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Water Diplomacy Center
WDC

CNRS
National Council for Scientific Research

Evaluating Transboundary Water Arrangements Training Programme

Modern Science in Hydro-diplomacy

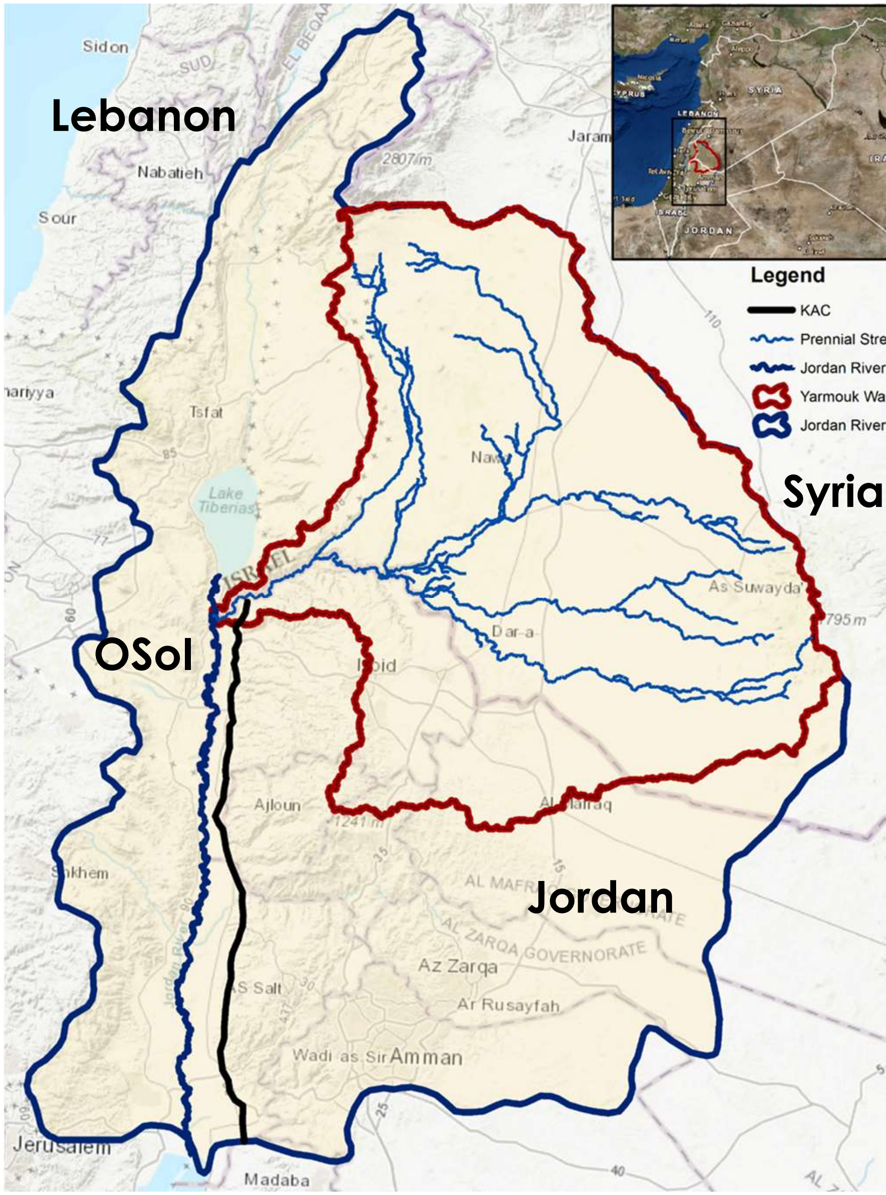
(Yarmouk Basin as a case Study)

By: Chadi Abdallah

Presenter: Hadi Abd Sater

Yarmouk River

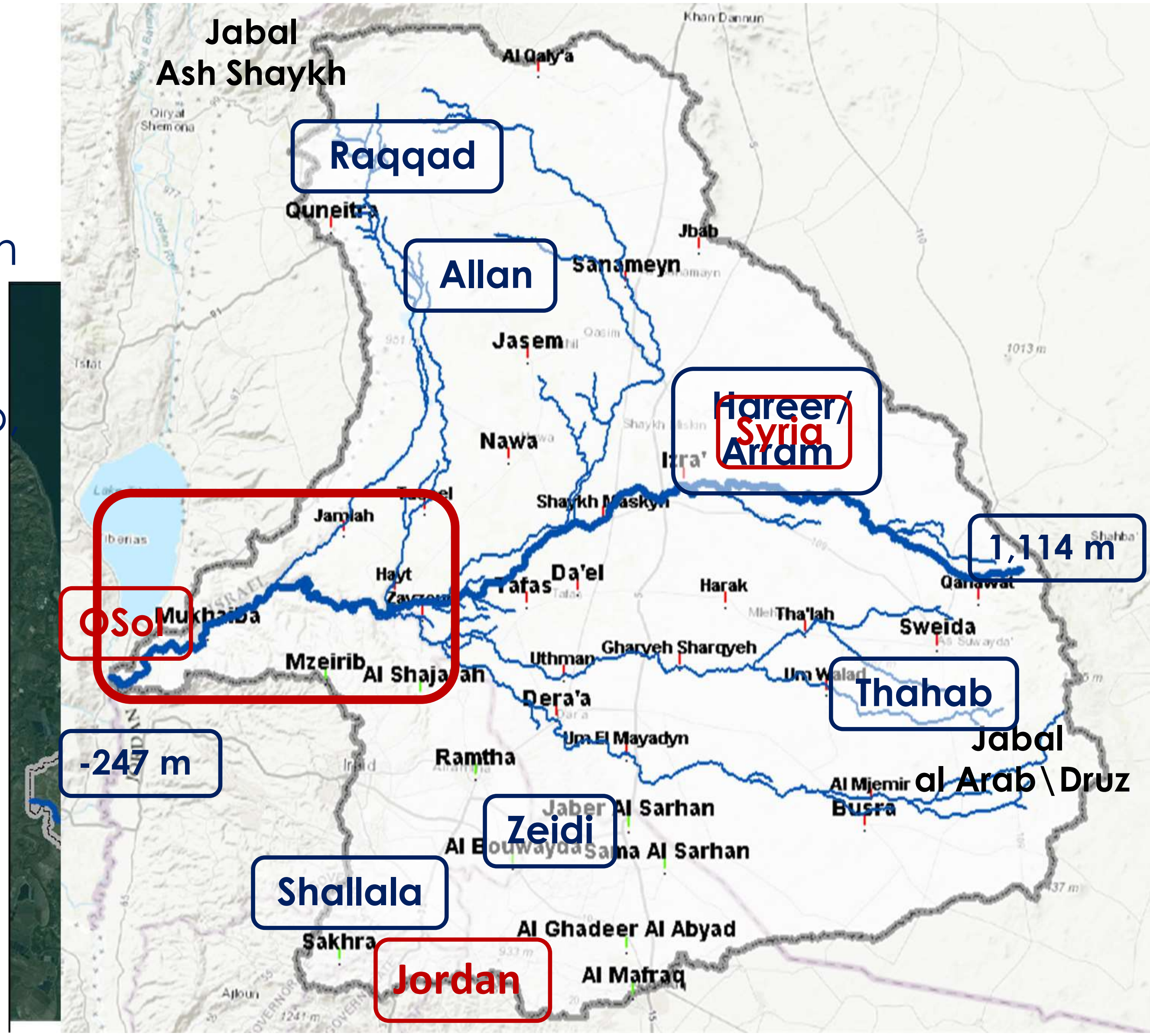
- The largest tributary of the Jordan River
- 40% of the surface water resources of Jordan
- Primary source of water for the KAC
- Originates from different sources in Syria and Jordan
- General E-W flow, surrounded by peaks of Jabal Ash Shaykh in the west and Jabal al Arab in the East, runs through the Hauran towards the JRV and joins the JR a few kilometers south of Lake Tiberias



Yarmouk River

- Area: 7,386 Km^2
- Length of Main Tributary from Highest to Lowest: 144Km
- Main tributaries: Raqqad, Allan, Hareer/Arram, Thahab, Zeidi, Shallala
- 3 countries: Syria (80%), Jordan (19.7%), OSol (0.3%)
- Borders:

- **Syria/Jordan: 31.2 Km**
- **Jordan/Golan: 19.4 Km**
- **Jordan/OSol: 11.1 Km**



Difficulties and challenges

- Difficulty to acquire in-situ data
- Sensitivity in data exchange
- Contradiction and gaps in data
  - Area of the watershed (varies from 6,700 Km2 to 8,378 Km2)
  - Length of the river (varies from 40 Km to 143 Km)
  - Flow data (variable, not always clear)
- Unavailable major datasets
  - Long-term accurate precipitation
  - Flow gauging stations
  - Springs discharge
  - Wells extraction
  - Dams actual retention
  - Detailed LUC

Data sets and characteristics

Digital Globe-ESRI-GeoEye (0.5m/2011& 2019)
LUC 2011& 2020

CORONA (2m/1966)
LUC 1966

SPOT (10m/2009)
CWR estimation

Landsat 5 to 8 (30m/1982-2020)
150 images
Dams actual retention
CWR estimation
LST, NDVI, ET, SMI

MODIS-MOD16 (1Km/2000-2020)
255 images
Evapotranspiration

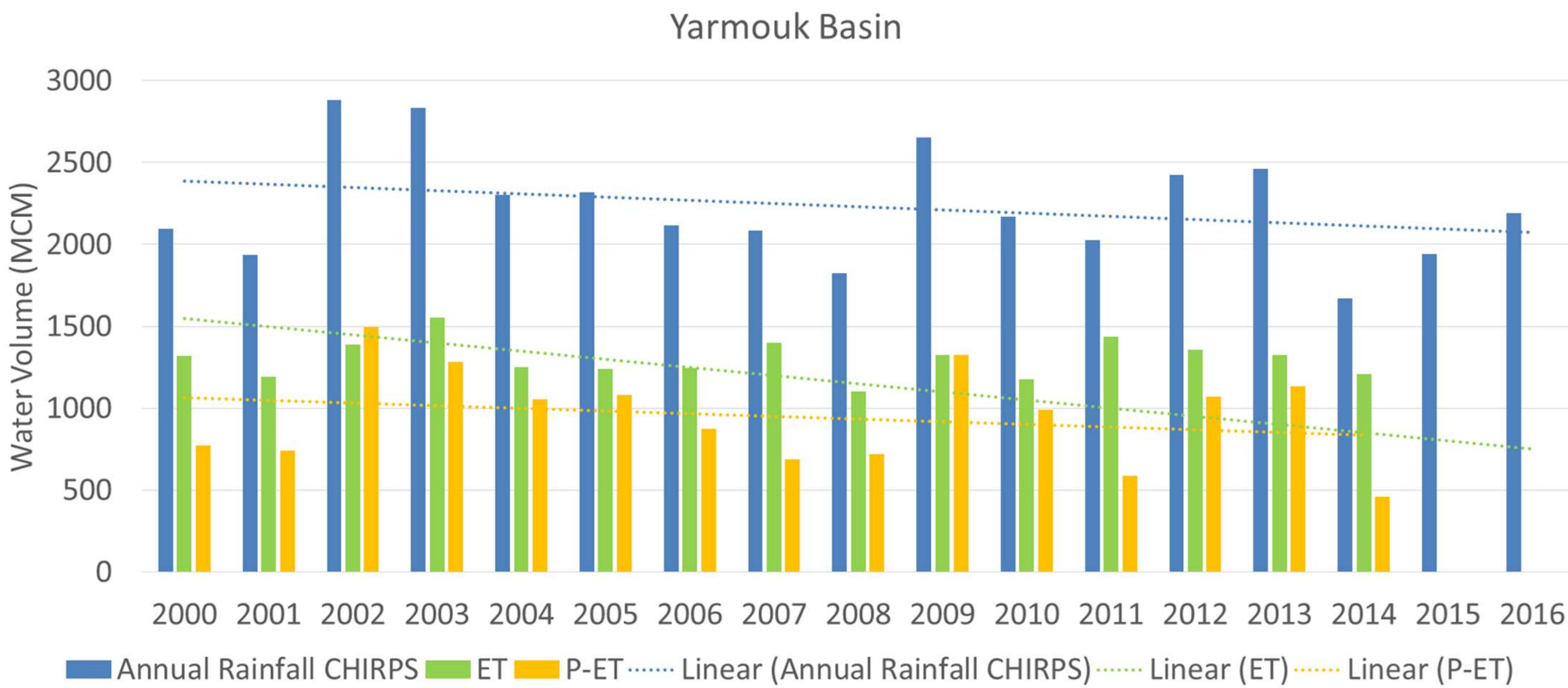
CHIRPS (5Km/1980-2015)
493 images
Precipitation

From the Remote Sensing analysis

- **Climatic properties** (coupled with ground gauging data when available)

  - *Rainfall*: ~ 273 mm/yr between 1981-2008 (CHIRPS)
  - *Maximum Land Temperature*: increase from ~28°C in 1980s to ~33 °C in 2010s (Landsat)

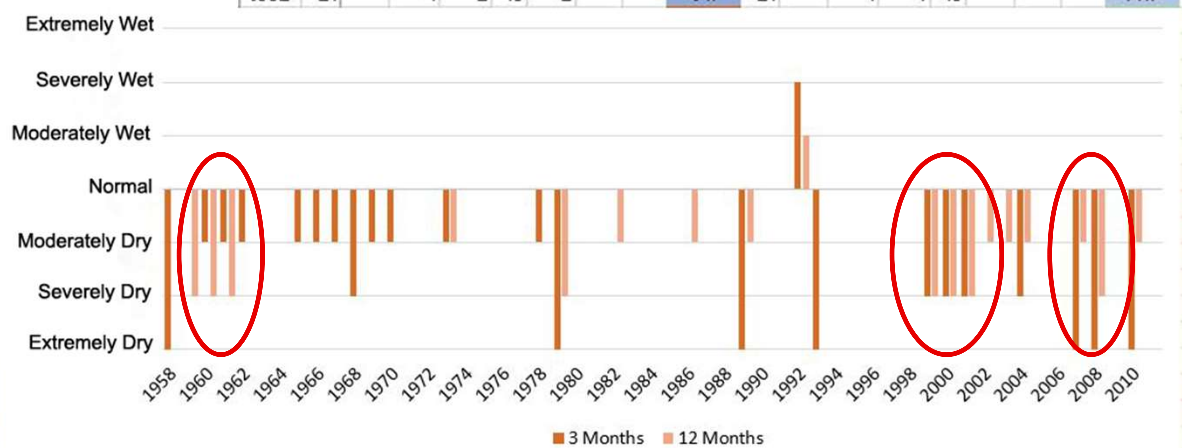
Rainfall, ET and P-ET



Climate – Droughts

- Several drought periods mentioned in literature
- SPI used to study both agricultural (3 months) and meteorological (12 months) droughts
- 21 stations in Syria from 1958 to 2010
- Drought periods in 1960/61, 1999/01 and 2007/08 (conforming with recorded in literature)
- More years classified as dry, especially on short term

	3 Months									12 Months								
	St	EW	VW	MW	N	MD	SD	ED	Class	St	EW	VW	MW	N	MD	SD	ED	Class
1981	21				17	4				21				20	1			
1982	21				20	1				21				14	7			MD
1983	21				21					21				21				
1984	21				21				N	21				20	1			N
1985	21				19	2				21				19	2			
1986	21				19	2				21				9	11	1		MD
1987	21				19	2				21				21				N
1988	21				18	1	1	1		21				19	1	1		
1989	21				2	5	4	10	ED	21				9	11			MD
1990	21				19	2			N	21				18	3			N
1991	21			1	17	3				21				19	2			
1992	21		1	2	16	2			VW	21		1	4	16				MW

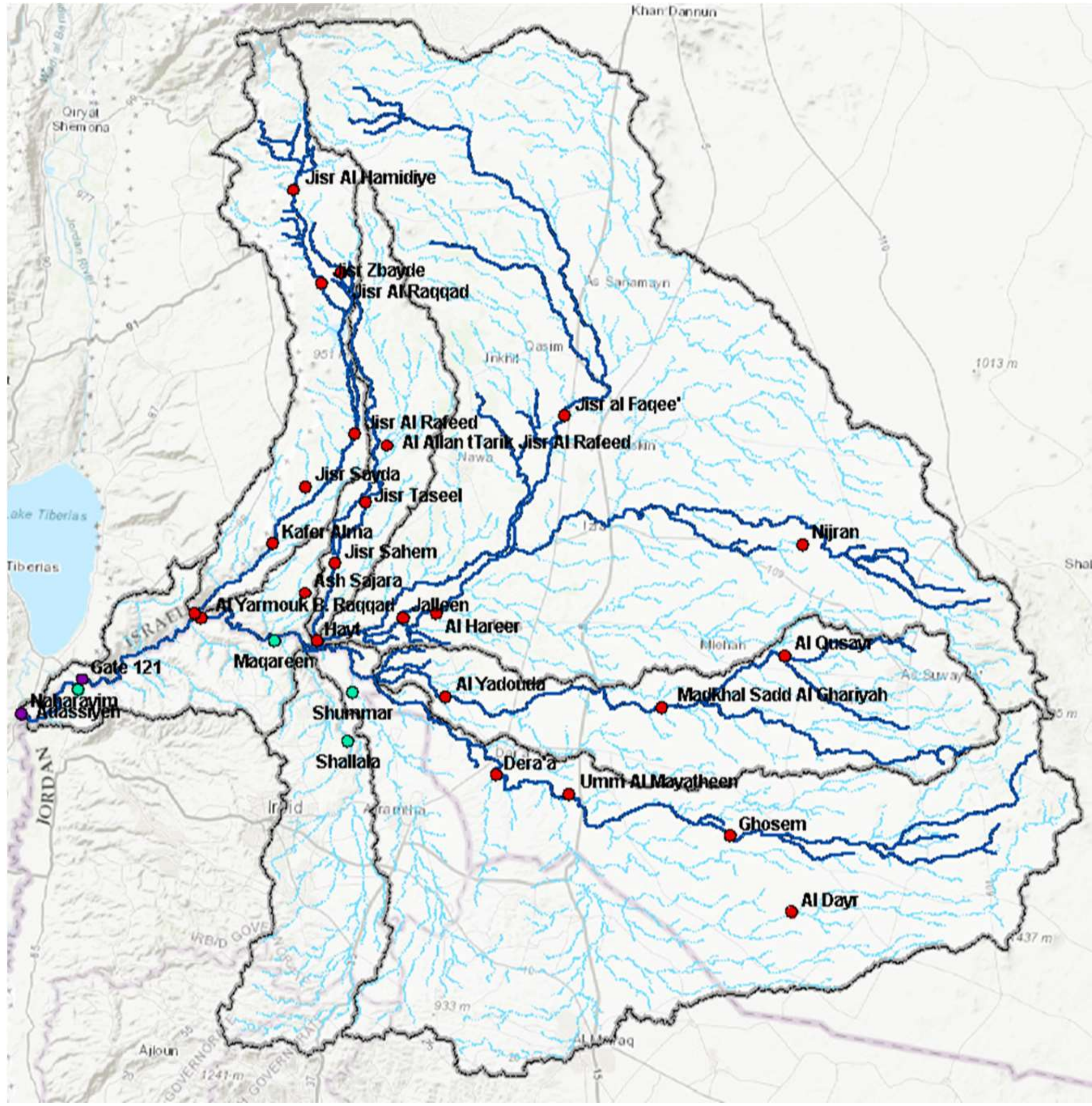


Year	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	198
Al Harra	-0.28	-0.41	-0.27	-0.91	-1.23	-0.04	-0.82	0.06	-0.18	0.07	-1.52	0.62	-0.12	-0.73	-0.[illegible]
Busr Sham	-0.63	-0.57	-0.43	-0.48	-0.86	-0.82	-0.89	-1.01	-1.37	-0.79	-0.36	-0.25	-0.65	-1.00	-0.[illegible]
Buthaina						0.49	-0.43	-0.47	-0.05	-0.78	-1.62	0.17	-0.13	-1.10	0.[illegible]
Dourin					-0.76	-0.29	-0.83	-1.05	-0.74	-0.08	-1.61	-0.25	-0.21	-0.98	-0.[illegible]
El Mesmiyee	-0.48	-0.37	-0.72	-0.33	-0.52	0.20	-2.82	-0.84	-0.66	-0.08	-1.71	0.47	-0.33	-1.05	0.[illegible]
Enkhel					-0.23	-0.45	-0.61	-1.06	-0.69	-0.87	-0.73	0.46	-0.25	-0.14	-0.22
Hadar												0.45	-0.72	-1.04	-0.[illegible]4
Izra	0.29	-0.24	-0.53	-0.51	-0.68	0.15	-0.30	-0.84	-0.45	-0.60	-1.80	0.63	-0.56	-0.98	-0.08
Jasem						-0.98	-0.71	-0.33	-0.91	-0.01	-1.82	0.07	-0.88	-0.96	-0.53
Khabab	0.23	-0.77	-0.57	-0.06	-0.98	0.04	-0.78	-0.23	-0.89	-0.50	-1.74	0.17	-0.53	-1.38	-0.47
Khelkhale								-0.18	-0.75	-0.49	-1.31	0.62	-0.01	-1.19	0.44
Museifrah	0.21	-0.60	-0.42	-1.01	-1.12	0.58	-0.45	-0.41	-0.66	-0.24	-1.56	0.36	-0.35	-0.28	-0.54
Nab'Sakher												0.48	[illegible]	-0.86	-0.01
Nava	-0.22	-0.58	-0.45	-0.30	-0.69	-0.40	-0.38	-1.03	-0.45	-0.40	-1.78	0.47	-0.93	-0.75	0.10
Salkhad	-0.17	0.00	-0.55	-0.13	-0.11	-0.41	-0.05	-0.75	-0.89	-1.06	-0.15	-0.20	-0.20	-0.69	-0.72
Sanameine	0.08	-0.66	-0.71	-0.80	-0.40	-0.63	-1.13	-0.69	-1.06	-1.00	-1.82	0.39	0.23	-0.70	0.37
Shahba	-0.24	-1.05	-0.25	-0.35	-1.15	-0.66	-1.00	-0.08	-1.05	-0.51	-1.53	0.36	-0.39	-0.59	0.25
Sowarah	-0.80	-1.07	-0.28	-0.69	-0.64	-0.61	-0.19	-0.16	-0.93	-0.70	-0.98	-0.01	-1.07	-0.98	0.26
Sweida	0.28	-0.80	-0.23	-0.37	-1.34	-0.04	-1.05	-0.95	-0.10	-0.78	-1.47	0.67	-0.50	-0.75	-0.40
Tel Shehab	-0.03	-0.62	-0.07	-0.72	-0.74	-0.11	-0.83	-0.72	-0.64	-1.05	-1.55	0.97	-0.67	-1.00	0.06
Ghabagheb	-0.24	-0.70	-0.25	0.27	-0.70	0.18	-0.46	-0.12	-0.91	-1.00	-0.84	-0.08	0.15	-0.49	-0.31

Year																						
Enkhel	-0.21	-0.68	-0.81	0.89	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
Hadar	-0.27	-0.23	-0.58	0.06	0.01	-1.11	-1.09	-0.83	0.85	-0.90	-0.18	-0.83	-0.79	-0.26	-0.65	-0.41	-0.81	-0.96				
Izra	-0.68	-0.57	-1.12	0.04	-0.73	-1.04	-0.21	-0.53	0.61	-0.10	-0.10	-0.02	-1.32	-0.14	-0.57	-1.77	-0.86	-0.88	-0.83	0.82		
Jasem	-0.15	-0.53	-1.26	0.05	-0.60	-1.08	-0.69	-0.67	0.98	-0.18	-0.11	-0.19	-0.48	-0.82	-0.08	-1.08	-0.04	-0.70	-0.74	0.62	0.02	-0.47
Khabab	-0.64	-0.41	-1.34	-0.41	-0.77	-1.22	-0.35	-0.51	0.47	-0.42	-0.34	0.20	-0.73	-1.03	-0.90	-1.65	-0.61	-1.37	-0.25	0.96	-0.28	-0.79
Khelkhale	-0.14	-0.47	-0.90	-0.24	0.02	-1.19	-1.20	-0.72	-0.55	-0.46	-0.38	0.00	-0.74	-0.55	-0.22	-1.62	-0.11	-0.97	-0.97	-0.97	0.15	-0.69
Museifrah	-0.08	-0.66	-0.87	-0.35	-0.35	-0.58	-0.29	-1.04	1.14	-0.01	-0.52	-0.02	-0.69	-0.26	-0.93	-1.97	0.17	-0.16				
Nab'Sakher	-0.09	-0.13	-1.13	0.59	-0.68	-1.26	-0.75	-0.83	0.68	-0.47	-0.32	-0.73	-0.19	-0.30	-0.88	-1.02	-0.37	-1.06	-1.06	0.68	-0.67	-0.19
Nava	-0.44	-0.58	-1.56	0.26	-0.38	-1.26	-0.72	-0.28	1.82	-0.51	-0.21	-0.27	-1.01	-0.90	-0.44	-1.77	-0.15	-0.59	-0.99	-0.99	-0.90	-1.18
Salkhad	-0.19	-0.80	-0.22	0.48	-1.36	-0.46	-0.85	-0.54	0.40	-0.72	-1.34	-0.15	-0.47	-0.45	-1.40	-1.56	-1.81	-0.54	-0.94	-1.39	-0.15	-0.54
Sanameine	0.17	-0.22	-1.31	-0.12	-0.58	-0.73	-0.90	-0.97	0.30													
Shahba	-0.95	-0.53	-0.86	0.80	0.12	-1.34	-0.98	-0.09	0.54	-0.42	-0.05	-0.84	-0.82	-0.43	-0.13	-1.80	-0.65	-0.78	-0.51	0.85	-0.17	-1.03
Sowarah	-0.05	-0.51	-0.13	-0.77	0.18	-3.08	0.23	-0.78	0.17	-0.79	-0.10	-0.41	-0.11	-0.47	-0.65	-0.87	-1.50	-1.66	-0.18	-2.37	-1.01	
Sweida	-0.28	-0.11	-0.96	-0.28	-0.59	-0.73	-0.03	-0.46	0.49	-0.32	-1.07	-0.44	-0.78	-0.14	-0.44	-2.12	-1.10	-0.85	-1.00	0.25	-1.22	-0.12
Tel Shehab	-0.83	-0.21	-0.88	-0.25	-0.54	-0.90	-1.06	-0.36	0.48	1.00	-0.21	-0.07	-0.11	-0.48	-0.39	-1.86	-0.51	-1.15	-0.36	0.84	-1.06	-0.39
Ghabagheb	-0.40	-0.27	-1.48	-0.57	-0.96	-0.55	-0.85	-1.13	1.32	-0.41	-0.14	-0.13	-0.55	-0.22	-0.91	-1.00	-1.05	-1.57	-1.39	0.27		

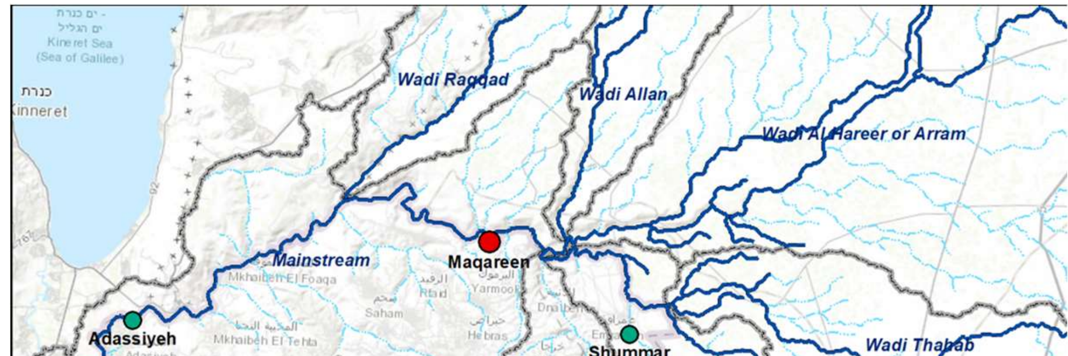
Surface Water – Gauges

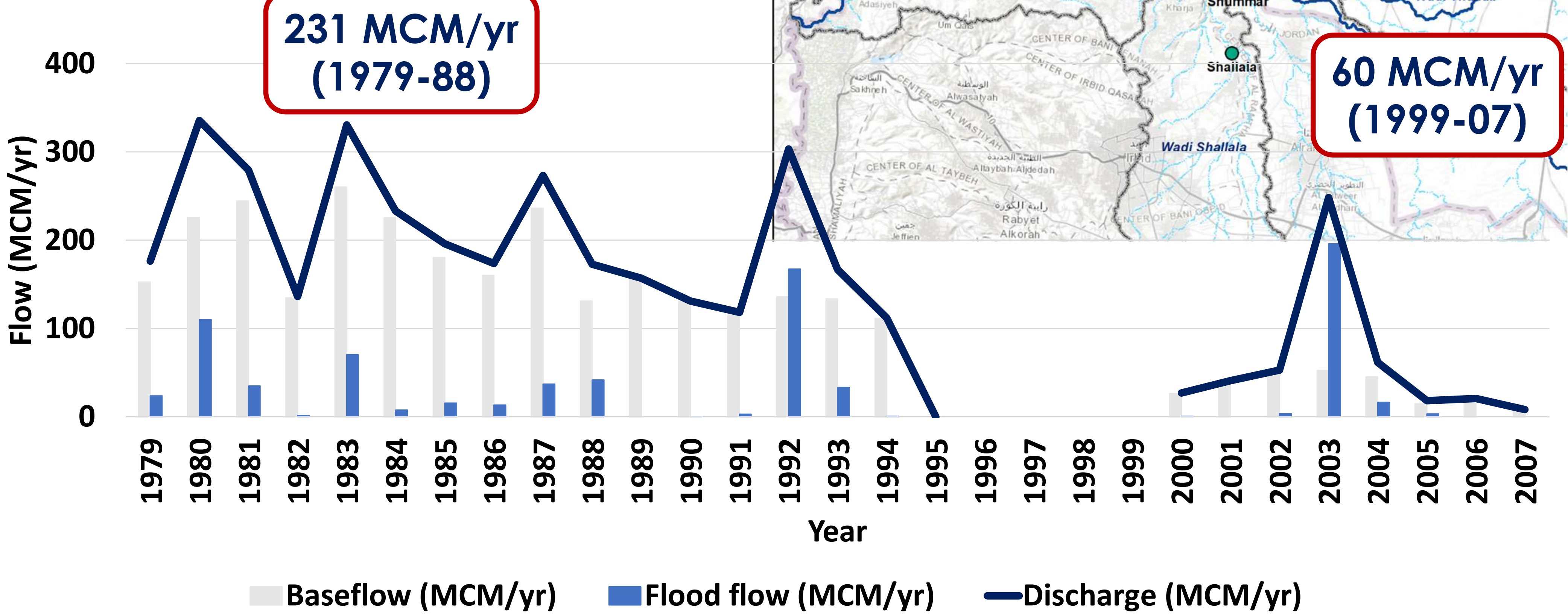
- Stations acquired from JVA, HSI and literature review in Syria
- Syria: approximations for sub-watershed
- Jordan: 4 stations with baseflow and flood flow data
- OSoI: 2 stations with only total flow



Jordan – Maqarin

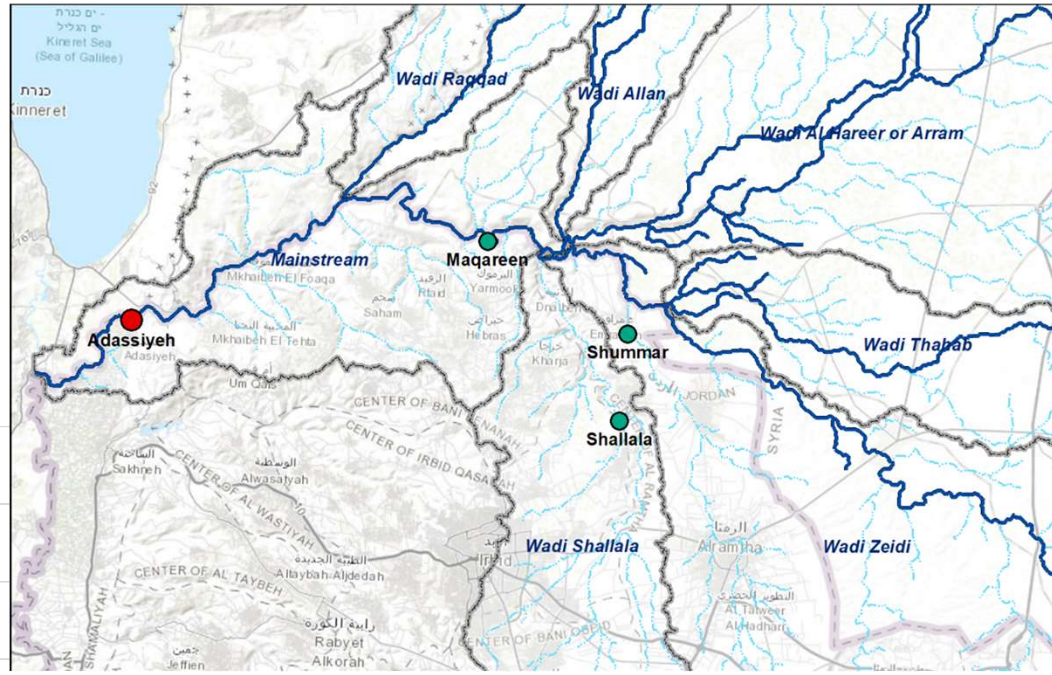
Near the site of the Wehdeh Dam.
Input from all sub-watersheds except Al Raqqad

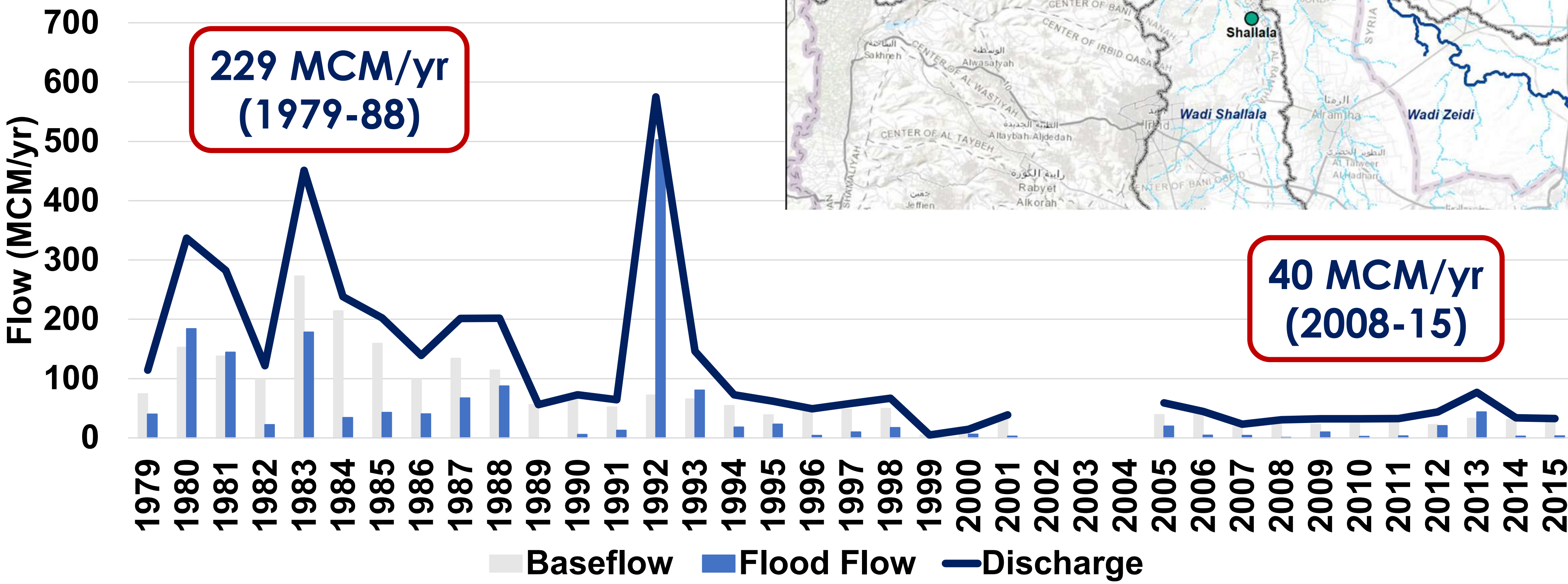




Jordan – Adassiyeh

Endpoint of the Yarmouk River,
location of the Adassiyeh weir.
Input from all sub-watersheds



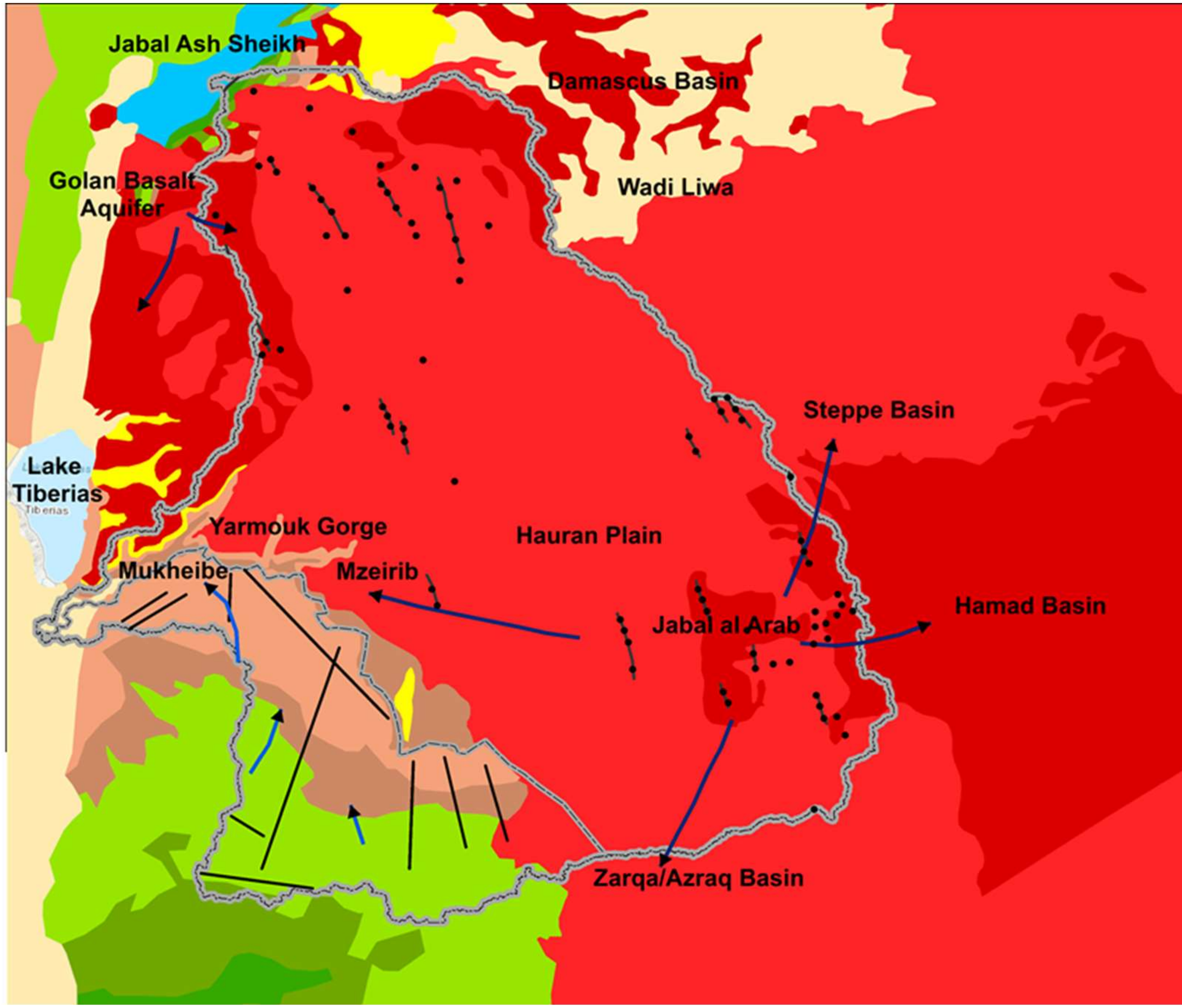


Geology

- From Upper Cretaceous to Quaternary
- Mainly basalt (78%) Al Husban (2016)
- Jordan: oldest outcrops = Upper Cretaceous → Eocene
- Syria: more recent outcrops = Paleogene → Quaternary deposits
- Difficulty: comparing the names and thickness of strata, the system used in Syria is the ***chronostratigraphic chart***, while the system used in Jordan is that of ***Formations***

Geological map

Compilation from different studies



Legend

- • Extinct Volcanoes in Syria
- Flow Direction in the Basalt Aquifer (Different Sources)
- Flow Direction in the A7/B2 (BGR, 2001)
- Faults in Jordan
- Faults in Syria
- Yarmouk Watershed
- International Border

Geology

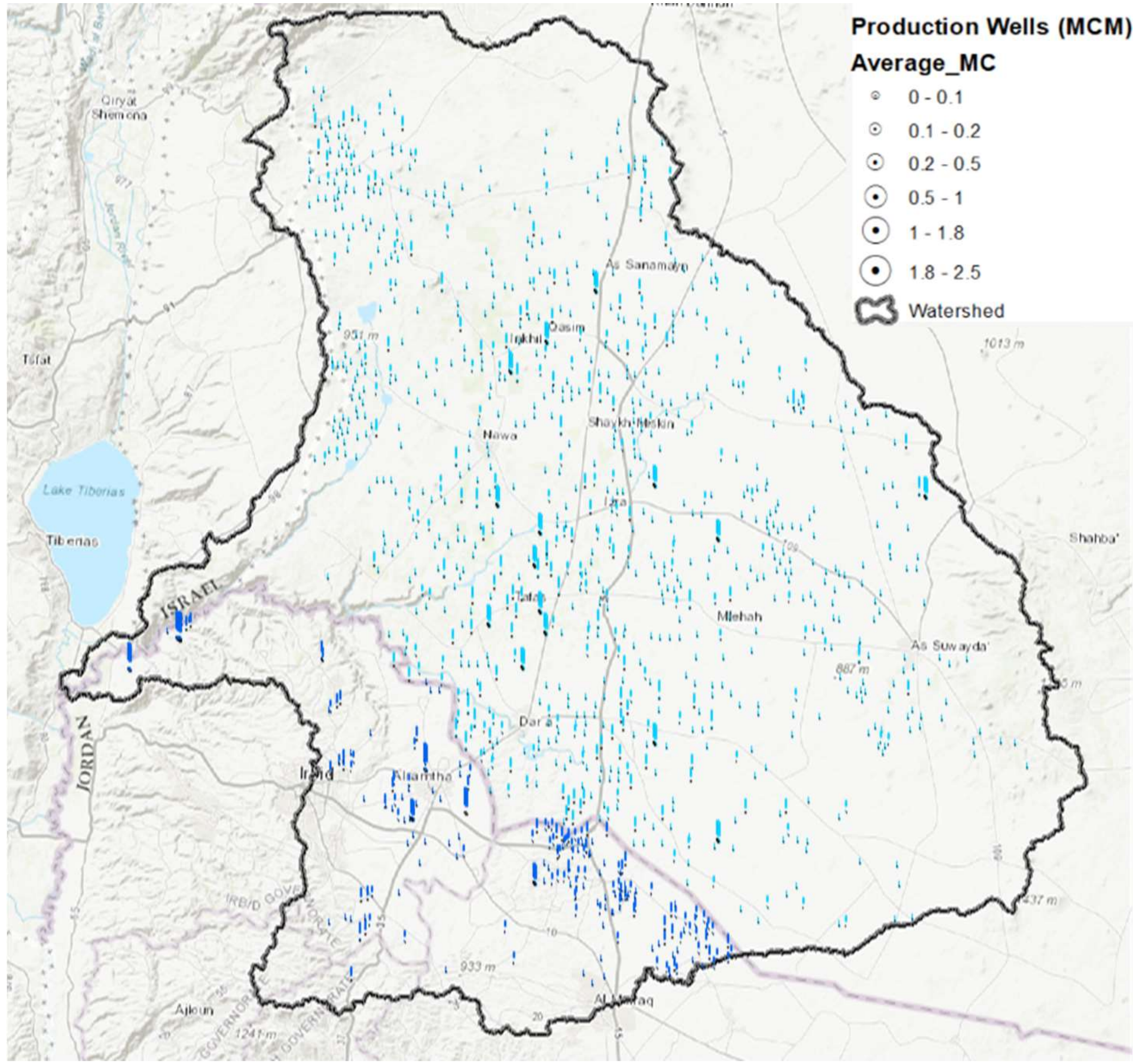
- Quaternary Basalts
- Neogene Basalt
- Quaternary Deposits
- Neogene
- B4/B5 - Pg2-2/Pg2-3
- B3 - Pg1-Pg2-1
- A7/B2 - Cr2cn cp/Cr2m-d
- A1/A6 - Cr2cm-t
- K - Cr1-Cr2t
- Jurassic
- Zarqa Group

Hydrogeology

System	Formation	Code	Age	Lithology	Type
Upper Aquifer	Basalt		Neogene - Quaternary	basalt	Aquifer
	Um Rijam/Wadi Shallala	B4/B5 – Pg_2^2 /Pg_2^3	Eocene	limestone, marl	Aquifer
	Muwaqqar	B3 – Pg_1-Pg_2^1	Paleocene	marl, chalky limestone	Aquitard
Middle Aquifer	Wadi As Sir/Amman - Al Hissa	A7/B2 – Cr_2cn cp/Cr_2m-d	Coniacian - Maastrichtian	chalky, dolomitic limestone	Aquifer
	Naur / Shueib	A1/A6 – Cr_2cm-t	Cenomanian – Coniacian	Marl, Chalky Limestone	Alternation
Deep Aquifer	Kurnub	K – Cr_1-Cr_2 t	Lower Cretaceous	Sandstone	Aquifer

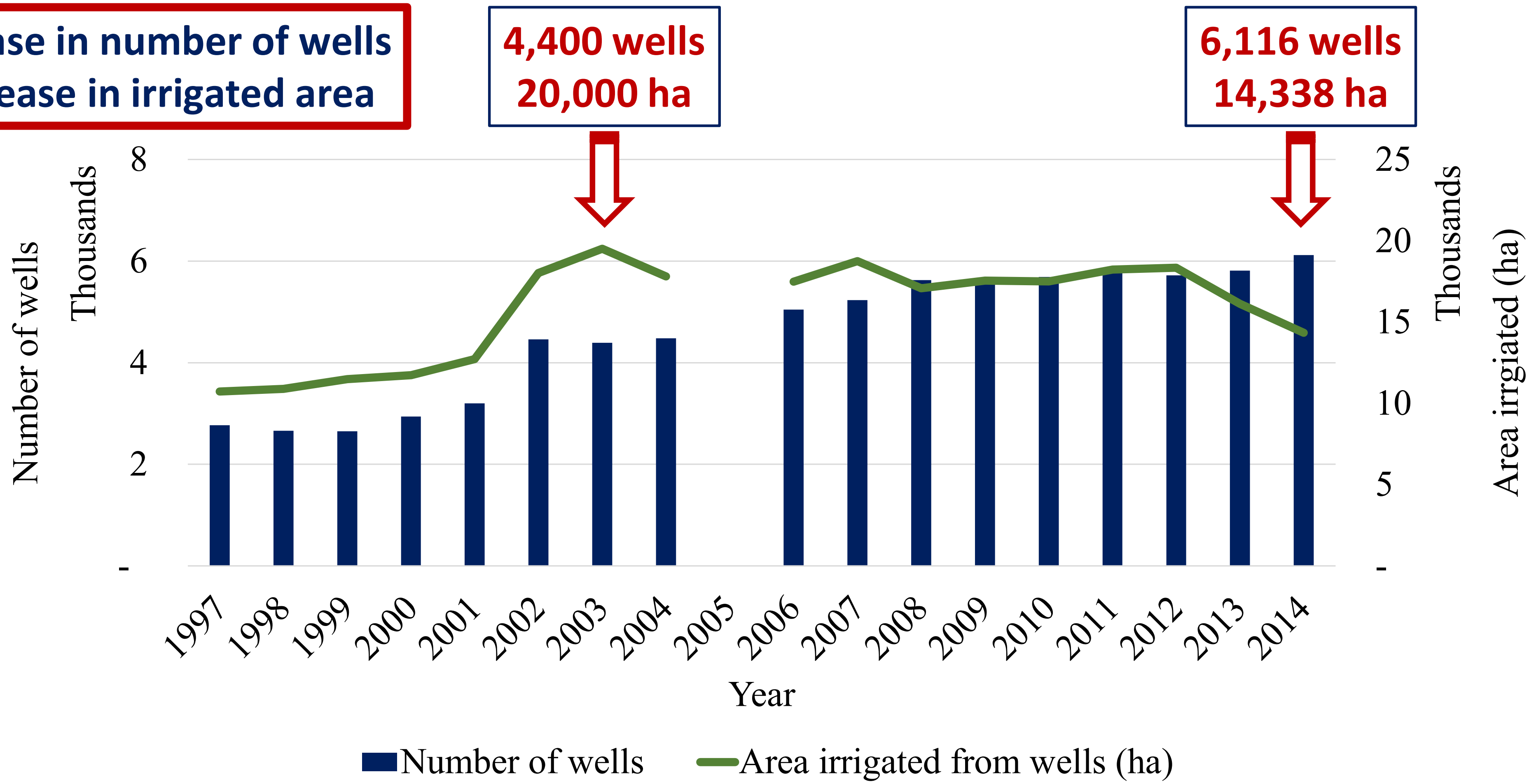
Groundwater abstraction

- More than 5,000 wells in the basin, including 4,000 in Syria (Al Husein, 2007)
- Syria: ~150 MCM/yr (>1,000 wells) from the Basalt Aquifer
- Jordan: ~40 MCM/yr (>200 wells) from the A7/B2 Aquifer
- More is actually pumped in both countries

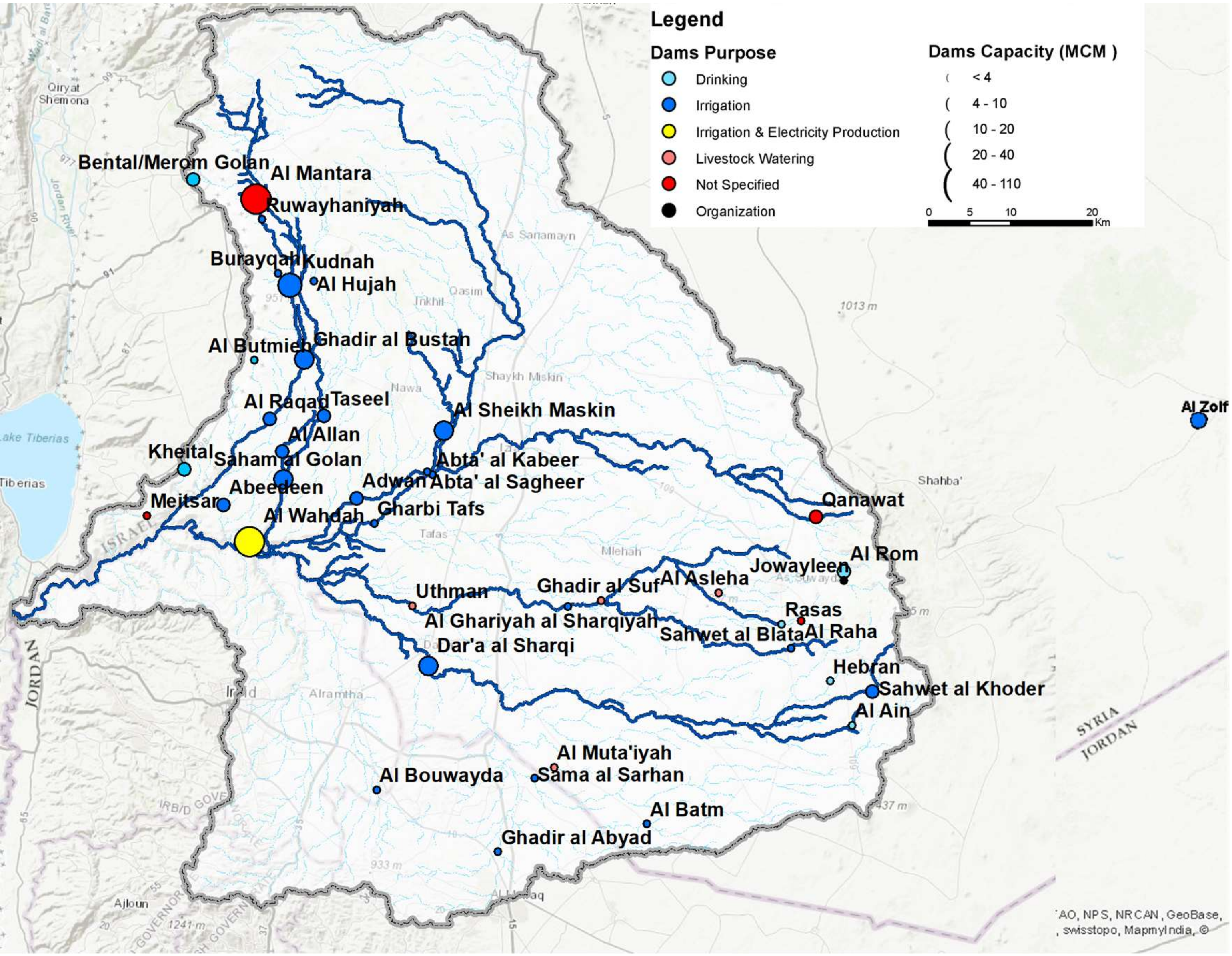


Number of wells and area irrigated in Syria

Increase in number of wells
Decrease in irrigated area



Dams and Surface water storage and use



Syria:
42 dams
247.5 MCM

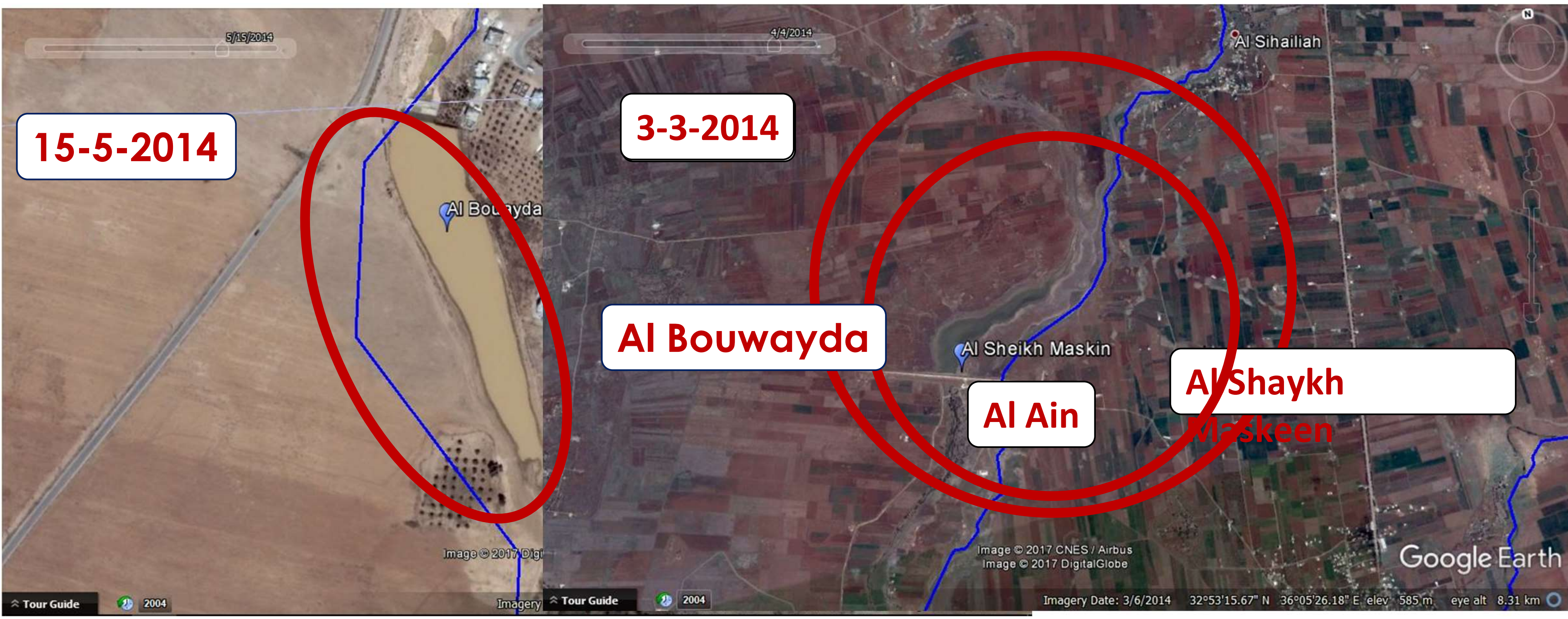
Jordan:
4 dams
113.1 MCM

Occupied Golan:
4 dams
10.1 MCM

Inside Yarmouk:
40 dams
~ 328 MCM

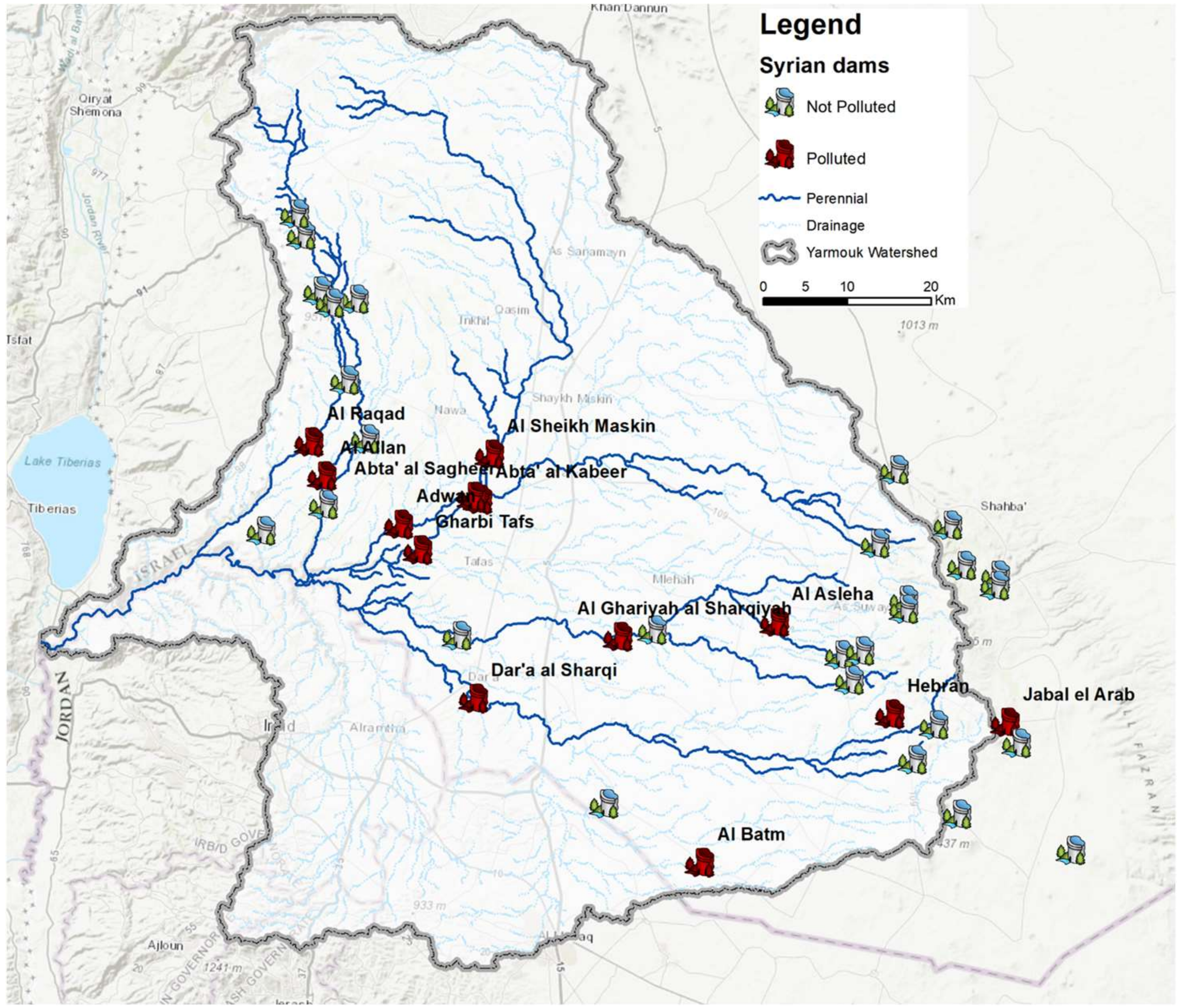
Dams' water retention

- Dams rarely totally filled (retention in Dera'a dams: 20-40%)
- Jordanian dams suffer from sedimentation



Dams' Pollution

- **Endpoint** of the accumulation of water coming from the valley → **wastewater contamination**
- Some became unexploitable due to extreme pollution
- 13 dams are out of service because of pollution (~63 MCM)



Dams’ actual retention

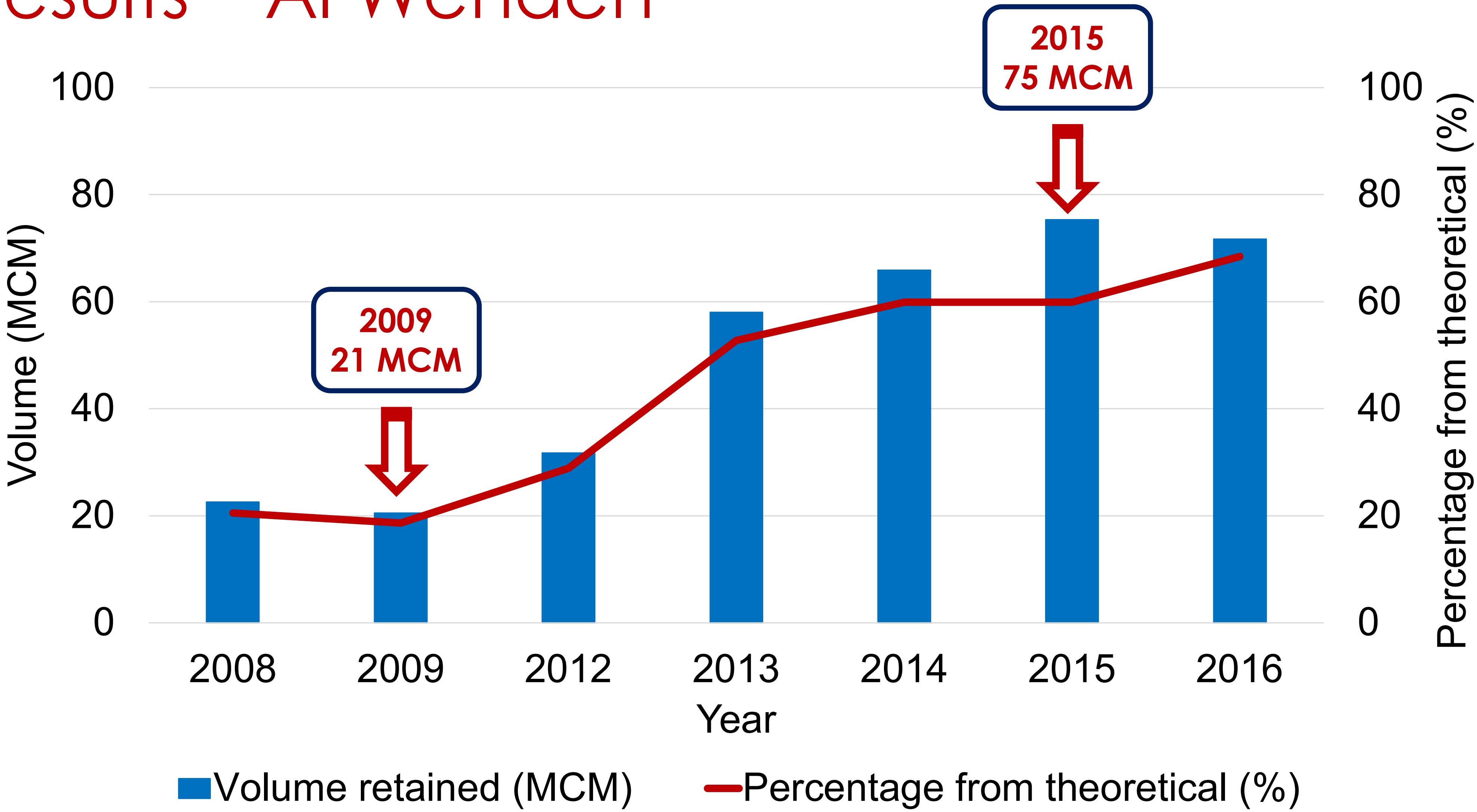
Due to lack in:

- Lack of accurate field estimates
- No field visits to the Syrian dams

Methodology

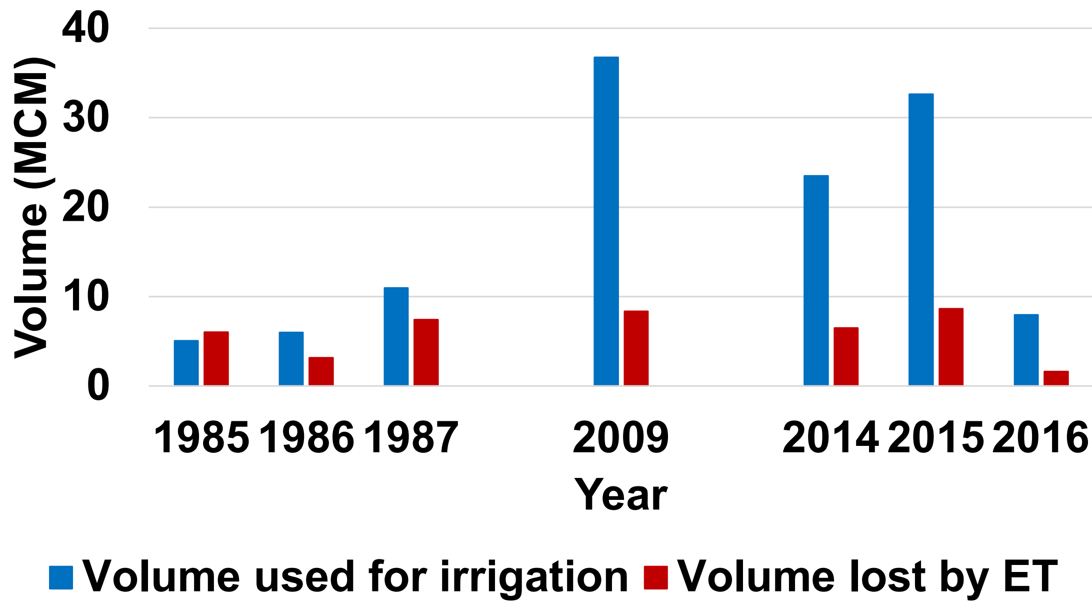
- Data acquisition (Landsat 5 and 7)
- Extraction of NIR band from Landsat data
- Delimitation of dams' area using GIS tools
- Estimation of volume (MCM) : V = A x D / 3
- Validation: maximum volume compared to theoretical volume => 80%

Results – Al Wehdeh

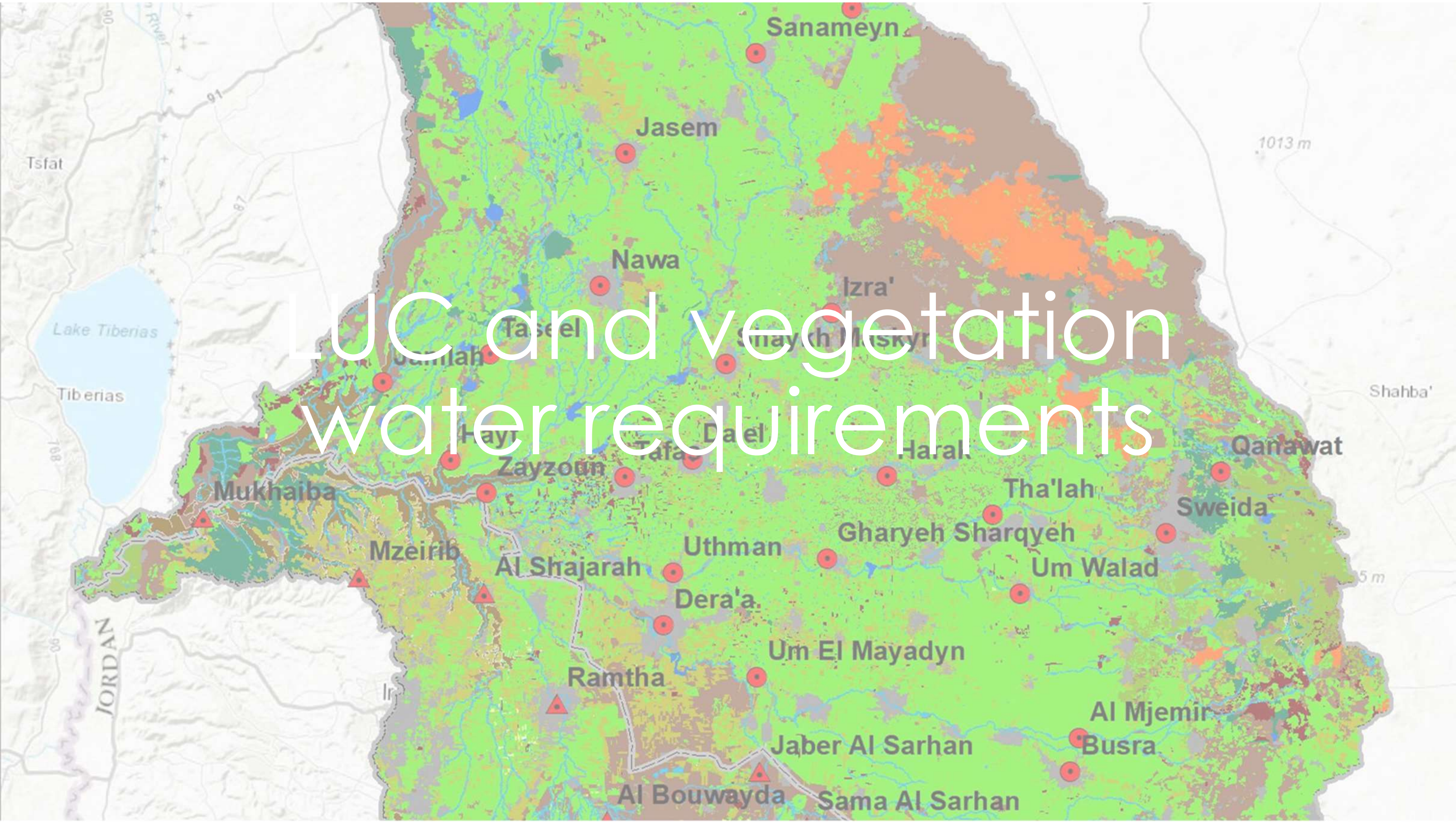


Volume used from dams

- Most of the dams are purposed for irrigation
- Estimation of the amount of water used for irrigation
- DI = (V Spring – V Summer) – ET dam
- Used volume reached a peak in 2009 and decreased afterwards

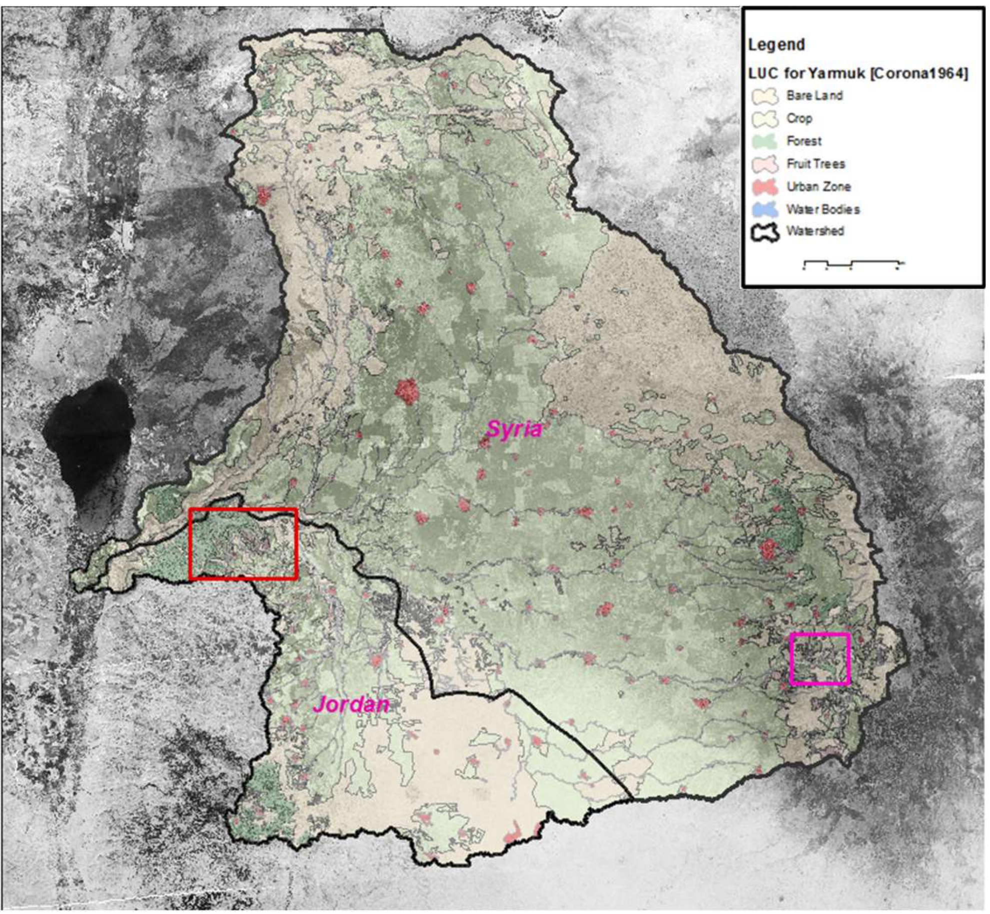


LUC and vegetation water requirements

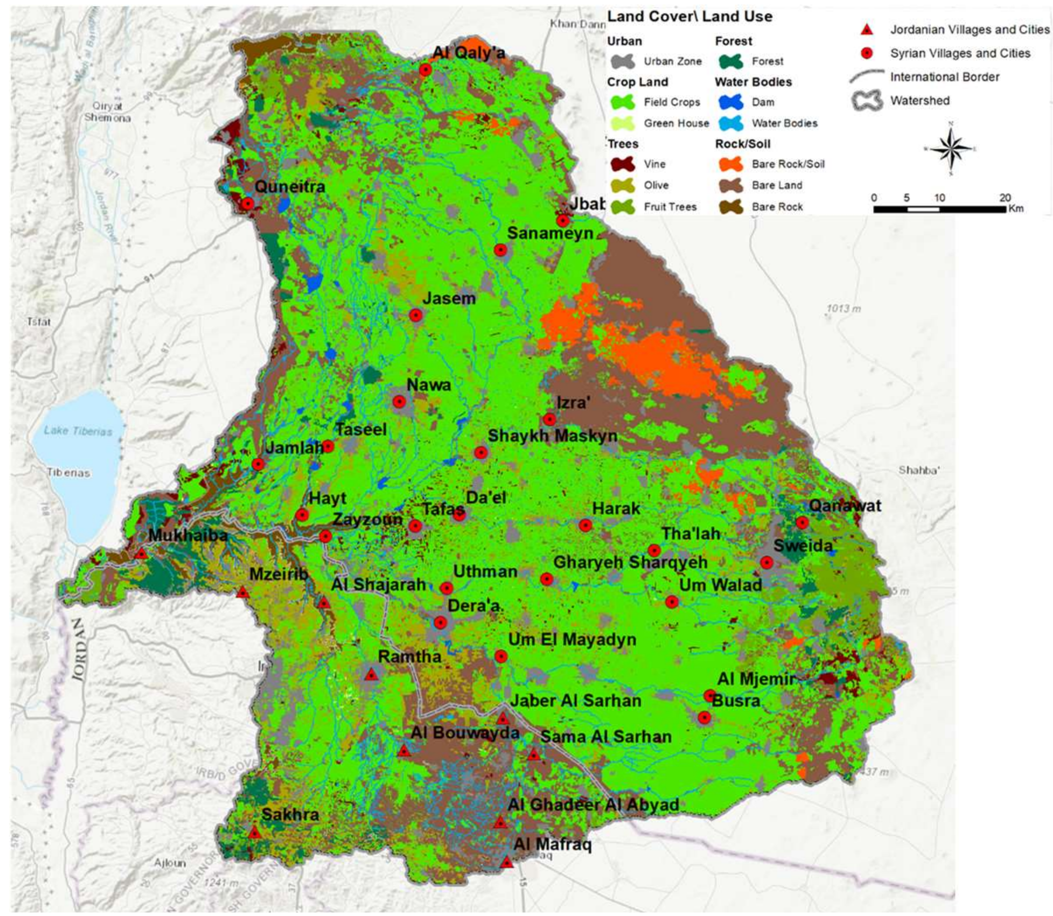


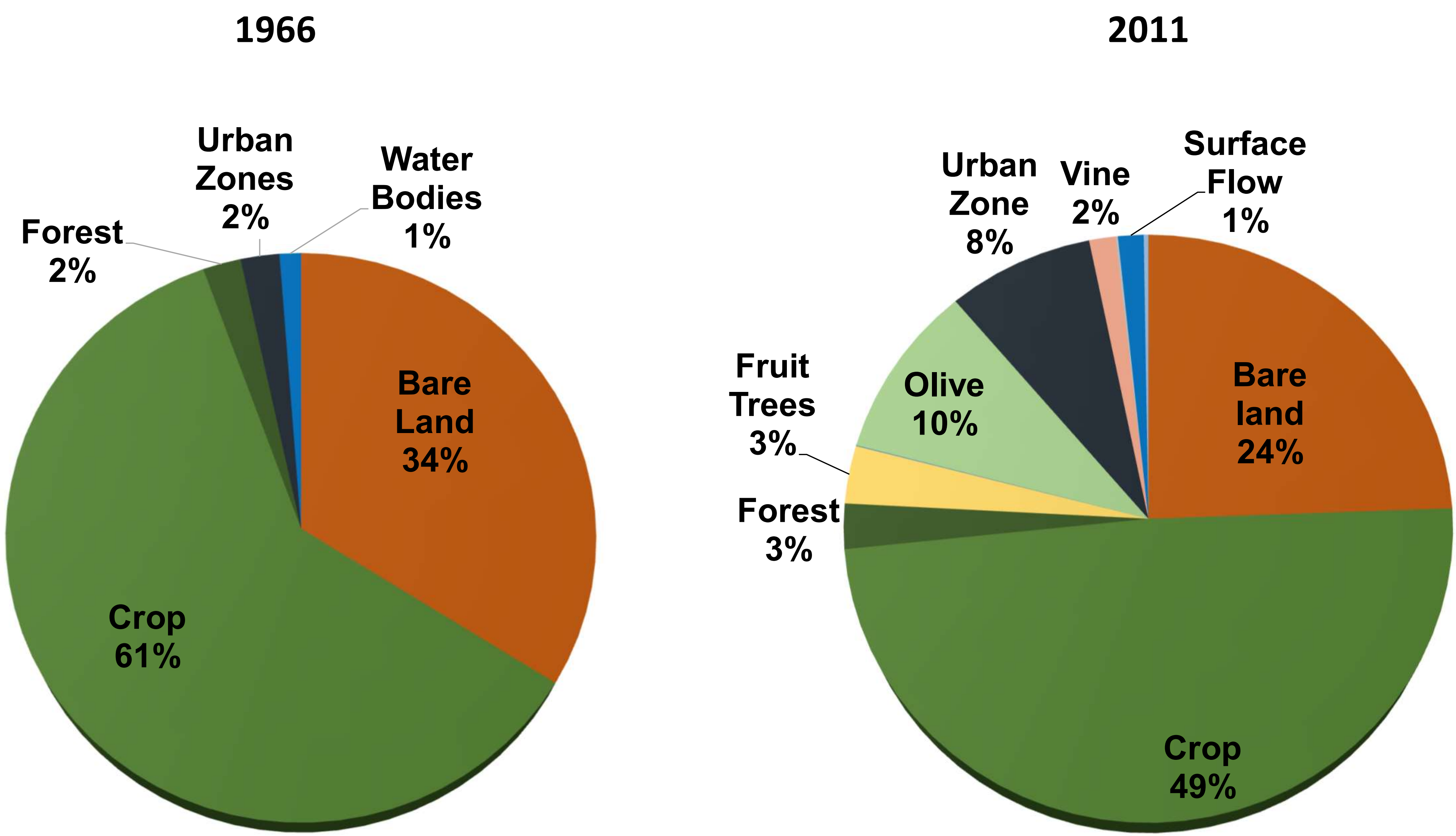
Land Use / Land Cover

Corona (1966)

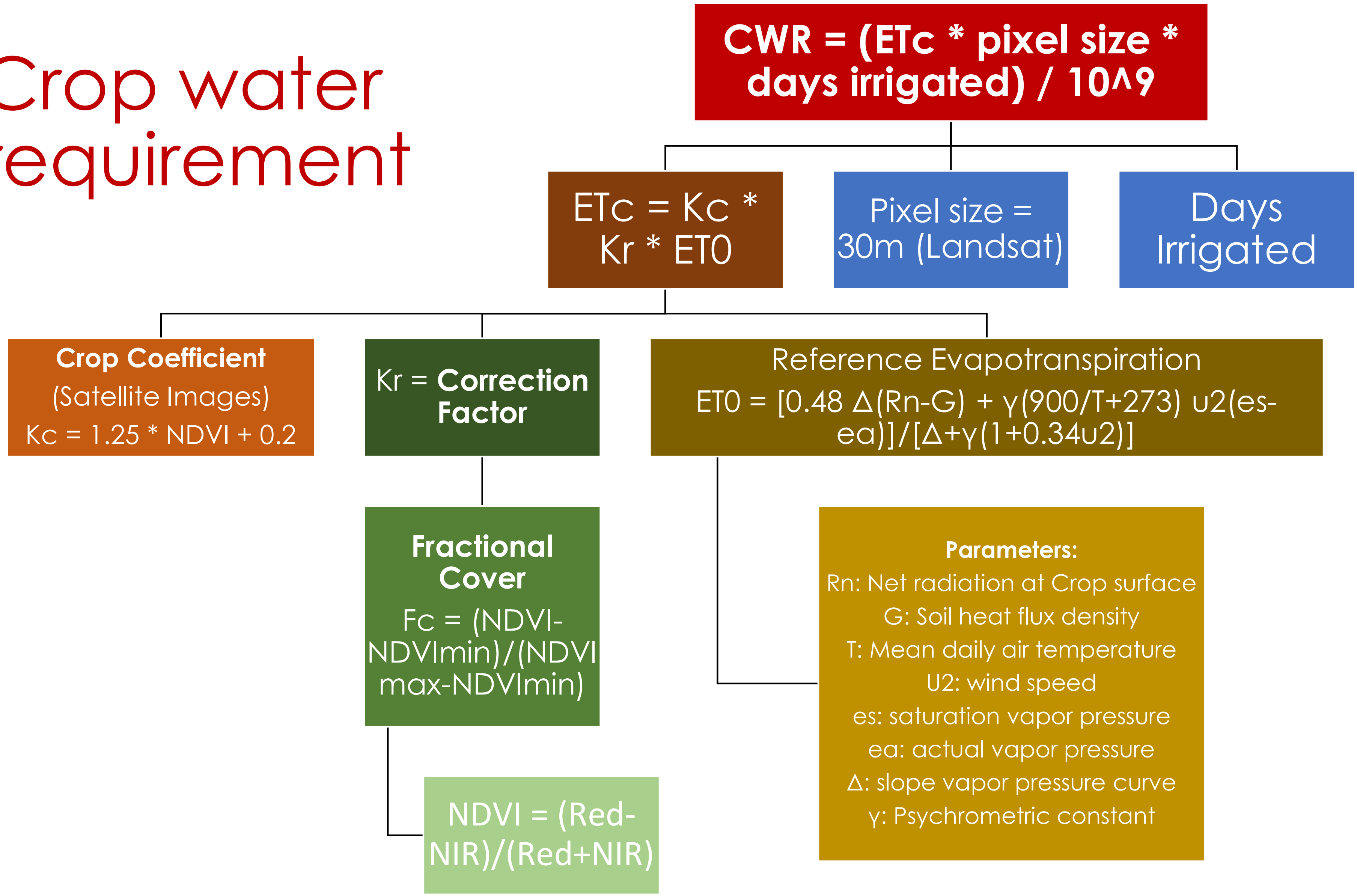


ESRI Basemap (2011)




1966
Urban Zones 2%
Water Bodies 1%
Forest 2%
Bare Land 34%
Crop 61%
2011
Urban Zone 8%
Vine 2%
Surface Flow 1%
Fruit Trees 3%
Olive 10%
Bare land 24%
Forest 3%
Crop 49%

Crop water requirement



Crop water requirement

Year	Winter		Summer	
	A (ha)	CWR (MCM)	A (ha)	CWR (MCM)
1985	83,849	182	7,967	28
1986	75,162	160	7,329	24
1987	70,983	153	7,960	23
2009	109,159	223	32,323	102
2014	102,702	180	14,480	58
2015	119,543	255	17,764	68
2016	106,595	212	17,763	69

Water accounting

Water Accounting + (WA+)

- New framework that can be filled with FREELY AVAILABLE satellite data in Data Active Archives
- Based on the definitions introduced by IWMI
- Provides a link between land use, water use, water balance, management options
- Distinguish between consumptive and non-consumptive use.

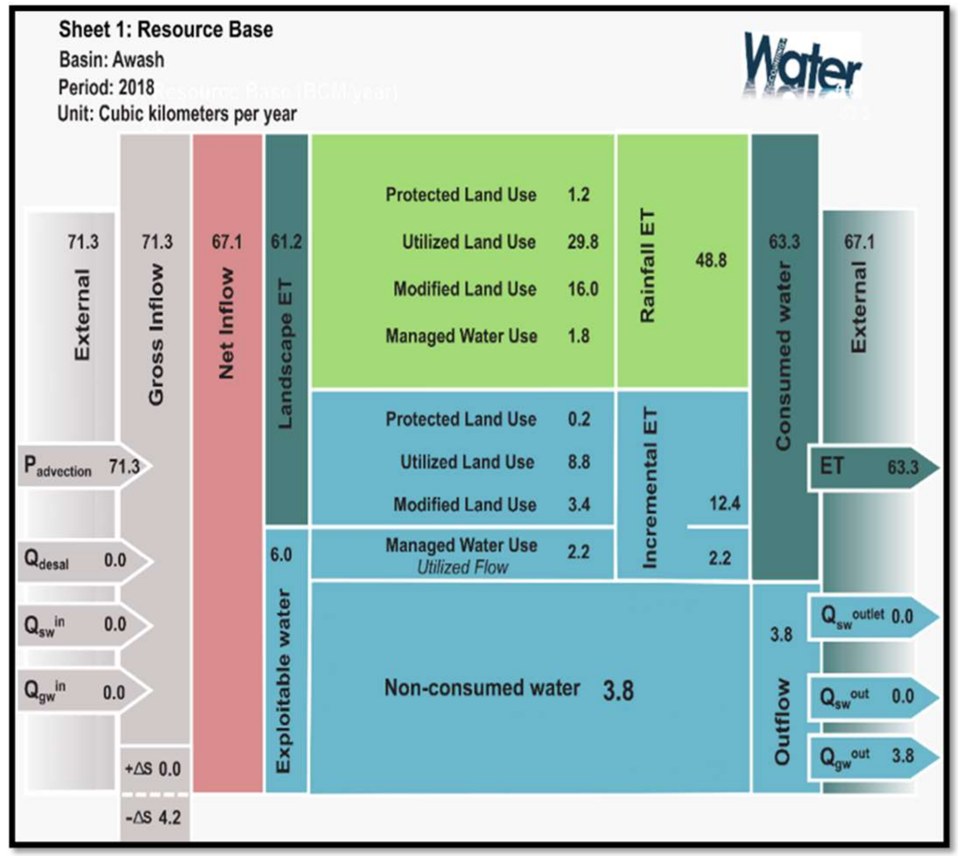
Datasets required for soil moisture water balance model:

- **Precipitation (monthly)**
- **Actual evapotranspiration (monthly)**
- **Reference evapotranspiration (monthly)**
- **Yearly land cover classification (yearly)**
- **Top-soil saturated water content (static)**

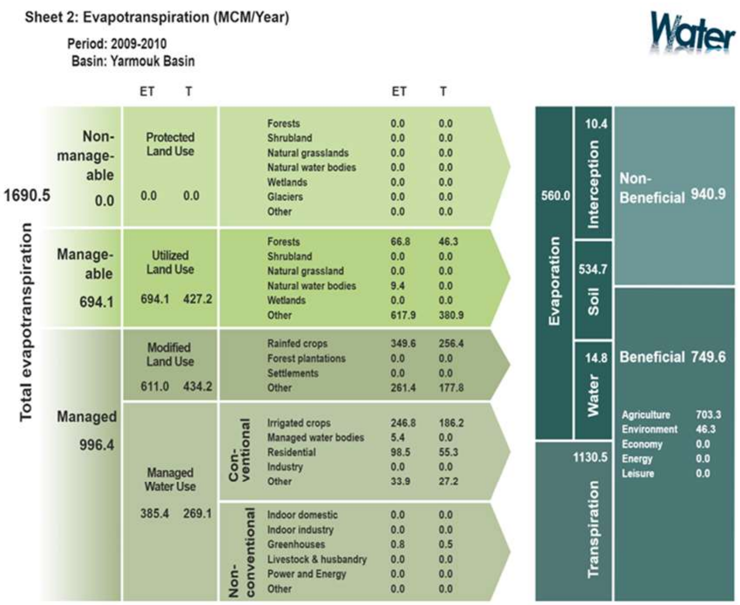
Outputs

- **Split actual ET to E/T/I**
- **Split ET to blue and green components**
- **Surface runoff**
- **Percolation**
- **Baseflow**

WA+ Uses a water balance approach to classify inflows and outflows into various categories.



Results)



Land Use Class	Land Use Group	E (MCM/Yr)	T (MCM/Yr)	Evaporation	Transpiration
Dams	MWU	5.4	0	Non-Beneficial	Non-Beneficial
Green House	MWU	0.26	0.54	Non-Beneficial	Beneficial (Agr)
Urban Zone	MWU	43.22	55.25	Non-Beneficial	Non-Beneficial
Bare land	ULU	236.93	380.94	Non-Beneficial	Non-Beneficial
Forest	ULU	19.59	46.3	Non-Beneficial	Beneficial (Env)
Water Bodies	ULU	9.37	0	Non-Beneficial	Non-Beneficial
Irrigated Crops	MWU	57.22	186.15	Non-Beneficial	Beneficial (Agr)
Irrigated Trees	MWU	6.2	27.22	Non-Beneficial	Beneficial (Agr)
Rain-fed Crops	MLU	89.66	256.39	Non-Beneficial	Beneficial (Agr)
Rain-fed Trees	MLU	81.6	177.85	Non-Beneficial	Beneficial (Agr)

WEAP Scenarios:

- **Reference scenario:** Inherits a "Business as Usual" trend from pre-war conditions
- **Agricultural intensification:** Explores the possible expansion of agriculture in the basin
- **Enhancement of Irrigation systems:** Explores the possibility of upgrading the irrigation systems and their efficiency.
- **Climate change scenarios:**
  - **RCP 4.5:** 1.5 °C temperature increase by 2100 and 7% decrease in precipitation
  - **RCP 8.5:** 3.2 °C temperature increase by 2100 and 13% decrease in precipitation
- **UN medium variant population projection:** Assumes a population growth based on the UN projection for each country. The projection is based on each countries historical trends and present conditions.

PROPOSED SOLUTIONS AND PRACTICES

○ Proposed solutions within bilateral context

- Addressing overexploitation.
- Improving the transboundary agreements.
- Equitable water distribution.

○ Proposed solutions on the national context

- Reducing leakage and seepage from water supply pipes and from dams.
- Water reclamation and reuse (on community, enterprises and household level).
- Reducing evaporation/transpiration.
- Water harvesting.
- Increasing water recharge.
- Efficient irrigation.

Conclusion:

- Under the current water allocation regime and BAU trend, no sustainability can be achieved in near and far future with water shortage reaching 291 MCM by 2050
- Growth of agriculture led to increased irrigation shortage that reached 195 MCM by 2050
- Climate change scenarios resulted in huge decrease in surface water what may render many dams useless
- Enhancing irrigation systems improved coverage and supply of all sectors
- Combining the UN medium variant projection with the improved irrigation systems showed the lowest water shortage between all scenarios
- Water shortage is certain to increase in the future but can mitigated by lessening demands
- Water management is an urgent necessity to reduce the gap between supply and demand
- Jordan is the country that will be most affected by climate change

4- GIS web mapping

1- Story telling: http://tiny.cc/j7mxtz

2- Dashboard: http://tiny.cc/q7mxtz

3- Webmap: http://tiny.cc/r7mxtz


Thank You