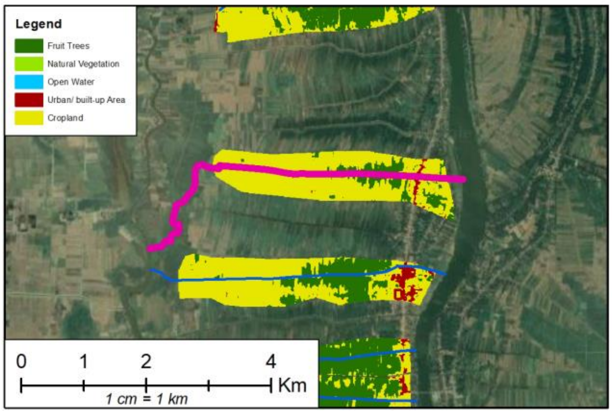
PREK TA DHOUNG	WB46
KEY FEATURES	
Classification	River Prek
CISIS Code	08041512
CISIS Area (ha)	262.8
Total Area (CISIS GIS)	424.2
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	8.7
Orchard Area (Ha)	222.9
Field Crop Area	189.5
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	135.6
Fallow Area (2020) Ha	46.5
Fallow Area (2019) Ha	55.9
Fallow Area (2018) Ha	29.2
Fallow Area (2017) Ha	57.2
Fallow Area (2017) Ha	80.9
Average Fallow (Ha)	53.9

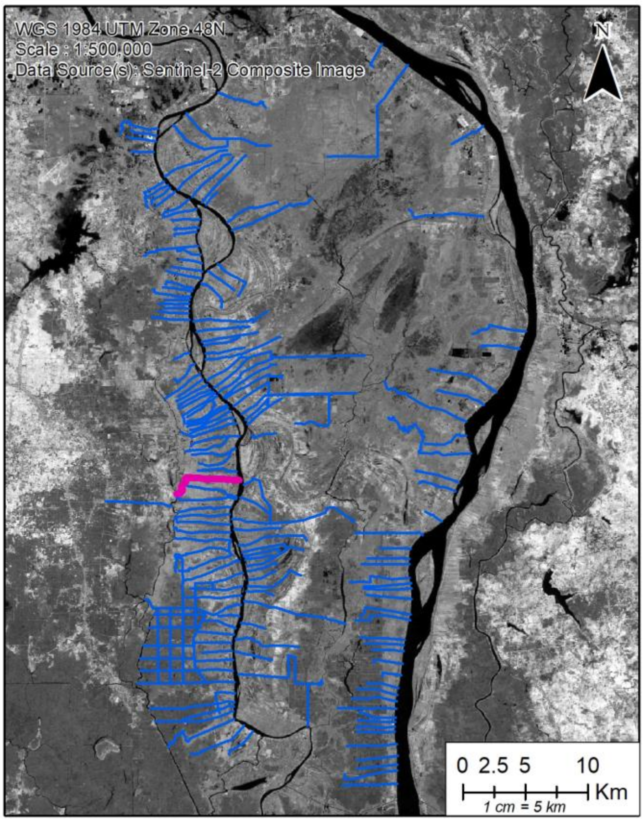


CHANNEL DIMENSIONS	
Channel Length	4.1 km
Channel Width	16 m
Inlet Bed Level	1.64 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	49.0 (m^3/s)
Av ETA(mm) in January (m3/s)	99.2 mm (0.157 m^3/s)
ETA (Feb)	84.2 mm (0.133 m^3/s)
ETA (March)	91.1 mm (0.144 m^3/s
ETA (April)	91.5 mm (0.145 m^3/s)

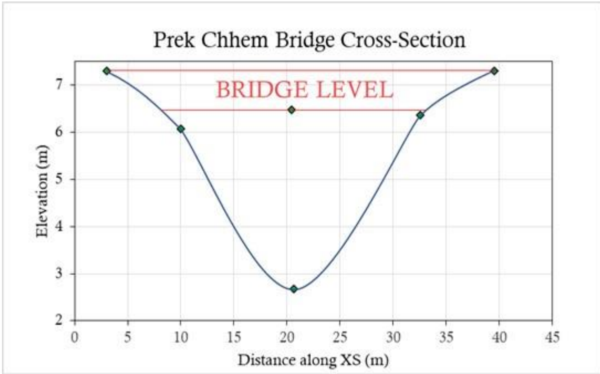
WAT4CAM	PREK CHHEM	WB49/08041509





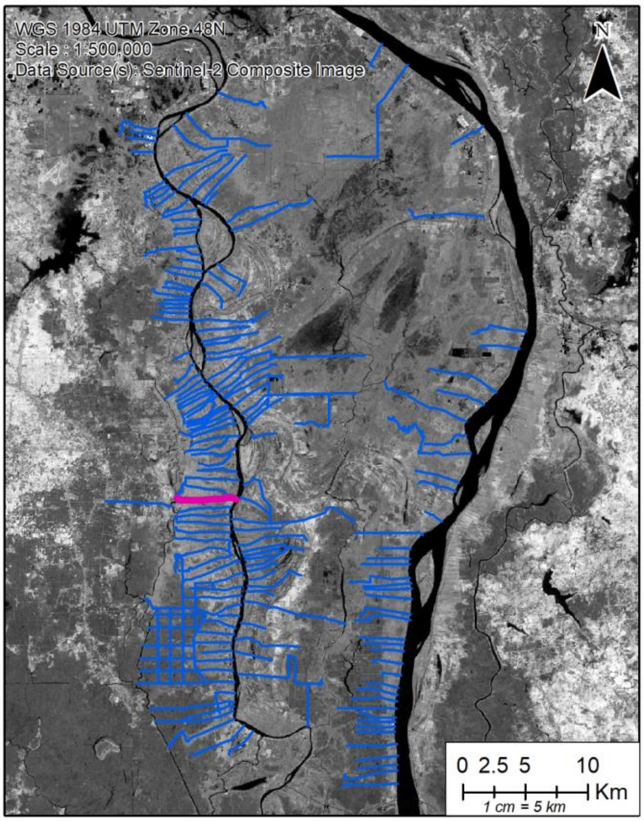


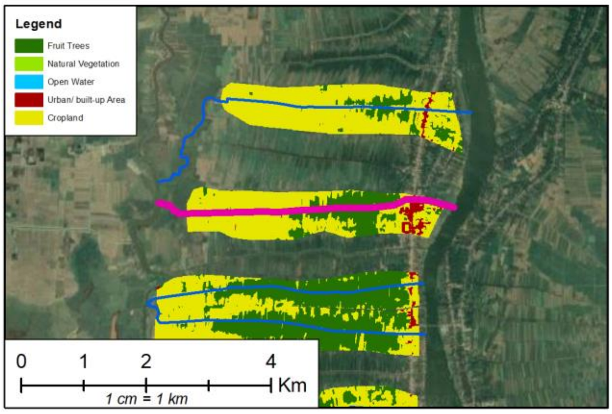
PREK CHHEM	WB49
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041509
CISIS Area (ha)	341.2
Total Area (CISIS GIS)	273.0
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	2.1
Orchard Area (Ha)	51.3
Field Crop Area	215.7
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	169.0
Fallow Area (2020) Ha	79.8
Fallow Area (2019) Ha	45.6
Fallow Area (2018) Ha	13.4
Fallow Area (2017) Ha	48.2
Fallow Area (2017) Ha	46.6
Average Fallow (Ha)	46.7



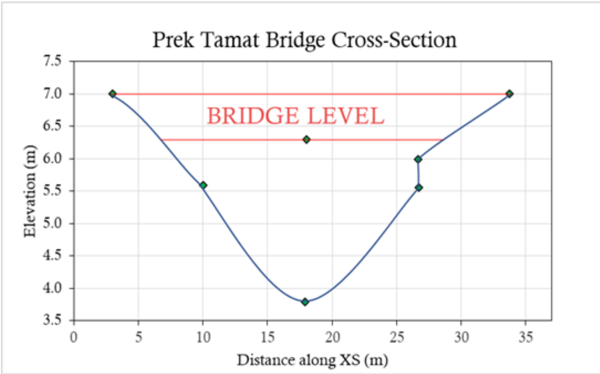
CHANNEL DIMENSIONS	
Channel Length	6.2 km
Channel Width	15 m
Inlet Bed Level	2.68 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	11.8 (m^3/s)
Av ETA(mm) in January (m3/s)	107.5 mm (0.110 m^3/s)
ETA (Feb)	87.7 mm (0.089 m^3/s)
ETA (March)	88.5 mm (0.090 m^3/s
ETA (April)	92.7 mm (0.095 m^3/s)

WAT4CAM	PREK TAMAT	WB51/08041507



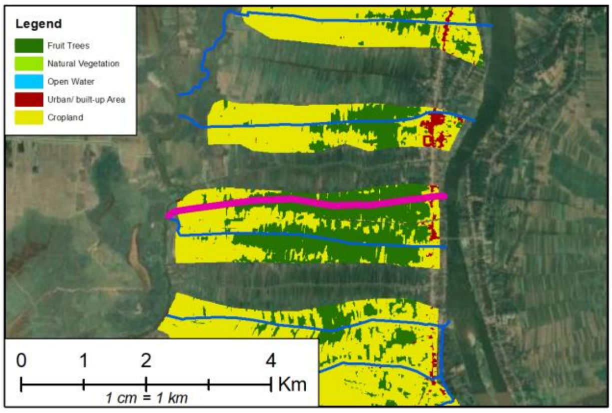


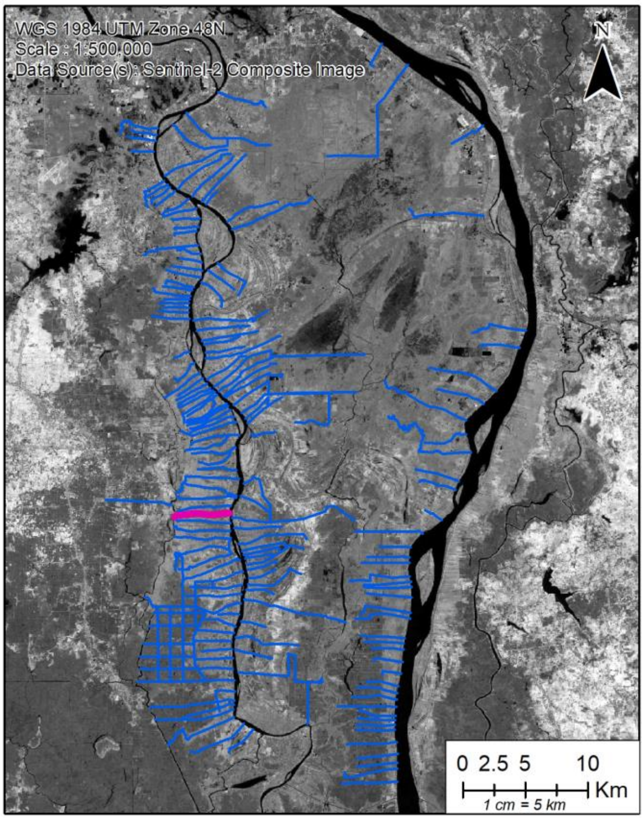
PREK TAMAT	WB51
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041507
CISIS Area (ha)	222.8
Total Area (CISIS GIS)	540.7
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	2.0
Orchard Area (Ha)	46.5
Field Crop Area	337.3
Natural (Ha)	152.8
Area of Water (Ha)	0.5
Average Field Crop Harvest (Ha)	294.9
Fallow Area (2020) Ha	34.3
Fallow Area (2019) Ha	41.5
Fallow Area (2018) Ha	24.4
Fallow Area (2017) Ha	37.0
Fallow Area (2017) Ha	74.7
Average Fallow (Ha)	42.4



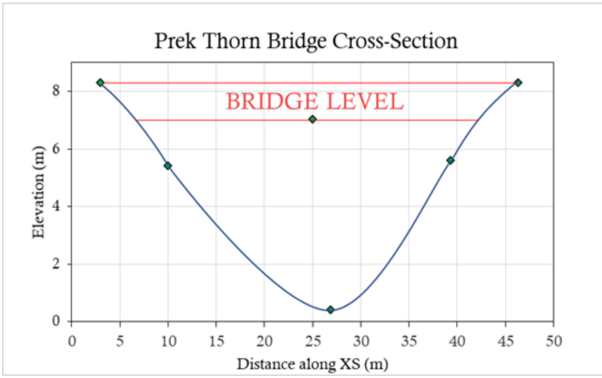
CHANNEL DIMENSIONS	
Channel Length	4.8 km
Channel Width	14 m
Inlet Bed Level	3.80 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	7.0 (m^3/s)
Av ETA(mm) in January (m3/s)	113.0 mm (0.228 m^3/s)
ETA (Feb)	97.4 mm (0.197 m^3/s)
ETA (March)	105.8 mm (0.214 m^3/s
ETA (April)	113.7 mm (0.230 m^3/s)

WAT4CAM	PREK THON	WB53/08041505



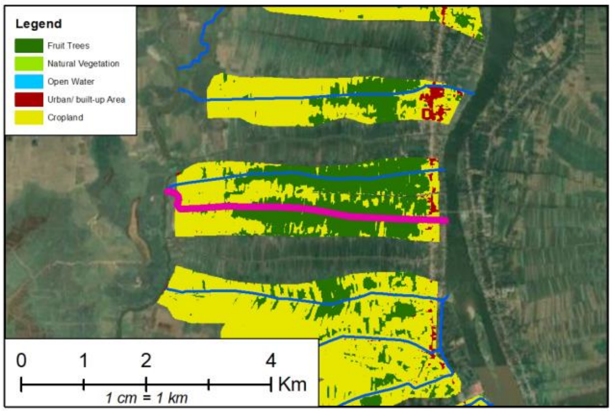


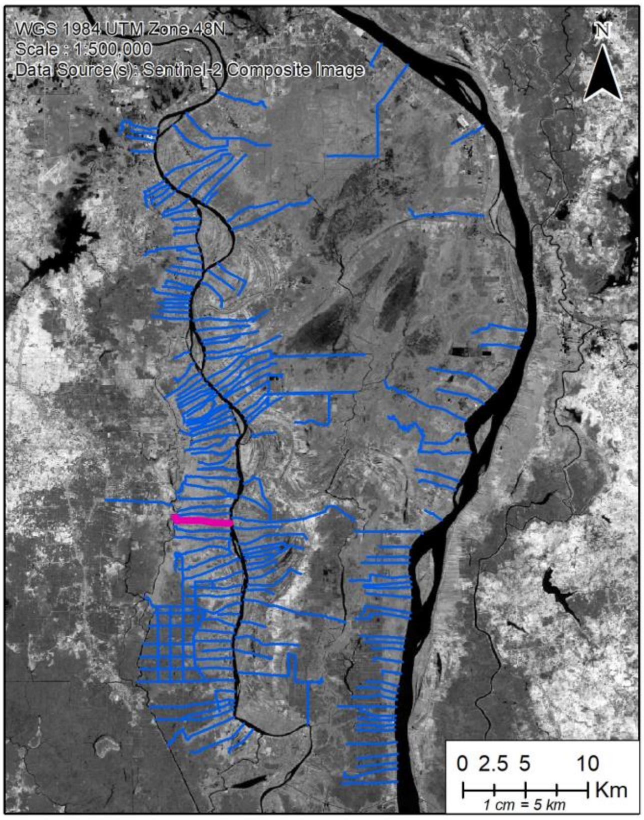
PREK THON	WB53
KEY FEATURES	
Classification	River Prek
CISIS Code	08041505
CISIS Area (ha)	200.4
Total Area (CISIS GIS)	225.9
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	4.8
Orchard Area (Ha)	126.3
Field Crop Area	96.0
Natural (Ha)	0.0
Area of Water (Ha)	0.1
Average Field Crop Harvest (Ha)	82.8
Fallow Area (2020) Ha	18.4
Fallow Area (2019) Ha	15.2
Fallow Area (2018) Ha	5.4
Fallow Area (2017) Ha	15.8
Fallow Area (2017) Ha	11.1
Average Fallow (Ha)	13.2



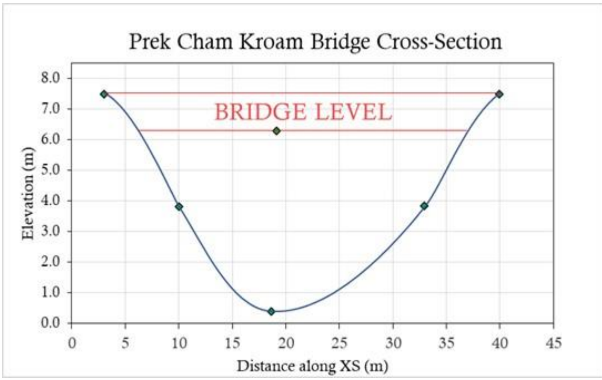
CHANNEL DIMENSIONS	
Channel Length	4.5 km
Channel Width	18 m
Inlet Bed Level	0.43 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.1 (m^3/s)
Flood peak	17.0 (m^3/s)
Av ETA(mm) in January (m3/s)	117.3 mm (0.099 m^3/s)
ETA (Feb)	90.2 mm (0.076 m^3/s)
ETA (March)	87.9 mm (0.074 m^3/s
ETA (April)	87.2 mm (0.074 m^3/s)

WAT4CAM	PREK CHAM KROUM	WB54/08041504



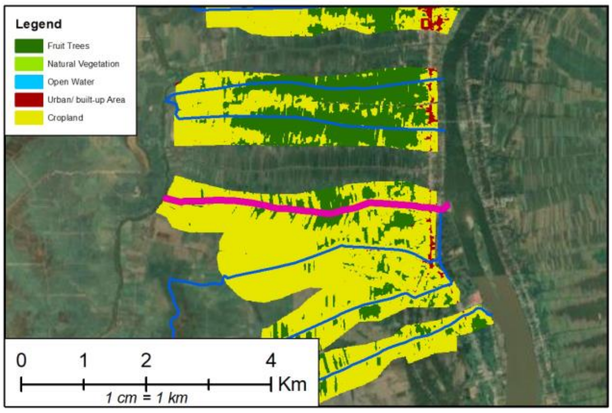


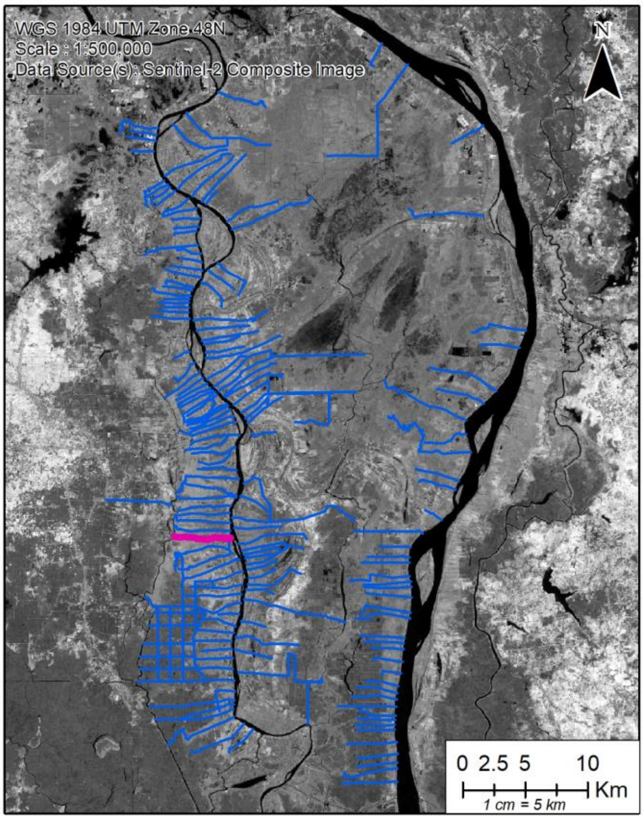
PREK CHAM KROUM	WB54
KEY FEATURES	
Classification	River Prek
CISIS Code	08041504
CISIS Area (ha)	357.2
Total Area (CISIS GIS)	268.3
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	9.5
Orchard Area (Ha)	146.7
Field Crop Area	117.0
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	98.3
Fallow Area (2020) Ha	20.1
Fallow Area (2019) Ha	23.7
Fallow Area (2018) Ha	7.9
Fallow Area (2017) Ha	23.7
Fallow Area (2017) Ha	18.1
Average Fallow (Ha)	18.7



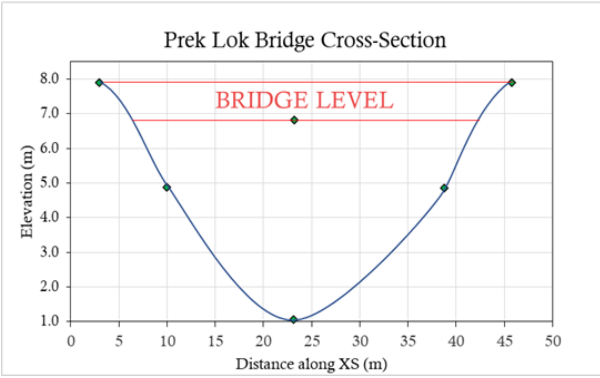
CHANNEL DIMENSIONS	
Channel Length	4.7 km
Channel Width	16 m
Inlet Bed Level	0.39 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.1 (m^3/s)
Flood peak	40.5 (m^3/s)
Av ETA(mm) in January (m3/s)	117.2 mm (0.117 m^3/s)
ETA (Feb)	90.1 mm (0.090 m^3/s)
ETA (March)	87.2 mm (0.087 m^3/s
ETA (April)	88.6 mm (0.089 m^3/s)

WAT4CAM	PREK LOK	WB57/08041502



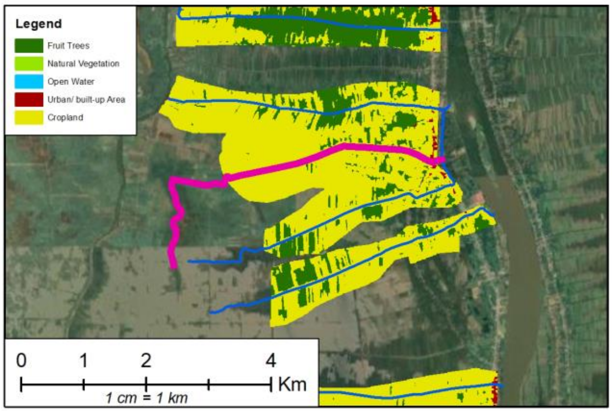


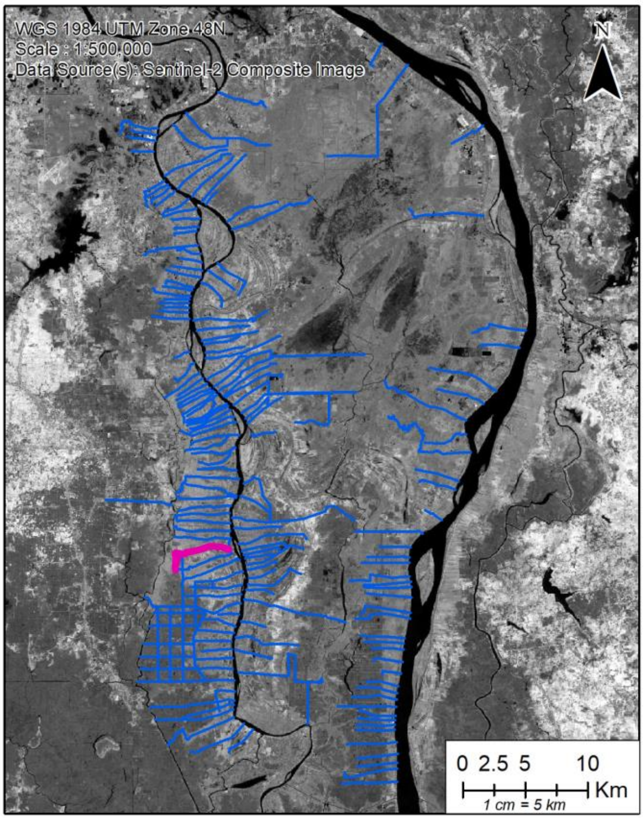
PREK LOK	WB57
KEY FEATURES	
Classification	River Prek
CISIS Code	08041502
CISIS Area (ha)	331.7
Total Area (CISIS GIS)	339.0
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	3.4
Orchard Area (Ha)	94.8
Field Crop Area	239.6
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	195.2
Fallow Area (2020) Ha	59.2
Fallow Area (2019) Ha	45.3
Fallow Area (2018) Ha	16.8
Fallow Area (2017) Ha	53.7
Fallow Area (2017) Ha	47.0
Average Fallow (Ha)	44.4



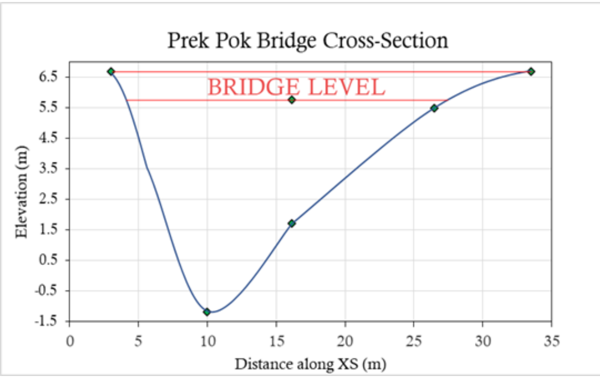
CHANNEL DIMENSIONS	
Channel Length	4.6 km
Channel Width	15 m
Inlet Bed Level	1.72 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.1 (m^3/s)
Flood peak	33.7 (m^3/s)
Av ETA(mm) in January (m3/s)	120.7 mm (0.153 m^3/s)
ETA (Feb)	92.4 mm (0.117 m^3/s)
ETA (March)	90.1 mm (0.114 m^3/s
ETA (April)	92.3 mm (0.117 m^3/s)

WAT4CAM	PREK POK	WB58/08041501



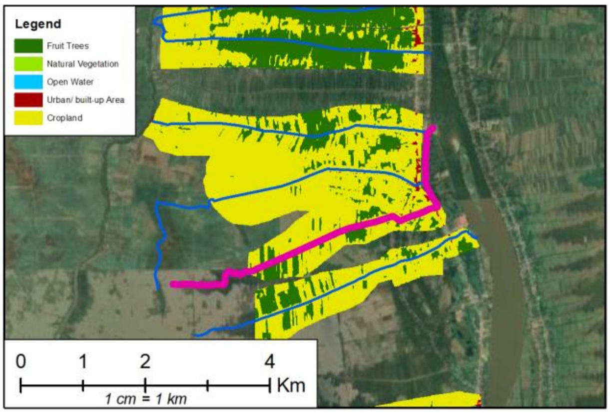


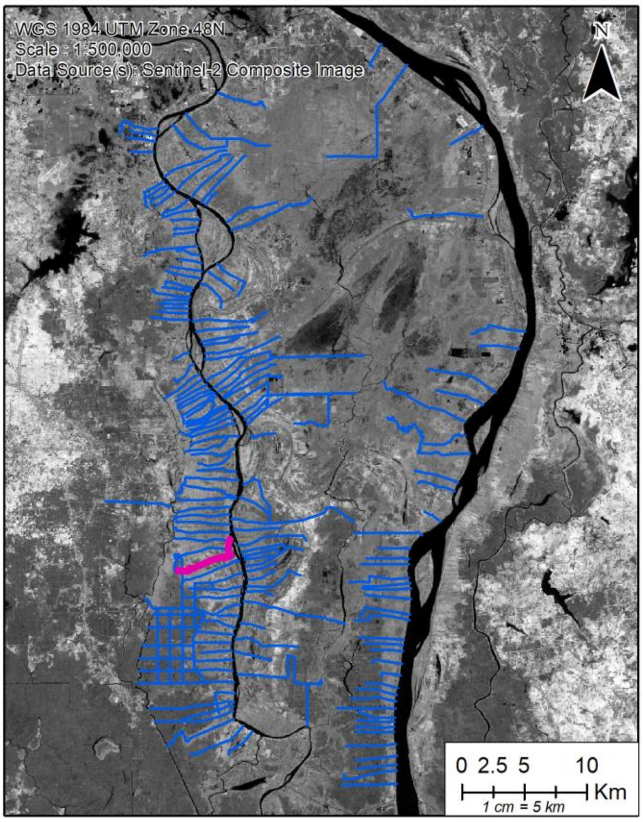
PREK POK	WB58
KEY FEATURES	
Classification	River Prek
CISIS Code	08041501
CISIS Area (ha)	434.7
Total Area (CISIS GIS)	297.0
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	5.0
Orchard Area (Ha)	39.5
Field Crop Area	251.3
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	175.9
Fallow Area (2020) Ha	95.5
Fallow Area (2019) Ha	69.9
Fallow Area (2018) Ha	22.4
Fallow Area (2017) Ha	76.1
Fallow Area (2017) Ha	113.2
Average Fallow (Ha)	75.4



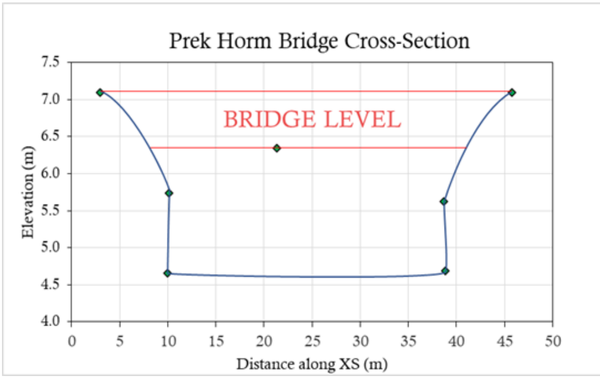
CHANNEL DIMENSIONS	
Channel Length	6.1 km
Channel Width	15 m
Inlet Bed Level	0.27 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.4 (m³/s)
Flood peak	44.4 (m³/s)
Av ETA(mm) in January (m3/s)	120.2 mm (0.133 m³/s)
ETA (Feb)	90.1 mm (0.100 m³/s)
ETA (March)	89.7 mm (0.099 m³/s
ETA (April)	93.4 mm (0.104 m³/s)

WAT4CAM	PREK HORM	WB59/08041500



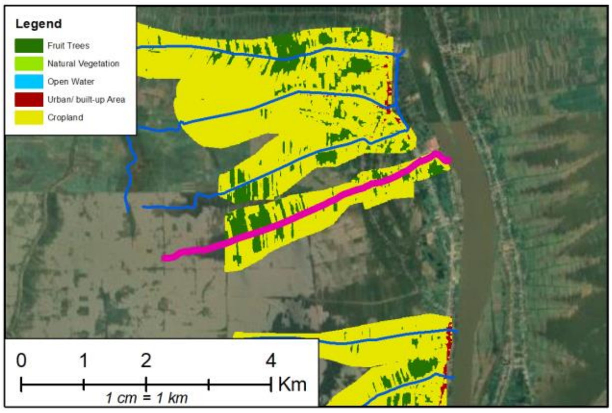


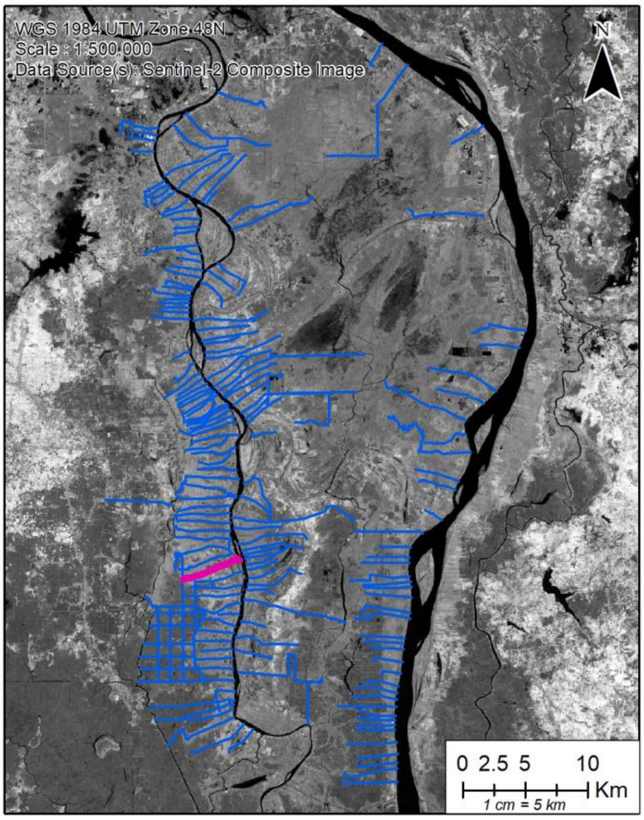
PREK HORM	WB59
KEY FEATURES	
Classification	River Prek
CISIS Code	08041500
CISIS Area (ha)	325.5
Total Area (CISIS GIS)	190.9
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	0.2
Orchard Area (Ha)	55.0
Field Crop Area	130.9
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	93.9
Fallow Area (2020) Ha	37.6
Fallow Area (2019) Ha	46.4
Fallow Area (2018) Ha	13.2
Fallow Area (2017) Ha	40.9
Fallow Area (2017) Ha	46.8
Average Fallow (Ha)	37.0



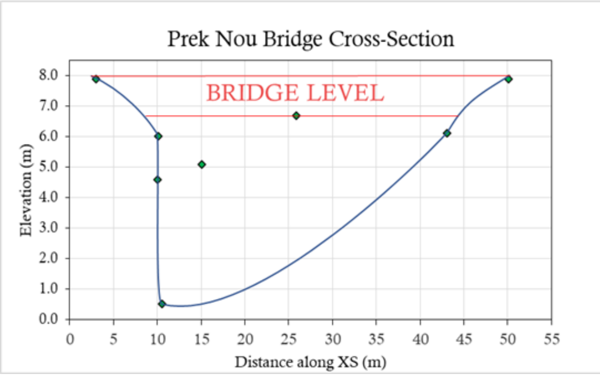
CHANNEL DIMENSIONS	
Channel Length	6.0 km
Channel Width	18 m
Inlet Bed Level	0.43 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.2 (m^3/s)
Flood peak	40.1 (m^3/s)
Av ETA(mm) in January (m3/s)	123.7 mm (0.088 m^3/s)
ETA (Feb)	91.1 mm (0.065 m^3/s)
ETA (March)	93.2 mm (0.066 m^3/s
ETA (April)	96.0 mm (0.068 m^3/s)

WAT4CAM	PREK NOU	WB60/08041499



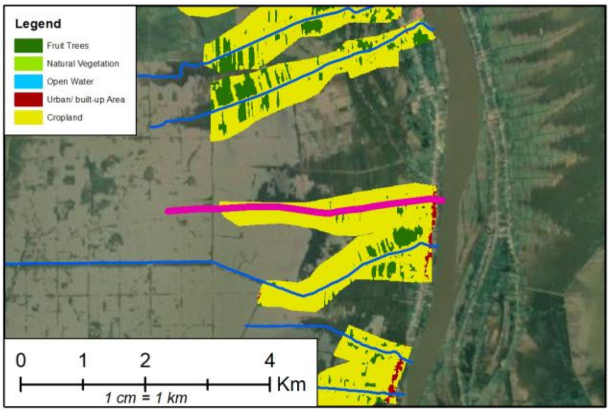


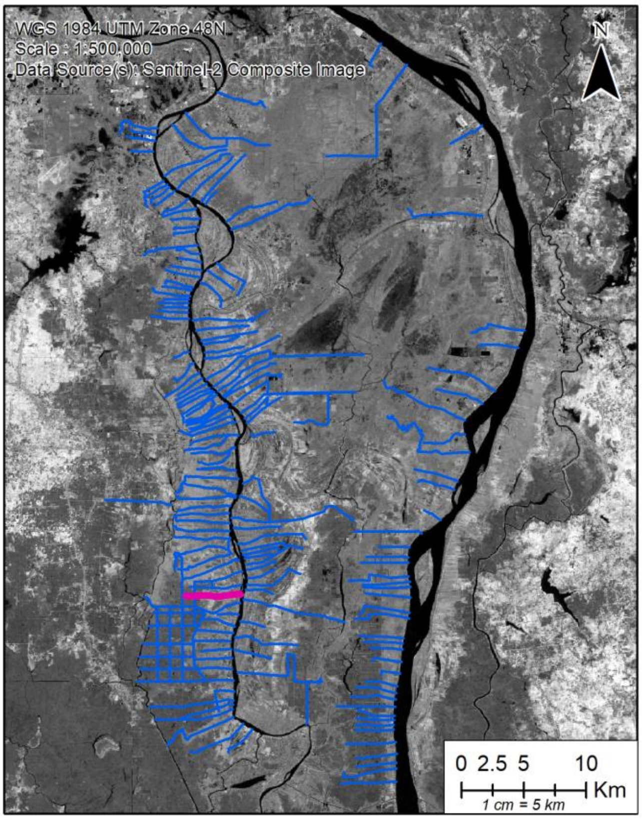
PREK NOU	WB60
KEY FEATURES	
Classification	River Prek
CISIS Code	08041499
CISIS Area (ha)	454.1
Total Area (CISIS GIS)	223.8
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	1.9
Orchard Area (Ha)	69.6
Field Crop Area	150.0
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	104.8
Fallow Area (2020) Ha	43.0
Fallow Area (2019) Ha	50.4
Fallow Area (2018) Ha	15.3
Fallow Area (2017) Ha	56.3
Fallow Area (2017) Ha	61.2
Average Fallow (Ha)	45.2



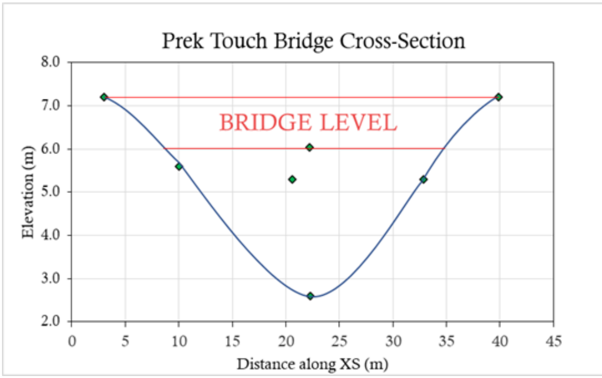
CHANNEL DIMENSIONS	
Channel Length	4.9 km
Channel Width	22 m
Inlet Bed Level	0.25 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	38.7 (m^3/s)
Av ETA(mm) in January (m3/s)	124.4 mm (0.104 m^3/s)
ETA (Feb)	92.4 mm (0.077 m^3/s)
ETA (March)	95.6 mm (0.080 m^3/s
ETA (April)	96.8 mm (0.081 m^3/s)

WAT4CAM	PREK TOUCH	WB63/08041496



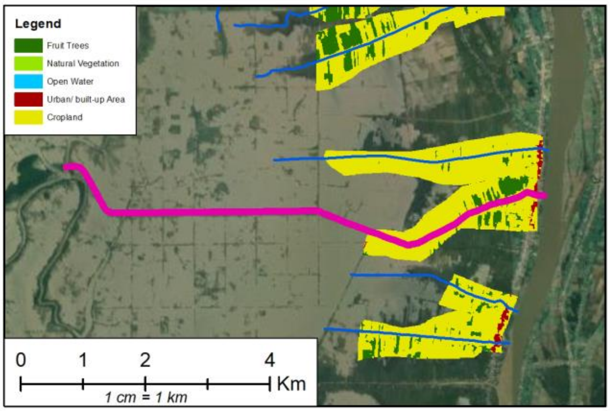


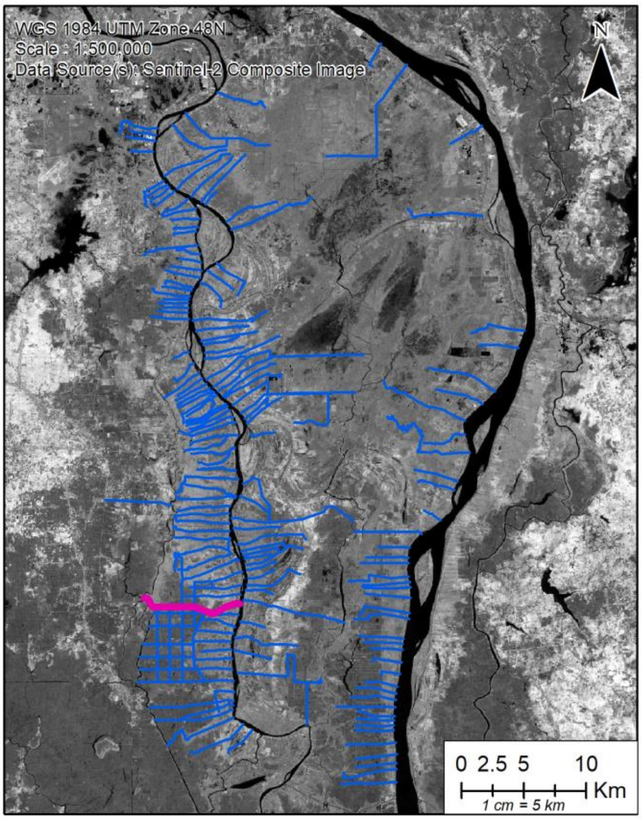
PREK TOUCH	WB63
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041496
CISIS Area (ha)	296.5
Total Area (CISIS GIS)	181.5
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	2.4
Orchard Area (Ha)	12.3
Field Crop Area	165.8
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	134.1
Fallow Area (2020) Ha	54.0
Fallow Area (2019) Ha	49.4
Fallow Area (2018) Ha	5.1
Fallow Area (2017) Ha	19.0
Fallow Area (2017) Ha	30.7
Average Fallow (Ha)	31.6



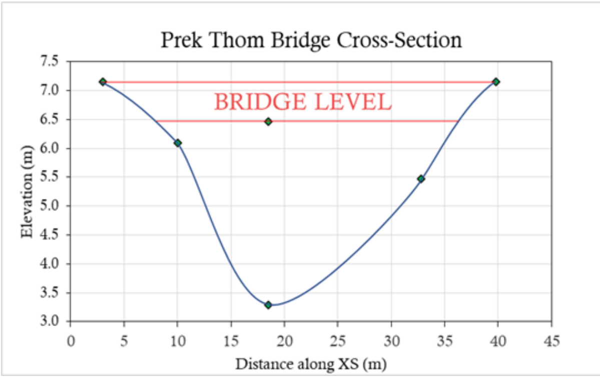
CHANNEL DIMENSIONS	
Channel Length	4.4 km
Channel Width	16 m
Inlet Bed Level	2.59 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	5.8 (m^3/s)
Av ETA(mm) in January (m3/s)	124.9 mm (0.085 m^3/s)
ETA (Feb)	95.4 mm (0.065 m^3/s)
ETA (March)	93.2 mm (0.063 m^3/s
ETA (April)	89.1 mm (0.060 m^3/s)

WAT4CAM	PREK THOM	WB64/08041495



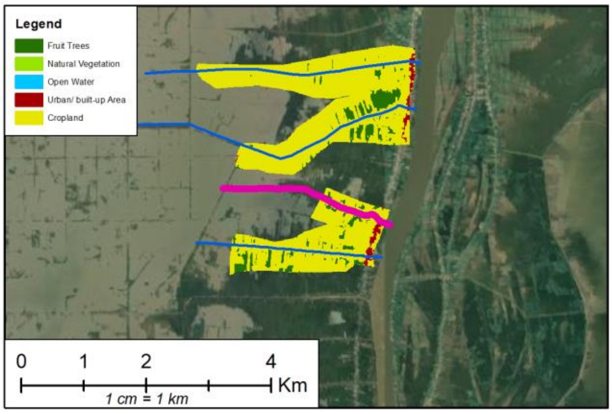


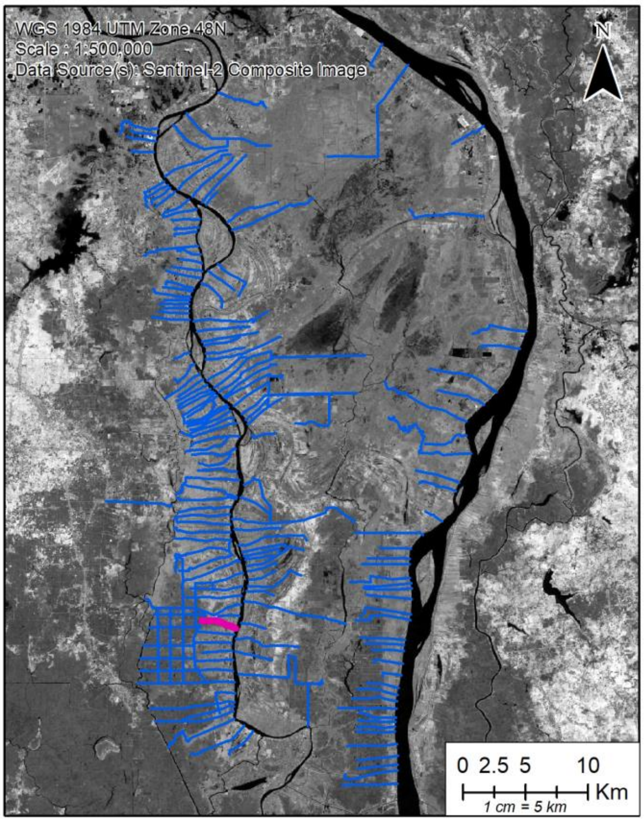
PREK THOM	WB64
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041495
CISIS Area (ha)	216.1
Total Area (CISIS GIS)	183.5
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	3.0
Orchard Area (Ha)	38.3
Field Crop Area	140.2
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	102.1
Fallow Area (2020) Ha	50.9
Fallow Area (2019) Ha	56.7
Fallow Area (2018) Ha	10.1
Fallow Area (2017) Ha	29.2
Fallow Area (2017) Ha	43.6
Average Fallow (Ha)	38.1



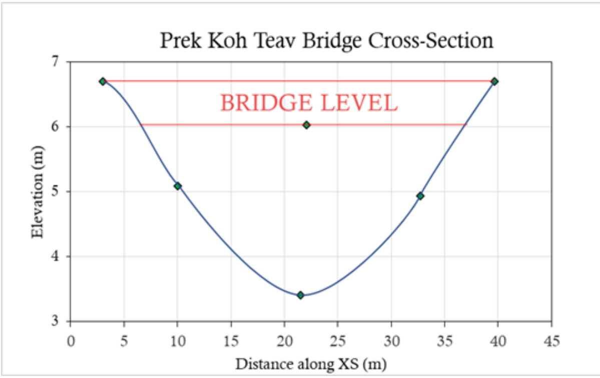
CHANNEL DIMENSIONS	
Channel Length	8.4 km
Channel Width	18 m
Inlet Bed Level	3.29 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	5.9 (m^3/s)
Av ETA(mm) in January (m3/s)	122.3 mm (0.084 m^3/s)
ETA (Feb)	94.2 mm (0.065 m^3/s)
ETA (March)	92.3 mm (0.063 m^3/s
ETA (April)	95.1 mm (0.065 m^3/s)

WAT4CAM	PREK KOH TEAV	WB66/08041487



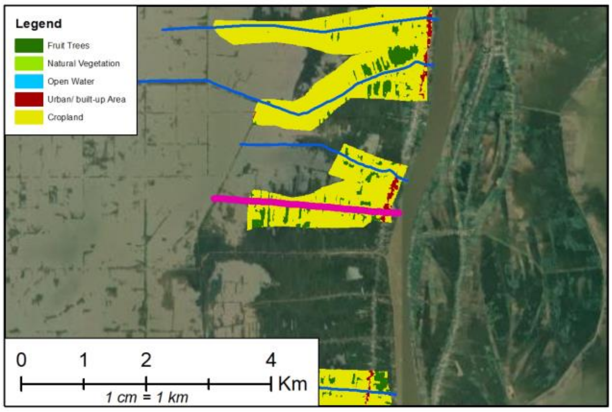


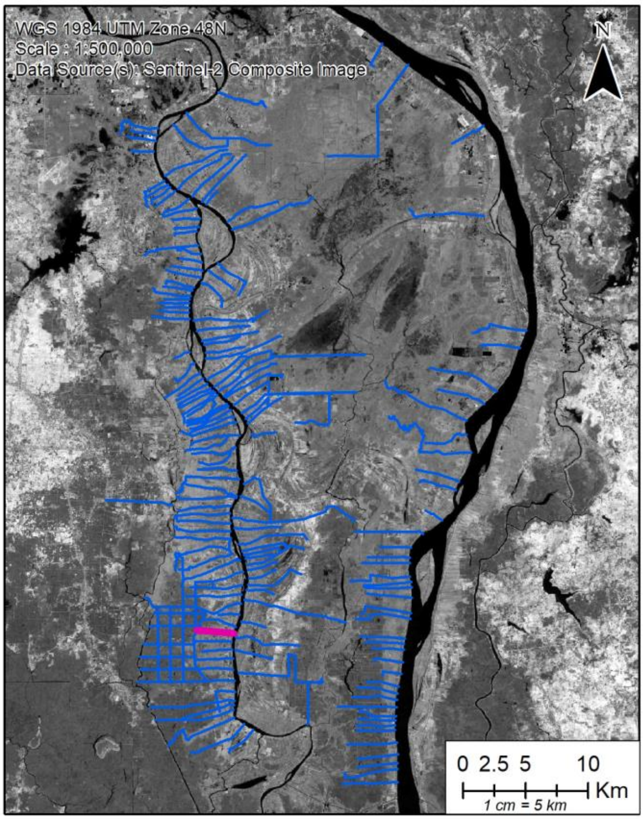
PREK KOH TEAV	WB66
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041487
CISIS Area (ha)	175.2
Total Area (CISIS GIS)	58.6
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	5.0
Orchard Area (Ha)	12.5
Field Crop Area	42.9
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	30.3
Fallow Area (2020) Ha	12.0
Fallow Area (2019) Ha	11.8
Fallow Area (2018) Ha	6.0
Fallow Area (2017) Ha	13.2
Fallow Area (2017) Ha	20.2
Average Fallow (Ha)	12.6



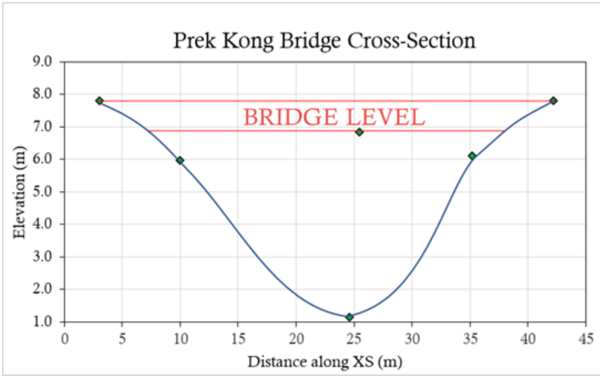
CHANNEL DIMENSIONS	
Channel Length	2.8 km
Channel Width	17 m
Inlet Bed Level	3.41 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	0.4 (m^3/s)
Av ETA(mm) in January (m3/s)	120.5 mm (0.026 m^3/s)
ETA (Feb)	90.5 mm (0.020 m^3/s)
ETA (March)	93.3 mm (0.020 m^3/s
ETA (April)	101.2 mm (0.022 m^3/s)

WAT4CAM	PREK KONG	WB67/08041489



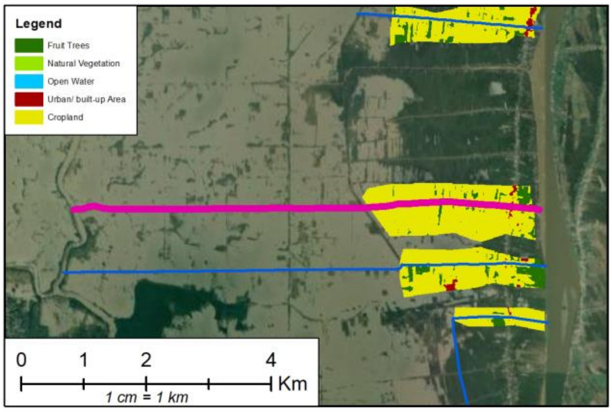


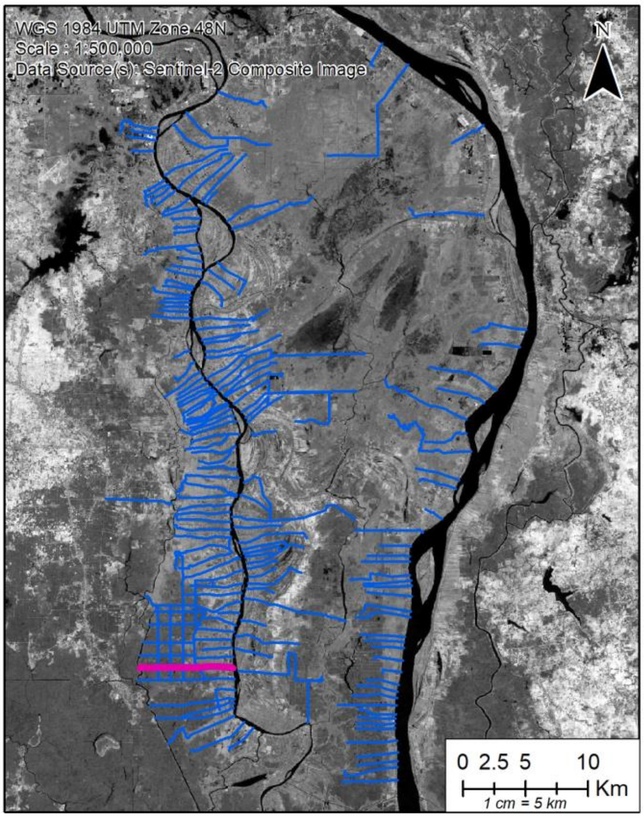
PREK KONG	WB67
KEY FEATURES	
Classification	River Prek
CISIS Code	08041489
CISIS Area (ha)	228.9
Total Area (CISIS GIS)	133.1
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	0.3
Orchard Area (Ha)	33.0
Field Crop Area	96.7
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	76.8
Fallow Area (2020) Ha	16.1
Fallow Area (2019) Ha	18.5
Fallow Area (2018) Ha	6.7
Fallow Area (2017) Ha	33.0
Fallow Area (2017) Ha	25.4
Average Fallow (Ha)	19.9



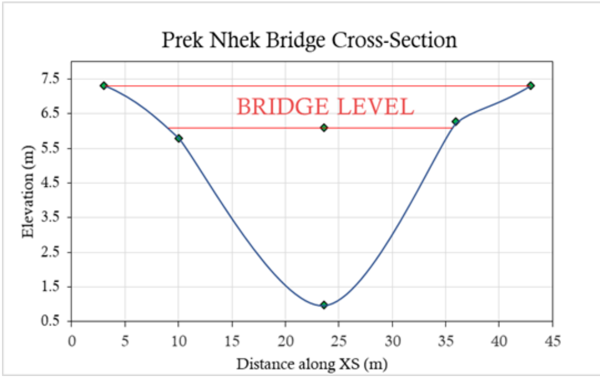
CHANNEL DIMENSIONS	
Channel Length	3.0 km
Channel Width	16 m
Inlet Bed Level	1.14 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m³/s)
Flood peak	9.8 (m³/s)
Av ETA(mm) in January (m3/s)	125.8 mm (0.063 m³/s)
ETA (Feb)	94.7 mm (0.047 m³/s)
ETA (March)	94.4 mm (0.047 m³/s
ETA (April)	97.2 mm (0.048 m³/s)

WAT4CAM	PREK NHEK	WB71/08041588



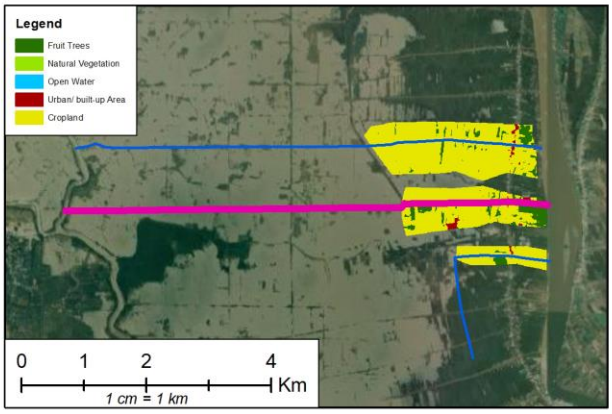


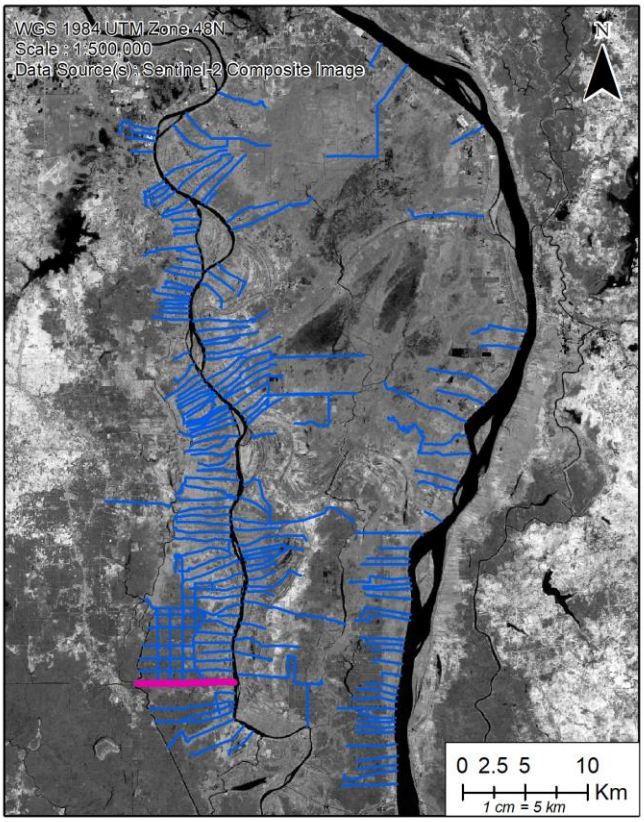
PREK NHEK	WB71
KEY FEATURES	
Classification	River Prek
CISIS Code	08041588
CISIS Area (ha)	214.1
Total Area (CISIS GIS)	212.7
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	3.2
Orchard Area (Ha)	26.9
Field Crop Area	180.7
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	160.1
Fallow Area (2020) Ha	22.2
Fallow Area (2019) Ha	25.4
Fallow Area (2018) Ha	10.3
Fallow Area (2017) Ha	19.1
Fallow Area (2017) Ha	26.0
Average Fallow (Ha)	20.6



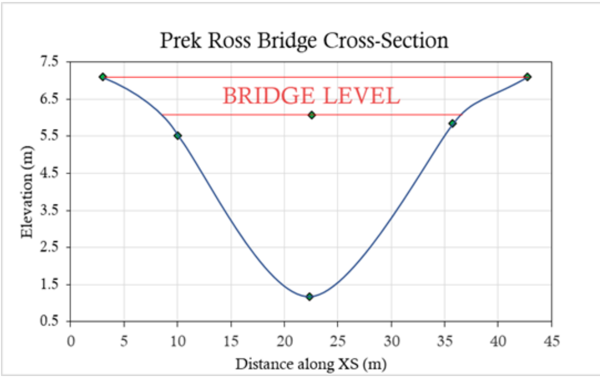
CHANNEL DIMENSIONS	
Channel Length	7.5 km
Channel Width	16 m
Inlet Bed Level	1.24 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	0.5 (m^3/s)
Av ETA(mm) in January (m3/s)	123.5 mm (0.098 m^3/s)
ETA (Feb)	94.3 mm (0.075 m^3/s)
ETA (March)	92.1 mm (0.073 m^3/s
ETA (April)	97.5 mm (0.077 m^3/s)

WAT4CAM	PREK ROSS	WB72/08041485



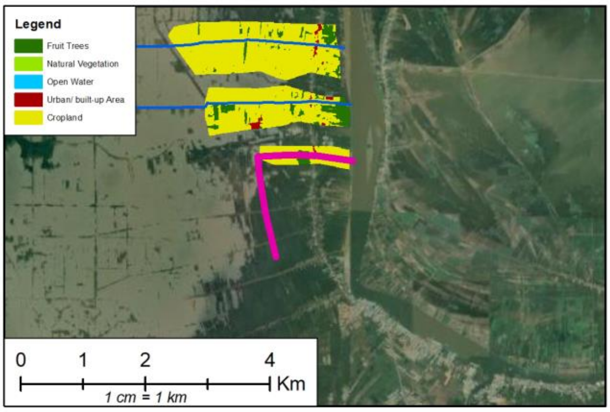


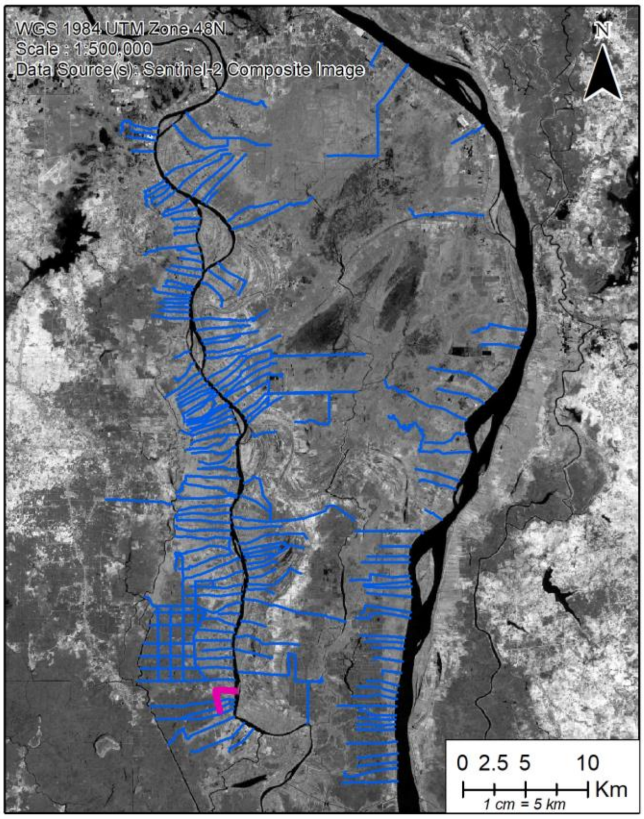
PREK ROSS	WB72
KEY FEATURES	
Classification	River Prek
CISIS Code	08041485
CISIS Area (ha)	244.7
Total Area (CISIS GIS)	137.1
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	4.2
Orchard Area (Ha)	33.8
Field Crop Area	98.3
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	80.1
Fallow Area (2020) Ha	27.2
Fallow Area (2019) Ha	22.4
Fallow Area (2018) Ha	5.8
Fallow Area (2017) Ha	13.5
Fallow Area (2017) Ha	22.3
Average Fallow (Ha)	18.2



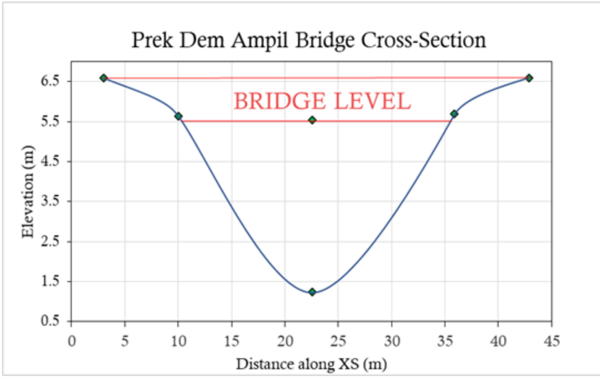
CHANNEL DIMENSIONS	
Channel Length	7.8 km
Channel Width	12 m
Inlet Bed Level	0.67 (m AHD)
FLOW	
Dry Season Min (m3/s)	2.0 (m^3/s)
Flood peak	51.0 (m^3/s)
Av ETA(mm) in January (m3/s)	120.1 mm (0.062 m^3/s)
ETA (Feb)	96.7 mm (0.050 m^3/s)
ETA (March)	99.9 mm (0.051 m^3/s
ETA (April)	94.2 mm (0.048 m^3/s)

WAT4CAM	PREK DEM AMPIL	WB79/08041484





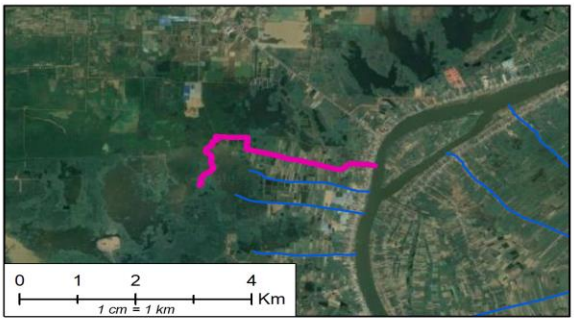
PREK DEM AMPIL	WB79
KEY FEATURES	
Classification	River Prek
CISIS Code	08041484
CISIS Area (ha)	371.3
Total Area (CISIS GIS)	41.2
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	1.0
Orchard Area (Ha)	5.4
Field Crop Area	34.9
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	26.0
Fallow Area (2020) Ha	16.1
Fallow Area (2019) Ha	14.0
Fallow Area (2018) Ha	1.2
Fallow Area (2017) Ha	7.6
Fallow Area (2017) Ha	5.6
Average Fallow (Ha)	8.9

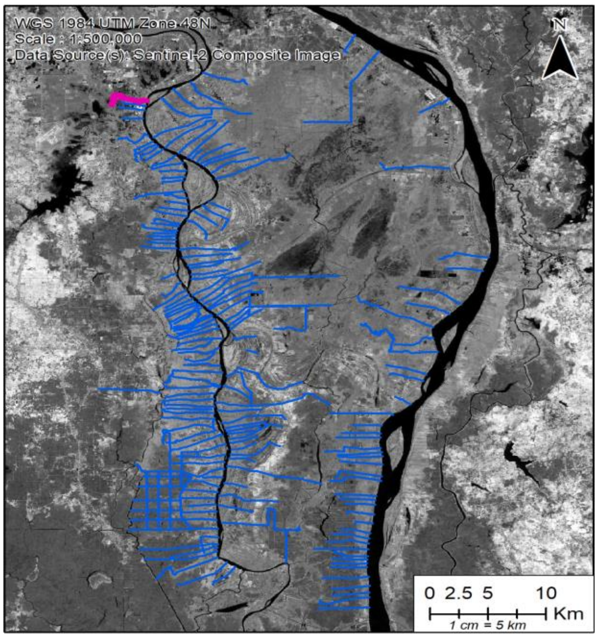


CHANNEL DIMENSIONS	
Channel Length	3.2 km
Channel Width	10 m
Inlet Bed Level	1.24 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	47.0 (m^3/s)
Av ETA(mm) in January (m3/s)	121.1 mm (0.019 m^3/s)
ETA (Feb)	91.5 mm (0.014 m^3/s)
ETA (March)	94.0 mm (0.014 m^3/s
ETA (April)	98.0 mm (0.015 m^3/s)

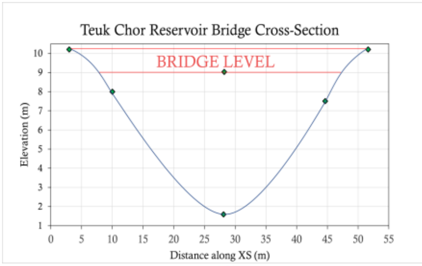
West Bassac Phase 2

WAT4CAM	TEUK CHOR RESERVOIR	WB1 /

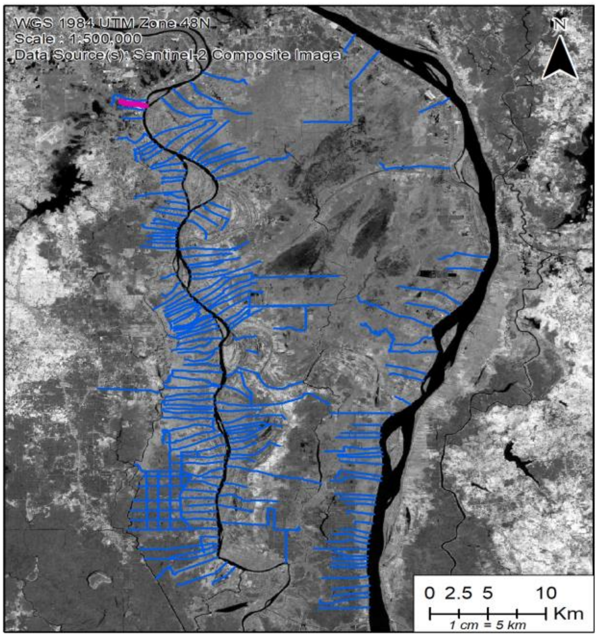




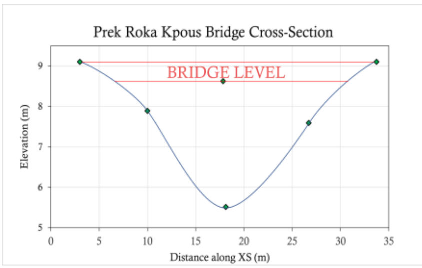
CHANNEL DIMENSIONS	
Channel Length	4.3 km
Channel Width	18 m
Inlet Bed Level	1.59 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08100989
CISIS Area (ha)	966.0



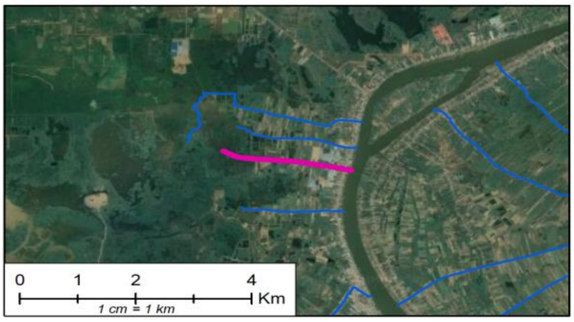
WAT4CAM	PREK ROKA KPOUS	WB2 /

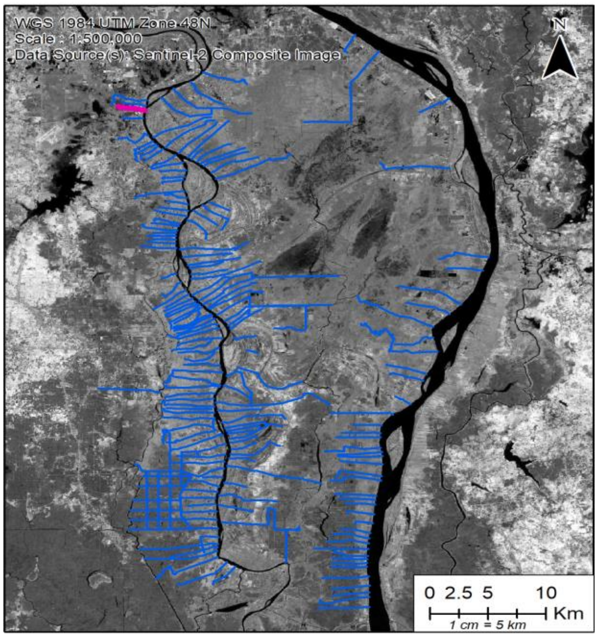


CHANNEL DIMENSIONS	
Channel Length	2.2 km
Channel Width	10 m
Inlet Bed Level	5.52 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0

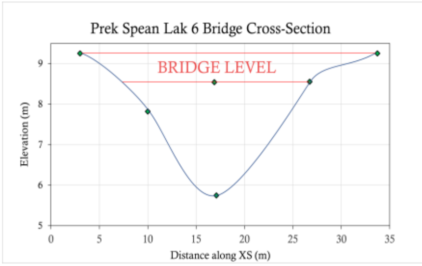


WAT4CAM	PREK SPEAN LAK 6	WB3 /

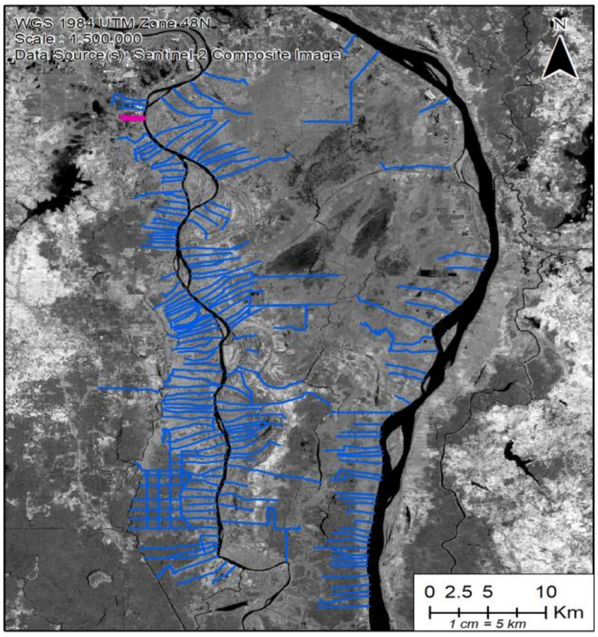




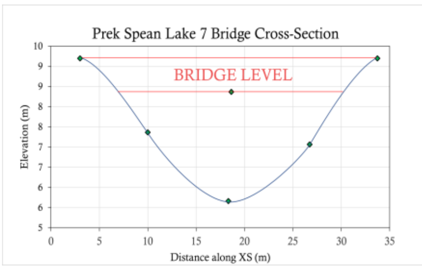
CHANNEL DIMENSIONS	
Channel Length	2.3 km
Channel Width	10 m
Inlet Bed Level	5.75 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0



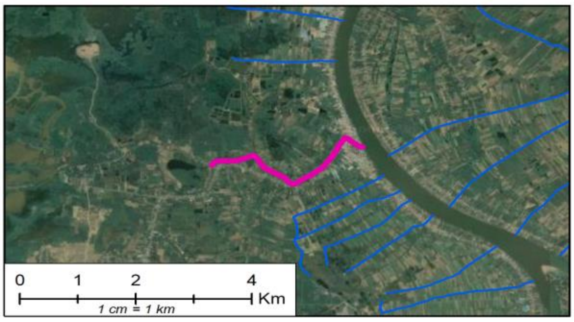
WAT4CAM	PREK SPEAN LAK 7	WB4 /

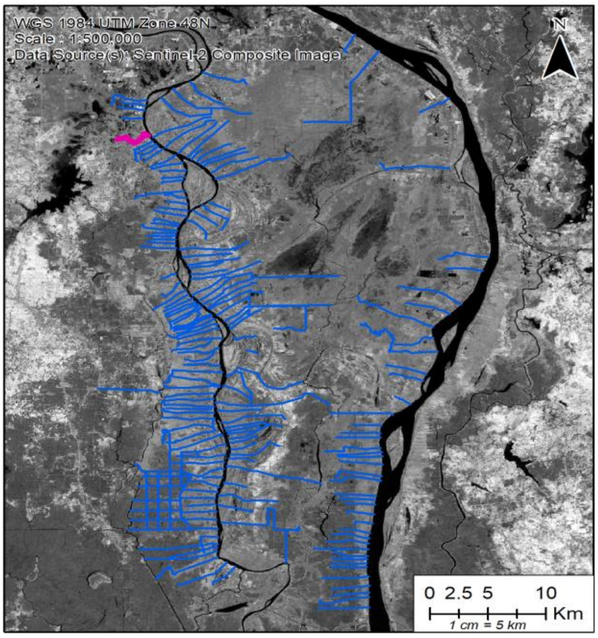


CHANNEL DIMENSIONS	
Channel Length	1.8 km
Channel Width	8 m
Inlet Bed Level	5.66 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0

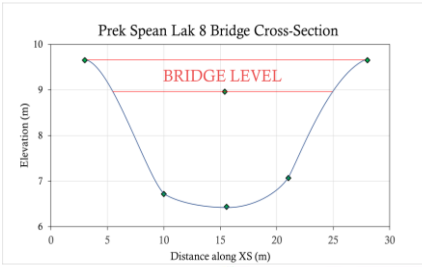


WAT4CAM	PREK SPEAN LAK 8	WB6 /

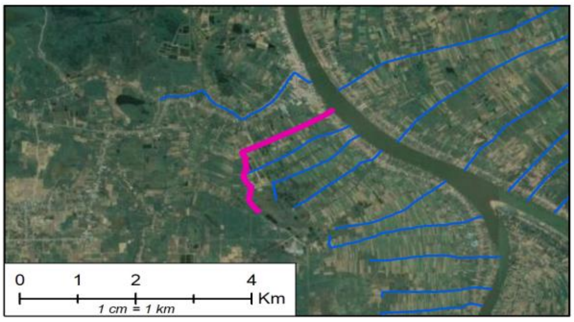


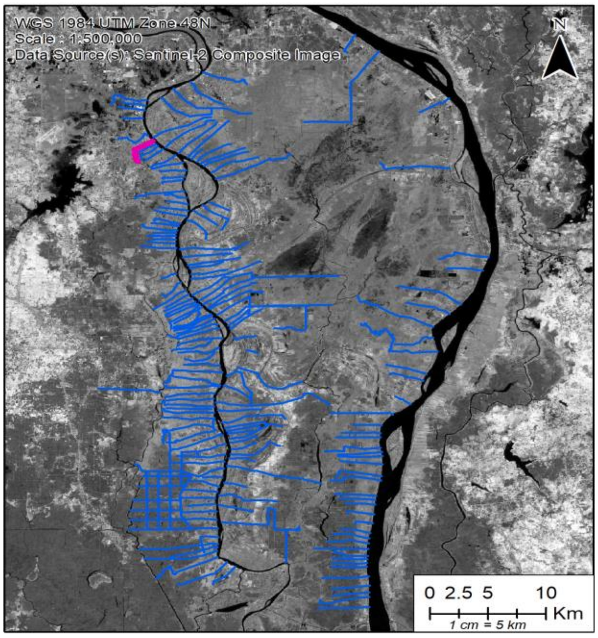


CHANNEL DIMENSIONS	
Channel Length	3.4 km
Channel Width	10 m
Inlet Bed Level	6.43 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0

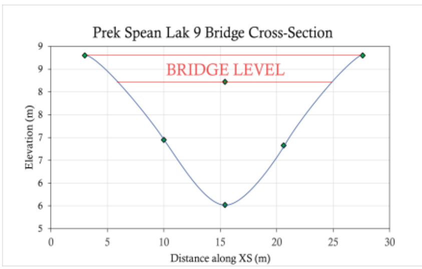


WAT4CAM	PREK SPEAN LAK 9	WB9 /

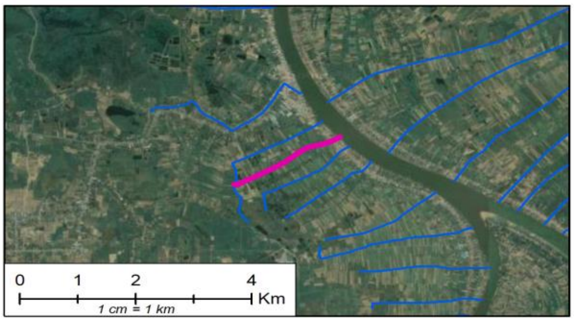


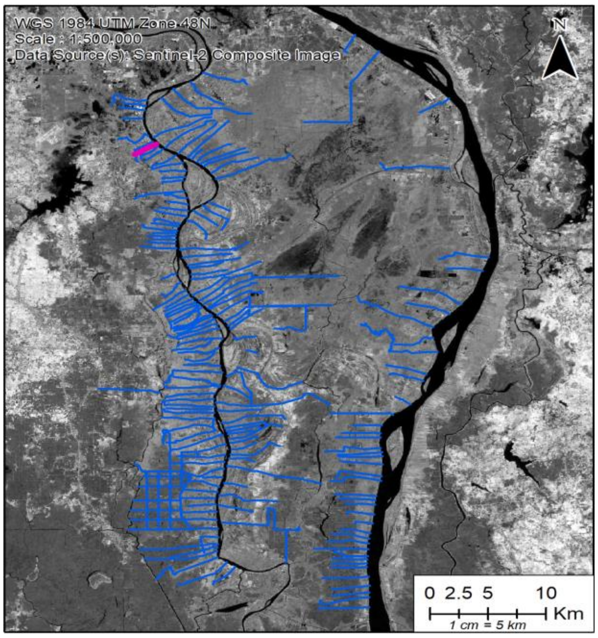


CHANNEL DIMENSIONS	
Channel Length	3.1 km
Channel Width	16 m
Inlet Bed Level	5.52 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	19.8

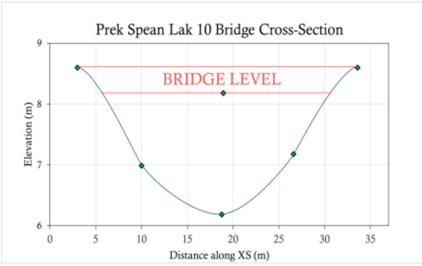


WAT4CAM	PREK SPEAN LAK 10	WB11 /

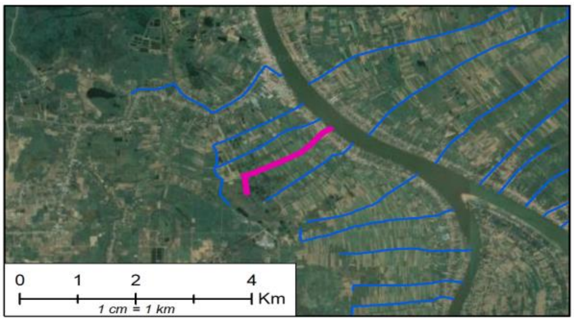


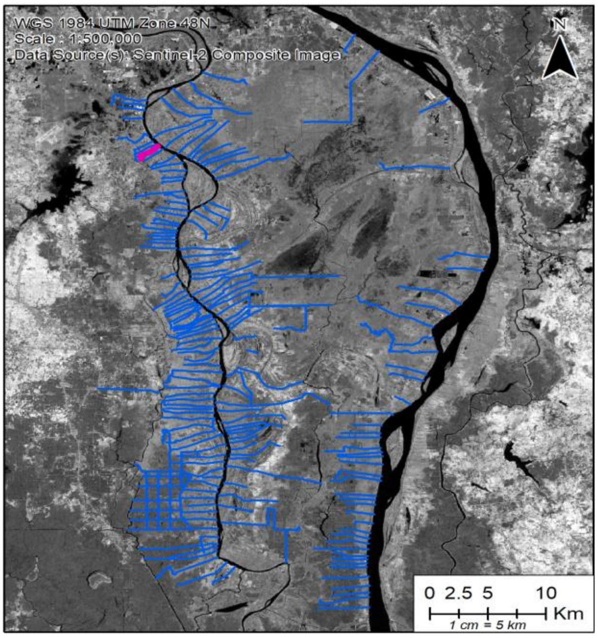


CHANNEL DIMENSIONS	
Channel Length	2.1 km
Channel Width	9 m
Inlet Bed Level	6.18 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0

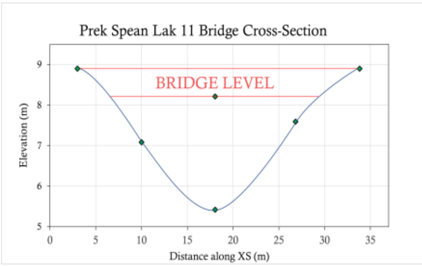


WAT4CAM	PREK SPEAN LAK 11	WB12/

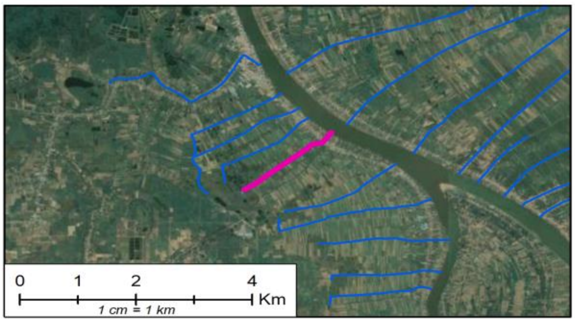


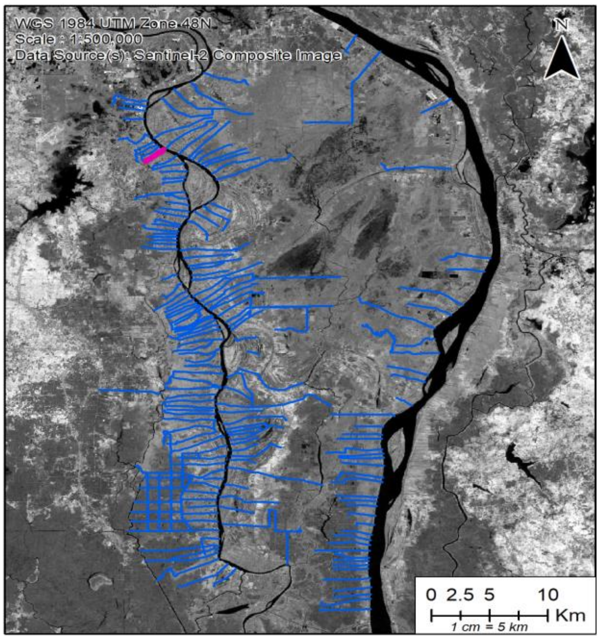


CHANNEL DIMENSIONS	
Channel Length	2.2 km
Channel Width	9 m
Inlet Bed Level	5.42 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0

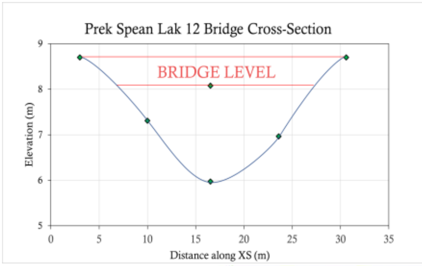


WAT4CAM	PREK SPEAN LAK 12	WB13/

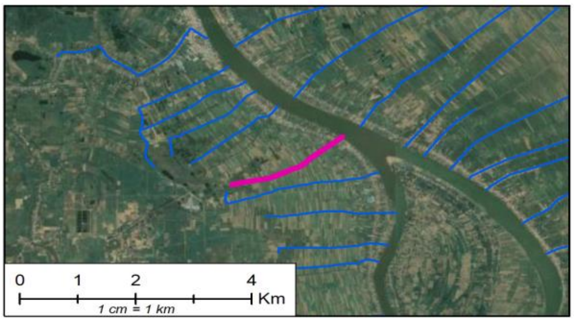


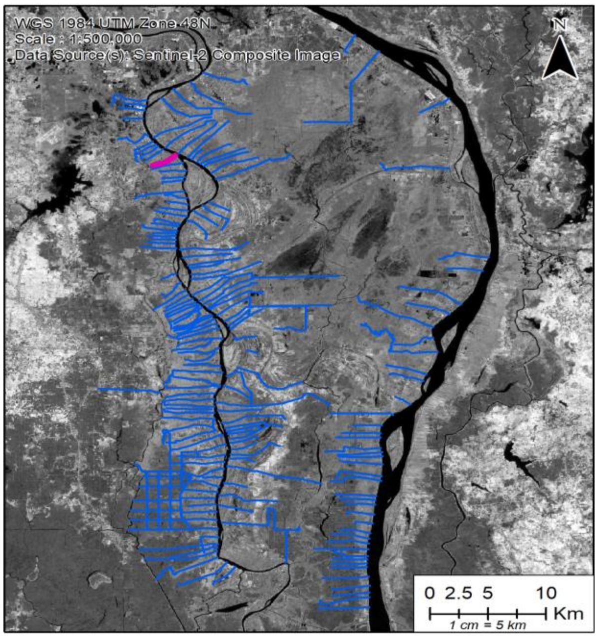


CHANNEL DIMENSIONS	
Channel Length	1.9 km
Channel Width	9 m
Inlet Bed Level	5.97 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0

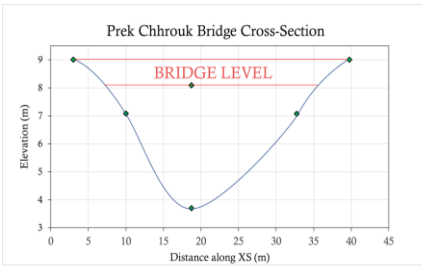


WAT4CAM	PREK CHHROUK	WB14/08101465

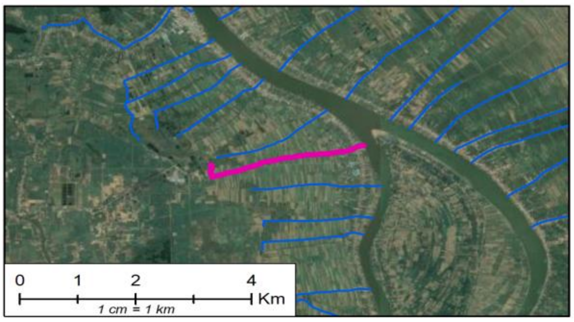


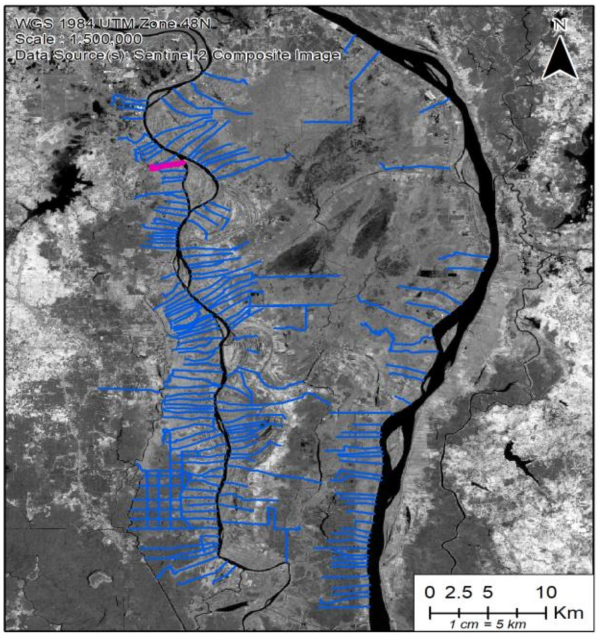


CHANNEL DIMENSIONS	
Channel Length	2.2 km
Channel Width	10 m
Inlet Bed Level	3.70 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101465
CISIS Area (ha)	83.0

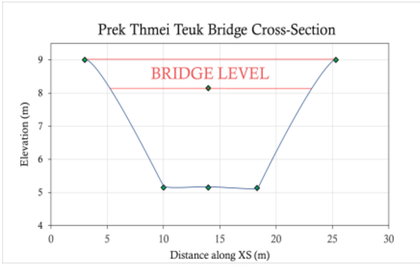


WAT4CAM	PREK THMEI TEUK	WB15/08101466

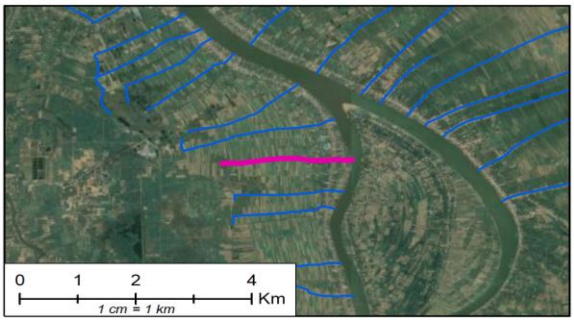


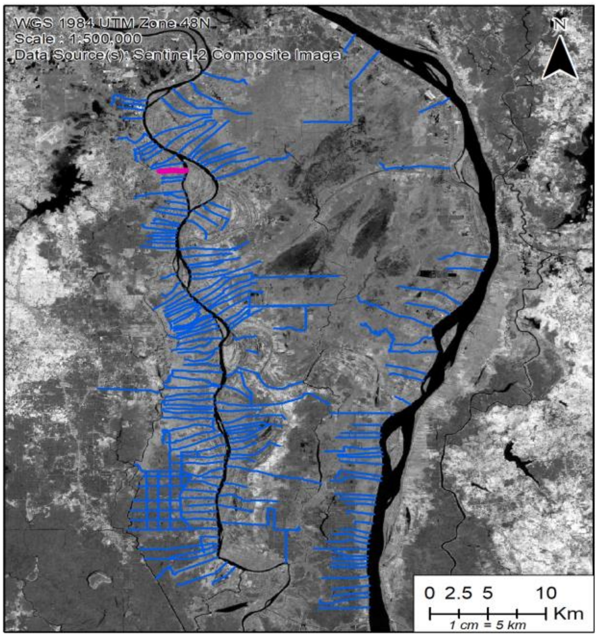


CHANNEL DIMENSIONS	
Channel Length	3.0 km
Channel Width	8 m
Inlet Bed Level	5.13 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101466
CISIS Area (ha)	120.9

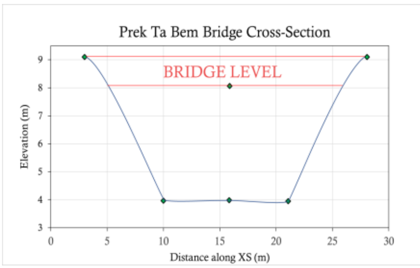


WAT4CAM	PREK TA BEM	WB16/08101464

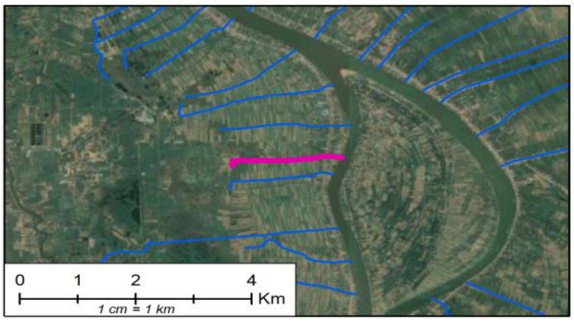


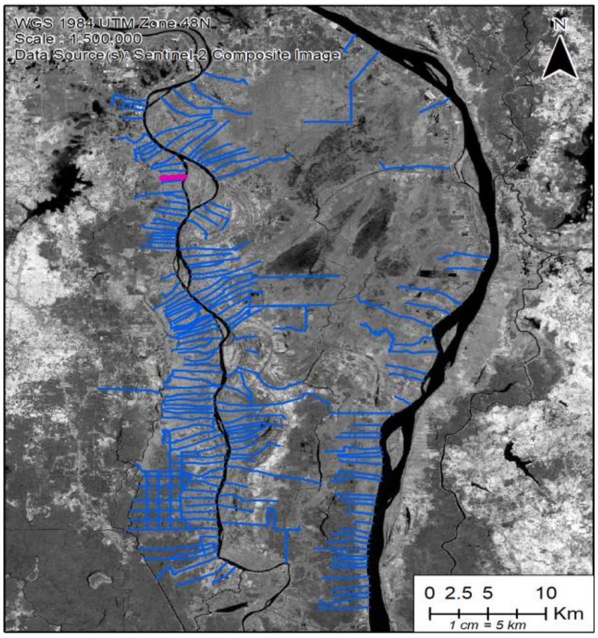


CHANNEL DIMENSIONS	
Channel Length	2.3 km
Channel Width	9 m
Inlet Bed Level	3.97 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101464
CISIS Area (ha)	165.0

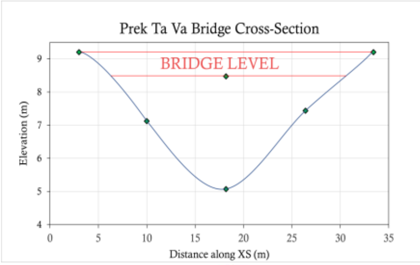


WAT4CAM | PREK TA VA | WB17/08101463

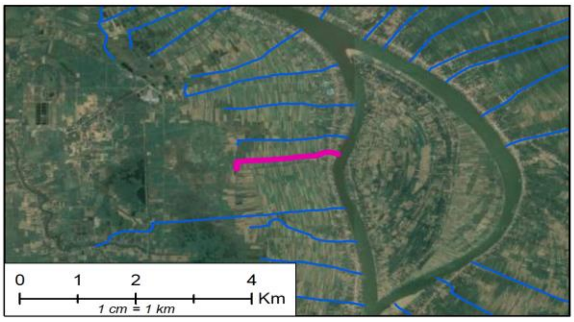


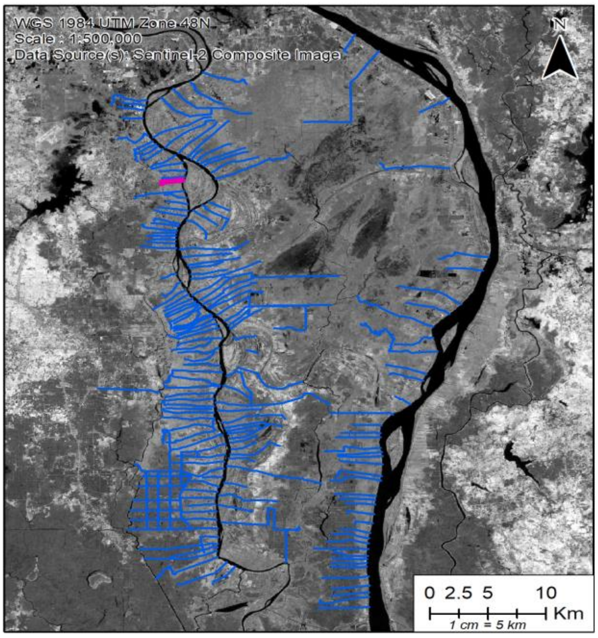


CHANNEL DIMENSIONS	
Channel Length	2.0 km
Channel Width	10 m
Inlet Bed Level	5.08 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101463
CISIS Area (ha)	146.3

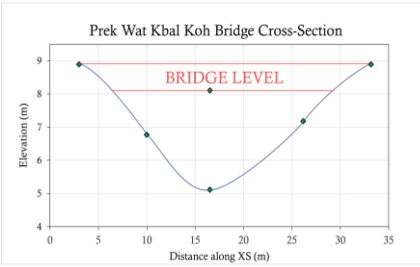


WAT4CAM | PREK WAT KBAL KOH | WB18/08101462

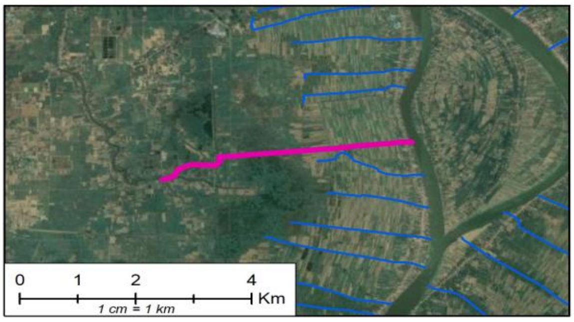


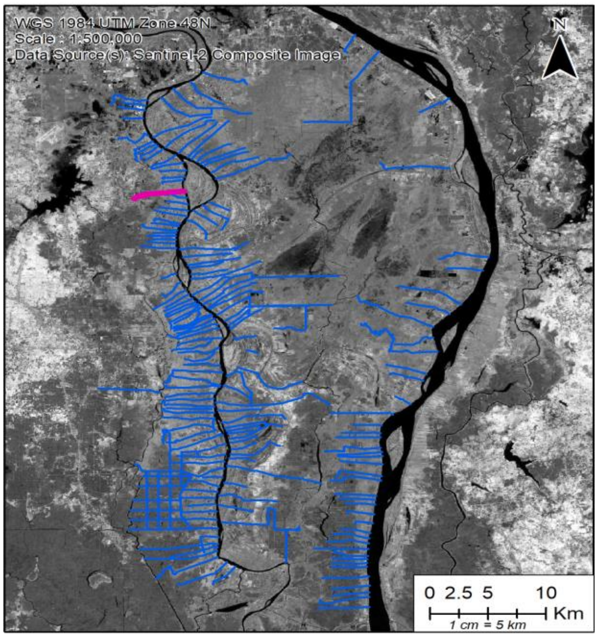


CHANNEL DIMENSIONS	
Channel Length	1.9 km
Channel Width	9 m
Inlet Bed Level	5.12 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101462
CISIS Area (ha)	111.3

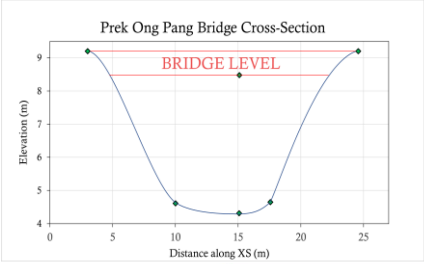


WAT4CAM	PREK ONG PANG	WB19/08100055

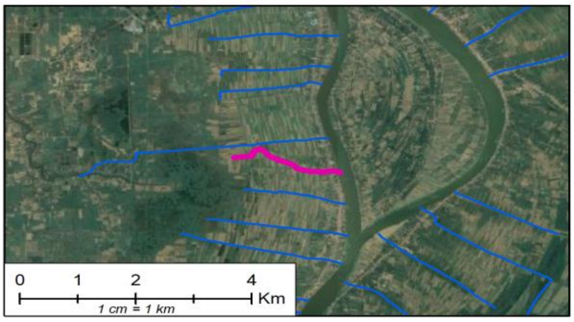


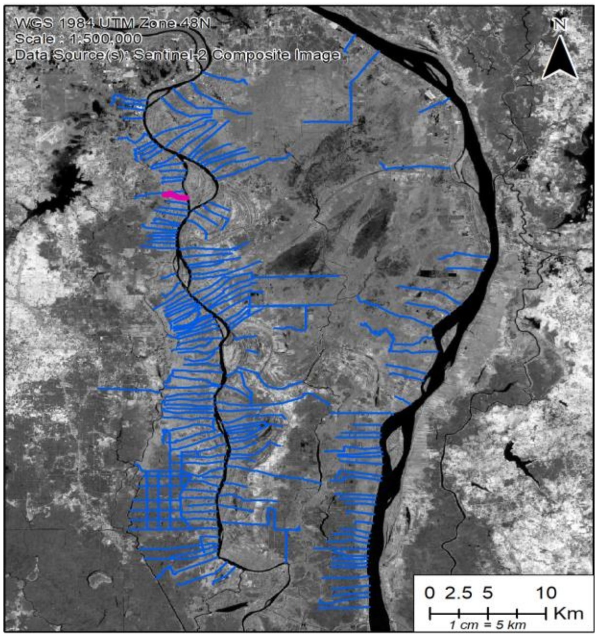


CHANNEL DIMENSIONS	
Channel Length	4.6 km
Channel Width	9 m
Inlet Bed Level	4.31 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08100055
CISIS Area (ha)	186.0

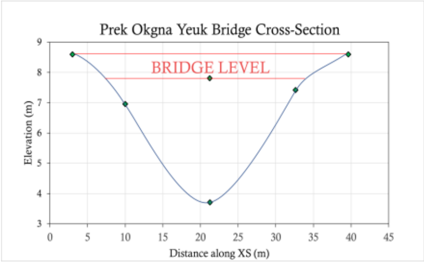


WAT4CAM	PREK OKGNA YEUK	WB20/08101544

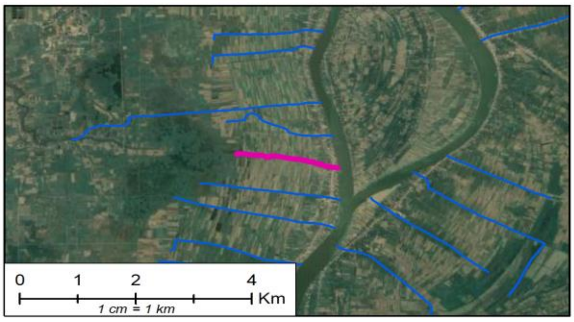


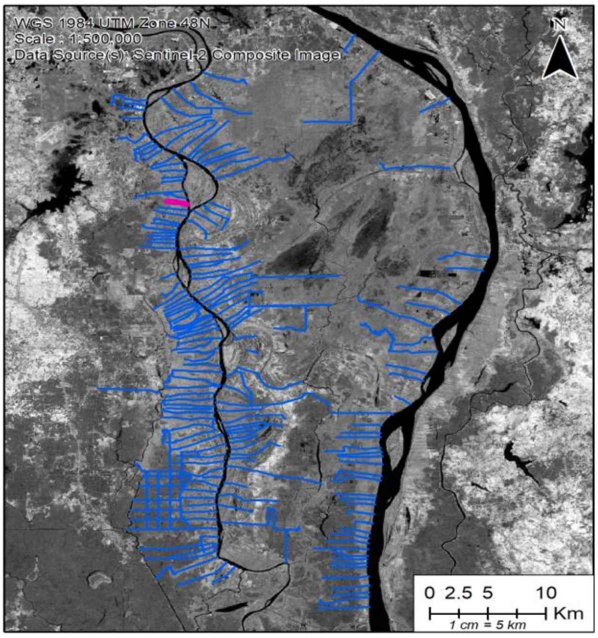


CHANNEL DIMENSIONS	
Channel Length	2.1 km
Channel Width	10 m
Inlet Bed Level	3.71 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101544
CISIS Area (ha)	146.4

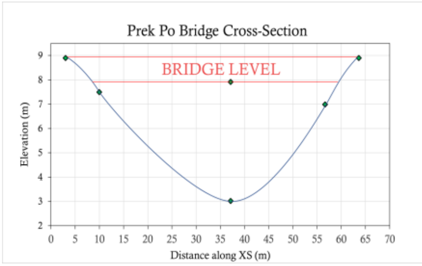


WAT4CAM	PREK PO	WB21/08101542

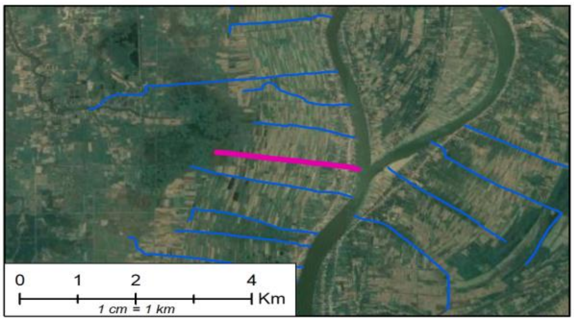


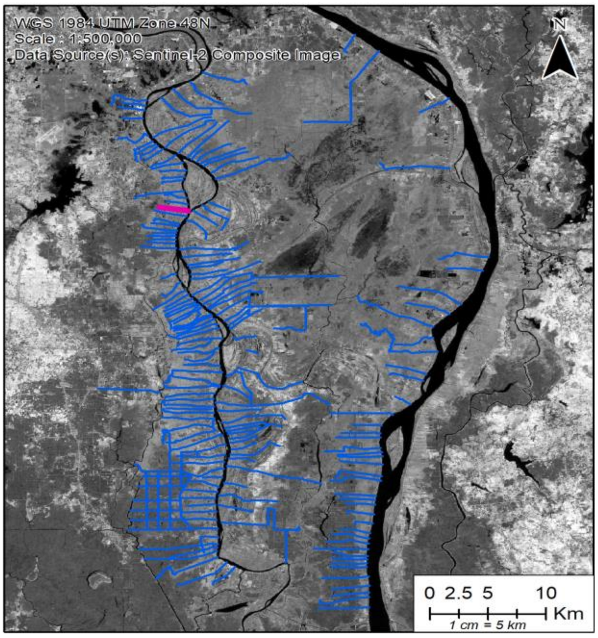


CHANNEL DIMENSIONS	
Channel Length	1.8 km
Channel Width	10 m
Inlet Bed Level	3.02 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101542
CISIS Area (ha)	102.6

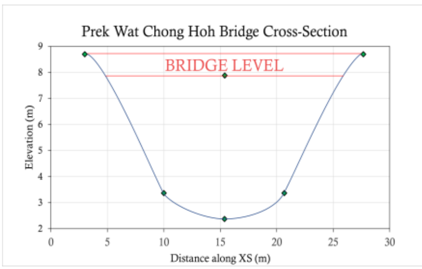


WAT4CAM	PREK WAT CHONG HOH	WB22/08101541

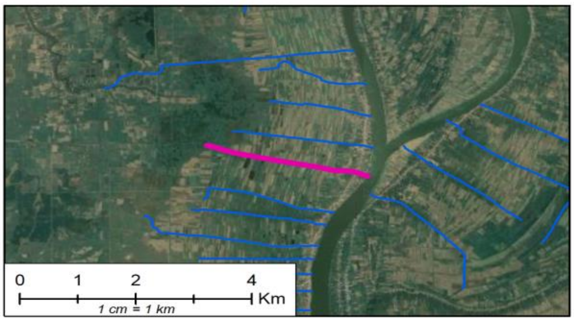


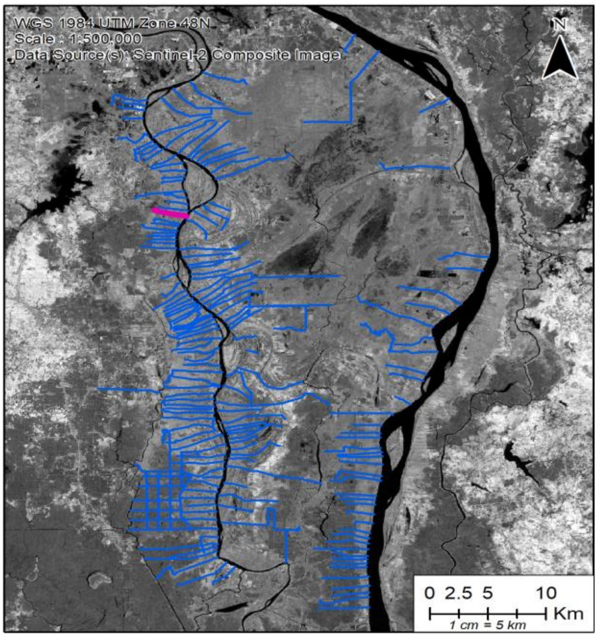


CHANNEL DIMENSIONS	
Channel Length	2.5 km
Channel Width	9 m
Inlet Bed Level	2.37 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101541
CISIS Area (ha)	171.0

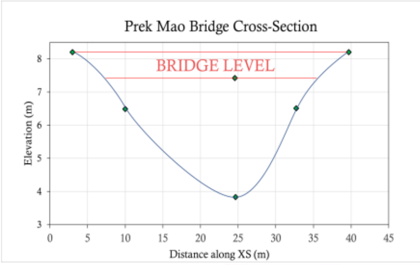


WAT4CAM	PREK MAO	WB23/08101467

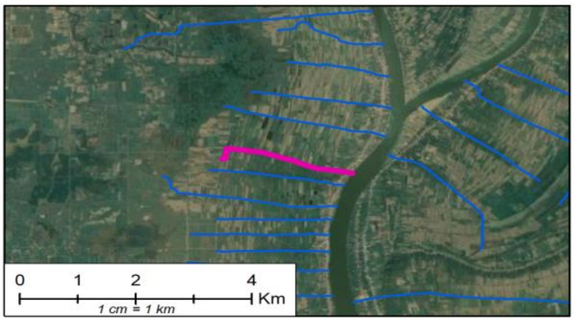


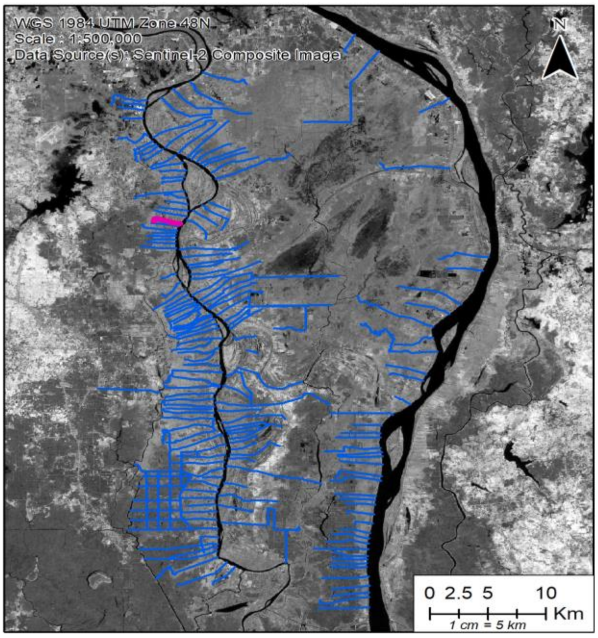


CHANNEL DIMENSIONS	
Channel Length	2.8 km
Channel Width	11 m
Inlet Bed Level	3.83 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101467
CISIS Area (ha)	189.5

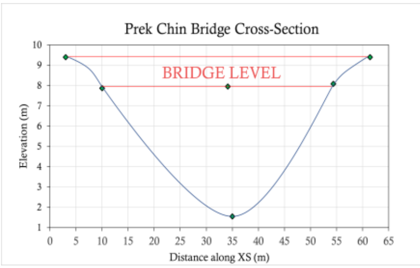


WAT4CAM	PREK CHIN	WB24/08101468

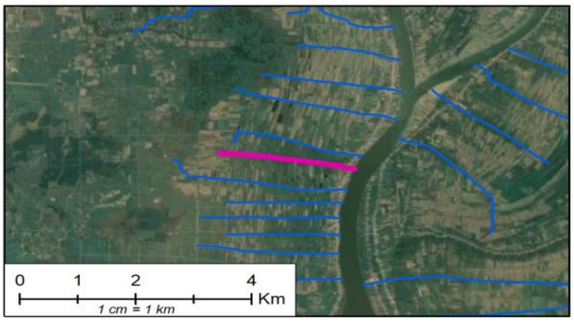


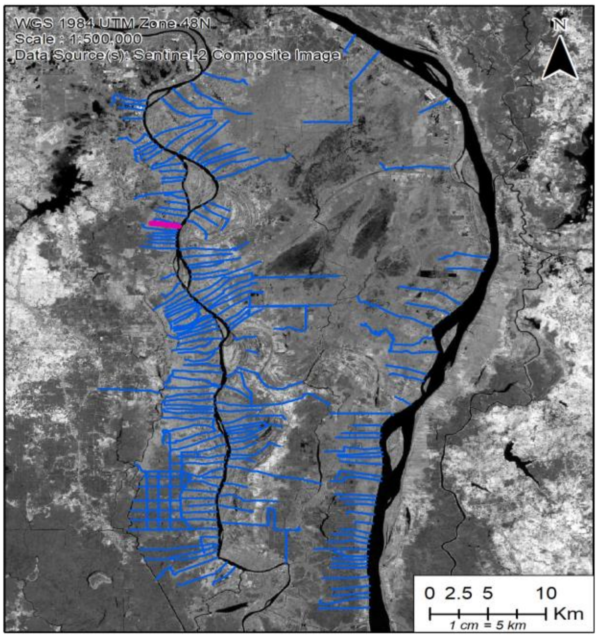


CHANNEL DIMENSIONS	
Channel Length	2.5 km
Channel Width	13 m
Inlet Bed Level	1.55 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08101468
CISIS Area (ha)	43.9

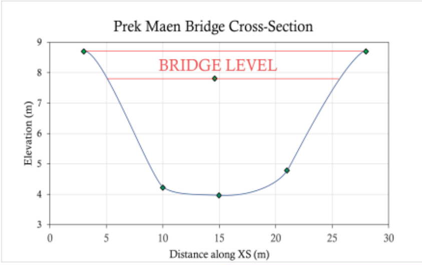


WAT4CAM	PREK MAEN	WB25/08101469

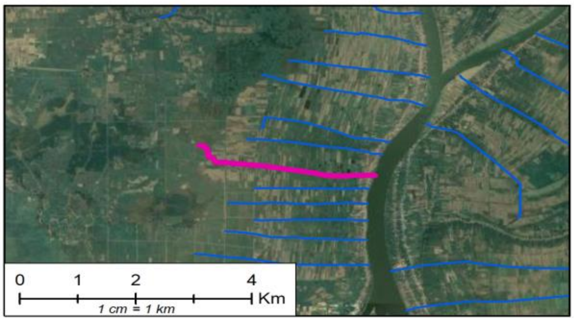


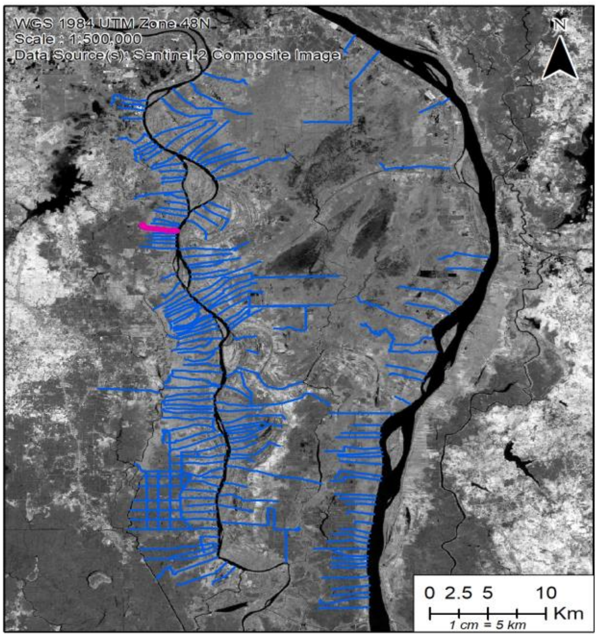


CHANNEL DIMENSIONS	
Channel Length	2.4 km
Channel Width	9 m
Inlet Bed Level	3.97 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101469
CISIS Area (ha)	59.6

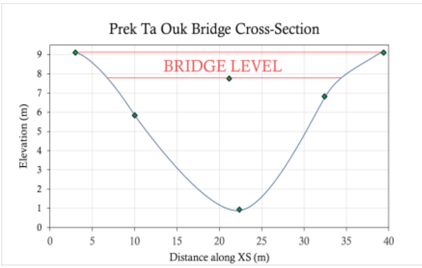


WAT4CAM	PREK TA OUK	WB26/08101470

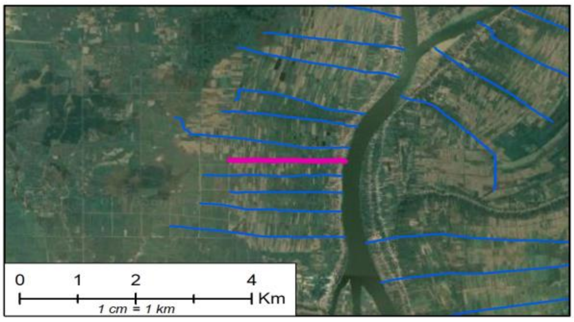


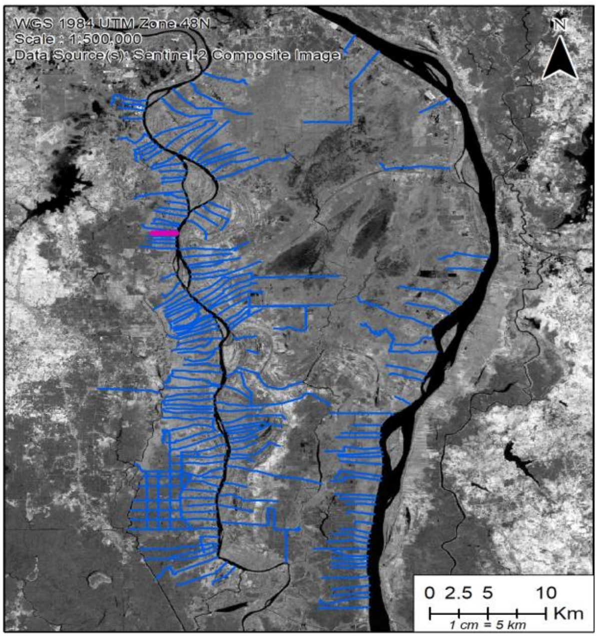


CHANNEL DIMENSIONS	
Channel Length	3.2 km
Channel Width	10 m
Inlet Bed Level	0.93 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08101470
CISIS Area (ha)	112.2

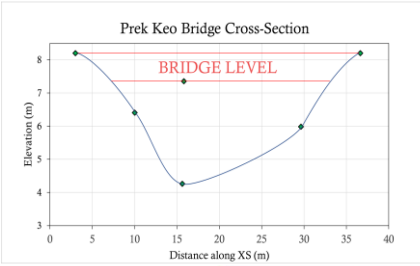


WAT4CAM	PREK KEO	WB27/08101471

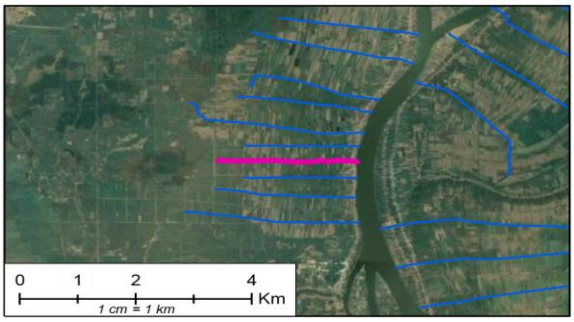


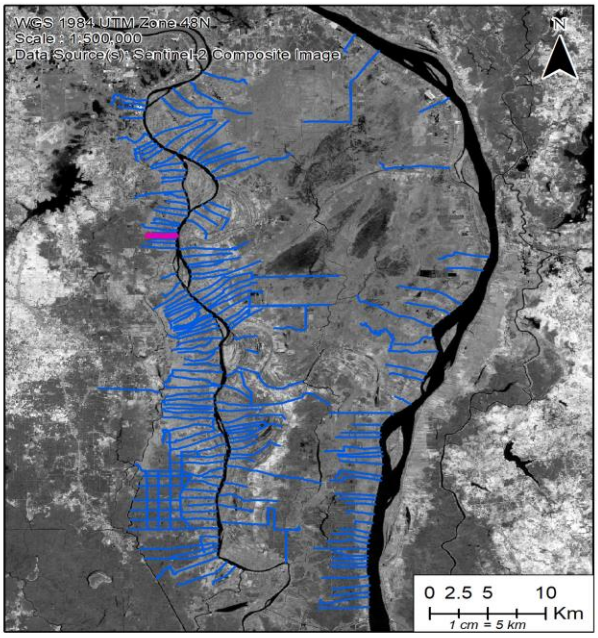


CHANNEL DIMENSIONS	
Channel Length	2.0 km
Channel Width	8 m
Inlet Bed Level	4.26 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101471
CISIS Area (ha)	77.9

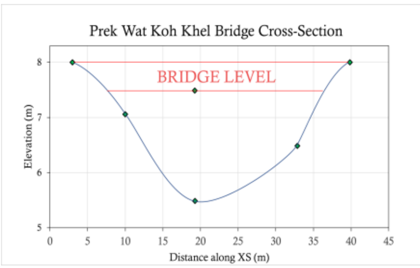


WAT4CAM	PREK WAT KOH KHEL	WB28/08101536

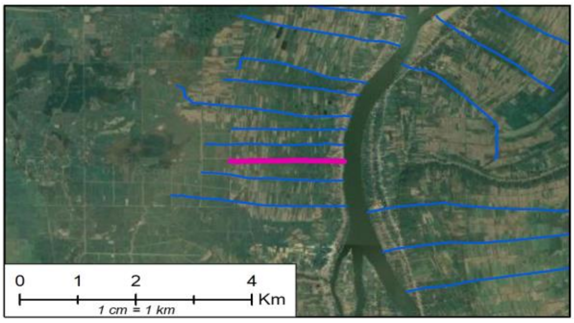


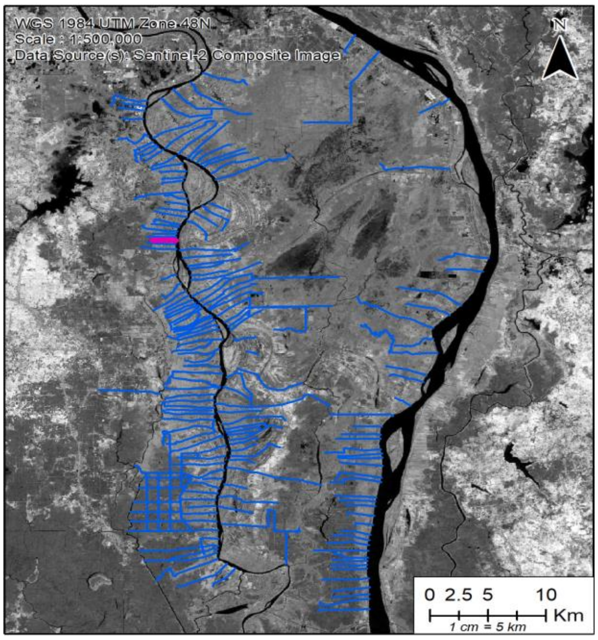


CHANNEL DIMENSIONS	
Channel Length	2.4 km
Channel Width	11 m
Inlet Bed Level	5.49 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101536
CISIS Area (ha)	67.2

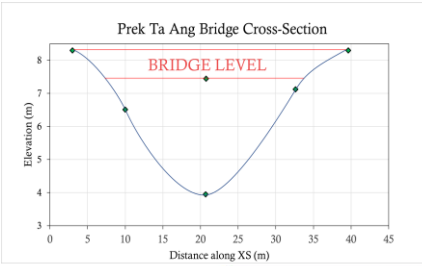


WAT4CAM | PREK TA ANG | WB29/08101538

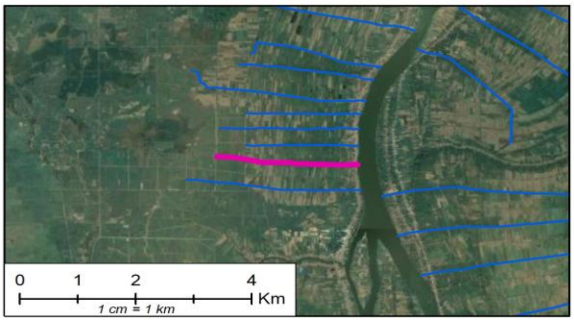


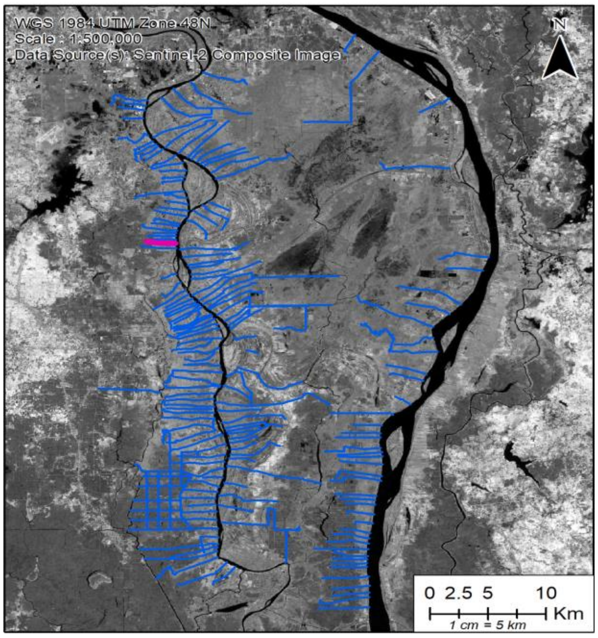


CHANNEL DIMENSIONS	
Channel Length	1.9 km
Channel Width	10 m
Inlet Bed Level	3.95 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101538
CISIS Area (ha)	83.5

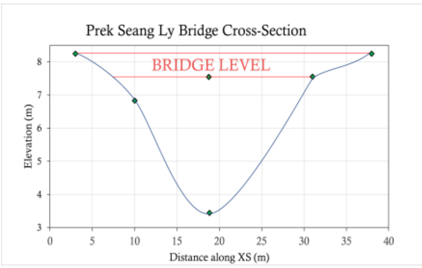


WAT4CAM | PREK SEANG LY | WB30/08101540

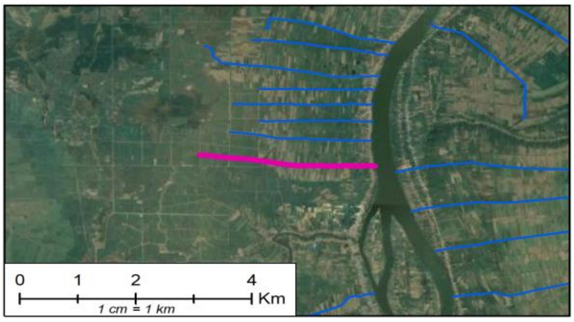


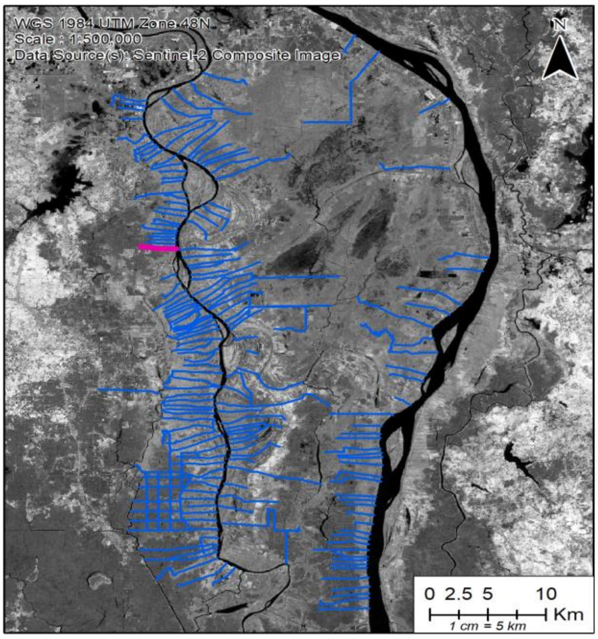


CHANNEL DIMENSIONS	
Channel Length	2.4 km
Channel Width	11 m
Inlet Bed Level	3.44 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101540
CISIS Area (ha)	92.4

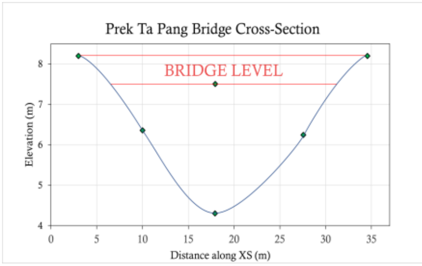


WAT4CAM	PREK TA PANG	WB31/08101539

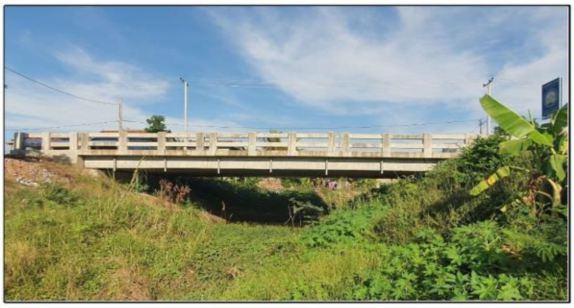


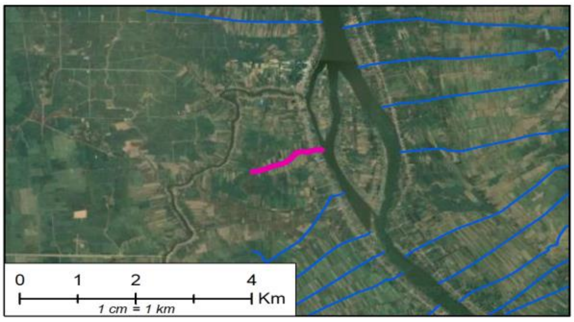


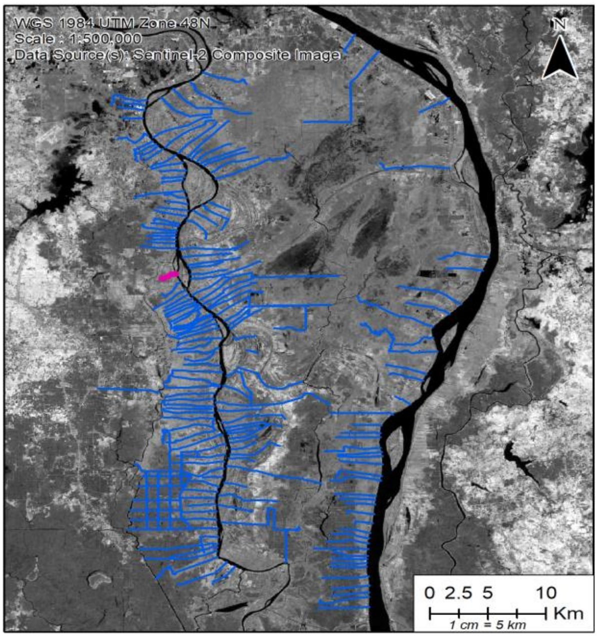
CHANNEL DIMENSIONS	
Channel Length	3.0 km
Channel Width	8 m
Inlet Bed Level	4.30 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101539
CISIS Area (ha)	140.8



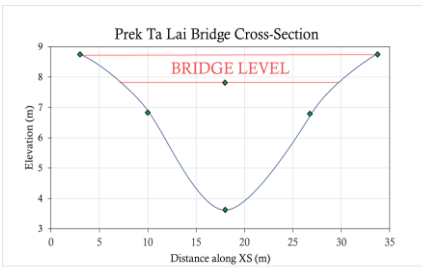
WAT4CAM	PREK TA LAI	WB32/08101535



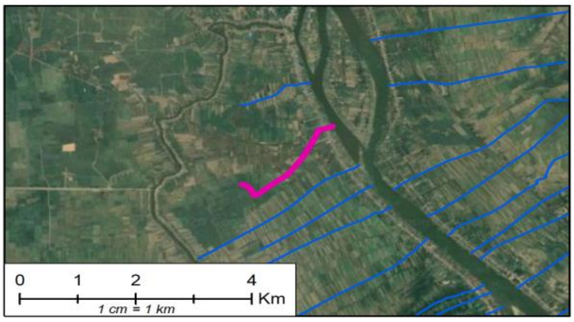


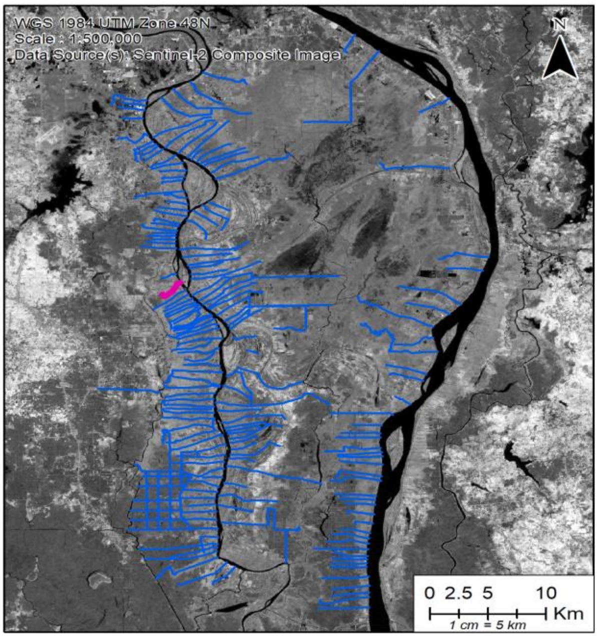


CHANNEL DIMENSIONS	
Channel Length	1.3 km
Channel Width	8 m
Inlet Bed Level	3.62 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101535
CISIS Area (ha)	99.2

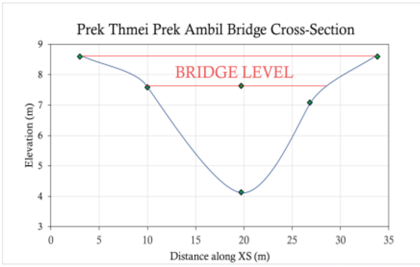


WAT4CAM	PREK THMEI PREK AMBIL	WB33/08101534

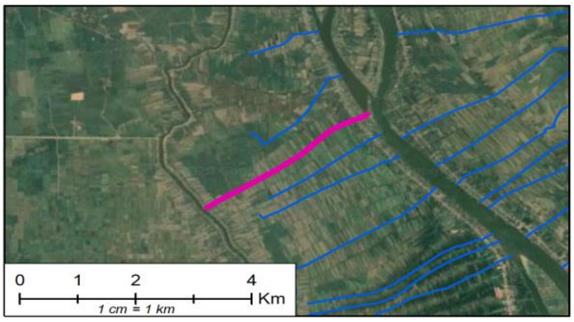


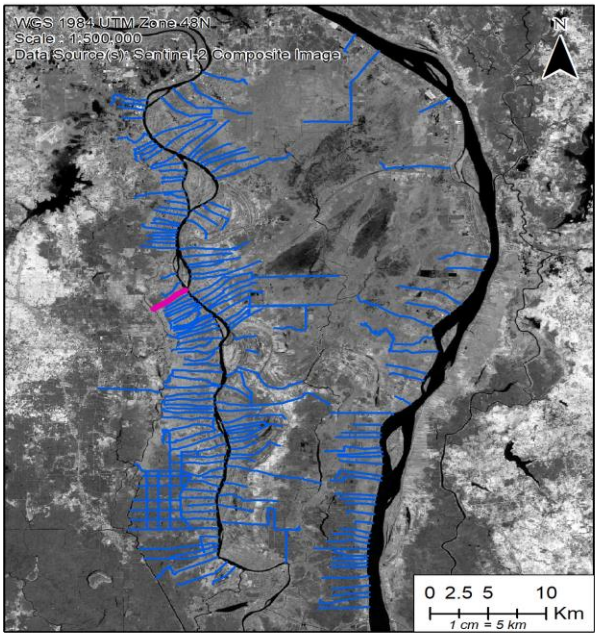


CHANNEL DIMENSIONS	
Channel Length	2.4 km
Channel Width	9 m
Inlet Bed Level	4.13 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101534
CISIS Area (ha)	132.1

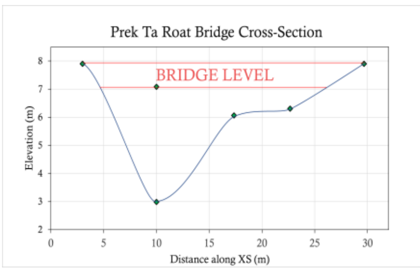


WAT4CAM	PREK TA ROAT	WB34/08100756

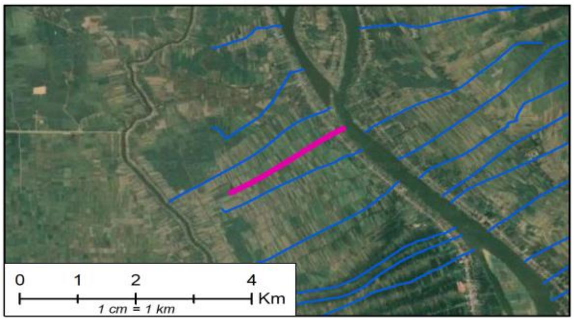


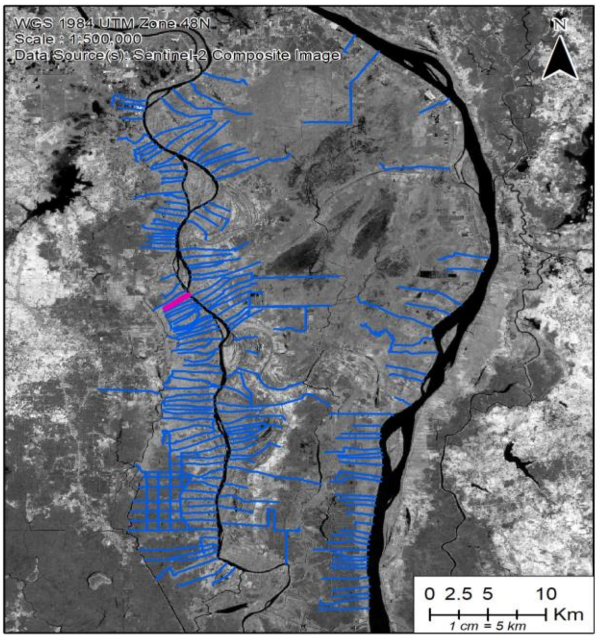


CHANNEL DIMENSIONS	
Channel Length	3.4 km
Channel Width	11 m
Inlet Bed Level	2.99 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08100756
CISIS Area (ha)	121.2

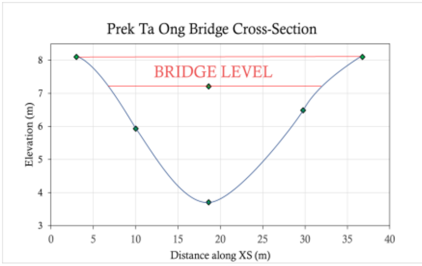


WAT4CAM	PREK TA ONG	WB35/08100757

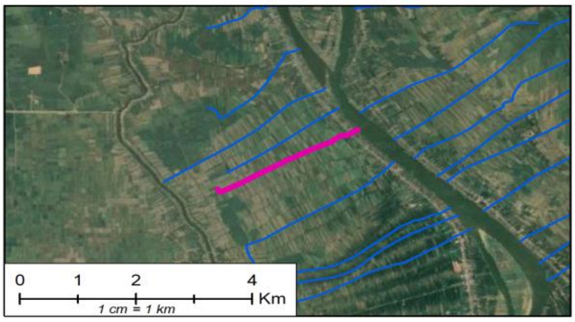


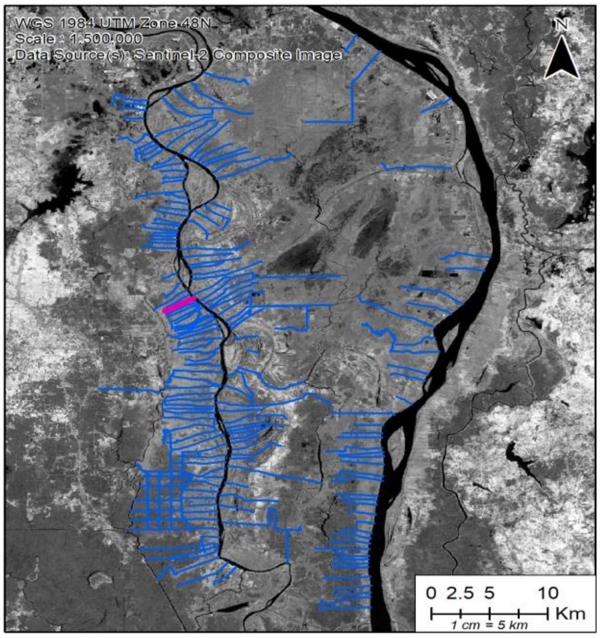


CHANNEL DIMENSIONS	
Channel Length	2.3 km
Channel Width	11 m
Inlet Bed Level	3.71 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08100757
CISIS Area (ha)	114.4

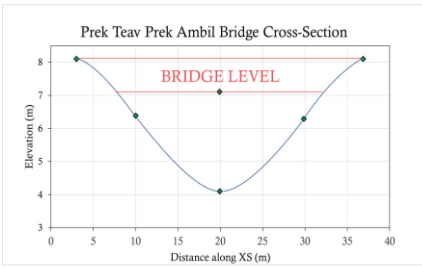


WAT4CAM	PREK TEAV PREK AMBIL	WB36/08101533

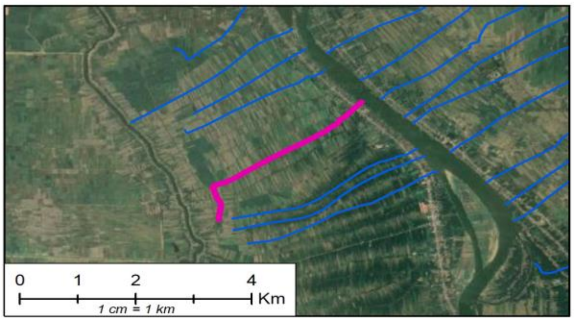


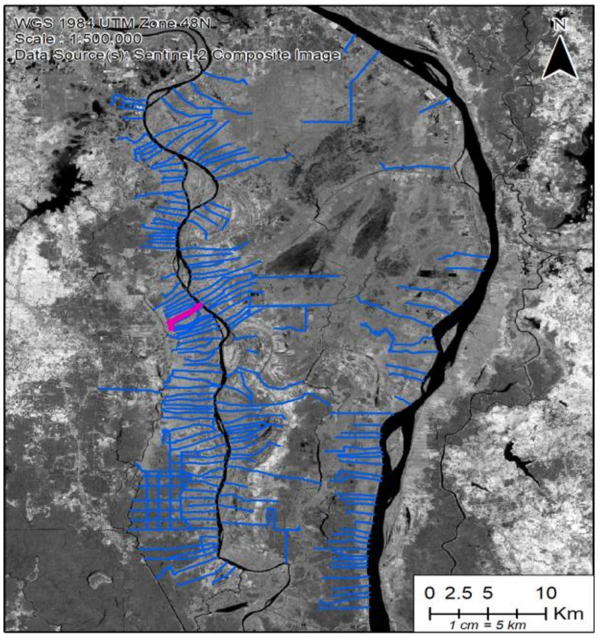


CHANNEL DIMENSIONS	
Channel Length	2.8 km
Channel Width	9 m
Inlet Bed Level	4.11 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101533
CISIS Area (ha)	92.6



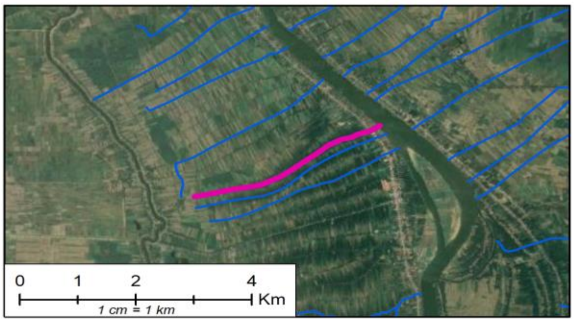
WAT4CAM	PREK THOM PREK AMBIL	WB39/08101530

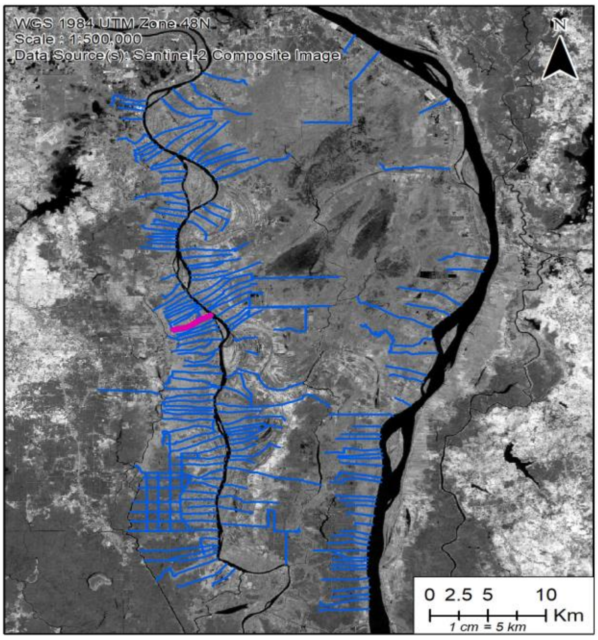




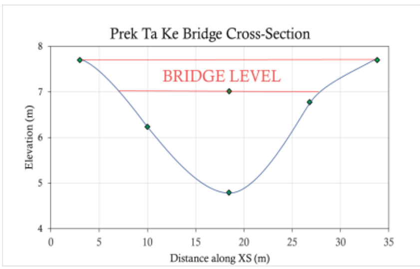
CHANNEL DIMENSIONS	
Channel Length	3.8 km
Channel Width	12 m
Inlet Bed Level	4.29 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101530
CISIS Area (ha)	103.7

WAT4CAM	PREK TA KE	WB41/08041474

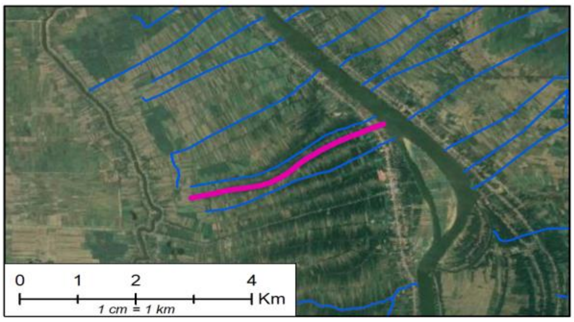


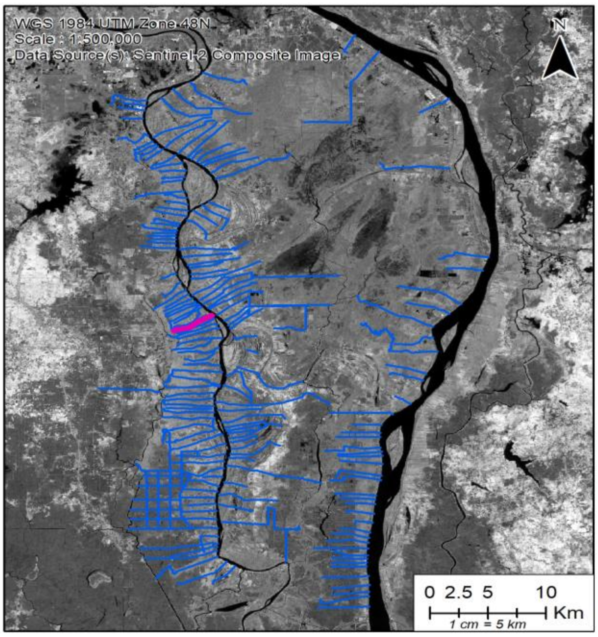


CHANNEL DIMENSIONS	
Channel Length	3.6 km
Channel Width	7 m
Inlet Bed Level	4.79 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041474
CISIS Area (ha)	61.2

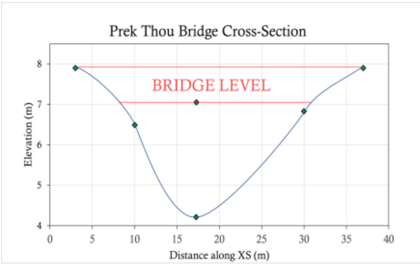


WAT4CAM	PREK THOU	WB42/08041473

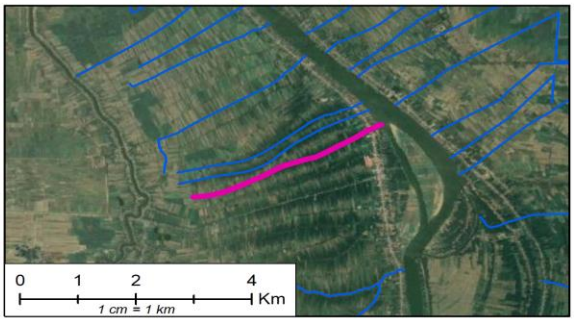


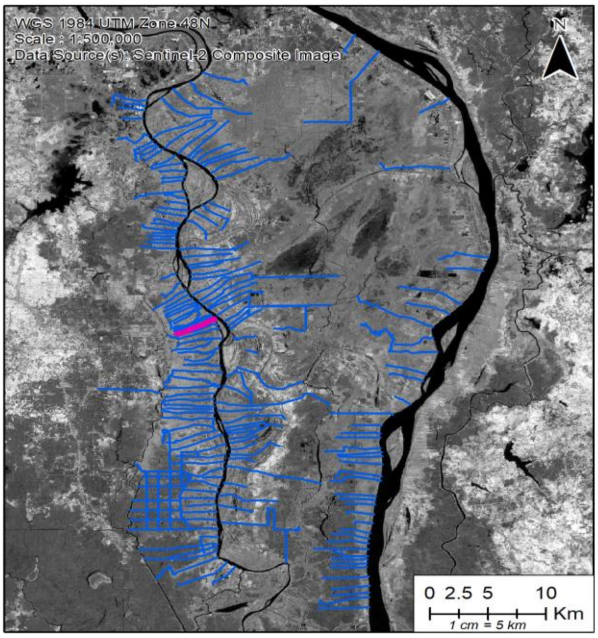


CHANNEL DIMENSIONS	
Channel Length	3.7 km
Channel Width	12 m
Inlet Bed Level	4.21 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041473
CISIS Area (ha)	88.6

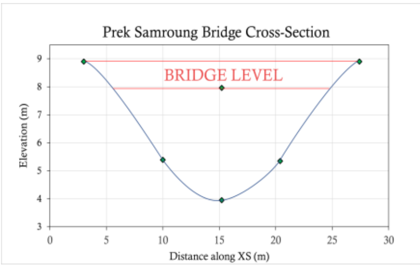


WAT4CAM	PREK SAMROUNG	WB43/08041472

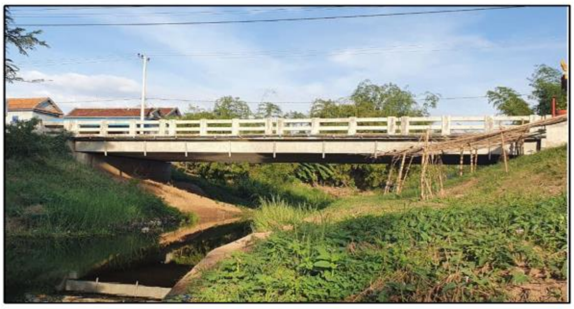


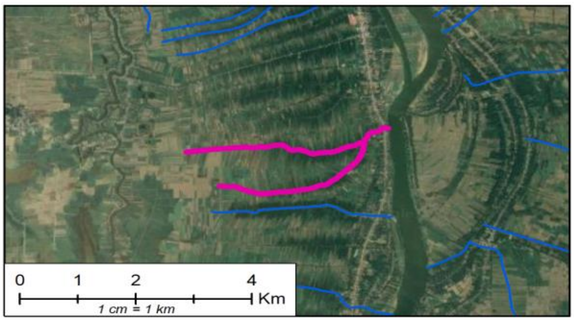


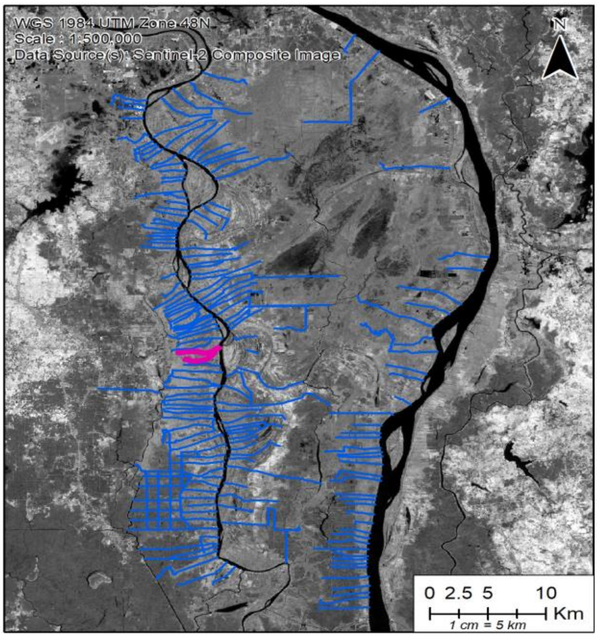
CHANNEL DIMENSIONS	
Channel Length	3.6 km
Channel Width	11 m
Inlet Bed Level	3.95 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041472
CISIS Area (ha)	102.4



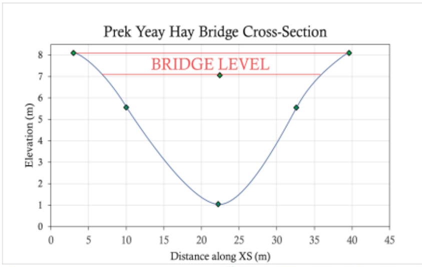
WAT4CAM	PREK YEAY HAY	WB47/08041511



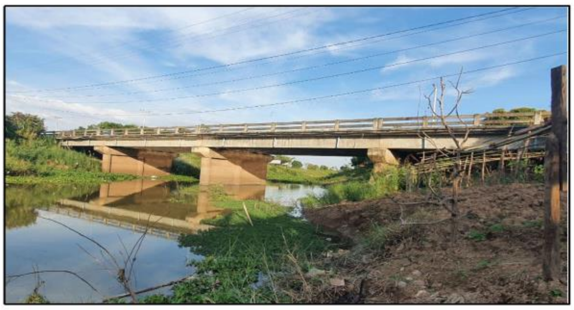


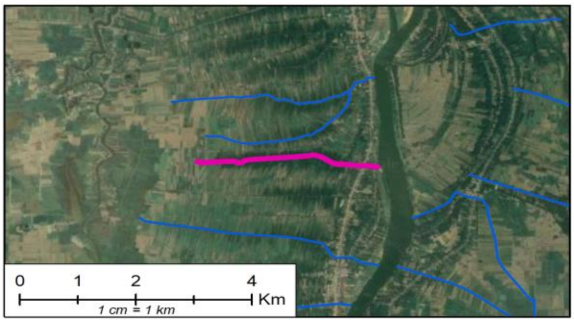


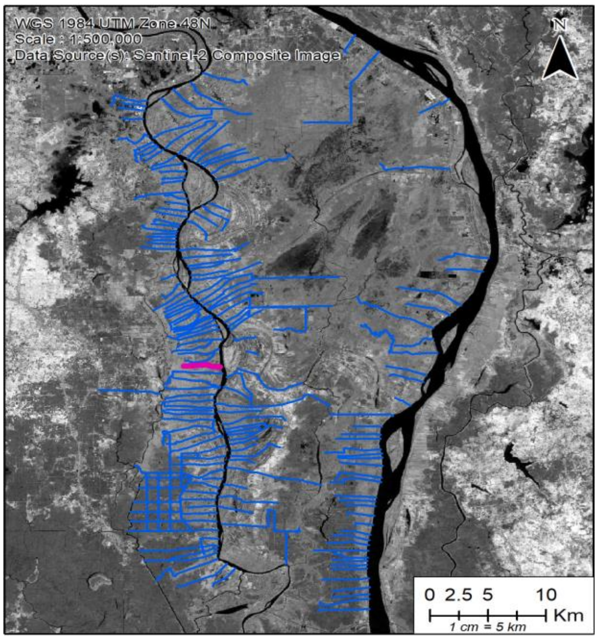
CHANNEL DIMENSIONS	
Channel Length	6.8 km
Channel Width	14 m
Inlet Bed Level	1.04 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041511
CISIS Area (ha)	572.0



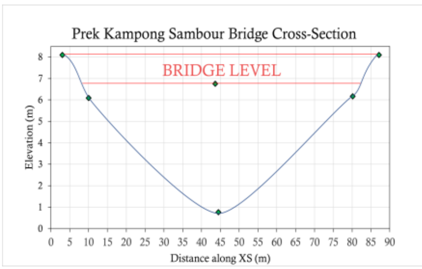
WAT4CAM	PREK KAMPONG SAMBOUR	WB48/08041510



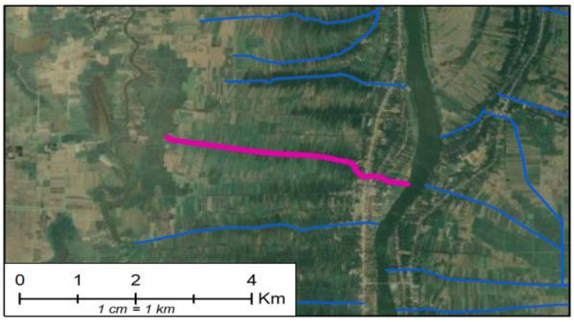


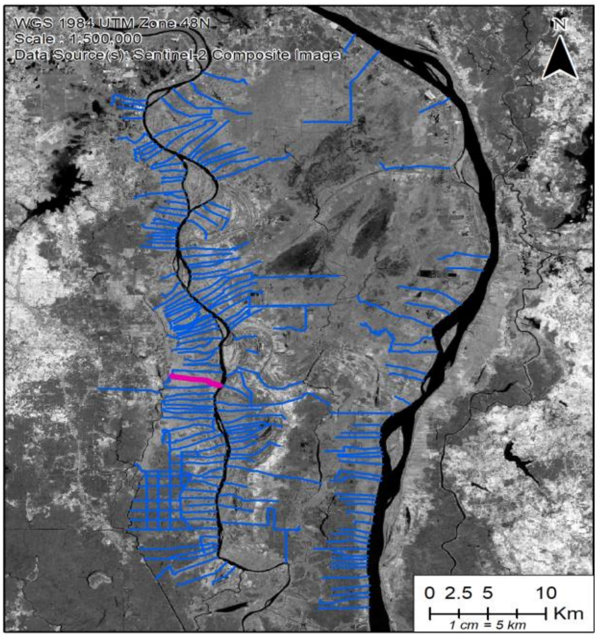


CHANNEL DIMENSIONS	
Channel Length	3.2 km
Channel Width	21 m
Inlet Bed Level	0.77 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041510
CISIS Area (ha)	258.8

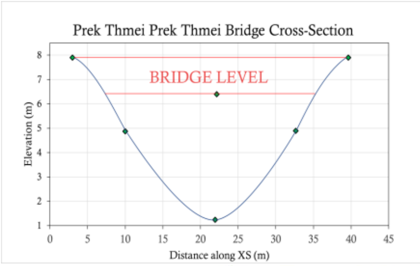


WAT4CAM	PREK THMEI PREK THMEI	WB50/08041508

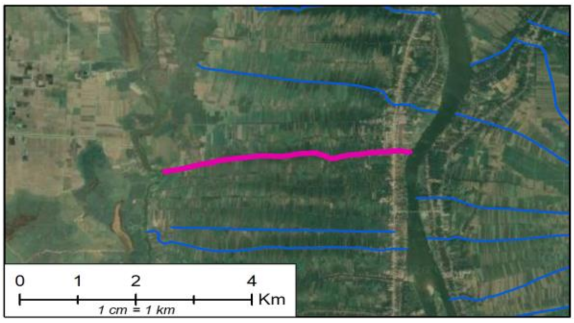


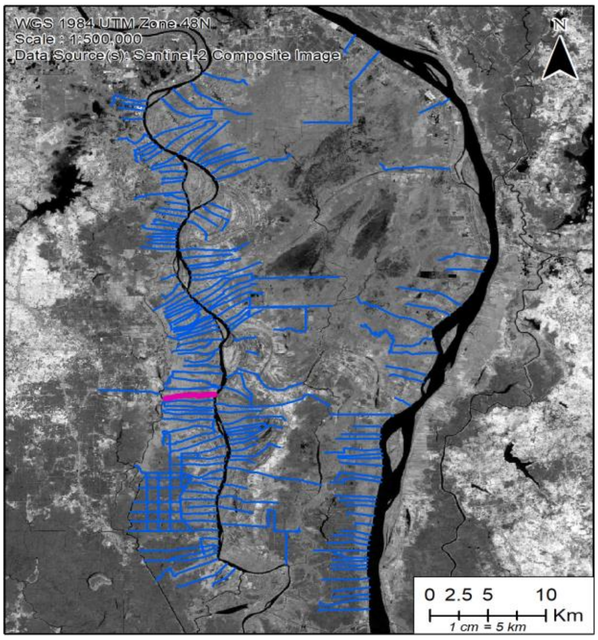


CHANNEL DIMENSIONS	
Channel Length	4.4 km
Channel Width	14 m
Inlet Bed Level	1.24 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041508
CISIS Area (ha)	617.4

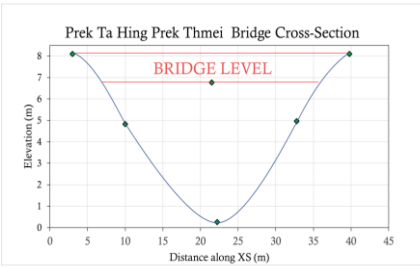


WAT4CAM	PREK TA HING PREK THMEI	WB52/08041491

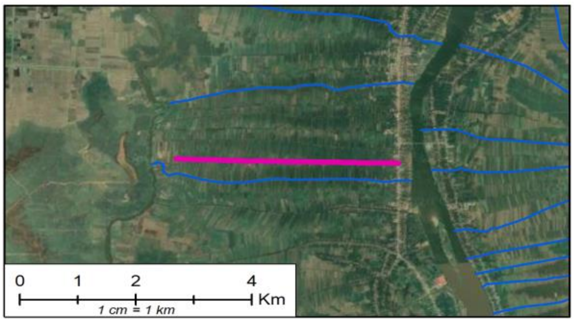


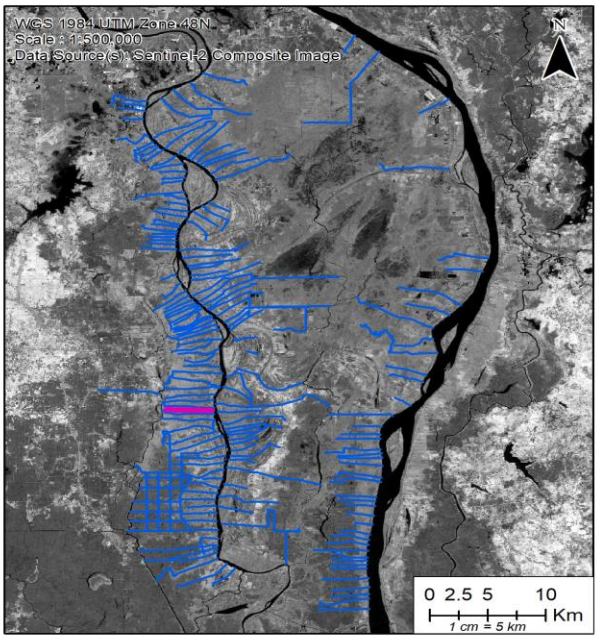


CHANNEL DIMENSIONS	
Channel Length	4.3 km
Channel Width	15 m
Inlet Bed Level	0.27 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041491
CISIS Area (ha)	253.4

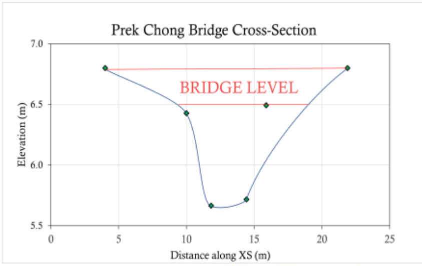


WAT4CAM	PREK CHONG	WB55/08041503

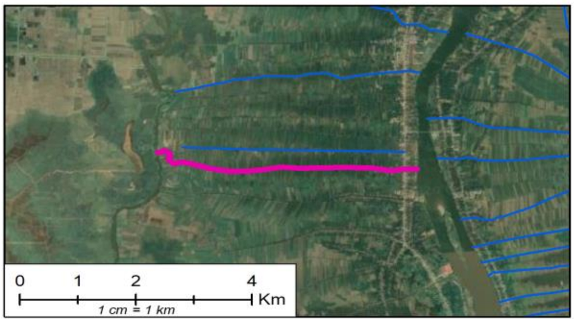


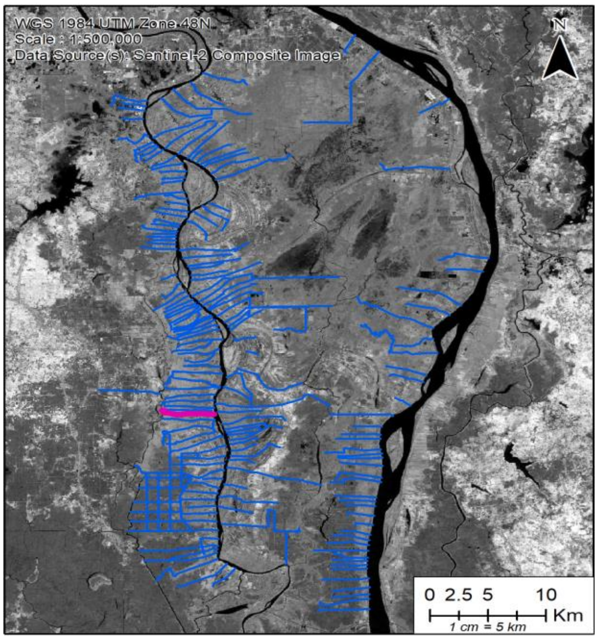


CHANNEL DIMENSIONS	
Channel Length	3.8 km
Channel Width	9 m
Inlet Bed Level	4.27 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041503
CISIS Area (ha)	278.5

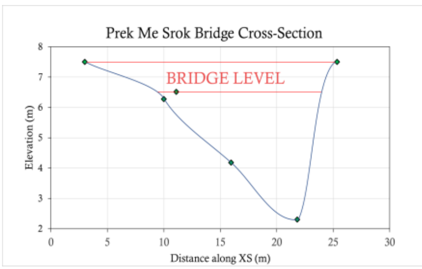


WAT4CAM	PREK ME SROK	WB56/08041503

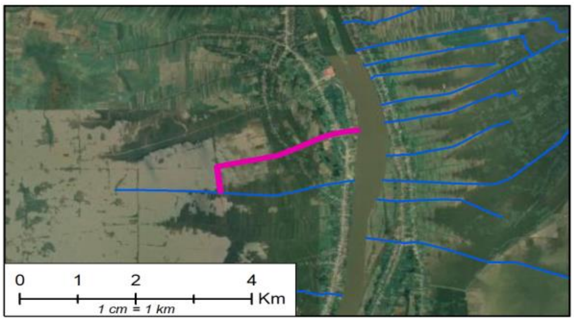


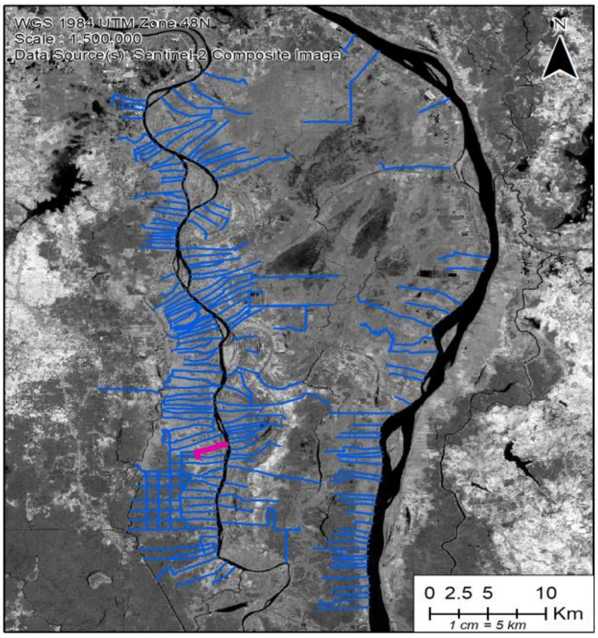


CHANNEL DIMENSIONS	
Channel Length	4.7 km
Channel Width	10 m
Inlet Bed Level	0.25 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041503
CISIS Area (ha)	278.5



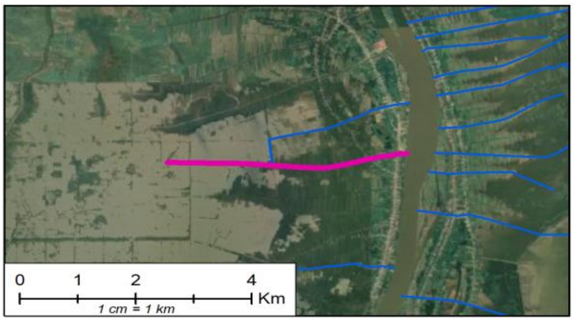
WAT4CAM	PREK PUT	WB61/08041498

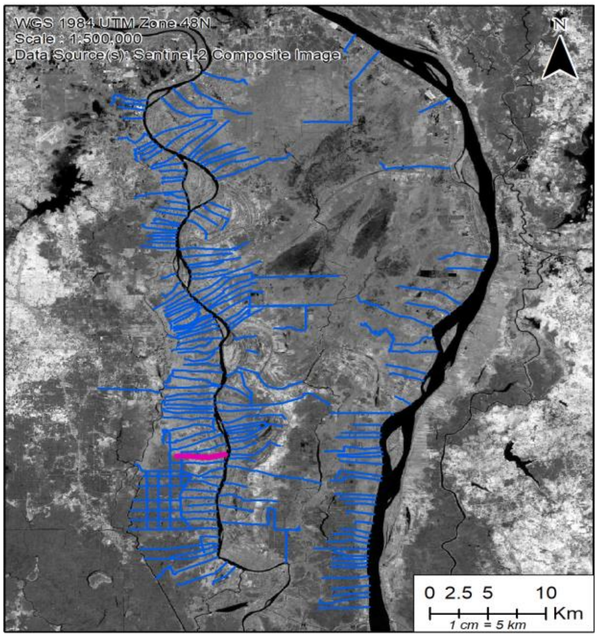




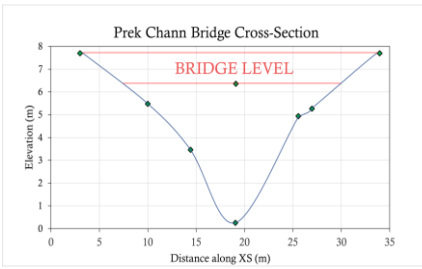
CHANNEL DIMENSIONS	
Channel Length	3.1 km
Channel Width	6 m
Inlet Bed Level	3.90 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041498
CISIS Area (ha)	236.0

WAT4CAM	PREK CHANN	WB62/08041497

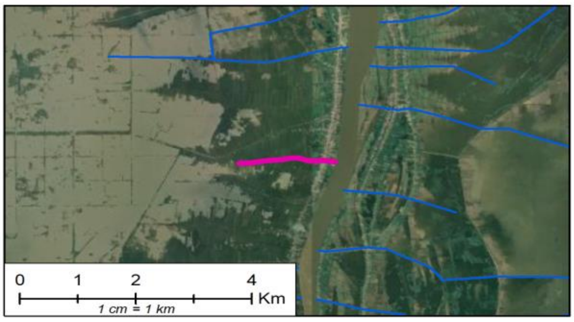


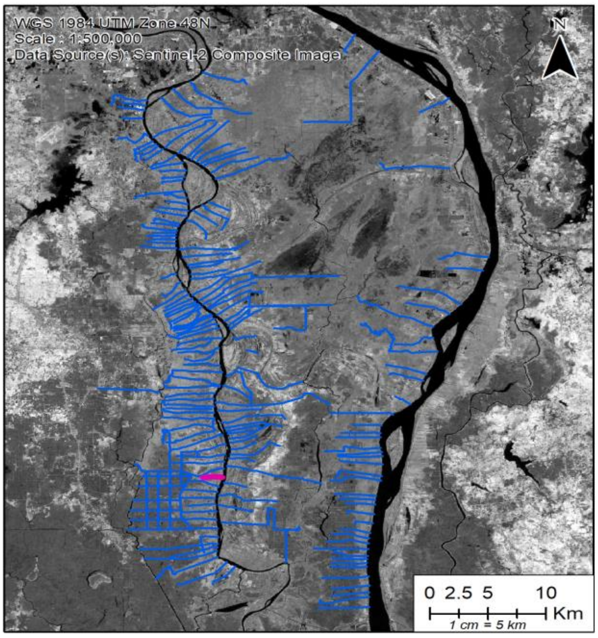


CHANNEL DIMENSIONS	
Channel Length	4.2 km
Channel Width	12 m
Inlet Bed Level	0.25 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041497
CISIS Area (ha)	247.3

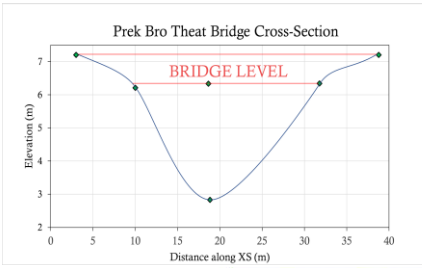


WAT4CAM	PREK BRO THEAT	WB65/08041494

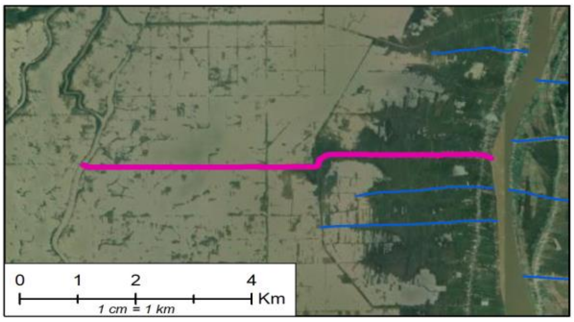


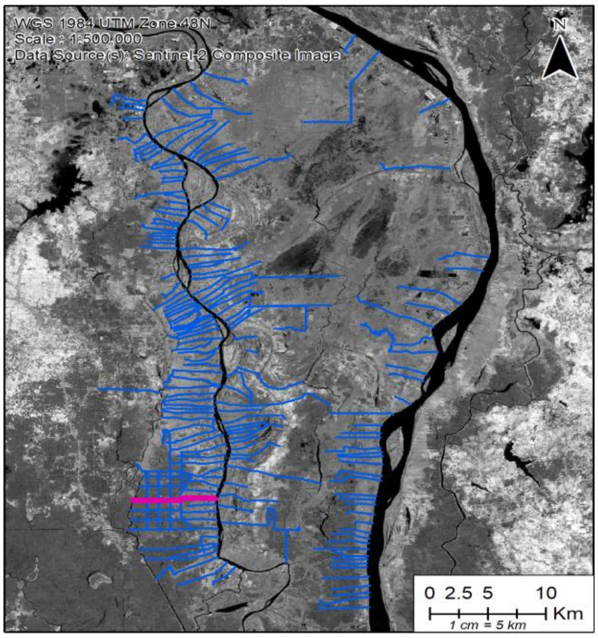


CHANNEL DIMENSIONS	
Channel Length	1.7 km
Channel Width	8 m
Inlet Bed Level	2.83 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041494
CISIS Area (ha)	131.4

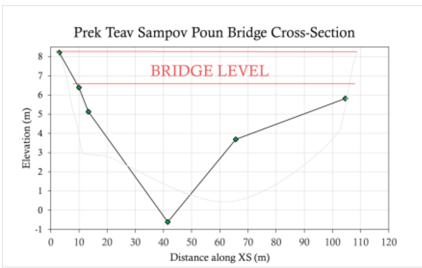


WAT4CAM	PREK TEAV SAMPOV POUN	WB68/08041488

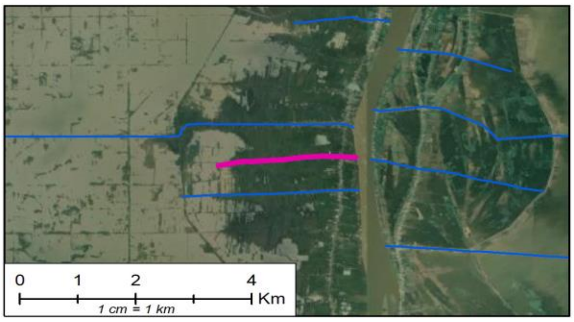


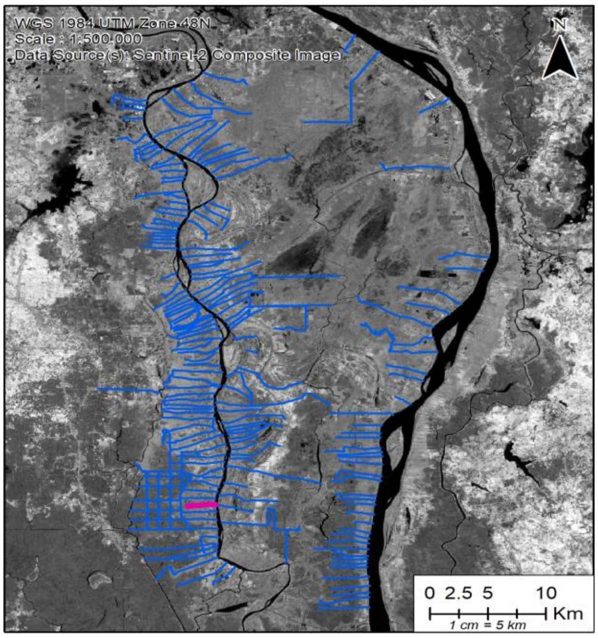


CHANNEL DIMENSIONS	
Channel Length	7.2 km
Channel Width	33 m
Inlet Bed Level	-0.61 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041488
CISIS Area (ha)	192.2

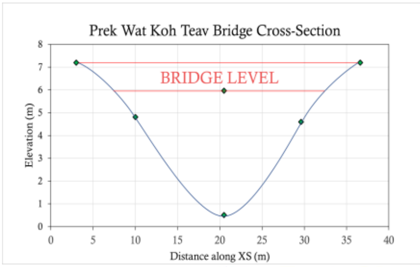


WAT4CAM	PREK WAT KOH TEAV	WB69/08041506

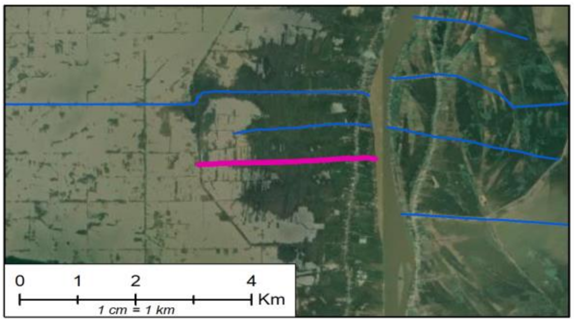


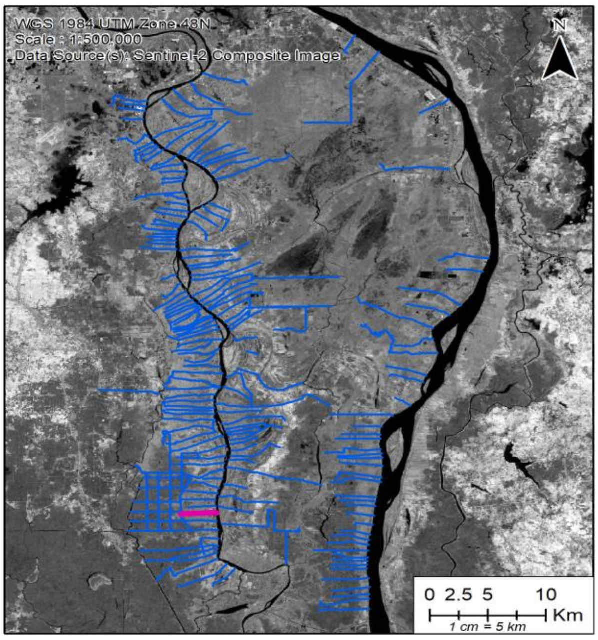


CHANNEL DIMENSIONS	
Channel Length	2.4 km
Channel Width	13 m
Inlet Bed Level	0.51 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041506
CISIS Area (ha)	131.1

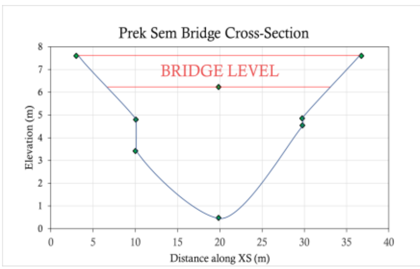


WAT4CAM	PREK SEM	WB70/08041486

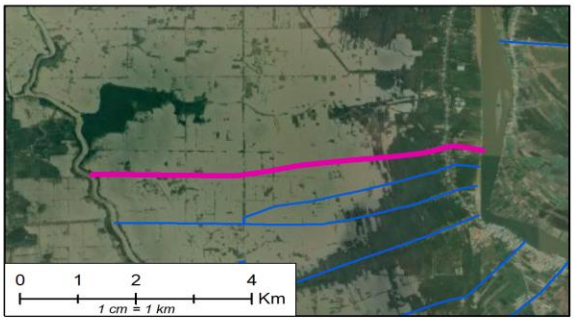


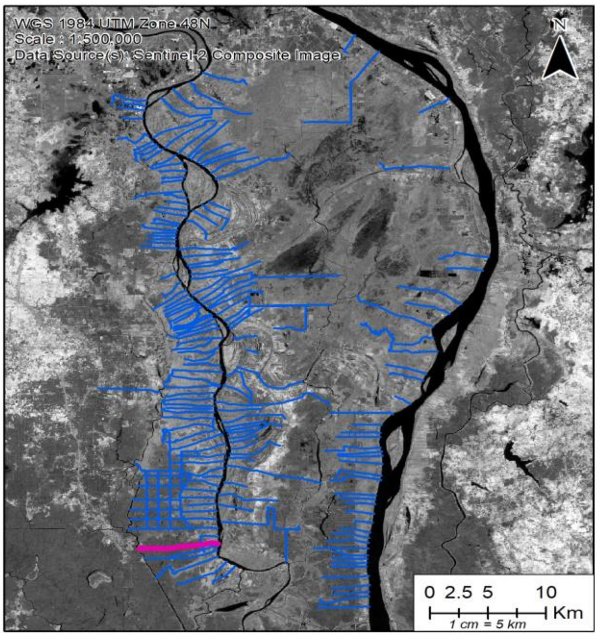


CHANNEL DIMENSIONS	
Channel Length	3.0 km
Channel Width	12 m
Inlet Bed Level	0.48 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041486
CISIS Area (ha)	140.7

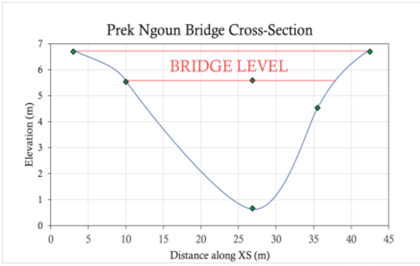


WAT4CAM	PREK NGOUN	WB73/08041587

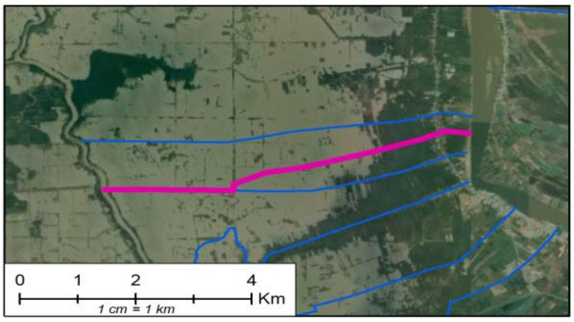


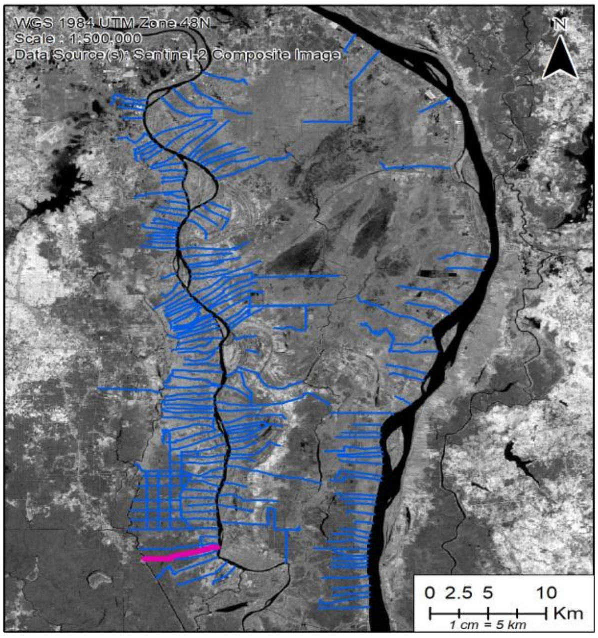


CHANNEL DIMENSIONS	
Channel Length	6.8 km
Channel Width	10 m
Inlet Bed Level	0.67 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041587
CISIS Area (ha)	238.9

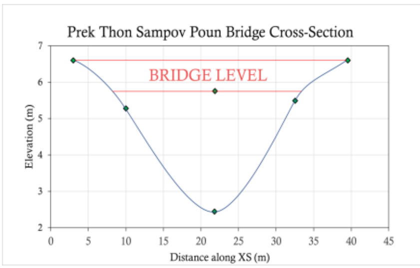


WAT4CAM	PREK THON SAMPOV POUN	WB74/08041586

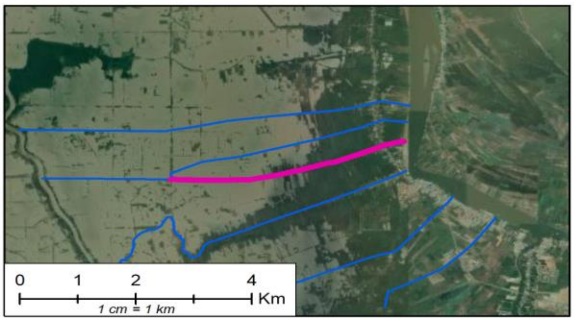


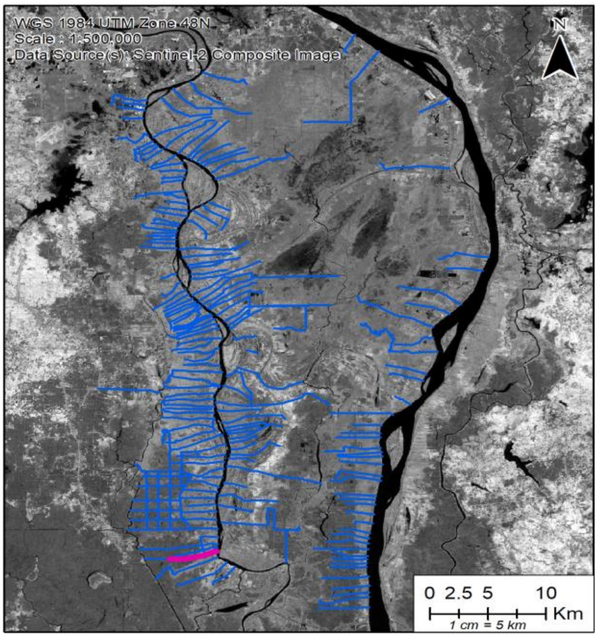


CHANNEL DIMENSIONS	
Channel Length	6.6 km
Channel Width	13 m
Inlet Bed Level	2.45 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041586
CISIS Area (ha)	160.6

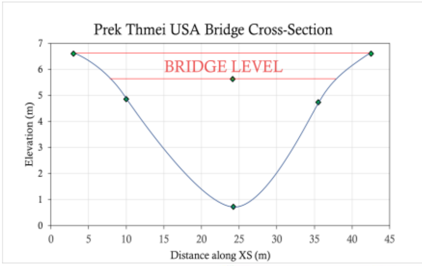


WAT4CAM | PREK THMEI USA | WB75/08041585

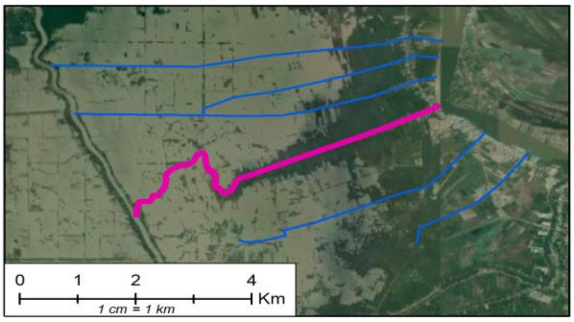


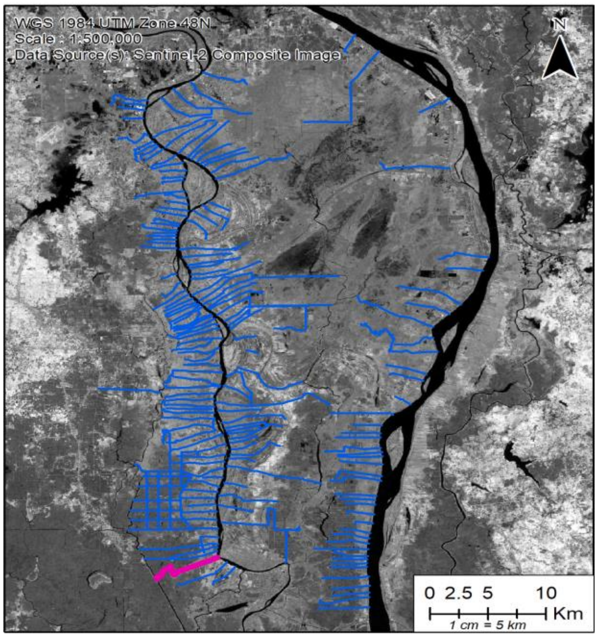


CHANNEL DIMENSIONS	
Channel Length	4.2 km
Channel Width	10 m
Inlet Bed Level	0.73 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041585
CISIS Area (ha)	226.6

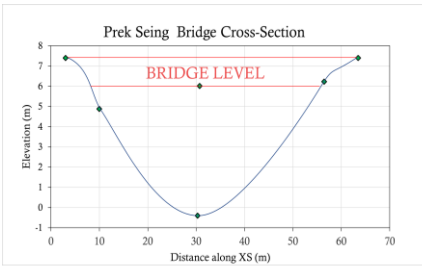


WAT4CAM | PREK SEING | WB76/08041584

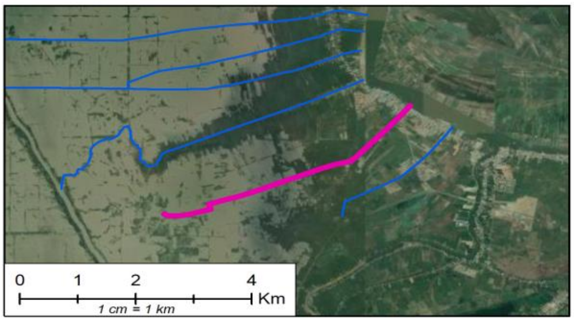


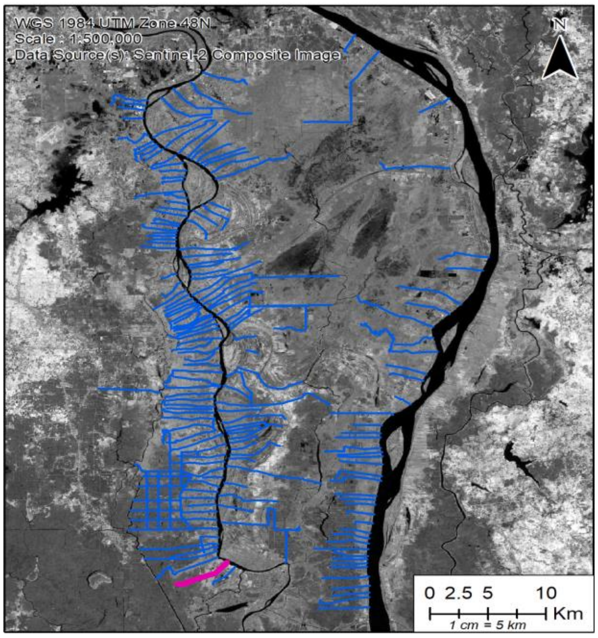


CHANNEL DIMENSIONS	
Channel Length	7.2 km
Channel Width	20 m
Inlet Bed Level	-0.40 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041584
CISIS Area (ha)	230.4

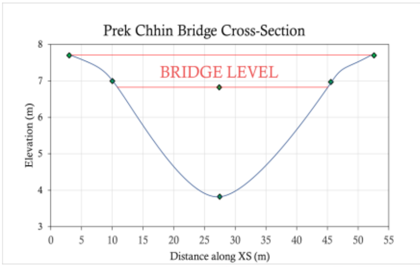


WAT4CAM	PREK CHHIN	WB77/08041583

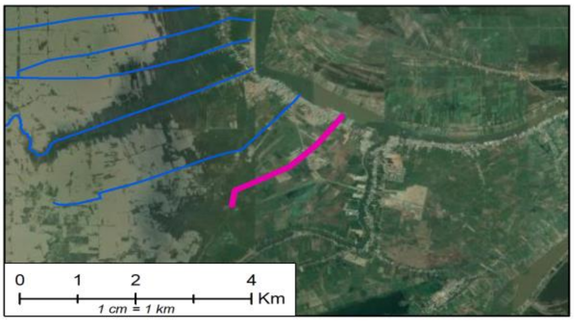


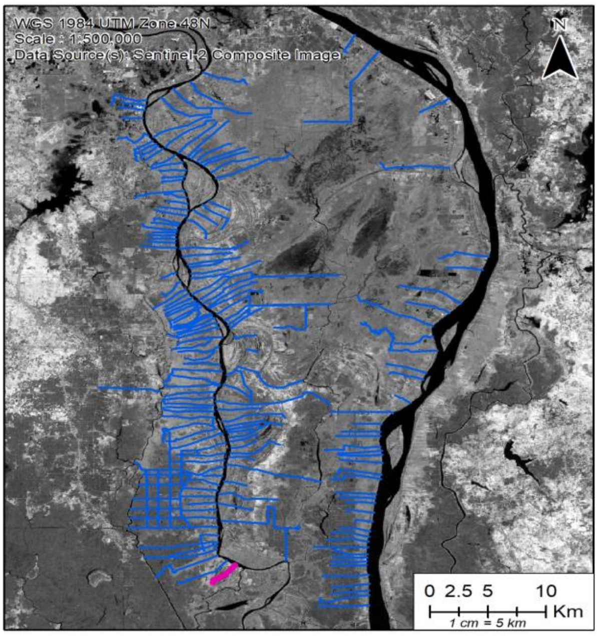


CHANNEL DIMENSIONS	
Channel Length	5.1 km
Channel Width	8 m
Inlet Bed Level	3.82 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041583
CISIS Area (ha)	123.5

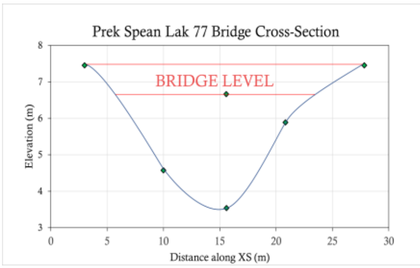


WAT4CAM	PREK SPEAN LAK 77	WB78/



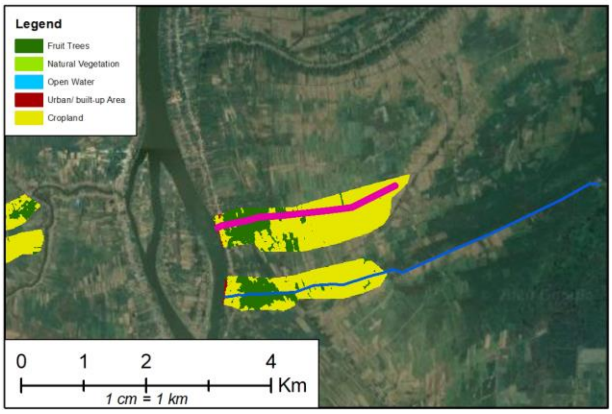


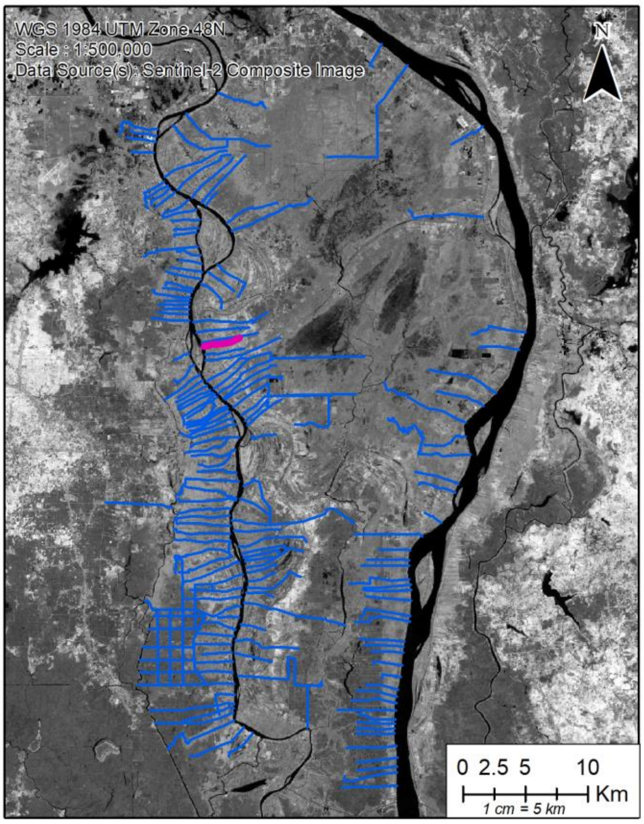
CHANNEL DIMENSIONS	
Channel Length	2.8 km
Channel Width	18 m
Inlet Bed Level	3.54 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0



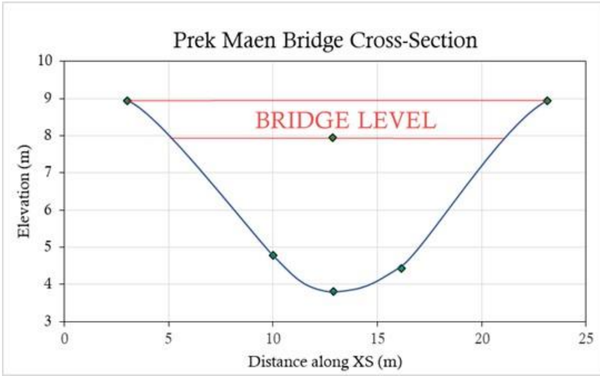
East Bassac Phase 1

WAT4CAM	PREK MAEN	EB22 / 08041600



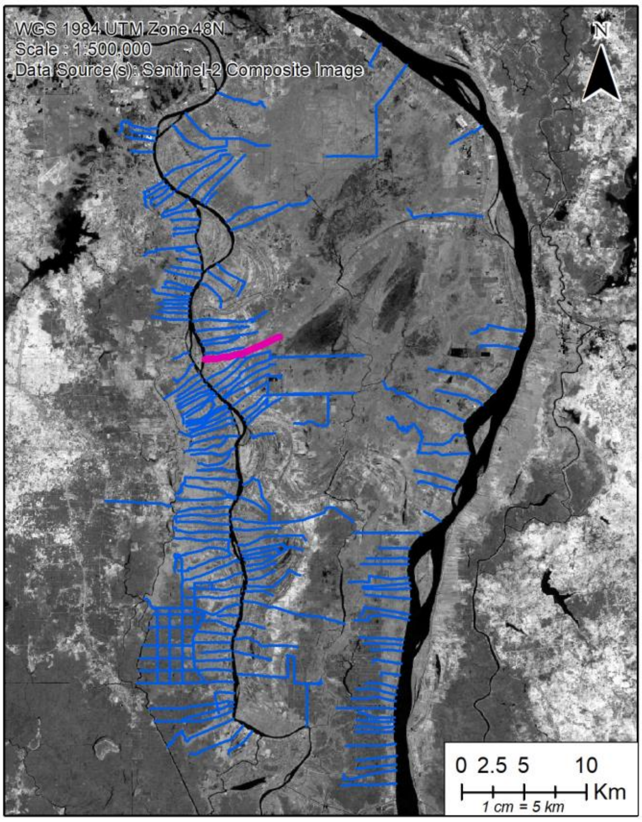


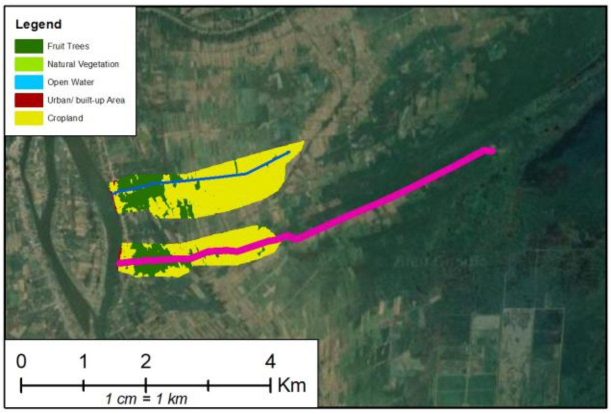
PREK MAEN	EB22
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041600
CISIS Area (ha)	180.6
Total Area (CISIS GIS)	199.9
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	4.7
Orchard Area (Ha)	51.7
Field Crop Area	146.3
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	117.2
Fallow Area (2020) Ha	24.3
Fallow Area (2019) Ha	51.5
Fallow Area (2018) Ha	6.2
Fallow Area (2017) Ha	19.0
Fallow Area (2017) Ha	44.5
Average Fallow (Ha)	29.1



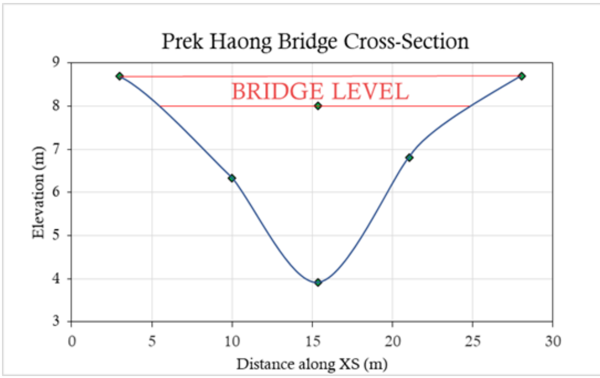
CHANNEL DIMENSIONS	
Channel Length	2.9 km
Channel Width	14 m
Inlet Bed Level	3.82 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	9.6 (m^3/s)
Av ETA(mm) in January (m3/s)	113.5 mm (0.085 m^3/s)
ETA (Feb)	94.6 mm (0.071 m^3/s)
ETA (March)	96.7 mm (0.072 m^3/s
ETA (April)	100.7 mm (0.075 m^3/s)

WAT4CAM	PREK HAONG	WG24/08041581





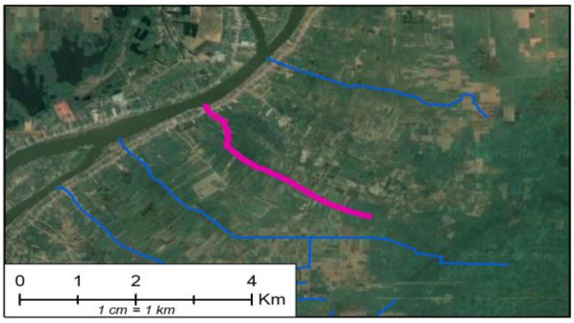
PREK HAONG	WG24
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041581
CISIS Area (ha)	327.5
Total Area (CISIS GIS)	126.8
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	0.9
Orchard Area (Ha)	37.6
Field Crop Area	87.8
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	66.1
Fallow Area (2020) Ha	17.9
Fallow Area (2019) Ha	28.4
Fallow Area (2018) Ha	8.7
Fallow Area (2017) Ha	11.6
Fallow Area (2017) Ha	41.7
Average Fallow (Ha)	21.7

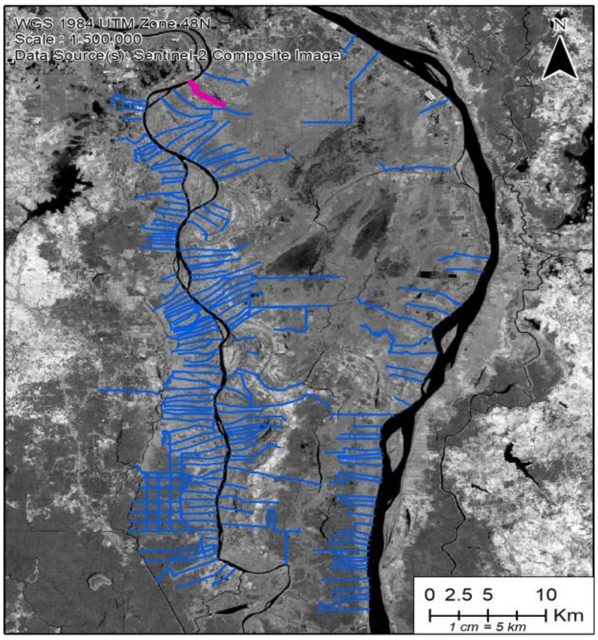


CHANNEL DIMENSIONS	
Channel Length	6.4 km
Channel Width	10 m
Inlet Bed Level	3.91 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	0.3 (m^3/s)
Av ETA(mm) in January (m3/s)	114.6 mm (0.054 m^3/s)
ETA (Feb)	90.5 mm (0.043 m^3/s)
ETA (March)	94.2 mm (0.045 m^3/s
ETA (April)	102.4 mm (0.048 m^3/s)

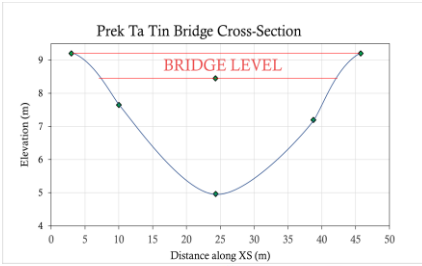
East Bassac Phase 2

WAT4CAM	PREK TA TIN	EB2 /08101529

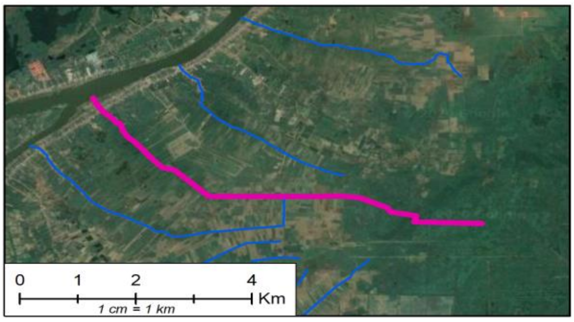


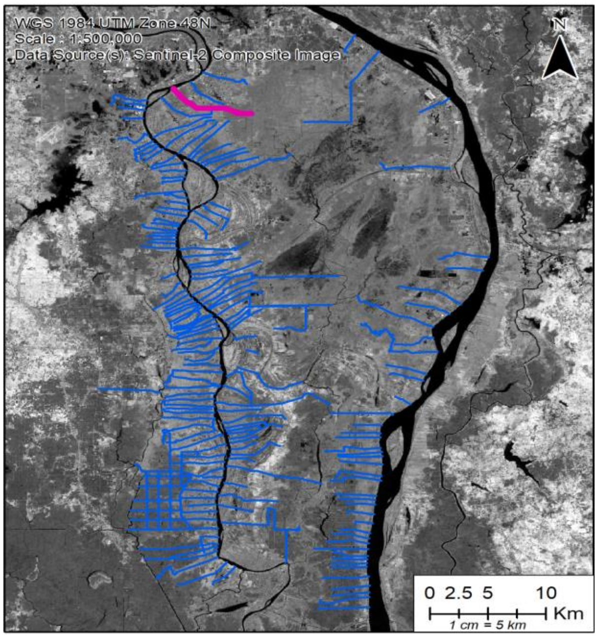


CHANNEL DIMENSIONS	
Channel Length	3.9 km
Channel Width	10 m
Inlet Bed Level	4.97 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101529
CISIS Area (ha)	459.2

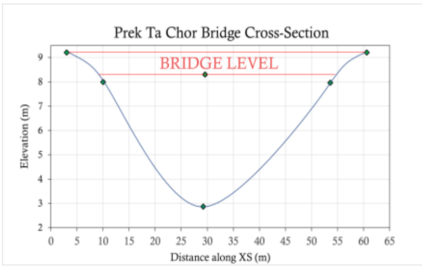


WAT4CAM	PREK TA CHOR	EB3 /08101528

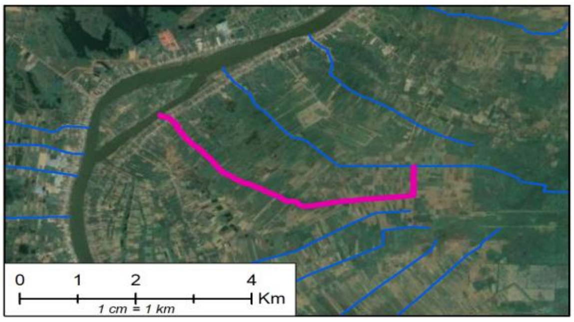


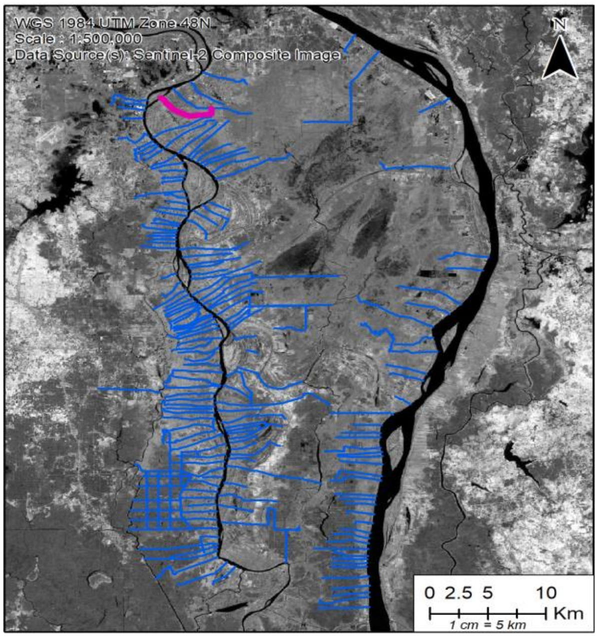


CHANNEL DIMENSIONS	
Channel Length	7.9 km
Channel Width	13 m
Inlet Bed Level	2.87 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101528
CISIS Area (ha)	1285.0

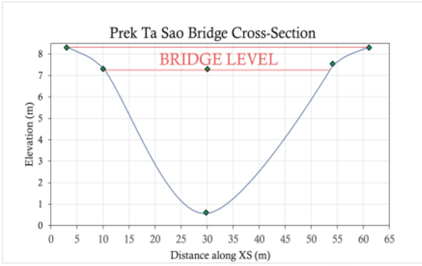


WAT4CAM	PREK TA SAO	EB4 /08101527

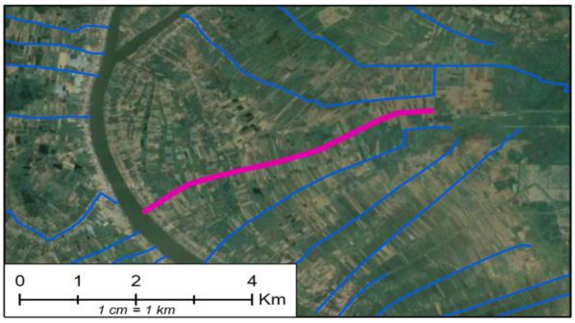


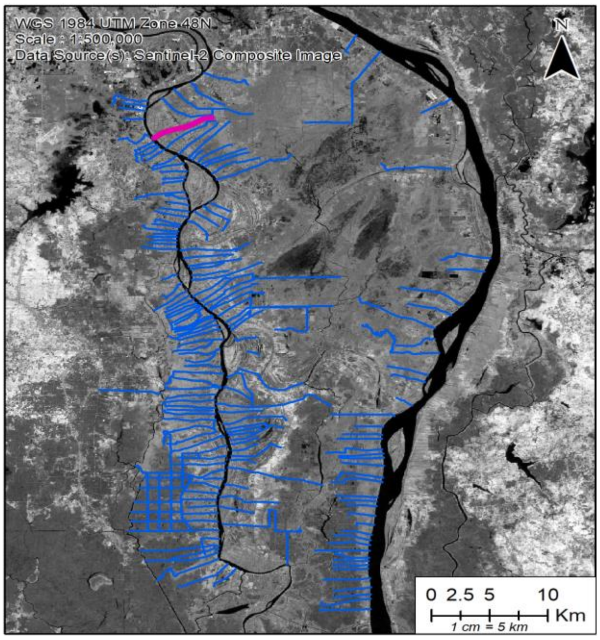


CHANNEL DIMENSIONS	
Channel Length	5.7 km
Channel Width	15 m
Inlet Bed Level	0.61 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08101527
CISIS Area (ha)	593.3

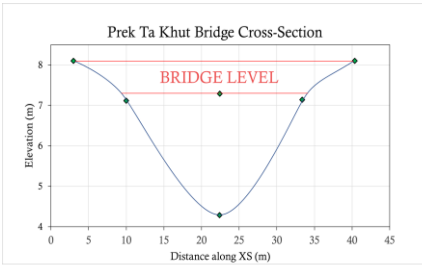


WAT4CAM	PREK TA KHUT	EB5 /08100063

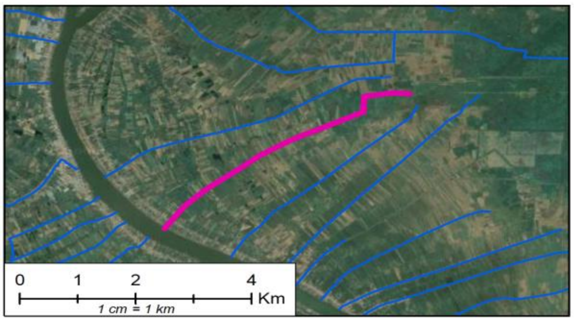


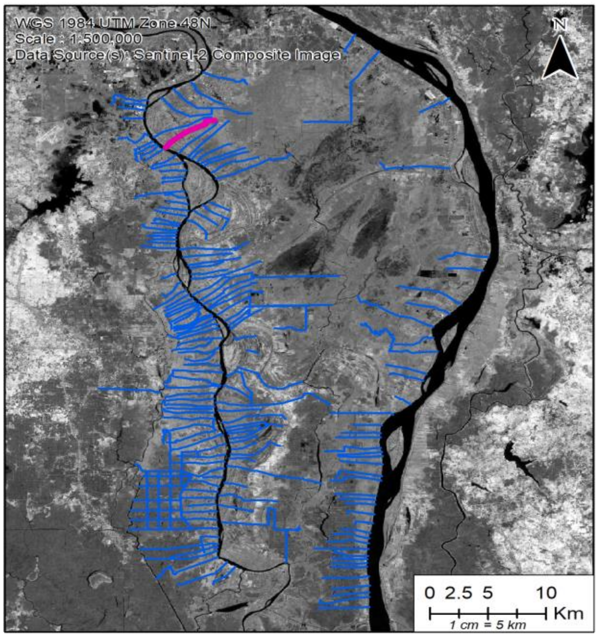


CHANNEL DIMENSIONS	
Channel Length	5.4 km
Channel Width	9 m
Inlet Bed Level	4.29 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08100063
CISIS Area (ha)	959.8

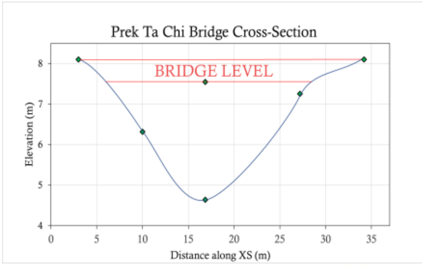


WAT4CAM	PREK TA CHI	EB6 /08101526

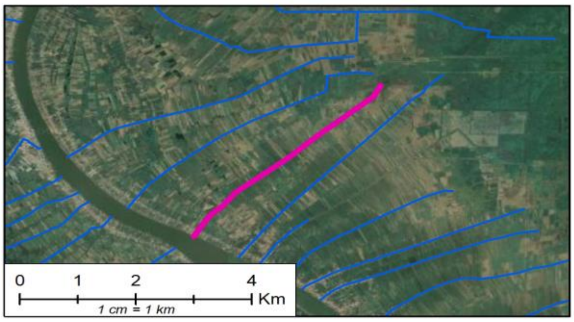


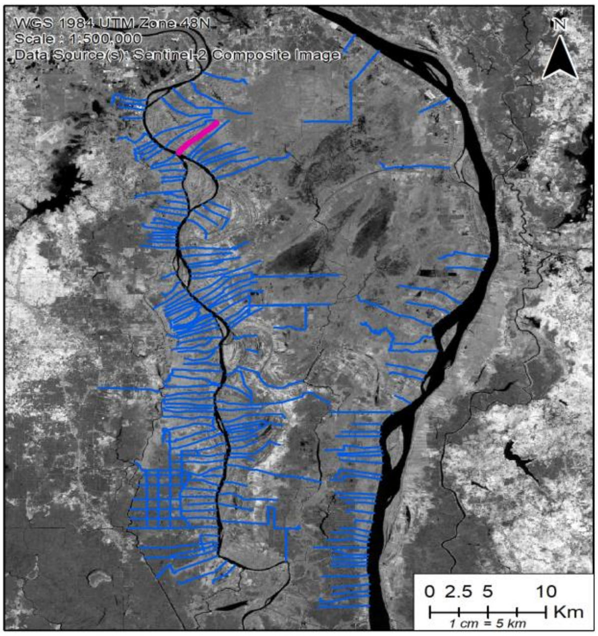


CHANNEL DIMENSIONS	
Channel Length	5.4 km
Channel Width	10 m
Inlet Bed Level	4.64 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101526
CISIS Area (ha)	359.7

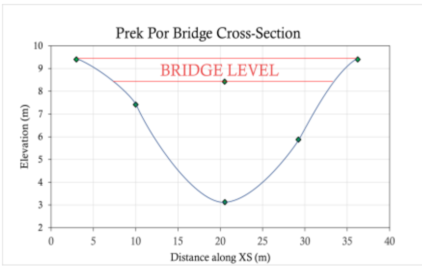


WAT4CAM	PREK POR	EB7 /08101525

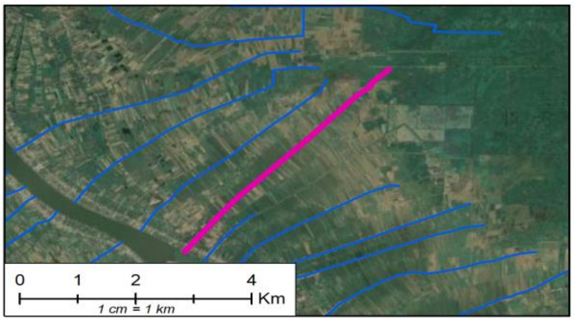


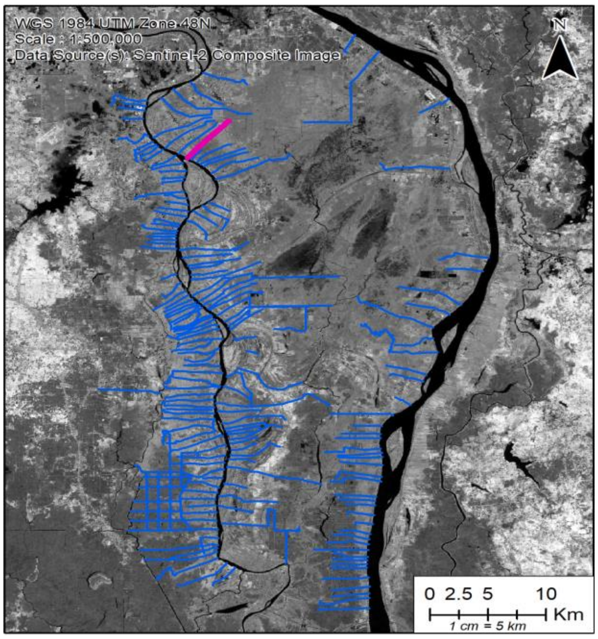


CHANNEL DIMENSIONS	
Channel Length	4.5 km
Channel Width	11 m
Inlet Bed Level	3.12 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101525
CISIS Area (ha)	332.8

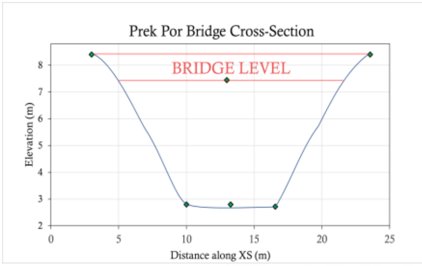


WAT4CAM	PREK YOU HEUNG	EB8 /08101524

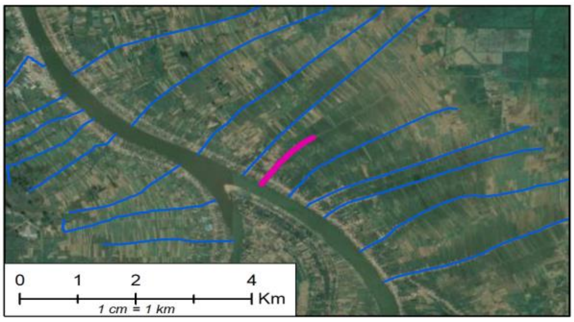


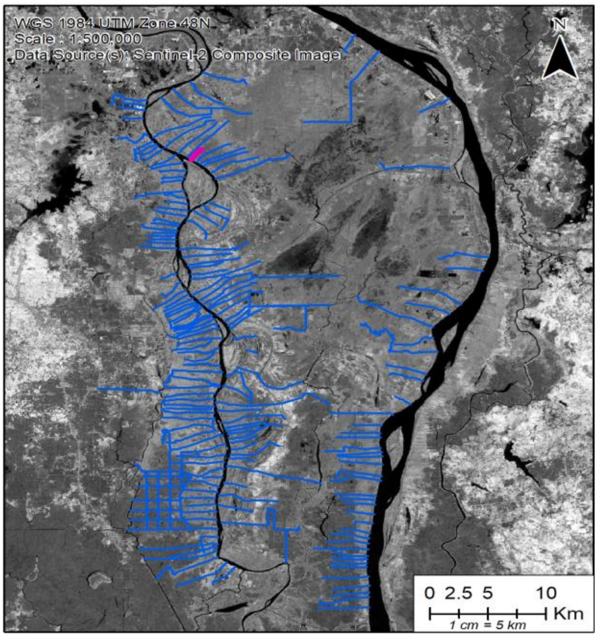


CHANNEL DIMENSIONS	
Channel Length	5.2 km
Channel Width	9 m
Inlet Bed Level	2.71 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101524
CISIS Area (ha)	294.9

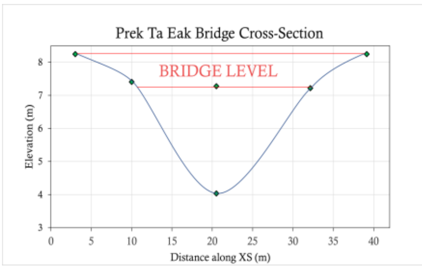


WAT4CAM	PREK TA EK	EB9 /08101523

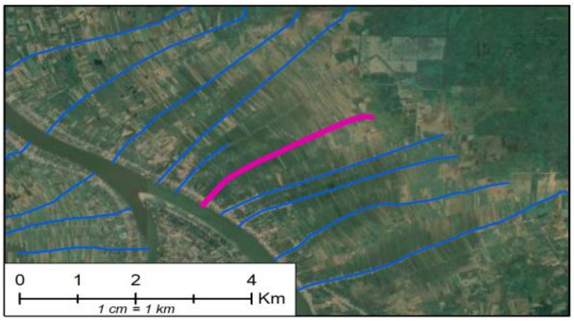


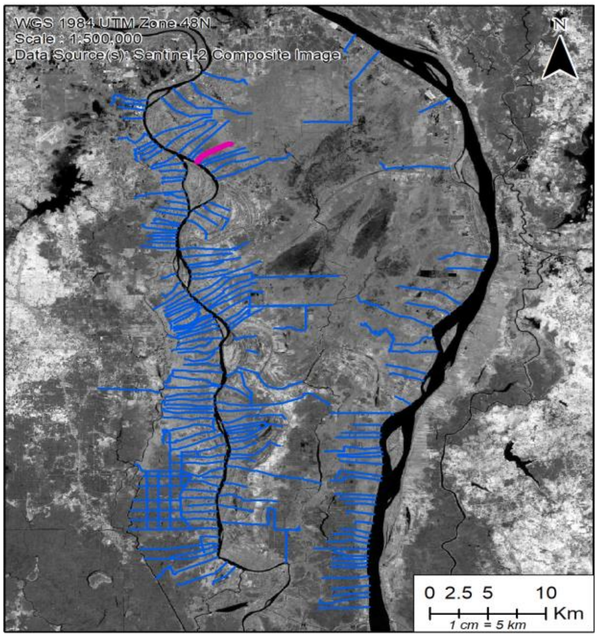


CHANNEL DIMENSIONS	
Channel Length	1.3 km
Channel Width	12 m
Inlet Bed Level	4.04 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101523
CISIS Area (ha)	214.4

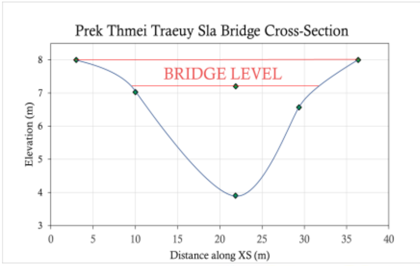


WAT4CAM	PREK THMEI TRAEUY SLA	EB10/08101522

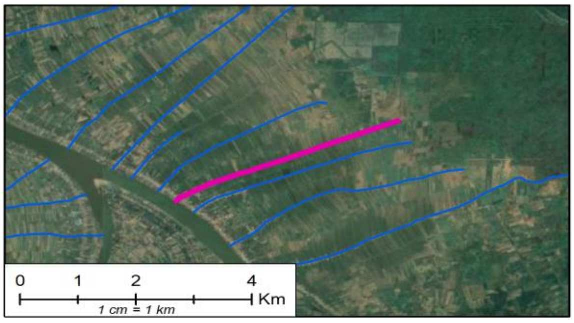


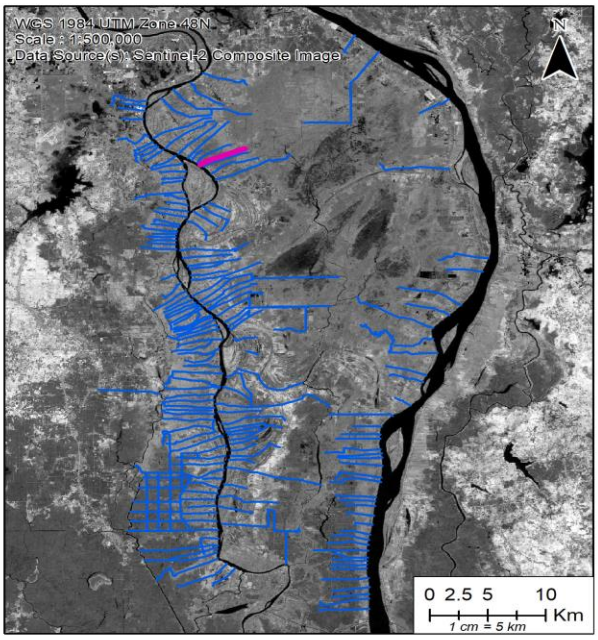


CHANNEL DIMENSIONS	
Channel Length	3.5 km
Channel Width	9 m
Inlet Bed Level	3.91 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101522
CISIS Area (ha)	283.2

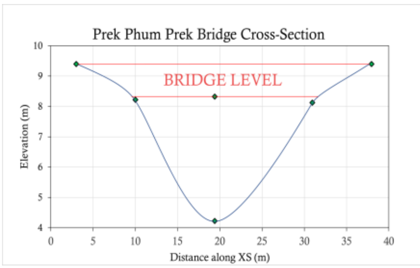


WAT4CAM	PREK PHUM PREK	EB11/08101521

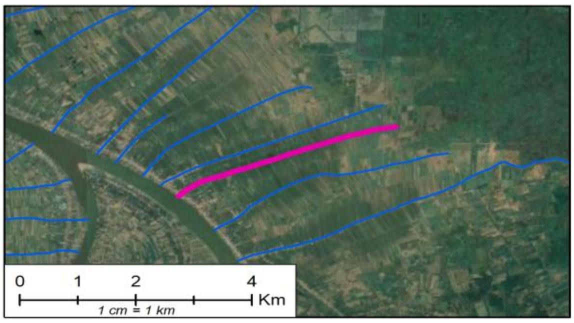


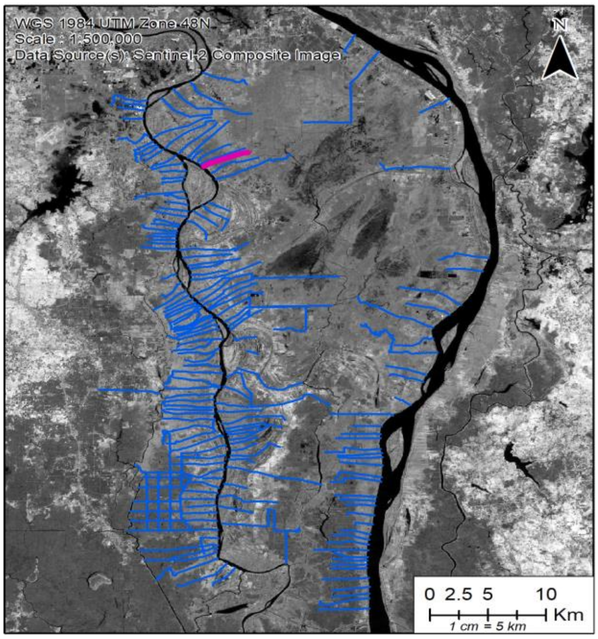


CHANNEL DIMENSIONS	
Channel Length	4.2 km
Channel Width	12 m
Inlet Bed Level	4.22 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101521
CISIS Area (ha)	196.8

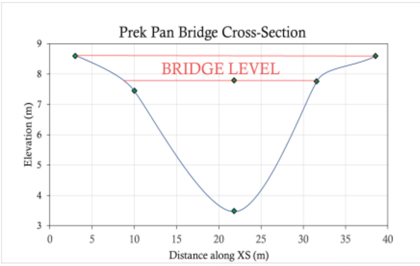


WAT4CAM	PREK PAN	EB12/08101520

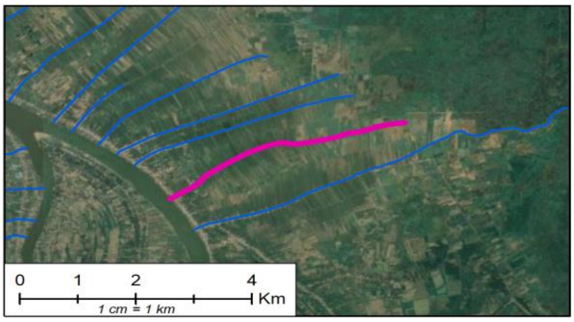


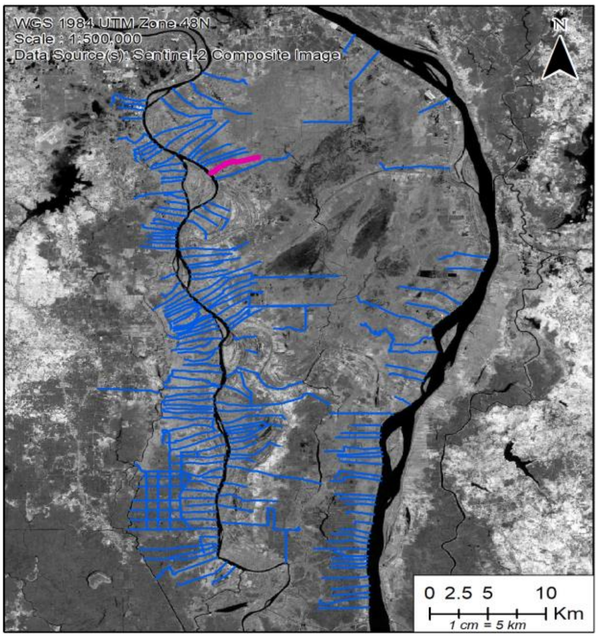


CHANNEL DIMENSIONS	
Channel Length	4.1 km
Channel Width	11 m
Inlet Bed Level	3.48 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101520
CISIS Area (ha)	207.6

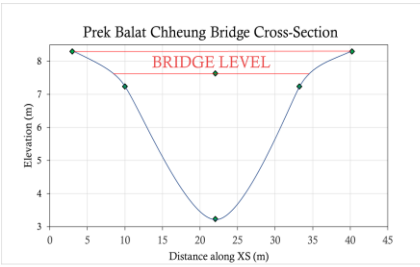


WAT4CAM	PREK BALAT CHHEUNG	EB13/08101519

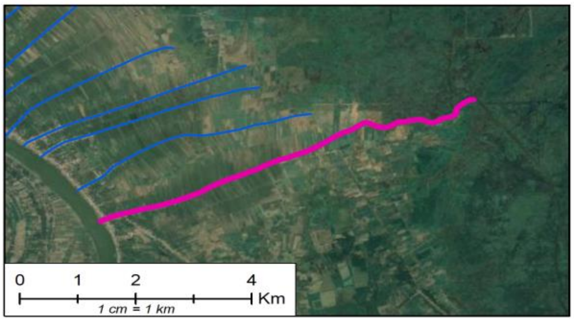


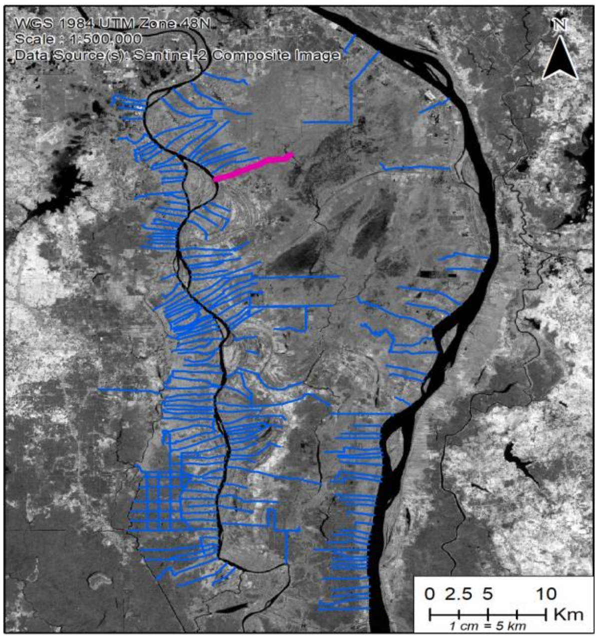


CHANNEL DIMENSIONS	
Channel Length	4.4 km
Channel Width	12 m
Inlet Bed Level	3.23 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101519
CISIS Area (ha)	315.6

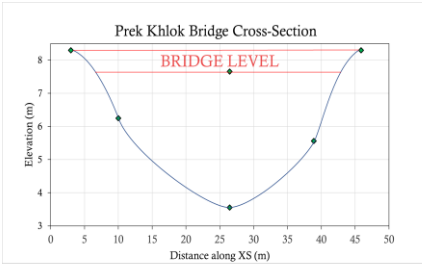


WAT4CAM	PREK KHLOK	EB14/08101518

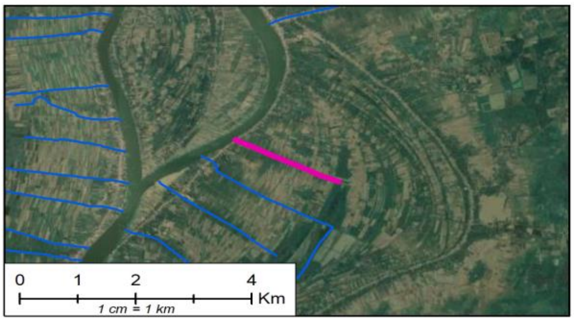


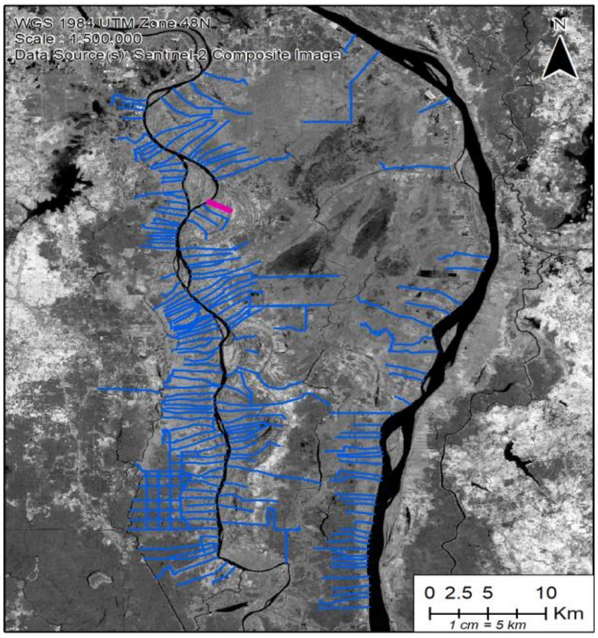


CHANNEL DIMENSIONS	
Channel Length	7.2 km
Channel Width	19 m
Inlet Bed Level	3.55 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101518
CISIS Area (ha)	388.8

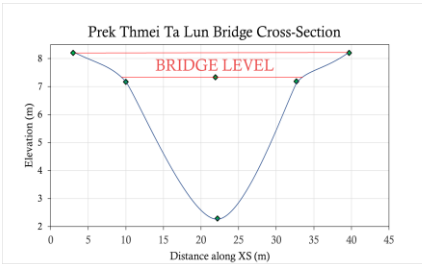


WAT4CAM	PREK THMEI TA LUN	EB15/08101517

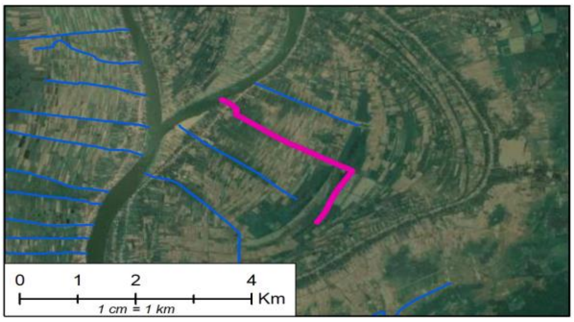


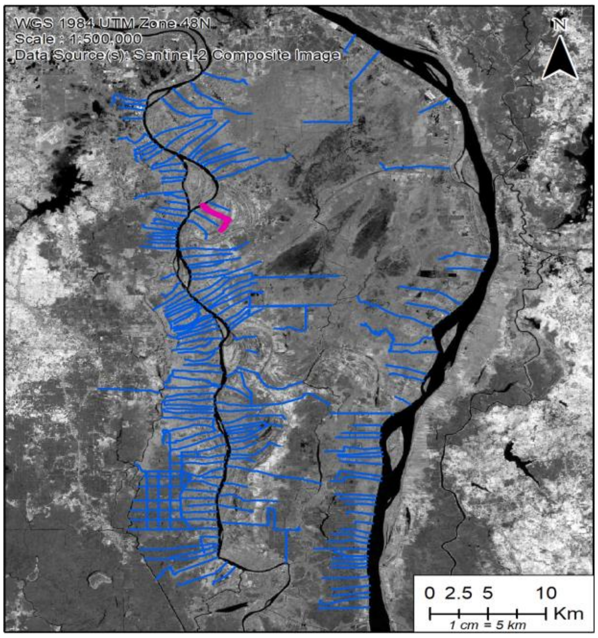


CHANNEL DIMENSIONS	
Channel Length	2.0 km
Channel Width	10 m
Inlet Bed Level	2.28 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101517
CISIS Area (ha)	196.8

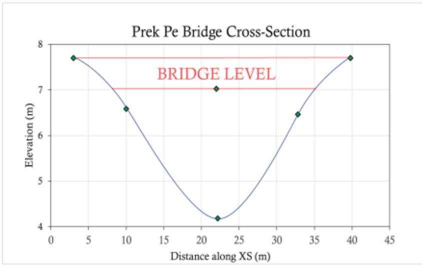


WAT4CAM	PREK PHE	EB16/08101516

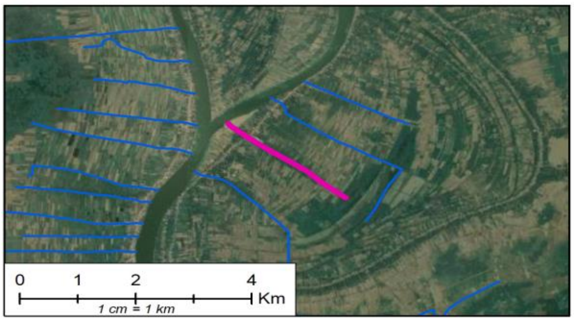


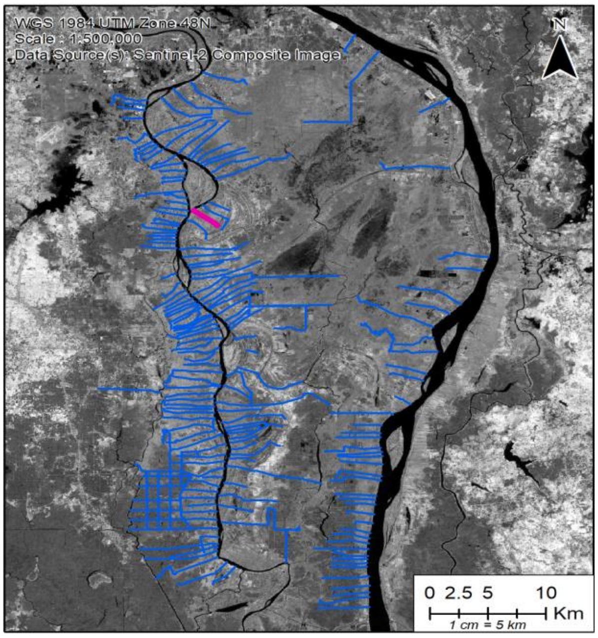


CHANNEL DIMENSIONS	
Channel Length	4.0 km
Channel Width	16 m
Inlet Bed Level	4.18 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101516
CISIS Area (ha)	804.1

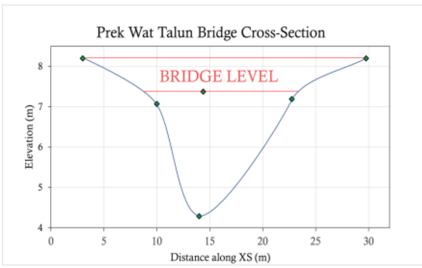


WAT4CAM	PREK WAT TALUN	EB17/08101481

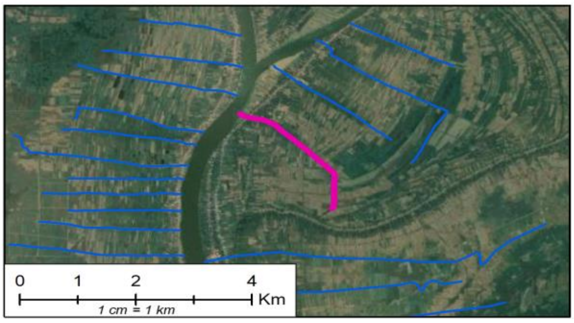


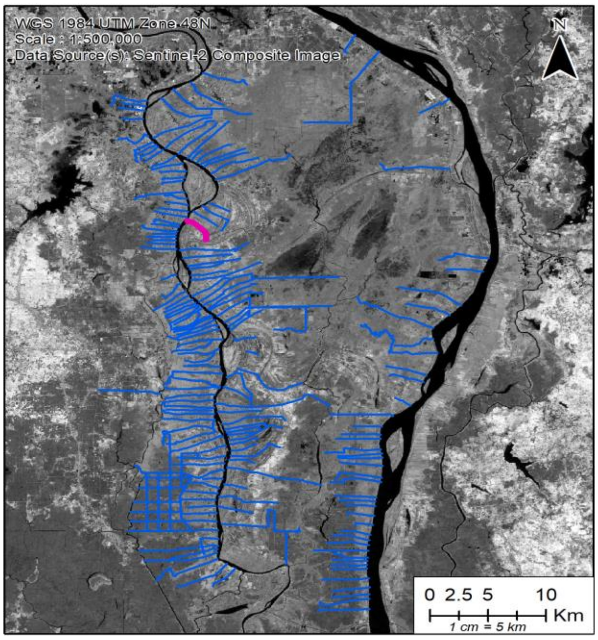


CHANNEL DIMENSIONS	
Channel Length	2.5 km
Channel Width	8 m
Inlet Bed Level	4.29 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101481
CISIS Area (ha)	789.6

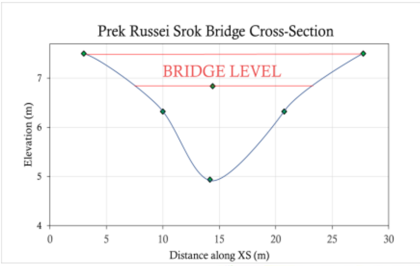


WAT4CAM	PREK RUSSEI SROK	EB18/08101479

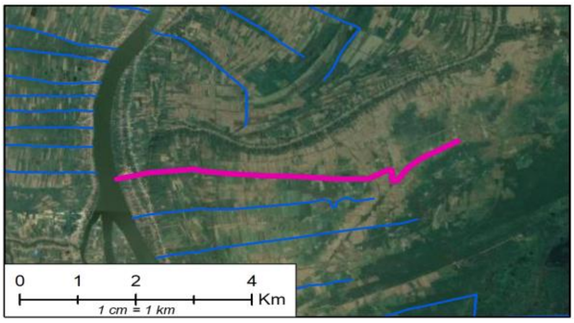


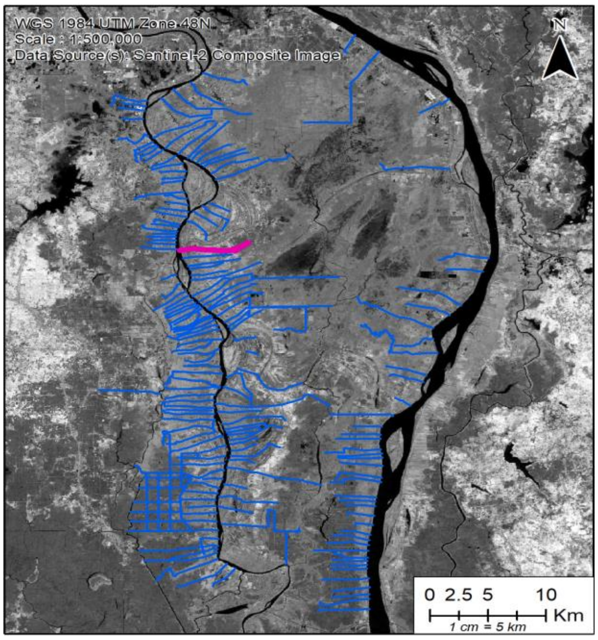


CHANNEL DIMENSIONS	
Channel Length	2.8 km
Channel Width	8 m
Inlet Bed Level	4.94 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101479
CISIS Area (ha)	801.7

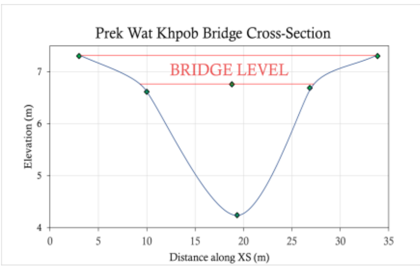


WAT4CAM	PREK WAT KHPOB	EB19/08101483

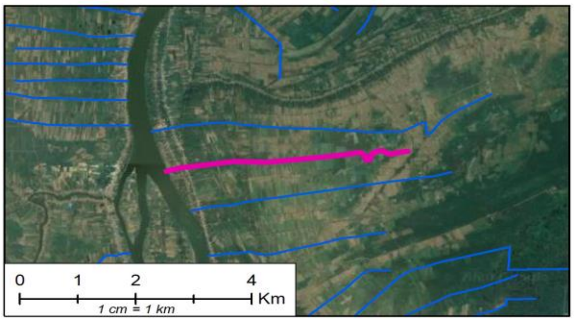


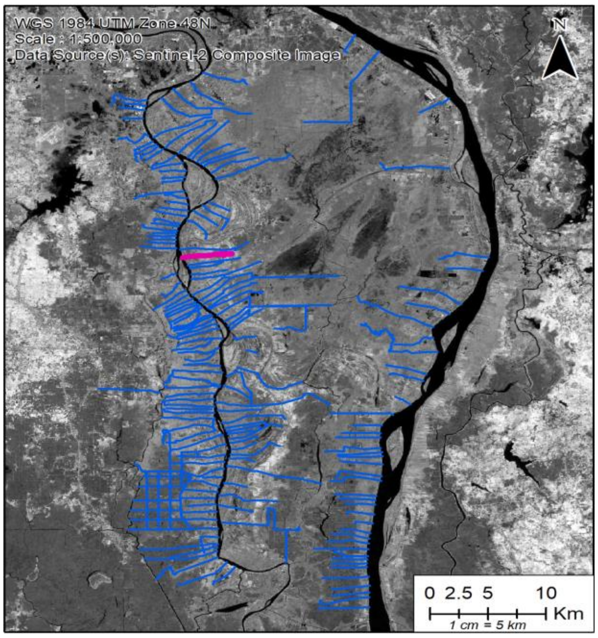


CHANNEL DIMENSIONS	
Channel Length	6.5 km
Channel Width	8 m
Inlet Bed Level	4.24 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101483
CISIS Area (ha)	423.0

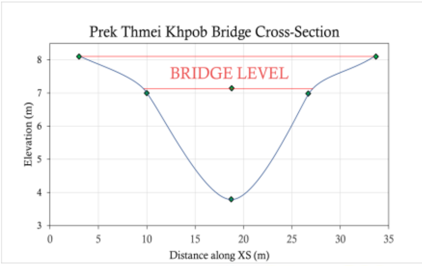


WAT4CAM	PREK THMEI KHPOB	EB20/08101476

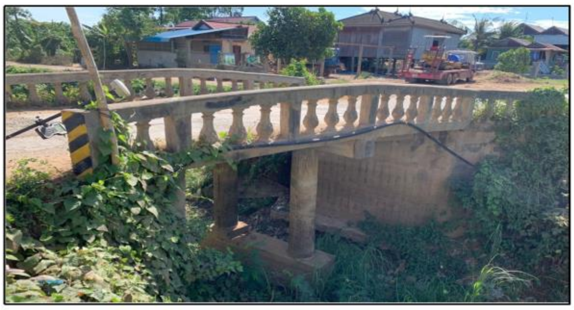


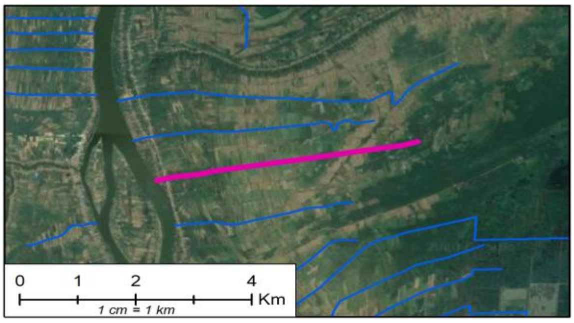


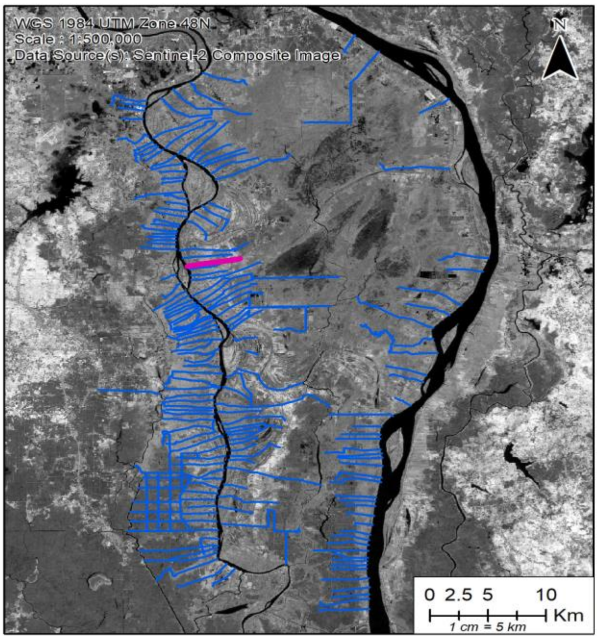
CHANNEL DIMENSIONS	
Channel Length	4.4 km
Channel Width	12 m
Inlet Bed Level	3.80 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08101476
CISIS Area (ha)	267.3



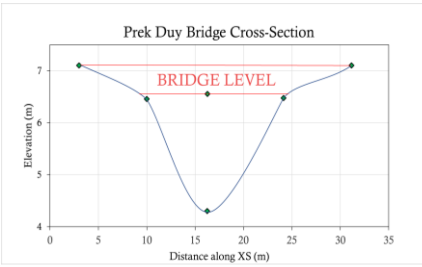
WAT4CAM	PREK DUY	EB21/08041582



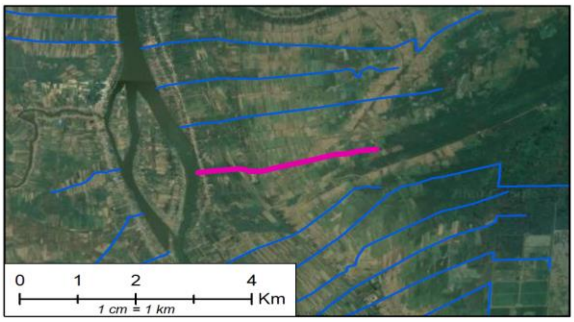


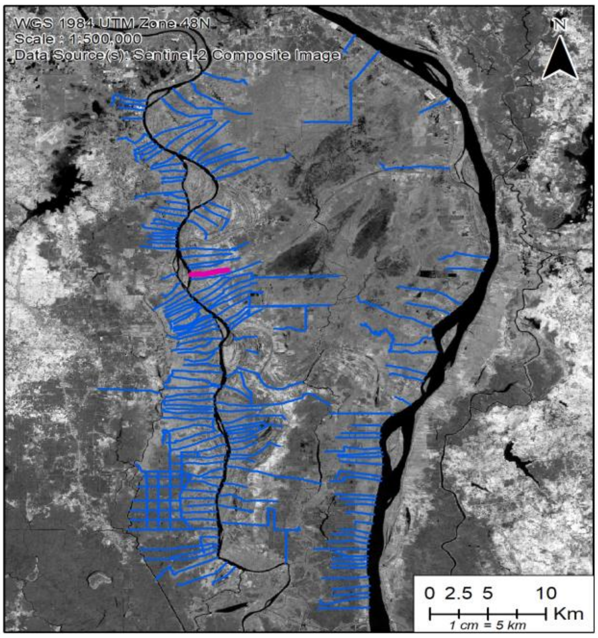


CHANNEL DIMENSIONS	
Channel Length	4.6 km
Channel Width	9 m
Inlet Bed Level	4.30 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041582
CISIS Area (ha)	205.3



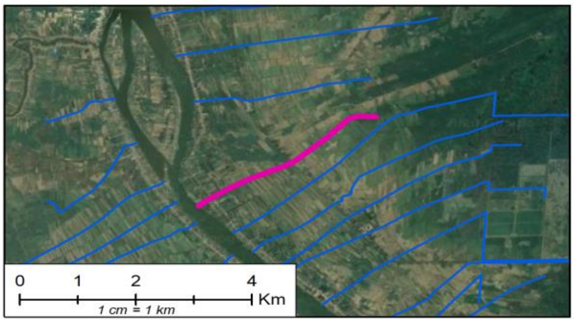
WAT4CAM	PREK KDEY TALANG	EB23/

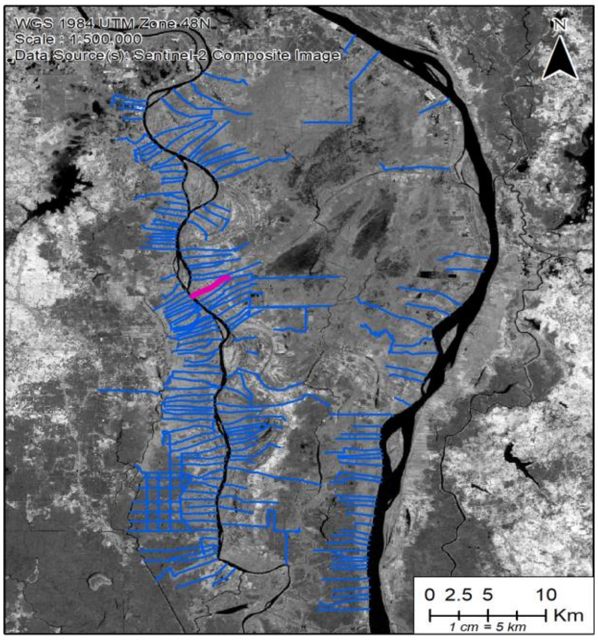




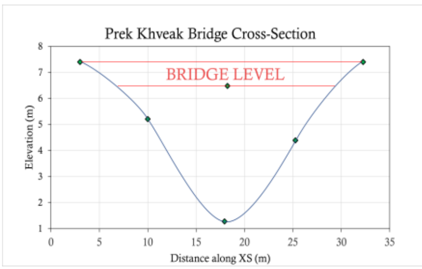
CHANNEL DIMENSIONS	
Channel Length	3.1 km
Channel Width	10 m
Inlet Bed Level	3.63 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0

WAT4CAM	PREK KHVEAK	EB25/08041515

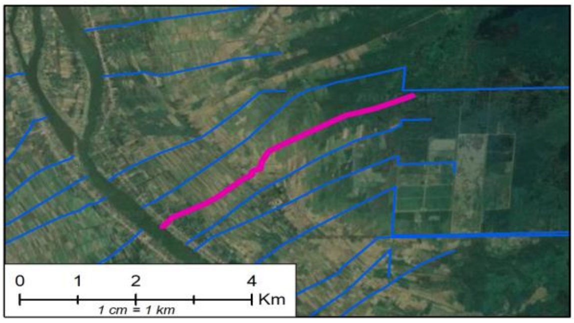


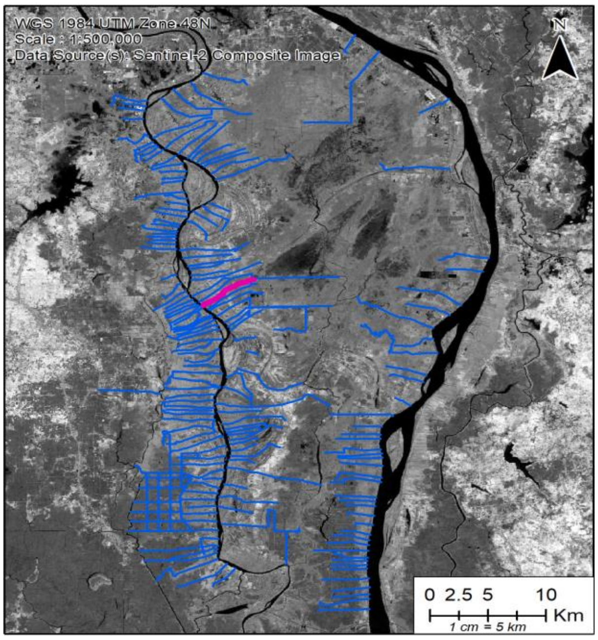


CHANNEL DIMENSIONS	
Channel Length	3.7 km
Channel Width	12 m
Inlet Bed Level	1.28 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041515
CISIS Area (ha)	225.3

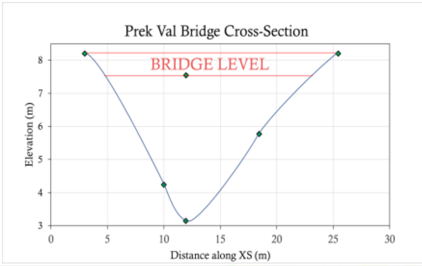


WAT4CAM	PREK VAL	EB27/08041579

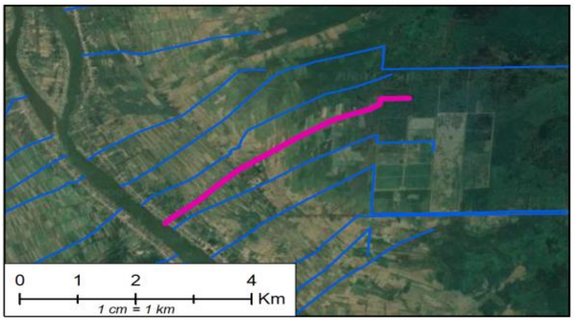


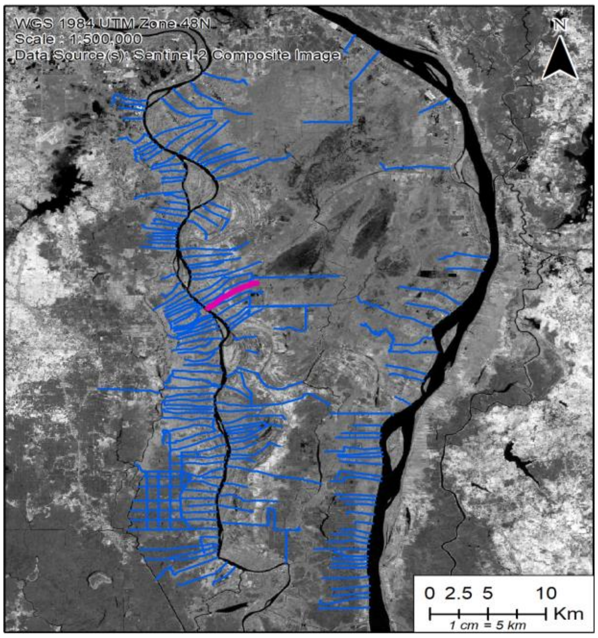


CHANNEL DIMENSIONS	
Channel Length	5.2 km
Channel Width	7 m
Inlet Bed Level	3.14 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041579
CISIS Area (ha)	204.0



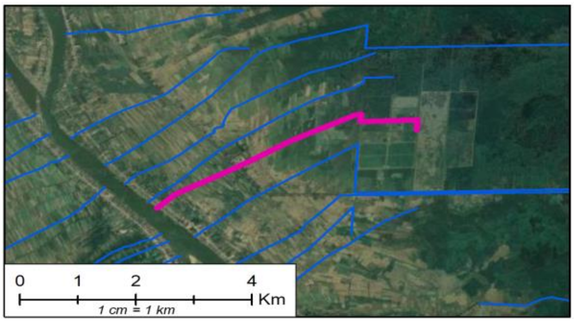
WAT4CAM	PREK TA INN	EB28/08041601

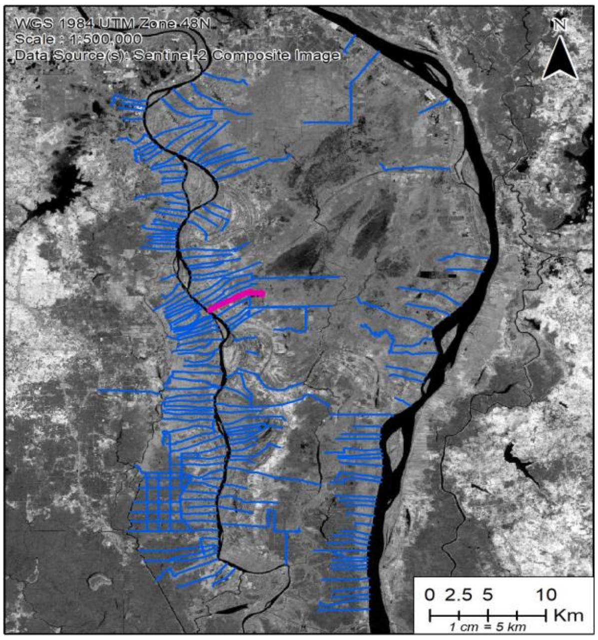




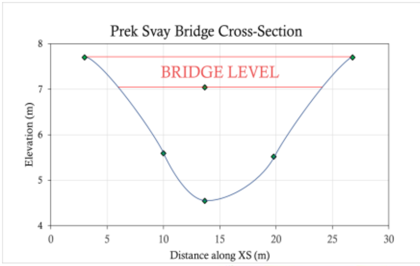
CHANNEL DIMENSIONS	
Channel Length	5.1 km
Channel Width	12 m
Inlet Bed Level	1.57 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041601
CISIS Area (ha)	206.1

WAT4CAM | PREK SVAY | EB29/08041602

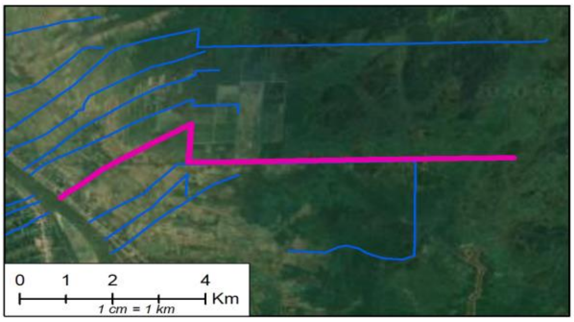


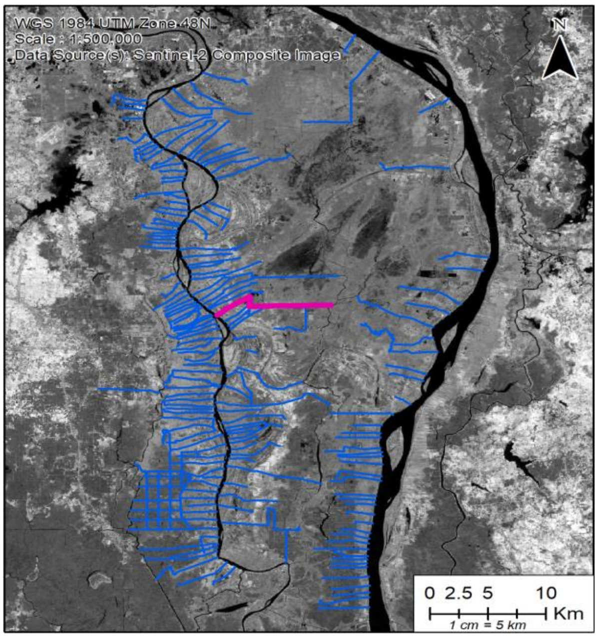


CHANNEL DIMENSIONS	
Channel Length	5.4 km
Channel Width	11 m
Inlet Bed Level	4.55 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041602
CISIS Area (ha)	138.9

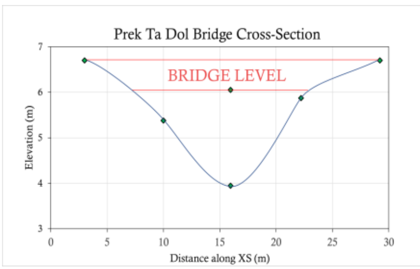


WAT4CAM | PREK TA DOL | EB30/08041545

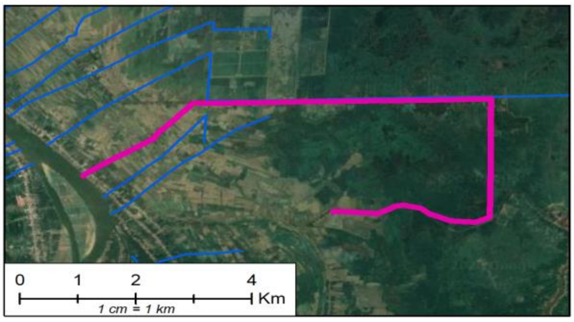


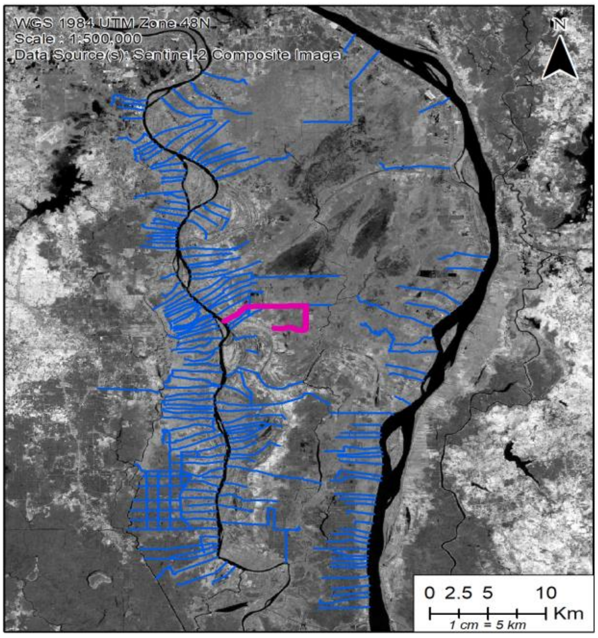


CHANNEL DIMENSIONS	
Channel Length	11.4 km
Channel Width	11 m
Inlet Bed Level	3.94 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041545
CISIS Area (ha)	42.1

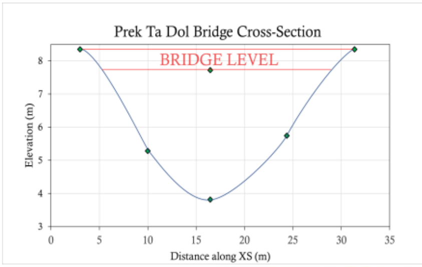


WAT4CAM	PREK TA ROT	EB31/08041546

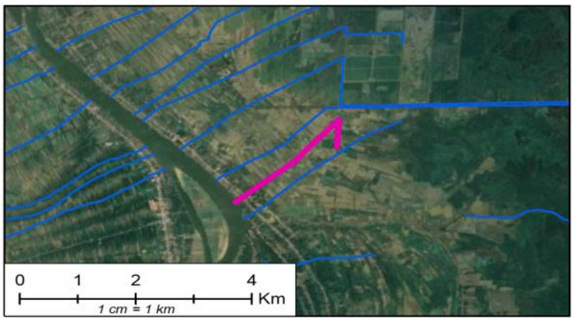


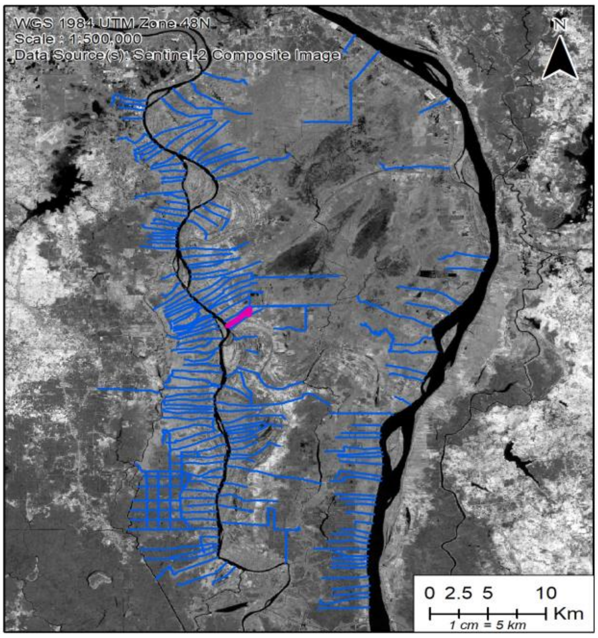


CHANNEL DIMENSIONS	
Channel Length	12.9 km
Channel Width	10 m
Inlet Bed Level	3.82 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041546
CISIS Area (ha)	3641.7

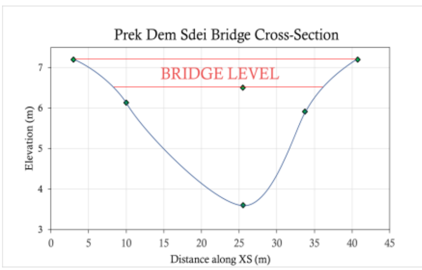


WAT4CAM	PREK DEM SDEI	EB32/08041547

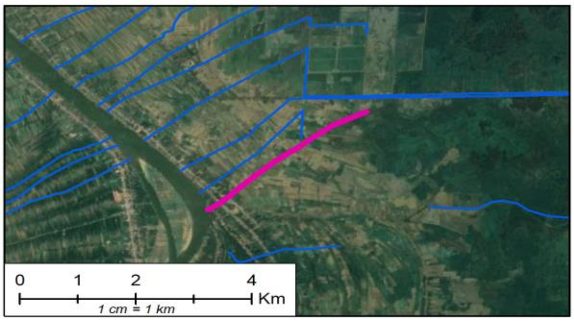


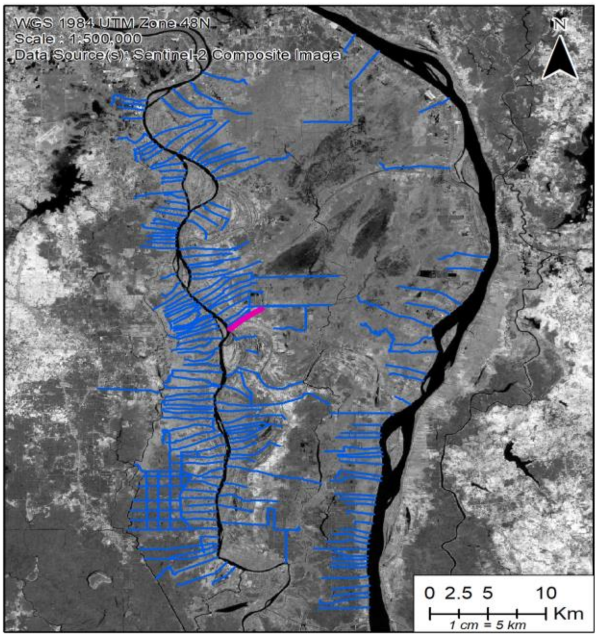


CHANNEL DIMENSIONS	
Channel Length	3.0 km
Channel Width	7 m
Inlet Bed Level	3.60 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041547
CISIS Area (ha)	159.0

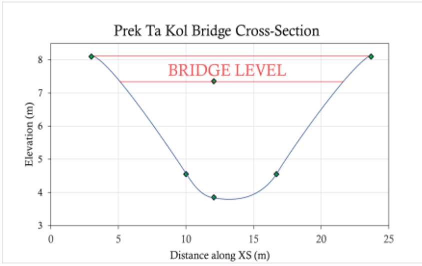


WAT4CAM	PREK TA KOL	EB33/08041548

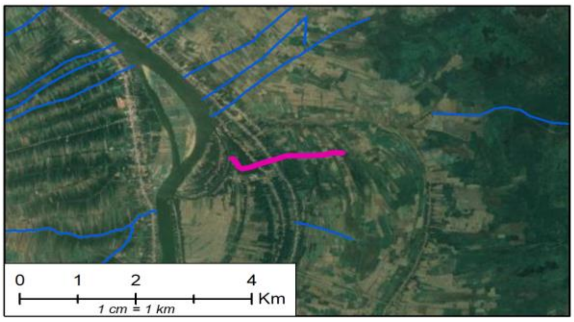


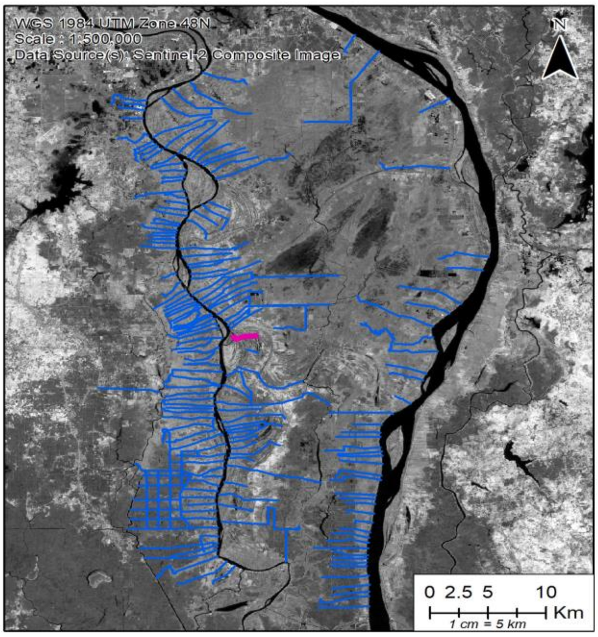


CHANNEL DIMENSIONS	
Channel Length	3.4 km
Channel Width	7 m
Inlet Bed Level	3.86 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041548
CISIS Area (ha)	224.6

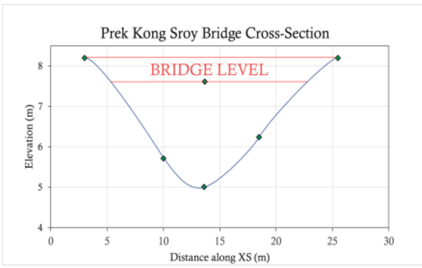


WAT4CAM	PREK KONG SROY	EB34/08041556

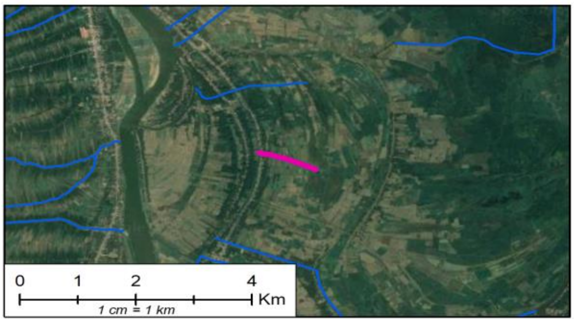


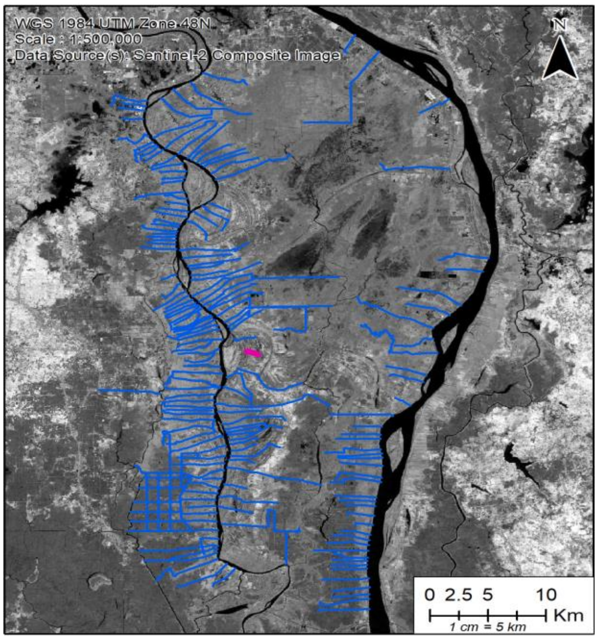


CHANNEL DIMENSIONS	
Channel Length	2.1 km
Channel Width	7 m
Inlet Bed Level	5.01 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041556
CISIS Area (ha)	104.8

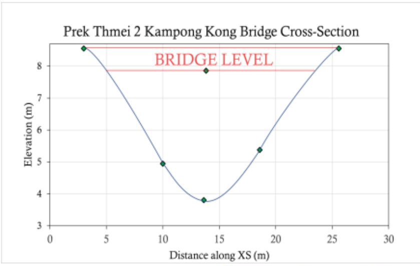


WAT4CAM	PREK THMEI 2 KAMPONG KONG	EB35/08041557

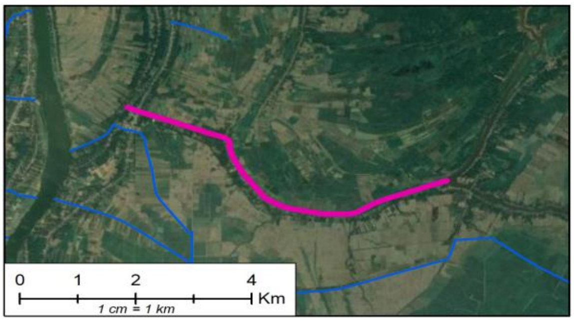


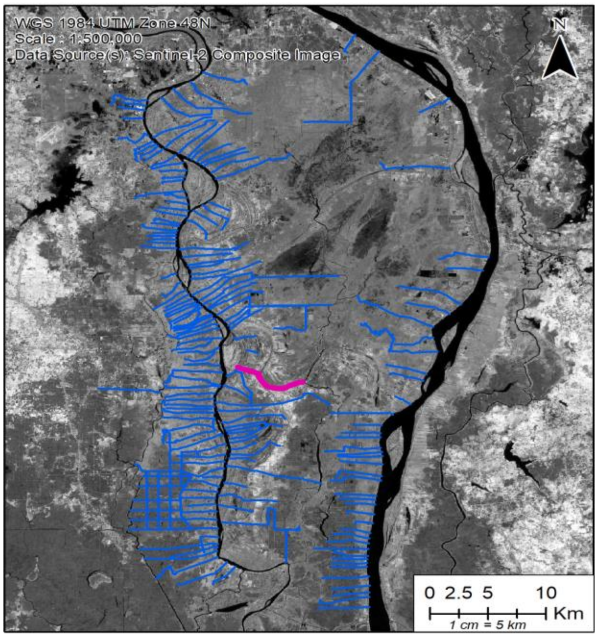


CHANNEL DIMENSIONS	
Channel Length	1.0 km
Channel Width	8 m
Inlet Bed Level	3.80 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041557
CISIS Area (ha)	76.7

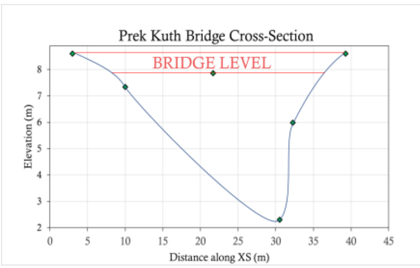


WAT4CAM	PREK KUTH	EB36/08041551

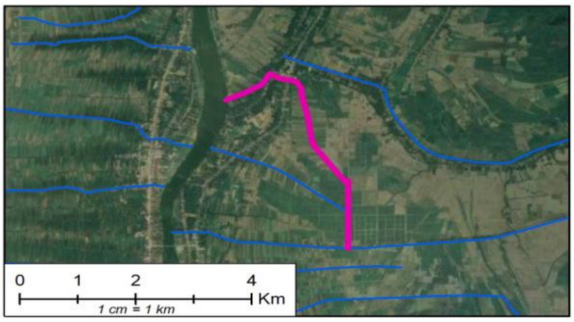


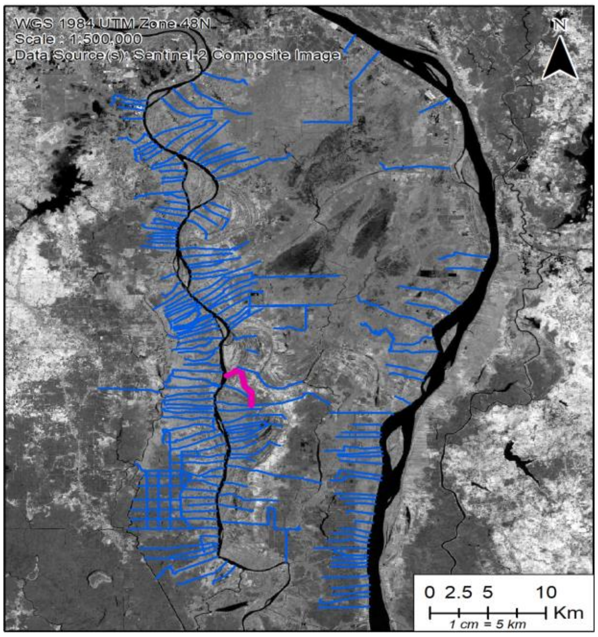


CHANNEL DIMENSIONS	
Channel Length	6.6 km
Channel Width	8 m
Inlet Bed Level	2.31 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041551
CISIS Area (ha)	0.0

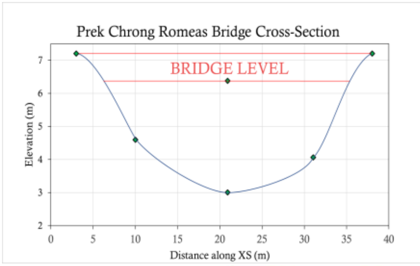


WAT4CAM	PREK CHRONG ROMEAS	EB37/08041552

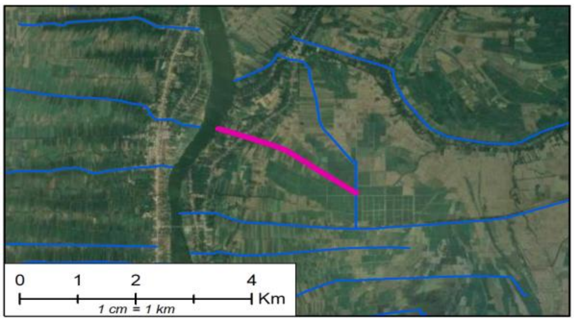


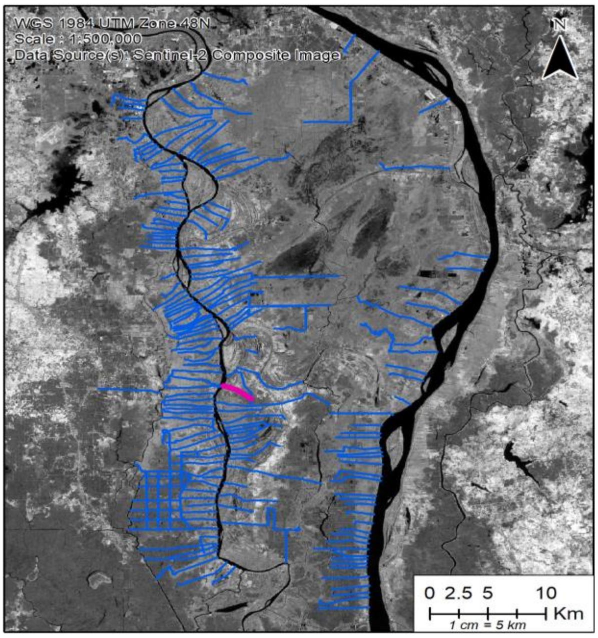


CHANNEL DIMENSIONS	
Channel Length	5.2 km
Channel Width	11 m
Inlet Bed Level	3.00 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041552
CISIS Area (ha)	626.7

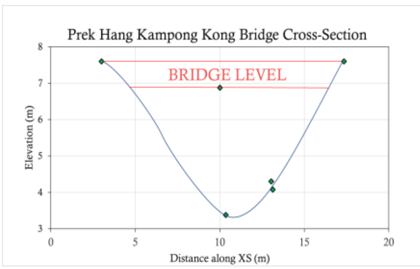


WAT4CAM	PREK HANG KAMPONG KONG	EB38/08041553

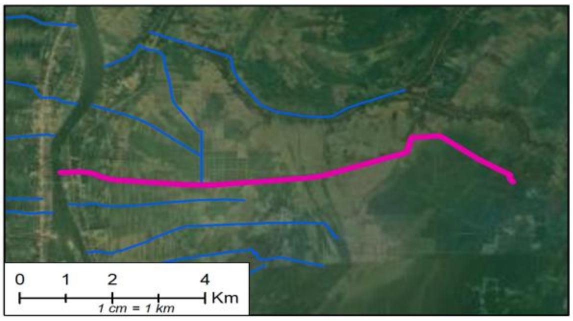


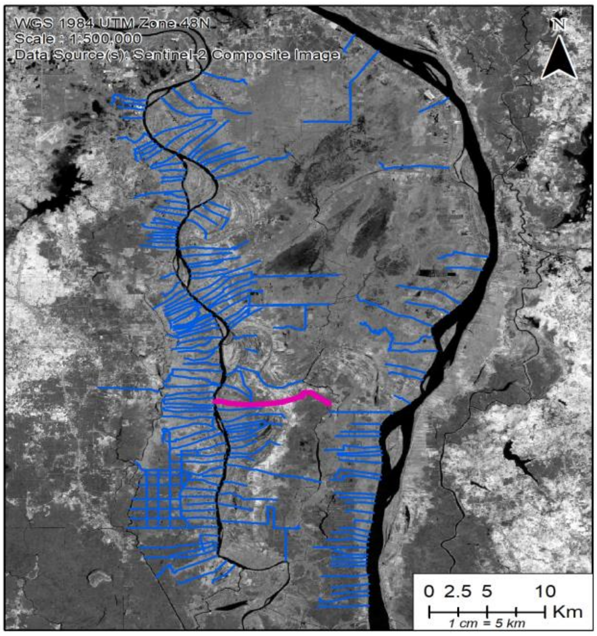


CHANNEL DIMENSIONS	
Channel Length	2.7 km
Channel Width	13 m
Inlet Bed Level	3.38 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041553
CISIS Area (ha)	239.3

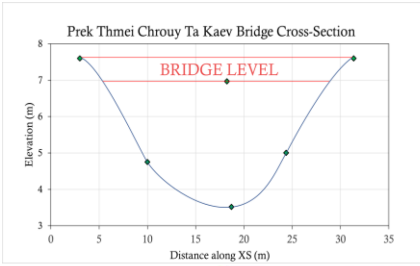


WAT4CAM	PREK THMEI CHROUY TA KAEV	EB39/08041599

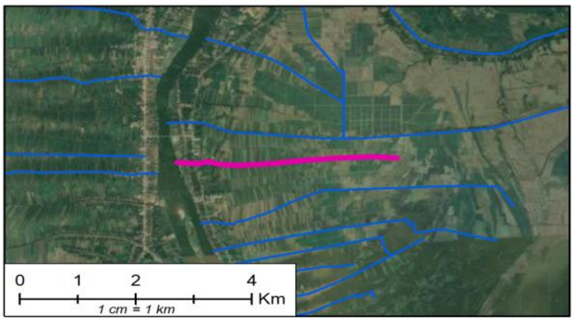


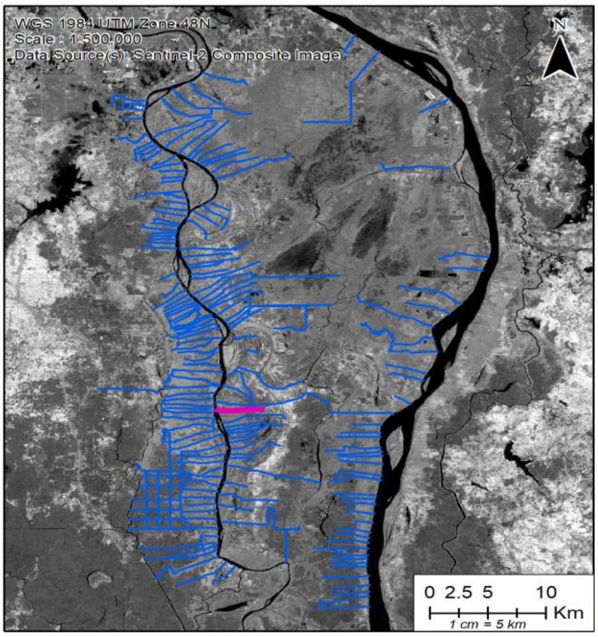


CHANNEL DIMENSIONS	
Channel Length	10.7 km
Channel Width	13 m
Inlet Bed Level	3.52 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041599
CISIS Area (ha)	5323.7

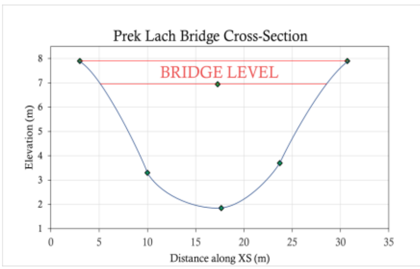


WAT4CAM	PREK LACH	EB40/08041598

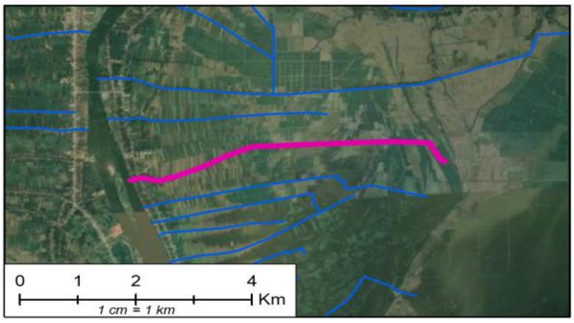


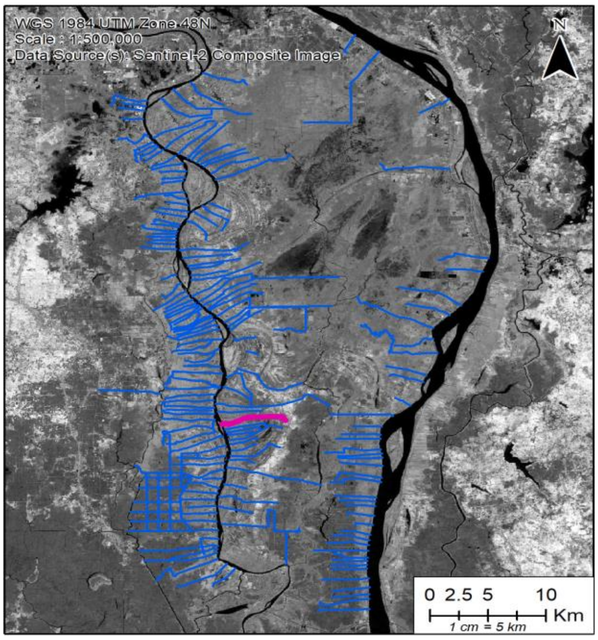


CHANNEL DIMENSIONS	
Channel Length	3.8 km
Channel Width	8 m
Inlet Bed Level	1.84 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041598
CISIS Area (ha)	154.7

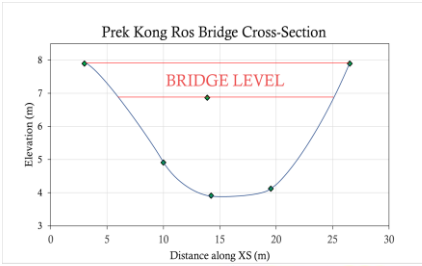


WAT4CAM	PREK KONG ROS	EB41/08041595

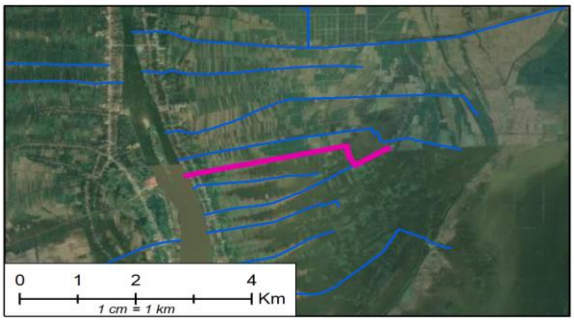


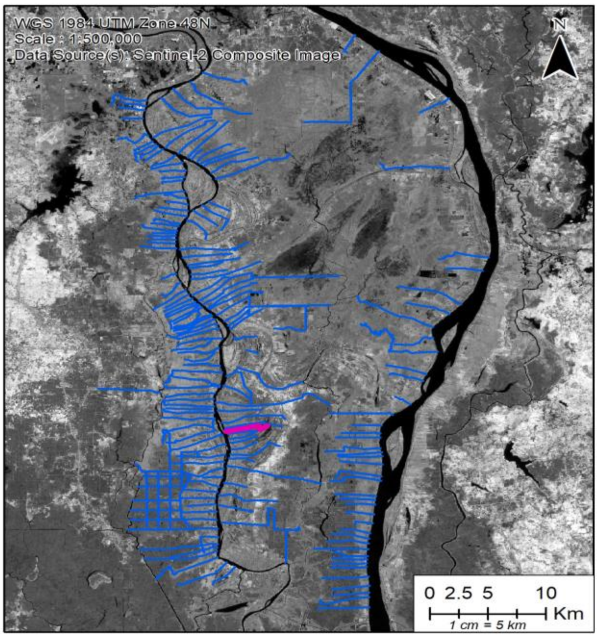


CHANNEL DIMENSIONS	
Channel Length	5.8 km
Channel Width	9 m
Inlet Bed Level	3.91 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041595
CISIS Area (ha)	450.9

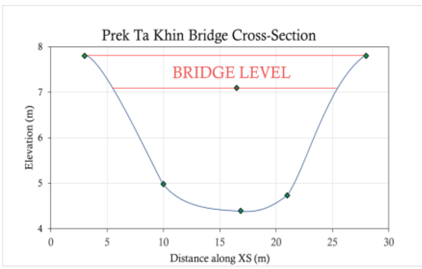


WAT4CAM	PREK TA KHIN	EB43/08041593

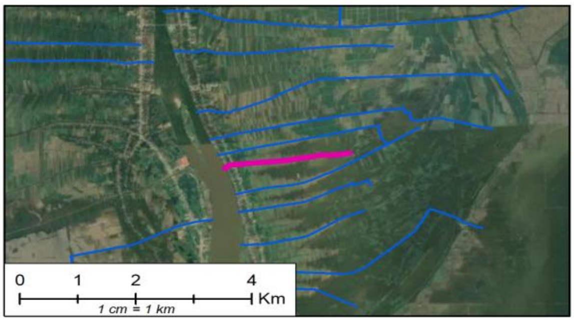


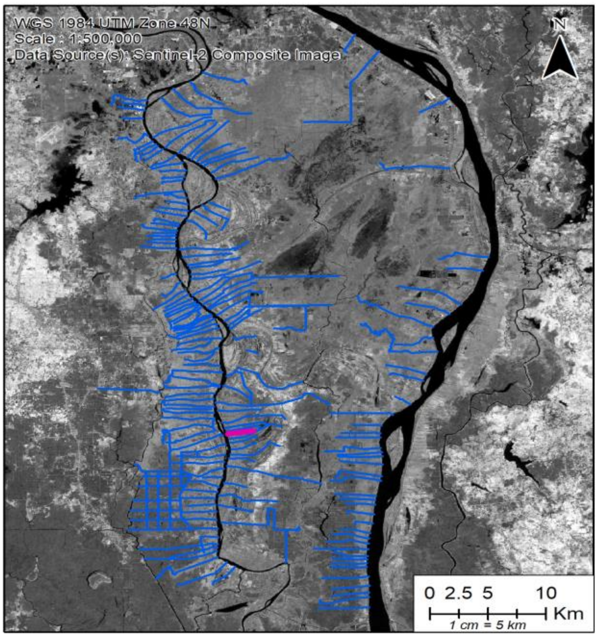


CHANNEL DIMENSIONS	
Channel Length	3.9 km
Channel Width	10 m
Inlet Bed Level	4.39 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041593
CISIS Area (ha)	212.1

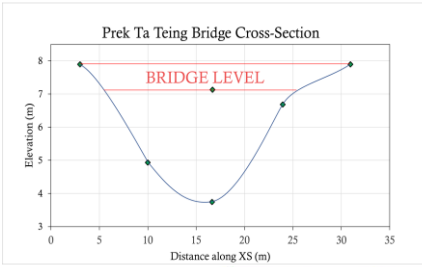


WAT4CAM	PREK TA TEING	EB44/08041592

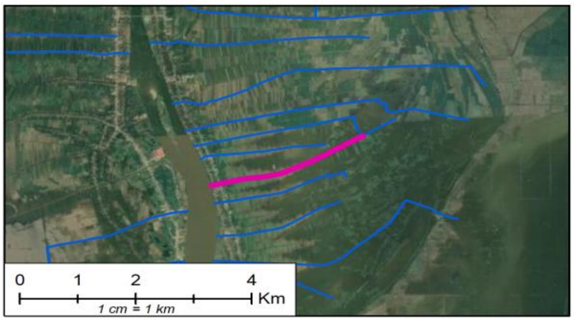


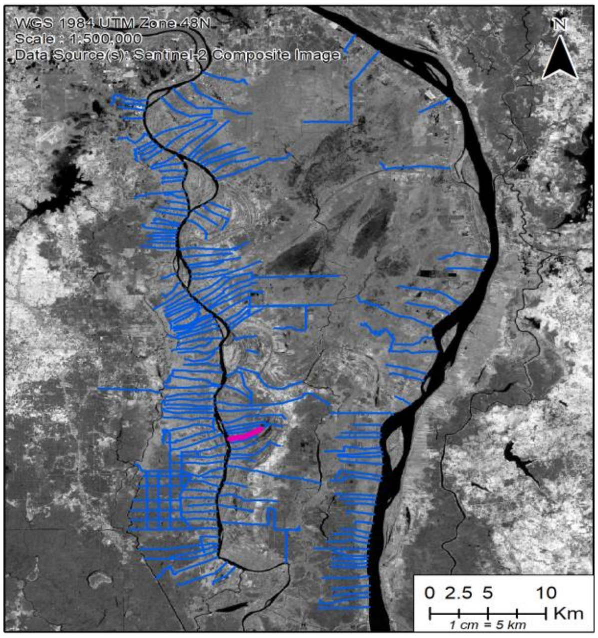


CHANNEL DIMENSIONS	
Channel Length	2.2 km
Channel Width	8 m
Inlet Bed Level	3.75 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041592
CISIS Area (ha)	159.5

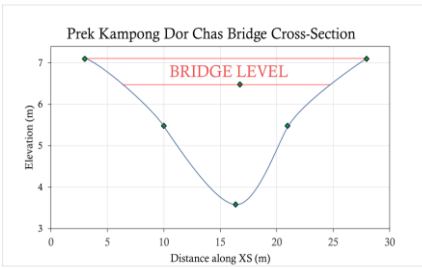


WAT4CAM	PREK KAMPONG DOR CHAS	EB45/08041591

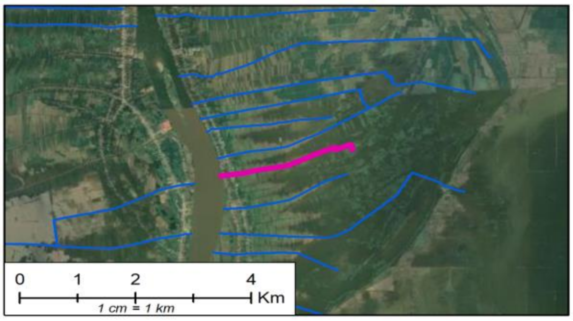


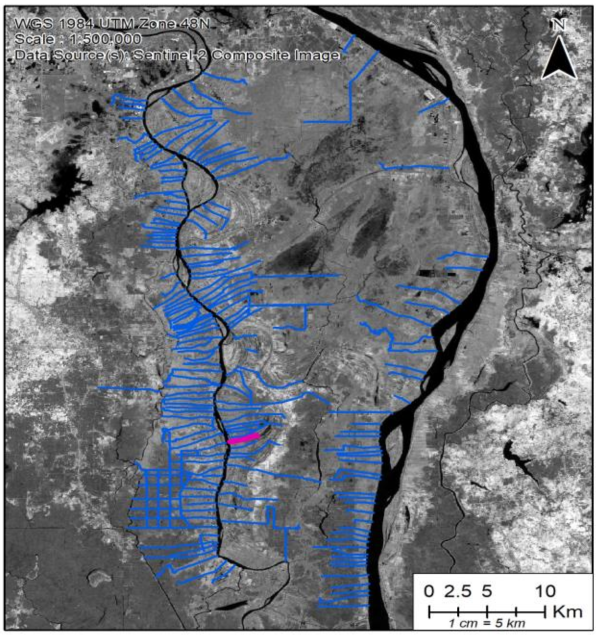


CHANNEL DIMENSIONS	
Channel Length	2.8 km
Channel Width	10 m
Inlet Bed Level	3.58 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041591
CISIS Area (ha)	442.0

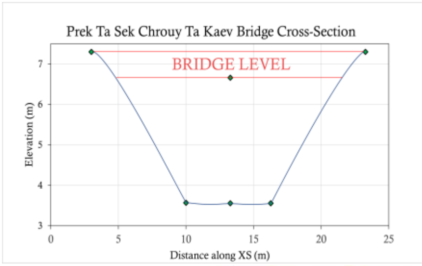


WAT4CAM	PREK TA SEK CHROUY TA KAEV	EB46/08041590

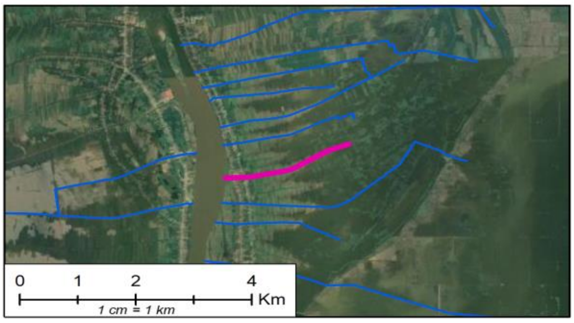


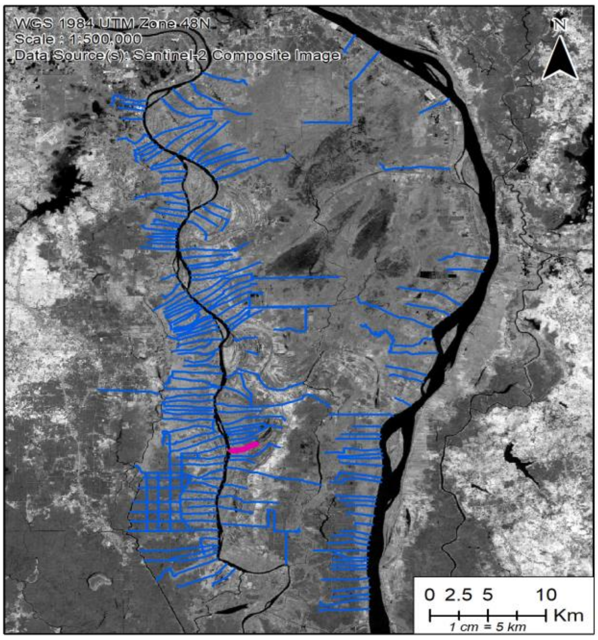


CHANNEL DIMENSIONS	
Channel Length	2.5 km
Channel Width	8 m
Inlet Bed Level	3.56 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041590
CISIS Area (ha)	148.2

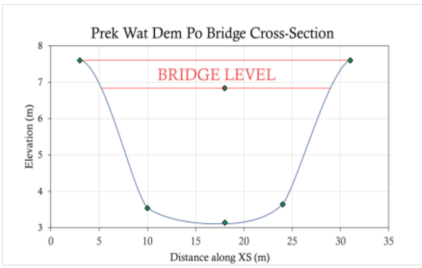


WAT4CAM	PREK WAT DEM PO	EB47/08041578

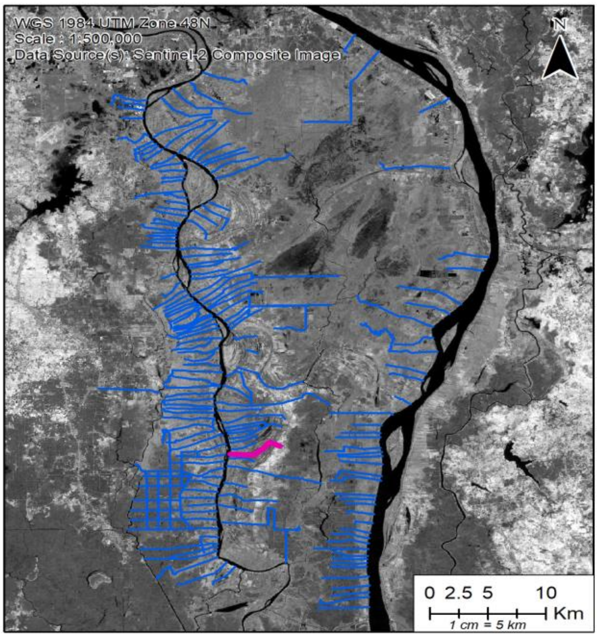


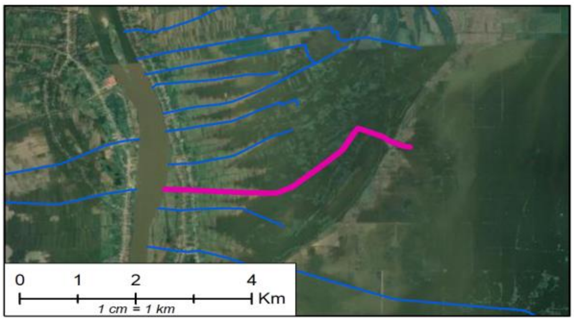


CHANNEL DIMENSIONS	
Channel Length	2.3 km
Channel Width	7 m
Inlet Bed Level	3.14 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041578
CISIS Area (ha)	185.2

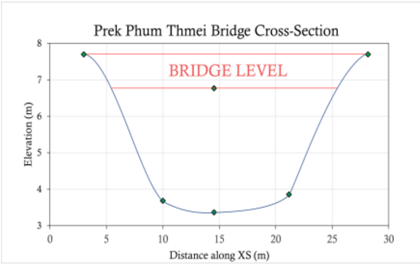


WAT4CAM	PREK PHUM THMEI	EB48/08041560

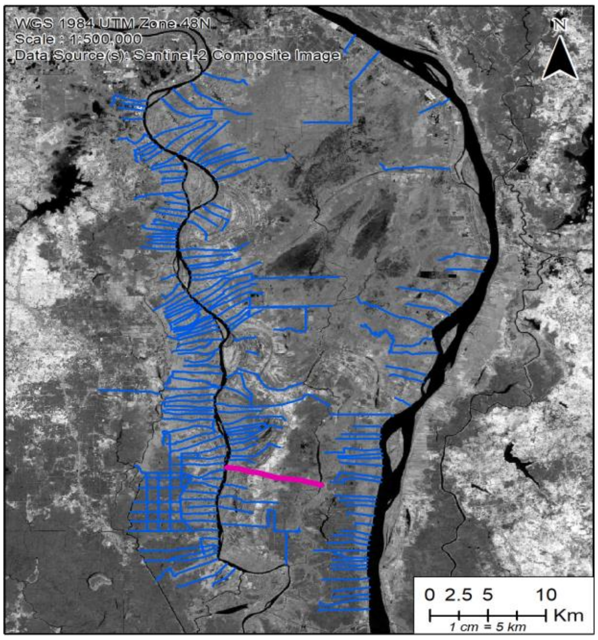


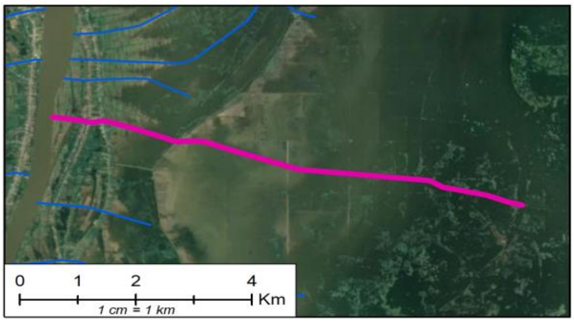


CHANNEL DIMENSIONS	
Channel Length	4.9 km
Channel Width	8 m
Inlet Bed Level	3.36 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041560
CISIS Area (ha)	276.8

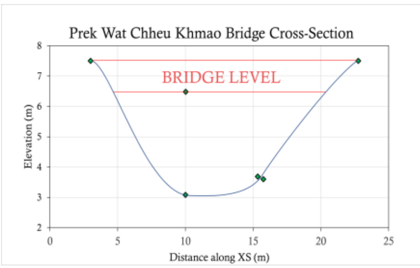


WAT4CAM	PREK WAT CHHEU KHMAO	EB49/08041563

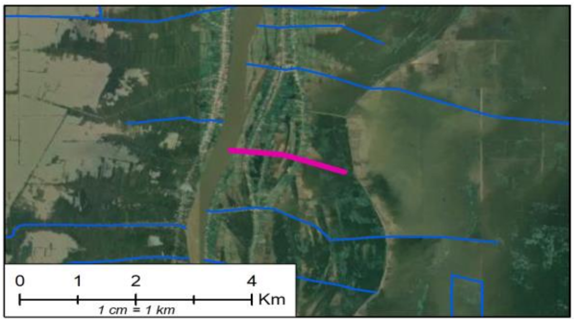


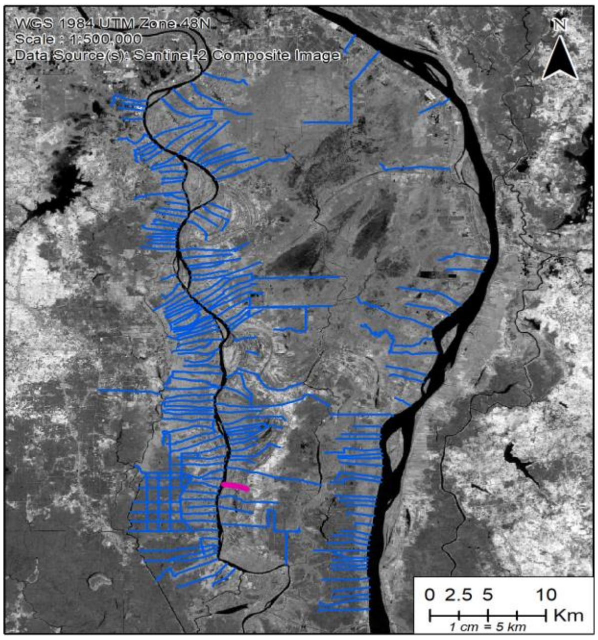


CHANNEL DIMENSIONS	
Channel Length	8.4 km
Channel Width	8 m
Inlet Bed Level	3.08 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041563
CISIS Area (ha)	4971.4

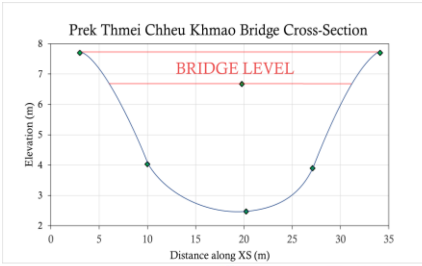


WAT4CAM	PREK THMEI CHHEU KHMAO	EB50/08041564

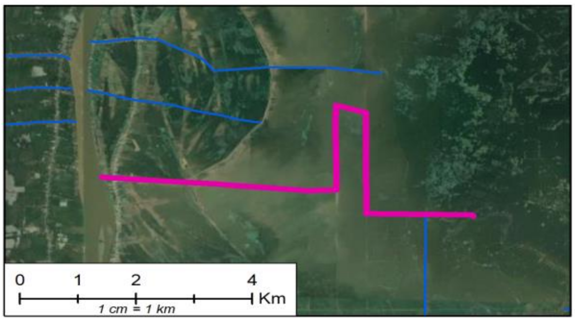


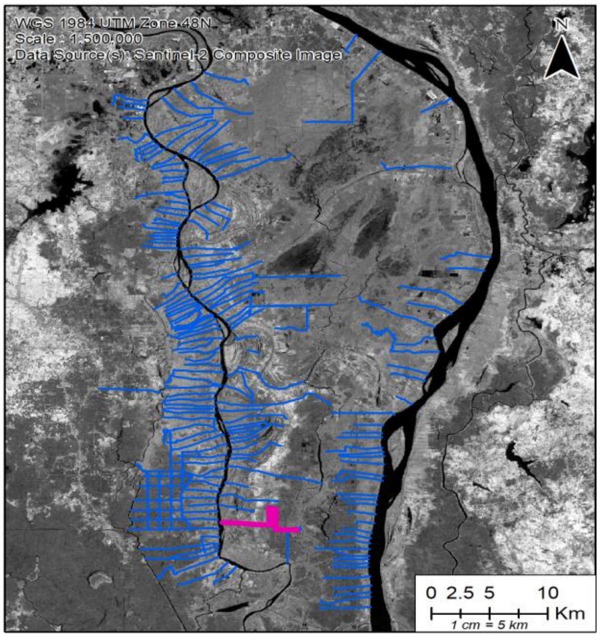


CHANNEL DIMENSIONS	
Channel Length	2.0 km
Channel Width	6 m
Inlet Bed Level	2.47 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041564
CISIS Area (ha)	195.8

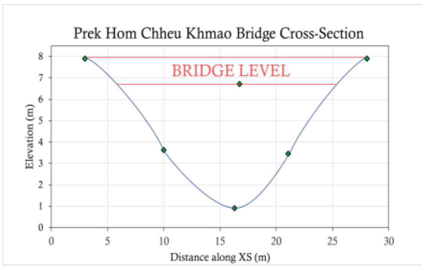


WAT4CAM	PREK HOM CHHEU KHMAO	EB52 /08041567

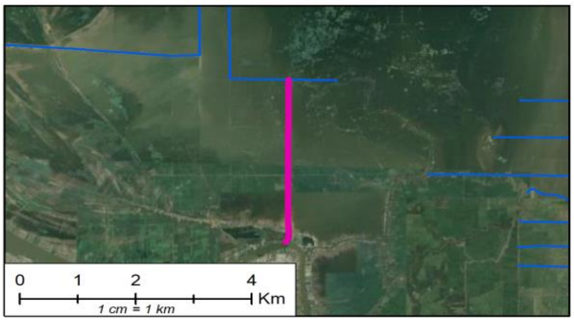


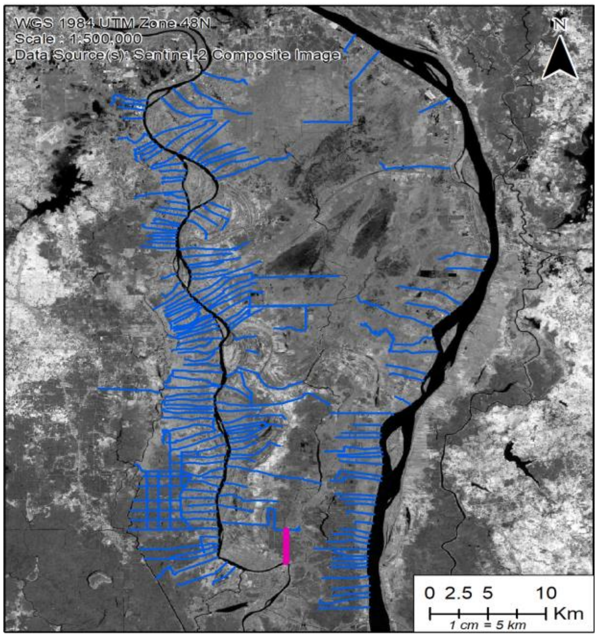


CHANNEL DIMENSIONS	
Channel Length	10.3 km
Channel Width	12 m
Inlet Bed Level	0.91 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041567
CISIS Area (ha)	4935.0

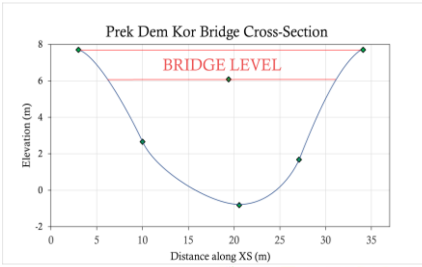


WAT4CAM	PREK DEM KOR	EB54/08041576

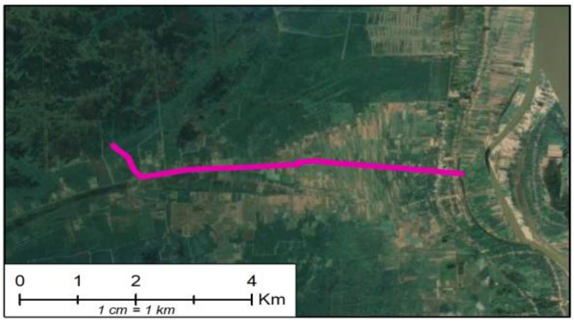


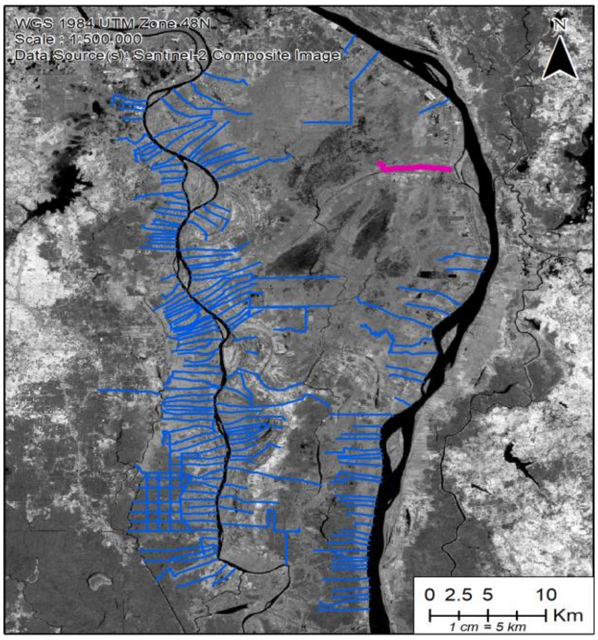


CHANNEL DIMENSIONS	
Channel Length	3.4 km
Channel Width	14 m
Inlet Bed Level	-0.82 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041576
CISIS Area (ha)	5322.9

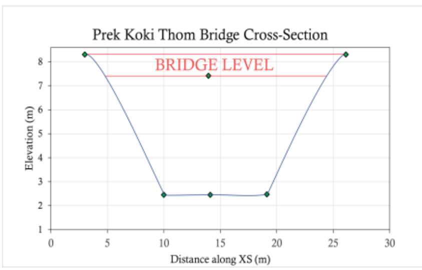


WAT4CAM	PREK KOKI THOM	WM0 /08021864

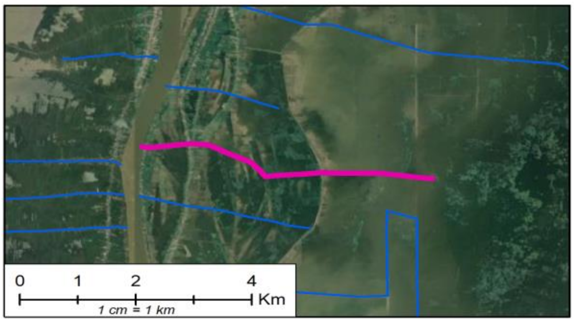


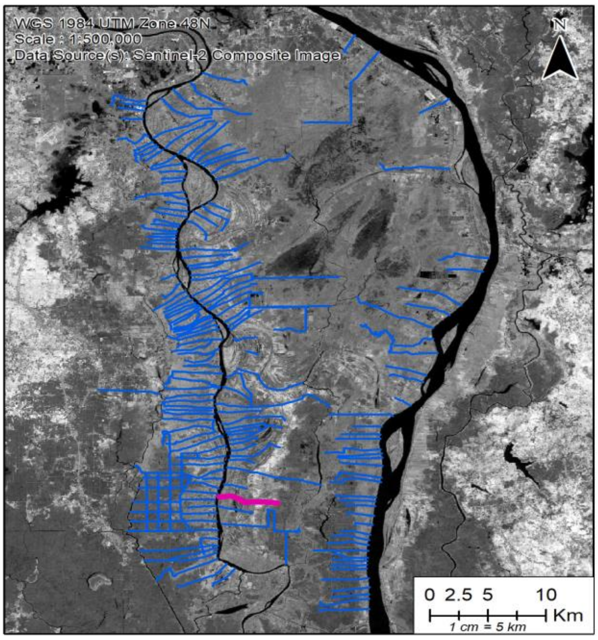


CHANNEL DIMENSIONS	
Channel Length	6.4 km
Channel Width	8 m
Inlet Bed Level	2.45 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08021864
CISIS Area (ha)	139.9

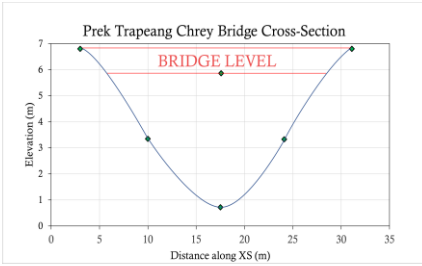


WAT4CAM	PREK TRAPEANG CHREY	WG51/08041565



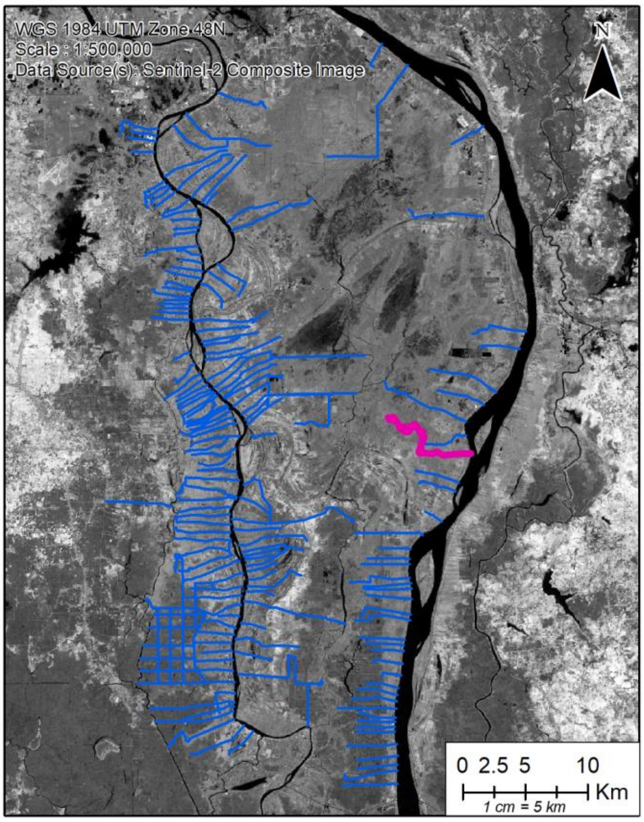


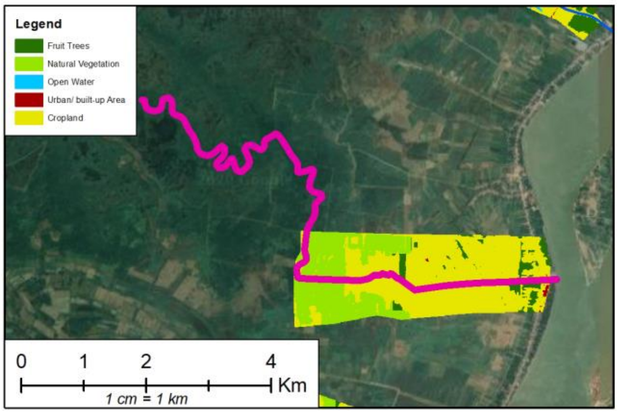
CHANNEL DIMENSIONS	
Channel Length	5.2 km
Channel Width	13 m
Inlet Bed Level	0.71 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08041565
CISIS Area (ha)	373.7



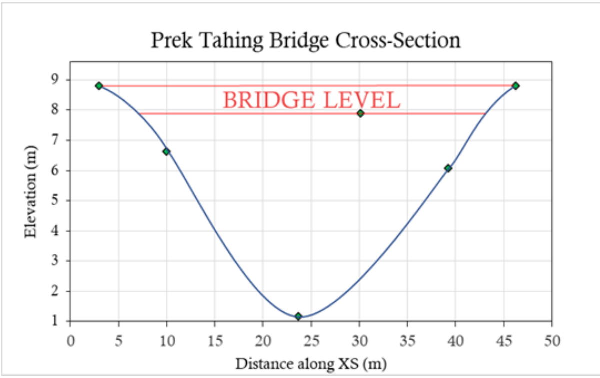
West Mekong Phase 1

WAT4CAM	PREK TAHING	WM6/08051457



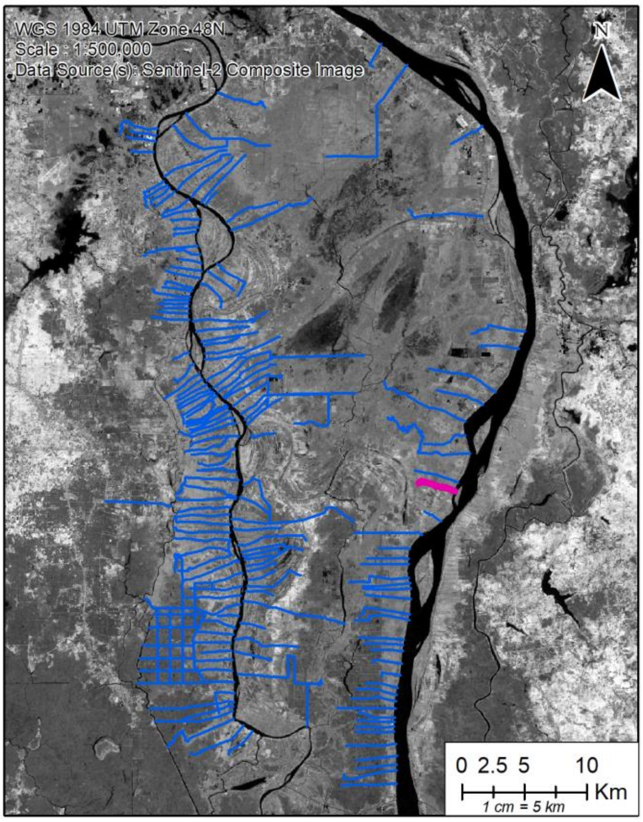


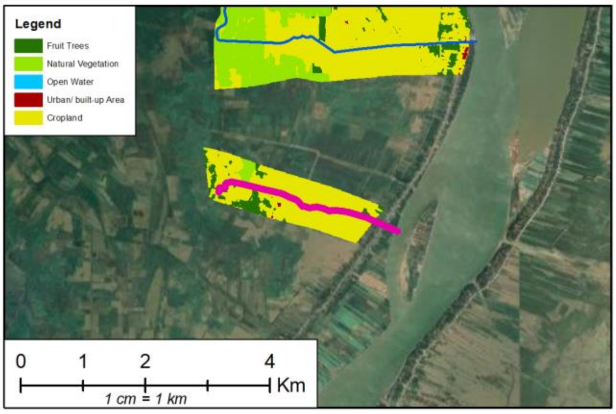
PREK TAHING	WM6
KEY FEATURES	
Classification	River Prek
CISIS Code	08051457
CISIS Area (ha)	412.5
Total Area (CISIS GIS)	206.3
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	1.0
Orchard Area (Ha)	29.4
Field Crop Area	166.4
Natural (Ha)	8.7
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	137.9
Fallow Area (2020) Ha	38.6
Fallow Area (2019) Ha	28.6
Fallow Area (2018) Ha	8.3
Fallow Area (2017) Ha	21.9
Fallow Area (2017) Ha	44.9
Average Fallow (Ha)	28.5



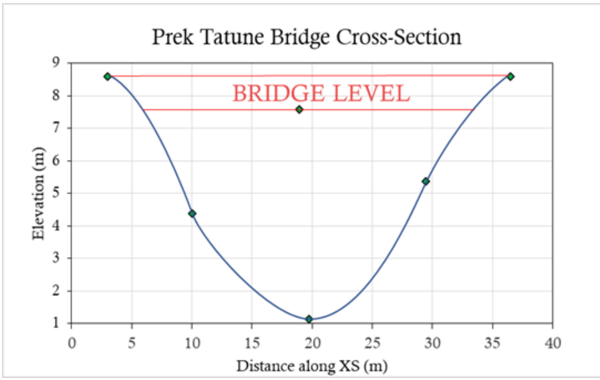
CHANNEL DIMENSIONS	
Channel Length	11.5 km
Channel Width	16 m
Inlet Bed Level	1.16 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	44.7 (m^3/s)
Av ETA(mm) in January (m3/s)	115.5 mm (0.089 m^3/s)
ETA (Feb)	101.3 mm (0.078 m^3/s)
ETA (March)	115.3 mm (0.089 m^3/s
ETA (April)	110.6 mm (0.085 m^3/s)

WAT4CAM	PREK TA TUNE	WM8 / 08051458



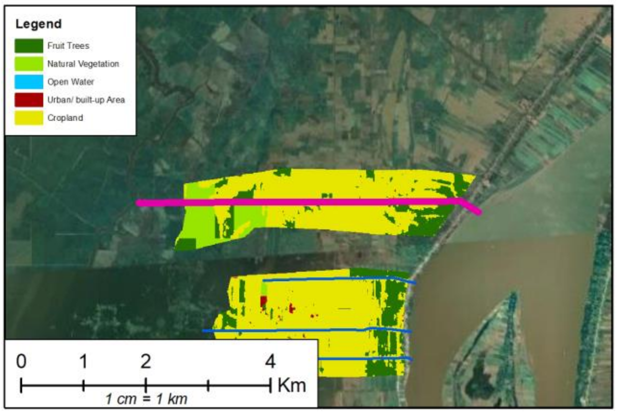


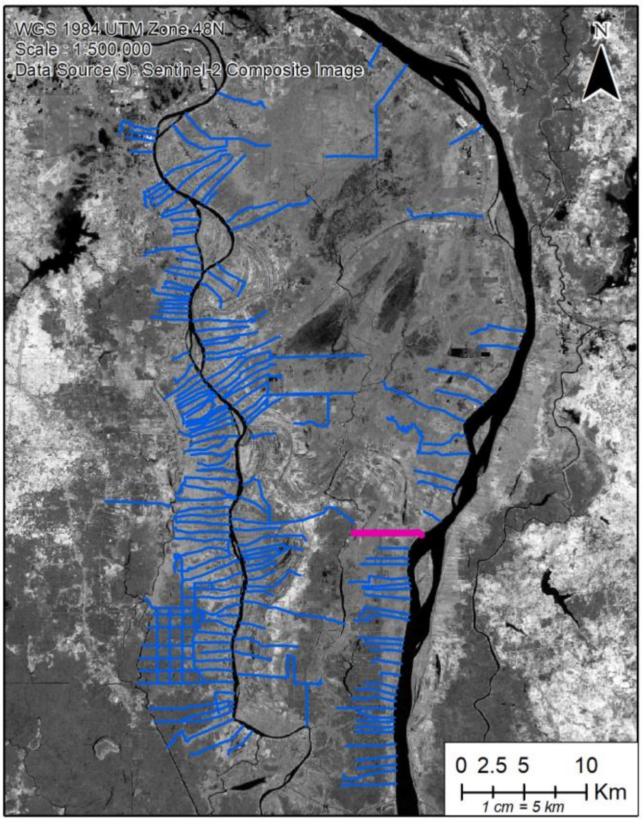
PREK TA TUNE	WM8
KEY FEATURES	
Classification	River Prek
CISIS Code	08051458
CISIS Area (ha)	251.1
Total Area (CISIS GIS)	440.8
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	11.8
Orchard Area (Ha)	87.1
Field Crop Area	284.2
Natural (Ha)	66.9
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	217.0
Fallow Area (2020) Ha	71.6
Fallow Area (2019) Ha	147.7
Fallow Area (2018) Ha	23.7
Fallow Area (2017) Ha	35.6
Fallow Area (2017) Ha	57.4
Average Fallow (Ha)	67.2



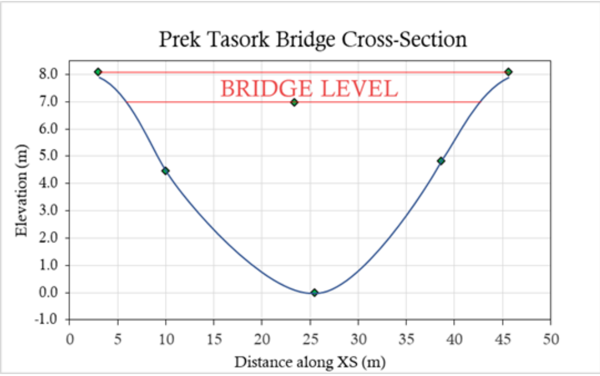
CHANNEL DIMENSIONS	
Channel Length	3.2 km
Channel Width	10 m
Inlet Bed Level	1.13 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.1 (m^3/s)
Flood peak	14.6 (m^3/s)
Av ETA(mm) in January (m3/s)	123.4 mm (0.203 m^3/s)
ETA (Feb)	93.2 mm (0.153 m^3/s)
ETA (March)	99.1 mm (0.163 m^3/s
ETA (April)	105.2 mm (0.173 m^3/s)

WAT4CAM	PREK TASORK	WM10/08052330



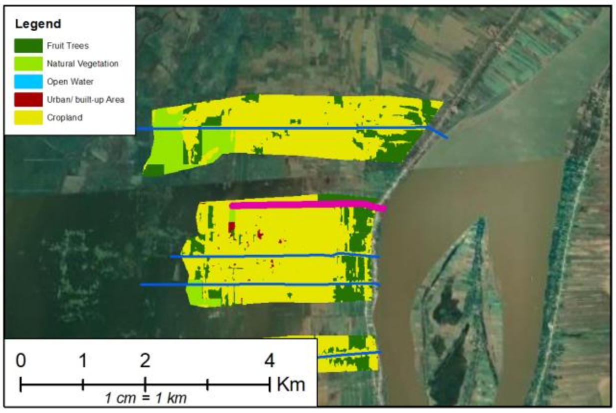


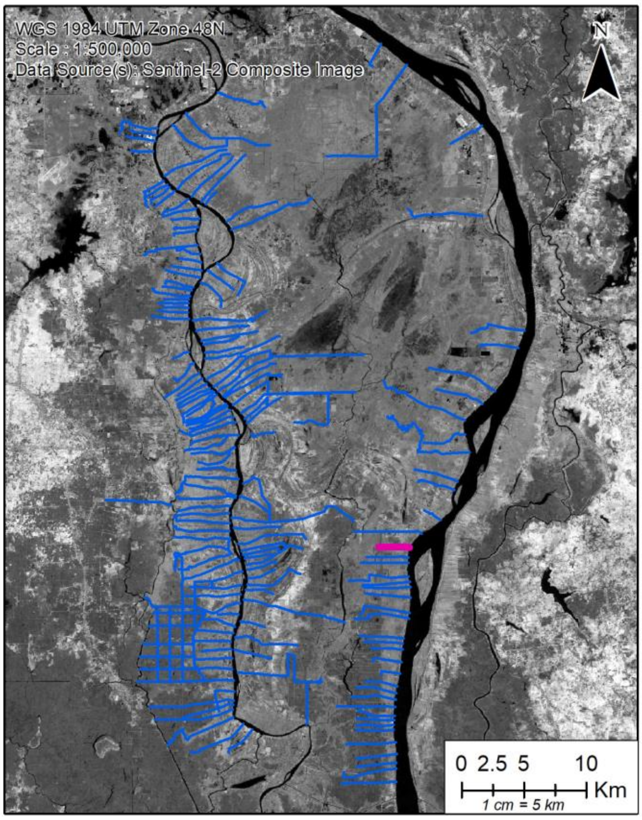
PREK TASORK	WM10
KEY FEATURES	
Classification	River Prek
CISIS Code	08052330
CISIS Area (ha)	526.6
Total Area (CISIS GIS)	172.1
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	4.1
Orchard Area (Ha)	30.7
Field Crop Area	125.0
Natural (Ha)	13.4
Area of Water (Ha)	0.1
Average Field Crop Harvest (Ha)	107.9
Fallow Area (2020) Ha	21.1
Fallow Area (2019) Ha	22.6
Fallow Area (2018) Ha	11.7
Fallow Area (2017) Ha	12.9
Fallow Area (2017) Ha	16.9
Average Fallow (Ha)	17.1



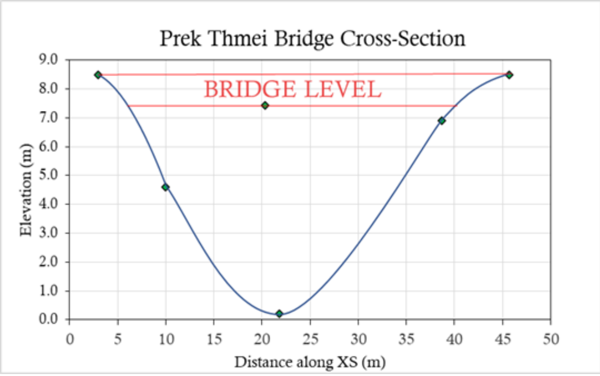
CHANNEL DIMENSIONS	
Channel Length	5.5 km
Channel Width	10 m
Inlet Bed Level	-0.01 (m AHD)
FLOW	
Dry Season Min (m3/s)	-60.0 (m^3/s)
Flood peak	4.7 (m^3/s)
Av ETA(mm) in January (m3/s)	116.9 mm (0.075 m^3/s)
ETA (Feb)	96.5 mm (0.062 m^3/s)
ETA (March)	108.1 mm (0.069 m^3/s
ETA (April)	108.1 mm (0.069 m^3/s)

WAT4CAM	PREK THMEI	WM11 / 08052331



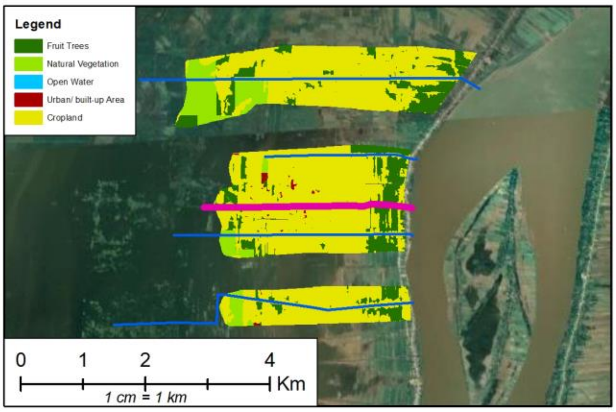


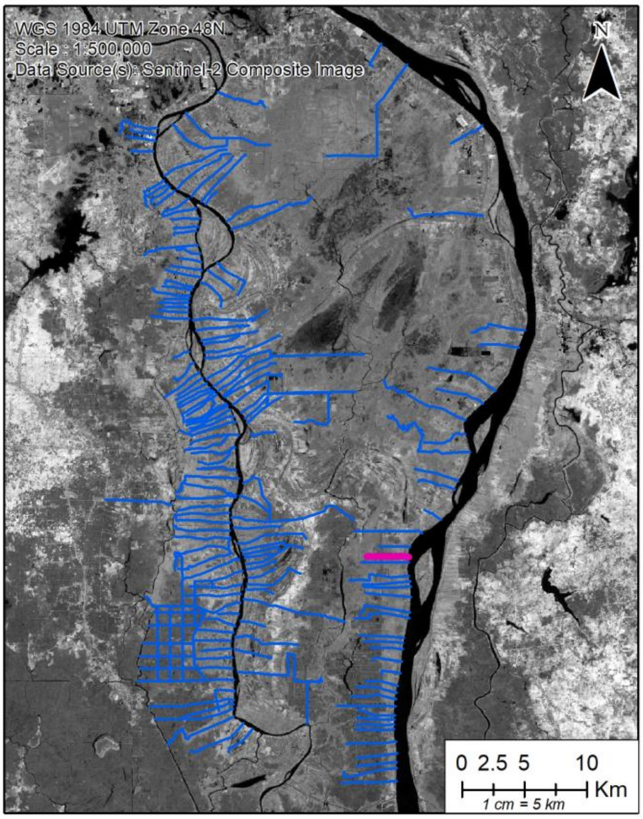
PREK THMEI	WM11
KEY FEATURES	
Classification	River Prek
CISIS Code	08052331
CISIS Area (ha)	175.8
Total Area (CISIS GIS)	167.7
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	14.6
Orchard Area (Ha)	36.6
Field Crop Area	123.4
Natural (Ha)	2.9
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	117.5
Fallow Area (2020) Ha	5.7
Fallow Area (2019) Ha	8.6
Fallow Area (2018) Ha	4.2
Fallow Area (2017) Ha	6.0
Fallow Area (2017) Ha	5.0
Average Fallow (Ha)	5.9



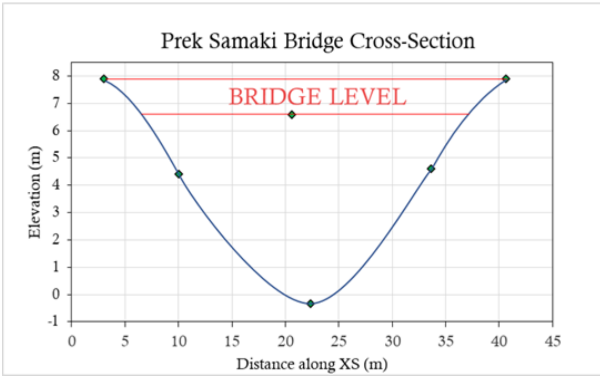
CHANNEL DIMENSIONS	
Channel Length	2.4 km
Channel Width	15 m
Inlet Bed Level	0.20 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.6 (m^3/s)
Flood peak	50.0 (m^3/s)
Av ETA(mm) in January (m3/s)	109.9 mm (0.069 m^3/s)
ETA (Feb)	96.7 mm (0.061 m^3/s)
ETA (March)	104.2 mm (0.065 m^3/s
ETA (April)	107.3 mm (0.067 m^3/s)

WAT4CAM	PREK SAMAKI	WM12/08052323



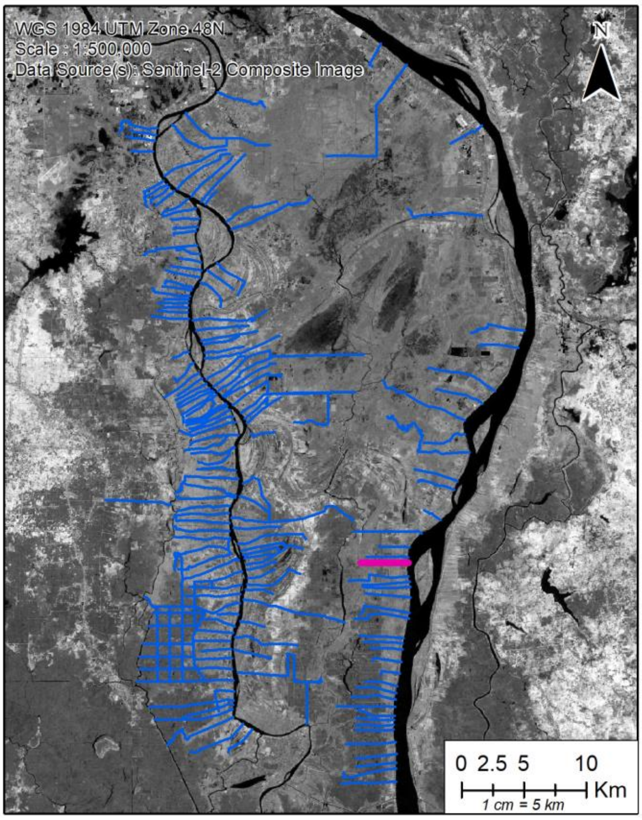


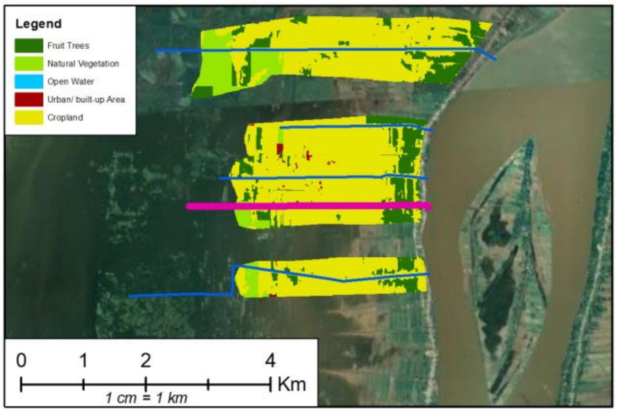
PREK SAMAKI	WM12
KEY FEATURES	
Classification	River Prek
CISIS Code	08052323
CISIS Area (ha)	0.0
Total Area (CISIS GIS)	173.5
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	6.2
Orchard Area (Ha)	35.1
Field Crop Area	129.5
Natural (Ha)	0.2
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	119.5
Fallow Area (2020) Ha	9.1
Fallow Area (2019) Ha	12.2
Fallow Area (2018) Ha	9.7
Fallow Area (2017) Ha	8.6
Fallow Area (2017) Ha	10.3
Average Fallow (Ha)	10.0



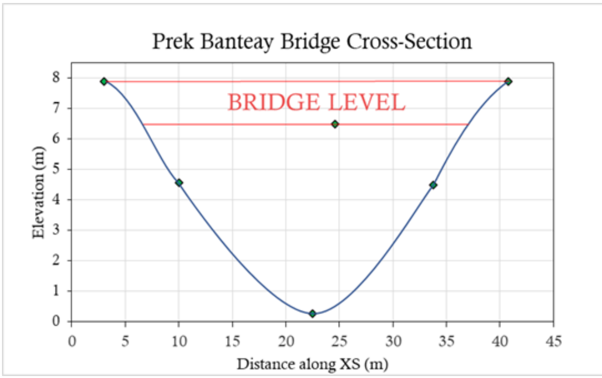
CHANNEL DIMENSIONS	
Channel Length	3.3 km
Channel Width	16 m
Inlet Bed Level	-0.33 (m AHD)
FLOW	
Dry Season Min (m3/s)	1.0 (m^3/s)
Flood peak	64.0 (m^3/s)
Av ETA(mm) in January (m3/s)	105.7 mm (0.068 m^3/s)
ETA (Feb)	98.4 mm (0.064 m^3/s)
ETA (March)	103.2 mm (0.067 m^3/s
ETA (April)	108.5 mm (0.070 m^3/s)

WAT4CAM	PREK BANTEAY	WM13/08051448



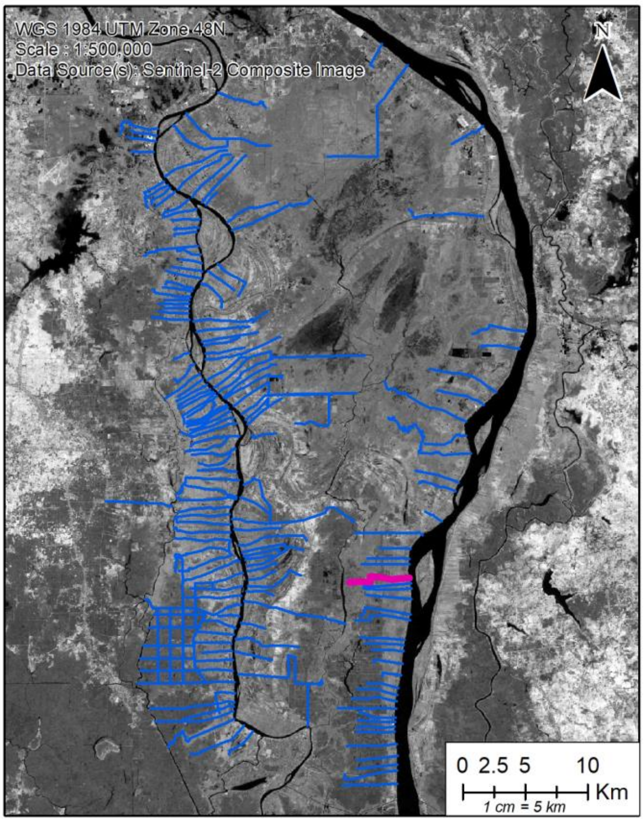


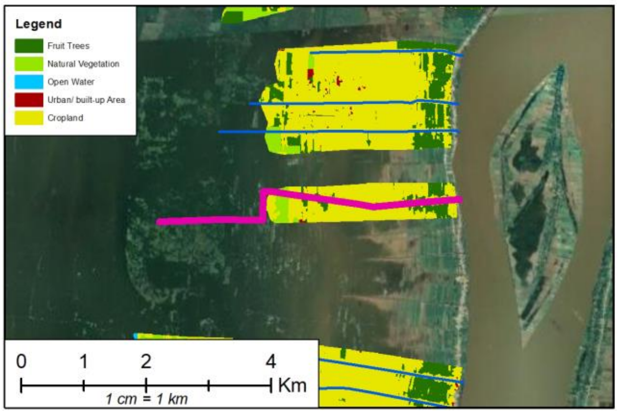
PREK BANTEAY	WM13
KEY FEATURES	
Classification	River Prek
CISIS Code	08051448
CISIS Area (ha)	46.3
Total Area (CISIS GIS)	156.0
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	0.1
Orchard Area (Ha)	33.7
Field Crop Area	108.5
Natural (Ha)	11.7
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	101.7
Fallow Area (2020) Ha	5.9
Fallow Area (2019) Ha	8.7
Fallow Area (2018) Ha	6.6
Fallow Area (2017) Ha	5.7
Fallow Area (2017) Ha	7.0
Average Fallow (Ha)	6.8



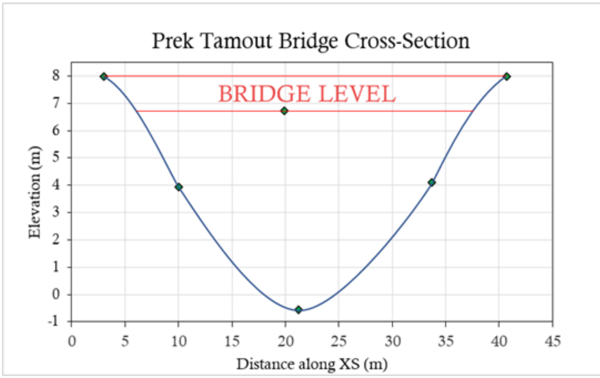
CHANNEL DIMENSIONS	
Channel Length	3.8 km
Channel Width	14 m
Inlet Bed Level	0.27 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.3 (m^3/s)
Flood peak	56.0 (m^3/s)
Av ETA(mm) in January (m3/s)	113.3 mm (0.066 m^3/s)
ETA (Feb)	99.2 mm (0.058 m^3/s)
ETA (March)	106.3 mm (0.062 m^3/s
ETA (April)	107.4 mm (0.063 m^3/s)

WAT4CAM	PREK TAMOUT	WM14/08052329



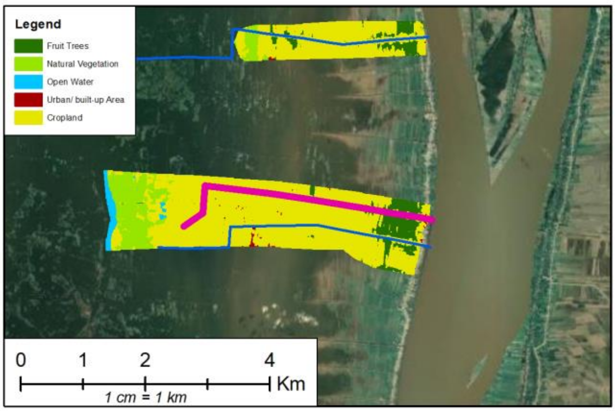


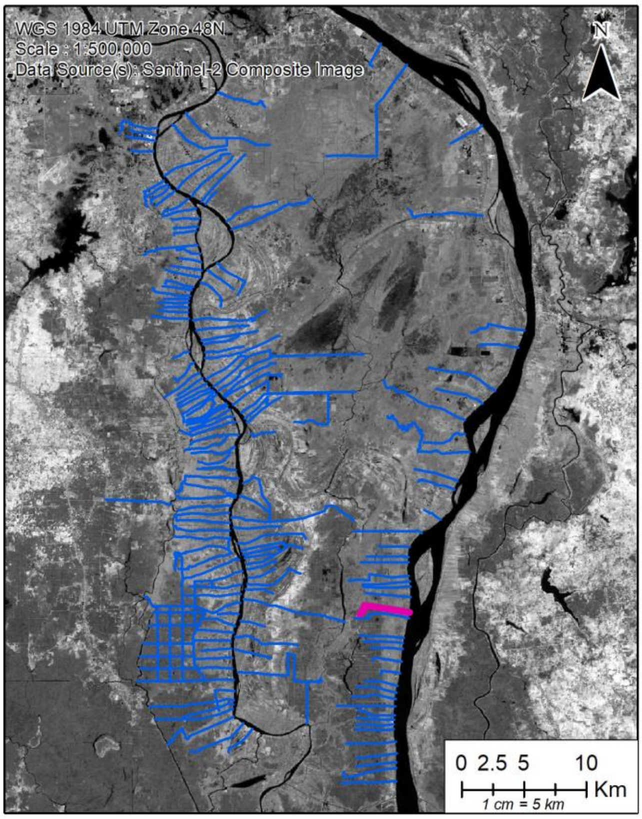
PREK TAMOUT	WM14
KEY FEATURES	
Classification	River Prek
CISIS Code	08052329
CISIS Area (ha)	299.3
Total Area (CISIS GIS)	279.3
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	1.8
Orchard Area (Ha)	83.2
Field Crop Area	181.5
Natural (Ha)	0.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	146.2
Fallow Area (2020) Ha	67.1
Fallow Area (2019) Ha	28.2
Fallow Area (2018) Ha	13.2
Fallow Area (2017) Ha	34.7
Fallow Area (2017) Ha	33.0
Average Fallow (Ha)	35.2



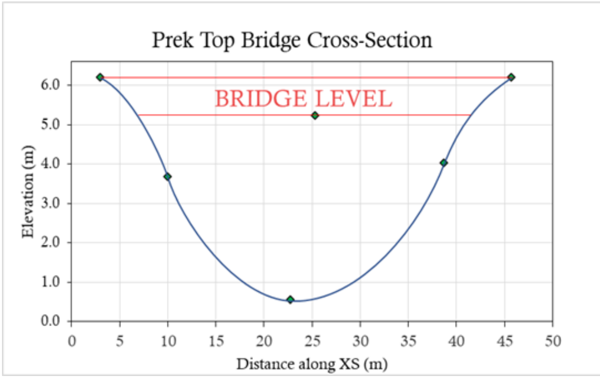
CHANNEL DIMENSIONS	
Channel Length	5.3 km
Channel Width	16 m
Inlet Bed Level	-0.56 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.5 (m^3/s)
Flood peak	44.0 (m^3/s)
Av ETA(mm) in January (m3/s)	110.3 mm (0.115 m^3/s)
ETA (Feb)	88.1 mm (0.092 m^3/s)
ETA (March)	84.1 mm (0.088 m^3/s
ETA (April)	87.3 mm (0.091 m^3/s)

WAT4CAM	PREK TOP	WM18/08052333



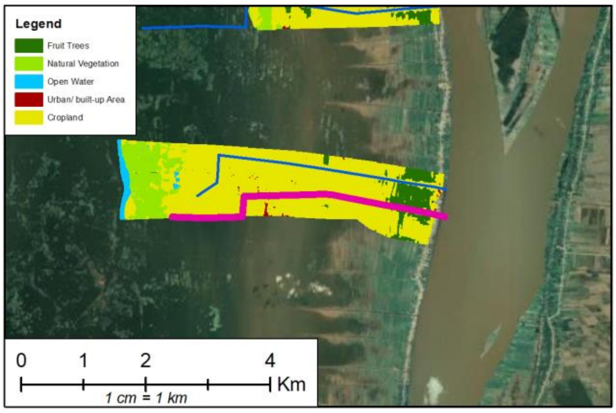


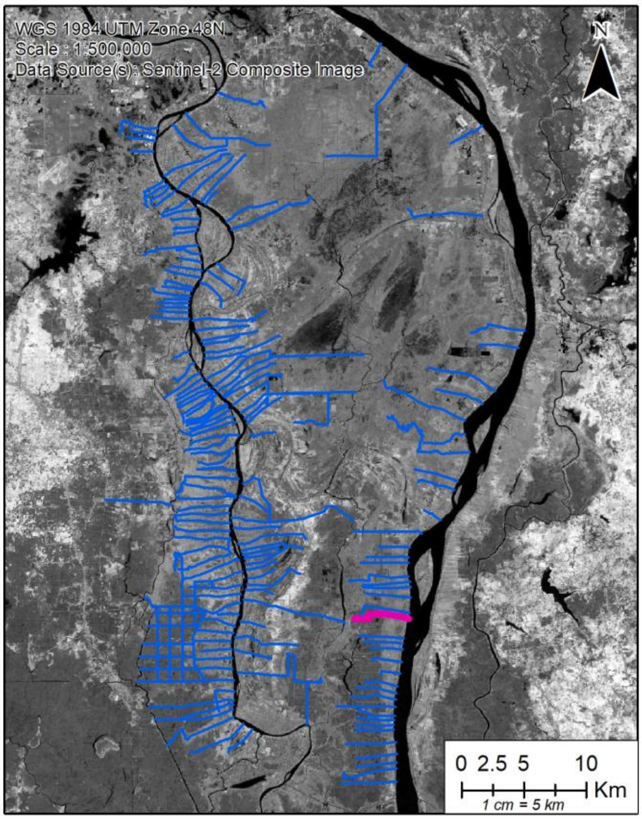
PREK TOP	WM18
KEY FEATURES	
Classification	River Prek
CISIS Code	08052333
CISIS Area (ha)	264.9
Total Area (CISIS GIS)	246.6
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	3.5
Orchard Area (Ha)	28.7
Field Crop Area	176.9
Natural (Ha)	32.5
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	167.1
Fallow Area (2020) Ha	11.5
Fallow Area (2019) Ha	8.9
Fallow Area (2018) Ha	9.7
Fallow Area (2017) Ha	8.7
Fallow Area (2017) Ha	10.2
Average Fallow (Ha)	9.8



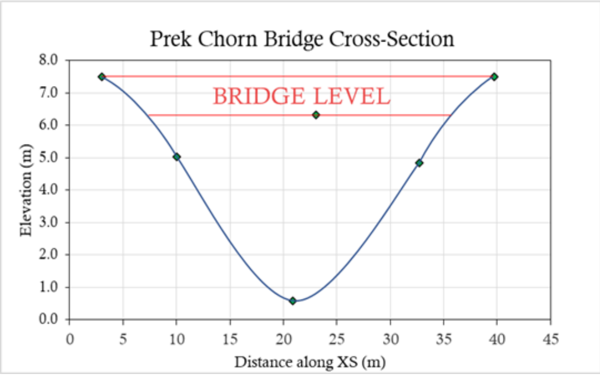
CHANNEL DIMENSIONS	
Channel Length	4.5 km
Channel Width	15 m
Inlet Bed Level	0.56 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.1 (m^3/s)
Flood peak	29.3 (m^3/s)
Av ETA(mm) in January (m3/s)	123.0 mm (0.113 m^3/s)
ETA (Feb)	99.0 mm (0.091 m^3/s)
ETA (March)	112.2 mm (0.103 m^3/s
ETA (April)	115.9 mm (0.107 m^3/s)

WAT4CAM	PREK CHORN	WM19/08052311



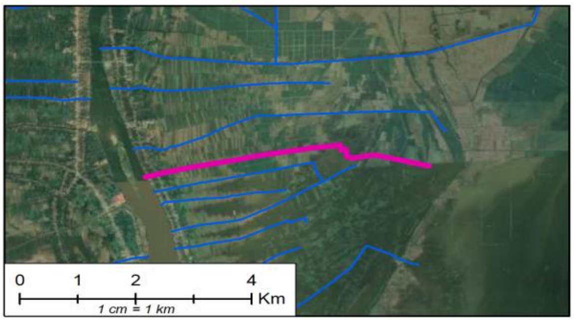


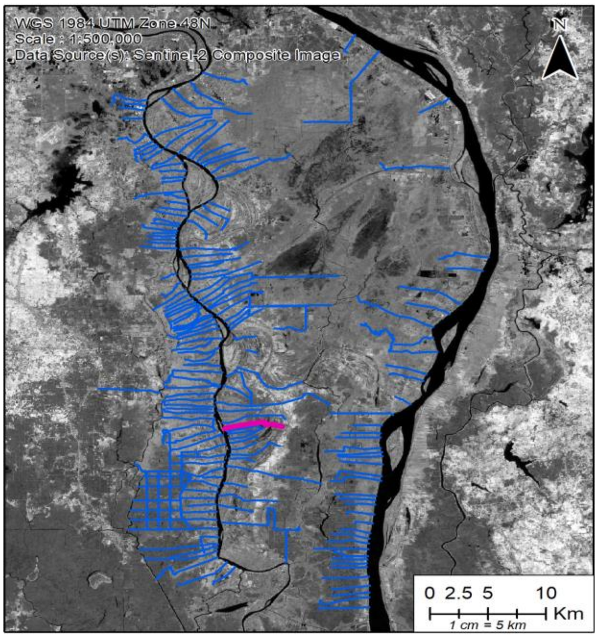
PREK CHORN	WM19
KEY FEATURES	
Classification	River Prek
CISIS Code	08052311
CISIS Area (ha)	207.2
Total Area (CISIS GIS)	326.1
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	6.0
Orchard Area (Ha)	24.3
Field Crop Area	248.9
Natural (Ha)	34.8
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	239.1
Fallow Area (2020) Ha	8.5
Fallow Area (2019) Ha	7.9
Fallow Area (2018) Ha	9.1
Fallow Area (2017) Ha	9.2
Fallow Area (2017) Ha	14.4
Average Fallow (Ha)	9.8



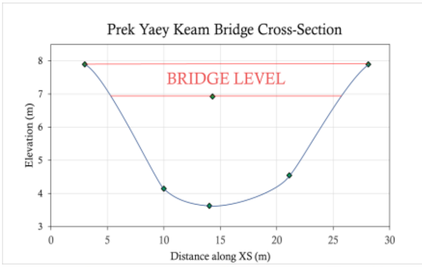
CHANNEL DIMENSIONS	
Channel Length	4.7 km
Channel Width	14 m
Inlet Bed Level	0.58 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.1 (m^3/s)
Flood peak	34.0 (m^3/s)
Av ETA(mm) in January (m3/s)	121.6 mm (0.148 m^3/s)
ETA (Feb)	99.0 mm (0.120 m^3/s)
ETA (March)	110.6 mm (0.135 m^3/s
ETA (April)	114.5 mm (0.139 m^3/s)

WAT4CAM	PREK YAEY KAEM	EA1 /08041594

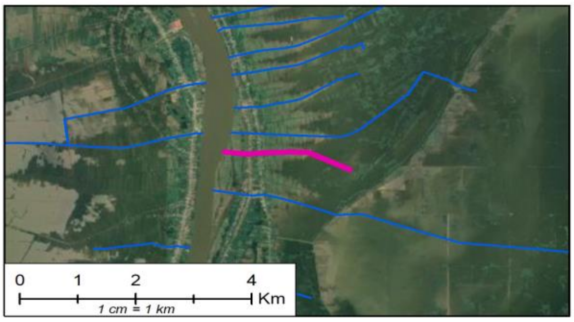


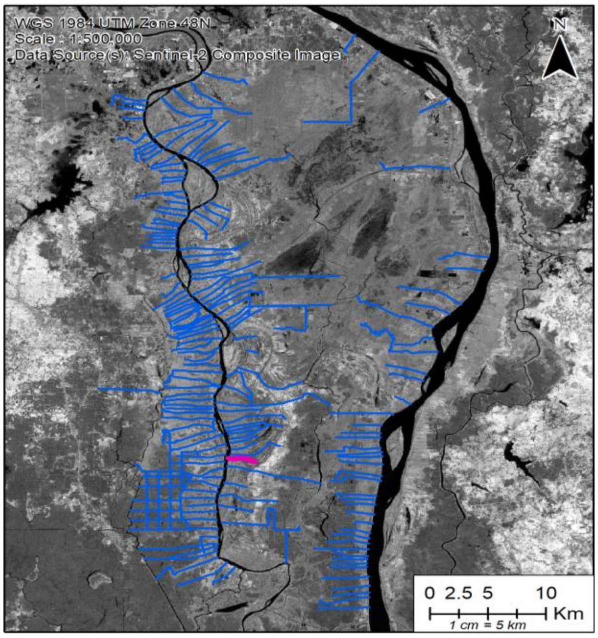


CHANNEL DIMENSIONS	
Channel Length	5.2 km
Channel Width	6 m
Inlet Bed Level	3.63 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041594
CISIS Area (ha)	343.7

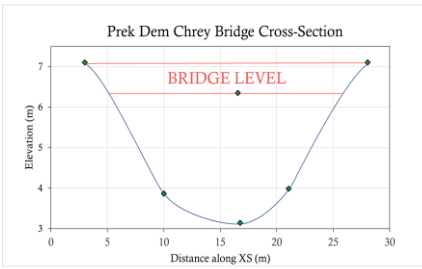


WAT4CAM	PREK DEM CHREY	EA2 /08041561

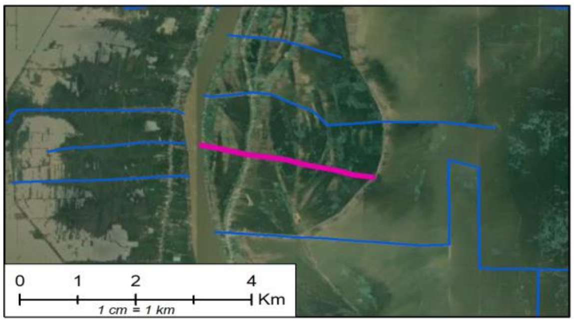


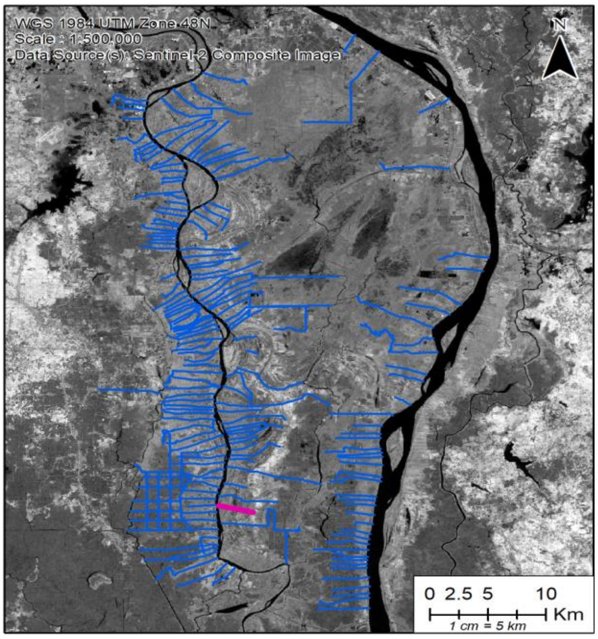


CHANNEL DIMENSIONS	
Channel Length	2.2 km
Channel Width	9 m
Inlet Bed Level	3.15 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041561
CISIS Area (ha)	86.9

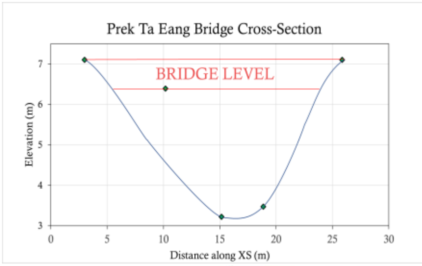


WAT4CAM	PREK TA EANG	EA3 /08041566

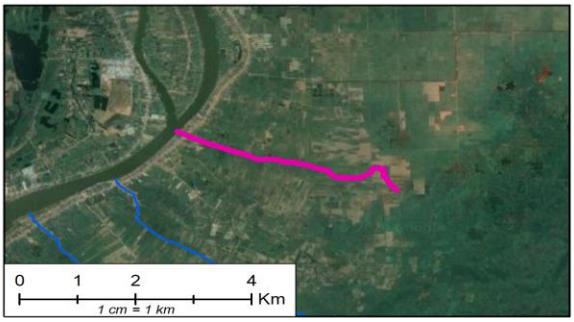


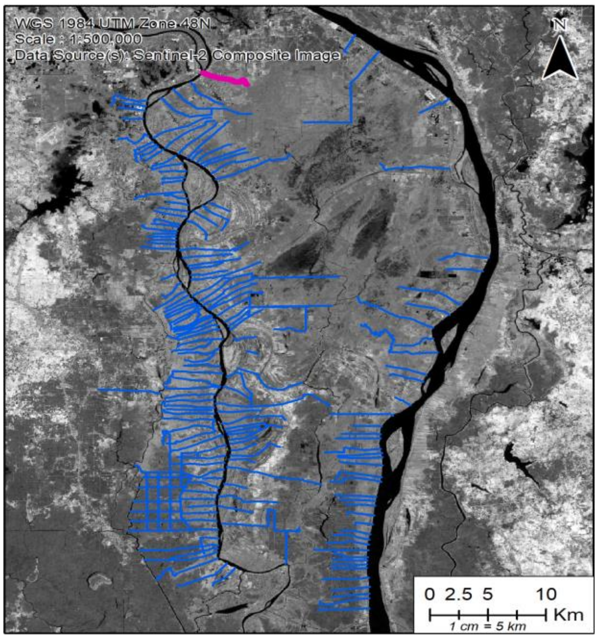


CHANNEL DIMENSIONS	
Channel Length	3.0 km
Channel Width	5 m
Inlet Bed Level	2.71 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041566
CISIS Area (ha)	281.9

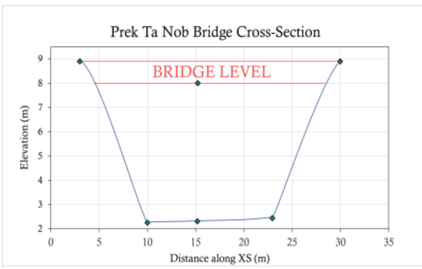


WAT4CAM	PREK TA NOB	EB1 /

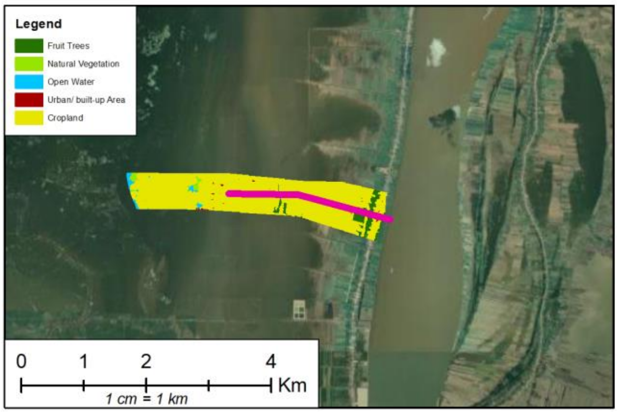


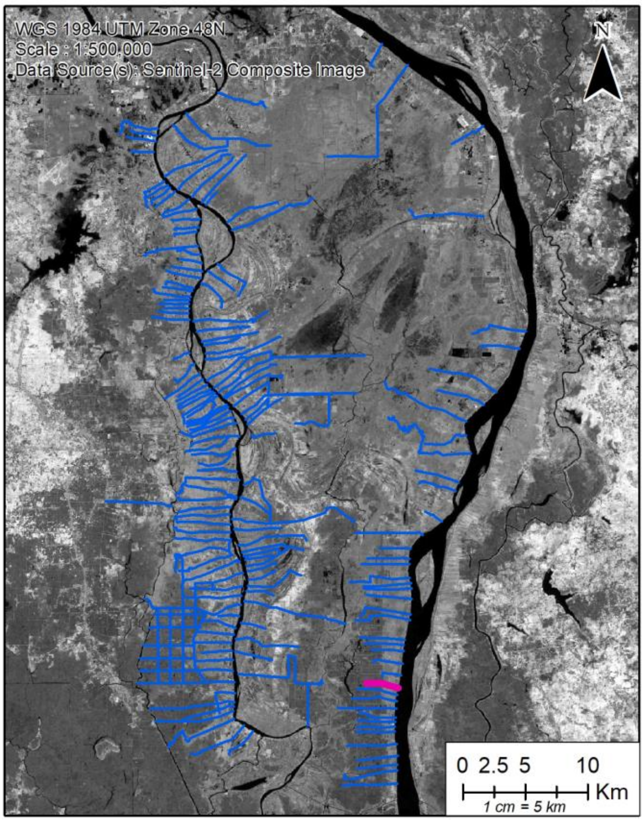


CHANNEL DIMENSIONS	
Channel Length	4.4 km
Channel Width	16 m
Inlet Bed Level	2.25 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0

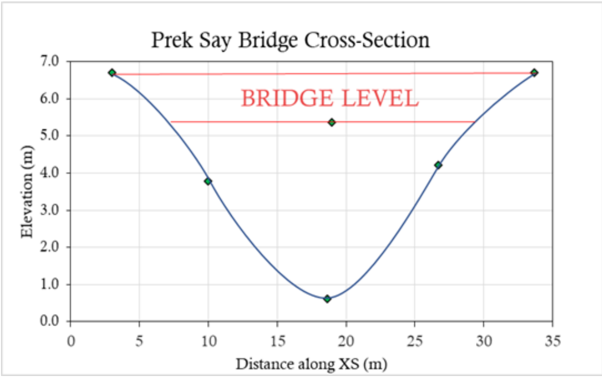


WAT4CAM	PREK SAY	WM25/08051461



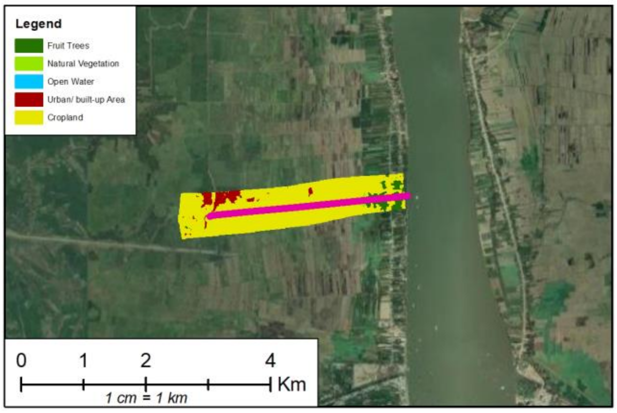


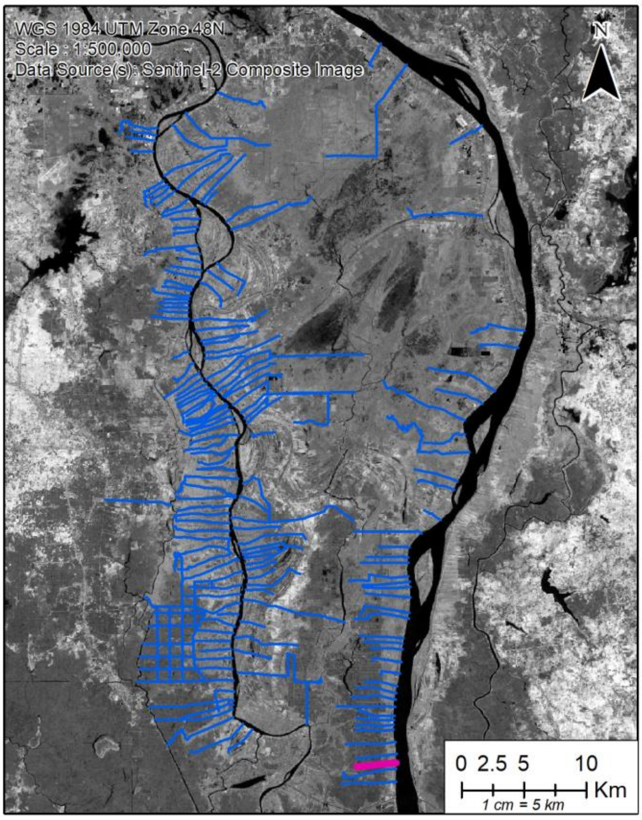
PREK SAY	WM25
KEY FEATURES	
Classification	River Prek
CISIS Code	08051461
CISIS Area (ha)	176.3
Total Area (CISIS GIS)	256.4
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	5.0
Orchard Area (Ha)	20.7
Field Crop Area	221.1
Natural (Ha)	5.7
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	210.8
Fallow Area (2020) Ha	9.8
Fallow Area (2019) Ha	10.0
Fallow Area (2018) Ha	7.3
Fallow Area (2017) Ha	10.7
Fallow Area (2017) Ha	13.7
Average Fallow (Ha)	10.3



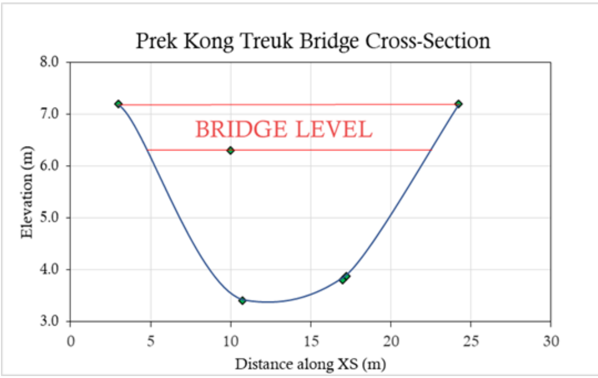
CHANNEL DIMENSIONS	
Channel Length	2.6 km
Channel Width	14 m
Inlet Bed Level	0.61 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	12.0 (m^3/s)
Av ETA(mm) in January (m3/s)	117.8 mm (0.113 m^3/s)
ETA (Feb)	95.4 mm (0.091 m^3/s)
ETA (March)	112.6 mm (0.108 m^3/s
ETA (April)	110.5 mm (0.106 m^3/s)

WAT4CAM	PREK KONG TREUK	WM35/08052317



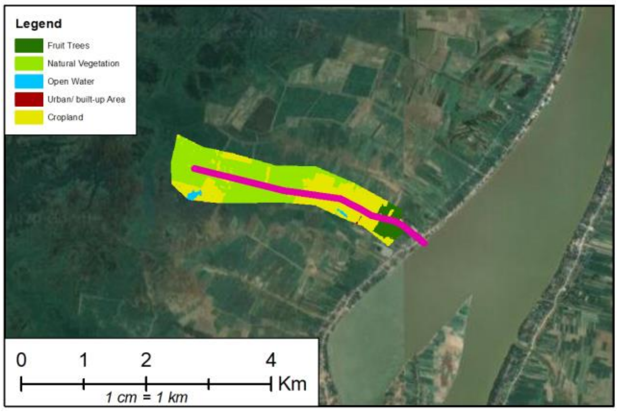


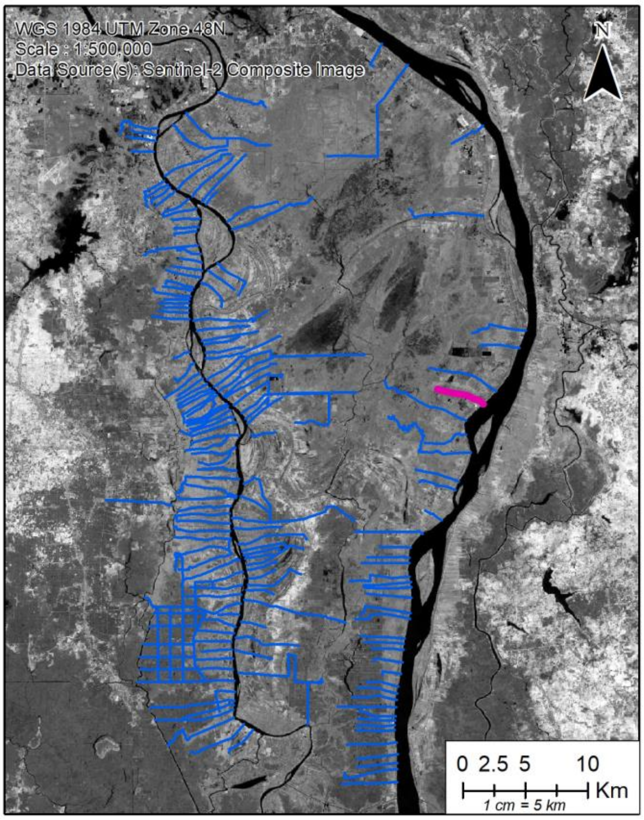
PREK KONG TREUK	WM35
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08052317
CISIS Area (ha)	190.5
Total Area (CISIS GIS)	238.6
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	3.1
Orchard Area (Ha)	18.1
Field Crop Area	199.6
Natural (Ha)	2.0
Area of Water (Ha)	0.0
Average Field Crop Harvest (Ha)	183.6
Fallow Area (2020) Ha	14.5
Fallow Area (2019) Ha	5.3
Fallow Area (2018) Ha	2.8
Fallow Area (2017) Ha	23.4
Fallow Area (2017) Ha	33.8
Average Fallow (Ha)	15.9



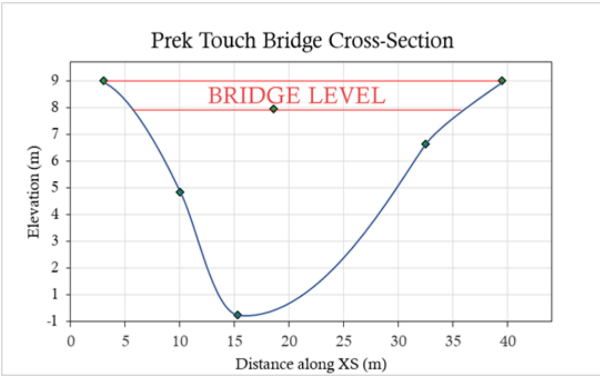
CHANNEL DIMENSIONS	
Channel Length	3.2 km
Channel Width	12 m
Inlet Bed Level	3.41 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	12.0 (m^3/s)
Av ETA(mm) in January (m3/s)	122.2 mm (0.109 m^3/s)
ETA (Feb)	110.7 mm (0.099 m^3/s)
ETA (March)	117.1 mm (0.104 m^3/s
ETA (April)	111.6 mm (0.099 m^3/s)

WAT4CAM	PREK TOUCH	WM38/08051455





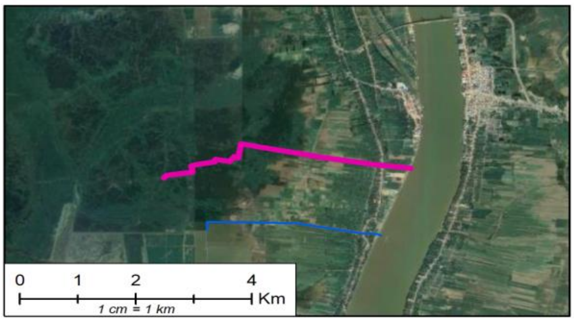
PREK TOUCH	WM36
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08051455
CISIS Area (ha)	506.0
Total Area (CISIS GIS)	257.6
Gates (Y/N)	N
Province	Kandal
LAND USE	
Urban Area (Ha)	3.9
Orchard Area (Ha)	18.3
Field Crop Area	106.9
Natural (Ha)	126.5
Area of Water (Ha)	4.6
Average Field Crop Harvest (Ha)	97.4
Fallow Area (2020) Ha	9.5
Fallow Area (2019) Ha	7.4
Fallow Area (2018) Ha	3.4
Fallow Area (2017) Ha	15.9
Fallow Area (2017) Ha	11.2
Average Fallow (Ha)	9.5

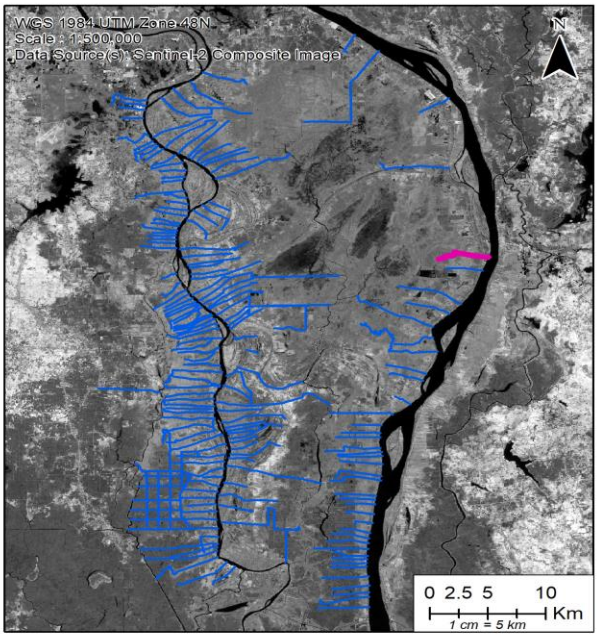


CHANNEL DIMENSIONS	
Channel Length	3.9 km
Channel Width	9 m
Inlet Bed Level	3.49 (m AHD)
FLOW	
Dry Season Min (m3/s)	0.0 (m^3/s)
Flood peak	12.5 (m^3/s)
Av ETA(mm) in January (m3/s)	117.5 mm (0.113 m^3/s)
ETA (Feb)	97.6 mm (0.094 m^3/s)
ETA (March)	113.8 mm (0.109 m^3/s
ETA (April)	116.8 mm (0.112 m^3/s)

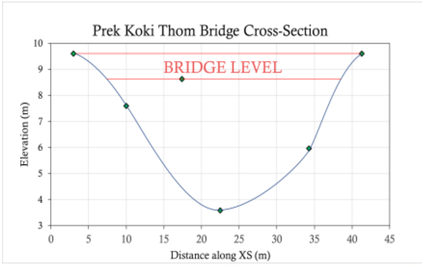
West Mekong Phase 2

WAT4CAM	PREK SPEAN DEK	WM1 /08051450

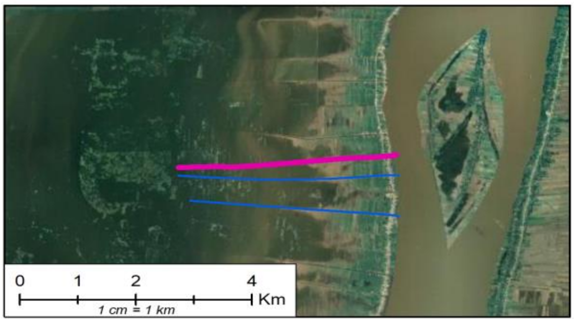


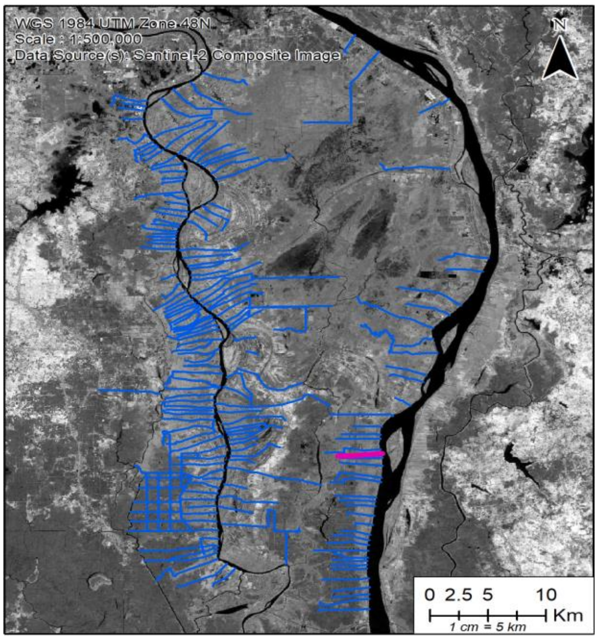


CHANNEL DIMENSIONS	
Channel Length	4.8 km
Channel Width	10 m
Inlet Bed Level	3.59 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08051450
CISIS Area (ha)	187.0

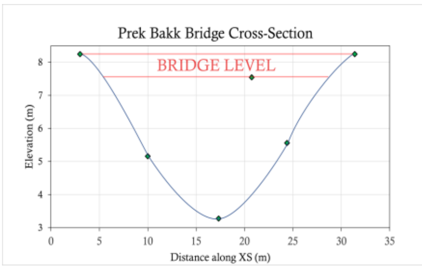


WAT4CAM	PREK CHIN SOK	WM15/08051445

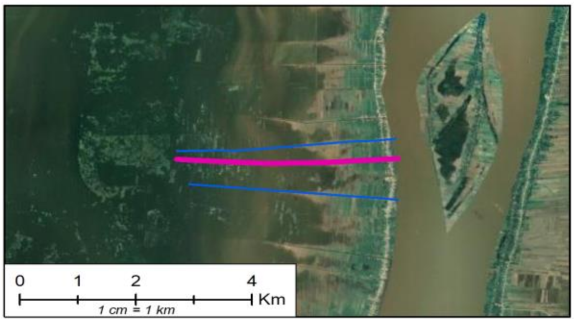


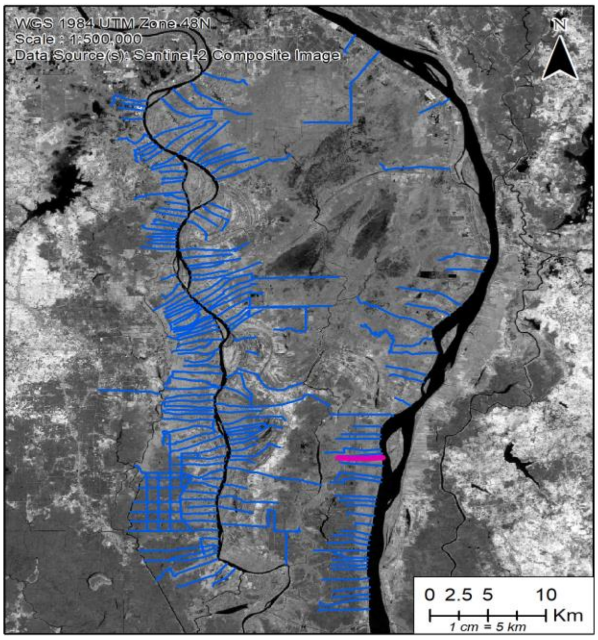


CHANNEL DIMENSIONS	
Channel Length	3.8 km
Channel Width	9 m
Inlet Bed Level	0.37 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08051445
CISIS Area (ha)	315.3

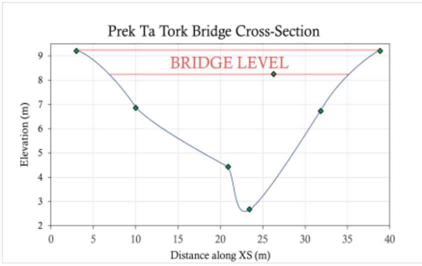


WAT4CAM	PREK BAKK TOUK	WM16/08052306

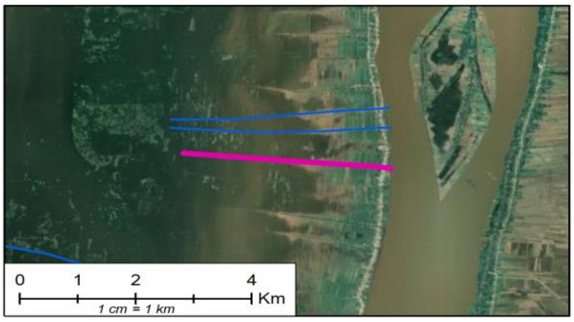


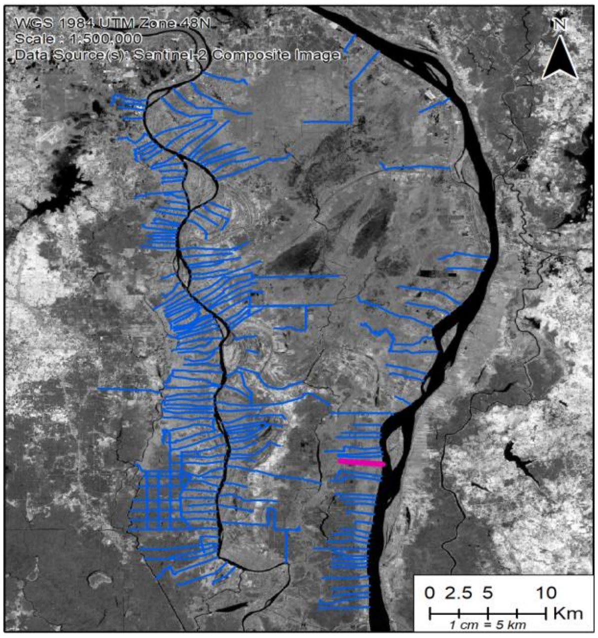


CHANNEL DIMENSIONS	
Channel Length	3.8 km
Channel Width	11 m
Inlet Bed Level	0.27 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08052306
CISIS Area (ha)	272.6

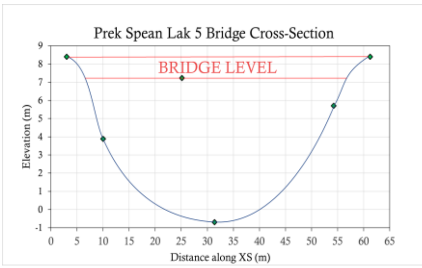


WAT4CAM	PREK YEAY KAM	WM17/08052334

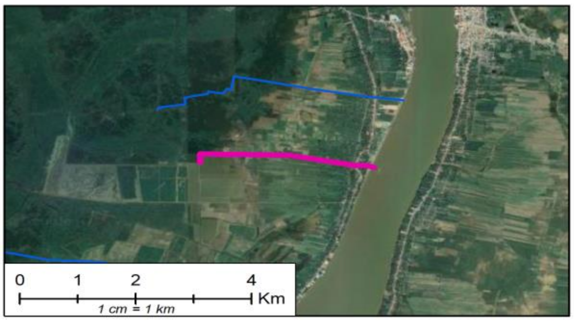


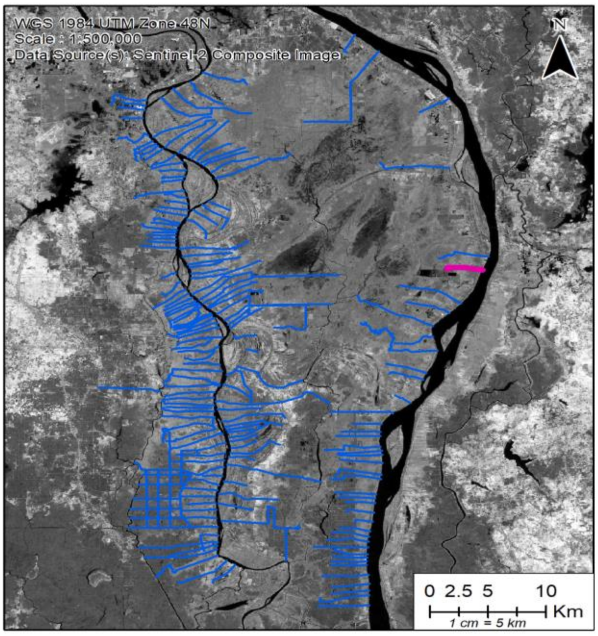


CHANNEL DIMENSIONS	
Channel Length	3.6 km
Channel Width	10 m
Inlet Bed Level	0.52 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08052334
CISIS Area (ha)	241.9

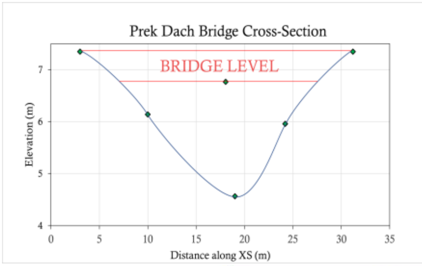


WAT4CAM	PREK BAKK	WM2 /08052307

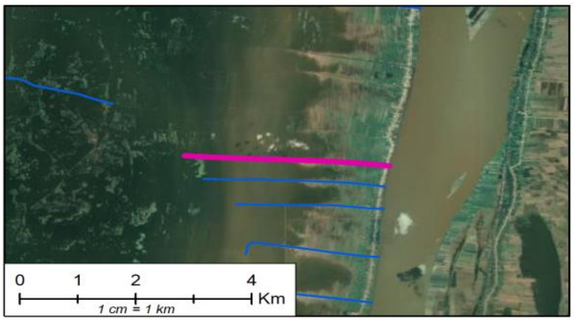


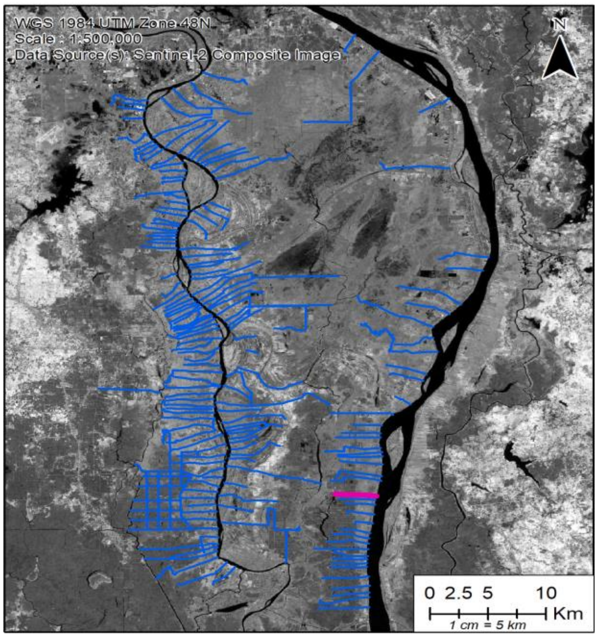


CHANNEL DIMENSIONS	
Channel Length	3.2 km
Channel Width	10 m
Inlet Bed Level	3.27 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08052307
CISIS Area (ha)	169.5

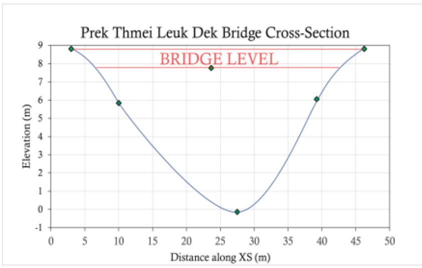


WAT4CAM	PREK BANH CHHAEV	WM20/08052309

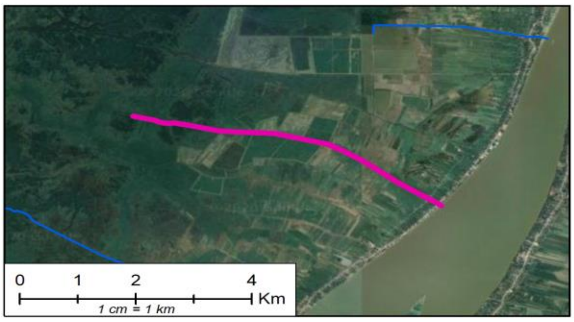


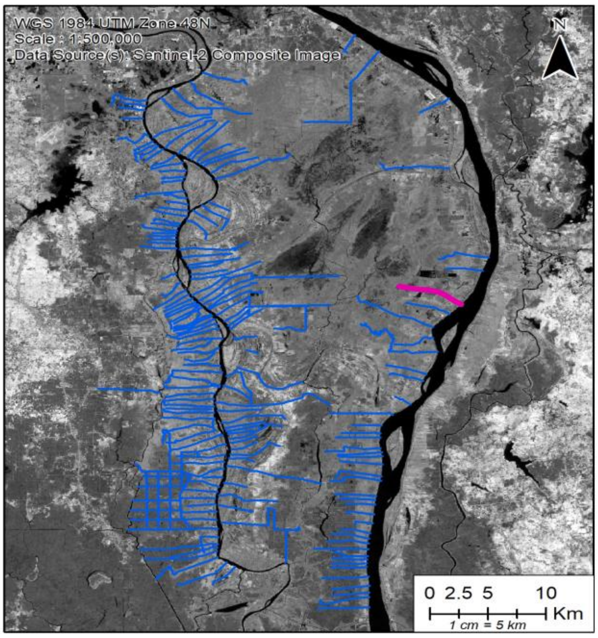


CHANNEL DIMENSIONS	
Channel Length	3.5 km
Channel Width	12 m
Inlet Bed Level	0.40 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08052309
CISIS Area (ha)	157.3

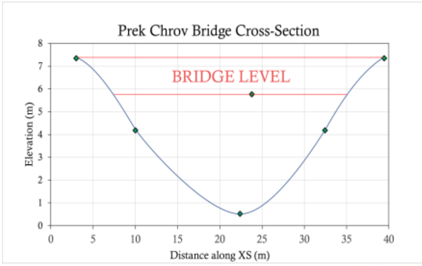


WAT4CAM	PREK TA TORK	WM3 /08051449

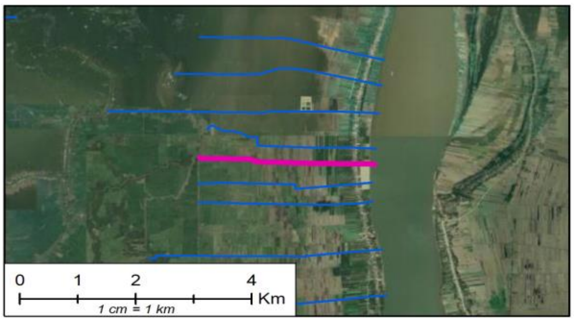


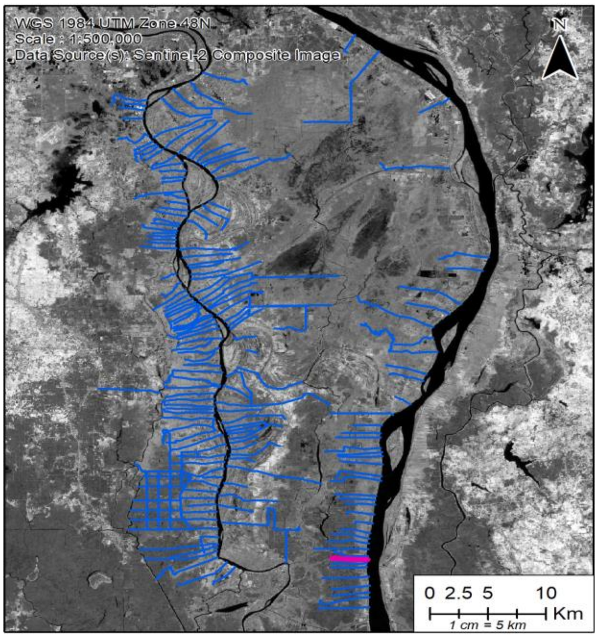


CHANNEL DIMENSIONS	
Channel Length	5.8 km
Channel Width	11 m
Inlet Bed Level	2.67 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08051449
CISIS Area (ha)	184.8

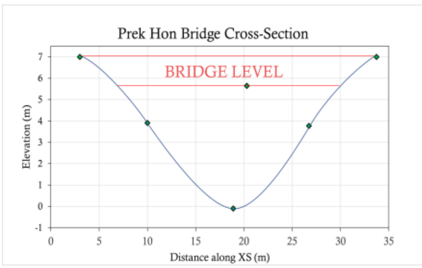


WAT4CAM	PREK SAMAKI	WM30/08052322

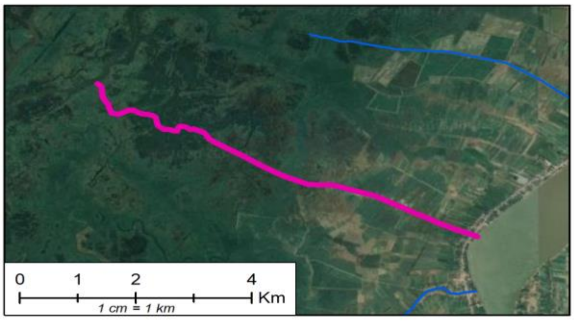


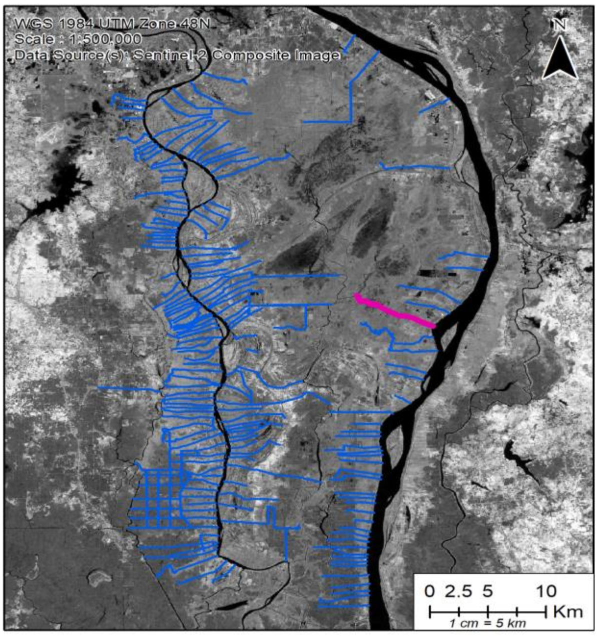


CHANNEL DIMENSIONS	
Channel Length	3.0 km
Channel Width	9 m
Inlet Bed Level	2.34 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08052322
CISIS Area (ha)	95.5

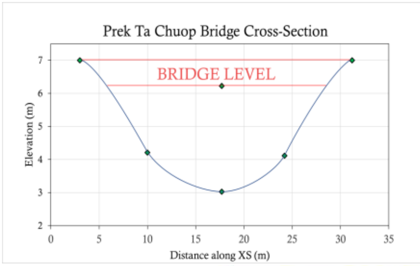


WAT4CAM	PREK SPEAN LAK 5	WM4 /

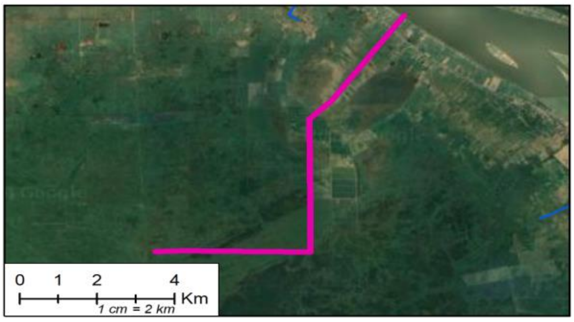


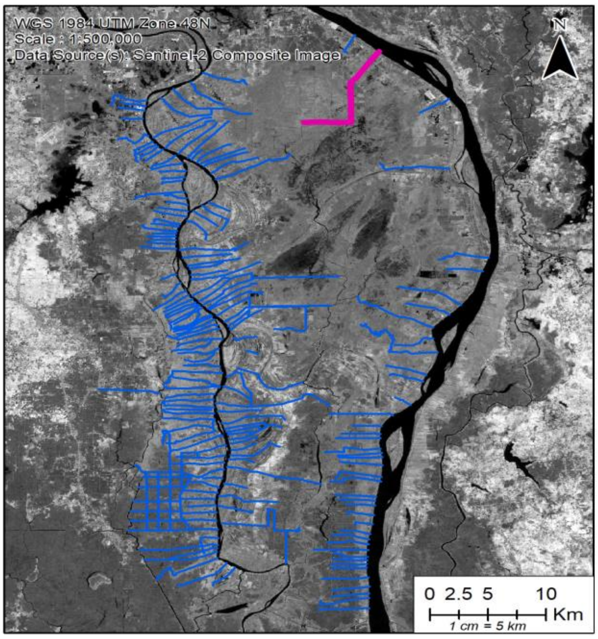


CHANNEL DIMENSIONS	
Channel Length	7.9 km
Channel Width	16 m
Inlet Bed Level	-0.69 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	N/A
CISIS Area (ha)	0.0

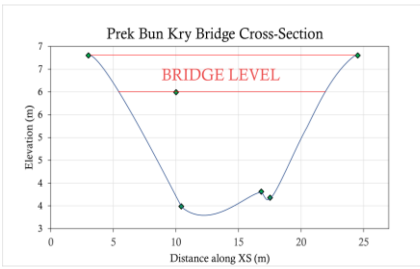


WAT4CAM	PREK YUON	WM40/08022335

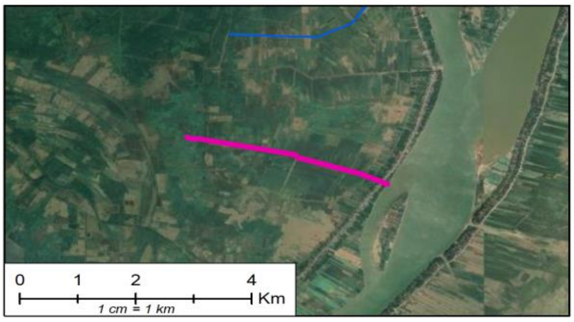


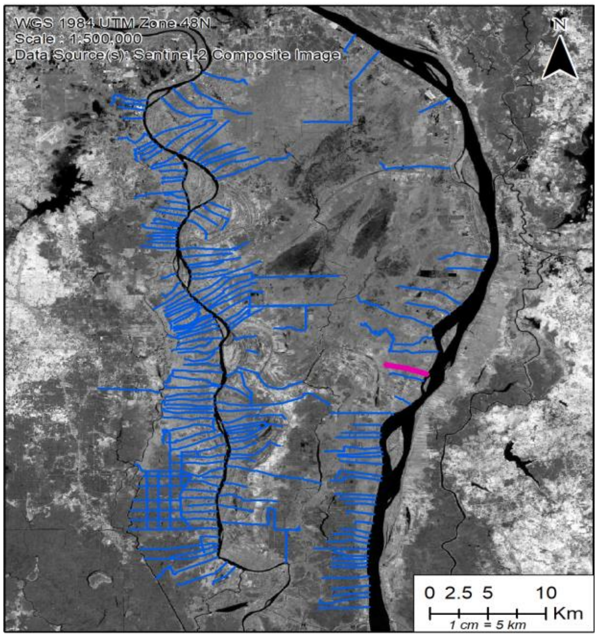


CHANNEL DIMENSIONS	
Channel Length	12.2 km
Channel Width	14 m
Inlet Bed Level	3.26 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08022335
CISIS Area (ha)	380.7



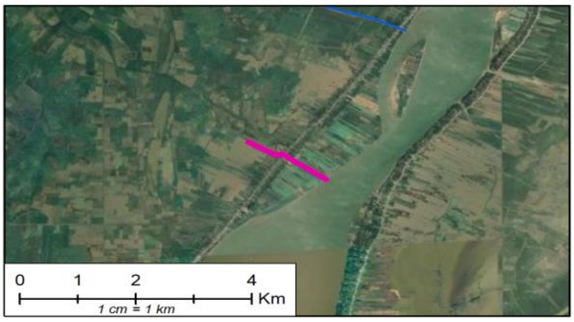
WAT4CAM	PREK THMEI LEUK DEK	WM7 /08051460

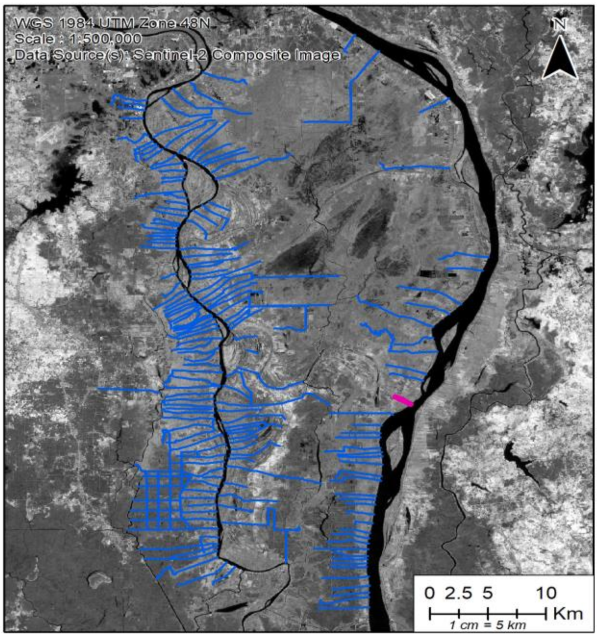




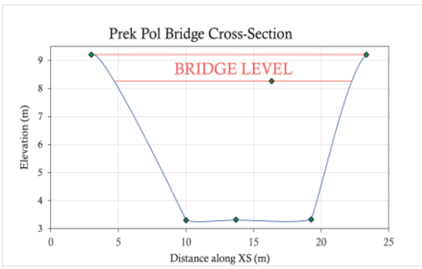
CHANNEL DIMENSIONS	
Channel Length	3.6 km
Channel Width	11 m
Inlet Bed Level	-0.14 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08051460
CISIS Area (ha)	295.4

WAT4CAM	PREK WAT	WM9 /08051459

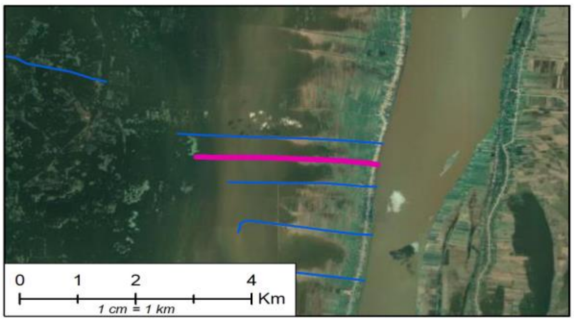


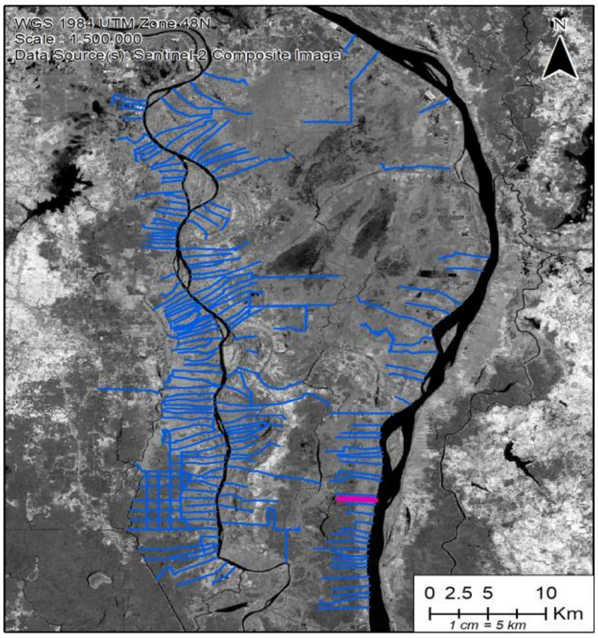


CHANNEL DIMENSIONS	
Channel Length	1.6 km
Channel Width	8 m
Inlet Bed Level	1.52 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08051459
CISIS Area (ha)	177.4

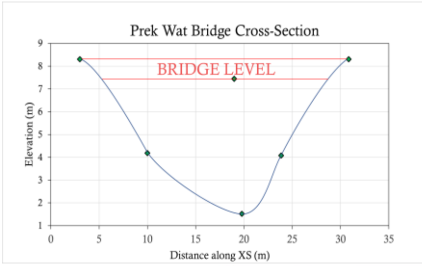


WAT4CAM	PREK PAK	WM21/08052320

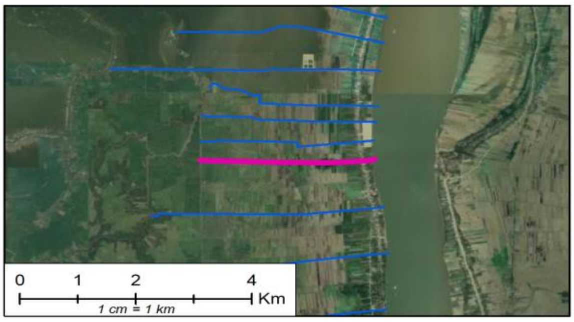


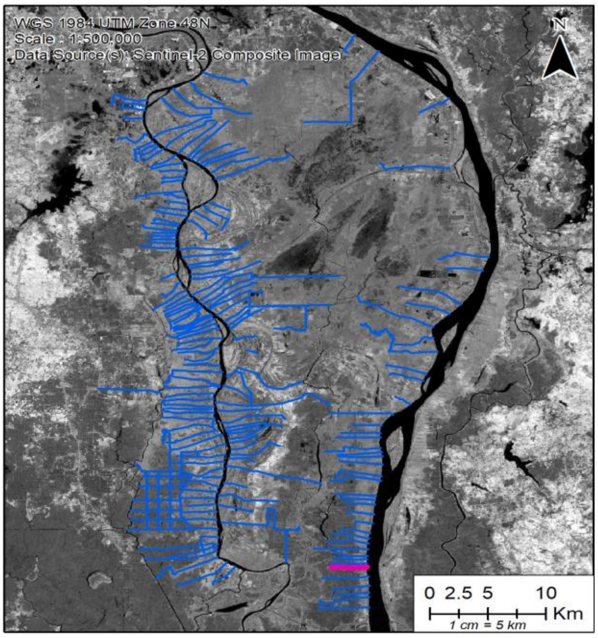


CHANNEL DIMENSIONS	
Channel Length	3.1 km
Channel Width	12 m
Inlet Bed Level	0.63 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08052320
CISIS Area (ha)	135.2

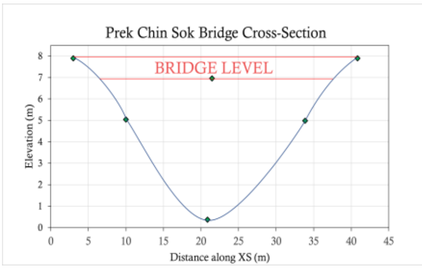


WAT4CAM	PREK KOH ROKA	WM22/

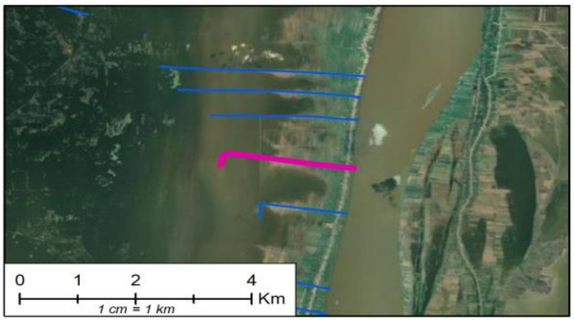


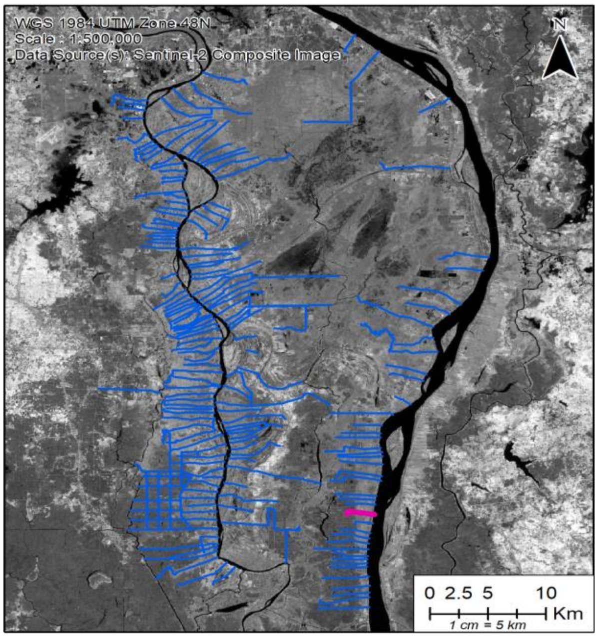


CHANNEL DIMENSIONS	
Channel Length	3.0 km
Channel Width	10 m
Inlet Bed Level	2.49 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	N/A
CISIS Area (ha)	0.0

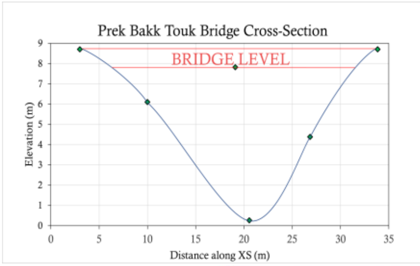


WAT4CAM | PREK NOY | WM23/08051452

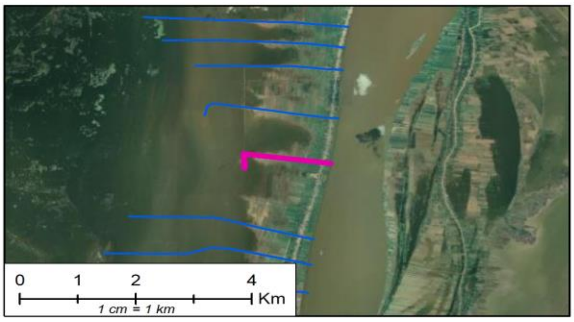


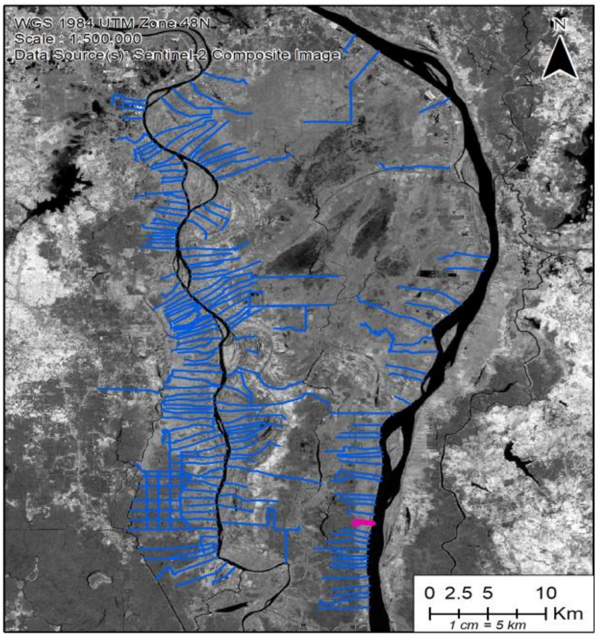


CHANNEL DIMENSIONS	
Channel Length	2.5 km
Channel Width	10 m
Inlet Bed Level	0.12 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08051452
CISIS Area (ha)	147.9

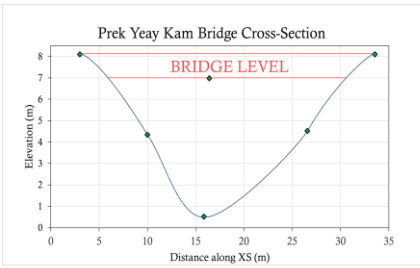


WAT4CAM | PREK CHROV | WM24/08052312

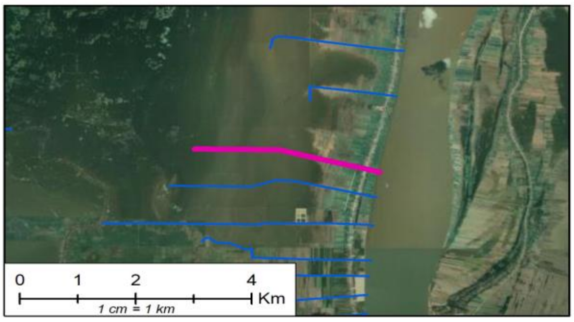


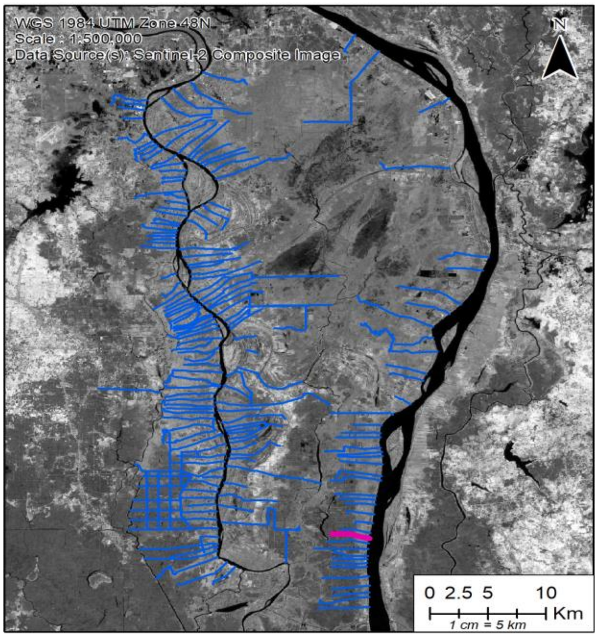


CHANNEL DIMENSIONS	
Channel Length	1.8 km
Channel Width	10 m
Inlet Bed Level	0.52 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08052312
CISIS Area (ha)	146.3

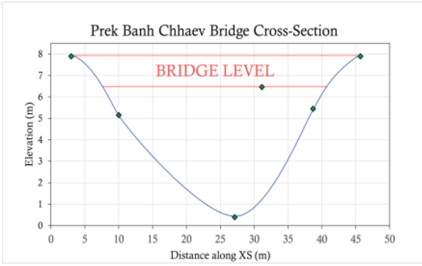


WAT4CAM	PREK HON	WM26/08052315

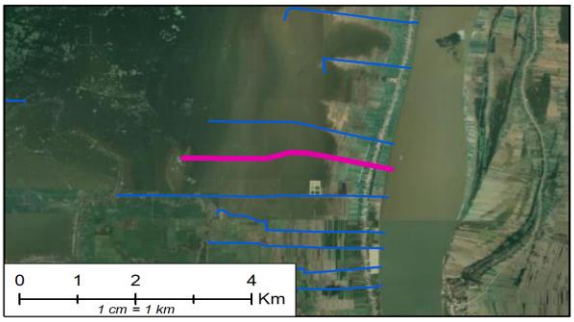


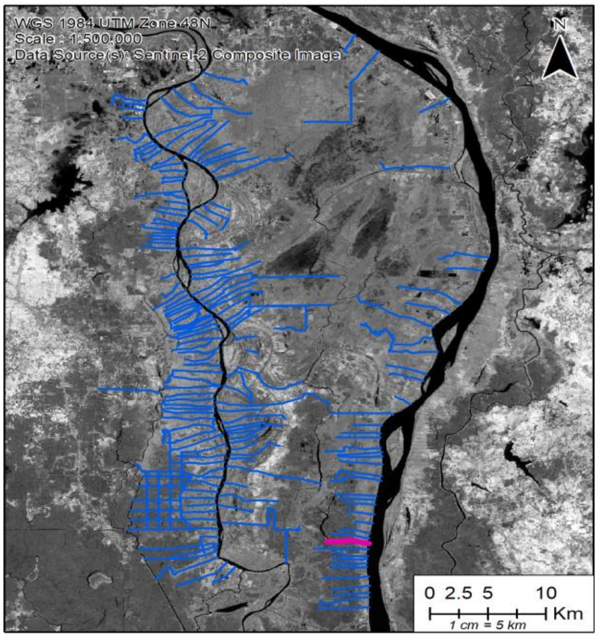


CHANNEL DIMENSIONS	
Channel Length	3.2 km
Channel Width	12 m
Inlet Bed Level	-0.10 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08052315
CISIS Area (ha)	280.3

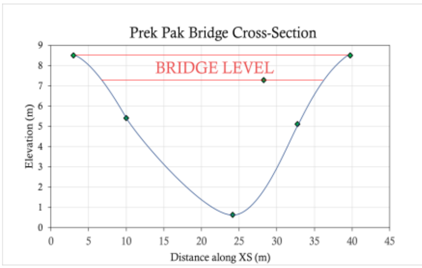


WAT4CAM	PREK TA CHHEANG	WM27/08052324

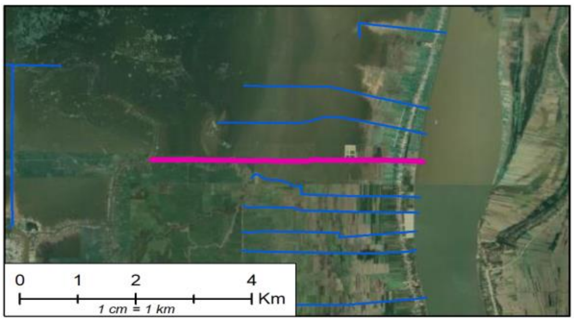


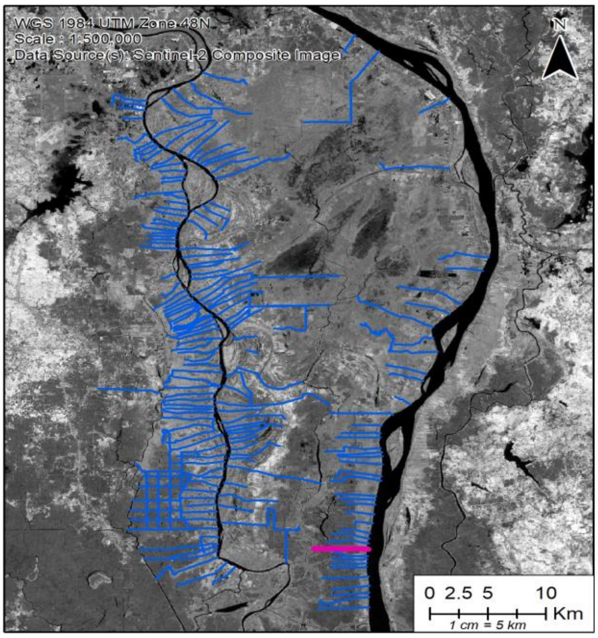


CHANNEL DIMENSIONS	
Channel Length	3.6 km
Channel Width	11 m
Inlet Bed Level	0.64 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08052324
CISIS Area (ha)	442.8

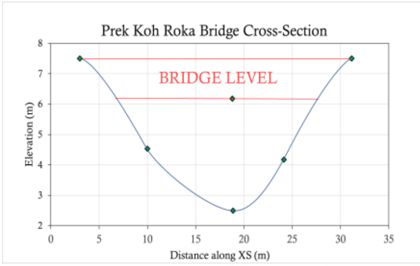


WAT4CAM	PREK TA SOUM	WM28/ 08051453

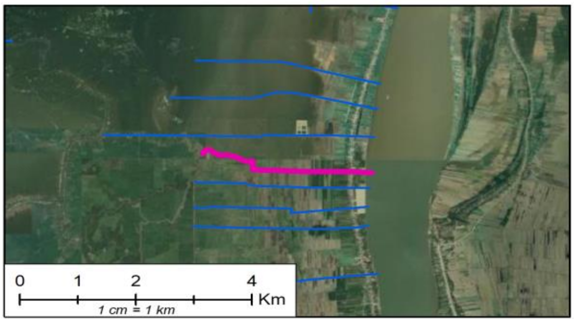


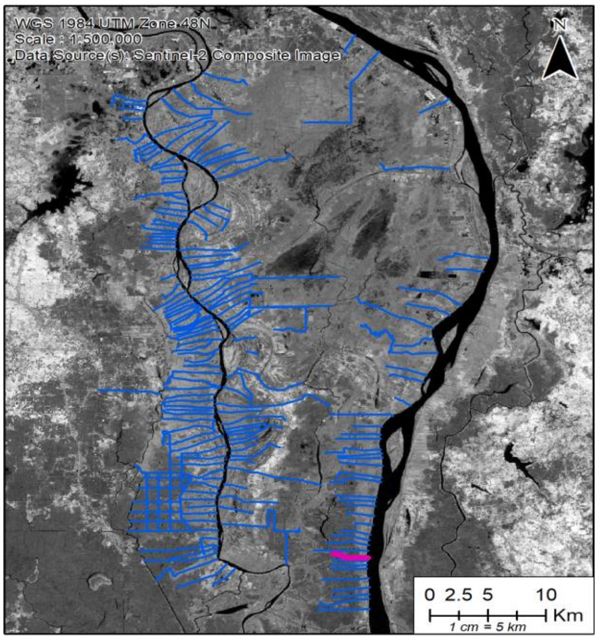


CHANNEL DIMENSIONS	
Channel Length	4.7 km
Channel Width	13 m
Inlet Bed Level	-0.46 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08051453
CISIS Area (ha)	279.4

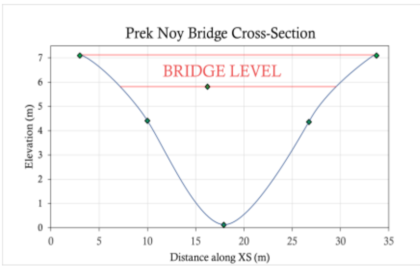


WAT4CAM	TA VANN CANAL	WM29/ 08052346

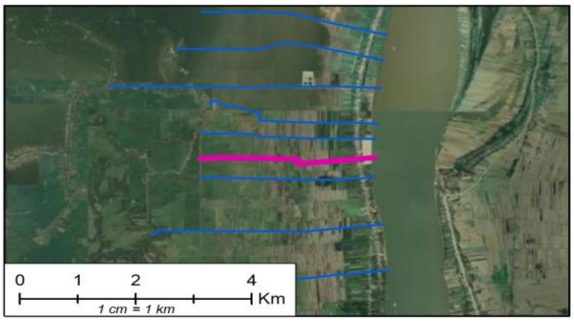


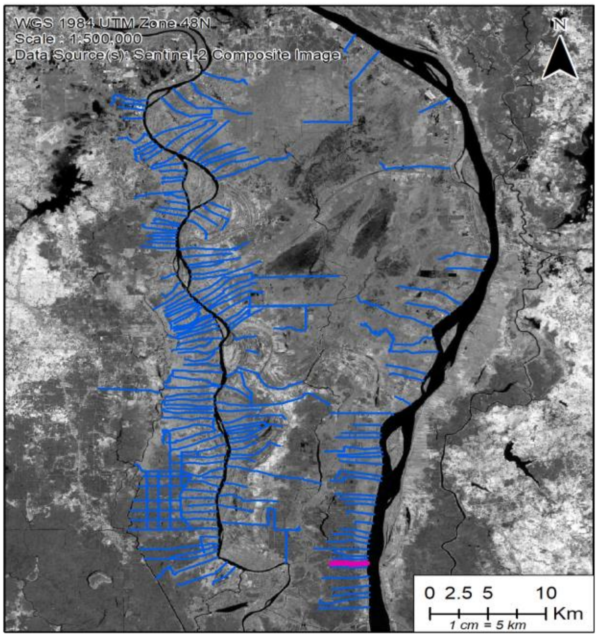


CHANNEL DIMENSIONS	
Channel Length	3.2 km
Channel Width	10 m
Inlet Bed Level	3.11 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08052346
CISIS Area (ha)	148.3

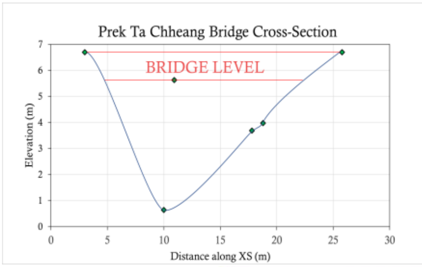


WAT4CAM	PREK TA NHOR	WM31/08052327

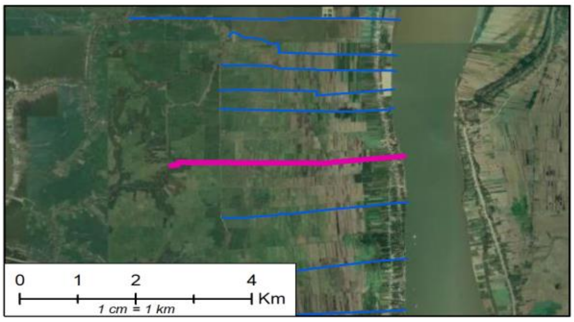


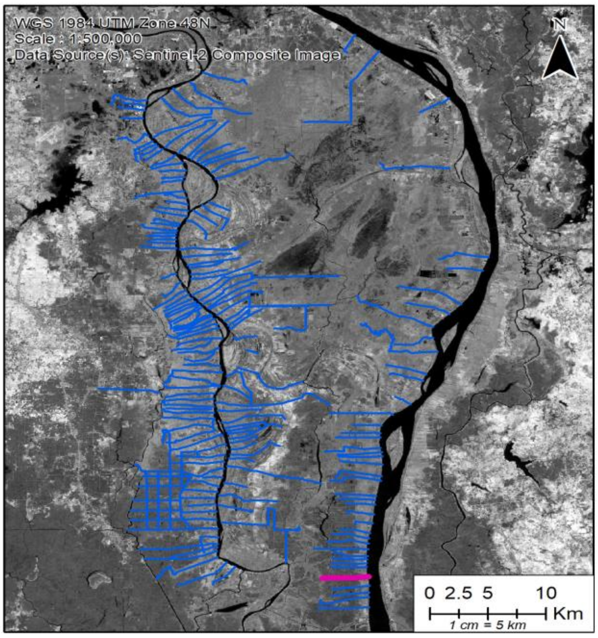


CHANNEL DIMENSIONS	
Channel Length	3.1 km
Channel Width	8 m
Inlet Bed Level	3.05 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08052327
CISIS Area (ha)	114.5



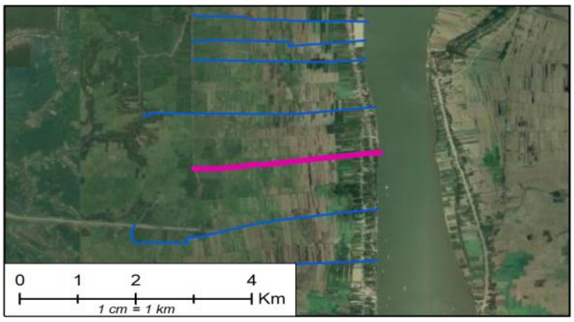
WAT4CAM	PREK TA MEAN	WM33/08051456

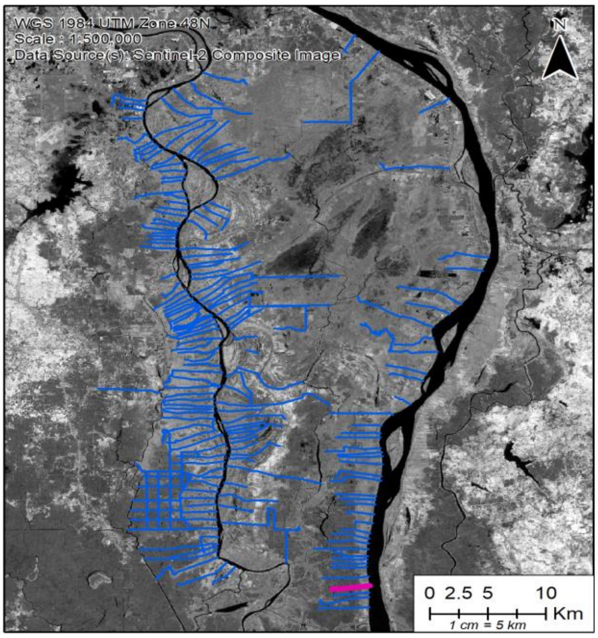




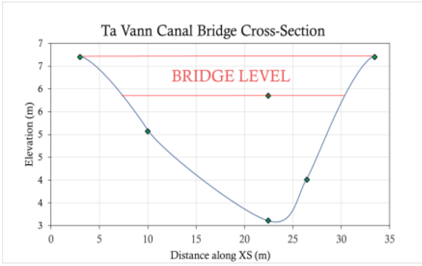
CHANNEL DIMENSIONS	
Channel Length	4.0 km
Channel Width	9 m
Inlet Bed Level	3.72 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08051456
CISIS Area (ha)	216.6

WAT4CAM	PREK TA CHUOP	WM34/08052325

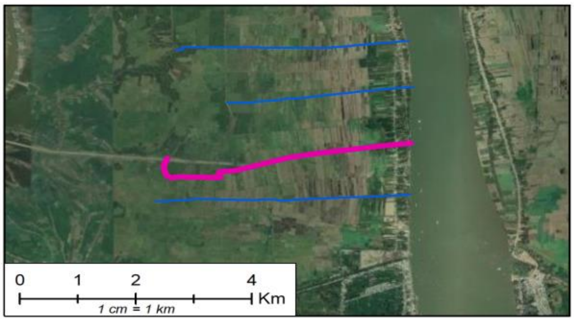


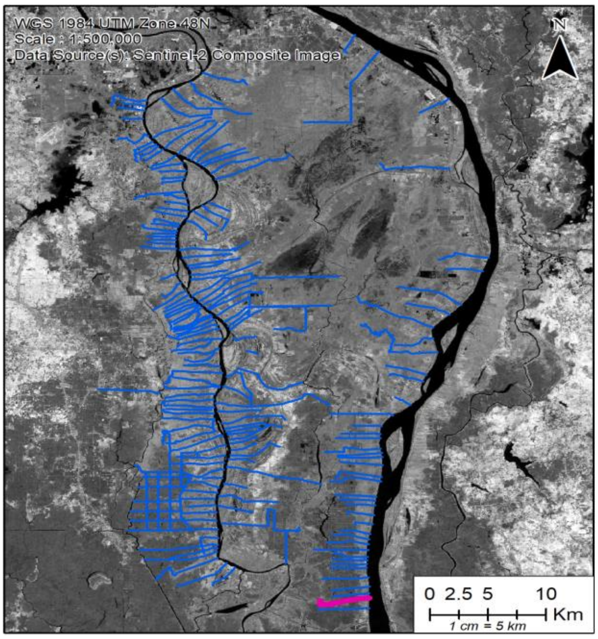


CHANNEL DIMENSIONS	
Channel Length	3.2 km
Channel Width	10 m
Inlet Bed Level	3.03 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08052325
CISIS Area (ha)	198.3

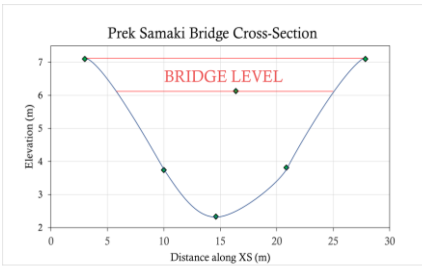


WAT4CAM	PREK BUN KRY	WM36/08052310

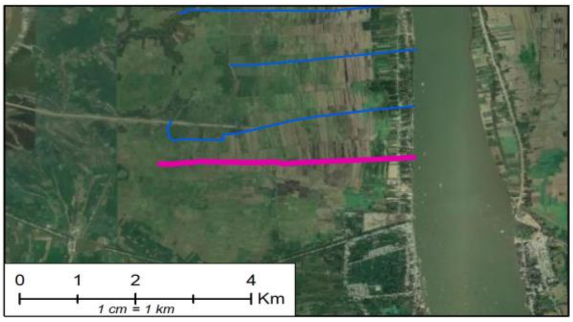


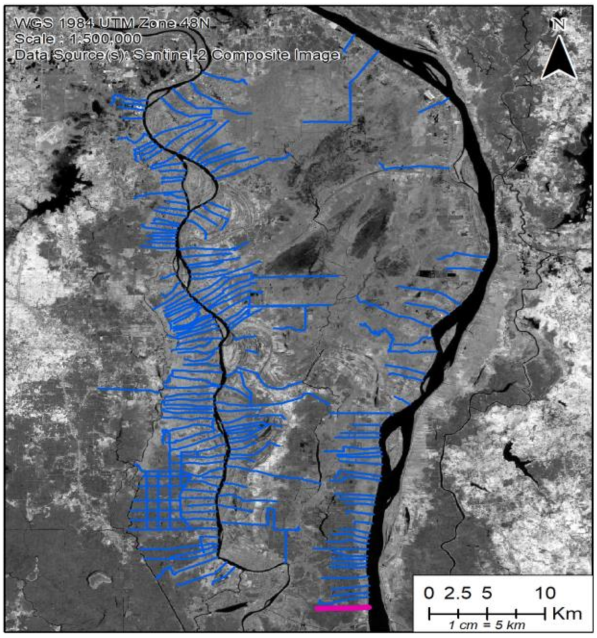


CHANNEL DIMENSIONS	
Channel Length	4.8 km
Channel Width	9 m
Inlet Bed Level	3.49 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08052310
CISIS Area (ha)	215.4

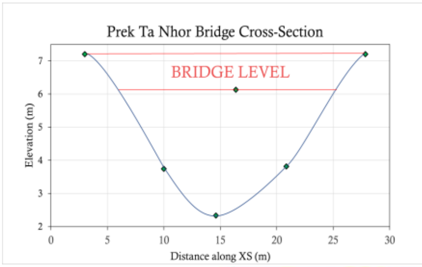


WAT4CAM | PREK APECH | WM37/08052305

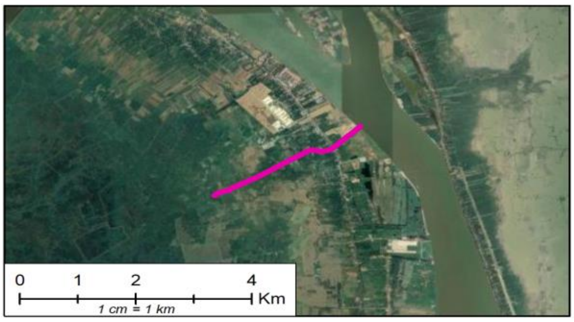


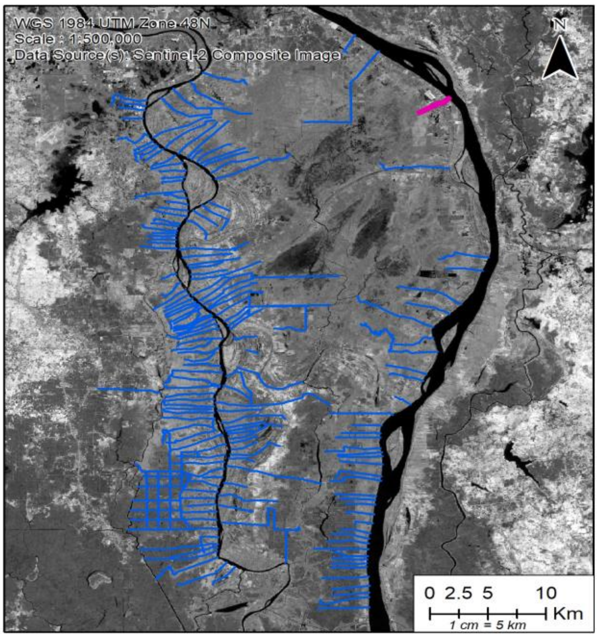


CHANNEL DIMENSIONS	
Channel Length	4.4 km
Channel Width	8 m
Inlet Bed Level	1.66 m AD
KEY FEATURES	
Classification	River Prek
CISIS Code	08052305
CISIS Area (ha)	156.1

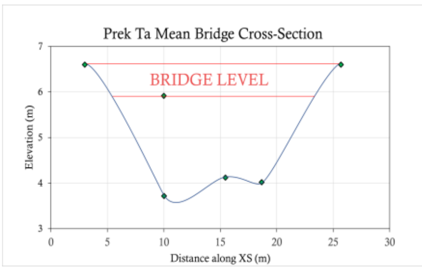


WAT4CAM | PREK CHREY | WM39/08021867

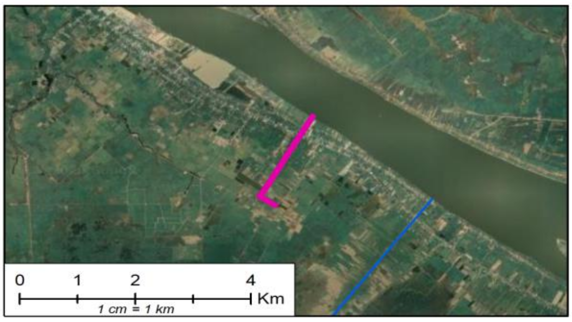


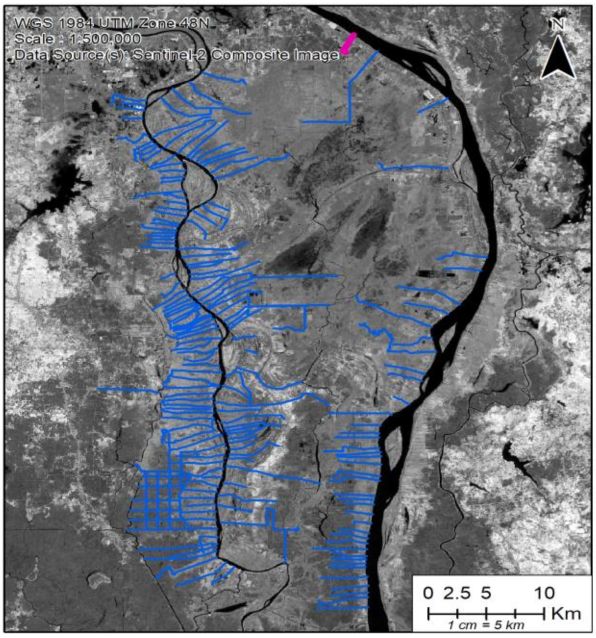


CHANNEL DIMENSIONS	
Channel Length	3.0 km
Channel Width	13 m
Inlet Bed Level	2.96 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08021867
CISIS Area (ha)	96.7

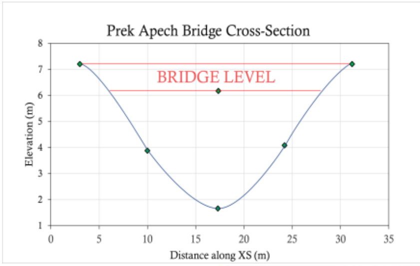


WAT4CAM	PREK POL	WM41/08021812

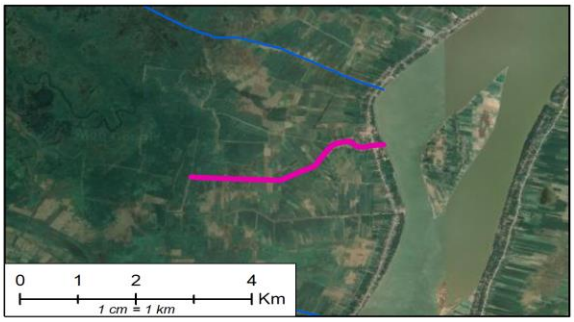


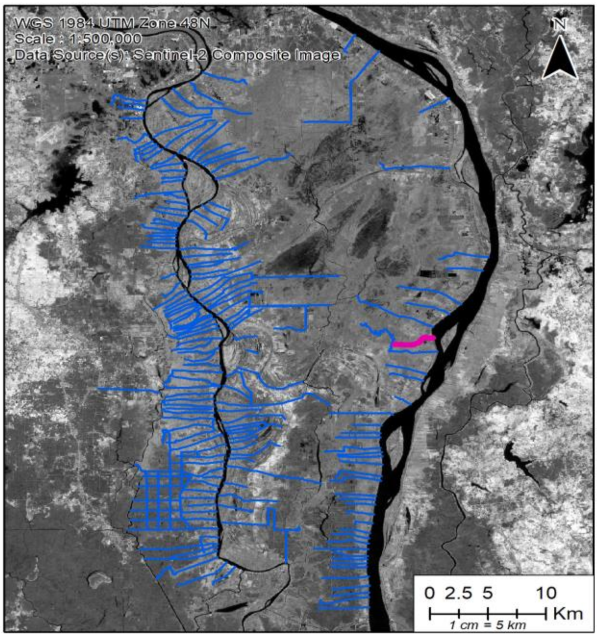


CHANNEL DIMENSIONS	
Channel Length	2.2 km
Channel Width	12 m
Inlet Bed Level	3.31 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08021812
CISIS Area (ha)	298.2

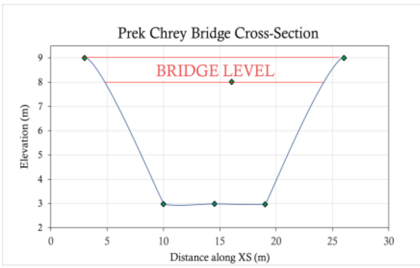


WAT4CAM	PREK DACH	WM5 /08052313

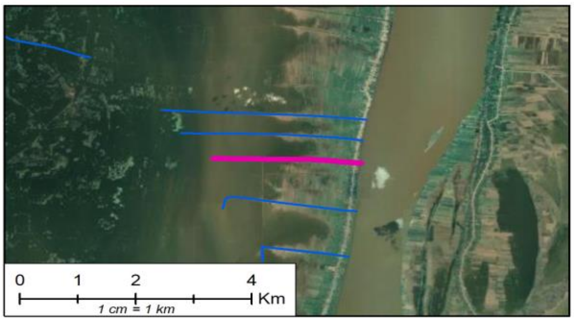


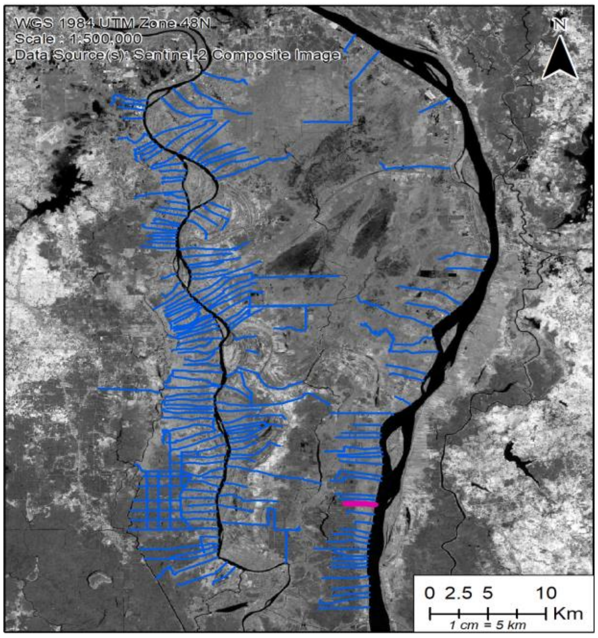


CHANNEL DIMENSIONS	
Channel Length	3.7 km
Channel Width	8 m
Inlet Bed Level	4.57 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08052313
CISIS Area (ha)	113.3

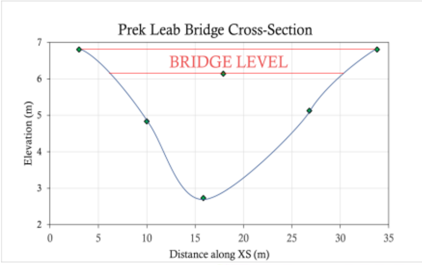


WAT4CAM	PREK LEAB	WG22/08051451

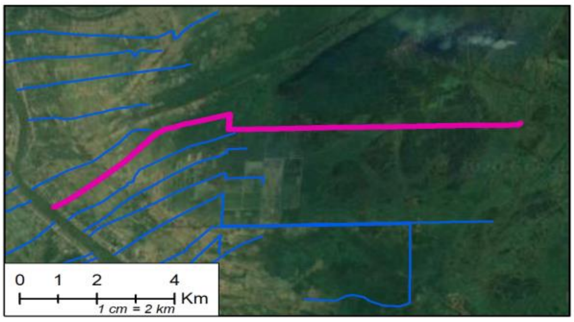


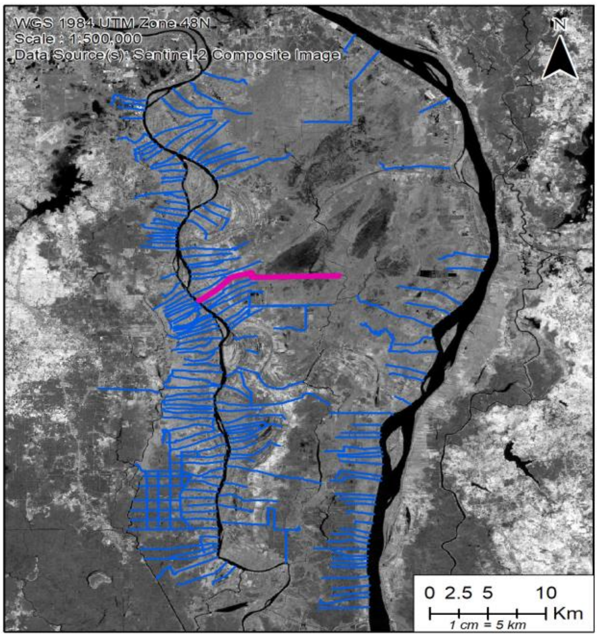


CHANNEL DIMENSIONS	
Channel Length	2.6 km
Channel Width	12 m
Inlet Bed Level	2.73 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08051451
CISIS Area (ha)	203.1

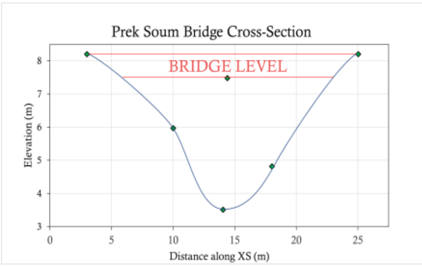


WAT4CAM	PREK SOUM	WG26/08041580





CHANNEL DIMENSIONS	
Channel Length	13.5 km
Channel Width	12 m
Inlet Bed Level	3.51 m AD
KEY FEATURES	
Classification	Agri Prek
CISIS Code	08041580
CISIS Area (ha)	222.8



14 APPENDIX 4 TABULATION OF WATER LEVELS BY RIVER DISTANCE AND MONTH

A4.1 Approach

To tabulate the water levels for each day and each kilometre along the Bassac requires assumptions on what is a typical condition for the present and future. Analysis in section 7 of water levels and flows In the last five years indicate change from the longer term mean, which has been attributed to the development and operation of the upstream dams affecting particularly the Tonle Sap Lake during the wet season and subsequently the dry season flows and levels in the lower basin below Phnom Penh. The tides have also been analysed and clearly have a strong impact around the mean level especially when flows are low.

The tabulation given thus gives:

1. A water level assuming a median flow and level as observed in the last five years (2016-2020) rather than the long-term average. This mostly results in lower levels especially early in the season
2. That tides are accounted for separately and will be a rise and fall above the median level given.

The water levels at the head of any Prek can thus be determined if the distance from Phnom Penh Chaktomuk gauge is measured.

Table 14.1 Median Water Levels (to datum) along the Mekong from Chaktomuk to the Vietnam Border through the Dry Season tabulated every 5km and 5 days November-May. Tide fluctuations above and below should be expected as well as natural variations. Analysis based on the period 2015-2020 only due to significant change (low levels)

Distance (Km) from Chaktomuk	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	97
Date	Chaktomuk											Neak Loueng								Border
15-Nov	4.53	4.46	4.40	4.33	4.27	4.20	4.14	4.08	4.01	3.95	3.88	3.82	3.74	3.67	3.59	3.51	3.44	3.36	3.28	3.17
20-Nov	4.18	4.13	4.07	4.02	3.96	3.91	3.85	3.80	3.75	3.69	3.64	3.58	3.51	3.43	3.35	3.28	3.20	3.13	3.05	2.95
25-Nov	3.84	3.79	3.75	3.70	3.66	3.61	3.57	3.52	3.48	3.43	3.39	3.34	3.27	3.19	3.12	3.05	2.97	2.90	2.82	2.72
01-Dec	3.43	3.39	3.36	3.33	3.29	3.26	3.23	3.19	3.16	3.12	3.09	3.06	2.98	2.91	2.84	2.77	2.69	2.62	2.55	2.45
05-Dec	3.15	3.13	3.10	3.07	3.05	3.02	3.00	2.97	2.94	2.92	2.89	2.87	2.79	2.72	2.65	2.58	2.51	2.44	2.36	2.26
10-Dec	2.81	2.79	2.78	2.76	2.74	2.73	2.71	2.69	2.68	2.66	2.64	2.63	2.56	2.49	2.42	2.35	2.28	2.21	2.14	2.04
15-Dec	2.47	2.46	2.45	2.44	2.44	2.43	2.42	2.42	2.41	2.40	2.40	2.39	2.32	2.25	2.18	2.11	2.04	1.97	1.91	1.81
20-Dec	2.36	2.36	2.35	2.34	2.34	2.33	2.32	2.32	2.31	2.31	2.30	2.29	2.23	2.16	2.09	2.03	1.96	1.89	1.83	1.73
25-Dec	2.26	2.25	2.25	2.24	2.24	2.23	2.23	2.22	2.21	2.21	2.20	2.20	2.13	2.07	2.00	1.94	1.88	1.81	1.75	1.66
01-Jan	2.12	2.11	2.11	2.10	2.10	2.09	2.09	2.08	2.08	2.07	2.07	2.06	2.00	1.94	1.88	1.82	1.76	1.70	1.64	1.56
05-Jan	2.03	2.03	2.03	2.02	2.02	2.01	2.01	2.00	2.00	1.99	1.99	1.98	1.93	1.87	1.81	1.75	1.69	1.63	1.58	1.50
10-Jan	1.93	1.93	1.92	1.92	1.92	1.91	1.91	1.90	1.90	1.90	1.89	1.89	1.83	1.78	1.72	1.66	1.61	1.55	1.50	1.42
15-Jan	1.83	1.83	1.82	1.82	1.82	1.81	1.81	1.80	1.80	1.80	1.79	1.79	1.74	1.68	1.63	1.58	1.53	1.47	1.42	1.35
20-Jan	1.74	1.74	1.74	1.74	1.73	1.73	1.73	1.73	1.73	1.72	1.72	1.72	1.67	1.62	1.57	1.53	1.48	1.43	1.38	1.31
25-Jan	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.61	1.56	1.52	1.47	1.43	1.38	1.34	1.28
01-Feb	1.53	1.53	1.54	1.54	1.54	1.54	1.54	1.55	1.55	1.55	1.55	1.55	1.52	1.48	1.44	1.40	1.36	1.32	1.28	1.23
05-Feb	1.46	1.46	1.47	1.47	1.47	1.48	1.48	1.48	1.49	1.49	1.50	1.50	1.46	1.43	1.39	1.36	1.32	1.29	1.25	1.20
10-Feb	1.37	1.38	1.38	1.39	1.39	1.40	1.40	1.41	1.41	1.42	1.42	1.43	1.40	1.37	1.34	1.30	1.27	1.24	1.21	1.17
15-Feb	1.29	1.29	1.30	1.31	1.31	1.32	1.33	1.33	1.34	1.35	1.35	1.36	1.33	1.31	1.28	1.25	1.22	1.20	1.17	1.13
20-Feb	1.26	1.26	1.27	1.28	1.28	1.29	1.29	1.30	1.31	1.31	1.32	1.33	1.30	1.28	1.25	1.22	1.20	1.17	1.14	1.11
25-Feb	1.23	1.23	1.24	1.25	1.25	1.26	1.26	1.27	1.28	1.28	1.29	1.30	1.27	1.25	1.22	1.20	1.17	1.15	1.12	1.09
01-Mar	1.20	1.21	1.21	1.22	1.23	1.23	1.24	1.25	1.25	1.26	1.26	1.27	1.25	1.22	1.20	1.17	1.15	1.13	1.10	1.07
05-Mar	1.18	1.18	1.19	1.20	1.20	1.21	1.21	1.22	1.23	1.23	1.24	1.24	1.22	1.20	1.17	1.15	1.13	1.11	1.08	1.05
10-Mar	1.15	1.16	1.16	1.17	1.17	1.18	1.18	1.19	1.20	1.20	1.21	1.21	1.19	1.17	1.15	1.12	1.10	1.08	1.06	1.03
15-Mar	1.12	1.13	1.13	1.14	1.14	1.15	1.15	1.16	1.16	1.17	1.17	1.18	1.16	1.14	1.12	1.10	1.08	1.05	1.03	1.00
20-Mar	1.11	1.12	1.13	1.13	1.14	1.15	1.15	1.16	1.17	1.17	1.18	1.19	1.17	1.14	1.12	1.10	1.08	1.06	1.04	1.00
25-Mar	1.10	1.11	1.12	1.13	1.14	1.15	1.15	1.16	1.17	1.18	1.19	1.20	1.17	1.15	1.13	1.11	1.08	1.06	1.04	1.00
01-Apr	1.09	1.10	1.11	1.12	1.14	1.15	1.16	1.17	1.18	1.19	1.20	1.21	1.18	1.16	1.14	1.11	1.09	1.06	1.04	1.01
05-Apr	1.09	1.10	1.11	1.12	1.13	1.15	1.16	1.17	1.18	1.19	1.20	1.21	1.19	1.16	1.14	1.11	1.09	1.07	1.04	1.01
10-Apr	1.08	1.09	1.11	1.12	1.13	1.14	1.16	1.17	1.18	1.20	1.21	1.22	1.20	1.17	1.14	1.12	1.09	1.07	1.04	1.01
15-Apr	1.07	1.09	1.10	1.12	1.13	1.14	1.16	1.17	1.19	1.20	1.22	1.23	1.20	1.18	1.15	1.12	1.10	1.07	1.04	1.01
20-Apr	1.08	1.09	1.11	1.12	1.13	1.15	1.16	1.18	1.19	1.21	1.22	1.23	1.21	1.18	1.15	1.13	1.10	1.07	1.05	1.01
25-Apr	1.08	1.10	1.11	1.13	1.14	1.15	1.17	1.18	1.19	1.21	1.22	1.24	1.21	1.18	1.16	1.13	1.10	1.08	1.05	1.01
01-May	1.09	1.10	1.12	1.13	1.14	1.16	1.17	1.19	1.20	1.21	1.23	1.24	1.21	1.19	1.16	1.13	1.11	1.08	1.06	1.02
05-May	1.09	1.11	1.12	1.13	1.15	1.16	1.18	1.19	1.20	1.22	1.23	1.24	1.22	1.19	1.16	1.14	1.11	1.09	1.06	1.02
10-May	1.10	1.11	1.13	1.14	1.15	1.17	1.18	1.19	1.21	1.22	1.23	1.25	1.22	1.19	1.17	1.14	1.12	1.09	1.06	1.03
15-May	1.11	1.12	1.13	1.14	1.16	1.17	1.18	1.20	1.21	1.22	1.24	1.25	1.22	1.20	1.17	1.14	1.12	1.09	1.07	1.03

Mean daily water levels to Hatien datum in m. Chaktomuk gauge zero=-1.05m so reading of gauge will be 1.05m more than indicated here

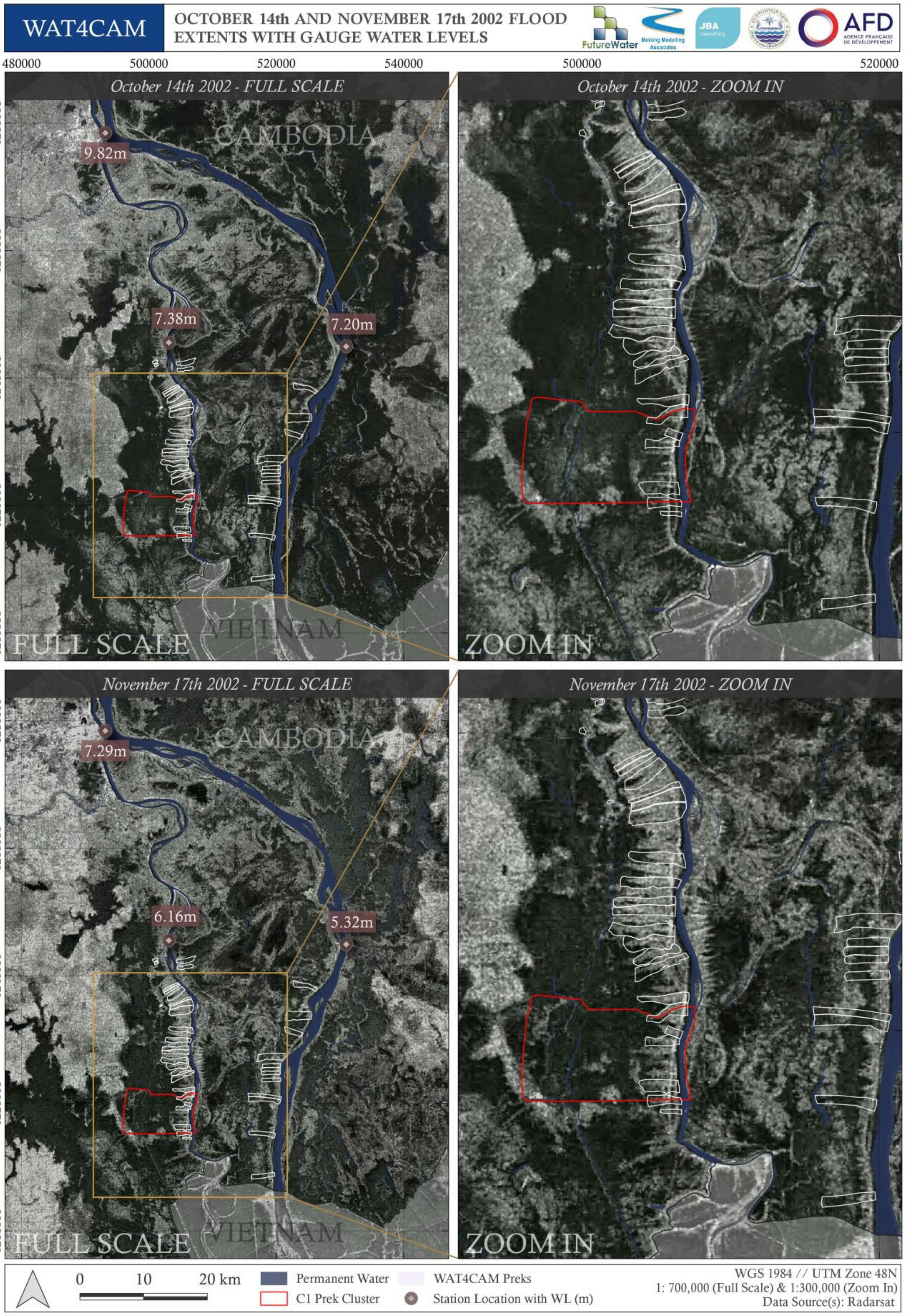
Table 14.2 Median Water Levels (to datum) along the Bassac from Chaktomuk to the Vietnam Border through the Dry Season tabulated every 5km and 5 days November-May. Tide fluctuations above and below should be expected as well as natural variations.

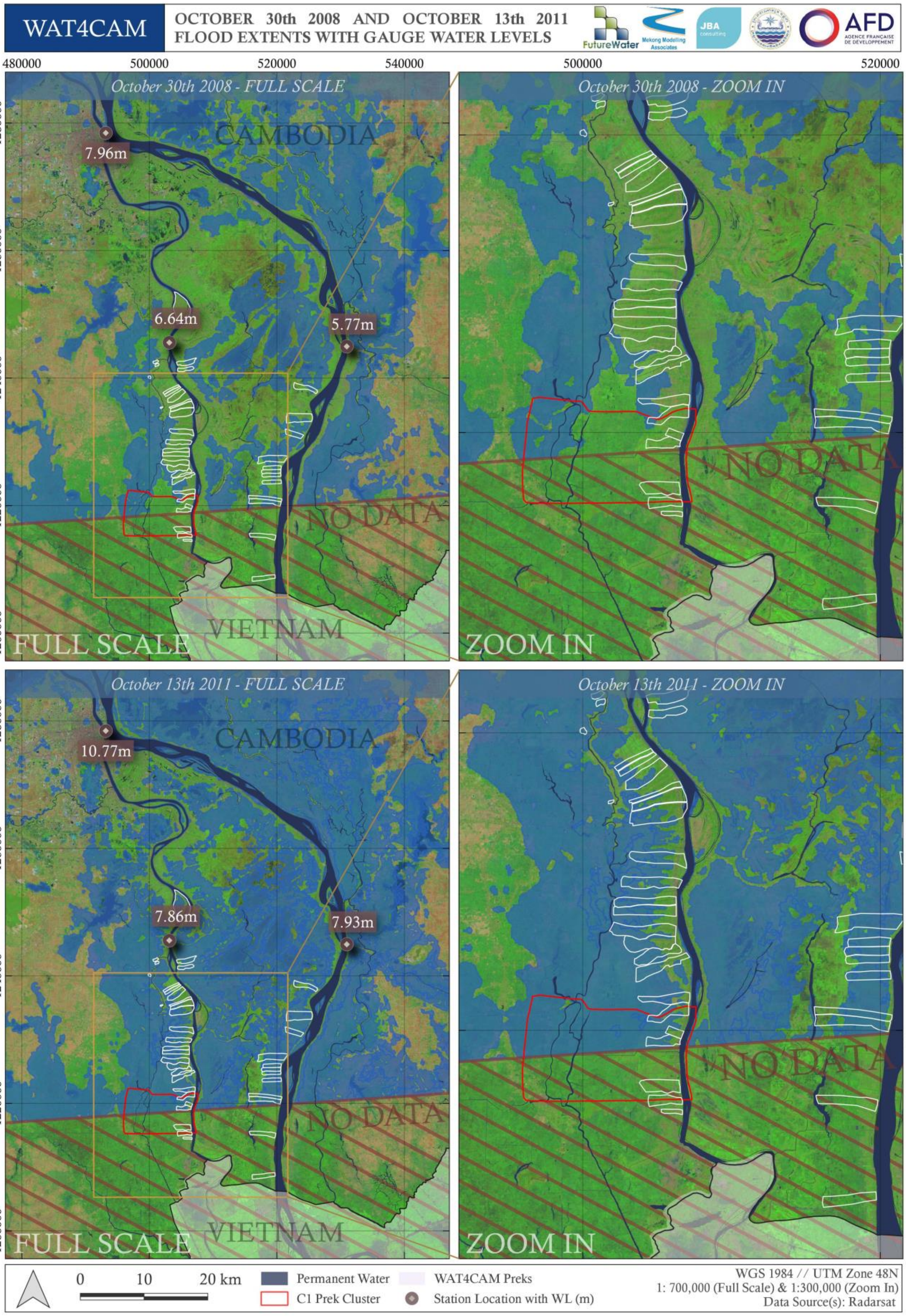
Distance (Km) from Chaktomuk	0	5	10	15	20	25	30	35	40	45	49	55	60	65	70	75	80	85
Date											Koh Khal							
15-Nov	4.53	4.46	4.40	4.34	4.28	4.22	4.16	4.09	4.03	3.97	3.92	3.74	3.60	3.45	3.30	3.16	3.01	2.86
20-Nov	4.18	4.13	4.07	4.02	3.96	3.91	3.86	3.80	3.75	3.69	3.65	3.49	3.35	3.22	3.09	2.95	2.82	2.68
25-Nov	3.84	3.79	3.74	3.70	3.65	3.60	3.56	3.51	3.46	3.42	3.38	3.23	3.11	2.99	2.87	2.75	2.63	2.50
01-Dec	3.43	3.39	3.35	3.31	3.27	3.24	3.20	3.16	3.12	3.08	3.05	2.92	2.82	2.71	2.61	2.50	2.40	2.29
05-Dec	3.15	3.12	3.09	3.05	3.02	2.99	2.96	2.92	2.89	2.86	2.83	2.72	2.62	2.53	2.43	2.34	2.24	2.15
10-Dec	2.81	2.78	2.76	2.73	2.71	2.68	2.66	2.63	2.61	2.58	2.56	2.46	2.38	2.30	2.22	2.13	2.05	1.97
15-Dec	2.47	2.45	2.43	2.41	2.39	2.38	2.36	2.34	2.32	2.30	2.29	2.21	2.14	2.07	2.00	1.93	1.86	1.79
20-Dec	2.36	2.35	2.33	2.31	2.30	2.28	2.26	2.25	2.23	2.22	2.20	2.12	2.06	1.99	1.92	1.86	1.79	1.72
25-Dec	2.26	2.25	2.23	2.22	2.20	2.19	2.17	2.16	2.14	2.13	2.12	2.04	1.98	1.91	1.85	1.78	1.72	1.66
01-Jan	2.12	2.10	2.09	2.08	2.07	2.05	2.04	2.03	2.02	2.00	1.99	1.92	1.86	1.80	1.74	1.68	1.62	1.56
05-Jan	2.03	2.02	2.01	2.00	1.99	1.98	1.97	1.96	1.94	1.93	1.92	1.85	1.80	1.74	1.68	1.62	1.56	1.51
10-Jan	1.93	1.92	1.91	1.90	1.89	1.88	1.87	1.86	1.85	1.84	1.84	1.77	1.72	1.66	1.60	1.55	1.49	1.44
15-Jan	1.83	1.82	1.81	1.81	1.80	1.79	1.78	1.77	1.76	1.76	1.75	1.69	1.63	1.58	1.53	1.48	1.42	1.37
20-Jan	1.74	1.73	1.73	1.72	1.71	1.71	1.70	1.69	1.68	1.68	1.67	1.61	1.56	1.51	1.47	1.42	1.37	1.32
25-Jan	1.65	1.65	1.64	1.63	1.63	1.62	1.62	1.61	1.60	1.60	1.59	1.54	1.49	1.45	1.40	1.36	1.31	1.27
01-Feb	1.53	1.53	1.52	1.52	1.51	1.50	1.50	1.49	1.49	1.48	1.48	1.43	1.39	1.35	1.32	1.28	1.24	1.20
05-Feb	1.46	1.46	1.45	1.45	1.44	1.44	1.43	1.43	1.42	1.42	1.41	1.37	1.34	1.30	1.27	1.23	1.19	1.16
10-Feb	1.37	1.37	1.37	1.36	1.36	1.35	1.35	1.35	1.34	1.34	1.33	1.30	1.27	1.23	1.20	1.17	1.14	1.11
15-Feb	1.29	1.28	1.28	1.28	1.27	1.27	1.27	1.26	1.26	1.26	1.26	1.22	1.20	1.17	1.14	1.11	1.09	1.06
20-Feb	1.26	1.25	1.25	1.24	1.24	1.24	1.23	1.23	1.23	1.22	1.22	1.19	1.16	1.13	1.11	1.08	1.06	1.03
25-Feb	1.23	1.22	1.22	1.21	1.21	1.20	1.20	1.19	1.19	1.19	1.18	1.15	1.13	1.10	1.08	1.05	1.03	1.00
01-Mar	1.20	1.20	1.19	1.19	1.18	1.18	1.17	1.17	1.16	1.16	1.15	1.12	1.10	1.08	1.05	1.03	1.00	0.98
05-Mar	1.18	1.17	1.17	1.16	1.16	1.15	1.14	1.14	1.13	1.13	1.12	1.10	1.07	1.05	1.03	1.00	0.98	0.96
10-Mar	1.15	1.14	1.14	1.13	1.12	1.12	1.11	1.10	1.10	1.09	1.09	1.06	1.04	1.02	0.99	0.97	0.95	0.93
15-Mar	1.12	1.11	1.11	1.10	1.09	1.08	1.08	1.07	1.06	1.06	1.05	1.02	1.00	0.98	0.96	0.94	0.92	0.90
20-Mar	1.11	1.11	1.10	1.09	1.09	1.08	1.07	1.07	1.06	1.05	1.05	1.02	1.00	0.98	0.96	0.94	0.91	0.89
25-Mar	1.10	1.10	1.09	1.09	1.08	1.08	1.07	1.06	1.06	1.05	1.05	1.02	1.00	0.97	0.95	0.93	0.91	0.88
01-Apr	1.09	1.09	1.08	1.08	1.07	1.07	1.06	1.06	1.05	1.05	1.05	1.02	0.99	0.97	0.94	0.92	0.90	0.87
05-Apr	1.09	1.08	1.08	1.07	1.07	1.07	1.06	1.06	1.05	1.05	1.04	1.02	0.99	0.97	0.94	0.92	0.89	0.87
10-Apr	1.08	1.08	1.07	1.07	1.07	1.06	1.06	1.05	1.05	1.05	1.04	1.01	0.99	0.96	0.94	0.91	0.88	0.86
15-Apr	1.07	1.07	1.07	1.06	1.06	1.06	1.05	1.05	1.05	1.04	1.04	1.01	0.98	0.96	0.93	0.90	0.88	0.85
20-Apr	1.08	1.07	1.07	1.07	1.06	1.06	1.06	1.05	1.05	1.04	1.04	1.01	0.98	0.96	0.93	0.90	0.88	0.85
25-Apr	1.08	1.08	1.07	1.07	1.07	1.06	1.06	1.05	1.05	1.04	1.04	1.01	0.98	0.96	0.93	0.90	0.88	0.85
01-May	1.09	1.08	1.08	1.07	1.07	1.06	1.06	1.05	1.05	1.04	1.04	1.01	0.98	0.96	0.93	0.90	0.88	0.85
05-May	1.09	1.09	1.08	1.08	1.07	1.07	1.06	1.05	1.05	1.04	1.04	1.01	0.98	0.95	0.93	0.90	0.88	0.85
10-May	1.10	1.09	1.09	1.08	1.07	1.07	1.06	1.06	1.05	1.04	1.04	1.01	0.98	0.95	0.93	0.90	0.88	0.85
15-May	1.11	1.10	1.09	1.08	1.08	1.07	1.06	1.06	1.05	1.04	1.04	1.01	0.98	0.95	0.93	0.90	0.87	0.85

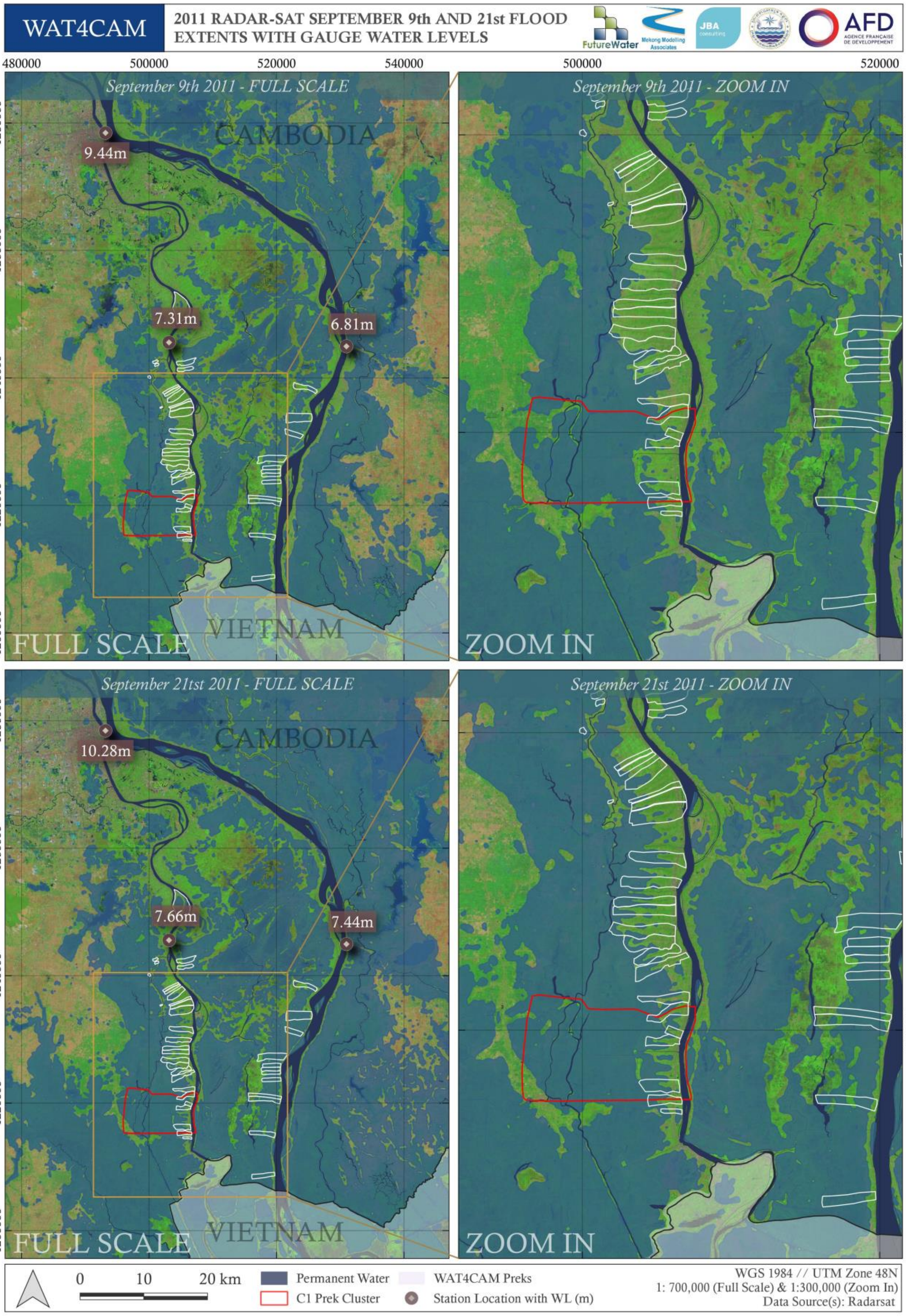
Mean daily water levels to Hatien datum in m. Chaktomuk gauge zero=-1.05 Koh Khal gauge zero =-1.0

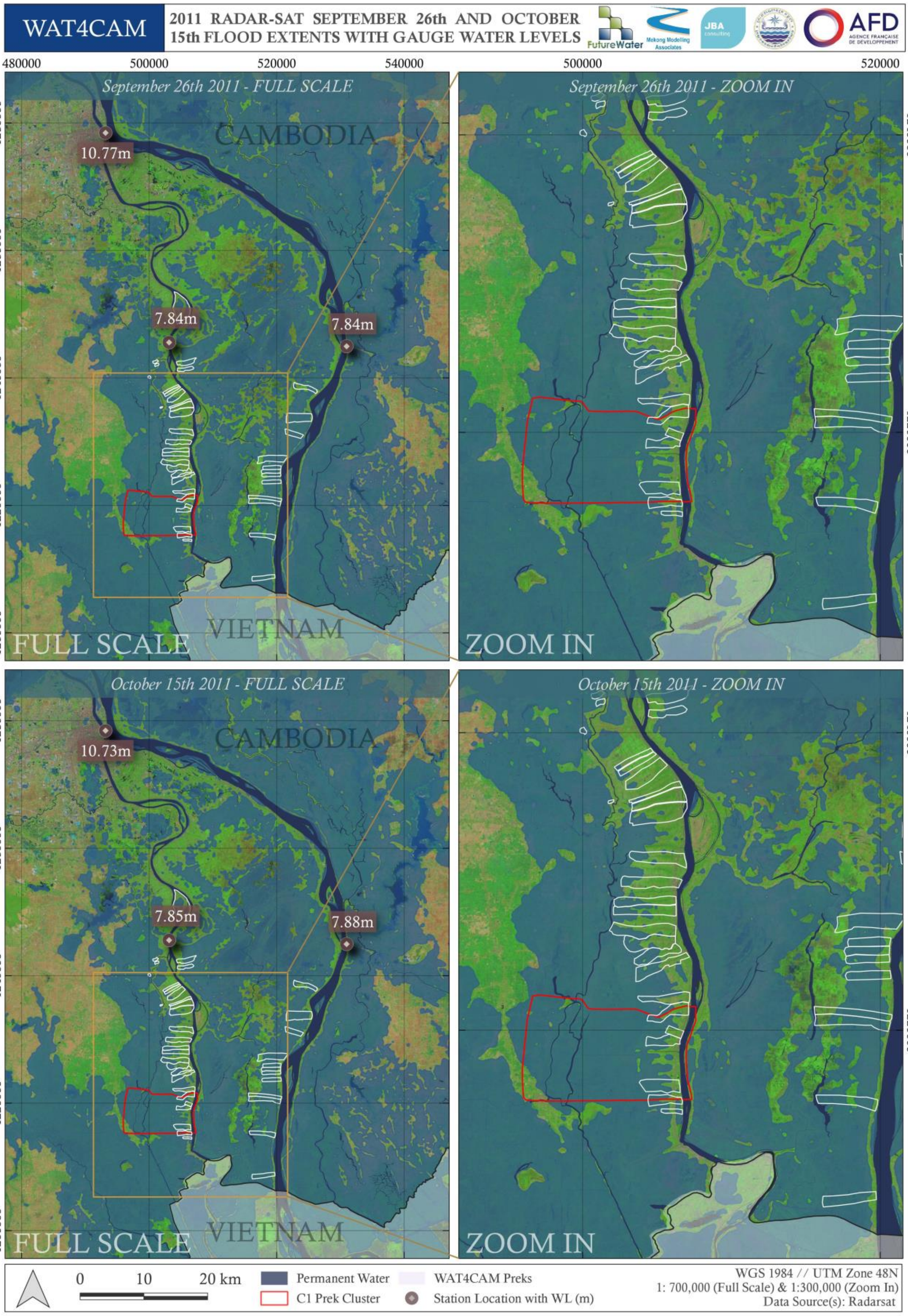
15 APPENDIX 5 FLOOD EXTENTS WITH CONTEMPORANEOUS GAUGE READINGS

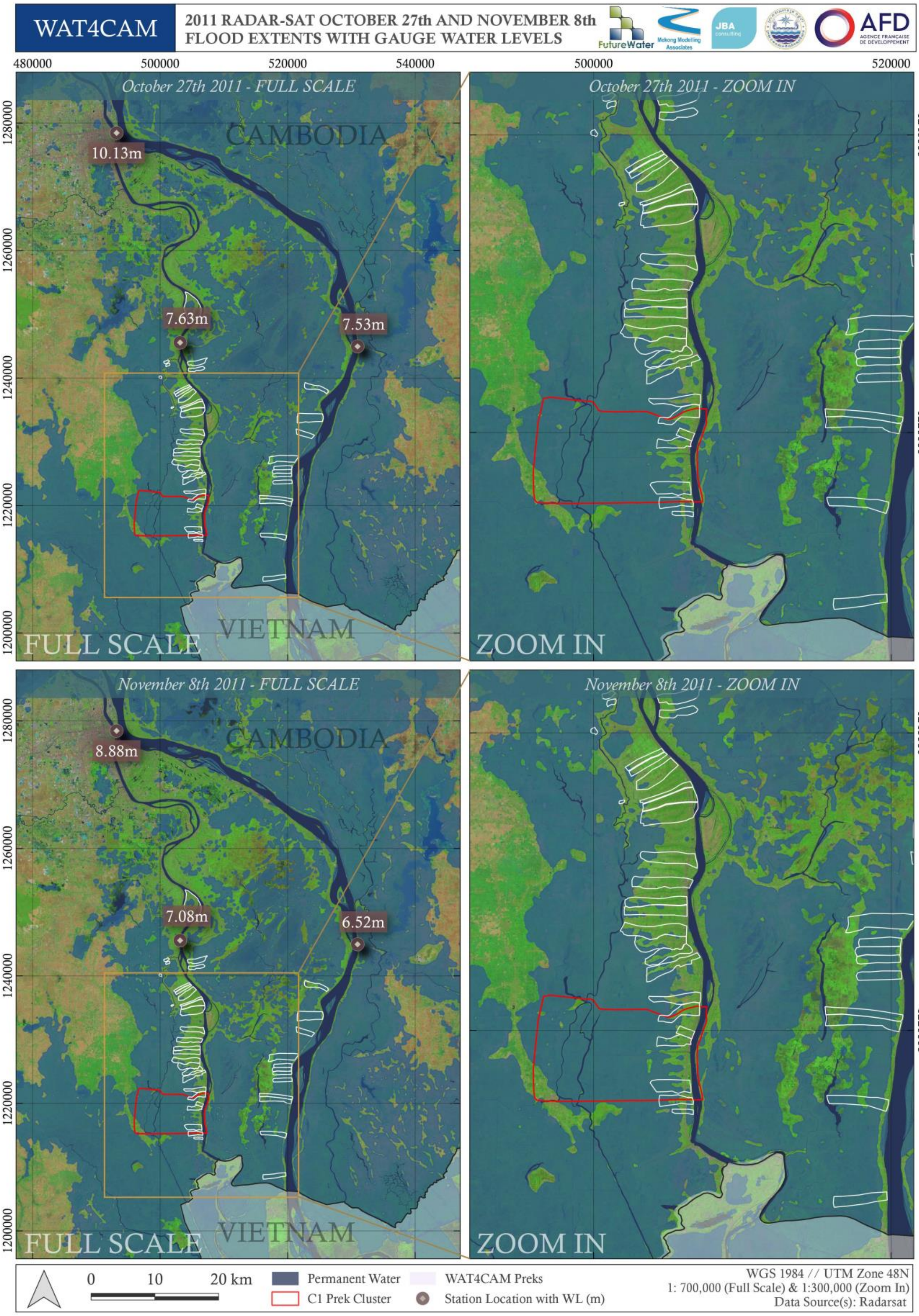
Note Levels given are not to datum but are as read on the gauges

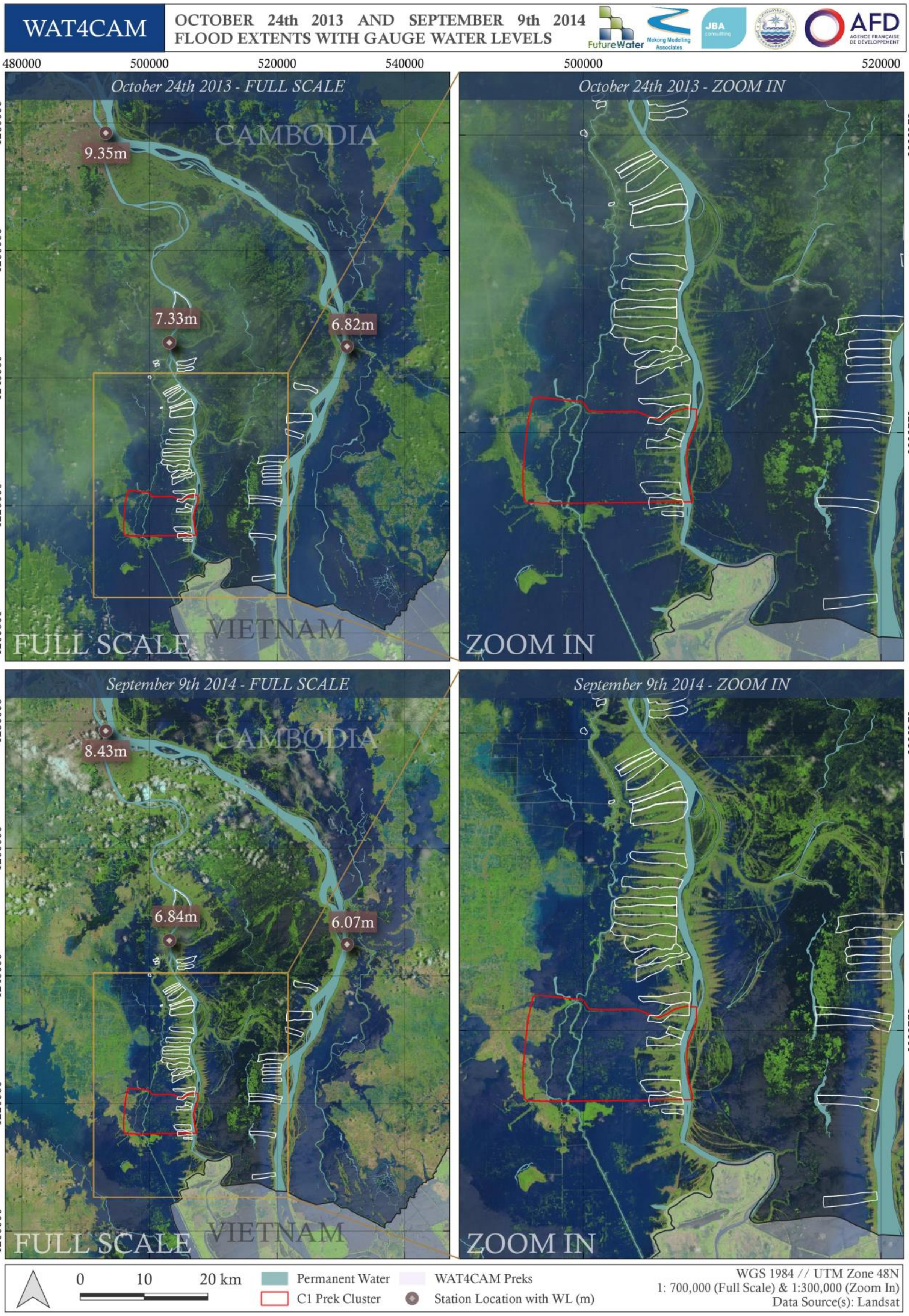

WAT4CAM
OCTOBER 14th AND NOVEMBER 17th 2002 FLOOD EXTENTS WITH GAUGE WATER LEVELS
FutureWater
Mekong Modelling Associates
JBA consulting
AFD AGENCE FRANÇAISE DE DÉVELOPPEMENT
October 14th 2002 - FULL SCALE
October 14th 2002 - ZOOM IN
November 17th 2002 - FULL SCALE
November 17th 2002 - ZOOM IN
CAMBODIA
VIETNAM
FULL SCALE
ZOOM IN
9.82m
7.38m
7.20m
7.29m
6.16m
5.32m
480000
500000
520000
540000
1200000
1220000
1240000
1260000
1280000
0
10
20 km
Permanent Water
WAT4CAM Preks
C1 Prek Cluster
Station Location with WL (m)
WGS 1984 // UTM Zone 48N
1: 700,000 (Full Scale) & 1:300,000 (Zoom In)
Data Source(s): Radarsat

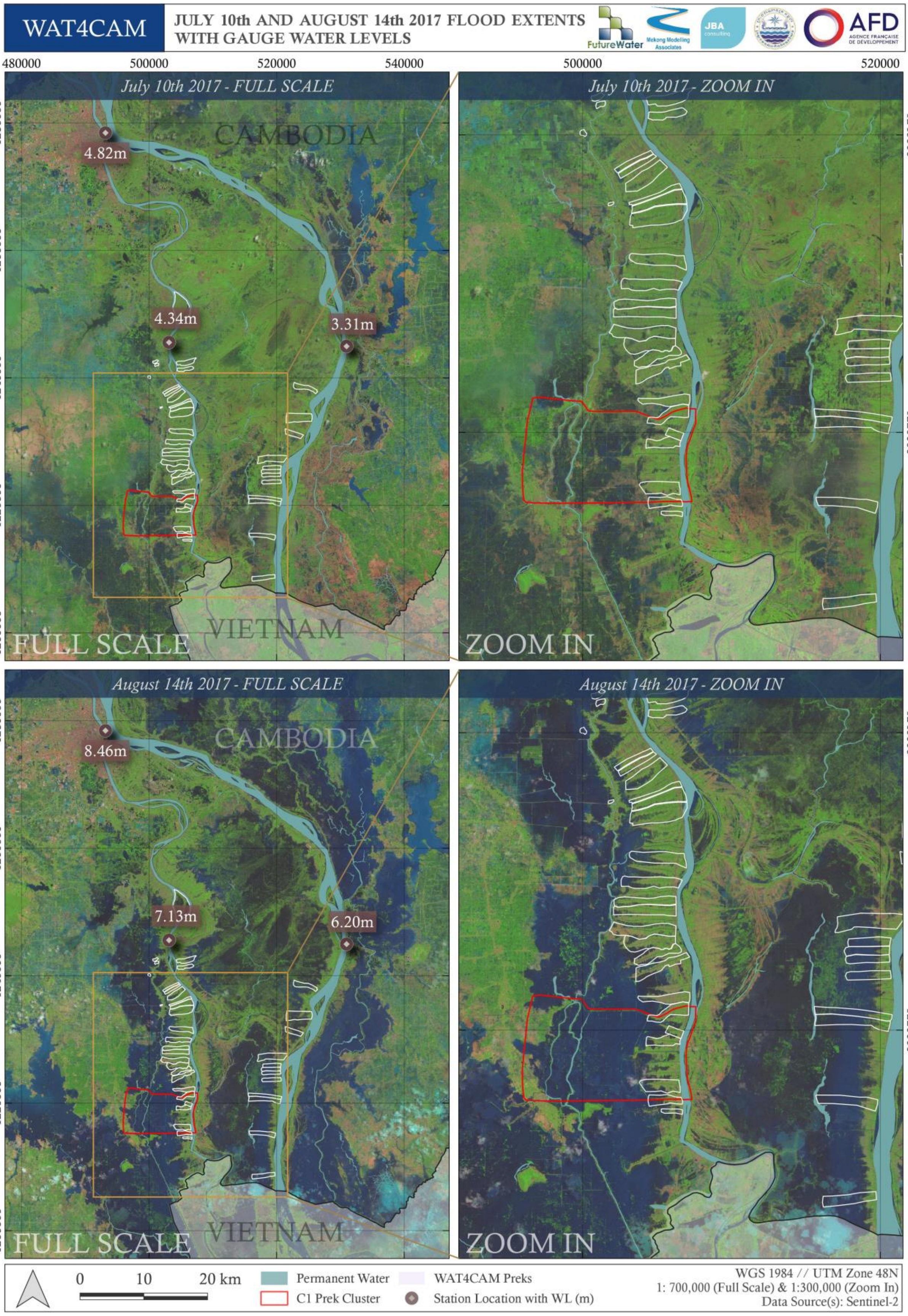

WAT4CAM
OCTOBER 30th 2008 AND OCTOBER 13th 2011
FLOOD EXTENTS WITH GAUGE WATER LEVELS
FutureWater
Mekong Modelling Associates
JBA consulting
AFD
AGENCE FRANÇAISE DE DÉVELOPPEMENT
October 30th 2008 - FULL SCALE
October 30th 2008 - ZOOM IN
October 13th 2011 - FULL SCALE
October 13th 2011 - ZOOM IN
CAMBODIA
VIETNAM
NO DATA
FULL SCALE
ZOOM IN
7.96m
6.64m
5.77m
10.77m
7.86m
7.93m
480000
500000
520000
540000
1280000
1260000
1240000
1220000
1200000
0
10
20 km
Permanent Water
WAT4CAM Preks
C1 Prek Cluster
Station Location with WL (m)
WGS 1984 // UTM Zone 48N
1: 700,000 (Full Scale) & 1:300,000 (Zoom In)
Data Source(s): Radarsat

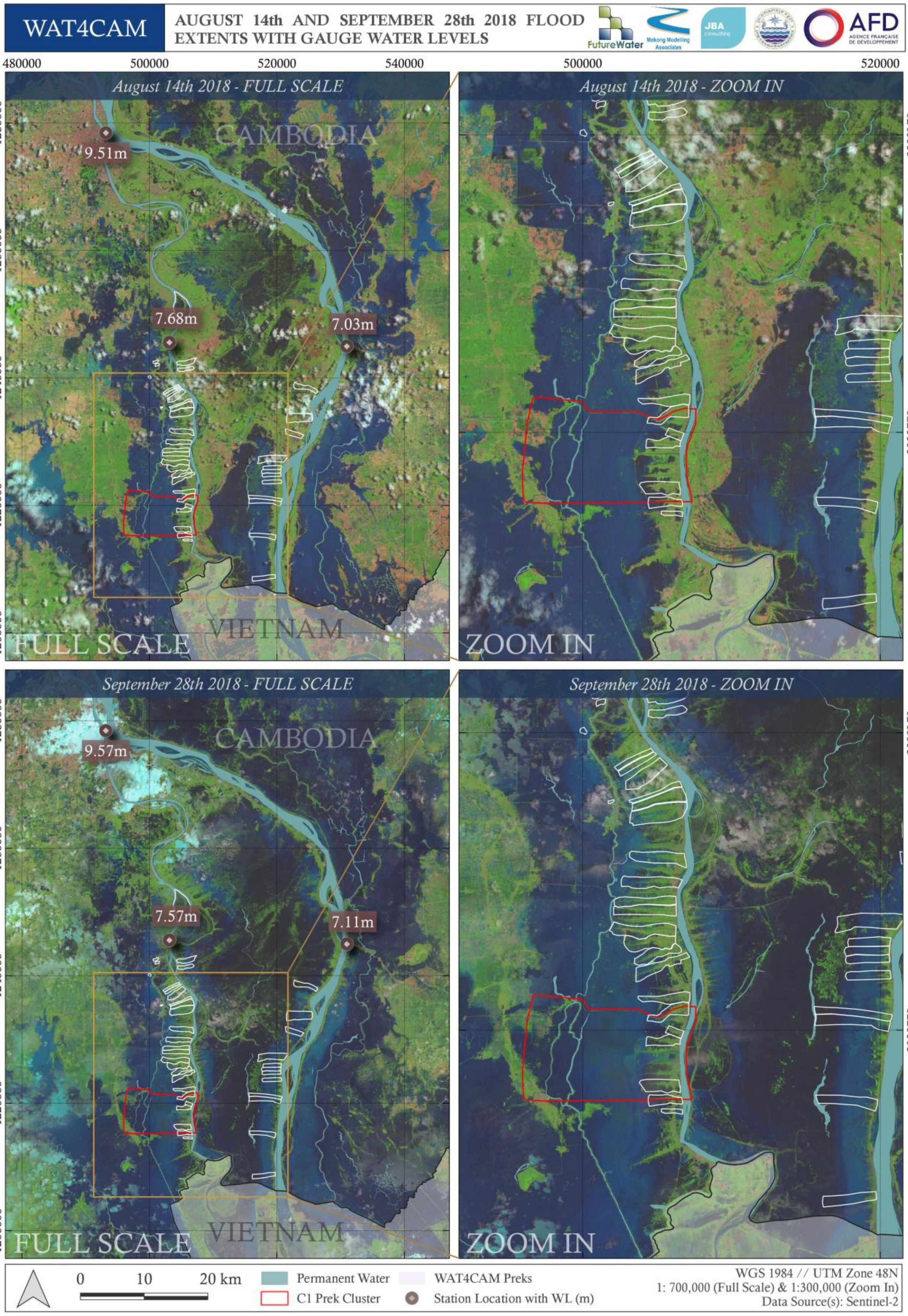

WAT4CAM
2011 RADAR-SAT SEPTEMBER 9th AND 21st FLOOD EXTENTS WITH GAUGE WATER LEVELS
September 9th 2011 - FULL SCALE
September 9th 2011 - ZOOM IN
September 21tst 2011 - FULL SCALE
September 21st 2011 - ZOOM IN
CAMBODIA
VIETNAM
FULL SCALE
ZOOM IN
9.44m
7.31m
6.81m
10.28m
7.66m
7.44m
480000
500000
520000
540000
1280000
1260000
1240000
1220000
1200000
0 10 20 km
Permanent Water
C1 Prek Cluster
WAT4CAM Preks
Station Location with WL (m)
WGS 1984 // UTM Zone 48N
1: 700,000 (Full Scale) & 1:300,000 (Zoom In)
Data Source(s): Radarsat

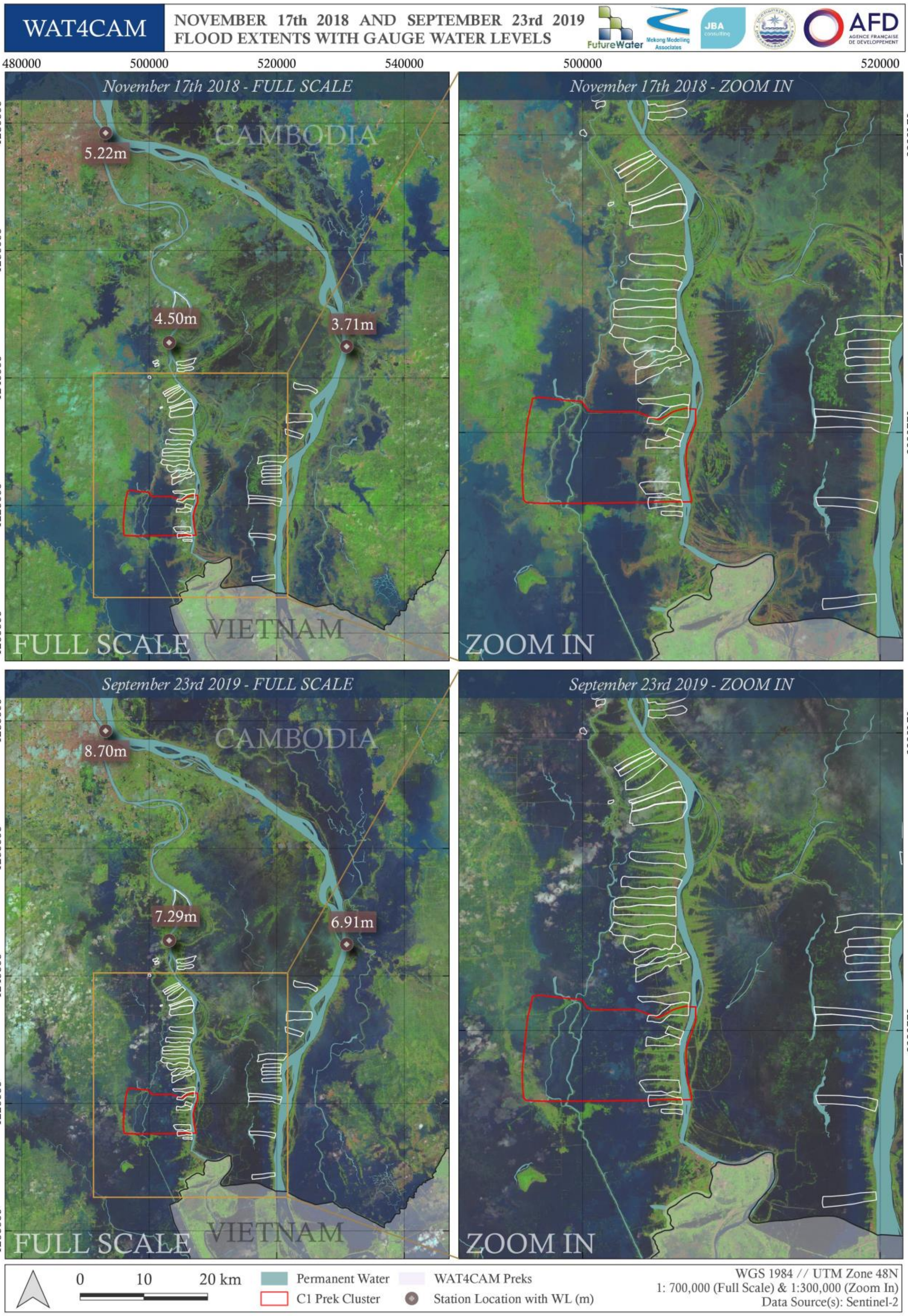

WAT4CAM
2011 RADAR-SAT SEPTEMBER 26th AND OCTOBER 15th FLOOD EXTENTS WITH GAUGE WATER LEVELS
AFD
September 26th 2011 - FULL SCALE
September 26th 2011 - ZOOM IN
October 15th 2011 - FULL SCALE
October 15th 2011 - ZOOM IN
CAMBODIA
VIETNAM
FULL SCALE
ZOOM IN
10.77m
7.84m
7.84m
10.73m
7.85m
7.88m
480000
500000
520000
540000
1280000
1260000
1240000
1220000
1200000
0
10
20 km
Permanent Water
WAT4CAM Preks
C1 Prek Cluster
Station Location with WL (m)
WGS 1984 // UTM Zone 48N
1: 700,000 (Full Scale) & 1:300,000 (Zoom In)
Data Source(s): Radarsat

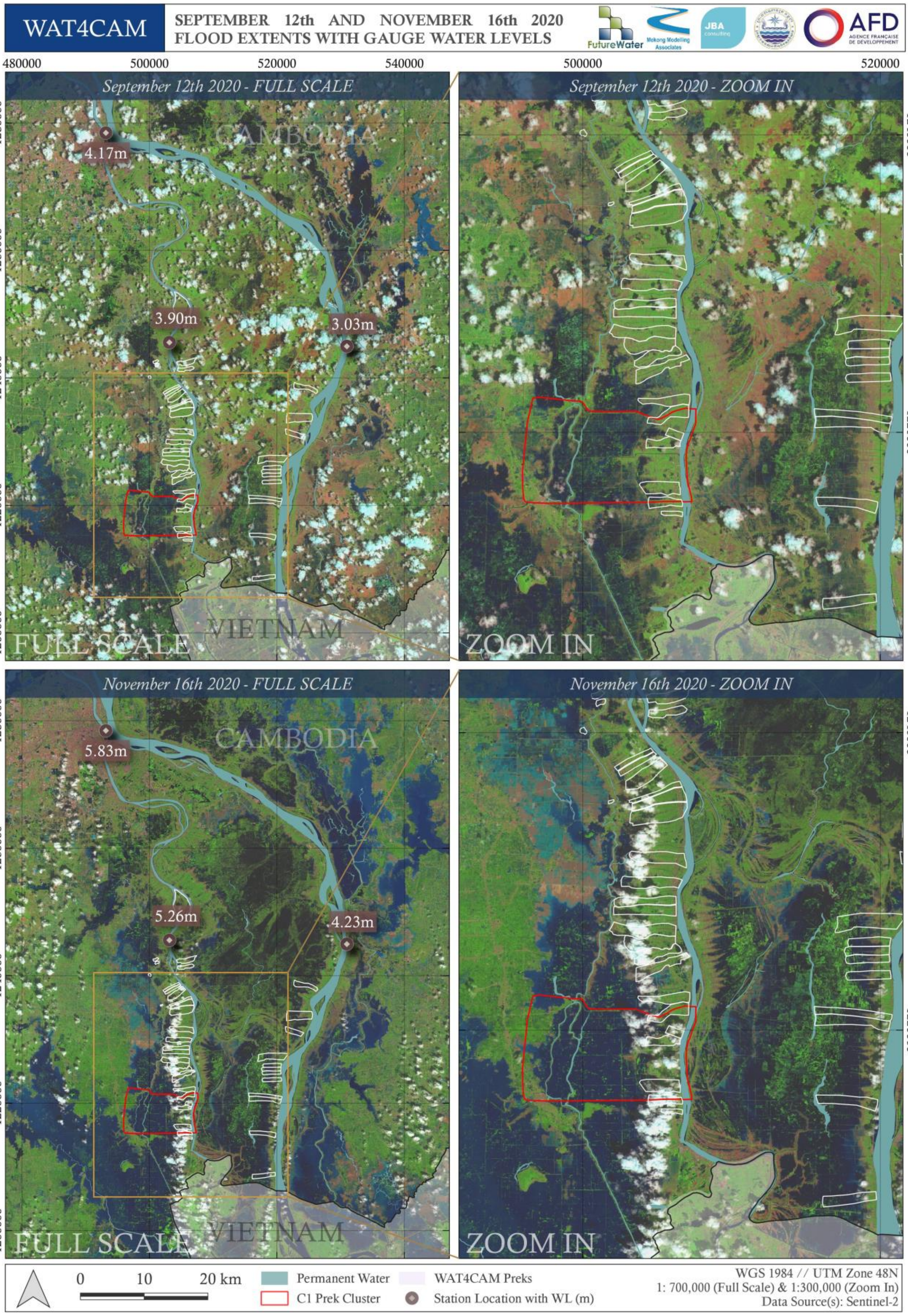

WAT4CAM
2011 RADAR-SAT OCTOBER 27th AND NOVEMBER 8th
FLOOD EXTENTS WITH GAUGE WATER LEVELS
October 27th 2011 - FULL SCALE
October 27th 2011 - ZOOM IN
CAMBODIA
VIETNAM
10.13m
7.63m
7.53m
FULL SCALE
ZOOM IN
November 8th 2011 - FULL SCALE
November 8th 2011 - ZOOM IN
8.88m
7.08m
6.52m
480000
500000
520000
540000
1280000
1260000
1240000
1220000
1200000
0
10
20 km
Permanent Water
WAT4CAM Preks
C1 Prek Cluster
Station Location with WL (m)
WGS 1984 // UTM Zone 48N
1: 700,000 (Full Scale) & 1:300,000 (Zoom In)
Data Source(s): Radarsat


WAT4CAM
OCTOBER 24th 2013 AND SEPTEMBER 9th 2014
FLOOD EXTENTS WITH GAUGE WATER LEVELS
FutureWater
Mekong Modelling Associates
JBA consulting
AFD
AGENCE FRANÇAISE DE DÉVELOPPEMENT
October 24th 2013 - FULL SCALE
October 24th 2013 - ZOOM IN
September 9th 2014 - FULL SCALE
September 9th 2014 - ZOOM IN
CAMBODIA
VIETNAM
FULL SCALE
ZOOM IN
9.35m
7.33m
6.82m
8.43m
6.84m
6.07m
480000
500000
520000
540000
1280000
1260000
1240000
1220000
1200000
0
10
20 km
Permanent Water
WAT4CAM Preks
C1 Prek Cluster
Station Location with WL (m)
WGS 1984 // UTM Zone 48N
1: 700,000 (Full Scale) & 1:300,000 (Zoom In)
Data Source(s): Landsat


WAT4CAM
JULY 10th AND AUGUST 14th 2017 FLOOD EXTENTS
WITH GAUGE WATER LEVELS
FutureWater
Mekong Modelling Associates
JBA consulting
AFD
AGENCE FRANÇAISE DE DÉVELOPPEMENT
July 10th 2017 - FULL SCALE
July 10th 2017 - ZOOM IN
CAMBODIA
VIETNAM
4.82m
4.34m
3.31m
FULL SCALE
ZOOM IN
August 14th 2017 - FULL SCALE
August 14th 2017 - ZOOM IN
8.46m
7.13m
6.20m
480000
500000
520000
540000
1280000
1260000
1240000
1220000
1200000
0
10
20 km
Permanent Water
WAT4CAM Preks
C1 Prek Cluster
Station Location with WL (m)
WGS 1984 // UTM Zone 48N
1: 700,000 (Full Scale) & 1:300,000 (Zoom In)
Data Source(s): Sentinel-2


WAT4CAM
AUGUST 14th AND SEPTEMBER 28th 2018 FLOOD EXTENTS WITH GAUGE WATER LEVELS
FutureWater
Mekong Modelling Associates
JBA consulting
AFD
AGENCE FRANÇAISE DE DÉVELOPPEMENT
480000
500000
520000
540000
500000
520000
August 14th 2018 - FULL SCALE
August 14th 2018 - ZOOM IN
1280000
1260000
1240000
1220000
1200000
1240000
1220000
CAMBODIA
9.51m
7.68m
7.03m
VIETNAM
FULL SCALE
ZOOM IN
September 28th 2018 - FULL SCALE
September 28th 2018 - ZOOM IN
9.57m
7.57m
7.11m
0
10
20 km
Permanent Water
C1 Prek Cluster
WAT4CAM Preks
Station Location with WL (m)
WGS 1984 // UTM Zone 48N
1: 700,000 (Full Scale) & 1:300,000 (Zoom In)
Data Source(s): Sentinel-2


WAT4CAM
NOVEMBER 17th 2018 AND SEPTEMBER 23rd 2019
FLOOD EXTENTS WITH GAUGE WATER LEVELS
FutureWater
Mekong Modelling Associates
JBA consulting
AFD
AGENCE FRANÇAISE DE DÉVELOPPEMENT
November 17th 2018 - FULL SCALE
November 17th 2018 - ZOOM IN
CAMBODIA
VIETNAM
5.22m
4.50m
3.71m
FULL SCALE
ZOOM IN
September 23rd 2019 - FULL SCALE
September 23rd 2019 - ZOOM IN
8.70m
7.29m
6.91m
480000
500000
520000
540000
1280000
1260000
1240000
1220000
1200000
0
10
20 km
Permanent Water
WAT4CAM Preks
C1 Prek Cluster
Station Location with WL (m)
WGS 1984 // UTM Zone 48N
1: 700,000 (Full Scale) & 1:300,000 (Zoom In)
Data Source(s): Sentinel-2


WAT4CAM
SEPTEMBER 12th AND NOVEMBER 16th 2020
FLOOD EXTENTS WITH GAUGE WATER LEVELS
FutureWater
Mekong Modelling Associates
JBA consulting
AFD
AGENCE FRANÇAISE DE DÉVELOPPEMENT
480000
500000
520000
540000
500000
520000
September 12th 2020 - FULL SCALE
September 12th 2020 - ZOOM IN
November 16th 2020 - FULL SCALE
November 16th 2020 - ZOOM IN
1280000
1260000
1240000
1220000
1200000
1240000
1220000
CAMBODIA
VIETNAM
4.17m
3.90m
3.03m
5.83m
5.26m
4.23m
FULL SCALE
ZOOM IN
0
10
20 km
Permanent Water
C1 Prek Cluster
WAT4CAM Preks
Station Location with WL (m)
WGS 1984 // UTM Zone 48N
1: 700,000 (Full Scale) & 1:300,000 (Zoom In)
Data Source(s): Sentinel-2

16 APPENDIX 6 MODEL AND DATA SUPPLIED

A6.1 Model and data supplied

A USB is supplied with this final report containing the GIS data generated from remote sensing analysis, , survey data , HEC RAS 2D model development input and example output, training material and report in word and pdf form.

The data supplied is categorized into 9 directories including the current version of the HECRAS software used(Version 6.2) and the model documentation. The model files for the full model and the Prek Cluster only are included. The total size of the USB storage is

Full tabulation of the contents of the USB are given below:

1. -GIS Data

```
|  +---LandUseAnalysis
|  |  |  analysis.xlsx
|  |  |  Fallow_2016.tif
|  |  |  Fallow_2017.tif
|  |  |  Fallow_2018.tif
|  |  |  Fallow_2019.tif
|  |  |  Fallow_2020.tif
|  |  |  NDVImax_dryseason_2016.tif
|  |  |  NDVImax_dryseason_2017.tif
|  |  |  NDVImax_dryseason_2018.tif
|  |  |  NDVImax_dryseason_2019.tif
|  |  |  NDVImax_dryseason_2020.tif
|  |  |  Prek_LULC_int.tif
|  |  |  Prek_LULC_int.tif.aux.xml
|  |  |
|  |  \---Figures
|  |          ET_dry_20032014.png
|  |          LULC_preks_full.png
|  |          LULC_preks_zoomed.png
|  |          NDVI_dry_2020.png
|  |          NDVI_jan_2016_2020.png
|  |          NDVI_mar_2016_2020.png
|  |
|  +---PDA_poly
|  |      AdditionalPDA.cpg
|  |      AdditionalPDA.dbf
|  |      AdditionalPDA.prj
|  |      AdditionalPDA.qmd
|  |      AdditionalPDA.shp
|  |      AdditionalPDA.shx
|  |
|  \---water_occurrences
```

```
|       +---differences
|       |       annual_1980-2010_vs_2010_2020.tif
|       |       juloct_1980-2010_vs_2010_2020.tif
|       |       Landsat_Sentinel_differences.tif
|       |       marmay_1980-2010_vs_2010_2020.tif
|       |
|       +---JRC
|       |       water_occurrence_JRC_30m.tif
|       |
|       +---LANDSAT
|       |       water_occurrence_LANDSAT_annual.tif
|       |       water_occurrence_LANDSAT_annual_1980_2010.tif
|       |       water_occurrence_LANDSAT_annual_2010-2021.tif
|       |       water_occurrence_LANDSAT_annual_2010_2020.tif
|       |       water_occurrence_LANDSAT_juloct.tif
|       |       water_occurrence_LANDSAT_juloct_1980_2010.tif
|       |       water_occurrence_LANDSAT_juloct_2010-2021.tif
|       |       water_occurrence_LANDSAT_juloct_2010_2020.tif
|       |       water_occurrence_LANDSAT_marmay.tif
|       |       water_occurrence_LANDSAT_marmay_1980_2010.tif
|       |       water_occurrence_LANDSAT_marmay_2010-2021.tif
|       |       water_occurrence_LANDSAT_marmay_2010_2020.tif
|       |
|       \---SENTINEL1
|               water_occurrence_SENTINEL1.tif
|               water_occurrence_SENTINEL1_juloct.tif
|               water_occurrence_SENTINEL1_marmay.tif
|
+--2. -ModelOutputs
|   +---Animation
|   |       Animations.pptx
|   |
|   \---FloodDepths
|           Depth2018CC30.tfw
|           Depth2018CC30.tif
|           DepthMax2000.tfw
|           DepthMax2000.tif
|           DepthMax2011.tfw
|           DepthMax2011.tif
|           DepthMax2018.tfw
|           DepthMax2018.tif
|           DepthMax2018CC20.tfw
|           DepthMax2018CC20.tif
|           DepthMax2019.tfw
|           DepthMax2019.tif
|           DepthMax2020.tfw
|           DepthMax2020.tif
|           Meta_FloodDepths.txt
```

```
|
+---3. Models
|   +---Full_62
|   |       HEC62_Model.zip
|   |       HEC62_Model_inputonly.zip
|   |
|   \---PrekCluster
|           Prek_Cluster_rep6.p13.zip
|
+---4.Presentations
|       AfD_Sep27_Wat4Cam3_1_1.pptx
|       KIckOffMeeting_Wat4Cam3_1.pptx
|       MidTermReview_Cam3_1.pptx
|       PreksGroupWat4Cam3_1.pptx
|       ReviewMeeting1_Wat4Cam3_1.pptx
|       Wat4Cam3_1 for SC Meeting.pptx
|
+-5.--Report
|   +---Appendices
|   \---Word
+---6. Software
|       Documents_HECRAS6.rar
|       HEC-RAS Release Notes-v9-20220311_202107.pdf
|       HEC-RAS_62_Setup.exe
|
+---7. SurveyData
|   +---0-Description Card of Control Points
|   |       WAT4CAM Description Card of BMs v2.pdf
|   |
|   +---1-Road Elevation Survey Points
|   |       PPK_SurveyPoints_04-Jan-2021.xlsx
|   |       PPK_SurveyPoints_11-16-Dec-2020_V3.xls
|   |       RTK_Check_Line_Route_060121.csv
|   |
|   +---2-Prek Cross-Section Survey Points
|   |       ECO-25-26Dec20.xls
|   |       RTK-20_22-23-Dec-2020.xls
|   |       RTK-21-26Dec2020.xls
|   |
|   +---2-Survey Points Selected by Prek
|   |       0-Other Prek Cross-Section Survey Points.xlsx
|   |       1-Prek Ambil Survey Points.xlsx
|   |       2-Preks Smaller.xlsx
|   |
|   +---3-Bridge Survey Points
|   |       BridgePoints_27Dec-05Jan-2021.xls
|   |       Bridge_Points_27Dec2020.xls
|   |       PPK_BridgeSurvey_06-10-Jan-2021.xls
```

```
|   |       PPK_BridgeSurvey_06-10-Jan-2021.xls.RTK-PPK-06-10-Jan-2021.vrt
|   |
|   \---4-Water Gauge Data
|           Description Card of Water Gauge.pdf
|           Water_Guage_Survey.xlsx
|
+---8.Training
|   |   Quick Guide on Hec_Ras 6Beta2_Khmer.pptx
|   |   Tentative Agenda_English.docx
|   |
|   +---ExerciseData
|   |       Boundaries.xls
|   |       Boundary_rain.xls
|   |       HECRAS 2D Exercise 1.docx
|   |       LC_PSUTM10.tif
|   |       pursat.zip
|   |       Terrain.purat_2.tif
|   |       Terrain_nohole.Resampled.tif
|   |
|   +---Presentations
|   |       Wat4Cam3_1_HECRAS_1.pptx
|   |       Wat4Cam3_1_HECRAS_2.pptx
|   |       Wat4Cam3_1_HECRAS_3.pptx
|   |       Wat4Cam3_1_HECRAS_4.pptx
|   |       Wat4Cam3_1_HECRAS_5.pptx
|   |       Wat4Cam3_1_HECRAS_6.pptx
|   |
|   \---Video
|           GenerateTerainModification.mp4
|           Newproject_Khmer.mp4
|           NodataAreas.mp4
|           Setupdambreakmodel.mp4
|
\--9. -WaterLevels
        LPC_regression_analysisTG_Append3.xlsx
```