ADB

Technical Assistance Consultant's Report

Project No. 42384-012
July 2018

Knowledge and Innovation Support for ADB's Water Financing Program

Viet Nam: Water Accounting in 36 River Basins

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For Asian Development Bank

Asian Development Bank

Water Accounting Plus in 16 Vietnamese Basins

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July 2018

Contents

List of Figures

List of Tables

1 Introduction

As part of a pilot study for the ADB by IHE-Delft, the Water Accounting Plus (WA+) framework has been applied to the 16 largest basins in Vietnam for a period of 12 years (from 2003 until 2014) on a monthly basis, please see Figure 1 for an overview of the 16 basins. Also note that the study only considered the Vietnamese parts of the basins.

This framework mainly consists of 6 accounting sheets that cover different parts a basins hydrology. Sheet 1 is called the "Resource Base" and focuses mainly on the basins' water balance. The second sheet is the "Evapotranspiration" sheet, which scrutinizes the second larges flux in the hydrological cycle, the evaporation and transpiration of water into the atmosphere. The third sheet, with the name "Agricultural Services", displays the water consumption, crop yield and water productivity of agricultural areas. Sheet 4 focuses on the so called "blue water" or water withdrawals from either ground or surface waters (opposed to "green water" from precipitation). Finally, sheet 5 and 6 are the surface- and groundwater sheets respectively, assessing and quantifying different fluxes related to these stocks.

The sheets for the 16 Vietnamese basins can be found on the wateraccounting.org website, along with more general information on definitions and explanations of the values displayed on the sheets.

This report aims to give an overview of the work done and data processed while producing the accounting sheets, besides presenting and discussing some of the values found on the sheets themselves.

2 Data

2.1 Landuse and landcover

An important aspect of WA+ is the displaying of different fluxes, like Evapotranspiration (ET) or transpiration (T) for example, per landuse class. Furthermore, crop yields are determined based on maps indicating the locations where certain crops are grown.

Although the landuse and landcover (LULC) map used has many different classes, sometimes a different kind of grouping is more useful. That's why the classes are also grouped into 4 categories, i.e. Utilized, Protected, Modified and Managed landuses. Utilized landuses are landscapes that still strongly resemble their pristine state, but are nevertheless used by humans in different ways (think for example about a grazing by a herd of sheep in a savanna like environment). Protected landuses are landclasses that are in their pristine shape and are protected from any human intervention. Modified landuse classes are types of landuse in which people have significantly altered the environment (think about a large metropolitan

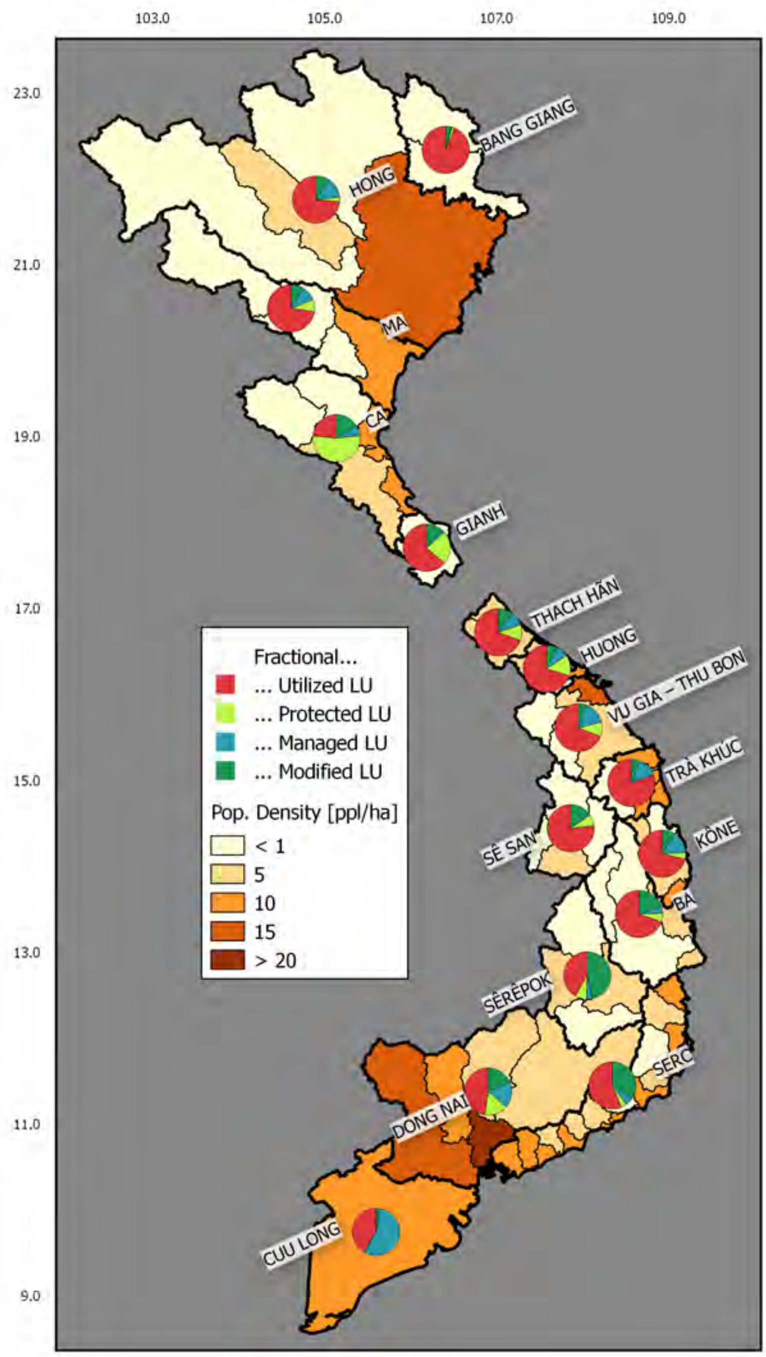

Figure 1: Overview of the 16 Vietnamese Basins.

area for example). And finally, Managed landuses are contain classes where the water is actively managed by humans (for example an irrigation system).

Figure 1, shows the relative landcover of each of these four classes in the pie charts over the 16 basins. The Hong (or Red River) basin for example consists of nearly 75% of Utilized landuse, while the Mekong river mouth (Cuu Long) has a significant amount Managed water practices.

The used landuse map was created by combining several global landuse products, including maps indicating the likelyhood of the occurence of irrigated versus rainfed agriculture, maps displaying the dominant regional croptypes, maps indicating protected nature reserves and population density maps. The orange shades in Figure 1 displays the population density per subbasin.

2.2 Precipitation

The largest flux in the global hydrological cycle is precipitation (P), making it one of the most important inputs into the WA+ framework. The precipitation product used in this study is called CHIRPS. Figure 2 shows several statistics regarding precipitation.

First of all, the dots on the map display the location of meteorological stations, while their color indicate the Nash Sutcliffe coefficient, which is a measure for how well the station data corresponds to the remote sensing product. Green indicates a good fit, while white means a bad fit. In most parts of Vietnam the product shows good agreement with the in-situ measurements, which is why the CHIRPS product has been used as it is, without any correction.

The blue shades in Figure 2 indicate the average yearly rainfall rate per subbasin. It is clearly visible here that the most rainfall falls in the middle of Vietnam, with a gradual decline in rainfall rate in both north and southern direction.

The bars in Figure 2 indicate the distribution of the rainfall over the year. They show that the rainfall is very unevenly distributed over the year. In the beginning and at the end of the year, the rainfall is many areas is near zero, while the rainfall peaks in most places around September. Although in the north and the south the peak occurs slightly before the peak of the rainy season in the middle of Vietnam.

The total yearly rainfall rates in the south of Vietnam vary from around 1900 mm/year in a dry year up to 2800 mm/year in a wet year, while the north has both a lower yearly rainfall rate and a smaller variation between dry and wet years, with 1400 mm/year for a dry year and 1900 mm/year in a wet year, see Figure 3. Chapter 3 looks closer into some of the information found on the water accounting sheets for two basins, focusing on a dry, average and wet year. For the Hong basin (in Northern Vietnam), these years are 2009, 2007 and

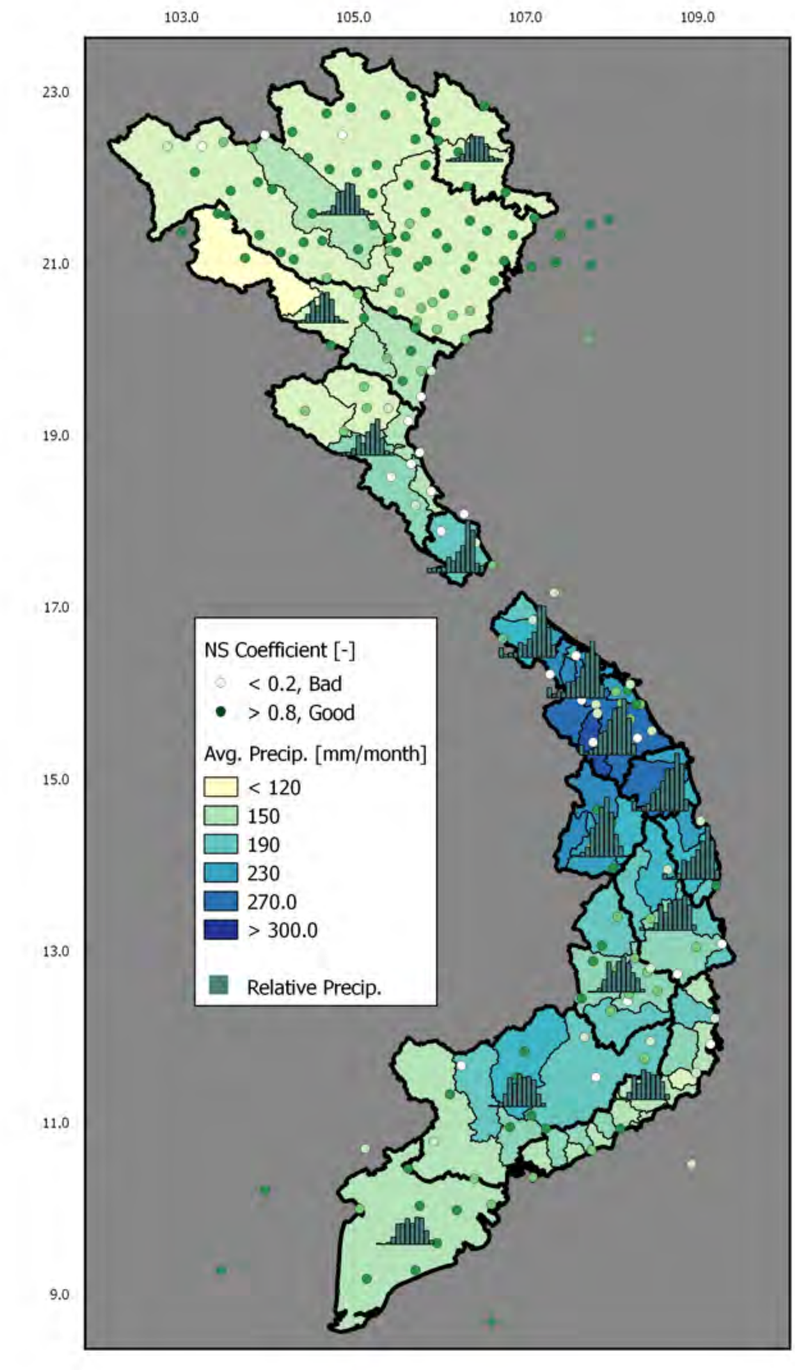

Figure 2: The average monthly rainfall per subbasin (shade), the relative rainfall per month (bars) and the Nash-Sutcliffe coefficient with station data (dots).

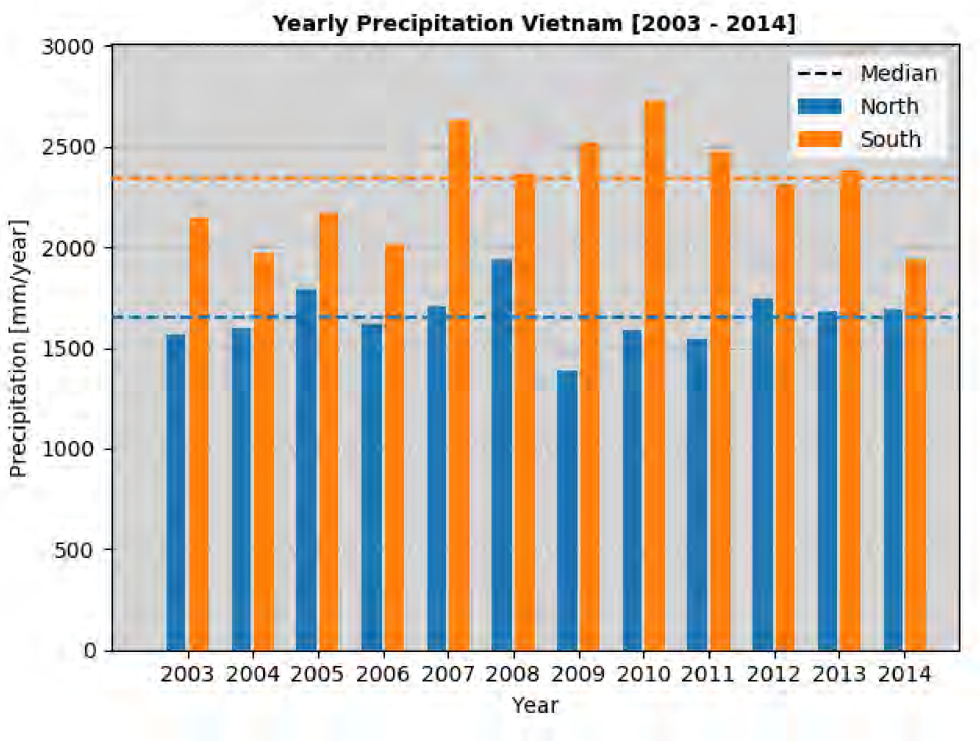

Figure 3: The yearly total rainfall in Northern and Southern Vietnam between 2003 and 2014.

2008 respectively. For the southern basin of Srepok the dry, average and wet years of 2006, 2008 and 2007 have been chosen.

2.3 Evapotranspiration

After precipitation, evapotranspiration is the largest flux in the global water cycle. Since it is a lot more complicated to measure ET in-situ and measurements are not as widely availble as for precipitation, validation of ET data is difficult.

In order to limit uncertainties in the ET dataset, 6 different ET products were used in the generation of the WA+ sheets. The MOD16, ALEXI, GLEAM), SEBS, SSEBop and CMRSET datasets were first compared to eachother. In areas (i.e. pixels) where one or several of these products deviated significantly from the others, those deviating products were exluded. After this removal of the outliers at every pixel, the average value of the remaining products was used for calculations. By applying this method, inaccurasies in the ET data were limited as much as possible. The resulting product is hereafter reffered to as ETensemble.

The average yearly ET in Vietnam ranges from around 80 mm/month in the North up to

120 mm/month in the southern parts, as can be seen in Figure 4.

This figure also displays the fractions of the different components, evaporation (E), interception (I) and transpiration (T), of which ET consists. These three terms have been determined using Leaf-Area-Index, Gross-Primary-Production and Rainfall data. After comparison of the three fluxes with another ET product (which is not part of the ETensemble and which delivers seperate products for E, T and I), Nash-Sutcliffe coefficients of around 0.7 were found.

In most of the vietnamese basins, transpiration makes up roughly one third to half of the evapotranspiration, while interception gives the smallest contribution.

2.4 Other

Besides the LULC map and the precipitation and evapotranspiration product, several other remote sensing products have been used in this study. The MODIS products for Leaf Area Index, Net Primary Production and Gross Primary production have been used in the calculation of several parameters, such as rainfall interception and Crop Yields. Besides these remote sensing products, several reanalysis products have been used to calculate reference evapotranspiration, which in its turn was used in the determination of the green and blue water consumption and in the WaterPix model that is discussed below. Table 1 gives an overview of the products used, their spatial and temporal resolutions and a link to website where more documentation can be found.

2.5 WaterPix

A pixel based vertical water balance model called WaterPix was used to derive extra information from the inputs specified in Table 1. WaterPix solves the water balance on a pixel scale by analysing precipitation, (reference) evapotranspiration, soil saturarion and leaf area index and by doing so, calculates the runoff, incremental runoff (due to water supply), changes in soil moisture storage, percolation and water supplies.

With these variables, we are able to calculate to complete water balance over time, and thus also the changes in basinwide storage changes. Figure 5 shows a comparison between the storage changes calculated by WaterPix / WA+ and GRACE, which is a satellite measuring changes in gravity (which has a strong correlation with the amount of water stored in an area).

First of all, the signs of the storage changes from GRACE and WA+ agree. For nearly all of the basins, the water storage in the basins has increased over the period from 2003 until 2014. Only for the basins of Dong Nai and Cuu Long (in the southern tip of Vietnam), the water storage has decreased with rates of 2.5 and 10.0 mm/year respectively, according to

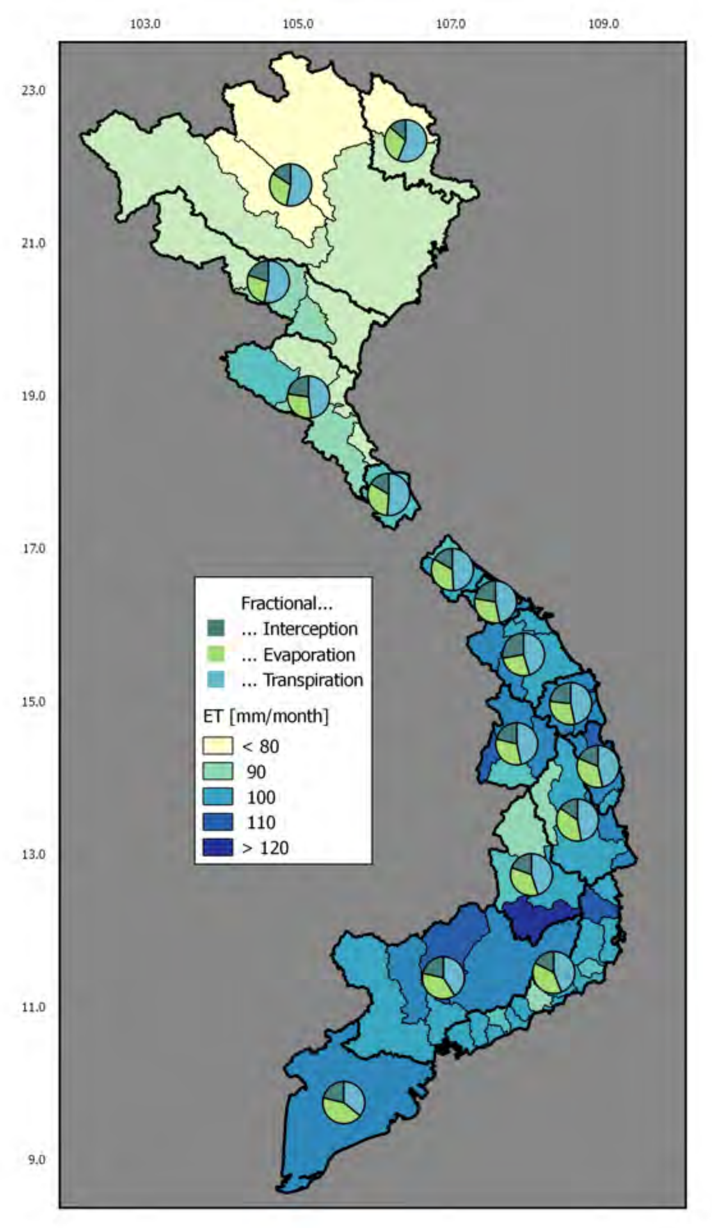

Figure 4: The average monthly evapotranspiration per subbasin (shade) and the relative contributions of Interception, Evaporation and Transpiration (circle).

Table 1: The products used for WA+ Vietnam.

Variable	Abbrev.	Product	Spatial Res.	Temp. Res.	Link
Precipitation	P	CHIRPS	0.05°	Daily	link
Evapotranspiration 1	ET	CMRSET	0.05°	Monthly	link
Evapotranspiration 2	ET	GLEAM	0.25°	Daily	link
Evapotranspiration 3	ET	MOD16	0.083°	8-Daily	link
Evapotranspiration 4	ET	SEBS	0.05°	Monthly	link
Evapotranspiration 5	ET	SSEBop	0.009°	Monthly	link
Evapotranspiration 6	ET	ALEXI	0.027°	Daily	link
Leaf Area Index	LAI	MOD15	∼ 500m	8-Daily	link
Upward Longwave Radiation	ULR	CFSR	∼ 38 km	3-Hourly	link
Downward Longwave Radiation	DLR	CFSR	∼ 38 km	3-Hourly	link
Downward Shortwave Radiation	DSR	CFSR	∼ 38 km	3-Hourly	link
Temperature	T	GLDAS	0.25°	3-Hourly	link
Humidity	H	GLDAS	0.25°	3-Hourly	link
Pressure	P	GLDAS	0.25°	3-Hourly	link
Wind speed	u	GLDAS	0.25°	3-Hourly	link
Elevation	DEM	HydroSHED	∼ 30m	N/A	link
Net Primary Production	NPP	MOD17A2/3	0.0083°	Yearly	link
Gross Primary Production	GPP	MOD17A3	0.05°	Monthly	link
Soil Moisture Content	SM	GLDAS	0.25°	3-Hourly	link

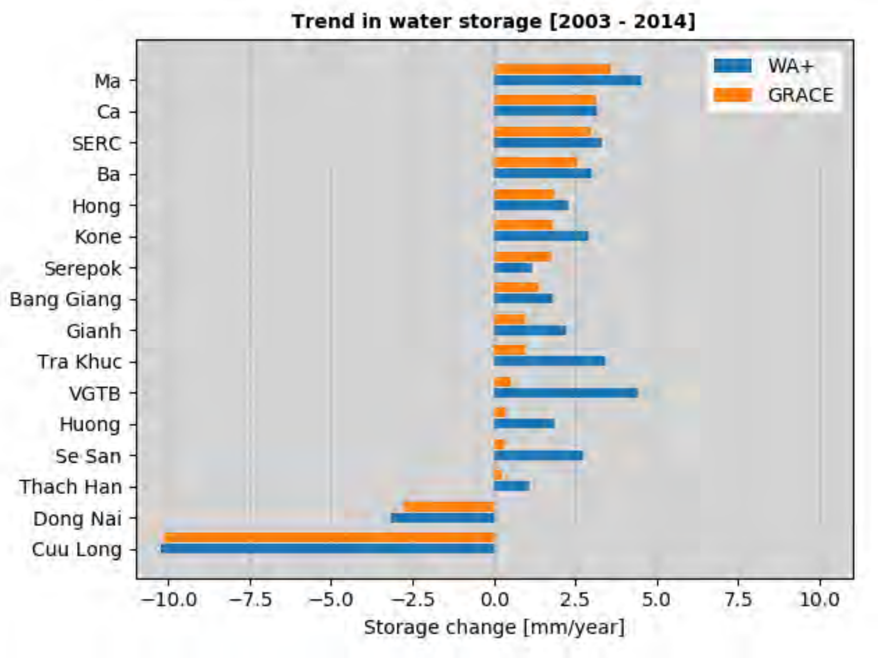

Figure 5: The trend in the water storage per basin as measured by GRACE and as calculated by WA+.

Table 2: The Srepok water balance terms for a dry, average and wet year.

Year	Precipitation	ET	Delta S	Qin	Qout	Qin	Qout
	mm/yr	mm/yr	mm/yr	mm/yr	mm/yr	m3/s	m3/s
2006	1715	1249	-180	0	646	0	339.11
2008	2082	1268	143	0	670	0	350.87
2007	2521	1207	30	0	1283	0	673.35

Table 3: Srepok evapotranspiration split into transpiration, evaporation and interception and into non-beneficial and beneficial evaporation for a dry, average and wet year.

Year	ET	E	T	I	Beneficial		Non Beneficial	
	mm/yr	mm/yr	mm/yr	mm/yr	mm/yr	% of ET	mm/yr	% of ET
2006	1249	410	625	213	648	51	601	48
2008	1265	456	572	236	599	47	665	52
2007	1207	401	527	278	550	45	656	54

both GRACE and this WA+ study.

The other basins, all exhibit an increase in water storage, up to almost 5 mm/year for Ma basin. For several basins in the middle of Vietnam (around the VGTB basin) the discrepansies between GRACE and wa+ storage changes are the largests. This is probable due to an over estimation of the runoff in WaterPix in this area.

3 A Closer Look

On the WA+ website, wateraccounting.org, sheets for 12 years for 16 Vietnamese basins can be found. The following section presents some of the values found on those sheets, focussing on the Srepok and Hong basins for three selected years; a dry, average and wet year (see Section 2.2 for details on how the years were selected)

3.1 Srepok

In Srepok basin, the yearly rainfall varies between 1715 and 2521 mm/year, while the evapotranspiration is fairly constant around 1250 mm/year. The outflow from the basin varies between 646 and 1283 mm/year. As a result, the storage change (Delta S) is negative in a dry year, requiring 180 mm in order to close the water balance of 2006. The next two year were a lot wetter however, with a total storage increase of 174 mm in 2007 and 2008, see Table 2. Considering a longer period, the wet years seem to be sufficient to compensate for the negative storage changes in dry years, since the storage has increased with around 24

Table 4: Srepoks land and water productivities for different crops in a dry, average and wet year.

			Land Productivity		Water Productivity	
Year	**Crop Type**	**Crop Subclass**	**Rainfed**	**Irrigated**	**Rainfed**	**Irrigated**
			kg/ha/year	kg/ha/year	kg/m3	kg/m3
2006	Other crops		51886		2.01	
	Beverage crops		3277	6356	0.15	0.29
	Non-cereals	Sugar crops		71355		3.17
	Cereals		3385	3901	0.58	0.73
	Fruit & vegetables	Vegetables & melons	30668		1.27	
	Fruit & vegetables	Fruits & nuts	458		0.07	
2008	Other crops		51292		1.95	
	Beverage crops		3360	6460	0.14	0.28
	Non-cereals	Sugar crops		73016		3.03
	Cereals		3373	3573	0.55	0.64
	Fruit & vegetables	Vegetables & melons	29508		1.13	
	Fruit & vegetables	Fruits & nuts	410		0.06	
2007	Other crops		52705		2.03	
	Beverage crops		3394	6537	0.15	0.29
	Non-cereals	Sugar crops		69589		2.99
	Cereals		3196	3566	0.57	0.67
	Fruit & vegetables	Vegetables & melons	29956		1.19	
	Fruit & vegetables	Fruits & nuts	425		0.06	

mm over the period from 2003 to 2014, see Figure 5.

Looking closer at the evapotranspiration (see Table 3, we see that the soil evaporation stays fairly constant over the three different years, while the transpiration and interception respectively decrease and increase as the years wetness increases. Translating this into beneficial and non-beneficial water-use, it is shown that in a dry year, 51% of all ET is used beneficially. In a wet year this percentage drops to 45 %. Indicating that in a dry year, the water-use is 6 % more efficient at utilizing water for the intended purposes based on the landuse.

Yields and water productivities have been determined for different crops in the Srepok basin, Table 4 shows these Yields (or land productivity) and water productivites for the selected dry, average and wet year. Cereals, consisting mostly of rainfed and irrigated rice, give a yield of around 3300 kg/ha/yr and 3600 kg/ha/yr, with corresponding water productivities of 0.57 and 0.70, i.e. irrigated rice is produced with a better water productivity than rainfed rice.

The water supplied to for example irrigated fields is shown in the first part of Table 5. A clear trend is visible over the three years, with a decreasing water withdrawal as more rainfall

Table 5: Blue water withdrawals and water consumptions for the Srepok basin in a dry, average and wet year.

Year				2006	2008	2007
Manmade	**Gross Withdrawal**		mm/yr	858.15	650.08	458.11
	Consumed	**ETb**	mm/yr	453.83	351.8	241.67
		Other	mm/yr	132.23	94.13	85.62
	Non Consumed		mm/yr	272.09	204.15	130.82
	ETb/Supply		%	52.88	54.12	52.75
Natural	**Gross Withdrawal**		mm/yr	1038.3	755.43	687.31
	Consumed	**ETb**	mm/yr	526.66	399.36	343.45
	Non Consumed		mm/yr	511.63	356.07	343.86

Table 6: The Hong water balance terms for a dry, average and wet year.

Year	P	ET	Delta S	Qin	Qout	Qin	Qout
	mm/yr	mm/yr	mm/yr	mm/yr	mm/yr	m3/s	m3/s
2009	1412	1036	-46	342	765	968.32	2163.94
2007	1698	984	-3	421	1139	1192.89	3221.2
2008	1977	1020	20	514	1450	1449.48	4090.26

is available, consequently, the (non-) consumed water also decreases, resulting in a fairly constant ETb/Supply ratio over the three years of around 53 %. Surprisingly, the natural water withdrawals are higher than the manmade withdrawals in all three years. Meaning that natural landuse classes (such as forests) consume significant amounts of water even when few rainfall is available, probably from groundwater aquifers.

3.2 Hong

The inter-yearly variability of rainfall in the Hong basin, ranges from 1412 to 1977 mm/year, yearly evapotranspiration rates vary between 984 and 1036 mm/year. The yearly discharge from the Hong river was 2163 m^3/s in 2009, which was a dry year, and 4090 m^3/s in the relatively wet year of 2008. In the 2009, 46 mm of water was required to close the water

Table 7: Summary of Sheet 2 for the Hong for a dry, average and wet year.

Year	ET	E	T	I	Beneficial		Non Beneficial	
	mm/yr	mm/yr	mm/yr	mm/yr	mm/yr	% of ET	mm/yr	% of ET
2009	1024	308	578	136	583	57	440	42
2007	973	260	548	165	552	56	421	43
2008	1008	287	553	167	557	55	450	44

Table 8: Land and Water productivities in the Hong basin for a dry, average and wet year.

			Land Productivity		Water Productivity	
Year	**Crop Type**	**Crop Subclass**	**Rainfed**	**Irrigated**	**Rainfed**	**Irrigated**
			kg/ha/year	kg/ha/year	kg/m3	kg/m3
2009	Other crops		10524		2.69	
	Beverage crops		11234		0.56	
	Fruit & vegetables	Fruits & nuts		1573		0.09
	Cereals		5144	3588	0.89	0.72
	Non-cereals	Root/tuber crops	46524		10.24	
	Non-cereals	Sugar crops	17641	17641	3.8	3.8
2007	Other crops		11025		2.96	
	Beverage crops		12022		0.6	
	Fruit & vegetables	Fruits & nuts		1659		0.1
	Cereals		5050	3764	0.95	0.82
	Non-cereals	Root/tuber crops	47570		10.92	
	Non-cereals	Sugar crops	17737	17737	4.16	4.16
2008	Other crops		10701		2.7	
	Beverage crops		11834		0.58	
	Fruit & vegetables	Fruits & nuts		1642		0.09
	Cereals		4943	3023	0.88	0.68
	Non-cereals	Root/tuber crops	46221		10.3	
	Non-cereals	Sugar crops	15748	15748	3.69	3.69

balance, while in 2008 there was a surplus of 20 mm to refill aquifers, see Table 6.

Compared to Srepok, the evaporation and interception terms are more constant over the dry, average and wet years. Also the percentage of beneficially used evapotranspiration is higher with an average of 56 %. I.e., more about 56 % water consumption is beneficial for the current landuse. For example, for an agricultural area, transpiration is considered to be beneficial (since it helps plants grow), while soil evaporation is non-beneficial, also see Table 7.

Similar to Table 4, Table 8 shows land and water productivities for the Hong basin. The rice yields in the Hong basin are very similar to those in the Srepok basin, with average irrigated rice yields across the years of around 3500 kg/ha/yr. In this case however, a bigger difference is seen between the dry, average and wet years. The average years has the highest water productivity for rice (0.82). The low amount of rain in 2008 seems to have had a significant impact on the production of rice, with a drop in the yield to 3023 kg/ha/year.

The manmade water withdrawals in the Hong basin (see Table 9 vary significantly over the years, although unsurprisingly the withdrawals are highest in the dry year of 2009. Interestingly, the water withdrawals in the wet year of 2008 exceeded those of 2007 with 65 mm.

Table 9: Blue water withdrawals and water consumptions for the Hong basin in a dry, average and wet year.

Year				2009	2007	2008
Manmade	**Withdrawal**		mm/yr	654.22	358.13	423.61
	Consumed	**ETb**	mm/yr	288.62	115.51	230.34
		Other	mm/yr	248.91	173.89	135.63
	Non Consumed		mm/yr	116.69	68.73	57.64
	ETb/Supply		%	44.12	32.25	54.38
Natural	**Withdrawal**		mm/yr	695.51	86.34	412.4
	Consumed	**ETb**	mm/yr	329.8	41.74	217.17
	Non Consumed		mm/yr	365.71	44.6	195.23

The consumptive fractions of the water withdrawals in the Hon basin are lower than those in the Srepok basin, meaning that less of the withdrawn water is actually consumed. There is also a stronger variation of this fraction over the years. In the average year of 2007 only 32 % of the withdrawn water is actually used. The natural water withdrawals are lower than the manmade withdrawals (opposed to the situation in Srepok), indicating that the Hong basin is a more significantly managed basin.

4 Conclusion

The water account for 16 Vietnamese basins for 12 years have been calculated and uploaded to the wateraccounting.org website on a monthly basis. Giving an insight into the basins water balances of the years, the amounts of managed and manageable water and quantifying the utilizable and non-recoverable flows (Sheet 1).

The Evapotranspiration in the basins has been scrutinized and percentages of beneficial ET have been determined, giving an insight into how much water is actually consumed for its intended purposes (Sheet 2). Additionally, the yield production and water consumption of agricultural areas has been investigated, indicating how efficient farmers are using their water resources (Sheet 3).

Water withdrawals have been quantified, allowing managers to see how much water different water sectors are withdrawing and consuming. Furthermore, the return flows of these withdrawals to either ground or surface water were determined (Sheet 4).

The surfacewater flows have been determined on a subbasin level, allowing managers to see where most of the withdrawals are actually happening and where most of a rivers flows is generated (Sheet 5). In a similar fashion, the groundwater flows have been determined per landuse class, giving insights into which landuse classes are important for a sustainable groundwater aquifer (Sheet 6).