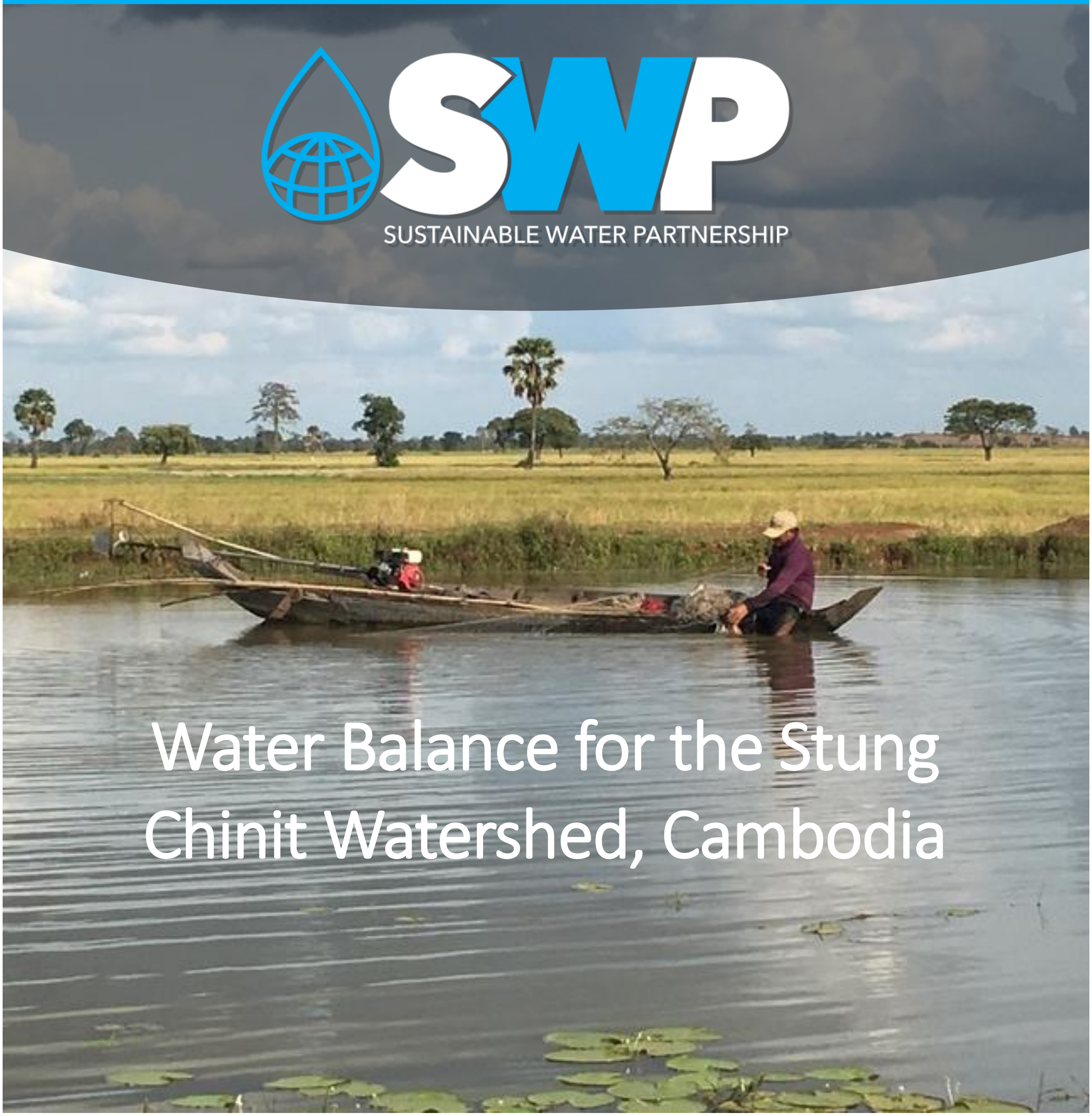

Water Balance for the Stung Chinit Watershed, Cambodia

SUSTAINABLE WATER PARTNERSHIP

September 2020

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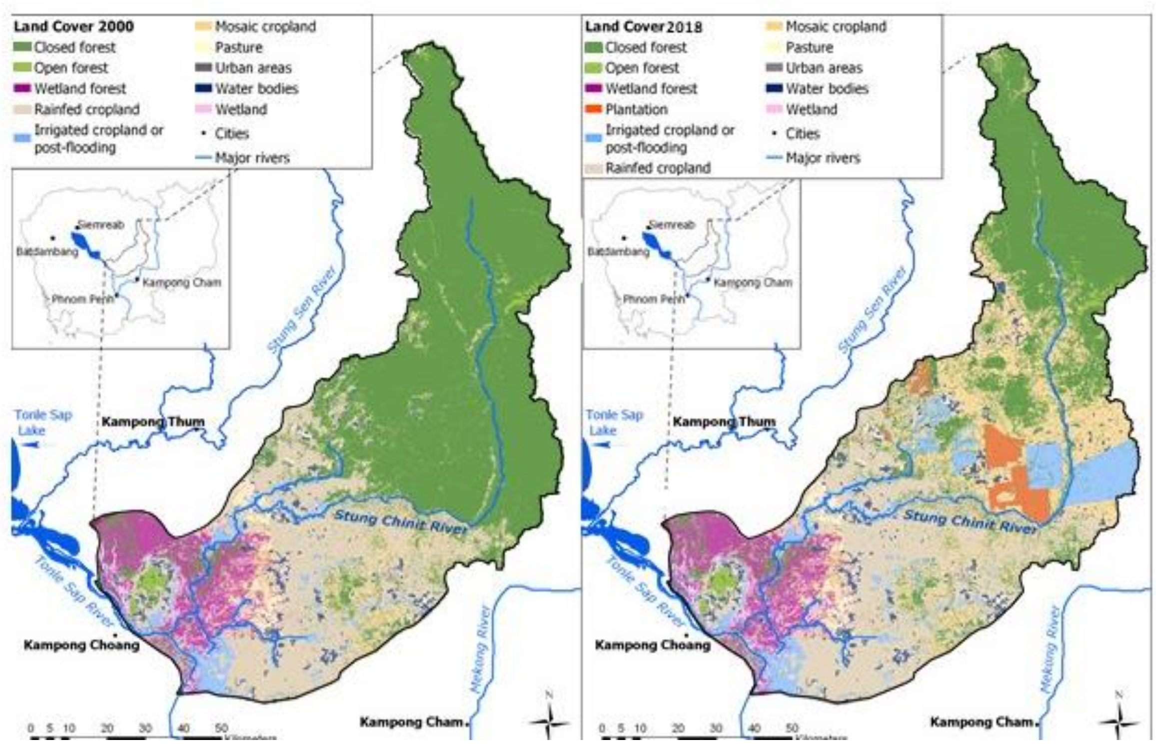
I. EXECUTIVE SUMMARY

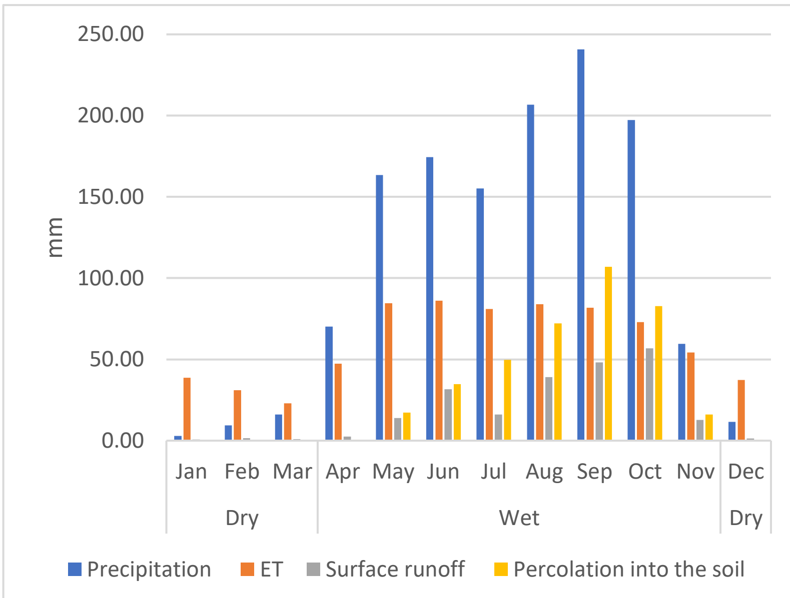
Water security is of key importance for the people living in the Stung Chinit watershed in central Cambodia. With a population that is growing by 2.2% annually, the watershed's communities are putting increasing stress on the landscape and its water resources. Land use changes in the watershed have resulted in the loss of 43% of its forests between 2000 and 2018 with the vast majority of those forests being converted into cropland or plantations. Cropland in the Stung Chinit is most commonly rice (around 80-90% of agricultural land) with some being upland rice and some being paddy rice (closer to major rivers). Many irrigation schemes have been put into place along the Stung Chinit river, which allow for dry season rice farming. The largest of these projects is the Stung Chinit Irrigation System and Rural Infrastructure Project, which irrigates about 1,800 ha in the dry season. These schemes are mostly created by damming the Stung Chinit river and its tributaries, creating problems for the fish populations which require free movement along the river for migration.



Stung Chinit watershed, comparing its landcover from 2000 (map on left) and 2018 (map on right).

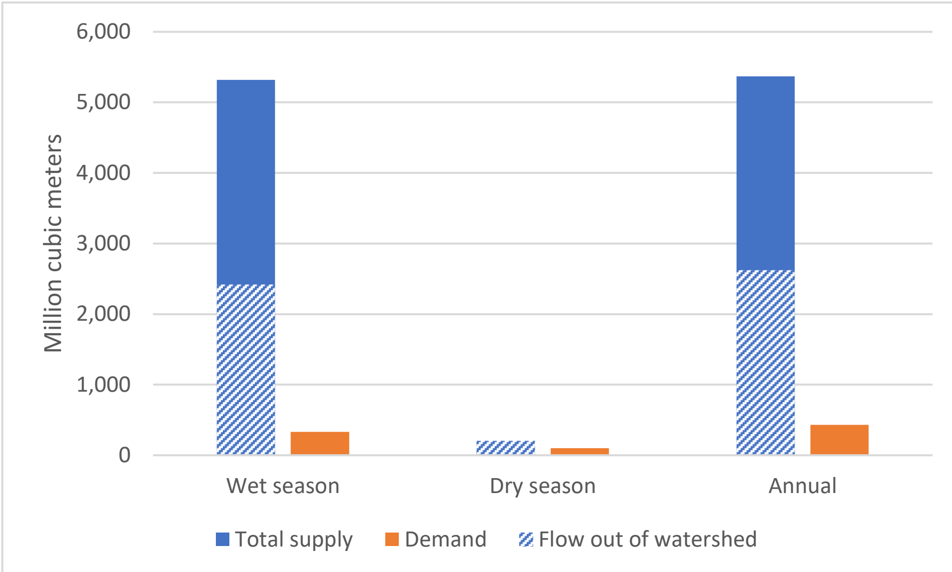
This report presents the results of a water balance study of the Stung Chinit watershed. Water balance studies provide an estimation of the supply of water through rainfall, the distribution and impact of that rainfall across the landscape and compares that to anthropogenic demand from agriculture and domestic uses. This information can be used to help in planning decisions related to water resources.

The data show that the Stung Chinit watershed is not water scarce on an annual basis, with annual rainfall of 1,300 mm. This equates to over 11 billion m^3 of water per year. However, most of this water is not available for use by the communities of the Chinit river—much it of returns to the atmosphere via evapotranspiration (55%) and some flows out of the watershed via the Chinit river before it can be stored and used (23%). This leaves just a portion of the rainfall remaining (about 2.7 billion m^3), which is stored in the surface water bodies (rivers and reservoirs) in the watershed and in the groundwater aquifers. The Stung Chinit also sees a large difference in wet season and dry season water supply. Over 95% of rainfall occurs in the wet season, making flooding a common problem. The opposite is true in the dry season, where water becomes scarce.



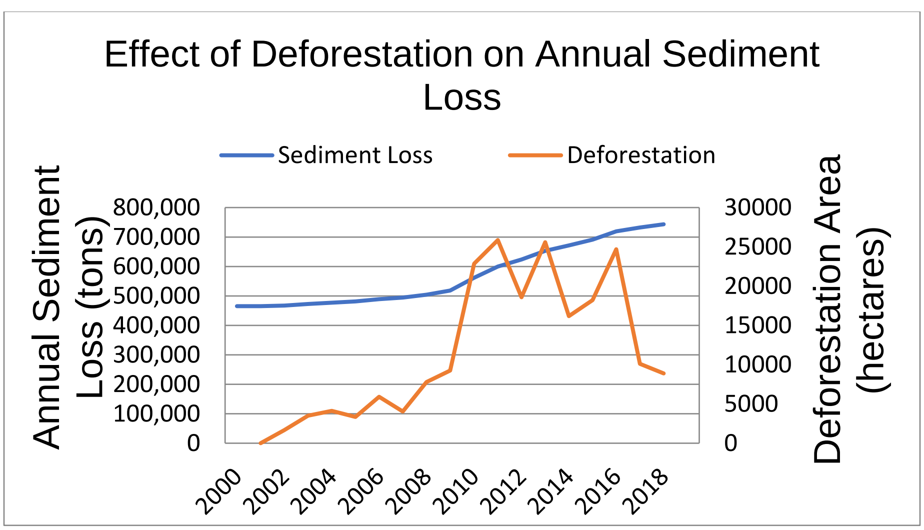
The components of the water cycle in the Stung Chinit watershed (precipitation, ET, surface runoff and percolation of water into the soil leading to both aquafer recharge and subsurface flow back to the river) by month in millimeters (mm).

The water demand of the watershed is almost entirely agricultural. In the wet season, one or two crops are grown and most of the water supply is rainfed. Because of the water scarcity in the dry season, the cultivated land shrinks significantly by 90 to 95% (based on spatial analysis of land cover and irrigation area). Domestic and industrial uses of water also contribute to the demand, but are not significant. In total, annual demand is 432 million m^3 .



Current seasonal and annual supply vs. demand, showing portion of supply that flows out of the watershed via river and is not available for use. During the dry season, there is so little supply that storage from the wet season must be used to satisfy demand.

The Stung Chinit watershed also faces several challenges in the future. Not only must it manage a growing population and intensifying agriculture, but it is losing ecosystem services provided by forests via land use change. This loss of forest has changed the water balance, creating more surface runoff in the form of flooding that cannot be stored in the watershed for use. Along with increased flooding, loss of forests has resulted in more erosion and less natural water purification. The loss of services is costing the Stung Chinit's population some of its resilience to climate change as well. According to climate models, the Stung Chinit watershed will see a rise in temperatures and more erratic rainfall patterns, with more intense storms in the wet season and less rainfall in the dry season.



Estimated impact of recent deforestation on sediment loss in the Stung Chinit watershed.

This study estimates that if demand rises equal to population at 2.2% per year and irrigation area continues to expand at a modest 2% per year, demand will be 25% of supply in 30 years and in 90 years would outstrip supply completely. However, if climate change causes a decrease in annual rainfall or an increase in intense wet season storms (causing a higher percentage of rainfall to become runoff that cannot be stored), then supply will drop as well. At the same time, land use changes could impact the availability and quality of water across the landscape. Together these impacts could cause demand to exceed supply faster than expected. Decision-makers must plan for this increased possibility of water scarcity to avoid water-related conflicts while also considering the loss of life and property damage that more-frequent floods could bring, as well as the detrimental health impacts of water pollution.

The findings in this report should prove useful for decision makers in the Stung Chinit watershed, giving them an overview of water supply and demand in the watershed and raising some of the major challenges that must be confronted in the future.

II. INTRODUCTION

This report provides a water balance assessment for the Stung Chinit watershed, located in central Cambodia, for the USAID funded Sustainable Water Partnership (SWP) Cambodia's Water Security Improvement Activity. The Stung Chinit watershed was identified as the target watershed for SWP's work in Cambodia because of its importance within the larger Tonle Sap River Basin, and because of the diversity of current activities and stakeholders in the watershed that make it a good pilot area for addressing broader water security issues impacting Cambodia.

First, a description of the water cycle and water balance is given followed by a brief background of the economy, land use and population of the Stung Chinit watershed. Then existing data and hydrological modeling results are used to determine a relative water balance for the watershed. The water balance weighs the supply of water entering the system against the estimated anthropogenic demand from agriculture, industry and domestic use. This provides a general understanding of the water availability across the landscape both spatially and seasonally. Finally, the report addresses potential water security issues and the potential impacts of future climate change on both water availability and quality. Much of the data used and charts and maps produced for this report were obtained from the WESTool, and interactive web-based decision-support tool that displays spatial and tabular data for all of Cambodia. In addition to this report, WESTool can be accessed by stakeholders in and around the Stung Chinit watershed for further understanding of many of the water security issues facing the area.

This report is meant to be an initial assessment of water balance for the Stung Chinit watershed, and an overview of the water security issues. As such, this report should be considered a working document that can be updated and improved as the SWP project moves forward.

III. THE WATER CYCLE AND A WATER BALANCE

The water cycle refers to the movement of water between different "reservoirs," or locations where water is stored. These reservoirs include the atmosphere, where water is stored as water vapor, surface water such as oceans, lakes, rivers and groundwater aquifers. Water moves between these reservoirs through various natural processes, including precipitation in the form of rain or snow, evapotranspiration of surface water from plants and soil into the atmosphere, and runoff of water traveling along the surface into water bodies (Figure 1). Humans can also influence the water cycle, through abstraction (removal) of water from surface water bodies or the aquifer, land use change and climate change, among other means.

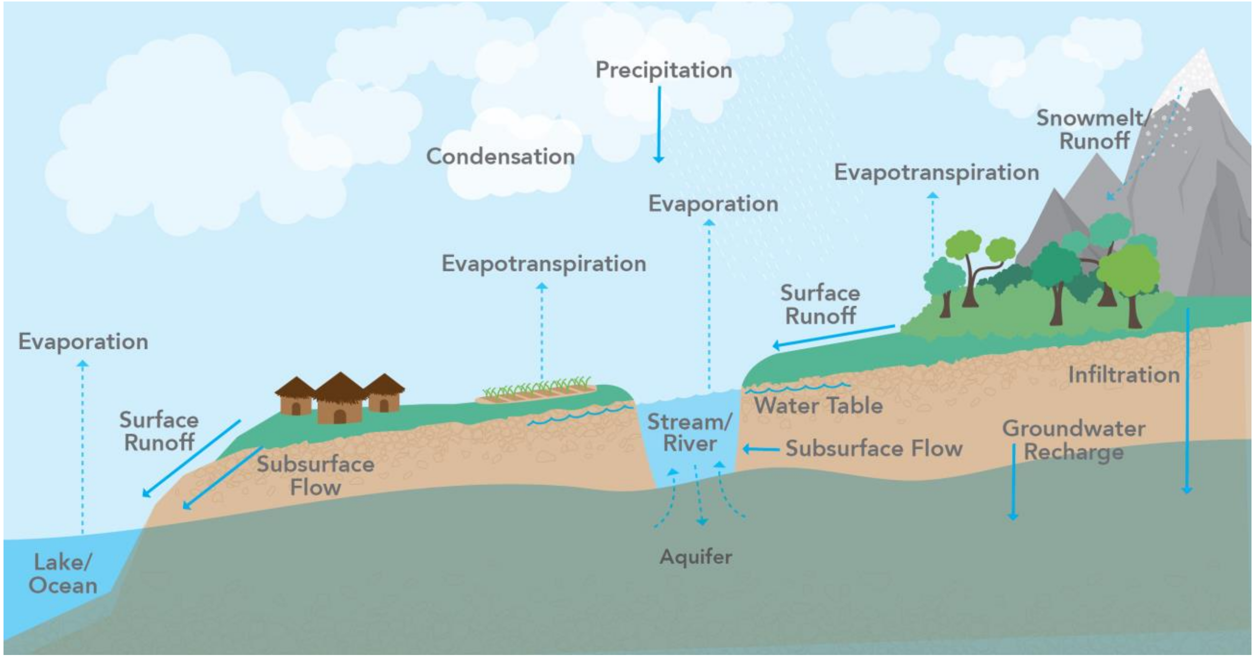


Figure 1. The various movements of water as it moves through the water cycle.

Water is in one sense a renewable resource in that it can never be "used up"—it continues to cycle through different reservoirs no matter what is done with it. However, it is a finite resource that is not always present in the quantity and quality that human populations need. For this reason, water resource management is necessary all around the world to ensure populations are able to access water and use it for their diverse set of needs.

One important tool to assist water resource management is a water balance equation. The water balance of a given area quantifies the magnitude of different aspects of the natural water cycle along with the anthropogenic demand. In an arid area, evapotranspiration might be very high because high temperatures encourage liquid water on the surface to become water vapor, but surface runoff is low because rainfall is scarce. In a very wet area, this trend might be reversed. In addition, certain areas may abstract more water from the aquifer, while other areas abstract more from lakes and rivers. For a water resource manager, understanding the magnitudes of these different components is critical to solving water-related problems.

Water balance equations are usually performed at the scale of a watershed. A watershed is a land area where all the water that falls in the area flows to the same point (Figure 2). Watersheds can be very large (regional river systems such as the entire Mekong River which includes land area in five different countries) and very small (such as a single hillslope). Since water is constantly cycled and largely contained within a watershed, it is a natural scale at which to study the water balance.

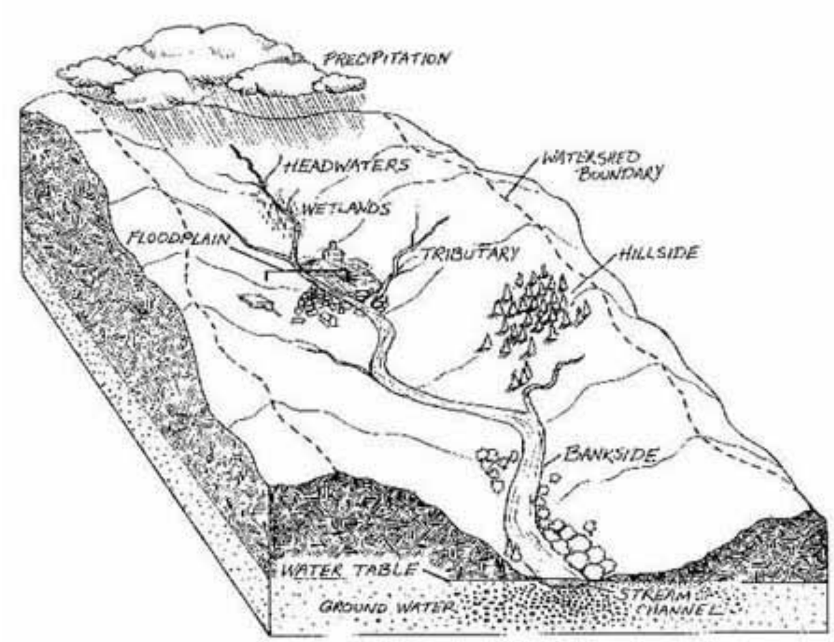


Figure 2. A diagram of a watershed for a river system (Source: www.rivanna.org).

A simple water balance equation accounts for what happens to all the precipitation in a given watershed:

$$Precipitation = Evapotranspiration + Surface\ Runoff + Percolation$$

This equation helps water resource managers understand what happens to their water supply after it arrives in the form of precipitation—it either reenters the atmosphere through evapotranspiration, travels across the surface into water bodies in the form of surface runoff or percolates[1] into the aquifer. All of these processes are dynamic—water may first travel as surface runoff and then evaporate out of a lake—but this basic equation is useful to see where the precipitation travels immediately after entering the watershed.

These components of the water balance equation show the water supply (rainfall) and how much of that rainfall is available for use by the watershed's population. However, it is also necessary to understand the magnitude of water demand—how much water humans need to satisfy their needs. Water demand includes the domestic use (drinking, bathing, food preparation) and productive use (livestock, industry, agriculture) of a watershed. Although this water is needed and used by humans, it is important to remember that it does not disappear—it reenters the water cycle in some form, through sewage, effluent, evaporation from an agricultural field or another way.

[1] Percolation is the water moved beyond the root zone and is either stored as groundwater or slowly returns to the stream as base flow. Infiltration, a similar concept, refers to water moving from the surface into the ground. Some infiltrated water is sucked back up by plant roots and forms part of evapotranspiration.

The following sections will describe the Stung Chinit watershed and the magnitude of different aspects of its water supply and demand.

IV. OVERVIEW OF THE STUNG CHINIT WATERSHED

The Chinit River, located primarily in Kampong Thom Province in Cambodia, is a major tributary of the Tonle Sap Lake, the largest and most important lake in Cambodia both in terms of economy and water supply. Its watershed is approximately 8,236 km^2 in size. The river itself is around 264 km long with highest point in the watershed being 277 m above sea level and its lowest point where it merges with the Tonle Sap at around 5-6 m above sea level.

POPULATION AND ECONOMY

The population in the Stung Chinit watershed from the 2008 Census is 495,387 and rising. If we assume a 2.2% population growth, which is the national average (FAO 2018), around 603,000 people will live in the watershed in 2017, growing to around 800,000 by 2030, and 1.2 million by 2050.

In Cambodia, 81% of the workforce is rural, with around 72% dependent on agriculture, fisheries and forest resources (ADB 2009), meaning a large portion of its water use is from the agricultural sector. For farm households roughly 90% rely on rice as their primary crop (ADB 2014). Cambodia's economy has grown rapidly over the last two decades reducing poverty levels from near 50% in early 2000's to 13% in 2014 (World Bank 2018). However, Cambodia remains vulnerable to economic and environmental shocks as most people have only barely risen above the poverty level and for most subsistence farming remains their safety net and ultimate security (World Bank 2018).

LAND USE

Land cover in the Stung Chinit watershed is 56% cropland and plantations, 31% forest, and the remainder urban and water (

Land type	2000 area (km^2)	2018 area (km^2)	Percent change
Cropland	2,980	4,769	60%
Plantation	0	231	N/A
Forest	4,908	2,801	-43%
Other	1,020	1,106	-8%%

Table 1, Figure 3). In the Stung Chinit watershed between 2000 and 2018, 43% of the forest area was lost amounting to around 2,107 km^2 according to the WESTool. As shown in the WESTool, around 36% of this deforestation occurred in government allocated Economic Land Concession (ELCs). The vast majority of the deforested land was converted into croplands, which saw a 60% increase in land area in the period, while forest area decreased by 43%. Some of the implications of this land use change are discussed in section VIII of this report.

Land type	2000 area (km²)	2018 area (km²)	Percent change
Cropland	2,980	4,769	60%
Plantation	0	231	N/A
Forest	4,908	2,801	-43%
Other	1,020	1,106	-8%%

Table 1. Major land uses in the Stung Chinit watershed in 2000 and 2018.

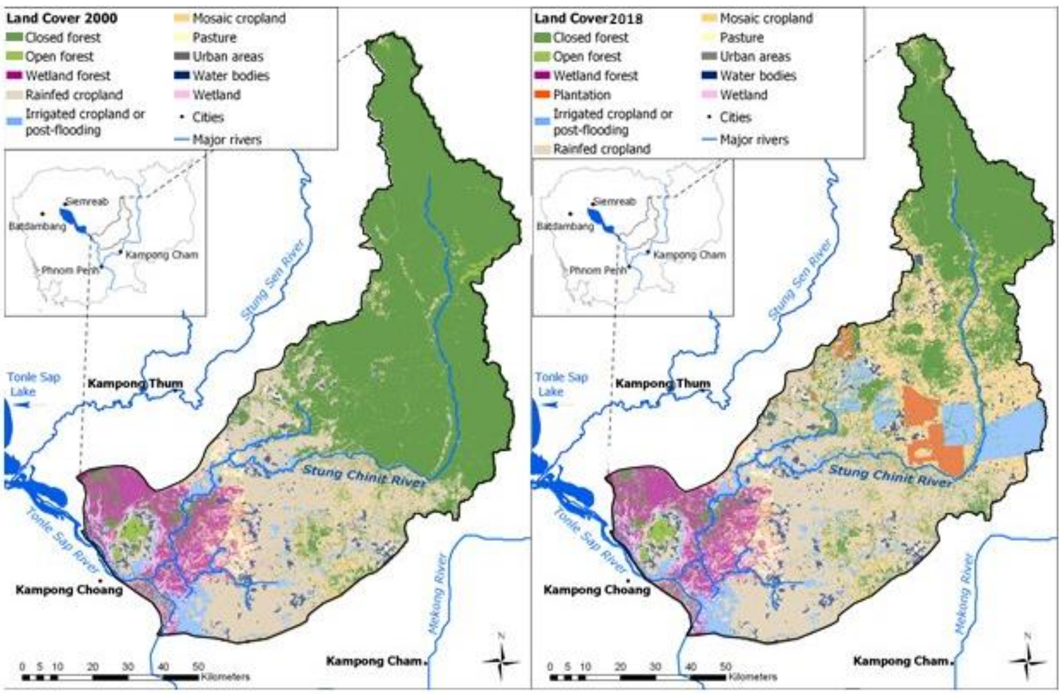


Figure 3. Stung Chinit watershed, comparing its landcover from 2000 (map on left) and 2018 (map on right).

Around 80-90% of the crop production in the Stung Chinit watershed is rice, with the remainder being a mix of other crops such as corn, peanut, watermelon, banana, cashew nut, etc. (ADB 2014). Without irrigation, the climatic regime in Cambodia typically allows for only one crop in the wet season. However, in many cases double cropping during the wet season is possible, but this generally requires well-managed supplementary irrigation. Dry season rice is completely dependent on irrigation and requires substantial cost, therefore is only grown on a very small portion of the landscape (EDI 2014).

The Ministry of Agriculture, Forestry and Fisheries (MAFF) estimates that around 50% of the total wet season rice has access to supplementary irrigation, mostly through direct pumping of surface water (mostly from rivers, but also from private lakes or ponds) and/or through an irrigation network. Most of the rice cultivation revolves around the wet season which extends from April to November (Figure 4). Dry season rice is limited to areas with more industrial irrigation which makes a very small fraction of the land.

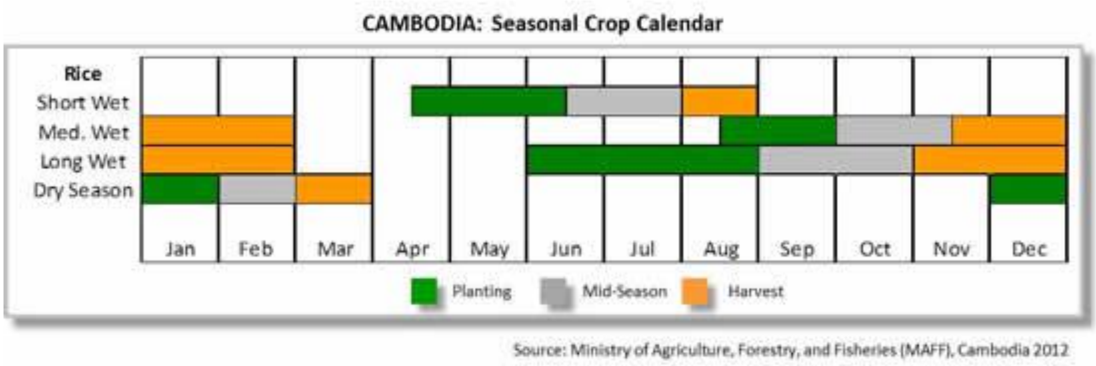


Figure 4. Crop calendar for rice in Cambodia.

IRRIGATION

For Stung Chinit, the functional irrigation system is one of the most important mechanisms for preventing or minimizing crop failure, increasing crop yields and establishing consistent cropping calendars. If properly designed, built, operated and maintained, irrigation systems can help farmers withstand water-related climatic shocks such as flood and drought by providing a more reliable means of water supply.

The Stung Chinit Irrigation System and Rural Infrastructure Project is currently the largest in Cambodia (Baran, 2007). This project has been in operation since 2006, as part of the Second Socio-Economic Plan of Cambodia, to reduce poverty by improving agricultural production. The Stung Chinit reservoir's surface area is approximately 50,000 ha with a total storage area of 25 km^2. The irrigated area the reservoir will serve is projected to be 3,000 ha in the wet season (supplemental irrigation) and 1,800 ha in the dry season (full irrigation). Despite operational and maintenance challenges, it is clear that the project has improved water security in the watershed through improved annual rice yields and enabling multiple crops per year over a larger area for most of the farmers within the system coverage.

However, most farm area in the Stung Chinit watershed continue to rely on rain fed agriculture with limited irrigation potential from things like community ponds. These farmers are typically limited to one rice crop per year.

GROUNDWATER

Information on groundwater is very limited in Cambodia. What is known is that most provinces include significant areas where groundwater is used as an important source of domestic water supply. Groundwater is being exploited at ever-increasing rates, particularly by shallow tubewells for community and household water supply, as well as for irrigation (FAO 2011).

There is a large aquifer in the alluvial sediments of the Tonle Sap flood plain. This shallow water table is largely filled by the flood-pulse of the Tonle Sap Lake. In the upland areas, groundwater is scarcer and tube wells need to be deeper to access consistent groundwater resources. The drought in 2016 forced many people to rely more on wells. Many of these wells went dry do to both the drought and increased extraction, forcing communities to dig deeper wells and in some cases, rely on water trucked from other areas (Open Development Cambodia 2016).

Increased extraction of groundwater in the Stung Chinit watershed is providing both opportunities for improving irrigation and posing management challenges as over exploitation of groundwater resources can draw down the water table. This can cause further water shortages that can be exacerbated during periods of drought (Figure 5; CHF Assessment Team 2016).

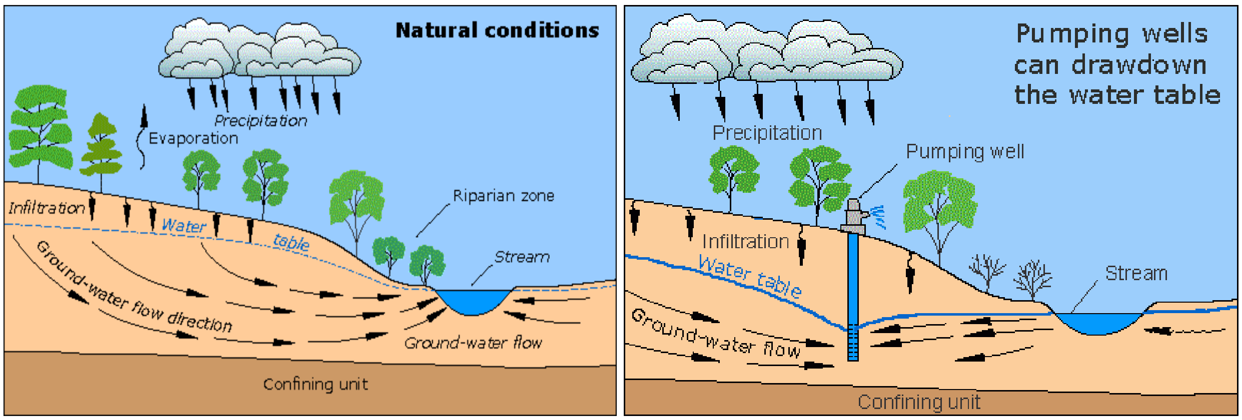


Figure 5. Interaction between surface and groundwater. Source: https://water.usgs.gov/edu

FISHERIES

The Stung Chinit River system has rich natural fish populations migrating upstream and downstream (USAID 2011). Seventy-nine species were found in 2003-2004 (USAID 2011). Prior to the construction of Stung Chinit reservoir, fish catch was 7,000 tons/year from five commercial fishing lots downstream in Tonle Sap Lake, and 1,406 tons/year from families and professional catches (USAID 2011). It is not known at this time what impact the Stung Chinit Irrigation System reservoir may have had on the production. In the northern portion of the Stung Chinit watershed it is heavily forested which supports fish populations by preventing sedimentation of the stream network. Heavy logging of this area could affect the richness of the fish populations, and biodiversity along the Stung Chinit River, as well as reduce fish catch yield (Baran et al 2007). A Chinese construction company has plans to build a dam in Stung Chinit upstream watershed. If it is completed, there could be further impacts to fish species and their migration.

V. ANALYSIS OF WATER SUPPLY IN THE STUNG CHINIT WATERSHED

The Soil and Water Assessment Tool (SWAT) was used to quantify different aspects of the water balance for the Chinit River to better understand the water cycle dynamics without factoring in human consumption and demand of the water. SWAT is a physically-based hydrological model that uses rain gauge data along with spatial data related to soil type, land use and slope to model the hydrological response of a watershed. For this study, the SWAT was used to simulate the hydrological response of the Stung Chinit watershed from 1991 to 2013. Data were gathered from Cambodian and global sources for these required inputs (Table 2). In watersheds lacking dense networks of weather stations and other instruments to measure hydrological indicators, modeling is a good option to roughly estimate the quantities of different aspects of the hydrological cycle.

Spatial data sources	**Source**	**Citation**
Land use/land cover	Custom map developed	https://www.winrock.org/westool/data-sources/
Elevation/slope	Shuttle Radar Topography Mission (SRTM) 90m DEM	Jarvis et al., (2008)
Soil type	Food and Agriculture Organization's (FAO) Digital Soil Map of the World	(FAO/IIASA/ISRIC/ISSCAS/JRC, 2012; Sanchez et al., 2009)
Weather station locations	Global Summary of the Day and Global Historical Climatology Network rain gauge locations, downloaded from the National Climatic Data Center (NCDC)	Menne et al., (2012)
Tabular data sources		
Rain gauge records	Selected gauges between 1986-2013, downloaded from NCDC	Menne et al. (2012)
Weather station records	Climate Forecast System Reanalysis (CFSR) data for relative humidity, solar radiation, temperature and wind speed	Fuka et al., (2014)
Management (Crop cycles, irrigation, fertilizer)	Government publications and scientific literature	MRC, (2003); Vibol and Towprayoon, (2010)

Table 2. Data sources for SWAT model inputs.

According to the SWAT model, the average flow of the Chinit River during the wet season is 107-123 m^3/s and during the dry season 18-21 m^3/s (Figure 6). Over the course of a year the total accumulated flow is just over 2 billion m^3 per year. That is around 3-4% of the Tonle Sap's accumulated flow.

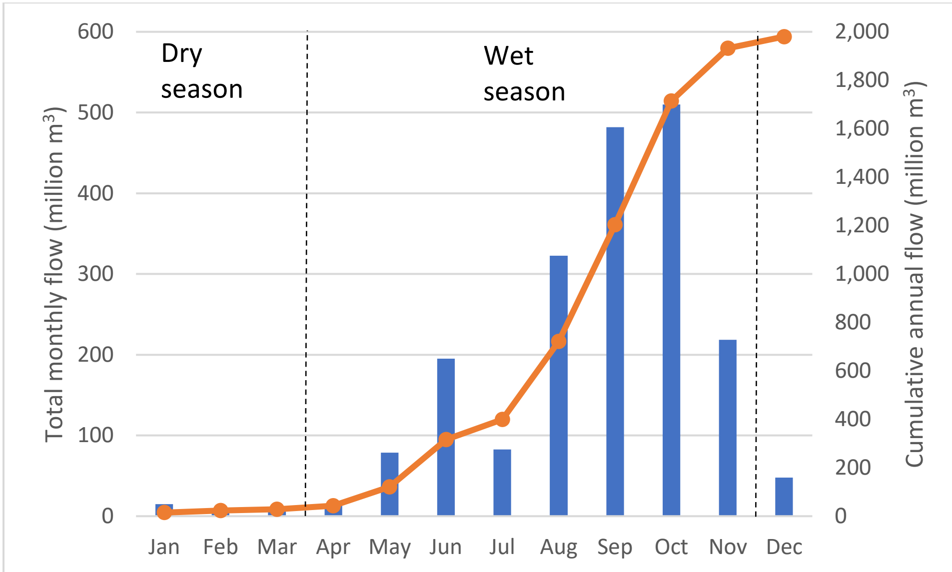


Figure 6. Historical average total monthly flow (blue bars) and annual cumulative flow (orange line) in the Stung Chinit river.

Precipitation gauges in and around the watershed analyzed in SWAT estimate the annual rainfall in the Stung Chinit is 1,300 mm. If taken over the entire watershed, this equates to 11,575 million m^3. The vast majority (~95%) of the rainfall occurs in the wet season (generally from April to November), with October being the wettest month and January being the driest month. This great disparity in seasonal rainfall helps explain the contrasting water security issues that face the populations that live in the watershed—both flooding in the wet season and drought in the dry season.

Planning for floods and droughts can be aided by considering the recurrence interval or return period of annual rainfall, which can help give an indication of how common very wet and very dry years are in a given watershed. An analysis of the rainfall gauges' records between 1991-2013 near the Stung Chinit watershed was done to understand the return periods of various annual rainfall amounts (Figure 7).

The exceedance return period is used for analyzing very wet years in which floods are common. This return period refers to the likelihood in any given year of the annual rainfall total exceeding a given amount. A five-year annual rainfall exceedance return period is equal to about 1,760 mm, meaning that in any given year, there is about a 20% chance that the annual precipitation will exceed 1,760 mm. More extreme wet years would have the 50-year return period annual rainfall (equal to about 3,290 mm) and a 100-year return period (~3,750 mm). For flood management, it is often best to prepare for such extreme wet years where floods are going to be more intense and frequent.

The shortfall return period is used for analyzing very dry years in which droughts may occur. This return period refers to the likelihood in any given year of the annual rainfall total falling short of a given amount. The five-year shortfall return period, or five-year drought, in the Stung Chinit is 672 mm of annual rainfall. This means that water resources planners should assume that in any given year, the Stung Chinit will have about a one in five chance of receiving less than 672 mm of rain, which is about half of the average annual rainfall. When these droughts occur, the water supply is greatly strained and storage from previous years would be necessary to satisfy demand.

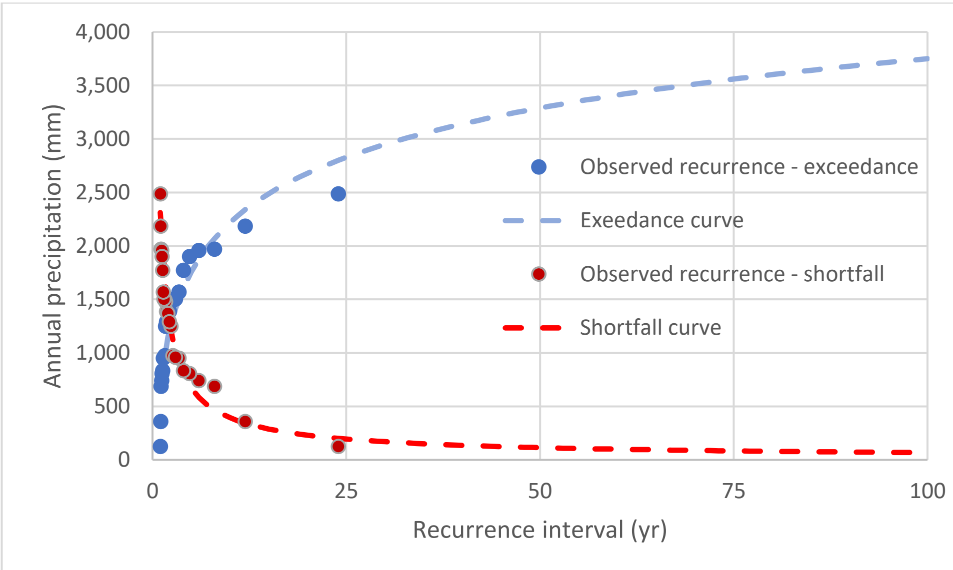


*Figure 7. Frequency curve of annual precipitation amounts according to observed rainfall in rain gauges near the Stung Chinit watershed. The exceedance curve shows probability of annual rainfall being **higher** than a given amount, while the shortfall curve shows the probability of annual rainfall being **lower** than a certain amount.*

Average values for different components of the water balance equation were derived from the SWAT modeling. In the wet season, on average, approximately 47% of the rainfall is returned into the atmosphere as evapotranspiration (ET), while 17% is collected on the surface as runoff, and 30% percolates into the aquifer with a small percentage of that returning to the river though subsurface flow (

	Annual rainfall (mm/season)	Evapotranspiration		Surface runoff		Percolation to shallow aquifer	
	Mm	mm	% of rainfall	mm	% of rainfall	mm	% of rainfall
All years							
Wet season April-November	1,267.5	592.1	47%	220.7	17%	380.3	30%
Dry season December - March	39.9	129.9	325%	4.4	11%	0.9	2%
Wet years							
Wet season April-November	1,980.6	782.7	40%	381.3	19%	744.4	38%
Dry season December - March	119.6	199.5	167%	9.3	8%	1.5	1%
Dry years							
Wet season April-November	1,232.7	618.6	50%	203.0	16%	306.5	25%
Dry season December - March	23.0	132.6	577%	3.2	14%	0.4	2%

Table 3). In the dry season, evapotranspiration is actually greater than rainfall on average, while runoff drops to 11% and percolation to 2% of rainfall. The water balance from the five wettest years simulated in the SWAT model were also compared against the five driest simulated years.

Wet years have more surface runoff and percolation as a percentage of rainfall than average, while dry years have more ET as a percentage of rainfall than average. These trends show that with more rainfall in the wet years, more water is available as surface water and more percolates into the groundwater. However, occasionally this water overwhelms reservoirs and waterways, causing damaging floods. Lack of surface water storage capacity also probably limits the ability of Cambodians to take advantage of the increased water availability in the wet season of wet years. In contrast, in dry years with less precipitation, much more of the water becomes ET meaning less water is available for use. Instead, water stored in the groundwater from wet years is needed to meet demand.

	Annual rainfall (mm/season)	Evapotranspiration		Surface runoff		Percolation to shallow aquifer	
	Mm	mm	% of rainfall	mm	% of rainfall	mm	% of rainfall
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Table 3. Comparison of water balance components between wet and dry seasons as well as wet and dry years.

During the first six months of the wet season, rainfall is typically more than the accumulated loss from ET, surface runoff and percolation (Figure 8). However, by the end of the wet season and all through the dry season, October to March, rainfall is less than the accumulated loss.

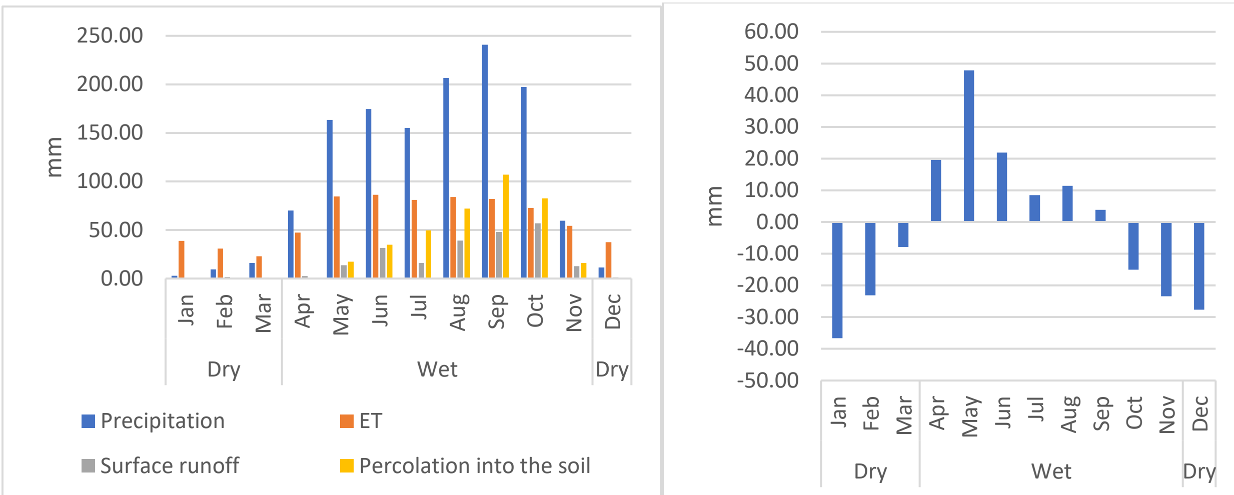

Figure 8. Left side shows all the components of the water cycle (precipitation, ET, surface runoff and percolation of water into the soil leading to both aquafer recharge and subsurface flow back to the river) by month in millimeters (mm). Right side: overall water balance precipitation minus ET, surface runoff and percolation by month in mm.

These patterns again highlight the contrast between the wet and dry seasons within the watershed. During the wet season, runoff rates are very high which indicates flooding potential, but the wet season is also when infiltration occurs and thus refilling of the shallow aquifer that is so important for agriculture, especially rice cultivation. In the dry season, much of the water becomes ET, while relatively little infiltrates into the aquifer. More water is available at the beginning of the dry season since much of the runoff and water in the shallow aquifer from the wet season rains is still available, even in shallow wells and small ponds. However, as ET and runoff into rivers take some of that excess away, by the end of the dry season less water is available. This highlights the necessity to store water from the wet season to be used in the dry season if any dry season agriculture is to be performed, and also shows that the end of the dry season (February and March) is the most water scarce time of the year.

This water balance does not consider one potential important non-renewable source of water—if there exists a deep aquifer that was filled many years ago in the watershed, it could be a potential source of freshwater supply. There is some indication that the young alluvium soil layer around the main rivers in the region (including the Tonle Sap that the Stung Chinit flows into) is impermeable, restricting any recharge to the old alluvium aquifer beneath it (Johnston et al. 2013). This old alluvium aquifer could therefore be a source of nonrenewable groundwater available to communities in the lower Stung Chinit watershed as long as they have wells deep enough to access it. However, aquifers filled with ancient water is often filled with heavy metals and its abstraction can sometimes cause subsidence of the land’s surface.

VI. ANALYSIS OF WATER DEMAND IN THE STUNG CHINIT WATERSHED

Water demand in the Stung Chinit is broken into two primary categories, 1) agricultural demand, and 2) domestic water demand. There is very little industrial demand in the Stung Chinit watershed.

AGRICULTURE

Agriculture and livestock make up around 95% of all water use in Cambodia. The amount of water use for agriculture in the Stung Chinit watershed was estimated using land cover maps along with data on the amount of water used per hectare by land use. Because rice makes up the vast majority of the cropland and land cover maps are not sufficiently detailed to differentiate between other agriculture types, all agricultural areas were assumed to be rice. The amount of water used per hectare for irrigation was established from existing literature (Mainuddin and Kirby 2009, Wokker et al. 2012) (

		Wet season	Dry season
		m^3	
Upland	Irrigated	5,900	10,300
	non-irrigated	0	0
lowland	Irrigated	5,900	10,300
	non-irrigated	1,500	0

Table 4).

		Wet season	Dry season
		m^3	
Upland	Irrigated	5,900	10,300
	non-irrigated	0	0
lowland	Irrigated	5,900	10,300
	non-irrigated	1,500	0

Table 4. Estimated irrigation demand for crops in the Stung Chinit watershed.

The annual demand for irrigation was based on literature review of the amount of water needed per hectare (m^3) for wet and dry season, and land cover maps showing the area in hectares of irrigated and rainfed cropland (Mainuddin and Kirby 2009, Wokker et al. 2012) (Figure 9). The logic of this assessment is broken down in Appendix A.

Based on this assessment the amount of irrigation used by agricultural lands is 420 million m^3 a year. It is clear that the majority of irrigation occurs during the wet season which is due to the fact that 90-95% (estimated based on spatial analysis) of the crops are grown only in the wet season. In the dry season only 5-10% of the crop area is planted, but irrigation demand per hectare is nearly twice that of the wet season due to lack of rainfall.

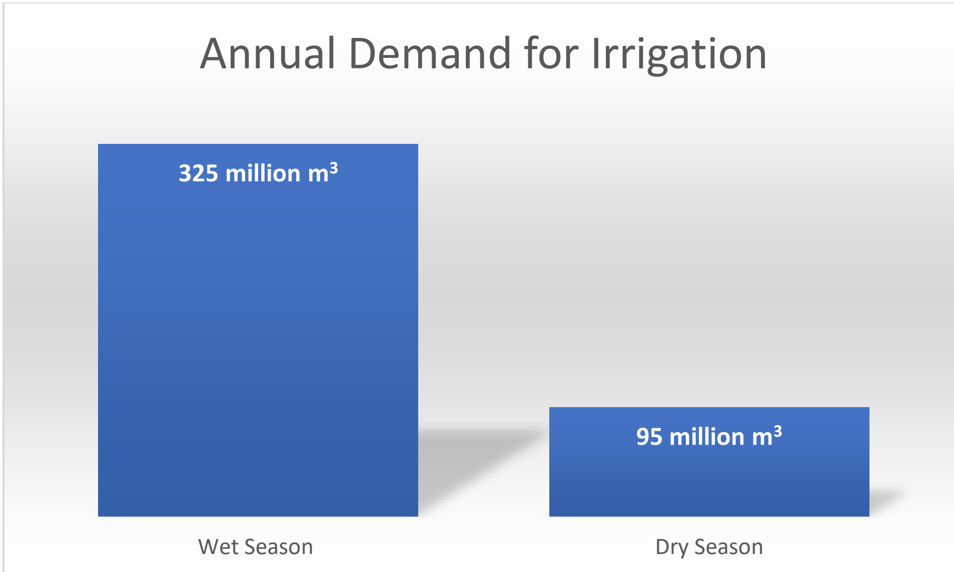

Figure 9. Annual demand for irrigation in the Stung Chinit watershed.

DOMESTIC

Data on domestic water demand specific to the Stung Chinit watershed is scarce. Data from FAO (2016) estimates the municipal water demand in Cambodia to be about 20 liters per day per person, which if applied to the Stung Chinit watershed's population would equate to about 3.5 million cubic meters per year. Another estimate by Sreymom and Sokhem (2015) puts domestic demand at 50 liters per day per person, but this estimate is based on a "recommendation of the World Health Organization" and is probably not from measured data. If the Sreymom and Sokhem (2015) estimate is used, total domestic demand in the watershed goes up to about 9 million cubic meters per year. A Ministry of Water Resources and Meteorology report (MOWRAM 2013) estimates that the total domestic water demand in the Chinit watershed is 36,237m^3/day, which equates to 13.2 million cubic meters per year. It is unlikely that domestic water demand makes up a large portion of overall demand in the watershed given the prominence of irrigation schemes and agriculture in the watershed. For Cambodia as a whole, FAO (2016) estimates that municipal water withdrawals make up only 4.5% of total water withdrawals.

VII. SUPPLY VS DEMAND

When comparing total water supply against total water demand, it is clear that the Stung Chinit watershed is currently not a water-scarce area on an annual basis. When total supply is taken as the sum of surface runoff and percolation and demand is domestic and agricultural, the watershed has an annual estimated supply of 5,400 million cubic meters while estimated demand is only a little over 432 million cubic meters. However, this masks a couple of factors. First, not all surface runoff and percolation are always available to communities. This is because much of the water that runs off and percolates into the shallow aquifer ends up in the riverways and flows out of the watershed into the Tonle Sap river before it can be used. Communities simply do not have the capacity to store all this water on the landscape, and downstream communities and wildlife depend on that flow. Second, nearly all the supply comes in the wet season, and without storage this limits the potential for dry season demand, which is already twice the dry season supply (estimated demand is 99 million m^3 compared to 47 million m^3 in supply) (Figure 10).

Therefore, despite the annual surplus of water, there is actually a deficit in the dry season. This deficit is largely filled by excess supply from the wet season, which is stored in surface water bodies and aquifers. However, it is only available through irrigation—farmers who rely on rainfed agriculture therefore cannot farm during the dry season.

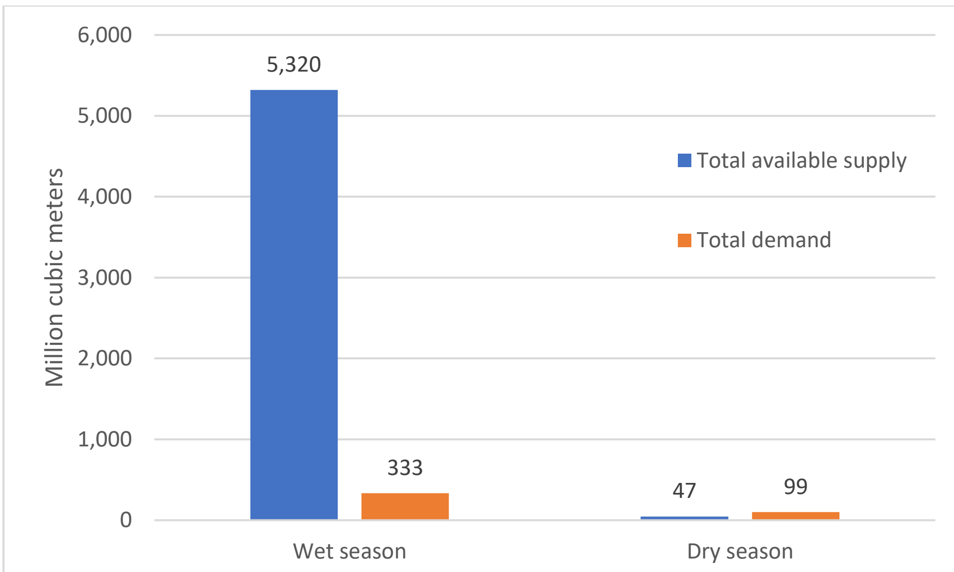

Figure 10. Total water supply vs. demand for the Stung Chinit watershed

Despite annual supply being greater than annual demand (Figure 11), future stresses such as increasing population, land cover change and climate change (discussed in section VIII) may cause this supply surplus to decrease. If demand rises equal to population at 2.2% per year, and irrigation area continues to expand at a modest 2% per year, demand will be 25% of supply in 30 years and in 90 years would outstrip supply completely. However, if climate change causes a decrease in annual rainfall or an increase in intense wet season storms (causing a higher percentage of rainfall to become runoff that cannot be stored), then supply will drop as well. This could cause demand to exceed supply faster than expected.

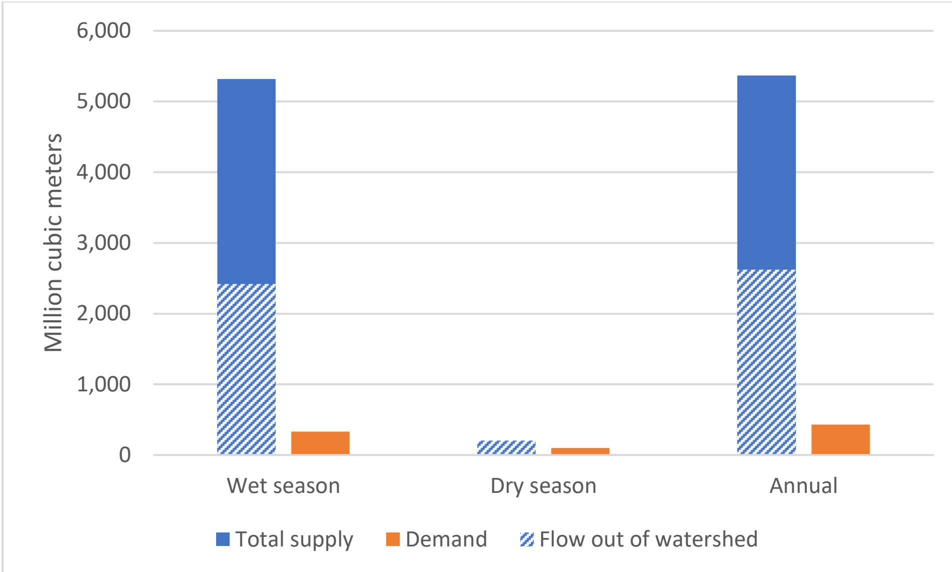

Figure 11. Seasonal and annual supply vs. demand, showing portion of supply that is flows out of the watershed via river and is not available for use. During the dry season, there is so little supply that storage from the wet season must be used to satisfy demand.

VIII. WATER SECURITY ISSUES IN THE STUNG CHINIT WATERSHED

FLOODS AND DROUGHTS

Given the large disparity in rainfall amounts between the wet and dry season in the Stung Chinit watershed, floods and droughts are both common causes of water insecurity. Floods are the scourge of the wet season, while droughts wreak havoc in the dry season. Floods are a yearly occurrence while droughts tend to happen only about every three years (VRICS 2011). Recent years of drought include 2004, 2008, and 2016 where periods without rain were observed for 1-3 months (EDI 2014). During the drought of 2004, some communities experienced losses of half of their rice crops along with losses to other cash crops, livestock and lower fish catches. These impacts caused villagers to migrate and seek other employment, sell livestock and rent pumps from others to have further access to groundwater aquifers (EDI 2014).

The main way to alleviate droughts is to store water from the wet season, either in groundwater aquifers or in surface water reservoirs, both of which have their benefits and drawbacks. Communities that have direct access to the irrigation schemes in the Stung Chinit watershed can mitigate drought somewhat and improve their food and water security more than communities with no functioning schemes. EDI (2014) provided village survey evidence that the Stung Chinit Irrigation Scheme mitigated droughts for nearby communities.

Severe floods have been observed in the Stung Chinit watershed in 2000, 2006, 2009 (related to Typhoon Ketsana), 2011 and 2014. Given the low elevation of the lower Stung Chinit watershed and flat topography, the area is very prone to flooding from heavy rain events in other watersheds, both upriver around the Tonle Sap Lake and downstream along the main stem of the Mekong river. This flooding that originates downstream is due to the flow reversal of the Mekong river, which sends floodwaters upstream from the Mekong to the Tonle Sap river.

These floods are very common and tend to cause river levels to rise very slowly, damaging agricultural fields but infrastructure less (VRICS 2011). It is important to note that some of this flooding is not considered detrimental by communities, as it provides water for ponding in rice fields. The result of this low elevation and prevalence of ponding in rice crops lead to much of the lower watershed being inundated for at least part of the year (Figure 12).

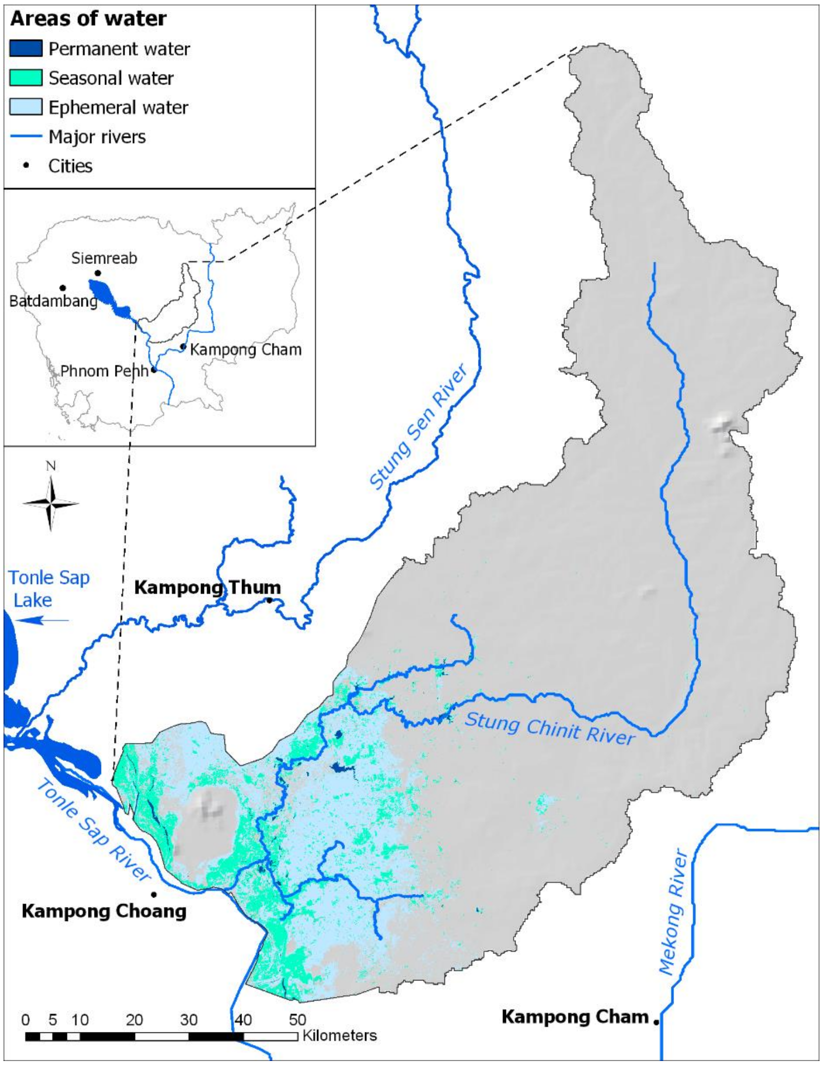

Figure 12. Areas of surface water in the Stung Chinit watershed.

In the middle and upper watersheds, flash flooding of the Chinit river itself is more common. For communities in the Stung Chinit watershed, flooding has caused equipment and building damages, crops to fail, livestock death and decrease in fish catches. It is generally perceived to be a greater threat than drought for villages closer to rivers, especially the Tonle Sap river. Unlike for drought, irrigation schemes and reservoirs do not provide relief from flooding (EDI 2014).

LAND USE CHANGE

Land use changes are known to have considerable impacts on hydrological flows (runoff, infiltration and ET), affecting the seasonal availability of water and water quality. In the Stung Chinit watershed these impacts are primarily driven by the conversion of forest to agriculture or plantation. Forests typically slows the flow of water across the earth's surface reducing runoff and enhancing soil infiltration that can increase groundwater recharge. The vegetation and roots control the erosion of soil and nutrients, while infiltration filters and purifies the ground and surface water. At the same time, the percolation of water through the soil profile slows the rate of water returning to the river and can help maintain river flows during dry periods. In contrast, agricultural and urban landscapes have less vegetation cover to slow the flow of water. Therefore, deforestation causes an increase in erosion leading to water pollution and can reduce the recharge of groundwater aquifers. As a result, flash floods are more common and lower groundwater recharge rates can lead to well water shortages in the dry season, exacerbating droughts. Increased runoff from agricultural lands can lead to excessive nutrients from organic and inorganic fertilizer in the rivers and lakes leading to eutrophication that can devastate fisheries, and at extreme levels be poisonous to humans.

Based on the results from the WESTool it is estimated that this deforestation in the Stung Chinit watershed between 2000-2018 (see section IV) resulted in an 13% decrease in groundwater recharge (Figure 13), a 60% increase in sediment entering the river (Figure 14) and a 55% increase in nitrate entering the river due to increase runoff (Figure 15).

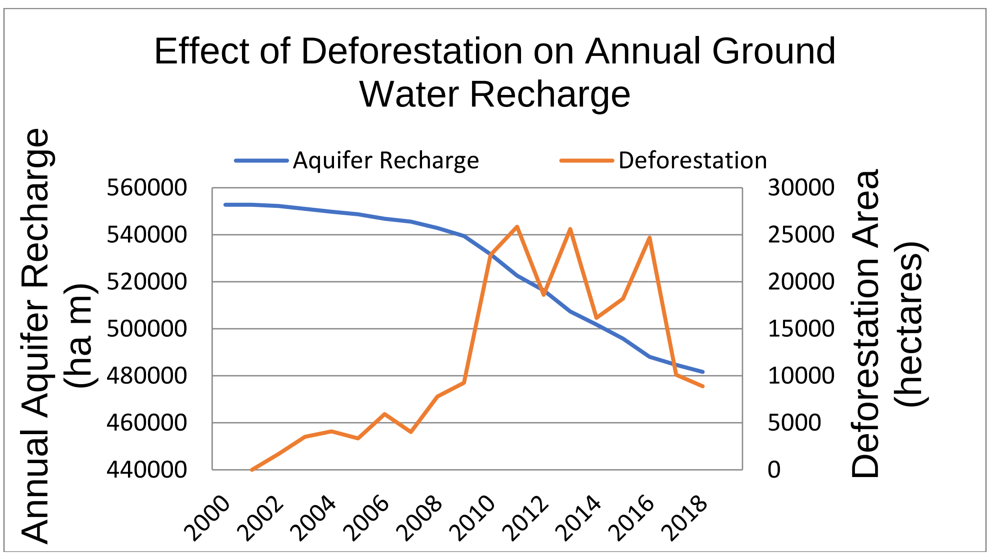

Figure 13. the impacts of deforestation of groundwater recharge.

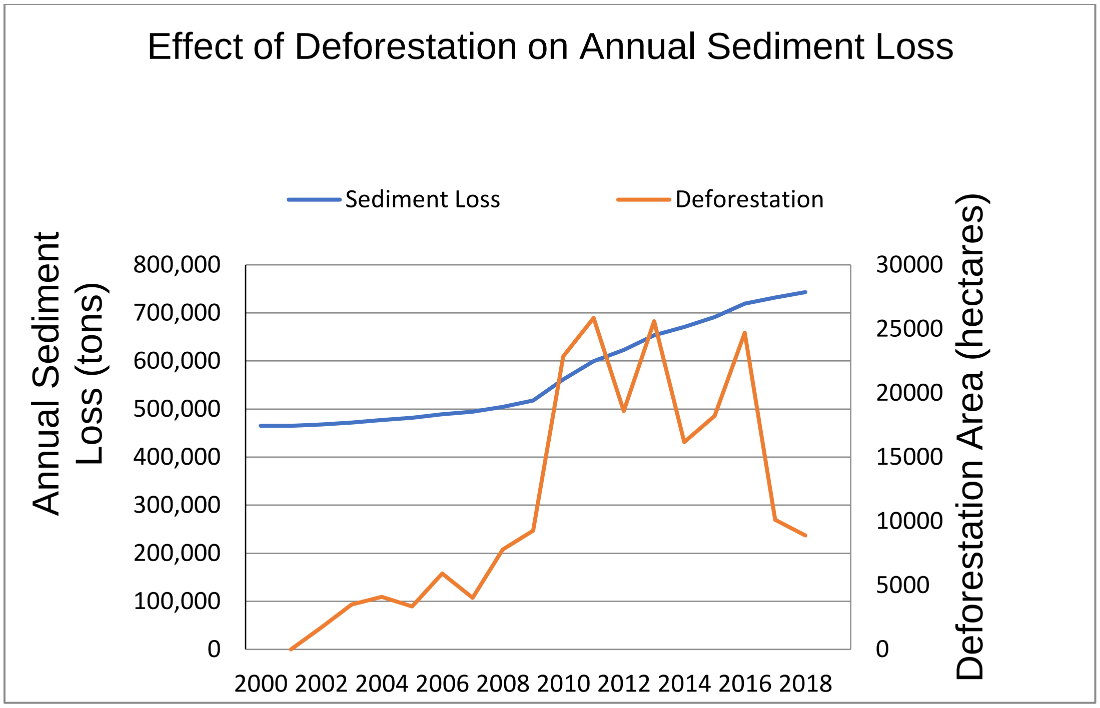

Figure 14. The impacts of deforestation on sediment loss from erosion.

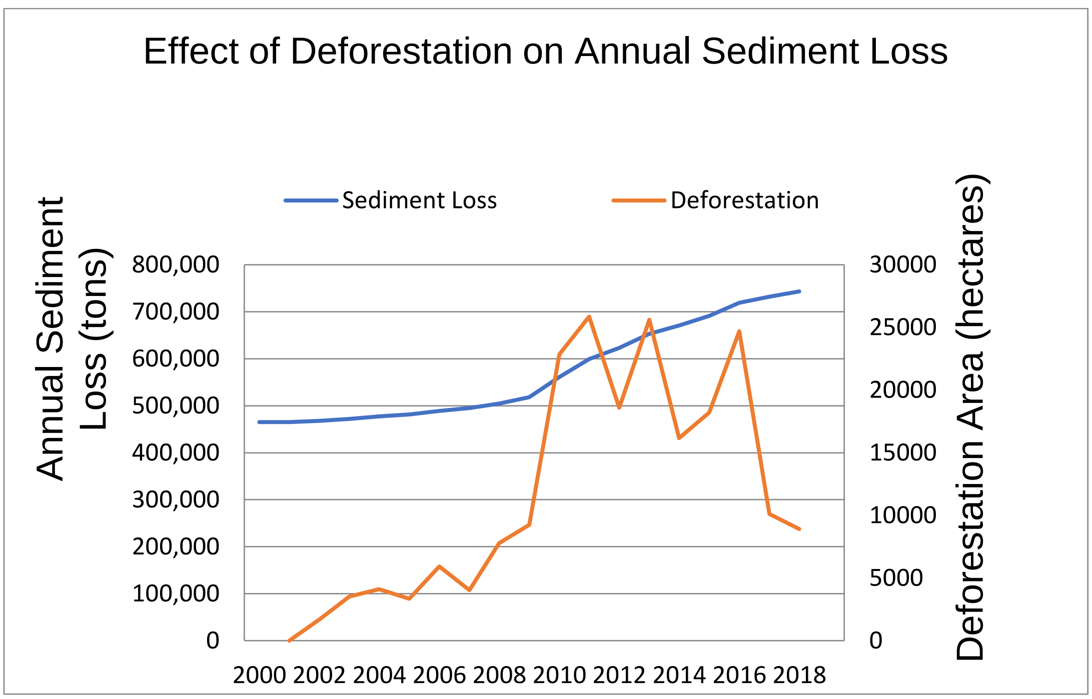

Figure 15. Th impacts of deforestation on nitrate loss from erosion.

These results are important for water security in the Stung Chinit for a number of reasons:

1. Forests still cover much of the land in the upper watershed. These forests are an important regulator for mitigating floods during times of high rainfall, maintaining flow during the dry season and periods of drought. Without the maintenance of these ecological services, flood and drought could be exacerbated in the more populated areas downstream.
2. Increasing areas of agriculture combined with increasing rates of fertilizer application could lead to water quality issues for both surface water and shallow aquifers. According to the WESTool, it is estimated that over the last decade land use change combined with current rates of fertilizer application caused a 167% increase in nitrate concentration in the Stung Chinit river just above the Stung Chinit reservoir. It is unknown what level of nitrate would begin to pose problems to water quality in this particular watershed, but nitrate can cause eutrophication and other water quality issues in reservoirs and rivers.
3. Similarly, increasing rates of sediment could pose a problem to existing infrastructure. This can be of critical importance to maintaining reservoirs, like the Stung Chinit reservoir, that are impacted by increasing sedimentation filling the reservoir which reduces its storage capacity. The WESTool suggests that over the last decade there was an almost 600% increase in sediment concentration just above the Stung Chinit reservoir. Again, the impacts of this increase are unclear without improved monitoring. However, it is likely that maintaining forest in the upper watershed and reducing sedimentation through activities like riparian buffers could have important implications for the long-term sustainability of the Stung Chinit reservoir, and other reservoirs in the watershed.

CLIMATE CHANGE

This IPCC 2014 report “Climate Change 2014 Impacts, Adaptation, and Vulnerability” identifies Southeast Asia as one of the most vulnerable areas in the world to climate change. This is due to a combination of environmental threats, many of which are already being felt, and high population densities.

In Cambodia, historical data shows a rising temperature of 0.8° C since 1950 and decreasing rainfall of 0.2% per year (Thoeun 2015). There has also already been an observed increasing frequency and intensity of extreme weather events. In addition, climate change is exacerbating the problem of water stress, affecting agriculture production, causing forest fires and increasing outbreaks of infectious diseases (ADB 2009).

Most climate projections show increasing temperatures of 2-4°C in the next 60-80 years, and do not show a significant change in annual precipitation across Cambodia (Thoeun 2015). The WESTool used a downscaled GCM “Model for Interdisciplinary Research on Climate (MIROC3.2)” that shows decreases in annual precipitation totals across Cambodia, with larger change in the northwest (Figure 16). This does mask a predicted seasonal trend though—more rain is expected in the wet season while less rain is expected in the dry season.

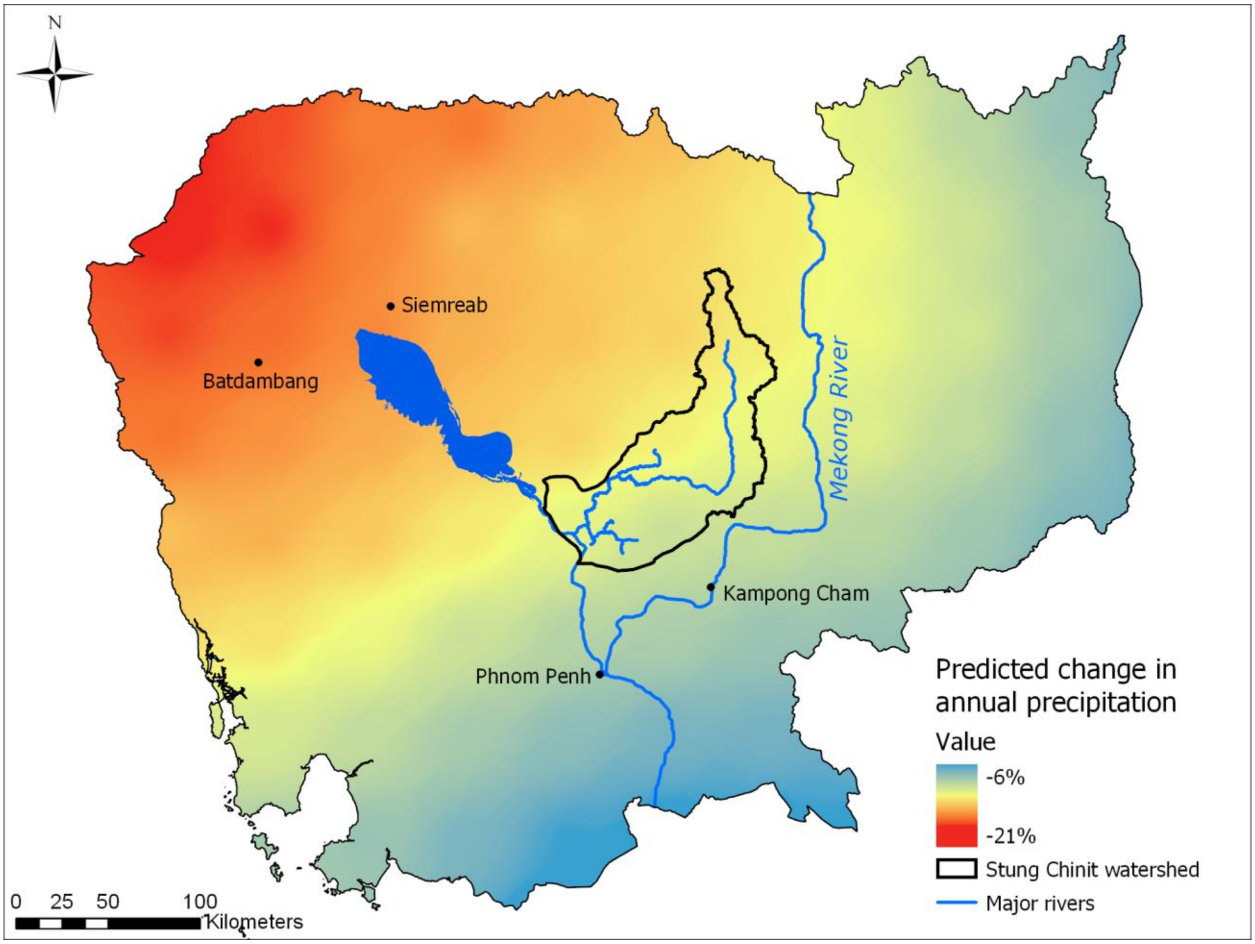

Figure 16. Predicted change in annual rainfall by 2046-2064 as shown in the WESTool using the MIROC3.2 GCM.

The WESTool indicates that by 2046-2064 temperatures in the Stung Chinit watershed may increase by 7% from a current annual average of 27°C, and rainfall decrease by 13% from an annual average 1,723mm y^{-1}. These climatic changes could alter the water balance in the Stung Chinit. Higher temperatures and less rainfall in the dry season will increase evapotranspiration, while stronger rains in the wet season will lead to more surface runoff. The overall effect of this could be less percolation into the aquifer and potentially less water available in the soil for rainfed agriculture.

Using a series of regressions with SWAT results, the WESTool estimated that this would decrease crop yields by 2%, assuming no changes in management (e.g. increasing irrigation could offset these decreases). Other reports suggest that climate change in South East Asia will decrease crop yields by 2% every decade (ADB 2009).

For key stakeholders in the watershed, it is important to consider the impact of these changes. Lower crop yields due to less rainfall could encourage conflict over water access and increased probability of food and water crises. More extreme rainfall events could lead to greater loss of life in flooding events and property damage. Planners must take these potential changes into account when deciding how to design key water infrastructure and land use development in the Stung Chinit watershed.

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APPENDIX A – STAKEHOLDER ASSESSMENT OF WATER SECURITY ISSUES IN THE STUNG CHINIT RIVER WATERSHED

In November of 2017 the SWP project conducted a stakeholder assessment of key water security issues relevant to the Stung Chinit and Stung Sen watershed. Subsequently the SWP project has decided to focus only on the Stung Chinit. These key water issues and their impacts are outline in **Error! Reference source not found.**.

Table 5. Key water issues in the Stung Chinit watershed according to stakeholder assessment.

Key water issues	Impact
Flood and Flash flood due to too much rain from July – Oct	Damage local infrastructures (road, wells, and other local irrigation system)
	Damage agriculture production and others crops
	Poor livelihood
	Increased migration because of water scarcity for agricultural development
Draught from December to June during dry season	Lack of clean water for drinking and family consumption
	Damage agriculture production and others crops
	Poor livelihood
	Increased migration because of water scarcity for agricultural development
Lack of clean water from Jan – May	Increased waterborne diseases
	Poor livelihood
Decline fishery resources in the river	Poor livelihood
	Increased migration because of water scarcity for agricultural development
Water pollution due to the pesticide and fertilizer using in agriculture	Lack of clean water for drinking and family consumption
	Poor livelihood
Deforestation and destruction of biodiversity	Lack of clean water for drinking and family consumption
	Damage agriculture production and others crops
	Poor livelihood
	Increased migration because of water scarcity for agricultural development
River bank degradation and erosion	Damage local infrastructures (road, wells, and other local irrigation system)
Sedimentation load into the river	Damage local infrastructures (road, wells, and other local irrigation system)

Increased both liquid and hard wastes	Poorer health and Increased waterborne diseases
Decreased of surface and groundwater resources	Damage agriculture production and others crops
	Poor livelihood

It was clear from the workshops that the major concerns were floods, droughts, deforestation, water pollution and poor infrastructure. A number of solutions were identified by the local stakeholders. In summary, these solutions were:

- **Improve infrastructure** – build water purification station, rehabilitate the existing irrigation systems and cannels, digging community ponds and wells, building local dams or ponds to store water in wet season.
- **Improve information and monitoring** – develop community preparedness plan, strengthening disaster respond mechanism at commune, district and provincial level; provide technical knowledge and build up capacity to farmers such as farming techniques to improve their crop's productivity; provide integrated farming approaches and methods to the farmers; awareness raising and strengthening people's practices in sanitation and hygiene; capacity building and awareness raising on water security related and the impacts to the local community
- **Restore the environment** – reforestation, forest protection (conservation and stop Illegal logging in upstream of the watershed)
- **Plan and adapt for climate change** – select diversify crops that relevant to the current climate condition and adaptation

APPENDIX B – DESCRIPTION OF HOW ANNUAL AGRICULTURAL WATER DEMAND WAS CALCUALTED

- The uplands are areas are not part of the Tonle Sap flood-pulse cycle, and therefore they do not benefit from the rich sallow aquifers and natural inundation of the Tonle Sap. Therefore:
    - In the wet season we estimate that around 5,874m3 ha-1 y-1 is needed (Wokker et al. 2012). In the wet season natural ponding and rain supplement the rest of the crop needs.
    - In the dry season we estimate 10,312m3 ha-1 y-1 is needed (Wokker et al. 2012). This increased amount of irrigation is because there is very limited natural ponding or rainfall.
- In the lowlands where the flood-pulse cycle inundates much of the land it is assumed that even areas classified as "non-irrigated" do use some supplementary irrigation systems. Wokker et al. (2012) reported that about 46% of farmers surveyed used some form of small-scale irrigation during the wet season. Therefore:
    - In the wet season we estimate 5,874m3 ha-1 y-1 for "irrigated" land, and for 46% of the "non-irrigated" land we take a low estimate of 1,500 m3 ha-1 y-1 (1,500m3 y-1 was reported by Mainuddin and Kirby (2009))
    - In the dry season we estimate 10,312m3 ha-1 y-1 is needed (Wokker et al. 2012).