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Cambodia: Water Accounting in Tonle Sap, Three S, Upper Mekong, Lower Mekong, Coastal Catchment Basins

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For Asian Development Bank

Asian Development Bank

Water Accounting in Selected Asian River Basins: Pilot study in Cambodia

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Executive Summary

1. Cambodia is facing challenges in satisfying the growing water demand. Sustainable water management strategies are fundamental to support a year-round clean and affordable water supply. These strategies needs to be based on reliable water resources data which is often not available. The concept of conducting country water assessments as a means to plan for improved national water security was suggested in the ADB Water Operational Plan 2011-2020. Essential to the concept of the ADB country water assessments is the element of water demand forecasting, per economic sector (agriculture, industry, energy and municipal), vs. the surface water and groundwater resources for each (major) river basin. Note that environmental water demands are usually excluded while natural land also consumes a large amount of water. At the core of the activity now proposed is a complementary "Water Accounting" procedure.

2. Water accounting can provide a coherent and consistent methodology for quantifying hydrological processes and the distribution of water over various competing sectors. It also considers the consumption of water and the benefits and services - including ecosystem services - that result from that consumption, including the return flow of non-consumed water. The Water Accounting Plus system (WA+) is based on open access remote sensing data - in conjunction with open access GIS data and hydrological model output. WA+ communicates information on water storage, flows and fluxes for a variety of land use systems using a number of intuitive resource sheets, tables and maps that are designed to be understood by people with technical and non-technical backgrounds alike. The WA+ framework is developed by IHE-Delft in partnership with the International Water Management Institute, the Food and Agriculture Organization, and the World Water Assessment Program.

3. The main objective of this project was to support the local recipient organizations and ADB Cambodia in defining sustainable water management strategies by: (a) applying the WA+ procedure to estimate, on a monthly scale, available, exploitable, utilized and utilizable water resources for the five River Basin Groups in Cambodia. Monthly and yearly accounts are produced, with a spatial resolution of 250 m, for selected historic years for the period 2000-2014, (b) providing inputs into the Country Water Assessment plan should it be undertaken in the future, (c) providing inputs for the Asia Water Development Outlook, and (d) providing training and capacity building on the WA+ system, including but not limited to: basic hydrology, GIS, remote sensing data, WA concepts, interpretation of WA+ results.

4. The project started in May 2016 with the first Inception Workshop and consultation with different national stakeholders, and the WA+ analysis of the selected river basins ends with this report (July 2017) and the last training session will be held in Cambodia in August 2017.

This is a rather short period for making comprehensive water resources analysis at country level, and provide training on the latest state of the art technologies in the field of water resources research and engineering.

5. The conditions of the five major River Basin Groups in Cambodia were analyzed for three historical years: a dry (2004), a wet (2007) and an average rainfall year (2008). In this report, we describe (1) the activity performed (data collection and analysis, training), (2) the major outputs obtained from the piloting of the Water Accounting + framework, and (3) we provide recommendations for water management options and possible water savings. The main observations are:

- the highest water consumption (ET) is experienced at the Cambodian coast ($\geq$ 1,600 mm/yr), where precipitation is the highest (4,000-5,000 mm/yr), and over and around the Tonle Sap lake, due to the receding water bodies.

- At the annual scale the Water Yield (P-Et) is negative ($\leq$ -200 mm/yr) on the Tonle Sap lake and in the Lower Mekong basin, which means actual ET is higher than precipitation. The water evaporating from these regions must have a different source, i.e. surface or groundwater.

- Large part of Cambodia is covered by natural surfaces which are not modified or actively managed (more than 60%).

- The majority of the blue water withdrawals are of natural origin and can be attributed to three groups: forest (groundwater), wetlands and water bodies (surface water).

- Man-made withdrawals are considerable less than natural withdrawals. The Tonle Sap basin has the highest rate on man-made withdrawals (6.8%)

- The Tonle Sap basin is currently experiencing the highest water stress (more than double than the other basins). Groundwater stress is higher than surface water stress in all the Cambodian basins.

- All the Cambodian basins utilize less than 70% of the available water resources (on a yearly base). Cambodian basins are significantly dependent on upstream flow (from other basins or other countries). The Tonle Sap receives 20% of its net inflow form external sources (reverse flow and from Thailand), the Three S basin 42% from Vietnam, 88-99% for the Upper and Lower Mekong.

- Non-beneficial water consumption is very high for all the river basins in Cambodia (40-65%), meaning that large volumes of water are consumed without producing any service.

- The Environment is the major responsible for Beneficial water consumption, followed by agriculture.

- land and water productivity are generally low in Cambodia compared to the world average and to neighboring countries. The Three S basin seems to be the best-performing food production area. In the Tonle Sap basin, irrigation systems near Phumi Samraong, and raindfed system near Battambang have the highest performance.

- Forested ares are the areas that contribute the most to groundwater recharge (40-50%).

6. Please note that this report describes the major results only, all accounting sheets and spatial maps are made available on our website (www.wateraccounting.org).

1 Introduction

7. Asia is the world's most dynamic region with fastest economic growth. Due to economic and demographic development pressures, water is becoming an increasingly scarce resource. If left unmanaged, this poses a real threat to continued growth and prosperity of the Asia region. The latest analysis by the International Institute for Applied Systems Analysis indicates that 80% of the population in Asia will be water insecure by the year 2050. Global water demand is projected to increase by about 55%, (from 4,500 billion cubic meters in 2010 to 6,350 by 2030) – growing demand from manufacturing, thermal electricity generation and domestic use. The role of wetlands, riparian corridors and shallow water table ecosystems remain undescribed.

8. In the monsoonal climate system of Cambodia there are urgent problems with water management due to an excess of water in the wet season, causing flooding and water pollution. In the dry season there is a lack of clean water to meet all agricultural, domestic and industrial needs. Sustainable water management strategies are fundamental to support a year-round clean and affordable water supply.

9. Various national water resources assessments and plans are underway or have been completed recently to reflect to this situation. The quality of these water resources plans depends on adequate input data. This is not self-evident in the water sector because generally the density of hydro-meteorological stations is declining, and databases are not shared. A review of investments in water resource measurements in the international community reveals that fewer hydro-meteorological stations are functional, despite the era of modern sensor technology, information technology (IT) and crowd sourcing.

10. Considerable progress has been made in many countries in processing and storing of basic geographic information systems (GIS) data. Yet routine access to this information contained in servers is often restricted to the host organization and the agency that "owns" the data. This limits the benefits that could be obtained by wider use and sharing with other agencies. Information on water resources has to be coherent and synchronized in order to provide an integrated picture useful for the assessment of the problems and possible solutions. The current democracy on hydrological data does not provide the required data necessary to all stakeholders. This hampers the development of good water stewardship. Dissimilar sources of information and terminologies jeopardize the transparency necessary for joint decisions on water, land and ecosystems. Hence, there is a need for independently gathered water resources related data sets that can be commonly understood by all parties.

11. Water Accounting + can meet this requirement. It provides a coherent and consistent methodology that quantifies hydrological processes, water storage, base flow, and the distribution of water to various competing sectors. It also considers the consumption of water and the benefits and services - including ecosystem services - that results from that consumption, including the return flow of non-consumed water and the gap between water demand and water supply. A water accounting system based on open access earth observation satellite

data for complete river basins - including transboundary basins - is therefore proposed: The Water Accounting Plus system (WA+). It goes beyond the classical water budgets, and describes all hydrological and physical water management processes in a river basin.

12. The concept of conducting country water assessments as a means to plan for improved national water security was suggested in the ADB Water Operational Plan 2011-2020. Subsequently, the Asia Water Development Outlook 2013 made a first attempt to quantify national water security, using five key dimensions: (i) household water security, (ii) economic water security, (iii) urban water security, (iv) environmental water security and (v) resilience to water related disasters. In 2013, according to the Asian Water Development Outlook, Cambodia was one of the eight country having a National Water Security Index (NWSI) of 1, meaning that the national water situation was hazardous with a large gap between current state and acceptable level of water security. The water security situation in Cambodia is improving but at a slow paste. In 2016, the NWSI moved to Stage 2: Engaged. The government is therefore working on legislations and policies, is active in capacity-building programs and the level of public investment is increasing. The Water Accounting + activity and the associated training fits the Cambodian present needs and it is strategic for consolidating the current positive trend.

13. The key water issues in Cambodia are irrigation, industry, domestic supply and sanitation, rural supply and sanitation, groundwater, hydro-power, aquaculture, navigation, natural disasters and the environment. The central issues in water management in Cambodia has always been about securing water for sustainable growth, food security, poverty reduction, and minimizing the impact of natural disasters. The climate change situation will exacerbate this situation.

14. Upstream developments of water resources in the Mekong river basin occur, and it can be expected that more upstream countries will increase their withdrawals from the Mekong river for meeting their own irrigation requirements and the extra water needed by the growing population. The upstream benefits are currently not shared with Cambodia. The implication is that the natural flow regime is highly contested and that flows downstream of large dams are mainly a result of hydropower requirements.

15. Water for agriculture is also a key issue in Cambodia as crop production contributes about 54 per cent of the sector GDP, with fisheries accounting for 25 per cent, livestock for 15 per cent and forestry and logging for about 6 per cent. Although only 8 per cent of the rice is irrigated, the rice production has increased steadily and made Cambodia not only self-sufficient in rice, but even an important exporter.

16. Essential to the concept of the ADB country water assessments is the element of water demand forecasting, per economic sector (agriculture, industry, energy and municipal), vs. the surface water and groundwater resources for each (major) river basin. This report follows an action plan (November 2015), an Inception Report (April 2016), a Drought Analysis report (June 2016), and reflects an approved proposal from IHE-Delft to assist ADB with Water

Accounting +. This study was initially intended for Viet Nam only. ADB subsequently requested to include Cambodia in this study. The inception phase report describes the planned steps to implement WA+ in the five major River Basin Groups (RBG) in Cambodia: the Tonle Sap RBG, the upper Mekong RBG, the 3S RBG, the Mekong Delta RBG, and the Coastal RBG, and the current report describes the major outcomes of the activity performed.

17. The Officer-in-Charge from ADB-HQ is the Principal Water Resources Specialist Ms. Yasmin Siddiqi. Ms. Dang Thuy Trang is the ADB Environmental Specialist from the Environment, Natural Resources and Agricultural Division/Cambodia Resident Mission. She is the point of contact. The Principal Investigator from IHE-Delft is Dr. Wim Bastiaanssen. Dr. Elga Salvadore, Water Accounting Expert of IHE-Delft, is responsible for the implementation of WA+ in the major Cambodia river basins and for the training and capacity building in Cambodia. Potential recipient organizations in Cambodia are three Ministries: Ministry of Water Resources and Meteorology (MOWRAM), Ministry of Agriculture, Forestry and Fisheries (MAFF), and Ministry of Environment (MOE). The list of recipient organizations was finalized after the kick-off meetings scheduled on 2-4 May 2016. Simultaneously, technical support has been provided to the major Cambodian universities in the field of engineering, agriculture and water resources.

2 Methodology

18. The Water Accounting Plus (WA+) framework is developed by IHE-Delft in partnership with the International Water Management Institute (IWMI), the Food and Agriculture Organization (FAO), and the World Water Assessment Program (WWAP). It is a multi-institutional effort that aims to provide a valuable and reliable source of information regarding presence and utilization of water resources. The WA+ framework communicates information on water storage, flows and fluxes for a variety of land use systems using a number of intuitive resource sheets that are designed to be understood by people with technical and non-technical backgrounds alike.

19. The WA+ framework focuses on the use of public access remote sensing data in an effort to maintain a high level of transparency. Remote sensing is a reliable and objective source of data. Data products from the National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) are provided free of charge for all users regardless of nationality or intended application. Datasets of precipitation, evapotranspiration, soil moisture, net primary production, land use, water surface areas and water level datasets can be downloaded or determined from the raw satellite data. An overview of open access data that can be downloaded or computed with WA+ tools is given in Tables 1.

20. The Water Accounting + reporting is based on sheets, tables and maps. Maps created from remote sensing, GIS and hydrological models form the basis of distributed computations on flows, fluxes and storage changes. This data is then compiled by Land Use - Land Cover (LULC) class. Class average values form the skeleton for presenting the results in tables. The results are also presented by means of tributaries and rivers; the monthly discharge at any point in the basin with a spatial resolution of 250 m can be computed. This practically means, that every 250 m of a river bed, the actual flow in that river can be estimated. The flow is changing continuously due to runoff, baseflow, withdrawals and return flows, apart from storage changes in lake and reservoirs. Tabular data are summarized by means of sheets, to ease the interpretation and overview of the key processes.

21. Computer software has been developed to read data from various open access data sources and convert the input data into added value hydrological and water management information. All scripts are programmed in Python language that is freeware and highly suitable for processing of spatial data sets. Supporting scripts are made for converting the information into the standard WA+ fact sheets. More background information can be found at www.wateraccounting.org. The software to perform computation and produce the accounting sheets is available free and open source on GitHub: https://github.com/wateraccounting.

Table 1: Input data consulted for WA+

RS data directly downloadable	More modelling needed indirectly available	GIS data	Hydrological data
Land Use Land Cover (LULC) - GlobCover	Actual Transpiration (T)	Protected Areas (A)	Ratio Fast/Slow Runoff
Precipitation (P) - CHIRPS, TRMM	Actual Soil Evaporation (E)	Bathemetry	Surface Runoff
Actual Evapotranspiration (ET) - ETEns	ET green water consumption (ET_green)	Weather data (meteo)	Baseflow
Soil Moisture (SM) - ASCAT	ET blue water consumption (ET_blue)	Terrain elevation (DEM)	Storage changes
Surface temperature (LST) - MODIS	Water withdrawals (Q)	Soil Physical data	Outflow from basins
Surface albedo (alpha) - MODIS	Beneficial/non-beneficial water consumption	Population density	Ration SW/GW withdrawals
Water levals (l) - Jason	Reference Evapotranspiration (ET0)	Livestock density	Lateral GW flow
Change in gravity (delta S) - GRACE	Interception (I)	Grey Water consumption	Groundwater Recharge
Snow cover (cl) - MSG	Soil erosion (Ero)	Environmental flow requirements	
Cloud cover (sn) - MODIS	Dry matter production (Bio)	Depth of root zone	
Leaf Area Index (LAI) - MODIS	Crop Yield (Y)		
Vegetation Cover (Vc) - MODIS	Crop Yield due to rainfall (Y_P)		
Net Primary Production (NPP) - MODIS	Crop Yield due to irrigation (Y_IRR)		
Total Dissolved Solids	Crop water productivity (WP)		
Chlorophyll	Water Productivity due to rainfall (WP_P)		
Water body area	Water Productivity due to irrigation (WP_IRR)		
	Carbon sequestration (C)		
	Lifestock feed production (LiveS)		
	Fuelwood production (Fuel)		

3 Project Objectives

22. The main objective of this project was to support the main local recipient organizations and ADB Cambodia in the development/update of the future National Water Resources Development Plan of Cambodia by:

a. applying the WA+ procedure to estimate, on a monthly scale, available and exploitable water resources for the five major basin groups in Cambodia. Monthly and yearly accounts are produced for selected historic years for the period 2000-2014 (2004, 2007, 2008),

b. input into the future Country Water Assessment plan and complement the National Water Status Report 2014 by providing additional recommendations based on water security diagnosis,

c. providing inputs for the Asia Water Development Outlook, and

d. training and capacity building on the WA+ system, including but not limited to: basic hydrology, GIS, remote sensing data, WA concepts, interpretation of WA+ results. Certificates will be distributed to successful training participants (October 2017).

23. At the end of the project, the main recipient organizations should become independent and able to perform the WA+ procedure in the future for monitoring of the country water resources. Software and tools used are opens source and are transferred to the main recipient organizations at the end of the project.

24. The WA+ project for Cambodia had a total duration of one year only. The number of working days from IHE-Delft staff, allocated for this project, was 175, which also includes 80 days for training and capacity building. This is a short period for the sake of a limited working budget. A very steep learning process had to be introduced for transferring basic skills related to accounting procedure to Cambodian entities. Such period is insufficient for solving all water resources related questions at the National scale, but can be regarded as a first step to show the latest technologies and get hands on experiences that can facilitate to the preparation of the National Water Resources Plan.

25. The work started in March 2016 and ended in April 2017. In this project we applied the Water Accounting + procedure to the five major River Basin Groups (RBG) in Cambodia (Figure 1) on a monthly scale with a spatial resolution of 250 m. The Work Plan and Milestones were described in the Inception phase report; below we summarize the Key Deliverables.

26. In addition to the agreed deliverables, during the course of this project additional requests were made: (a) Remote Sensing based drought Analysis for the period April 2015-May 2016, (b) Sheet 7: ecosystem services analysis, (c) two additional training sessions. The current

project serves as a pilot for the new Water Accounting + methodology, therefore part of the work plan also takes into account a development and testing phase.

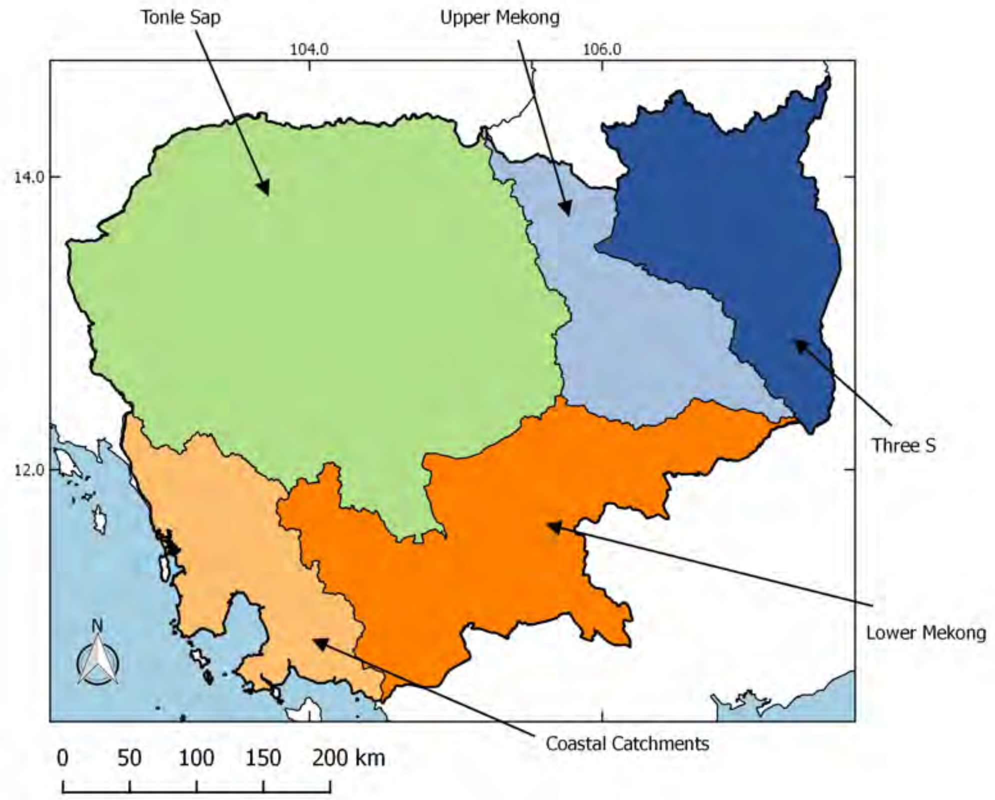


Figure 1: WA+ was implemented for the five major River Basin Groups in Cambodia.

3.1 Key Deliverables

- Standardized WA+ sheets 1-6, tables and maps uploaded on the www.wateraccounting.org data repository with open access, for three selected years in the period 2000-2014 (wet, dry and average year) with a monthly time-scale, for the following Cambodian basin groups: (a) Tonle Sap, (b) 3S, (c) Upper Mekong, (d) Mekong Delta, (e) Coastal Catchments.
- In a second stage, it has been agreed to also generate sheet 7 (Ecosystem services) as part of the WA+ analysis of Cambodian basins
- Water Security Diagnosis (i.e. interpretation of the produced sheets)
- Review report of national and international experts

- Input into Country Water Assessment should it be undertaken in the future
- Input into Asian Water Development Outlook
- Training and capacity building in the WA+ system
- Scripts and tools transferred to the main recipient organizations
- Inception, mid-term and final reports.

4 Training and Workshops

27. We initially planned two training sessions for technical staff of relevant ministries. After the first visit in May 2016 of Prof. Wim Bastiaanssen and Dr. Elga Salvadore, we have agreed in offering three sessions of training for three groups: technical staff, higher officials, and universities.

28. The following training schedule was devised after consultations with the ADB project leader and the principal water resources:

- Inception mission (Phnom Penh): May 2016
  - 2 May: preparatory meeting with ADB representatives;
  - 3 May: workshop with government agencies (higher officials and technical staff from MAFF, MOWRAM, MEF, Ministry of Environment, Ministry of Public Works and Transport, Ministry of Mines and Energy, Council for Agriculture and Development, Ministry of Rural Development, and Water Authority, Tonle Sap Authority)
  - 4 May: consultation with development partners, NGOs, and major Cambodian universities
- On the job training (Phnom Penh): June-July 2016
  - 21-24 June: On the job training for MOWRAM technical staff. Topics: introduction to WA+ framework and rationale, basics of GIS, Remote Sensing, Python programming, exposure to open access (RS) platform for data download, RS vegetation indexes, basic theory of energy balance modeling.
  - 27-30 June: On the job training for MAFF technical staff. Topics: same as above
  - 1 July: one-day workshop for professors and PhD students of the major Cambodian universities. Topics: same as above.
- Second training session (Siem Reap): August 2016
  - 22-24 August: training for technical staff (MOWRAM, MAFF, MOE, Tonle Sap Authority). Topics: revision previous session, ET reference, more of Python, GIS and RS, ET green and ET blue, RS land use classification, WA+ Sheet 2, SVI (vegetation Index used for drought analysis).
  - 25 August: training for higher officials (MOWRAM, MAFF, MOE). Topics: Introduction to WA+, presentation of preliminary project results, Accounting sheets, RS, hydrological models, WA+ for water policy development, drought analysis.

  - 26-27 August: 1st Symposium on Tonle Sap water environment. Presentation WA+ project and drought analysis. Set up collaboration for joint publication.

- Third training session (Siem Reap and Phnom Penh): November-December 2016

  - 21-24 November: training for technical staff (MOWRAM, MAFF, MOE, Tonle Sap Authority). Topics: Revision of major topics of Water Accounting (Beneficial and non-beneficial water consumption, Python programming, Energy balance modelling, Drought analysis, GIS), Hands-on Python modules for Water Accounting, GitHub, ET sheet script + separation ET (E,T,I), Interpretation Sheet 2, Theory and exercises on Biomass: NPP NDM seasonal accumulation, Green and blue water theory + spatial exercise, Rainfed and Irrigated agriculture, Representative crop types, Crop calendars, Introduction on Water Productivity, Harvest Index theory + exercise, FAO AquaSTAT theory and practical session, Theory + website exercise on Sheet 3.

  - 2 December: workshop for higher officials and technical staff (MOWRAM, MAFF, MOE, Tonle Sap Authority). Topics: Introduction WA+, presentation of intermediate results, RS rainfall and ET, validation with ground measurements, land and water productivity, sheet 1, 2, and 3, link to National Water Status Report, Water Resources Assessment and Monitoring, scenario analysis and proposal for Cambodia.

- Fourth training session (Siem Reap and Phnom Penh): April 2017

  - 24 April: workshop for higher officials and technical staff (MOWRAM, MAFF, MOE, Tonle Sap Authority). Topics: Presentation of results of WA+ activity in Cambodia (5 basins), WA+ from Facts to Policy, and consultation with development partners.

  - 25-28 April: training for technical staff (MOWRAM, MAFF, MOE, Tonle Sap Authority). Topics: Python and QGIS hands-on exercises, Fact Sheets 1, 2, 3, and 4, water balance computations, PCRGLOB-WB, Water-Pix and Surf-Wat, Grey water footprint, environmental flows, moisture recycling, and scenarios analysis.

29. One more training session will take place at in the month of September-October 2017.

5 Input Data and Data Validation

30. The WA+ procedure is strongly based on the use of Remote Sensing and open-access datasets. It is however important to validate (and possibly improve or correct) these data with locally obtained data for ensuring reliable results. We prepared a list of data sets needed to produce the WA+ sheets. With the support of the ADB local office we have submitted a formal request to several Cambodian Ministries to collect the necessary ground and local data. Data from several meteorological stations and a few discharge station have been provided together with two RS-based land cover maps.

5.1 Land Use Land Cover Map

31. Of particular importance is to obtain or produce a high-resolution, reliable and thematically-detailed land use land cover map of the major basin groups of Cambodia. An initial map was provided by IWMI-Laos (Figure 2), this map however only covers catchments that belong to the Mekong basin; the coastal catchments are therefore excluded. Additionally, we have received by the Ministry of Agriculture, Forestry, and Fishery (MAFF) two land cover maps relative to the years 2006 and 2010 (Figure 3).

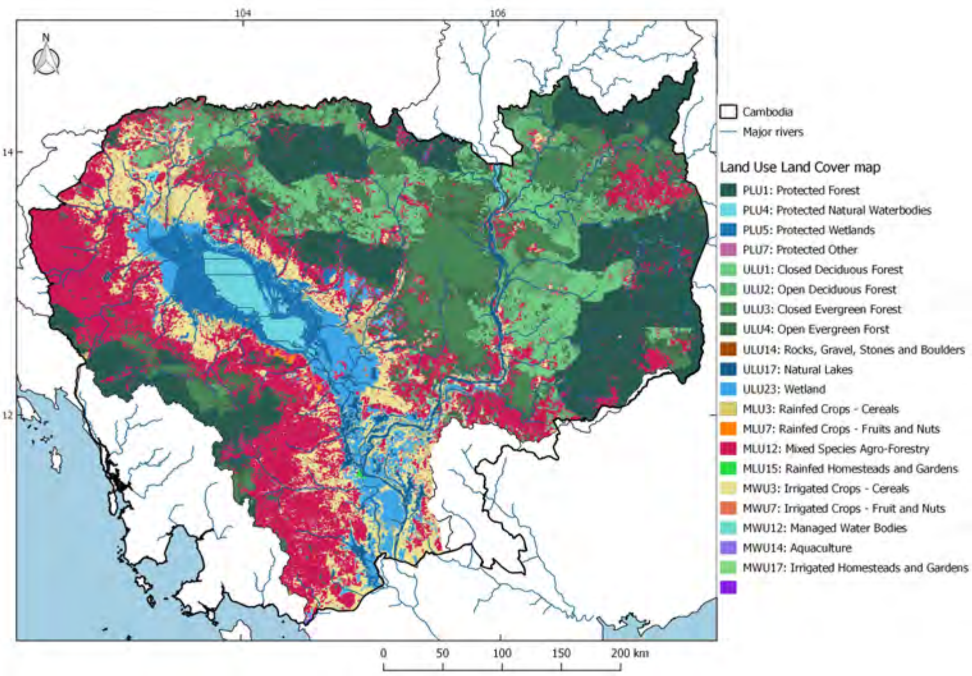


Figure 2: Detailed land use land cover maps for the major basins groups in Cambodia belonging to the Mekong catchment (source IWMI).

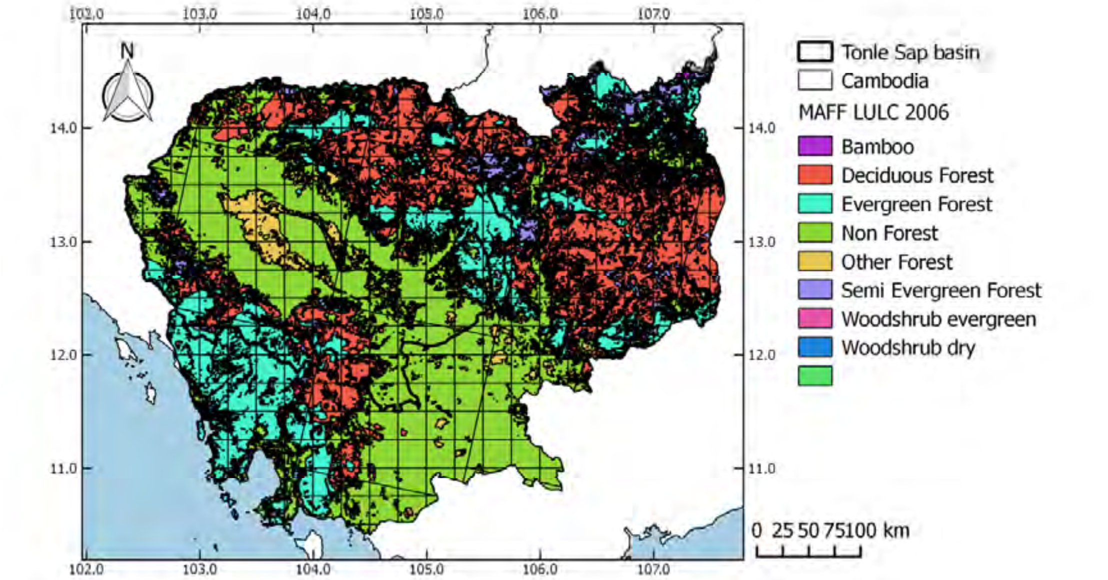


Figure 3: Remote Sensing based Land Cover map of Cambodia for the year 2006, provided by MAFF.

32. To produce the final Land Use Land Cover (LULC) map according to the standard Water Accounting + classification (80 classes), we combine the information from the previous two maps with other open access data, namely: the map of protected areas obtained from the World Database of Protected Areas ($https://www.protectedplanet.net$), and an irrigation map referring to the period 2000-2010, produced by the International Water Management Institute ($http://waterdata.iwmi.org/applications/irri\_area/$). The two input maps are displayed in Figure 4. The final result was used to compute the Water Accounting + sheets for the five major River Basins in Cambodia (Figure 5).

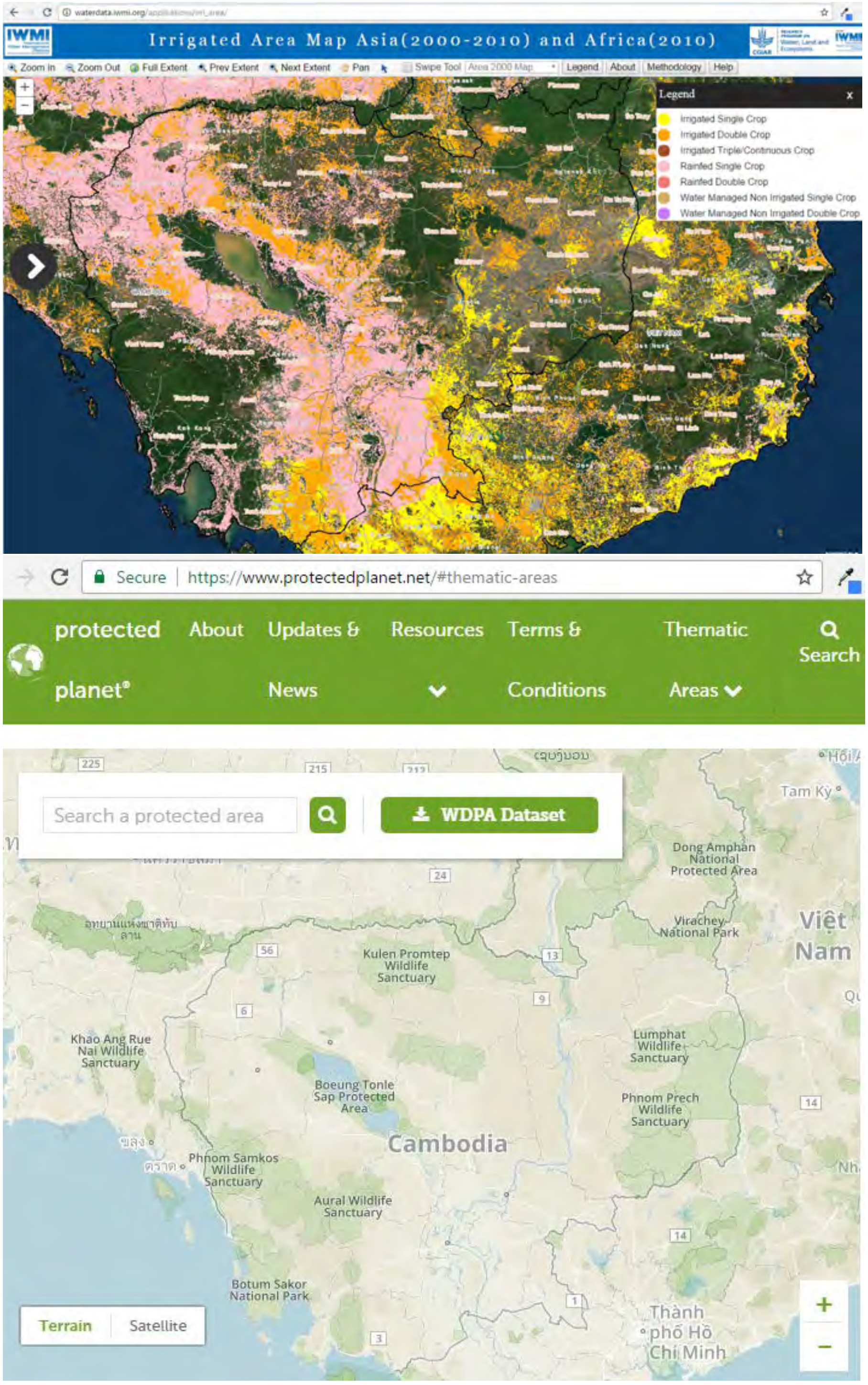


Figure 4: Irrigated mask of Cambodia (source: IWMI) and the protected areas (source: WDPA) that were used to create various water and land management categories required by WA+ and demonstrated in Figure 5.

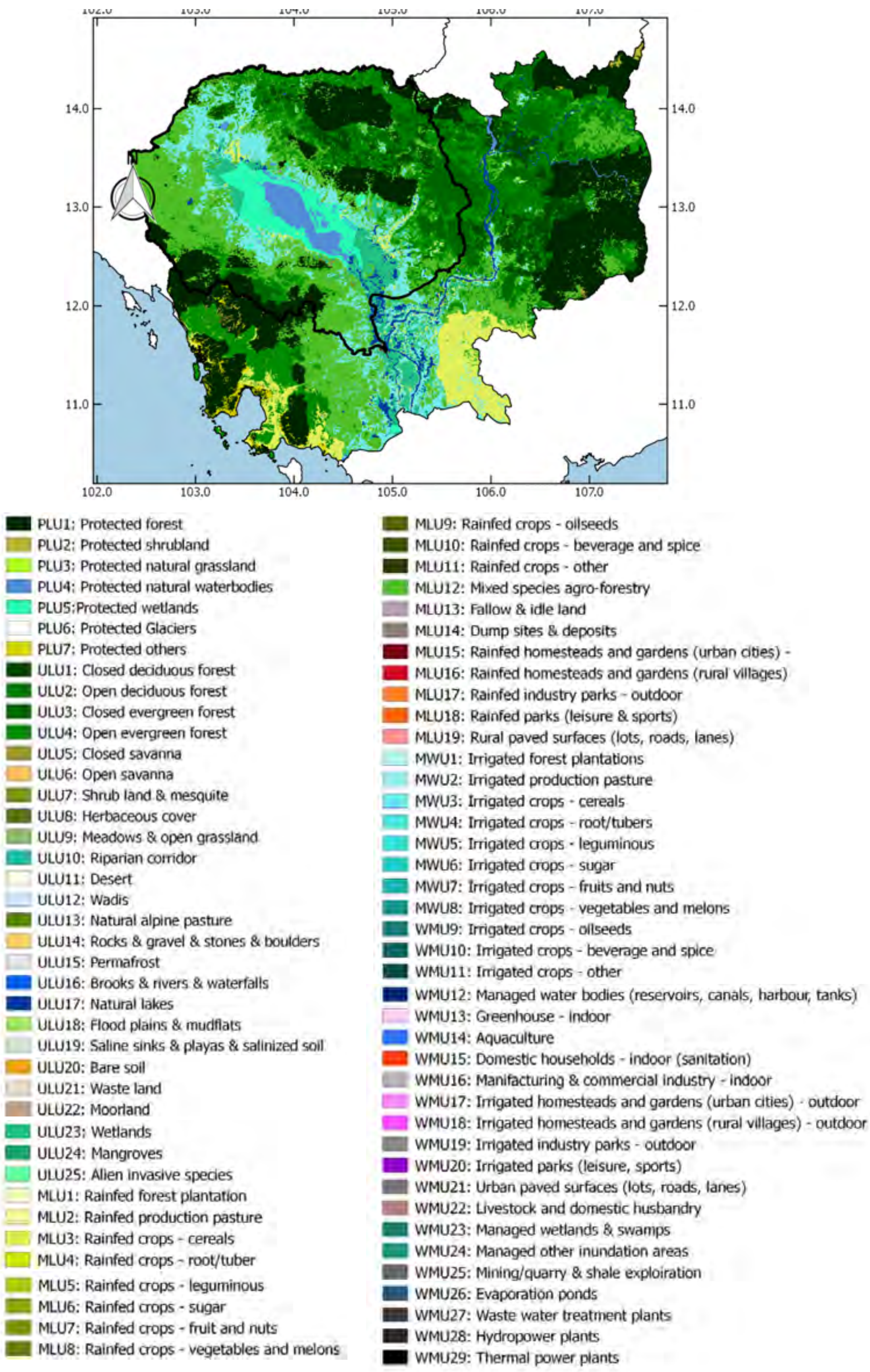


Figure 5: Final Land Use Land cover map, produced for this study for the year 2006 according to the Water Accounting standard classification scheme.

33. The Water Accounting + system takes into account both land and water management. For this reason, the land use land cover classes (80) are grouped into four major categories:

- *Protected Land Use*: Environmentally sensitive land uses and natural ecosystem that cannot be modified due to protective measures;
- *Utilized Land Use*: Represents land use classes with a low to moderate utilization of natural resources, such as savannah, woodland and mixed pastures;
- *Modified Land Use*: Represents land use elements where vegetation is replaced with the intention to increase the utilization of land resources. Examples are plantation forests, pastures and rainfed crops, among others;
- *Managed Water Use*:Represents land use elements with anthropogenic regulation of withdrawals and water supplies. It includes water withdrawals for irrigation, aquaculture, domestic use and industries, among others

34. An overview of these category for the five analyzed catchments is presented in Figure 6. A summary of the different land cover types and respective areas for Cambodia is displayed in Table 2. In the next sections we also discuss more in details the situation of each catchment.

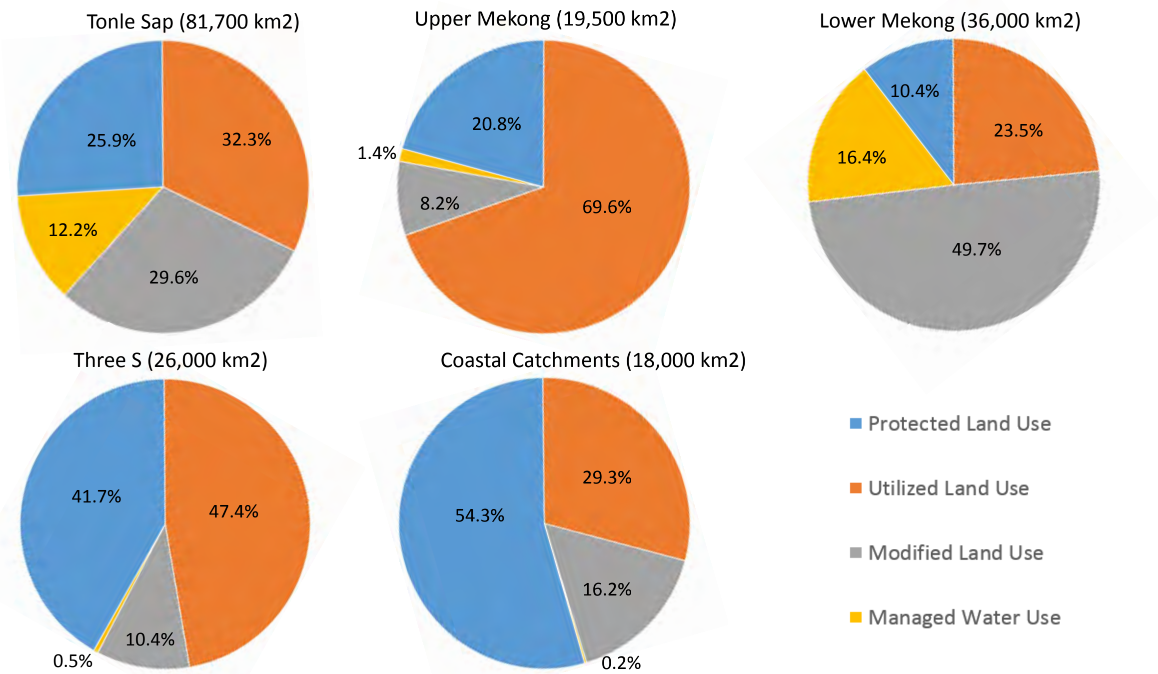


Figure 6: Distribution of the four major WA+ land use land cover category in the five analyzed catchments in Cambodia.

Table 2: Distribution of land use land cover types in Cambodia for the year 2006

LULC	type	Area [km2]
PLU1	Protected Forest	39,019
PLU2	Protected Shrubland	576
PLU4	Protected Natural Water Bodies	3,370
PLU5	Protected Wetlands	5,656
PLU7	Protected other	1,183
ULU1	Closed deciduous forest	9,960
ULU2	Open deciduous forest	11,995
ULU3	Closed evergreen forest	10,708
ULU4	Open evergreen forest	22,131
ULU7	Shrub land & mesquite	329
ULU14	Rocks & gravel & stones & boulders	3
ULU17	Natural Lakes	3,425
ULU23	Wetlands	7,835
MLU3	Rainfed crops - cereals	10,262
MLU7	Rainfed crops - fruit and nuts	100
MLU12	Rainfed crops - mixed species agroforestry	39,040
MLU15	Rainfed homesteads and gardens (urban)	30
MWU3	Irrigated crops - cereals	15,886
MWU7	Irrigated crops - fruits and nuts	115
MWU12	Managed water bodies	36
MWU14	Aquaculture	20
MWU17	Irrigated homesteads and gardens (urban)	4
MWU21	Urban paved surfaces	267

5.2 Elevation

35. Most of the basins in Cambodia are relatively flat lowland catchments with average elevation of about 120 m; Tonle Sap and the Lower Mekong, in particular, have the lowest average elevation (below 100 m). The Coastal Catchments represent an exception, with average elevation three times higher than the other basin groups, slopes are also high as the elevation ranges from -27 m at the coast to 1760 m inland (Figure 7). The Three S basin has also significantly large mountainous regions reaching about 1400 m.

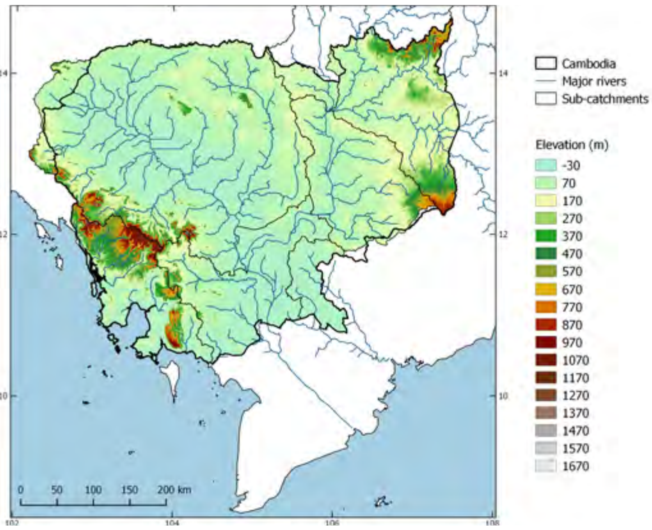


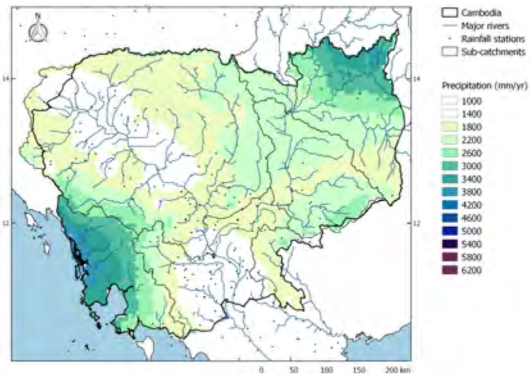
Figure 7: Digital Elevation Map of the five major basin groups in Cambodia (source: USGS HydrSHED).

5.3 Rainfall Data

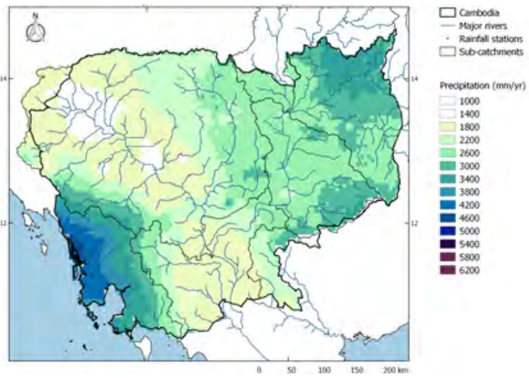
36. We collected monthly RS precipitation for the five major basin groups for the period 2000-2014. In the Inception report we presented the comparison of two remote sensing products, TRMM and CHIRPS, for the entire Cambodia and we selected CHIRPS for the subsequent analysis. We also selected three representative years for the creation of Accounting sheets: 2004 (driest, 1860 mm/yr), 2007 (wettest, 2270 mm/yr), and 2008 (average, 2100 mm/yr). Spatially distributed maps for the selected years are displayed in Figure 8. The Coastal Catchments receive most of the precipitation while the center of Cambodia (part of Tonle Sap and Mekong Delta) receive about forty percent less rainfall in a yearly scale (from 3100 mm/yr to 1800 mm/yr), the Three S basin has an average condition of about 2400 mm/yr.

37. The Ministry of Water Resources and Meteorology (MOWRAM) has kindly provided for this project ground measurements of rainfall (95 stations). We have computed the Nash-Sutcliffe (NS) efficiency to compare the RS-based rainfall measurements with the rain gauge

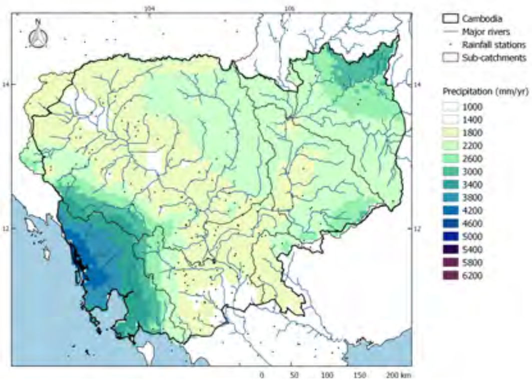
measurements. About 40% of the stations have a NS $>$ 0.5 (good agreement) and 25% have a NS$<$ 0.25 (poor agreement) (Figure 9). For some unknown reason, the agreement for the southeastern part is less satisfactory which could be caused by mountainous and rugged terrain. No systematic bias as noticed, therefore the CHIRPS rainfall products were used as they are provided from the USGS standard websites.



(a) Yearly rainfall (CHIRPS 2004)



(b) Yearly rainfall (CHIRPS 2007)



(c) Yearly rainfall (CHIRPS 2008)

Figure 8: Spatially distributed yearly rainfall the (a) dry -2004-, (b) wet -2007-, and (c) average -2008- year.

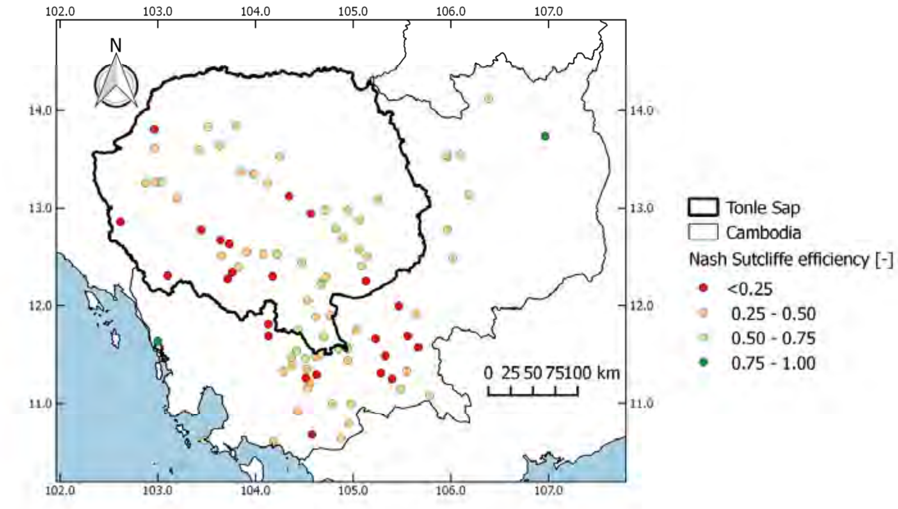


Figure 9: Statistical comparison of the Remote Sensing precipitation product (CHIRPS) and gaged rainfall data from 95 station for the period 2000-2015 (monthly values, Nash-Sutcliffe statistics, source ground data: MOWRAM).

5.4 Other Open Access (Remote Sensing) Data

Actual Evapotranspiration and Water Yield

38. We have developed monthly maps Actual Evapotranspiration (250 m resolution) for entire Cambodia for the period 2003-2012. This Actual ET dataset is the ensemble of seven global RS-based surface energy balance models (ETMonitor, GLEAM, CMRS-ET, SSEBop, ALEXI, SEBS, and MOD16) developed by IHE-Delft. As an example in Figure 10, we show the yearly total Actual ET for Cambodia for the average year (2008). The highest ET values (blue), above 1600 mm/yr, are localized at the coast (Coastal catchments), where precipitation is also high (P is 4,000-5,000 mm/yr), over and around the Tonle Sap lake due to the receding water bodies. The water divide between the Tonle Sap basin and the upper Mekong basin, as well as in the Northern part of the Three S basin depicts high ET fluxes from forests. Due to the rainfall shadow, the northwestern part of the Tonle Sap basin exhibits ET values often below 1000 mm/yr (red). Lower ET rates prevails in the lower Mekong where agricultural land has fallow periods that reduces the annual ET. The average Actual ET for Cambodia for the year 2010 was around 1300 mm/yr.

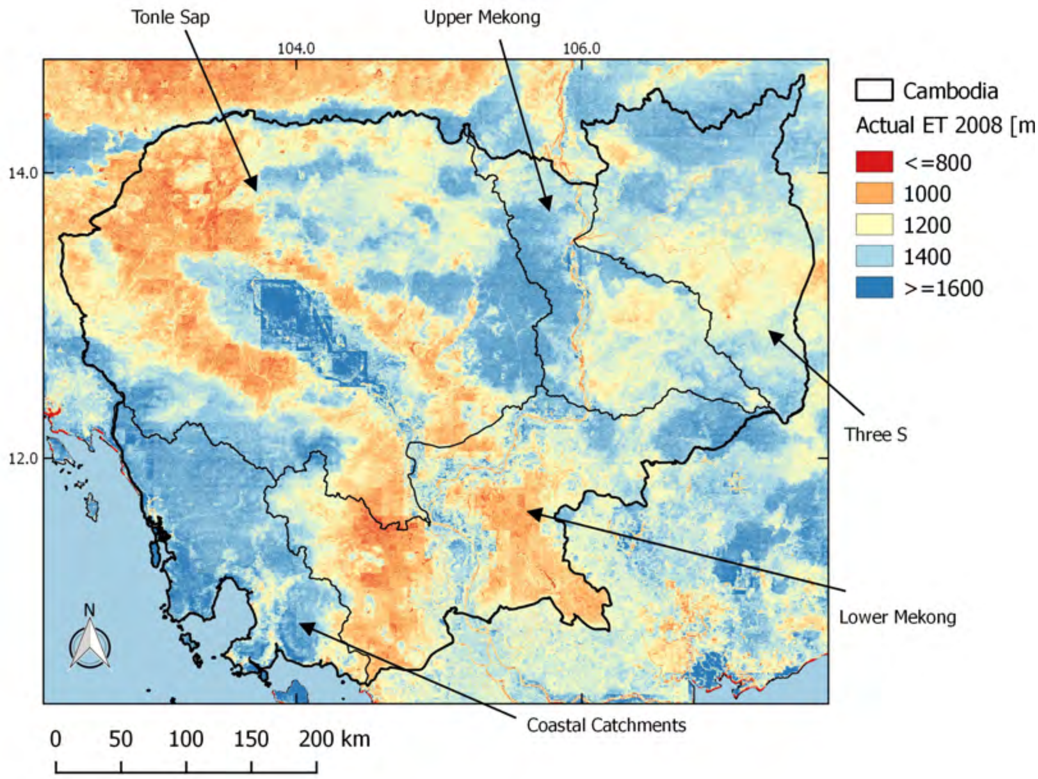


Figure 10: Yearly total ET for the year 2008 for the entire Cambodia (Ensemble ET developed by IHE-Delft on the basis of 7 different surface energy balance models at 250 m resolution).

39. We compared Actual ET with RS-based rainfall data and created maps of Water Yield for the selected years, both monthly and yearly, by subtracting ET from P (Figure 11 shows spatially-distributed results for P-ET during 2008). This simple calculation provides relevant information on water use, water scarcity and water excess. As expected, most of the runoff is generated at the coast and flows non-utilized directly to the sea. The excess of 2000 mm/yr forms a substantial amount of non-utilizable water and options for more utilization or perhaps interbasin transfer should be investigated.

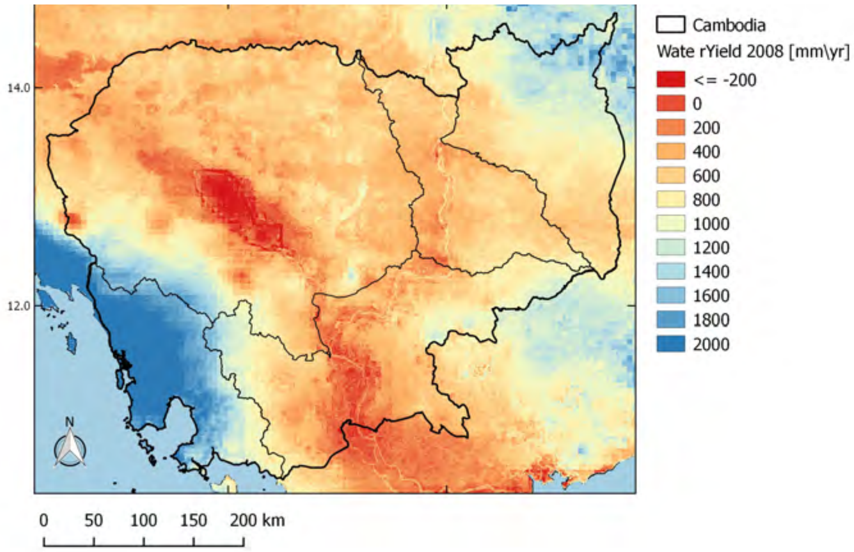


Figure 11: Water Yield (P-ET) for the year 2008, values are expressed in mm/yr.

40. The Water Yield on the Tonle Sap lake and in the Lower Mekong is negative (<= -200 mm/yr), which means that in these location the Actual ET is higher than the Precipitation on the yearly scale. The water evaporating form those regions must therefore have a different source, i.e. groundwater or surface water (blue water). This behavior is typical of irrigated crops, water bodies, and downstream parts of catchments where floods occur.

41. In Table 3, we provide a summary of Precipitation (P), Actual Evapotranspiration (ET) and Water Yield (P-ET) for the five analyzed basins with a break down to the four water management land use categories. As expected Water Yield is generally highest during the wet year and lowest during the dry year. In some extreme cases the water yield of the wet year is double than in the dry year (Upper and Lower Mekong basins), which implies a high yearly variability. In the Tonle Sap basin Protected and Utilized Land Use classes have the highest water yield (50-100 mm/yr more). In the Three S basin there is not a clear separation between water yield among different LULC classes, only the Protected Land Use areas seems to generate a lower water yield. The Three S is the only basin experiencing this condition. In the Coastal catchments the Managed Water Use group produces the lowest water yield (400-500 mm/yr less then the other classes), mainly due to a lower rainfall. Finally in the Lower Mekong the highest water yield is generated by the Protected Land Use group.

Table 3: Yearly average Precipitation (P), Actual Evapotranspiration (ET), and Water Yield (P-ET) for the five analyzed basins. Units are expressed in [mm/yr]. Land Use Land Cover (LULC) groups analyzed are: PLU = Protected Land Use, ULU = Utilized Land Use, MLU = Modified Land Use, and MWU = Managed Water Use.

Tonle Sap	2004 -dry-			2007 -wet-			2008 -avg-		
LULC	P	ET	P-ET	P	ET	P-ET	P	ET	P-ET
PLU	1744	1264	480	2082	1294	789	1859	1322	538
ULU	1685	1205	480	1984	1236	748	1818	1259	559
MLU	1548	1098	450	1774	1135	639	1771	1164	606
MWU	1416	946	470	1613	998	615	1605	1035	570
Three S	2004			2007			2008		
LULC	P	ET	P-ET	P	ET	P-ET	P	ET	P-ET
PLU	2252	1256	996	2747	1264	1483	2215	1318	897
ULU	2380	1304	1075	2776	1297	1478	2208	1337	871
MLU	2333	1264	1069	2784	1252	1532	2234	1286	948
MWU	2225	1054	1171	2587	1096	1491	2005	1131	874
Coastal Catchments	2004			2007			2008		
LULC	P	ET	P-ET	P	ET	P-ET	P	ET	P-ET
PLU	2899	1449	1448	3513	1458	2053	3371	1477	1892
ULU	2749	1415	1334	3298	1405	1893	3211	1448	1763
MLU	2434	1217	1210	3049	1241	1801	2897	1284	1606
MWU	1861	1054	808	2414	1089	1326	2260	1154	1107
Upper Mekong	2004			2007			2008		
LULC	P	ET	P-ET	P	ET	P-ET	P	ET	P-ET
PLU	1898	1253	645	2499	1295	1204	1965	1344	622
ULU	1919	1262	657	2410	1292	1118	1857	1345	512
MLU	1853	1201	652	2400	1246	1153	1859	1293	566
MWU	1763	1090	674	2304	1169	1135	1754	1219	535
Lower Mekong	2004			2007			2008		
LULC	P	ET	P-ET	P	ET	P-ET	P	ET	P-ET
PLU	2181	1350	831	2749	1370	1379	2394	1420	974
ULU	1534	1220	314	1968	1262	706	1698	1300	398
MLU	1589	1058	530	2014	1106	908	1765	1154	611
MWU	1347	1035	312	1721	1096	625	1528	1141	387

42. The monthly variability of Water Yield (P-ET) is also very informative. In Figures 12-16, we present the monthly dynamics of P-ET for the 5 analyzed basins in the dry year (2004). Negative values of P-ET are visible 5-7 months per year (dry season). Water Yield reaches up to about 700 mm/month in July 2004 in the Coastal catchments; in the other basins high values of P-ET range from 250-400 mm/month (Tonle Sap and Three S respectively). The values of blue water consumption have less monthly variation and less variation among different basin groups. In the dry season P-ET ranges between -120 mm/month (Coastal catchments) and -50 mm/month.

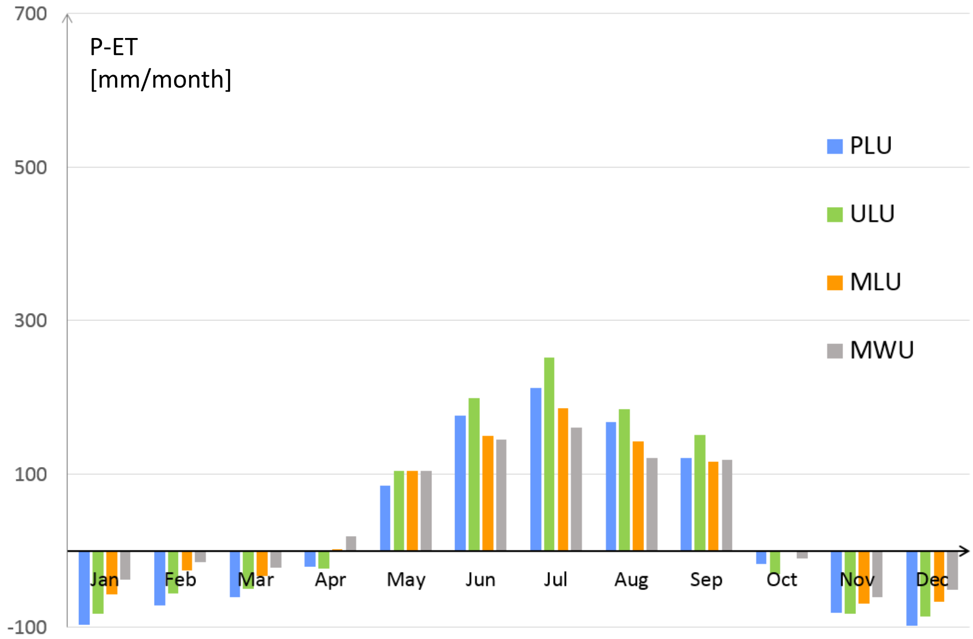


Figure 12: Monthly Water Yield (P-ET)of the four water management land use classes in the Tonle Sap basin for the year 2004 (dry year).

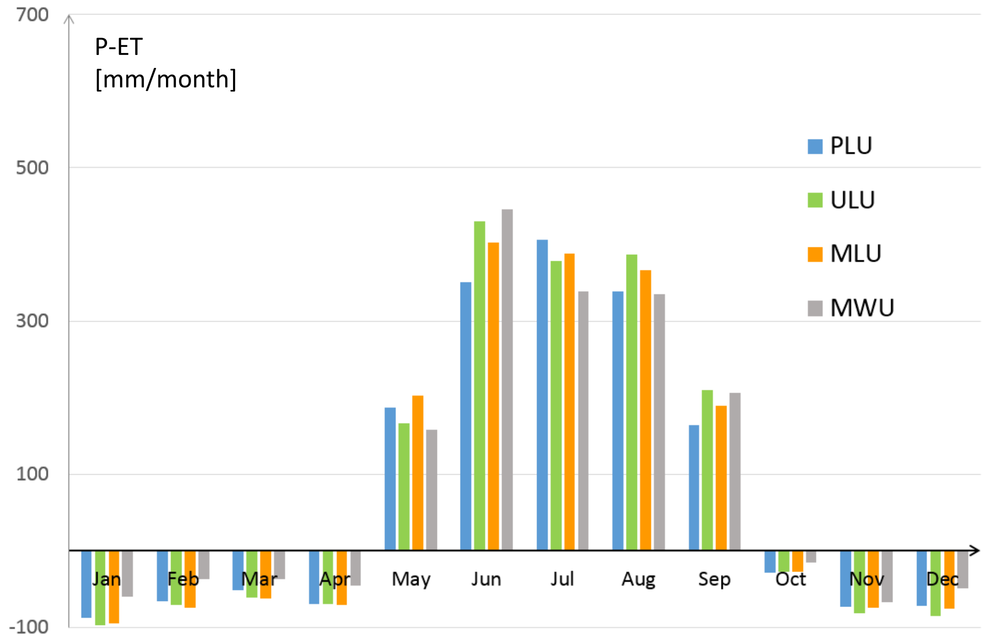


Figure 13: Monthly Water Yield (P-ET)of the four water management land use classes in the Three S basin for the year 2004 (dry year).

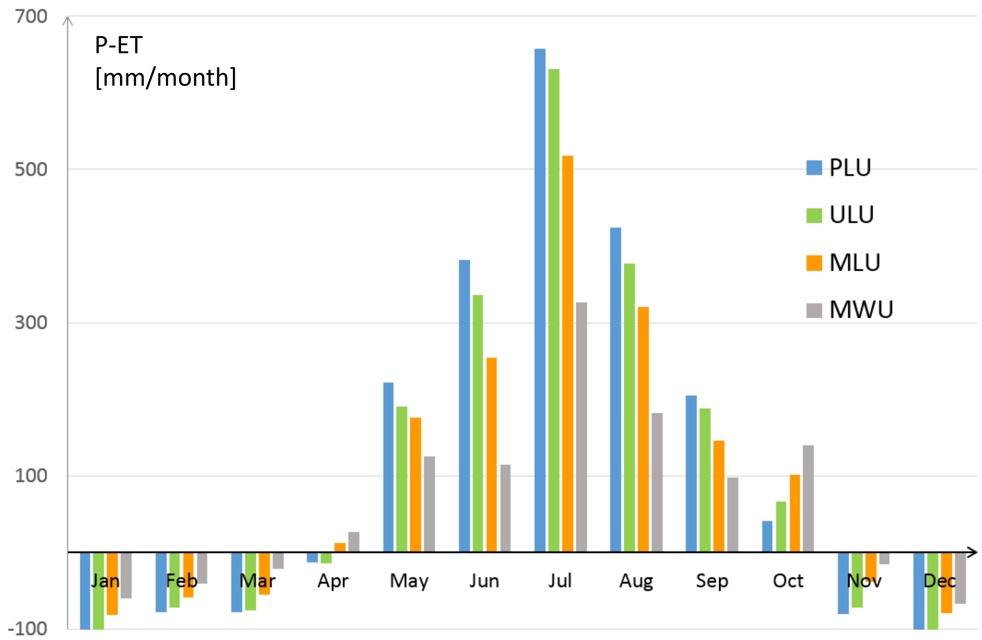


Figure 14: Monthly Water Yield (P-ET)of the four water management land use classes in the Coastal basins for the year 2004 (dry year).

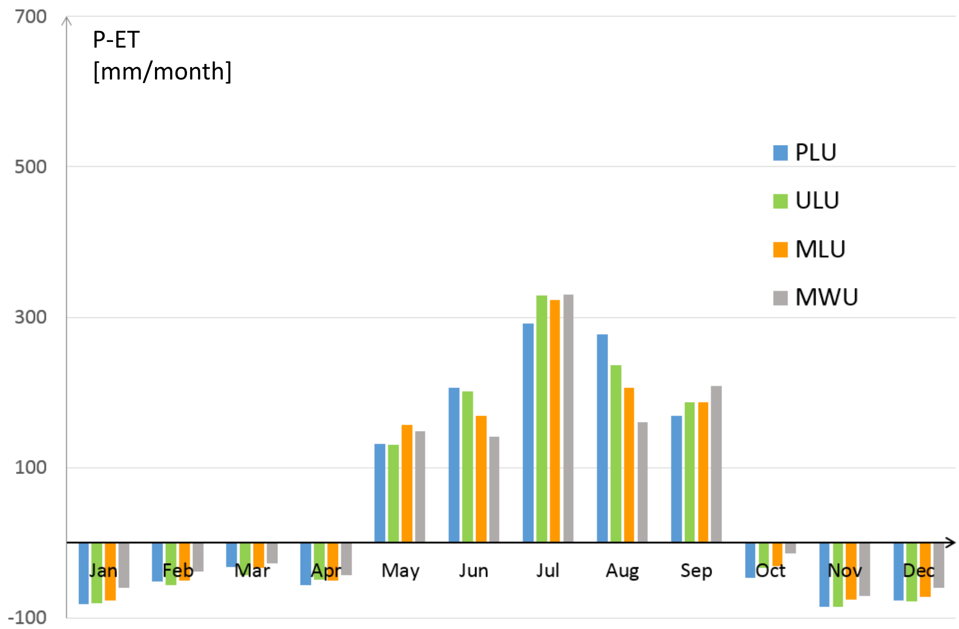


Figure 15: Monthly Water Yield (P-ET)of the four water management land use classes in the Upper Mekong basins for the year 2004 (dry year).

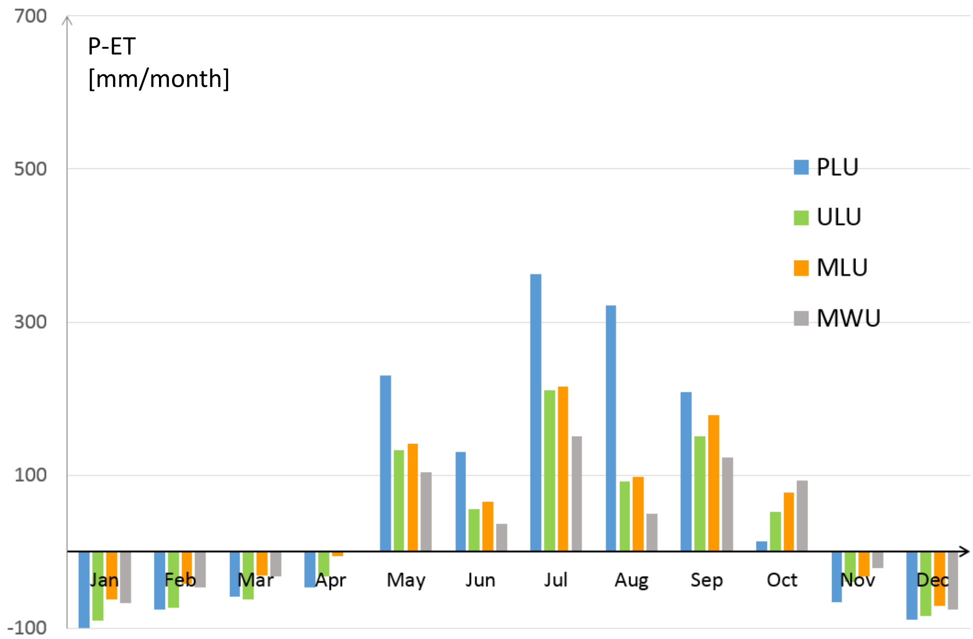


Figure 16: Monthly Water Yield (P-ET)of the four water management land use classes in the Lower Mekong basins for the year 2004 (dry year).

Other (RS) data collected and processed

43. We have collected two Remote Sensing based vegetation index: LAI (2000-2015) from MOD15, NDVI (2001-2015) from MOD13 ($https://modis.gsfc.nasa.gov/data/dataprod/$) being standard MODIS products available for free usage. We have derived monthly 250 m resolution Net Primary Productivity (NPP) based on yearly NPP (MOD17), monthly Gross Primary Productivity (MOD17) and spatial resolution of NDVI. These monthly NPP are used to separate ET into evaporation (E) and transpiration (T). We have computed also spatially distributed reference ET based on FAO56 and climatic data from the global GLDAS model for the period 2000-2015 for the purpose of estimating ET that is related to rainfall ("ETgreen") and other water sources ("ETblue"). Statistical data on livestock and fish production were collected from FAOSTAT ($http://www.fao.org/faostat/en/$).

Global Hydrological simulation results

44. For certain accounting sheets we make use of the results of the global hydrological model PCR-GLOBWB (spatially distributed 10 km resolution, daily, developed by the University of Utrecht). For every grid cell of 10 km X 10 km, the water balance is simulated as described in Figure 17. We compared the simulated river flow with the river flow measurements kindly provided by MOWRAM for several stations, and the results are encouraging (Figure 18). Results of PCR-GLOBWB are used specially for estimating the groundwater fluxes.

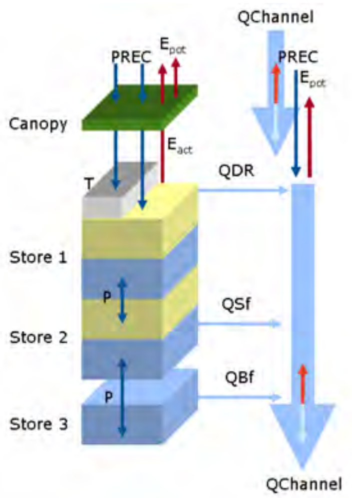


Figure 17: Schematic representation of the water balance computed by the global scale model PCR-GLOBWB.

45. As part of the development of automated tools for Water Accounting Plus computations, we have implemented a new water balance software which calculates, at a monthly time step, the major water balance components at pixel level (Water-Pix). Water-Pix inputs are fully based on Remote Sensing measurements. Surface water results of the Water-Pix tool are then used to calculate the river flow every 250 m using a newly developed tool specifically designed

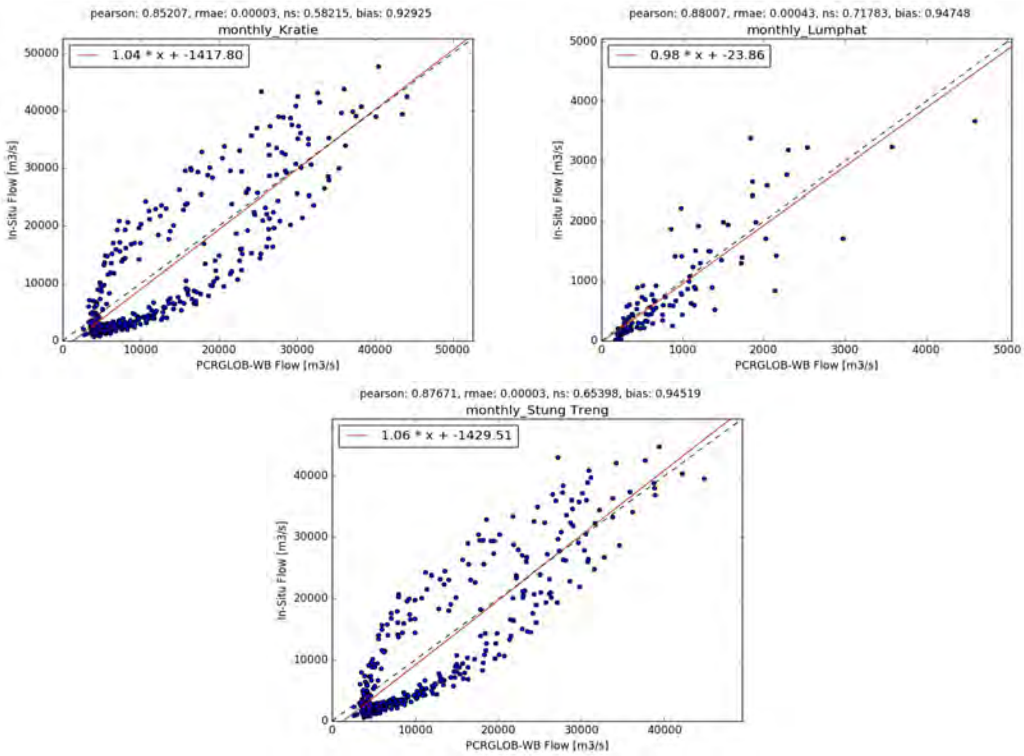


Figure 18: Comparison between simulated river flow (PCR-GLOBWB) and river flow measurements from three ground stations (source: MOWRAM)

for Water Accounting computations (Surf-Wat). Both tools are in testing phase and will be released on our GitHub repository: GitHub: https://github.com/wateraccounting. We compared results of an uncalibrated Surf-Wat model with ground measurements in several stations. It is remarkable that the uncalibrated results of Water-Pix Surf-Wat results, in some locations, match very well with ground measurement (Figure 19, first three cases). In other locations however, calibration is necessary due to inflows from the upstream part of the basin not belonging to Cambodia (i.e. Three S, Figure 19 last case). In other cases, such as small rivers flowing to the Tonle Sap lake, the agreement is not perfect for all tributaries (Figure 20). In this particular case, errors are due to the fact that Surf-Wat automatically generate the location of stream. Stream might therefore be located a few pixels away from the real location. These "geographical" errors however do not significantly influence the final outflow of the basin or other water balance components.

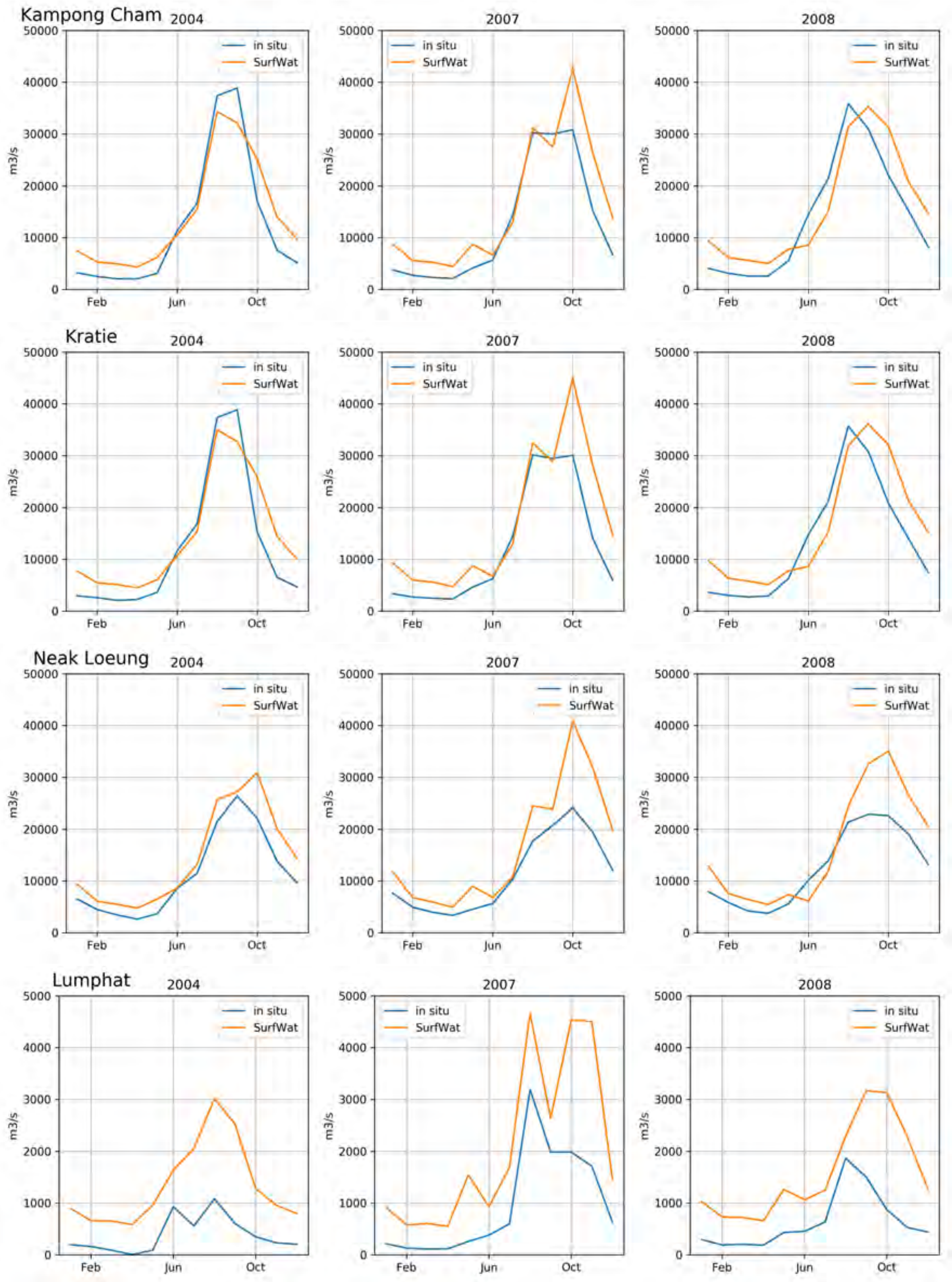


Figure 19: Comparison between simulated river flow (Water-Pix and Surf-Wat) and river flow measurements from four ground stations for the analyzed years (source: MOWRAM).

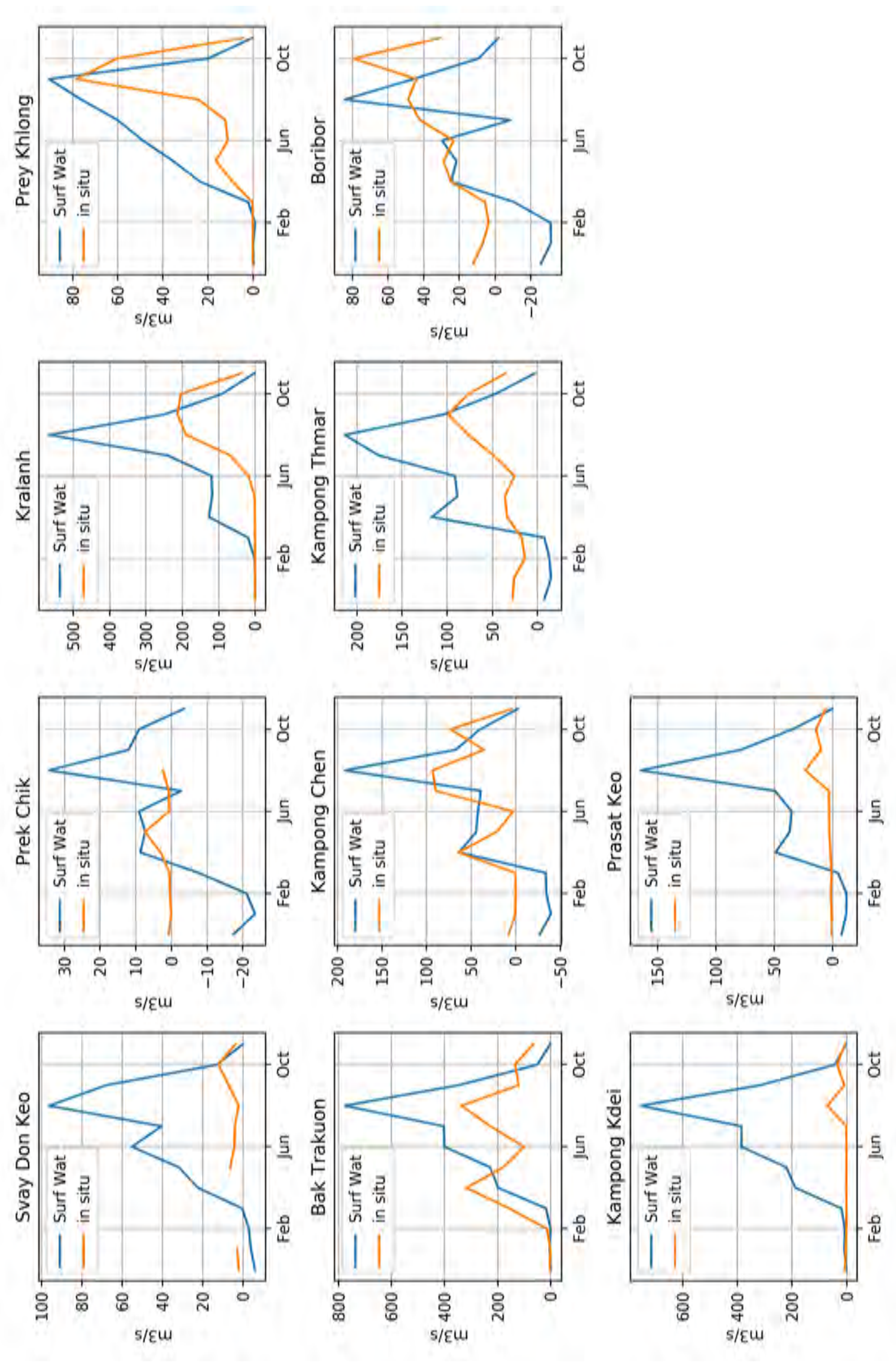


Figure 20: Comparison between simulated river flow (Water-Pix and Surf-Wat) and river flow measurements for stream flowing into the Tonle Sap lake.

46. These river flow data, together with PCRGLOB-WB, are used to compute Fact Sheets 1 (Resource Base) and 5 (Surface Water). Tonle Sap basin is a very particular case, which is very hard to correctly simulate due to its reverse flow conditions. To assess inflows during the wet season from the Mekong river we used a combination of simulated data and ground measurements.

6 Water Accounts for the five major River Basin Groups of Cambodia

47. In this section, we will describe the major results of the Water Accounts for the five Cambodian basin groups, which includes accounting sheets and spatial maps. The Accounting sheets for the selected years are available for download from the Water Accounting + website: $http://wateraccounting.org/projects.html$

48. The strategy for the future of the environmental sector in Cambodia should be based on the synthesis of several accounting parameters. The first indicator relates to the partitioning of land use categories by river basins (Table 4). Large part of Cambodia is still covered by natural surfaces (PLU: Protected Land Uses and ULU: Utilized Land Uses) which are not modified or actively managed. The least natural catchments are the Lower Mekong and the Tonle Sap basins with 16.3% and 12.2% of Managed Water Use respectively (mainly irrigated agriculture and urban areas).

Table 4: Partitioning of land use categories for Cambodian basins. PLU = Protected Land Use, ULU = Utilized Land Use, MLU = Modified Land Use, and MWU = managed Water Use

Basin	PLU [%]	ULU [%]	MLU [%]	MWU [%]
Tonle Sap	25.9	32.3	29.6	12.2
Three S	41.7	47.4	10.4	0.5
Upper Mekong	20.8	69.6	8.2	1.4
Lower Mekong	10.4	23.6	49.7	16.3
Coastal catchments	54.3	29.3	16.2	0.2

49. The second indicator relates to the distribution of ETblue into manmade and natural withdrawals, with the pre-assumption that natural withdrawals are fit for creating healthy ecosystems (Table 5). In all five basins, the majority of blue water withdrawals are of natural origin and can be attributed mainly to three groups: forest, wetlands and water bodies. Wetlands and water bodies rely on surface water, while forests root deep and use groundwater during the dry season and can be considered partially groundwater dependent ecosystems. The Tonle Sap basin has the highest man-made withdrawals that originate from irrigated agricultural areas (6.8 % of the total blue water consumption).

Table 5: Blue water consumption partitioning into natural and man-made withdrawals for the five analyzed basins. The values are an average of the selected years.

2004

Basin	ET blue man-made [%]	ET blue natural [%]
Tonle Sap	6.79	93.21
Three S	0.32	99.68
Upper Mekong	0.99	99.01
Lower Mekong	0.67	99.33
Coastal catchments	0.11	99.89

50. It would also be useful to specify the water stress imposed on natural ecosystems, which is a first indication of the amount of extra available water that should be allocated to environments. The water stress can be inferred from WA+ fact sheet 4 by subtracting supply from demand. The water scarcity is expressed into a volumetric quantity for relating it to the water demand for other water use sectors. In Table 6, we present the Water Scarcity indicators for the five Cambodian river basin groups during the three analyzed years. Obviously in the driest year, water stresses (both surface and ground water) were higher than in other years for all the analyzed basins.

Table 6: Water Scarcity in the five major basin groups of Cambodia for the three analyzed years, expressed as volumetric difference between water demand and supply per water use sector. A separation is made to assess groundwater and surface water stresses. The values are expressed in km^3/yr.

2004 -dry-								
	Forests	Shrubland	Forest plantations	Natural water bodies	Wetlands	Natural grasslands	Other	
Basin	Groundwater stress			Surface water stress				Total stress
Tonle Sap	19.58	0.01	8.55	1.95	0.00	0.00	0.00	30.09
Three S	13.71	0.14	1.49	0.03	0.01	0.00	0.00	15.38
Upper Mekong	11.36	0.00	0.85	0.32	0.04	0.00	0.00	12.57
Lower Mekong	4.37	0.11	3.7	0.14	0.00	0.00	0.00	8.32
Coastal catchments	5.47	0.11	0.14	0.00	0.00	0.00	0.00	5.72
2007 -wet-								
	Forests	Shrubland	Forest plantations	Natural water bodies	Wetlands	Natural grasslands	Other	
Basin	Groundwater stress			Surface water stress				Total stress
Tonle Sap	17.35	0.02	7.51	1.12	0.00	0.00	0.0	26.0
Three S	3.86	0.07	0.3	0.00	0.00	0.00	0.00	4.23
Upper Mekong	6.45	0.00	0.46	0.00	0.00	0.00	0.00	9.11
Lower Mekong	3.41	0.07	3.36	0.86	1.41	0.00	0.00	9.11
Coastal catchments	6.99	0.17	0.13	0.00	0.00	0.00	0.07	7.36
2008 -average-								
	Forests	Shrubland	Forest plantations	Natural water bodies	Wetlands	Natural grasslands	Other	
Basin	Groundwater stress			Surface water stress				Total stress
Tonle Sap	10.59	0.01	5.25	0.00	0.00	0.00	0.00	15.85
Three S	2.68	0.09	0.10	0.00	0.00	0.00	0.00	2.87
Upper Mekong	3.12	0.00	0.14	0.00	0.00	0.00	0.00	3.26
Lower Mekong	0.65	0.02	0.05	0.00	0.00	0.00	0.00	0.72
Coastal catchments	1.53	0.00	0.03	0.00	0.00	0.00	0.00	1.56

51. The results of the accounts also point out that the Tonle Sap basin experiences the highest water stress (more than double than the other basins). The Coastal catchments have lower water stresses for mainly two reasons: (1) these basins receive the highest rainfall rate, and (2) do not rely on external source of water. Groundwater stress is higher than surface water stress which relates to groundwater dependent ecosystems. Noticeable is also

the fact that the wettest year is not the year with the lowest water stress. Seasonal variability of rainfall plays a great role in this context and the average year, with a more homogeneous distribution of rainfall is also the year with the lowest water stress for all the analyzed basins.

52. Sheet 1 or Resource Base Sheet gives a general overview on over-exploitation, unmanageable, manageable, exploitable, reserved, utilized and utilizable flows at river basin scale. In this sheet we can discern between landscape ET (by rainfall) and incremental ET (by natural and man-made withdrawals). It can also be used to assessing commitments to environment and legal agreements and to understand water scarcity during dry years.

53. In Table 7, we present a comparison of the five Cambodian catchments in terms of parameters that can be directly extracted from Sheet 1. We focus on two particular elements of Sheet 1, being the Utilizable Outflow and the Exploitable Water Resources. Exploitable water resources is the difference between net inflow (rainfall, inflows from outside the basin, and change in storage) and landscape ET from soil moisture infiltrated after rainfall events. It is the maximum available amount of blue water resources in lakes, reservoirs, rivers, streams and aquifers. Not all this water is available, as certain volumes have to be set aside for environmental purposes or might not be utilizable (i.e., floods). The Available Water is therefore a better basis for assessing the extra withdrawals and abstractions. The Utilizable outflow represents water that is not used and could be considered for future allocation. Note that the data in Table 7 depicts the annual situation, and that monthly conditions may vary greatly.

54. The fifth column in Table 7 is the ratio between Utilizable Outflow and the Available Water. This parameter gives indications on the space for water development of the basin. All the basins utilize less than 70% of the available water resources. It is therefore clear that they are not, at the yearly scale, closed basins. The last column expresses the surface water flow from outside the river basin and how this water affects the net inflow. This parameter depicts the dependency of water coming from upstream basins or countries because only the Cambodian component of the river basins have been accounted for. While the accounting sheets reflect the situation in Cambodia, the upstream hydrological processes are processed as well. Tonle Sap receives water from Thailand and from the reverse flow from the Mekong, which is 20% of the yearly net inflow. The Three S basin receives 42% of its net inflow from Vietnam. As expected the Upper and Lower Mekong are almost entirely dependent from upstream flow (88-100% of the annual inflow). Negotiations with upstream countries are very important for Cambodia, and as a matter of fact, the total picture at the entire river basin is rather valuable for the Cambodian Government. Future studies should also describe the upstream water accounts to facilitate the negotiation processes.

55. The Evapotranspiration Sheet quantifies water consumption for all land use classes throughout the basin. It describes the anthropogenic impact on ET and concepts of ET management to reduce total water consumption from withdrawals and inundations. This sheet can be used to understand impact of land use planning on consumptive use and to relate water consumption to intended processes (beneficial vs. non-beneficial ET). Since

Table 7: Summary of some components of the Resource Base sheet (U_O = Utilizable Outflow, A_W = Available Water).

Basin	P $[km^3/yr]$	ET $[km^3/yr]$	U_O $[km^3/yr]$	U_O/ A_W [%]	Qsw in/ net inflow [%]
Tonle Sap	143.8	99.2	40.5	51.0	22.0
Three S	62.6	33.3	37.2	44.9	42.9
Upper Mekong	40.0	25.0	283.7	59.3	92.0
Lower Mekong	64.5	41.6	274.9	52.2	89.8
Coastal basins	56.1	25.3	9.6	31.7	0.0

ET is computed from an energy balance, it does not need information on the soil-physical growing conditions, and complex hydrological processes such as interflows, seepage zones etc. Groundwater dependent ecosystems can be detected in this manner.

56. Non-Beneficial water consumption is very high for all the analyzed catchments (between 42% to 65% of the total ET, see Table 8). A large fraction of the exploitable water is therefore not consumed for an intended purpose, meaning that the consumption of these large volumes of water does not produce any service. This is related to the large amount of partially flooded soils that after the monsoon remain wet for a very long time. In only two catchments the proportion of Beneficial Consumption is slightly higher than the Non-Beneficial Consumption (Three S and the Coastal Catchments). These are basins with large tracts of lush green vegetation.

Table 8: Summary of Beneficial Consumption (BC) and Non-Beneficial Consumption (N-BC) for the five major river basins in Cambodia. The values are averages of the analyzed years.

Basin	BC $[km^3/yr]$	Relative BC [%]	N-BC $[km^3/yr]$	Relative N-BC [%]
Tonle Sap	49.0	45.2	59.5	54.8
Three S	19.0	57.9	13.8	42.1
Upper Mekong	12.2	47.1	13.8	52.9
Lower Mekong	10.9	35.2	20.1	64.8
Coastal basins	14.0	56.0	11.0	44.0

57. Interesting is also to analyze the benefits that water consumption produces. In the Water Accounting + framework we divide the Beneficial Consumption into five categories: Environment, Agriculture, Leisure, Economy, and Energy. In Figure 21, the reader can see the break down of the Beneficial Consumption in these categories for the five major basins in Cambodia. Water Consumption in Cambodia is primary beneficial for the Environment (between 32 and 80% of the beneficial consumption), while only a very limited fraction is consumed producing energy or economical value (the maximum value is 6.7% in the Lower Mekong). The Lower Mekong basin is also the only basin where water consumption for agriculture has a higher beneficial fraction than the environment due to the intensive

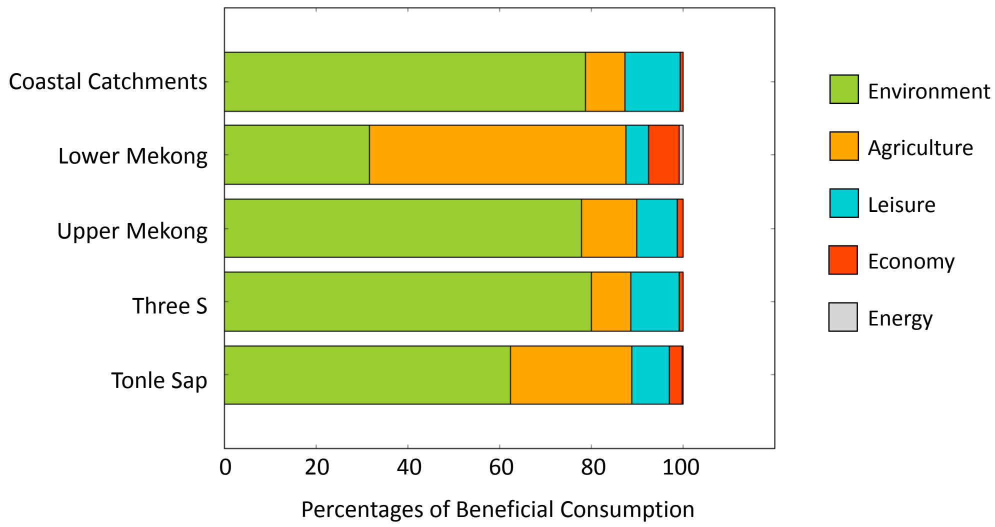


Figure 21: The beneficial consumption is further subdivided into five groups that refer to the services produced: Environment, Agriculture, Leisure, Economy, and Energy.

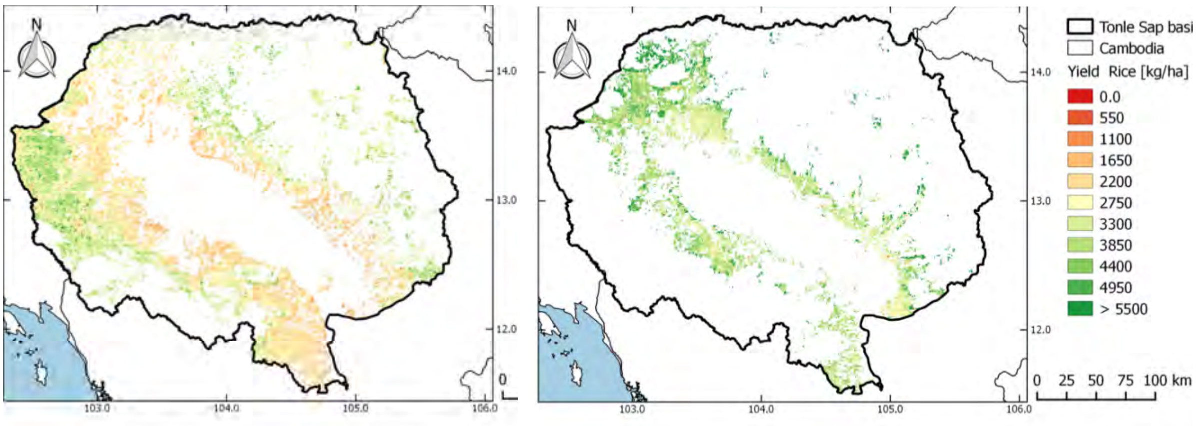
cropping patterns in one of the rice belts of Asia. Hence, Cambodia contributes significantly towards environmental water use and ecosystem services. The majority of this water is green ET, but also blue ET does occur throughout. Environmental water demands should be recognized in the national scale water allocation plans.

58. Sheet 3 is mainly used to assess the agricultural production (kg/ha) in terms of food, feed, timber and fish products, to compute the related water productivity (kg/m^3) and the gap to demonstrate loss of returns (kg, $) and showing which geographical areas can become more efficient with water use. It can help in providing extra attention to certain rainfed and irrigated cropping systems and it indicates possibilities for saving water in agriculture, with an emphasis on non-beneficial water consumption and shifts from irrigated to rainfed crops and agroforestry systems.

59. The major results of the yearly Sheets 3 are summarized in Table 9. The values of agricultural production and water productivity of cereals are generally low if compared with world average and with neighboring countries (Thailand and Vietnam). Irrigated area have both higher yield and higher water productivity as compared to the rainfed systems, partially because they can cover two crops per year, while the rainfed systems have one rotation per year. The Three S basin seems to contain the best-performing food production area (cereals). The WP value is however still low, also for Three S, but close to the global average water productivity score for rice which is approximately 1.1 kg/m^3. It would be good to set up exchanges with Thailand and Vietnam to increase agricultural production.

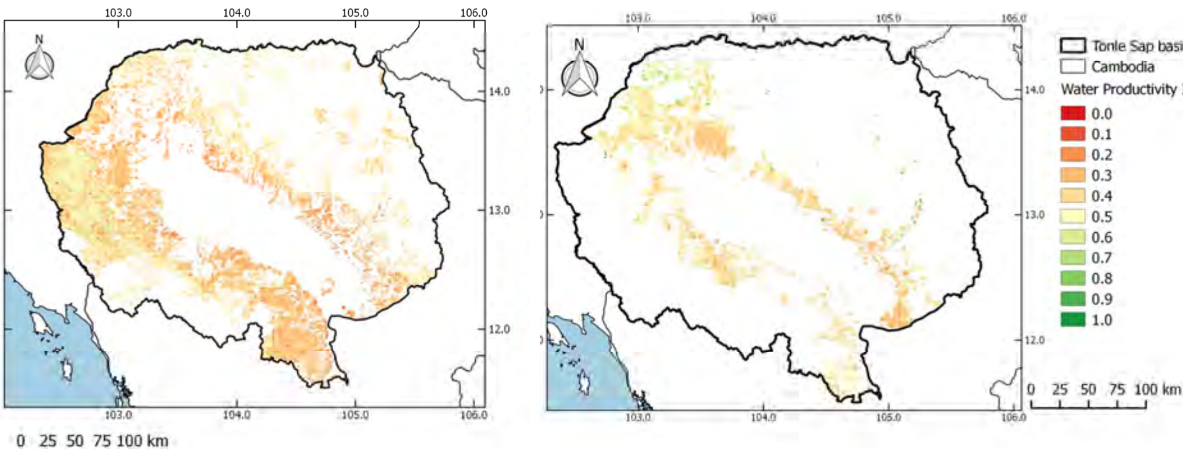
60. Crop Yield and Water Productivity (ratio between crop yield -production- and Actual ET

-consumption-) can be estimated using Remote Sensing data. In Figure 22, we show, as an example, the spatial distribution of rice yield generated from rainfed and irrigation systems for the Tonle Sap in 2008, and in the associated Figure 23 Water Productivity. It seems that the Northwestern part of the basin bordering Thailand has the highest production performance in the irrigation systems near the town of Phumi Samraong. The rainfed rice system score the best in the mountain hills that border Thailand near the town of Battambang where rainfall comes with vast amounts.



(a) Yield from Rainfed rice fields (b) Yield from Irrigated rice fields

Figure 22: Yield produced by rice fields in the Tonle Sap river basin in the year 2008.



(a) Water Productivity from Rainfed rice fields (b) Water Productivity from Irrigated rice fields

Figure 23: Water Productivity of rice fields in the Tonle Sap river basin in the year 2008.

Table 9: Summary of the results of Sheet 3 for the five basin groups of Cambodia. Values are yearly averages for the basin and values in brackets represents the standard deviation.

Tonle Sap 2004	Crop Type	Area [km2]	Yield [kg/ha]	Food Prod. [Mt/yr]	ET [mm/yr]	WP [kg/m3]
	Cereals rainfed	1,107	2,984(818)	0.33	983(151)	0.50(0.14)
	Mixed species agroforestry rainfed	22,699	3,813(863)	8.65	1,103(138)	0.61(0.13)
	Cereals Irrigated	9,664	5,575(1,252)	5.39	943(77)	0.932(0.236)
	Fruits & Nuts rainfed	95	12,393(3,375)	0.12	1,201(127)	1.35(0.38)
	Fruits & Nuts irrigated	108	12,898(3,777)	0.14	1,132(111)	1.41(0.39)
2007						
	Cereals rainfed	1,107	2,706(875)	0.30	1041(138)	0.41(0.13)
	Mixed species agroforestry rainfed	22,699	3,719(920)	8.44	1,139(125)	0.53(0.13)
	Cereals Irrigated	9,664	5,305(1,300)	5.13	945(74)	0.80(0.21)
	Fruits & Nuts rainfed	95	11,600(3,500)	0.11	1,259(121)	1.12(0.34)
	Fruits & Nuts irrigated	108	11,889(3,983)	0.3	1,200(106)	1.14(0.37)
2008						
	Cereals rainfed	1,107	2,417(836)	0.27	1076(140)	0.39(0.12)
	Mixed species agroforestry rainfed	22,699	3,434(902)	7.80	1,168(119)	0.51(0.12)
	Cereals Irrigated	9,664	4,728(1,120)	4.57	1031(77)	0.77(0.21)
	Fruits & Nuts rainfed	95	11,011(2,975)	0.10	1,301(115)	1.14(0.32)
	Fruits & Nuts irrigated	108	10,479(3,577)	0.11	1,242(103)	1.09(0.37)
Three S 2004	Crop Type	Area [km2]	Yield [kg/ha]	Food Prod. [Mt/yr]	ET [mm/yr]	WP [kg/m3]
	Cereals rainfed	34	4,686(1,282)	0.02	1,168(183)	0.79(0.25)
	Mixed species agroforestry rainfed	2,661	4,930(786)	1.31	1,266(136)	0.76(0.14)
	Cereals Irrigated	130	6,986(1,934)	0.09	1,055(143)	1.34(0.47)
2007						
	Cereals rainfed	34	3,898(315)	0.01	1,164(147)	0.81(0.09)
	Mixed species agroforestry rainfed	2,661	4,838(729)	1.29	1,253(101)	1.03(0.23)
	Cereals Irrigated	130	7,002(1,695)	0.09	1,055(143)	1.34(0.47)
2008						
	Cereals rainfed	34	4,061(586)	0.01	1,202(135)	0.73(0.20)
	Mixed species agroforestry rainfed	2,661	4,774(728)	1.27	1,287(93)	0.84(0.15)
	Cereals Irrigated	130	7,403(2,045)	0.10	1,132(94)	1.35(0.40)
Upper Mekong 2004	Crop Type	Area [km2]	Yield [kg/ha]	Food Prod. [Mt/yr]	ET [mm/yr]	WP [kg/m3]
	Cereals rainfed	57	3,812(993)	0.02	1,167(213)	0.62(0.20)
	Mixed species agroforestry rainfed	1,533	4,404(861)	0.68	1,202(154)	0.65(0.13)
	Cereals Irrigated	266	7,084(2,099)	0.19	1,091(135)	1.09(0.38)
2007						
	Cereals rainfed	57	3,650(814)	0.02	1,226(182)	0.54(0.16)
	Mixed species	1,533	4,4142(815)	0.64	1,247(111)	0.62(0.16)

	agroforestry rainfed					
	Cereals Irrigated	266	5,908(1,413)	0.16	1,171(107)	0.92(0.39)
2008						
	Cereals rainfed	57	3,407(830)	0.02	1,271(171)	0.53(0.15)
	Mixed species agroforestry rainfed	1,533	4,425(783)	0.62	1,294(113)	0.65(0.15)
	Cereals Irrigated	266	7,084(2,099)	0.19	1,091(135)	1.09(0.38)
Lower Mekong 2004	Crop Type	Area [km2]	Yield [kg/ha]	Food Prod. [Mt/yr]	ET [mm/yr]	WP [kg/m3]
	Cereals rainfed	6,407	2,970(726)	1.90	1,020(123)	0.46(0.11)
	Mixed species agroforestry rainfed	11,482	3,460(974)	3.97	1,079(158)	0.53(0.15)
	Cereals Irrigated	5,637	5,088(1,123)	2.87	1,035(138)	0.99(0.28)
2007						
	Cereals rainfed	6,407	2,546(724)	1.63	1,105(108)	0.37(0.10)
	Mixed species agroforestry rainfed	11,482	3,206(857)	3.68	1,107(145)	0.47(0.12)
	Cereals Irrigated	5,637	4,642(1,193)	2.62	1,095(136)	0.66(0.21)
2008						
	Cereals rainfed	6,407	2,461(724)	1.58	1,123(119)	0.44(0.12)
	Mixed species agroforestry rainfed	11,482	2,979(840)	3.42	1,140(134)	0.51(0.13)
	Cereals Irrigated	5,637	4,473(1,022)	2.52	1,140(139)	0.86(0.25)
Coastal 2004	Crop Type	Area [km2]	Yield [kg/ha]	Food Prod. [Mt/yr]	ET [mm/yr]	WP [kg/m3]
	Cereals rainfed	2,611	4,335(1120)	1.13	1,205(158)	0.64(0.18)
	Mixed species agroforestry rainfed	310	4,432(946)	0.14	1,316(192)	0.64(0.16)
	Cereals Irrigated	25	5,699(1,580)	0.01	1,015(82)	0.85(0.25)
2007						
	Cereals rainfed	2,611	3,922(1009)	1.02	1,230(157)	0.56(0.27)
	Mixed species agroforestry rainfed	310	3,849(863)	0.12	1,334(192)	0.52(0.13)
	Cereals Irrigated	25	5,012(1,439)	0.01	1,056(117)	0.63(0.20)
2008						
	Cereals rainfed	2,611	3,722(1053)	0.97	1,275(137)	0.60(0.18)
	Mixed species agroforestry rainfed	310	3,655(737)	0.11	1,363(183)	0.56(0.16)
	Cereals Irrigated	25	4,697(1,232)	0.01	1,127(95)	0.66(0.25)

61. Sheet 6 gives information regarding the groundwater conditions of the analyzed river basin. The five Cambodian basins show similar conditions which vary mainly due to the seasonal climate variations and therefore are less dependent on anthropogenic impacts (Table 10). In all five river basin, the groundwater storage change is negative in 2008. This is surprising since 2007 was the wet year and 2008 is the average year. This is due to the fact that, even if 2008 was an average year, during this year the groundwater recharge was the lowest. Except for Tonle Sap, 2007 also shows negative values for the groundwater storage

(less severe than in 2008). Groundwater recharge however is always almost double than groundwater withdrawals. The fact that the groundwater system does not follow the rainfall variability (dry, wet and average years) can be explained by the different dynamics between surface and groundwater. Groundwater flow is usually several orders of magnitude slower than surface processes. More analysis is therefore needed to draw final conclusions and more historical years should be analyzed.

Table 10: Summary of the flow components that can be derived from Sheet 6 (Groundwater) for the five analyzed basins. Values are expressed in km^3/yr

Tonle Sap	2004	2007	2008
Groundwater recharge	32.7	37.2	31.2
Withdrawals	15.9	13.1	17.9
Total return	1.2	1.0	1.5
Baseflow	13.3	21.3	22.3
Storage change	+4.5	+3.8	-7.7
Three S	2004	2007	2008
Groundwater recharge	21	14.3	8.6
Withdrawals	8.2	11.6	11
Total return	8.2	11.6	11
Baseflow	8.6	10.3	10.2
Storage change	+4.2	-7.7	-12.6
Mekong Delta	2004	2007	2008
Groundwater recharge	13.9	17.4	10
Withdrawals	5.7	4.4	9.5
Total return	0.5	0.4	0.8
Baseflow	6.6	10.8	9.4
Storage change	+3.2	-1.9	-7.1
Upper Mekong	2004	2007	2008
Groundwater recharge	11.4	10.3	4.3
Withdrawals	4.8	6.4	7.5
Total return	0.0	0.1	0.1
Baseflow	3.4	5.8	3.9
Storage change	+3.2	-1.9	-7.1
Coastal Catchments	2004	2007	2008
Groundwater recharge	9.8	17.2	11
Withdrawals	7.5	4	6.2
Total return	0.2	0.2	0.2
Baseflow	8.3	14	18.3
Storage change	-5.8	-0.7	-13.4

6.1 Tonle Sap

62. Tonle Sap is the largest freshwater lake in Southeast Asia. It contains an exceptionally large variety of interconnected eco-regions with a high degree of biodiversity (UNESCO biosphere reserve in 1997). Unique aspects of the Tonle Sap hydrological system are:

a. The direction of the flow changes twice per year. During the dry season the water flows from the lake into the Mekong in Phnom Penh; while in the wet season the river flow reverses and the lake receives water from the Mekong river, causing the water levels to rise by 1 to 10 m;

b. The size of the lake varies seasonally, from 2,500 km2 in the dry season up to 15,000 km2 in the wet season, a factor 6, which creates a perfect environment for flooded forests and recession agriculture.

c. Outside the protected areas, water consumption of forests and rainfed crops are almost identical.

d. Being one of the world's largest wetland ecosystems, the region has been an important natural resources for ancient civilizations for providing food and fish. More than 1 million Cambodians are nowadays supported by fishery and it provides the largest source of proteins for Cambodia population.

63. The Tonle Sap river is a tributary of the Mekong river, the outlet of the catchment is located in Phnom Penh capital city. The total area of the basin is about 81,700 km^2, which is nearly half of the total surface area of Cambodia. The Protected Area covers a surface of about 21,000 km^2 (26%) which includes both Protected Forest and the Tonle Sap lake. Most of the lake area is protected even if it is utilized by the local community for fishery. In a relative small fraction of the basin the water is actively managed (irrigated agriculture and urban areas, 12.2%). Due to the Asian monsoon, rainfed agriculture is quite common in the basin (29.6%), being a major source of income to rural communities. The major crops considered in this study are cereals (rice), and fruits and nuts (mango). The forest covered area, protected and non-protected, is about 33,500 km^2. The amount of forest and agriculture is approximately equal (about 41.5% each). Forest plantations do occur, but deforestation goes at a more rapid pace than reforestation, yielding into a forest cover decrease of more than 3500 km^2 in the period 2006-2010. This is a forest cover decline of 2% per year. The water area (water bodies and wetlands) covers and area of about 500 km^2.

64. The annual totals of rainfall, ET, and Water Yield (P-ET) are summarized in the Table 11 for the selected years. It is obvious - and normal – that the variability in P is more prominent than the variability in ET (the same consideration is valid for other basins as well). As a consequence, the variability of rainfall is essentially converted into net outflow

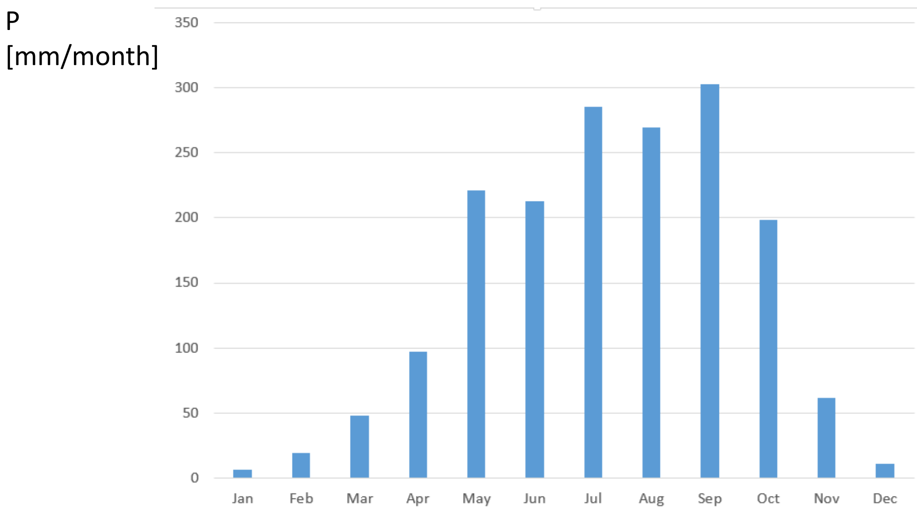


Figure 24: Monthly average precipitation in the Tonle Sap river basin.

(P – ET) variability. In a dry year this becomes 34.9 km^3/yr while during a wet year this can increase to 54.2 km^3/yr, being 50% more than the dry year, if the dry year is taken as reference.

Table 11: Yearly average precipitation (P), evapotranspiration (ET), and water yield (P-E) for the Tonle Sap basin.

Year	P [km^3/yr]	ET [km^3/yr]	Water Yield (P-ET) [km^3/yr]
2004 (dry)	131.2	96.3	34.9
2007 (wet)	153.7	99.5	54.2
2008 (average)	146.4	101.7	44.7

65. There is however a high variability at the monthly scale (Figure 24), with the average wet season running from May till October and the average wet season from November till April. This has significant consequences on the monthly flows and monthly storage changes. The most convenient overview on the water balance is the Resource Base sheet. An example is presented in Figure 25 (2004, dry year). The surface water inflow (40.4 km^3/yr) and outflow (61.3 km^3/yr) presents large volumes of water. The utilized flow (28.8 km^3/yr) is a small fraction of the net inflow, as was observed before. Ideally, a portion of the utilizable outflow of 42.9 km^3/yr should be converted into utilized flow. This can only occur if more water is stored.

66. Because of the monsoonal climate, water storage in the basin steadily increases and can reach to an intensity of +65 km^3/month. At a total basin area of 81.700 km^2, this is an equivalent depth of 796 mm/month. Such high storage change can only occur by higher water levels in open water bodies. Delta S decreases again during the dry season, and in

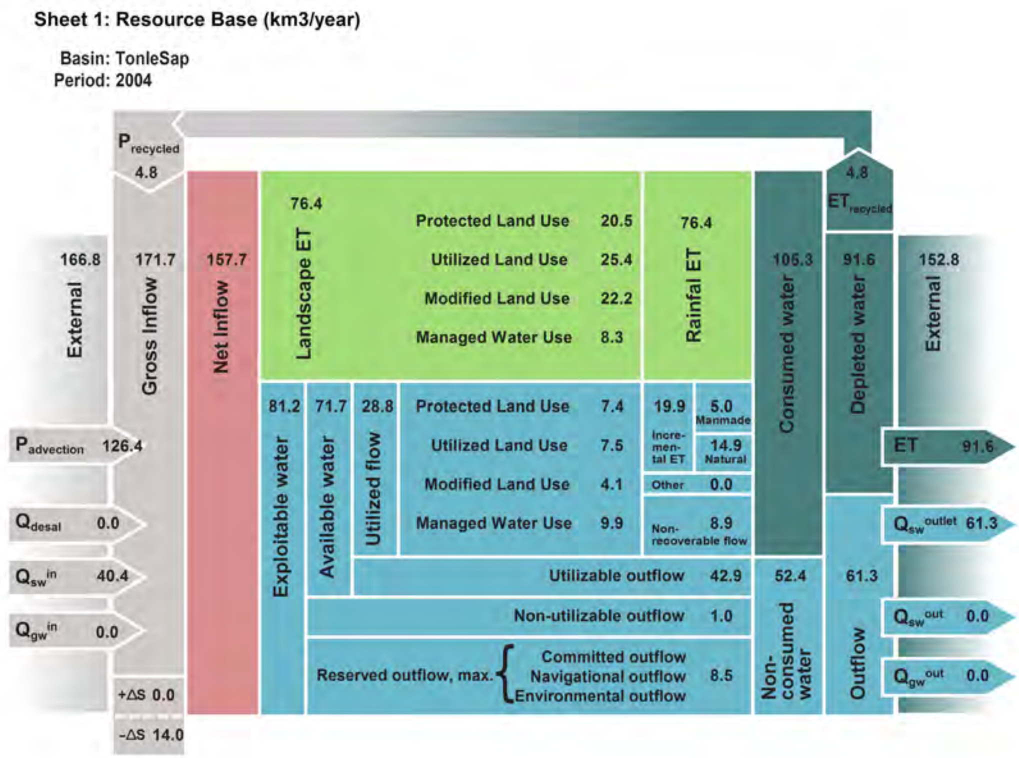


Figure 25: Resource Base sheet for the Tonle Sap during the dry year (2004).

fact too rapidly with the maximum amount of -45 km^3/yr. In the Tonle Sap river basin this balance is mainly regulated by the expansion and contraction of the Tonle Sap lake volume (Figures 26 and 27).

67. The year 2004 was the driest year analyzed in this study. This year was probably significantly dry for the Tonle Sap basin, because the annual storage change across the period January 2004 to December 2008 is not negative, which means that more water is taken out of stock than is being replenished by wet years. In this period, about 60% of the net inflow is consumed through evapotransiration, or a consumed fraction of 60%. ET green on the annual scale is more than three times ET blue. On months without rainfall, ET blue has the same magnitude as ET green (Figure 28).

68. From November to March, the consumptive use depends entirely on water released from storage (lakes, reservoirs and groundwater, in the case of the Tonle Sap mainly from the Tonle Sap lake). Hence, storage is the main source of water during 5 months per year and this is mainly feasible due to the recession of the lake shore. Any solution in enhancing the storage capacity would be worth to consider and evaluate. Likely a combination of local

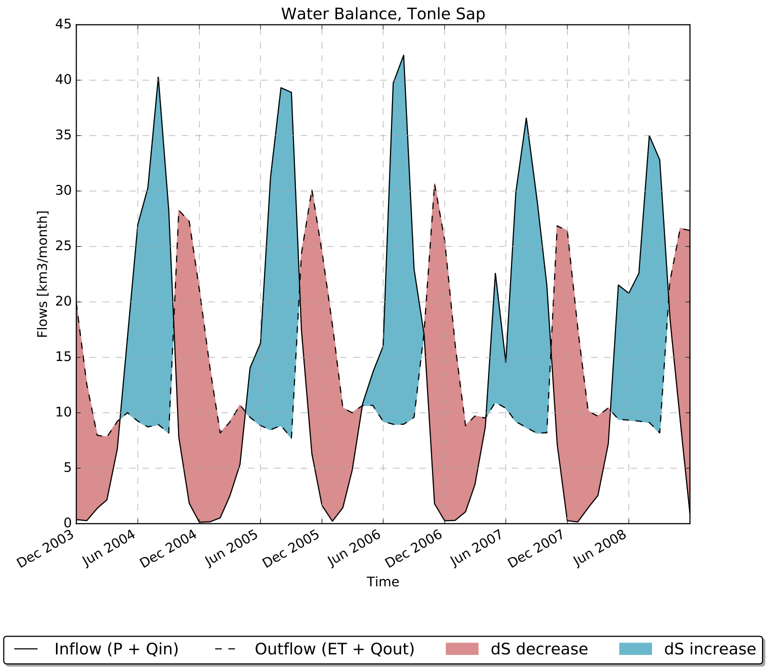


Figure 26: Water Balance for the Tonle Sap river basin.

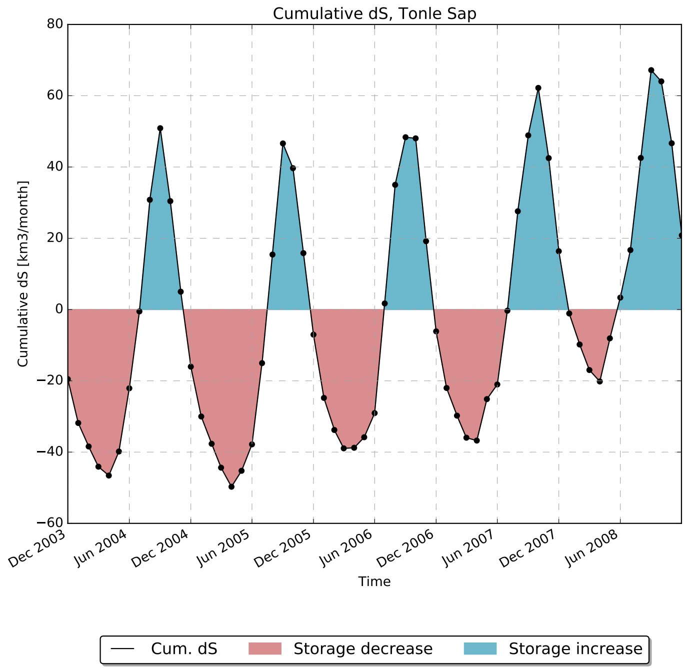


Figure 27: Storage Change for the Tonle Sap river basin.

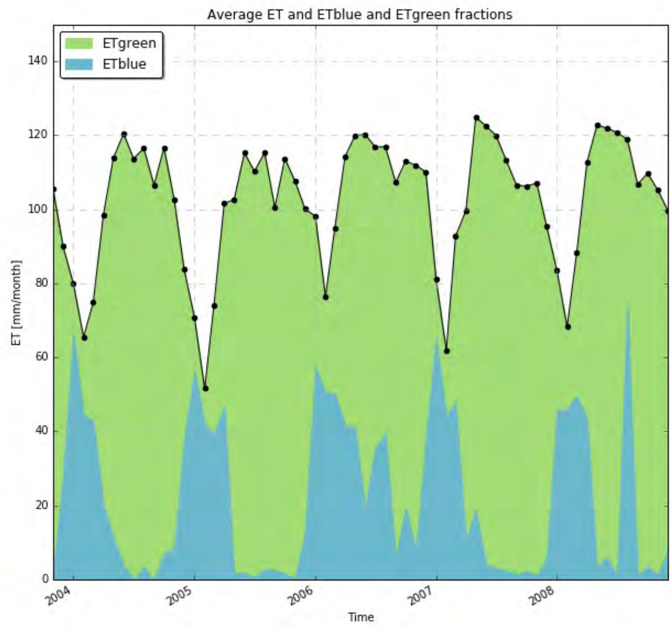


Figure 28: Average monthly ET for the Tonle Sap, including the ET green and blue fractions.

storage mechanism and some large scale interventions will lead to the best results.

69. A remarkable finding is that the environmental flow – currently set as 25% of the exploitable water, according to the Water Accounting + standard values – does not meet the minimum requirements during several months (and several years) at the end of the dry season (April and May). The adverse impact on environmental ecosystems such as fish production and biodiversity for such a short duration is not assessed, but this aspect needs to get attention.

70. Besides the consumption trough ET, water resources also become consumed when they are unsuitable for reuse (pollution). This is indicated on the sheets by the 'non-recoverable flow' term. In 2004 for example, roughly 8.9 km^3 of the 81.2 km^3 of exploitable water was non-recoverable, based on the gray water footprint of the basin. The recycling of precipitation within the catchment is significant with an average of 5.0 km^3 per year, which is not uncommon for a catchment of this size, meaning that the consumption of water through ET is partially recovered within the basin.

71. The remainder, the non-consumed water, gives an indication of the possibility for water development in the Tonle Sap basin. After accounting for water that is not utilizable, either because of the location or time of precipitation (for example, rainfall near the outlet of the basin is less likely to be usable than rainfall that falls at a high latitude upstream in the basin) or because the flow is required to preserve some key functions like an environmental flow, the remaining is called the utilizable flow. In the Tonle Sap basin the utilizable flow ranges

between 35 km^3 and 43 km^3 per year during the investigated years (2004-2008), which on average is 40-50% of the total exploitable water. Unsurprisingly, the lowest utilizable flows were observed in the driest years.

72. A non-negligible part of the ET, i.e. nearly 30%, is non-manageable because it is consumed in protected areas. A large part of the ET in the Tonle Sap basin is manageable, because there are many areas covered by natural vegetation that are categorized by WA+ into Utilized Land Use (ULU). The remaining (non-protected) forests in the basin has a manageable ET (about 35%), which implies that forest cover could be intensified or other species, requiring less water, could be planted. Also the combination of forestry and agriculture should get more attention.

73. The most significant beneficial water consuming sectors are the environment and agriculture (forest and rice fields). The Beneficial Environmental consumption accounts for 62 % of the total beneficial consumption. Implying that although much land can potentially still be converted into managed water consumers, the environment and related bio-diversity is likely to pay a price. The historic landscapes of Cambodia were more biodiverse, and one thought is to allocate also more blue water resources for environmental purposes. The latter becomes more relevant if climate change is developing with higher ET rates and perhaps a lower rainfall intensity. The same ecosystem would then need a compensation for the lack of green water demands.

74. The non-beneficially used water consumption constitutes around 50% of the total ET. For example, in 2004 the rainfed crops consumed 26.2 km^3 of water through ET, of which only 9.6 km^3 was transpired -T (beneficial ET process for rainfed crops). A very large portion of ET is evaporation from wet soils. This is the result of slowly receding water surfaces (lakes, ponds) and the overall shallow water table condition that prevails in the lower geographies of Tonle Sap.

75. The Tonle Sap basin natural land uses are significantly dependent on groundwater withdrawals (about 16 km^3/yr in 2004) and surface water withdrawals (about 23 km^3/yr in 2004) that occur in a natural manner, thus without pumping. The total average blue water withdrawals amounts to about 40 km^3/yr on average between 2004 and 2008. Natural forests are, with 10.5 km^3/yr, the biggest consumer of shallow groundwater systems. In case where the water table is deeper, root systems of trees have been adapted to greater depth for achieving access to water during the dry season. Thus many natural forests are Groundwater Dependent Ecosystems. Note that these amounts of water are vast, and not included in the allocation plan, whereas the effect of natural water uptake by roots is the same as pumping groundwater away for domestic purposes. The wetlands and natural water bodies rely on natural surface water withdrawals due to flooding and inflow respectively.

76. The degree of water scarcity can be determined by comparing the blue water withdrawals (supply) to the demand of the classes specified in the utilized flow Sheet 4. It is apparent that the basin is a water restricted basin, opposed to an energy limited basin, meaning

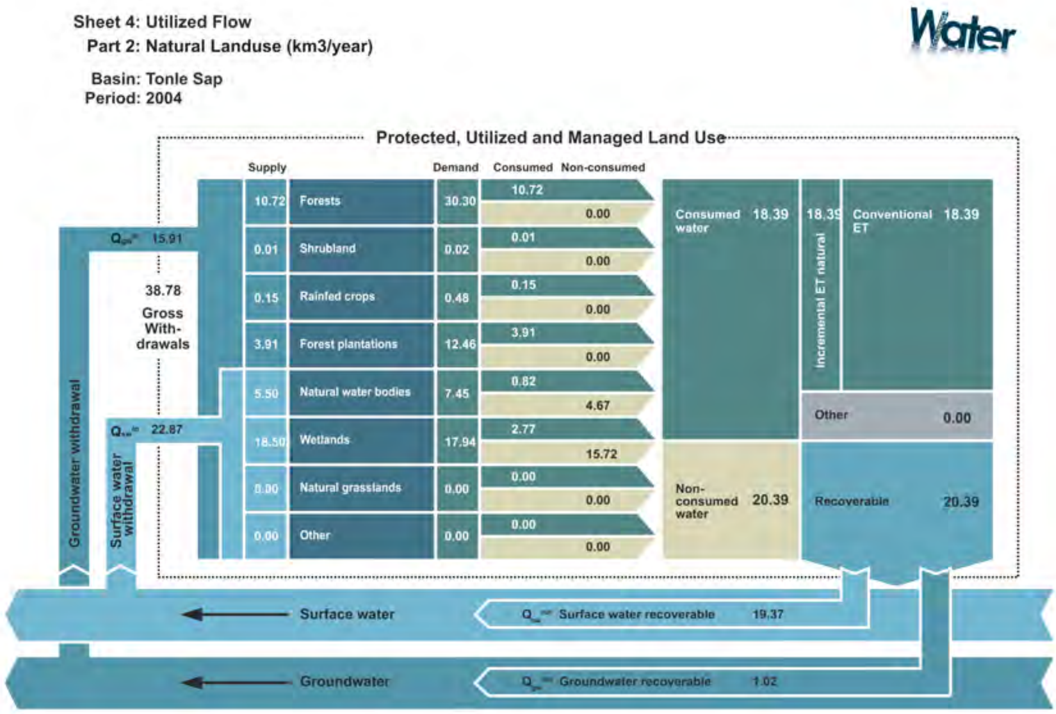


Figure 29: Utilized Flow sheet for the Tonle Sap basin during the dry year(2004).

that water is a more limiting factor to ET than solar energy. Especially the Groundwater Dependent Ecosystems experience stress, and more water could be consumed (30.3 km^3/yr) if it had been available. This is a rather interesting observation that is a result of systematic accounting. In other words, forests seek for groundwater to survive the dry season, and are only partially successful in achieving that goal. While their blue water demand is 30.3 km^3/yr, they capture only 10.7 km^3/yr. Perhaps in the past, groundwater tables were higher and water was easier accessible to these forests than during these days. Local storage of water in forests should be considered to reduce the water scarcity in forests.

77. Fact sheet 5 describes the surface flow (runoff generated within the basin and interbasin transfer), storage change, surface water withdrawals and return flow to surface water in the analyzed river basin and its sub-basins at monthly and yearly scale. The outflow of each sub-basin is also separated into four sub-components: committed, non-recoverable, non-utilizable, and utilizable. Sheet 5 is composed of two parts: part 1 describes the hydraulic connectivity and geographical location of the sub-basins (Figure 30), part 2 shows the main water fluxes for each sub-basin (Figure 31).

78. A maximum of nine sub-basins can be identified and analyzed, the user can input the geometry of the sub-basins or can simply supply the tool with the coordinates of the outlets of the sub-basins and the software will automatically delineate the sub-basins based on the

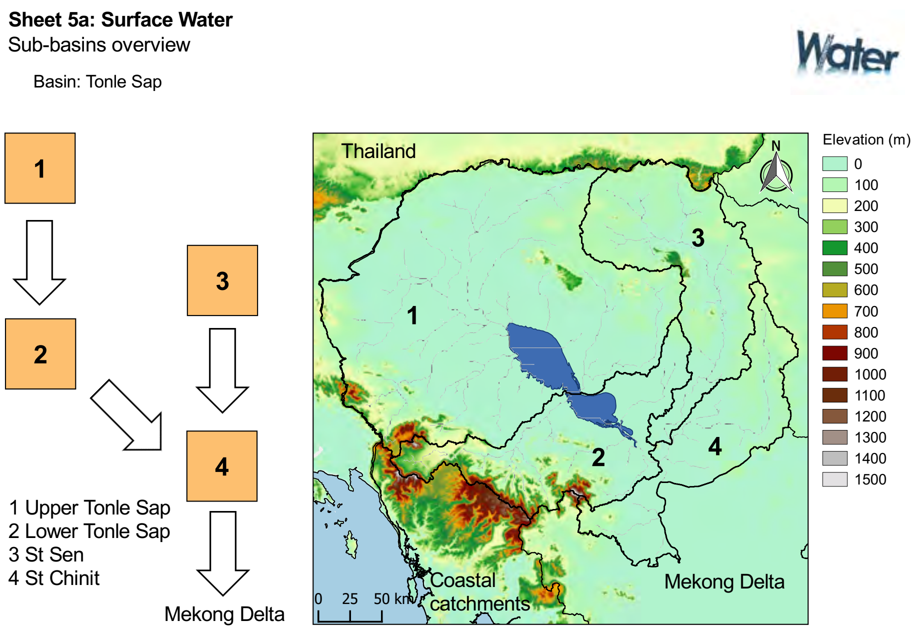


Figure 30: Sheet 5a: Surface water, Sub-basin overview for the Tonle Sap river basin.

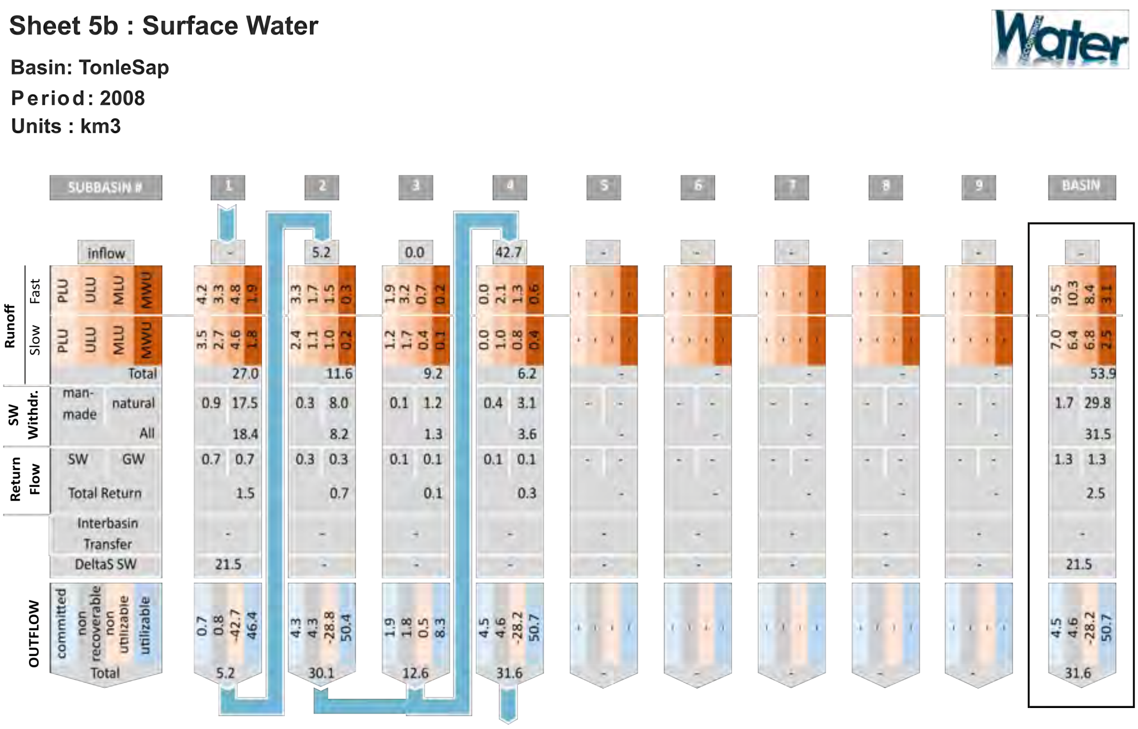


Figure 31: Sheet 5b: surface water for the four selected Tonle Sap sub-basins for the year 2008.

elevation map (DEM from HydroSHED). For the Tonle Sap basin, and for the other Cambodian basins, we used the global and open access HydroSHEDS database in combination with the National river basin data to identify the sub-basins.

79. We have subdivided the Tonle Sap basin into four sub-basins: Upper tonle Sap, Lower Tonle Sap, St Sen, and St Chinit. The example in Figure 31 shows the surface flow components of the sub-basins of the Tonle Sap basin for the year 2008. Negative values are used in this particular case to account for the reverse flow and the storage change in the lake which is separated in two sub-basins (sub-basin 1 and sub-basin 2). Runoff is therefore the net runoff generated within the (sub-)basin. Sheet 5 can be used to assist the planning of infrastructure and testing water allocation options within a river basin, and to prepare (surface) water allocation plans also in dry years.

80. In this particular case, sub-basin 1 is the largest sub-basin in the Tonle Sap basin. As one could expect, this sub-basin is providing most of the runoff generated in the Tonle Sap basin (about 45% of the total net runoff). This sub-basin also sustains about 65% of the total surface water withdrawals (16.2 km^3/yr).

81. Sheet 6 describes groundwater flow and storage within a river basin. This accounting sheets includes: vertical recharge, capillary rise, vertical groundwater withdrawals, return flow to groundwater from groundwater and from surface water withdrawals, groundwater storage change, groundwater discharge (baseflow), and groundwater flow (Figure 32).

82. These fluxes and storages are expressed as total volume within the basin but also subdivided per land use type. Negative values indicate a decrease in storage. Sheet 6 as well as Sheet 5 are strongly based on simulation results, and therefore on either PCRGLOB-WB (global hydrological model) or Water-Pix and Surf-Wat (pixel-based and RS-based water balance and river flow models). For this analysis we did not consider groundwater flow as results from PCRBLOB-WB were not satisfactory and the implementation Water-Pix and Surf-Wat is still in testing phase. Additional analysis therefore needed to accurately estimate groundwater flow in the Cambodian basins.

83. The example in Figure 32, refers to the groundwater-related fluxes that occurred in Tonle Sap in 2008. In this particular year the storage change is negative and thus the natural recharge and return flows to groundwater are not sufficient to prevent the declining of the water table elevation. This is the only case in the three analyzed years, in 2004 the storage change was positive (+4.5 km^3/yr) as well as in 2007 (+3.8 km^3/yr).

84. As identified in Sheet 4 (Utilized flows), forests are the major contributors to natural groundwater withdrawals. In Sheet 6, the reader can notice that forest are also the largest contributors to groundwater recharge. If we combine the contribution of natural forests with forest plantations (23.7 km^3/yr), this value accounts for 76 % of the total groundwater recharge (31.2 km^3/yr).

85. If we analyze the monthly results, we notice that the groundwater storage change is

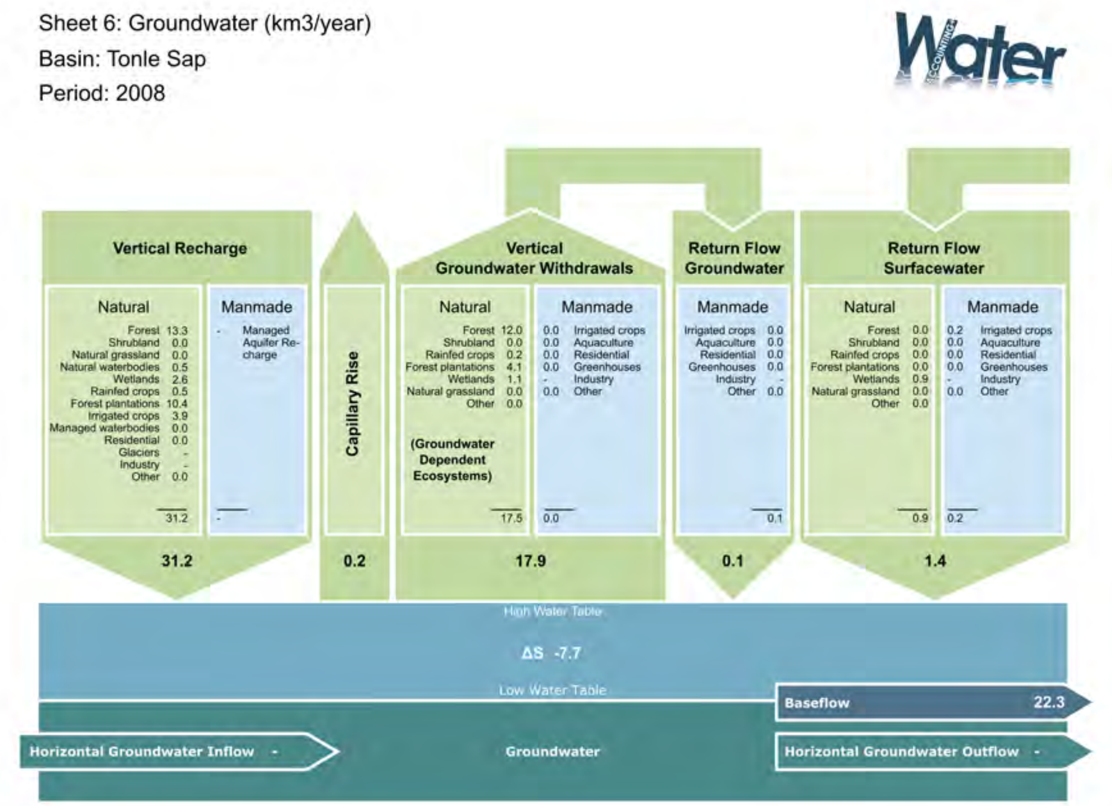


Figure 32: Sheet 5b: surface water for the four selected Tonle Sap sub-basins for the year 2008.

negative during most of the dry season months (between December and April-May) and positive during the wet months (May/June to November). This means that during the dry season the water table elevation decreases and during the wet season groundwater recharge compensates for the storage decrease. It is therefore important to monitor these changes and relates them to changes in water and land management.

86. Sheet 7 reports on Ecosystem services produced within a basin by consuming water resources. It expressed provisioning and regulating services and the benefit from the consumption of water, and relates them to land use categories (Figure 33).

6.2 Three S

87. The Three S river is a tributary of the Mekong river; part of the river basin is located in Vietnam, but the majority is within the Cambodian borders. The total area of the basin, in Cambodia, is about 26,000 km^2. The Protected Area covers a surface of about 11,000

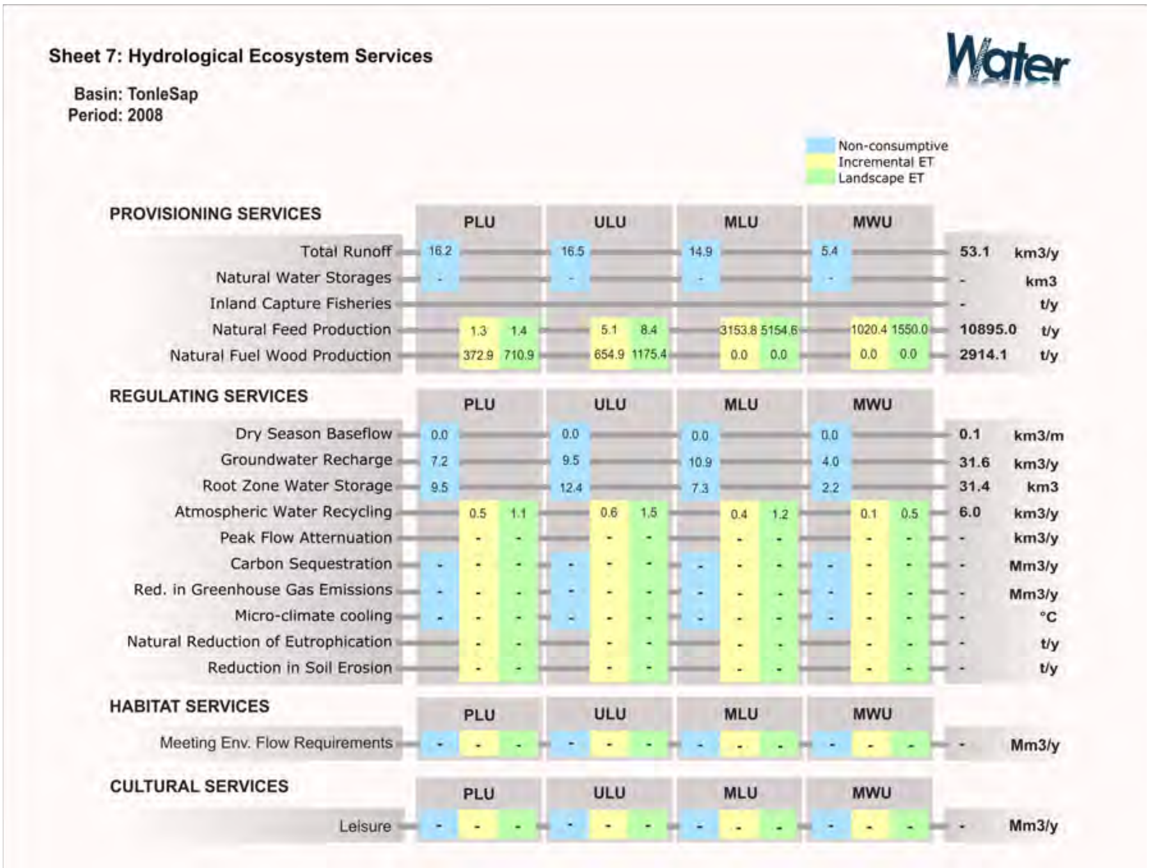


Figure 33: Sheet 7: Ecosystem service provided by the Tonle Sap basin in 2008

km^2 (41.7%), and the most common land cover type of this group is Protected Forest. The fraction of area where the water is actively managed (irrigated agriculture and urban areas) is insignificant (0.5%). Rainfed agriculture is quite common in the basin (10.4%), the major crop considered in this study are cereals (rice). The forest covered area, protected and non, is about 22,500 km^2. 47% of the basin is covered by natural forest in the land use category Utilized Land Use (non protected).

88. The year with average rainfall for Cambodia (2008) appeared to be the driest year for the Three S basin. This situation reveals that undertaking accounts for one particular year never provides a good picture of the water resources. The lowest net outflow (P – ET) is 12.4 km^3/yr while the highest of this limited time frame is 24.4 km^3/yr. This is a doubling of total runoff.

Year	P $[km^3/yr]$	ET $[km^3/yr]$	Water Yield (P-ET) $[km^3/yr]$
2004 (dry)	59.7	41.9	17.8
2007 (wet)	70.4	46.0	24.4
2008 (average)	56.9	44.5	12.4

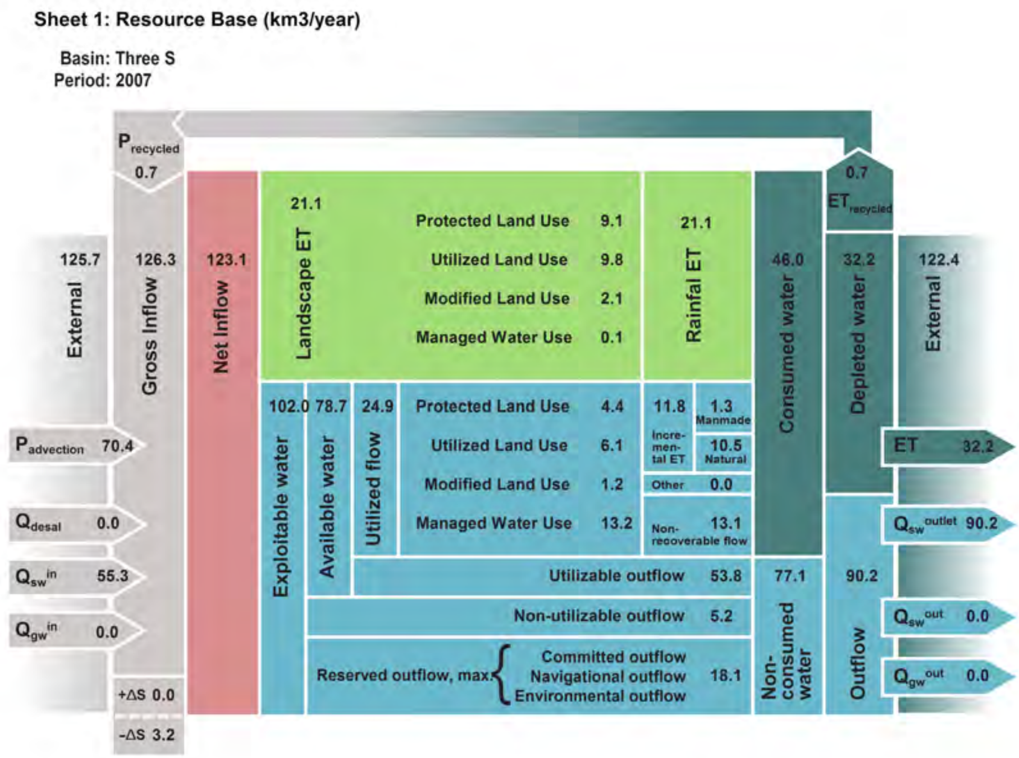


Figure 34: Resource Base sheet for the Three S basin during the wet year(2007).

89. For the case of the Three S basin, we present Sheet 1 for wet year (2007) in Figure 34. During this year the storage (surface and groundwater) has increased by 3.2 km^3/yr, while in the other years analyzed the storage was depleted. It seems to suggest that Three S exhibits more hydro-meteorological fluctuations and that this basin is more vulnerable to rainfall regimes. The Three S basin in Cambodia has received about 55.3 km^3/yr of surface water from Vietnam, and in this year the utilizable outflow was similar with 53.8 km^3/yr (the average 2004-2008 was 43.5 km^3/yr). The lowering of water stocks during a wet year is not obvious, and the only diagnosis needed is to study the storage mechanisms on a month-by-month basis. It is however unavoidable to conclude that most water received from Vietnam is send downstream untouched (arriving in the delta of the mighty Mekong river).

90. The ratio of moisture recycling is quite low (0.7 km^3/yr), which is however normal for small river basins. The total amount of Landscape ET (21.1 km^3/yr) is nearly double than ET blue (11.8 km^3/yr) and the non-recoverable flow due to grey water consumption (13.1 km^3/yr). Forest is the major contributor to landscape ET as well as blue water consumption.

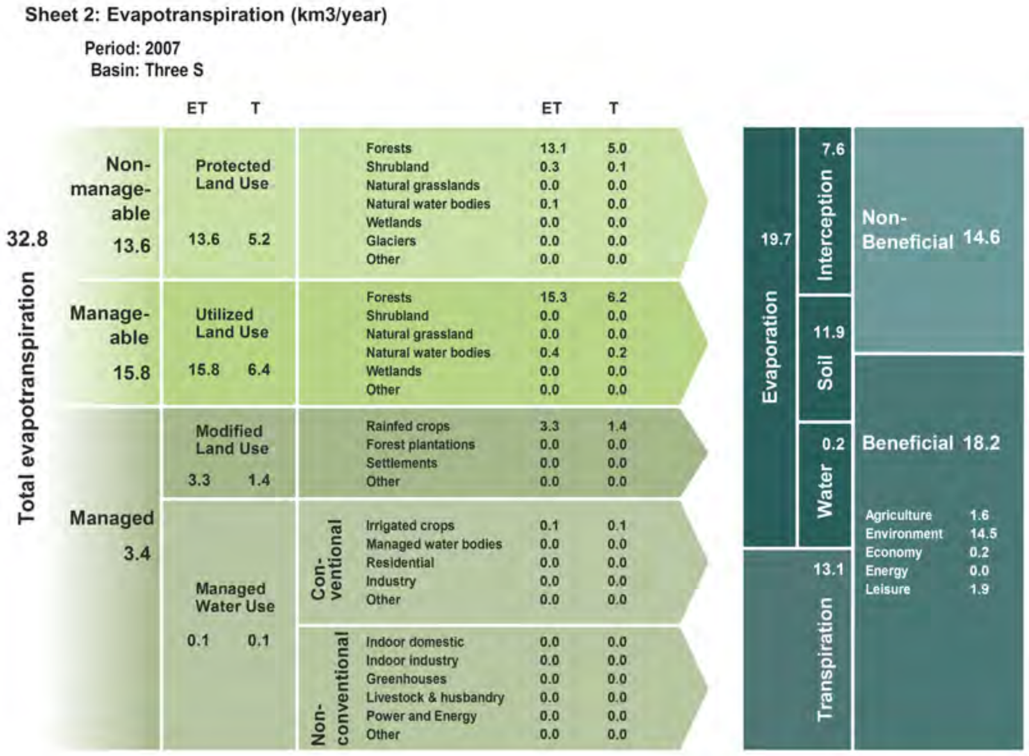


Figure 35: Evapotranspiration sheet for the Three S basin during the wet year(2007).

The total ET for the Three S basin in 2007 was 32.8 km^3/yr.

91. Like in the Tonle Sap case, a large part of the ET in the basin is unmanaged (Protected Land Use 13.6 km^3/yr and Utilized Land Use 15.8 km^3/yr). The non-protected forests consume with 15.3 km^3/yr a large portion of the total water consumption of 32.9 km^3/yr (46.6%). Beneficial Consumption mainly relates to the Environment (14.5 km^3/yr), and 1.6 km^3/yr is beneficially consumed for agricultural purposes. The most significant beneficial water consuming sectors are the environment and agriculture (forest and rice fields). The most significant beneficial water consuming sectors are the environment and agriculture (forest and rice fields). The Beneficial Environmental consumption accounts for 62% of the total beneficial consumption. It would be desirable from an ecological point of view to protect these forested areas.

92. Very little water is used for hydropower. Three S will have several mountain ranges and valleys were reservoirs for hydropower could be constructed. The evaporation losses from these reservoirs will not pose any problem.

6.3 Upper Mekong

93. The Upper Mekong sub-catchment receives water from upstream Laos and, on the East side, from the Three S basin, apart from the inflow of the mighty Mekong. The total area of the basin is about 19,500 km^2. The dominant land cover group is Utilized Land Use (natural land which is not protected, mainly forest). The Protected Area covers a surface of about 4,000 km^2 (20.8%). A small part of the basin is covered by agricultural land (8% is rainfed cereals, and only 1.4% is irrigated cereals). The forest covered area, protected and non, is about 17,000 km^2.

[h!] Year	P $[km^3/yr]$	ET $[km^3/yr]$	Water Yield (P-ET) $[km^3/yr]$
2004 (dry)	36.9	24.1	12.8
2007 (wet)	46.9	24.8	22.1
2008 (average)	37.3	25.8	11.5

94. During the wet year (2007) the Upper Mekong basin is endowed with 10 km^3/yr extra rainfall than during the dry year (2004). This will increase the amount of internally generated water resources. The inflow from the main Mekong river is with 360 km^3/yr substantially more. Because the Upper Mekong basin in Cambodia is a net water producer, the outflow is larger (381.8 km^3/yr). Only a small amount of these water resources are consumed. The incremental ET due to blue water withdrawals is 5.0 km^3/yr only, out of which the vast majority of 4.6 km^3/yr can be attributed to water uptake by the forests. Due to the sparse irrigation systems in this basin, very little water is used for manmade withdrawals.

95. During 2004, the amount of water consumed (ET and polluted) within the basin was 79.8 km^3/yr, which is 20 % of the Net Inflow. The consumptive use of grey water is with 55.6 km^3/yr far outweighing the green (19.1 km^3/yr) and the blue (5.0 km^3/yr) water consumption. According to the global water foot print map used in this study, pollution account for 70% of the total consumption use. This 'non-recoverable flow' is related to the pollution of the waters of the main Mekong river.

96. Similarly to other basins in Cambodia, the monsoonal climate controls the change in storage of the basin, this time however the balance is more precarious than in the Tonle Sap case (Figure **??**). At the end of 2005, the system could not recuperate to a positive balance of storage, which was achieved only in the end of 2006 (Figure 38). This means that the basin was drying out, despite the significant river flow. This can be understood by the natural character of the basin, with minimal interference between the hydraulic processes in the main stream and water withdrawals and return flows.

97. The year 2004 was the driest year analyzed for the Upper Mekong, and the subsequent year was also dry (32.2 km^3/yr of rainfall). This fact is also visible in the yearly sheet as water is taken from the storage to cope with the limited external sources: the net inflow

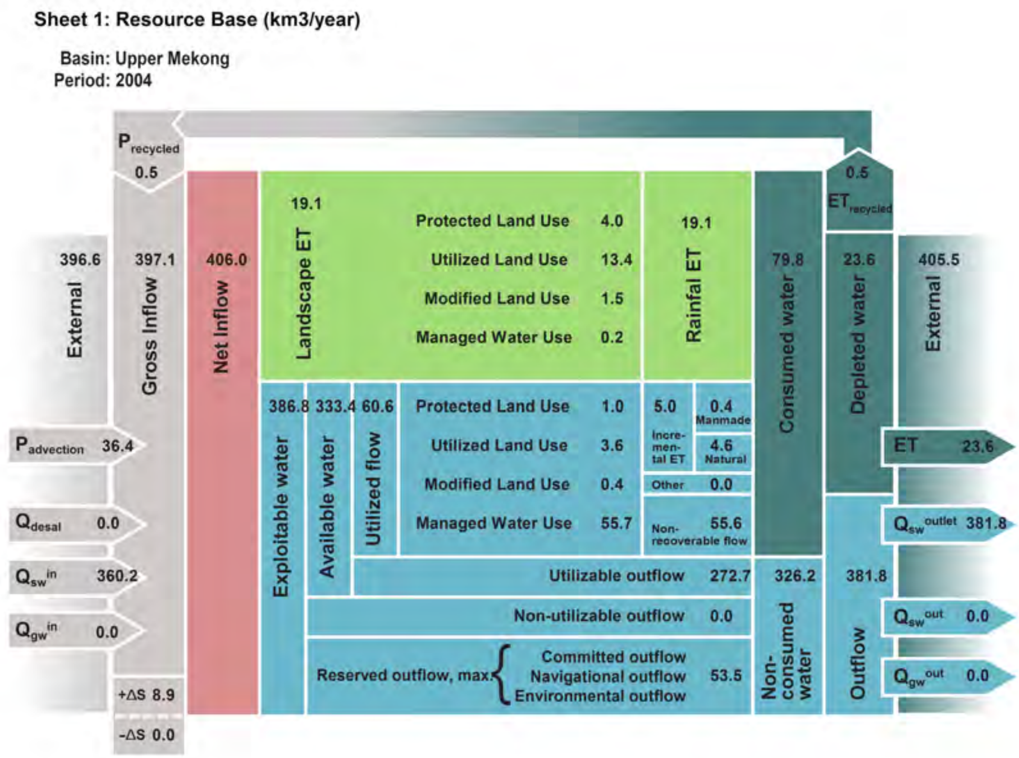


Figure 36: Resource Base sheet for the Upper Mekong basin during the dry year(2004).

exceeds the gross inflow. In 2004 the net change in storage was 8.9 km^3/yr and in 2005 it increased to 35.9 km^3/yr (combined result of two dry years). The separation between ET green and ET blue varies by month. While in certain dry months ET blue can accounts for up to 90% of ET, during wet months it can reach almost zero. The recycling of precipitation within the basin is limited, like in the case of the Three S basin, only 0.5 km^3/yr are in fact recycled.

98. In the Upper Mekong basins, natural land uses in 2004 withdrew 5.5 km^3 of water (blue water). Groundwater withdrawals account for 87% of the total withdrawals. Natural forests are the biggest consumer of this groundwater, while wetlands and natural water bodies essentially rely on natural surface water withdrawals. As for the Tonle Sap basin, blue water withdrawals (supply) are lower than the demand for each land use class, the basin is therefore water restricted, opposed to an energy limited basin. The non-consumed water originates from the natural water bodies and wetlands and it is released to surface water.

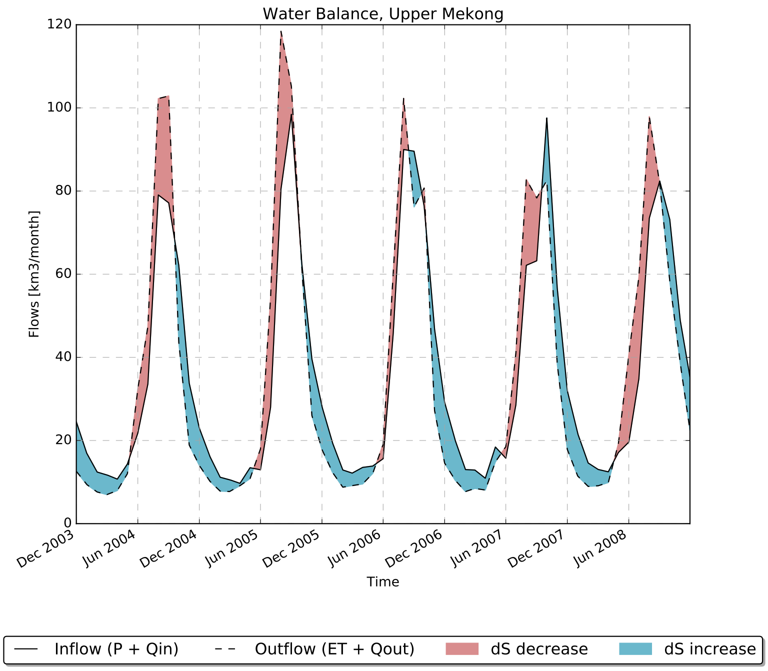


Figure 37: Water Balance for the Upper Mekong river basin.

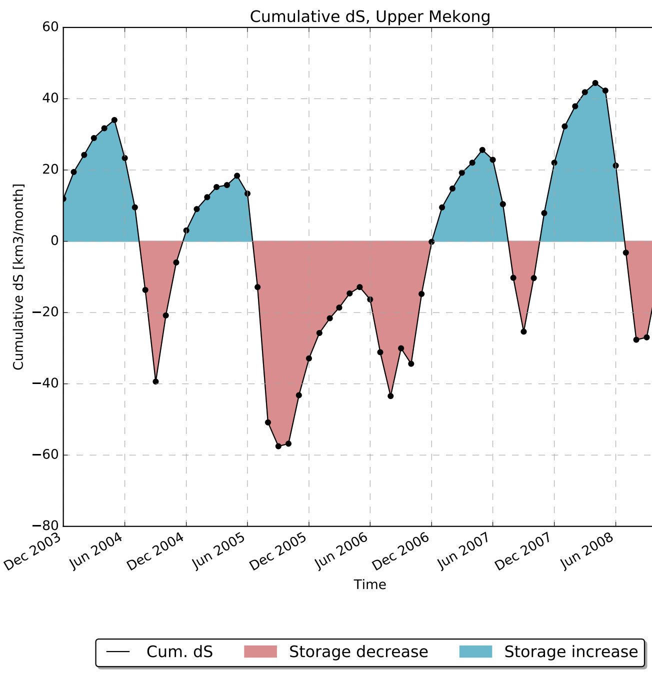


Figure 38: Storage Change for the Upper Mekong river basin.

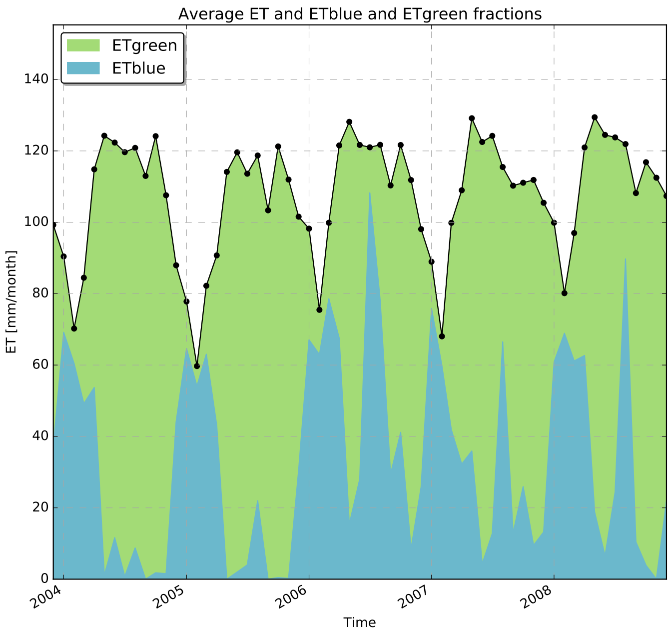


Figure 39: Average monthly ET for the Upper Mekong basin, including the ET green and blue fractions.

6.4 Lower Mekong

99. The Lower Mekong sub-catchment is situated downstream of the Tonle Sap basin and the Upper Mekong basin. It covers an area of 36,000 km^2. An essential difference with the other basin is the land cover types. This basin has the highest proportion of Modified Land Use (rainfed agriculture), reaching nearly 50% of the basin, while 16.4 % is Managed Water Use (irrigated agriculture and urban areas). Natural areas (protected and not protected) account for 34%. The total agricultural area is 23,500 km^2 (of which 76% is rainfed agriculture), and forests only cover 6,700 km^2. The major crops in the basin are cereals and fruits and nuts.

100. The Lower Mekong receives most of its Net Inflow from the upstream basins (93% in average for the period 2004-2008 from the combined Tonle Sap basin and Upstream Mekong basins). During 2004 the incoming surface water flow was 420 km^3/yr. The landscape ET in 2004 was 31.5 km^3, roughly half of this amount was consumed by Modified Land Use types (rainfed agriculture). The surface outflow at the outlet to Vietnam is generally higher than the Net Inflow, as can be interpreted from the differences in annual P and ET.

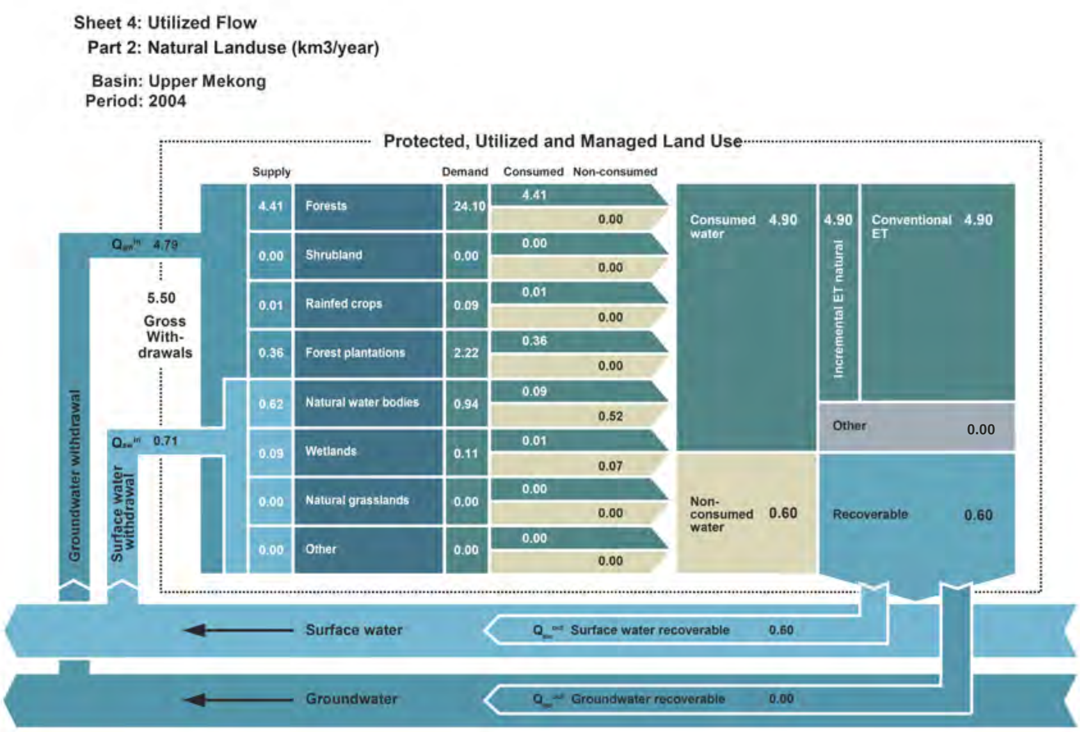


Figure 40: Utilized Flow sheet for the Upper Mekong basin during the dry year(2004).

[h!] Year	P $[km^3/yr]$	ET $[km^3/yr]$	Water Yield (P-ET) $[km^3/yr]$
2004 (dry)	57.3	39.4	17.9
2007 (wet)	72.8	41.0	31.8
2008 (average)	63.6	42.7	20.9

101. During 2004, the amount of water consumed (ET and polluted water) within the basin was 126.7 km^3/yr. According to the global water footprint map, the major component of this flux is the non-recoverable flow (87.2 km^3/yr or 70%) that may arise from the lack of waste water treatment of Phom Penh. This contaminated water will flow downstream into the delta of the Mekong. The remaining consumption is Evapotranspiration, which is mainly green ET for the Lower Mekong (80% of the total ET). In average natural and man-made consumption of ET blue are equal (about 4 km^3/yr). As for all the other Cambodian catchments, except Tonle Sap, the recycling of precipitation within the basin is limited, only 0.4 km^3/yr are in fact recycled in 2004.

102. The Utilizable Outflow (Net Inflow - Landscape Et - Blue water consumption - Reserved Flow - Non Utilizable outflow) is more than half of the Net Inflow, meaning that a large

portion of utilizable water flows to downstream Vietnam. This water could be used within the boundaries of the Lower Mekong without affecting the Committed outflows to Vietnam nor the Navigational outflow or the Environmental flows (estimated as 20% of the yearly average monthly flow).

103. Surface water in the Lower Mekong basin is more accessible than in the Upper Mekong basin; 56% of the gross withdrawals originates from surface water and the rest from groundwater. Natural forests and forest plantations are the biggest consumer of this groundwater, while wetlands and natural water bodies essentially rely on natural surface water withdrawals. The blue water withdrawals (supply) are lower than the demand for each land use class, hence the basin is water restricted, despite the huge quantities of water passing through it on its way to the ocean.

6.5 Coastal Catchments

104. The total surface of the Coastal catchments is about 18,000 km^2. The Natural (Unmanaged) surface accounts for about 84% of the basin, specifically 75% of the basin is covered by forest (protected and non-protected). The agricultural area only accounts for about 16% of the total surface of the basin and 99% of it is rainfed cereals. Protected areas (mainly forest) covers 65% of the natural areas.

105. The Coastal basins are the only part of Cambodia that does not belong to the Mekong system. This basin group does not receive any external inflows from other river systems. The external inflows are therefore only represented by rainfall. The Coastal catchments are located at the Cambodian coast where rainfall is the highest in Cambodia.

Year	P $[km^3/yr]$	ET $[km^3/yr]$	Water Yield (P-ET) $[km^3/yr]$
2004 (dry)	49.7	25.0	24.7
2007 (wet)	60.4	25.1	35.3
2008 (average)	58.2	25.7	32.5

106. Modified and Managed land uses are only responsible for 14% of the consumption. Since there is high rainfall in the coastal catchment, green water consumption is also significantly higher than blue water consumption, about 70% and 30% respectively.

107. 55% of the water consumed in the Coastal Catchments is Beneficial, mainly for the Environment. The Non-Beneficial fraction of ET is equally divided between soil evaporation and interception, which means that only half of the non-beneficial consumption (soil evaporation) could be taken into account for water savings.

7 Conclusions

108. Cambodia is a country that has been traditionally rich in water resources and has a lush green environment with a high degree of biodiversity. However upstream water resources developments, deforestation and climate change will have an adverse impact on the land and water ecosystems of Cambodia. A sufficient amount of internally produced water resources are available (ΣP=356 km^3/yr; ΣET=217 km^3/yr; P–ET = 139 km^3/yr), but the distribution of water resources in space and time requires a better balance. Water accounting (WA+) provides a quick scan to make a first assessment of the monthly and annual water resources conditions, as well as the benefits and services rendered from it. This report describes some first findings, and the factual data can be reviewed from www.wateraccounting.org. The data can be used as an input for making strategic plans for the agricultural and environmental sectors, further to the creation of a national water resource plan.

109. The ungauged inflow from Three S basin into the Cambodian part of the watershed is estimated to be 55 km^3/yr. The upper Mekong basin receives approximately 360 km^3/yr on lateral surface water inflow. Hence the total inflow from neighboring countries is 415 km^3/yr. The outflow from the Lower Mekong should then be approximately 554 km^3/yr.

110. Competition and conflicts over the access to water in the dry season are becoming apparent. Increasing water allocations for economic development is only wise if more storage facilities are created. The flow in the dry season depends entirely on water stored during the wet season. Climate change may affect the natural availability of water resources. It is inevitable that the temperature rise will enhance the actual evapotranspiration, and hence consumptive use of agro-ecosystem will increase.

111. The benefits of water consumption in Cambodia are mainly of an environmental nature. Many forests behave as groundwater dependent ecosystems. They withdraw groundwater without human intervention. While this is a clever biology strategy to survive periods with insufficient rainfall, it seems that many forests are experiencing water scarcity, i.e. their demand is not met by the natural water withdrawals. It would be interesting to know more about the groundwater tables and their dynamics and how they affect the groundwater uptake by forests.

112. The grey water consumption in Upper and Lower Mekong basins is much more than their green and blue water counterparts, likely due to a combination of untreated waste water discharge and agro-chemicals used in the monoculture rice systems.

113. A remarkable large portion of consumed water appears to be non-beneficial. This is mainly related to the extensive wet soils that are moist from rainfall or from receding lake water. Land use planning in this flood plains should get more attention, as currently large volumes of water are consumed without economical services, although their ecological

services could be significant.

114. This pilot study is meant to make the Governmental officials, universities and NGO's aware of these new remote sensing technologies. Training and capacity building has been provided. In the future, the Ministries should employ these technologies and validate the results with the conditions encountered in the field.

8 Recommendations

- Store more flood water seasonally. This can be achieved locally from filling ponds, artificial recharge, local movable gates in small embankments etc. Local harvesting of water will make rural population less vulnerability to climate change and natural disasters.

- Groundwater is a great water buffer that can carry over water from the wet season to the dry season. Recharge should be promoted and pumping should be regulated in order to keep the aquifer system fit.

- Continue to look at solutions with multi-purpose infrastructure that can hold the seasonal water resources, generate hydropower, protect against floods and ensure navigation.

- Delay the fast surface runoff by reforestation that enhances the infiltration of water and create more base flow during the dry season. The forest cover decline of 2% per year should be arrested. Create water recharge schemes in forested areas for reducing their water scarcity during the dry season, hence new solutions for forest hydrology. Enhance agro-forestry and optimize their management further. A higher forest cover will reduce soil erosion.

- Protect pristine forested areas by providing them the status of natural parks. Three S basin has many forested areas in the land use category Utilized Land Use (ULU). They could be conserved by adding them to the list of protected areas by means of creation of national parks.

- Develop a smart subsurface drainage system that evacuates excess water during the recession period and retains water during the dry period. Explore the presence of a shallow water table by intensifying fruit tree crops that root deeper and can produce without irrigation system, but with a smart drainage system only.

- Expand irrigation systems to reduce adverse impact of erratic rainfall, and evaluate the shift to more tropical fruits that create more jobs and income. Extra storage facilities should be created first, small and larger scale.

- Increase the yield of rice by 25% using better varieties, technologies and agricultural extension services. This can be achieved by setting up an exchange with agronomic experiences from Thailand and Vietnam related to crop protection, seed quality and other essential agronomic practices.

- The environmental water requirements should be included in the water allocation plan. They constitute a major component of the blue water resources utilization

- Provide more attention to grey water consumption, i.e. consumptive use of water due to pollution. It is currently exceeding the green and blue water consumption in Upper and Lower Mekong basin.

- Future water accounting studies should also report on the conditions prevailing in the upstream countries for achieving a more fair basis for international negotiations. Ideally, the Mekong River Commission is embarking on the same WA+ system simultaneously.