MEWAC

Middle East Regional Water Research Cooperation Program

Transfer Conference 2025 Module A Proceedings

Coupling Thermal Desalination And Extraction Of Dewatered Salt With Hydroponic Greenhouse Cultivation Via Heat Pumps (EXALT)

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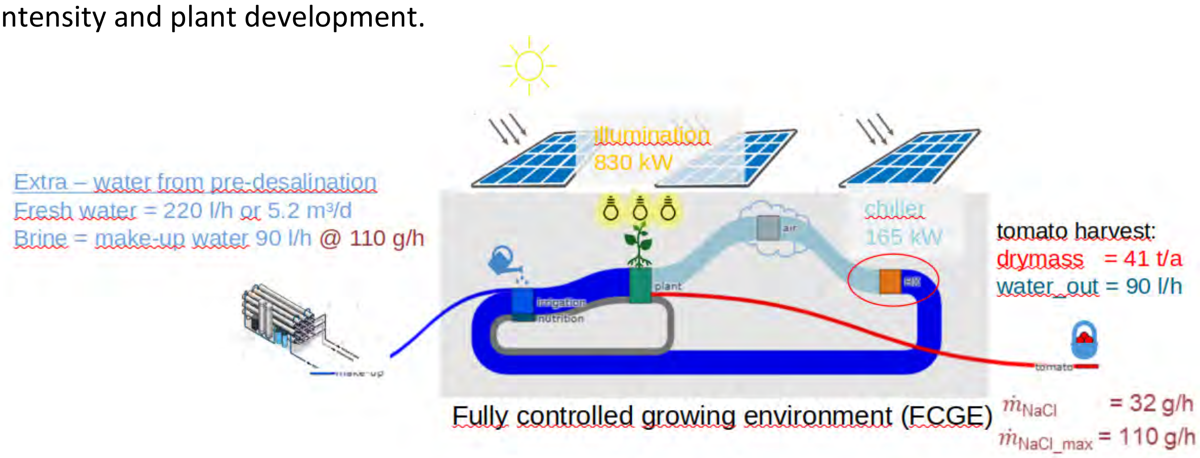
KEY RESULTS

Agriculture is the greatest water consumer, even in severely water scarce countries of the Near and Middle East. Therefore, an **increase in agricultural water use efficiency**, especially for production of crops with high water demand such as vegetables, has an inherently high potential to reduce pressure on limited water resources. The EXALT project brought together agronomists, experts in heat pumps and renewable energy, and local stakeholders in an integrative approach, with the goal to develop blueprints for improving water use efficiency in greenhouse cultivation and mitigating the negative effects of the inherent salt load in locally available irrigation water. The team studied the local environmental conditions and current greenhouse management, the response of plants to saline nutrient solutions under specific climatic framework conditions and the suitability of different nutrient solutions. Integration of the information resulted into the **design of a fully controlled growing environment**.

The most important energy-related aspect of this growing environment is its **complete isolation from external climatic conditions**, which allows it to avoid the greatest energy input in traditional greenhouses: **direct sunlight**. Experiments conducted at the University of Hohenheim have shown that **cost-effective LED lamps** can replace sunlight and sodium vapor lamps with over 50% greater energy efficiency, while maintaining comparable light intensity and plant development.



Due to the **reduced internal temperature**, plant **transpiration decreases**, allowing for the elimination of active and/or passive ventilation. Instead, a concept developed by the Fraunhofer Institute for Solar Energy Systems controls humidity and temperature via heat exchangers, which simultaneously enables recovery of transpired water. This approach allows for the **recovery of 91–93% of plant transpiration**, resulting in very high water use efficiency. Consequently, the system requires only minimal external water input.
Greenhouse trials at UHOH further demonstrated that, depending on species and variety, **plants can incorporate up to 24 mg of NaCl per gram of dry biomass** without negatively affecting growth—provided environmental conditions are carefully controlled. This opens the possibility of using slightly saline water, such as that from the King Abdullah Canal in Jordan or treated wastewater, without the need for energy-intensive desalination when water losses are minimised. However, as shown in trials at the Hebrew University of Jerusalem, such systems require specifically **adapted nutrient solutions to avoid precipitation** of certain nutrients.
Based on GIS surveys coordinated by EPJ, the **total greenhouse area in the Jordan Valley** is estimated to exceed **5,000 hectares**, with fundamental differences in production systems between Jordan and Israel. In Jordan, mostly simple plastic tunnels with soil-based drip irrigation are used during the cooler season. Water from the KAC is typically not desalinated, resulting in a water use efficiency of about 25 kg of tomatoes per m^3 of water. In contrast, Israeli greenhouses are more frequently permanent structures with hydroponic systems and typically use desalinated water, achieving a water use efficiency of up to 40 kg of tomatoes per m^3.
Annual water use is estimated at **approximately 600 liters per square meter** in both countries. While Israel has higher water use efficiency, it also extends production into the hotter months, which balances the overall usage. Thus, a **potential water saving** of at least **500 liters per square meter** can be expected by switching to fully controlled growing environments. Applied to the entire greenhouse area, this corresponds to a **water-saving potential exceeding 20 million cubic meters per year**. In addition to improved water use efficiency, fully controlled growing environments significantly boost productivity by better growing conditions and year round production: in Jordan, yields per unit area are expected to more than double, while in Israel, an increase exceeding 25% is anticipated. As a result, land can be repurposed for less water-intensive crops or restored to natural habitats, offering a haven for endemic biodiversity.

TRANSFER POTENTIAL AND FUTURE APPLICATIONS

The EXALT project demonstrates that coupling site-specific environmental design with fully controlled growing environments enables highly efficient plant production without brine discharge. By eliminating water losses from transpirative cooling, the system offers a unique opportunity to significantly reduce agricultural water demand in arid regions.
However, this solution requires a paradigm shift: sustainable agriculture depends on advanced technology and education, which come at a cost. These investments must be viewed in light of the opportunity costs of continuing unsustainable practices.
To fully realize the system's potential, two key steps are needed:
=> Interdisciplinary collaboration to optimize system design—combining expertise from architecture, engineering, lighting, and plant sciences to further improve energy and water efficiency;
=> The development of a demonstrator facility to provide tangible comparisons with conventional systems and highlight the multiple benefits of this approach.

TransFresh: Transboundary Freshwater Resource Real-Time Monitoring and Modelling the Yarmouk River Case Study

PARTNER INFORMATION

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KEY RESULTS

The Lower Yarmouk and the groundwater wells in the area have to be considered as strategic resource for Jordan and Israel, while knowledge about its fundamental mechanism was not available, a result of lacking monitoring and data-driven modelling. The TransFresh project aimed to close that gap. Though external circumstances significantly challenged that plan, the **first comprehensive and most detailed monitoring and assessment of both, ground- and surface water flows in the wider area of the transboundary Lower Yarmouk Gorge (LYG)** is developed. It outlines where interactions among the hydrological compartments exist and where they are absent, a crucial information in a jointly used transboundary water resource.

Monitoring. We realized to instrument and monitor the amount and dynamic of discharge in the highly anthropogenically controlled surface water flows from the Syrian upstream part of the basin till the outlet of the Yarmouk River into the important water supply systems in the Jordan Valley. That monitoring scheme provided **a tool to effectively differ between natural and artificial sources** for the intensely fluctuating water flow of the river and to connect it to climatic events and conditions. The monitoring of groundwater dynamics along both sides of the Yarmouk provided **first time insights into the seasonal reaction of the** different groundwater hosting **geological units**, feeding the wells and springs in the LYG **and the impacts of groundwater abstraction** across the valley (Fig. 1). Furthermore, it was possible to reveal, the large amount of **groundwater abstraction** in the wider area of the LYG **leads to earthquakes** in the region and in turn, the groundwater resources react on seismic events like the Turkey earthquake by remarkably changing temperatures and discharge of springs and artesian wells.

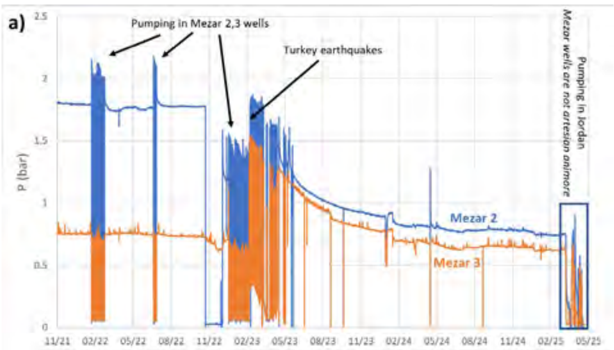

Fig. 1: pressure fluctuations in Mezar wells due to pumping or relaxation along the other side of the LYG.

The continuous quality monitoring and repeated sampling of groundwater during the project phase and the conjoint interpretation of **hydrochemical patterns and isotopic signatures provided the necessary building block to further confirm our conceptual model** regarding the mechanisms of the different aquifers and where the groundwater gets recharged. Including such data from former BMBF-funded projects (e.g. SMART) revealed **insights into seasonal changing contributions of different**

aquifers (Fig. 2) and bituminous horizons. As an example, chemical, isotopic and continuous temperature data in Himma Spring reveal, recharge events during the wet season with increased pressure heads in the recharge areas activate enhanced ascent of deeper, hotter and more saline groundwater than during the dry season. A phenomenon, observable in all the groundwaters along the southern LYG (Mukheibeh well field) and in Hammat Gader, while groundwater along the Northen rim is not infected by such a process. Groundwater dating by radiocarbon and tritium/helium indicates **travel times through the subsurface up to 35,000 years and** deep immersion of groundwater before it ascends. Possible young components

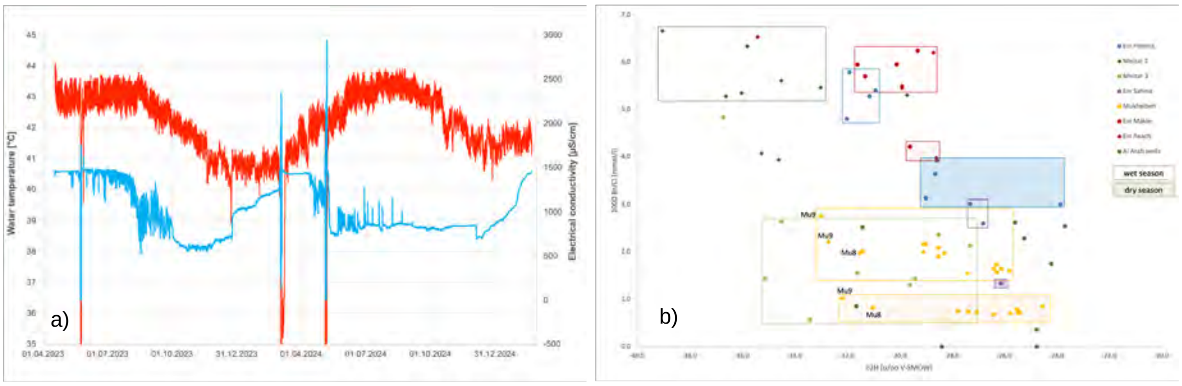

Fig. 2: show (a) temperature (red) and electrical conductivity (blue) in Himma Spring and (b) respective changes in all the groundwaters as for contributing of deep formation water, indicated by salinity tracer (Br/Cl) and Deuterium signatures during wet and dry seasons, respectively.

could be excluded by a non-target screening as for organic components, revealing **no anthropogenic pollutants** within the groundwaters.
Our most recent observations show, since March 2025, the discharge from Mukheibeh well field increased due to newly drilled and refurbished wells and caused strong reactions in Meizar wells situated on the northern side of the LYG, which eventually lost their artesian character. **Though the chemical and isotopic results still indicate no water exchange across the LYG, changes in the pressure field on one side obviously force reactions on the other.**

Modelling. All the aforementioned monitoring data and information sharpened the conceptional model of subsurface flow and revealed no natural interactions between the Yarmouk and the surrounding aquifers. That conceptual model was finally translated into the **first numerical groundwater flow model, covering the entire subsurface basin of the LYG.** Its driving force is provided by the second model, which runs on surface hydrology and provides **surface flow in the river catchment and recharge amounts of groundwater.**
However, the base is the **first comprehensive geological and structural model of the relevant freshwater aquifers** from Cenomanian to Quaternary ages, constructed on German, Syrian, Israeli and Jordanian data from the late 19th century until recent times (Fig. 3). The model reveals that the Yarmouk Gorge is the dominant draining feature in the region, its subsurface catchment much larger than its surface drainage basin. Moreover, **the model supports our hypothesis**, which was developed on hydrochemical and isotopic analyses: **the hydraulic functionality of the proposed and implemented structural features is important**, to allow the flow field in all observed aquifers (A7/B2, B4 and Basalt) to develop realistically. Drinving the model with climate projections also reveals important knowledge gain, how particularly the groundwater resources may develop in future.

TRANSFER POTENTIAL AND FUTURE APPLICATIONS.

These results in combination with scenarios, giving a foresight of the development of the groundwater resources of the Yarmouk are of high relevance to the water managers and decision makers responsible for its future development. The thirst for water will increase further. However, the possibility to manage the resources in a higher sustainable way must be coupled to a well-established numerical flow model and to reliable and up to date monitoring data of outflow through the Mukheibeh well field and technical solutions to control it. Through TransFresh we know the significant importance of such measures and how changes in outflow immediately affect the surrounding resources and we substantiate the need for a future transboundary management of the high-quality groundwater resources.

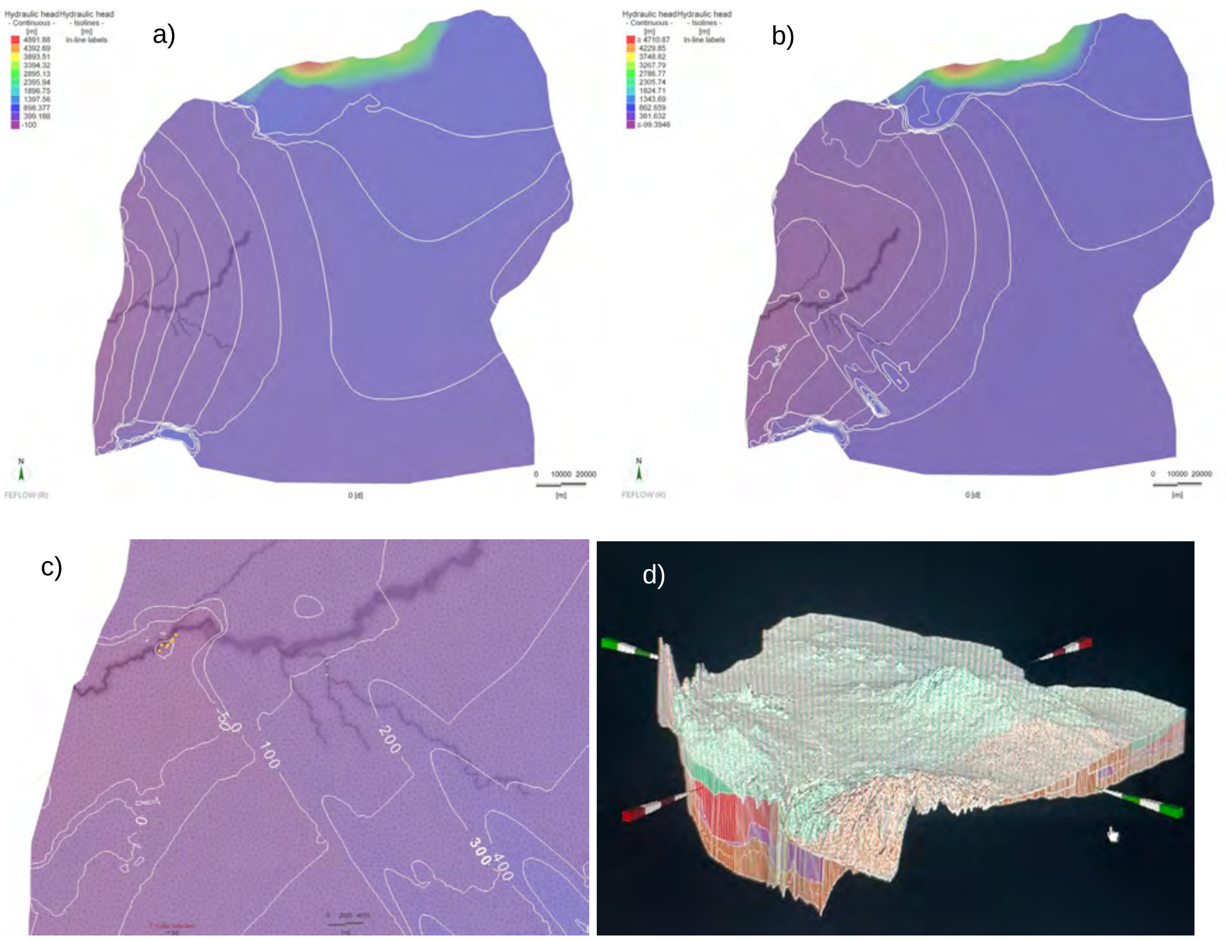

Fig. 3: a) showing contour line maps of the A7/B2 aquifer without faults and b) including structural features. c) shows the resulting flow field in the LYG, with orange dots marking the artesian wells in Mukheibeh well field and Meizar. D) is showing the 3D subsurface structure of the aquiferous units A7/B2, B4 and Quaternary Basalt model. Its extension comprises the Golan Heigths, Mt. Hermon, Djebel Druze, parts of the Damaskus basin and the Jordanian Highland.

Groundwater Recharge and Climate Change Effects (GRaCCE)

-Quantification of resilience of water resources in carbonate aquifers to drought conditions-

GRaCCE

With funding from the:
Federal Ministry of Research, Technology and Space

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PROJECT SUMMARY

The main objectives in GRaCCE are "*to observe, simulate, and characterize the spatio-temporal variations in the (1) available water for the infiltration at the surface, (2) flow, storage, and discharge of the subsurface water (either in the unsaturated or saturated zones), with (3) subsequent translation of 1 and 2 with the state-of-the-art drought indices, under historical, near future (i.e., next season(s)), as well as projected climate change of different scenarios*". Accomplishing the main objectives, one is able to *(a) identify the historical decrease in groundwater reserve, (b) quantify the impacts of climate changes on hydrogeological system in long- and short-term scales, (c) determine the spatiotemporal dynamics of subsurface water storage and availability, and (d) identify the climatological and hydrogeological drought states*, to determine groundwater resources resilience under changing climate, among others.

GRaCCE involves three different carbonate karst aquifer systems in the Eastern Mediterranean region located in different, yet comparable, climatic zones:

- **Western Mountain Aquifer (WMA)**, a transboundary karst system covering Israel and the West-Bank, served as the main study site for different model applications; mainly because of its relative importance for water resources, available long-term historical datasets on the climate and the hydrogeological system (partners: UGOE, VisDat, TUB, UFZ, HEC, and HUJI), and the degree of system understanding from past research.
- **Eocene Chalk Aquifer (ECA)** in the Northern Negev, was considered as the main site for the field-based investigations of preferential flow infiltration processes (partner: BGU).
- **Tanour and Rasoun Karst Catchment (TRKC)** in Northern Jordan mainly served as transfer site for model application with scarce data. Continuous measurements at the springs are available. The catchment constitutes among the most important karst springs in Jordan (partners: UGOE, AABU).

In addition, process understanding of the infiltration process in a unsaturated fractured carbonate vadose zone is studied in **Rüdersdorf (RQS)**, near Berlin (partners: TUB and UFZ).

KEY RESULTS

1. **Development of the daily recharge model, SWBMv2**: The model uses daily climatic variables across the subbasins of the WMA, considering runoff generation (Figure 1). The model used to estimate recharge for historical periods, and subsequently, short- and long-term forecasts/projections. The results show **strong intraannual cycles** of increasing and decreasing precipitation, and consequently recharge depending on climate model RCP scenarios.

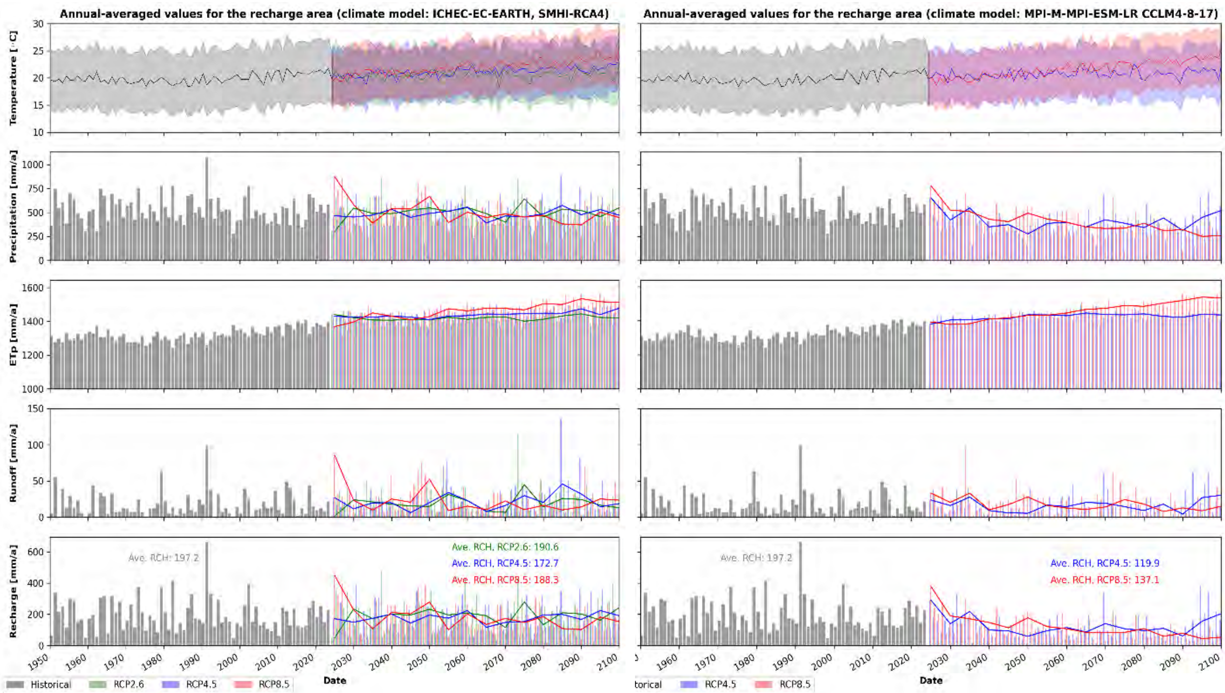

Figure 1: Comparison of temporal distribution of annual recharge and associated climatic variables used for recharge estimation, all averaged for the recharge area for the historical and projection periods of two projection models with 5 scenarios. The colored lines over the barcharts represent the five-year averages.

2. **Assessment of future climatological and hydrogeological droughts** in the WMA for historical periods as well as long- and short-term forecasts/projections. Drought and wet periods of multiannual duration (ranging from ~3 to >10 years) and different range of severity were computed.
3. **Development of a deep auto-regressive neural network surrogate model**, to replace a computationally demanding process-based numerical model of the WMA (HydroGeoSphere)
4. **Development of Drought Monitor Web Application**, which integrates and visualize datasets and models developed for the WMA (Figure 2 & 3).
5. **Model of infiltration process and preferential flow in the ECA**. Field monitoring of geo hydraulic variables, isotopic and hydrochemical signatures.

6. **Provision of long-term data set (10 + years)** by monitoring of geohydraulic variables, physico-chemical variables for the TRKC springs, as well as machine learning techniques to fill data gaps.
7. **Quantification of infiltration process for controlled conditions in a 100 m vadose zone at RQS** by continuous monitoring of geohydraulic variables, geophysical investigation and model interpretation.

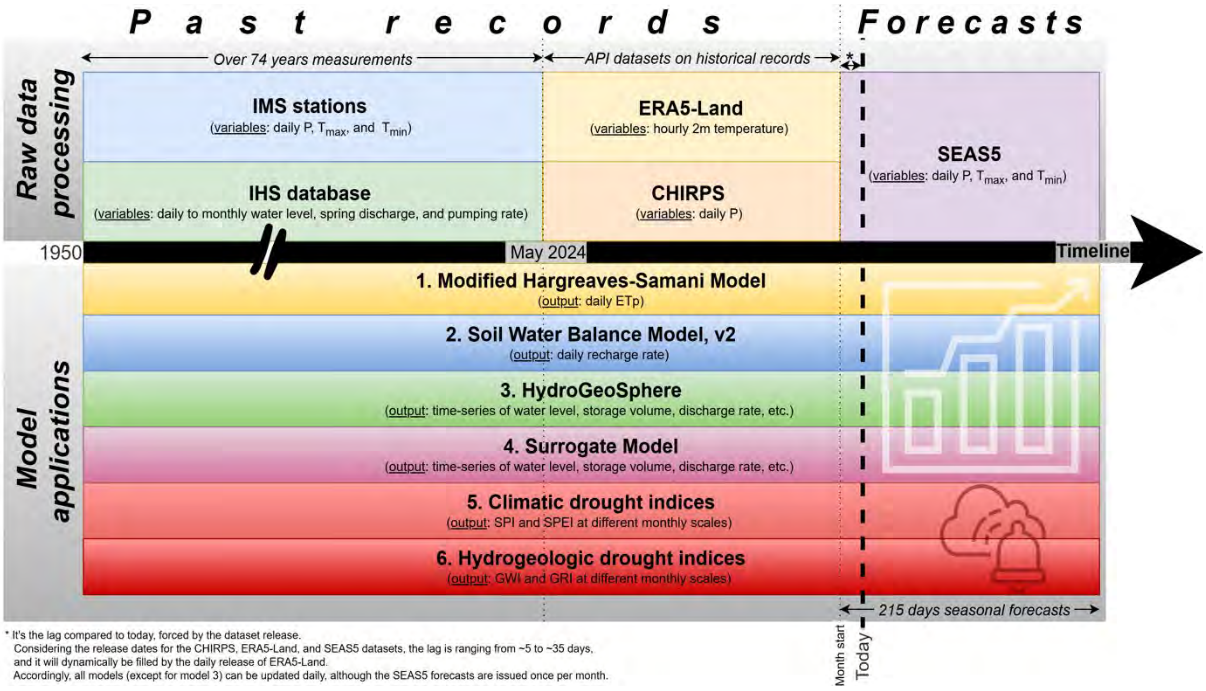

Figure 2: Integration of different datasets and models used for the WMA, as used in the Drought Monitor Web Application.

TRANSFER POTENTIAL AND FUTURE APPLICATIONS

1. The methods employed at different sites can effectively be transferred across the sites, providing the availability of data and/or equipment requirements.
2. The project partners, as well as the project stakeholders of water authorities of the respective regions (i.e., Ministry of Water and Irrigation of Jordan (MWI), Israel Water Authority (IWA, HIS), and Palestinian Water Authority (PWA)) were targeted as the advanced users of the web application. Moreover, by providing access to the public by the online web application (expected by June), international end-users from the MENA-region may benefit from our GRaCCE methodologies. To the best of our knowledge on online resources, the early warning for seasonal groundwater drought can be classified as a novel tool and there is no similar web application for groundwater management available yet.
3. Change in climate and increasing water demands in the region are the main driving forces for the spatiotemporal variation of water resources. Therefore, follow-up interdisciplinary research is required to investigate the impact of extreme precipitation events on water resources in the region with an improved delineation of short- and long-term climate forecast/projections.
4. Given the war conflict situation in the region, hydropolitic aspects are needed to be considered for any future applications.

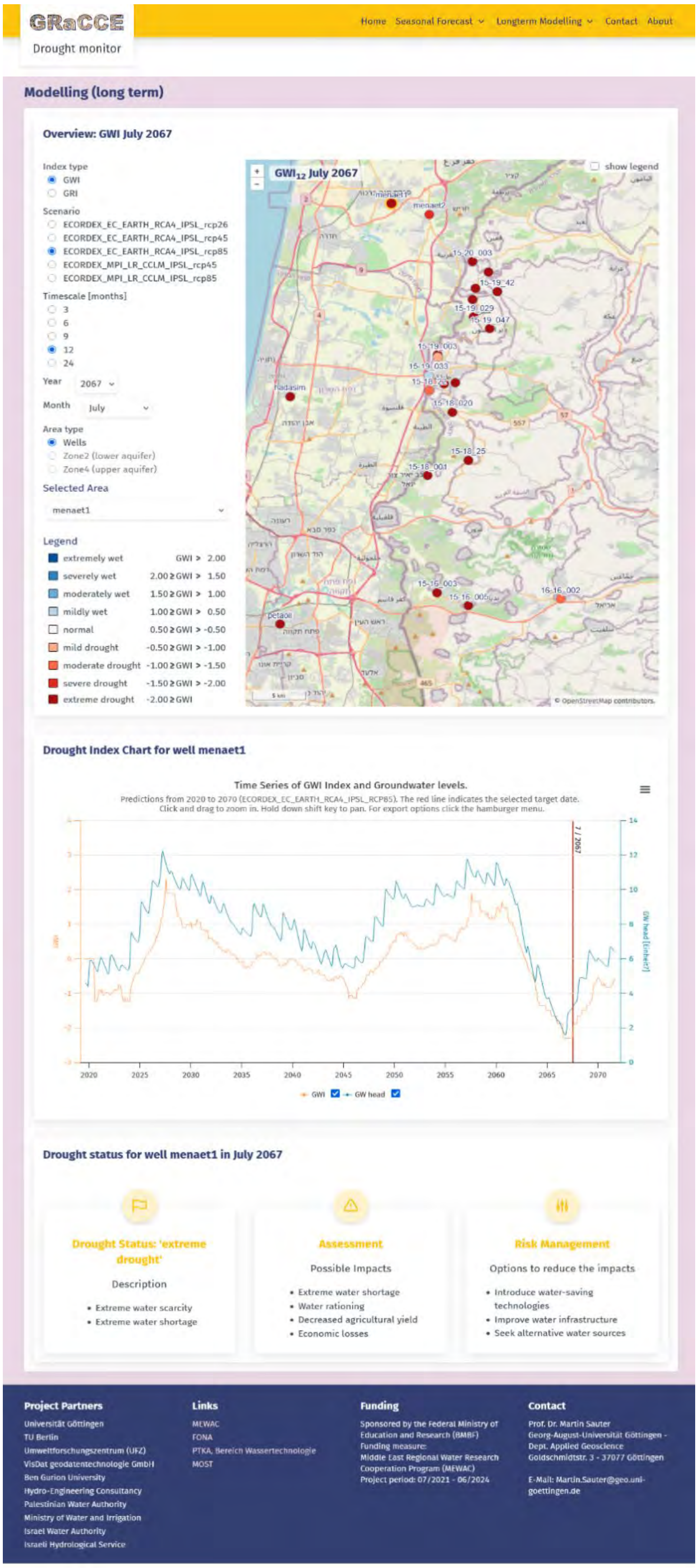

Figure 3: Demonstration of application of web-based graphical user interface for the generation of future recharge time series, spatial distribution, as well as drought indices, here the SPEI, in contrast to groundwater based variable (e.g. GWI).

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Contacts to additional ministries of participating countries (e.g. Ministry of Water and Irrigation, Jordan) are available via the individual projects

Further information on the MEWAC funding measure is available at
https://www.fona.de/en/measures/funding-measures/mewac-multilateral-water-research.php

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