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AI4Water

Water optimization in AI4Water: global allocation and irrigation

Index

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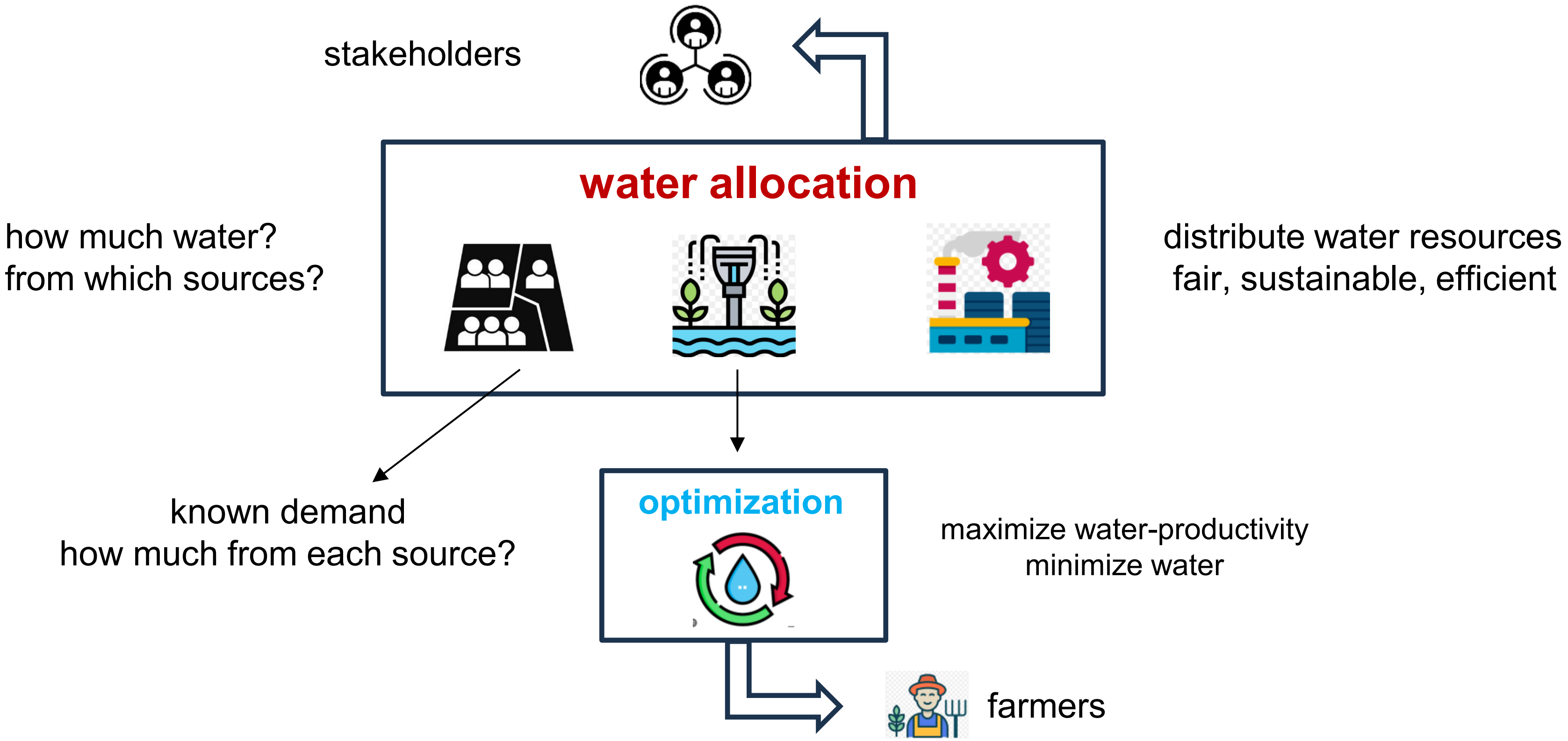
1. Overview of AI4Water: the objective



stakeholders

water allocation

how much water?
from which sources?

distribute water resources
fair, sustainable, efficient

known demand
how much from each source?

optimization

maximize water-productivity
minimize water

farmers

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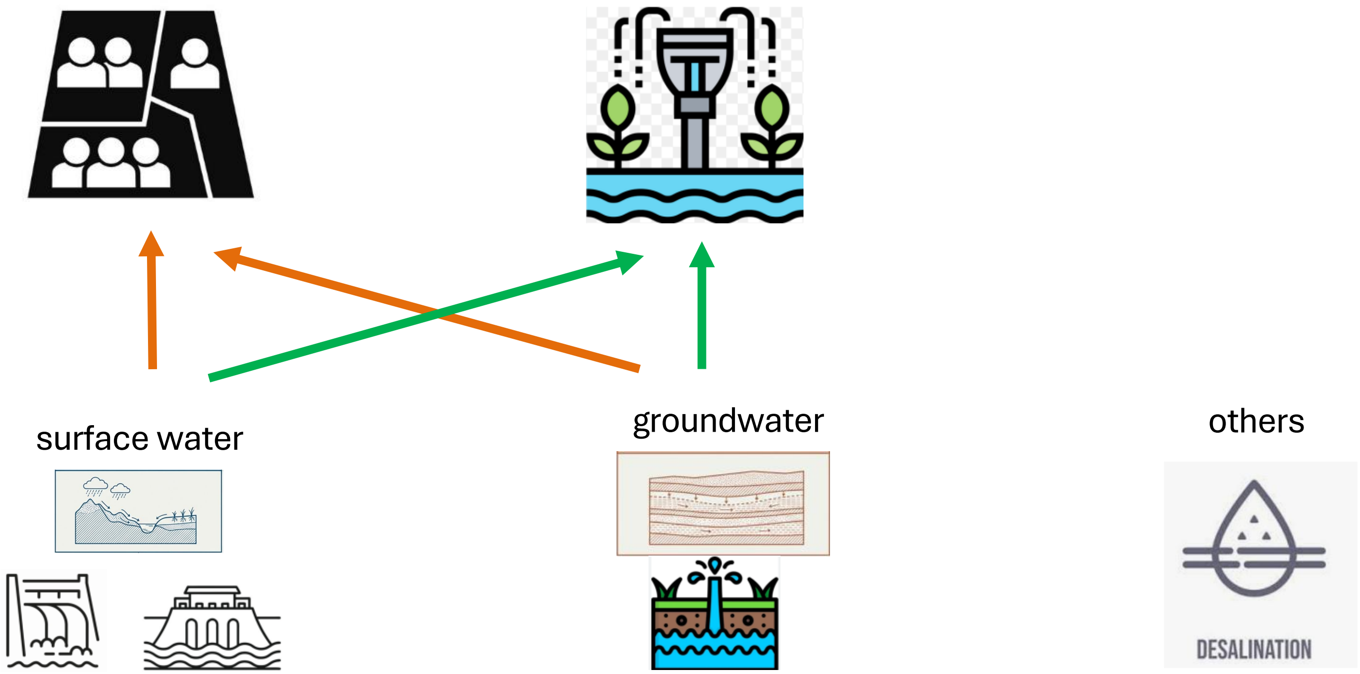
1. Overview of AI4Water: water allocation



water consumption

population

agriculture

water sources

surface water

groundwater

others

reservoirs basins dams

acquaifers

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1. Overview of AI4Water: crop-water optimization

water consumption

how much water?
from which sources?

agriculture

crop-water model

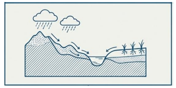
water demand

irrigation schedule

full irrigation schedule

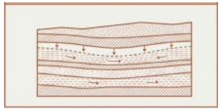
water sources

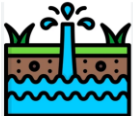
surface water



reservoirs basins dams

groundwater





acquaifers

water availability -> constraint

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1. Overview of AI4Water: a three-layer architecture

Layer 3	**Decision support Operational**	Turn the solution returned by the optimization process into something usable by farmers and stakeholders Solutions translated into calendar-like irrigation plan, including rules for specific and practical implementations. **GUI**.
Layer 2	**Optimization decision**	Optimizer: Genetic Algorithm, Reinforcement Learning Search for irrigation plans that the model layer can evaluate Objective and constraints
Layer 1	**System model**	crop-soil-water model used as simulation model for optimization candidates digital twin that mirrors the real-world behavior of the irrigation system

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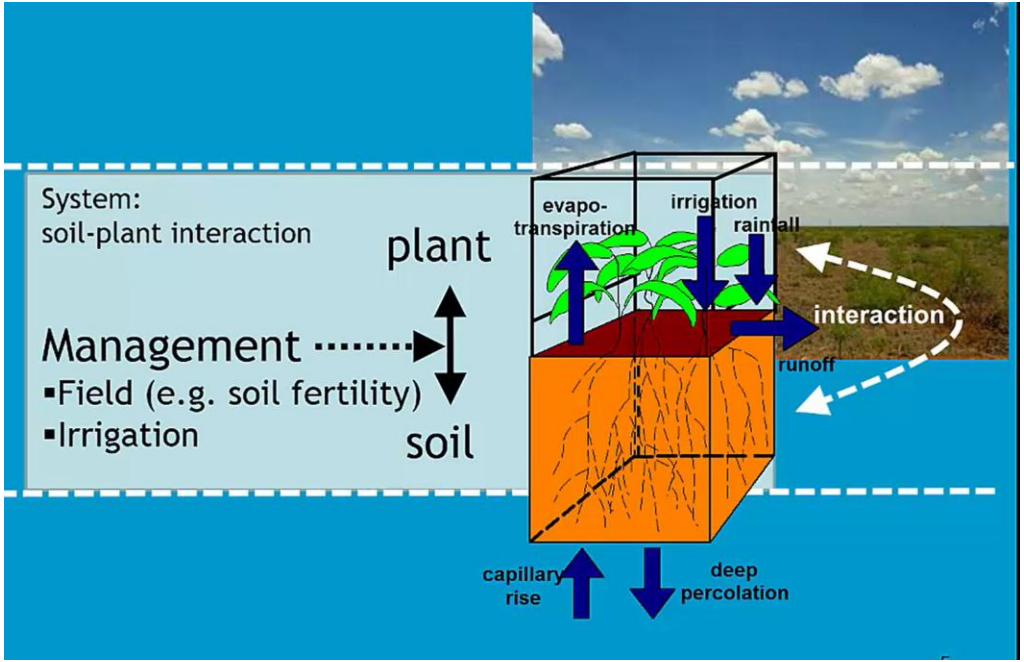
2. Crop-water optimization framework: layer 1

AquaCrop: FAO crop growth model to simulate yield response of herbaceous crops to water



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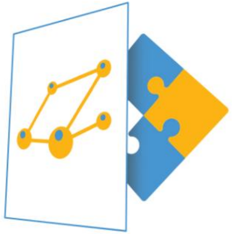
2. Crop-water optimization framework: layer 1

AquaCrop versions

1. AquaCrop software

version 7.1
standard crop water productivity software model with GUI and database, developed by the Land and Water Division of FAO

2. AquaCrop plugin



to run several predefined "projects" and to store results in output files for individual locations without using GUI

3. AquaCrop-OSPy

python Package Index

aquacrop · PyPI
Soil-Crop-Water model based on AquaCrop-OS.
pypi.org

aquacrop 3.0.12

```
pip install aquacrop
```

https://pypi.org/project/aquacrop/

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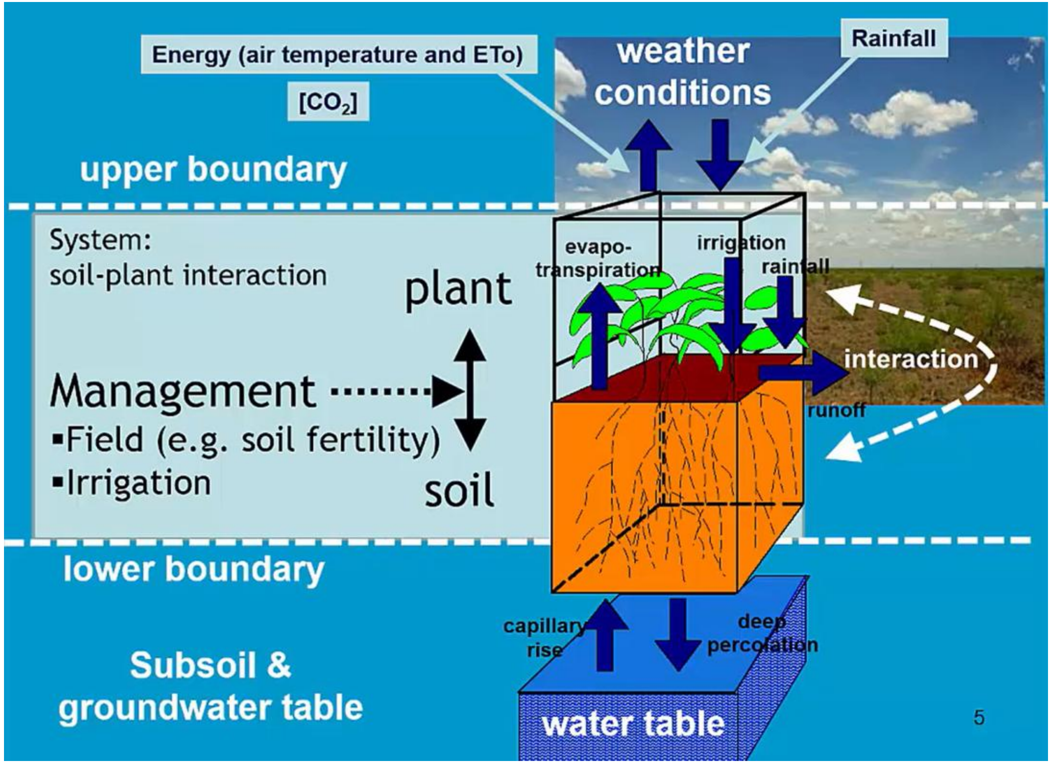
2. Crop-water optimization: layer 1

AquaCrop model

No simulations of water table variations or depth, or water quality → user defined



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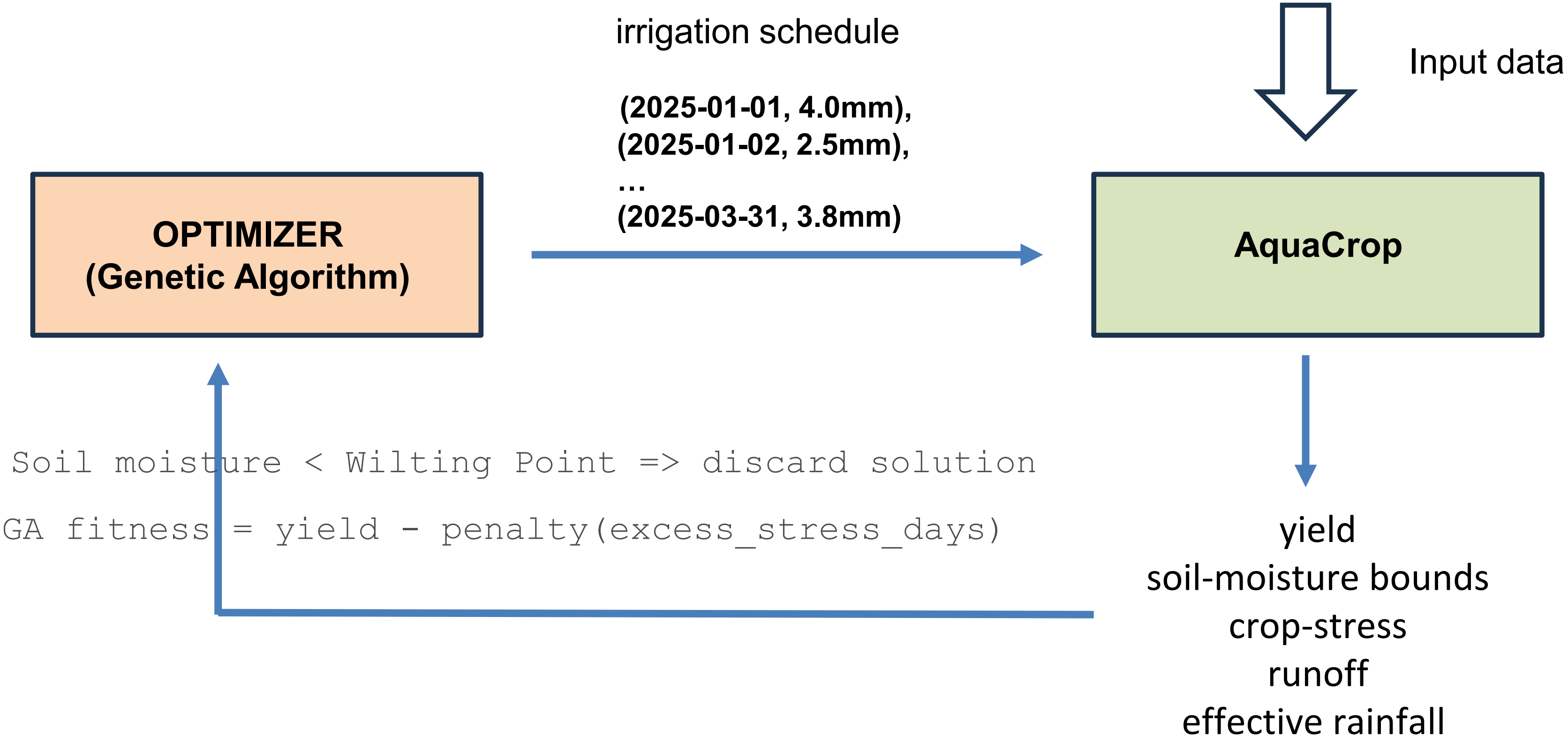
2. Crop-water optimization framework: layer 1 & layer 2



irrigation schedule

(2025-01-01, 4.0mm),
(2025-01-02, 2.5mm),
…
(2025-03-31, 3.8mm)

Input data

OPTIMIZER
(Genetic Algorithm)

AquaCrop

```
Soil moisture < Wilting Point => discard solution
GA fitness = yield - penalty(excess_stress_days)
```

yield
soil-moisture bounds
crop-stress
runoff
effective rainfall

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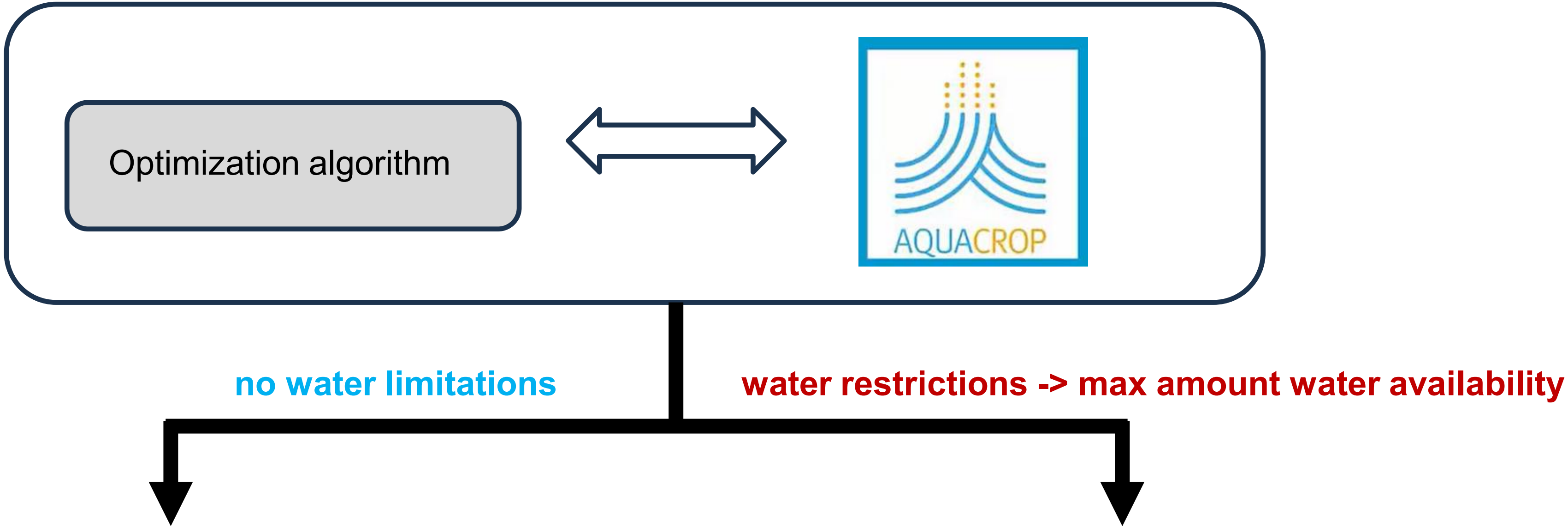
2. Crop-water optimization framework: layer 1 & layer 2



Optimization algorithm

no water limitations

water restrictions -> max amount water availability

how much water is needed for the crops to grow optimally (full irrigation)
max yield
min water

best solution under water restrictions (deficit irrigation)
max yield
water constraint

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3. AquaCrop input data: mandatory input data

Irrigation schedule ➔ from the GA

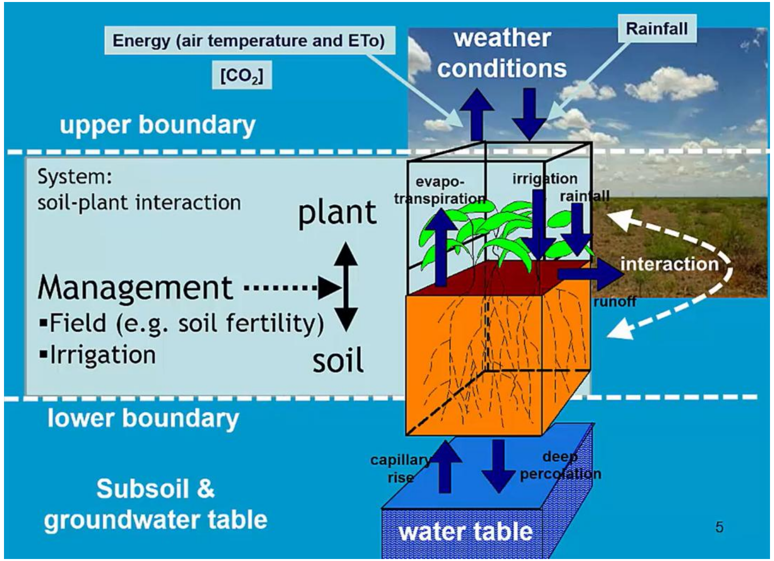
Initially available soil water: typically set to the Field Capacity (FC)

Crop: type, calendar parameters, CC, root-zone parameters, water-stress thresholds, crops coefficients, ...

Soil: FC, Wilting point, saturation, Ksat, CN, REW

Weather: (daily) min temperature, max temperature, rainfall

ET_0 $ET_C = K_c \times ET_0$



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3. AquaCrop input data: non-mandatory data

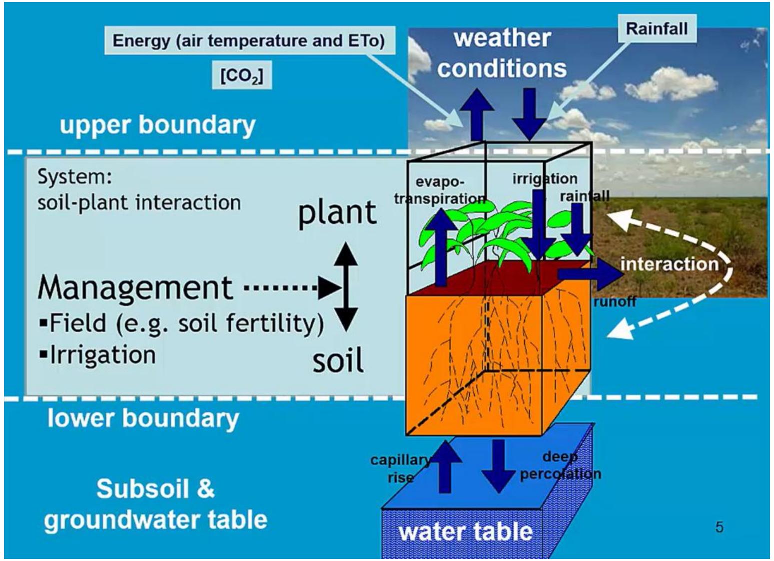
Groundwater depth

- not a parameter
- time-varying fixed value
- lower soil boundary condition

If **no GW table depth is specified**, AquaCrop assumes a very deep water table > 5-6 m.

WITH GW depth ➔ drainage + capillary rise from GW

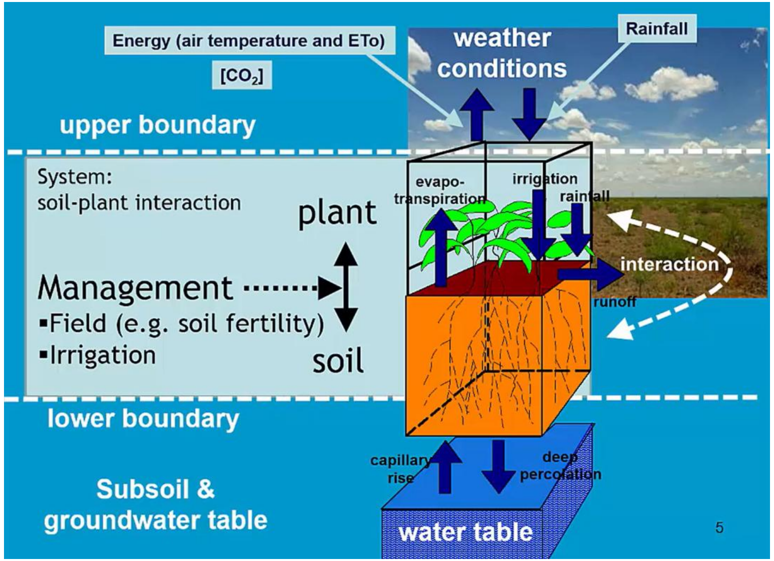
NO GW depth ➔ free drainage

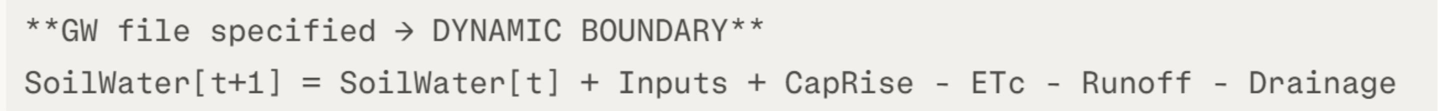


3. AquaCrop input data: non-mandatory data

if GW depth > soil bottom depth
then free drainage

if GW depth <= soil bottom depth
then drainage + capillary rise



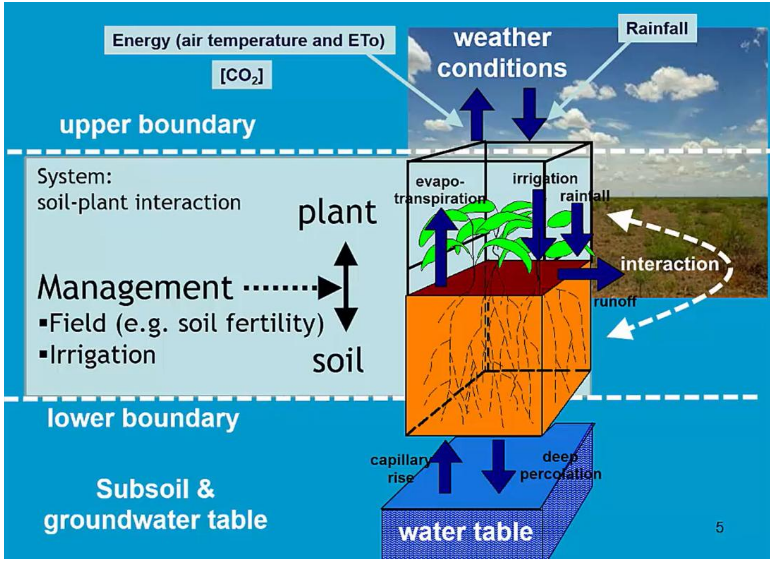


```
**GW file specified → DYNAMIC BOUNDARY**
SoilWater[t+1] = SoilWater[t] + Inputs + CapRise - ETc - Runoff - Drainage
```

3. AquaCrop input data: non-mandatory data

```
Groundwater input file format:
Date | Depth (m) | EC (dS/m)
```

```
Shallow saline GW - sparse measurements
12
1980-01-01  180  3.2
1980-03-15  175  3.4
1980-07-01  200  4.1
1980-10-30  165  2.8
```



- Linearly interpolates between dates
- Computes daily capillary rise based on interpolated depth
- Handles salt transport from varying groundwater quality
- Simulates root zone water balance with groundwater interaction
- Simulates dynamic equilibrium between soil profile and groundwater

4. Handling water quality in the optimization framework

AquaCrop
software

AquaCrop handles water quality as **GW salinity** specified as Electrical Conductivity (EC) in units of dS/m

ECe: Electrical Conductivity of a saturated soil extract (GW file)

1. **Capillary rise** brings salts upward (ECe from GW file)
2. **Soil salinity** increases in bottom layers
3. **Crop stress** calculated via standard salinity thresholds:
    - ECe_threshold (crop-specific)
    - ECe_max (crop death)
4. **Ks_salt [0,1]** accounts for the impact of soil salinity in the crop

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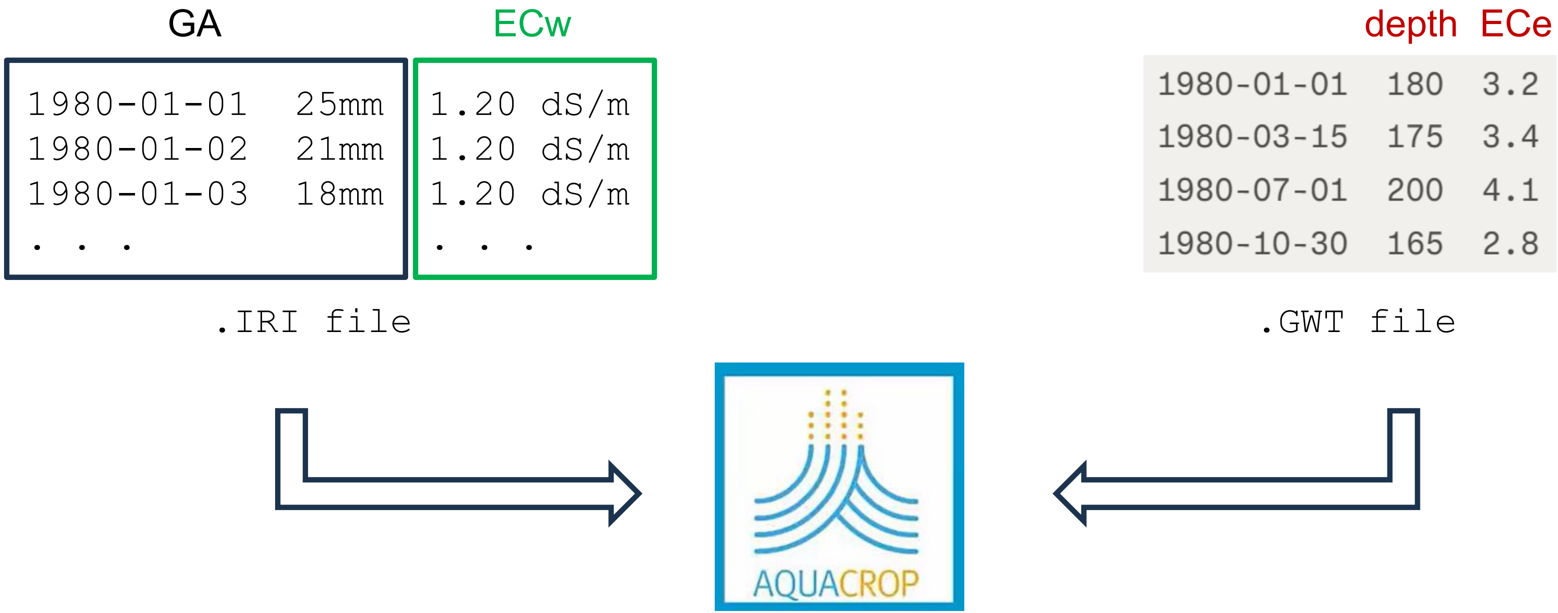
4. Handling water quality in the optimization framework

Add to the optimization algorithm output the value of **ECw**:

irrigation schedule + **ECw** (Electrical Conductivity of Irrigation Water)



GA		ECw
1980-01-01	25mm	1.20 dS/m
1980-01-02	21mm	1.20 dS/m
1980-01-03	18mm	1.20 dS/m
. . .		. . .

`.IRI file`

	depth	ECe
1980-01-01	180	3.2
1980-03-15	175	3.4
1980-07-01	200	4.1
1980-10-30	165	2.8

`.GWT file`

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4. Handling water quality in the optimization framework

What about using IWQI (Irrigation Water Quality Index)?

- **Extending irrigation schedules with IWQI won't work directly in AquaCrop.**
- AquaCrop strictly requires ECw (EC in dS/m) as the salinity input, not composite indices like IWQI
- Is there a direct matching (standard conversion) between IWQI and ECw?

Potential Solution

Apply a penalty in the fitness function of the optimization algorithm

Determine the values of the non-ECw components of IWQI and assign penalty

SAR=12 → SAR_penalty = 0.10
Cl- = 250 mg/L → toxicity_penalty = 0.05

```
fitness= fitness * (1 - sum_penalties)
```

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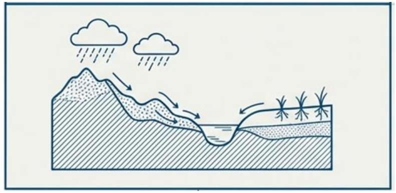
4. Handling water quality in the optimization framework

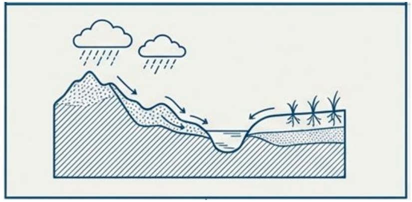
What if we have more than two reservoirs?

R1



ECw= 1.20 dS/m

R2



ECw= 1.30 dS/m

- New decision variable

```
1980-01-01  25mm  1.20 dS/m
1980-01-02  21mm  1.20 dS/m
1980-01-03  18mm  1.30 dS/m
```

- Mixing water: adds a new dimension to the problem

```
1980-01-01  20mm 1.20 dS/m  5mm 1.30 dS/m
1980-01-02   6mm 1.20 dS/m 15mm 1.30 dS/m
```

$\text{ECw\_blend} = (V_{R1} \times ECw_{R1} + V_{R2} \times ECw_{R2}) / (V_{R1} + V_{R2}) \rightarrow$

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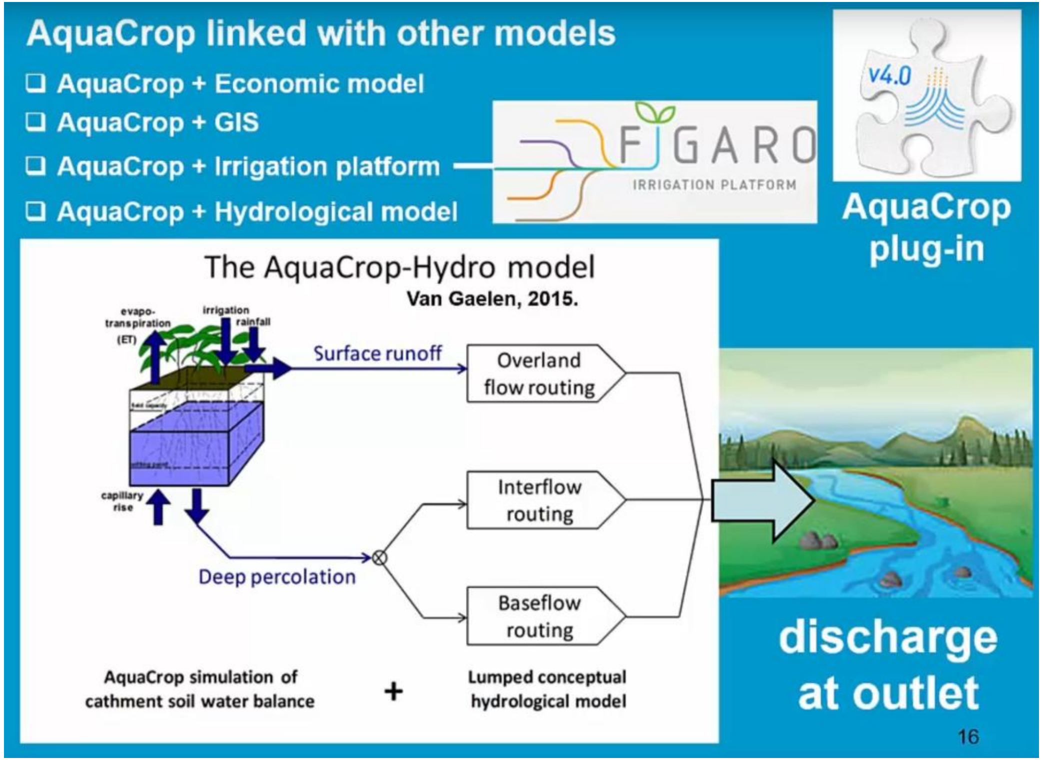
5. Linking AquaCrop to a hydrological modeling



AquaCrop linked with other models

☐ AquaCrop + Economic model
☐ AquaCrop + GIS
☐ AquaCrop + Irrigation platform
☐ AquaCrop + Hydrological model

AquaCrop plug-in

The AquaCrop-Hydro model

Van Gaelen, 2015.

AquaCrop simulation of cathment soil water balance + Lumped conceptual hydrological model

discharge at outlet

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5. Linking AquaCrop to a hydrological modeling

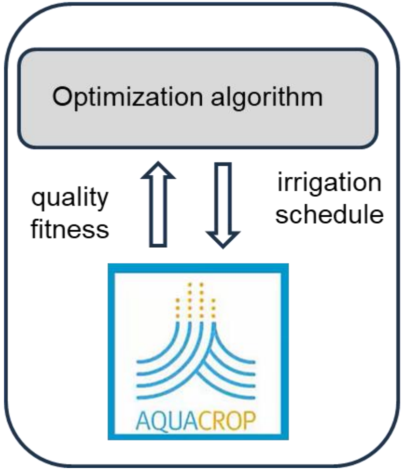
Actual water withdrawals and timing: info on **water use + irrigation schedule** ➔ helpful for farmers

Estimates of **surface return flows** (e.g., runoff, deep percolation that reaches nearby streams) and **spatial patterns of reuse**.

Information on **sections or periods where demand exceeds surface-water availability**, highlighting potential conflicts between irrigation and in-stream ecological needs.

Time-series of **total basin-scale irrigation demand** under different optimized scenarios (e.g., deficit-irrigation vs full-irrigation)

crop-water optimization



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