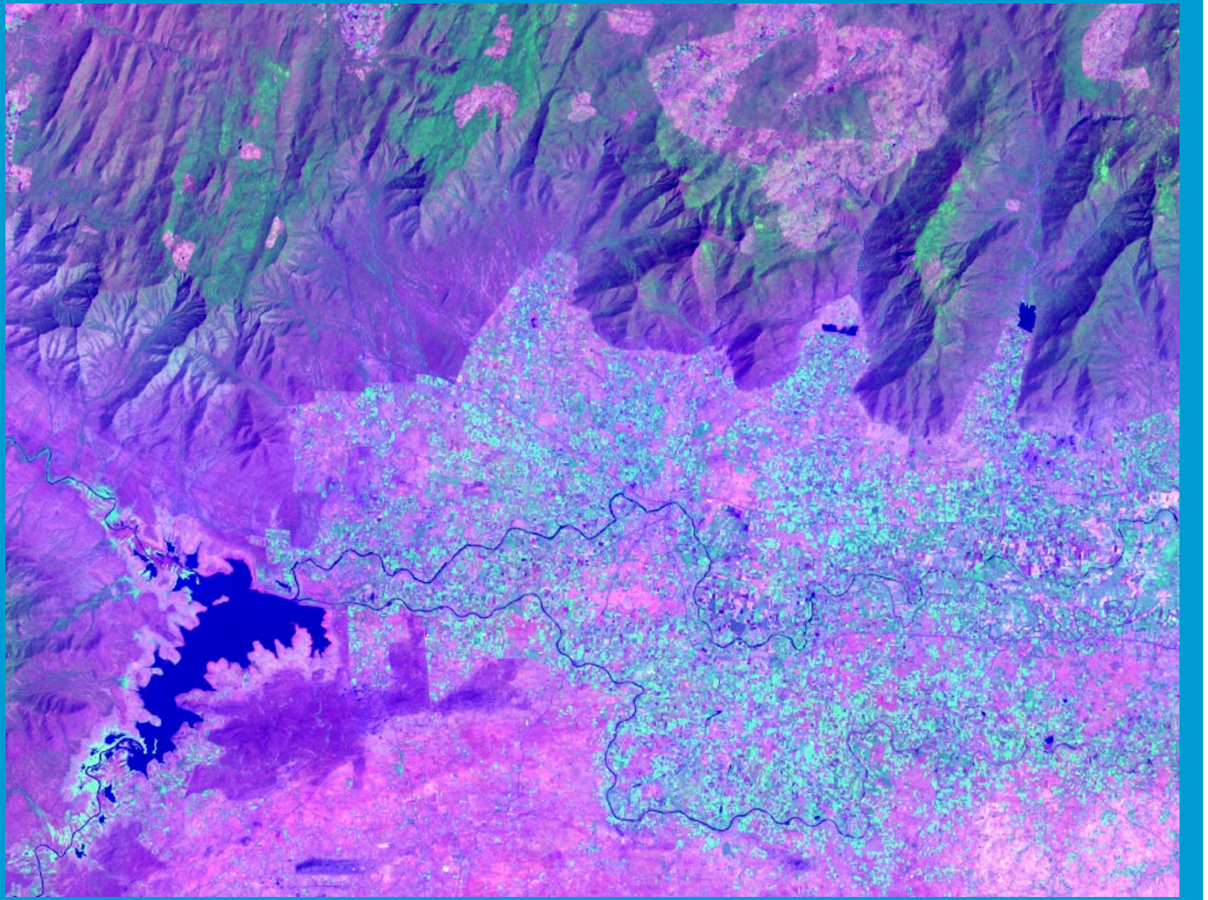
“Improved Water Allocation for Agriculture in the Arab Region”

Technical meeting

26-27/09/2022

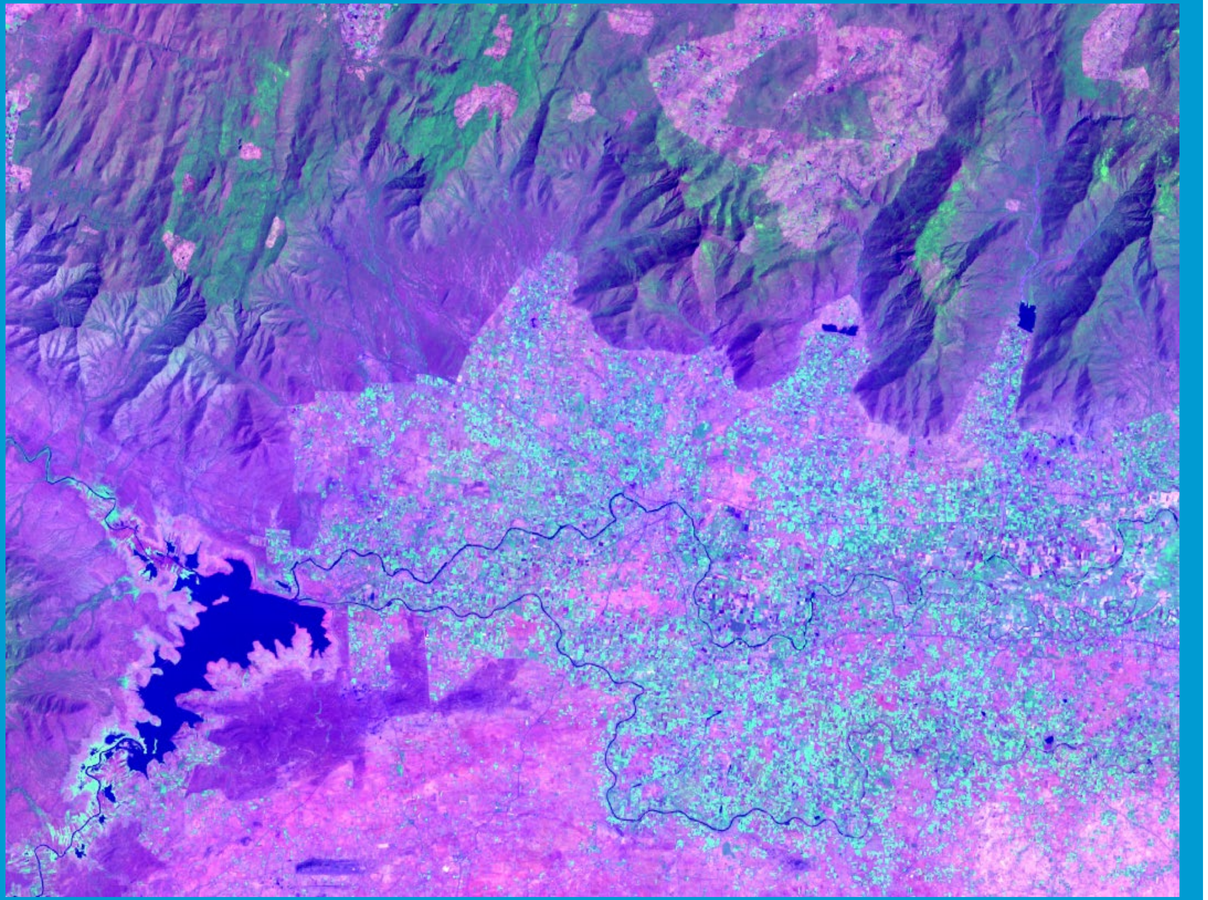
Water Accounting



Dr. Salvadore Elga

We cannot plan and manage

what we do not measure



Session 1: Water Accounting Principles and examples from past applications

What is Water Accounting?

What can I do with Water Accounting?

How can WA+ support IWRM?

What types of Water Accounting Systems exist?

The WA+ is a WA system based on Remote Sensing data

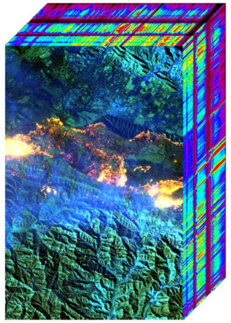
Examples

Data alone is not sufficient for effectively manage water resources

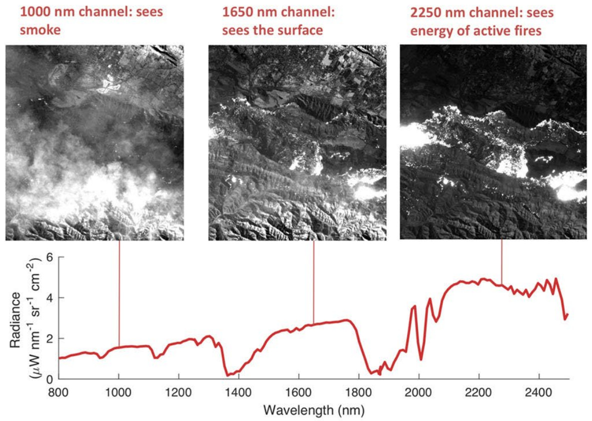
Have decision makers access to the necessary data?

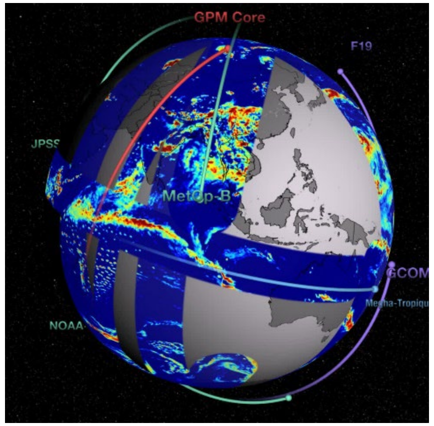
Can decision makers work with these datasets?

Are these datasets alone sufficient for making water allocation plans?



False color image from AVIRIS data cube acquired on Dec 5 2017. The front face shows: (red) active fires at 2250 nm; (green) surface at 1650 nm; and (blue) smoke at 1000 nm.





What is water accounting?

Water accounting is a tool to support decision making

Name comes from financial accounting

Identification and tracking of sources of revenue and expenses

> *"Water Accounting makes sense of how much water is available and how to use it"*
>
> *"Water Accounting is the systematic **quantitative assessment** of the **status** and **trends** in water supply, demand, distribution and accessibility"*

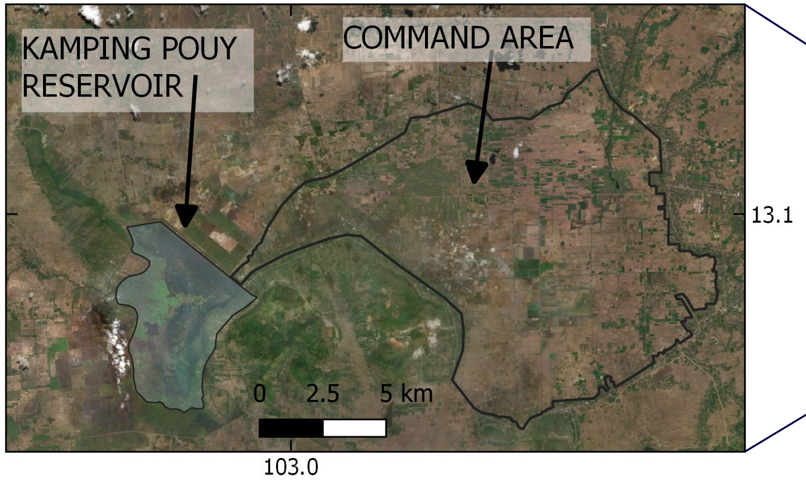
Definitions from: FAO, Water Accounting for Water Governance and Sustainable Development

Reporting system to translate data to useful information

What is Water Accounting

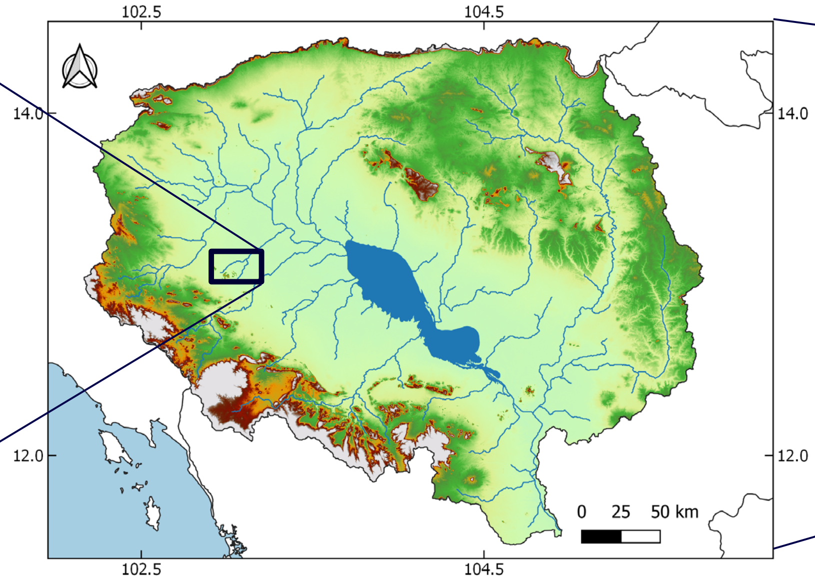
Water Accounting analyses water resources and their use in a specific geographical domain

Irrigation Scheme Level



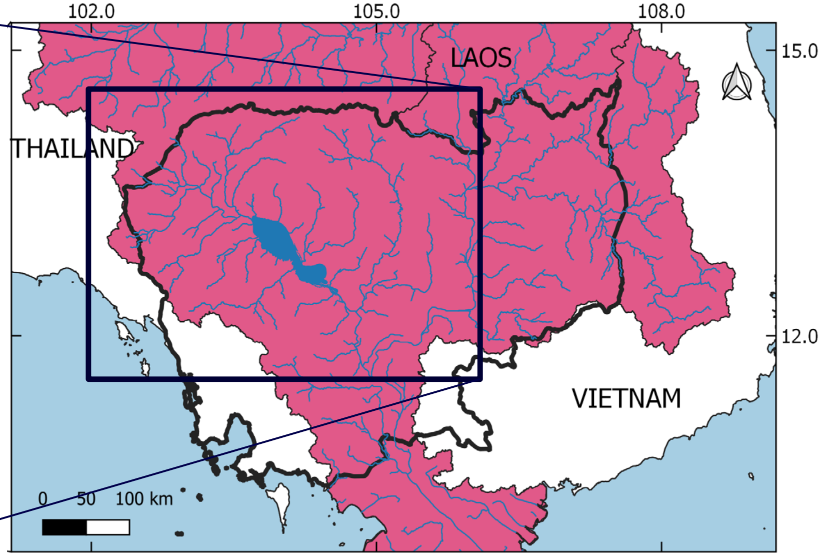
Bing VirtualEarth and data from the Irrigated Agriculture Improvement Project (Cambodia)

Basin Scale



Tonle Sap basin elevation, HydroSHED data

Country Scale



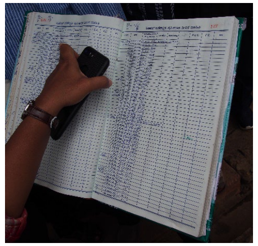
Cambodia and the Mekong river system

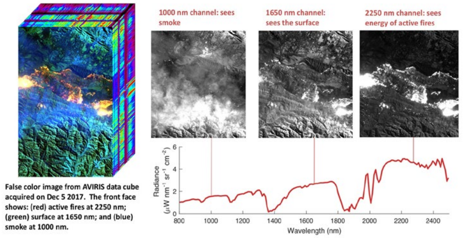
Water Accounting uses a three-step approach

Data collection
gaps identification

Data analysis
from data to information

Communication
making information available to stakholders





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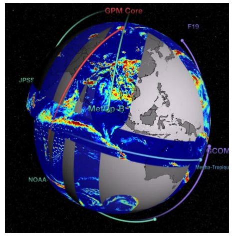
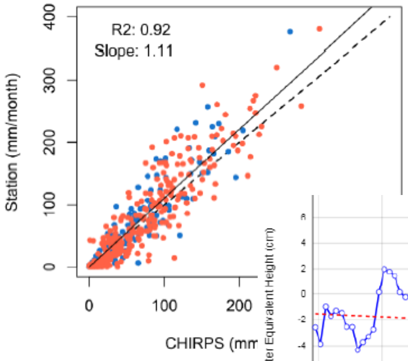
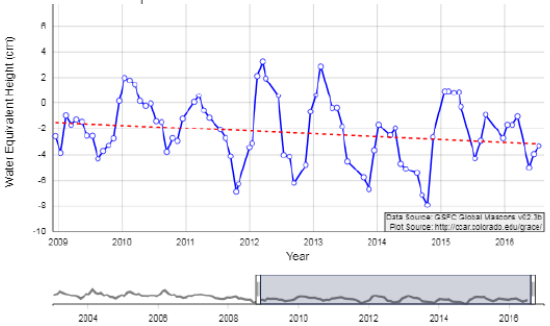
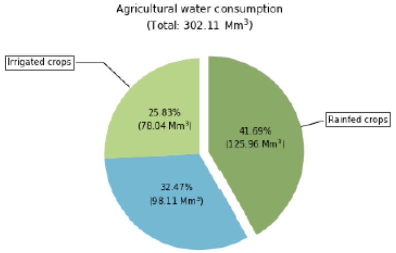






Crop												Agricultural water consumption	302.11
Cereals	Non-cereals				Fruit & vegetables			Oil-seeds	Feed crops	Beverage crops	Other crops		
15.28	3.64	17.54	-	-	5.85	55.49	-	28.16	-	-	-	ET rainfed	125.96
	Root / tuber crops	Leguminous crops	Sugar crops	Merged	Vegetables & melons	Fruits & nuts	Merged						
16.29	8.18	13.74	-	-	9.82	28.55	-	1.46	-	-	-	ET from rainfall irrigated	78.04
23.22	11.14	19.94	-	-	14.68	28.27	-	0.87	-	-	-	Incremental ET irrigated	98.11
39.51	19.32	33.67	-	-	24.50	56.82	-	2.33	-	-	-	Total ET irrigated	176.15



Session 1: Water Accounting Principles and examples from past applications

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Examples

Water Accounting: A simple idea to track a complex system

How much is the water use?

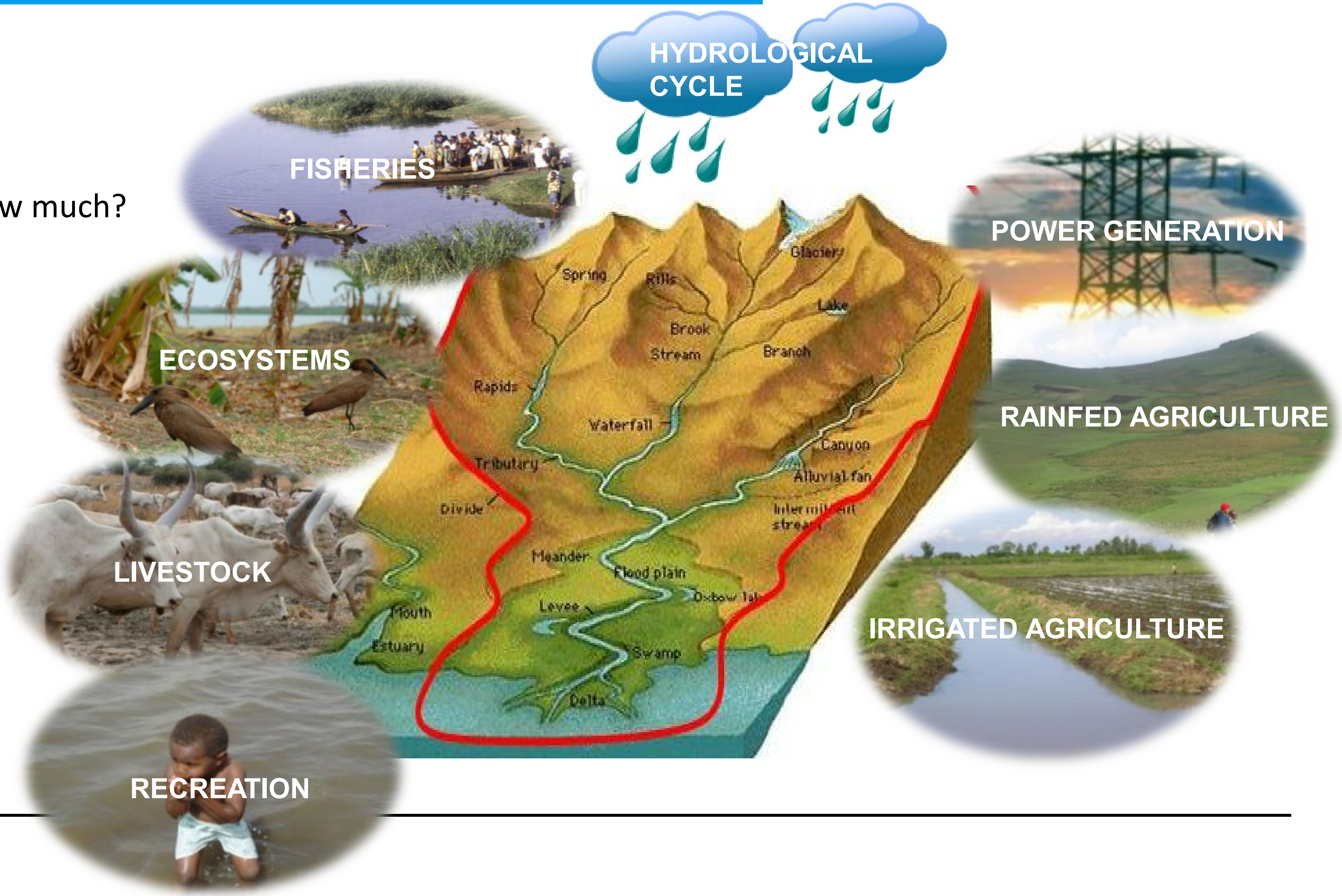
Which sector is consuming how much?

Demand vs. Supply

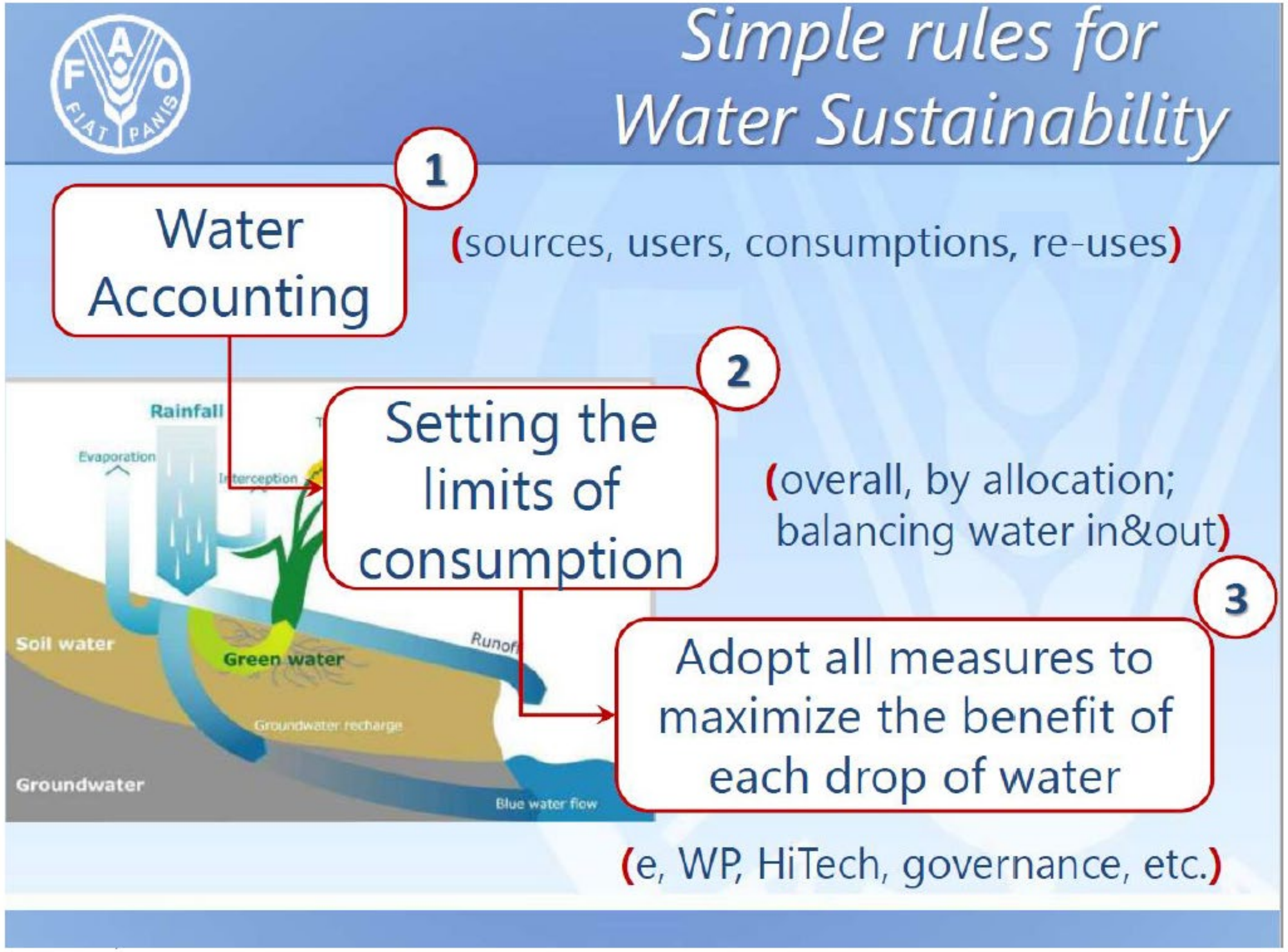
Availability driven by the hydrological cycle and infrastructure

Consumptive

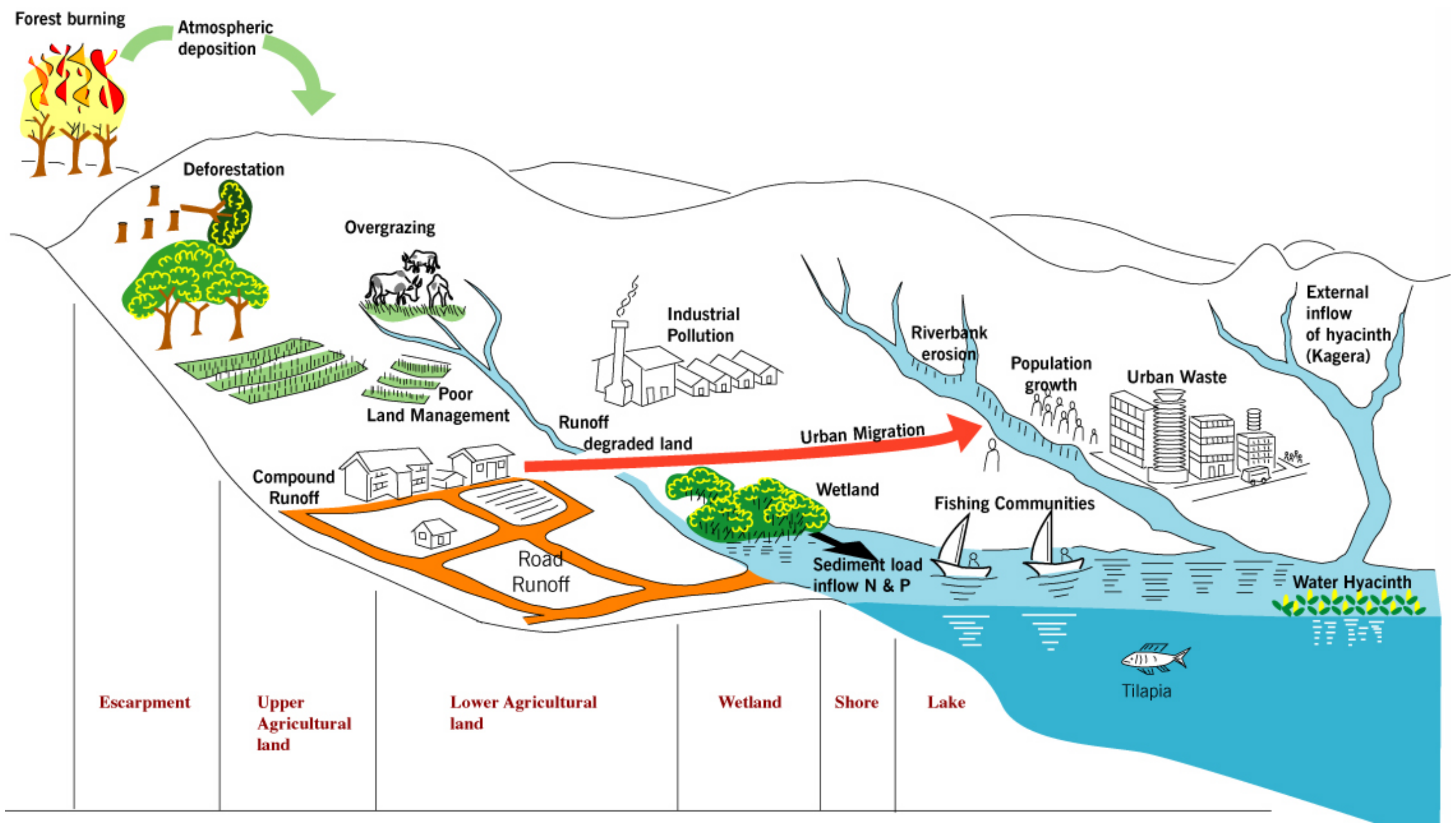
Non-consumptive use



Water Accounting: A simple idea to track a complex system



Integrated Water Resources Management



All water flows are embedded in drainage basins

creating interdependencies between uses and users

IWRM definition

Global water partnership (2000) defines IWRM –

"IWRM is a process, which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystem."

IWRM

- Water Resource Management of a river basin requires monitoring
  - water availability and
  - water demand

- To monitor water availability and demand:
  - Accurate identification and delineation of catchment and river channels
  - Characteristics of the basin – soil and vegetation, lakes and reservoirs, aquifer/groundwater storage
  - domestic, agricultural, and industrial within the basin

- Organized data and information at river basin level are key factor in order to implement Integrated Water Resource Management

Water Accounting: A multi-stakeholders platform

Water managers

Farmers

Irrigation specialists

Mayors

Lawyers

Energy utilities

Environmentalists

Industry representatives

Data Democracy

Standardized Framework

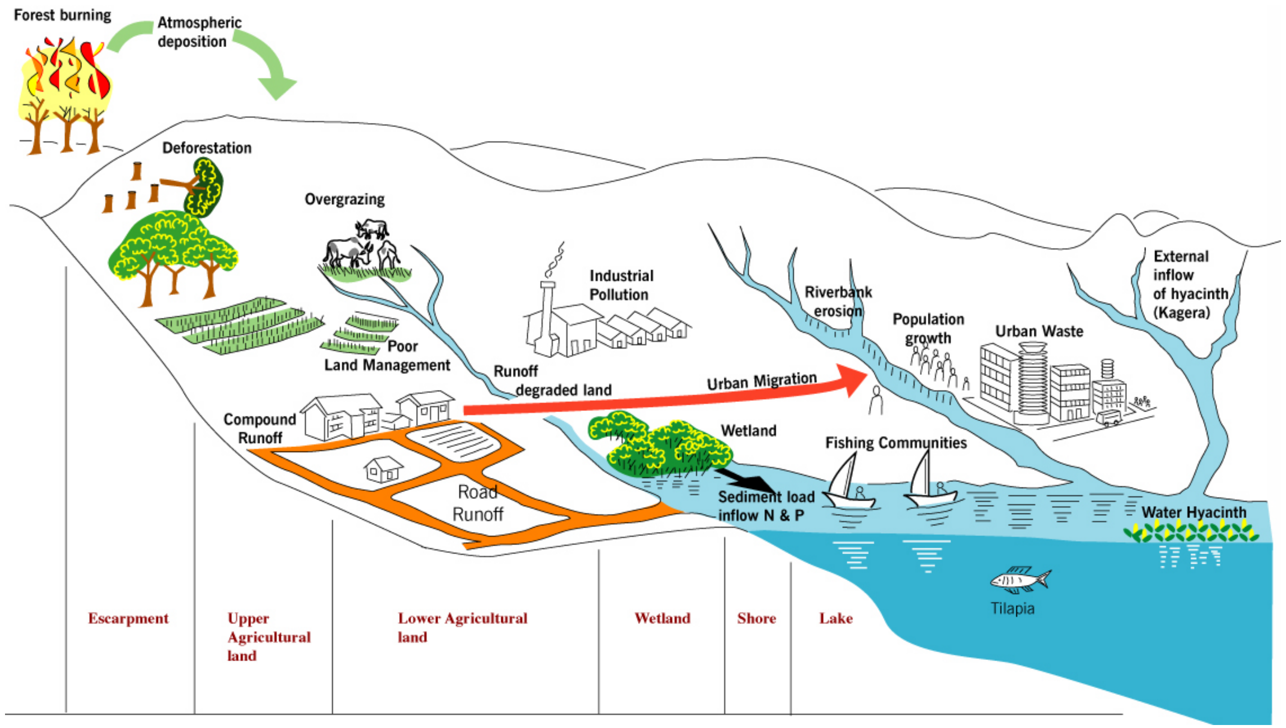
River basin reports

Loucks, Daniel, P.; van Beek, Elco. Chapter 11 Water Resources Systems Planning and Management: An introduction to Methods, Models and Applications (https://ecommons.cornell.edu/handle/1813/2997)

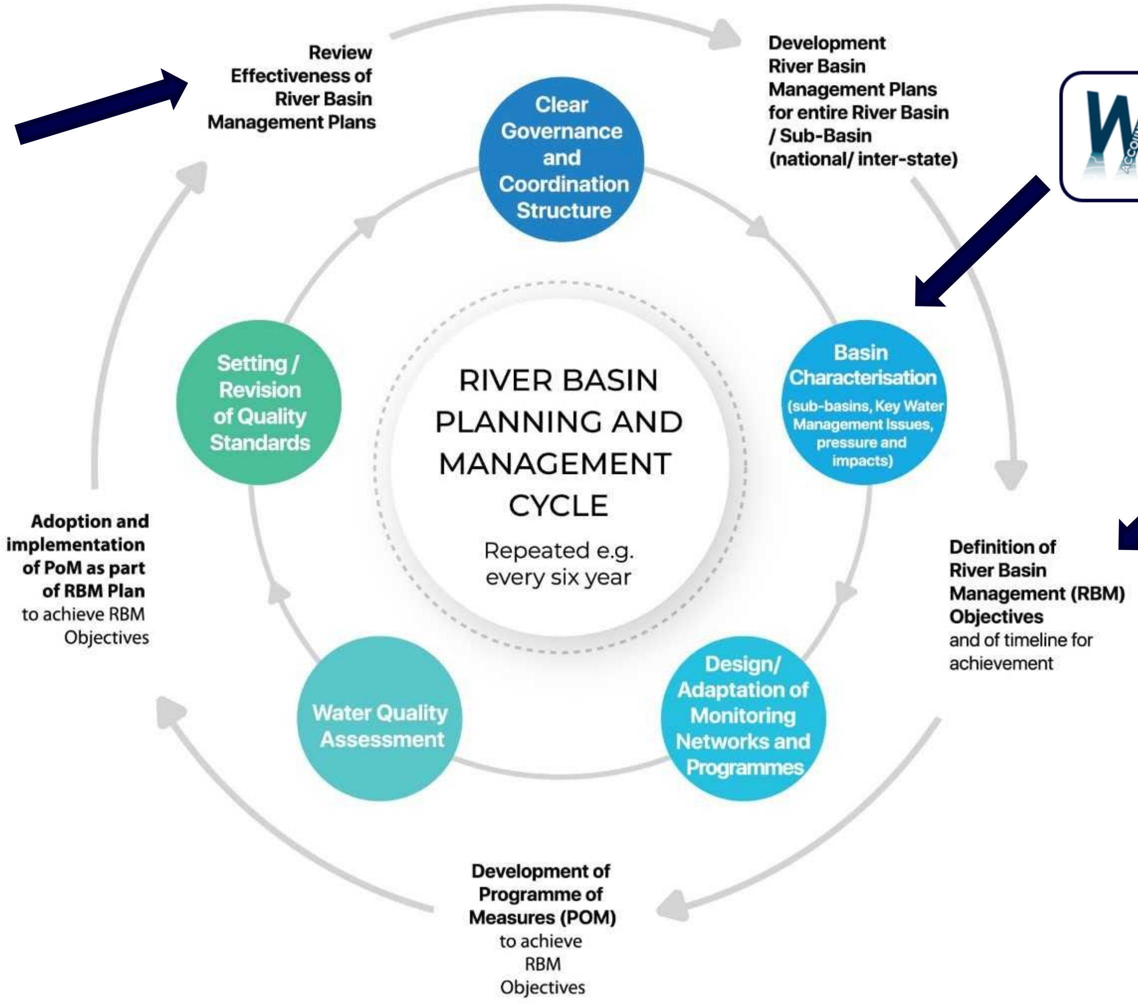
Data requirements

- To manage water resources you need to know
  - How much water is available
  - How much is being used and by which sector
  - Where is the water used
  - How efficient is water being used
  - …

Requiring spatial disaggregated data on water availability and utilisation



Water Accounting is a tool for long-term planning



Source: Tapi River Basin Management Plan

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Examples

Main Differences between WA frameworks

Scale of application

Type of data used

Overall approach: what are they tracking and how

Main Categories of WA frameworks

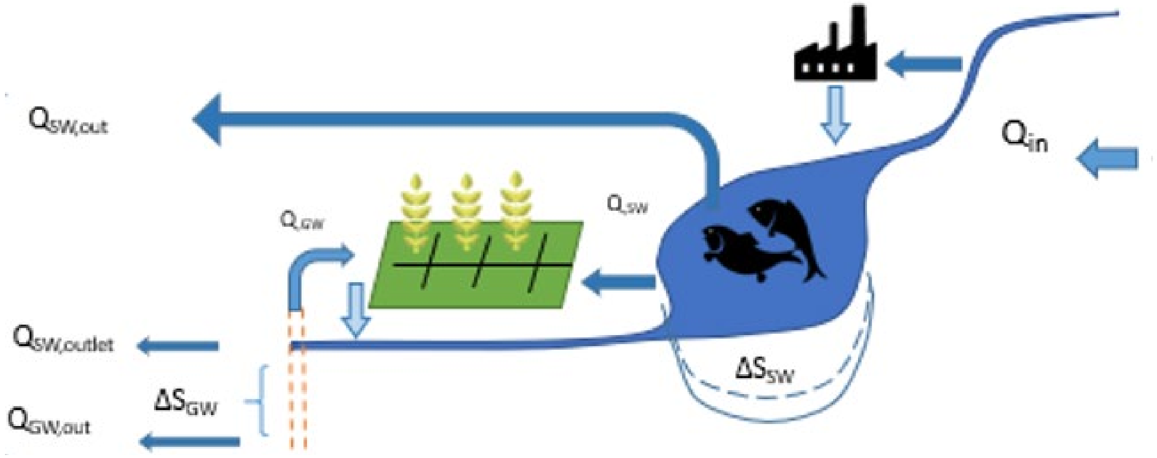
Two main categories:

FLOW ACCOUNTING: tracking and accounting actual flows, deliveries, and abstractions

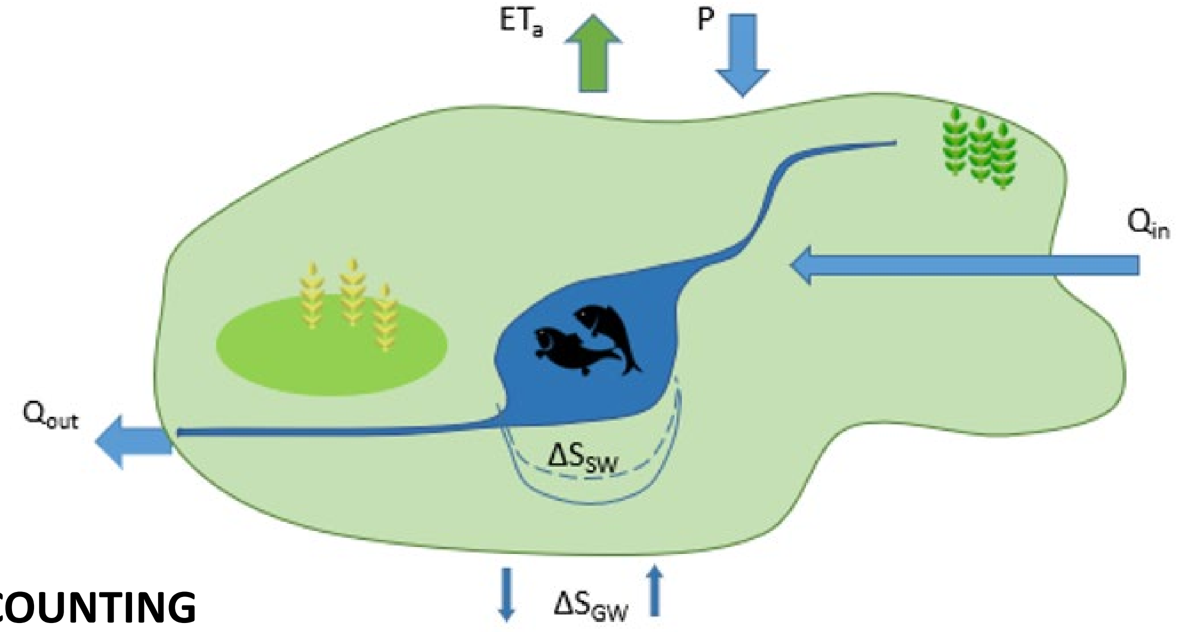
focusing mostly on blue water in cross-sectoral context

DEPLETION ACCOUNTING: focusing on water consumption with a landscape prospective

depleted water: ET, sinks, water in products



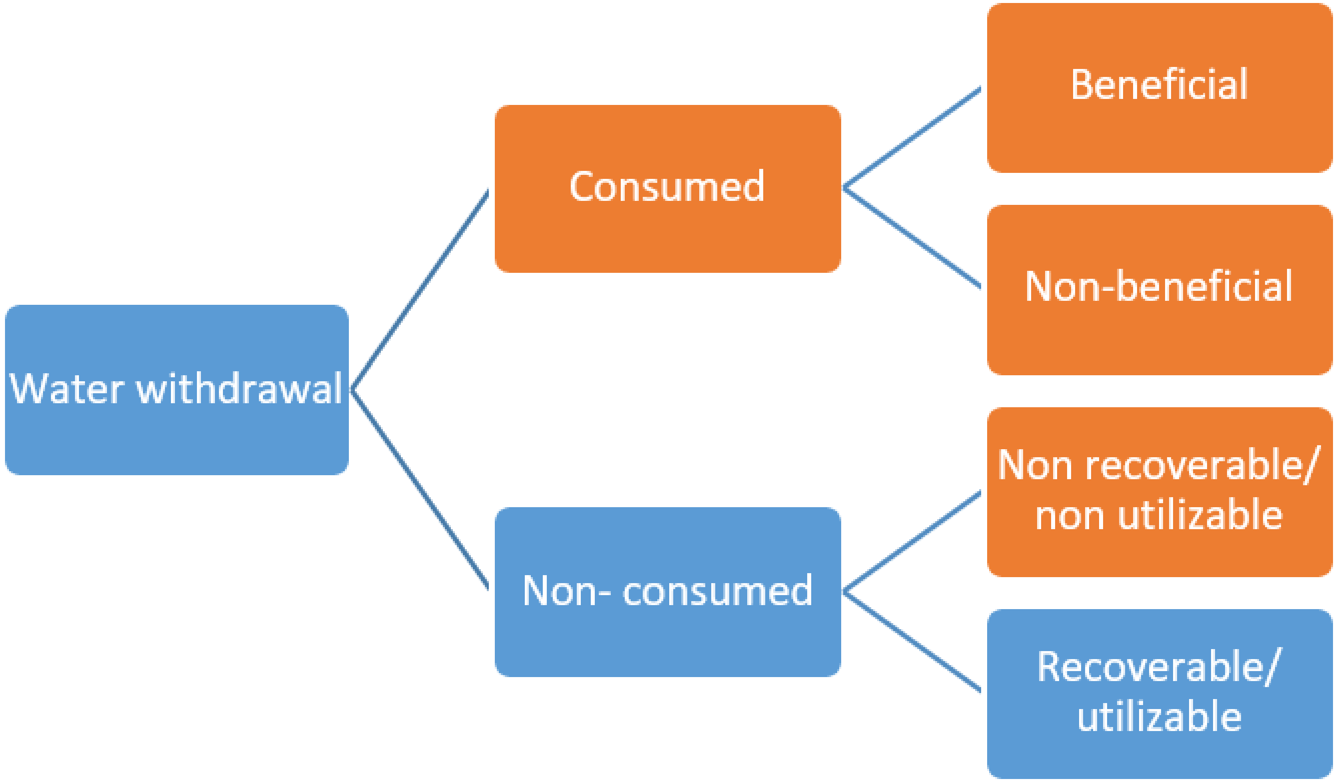
FLOW ACCOUNTING



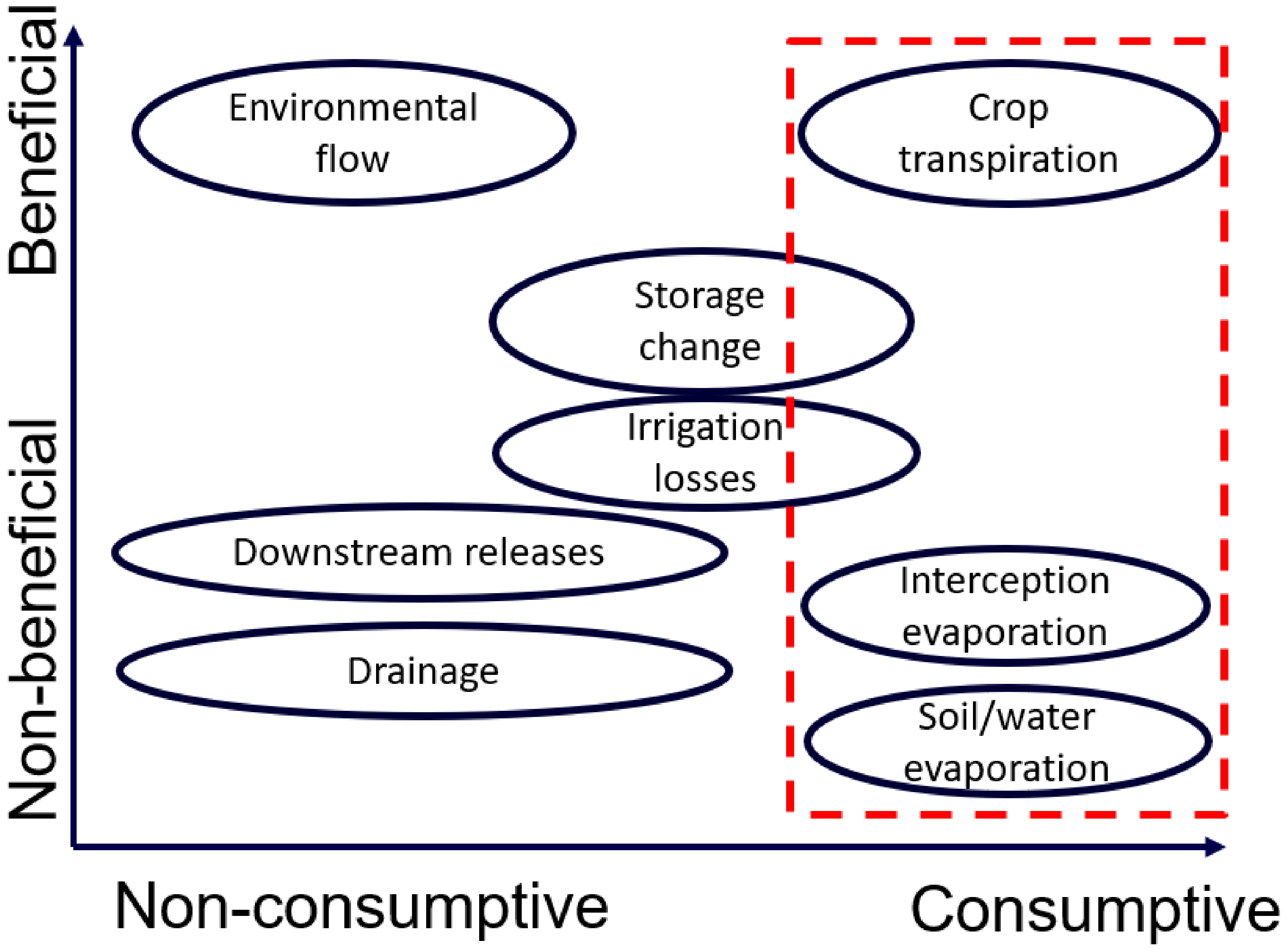
DEPLETION ACCOUNTING

Consumptive use of water

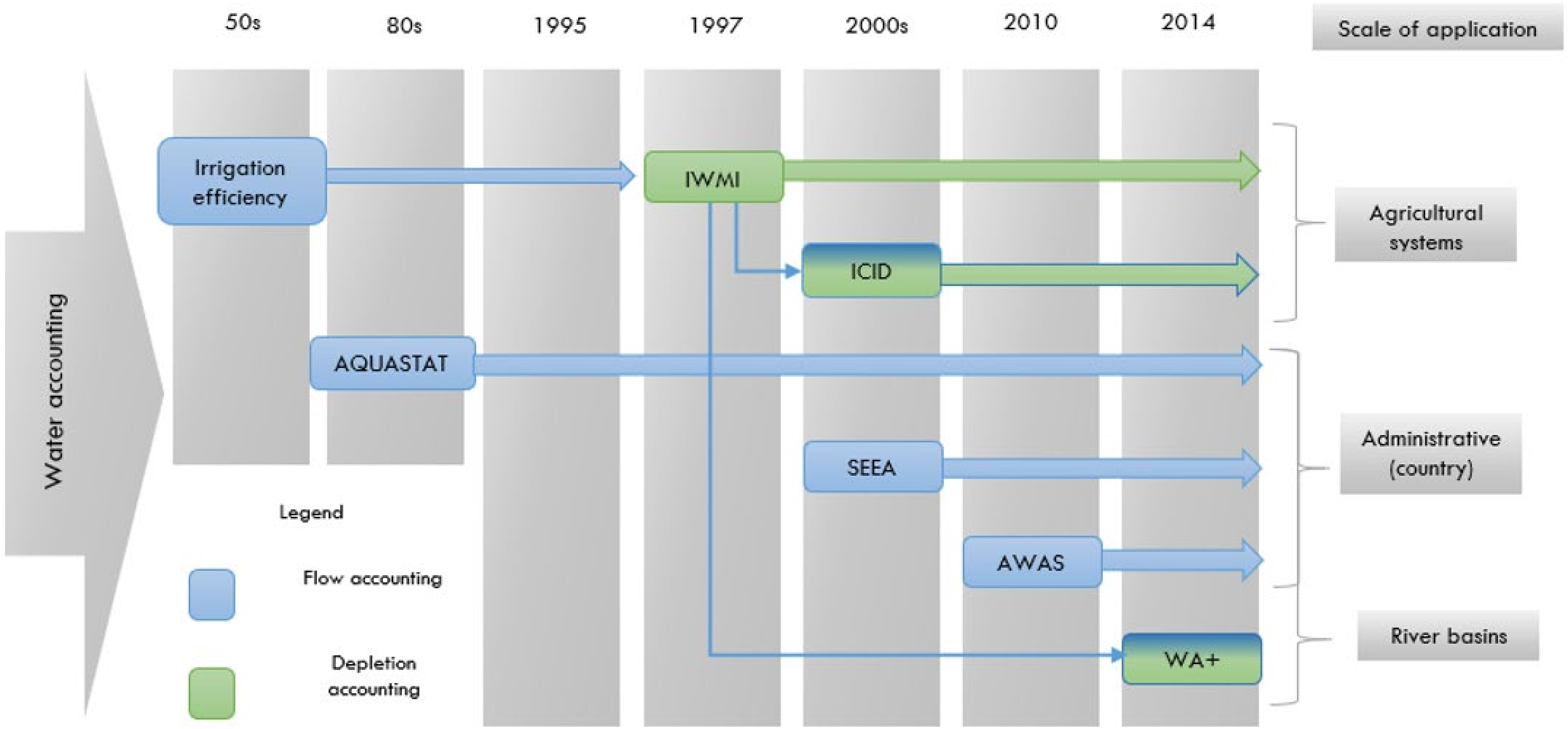
Depletion accounting can also include the concept of **non-recoverable** or **non-utilizable** water



Examples of consumptive use of water



History of Water Accounting Frameworks



Overcoming data issues

Use of remote sensing data, open source models and global datasets

Advantage for us:

data is available near-globally

data is available in a predictable manner

Advantage for stakeholders:

accounts are reproducible, based on open source code and data

➡ **Transparency**

Opportunities and limitations for using RS data for WRM&P

- In last decade reliability of RS data for WRM has improved significantly
- Continuous data set for various water resources related data sets (P, ET) for 10+ years
- Provides estimation of water consumption of largest water user (agriculture)
- Provides spatial information

But

- Need for adjusting hydrological models for incorporating water consumption data
- Requires ground validation data
- Long time series missing (>30 year) needed for trend analyses
- Methodology for scenario assessments (eg climate change etc) to be developed
- Water quality not well presented

Water Accounting Plus (WA+)

Hydrol. Earth Syst. Sci., 17, 2459–2472, 2013
www.hydrol-earth-syst-sci.net/17/2459/2013/
doi:10.5194/hess-17-2459-2013

Hydrology and Earth System Sciences
Open Access

Water Accounting Plus (WA+) – a water accounting procedure for complex river basins based on satellite measurements

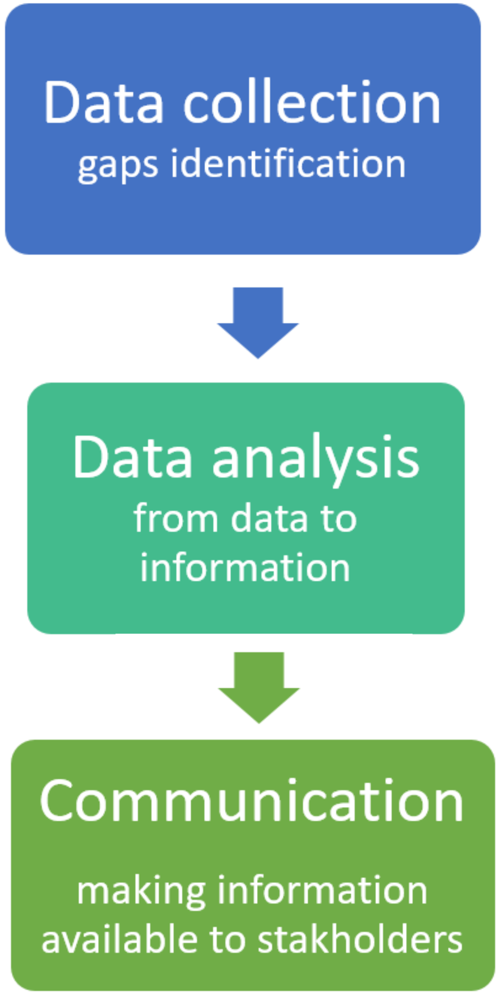
P. Karimi[1,2], W. G. M. Bastiaanssen[2,3], and D. Molden[4]

[1]International Water Management Institute, Battaramulla, Sri Lanka
[2]Faculty of Civil Engineering and Geosciences, Water Management Department, Delft University of Technology, Delft, The Netherlands
[3]eLEAF Competence Centre, Wageningen, The Netherlands
[4]International Centre for Integrated Mountain Development, Kathmandu, Nepal

Water Accounting Plus (WA+)

Developed by IHE Delft in partnership with IWMI and FAO

- Geographical domain: river basin
- Combination of flow and depletion accounting
- Data acquisition
  - Open access spatial data bases and remote sensing data
  - Other open access data and information
  - Validated using ground observations and literature values
- Data analyses
  - Standardized analyses
  - Using open access programming tools and scripts (python, QGIS)
- Reporting
  - Standardized sheets, maps, tables and graphs



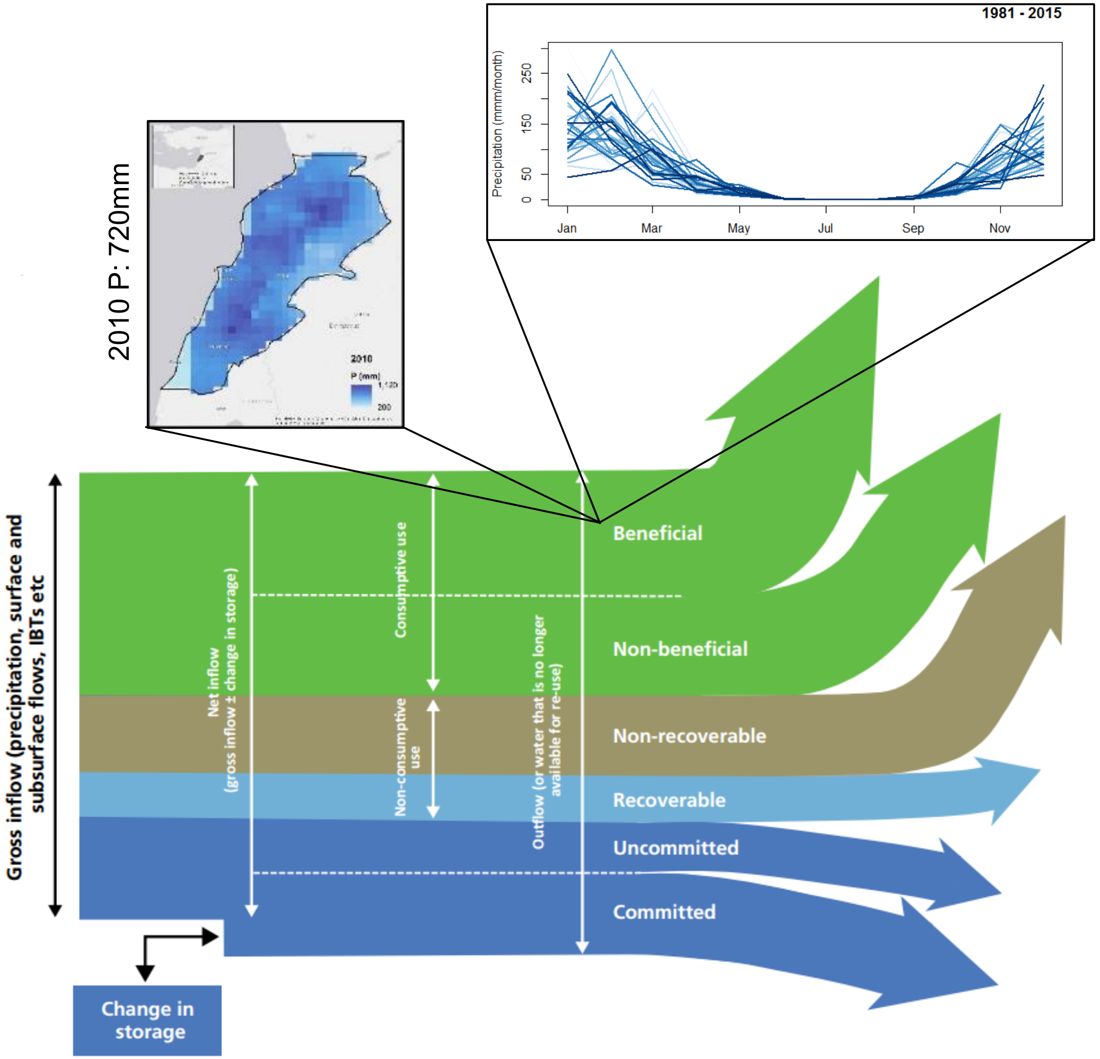
Water Accounting Plus (WA+)

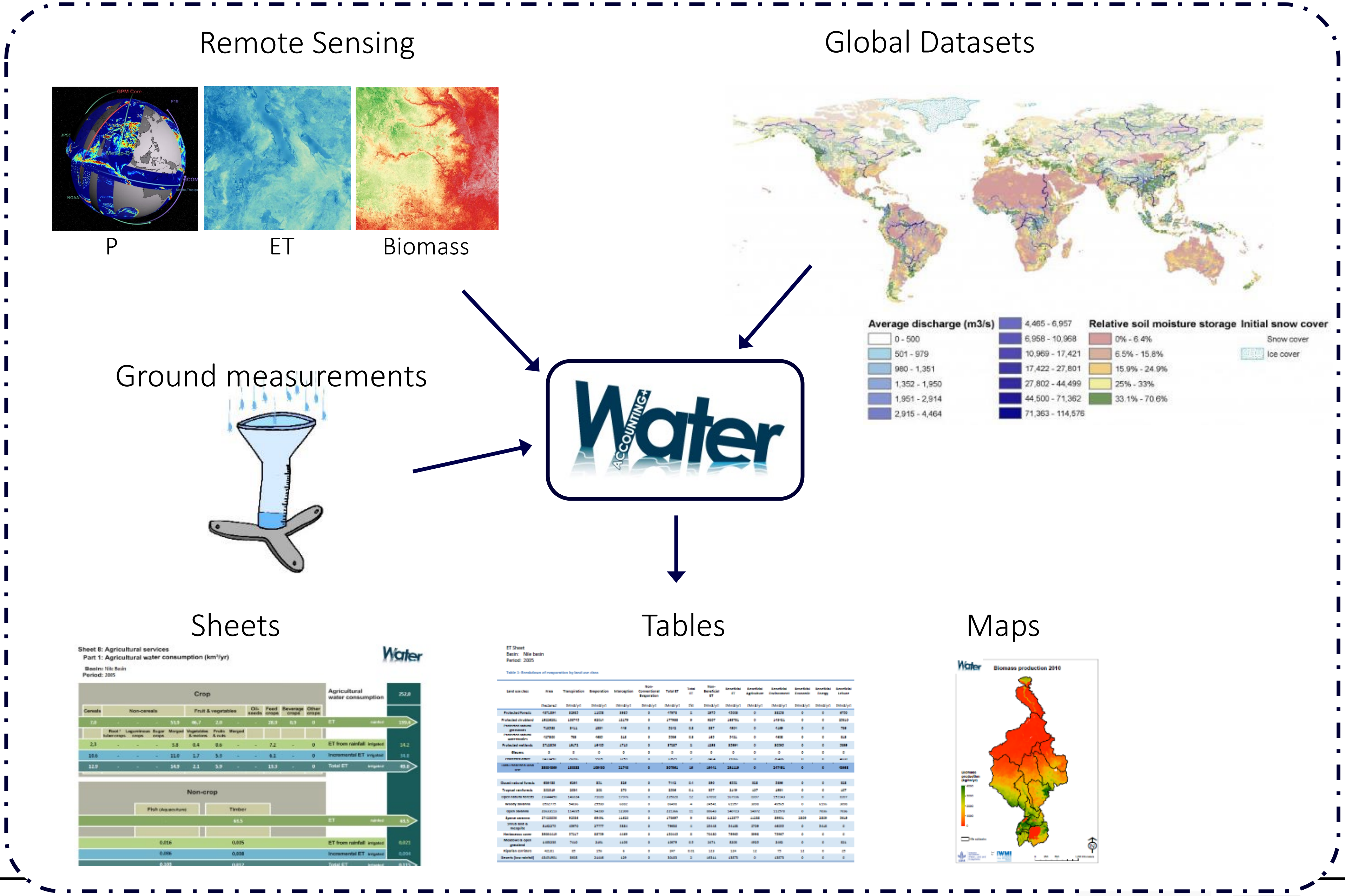
WA+ attempts to make WA

scalable

spatially explicit

temporally detailed



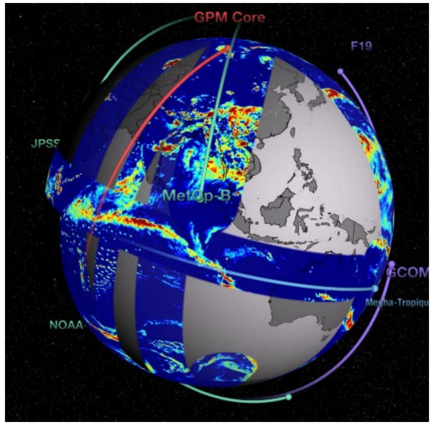


UNESCO IHE DELFT

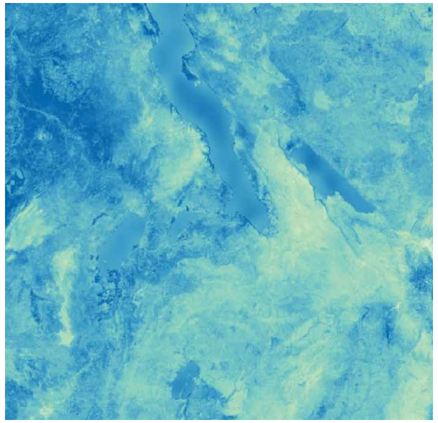
QGIS GitHub python

Water Accounting Plus (WA+): using RS for water resources management

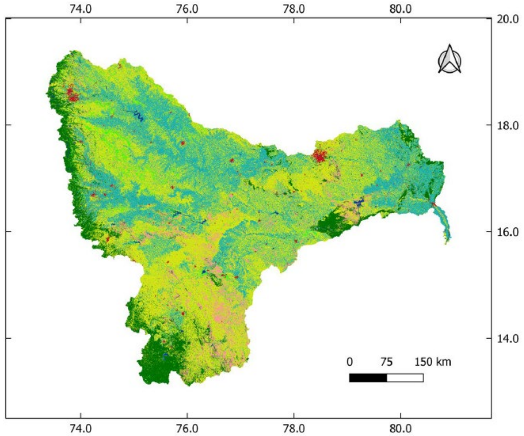
Rainfall



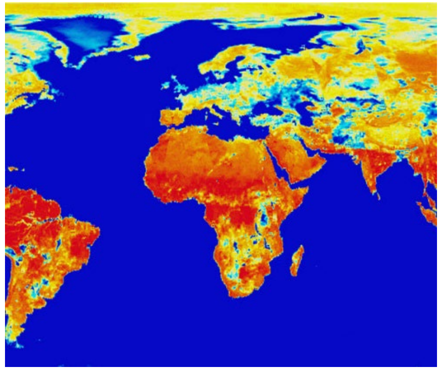
Evapotranspiration



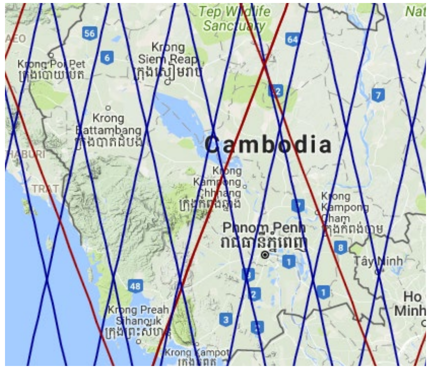
Land use



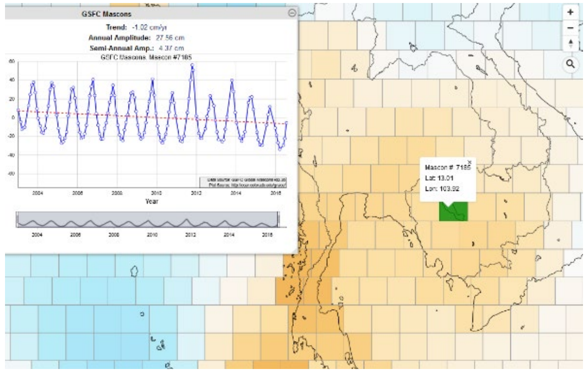
Soil Moisture



Water Levels

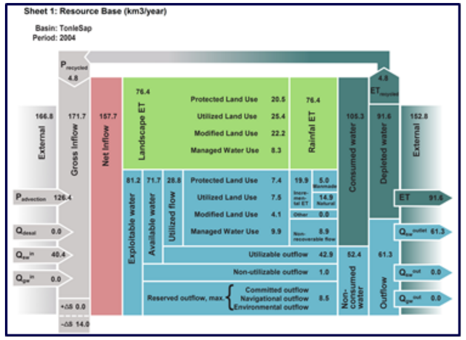


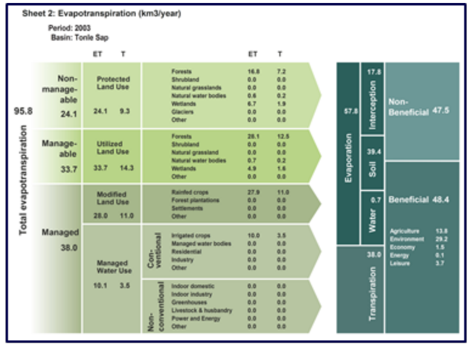
Groundwater

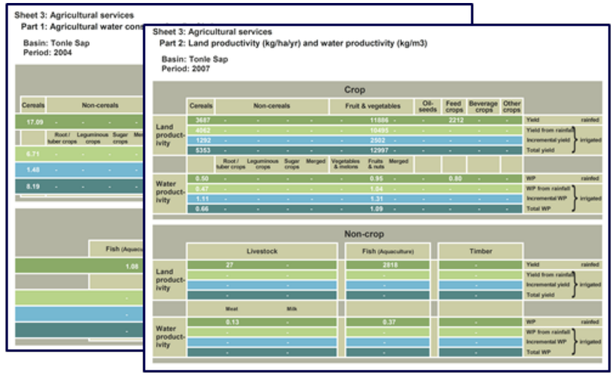


Rainfall, GPM: NASA Goddard Space Flight Center from Greenbelt, MD, USA [Public domain]
Evapotranspiration, and biomass WaPOR: FAO, IHE-Delft.WaPOR quality assessement
Soil Moisture, SMAP: NASA/JPL-Caltech/GFSC. https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA18057

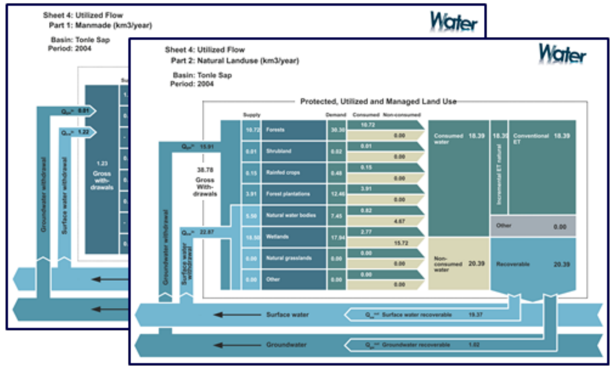
Water Accounting Plus (WA+)

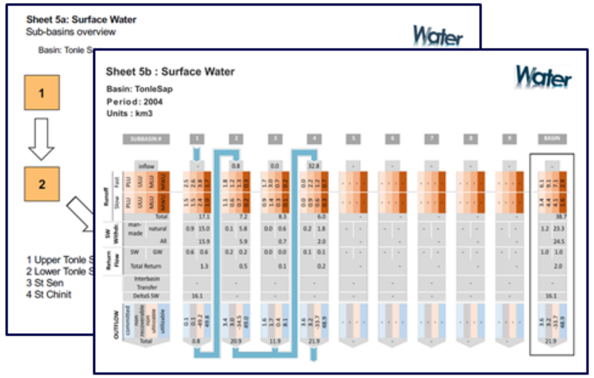


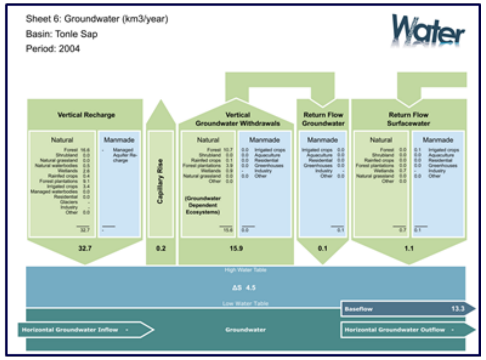




Finger diagram → thematic accounting sheets







Water Accounting Plus (WA+): river basin management options

- Modify water flows
  - Diversions
  - Retentions
  - ….
- Modify land use practices
  - Cropland
  - Urban
  - Forests
  - ….

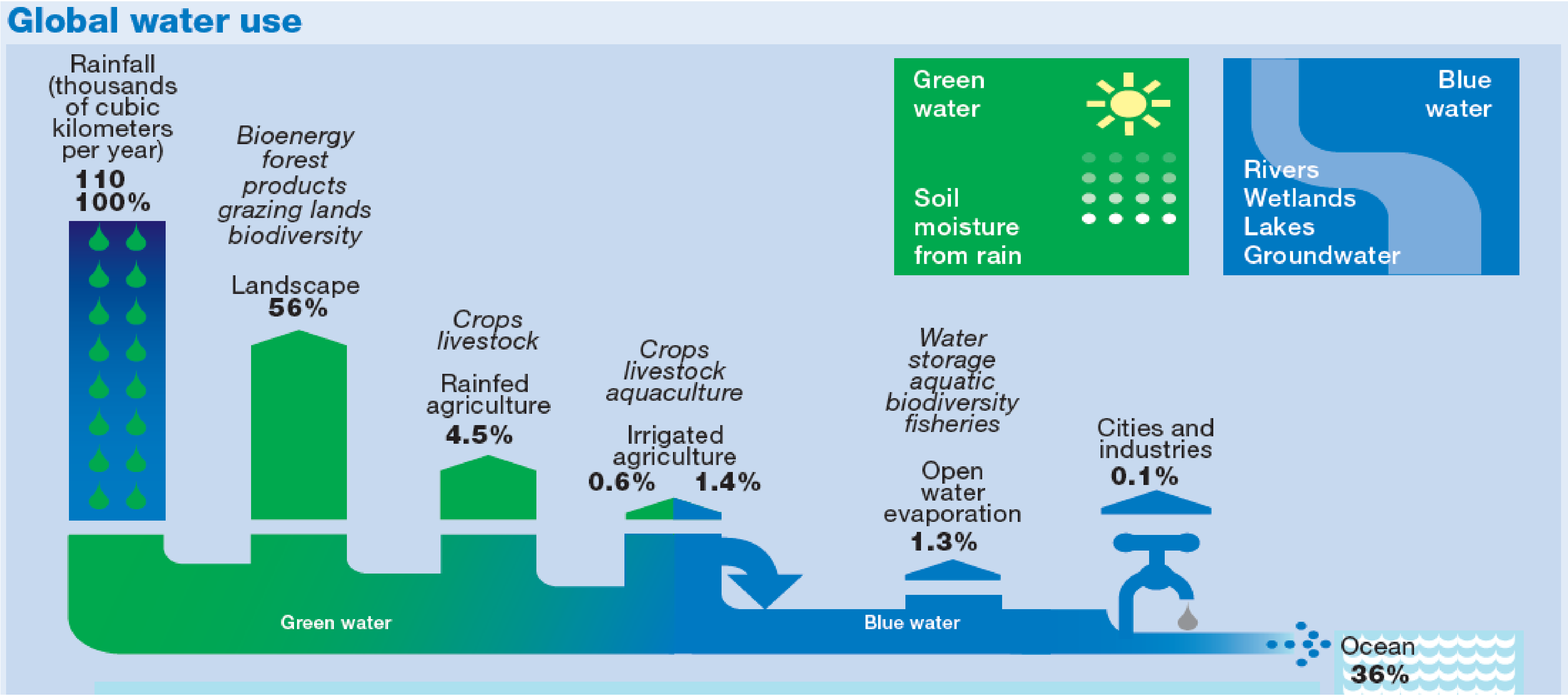
Protected Land Use

Utilized Land Use

Modified Land Use

Managed Water Use

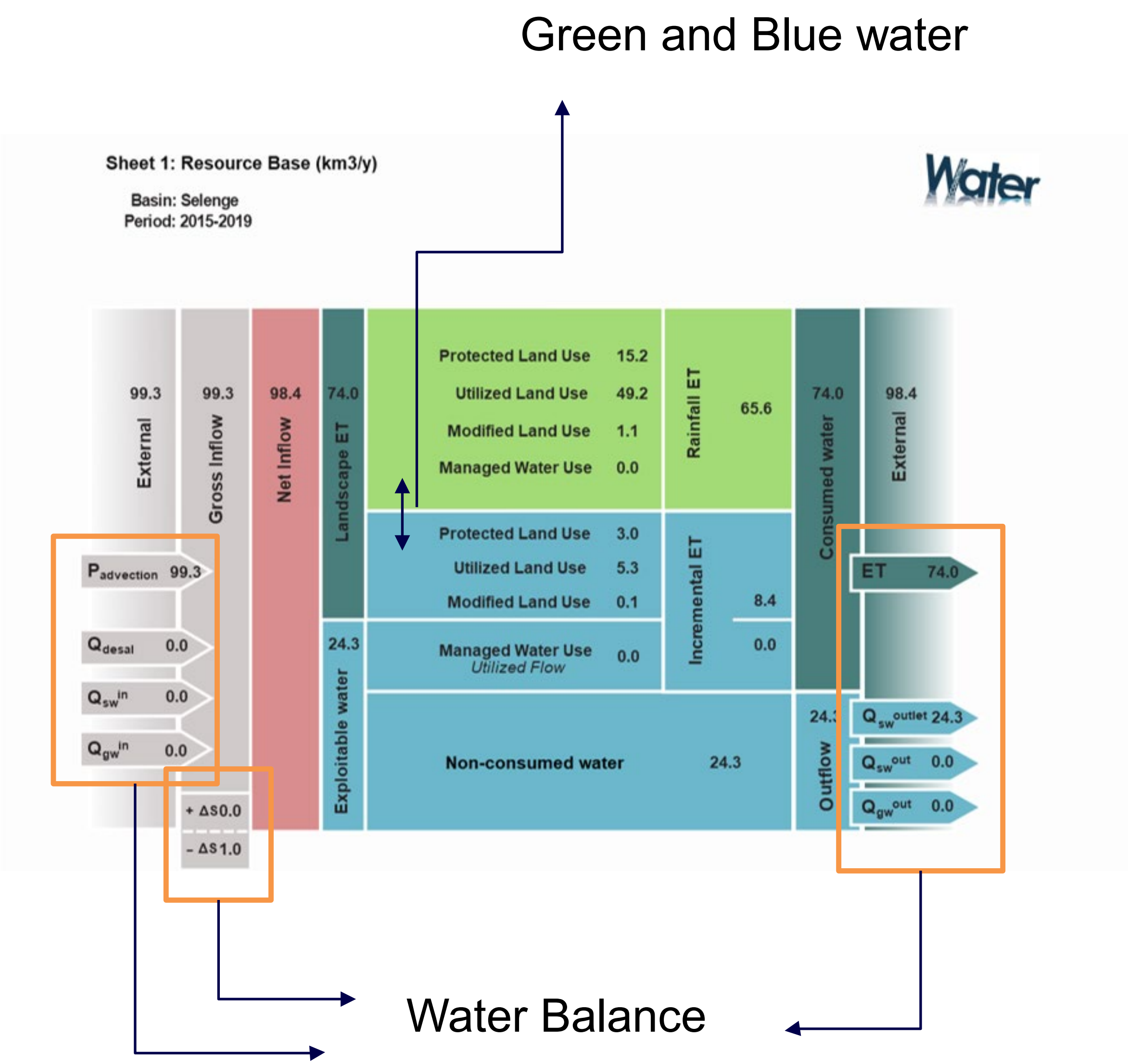
Water Accounting Plus (WA+): concepts of green and blue water



WA+: Sheet 1 Resource base

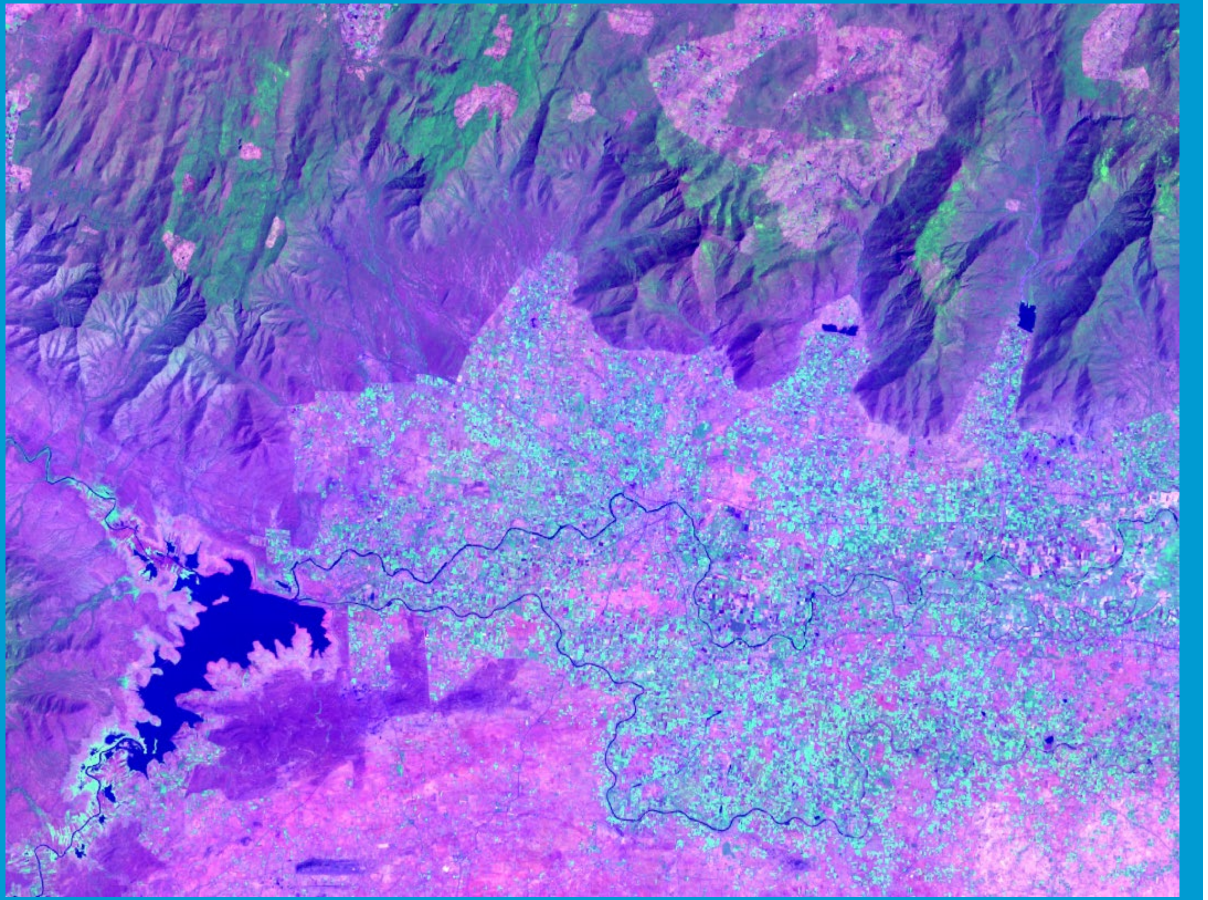
General overview at river basin scale of

- water availability vs water consumption
- exploitable flows
- manageable vs unmanageable flows
- over-exploitation
- green and blue water

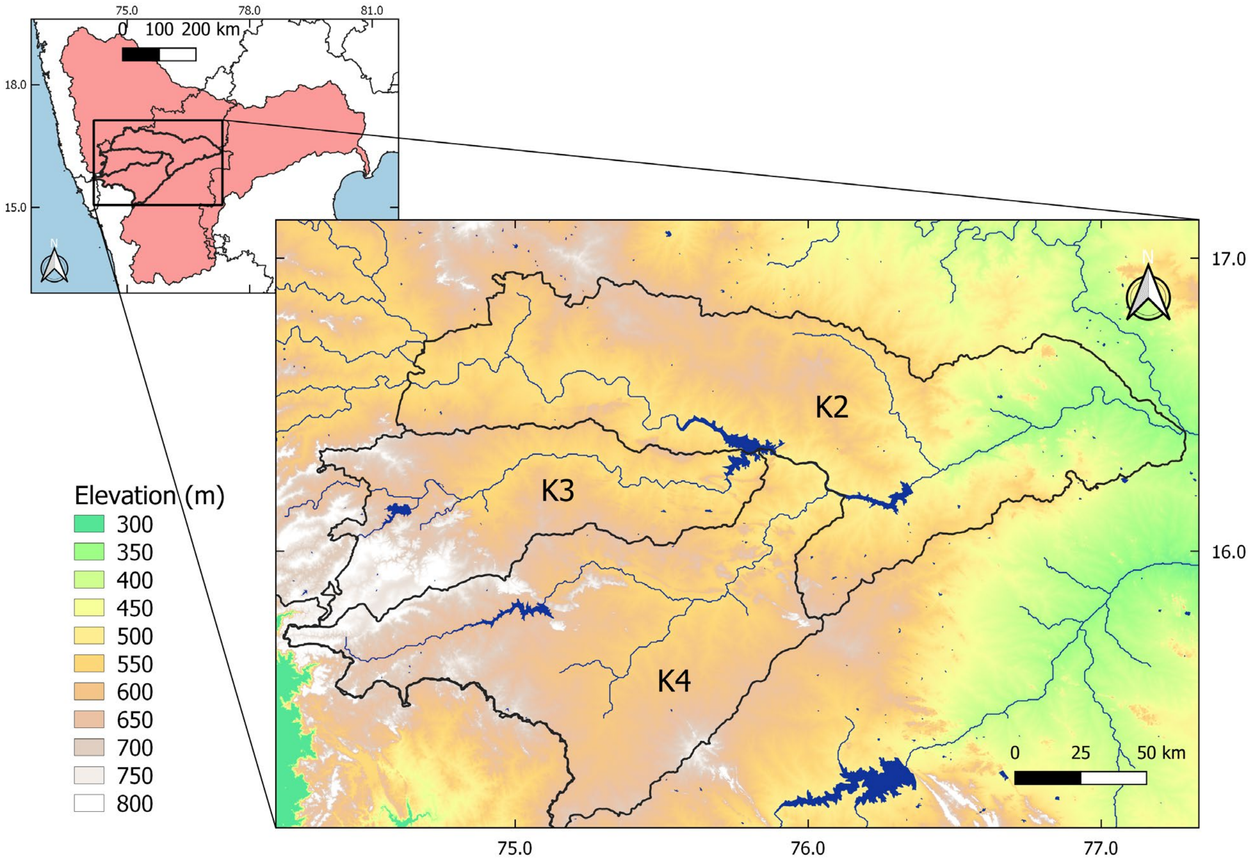


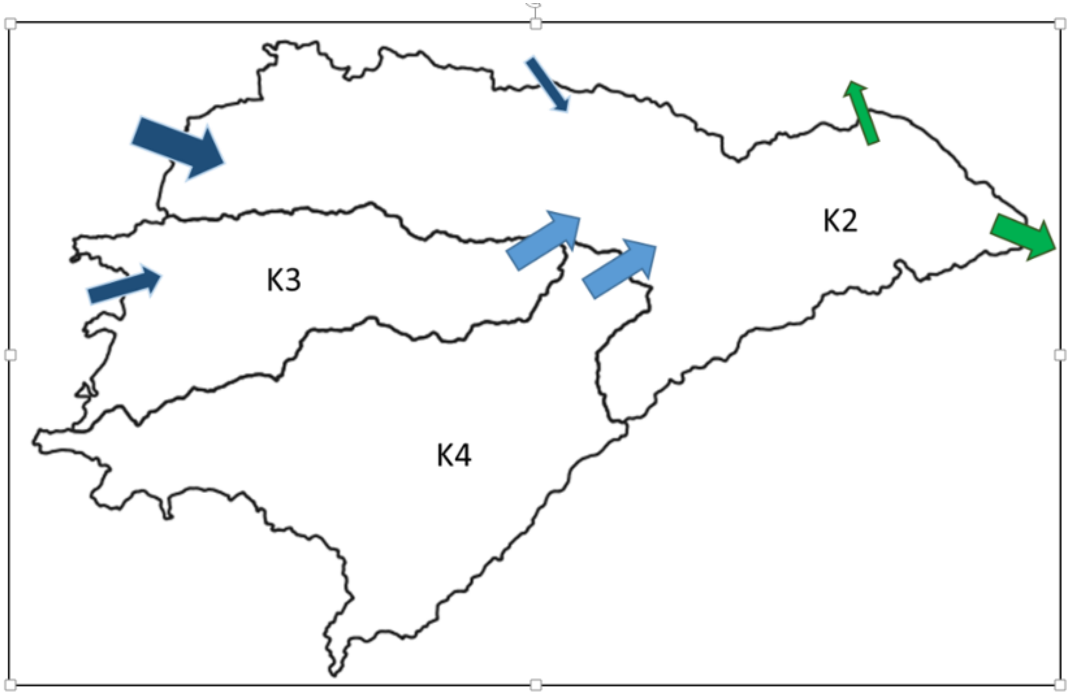
Examples of the application of WA+ in India

Results from a recent ADB funded project



Case Study: 3 Krishna sub-basins in Karnataka



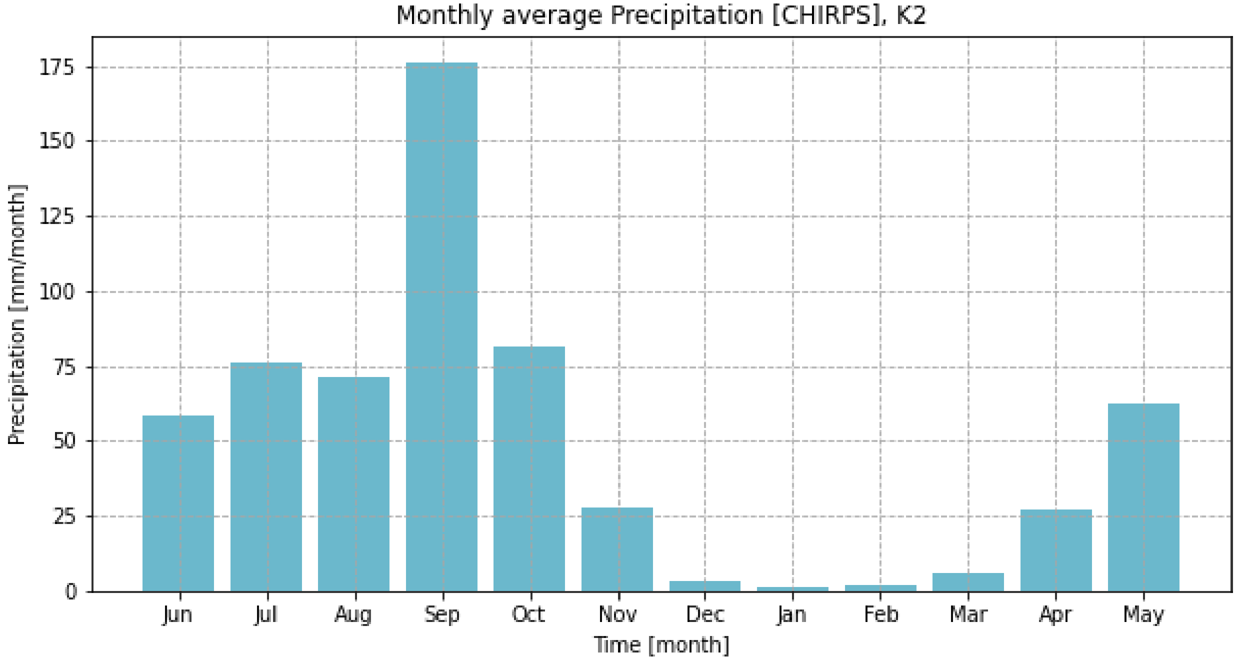


Sub-basin	Area in Karnataka (km²)	% area of Krishna basin in Karnataka		Average elevation (m) (min and max)	Average yearly rainfall (mm/yr), CHIRPS (2006-2018)
K2: Middle Krishna	15,829	13.93%		530 (308-796)	594
K3: Gatprabha	6,833	6.02%		633 (484-1024)	714
K4: Malprabha	11,780	10.38%		627 (167-1022)	671
Total:	**34,442**	**30.33%**	**Average:**	**583 (167-1024)**	**644**

Data Collection

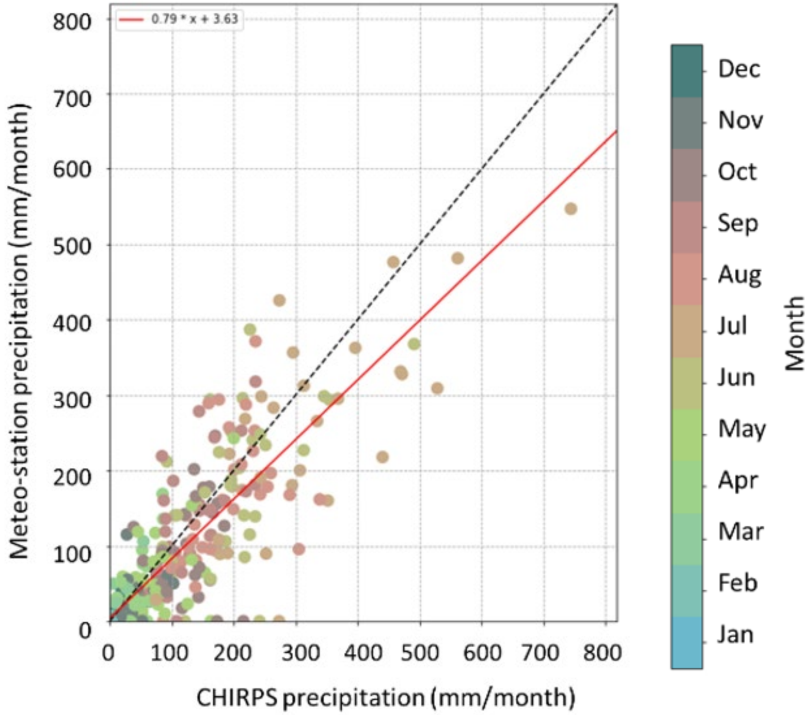
Dataset	Start	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Temporal resolution	Used
Precipitation																
CHIRPS	1981														monthly	X
CHIRPS	2007														daily	X
GPM v5	2014														monthly	
GPM v6	2007														monthly	
GPM v6	2007														daily	
TRMM	1998														monthly	
Evapotranspiration																
SSEBop	2003														monthly	X
ALEXI	2003														monthly	
CMRSET	2003														monthly	
ETens	2003														monthly	
SEBS	2000														monthly	
Other data																
ASCAT (SWI)	2007														daily	
LAI	2007														8-daily	X
GPP	2007														8-daily	
NPP	2007				Data is currently unavailable due to unexpected errors in the input data										yearly	
DMP	2014														decadal	X
GDMP	2014														decadal	X
ET reference	2007														monthly	X
ET reference	2007														daily	
GRACE	2003														monthly	
GLDAS qs	2007														monthly	
GLDAS qbs	2007														monthly	

Data Validation and Analysis



Monthly average 2007-2019

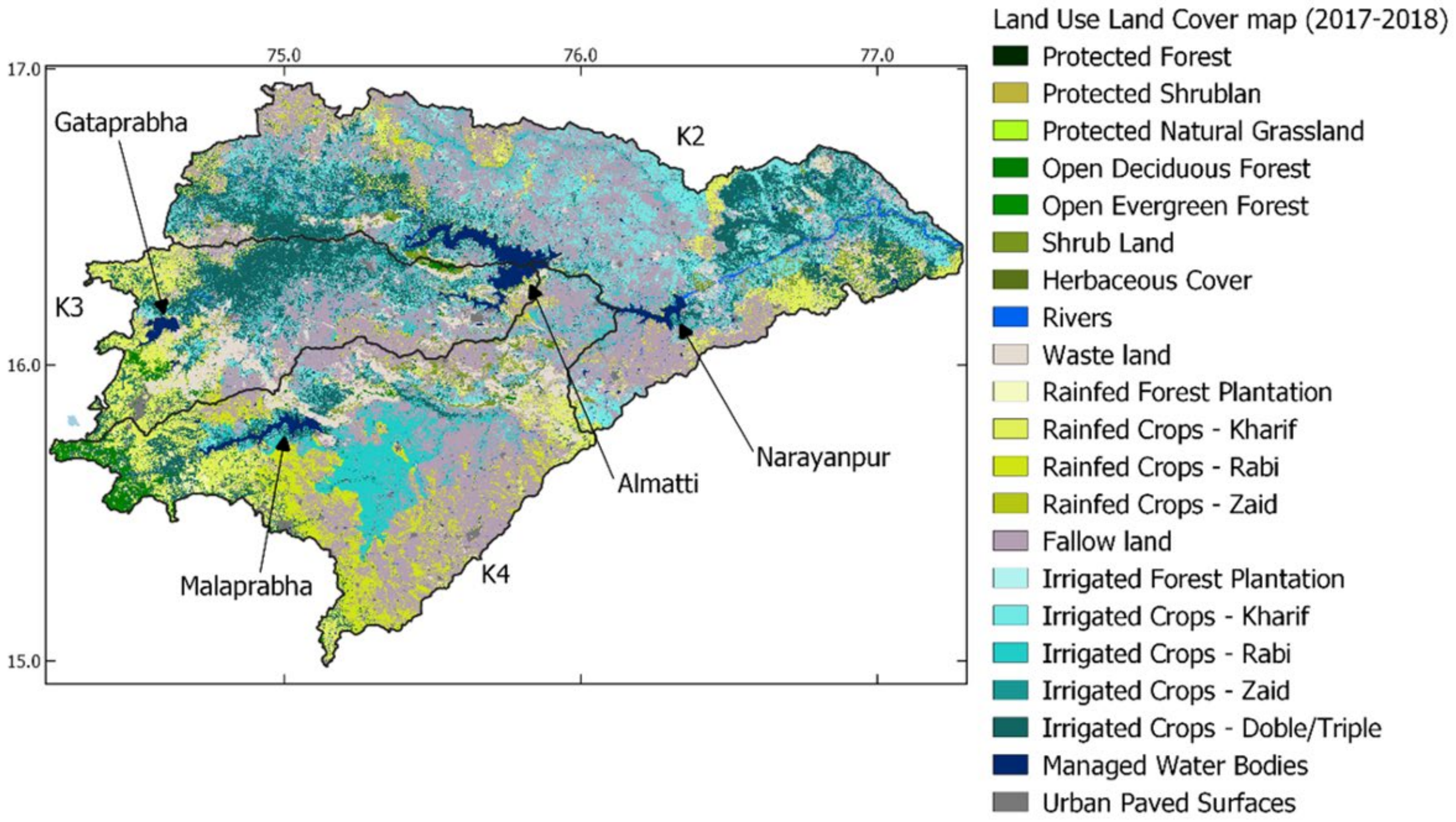
→ strong seasonal variation



CHIRPS data validated with 139 stations

Dataset	Average NS	Average Pearson Coefficient	Average Relative Bias	Average RMSE
CHIRPS	0.32	0.73	0.93	52.67
TRMM	0.45	0.77	0.68	71.12
GPM	0.48	0.78	0.71	62.88

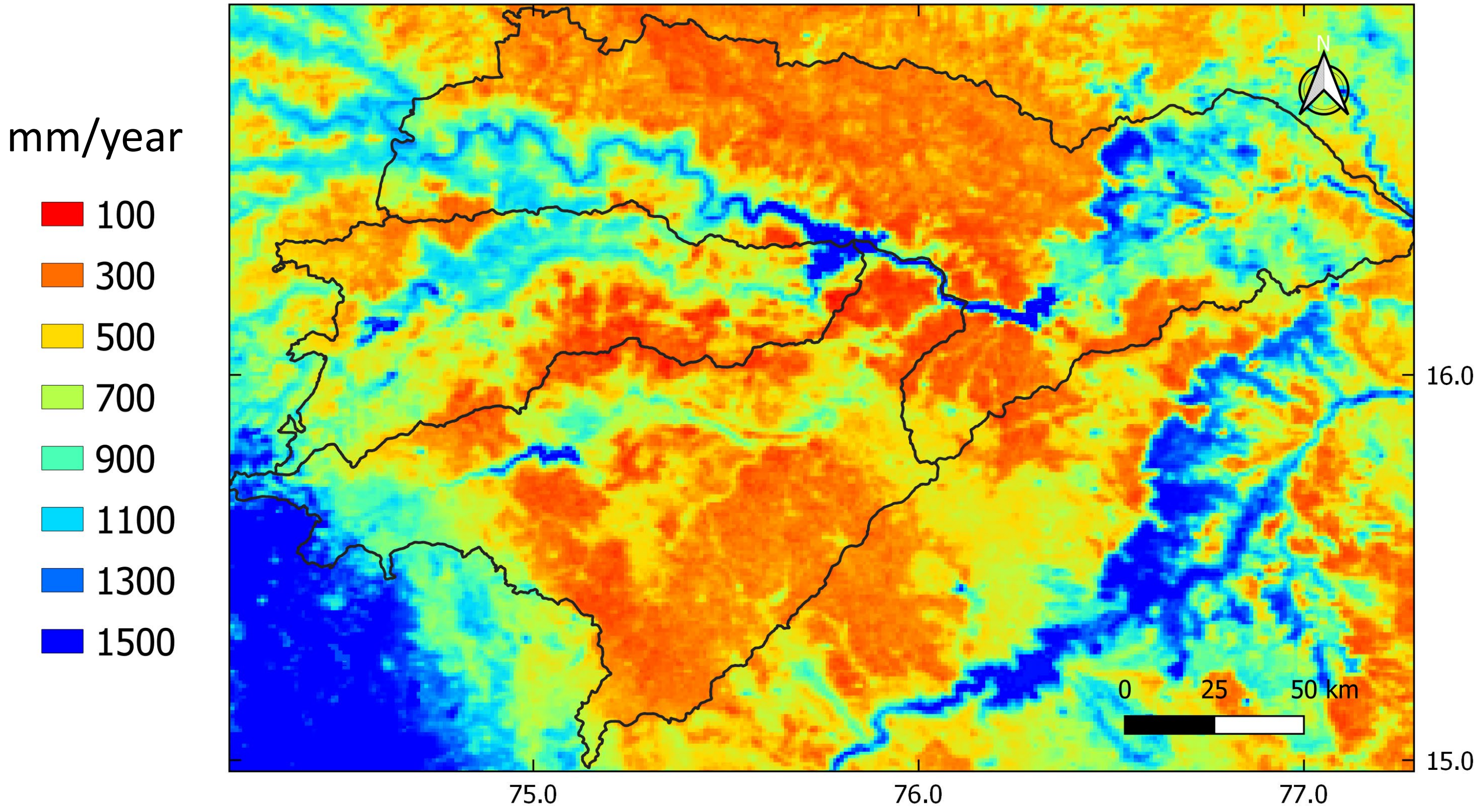
The 3 sub-basins are highly modified by human activity



2010 → 2018

Cultivated area –16.5% (especially double and triple crops)

Spatial Distribution of Water Consumption



RS-based evapotranspiration:
SSEBop (global ET product)

SSEBop was the only RS open access product available in recent years in India at the time of this study

Low values of ET (100-300 mm/yr) seems too low for this climatic zone (up to 600 mm/yr rainfall)

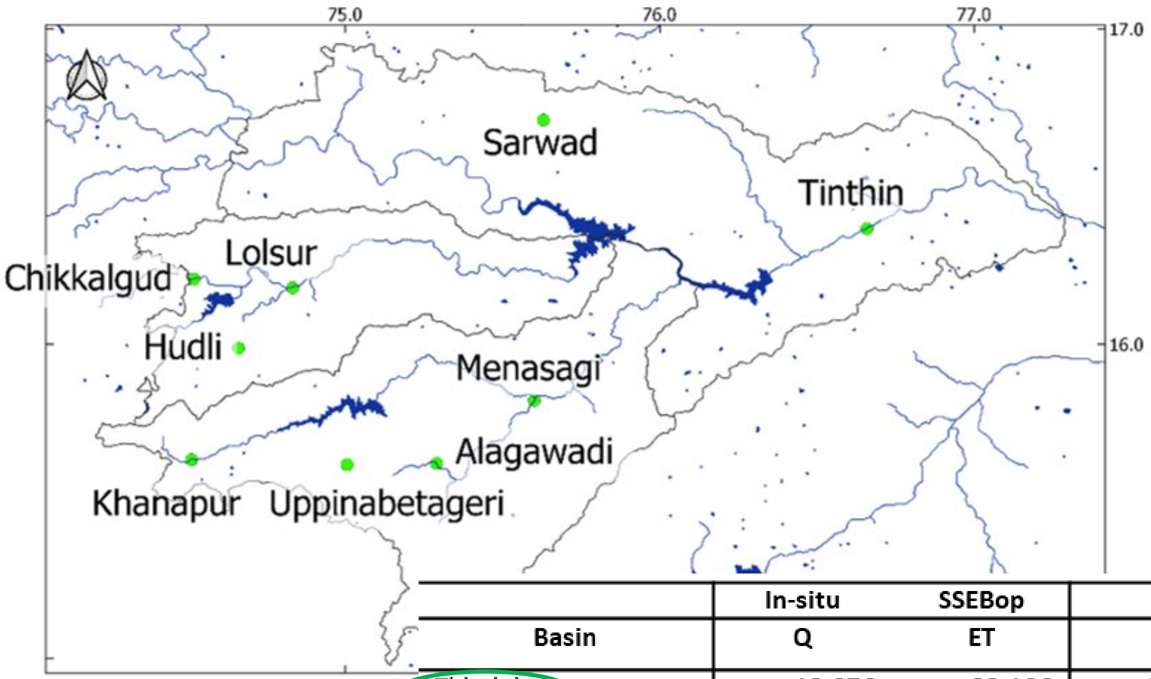
→ **Additional validation required!**

Data Selection: RS yearly water balance v.s. in-situ measurements

We need to know the physical boundaries of the watersheds, and inflows and outflows

Nine stations:

$$\frac{\Delta S}{\Delta t} = P - ET - Qout + Qin$$

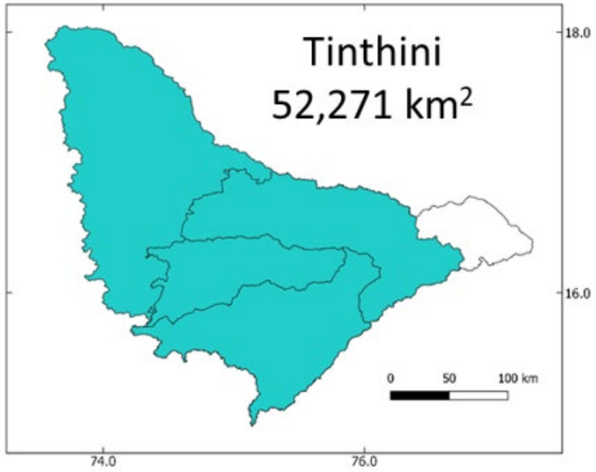


10 year period

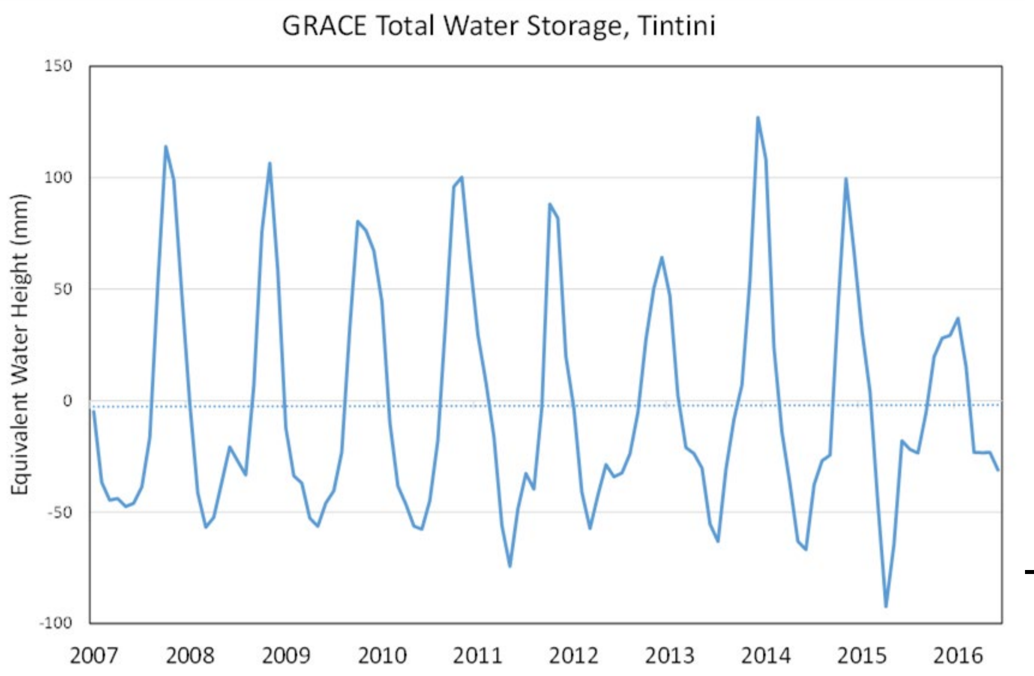
	In-situ	SSEBop	GPM				CHIRPS			
Basin	Q	ET	P	P-ET-$\frac{\Delta S}{\Delta t}$	Diff	% Diff	P	P-ET-$\frac{\Delta S}{\Delta t}$	Diff	% Diff
Thintini	13,076	33,106	59,092	26,421	13,345	102	46,620	13,950	873	7
Menasagi	418	1,823	4,489	2,667	2,249	538	2,791	969	551	132
Lolsur	1,633	3,183	6,320	3,137	1,505	92	5,126	1,943	311	19
Alagawadi	122	578	1,502	924	802	656	807	230	108	88
Khanapur	1,348	581	1,061	480	-868	-64	876	295	-1,053	-78
Chikkalgud	1,990	864	1,841	977	-1,014	-51	1,543	678	-1,312	-66
Sarwad	80	191	387	196	116	144	391	200	120	149
Hudli	115	190	406	215	100	87	288	98	-17	-15
Uppinabetageri	25	160	367	207	183	741	218	57	33	133

More in-depth analysis at Tinthini station

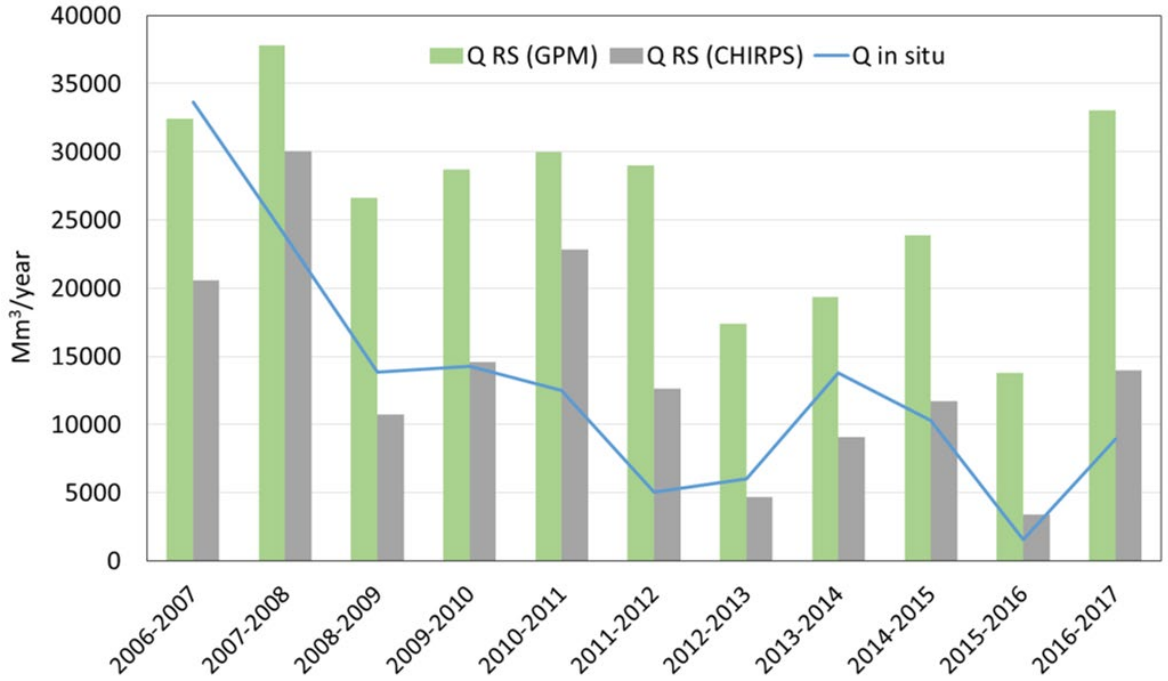
Largest watershed



No significant long-term trend in storage change was observed by GRACE (slightly negative)



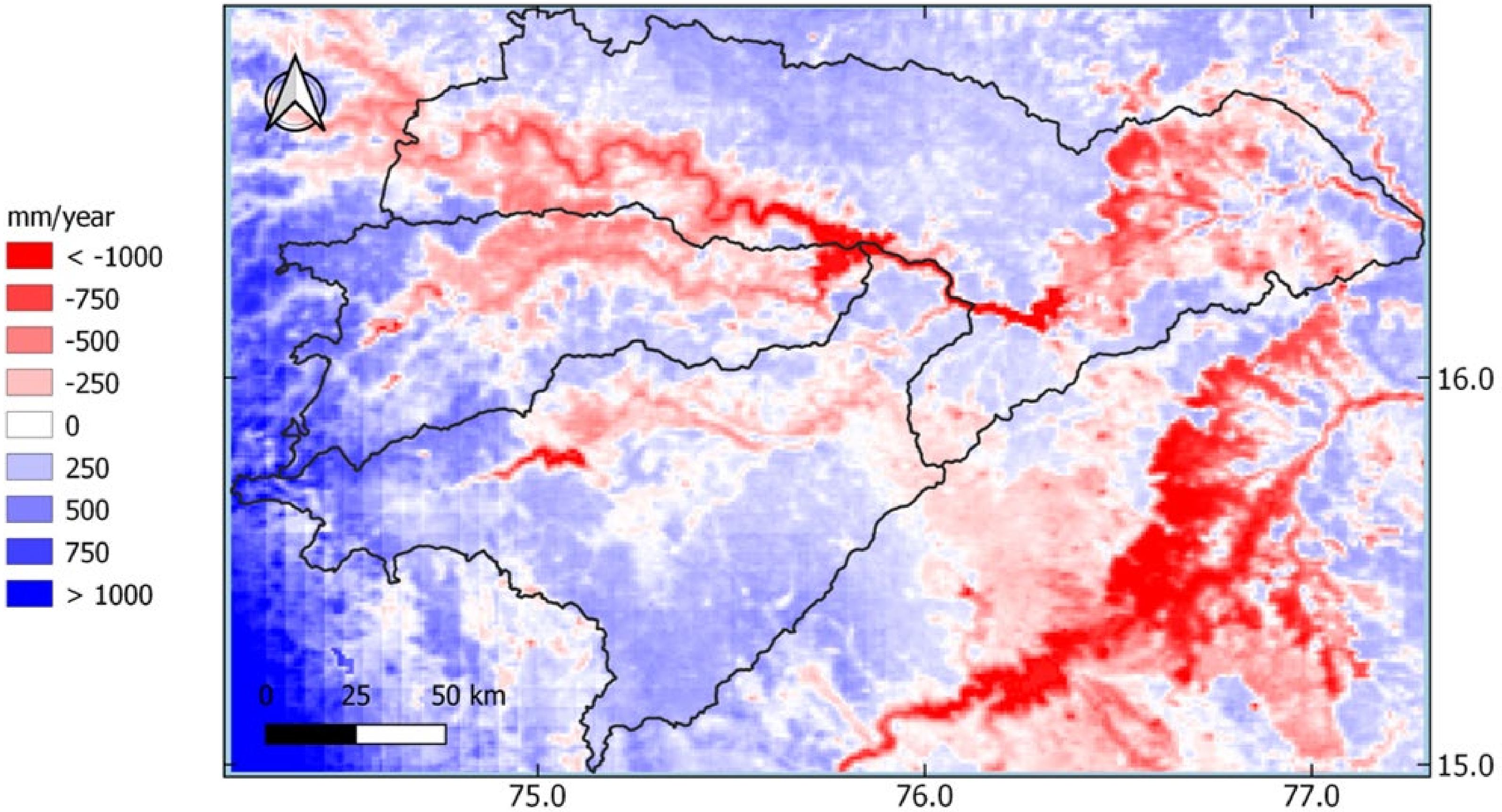
The water balance computed with CHIRPS data has a closer match to the observations



Water Yield (P-ET)

P > ET → runoff generation (blue)

P < ET → net consumption (red)



Most of the **runoff** is generated in the **upstream mountainous areas**

Agricultural areas and reservoirs are net consumers

The long-term average of P-ET <0 in K2 and P-ET>0 in K3 and K4

→ K3 and K4 are generating water, part of which is then consumed in K2

Annual Average Water Balance in K2 2010/2011 – 2017/2018

Total ET
9.9 km^3/yr

K2 15,800 km^2

P
9.1 km^3/yr

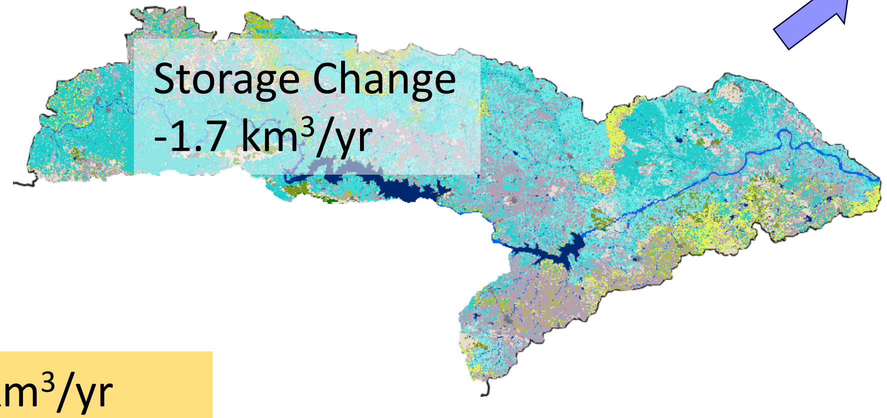
Rainfall ET
6.7 km^3/yr

Incremental ET
3.2 km^3/yr

NLBC
5 km^3/yr

Inflow
17.6 km^3/yr

Storage Change
-1.7 km^3/yr



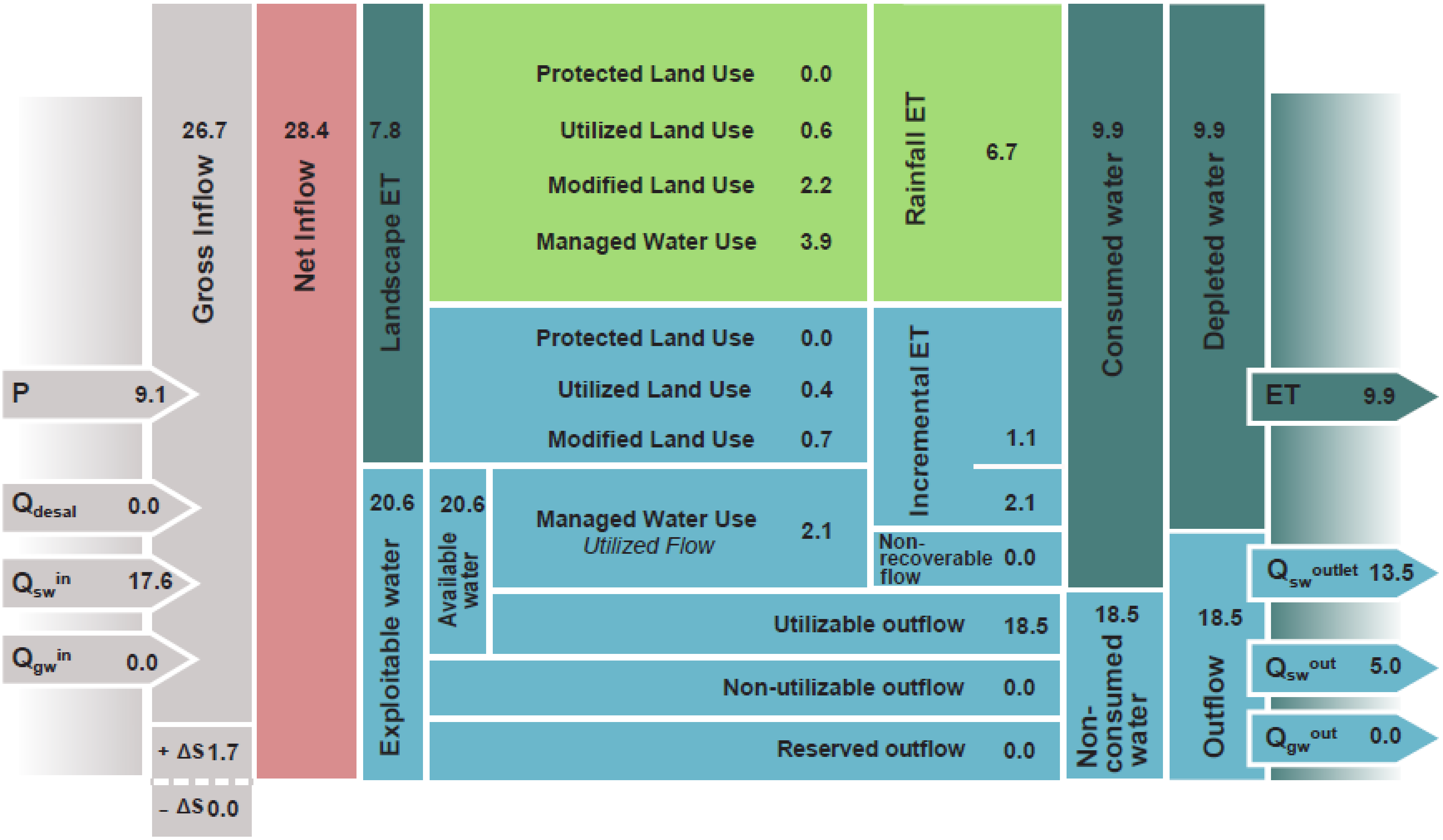
Outflow
13.5 km^3/yr

Dry weather outflow
4.6 km^3/yr
Wet weather outflow
18.4 km^3/yr

Available	20.6 km^3/yr
Utilized flow	2.1 km^3/yr

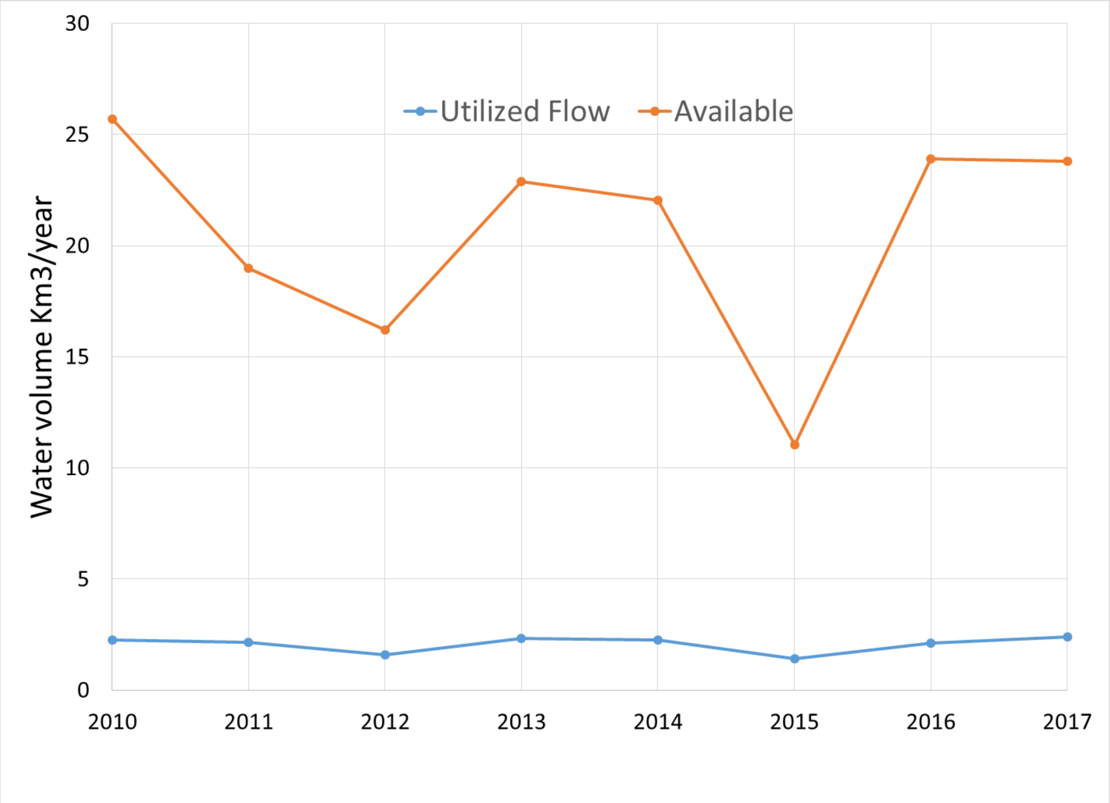
Sheet 1: Resource Base (km3/year)

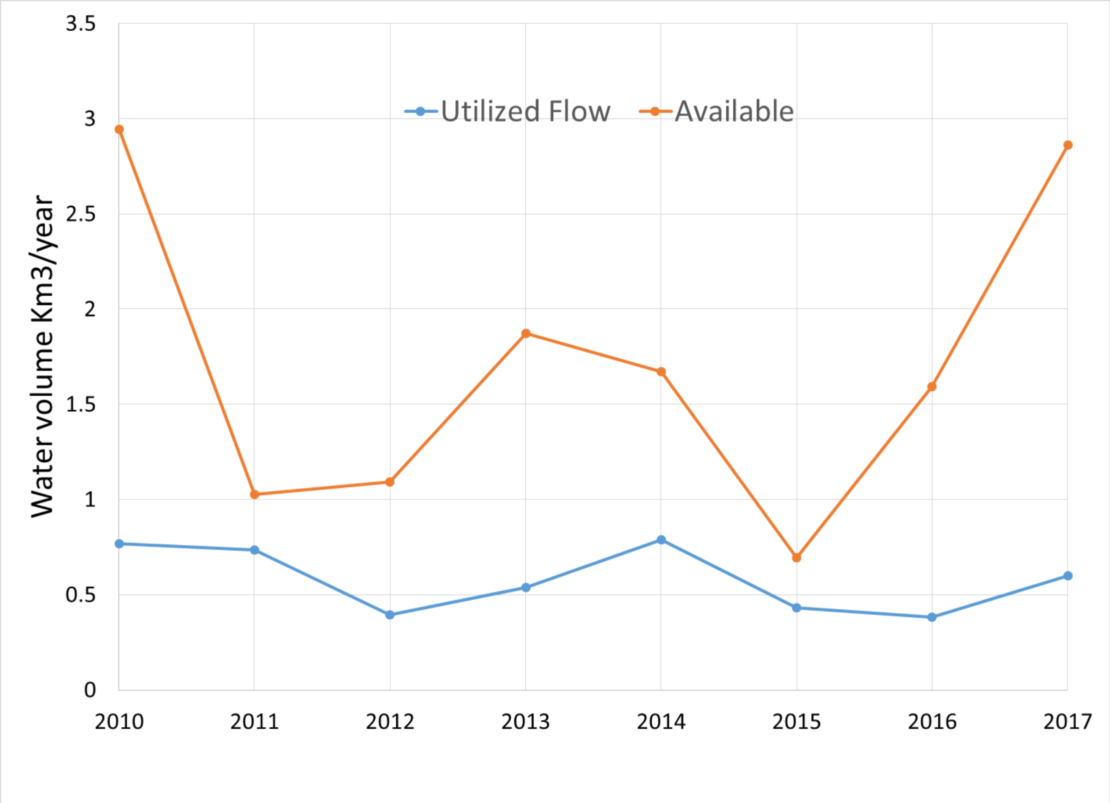
Basin: K2
Period: 2010-2017



K2: the available water in the basin is 8-10 times the utilized flow

K4: the available water in the basin is 2-3 times the utilized flow





High water availability because of inflows.

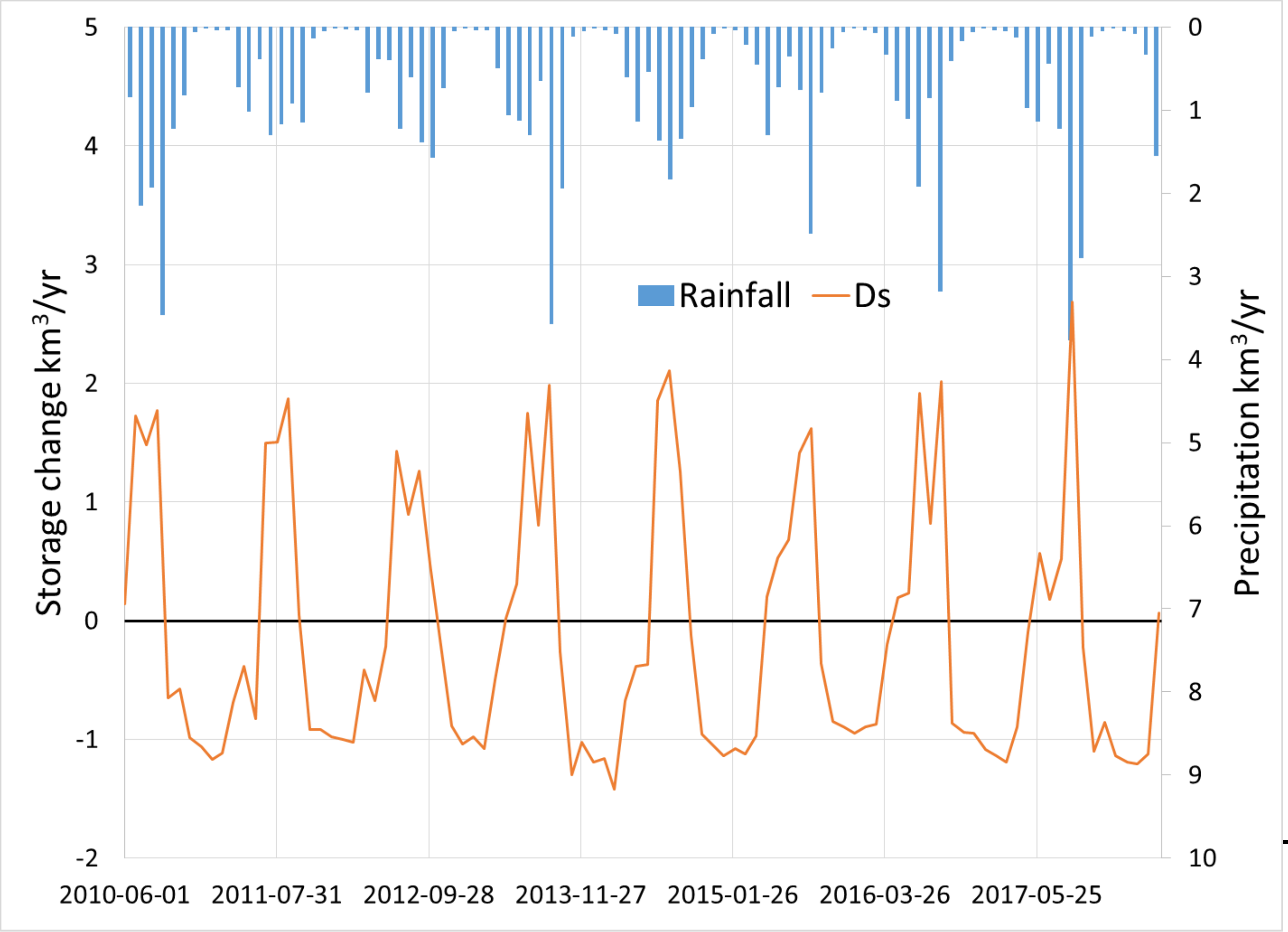
The available water has a high inter-annual variability (11-26 km^3/year)

During dry years most of the available water is utilized

K2: storage change monthly scale

K2 as the other two basins has a strong seasonal variability → monsoon

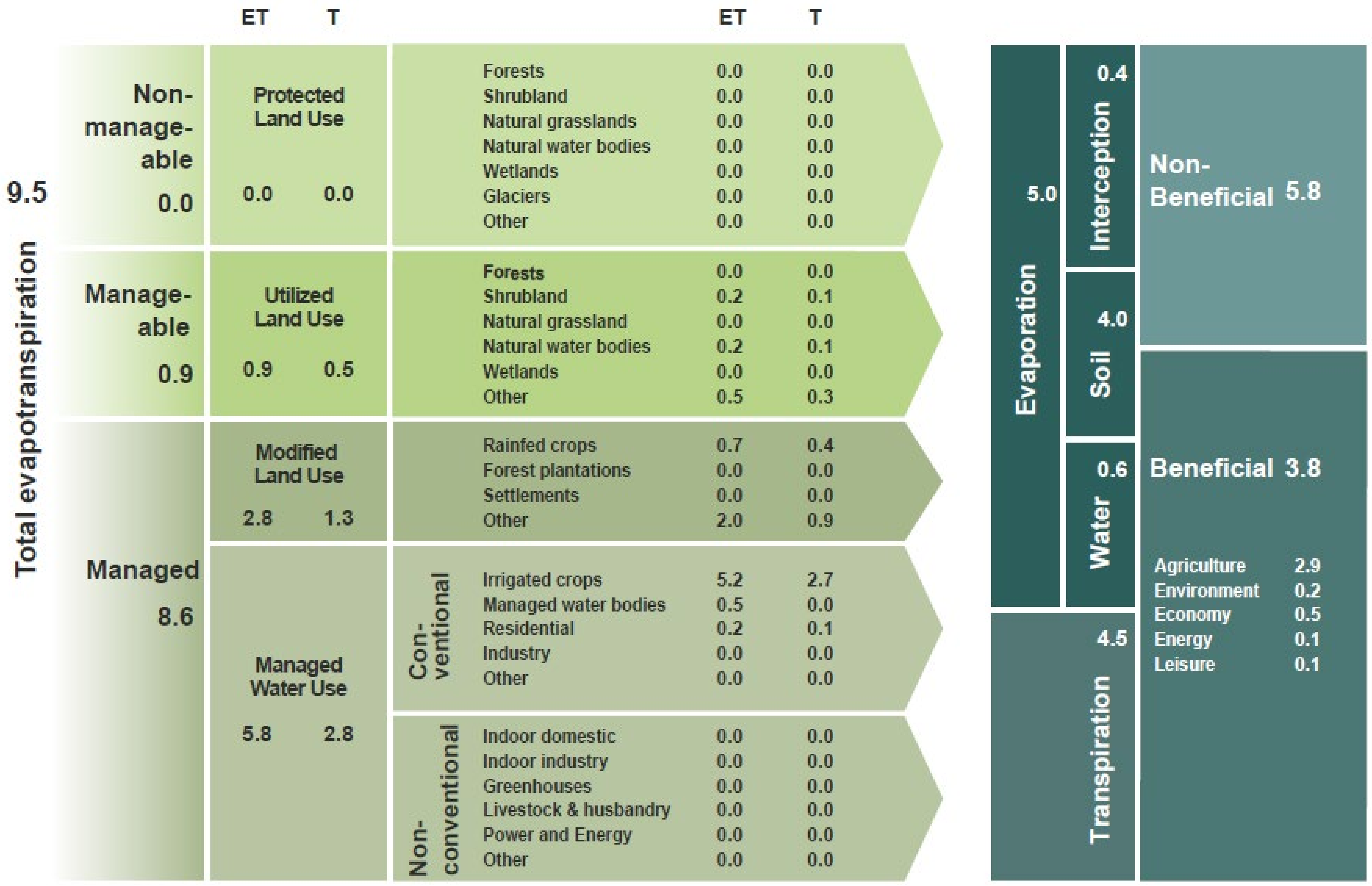
Delicate balance



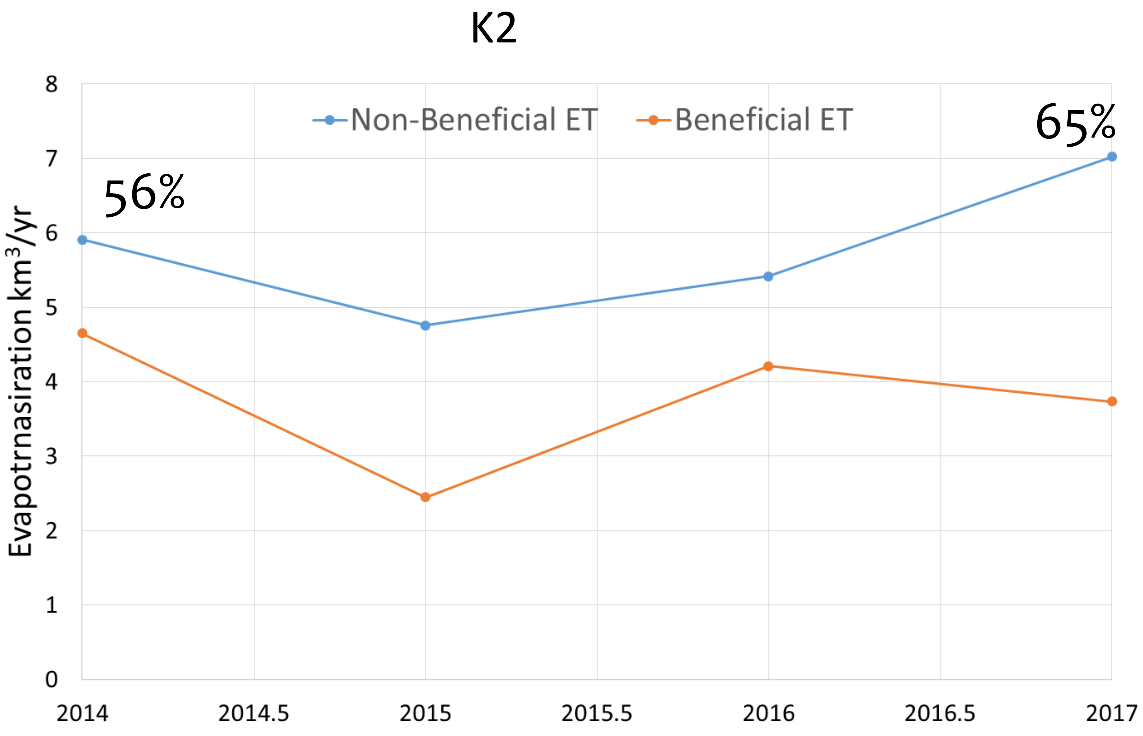
Evapotranspiration

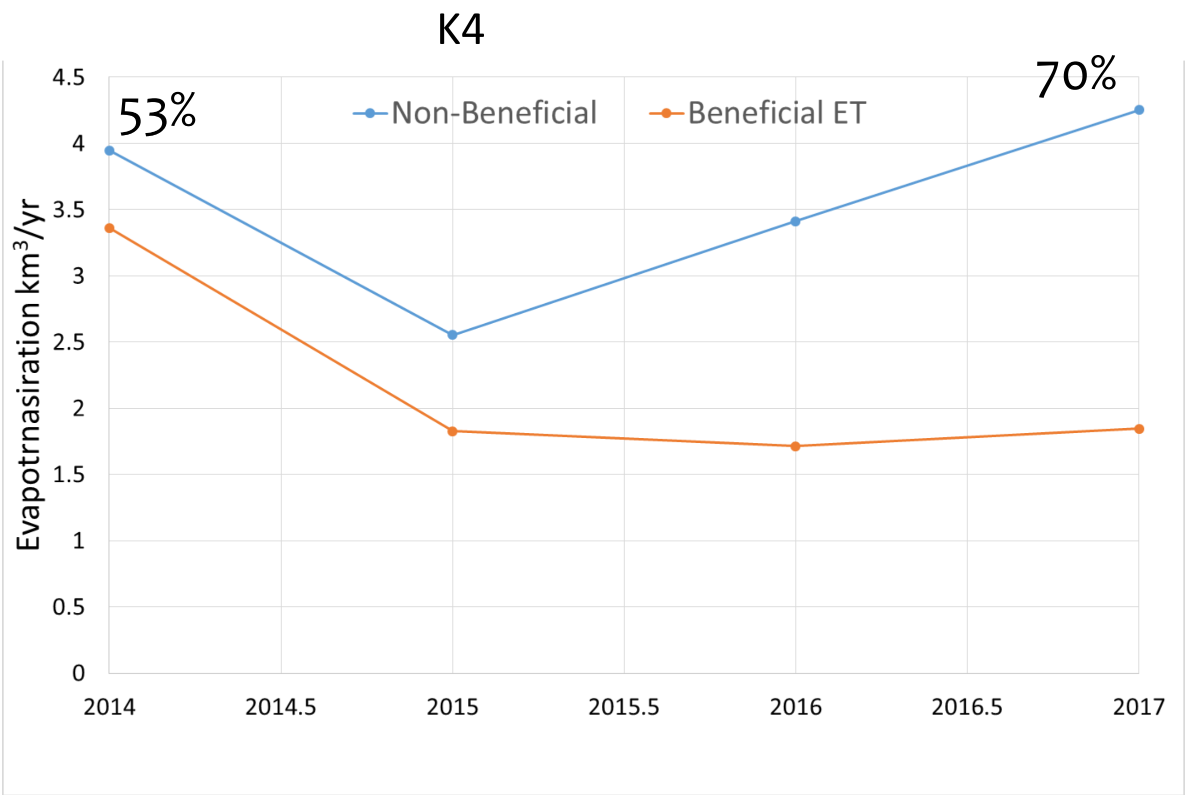
Sheet 2: Evapotranspiration (km3/year)

Period: 2014-2017
Basin: K2



Beneficial and non-beneficial ET inter-annual variability

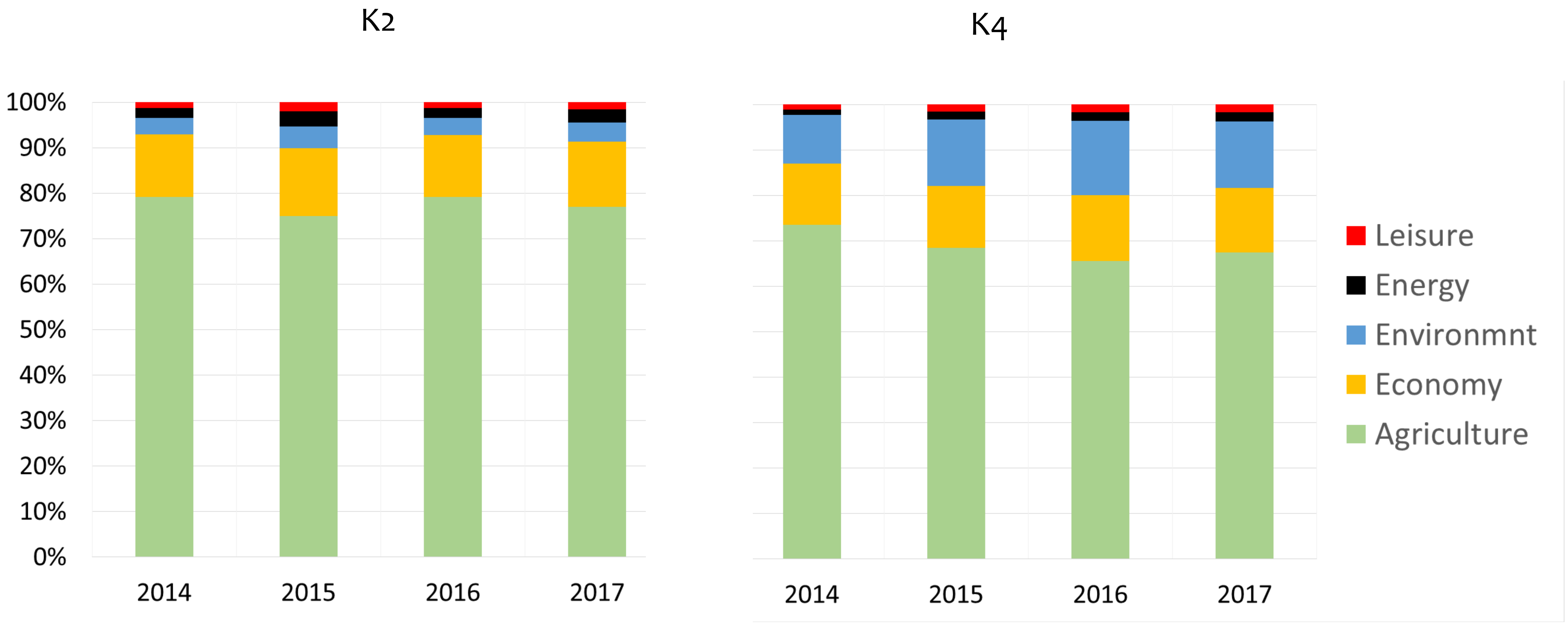




Non-beneficial fraction is increasing mainly due to increased soil water evaporation

→ More efficient irrigation techniques should be considered

The agricultural sector is responsible for 80% of the beneficial consumption



Biomass production and biomass water productivity

K2 2015-2016	Kharif	Rabi	Zaid	Double/Triple Crop	Forest Plantation	
ET	0.77	0.19	0	1.95	0.01	km3/yr
GBP	3492	4917	569	7401	4293	kg/ha
GBWP	1.10	5.50	0.67	1.48	1.69	kg/m3

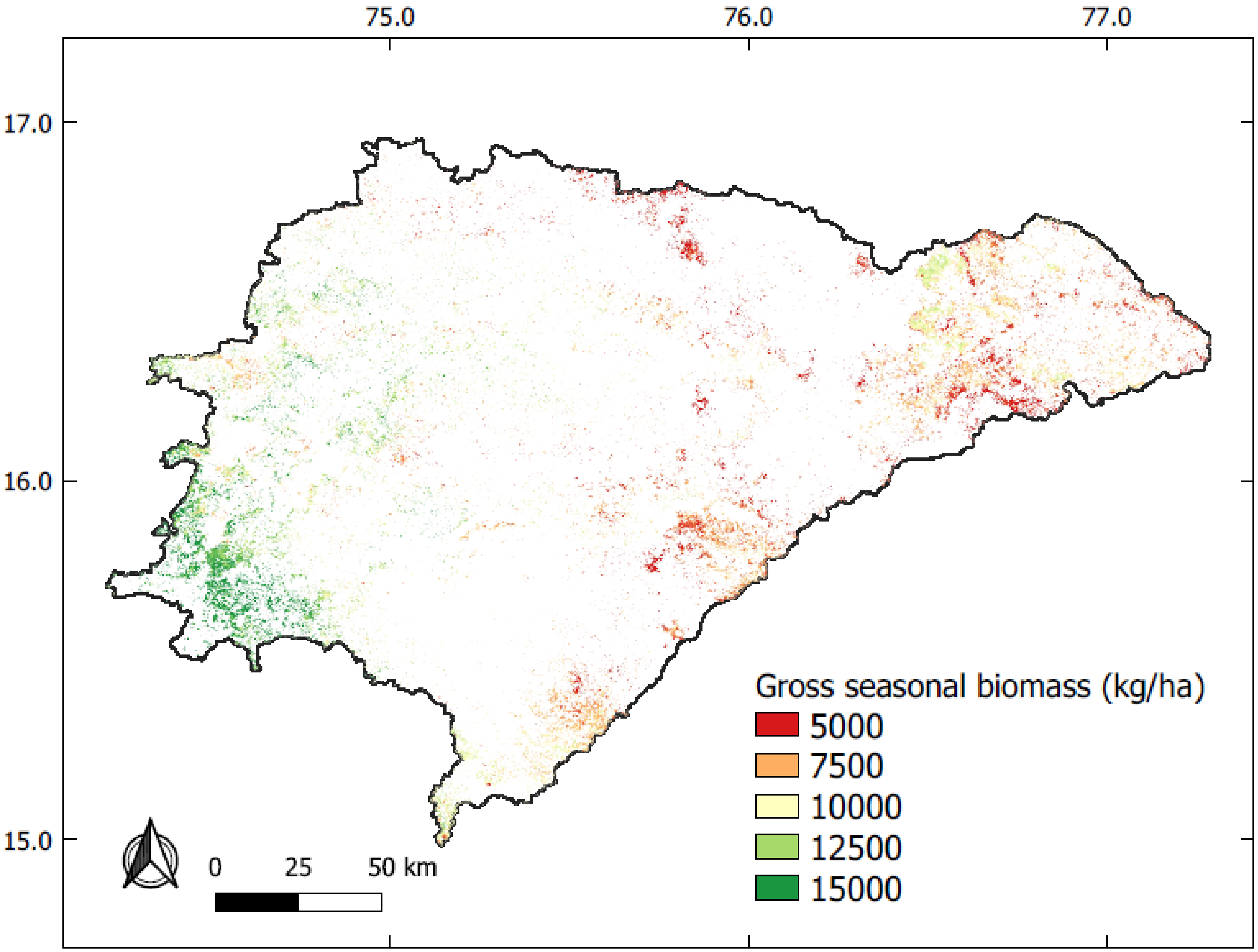
K2 2016-2017	Kharif	Rabi	Zaid	Double/Triple Crop	Forest Plantation	
ET	0.77	0.19	0	1.95	0.01	km3/yr
GBP	4582	7354	334	7279	5088	kg/ha
GBWP	1.56	3.33	0.94	1.70	2.27	kg/m3

K2 2017-2018	Kharif	Rabi	Zaid	Double/Triple Crop	Forest Plantation	
ET	0.77	0.19	0	1.95	0.01	km3/yr
GBP	3467	7757	624	7535	4656	kg/ha
GBWP	1.09	3.00	0.73	1.38	1.65	kg/m3

Biomass production and biomass water productivity

Kharif 2015-2016 (May → October)

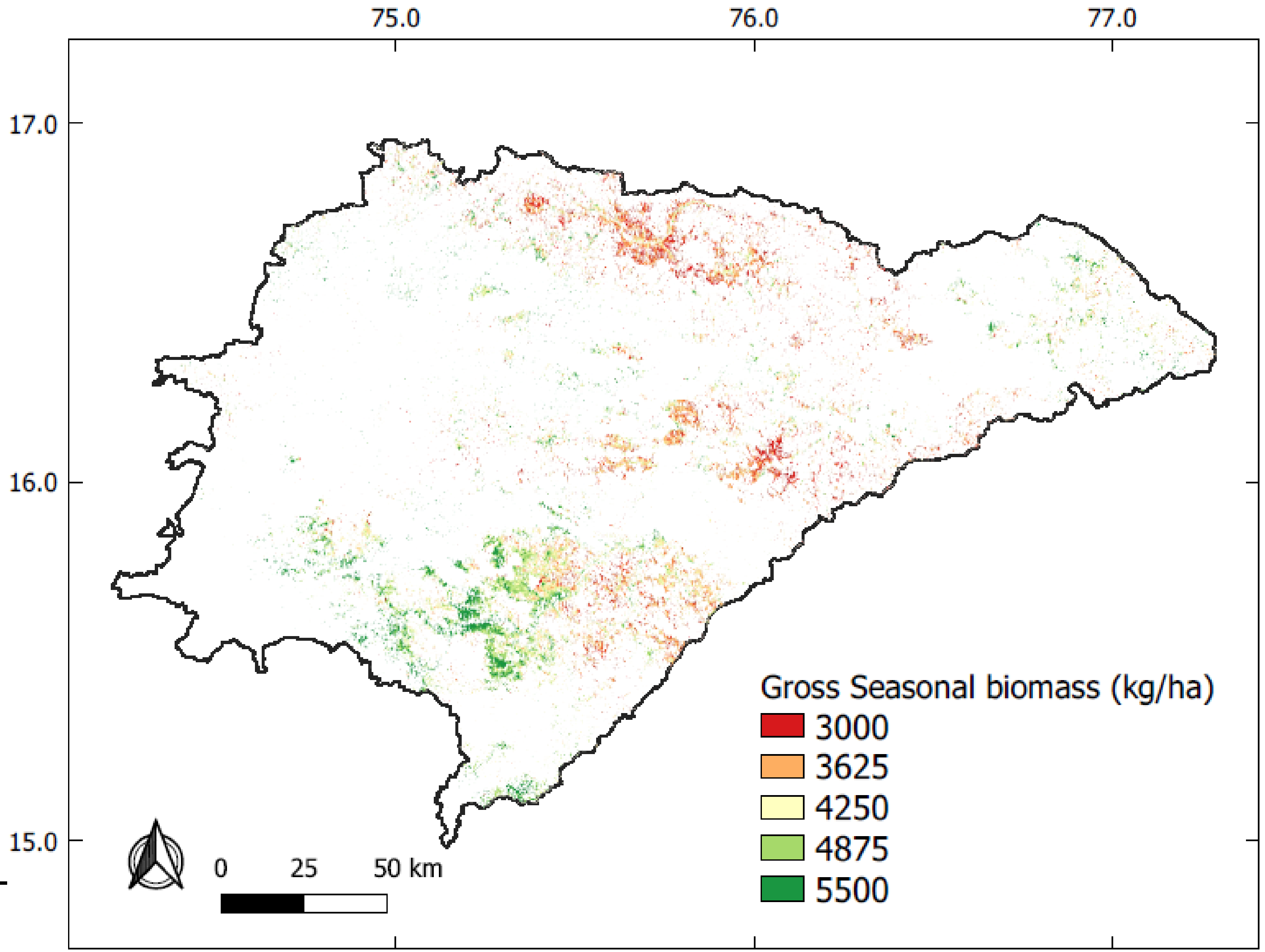
Higher productivity zones
in the upstream areas
→ water availability



Biomass production and biomass water productivity

Rabi 2015-2016 (Nov → Apr)

Similar patterns
→ K4 is more productive
Than the other two basins



Conclusions and recommendations

- We have analysed three basins (K2, K3, K4) using RS data in a 8 year period
  2010-2011 → 2017-2018

- The three basins are highly modified by human activity (agriculture)

- Monsoon climate and high spatial variability of rainfall

- The upstream areas generate most of the runoff while agriculture and reservoirs are net consumers

- P-ET is negative in K2 and positive in K3 and K4
  → K3 and K4 generate water, part of which is then consumed in K2

Conclusions and recommendations

- The three basins are highly dependent on upstream flows (72% of the available water resources in K2). Evaluation of scenarios where inflows are reduced should be tested.

- There is a strong seasonal variability due to the monsoon climate.
  The storage change (both surface and groundwater)
  should be carefully monitored at monthly/seasonal scale.

- The amount of non-beneficial water consumption is high in all basins
  (up to 70% of the total ET) → unproductive soil evaporation.
  Measures limiting soil evaporation should be considered.

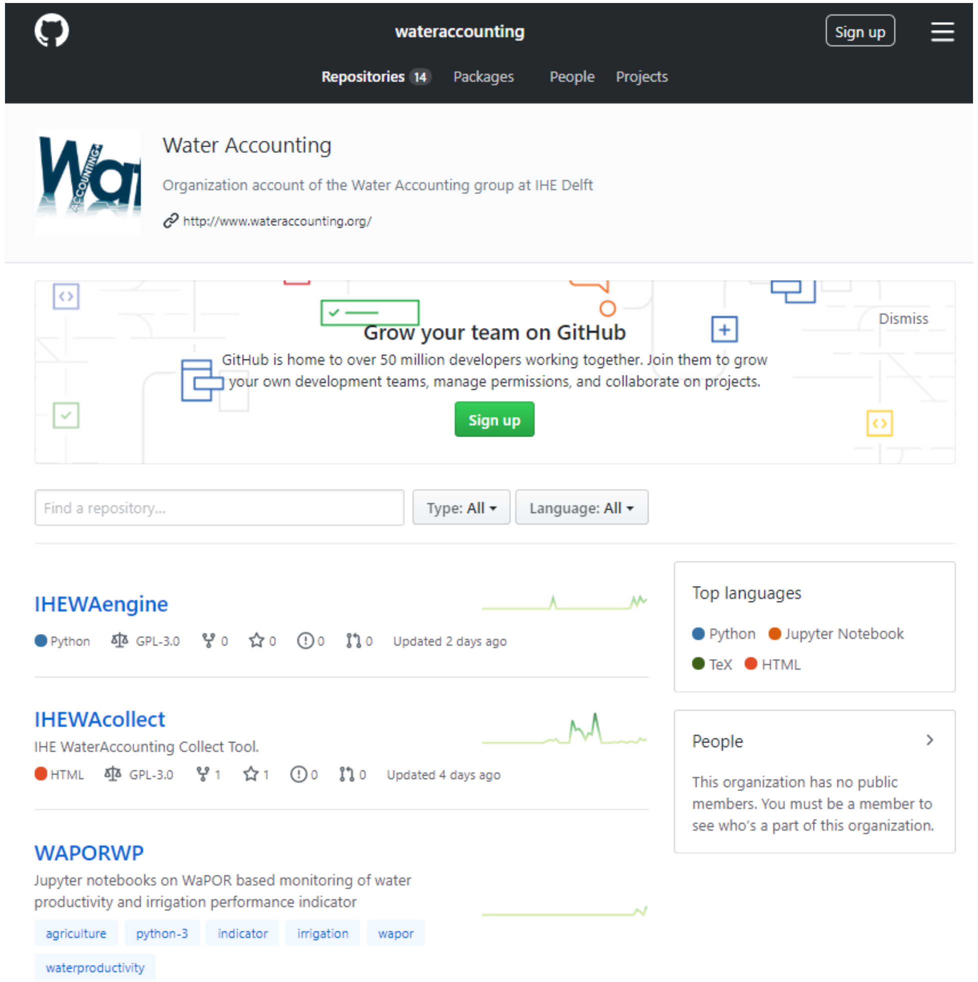
Conclusions and recommendations

- Additional validation and a field survey should be carried out for evaluating the WA+ results and for improving accuracy of the land use map.

Thank you for your attention!

Website: https://wateraccounting.un-ihe.org/

Open Source software on GitHub: github.com/wateraccounting



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