Water scarcity versus agricultural production – a new way for an optimal and sustainable management of resources under arid conditions –

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Outline

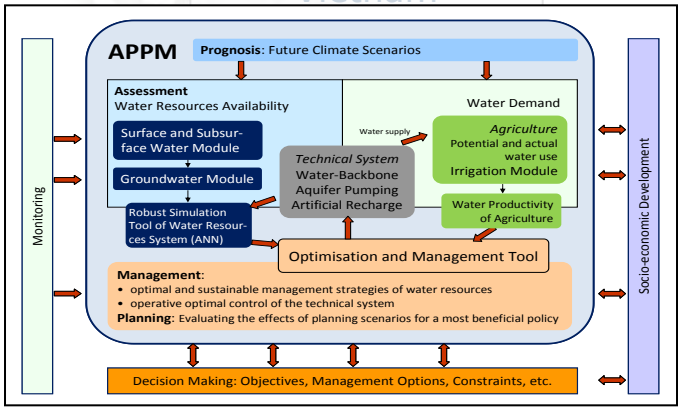
1 Motivation & Objectives

2 A new Tool for sustainable Management of Resources

- Structure & Modules
- Water Resources
- Agriculture
- Management

3 Implementation

4 Summary, Conclusion



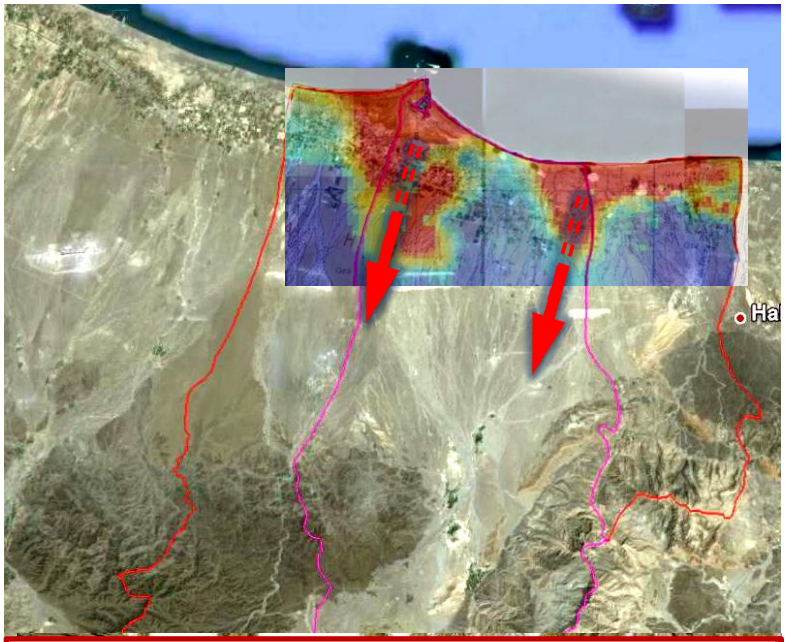
1 Motivation & Objectives

Batinah Region of Oman

- excessive groundwater abstraction due to irrigated agriculture
- Inversion of groundwater's natural gradient (flow direction)

  → Marine saltwater intrusion
- Saline irrigation water and thus – saline soils
- Destruction of agricultural resources
- Decreasing farm income & abandoned farms
- impacts the food security of the country

Wadis Bani Kharus, Ma'awil, Taww



Saline intrusion in coastal areas

1 Motivation & Objectives

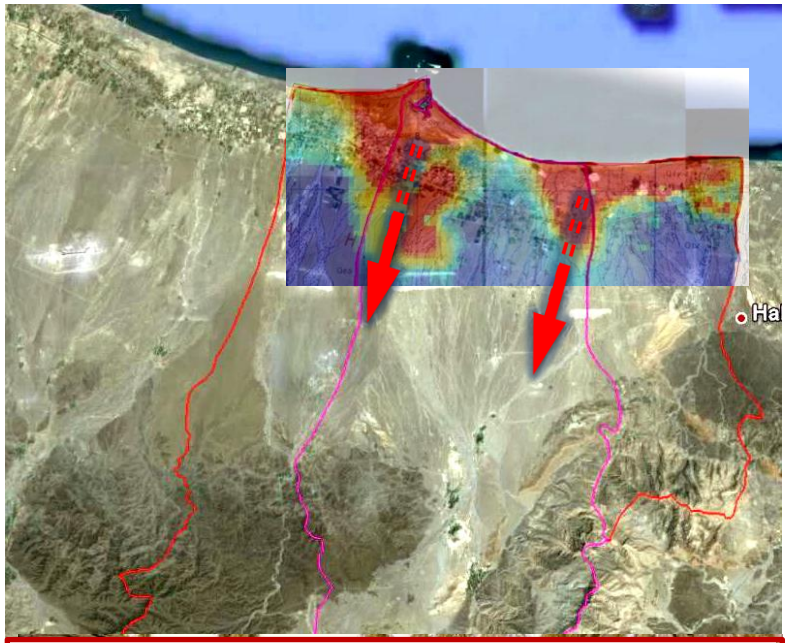
Objectives

- Optimal integrated water management and long-term planning system for water quality and quantity
- Sustainable management of water and soils
- Balancing water demand and availability
- Improvement of water use efficiency in irrigated agriculture by novel irrigation techniques

Challenges

- Coupled dynamic agricultural - coastal aquifer system
- Climate and global change

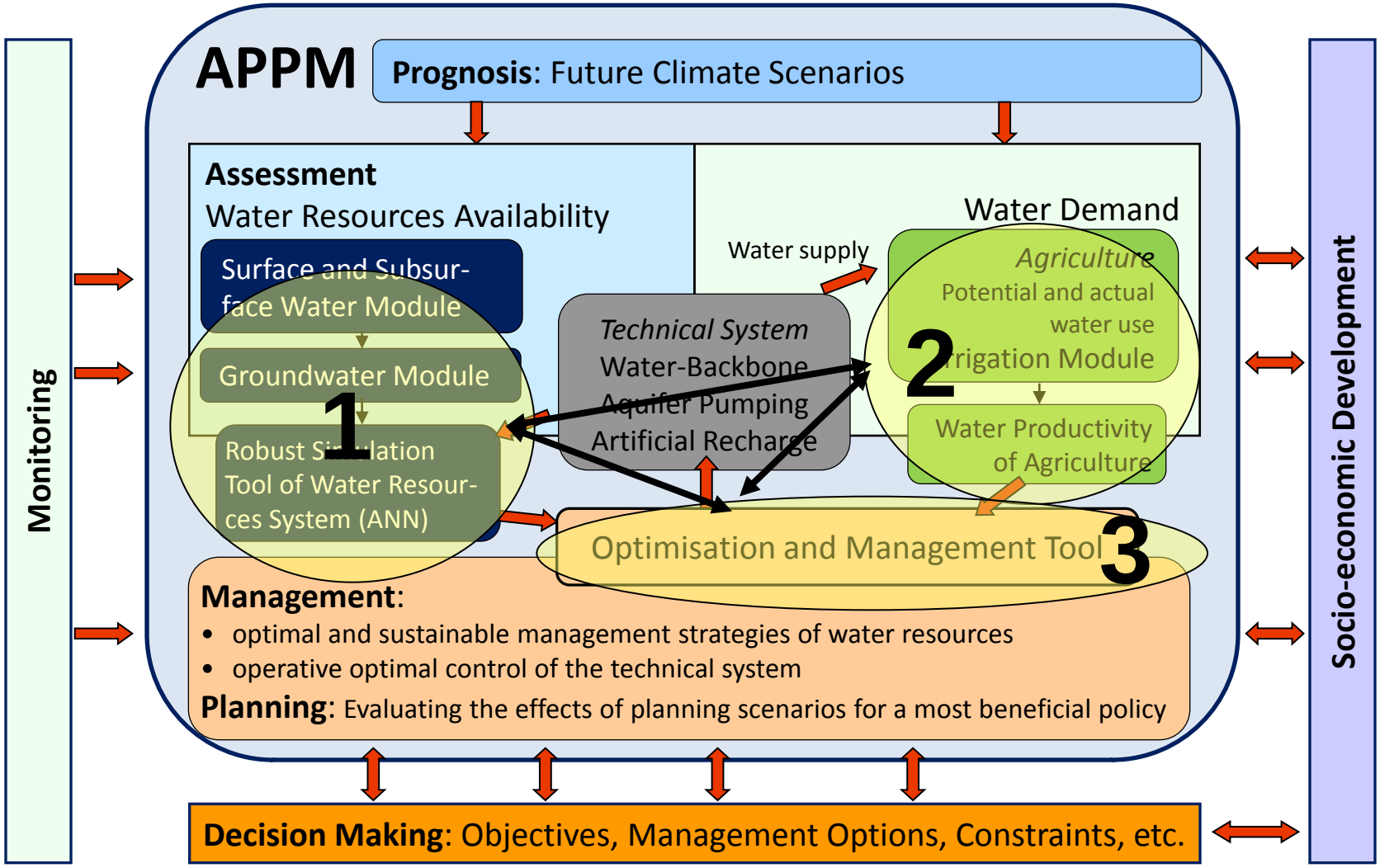
Wadis Bani Kharus, Ma'awil, Taww



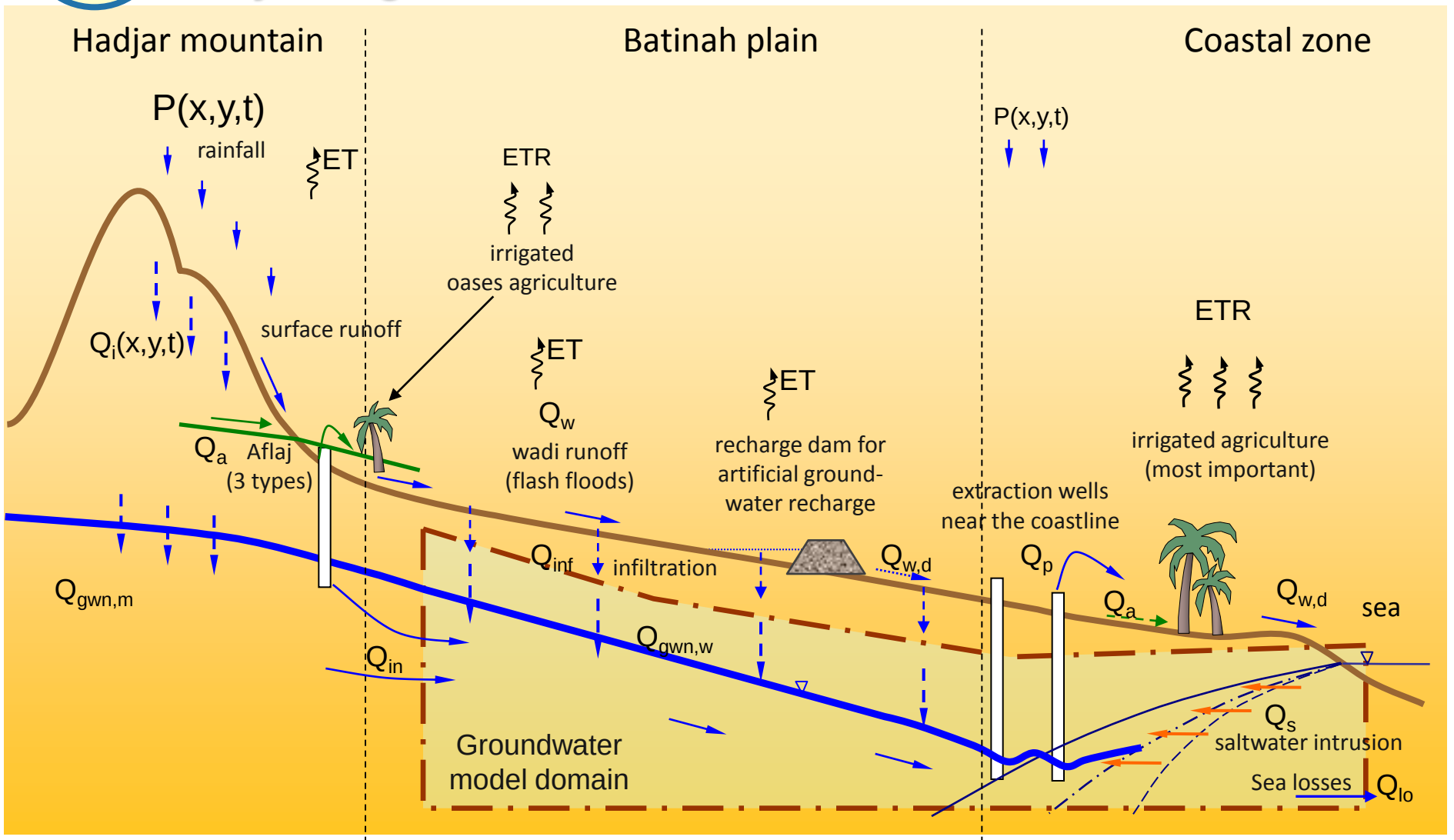
Saline intrusion in coastal areas

2 A Tool for sustainable IWRM in arid Regions

Structure and Submodules

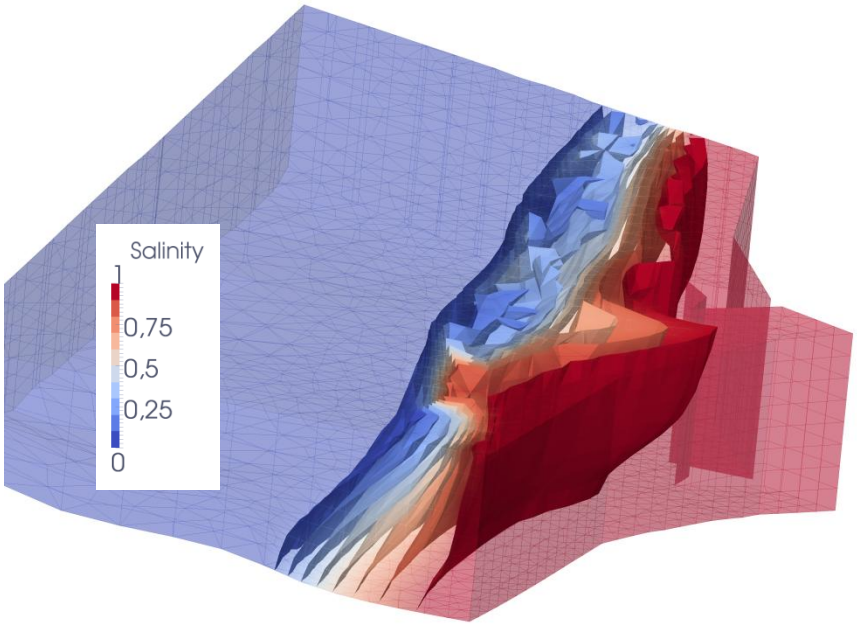


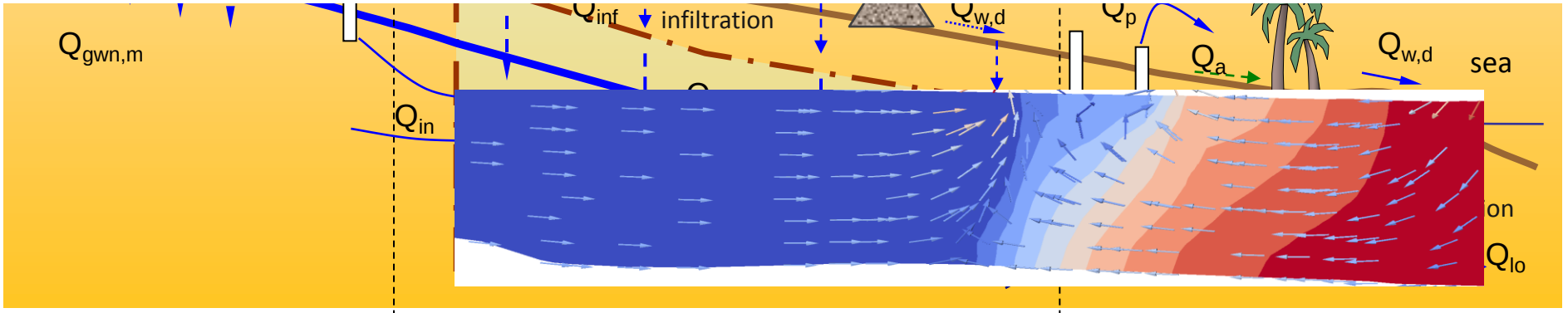
1 Assessment Tools for Water Resources
- Hydrological Processes -



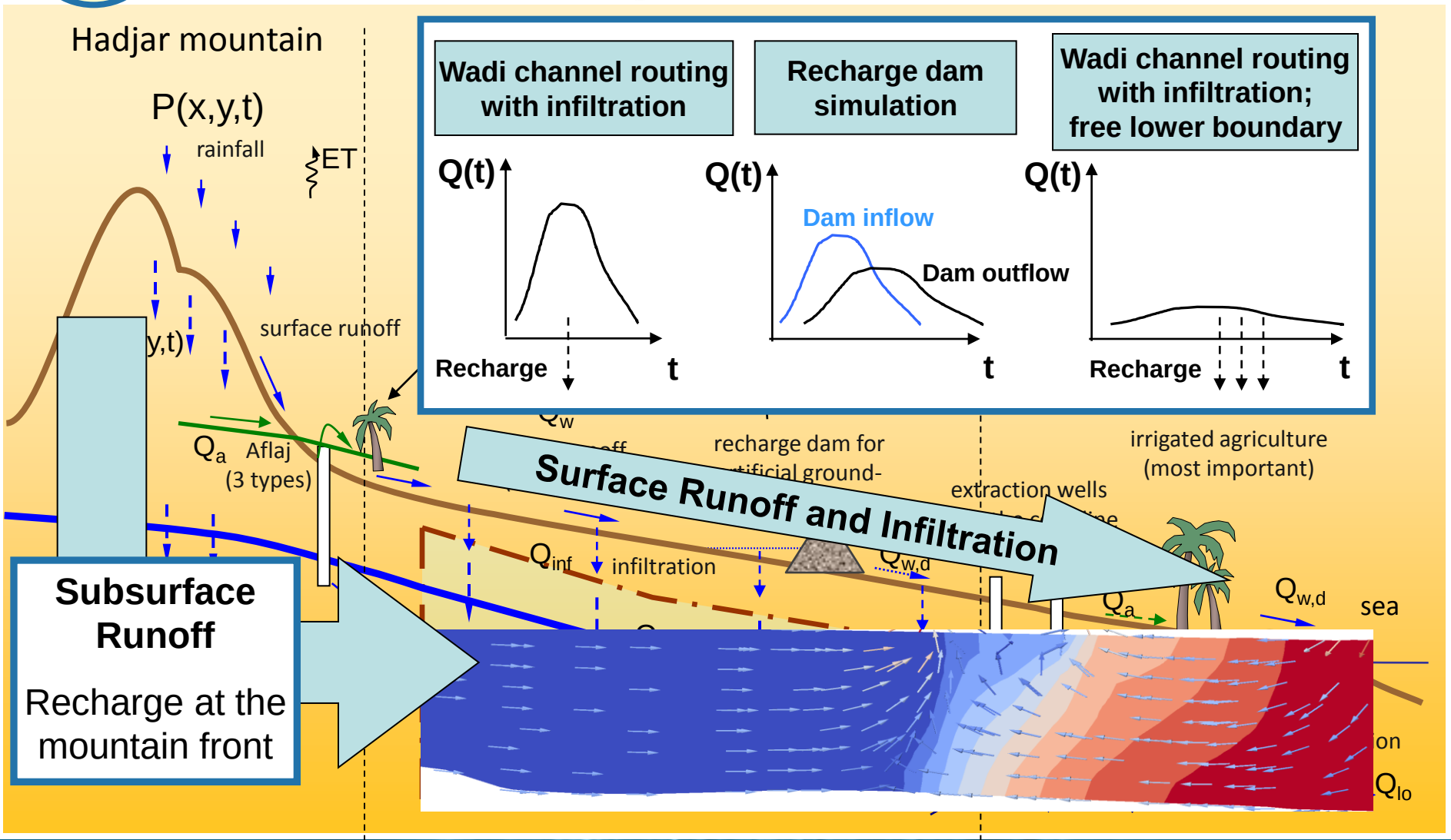
1 Assessment Tools for Water Resources
- Groundwater Modelling -

- Three-dimensional density driven groundwater flow model for simulating the aquifer behavior inclusive salt water intrusion phenomena based on OpenGeoSys (OGS) Kolditz et al. 2012
- Development of a hydrogeological model of the coastal aquifer for the pilot area
- Steady state calibration



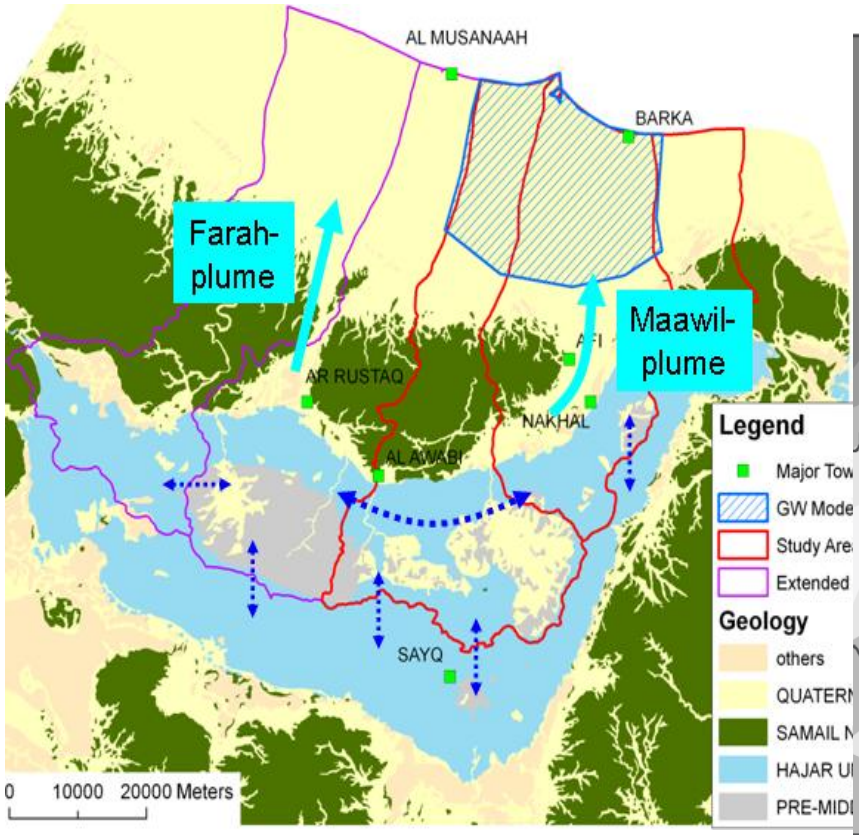


1 Assessment Tools for Water Resources
- Groundwater Recharge -

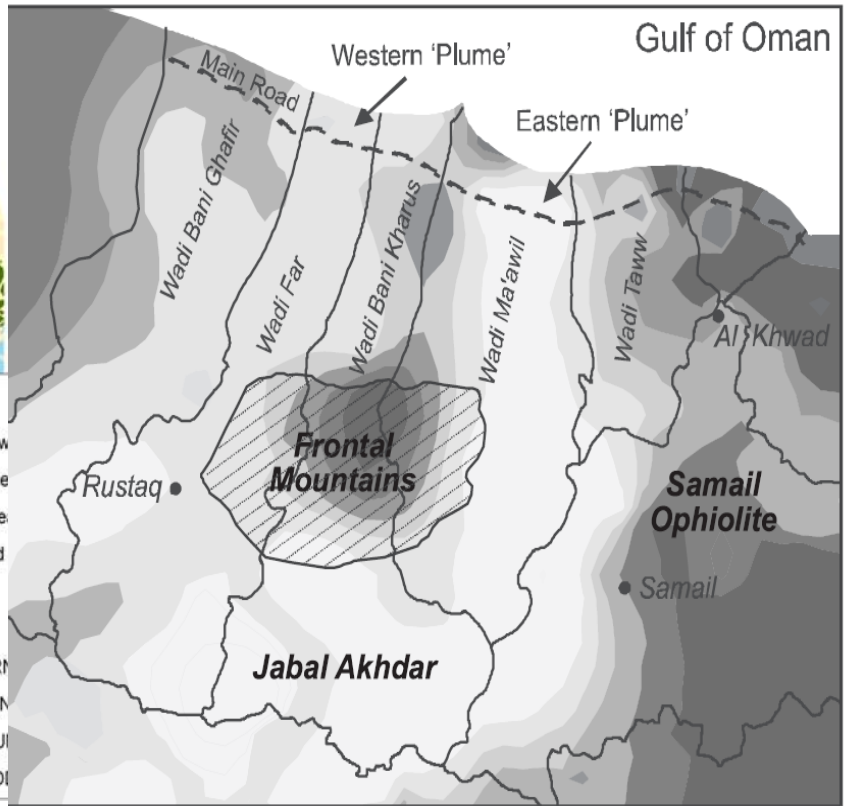


1 Assessment Tools for Water Resources
- Groundwater Recharge -

- Boundary Conditions for the Groundwater-Model
- Uncertain subsurface catchment divide due to geological characteristics



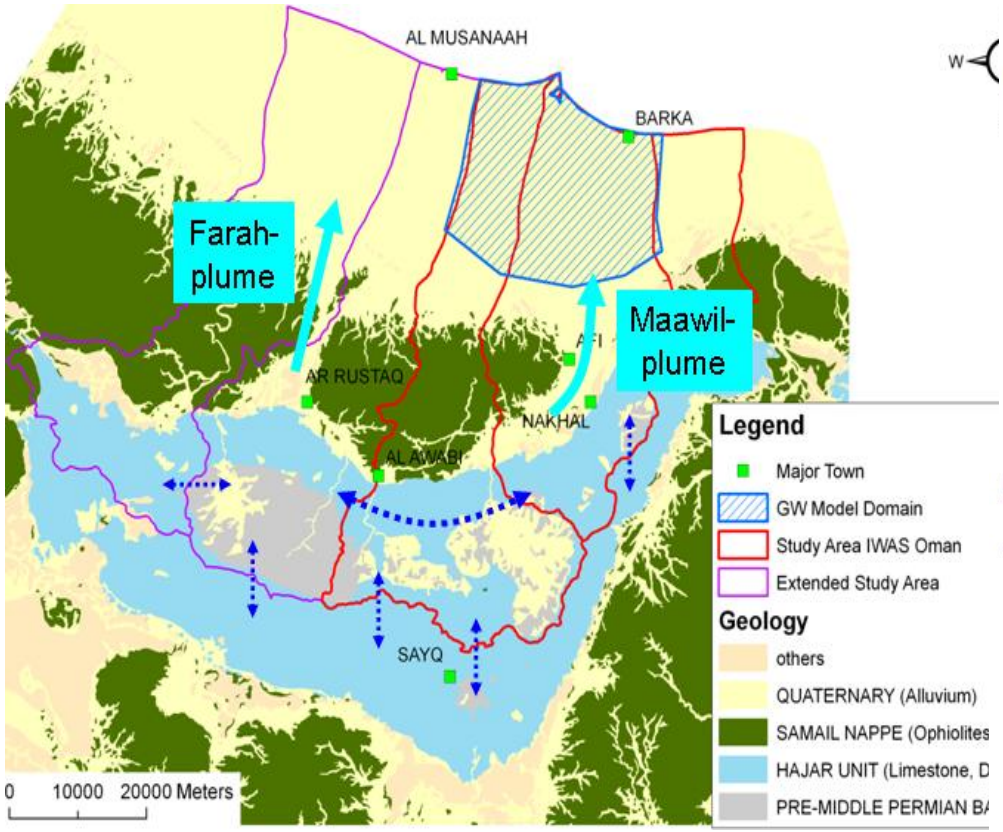
Contour plot of oxygen isotopes ($\delta^{18}O$)
(Weyhenmeyer et al., 2002)

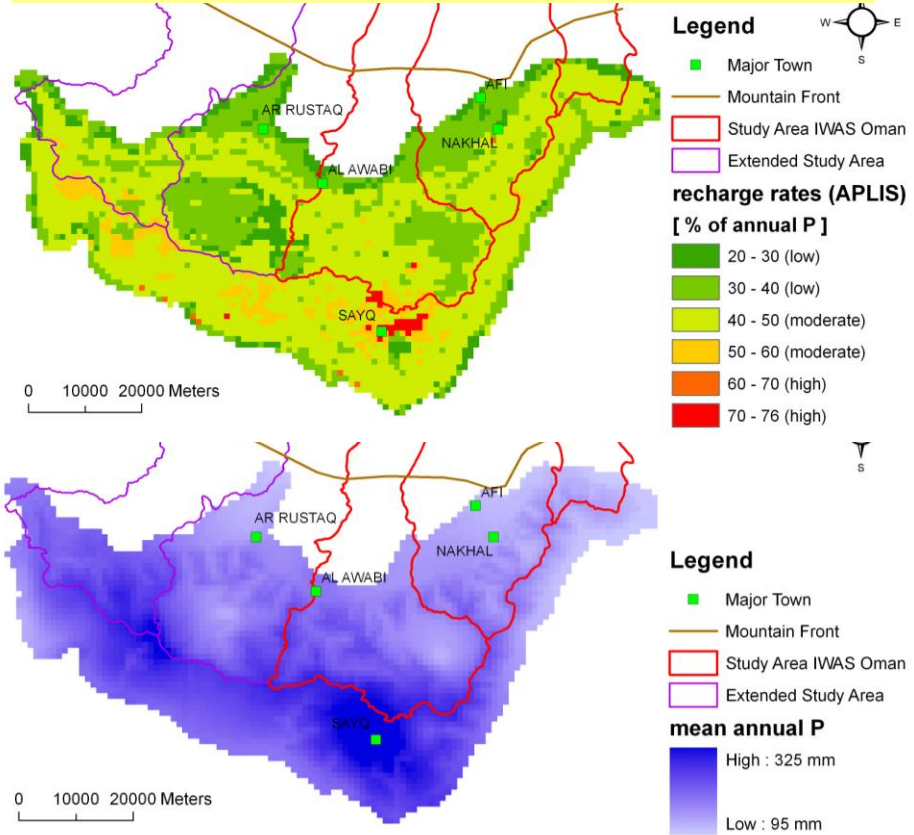


1 Assessment Tools for Water Resources
- Groundwater Recharge -

- Boundary Conditions for the Groundwater-Model
- Uncertain subsurface catchment divide due to geological characteristics

GIS-based approach for spatially distributed recharge-rates in % of annual areal precipitation based on geomorphologic variables (height, slope, lithology, soils)

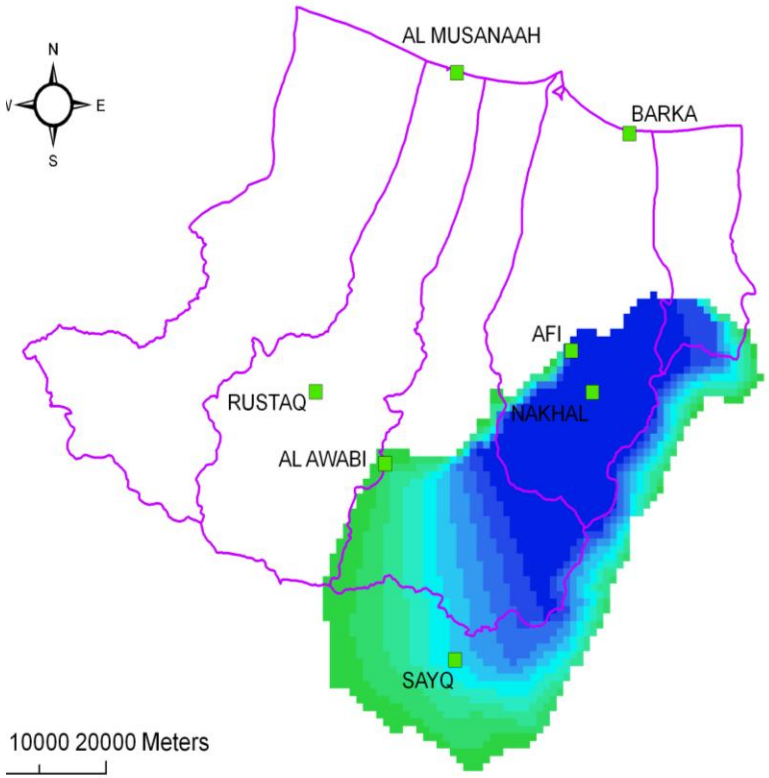


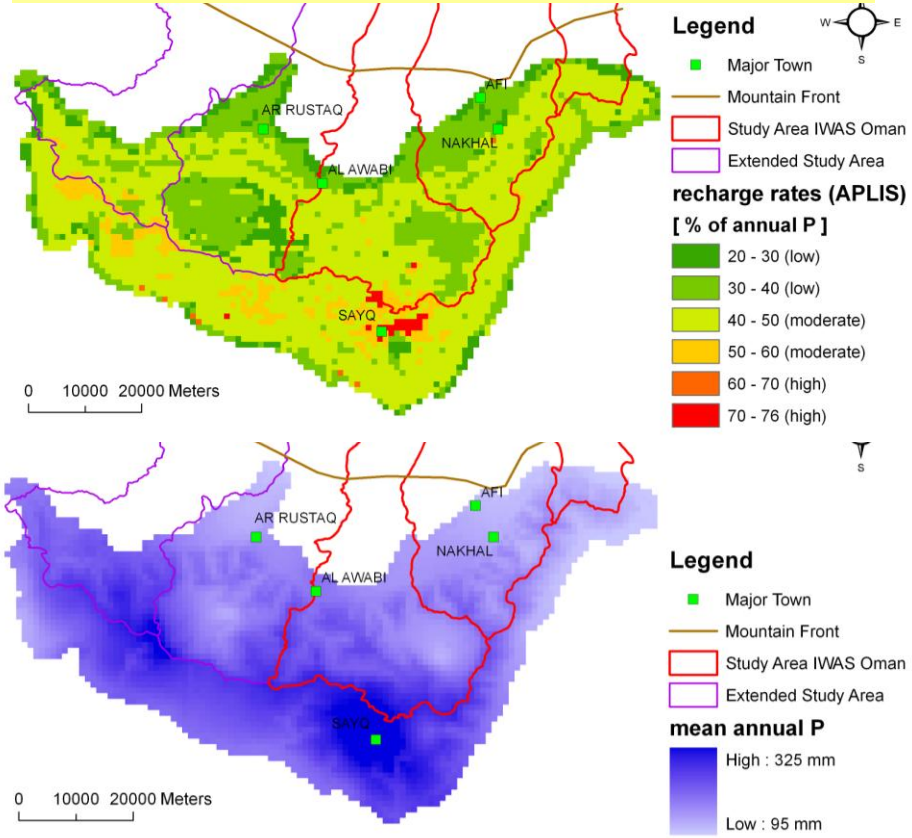


1 Assessment Tools for Water Resources
- Groundwater Recharge -

Fuzzy-approach for characterising uncertain subsurface catchments → estimation of potential ranges of fresh water availability

GIS-based approach for spatially distributed recharge-rates in % of annual areal precipitation based on geomorphologic variables (height, slope, lithology, soils)





1 Assessment Tools for Water Resources
- Groundwater Recharge -

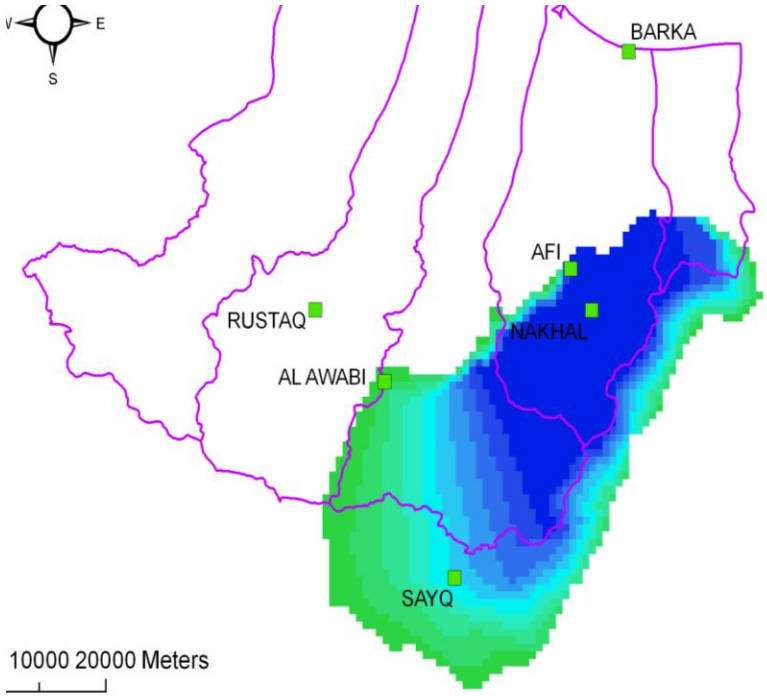
Groundwater recharge estimation

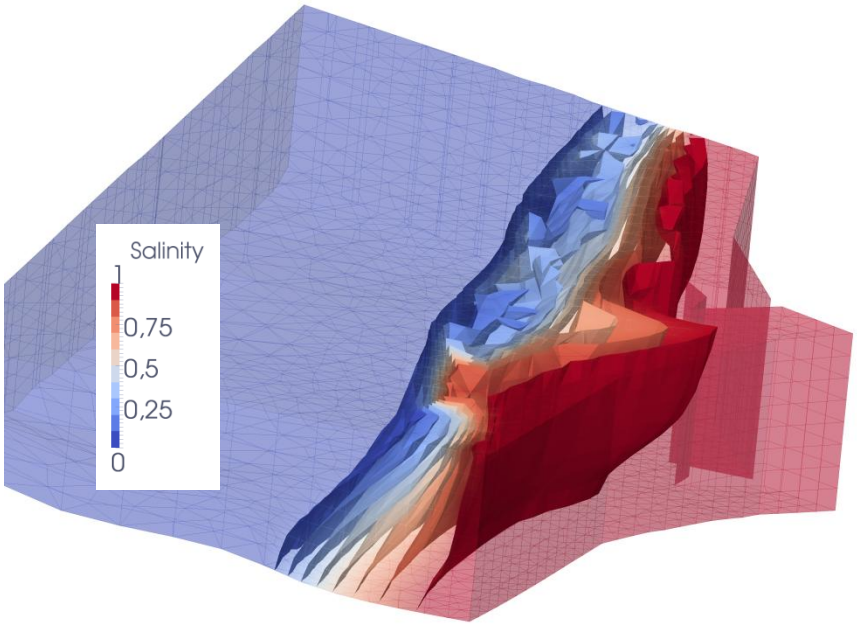
Approach 1: Straightforward

60 – 73 MCM/a

Mean annual value

Gerner et al. 2011





Groundwater recharge estimation

Approach 2: Inverse

68 MCM/a

Steady state calibration of Groundwater model using optimization

Walther et al. 2012

2 Assessment & Planning Tools for Agriculture
- Increasing water use efficiency and food production -

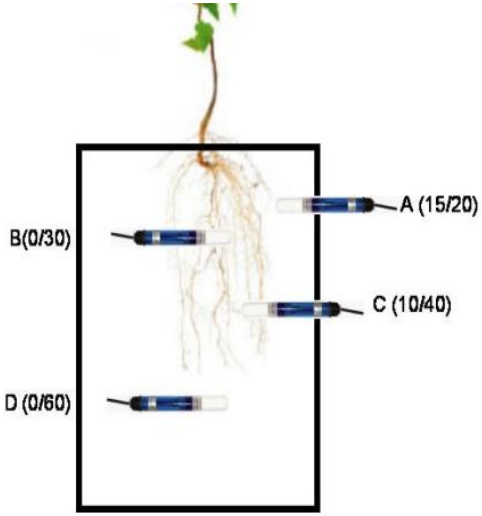
„more crop per drop“

The UN World Water Development Report, 2003

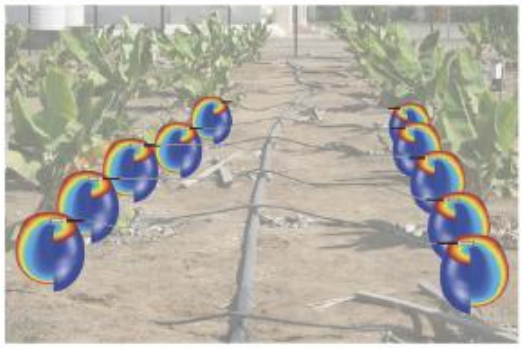
sustainable IWRM requires reducing the amount of water used in Oman’s agriculture without reducing food production

Higher water productivity

2 Assessment & Planning Tools for Agriculture
- Simulation optimization of irrigation control and scheduling -

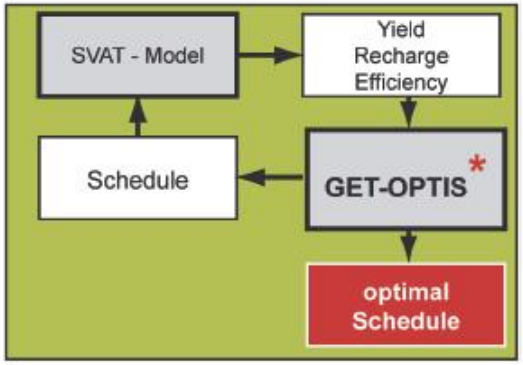


Real world irrigation system



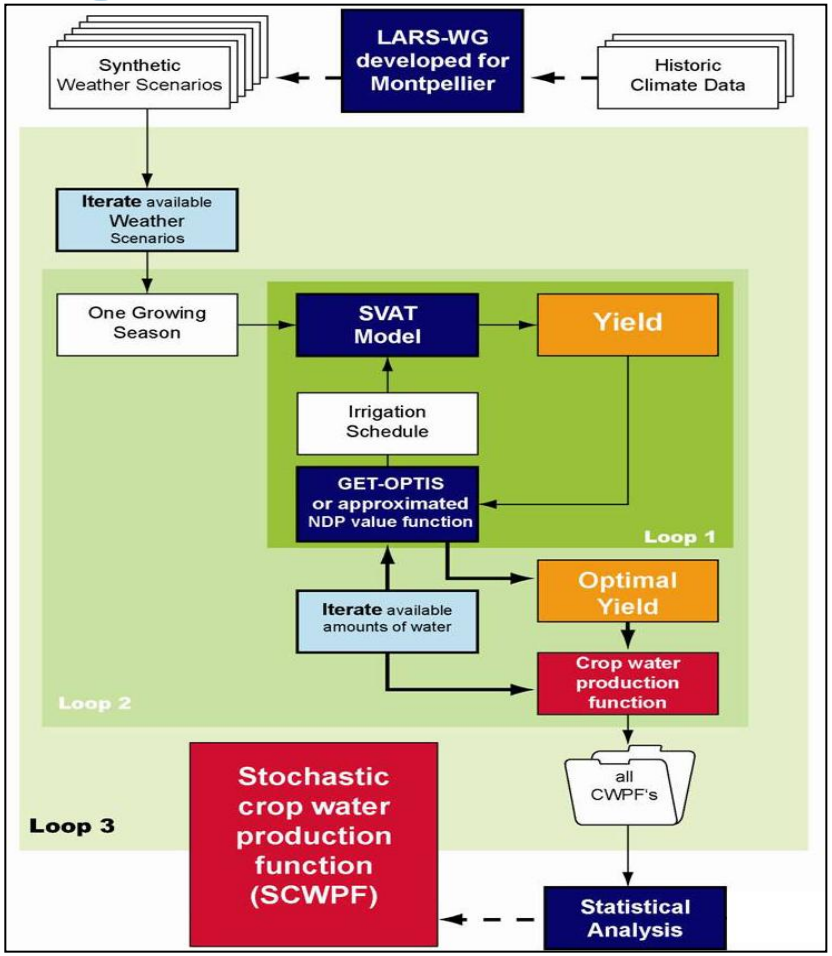
Modeling the field in virtual reality and simulation of water, nutrient and salt transport

Implementation of optimal scheduling and control in the real world



Optimal and robust irrigation scheduling and control

2 Assessment & Planning Tools for Agriculture
- Increasing water use efficiency and food production -



Schütze & Schmitz, 2010: **OCCASION**: A new Planning Tool for Optimal Climate Change Adaption Strategies in Irrigation. In: *Journal of Irrigation and Drainage Engineering* 136

Basic TOOLS for Assessment, Management, Planning and Adaption:

- Irrigation experiments
- Validated SVAT Models

→ **transfer of experiments in space and time**

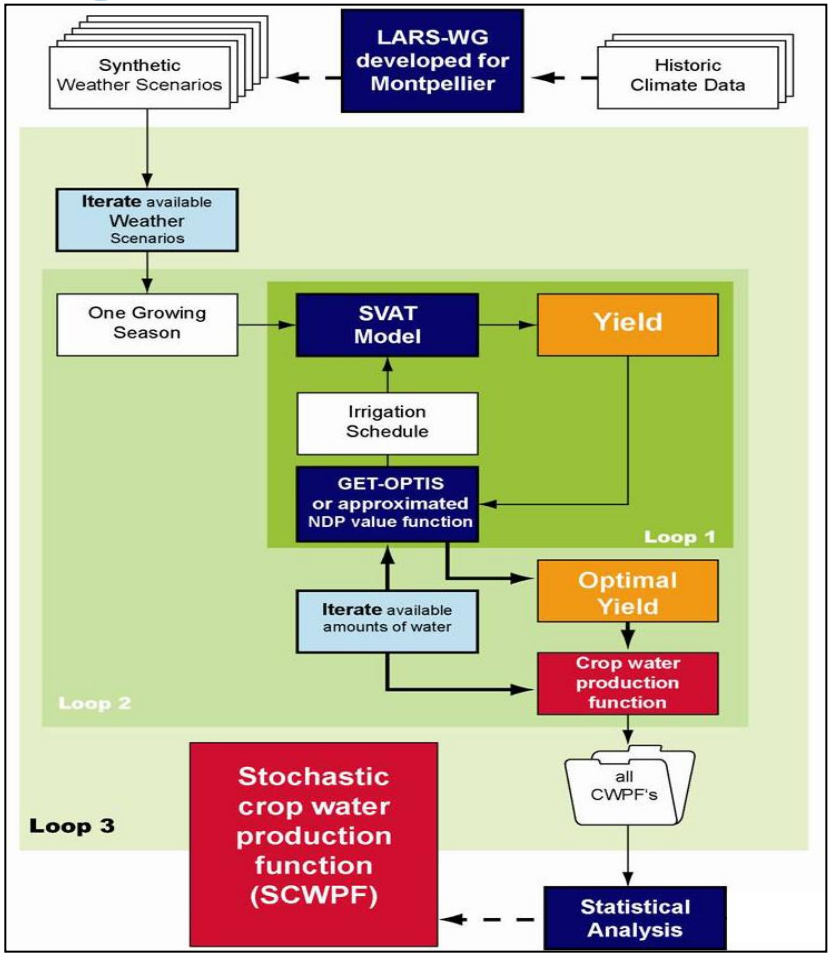
- Optimization tools

→ **best layout, scheduling, cropping pattern**

- Monte Carlo simulation

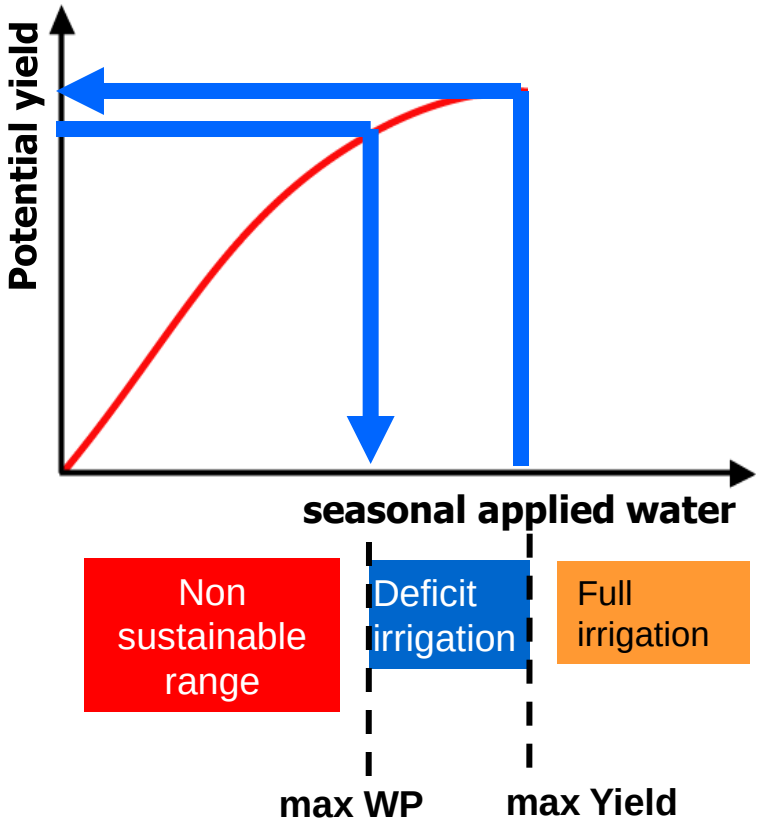
→ **high reliability of irrigation management under climate and soil variability**

2 Assessment & Planning Tools for Agriculture
- Increasing water use efficiency and food production -

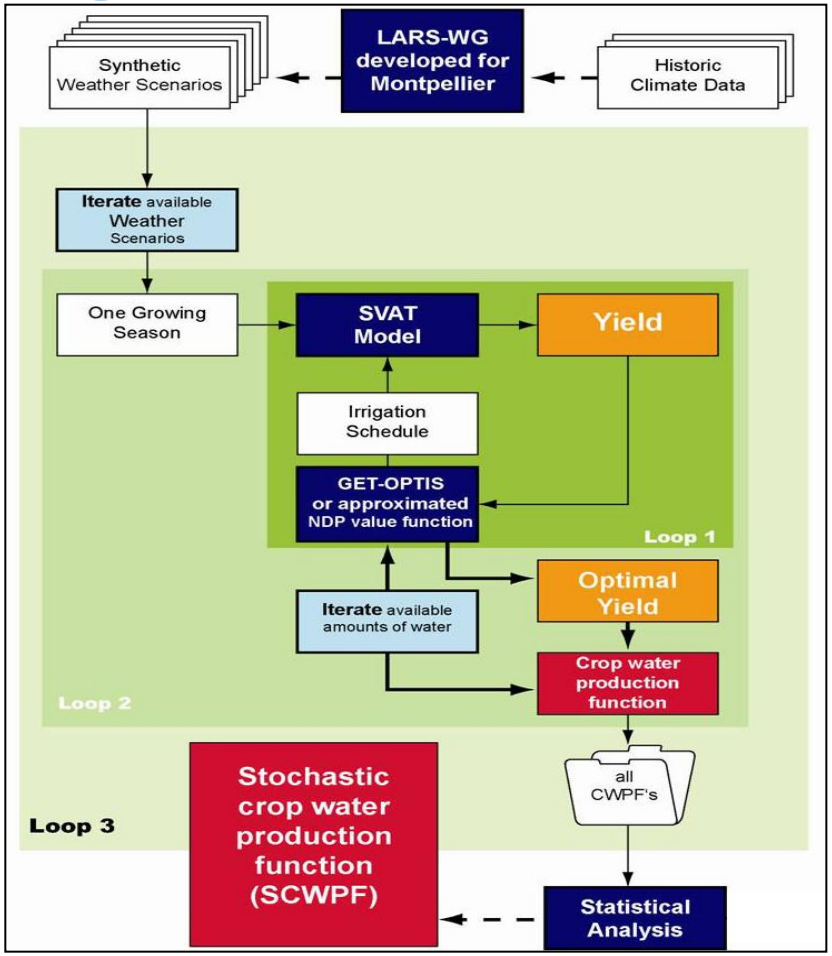


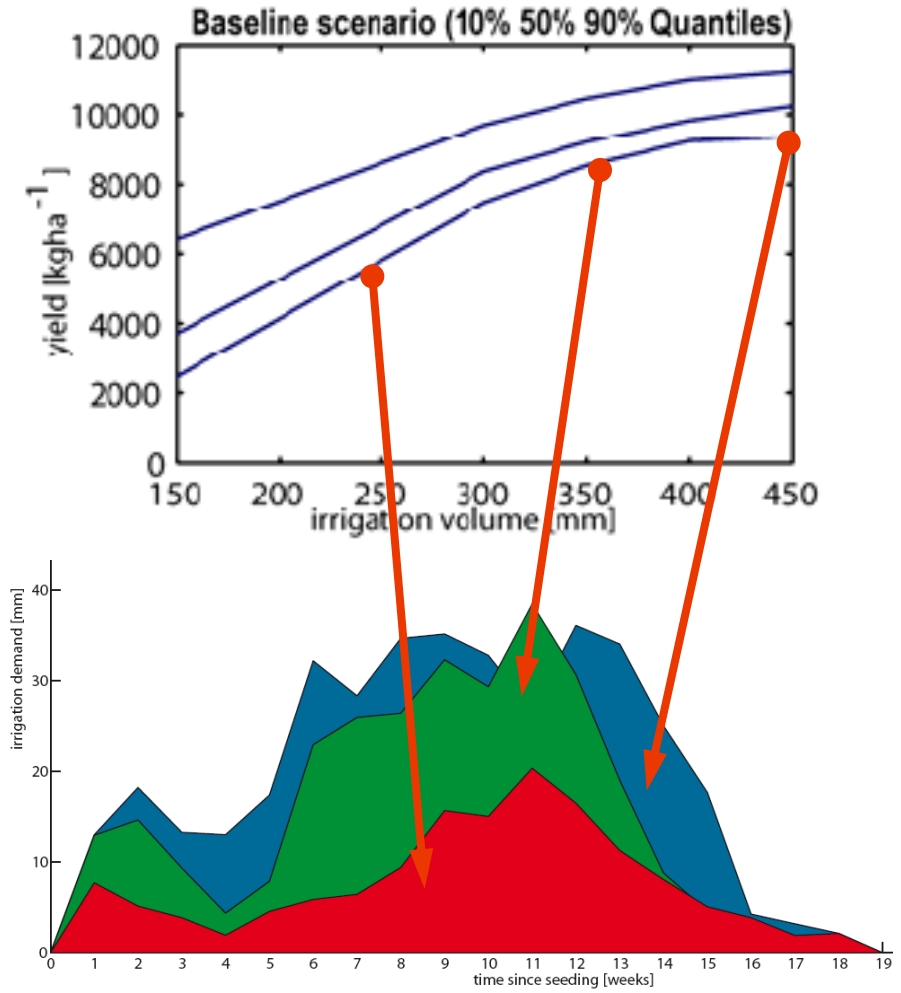
Schütze & Schmitz, 2010: **OCCASION**: A new Planning Tool for Optimal Climate Change Adaption Strategies in Irrigation. In: *Journal of Irrigation and Drainage Engineering* 136

Estimation of **C**rop **W**ater **P**roduction **F**unctions - CWPF



2 Assessment & Planning Tools for Agriculture
- Increasing water use efficiency and food production -





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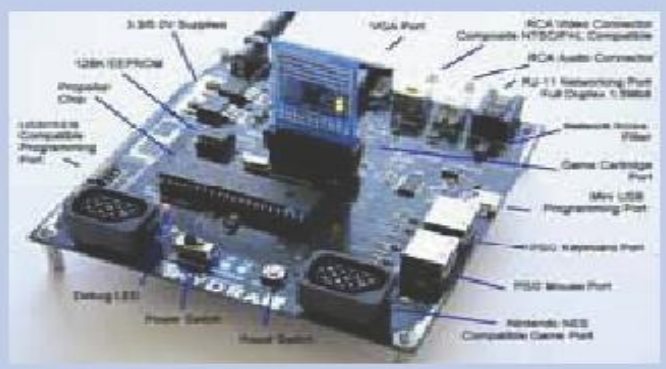
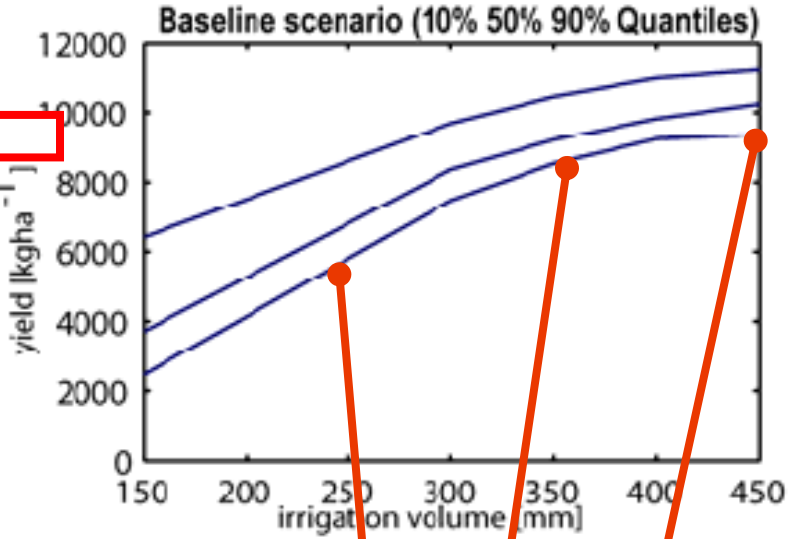
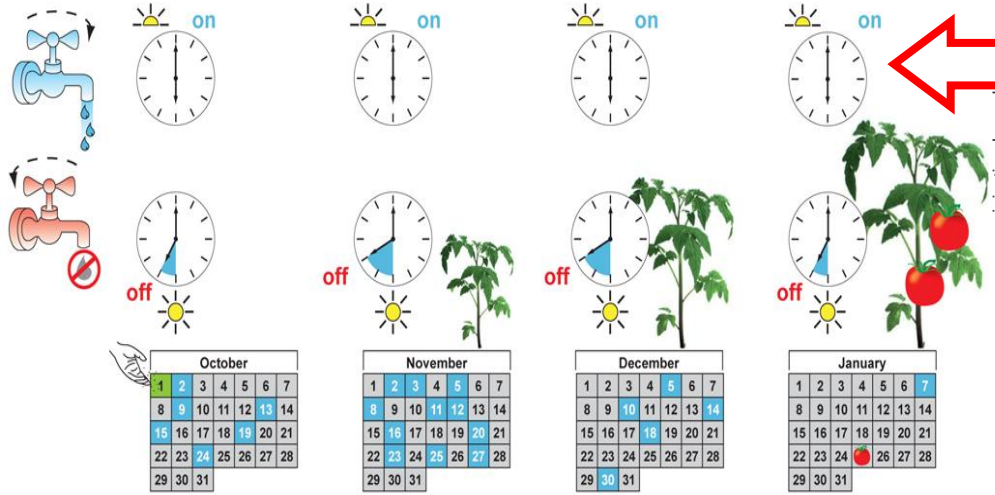
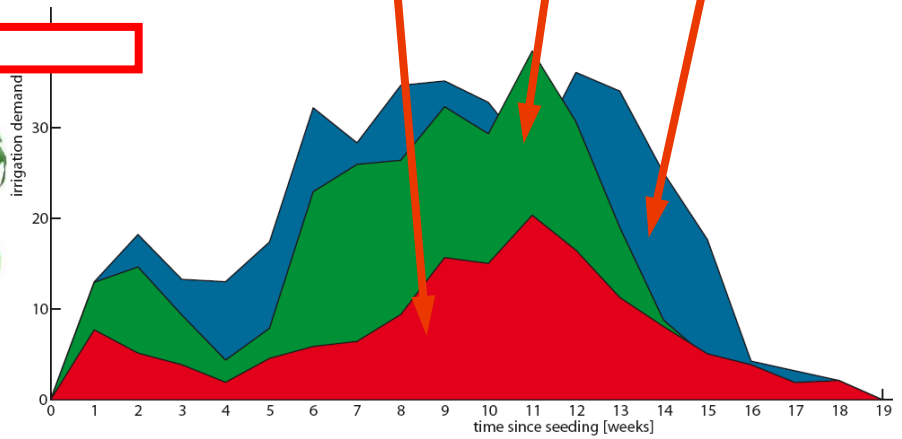
2 Assessment & Planning Tools for Agriculture
- Increasing water use efficiency and food production -

low cost **Wifi Microcontroller system**



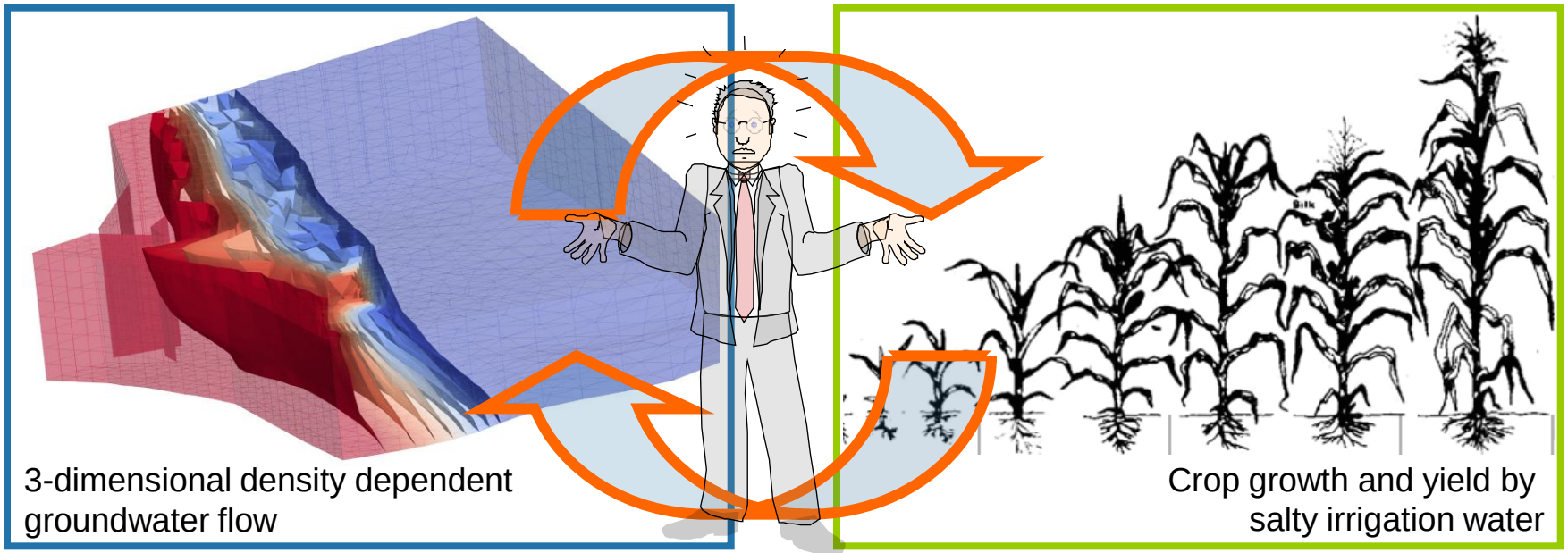






3 Optimal Management of coupled Hydrosystems
- Challenges -

How can we manage an interacting groundwater - agriculture system sustainably regarding water quantity and quality under uncertain climatic and global impacts ?



3-dimensional density dependent groundwater flow

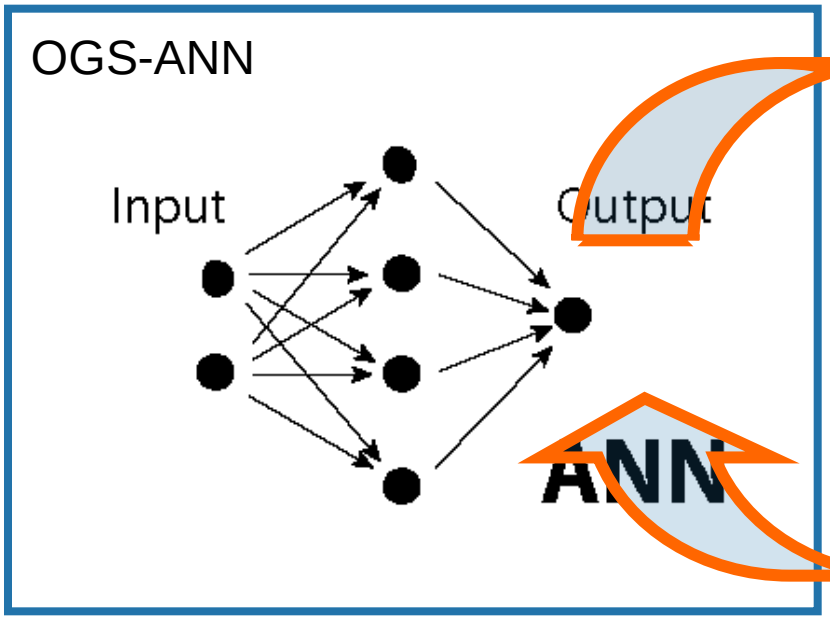
Crop growth and yield by salty irrigation water

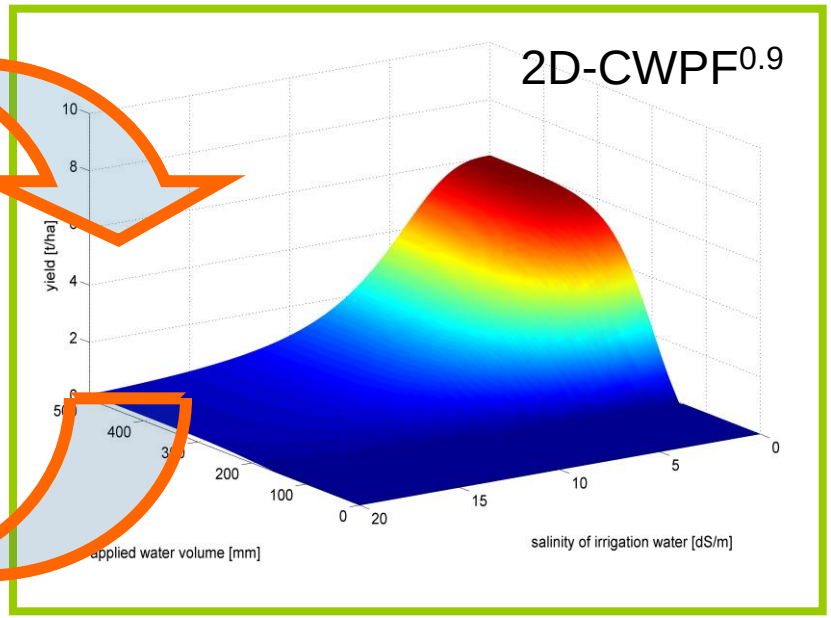
Challenges

- Long simulation times and the complexity of physically based models as well as global optimization procedures
- Consideration of the model interactions within the optimization process

3 Optimal Management of coupled Hydrosystems
- The use of surrogates -

How can we manage an interacting groundwater - agriculture system sustainably regarding water quantity and quality under uncertain climatic and global impacts ?



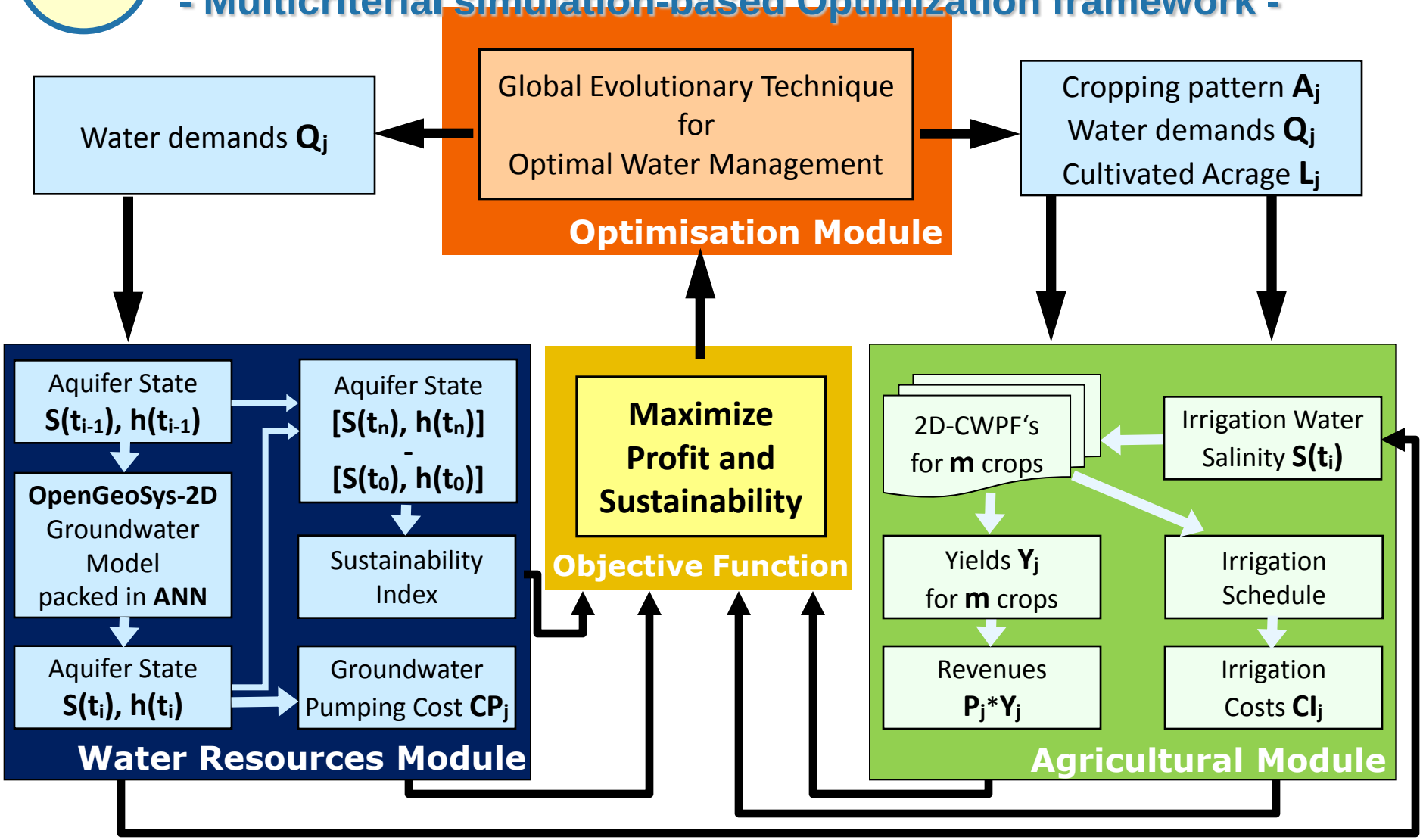


Methodology

1. Development of appropriate surrogate models

2. Multicriterial simulation-based optimization

3 Optimal Management of coupled Hydrosystems
- Multicriterial simulation-based Optimization framework -



3 Optimal Management of coupled Hydrosystems
- Multicriterial simulation-based Optimization -

How can we manage an interacting groundwater - agriculture system sustainably regarding water quantity and quality under uncertain climatic and global impacts ?

Management objective: Groundwater

Long term availabili of water resource

good water quality

Abstraction < recharge

Contradicting objectives

Management objective: Farmer

High profit

Low costs

High quality products

Water with good quality

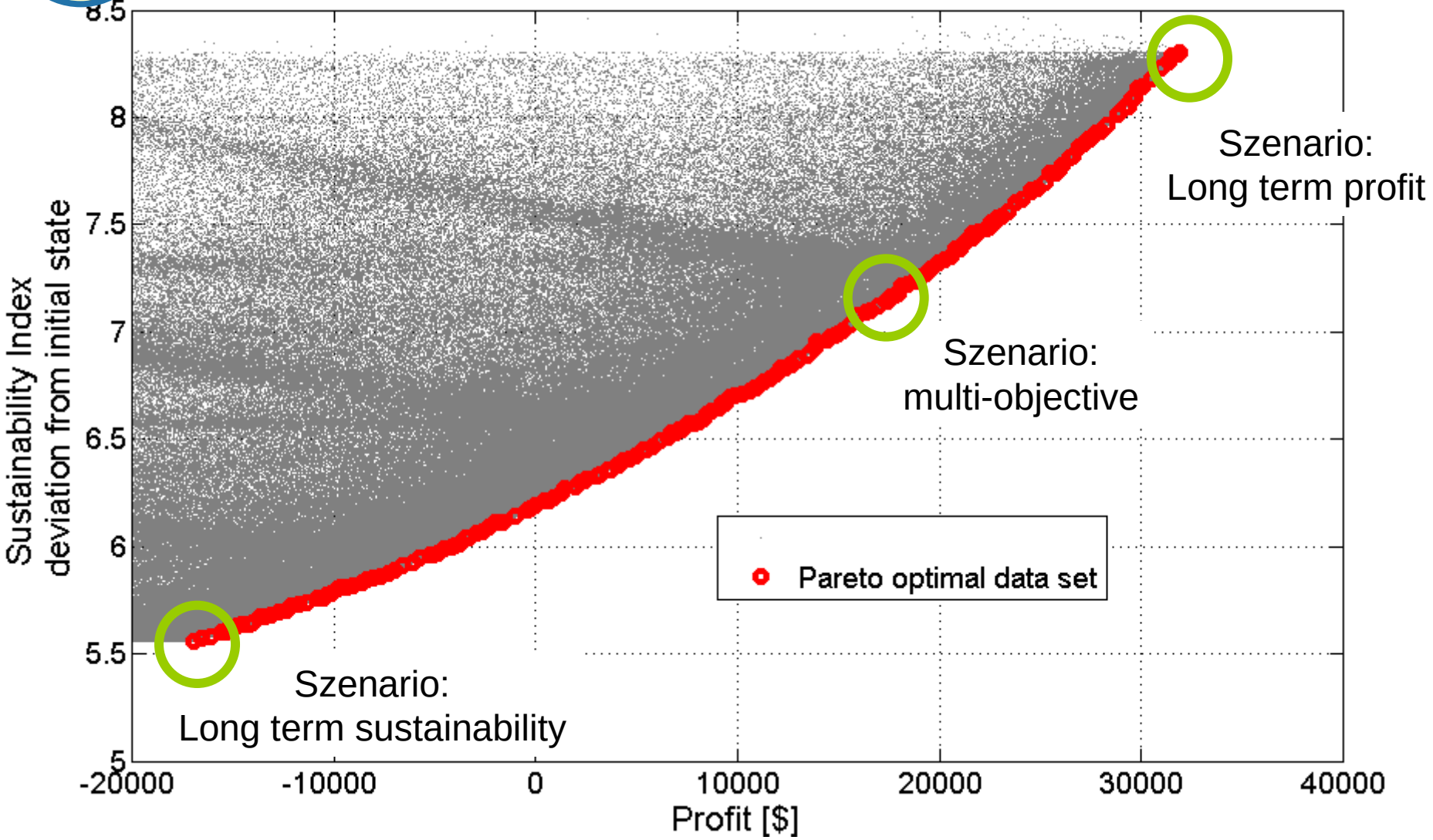
How to find the **best compromise** between the two objectives ?

→ depends on the actual preferences of the decision makers

Multicriterial optimisation → Evaluation of ***pareto-optimal solutions***

3 Optimal Management of coupled Hydrosystems

- Exemplary Application - Results -

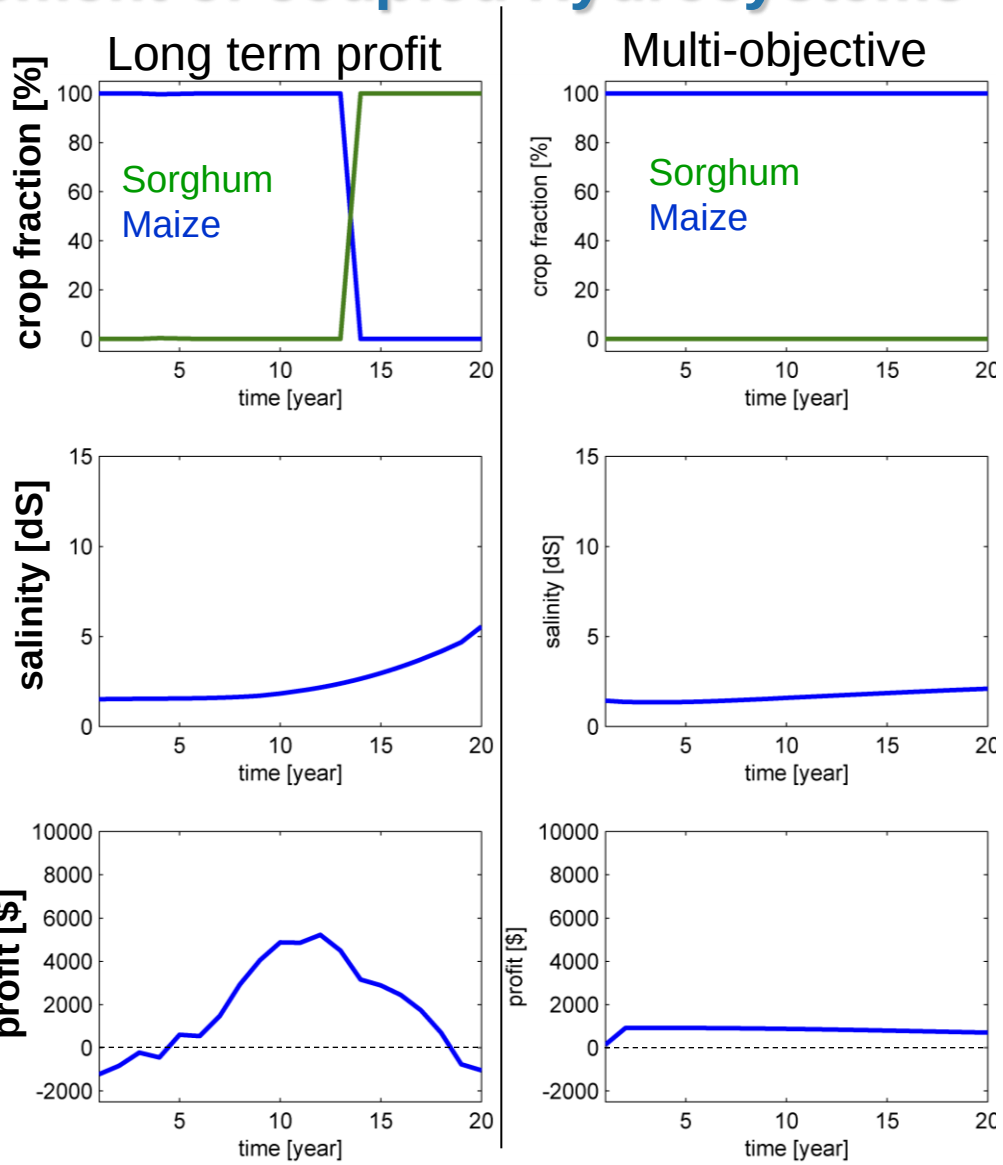


3 Optimal Management of coupled Hydrosystems

- Results -

OUTPUT

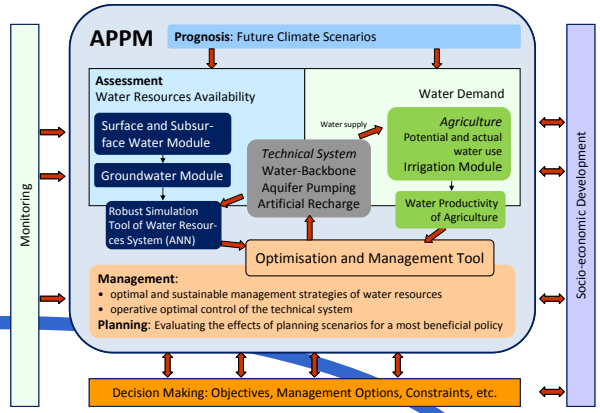
- Crop pattern
- Abstraction rates
- Cultivated acreage
- Salinity of irrigation water
- Irrigation schedule
- Profit for farmers
- Salinity of the aquifer
- Water levels of the aquifer
- Cost benefit analysis for stakeholders



3 Implementation

The integrated management process

Aim: sustainable IWRM and development of resources



Assessment
Resources,
Impacts / Pressures,
Players / Needs

Management options
Development,
Investigation

Decision making
Evaluation
of options

Implementation
Measures,
Investments,
Awareness

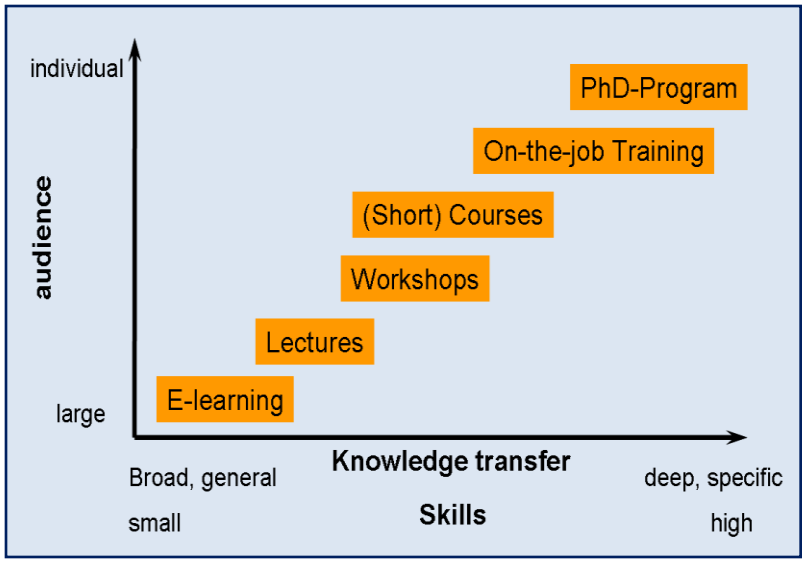
Monitoring Follow up
Lessons learned

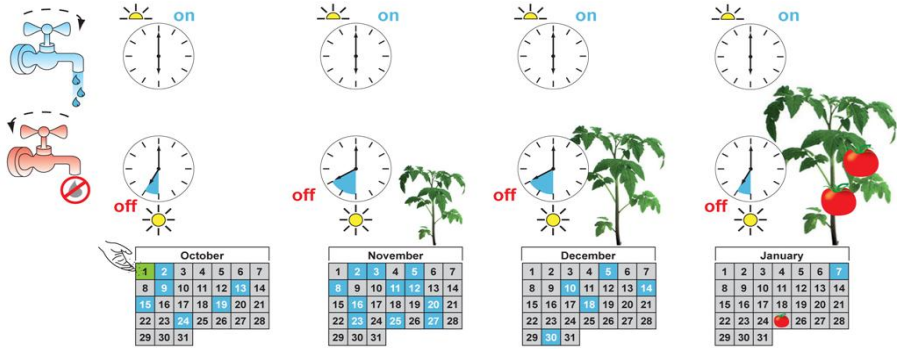
Appropriate methods and models are required

time

Recursion after 6-10 years

3 Implementation - Capacity Development & Activity Plan





Pilote Farms & Guidebook

4 Summary

- Some key issues of the new APPM-Tool for an integrated management of arid zone water resources were presented inclusive first steps of implementation.
- Modelling of density driven groundwater flow is mandatory.
- An increase of water productivity can be achieved by introducing novel irrigation methods.
- A prototype of a simulation based water management model for managing both water quality and quantity was presented.
- The methods of artificial intelligence (ANN) allow for a fast and robust application of the process models in an optimisation framework.
- Multicriterial optimization can provide a tool for decision makers to find sustainable solutions in an environmental, economical and social sense.
- A sustainable management of water and soils is a precondition for food security

Thank you for your attention !

Thanks to

Niels Schütze, Gerd H. Schmitz, Franz Lennartz,
Alex Gerner, Sebastian Kloss,
Marc Walther, Hamed Al-Hatmi

The Omani Ministries of:
Regional Municipalities and Water Resources
Agriculture and Fisheries

Thanks for funding

Federal Ministry
of Education
and Research

Journal papers

Schütze, N., & Schmitz, G. H., 2010: OCCASION: A new Planning Tool for Optimal Climate Change Adaption Strategies in Irrigation. Journal of Irrigation and Drainage Engineering. doi: 10.1061/(ASCE)IR.1943-4774.0000266

HONORABLE MENTION PAPER AWARD 2012

Grundmann, J., Schütze, N., Schmitz, G.-H., & Al-Shaqsi, S., 2011: Towards an integrated arid zone water management using simulation based optimisation. Environmental Earth Sciences. Doi: 10.1007/s12665-011-1253-z.

Schütze, N., de Paly, M., & Shamir, U., 2011:. Novel simulation-based algorithms for optimal open-loop and closed-loop scheduling of deficit irrigation systems. Journal of Hydroinformatics. doi:10.2166/hydro.2011.073

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Walther, M., Delfs, J.-O., Grundmann, J., Kolditz, O., Liedl, R., 2012: Saltwater Intrusion Modeling: Verification and Application to an Agricultural Coastal Arid Region in Oman, Journal of Computational and Applied Mathematics (accepted)

Gerner, A., Grundmann, J., Walther, M., Schmitz, G.H., 2011: Groundwater recharge as a crucial aspect in water resources development for the Barka region. International Conference on Drought Management Strategies in Arid and Semi-Arid Regions, Muscat, Oman

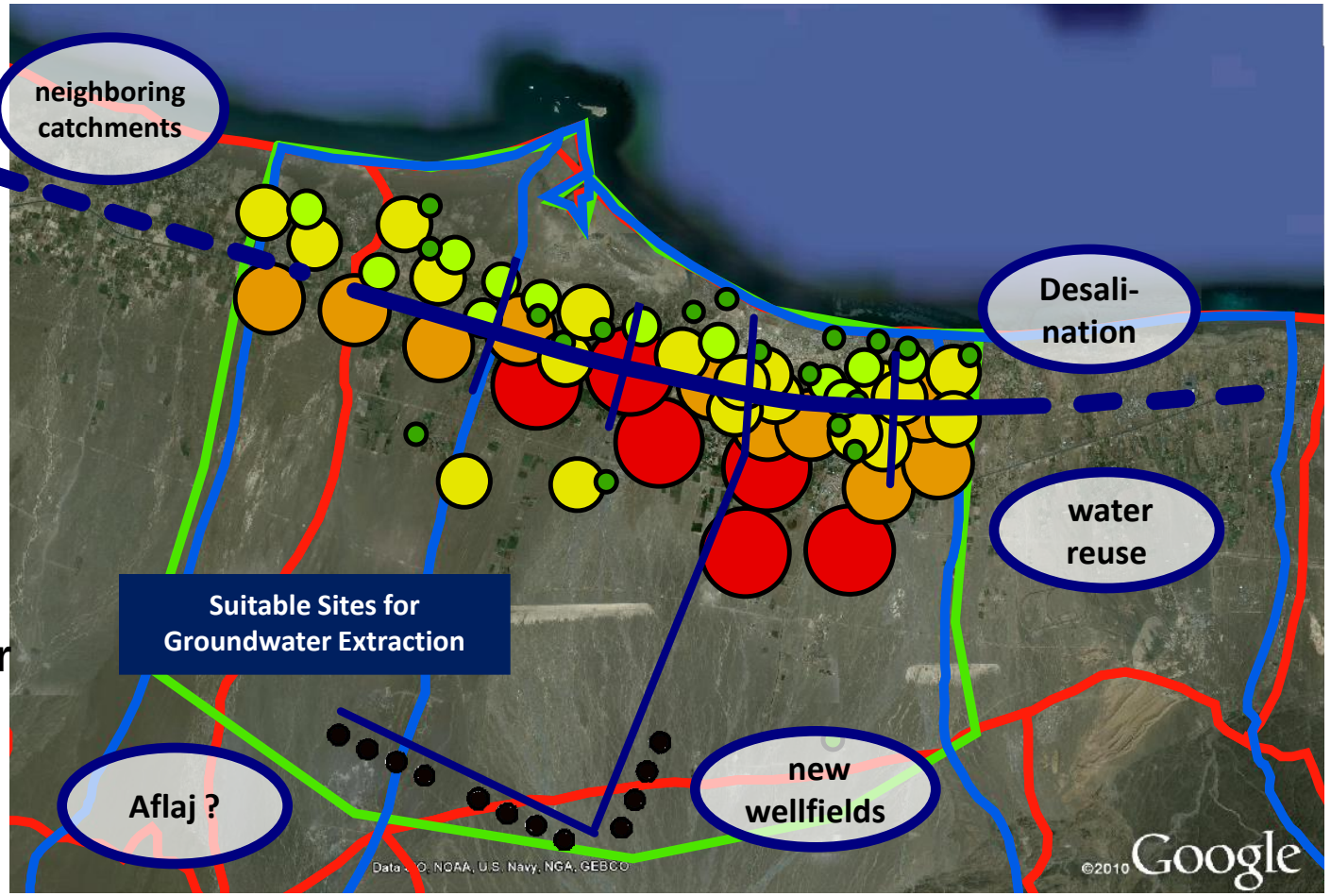
Philipp, A., G. H. Schmitz, R. Liedl (2010): An Analytical Model of Surge Flow in Non-Prismatic Permeable Channels and Its Application in Arid Regions. Journal of Hydraulic Engineering 136(5), 290-298

Perspectives of an Integrated Management

Technical realisation by
Supply System

- Water of better quality delivered to consumers
- Extraction of ground-water at suitable sites

- Design of a water distribution network (Water-Backbone) to deliver water of good quality to the farms



- **Recultivation** of salty farm land and of valuable soils for agriculture
- **Incorporation** of other sources of water
- **Recycling of water** for a sustainable economic and environmental development