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Agricultural Water Balance, Water Productivity and Water Stress Indices:

Theoretical background

Alexander Arakelyan,
American University of Armenia

March 9-11, 2022
Thessaloniki, Greece

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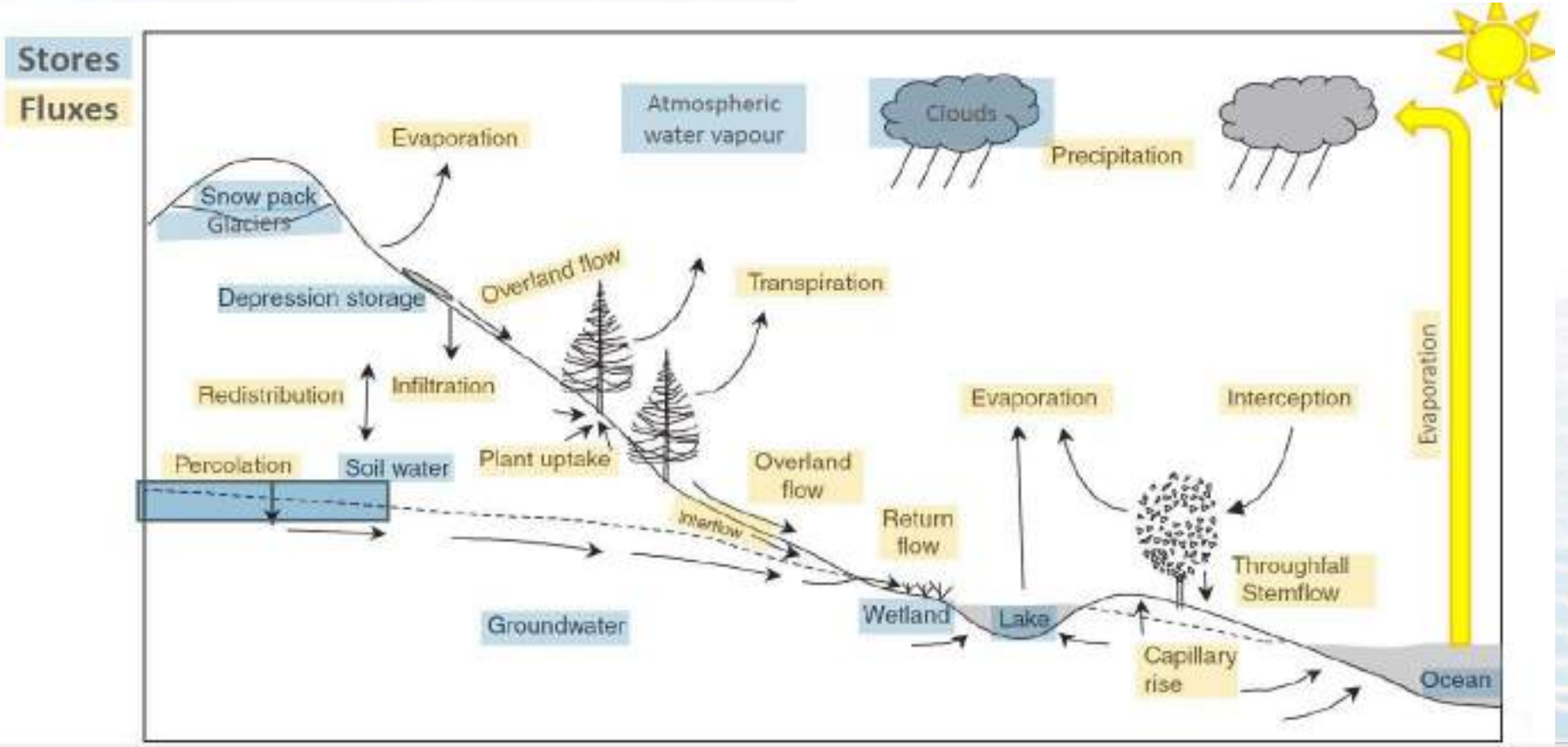
The Global Water Cycle



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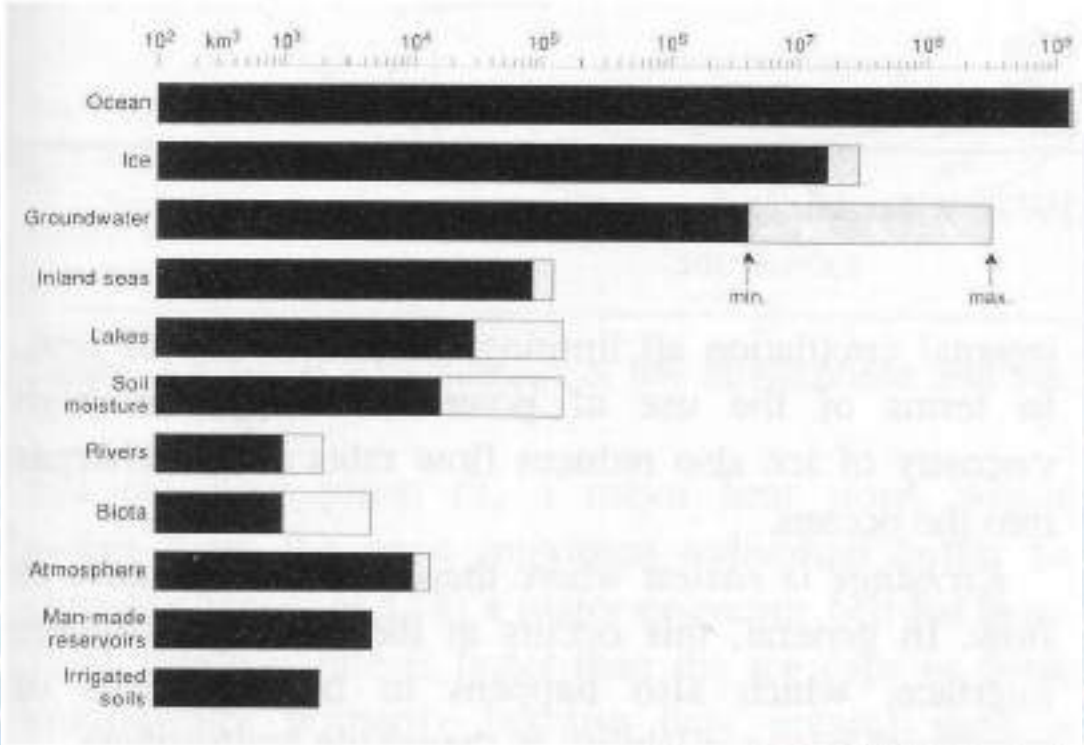
Major storages in the water cycle

Earth holds 1 377 million km^3 of water

- 97% in the ocean
- 3% freshwater, of which:
  - ✔ 62.8% in icecaps, glaciers, permafrost
  - ✔ 36.4% in groundwater
  - ✔ 0.4% in lakes and rivers
  - ✔ 0.3% in soils
  - ✔ 0.03% in the atmosphere (~25 mm globally)



[Jones, 1997; *Global Hydrology*]

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Annual Flux Rates within Global Hydrological Cycle

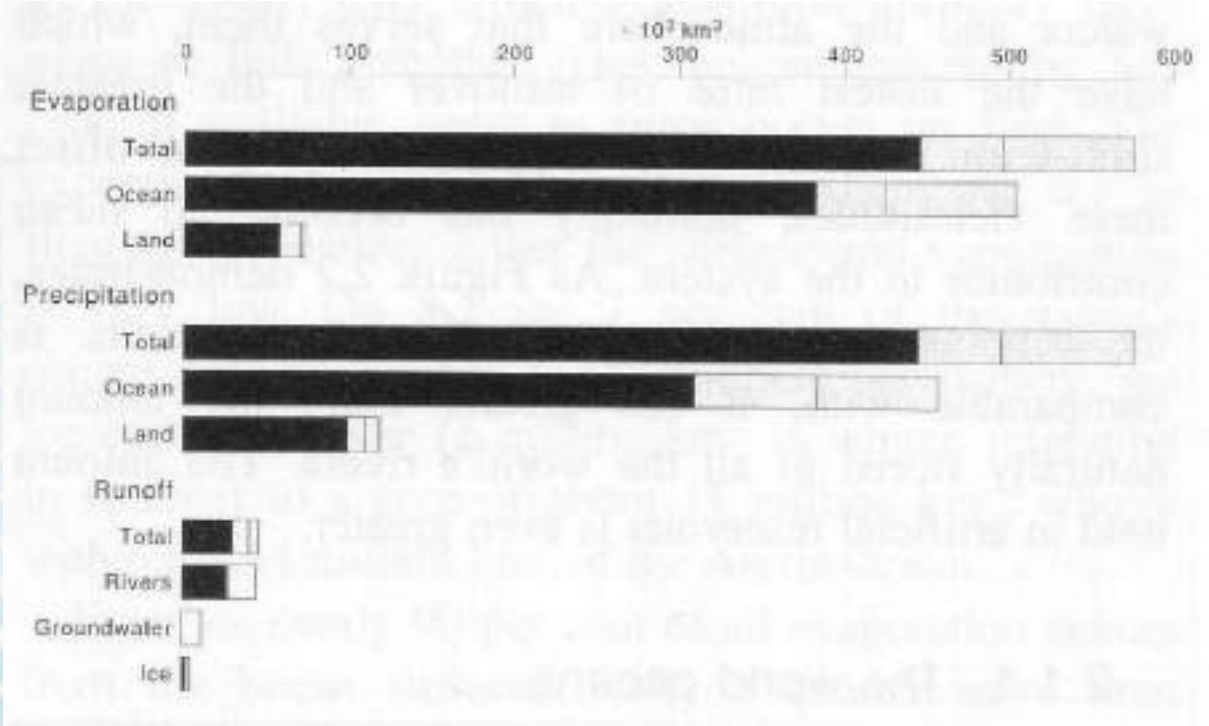
Strongly connected to :

- Energy cycle

- Evapotranspiration
- Ocean atmospheric circulations
- Global warming (atmospheric H_2O)

- Carbon cycle

- Photosynthesis / vegetation growth
- Carbon sequestration dissolving in oceans
- Heterotrophic respiration



[Jones, 1997; *Global Hydrology*]

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Annual cycling of water

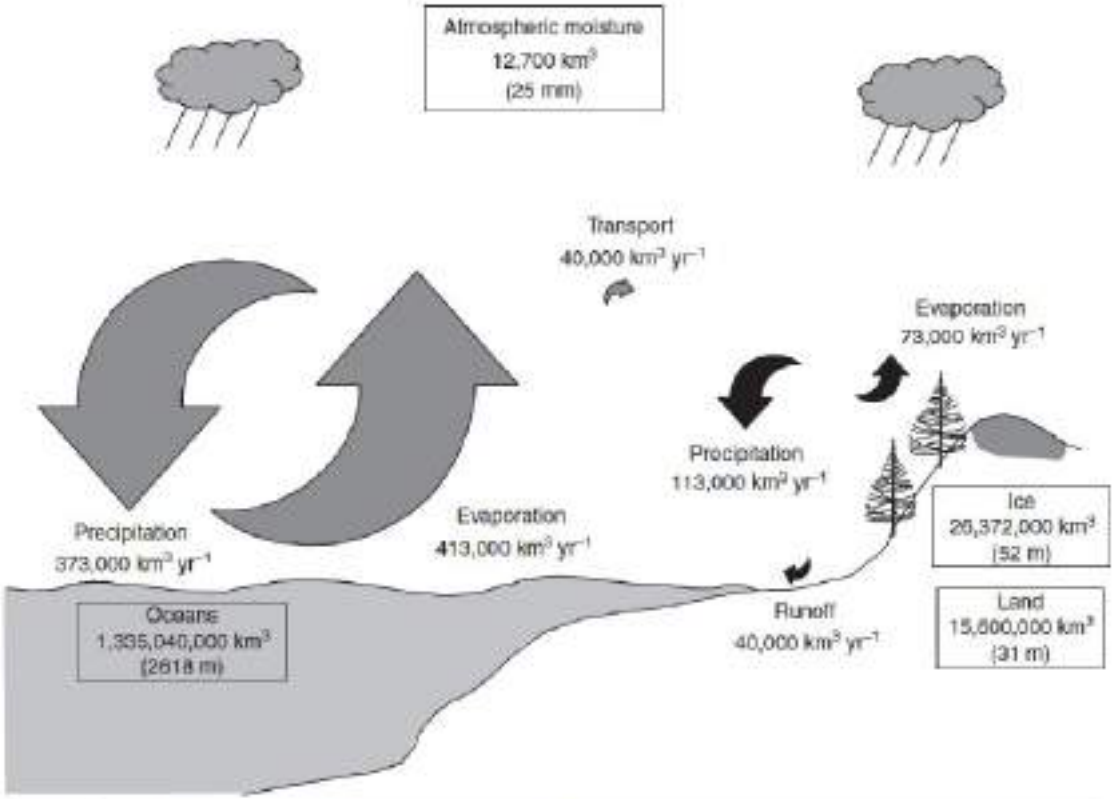

Fig. 3.4 The global hydrologic cycle. Units are km³ of water or, in parentheses, the depth of water spread over Earth's 510 million km² surface area. Data from Trenberth et al. (2007). See also Oki and Kanae (2006).

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Water Balance

The water balance portrays the hydrological cycle quantitatively.

The general water balance equation is:

$$P - R - G - E - T = DS$$

P – precipitation [unit of heigt] or [unit of volume/unit of time]

R – runoff, [unit of height] or [unit of volume/unit of time]

$R = R_{out} - R_{in}$

- R_{out} = runoff as outflow from the water body/hydrologic regin
- R_{in} = runoff as inlfux into the water body/hydrologic region

G – groundwater flow, [unit of height] of [unit of volume/unit of time]

$G = G_{out} - G_{in}$

G_{out} = groundwater as outflow from the water body/hydrologic region

G_{in} = groundwater as influx into the water body/hydrologic region

E – evaporation, [unit of height] or [unit of volume/unit of time]

T – transpiration, [unit of height] or [unit of volume/unit of time]

DS – change in storage, [unit of height] or [unit of volume/unit of time]

Agricultural water balance [surplus and deficit] is the balance between water available for agriculture and use for existing crops.

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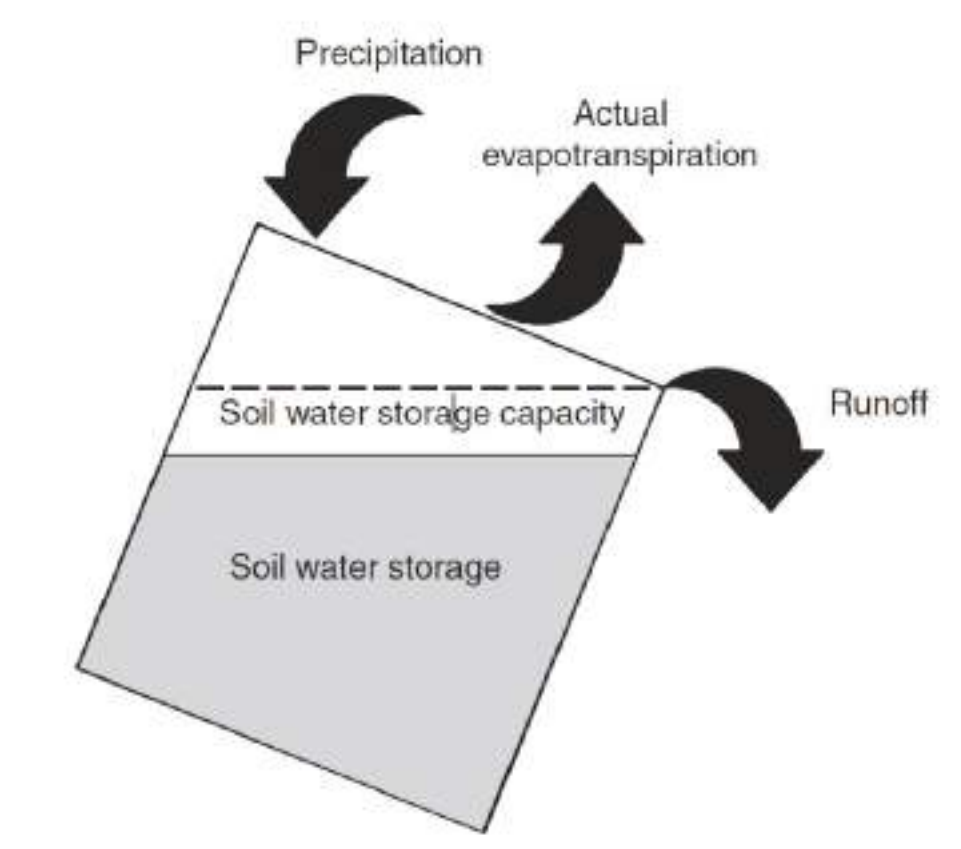
A Simple Water Balance Model



$\Delta S = P - ET - R$

- ΔS = Change in storage
- P = Precipitation
- E = Evapotranspiration
- R = Runoff

Or slightly less simple:

$\Delta GW + \Delta SM = P + I - ET - R$

- GW = Ground Water
- SM = Soil Moisture
- I = Irrigation

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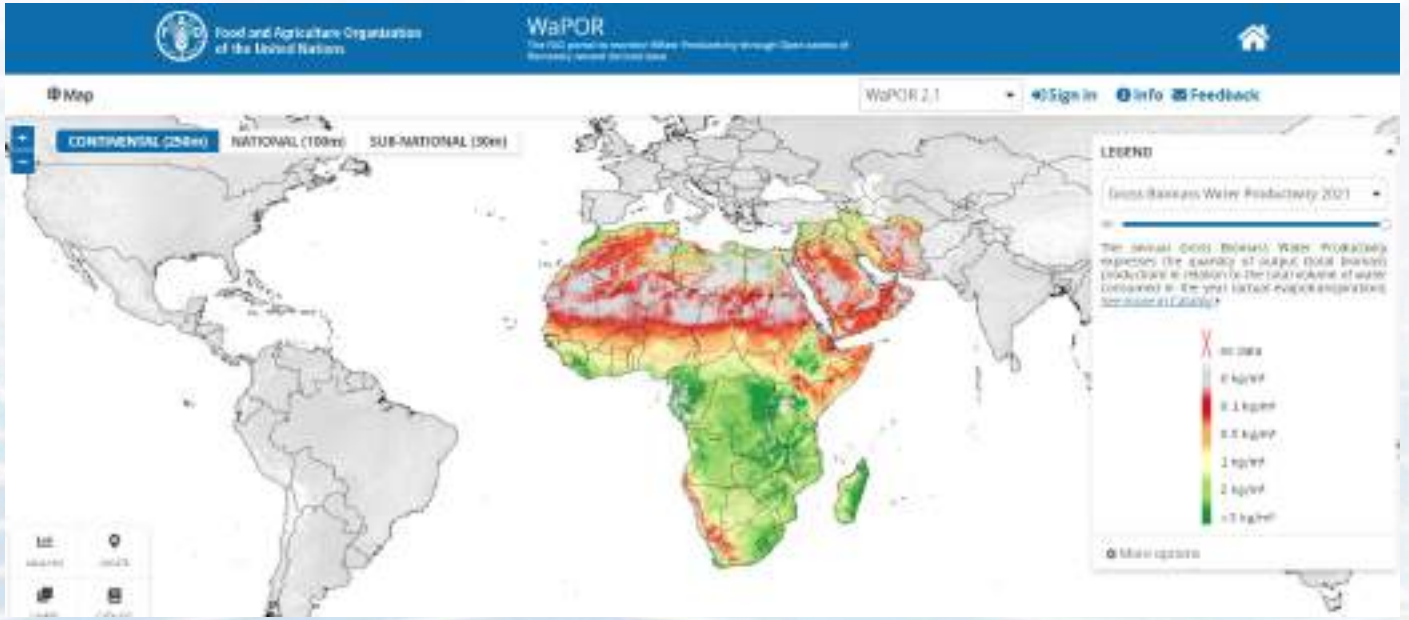
Water Productivity

Water productivity is generally defined as crop yield per cubic metre of water consumption, including 'green' water (effective rainfall) for rain-fed areas and both 'green' water and 'blue' water (diverted water from water systems) for irrigated areas.



https://wapor.apps.fao.org/home/WAPOR_2/1

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Water Scarcity

Water scarcity refers to an imbalance between the supply of and demand for water in a specified domain (country, region, catchment, river basin, etc.) as a result of a high rate of demand compared with available supply, under prevailing institutional arrangements (including price) and infrastructural conditions. (SOFA, FAO, 2020 (ND543))

In popular usage - *scarcity - is a situation where there is insufficient water to satisfy normal requirements.*

Degrees of scarcity: absolute, life-threatening, seasonal, temporary, cyclical, etc.

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Major Causes of Water Scarcity

- Climate change
- Natural hazards such as droughts and floods
- Increased human consumption
- Overuse and wastage of water
- A global rise in freshwater demand
- Overuse of aquifers and its consequent slow recharge

https://guardian.ng/opinion/climate-change-agriculture-and-biotechnology-part-1/

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Water Stress

Water stress includes water scarcity within its definition but also takes into consideration the accessibility of available water and its quality (i.e. whether it is clean enough for specified use).

According to an OECD report on the environmental outlook for the year 2050, the number of people living in river basins under severe water stress is projected to more than double between 2000 -2050, reaching 3.9 billion people.

Scarcity of water can also cause water pollution. For instance, if inadequate water is available for agriculture, there will be higher concentration of pesticides and fertilizers.

Furthermore, water scarcity can cause an imbalance in the ecosystem. Food chains are affected, and biodiversity is harmed.

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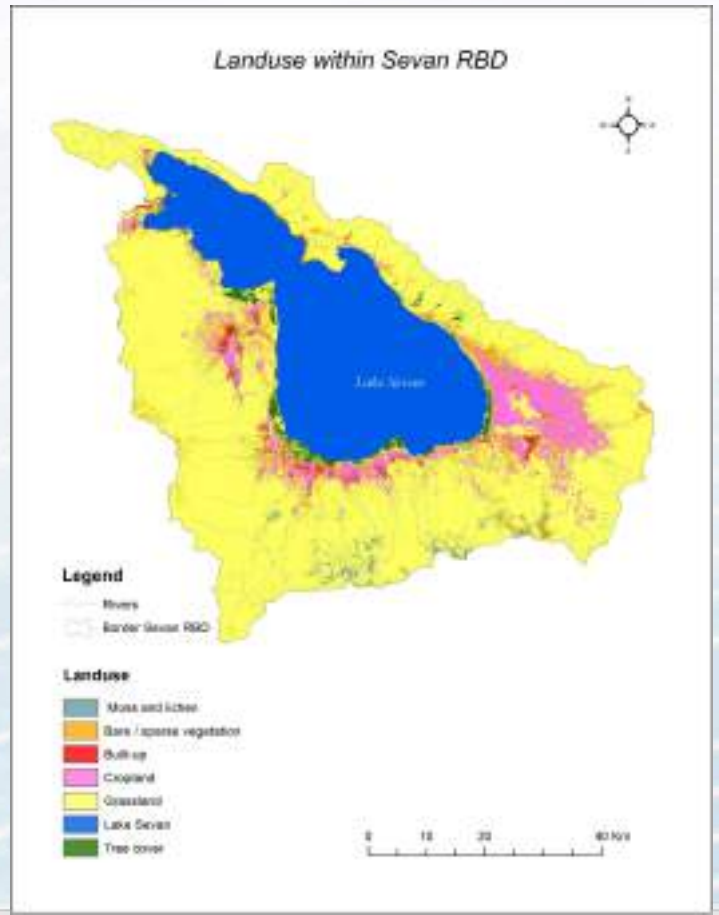
Agricultural Water Use Problems in the Armenian Study Area – Lake Sevan Basin



Land Cover Type	Area, km^2	Percentage, %
Arable land	**401.7**	**8.54**
Pastures and grasslands	2241.9	47.68
Forests	395.9	8.42
Shrub	0.2	0.004
Spaces with little or no vegetation	6.2	0.13
Inland waters	1508.3	32.08
Inland wetlands	0.5	0.01
Urban fabric	141.8	3.02
Industrial, commercial and transport units	0.6	0.01
Mine, dump and construction sites	4.5	0.10

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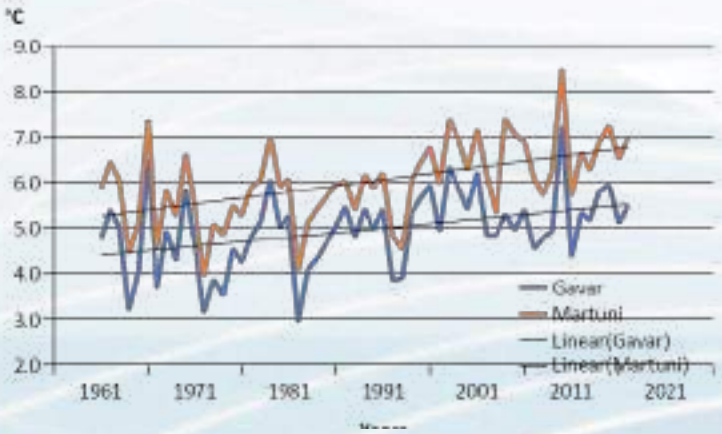
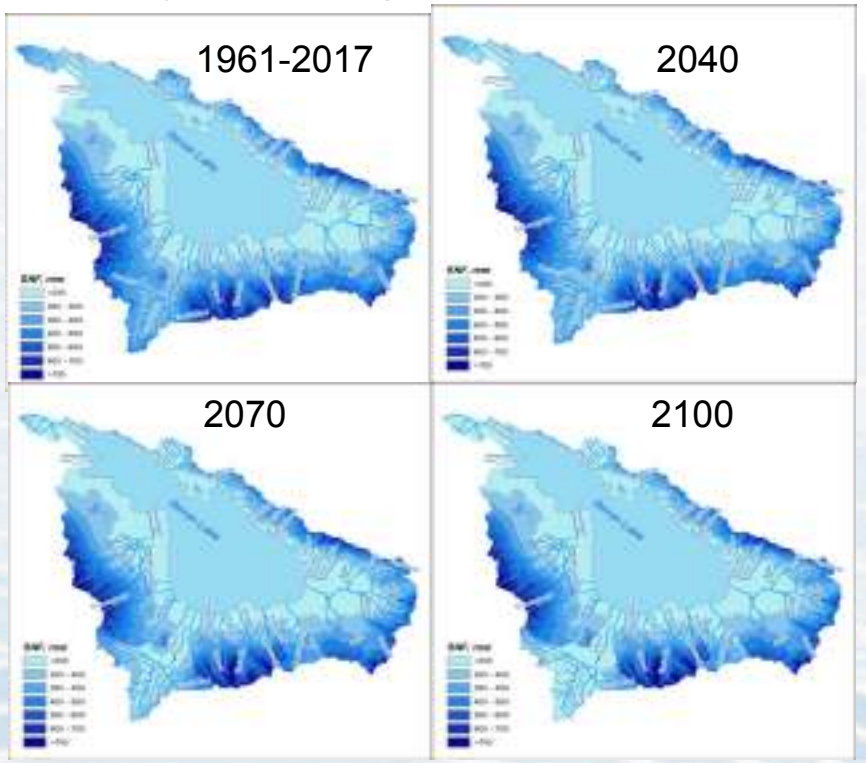
Assessment of the Impact of Climate Change on Surface Water Resources



Hydropost Code	River-Post	RCP8.5		
		2040	2070	2100
85339	Pambak-Pambak	0.8	1.7	2.5
85352	Dzknaget-Tsovagyugh	-19.7	-42.7	-62.8
85353	Drakhtik-Drakhtik	-20.3	-44.4	-64.8
85363	Masrik-Tsovak	3.4	7.9	11.1
85366	Karchaghbyur-Karchaghbyur	-12.3	-27.3	-39.6
85371	Vardenis-Vardenik	3.5	8.3	11.7
85376	Martuni-Geghhovit	0.2	1	1.1
85378	Argichi-Verin Getashen	-17.5	-38.4	-56
85379	Tsaghkashen-Vaghashen	-13.3	-28.9	-42.5
85380	Lichq-Lichq	10.3	22.9	33.1
85381	Bakhtak-Tsakqar	-2.2	-4.9	-7.2
85384	Gavaraget-Noratus	0.7	1.5	2.3

Projected Changes in Runoff depth, mm



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Crop Gross Production in the Sevan RBD

Crop	Cultivated land, 1000 ha								
	2013	2014	2015	2016	2017	2018	2019	2020	2021
Grain	41,75	40,90	38,62	35,87	30,91	26,20	22,70	22,90	22,90
Potato	14,11	13,28	10,23	10,23	9,43	8,70	8,10	7,90	7,60
Vegetables	2,02	2,09	1,61	1,68	1,59	1,40	1,40	1,40	1,20
Fruits	1,49	1,49	1,38	1,40	1,41	1,30	1,40	1,40	1,40
Other	19,67	19,95	21,79	-	-	-	-	-	-

In the Sevan basin, the main crops are grains which are cultivated on about 44% of the cultivated land, 14.7 % are fodder crops and potato.

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Pesticides Consumption in Gegharkunik Province

Assessment Parameters	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Agricultural land, 1000 hectares	481,8	481,5	481,5	481,0	481,1	481,1	481,5	481,3	481,4	481,7
Total area treated with pesticides, 1000 hectares	290,6	299,0	285,0	282,0	282,0	272,4	275,2	265,3	220,5	220,2
Total consumption of pesticides (according to the quantity of active substance), t	431,0	349,4	412,9	508,6	348,7	403,4	385,2	344,9	264,6	275,3
Total consumption of pesticides per unit of land, kg/hectare	1,5	1,2	1,4	1,8	1,2	1,5	1,4	1,3	1,2	1,25

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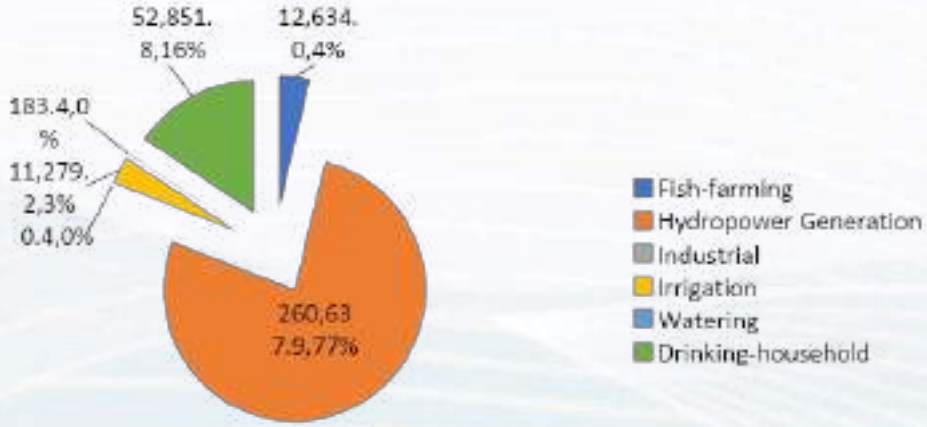
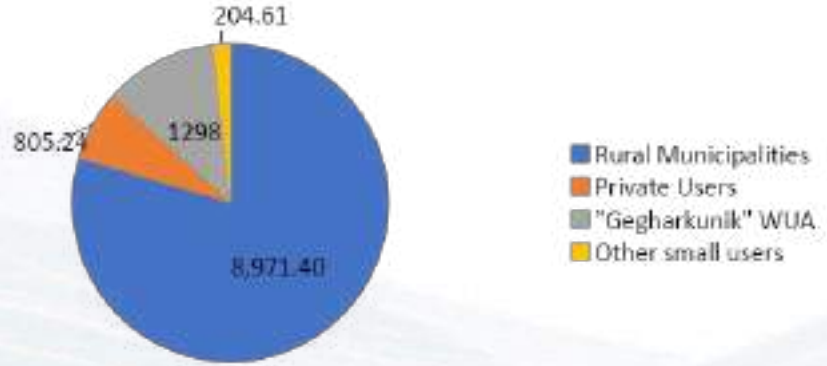
Structure of Annual Water Abstraction by the Sectors in Sevan RBD, 1000m^3



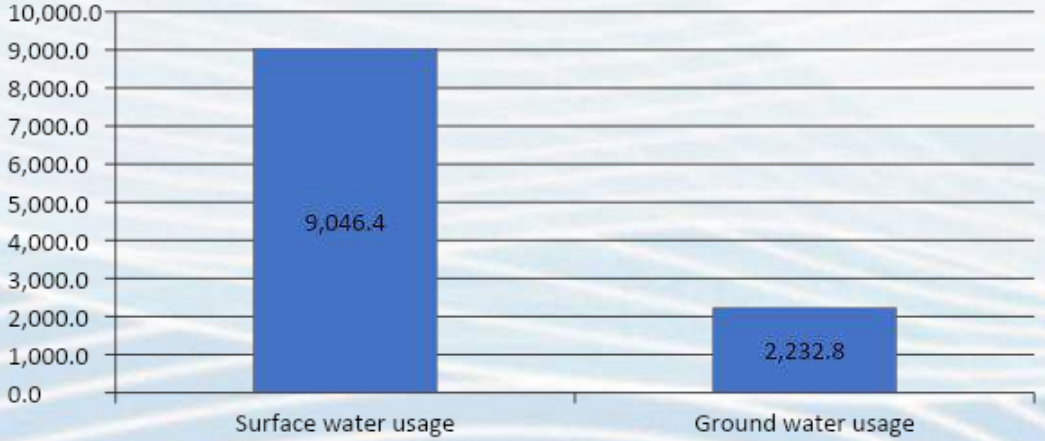
Source: (http:// http://wrma.am/4_1.php), 2017

Irrigation services in the Sevan RBD is provided by “Gegharkunik” Water Users Association (WUA). The total service area of the WUA is 3742 ha. The irrigation infrastructure consists of about 19 secondary irrigation canals, which provide water from rivers and springs. The water used for irrigation purposes was 11,279.3 thousand m^3 or 3.3 % of total water use permit volume in RBD.

Structure of Annual Water Abstraction for Irrigation, in 1000m^3



Surface and groundwater abstraction for Irrigation in Sevan RBD, in 1000m^3



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Demand of water for irrigation

Demand of water for irrigation was calculated by taking into account the irrigation norms for different crops as defined by ministry of agriculture for different regions of Armenia ("Norms and regimes for irrigation of agricultural crops in RA, Manual, Yerevan, 2007, 203 p.).

- Potato – 2400 m^3/ha,
- Vegetables – 2400 m^3/ha,
- Wheat – 800 m^3/ha,
- Fruits and berries – 1800 m^3/ha

Crops	Irrigated land	Water required per ha (m^3)	Required water (mln m^3)
Potato	4090	2400	9.816
Vegetable	120	2400	0.288
Wheat	45	800	0.036
Total water demand for Irrigation	4255		10.14
NRW%			40%
Adjusted water demand for irrigation			14.196

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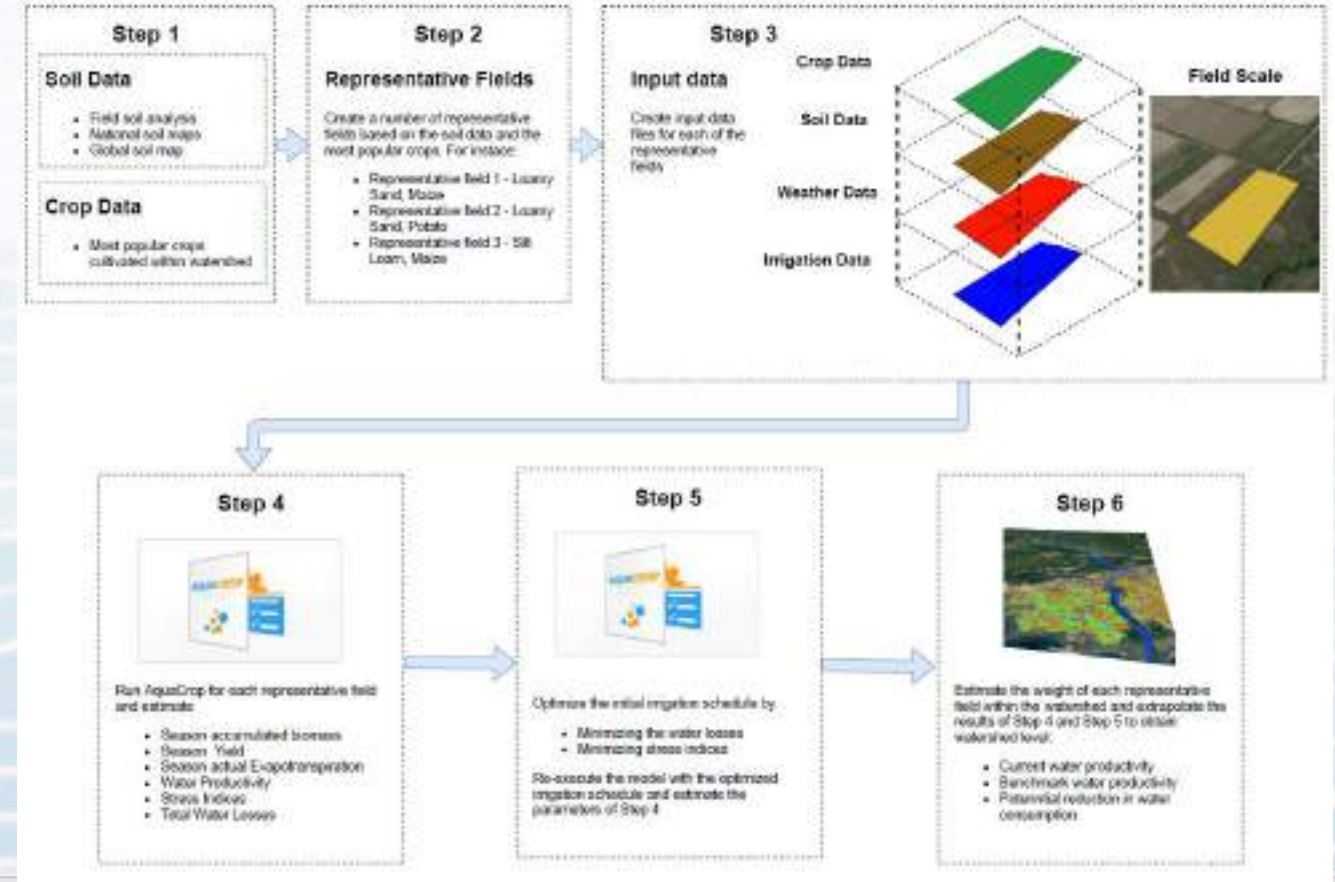
Assessment Methodology



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Pilot Site 1: Zolakar

Crop type: Potato

Land plot area: 1.18 ha

Soil type: Floodplain terrace soil; soil subtype: meadow; genus: pebble; depth: moderately deep; texture: clay; erosion: not eroded; stones: slightly stony.

Start date of seeding: May 15, 2021

Harvesting: ~September 15, 2021

Irrigation: Started from July 1, once 10 days, ~5 times (up to ~August 20), 1,100-1,200 m3 of water each time

Fertilizers/pesticides: yes (pesticide)

Estimated yield: 35 t

Reference meteo station: Martuni

June 19: Crop wet weight: 74g; Crop dry weight: 9g; Crop moisture content: 87.8%

July 30: Crop wet weight: 117; Crop dry weight: 20g; Crop moisture content: 82.9%

August 23: Crop wet weight: 136; Crop dry weight: 27g; Crop moisture content: 80.2%

Harvest: September 11; 18-19 tons of potato

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Pilot Site 2: Noratus

Crop type: Wheat

Land plot area: 2.2 ha

Soil type: Mountain chernozem soil; soil subtype: ordinary; genus: mealy-calcic; depth: shallow; texture: loam; erosion: slightly eroded; stones: -.

Start date of seeding: August 20, 2020

Harvesting: ~September 10, 2021

Irrigation: rainfed

Fertilizers/pesticides: no

Estimated yield: 1.5-2 t

Reference meteo station: Gavar

May 15: Crop wet weight: 55.31g Crop dry weight: 41.33g Crop moisture content: 25.27%

June 19: Crop wet weight: 22g; Crop dry weight: 15g; Crop moisture content: 31.8%

Soil temperature: 20.8 C (July 30)

Harvest: August 1; 800 kg of wheat

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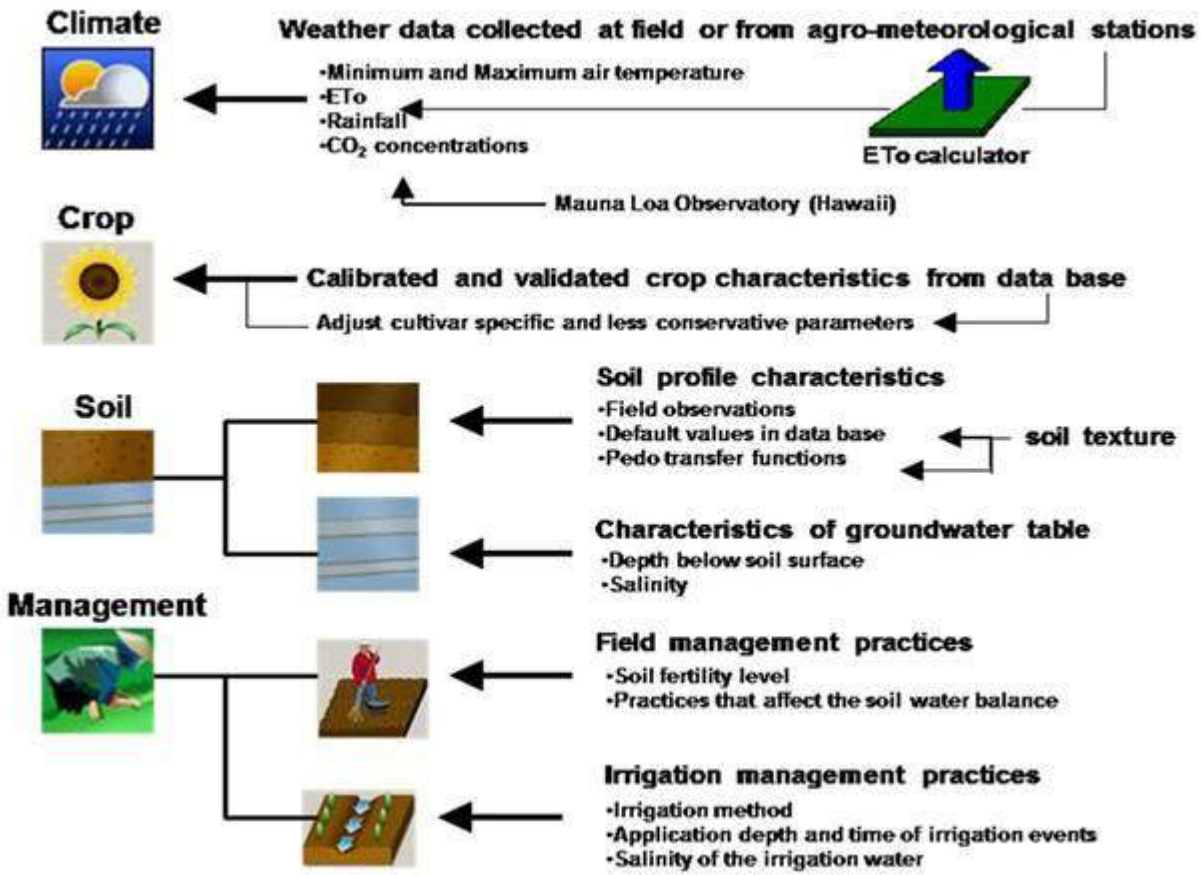
AquaCrop Model Input Data



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Available Data

List of Observations conducted in the Meteorological Posts of Lake Sevan Basin

Observation	Gavar	Sevan	Semyonovka	Shorzha	Chambarak	Masrik	Martuni	Vardenyats pass
Mean air temperature	+	+	+	+	+	+	+	+
Minimum air temperature	+	+	+	+	+	+	+	+
Maximum air temperature	+	+	+	+	+	+	+	+
Relative air humidity	+	+	+	+	+	+	+	+
Partial pressure	+	+	+	+	+	+	+	+
Saturation deficit	+	+	+	+	+	+	+	+
Dew point temperature	+	+	+	+	+	+	+	+
Atmospheric pressure at the station	+	+	+	+	+	+	+	+
Isobar level height	+	+	+	+	+	+	+	+
Precipitation amount (daytime, nighttime)	+	+	+	+	+	+	+	+
Atmospheric phenomena	+	+	+	+	+	+	+	+
Weather between observations	+	+	+	+	+	+	+	+
Cloud percentage (total)	+	+	+	+	+	+	+	+
Cloud percentage (lower level)	+	+	+	+	+	+	+	+
Cloud type	+	+	+	+	+	+	+	+
Height of the lower cloud boundary	+	+	+	+	+	+	+	+
Mean wind speed	+	+	+	+	+	+	+	+
Wind direction	+	+	+	+	+	+	+	+
Maximum wind gusts	+	+	+	+	+	+	+	+
Horizontal visibility	+	+	+	+	+	+	+	+
Land surface temperature	+	+	+	+	+	+	+	+
Minimum land surface temperature	+	+	+	+	+	+	+	+
Maximum land surface temperature	+	+	+	+	+	+	+	+
Sunshine duration	+	+	-	+	-	-	+	+
Snow cover height	+	+	+	+	+	+	+	+

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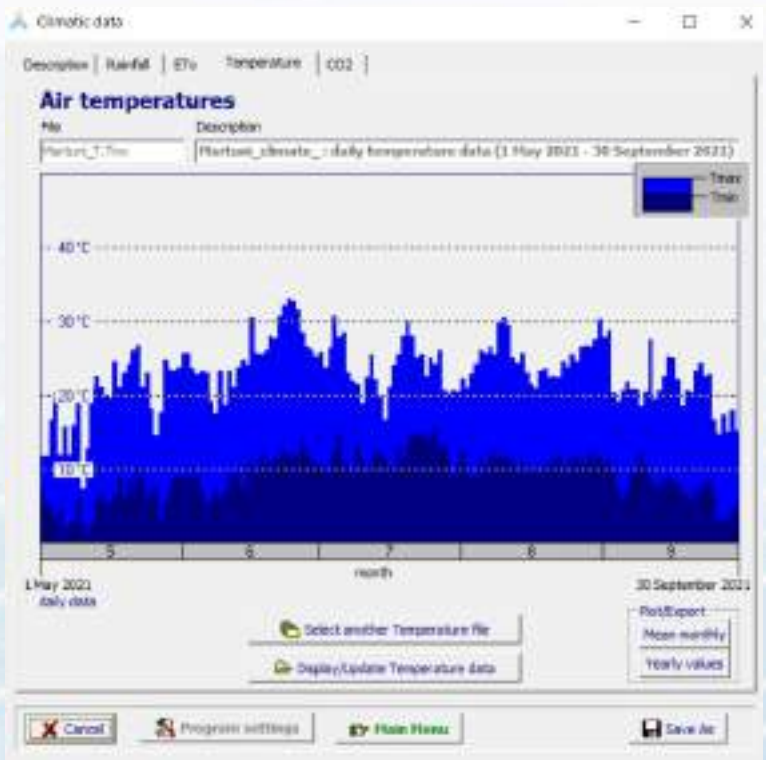
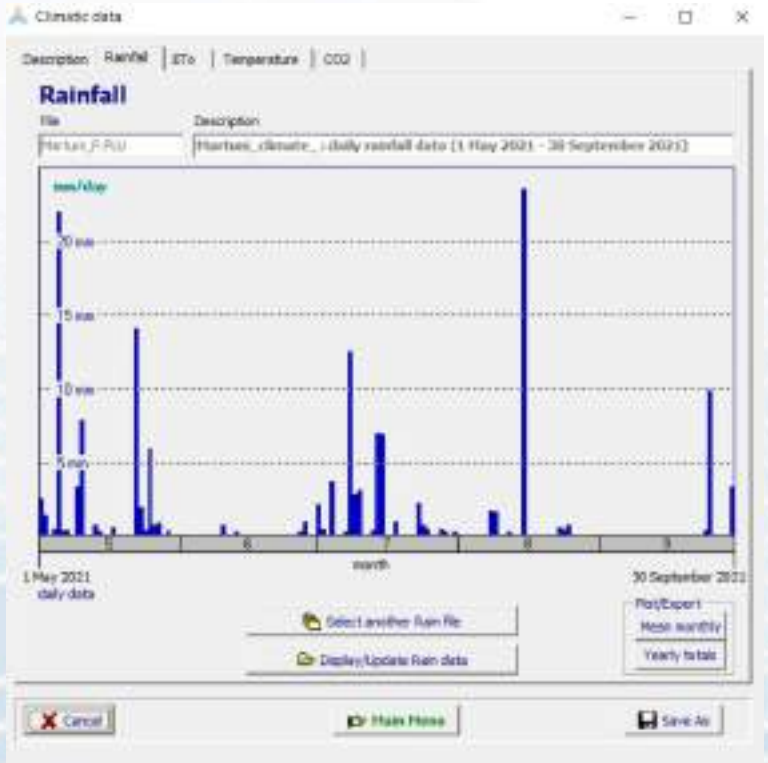
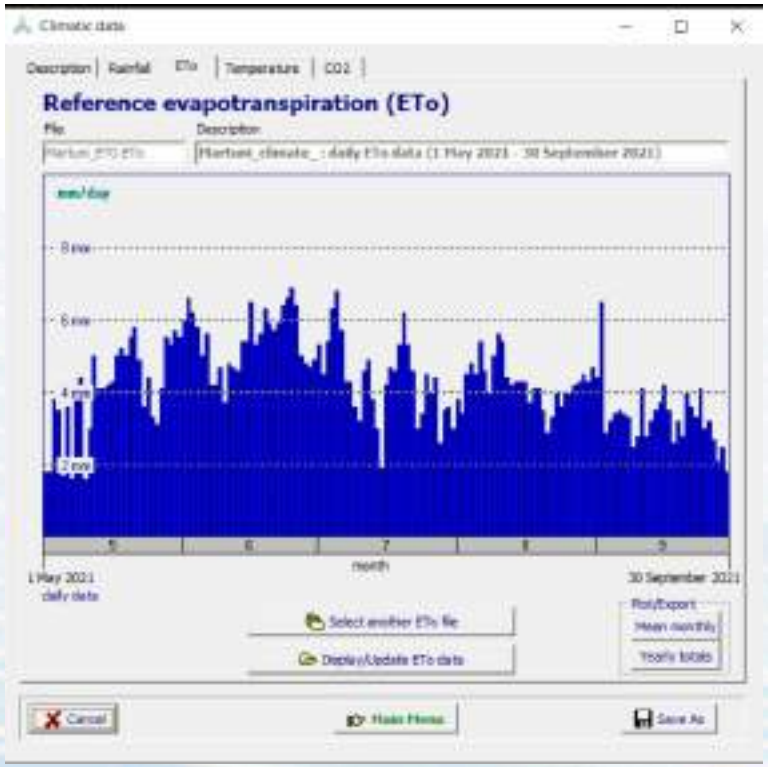
Climate Data (Martuni)







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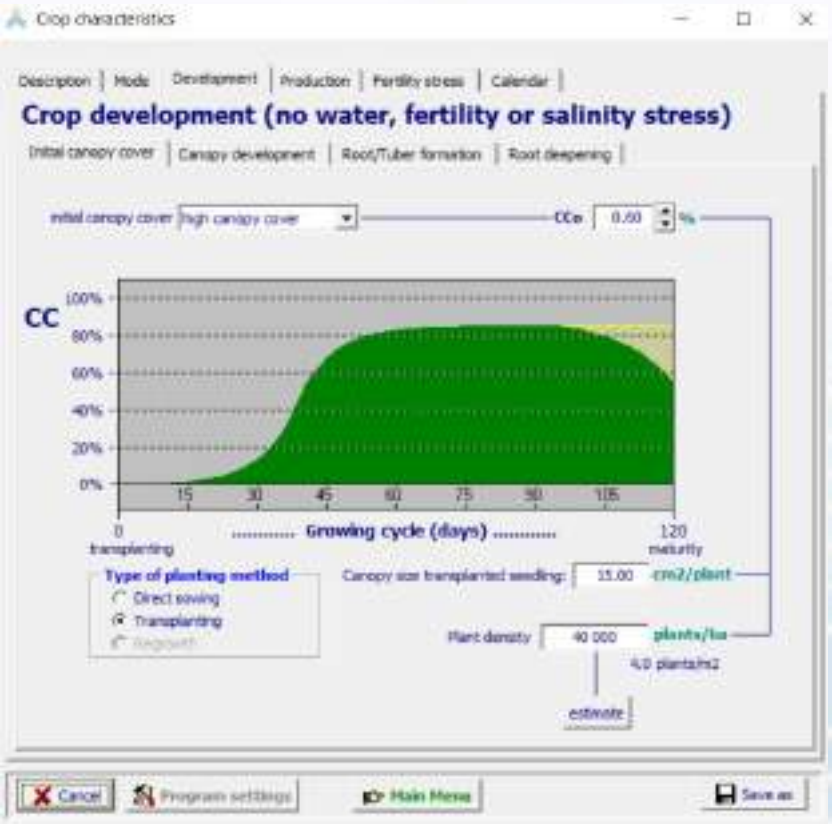
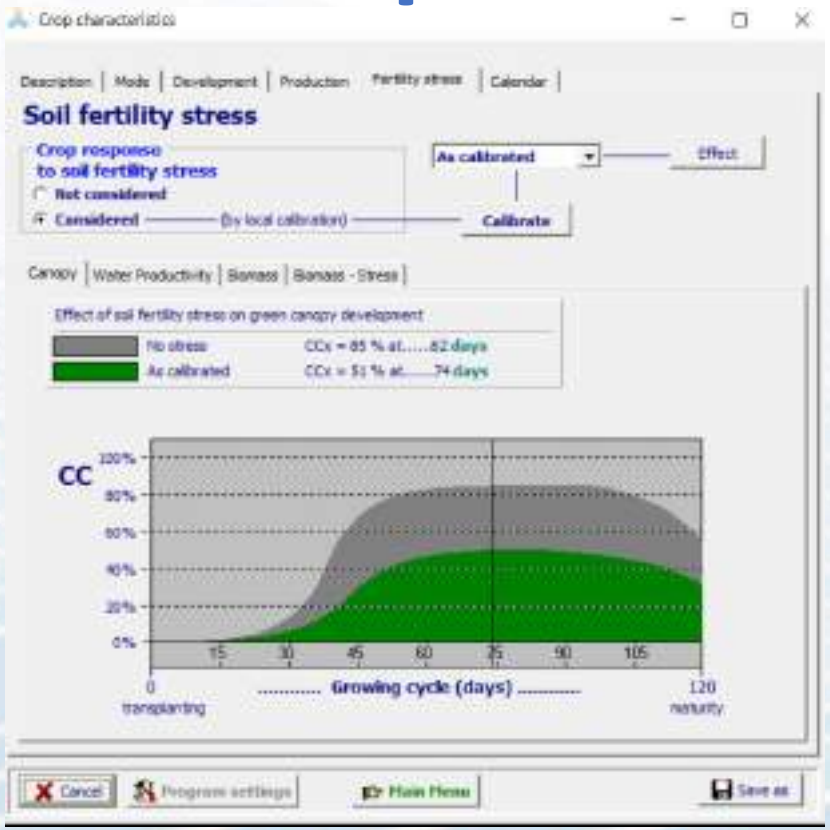
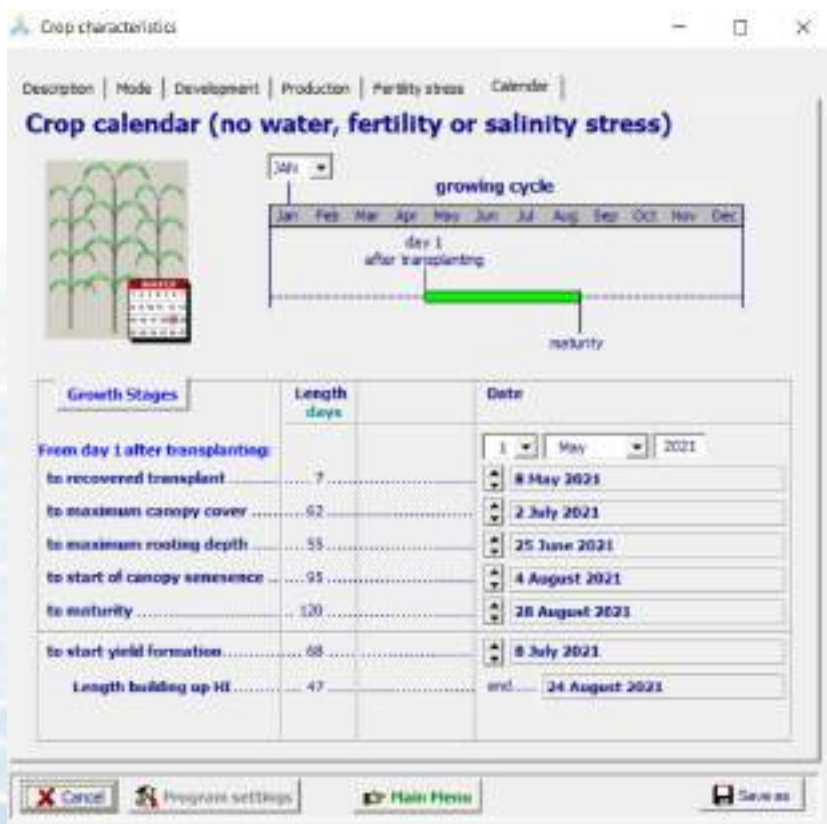
Crop Data







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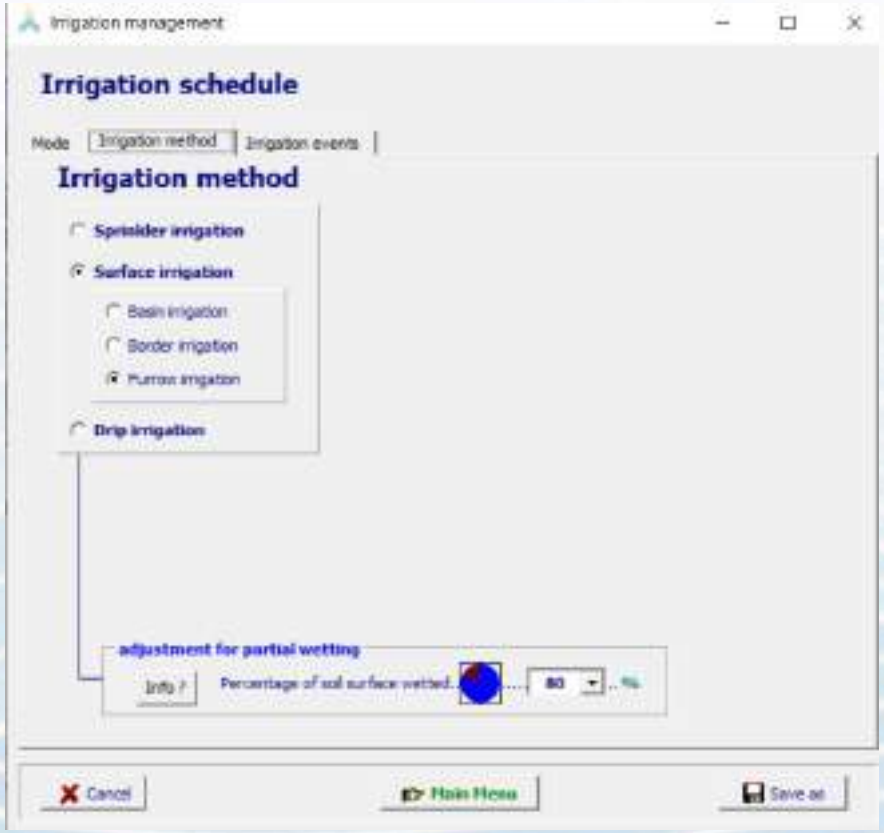
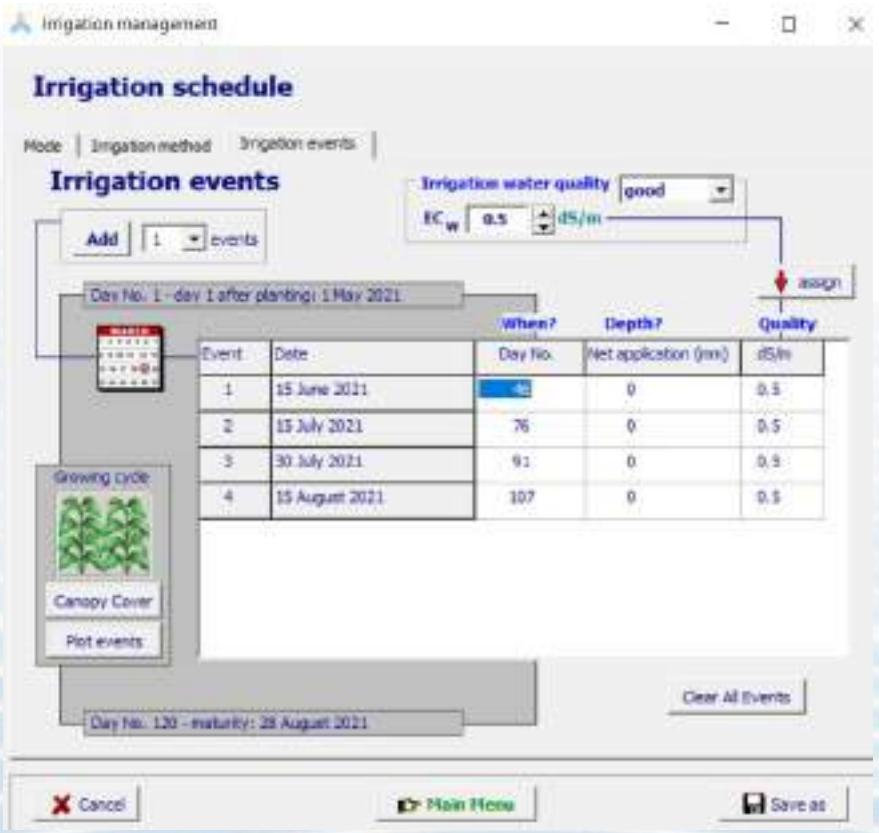
Irrigation Data





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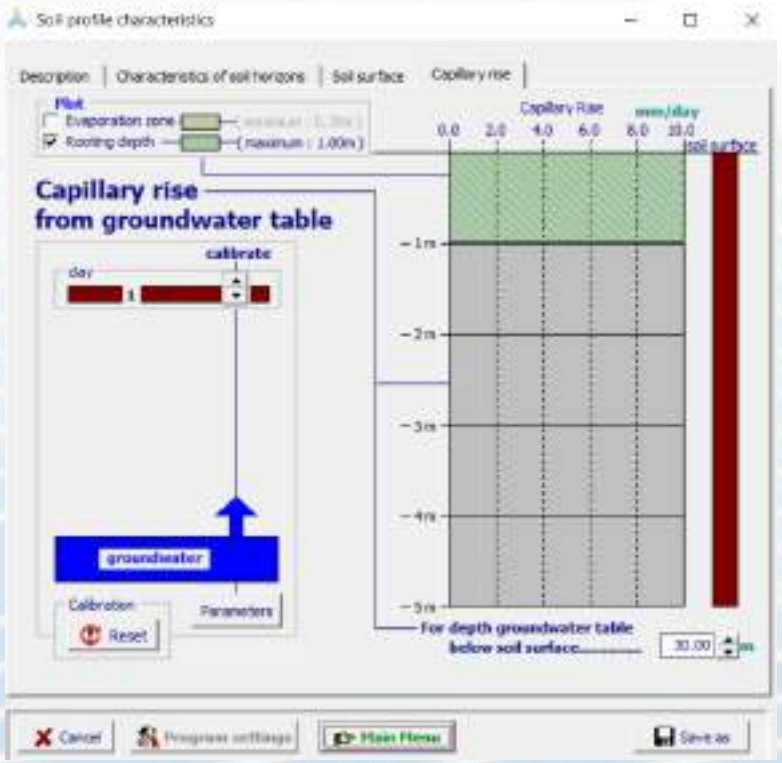
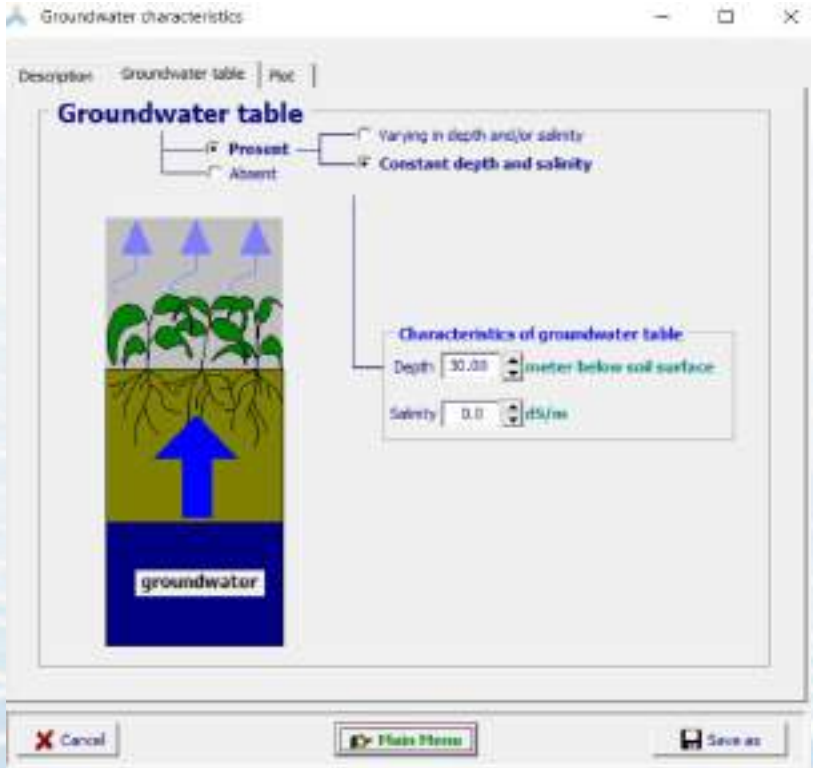
Soil and Groundwater Data





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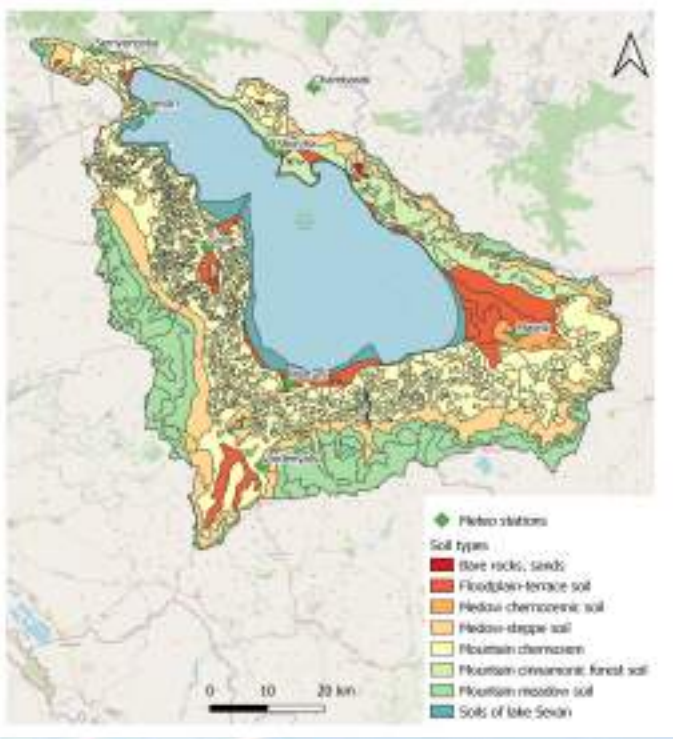
Available Data



NDVI, MAXAR VHR Data (13.08.18)

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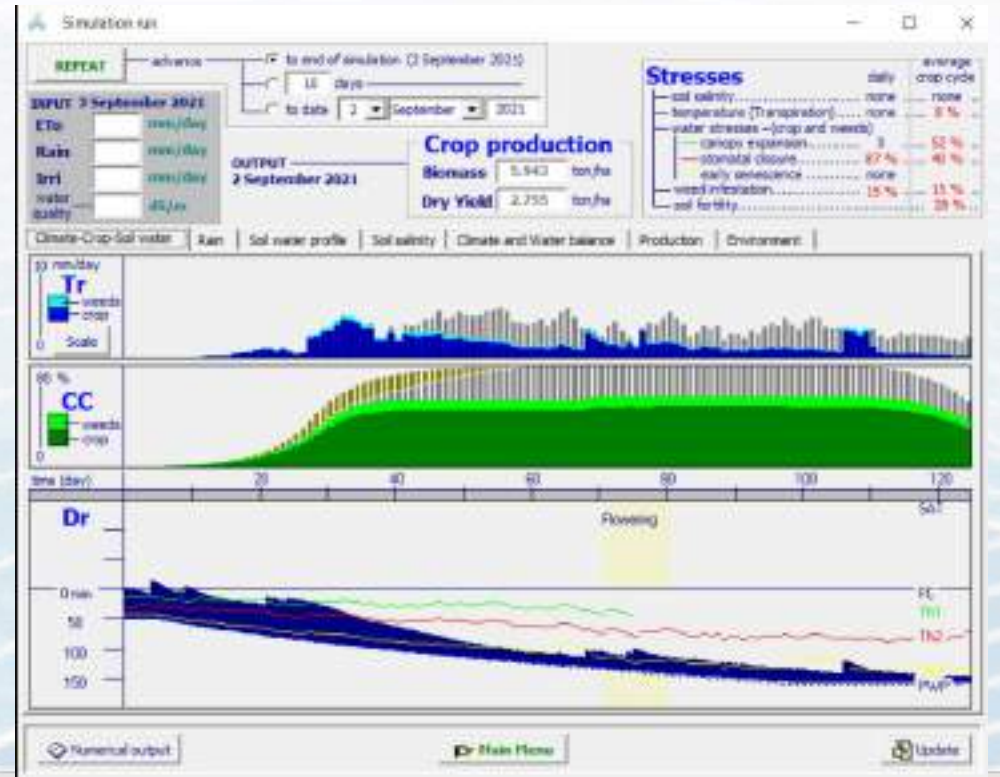
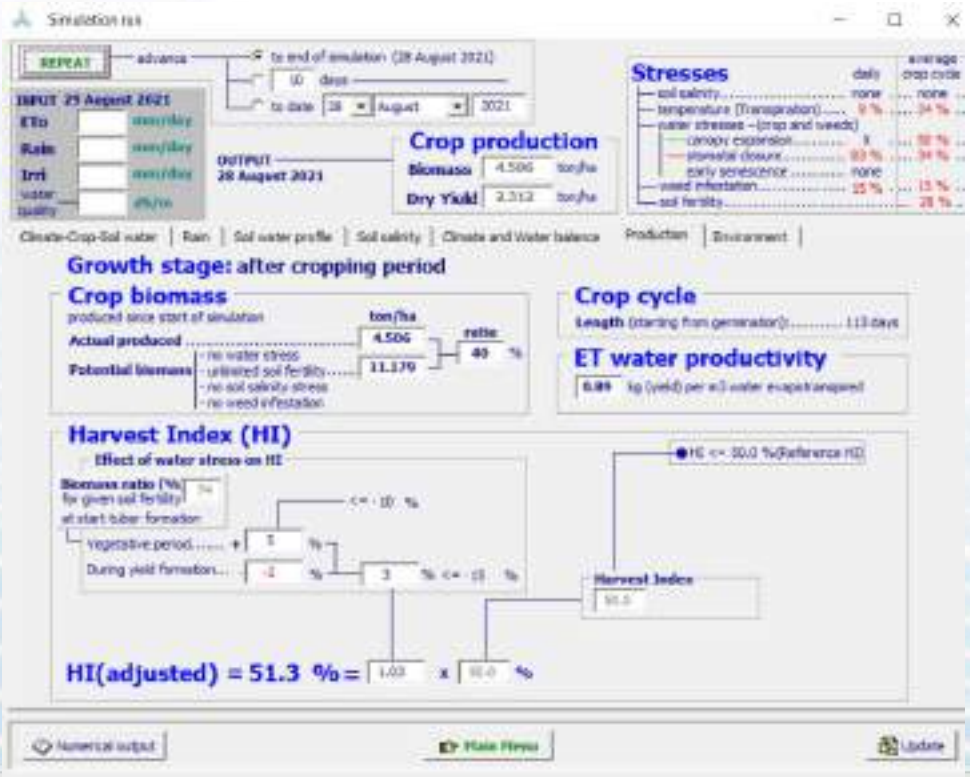
FAO AquaCrop Model for Water Productivity, Scarcity, and Stress Analysis





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PONTOS

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Black Sea CROSS BORDER COOPERATION

Thank you!!