The SALAM Initiative

TRANSBOUNDARY STRATEGIES FOR THE RESOLUTION OF THE WATER DEFICIT PROBLEM IN THE MIDDLE EAST

Key Products – Policy Briefs

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SALAM IWRM

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Contents

Preface Prof. Dr. Georg Teutsch

Helmholtzzentrum für Umweltforschung

As a result of population growth, the adverse effects of climate change and the scarcity of water resources in many parts of the world major, efforts towards sustainable management of water resources are required. One of the focal points of most severe water stress constitutes the situation in the semi-arid to arid areas of the Eastern Mediterranean. In addition to the most pressing problem of providing sufficient drinking water, water is also needed for irrigated agriculture, industry, the ecosystem of the Jordan River and the alluvial plain, and for the Dead Sea, characterized by a continuously dropping sea level.

In response, integrated measures and innovative technologies are required to address the region's major water problems.

Following a 20 years history of BMBF-funded projects in the region, addressed at the assessment of available water resources (e.g. German-Israeli-Jordanian-Palestinian Multilateral Research Program for the Sustainable Utilisation of Aquifer Systems, SMART, SMART-MOVE), the SALAM Initiative was conceived in the spirit of the concept of Integrated Water Resources Management (IWRM), providing innovative system solutions to the water deficit problem of the region.

To my knowledge, it is the first time that a research program consequently targets water resources system planning solutions based on transboundary cooperation between Israel, Jordan and Palestine to tackle the water related challenges of the region. The project starts with a diligent assessment of the regional water and wastewater infrastructure, followed by a structuring of the project area into demand centers (clusters) and their characterization with respect to the analysis of water availability

Prof. Dr. Georg Teutsch

at cluster level. Available water resources are assessed at cluster level and water budgets are estimated for the period 2020 to 2050 for domestic, industry and irrigated agriculture demands based on different scenarios. Strategies for freshwater production by seawater desalination and water distribution in the region are identified and options for renewable energy in the production and distribution are examined. In order to compensate for the seasonal and interannual variability of water demand and available resources, water storage in lakes and large-scale aquifer systems are investigated. The project also addresses options to further develop wastewater infrastructure as well as the reuse of treated wastewater in irrigated agriculture and for ecological purposes. All project alternatives are evaluated in terms of their economic viability and compared with each other by a multi-criteria analysis within the framework of a participatory multilateral decision-making process, taking economic, technical, social, environmental and political aspects into account.

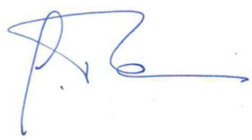
In addition, SALAM developed an expert system with quantitative tools for decision support. These include among others, tools for the analysis of freshwater distribution in the region, for water budget calculations, the evaluation of minimum cost freshwater production and transfer strategies, and for the comparison of water production and distribution options, based on relevant decision criteria. This way, a quantitative and transparent analysis is presented, providing decision-makers with a basis for the identification of an economically feasible, environmentally sound solution, acceptable by the public.

In this brochure, a set of SALAM policy briefs summarizes the main project findings and key products and I am convinced that it will be of use not only to specialists and decision makers but also to a broader audience.

I congratulate the SALAM partners who invested brains and energy during difficult times of a pandemic, economic uncertainty, still achieving remarkable results. It is my wish that the seeds and recommendations of this research receive wide attention so that they can grow for the benefit of the people in the region of the Eastern Mediterranean region.

Prof. Dr. Georg Teutsch

Helmholtzzentrum für
Umweltforschung



Preface of the regional SALAM Partners

Dr. Subhi Samhan, PWA; H.E. Dr. Jihad Al-Mahamid, MWI

Palestine faces the major challenge of securing the water supply for its growing population. Several political and environmental drivers worsen the situation. Today, an average Palestinian citizen consumes 80 L of water per day, far below the average consumption of 120 L/capita/day necessary to cover the basic water needs. Pressure on water resources can be expected to continue to increase during the years to come given the expected sharp population rise, the projected industrial development and the future extension of the agricultural area in the Jordan Valley and in the highlands. The most important issue is to enable the Palestinians to manage their water to secure and plan their future water needs.

SALAM addresses the water scarcity issue and lays the basis for a sustainable water management in the region. In addition to renewable water sources,

Dr. Subhi Samhan, PWA

seawater desalination at the Mediterranean Coast in conjunction with transboundary water management is the key to cover the freshwater needs of the West Bank and Gaza. Wastewater reuse is one of our key priorities for the years to come, and we welcome the ideas and efforts invested by the SALAM consortium in this field. Sustainable water management requires reliable storage solutions. We believe that Managed Aquifer Recharge (MAR) is a very promising technique and we do support the work carried out by the project partners by our own groundwater modelling contributions.

The project is unique since it is currently the only initiative gathering water planners of the region. This collaborative research platform has been very successful for more than 25 years and we would like to thank Germany and the Bundesministerium für Bildung und Forschung (BMBF) for their technical and financial support throughout this time. We do sincerely hope that this fruitful cooperation will continue and help us building a safe and dignified future for the next generations.

Dr. Subhi Samhan

Director of Research and Development of the Palestinian Water Authority

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During the last decades Jordan built large-scale water transfer infrastructures such as the Disi Water Conveyance to cover national water needs, together with an extensive wastewater reuse programme. Due to rapid population growth, the recent influx of refugees and climate change impact on water resources, these efforts do not suffice to cover the future water needs of our country. Therefore, the Aqaba Amman Water Desalination and Conveyance Project (AAWDCP) was conceived. Major hydro-infrastructure will be built to desalinate water at Aqaba and transport it to the urban centres of Southern, Central and Northern Jordan.

The SALAM-Initiative developed water production and transfer strategies that integrate the AAWDCP into their concepts. SALAM concepts and strategies form essential components of our future water production and transfer network. Further water research projects will have to consider the dynamics of water production, distribution and

H.E. Dr. Jihad Al-Mahamid, MWI

consumption to be able to respond to the temporally variable system characteristics and increasing drought risk due to climate change, studying the integration of water storage components and optimal operation of the water transfer projects. The cooperation initiated during SALAM in the field of wastewater management is believed to successfully continue in a future project. SALAM options and suggestions for wastewater management and reuse in the highlands and the Jordan Valley may serve as basis for further research in order to ensure sustainable agricultural development and ecosystem rehabilitation.

Research has to make scientific knowledge understandable and enable stakeholders to make informed decisions. The SALAM Initiative provides us DS-tools and methodologies to determine water resources system planning and management solutions to address the upcoming challenges of the water sector in Jordan, guiding the long-term strategic planning. We would like to very much thank the German Ministry of Education and Research (BMBF) for funding the programme and we look forward to continuing this successful collaboration.

H.E. Dr. Jihad Al-Mahamid

Secretary General of the Ministry of Water and Irrigation: Amman, Jordan

Preface of the regional SALAM Partners

Mr. Guy Reshef, HSI

Preserving water resources is of primary importance in the Eastern Mediterranean. Our groundwater resources are scarce and have to be monitored diligently, both in terms of quantity and quality. Israel successfully implemented Managed Aquifer Recharge (MAR) concepts for treated waste water, flood water and desalinated water, mainly in the Coastal Aquifer. With great interest we follow the MAR modelling work, conducted during the SALAM-Initiative both in the Coastal and Western Mountain Aquifer.


Mr. Guy Reshef

In Israel, renewable freshwater resources are limited. The country had been massively investing into seawater desalination and wastewater reuse during the last decades. The country's expertise in seawater desalination is being recognized worldwide. Given the high population density and the great attractiveness of the coastal area, constructing new plants on the shore would be challenging. This makes the concepts for offshore desalination plants developed during the SALAM project very promising. Discussions were initiated last year with Jordan to swap solar energy produced in Jordan for desalinated water from Israel. The SALAM investigations and innovative concepts on water-energy SWAP between both countries lay the ground for more extensive studies.

The SALAM-Initiative established a platform for cooperation at the technical level between stakeholders of our region, developing and discussing national and transboundary solutions for the upcoming water related challenges. This collaborative research project is essential since it fosters multilateral communication , creating the basis for transboundary cooperation and sustainable regional development. We would like to thank the project coordination team for the long-term fruitful scientific collaboration and Germany and the Federal Ministry of Education and Research (BMBF) for financial support.

Mr. Guy Reshef

Head of the Hydrological Service of Israel, Israel Water Authority


Mediterranean Coast in Tel-Aviv, Israel ©Nußbaum

Preface by the Project Coordinators

Prof. Dr. Martin Sauter, Dr.-Ing. Bernd Rusteberg

Prof. Dr. Martin Sauter
(Georg-August-Universität Göttingen)

Dr.-Ing. Bernd Rusteberg
(Rusteberg Water Consulting)

Within the framework of the „Research for Sustainability" (FONA) programme, four billion euros in funding are made available by the German Federal Ministry of Education and Research (BMBF) between 2020 and 2025 to advance the implementation of the Sustainable Development Goals. Reducing water crises on a global scale is a thematic focus of the new FONA strategy, with particular importance attached to the Middle East due to the region's extreme water stress.

Our research findings indicate that unless countermeasures are taken, Jordan and Palestine in particular will face rapidly increasing, significant water deficits during the coming decades. The Eastern Mediterranean region has long been characterized by political tension that hampers transboundary cooperation in the management of the scarce water resources.

The SALAM initiative, coordinated by the University of Göttingen and the German company Rusteberg Water Consulting, developed transboundary strategies to counteract expected freshwater deficits in Jordan and Palestine. The consortium can refer to a long and close scientific cooperation with the partners in the region and thus developed a basis of trust, established during a large number of BMBF-funded collaborative research projects since the middle of the 1990s. These include the so-called SMART projects (2006-2018) in cooperation with Israel, Jordan and Palestine on the integrated management of the local water resources as part of the IWRM funding measure.

The pilot study of the SALAM initiative (2015-2018) showed that the large volumes of freshwater required can only be provided by seawater desalination at the Mediterranean and Red Sea coasts and a combination of several transboundary water transfer projects. The water production and transfer solutions developed in the pilot study were consolidated and combined by the SALAM Initiative into 12 alternative water strategies. For the first time, feasible and cost-effective transboundary strategies are now available to address the water deficit problem in the Middle East.

This brochure compiles the most important results of the second project phase of the SALAM Initiative in 18 specific Policy Briefs, addressing the construction of offshore seawater desalination plants, the integration of renewable energy by hydropower, solar energy generation and innovative water-energy SWAP concepts, the techno-economic analysis of hydro-infrastructure projects, the temporary storage of desalinated seawater in regional aquifers, the optimal operation of surface water resources systems, as well as the expansion of wastewater infrastructure and wastewater reuse concepts. Various planning tools for decision support are being provided to the regional stakeholders as an online expert system.

Detailed information on key results of the project can also be found in the special issue recently published in the German Journal „WasserWirtschaft" (water resoures management) as well as on the SALAM project website (www.iwrm-salam.de).

We thank the BMBF for the financial support and the project management agency Karlsruhe for the professional support of the project and wish you an exciting reading time.

Shore of the Dead Sea, Jordan ©Nußbaum

Consortium

SALAM PARTNERS & STAKEHOLDERS

GERMANY

- University of Göttingen (UGOE)
- Rusteberg Water Consulting (RWC)
- Helmholtz Center for Environmental Research (UFZ)
- Karlsruhe Institute of Technology (KIT)
- University of Kassel (UK)
- University of Duisburg-Essen (UDE)
- STEP Consulting (STEP)
- Dorsch International Consultants (DI)
- INTEND Geoinformatik (INT)
- I3 Systems Information Technology (I3S)

ISRAEL

- MEKOROT (MEK)
- Hydrological Service of Israel (HSI)
- Environmental & Water Resources Engineering (EWRE)

JORDAN

- Ministry of Water and Irrigation of the Hashemite Kingdom of Jordan (MWI)
- Arab Technologist for Economic and Environmental Consultation (ATEEC)
- University of Jordan (JUA)

PALESTINIAN TERRITORIES

- Palestinian Water Authority (PWA)
- Hydro-Engineering Consultancy (HEC)
- Palestinian Hydrology Group (PHG)

Introduction

BACKGROUND

The Middle East is one of the driest regions in the world and must cope with increasing water deficits. The semi-arid climate of the region is characterized by a high variability of available water resources. In fact, the dynamics of supply and demand are inverted. Highest water demand coincides with times of low water availability leading to corresponding shortages in water supply. (Ground)water contamination, especially by untreated wastewater and saltwater, as well as inefficient water use and management, contribute to a further deterioration of the water supply situation. The scarce freshwater resources cannot meet the increasing demand for water, the vital groundwater resources are already heavily overexploited and their quality impaired by salinization. In addition, ongoing political tensions in the region make collaborative water management a challenge. As a result, freshwater resources in Palestine and Jordan are almost exhausted. The local populations depend on imported water to meet their needs. According to our predictions, by 2050 Palestine and Jordan will have to face annual water deficits of ca. 600 and 700 Mio. m^3, respectively, agricultural water consumption not yet included. This means that unless countermeasures are taken, the regional water crisis can be expected to worsen dramatically. Israel, in contrast, has been investing heavily for the past 20 years into the construction of seawater desalination plants to secure national water supply. Today, the plants produce some 600 Mio. m^3 per year. Besides, Israel reuses close to 90% of its wastewater, mostly for irrigation purposes. Seawater desalination and wastewater reuse enable Israel to cope with drought periods and mitigate the effects of climate change on water resources.

The SALAM Initiative (2020-2022) is a unique multilateral research and development project funded by the Federal German Ministry of Education and Research (BMBF) focusing on transboundary water transfer and national water strategies to solve the water deficit problem of the region and to deescalate a regional water crisis, bringing together decision-makers and stakeholders of the region. It builds on a basis of trust, developed during more than 20 years of cooperation between German researchers and regional partners. The project consortium consists of 19 partner organisations from Jordan, Israel, the Palestinian Territories and Germany and includes universities, research centers, consulting companies, engineering firms, water utilities and the region's national water authorities. SALAM is an initiative of the Georg-August-University of Göttingen and the German company Rusteberg Water Consulting.

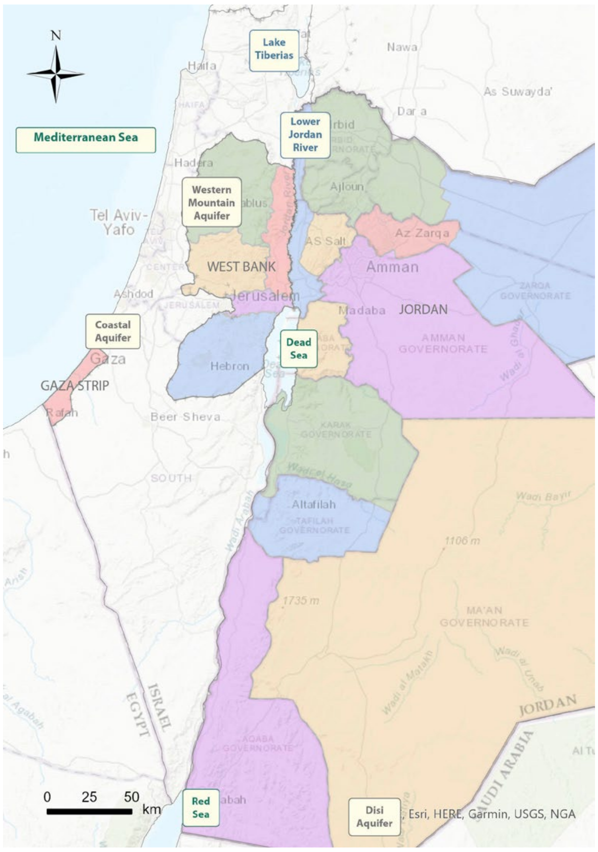
OBJECTIVES

The SALAM pilot study, as part of the BMBF financed SMART-MOVE project, showed that the large freshwater volumes required to cover the projected water deficits of Palestine and Jordan can be covered only by seawater desalination. The second phase of the SALAM Initiative directly builds on these results, aiming at the development of regional and national strategies to see to the future water needs of Jordan and Palestine. A coordinated interplay of new technologies, hydro-infrastructure, and management concepts for the production, distribution, intermediate storage, and reuse of water is planned to compensate for deficits in a sustainable and cost-effective manner. For the first time, the SALAM Initiative now presents feasible and cost-effective transboundary strategies as system planning solutions to address the water deficit problem in the Middle East. All strategies are based on seawater desalination at the Mediterranean and Red Sea and a combination of transboundary water transfer projects.

CONTENT OF THE BROCHURE

This brochure summarizes the findings of our research in 18 Policy Briefs and presents specific recommendations and measures with regards to the SALAM key products, including numerous innovative results, such as a

SALAM members at the SALAM Regional Status Conference at the Dead Sea, Jordan (October 10-11, 2021)



Overview map of the SALAM project region

Water-Energy-SWAP concept between Israel and Jordan, exchanging Jordanian solar energy for Israeli drinking water produced by seawater desalination. A SWAP agreement between the two countries was signed in November 2021, underlining the high political importance of the concept. SWAP agreements for water and energy between partner countries increase economic efficiency and constitute a trust building effect. Further SALAM key products include the construction of onshore and offshore seawater desalination plants at the Mediterranean and Red Sea, the integration of renewable energy by hydropower and solar energy generation to lower water cost, techno-economic analysis of water transfer projects, temporary storage of desalinated seawater in regional aquifers, as well as the expansion of wastewater infrastructure and wastewater reuse concepts towards sustainable irrigation development and ecosystem rehabilitation.

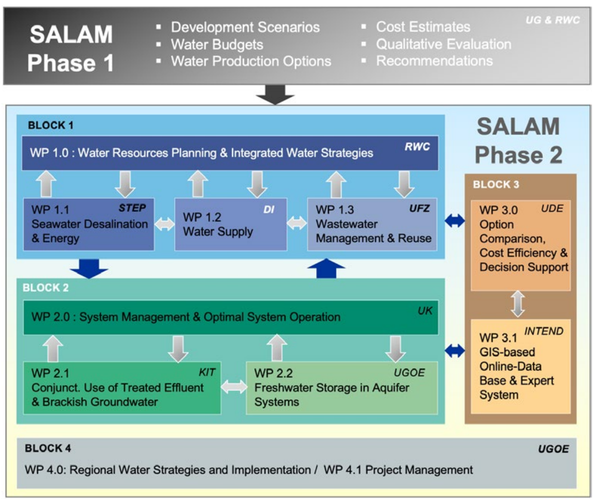
APPROACH

SALAM is divided into closely interconnected work blocks. The first work block focuses on water resources system planning, investigating technologies and infrastructures that support the implementation of regional water strategies. This block includes individual work packages such as water production (on- and offshore seawater desalination), water transfer and supply, and wastewater management and reuse. Covering future water demands will require extensive infrastructure upgrades, both with respect to freshwater supply and wastewater management.

The second work block examines how to manage freshwater in conjunction with surface water, groundwater, and wastewater resources. The import of desalinated seawater results in an increased wastewater production which could benefit irrigated agriculture. Transferring treated effluent to the Jordan Valley could possibly contribute to reduce the rate of water level drop of the Dead Sea. The project optimizes the management of Lake Tiberias and investigates employing groundwater flow models the capacity of aquifers to act as temporary reservoirs (Managed Aquifer Recharge). With subsurface storage, imported water can be made available seasonally and independently of peak demands.

In the third work block, SALAM evaluates and compares regional water transfer and management alternatives. The economic viability of alternative solutions is studied in detail, taking also technical, social, environmental, and political factors into account. In close collaboration with regional stakeholders and decision makers, multi-criteria analyses of the regional strategies for water transfer, wastewater treatment and reuse, and seawater desalination are conducted to make the strengths and weaknesses of all decision alternatives transparent.

The findings are incorporated into a web-based information and expert system that supports decisions with regard to strategy implementation on a national and regional level. Used collectively at the national and intergovernmental levels, the system creates the basis for trust based cooperation in the water sector. The SALAM Initiative thus contributes decisively towards a solution for the water deficit problem in Palestine and Jordan and, therefore, reducing political tensions resulting from water scarcity problems.



Overview of SALAM work packages

Einleitung

HINTERGRUND

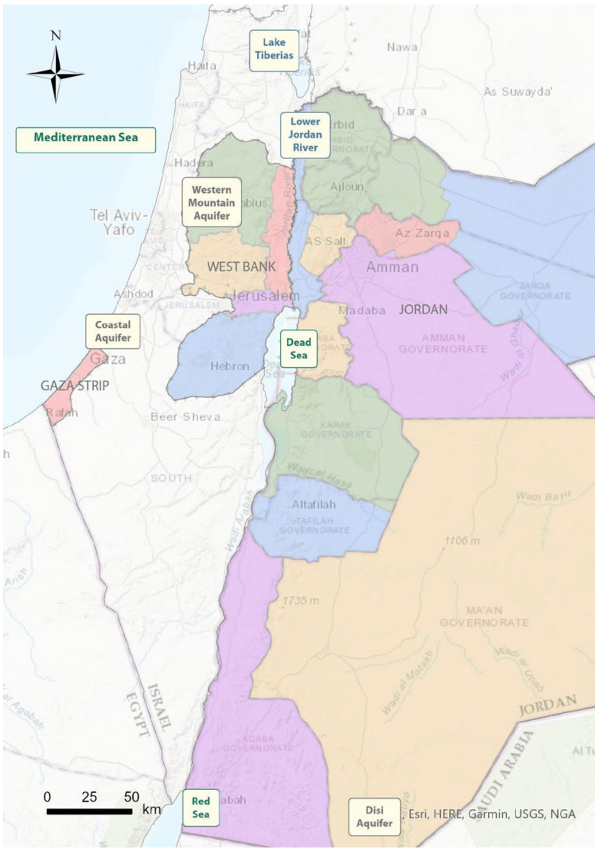
Der Nahe Osten und der Östliche Mittelmeerraum gehören zu den trockensten Gebieten der Welt und ist mit zunehmenden Wasserdefiziten konfrontiert. Das semi-aride Klima der Region ist durch eine hohe räumliche und zeitliche Variabilität der verfügbaren Wasserressourcengekennzeichnet. Die Dynamik von verfügbaren Wasserressourcen und Wasserverbrauch ist zeitlich invers. Die höchste Wassernachfrage fällt mit Zeiten niedrigster Wasserverfügbarkeit zusammen, was zu entsprechenden Engpässen in der Wasserversorgung führt. Die lebenswichtigen Grundwasservorkommen sind bereits stark übernutzt und ihre Qualität durch Versalzung beeinträchtigt. Zudem erschweren anhaltende politische Spannungen in der Region eine gemeinschaftliche Wasserbewirtschaftung. Infolgedessen sind die Süßwasserressourcen in Palästina und Jordanien nahezu erschöpft. Die Gebiete sind daher dringend auf Wasserimporte angewiesen, um ihren Bedarf zu decken. Unseren Prognosen zufolge werden Palästina und Jordanien in 2050 mit einem jährlichen Wasserdefizit von ca. 600 bzw. 700 Mio. m3 konfrontiert sein, wobei der Wasserverbrauch in der Landwirtschaft noch nicht berücksichtigt ist. Folglich ist zu erwarten, dass sich die regionale Wasserkrise voraussichtlich weiter ausweiten wird, sofern keine Gegenmaßnahmen ergriffen werden. Israel hingegen investiert bereits seit ca. 20 Jahren massiv in den Bau von Anlagen zur Meerwasserentsalzung, um die nationale Wasserversorgung zu sichern. Die Anlagen produzieren ca. 600 Millionen Kubikmeter Süßwasser pro Jahr. Ergänzt von einem umfassenden Programm zur Abwasserwiederverwertung kann Israel so die Auswirkungen zunehmender Dürreperioden abmildern.

Die SALAM-Initiative (2020-2022) ist ein multilaterales Forschungs- und Entwicklungsprojekt, das vom Bundesministerium für Bildung und Forschung (BMBF) gefördert wird. SALAM setzt auf grenzüberschreitenden Wassertransfer, um das Wasserdefizitproblem der Region zu lösen und um eine Ausweitung der regionalen Wasserkrise zu vermeiden, sowie eine enge Zusammenarbeit mit Entscheidungsträgern und Stakeholders aus der Region. Es baut auf einer Vertrauensbasis auf, die sich zwischen deutschen Forschern und regionalen Partnern über mehr als 20 Jahre der Zusammenarbeit entwickelte. Das Projektkonsortium umfasst 19 Partnerorganisationen aus Jordanien, Israel, den Palästinensischen Gebieten und Deutschland und schließt Universitäten, Forschungszentren, Beratungsunternehmen, Ingenieurbüros und nationale Wasserbehörden ein. SALAM ist eine Initiative der Georg-August-Universität Göttingen und des deutschen Unternehmens Rusteberg Water Consulting.

ZIELE

Die vom Bundesministerium für Bildung und Forschung (BMBF) im Rahmen des Verbundvorhabens SMART-MOVE geförderte Pilotstudie SALAM zeigte, dass die enormen Wasserdefizite Palästinas und Jordaniens zukünftig nur durch den Bau weiterer Meerwasserentsalzungsanlagen sowohl am Mittelmeer als auch am Roten Meer gedeckt werden könnten. Die zweite Phase der SALAM-Initiative knüpft an diese Ergebnisse an. Die zukünftigen Wasserdefizite in palästinensischen und jordanischen Bedarfszentren werden quantifiziert und regionale Strategien für den grenzüberschreitenden Transfer von entsalztem Meerwasser und dessen Bewirtschaftung erarbeitet. Abgestimmte Konzepte aus technischen Anlagen und Bewirtschaftungskonzepten zur Gewinnung, Verteilung, Zwischenspeicherung und Wiederverwendung von Wasser sollen Defizite nachhaltig und kosteneffizient ausgleichen. Im Rahmen der SALAM-Initiative werden erstmalig machbare und kosteneffiziente grenzüberschreitende Strategien als Systemplanungslösungen zur Bewältigung des Wassermangels im Nahen Osten vorgestellt. Sämtliche Strategien beruhen auf der Meerwasserentsalzung am Mittelmeer und am Roten Meer sowie auf einer Kombination von grenzüberschreitenden Wassertransferprojekten. Diese Broschüre fasst die

SALAM Projektpartner und Stakeholder anlässlich der "SALAM Regional Status Conference" am Toten Meer, Jordanien (10.-11. Oktober 2021)



Übersichtskarte der SALAM-Projektregion

SALAM-Forschungsergebnisse in 18 „Policy Briefs“ zusammen und stellt konkrete Maßnahmen und Empfehlungen in Form von „SALAM-Schlüsselprodukten“ vor.

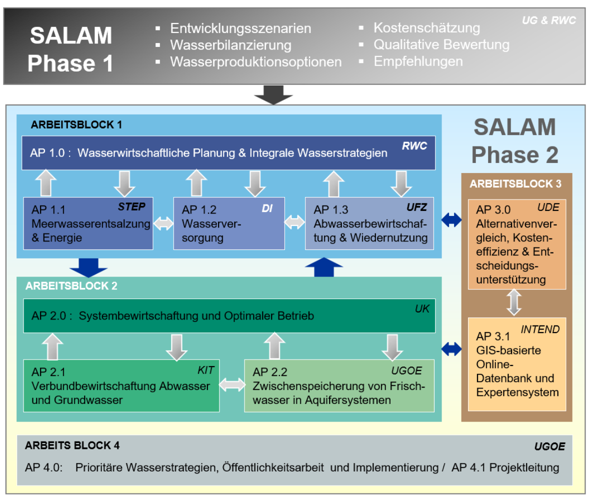
ANSATZ

SALAM gliedert sich in drei zentrale, eng miteinander vernetzte Arbeitsblöcke. Block eins setzt sich mit wasserwirtschaftlicher Planung, innovativen Technologien und damit dem Ausbau der regionalen Infrastruktur auseinander, der zur Umsetzung regionalen Wasserstrategien notwendig ist. Die Deckung des künftigen Wasserbedarfs erfordert einen umfassenden Ausbau der Infrastruktur, sowohl in Bezug auf die Süßwasserversorgung als auch auf die Abwasserentsorgung. SALAM entwickelt z.B. ein Simulationswerkzeug, das es ermöglicht, innovative Technologien zur Meerwasserentsalzung mit erneuerbaren Energien nach wirtschaftlichen und ökologischen Kriterien bestmöglich zu kombinieren. Zu Block eins gehören Arbeitspakete wie die Wasserproduktion (On- und Offshore Meerwasserentsalzung), Wassertransfer und -versorgung sowie Abwassermanagement und Abwasserwiederverwertung.

Im zweiten Arbeitsblock wird untersucht, wie die Süßwasserimporte im Verbund mit Oberflächenwasser, Grundwasser und Abwasser bewirtschaftet werden können. Die erhöhte Abwasserproduktion durch den Import von entsalztem Meerwasser kommt in erster Linie der Bewässerungslandwirtschaft zugute. Denkbar ist auch der kontrollierte Transfer des gereinigten Abwassers in das Jordantal, um das weitere Absinken des Wasserspiegels des Toten Meers zu stabilisieren. Das Projekt optimiert die Bewirtschaftung des See Genezareth und untersucht mit Grundwasserströmungsmodellen den Einsatz von Grundwasserleitern als temporäre Speicher (Managed Aquifer Recharge). So kann das importierte Wasser saisonal und unabhängig von Bedarfsspitzen verfügbar gemacht werden.

Im dritten Projektblock bewertet und vergleicht SALAM die regionalen Wassertransfer- und Bewirtschaftungsalternativen. Dabei stehen sowohl Kosten und wirtschaftliche Tragfähigkeit als auch soziale, ökologische und politische Faktoren im Fokus. In enger Zusammenarbeit mit regionalen Stakeholdern und Entscheidungsträgern werden multikriterielle Analysen der regionalen Strategien für Wassertransfer, Abwasserbehandlung und -wiederverwendung sowie Meerwasserentsalzung durchgeführt und Entscheidungstabellen entwickelt, um die Stärken und Schwächen der Entscheidungsalternativen sichtbar zu machen.

Die Erkenntnisse fließen in ein webbasiertes Informations- und Expertensystem ein, das die Umsetzung der SALAM-Ergebnisse auf nationaler und zwischenstaatlicher Ebene unterstützt. Nutzer sind vor allem die nationalen Wasserbehörden. Gemeinschaftlich verwendet schafft es die Grundlage für eine vertrauensvolle Zusammenarbeit im Wassersektor. Damit geht die SALAM-Initiative einen entscheidenden Schritt voran, um das Wasserdefizitproblem im Nahen Osten zu lösen und leistet einen Beitrag zum Abbau der, die durch Wasserknappheit bedingten, politischen Spannungen.



Übersicht der SALAM Arbeitspakete


West Bank ©Bresinsky


Wastewater Reuse in Madaba ©Breulmann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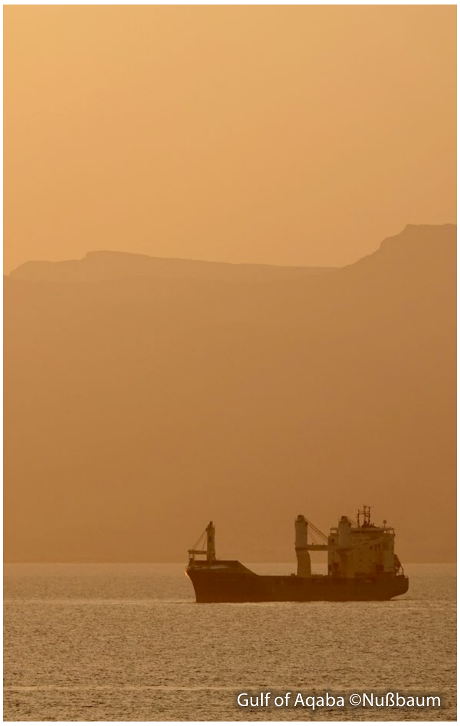
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Water Production and Transfer Strategies
On- and Offshore Solutions for Large-Scale Seawater Desalination at the Mediterranean Coast
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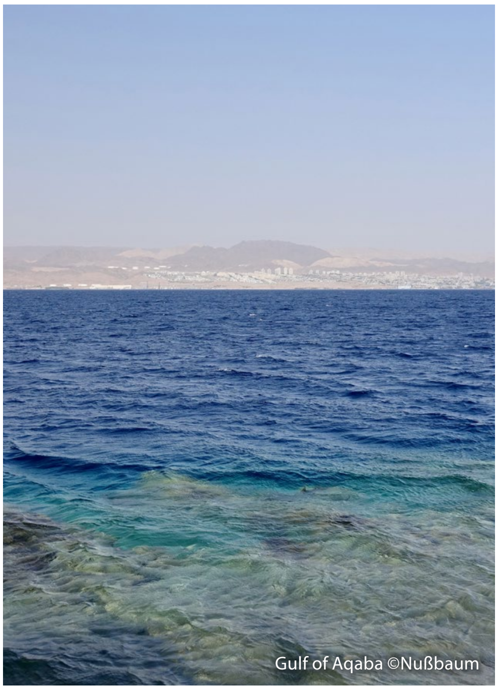
WATER STRATEGY COMPARISON AND IMPLEMENTATION
Assessment of Freshwater Strategies and Recommendations for Implementation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Haifa Bay ©Rusteberg


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Water Resources Planning

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Future Freshwater Deficits in Palestine and Jordan

Philippe de Bourgoing[1], Emad Al-Karablieh[2], Muath Abu Sadah[3], Bernd Rusteberg[4]

KEY FINDINGS

Baseline Scenarios were developed in Palestine and Jordan based on realistic assumptions for population growth, economic and agricultural development, and future water supply until 2050.

Freshwater deficits between 2020 and 2050 were estimated in both countries. To get insight into the spatial distribution of the deficits, the national territories were divided in 17 demand areas.

Palestine and Jordan will need 605 and 712 Mio.m^3 of water per year to cover their respective domestic and industrial water demand in 2050.

Domestic and industrial water deficits will be especially high in Gaza and in the urban centers of Northern and Central Jordan.

MOTIVATION

Jordan and Palestine are witnessing a significant population growth, especially in the urban centers. Both countries are developing quickly, intensifying their use of natural resources. Large-scale projects to expand the irrigated agriculture area and create new industrial hubs are underway (Ministry of Water and Irrigation, 2016; Palestinian Water Authority, 2013). All these factors exert a significant pressure on the available freshwater resources. Today, 58% of the water consumed in the region is extracted from the aquifers by both countries. Overexploitation of the aquifers put a strain on the groundwater resources. Climate change is also predicted to have an impact on both surface water and groundwater resources. The SALAM Initiative aims at finding solutions to cover the future water demand of all economic sectors in each region of Palestine and Jordan. Given the importance of the task, long-term planning until 2050 is essential. The extent of the problem should be clearly defined before decision-makers can start planning and implementing solutions. The first step of the assessment is to calculate the current water budget and agree on realistic assumptions to compute all components of the water demand and supply by 2050. In this policy brief, the future water budget is estimated in the main economic sectors for each region in Palestine and Jordan.

METHODOLOGY

The study follows a two-step process: compute the current freshwater budget gathering water demand and supply data, and estimate the future water deficits or surpluses in each demand area. Palestine and Jordan are divided in demand areas (clusters), defined taking administrative divisions but also topography and the existing water infrastructure into consideration. Local water supply and demand data from 2020 is aggregated by demand cluster. Supply includes freshwater supply (fresh groundwater and surface water, desalinated water), which is based on a detailed assessment of the availability of renewable freshwater resources for each cluster, and reclaimed water (reused wastewater, brackish groundwater). Demand in the agricultural sector is partially covered by reused wastewater.

Projecting future water demand and supply until 2050 implies making assumptions on the socio-economic development of the region and on the future state of freshwater resources. The set of assumptions for each country defines the baseline development scenario. The baseline scenario follows a Business-As-Usual approach, assuming that no major interventions in the regional water resources system, such as water transfer projects, are implemented during the planning horizon. The strategic master plans of both countries were used as basis to assess future freshwater budgets (Ministry of Water and Irrigation, 2016; Palestinian Water Authority, 2013). Projections for freshwater supply in Jordan were based

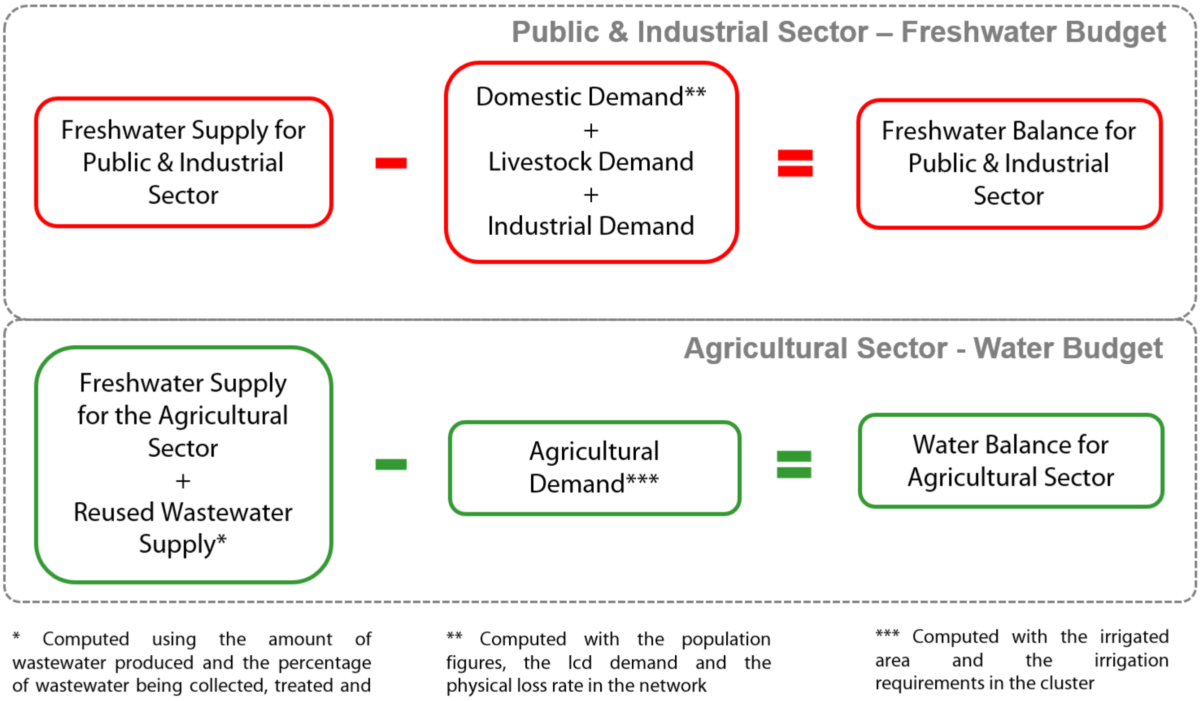

Figure 1: Assessing the future water budgets

on the findings of Margane & Al-Dweiri (2010). The underlying assumptions were refined in close cooperation between German and regional partners. Figure 1 shows how freshwater budgets are computed for domestic and industrial water uses as well as for agricultural water use.

RESULTS

The freshwater budget was assessed between 2020 and 2050 for all demand clusters. The main underlying assumptions for the baseline scenarios are summed up in Table 1. The population should increase significantly in both countries, which will induce a dramatic increase in domestic water demand. The water authorities of both countries plan to increase the daily water supply per capita up to 120 L by 2030, which will contribute to a further rise in water demand. In the baseline scenarios, no reduction of physical losses is considered for the following decades. Both countries expect significant industrial developments, that will increase pressure on water resources. However, industrial water demand in Jordan and Palestine will remain comparatively much lower than the domestic demand, respectively 10 and 5 times lower. Irrigated area should be extended, especially in the Jordanian highlands, the Northern Cluster in the West Bank and the Palestinian section of the Jordan Valley. Both countries plan to intensify the wastewater reuse program to reduce the share of freshwater being used in the agricultural water balance. While freshwater supply should decrease in Jordan due to groundwater overexploitation and climate change, it is planned to increase in Palestine.

Figure 2 shows the expected freshwater deficits for domestic and industrial water uses. If the assumptions defined in the baseline scenarios turn out to be valid, both countries will face steadily increasing freshwater deficits in the following decades. Palestine and Jordan will need 605 and 712 Mio.m^3 of water per year to cover their respective domestic and industrial water demand in 2050. The geographical repartition of these deficits is shown in Figure 3. Gaza, the Northern and Southern clusters in the West Bank and Northern and Central Jordan will be especially impacted. The agricultural sector will also face water shortages: 447 Mio.m^3/a in Palestine and 479 Mio.m^3/a in Jordan.

DISCUSSION AND CONCLUSIONS

The projected water budgets in Palestine and Jordan are considerable. The situation should be first addressed by improving water use efficiency and reducing losses in the network. Eliminating losses in the public water network by 2050 would allow to save up to 120 Mio.m^3/a in Palestine and 80 Mio.m^3/a in Jordan. Further studies are required to consolidate these numbers and to estimate the related cost. This would however only cover a small fraction of the expected deficits. Desalinating seawater, therefore, is the only solution to cover the increasing water needs of the region. [Water Production and Transfer Strategies, p. 22] were designed during the SALAM-Initiative to develop water resources system planning solutions to the freshwater deficit problem of the region. Because of these water imports to the region, public

	PALESTINE	JORDAN
Population Growth	Annual growth rate estimated at national level 2020-2025: 2.5% / 2025-2050: 3.5% Population *2.7 between 2020 and 2050	Annual growth rate estimated at cluster level National average: gradual decrease between 2020 (2.20%) and 2050 (1.70%) Population *1.8 between 2020 and 2050
Public	Public = Domestic + Tourism + Commercial Domestic: Gradual increase of the minimum water supply per capita from 80 lcd (2020) to 120 lcd (2030); 2030-2050: 120 lcd	Public = Domestic + Tourism + Livestock + Commercial + Small Industries Domestic: Gradual Increase of the minimum water supply per capita from 95 lcd (2020) to 120 lcd (2030); 2030-2050: 120 lcd
Public Network Losses	Physical loss rate estimated at national level Fixed at 28% Economic losses (non-billed) 15%, not considered	Physical loss rate estimated at cluster level Physical Loss Rate fixed. National average: 18% Economic losses (non-billed) 26%, not considered
Industry	Small and large industries Computed at national scale based on public demand: 7% of the public demand in 2020, 20% in 2050 *11 between 2020 and 2050	Large industries Annual growth rate estimated at cluster level *2.5 between 2020 and 2050
Irrigated Area	*3 between 2020 and 2050, large increases in the Northern Cluster and in the Lower Jordan Valley (*5)	*1.4 between 2020 and 2050, large increases in Ma'an (*2) and Northern Cluster (*1.7)
Wastewater Reuse	Goal at Cluster Level National Average: Volume recovered after collection, treatment and reuse amounts in 2050 to 75% of the produced wastewater (vs 9% in 2020)	National Goal: Volume recovered after collection, treatment and reuse amounts in 2050 to 64% of the produced wastewater (vs 38% in 2020)
Freshwater Supply	*2.2 between 2020 and 2050: new wells in the West Bank, desalination plant in Gaza (55 Mio. m^3/a), additional purchase agreements from Israel	20% decrease in surface water and groundwater resources between 2020 and 2050 due to groundwater overexploitation and climate change

Table 1: Main underlying assumptions used to compute freshwater budgets

water consumption and hence wastewater production will increase. This creates a huge potential for wastewater reuse, which will lower water deficits in the agricultural sector.

In this study, only one baseline scenario, based on commonly agreed realistic assumptions, was considered for each country. Nevertheless, other development scenarios can be investigated in the Water Budget Tool (see box). This helps to reflect on the uncertainties related to the projections of the baseline scenario. It could be argued that assumptions for population growth in Palestine are a bit optimistic. Likewise, predictions for the evolution of the irrigated area and extension of the wastewater reuse program in Palestine might be overestimated. Further studies should refine the assumptions for the agricultural sector. Non-revenue losses are included now in the domestic and industrial water consumption and aren't

THE WATER BUDGET TOOL

Several decision-support tools were designed in the SALAM Initiative and are compiled in the [SALAM Information and Expert System, p. 86]. The Water Budget Tool (WBT) allows the user to compute future freshwater deficits at cluster and national level and visualize the results in graphs. New development scenarios can be created by the system user, just by modifying the underlying assumptions. The numerous functionalities and user-friendly interface of the WBT make it a great planning tool for regional decision-makers.

deducted from the water supply unlike physical losses. However, these amounts are mostly used for irrigation purposes and should be added to the water supply for agriculture instead of the domestic and industrial supply. Furthermore, the impacts of climate change on freshwater supply and demand should be assessed in depth in both countries.

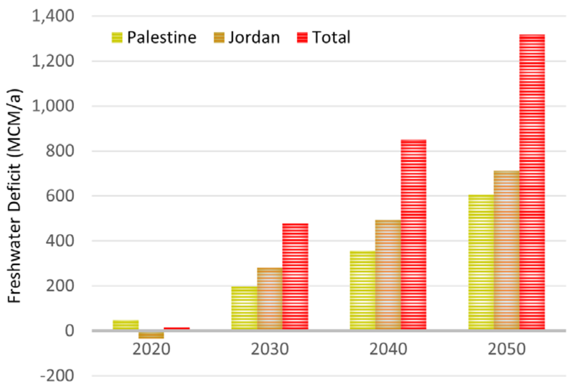

Figure 2: Freshwater deficits for public and industrial water (2020-2050)

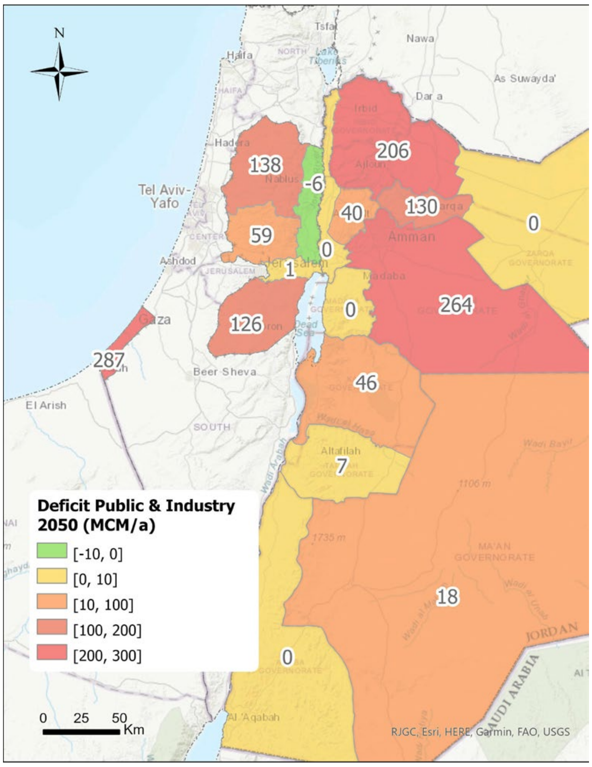

Figure 3: Freshwater deficits in 2050 for public and industrial water. In Jordan, it is assumed that water transfers will occur using the current hydro-infrastructure between the demand clusters with surpluses in 2050 (Aqaba, Jordan Valley, Madaba, Eastern Cluster) and other clusters with large deficits. Given that there is currently no centralized water transfer infrastructure in Palestine, water transfers between clusters are not considered.

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Water Pipeline in Sorek, Israel ©Sorek Desalination

Water Production and Transfer Strategies

Bernd Rusteberg[1], Philippe de Bourgoing[2], Jacob Bensabat[3]

KEY FINDINGS

A conceptual approach for developing and evaluating water production and transfer strategies is presented and applied to the project region

12 water strategies were developed. They cover the expected freshwater deficit in 2050. Freshwater supply will rely on seawater desalination along the Mediterranean coast and at Aqaba, Red Sea. The desalinated water will be transported to Jordan and Palestine via a pipe network.

MOTIVATION

The project area, which includes Jordan, Israel and the Palestinian Territories, is characterized by semi-arid to arid conditions and limited natural freshwater resources, suffers from acute water scarcity, which is expected to worsen in the near future. The main regional aquifers have been overexploited for years, resulting in a steady decline of the groundwater levels, and subsequently of the amount of water that can be extracted in a sustainable way. Due to rapid population growth, augmented by the influx of refugees from the adjacent conflict zones, many areas are already affected by acute water shortages. Work conducted under the SALAM Initiative [Future Freshwater Deficits in Palestine and Jordan, p. 18] shows that both Jordan and Palestine will face a serious water crisis unless additional freshwater resources are made available. Israel, on the other hand, has been investing in the expansion of seawater desalination (SWD) since the beginning of the 21st century and will continue to be able to meet the growing demand for freshwater in the future. Cost-effective and implementable solutions are urgently needed to mitigate the emerging regional water crisis. According to the SALAM pilot study (Rusteberg et al., 2019), future freshwater deficits in Jordan and Palestine can only be met by means of SWD in conjunction with water transfer projects. Due to the complexity of the task, the sensitive political context and the preferences at national levels, a conceptual participatory water resources planning approach is needed to develop and evaluate alternative water production and transfer strategies as potential solutions to the freshwater deficit challenge. This Policy Brief shortly presents the suggested approach and summarizes the results of its application to the project region.

METHODOLOGY

Water production and transfer strategies are options for expanding the regional water infrastructure to create a connection, by means of pipeline network, between the prospective SWD Plants and the demand centers. We developed a methodology to identify and evaluate solutions for this water resources planning task. Figure 1 presents the new approach in form of a flowchart containing 10 main planning steps, based on a participatory multilateral decision-making and planning process. The freshwater deficits in the regional demand centers (cluster) in the planning period 2020- 2050 were evaluated on an annual basis by means of water budget calculations [Future Freshwater Deficits in Palestine and Jordan, p. 18]. A baseline scenario was outlined for each country and used for determining the freshwater deficits, assuming that no large-scale interventions in the regional water infrastructure will be implemented in the planning period 2020 to 2050. For each demand cluster, a connection point (CP) for water transfer (existing or planned water reservoir) is identified, from which the imported water can be distributed in the entire cluster. An essential additional step towards the development of water production and transfer strategies was to identify alternative sites for the construction of SWD plants denoted as water production points (PP), both on the Red Sea and along the Mediterranean Sea coast. In order to define a set of potential solutions to the water resources planning challenge, locations and production capacities of the SWD plants are carefully selected in such a way that the projected freshwater deficits of all demand centers for the

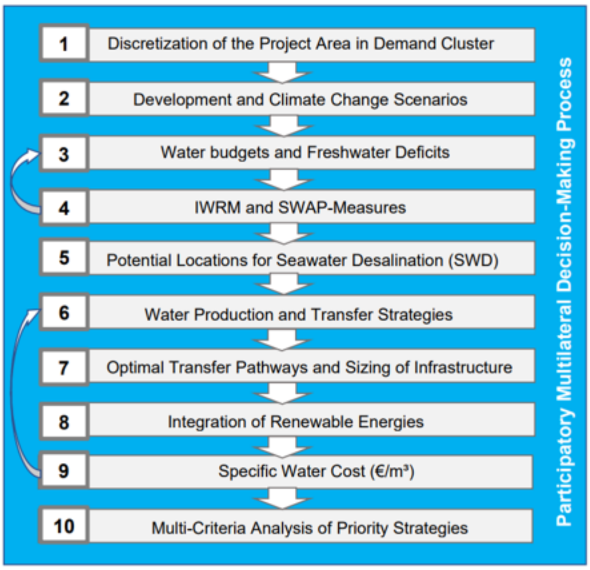

Figure 1: Flowchart – Development and evaluation of water production and transfer strategies

planning horizon 2050 are covered. Increasing the size and capacity of water infrastructure (SWD-plants, pipelines, pumping stations), leads in principle to a reduction of the specific water cost (€/m^3). Consequently, a focus was given to planning solutions that rely on large-scale water infrastructure. According to the defined water production and transfer strategies (see Figure 2), optimal routes for water transfer between the potential locations of the SWD plants (PP) and the connection points (CP) of the demand centres are determined and the water infrastructure (pipelines, pumping stations) dimensioned. Infrastructural, political (border), topographical and energetic aspects are of particular importance [Water Conveyance System for Freshwater Deficit Coverage in Jordan and Palestine, p. 37]. The economic and multi-criteria assessment of the alternative water strategies are presented under [Techno-Economic Assessment of Water Infrastructure Projects, p. 72], [Multi-Criteria Analysis of Water Resources Planning Options, p. 80]. More detailed information on the developed conceptual approach for water strategy development can be found in (Rusteberg et al., 2022).

RESULTS

According to water budget calculations [Future Freshwater Deficits in Palestine and Jordan, p. 18], Jordan and Palestine will face a rapidly increasing freshwater deficit, which could be as high as 1.3 billion m^3/year by 2050 (712 m3/year in Jordan, 323 Mio. m3/a in the West Bank and 287 Mio. m3/a in Gaza). Following the suggested conceptual approach, we developed 12 alternative water strategies, capable of covering the expected substantial freshwater deficits. All solutions are based on seawater desalination at the Mediterranean and Red Sea and transfer of the desalinated water to demand centres in Jordan and Palestine. Figure 2 compiles the different water strategies, distinguishing between national and regional solutions. Further regional solutions may result from a combination of national solutions. The strategic linkage between water production points and demand centers is presented by arrows, indicating the required water production and transfer in Mio. m3/a of desalinated seawater. The strategies are numbered according to production points (PP) which refer to the SWD plants. The desalination facility near to Netanya (PP-1) exploits the close vicinity to the Palestinian demand areas in the northern Westbank. Similarly, the potential expansion of the SWD facility near to Ashdod (PP-5) exploits the relatively small distance to the Palestinian demand areas in the southern Westbank. This is an important aspect, since land use rights may significantly complicate the construction of a transfer pipeline on

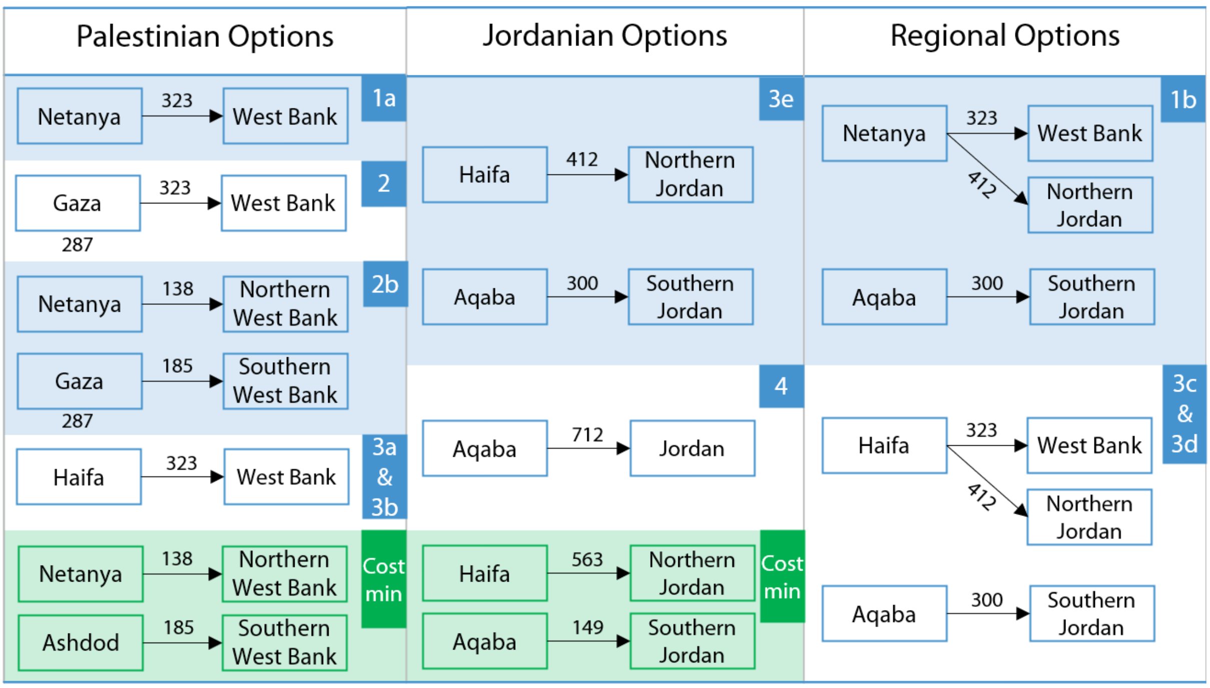

Figure 2: Water production and transfer strategies – planning horizon 2050

Figure 3: Regional water strategy, constituted of the national strategies 2b (Westbank) and 3e (Jordan)

Israeli territory. Regardless of water transfer considerations, the Gaza Strip will rely on the SWD to meet its freshwater needs (PP-2). Alternatively, a water transfer from Gaza to the West Bank is also being considered, as Palestine associates it with greater independence from Israel in terms of water supply. Shavei Zion (PP-3), north of Haifa Bay, has been considered as another potential site for the construction of a large SWD plant due to its proximity to the Lake Tiberias (Sea of Galilee). The produced water could then be transported by gravity via a tunnel to the Lake Tiberias which would act as regional large-scale storage and regulating facility. Furthermore, hydropower may be generated at Lake Tiberias by exploiting the topographic drop between the Mediterranean Sea and the lake [Large-Scale Hydropower Plant at Lake Tiberias in the Context of Transboundary Water Transfer, p. 50]. Furthermore, Aqaba (PP-4) is available as a potential site for SWD, being located on the only Jordanian coastline. [On- and Offshore Solutions for Large-Scale Seawater Desalination at the Mediterranean Coast, p. 26] and [Renewable Energy for Seawater Desalination in the Middle East: Case Study Aqaba, Jordan, p. 30] provide further information on the implementation of SWD plants in the region, taking also offshore solutions into account. Finally, a cost-minimal solution (green colour) could be developed by a non-linear cost minimization model [Regional Macro-Model for Transboundary Water Resources Planning, p. 76]. Figure 3 shows a regional water strategy combining the Palestinian strategy 2b with the Jordanian strategy 3e. This solution considers the expansion of the Gaza SWD plant (PP-2) to cover the water needs of Gaza and the south of the Westbank, while the North of the Westbank is being supplied from Netanya (PP-1). In accordance with the current plans of the Jordanian Government, 300 Mio. m3/a of desalinated seawater will be produced at Aqaba and transferred to southern and central Jordan. The remaining freshwater deficit of 412 Mio. m3/a in North and Central Jordan is covered by the above-mentioned "Haifa-solution"(3e). Figure 4 presents the regional water allocation network, used as basis for cost minimization studies [Regional Macro-Model for Transboundary Water Resources Planning, p. 76], which is an overlay of all alternative planning solutions, taking the optimal water transfer pathways into account.

CONCLUSIONS

The development of expansion variants of the regional water resource system to cover the freshwater deficits in the project region is a water resources planning task. Its solution requires, partly due to the sensitive political context, a structured participatory approach to ensure transparency and thus acceptance of the results. Based on the suggested conceptual approach, it was possible for the first time to provide implementable water production and transfer strategies to solve the freshwater deficit problem in the region. All strategies are based on seawater desalination at different locations on the Mediterranean Sea as well as the Red Sea and a combination of water transfer projects. The project work on individual steps of the approach, such as the water budget calculations, the design of the SWD plants, the optimal routing between the plants and demand areas, the cost calculation, the integration of renewable energies as well as the multi-criteria analysis of alternative strategies are detailed in other policy briefs in this brochure. Due to its general structure, the approach can also be applied to neighbouring countries or other regions that face similar problems and which need to rely on desalination and water transfer in the future (e.g. Egypt). The results show that transboundary cooperation between Israel, Jordan and Palestine is needed to solve the water deficit problem and avoid a further extension of the emerging water crisis in the region. In view of the region´s rapidly increasing freshwater deficits, there is an urgent need for action regarding the implementation of a jointly supported regional water strategy. Further recommendations towards strategy implementation will be provided under [Assessment of Freshwater Strategies and Recommendations for Implementation, p. 92].

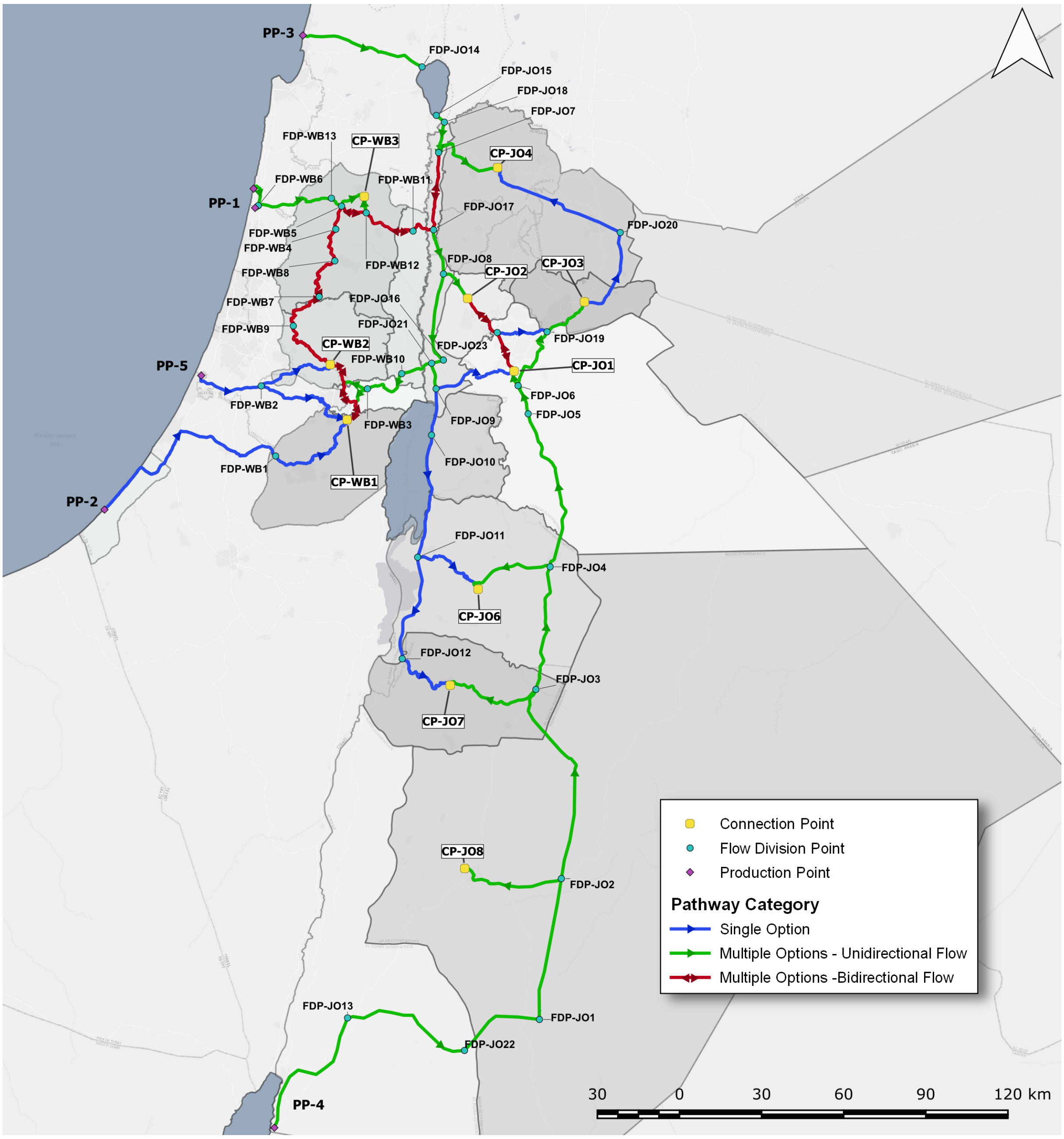

Figure 4: Regional water allocation network as overlay of all water production and transfer strategies, based on the optimal water transfer pathways

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Sorek Desalination Plant, Israel ©Sorek Desalination

On- and Offshore Solutions for Large-Scale Seawater Desalination at the Mediterranean Coast

Süleyman Yüce[1], Daniel Janowitz[1]

KEY FINDINGS

Additional large-scale seawater desalination plants at the Mediterranean coastline are essential to overcome water scarcity in Israel, Palestine, and Jordan.

Seawater desalination plants on offshore structures such as artificial islands are economically viable and have ecological advantages concerning the intake and outfall compared to onshore solutions.

The integration of renewable energy sources can reduce water production costs. In addition, offshore generation of renewable energy could reduce the amount of energy to be stored.

MOTIVATION

Water scarcity in regions where groundwater sources are mostly depleted can only be reduced by bringing new freshwater sources into the water balance. In this respect, building large-scale seawater desalination plants at the Mediterranean coastline could be the only economically viable option to cover parts of the projected freshwater deficits in Jordan and Palestine. Since the late 90s, Israel is investing in large-scale seawater desalination, producing today around 600 million cubic meters per year (Mio. m^3/a) of freshwater, using membrane-based technologies. Process innovations led to significant reductions in energy demand from 20 kWh/m^3 in 1970 to 2.5 kWh/m^3 in 2010 (Fritzmann et al., 2007). Therefore, the water production costs of reverse osmosis seawater desalination plants also significantly decreased to around 0.5 $\$/m^3$. However, implementing large-scale seawater desalination plants is still a major challenge. Population growth and urbanization lead to significant shortages in available land, which can trigger public resistance. This effect is likely to increase in the future, driving up land prices and resulting in land use conflicts at the coastline. Offshore structures such as artificial islands or land reclamation can be a viable option to create new land for desalination purposes. Large projects as the Kansai Airport in Osaka or the artificial islands at the Upper Zakum Field offshore Abu Dhabi show the feasibility of the approach for decades. Creating new land for desalination purposes on artificial islands or land-reclamation is a new approach, only desalination concepts implemented on ships, drilling rigs, or small-scale floats have been discussed so far. Within the SALAM Initiative, the economic feasibility of different desalination concepts was investigated to determine the offshore effect on the specific water production costs.

METHODOLOGY

First, the existing desalination infrastructure in Israel was analyzed, and important trends in the desalination market were identified. This approach enabled the identification of the most appropriate technologies for large-scale seawater desalination. The desalination sites were determined according to the developed water production and transfer strategies and underlying conceptual approach [Water Production and Transfer Strategies, p. 22], selecting the most suitable feeding points to potential water transfer pathways to the regional water demand centers as shown in Figure 1. In addition to the plants on the Israeli coast, a desalination plant in Gaza was considered. In addition to onshore desalination solutions, alternative offshore concepts were developed based on rubble mound breakwaters at various water depths. Figure 1 shows two alternatives that were created for the so-called „Haifa option". Depending on the distance from the coast and location, different

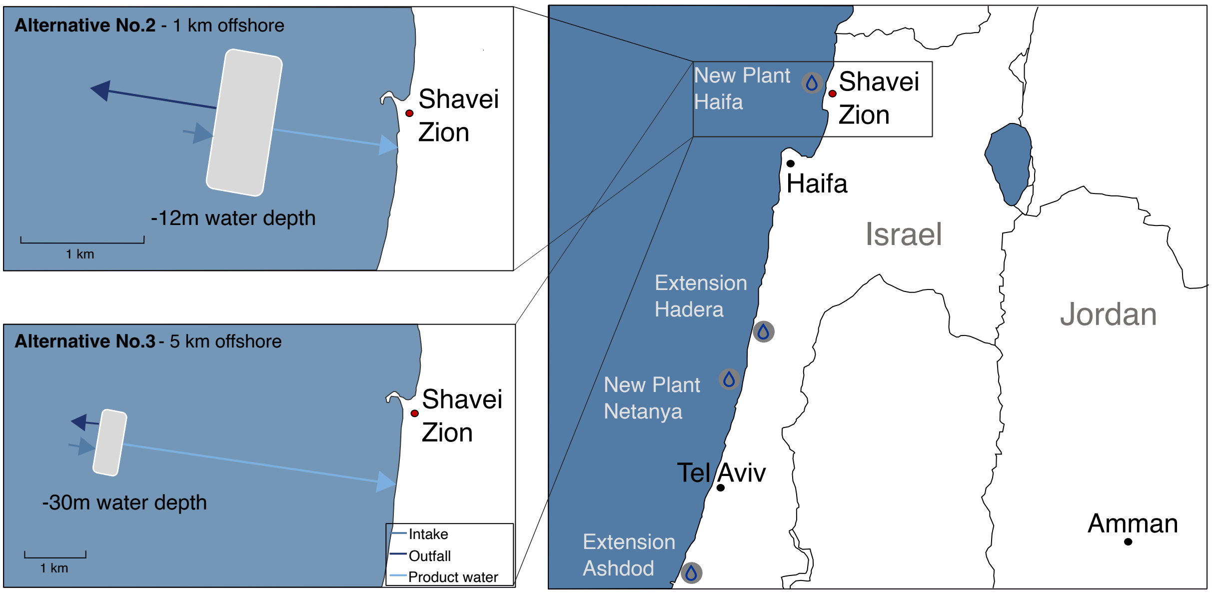

Figure 1: Considered locations for new desalination plants and plant extensions and a zoom-in on the offshore alternatives in the North of Haifa

water depths must be taken into account (Table 1). The preliminary design of the offshore structures was based on the analysis of historical wind data, taking the expected wave heights at the study locations into consideration Based on the water depth at the alternatives locations, an armour layer was designed to protect the structure from erosion by currents and waves. In addition, filter layers were considered to prevent the washing out of the core fill and cover the sub-layers from erosion. The resulting quantities of components and unit prices determined the construction costs of the alternatives. A more detailed description of the methodology for the design of the artificial structures and their cost calculation can be found in Janowitz et al. (2022). All alternative onshore and offshore solutions were evaluated based on a multi-criteria assessment, taking technical, economic, social, and ecological decision criteria into account [Multi-Criteria Analysis of Water Resources Planning Options, p. 80].

RESULTS

The economic analysis conducted within the SALAM Initiative indicates that large-scale seawater desalination plants on offshore structures like artificial islands are economically viable [Techno-Economic Assessment of Integrated Water Resources Management Infrastructure Projects, p. 72] and present ecological advantages concerning the intake and outfall compared to onshore solutions. Figure 2 shows the pre-design of the desalination plant on the artificial island. The entire plant technology must be constructed on the artificial island, as for an onshore plant, and transmission lines and pipelines must be routed to the coastline. In the case of the „Haifa option“, the difference in specific water production cost between the „land reclamation“ alternative No.1 (directly at the coast) and the most distant alternative No.3 from the shoreline (5 km offshore) is only 0.03 US$/m^3. The specific water production costs for alternatives 1 and 3 are 0.63 and 0.66 US$/m^3, respectively (Table 1). For a desalination facility with a capacity of 200 Mio. m^3/a , the cost difference is 6 Mio. US$/y during the plant's lifespan. Accepting the increased investment costs of offshore alternatives enables a significant reduction of the environmental impact of the intake and outfall. In addition, artificial islands' influence on the hydrodynamic currents can even be reduced with increasing distance to the shoreline, so beach erosion is prevented (Janowitz et

Table 1: Alternatives for large-scale offshore desalination within the "Haifa option" (Janowitz et al., 2022)

ALTERNATIVES	WATER DEPTH	CREST HEIGHT OF THE STRUCTURE ABOVE CHART DATUM	WATER PRODUCTION COST
No. 1 – Artificial Island Land reclamation	- 5 meter	+ 8 meter	0.63 $/m^3
No. 2 – Artificial Island 1 km offshore	- 12 meter	+ 14 meter	0.64 $/m^3
No. 3 – Artificial Island 5 km offshore	- 30 meter	+ 14.4 meter	0.66 $/m^3

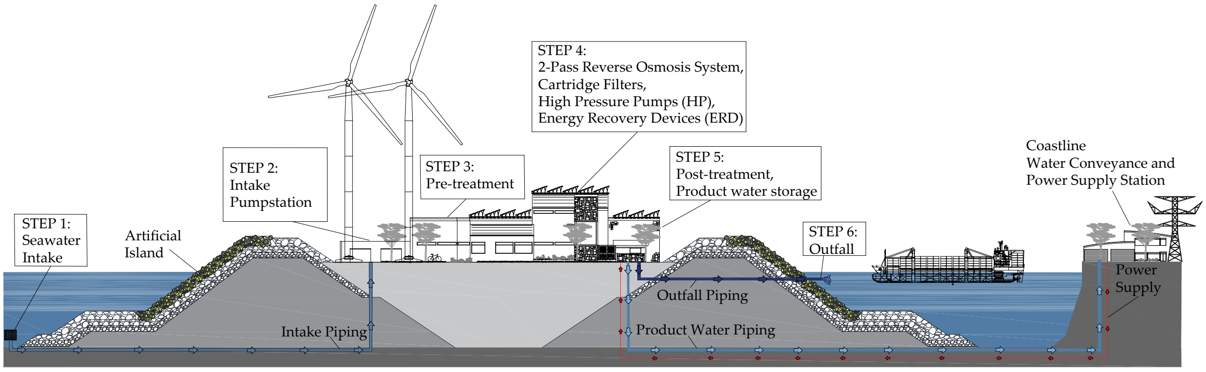

Figure 2 Desalination project layout on the artificial islands (Janowitz et al., 2022)

al., 2022). The specific water production cost is highly dependent on the specific footprint, the plant's capacity, and the financing structure of capital expenditures. However, the influence of energy cost on water production cost is still more significant (Janowitz et al., 2022). Therefore, the greatest potential for reducing the cost of water production lies in the reduction of the costs for energy generation. The specific costs of generating electricity from renewable energy sources, especially photovoltaic systems, have decreased significantly. Therefore, a large part of the electrical power needed could be covered by photovoltaic systems and energy transport from Jordan to Israel, according to the Water-Energy-SWAP concept, developed within the SALAM Initiative [Innovative Water-Energy-SWAP Concept between Israel and Jordan, p. 33].

CONCLUSIONS

An environmental impact assessment combined with a technical feasibility study is an essential next step to facilitate the realization of artificial islands for desalination. A pilot study should include an in-depth investigation concerning suitable sites, studying nearby quarries and possible dredging locations, and taking environmental concerns, especially water quality issues, into account (Janowitz et al., 2022). In addition, mapping and investigating the biodiversity at the offshore sites are essential to collecting location-specific data for quantifying the influences. The operating costs for the pre-treatment of the desalination plant could be reduced depending on the offshore water quality compared to conventional onshore desalination plants. From a mid-term perspective, an alternative chemical energy storage option such as hydrogen should be explored to facilitate the transition from natural gas-powered to a carbon-neutral seawater desalination industry in Israel. Renewable energy generation on the artificial islands, such as wind turbines or wave energy, could reduce energy storage needs. However, the increase in the share in renewable energy needs to be provided on a much larger scale from onshore facilities. The electricity generation cost for photovoltaics has significantly decreased in the last years, which has the potential to further reducing the water production cost. In this respect, concepts for exchanging water and energy between Israel and Jordan could be a win-win for both sides.

ESSENTIALS FOR REALIZING LARGE-SCALE DESALINATION PROJECTS

Reverse osmosis is the dominant technology for the realization of large-scale seawater desalination plants due to its technical maturity and scalability worldwide. The driving force in reverse osmosis is the pressure difference between the applied pressure and the osmotic pressure of the salt solution. Therefore, the high-pressure pumps need electrical energy based on conventional or renewable energy sources. In this respect, reverse osmosis will always be an energy-intensive process (Elimelech & Phillip, 2011). Private sector participation, including market-oriented tendering, is essential to reach competition, leading to fair-priced bids for the site-specific desalination project (Janowitz et al., 2022). Desalination plants are typically purchased according to the Build-Operate-Transfer scheme (BOT). Within BOT projects, governments usually provide take-or-pay guarantees reducing the commercial risk, so these schemes are attractive to the private sector.

Sorek Desalination Plant, Israel ©Sorek Desalination

Sorek Desalination Plant, Israel ©Sorek Desalination

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Shore of the Dead Sea, Jordan ©Nußbaum

Renewable Energy for Seawater Desalination in the Middle East: Case Study Aqaba, Jordan

Süleyman Yüce[1], Daniel Janowitz[1]

KEY FINDINGS

The overall strategy for minimizing water scarcity in Jordan should take seawater desalination plants on Jordanian territory into consideration.

Integrating renewable energy sources (e.g., solar energy) will reduce the costs of seawater desalination in Jordan.

Combining Nanofiltration, Reverse Osmosis and Multi-effect-desalination allows for tailor-made brine disposal into the Dead Sea and increases water recovery

MOTIVATION

Several factors hinder Jordan from harnessing seawater to cover the growing freshwater deficit, which is expected to reach ~700 Mio.m^3/a by 2050 [Future Freshwater Deficits in Palestine and Jordan, p. 18]. Jordan has a very short coastline along the Red Sea near Aqaba. In addition, the salt content of the Red Sea is up to 43,000 ppm, significantly higher than the salt content of the Mediterranean Sea. A further regional challenge is the sinking of the water level of the Dead Sea. This is accompanied by sinkholes on the Dead Sea coast that destroy infrastructure and loss of freshwater due to a modified groundwater regime (Yechieli et al., 2016).

While Jordan has no fossil energy resources, it is a country with high solar radiation. This huge solar potential can be exploited to power desalination plants. However, the bottleneck in this approach lies in energy storage technologies. Innovative concepts must be developed to combine available storage technologies with suitable energy production and desalination technologies. Therefore, solutions have been developed in which Jordan could counteract water shortages by utilizing its own renewable energy sources, thus lowering seawater desalination costs on Jordanian territory. In the SALAM Initiative, STEP has developed concepts that combine membrane-based and thermal seawater desalination technologies with suitable methods of solar energy production. Additional efforts have been made to develop a desalination concept that counteracts the Dead Sea drying by discharging suitable brines. The challenge here lies in the different compositions of the Dead Sea and the Red Sea and the large distances between them. Growing environmental awareness and potential conflict over land must be considered in finding regionally specific solutions.

METHODOLOGY

Jordan's existing seawater desalination infrastructure was analyzed, and the essential trends in the renewable energy market were identified. This approach enabled the selection of the most appropriate technologies for solar energy production in combination with membrane-based and thermal desalination. The SALAM partner DI identified the renewable energy potential in Jordan and calculated the resulting production costs for electricity. Optimizing the entire process chain is an iterative process that requires developing simulation tools. Our simulation tool developed by STEP combines the water flow, recovery and rejection data of RO and MED, resulting in electrical and thermal energy demand. Based on this, the capacity of concentrated solar power and photovoltaics can be estimated. Additionally, all concepts were evaluated using technical, economic, social, political and environmental criteria as a basis for the multi-criteria assessment of seawater desalination plants combined with renewable energy, which was carried out by UDE [Multi-Criteria Analysis of Water Resources Planning Options, p. 80].

The saturation indices of the concentrate and Dead Sea water mixture were determined using the PHREEQC software package to analyze the impact of brine disposal into the Dead Sea. Based on these values, it was possible to determine whether implementing the concept would cause gypsum precipitation in the Dead Sea.

RESULTS

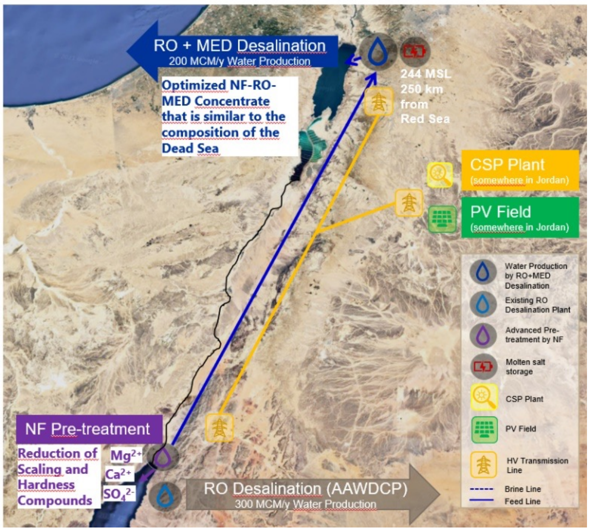
Concept A: Desalination at Aqaba – Brine discharge into the Red Sea

Beside the planned Aqaba-Amman Water Desalination and Conveyance Project (AAWDCP) for 300 Mio. m^3/a, 200 Mio. m^3/a freshwater are also produced by Reverse Osmosis (RO) desalination at Aqaba Port. The capacities chosen here are scalable. The electrical energy is generated from PV during sunshine hours and stored in molten-salt storage to generate electricity at night. The advantage is that the maximum temperature in the heat accumulator and the steam cycle is higher, as the accumulator can be heated up to ~600 °C with electricity. This increases the efficiency of the energy conversion.

Concept B: Desalination in Wadi Araba & Aqaba – Brine discharge into the Red Sea

The second solar concept includes both Photovoltaics (PV) and a Concentrated Solar Power (CSP) system to supply energy. The PV system produces low-cost electricity that is used directly for desalination. In addition, the CSP plant fills up the thermal energy storage. The seawater is pretreated at Aqaba with Nanofiltration (NF) to reduce scaling and hardness compounds, which protects the pipes from corrosion. The NF permeate is pumped inland to Wadi Araba. The CSP plant is located far enough away from the Red Sea that the collectors of the CSP plant are not affected by the salty sea air. For seawater desalination, RO and Multi-Effect Desalination (MED) are used. Due to the pretreatment by NF, higher water recoveries can be achieved. The steam cycle of the CSP plant is coupled with the MED as the waste heat from the CSP is utilized for thermal desalination. The concentrate is transported back to Aqaba and disposed into the Red Sea.

Concept C: Desalination at the Dead Sea – Brine discharge into the Dead Sea



Unlike the other concepts, this concept includes brine disposal into the Dead Sea and therefore counteracts the drying up of the Dead Sea. Like in Concept B, the seawater is pretreated with NF, and the NF permeate is desalinated at the Dead Sea using RO and MED. The desalination setup makes it possible to adapt the concentrate to the Dead Sea composition and prevents gypsum precipitation in the Dead Sea. As brine is discharged into the Dead Sea, this concept could prevent harm to the unique ecosystem of the Gulf of Aqaba. The energy supply is similar to Concept B.

CONCLUSIONS

Three possible desalination concepts for Jordan were identified. Desalinating seawater at the Dead Sea and discharging the brine there (Concept C) is a particularly innovative approach to address the regional challenges. In the current context, integrating renewable energy sources is the solution to decrease costs and promote the large-scale use of seawater desalination in Jordan. Using nanofiltration as an innovative pretreatment technology enables the separation of scaling compounds directly at the Red Sea. This would allow the desalination concentrate to be adjusted to the composition of the Dead Sea while simultaneously protecting the Gulf of Aqaba from harmful desalination brine disposal. However, further studies are required on the path towards implementing this innovative concept, including the safe transport of the NF permeate from the Red Sea to the Dead Sea. Furthermore, integrating renewable energies and storage technology like hydrogen into the concept needs to be further investigated.

CONCENTRATED SOLAR POWER

Solar radiation can be directly converted into electricity by photovoltaics. As seawater desalination plants should also be supplied at night, suitable energy storage is needed. The Concentrated Solar Power (CSP) technology offers a solution to this problem. In CSP, solar radiation is converted to thermal energy stored in molten salt storage systems. At night, the thermal energy can be extracted from the molten salt storage to produce electricity in a steam cycle. The waste heat from the steam turbine can be utilized in thermal seawater desalination plants to increase water recovery.

Gulf of Aqaba ©Nußbaum

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Quweira PV Plant ©Nußbaum

Innovative Water-Energy SWAP Concept between Israel and Jordan

Daniel Janowitz[1], Süleyman Yüce[1], Marco Margheri[2], Hamzeh Yakhoul[2], Jacob Bensabat[3], Bernd Rusteberg[4], Martin Sauter[5]

KEY FINDINGS

A SWAP, i.e. exchange, of desalinated water from Israel for solar energy from Jordan is a viable concept from which both sides benefit

The SWAP concept could be realized even without any financial compensation from either side, targeting on a fair exchange with mutual dependencies.

The SWAP implementation strategy consists of the production of 400 Mio. m³/a freshwater from large-scale desalination plants North of Haifa, and the transfer to Jordan in exchange for the supply of Electrical Solar Energy by Jordan.

MOTIVATION

Jordan is one of the most water-scarce countries in the world, with a per capita volume of 94 m³ of renewable freshwater per year. Jordan is heading towards a serious water crisis, facing a freshwater deficit of more than 700 million m³ per year by 2050 [Future Freshwater Deficits in Palestine and Jordan, p. 18]. The substantial freshwater deficit in Jordan can only be met by the large-scale deployment of seawater desalination (SWD), together with a water transfer to the demand centers. SWD plants could be built at the Red Sea (Aqaba) or on the Mediterranean coast. However, due to significantly shorter distances, water transfer from the Israeli coastline to Jordanian demand centers is more advantageous in economic terms compared to solutions relying on SWD at Aqaba [Techno-Economic Assessment of Integrated Water Resources Management Infrastructure Projects, p. 72]. Therefore, transboundary water production and transfer (WPT) strategies should form the key instrument to face the challenges of the rapidly increasing freshwater deficits in Jordan.

Like all countries in the Eastern Mediterranean, Israel is characterized by substantial solar radiation rates. However, solar energy solely is not a viable solution because it depends on weather conditions, seasons, and sunlight hours, reducing its reliability. This would also require the allocation of large land areas for this purpose, since the Ministry of Energy intents to increase the share of renewable energy in the energy mix to 30% in 2030. But land availability is a limiting factor in Israel (Tal, 2018). In contrast, Jordan has large amounts of land available for solar energy production and higher solar irradiation, which makes solar plants in Jordan even more economical.

These national challenges create a potential synergy for cooperation that is advantageous for the development of Water-Energy-SWAP concepts. In this respect, Israel and Jordan have recently signed a declaration of intent (DoI) that is in line with the concepts described above. The SWAP DoI aims to intensify the cooperation between the two countries through the supply of 200 Mio. m³/a freshwater from Israel to Jordan in exchange for 600 MW of electricity based on renewables to be produced in Jordan and supplied to Israel (Israel Ministry of Energy, 2021). This Policy Brief takes the approach further and specifies the exchange concept based on the results of the SALAM Initiative.

METHODOLOGY

In order to assess and discuss the feasibility and economic viability of a Water-Energy-SWAP between Israel and Jordan, the following steps were taken: (1) identification of alternative sites for seawater desalination (SWD) on the Mediterranean coast of Israel, (2) identification of optimal

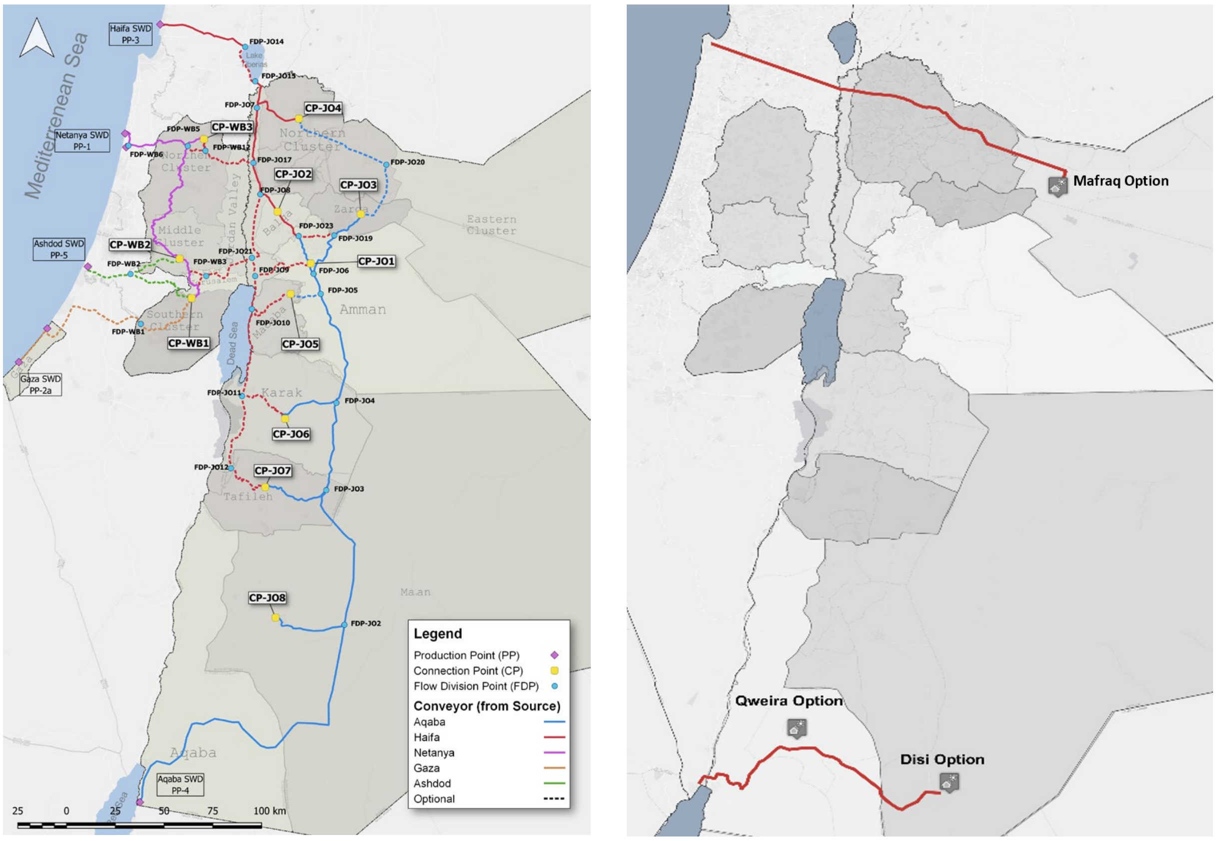

Figure 1: (A) Relevant Water Production and Transport Options (B) Potential sites for the production of electric power in Jordan for transport to Israel

routes for water transfer between the SWD-plants and demand centers, (3) selection of promising strategies for water production and transfer, (4) selection of options for renewable energy production by photovoltaics in Jordan, and (5) analysis of energy transfer to Israel.

Within the SALAM Initiative, we developed 12 water strategies based on seawater desalination at the Red Sea and/or the Mediterranean Sea and water transfer via pipelines to regional demand centers in Jordan and Palestine [Water Production and Transfer Strategies, p. 22]. These solutions are technically feasible and cost-effective. Figure 1A compiles the most technically and economically advantageous options with respect to a regional water distribution network (Rusteberg et al., 2018). It shows potential sites for seawater desalination and the corresponding positioning of pipelines for water transfer. Offshore solutions for seawater desalination were also considered. For the SWAP concept, a highly cost-effective water production and transfer solution for Jordan was chosen, based on a transboundary approach in cooperation with Israel.

After selecting a cost-effective water production and transfer solution from Israel to Jordan, potential sites for renewable energy production in Jordan were investigated. Two selection criteria were established to identify the possible locations for the PV plant: (1) the proximity to Israel's major load centers and / or grid, and (2) the solar radiation level in Jordan. After a first preliminary assessment of possible locations for suitable sites for a large-scale project, three alternatives were selected for further evaluation. Furthermore, energy simulations were conducted using PVsyst simulation software to assess the proposed alternatives' generation potential. This leads to the following location-specific key figures for the production and necessary length of the transmission lines:

> Mafraq Governorate (close to Mafraq city):
  2,165 kWh/kWp, 180km Transmission Line length
> Aqaba Governorate (Qweira):
  2,360 kWh/kWp, 70km TL length
> Ma'an Governorate (Disi):
  2,402 kWh/kWp, 140km TL length

Based on the assumptions in Table 1, the Levelized Cost of Energy (LCOET) for electrical generation by PV, including the transmission costs to Israeli grid was calculated. The LCOET is the average generation cost and transmission costs, including CAPEX and OPEX.

RESULTS

Due to shorter distances, freshwater transfer from the Mediterranean Sea to the demand centers in Northern Jordan significantly reduces the infrastructure investments and the energy required for water conveyance. In particular, the significantly lower energy demand of Mediterranean water production options for water transfer compared to Aqaba options is the basis of the economic advantage of the cooperation between Jordan and Israel under a SWAP

PARAMETER	VALUE	UNIT
PV cost	630	USD/kWp
HV Substations	200	USD/kWp
HV Transmission Line	1,000,000	USD/km.GWp
PV O&M	10	USD/kWp/year
HV TL O&M	2,000	USD/km.GWp/year
O&M Increase	3	%/year
PV Degradation	0.6	%/year
Transmission Losses	7	%/1000km
Financing + Developer Profit	5	USD/MWh

Table 1: LCOE key assumptions

agreement. The construction of a large-scale SWD plant north of Haifa with a production capacity of 400 Mio. m^3/a would cover most of the freshwater deficit in Jordan by 2050, which cannot be covered by the projected new 300 Mio. m^3/a SWD plant near Aqaba.

The analysis of potential sites for solar energy production in Jordan indicates that the Disi Option (Figure 1B) is economically attractive, resulting in an LCOET of 30 USD/MWh.

In addition, Disi has a large area availability and the best energy yield, which means the highest energy supply reliability and viability. Therefore, the Disi option was selected for the generation of renewable energy for a potential Water-Energy-Swap. Figure 2 illustrates the potential Water-Energy-Swap between Israel and Jordan, including key values calculated by using Equation 1 (see box).

The amount of energy equivalent to the cost of producing and transmitting 400 Mio. m^3/a of freshwater from Israel and Jordan would be 12,776 GWh/y of energy (yearly average of the 25 years lifetime of the PV plant where the first year has the highest production due to PV system degradation). That amount of energy can be produced by installing a 5.8 GWp PV plant with an area of ~72.9 km^2 in Disi. The swapped renewable energy will allow Israel to increase the renewable energy share in its electrical generation mix significantly. Based on 2019 reports, the contribution of renewables in the energy mix was 2,326 MW of a total of 19,366 MW (12%) in terms of power capacity and 3,300 GWh of a total of 72,500 GWh (5%) in terms of energy. Including the power and energy required by water desalination and conveyance, the Israeli renewable energy penetration would reach up to 36% in power capacity and 21% in terms of energy based on 2019 figures.

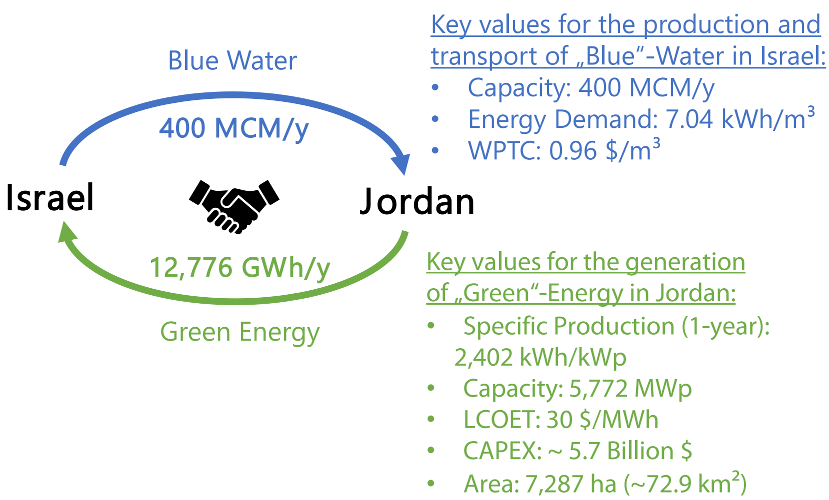

Figure 2: Potential water-energy SWAP between Israel and Jordan based on SALAM findings

CONCLUSIONS

The mitigation of water scarcity in Jordan and simultaneously covering part of the renewable energy demand in Israel is feasible by conducting a fair Water-Energy-SWAP. A promising bartering strategy could create a win-win situation by exchanging 400 Mio. m^3 of freshwater per year from a large-scale SWD plant located North of Haifa bay for megawatt-hours of renewably generated electrical energy from Jordan. With this approach, a fair exchange is achieved with mutual dependencies without monetary compensation. We recommend carrying out technical/economic pre-feasibility studies for both selected water and energy production and transfer options. The selection of the most suitable SWAP solution with the highest mutual benefit and political acceptance level should be based on a multi-criteria option comparison, considering economic, political, environmental, technical, and social aspects. There are several further research needs to be addressed before implementation. In particular, strategies must be developed to adapt the regulatory framework enabling the production and transmission of renewable electrical energy from Jordan to Israel. It needs to be investigated whether the Israeli grid can handle the additional electricity loads and how it could be expanded. In addition, the land ownership and its availability need to be clarified, including the social acceptance of such large-scale projects. Sustainable implementation of such a SWAP concept requires further research and close cooperation between the water, energy, and environmental authorities on both sides.

BARTERING WATER FOR ENERGY

Aiming at a SWAP concept where money is not part of the deal, the Israeli water production and transport costs need to equal Jordan's energy generation and transport costs. Based on this assumption, the amount of electrical power P_{Swap} for swapping from Jordan to Israel is calculated according to equation (1):

$$P_{Swap}\left[\frac{MWh}{y}\right] = \frac{WPTC\left[\frac{\$}{m^3}\right] * C_{Desal}\left[\frac{m^3}{y}\right]}{LCOET_{PV}\left[\frac{\$}{MWh}\right]}$$

P_{Swap} significantly depends on the water production and transfer costs (*WPTC*) bringing desalinated water from the Israeli coast to the demand center Amman in Jordan. The *WPTC* is calculated using the levelized costs of electricity generation and transfer ($LCOET_{PV}$) bringing the electricity from photovoltaics from Jordan to Israel. In addition, the desalination capacity C_{Desal} and the $LCOET_{PV}$ itself must be considered.

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Zay Water Treatment Plant with Pump Station and Reservoirs at the Jordan Valley ©Maria Scheday

Water Conveyance Systems for Freshwater Deficit Coverage in Jordan and Palestine

Maria Scheday[1], Gibran Zarzar[1]

KEY FINDINGS

Covering the projected water deficits in 2050 will require constructing new large-scale hydro-infrastructure and multiplying the capacity of the existing water infrastructure of Jordan and Palestine by about twice and four times, respectively.

It is reasonable to expand primary infrastructure in stages along existing conveyance systems.

Developing alternative water transfer options will allow for more flexibility and security with regards to the water supply situation of the region.

MOTIVATION

By 2050, freshwater quantities of about 1,140 Mio. m^3 per year (Jordan) and 1,040 Mio. m^3 per year (Palestine) will have to be distributed to 11 Jordanian and 6 Palestinian demand clusters (West Bank and Gaza). This amount is 80% (Jordan) and 340 % (Palestine) higher than the 2020 water demands. Most of the water in Jordan is currently produced on national territory, less than 10% is imported (Lake Tiberias). Palestine, in agreement with Israel, covers about 52% of the current freshwater demand from internal sources while 48% are imported. The water deficits in these two countries in 2050 indicate the need for producing an additional 712 Mio. m^3/a (62% of total demand) for Jordan and 605 Mio. m^3/a of water (58% of total demand) for Palestine. The huge increase in water production, as well as the high water demands in 2050, will require a tremendous extension and modernization not only of the conveyance systems but also of the distribution networks. The water infrastructure needs to be expanded according to the population's growth and industrial expansion per demand cluster. As internal water sources, i.e. well yield, are gradually depleting due to overexploitation, and because of the effects of climate change, water scarcity in the region is increasing rapidly. Pragmatic and economic solutions for reliable alternative freshwater sources from Seawater Desalination (SWD) Plants in combination with major conveyance systems must be developed and implemented over the next two to three decades.

METHODOLOGY

The water produced at potential SWD locations on the Rea Sea (Aqaba) and along the Mediterranean Sea needs to be supplied to the demand clusters in Jordan and Palestine which are projected to suffer from significant water deficits in 2035 and 2050. It is expected that some clusters such as the Eastern Cluster, the Jordan Valley, and Aqaba have a surplus of water production, which will continue to be exported to clusters with water gaps. This reduces the amount of water to be provided from the SWD to these benefiting clusters and has been taken into consideration in the analysis of the required conveyance systems. The desalinated water must be transported via newly planned and constructed water transmission systems (WTS) including transmission lines, reservoirs, and pumping stations. The assessment of digitalized network data in GIS in combination with an evaluation of system schematics and inquiries at responsible water companies leads to the identification of relevant conveyance systems and potential routing of the new WTS. The location and capacities of planned SWD on the one hand [On- and Offshore Solutions for Large-Scale Seawater Desalination at the Mediterranean Coast, p. 26], and the water deficit calculations per demand on the other hand determine the needed capacities and routes of the proposed WTS. The sizing of the transmission lines between the SWD plants and the demand centers is based on the required conveyed quantity. The topography, length, and dimension of the pipe will result in the required pump head, and thus energy demand and operational costs. The elevation profile of each WTS is prepared using GIS to determine the length and static head for each system. The friction loss is estimated at about 2 m/km pipe length. The energy consumption per WTS is calculated assuming a 75% system efficiency. The energy requirement in kWh per m^3 conveyed water for each WTS is the key indicator for comparing the systems' efficiencies and operational costs.

Water production and transfer strategies were developed and are detailed in [Water Production and Transfer Strategies, p. 22]. To evaluate the technical feasibility of all strategies, an analysis was carried out using a decision-making matrix comparing different water transfer options required to cover the 2050 water deficits. The three technical criteria taken into consideration are the connectivity to the existing water infrastructure, the technical complexity, and the length of the network, which provides an indication about the duration of hydroinfrastructure implementation.

RESULTS

12 alternative water transfer strategies were assessed with technical criteria. Supplying the West Bank from Netanya or Ashdod requires a shorter network than from Haifa or Gaza, which likely means that the construction time will be lower. Differences in the length of the alternative transfer paths are comparatively lower in Jordan than in Palestine. It could be noted that the cost-minimal option in Jordan has the longest network length hence highest duration of implementation among all transfer strategies. As a tunnel should be built between Haifa and Lake Tiberias, transferring water from Haifa will be more technically challenging as from other desalination plants. The strategies with a direct pipeline between Jenin and Ramallah have a good connectivity to the water distribution infrastructure in the West Bank. Strategies where Central Jordan is supplied by 2 sources rather than just one perform better on the criterion „connectivity to the existing water infrastructure". Supplying the West Bank from a SWD plant in Netanya (strategy 1a) and Jordan from SWD plants in Haifa and Aqaba (strategy 3e) is in technical terms the most feasible option and will be here further described.

The annual freshwater deficit for Jordan is 386 Mio. m^3 for 2035 and 712 Mio. m^3 for 2050 [Future Freshwater Deficits in Palestine and Jordan, p. 18]. The planned Amman Aqaba Water Desalination and Conveyance System (AAWDC), with 300 Mio. m^3 capacity, is planned to be in operation by 2030. Under consideration of the AAWDC, the future freshwater deficits can be covered by conveying 86 Mio. m^3 for 2035 and 412 Mio. m^3 for 2050 from the Haifa SWD. The Palestinian annual freshwater deficit is estimated including the Gaza Strip's water demand. The total deficit amounts for 268 Mio. m^3 for 2035 and 605 Mio. m^3 for 2050. To cover this deficit, Netanya SWD is to convey 156.4 Mio. m^3 to the West Bank by 2035 and 323 Mio. m^3 in 2050. Having the highest deficits of all clusters, the Gaza Strip would be directly supplied from Gaza SWD producing 116.6 Mio. m^3 in 2035 and 287.3 Mio. m^3 in 2050.

Table 1 sums up key technical characteristics of the regional solution to cover freshwater deficits in 2050 in Palestine and Jordan: Jordan would receive desalinated water from Aqaba and Haifa while the West Bank would obtain water from SWD at Netanya. This option, together with potential WTS alternatives, is illustrated in Figure 1.

CONCLUSIONS

Options for expanding the water transfer systems in Jordan and Palestine have been investigated and evaluated in technical terms. The water transfer systems relate to different water production and transfer strategies described in [Water Production and Transfer Strategies, p. 22]. A multi-criteria decision-making tool will support the ranking of these alternatives [Multi-Criteria Analysis of Water Resources Planning Options, p. 80]. The energy demand for producing and conveying 1 m^3 of water to the demand center is a key decision criterion. Therefore, topographical conditions along transfer routes have a major impact on water costs. In contrast, the length of the water transmission network is of minor significance in economic terms. Coordination between the energy and water sectors is required for cost optimization in view of the exorbitant energy requirement for water production and transport on

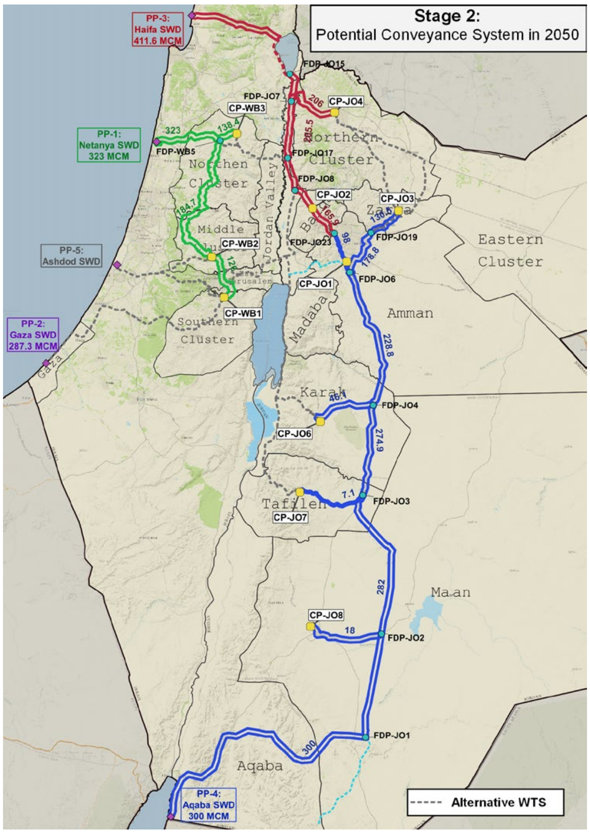

Figure 1: A regional solution to transfer water to the demand clusters in 2050.

the one hand, and the increasing production of renewable energy in the region on the other hand. The expansion of the hydro-infrastructure will require huge investments and operation costs. Current prices for water services are too low to ensure sustainable service provision; the operation of such high-capacity systems will require substantially higher contributions from users. All financing options, including potentials for Private Sector Participation (PSP), should be assessed. PSP considerations need to include social aspects of direct users (ability to pay for water) and complementary public budget implications.

SOURCE	SECTION / BRANCH	SUPPLIED CLUSTER	LENGTH (KM)	2050 FLOW (MIO. M³/A)	DN WTS (MM)
Aqaba SWD (300 Mio. m³/a))	PP-4 to FDP-JO2		190	300,0	2x2000
	FDP-JO2 to CP-JO8	Ma'an	40	**18,0**	700
	FDP-JO2 to FDP-JO3		78	282,0	2x2000
	FDP-JO3 to CP-JO7	Tafilah	39	**7,1**	500
	FDP-JO3 to FDP-JO4		47	274,9	2x2000
	FDP-JO4 to CP-JO6	Karak	34	**46,1**	1200
	FDP-JO4 to FDP-JO6		74	228,8	2x1800
	FDP-JO6 to CP-JO3	Zarqa	47	**130,5**	2x1400
	FDP-JO6 to FDP-JO23	Amman	40	**98,3**	1700
Haifa SWD (412 Mio. m³/a))	FDP-JO15 to FDP-JO7		15	411,6	3x2000
	FDP-JO7 to CP-JO4	NC Jordan	31	**206,0**	2x1700
	FDP-JO7 to FDP-JO8		46	205,6	2x1700
	FDP-JO8 to CP-JO2	Balqa / Amman	14	205,5	2x1700
	CP-JO2 to FDP-JO23	Amman	18	**165,9**	2x1500
Netanya SWD (323 Mio. m³/a))	PP-2a to FDP-WB5		38	323,0	2x2100
	FDP-WB5 to CP-WB3	NC Palestine	11	**138,4**	2x1400
	FDP-WB5 to CP-WB2	MC / SC Palestine	94	184,7	2x1600
	CP-WB2 to CP-WB1	SC Palestine	33	**126,0**	2x1400
Gaza SWD		Gaza		**287,3**	

Notes: PP= Production Point, CP=Cluster Center, FDP=Flow division point, DN=Nominal Diameter (of WTS pipe)

Table 1: Key technical characteristics of the regional solution

TECHNICAL BACKGROUND

The alternative water transmission systems have been technically analyzed with regards to elevation, length, dimension, investment cost, and energy demand for water conveyance. The routing of the conveyors was chosen based on existing water systems, roads to allow for enhanced connectivity and topography. This approach, in combination with the utilization of available capacities of installed systems, reduces capital and operational costs. Costs are also optimized minimizing friction losses by keeping the flow velocity below 1.5 m/s and laying several parallel pipes instead of a single large pipe to allow for gradual expansion (maximum pipe diameter of 2,200 mm).

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Wastewater Treatment Plant in Wadi Esseir ©Manfred van Afferden

Regional Wastewater Infrastructure Development Strategies for Jordan and Palestine

Ganbaatar Khurelbaatar[1], Moritz Sanne[1], Roland A. Müller[1], Manfred van Afferden[1]

KEY FINDINGS

The GIS-based tool SWAMP (Multi-Scale Wastewater Master-Planning) was developed within the SALAM Initiative to estimate the additionally required wastewater infrastructure at high temporal and spatial resolution.

By 2050 it is expected that 954 Mio. m^3 per year of wastewater will be generated in Jordan and the West Bank, Palestine, which represents a significant water reuse potential, provided that it is safely collected and adequately treated.

The SWAMP tool was used to develop two technical options -decentralized and centralized- for expanding wastewater infrastructure.

As results, the required infrastructure and costs of centralized and decentralized expansion options for wastewater treatment and reuse in the region were defined.

MOTIVATION

The increasing water deficit in the Middle East is due to a combination of a rapid increase in water demand and a rapid decline in available water resources. Against this background, the SALAM initiative explored sustainable options for the provision of additional freshwater resources to meet the region's future water needs. In the context of an Integrated Water Resources Management (IWRM), wastewater is a resource that has not been sufficiently tapped in the region so far. However, wastewater can only be considered a reusable source for irrigation and other purposes if it is properly collected and adequately treated, thus also protecting existing water resources from pollution. Within the SALAM Initiative, a GIS-based Multi-Scale Wastewater Master-Planning (SWAMP) tool was developed to i) quantify the current and future wastewater potentials with a spatial and temporal distribution, ii) develop country-wide expansion options for the wastewater management infrastructure, iii) estimate the infrastructure demand for the expansion options, and iv) estimate the related costs.

METHODOLOGY

The Global Human Settlement database (GHSL, 2019) provides data on population distribution at a 250 x 250 m resolution. These data were used as the main data base for the analysis and were cross-checked and supplemented with local information from Jordan and the West Bank such as population, villages, governorates, demand clusters, topography, connection degree, and water consumption. Within each grid cell, proxy data were generated e.g. a correlation between the street and the sewer network, to estimate the sewer demand for the areas, which currently lack infrastructure.

A strategic goal of the SALAM Initiative is to increase the population share connected to wastewater collection and treatment facilities to 95% by 2050. To achive this, two main development options were investigated: centralized and decentralized expansion of the wastewater management and reuse infrastructure. For both options, the sewer network requirements at settlement level were estimated. In the centralized expansion option, water flows by gravity through pipelines to a single wastewater treatment plant (WWTP) located near the outflow point of each surface

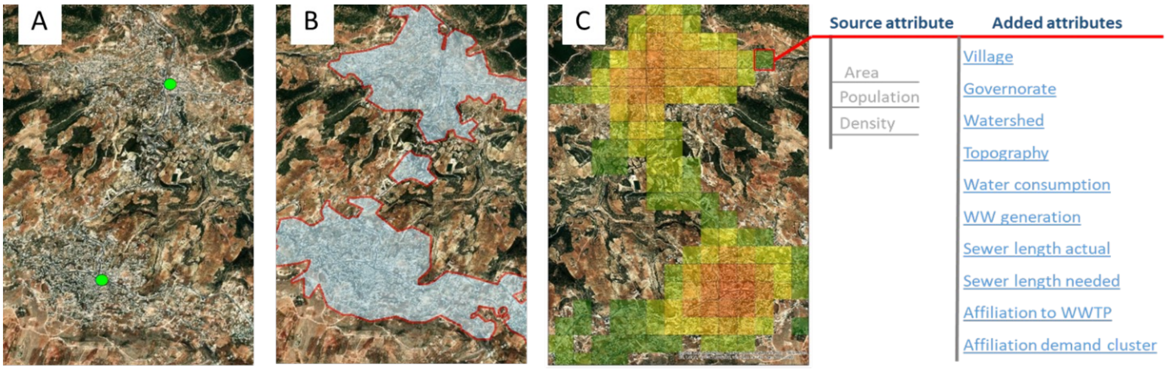

Figure 1: Various data representing the same settlement. A: Settlement is presented as a point Geo-data. B: Polygon Geodata showing the settlement. C: The settlement is shown as a combination of gridr cells, where the data of each cell is calibrated and supplemented with local data.

catchment. The surface catchments were defined by the location of the main dams and wadi outflow points with preference given to gravity sewer systems and consequently minimizing the need for wastewater pumping. The treated effluent is then to be used in the Jordan valley. In the decentralized expansion option, WWTPs are located in the immediate vicinity of the individual settlements. The treated wastewater is preferably reused locally or discharged into the wadis leading to the Jordan Valley.

Expansion costs were calculated using the estimated infrastructure requirements in terms of capital investment, reinvestment, and operation and maintenance (O&M) costs. Local and international benchmark cost data were used and the net present cost of the whole system was calculated over 60 years for each expansion option according to the DWA (2011) guidelines. Based on the calculated net present cost, the specific treatment costs for each surface catchment and expansion option are available to identify the most cost-effective option.

RESULTS

At different scales (regional, local), the SWAMP tool enables both an assessment of the current wastewater management situation as well as the development of technical expansion options and forecasts of the wastewater generation (year 2050).

Currently, Jordan has 33 centralized wastewater treatment plants, where approximately 65% of the total wastewater is treated (288 Mio.m^3 per year as of 2020). Reports indicate that approximately 90% of the treated effluent is reused in Jordan (MWI, 2015). In the West Bank 10 centralized wastewater treatment plants receive and treat 16% of the wastewater (60 Mio.m^3 per year as of 2020) with a 30% reuse rate (Figure 2) (HWE, 2012).

Assuming water supply increases by 2050 according to the [Water Production and Transfer Strategies, p. 22], Jordan and the West Bank will annually generate 666 Mio.m^3 and 286 Mio.m^3 of wastewater respectively. At the same time, the agricultural water demand will increase to 965 Mio. m^3 per year in Jordan and 787 Mio.m^3 per year in the West Bank [Future Freshwater Deficits in Palestine and Jordan, p. 18], meaning that up to 69% and 36%, could be covered by the reuse of treated effluent.

Although a significant part of the agricultural water demand can potentially be covered by the reuse of treated effluent, the spatial distribution of the treated effluent is a challenge to overcome (Figure 3). For instance, the

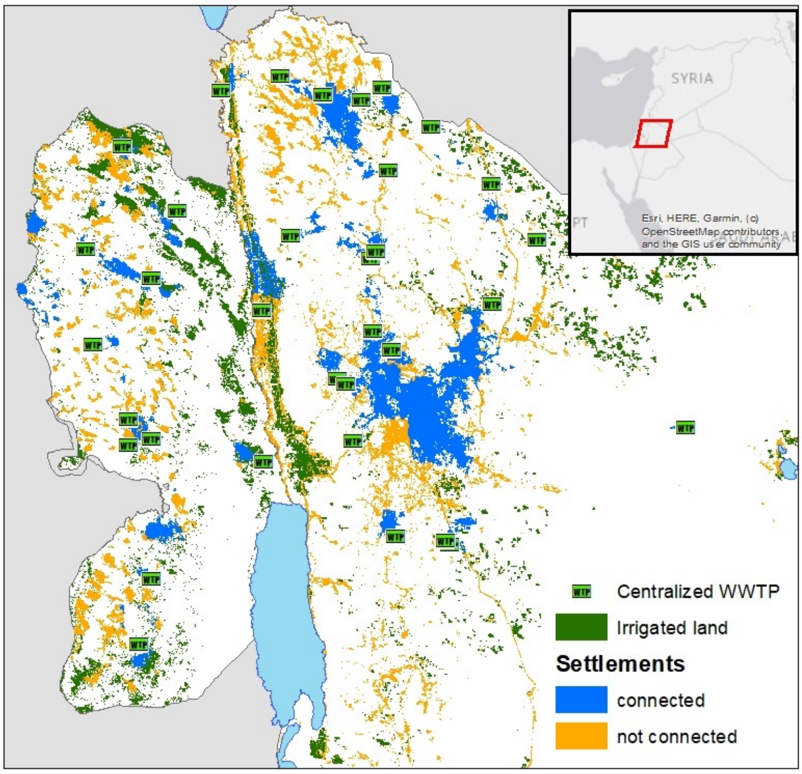

Figure 2: Current wastewater management in Jordan and the West Bank

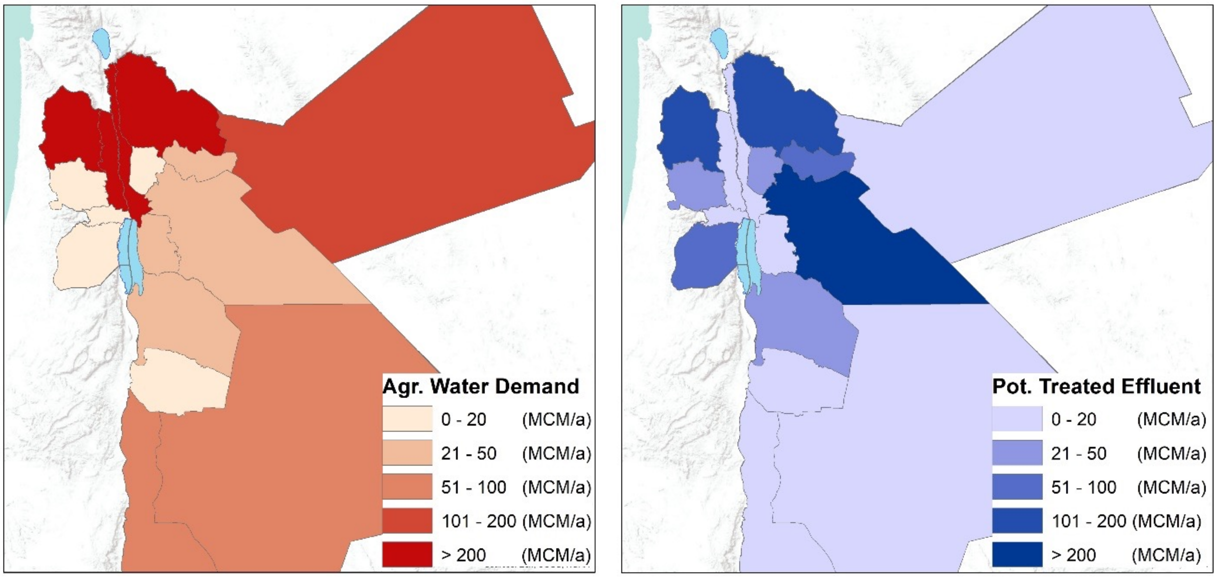

Figure 3: The agricultural water demand (left) and the treated effluent potential (right) of the region projected for 2050

southern clusters in the West Bank will produce more treated effluent than the agricultural water demand, while additional quantities of treated effluent will be required in the north for irrigation.

In Jordan the amount of treated effluent will exceed the agricultural water demand in the northern and central part of Jordan, so that the transport through trunk lines to areas with high agricultural water demand (e.g., Jordan Valley) might be a viable reuse solution. Considering that some clusters produce more treated effluent than their agricultural reuse demand, the combination of centralized and decentralized expansion options should be implemented. This way, surplus treated effluent can be transported to clusters with high demand to increase the reuse efficiency, while a local treatment and reuse level is suggested for the areas with high agricultural demand.

Table 1 shows the estimated infrastructure requirements for the centralized and decentralized expansion and management options for 2050.

CONCLUSIONS

Safe collection and adequate treatment of wastewater is of imminent importance in the Middle Eastern region, which suffers from increasing water deficits. A tool capable of planning wastewater infrastructure and estimating its cost is crucial for the successful implementation of sustainable water management. The SWAMP tool developed within the SALAM initiative allows an analysis and pre-planning process with high spatial resolution. For each settlement and city, demand cluster, and the entire region the demand for wastewater management and reuse infrastructure can be estimated. As a result, the projected wastewater potential for 2050 was assessed for both Jordan and the West Bank and the required wastewater infrastructure estimated. The SWAMP tool can be used as a preparation tool for investment projects in Jordan and Palestine and is transferable to other regions once the database is calibrated through region-specific data.

COUNTRY	EXPANSION OPTION	LOCAL SEWERS (KM)	TRUNK LINES* (KM)	WASTEWATER TREATMENT PLANTS**	TREATED EFFLUENT FOR REUSE (MIO.M^3/A)	SPECIFIC TREATMENT COST (€/M^3)
Jordan	Central	8,819	1,790	26	633	1.09
	Decentral	8,819	466	370	520	1.812
West Bank, Palestine	Decentral	6,576	-	243	272	0.99

*Trunk lines for raw wastewater for the centralized option and treated effluent for the decentralized option
**The sizes of the wastewater treatment plants range from 100 (Person Equivalent PE) to 370,000 PE

Table 1: Required infrastructure for the expansion options in 2050

Wastewater Treatment Plant in Wadi Esseir ©Manfred van Afferden

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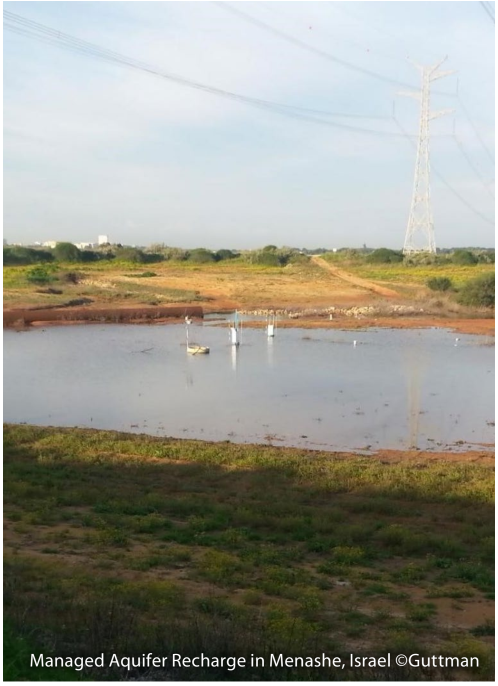
Managed Aquifer Recharge in Menashe, Israel ©Guttman


Al Adassiyah, Jordan ©Al-Karablieh


Lower Jordan Valley ©Klein


Al-Karameh Dam ©Theobald


King Abdullah Canal ©Al-Karablieh


Recharge Area of the Western Mountain Aquifer ©Bresinsky

System Management, Water Storage and Reuse

> Multipurpose Management Tool of Lake Tiberias and the Lower Jordan Valley

> Large-Scale Hydropower Plant at Lake Tiberias in the Context of Transboundary Water Transfer

> Groundwater Models of the Lower Jordan Valley Aquifer

> Management Strategies for the Reuse of Treated Wastewater in the Lower Jordan Valley

> Inventory of Fractured-Porous Rock Aquifers for Managed Aquifer Recharge with Desalinated Seawater

> Regional Models of Large-Scale Storage of Desalinated Seawater

View on the King Abdullah Canal in the Lower Jordan Valley ©Klein

Multipurpose Management Tool of Lake Tiberias and the Lower Jordan Valley

Martin Klein[1], Stephan Theobald[1]

KEY FINDINGS

The operation of Lake Tiberias is a multi-objective optimization task as multiple management goals are considered.

A model predictive control-based optimization model has been developed to improve the lake´s water release according to defined constraints and management objectives.

Based on defined management scenarios, the tool allows to react dynamically to different hydrological situations.

To apply the predictive control optimization model of Lake Tiberias, forecast data on water inflows and withdrawals is necessary.

MOTIVATION

Lake Tiberias is the largest freshwater reservoir in Israel. It is located in the Northeast of Israel and stores mainly surface water of the Jordan River. In the past, the lake supplied significant amounts of freshwater to Israel, but due to the increasing production of desalinated water it lost some of its relevance. However, because of its size and its location above the Lower Jordan Valley (LJV), Lake Tiberias is highly relevant for Jordan's water supply. As agreed in bilateral agreements, the lake provides Jordan with ca. 50 Mio. m^3 water per year. This amount is set to increase to 100 Mio. m^3 per year, following recent agreements in 2021. The water is delivered to the Jordanian King Abdullah Canal (KAC), a major water supply line in the LJV. The KAC runs in a north-south direction for a length of 110 km from the Yarmouk tributary parallel to the flank of the LJV. The KAC conveys substantial proportions of the public water supply for Amman as well as for agricultural water supply in the LJV.

There is currently no water management instrument considering the water release of Lake Tiberias to the Jordan Valley on a transboundary basis. In the future, the importance of a coordinated transboundary water transfer will further increase, due to additional water transfer agreements with Israel's neighbors. For example, the water transfer to Jordan will increase by additional 200 Mio. m^3/a to annually 300 Mio. m^3 in exchange for Jordanian solar energy („Water-Energy SWAP"), according to the latest agreement in 2021. The SALAM Initiative developed innovative and cost-effective water transfer solutions via Lake Tiberias [Water Production and Transfer Strategies, p. 22], using the lake as regional water reservoir in connection with hydropower generation [Large-Scale Hydropower Plant at Lake Tiberias in the Context of Transboundary Water Transfer, p. 50].

To use the lake's available water resources most efficiently, water release from the lake to the LJV and regional water demand centers must be further improved, taking operating guidelines of the lake and the temporal and spatial water demands into account. This complex task can be realized for different scenarios by applying a hydraulic model of the LJV with a predictive multi-objective discharge optimization of Lake Tiberias. Therefore, a Multipurpose Management Tool as Decision Support System (DSS) for an optimized lake operation under different demand scenarios has been developed.

METHODOLOGY

The operation of surface water reservoirs pursuing short-term objectives can be challenging for the operating staff, because current and future hydrological developments

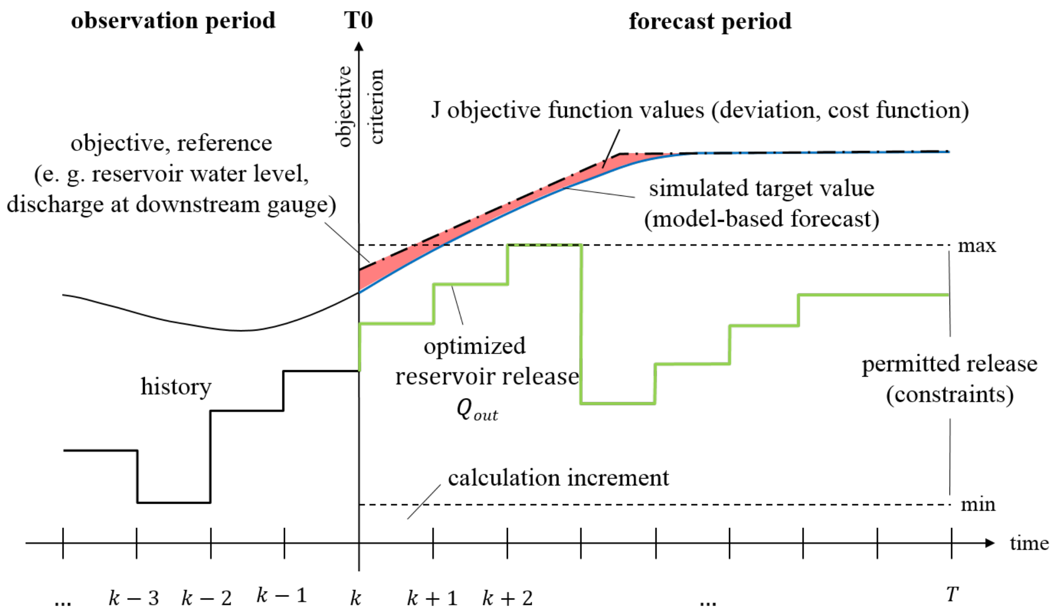

Figure 1: Principle of the Model Predictive Control (MPC) (Rötz & Theobald, 2019)

of the system must be considered in the decision-making process. Computer-based simulation and optimization processes can be used as a DSS with Model Predictive Control (MPC) to support the operating staff with this complex task (Rötz & Theobald, 2016). Such a MPC-based support system consists of a process model, which represents the hydrological system of rivers and dams, and a predictive optimization method, which determines the best possible control strategy for the dams.

For the process model, Lake Tiberias is defined as a reservoir with an optimizable water release to the KAC. The geometry of the lake is considered by a volume-elevation relationship. In addition, water level restrictions such as the upper red line (-208.8 m asl), lower red line (-213 m asl), and the black line (-241.87 m asl) are implemented as optimization constraints and objectives. The hydraulic model of the LJV calculates the hydraulic values of the KAC and the LJR according to the diffusive wave equation at the cross sections of the river systems. For both the KAC and LJR, all relevant in- and outflows are integrated into the model as objectives or boundary conditions.

Connected to the process model, the predictive optimization method identifies an optimal control strategy for achieving future objectives while taking defined constraints, e.g. fixed technical or operational restrictions, into account. With this method, starting from a point in time T0, a sequence of control steps is determined to achieve defined future optimization objectives, e.g. flows in a canal or water level in a reservoir, as accurately as possible (Figure 1). Due to the predictive character of this method, forecast data on the inflows and outflows of the system are essential.

To simulate the storage operation of Lake Tiberias and its connected water system in the LJV, the MPC approach is implemented by a computer-based simulation and optimization model using the Software RTC-Tools (Real Time Control-Tools).

RESULTS

The aim of the optimization is to minimize the water release of Lake Tiberias' (green arrow) while serving all water

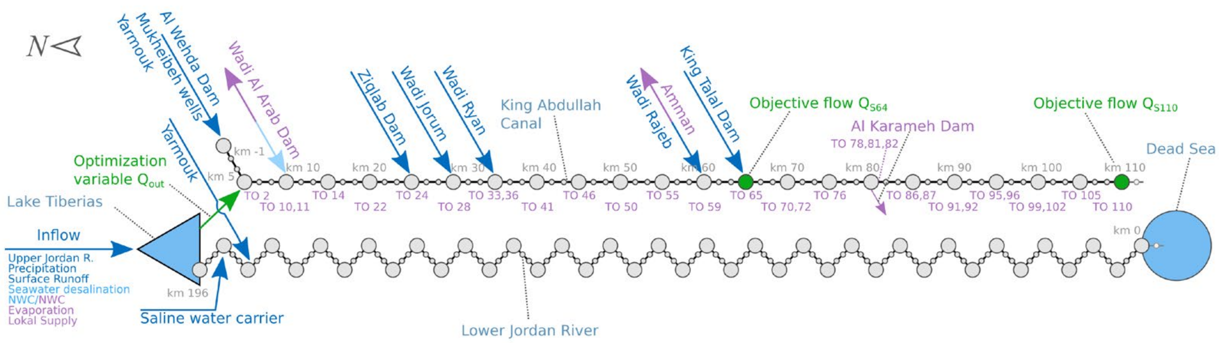

Figure 2: System sketch of the developed model

demands at the KAC. To address this goal, two auxiliary objectives with Q_{S110} = 0.20 m^3/s (station 110) and Q_{S64} > 0.25 m^3/s (station 64) for a minimum flow in the channel are defined. A system sketch of the model with the objected flows (green dots) and the in- and outflows (blue/purple arrows) are shown in Figure 2. Due to its high relevance for the water supply in the valley, the focus of the analysis is on the KAC.

scenarios 2 (blue dotted) and 3 (blue dashed) significantly reduces the released water of the lake into the KAC by ca. 15% and 65% compared to scenario 1 (blue solid). In the context of the withdrawals by the TOs, the flow at station 110 oscillates with only small deviations around the objective value of Q_{S110} (purple lines) while Q_{S64} is maintained throughout the simulation (not shown). The reduction in water release is achieved at the expense of water withdra-

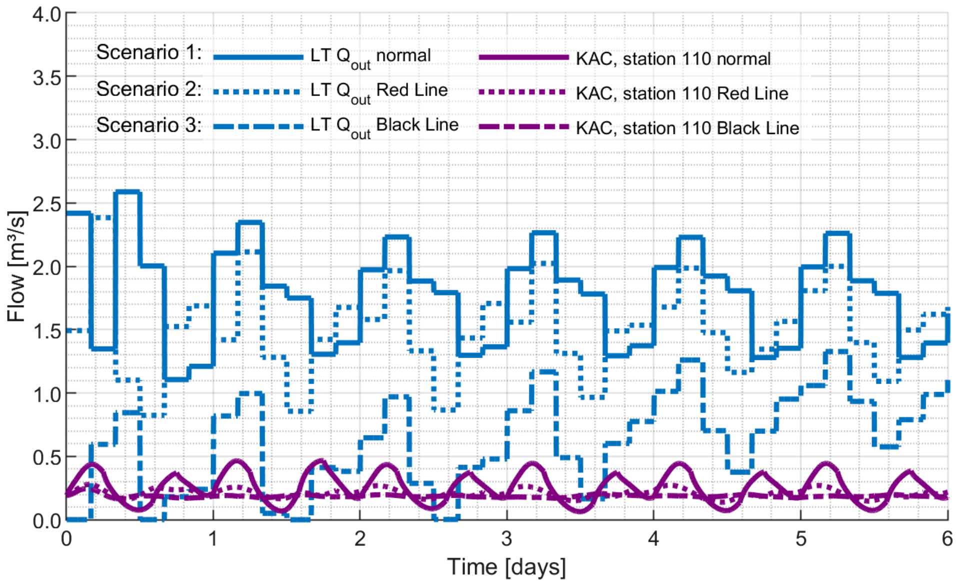

Figure 3: Comparison of the simulated water release of Lake Tiberias under different management scenarios

In this preliminary study, most of the boundary conditions, like rivers and dams, are implemented as steady values. Only the 31 agricultural water abstraction points at the so-called turn outs (TOs) are implemented as unsteady.

Simulation runs with constant water release of Lake Tiberias with and without optimization show, that the water release of the lake into the KAC can be reduced through optimization by ca. 8% while serving all water abstraction points.

To allow a further reduction of the lake discharge at low water levels, example scenarios for water levels at the lower red line (scenario 2) and the black line (scenario 3) are developed (Figure 3). For this purpose, the water abstraction points at the southern KAC are changed from solid boundary conditions, which have to be met, to flexible objective targets, which the tool is aiming at. Scenario 1 is an optimization simulation with a lake water level far above the lower red line (blue solid). The simulations of

wals at the KAC and can be regulated by weighting in the optimization. However, the application of a model for predictive control of the Lake Tiberias presupposes that the necessary forecast data of inflows of dams and rivers and withdrawals of Lake Tiberias and the KAC are available.

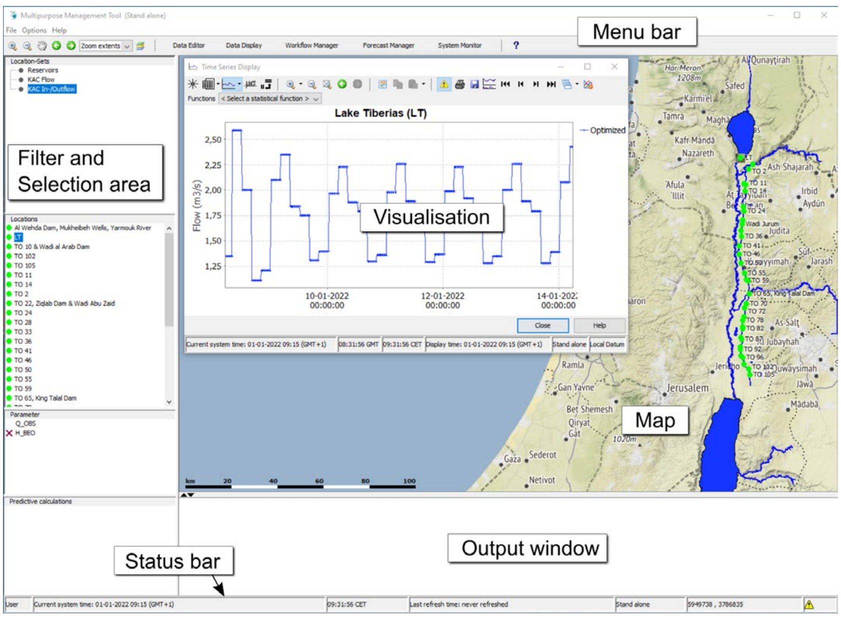

Figure 4: Graphical user interface of the developed Multipurpose Management Tool

For the intuitive and comprehensible application by the user, the functionalities have been integrated into a graphical user interface as a stand-alone application (Figure 4). The design of the interface is specifically geared to the requirements of the tool created and includes various functions such as importing observation and forecast data, running simulations, and displaying simulation results.

CONCLUSIONS

Given the increasing water shortage in the Middle East, the effective use of the available water resources of Lake Tiberias is of particular importance. The lake is of strategic relevance for Israel's water supply and an important freshwater source for the public and agricultural water supply in Jordan. In order to optimize the management and operation of the water transfer systems, suggested by the SALAM Initiative, this study demonstrates the application and benefits of an integral, transboundary, and MPC-based Multipurpose Management Tool. With the developed tool, the optimal control strategy for the water transfer to the LJV can be determined predictively according to defined management objectives, taking the temporal and spatial water demands into account. Thus, the DS-tool enables the development of optimized operational rules for Lake Tiberias as important regional water reservoir in case of freshwater transfers from the Mediterranean Sea to demand centers in Jordan and Palestine.

However, due to the predictive character of the applied method, forecast data on inflows and withdrawals must be available to the operating staff. This requires an exchange of data and a high level of transnational cooperation. In the next step, the Multipurpose Management Tool should be further refined and extended to include other relevant regional hydro-infrastructure such as the Jordanian dams.

MODEL PREDICTIVE CONTROL (MPC)

At the MPC, the n optimization objectives are described by a cost function for each time step k. Each optimization objective is defined by a reference set point $x_{i,sp,k}$, a specific weight ω, and an order a corresponding to the required or preferred prioritization. At each iteration step, the deviations J from the simulated objectives $x_{i,sim,k}$ to the reference set points are calculated as so-called costs. Through an iterative process, the control strategy is determined which, in total, contains the smallest deviations min J from the defined target variables. The software-internal optimizer IPOPT is used to optimize the cost function.

$$\min J = \sum_{i=1}^{n}\left(\omega_i \cdot \sum_{k=1}^{T}\left(x_{i,sp,k} - x_{i,sim,k}\right)^a\right)$$

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View on Lake Tiberias from Jordan toward the northwest ©Klein

Large-Scale Hydropower Plant at Lake Tiberias in the Context of Transboundary Water Transfer

Martin Klein[1], Stephan Theobald[1]

KEY FINDINGS

A hydropower plant could make use of the elevation gradient of ca. 200 m between a seawater desalination plant at the Mediterranean Sea and Lake Tiberias.

Depending on the water production scenario and flow system, the hydropower plant could recover 11 to 16% of the electricity used by the desalination plant.

Intermittent operation of the hydropower plant in combination with the use of solar energy could increase the share of renewable electricity generation.

MOTIVATION

Renewable freshwater resources in Israel, Palestine, and Jordan are already mostly depleted. While Israel increases its freshwater production by seawater desalination, this option is not immediately available for Palestine and Jordan because of the restricted access to the sea.

Until 2050, large freshwater deficits are to be expected for both countries [Future Freshwater Deficits in Palestine and Jordan, p. 18]. An innovative and cost-effective water production and transfer alternative consists in desalinating seawater north of Haifa and transferring it via Lake Tiberias to Jordan and Palestine, using the lake as a regional water reservoir [Water Production and Transfer Strategies, p. 22]. Today, based on bilateral agreements, the lake already provides Jordan with 50 Mio. m^3 of water per year, increasing to 100 Mio. m^3 per year according to recent agreements in 2021. An additional volume of 200 Mio. m^3/a of freshwater is planned to be exchanged for Jordanian solar energy in the context of a Water-Energy-SWAP.

According to the above solution, water will be conveyed by a supply line to the lake (Figure 1), which is located at an altitude of -209 m asl. In a country where hydropower resources are limited, supplying from the Mediterranean coast the deeper-lying Lake Tiberias with desalinated water presents a potential for hydropower generation. This

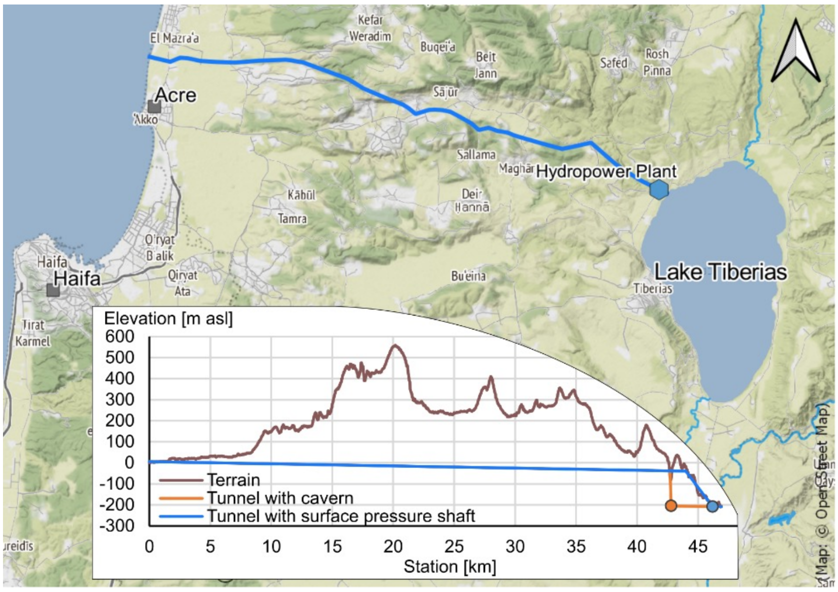

Figure 1: Overview and longitudinal cut of a tunnel between the coast and a hydropower power plant at Lake Tiberias

hydropower plant would also be a contribution to Israel's energy policy by reducing its high dependence on fossil fuels (Ashwarya, 2022). In 2020, around 94% of Israel's produced electricity was generated from coal, oil, or gas. In order to reduce the use of fossil fuels and to achieve the climate protection commitments, 17-20 % of the electricity supply is to be provided by renewable energies by 2025, which is to be achieved primarily by expanding solar energy. This expansion is flanked by an expansion of pumped hydro-storage capacity to keep the power grid stable and to absorb peaks in demand.

The objective of this study is to conduct a hydraulic and energy analysis of the hydropower potential at Lake Tiberias in conjunction with seawater desalination and the use of solar power in order to quantify potential cost reduction of water conveyance and the potential increase in the production of renewable energy in Israel.

METHODOLOGY

Several aspects, such as water production in the desalination plant as well as hydraulic and energy boundary conditions, must be considered to estimate desalinated seawater-driven hydropower potential. These boundary conditions are, for example, the hydraulic capacity and discharge system of the supply tunnel. The current Israeli energy policy with the expansion of solar energy should also be considered in the analysis.

Regarding the hydraulic system, two flow systems of gravity flow and pressure pipe are analyzed. In the context of the Water-Energy-SWAP already agreed with Jordan and prospective additional agreements in the future, a range between 200 Mio. m^3 and 1,000 Mio. m^3 per year is being studied as water production and transfer options. Assuming an operational shutdown of 14 days per year, the inflow to the hydropower plant ranges between Q = 6.6 and 33.0 m^3/s for 351 operating days. In order to combine the advantages and disadvantages of different energy sources such as the day-night cycle of solar energy production, a time-delayed electricity generation by the hydropower plant is also analyzed.

The route of the 47 km conveyance tunnel with a slope of J = 0.001 is adopted from the SALAM pilot study (Bensabat et al., 2018). The usable effective energy height heff [m] of the hydropower plant at gravity flow corresponds to the elevation difference between the inlet of the pressure shaft and the water level of the lake. At the pressure pipe, the effective energy head is calculated based on the elevation difference between tunnel entrance at the coast and lake water level, plus energy losses. Because of this conceptual approach, the determination of energy losses is limited to pipe friction losses due to the roughness k [m] along the tunnel length; local losses are neglected. For both hydraulic systems, the integral efficiency coefficient of the hydropower plant is assumed to 0.85.

RESULTS

Between a desalination plant at about 5 m asl and Lake Tiberias at -209 m asl, potential energy is h_{pot} = 214 m. Figure 1 shows the longitudinal cut cross-section of the tunnel with two potential locations for a hydropower plant. While the effective energy height for the gravity flow option is independent of a tunnel diameter, the diameter of the pressure pipe strongly effects the usable energy height due to energy losses. A sensitivity study (Figure 2) shows, that flow velocities and energy losses decrease with increasing diameter. For pressure discharge, high effective energy heads can thus be achieved at low flow velocities and large tunnel diameters.

For the approximation of the produced energy for the pressure pipe, two examples are analyzed with respect to

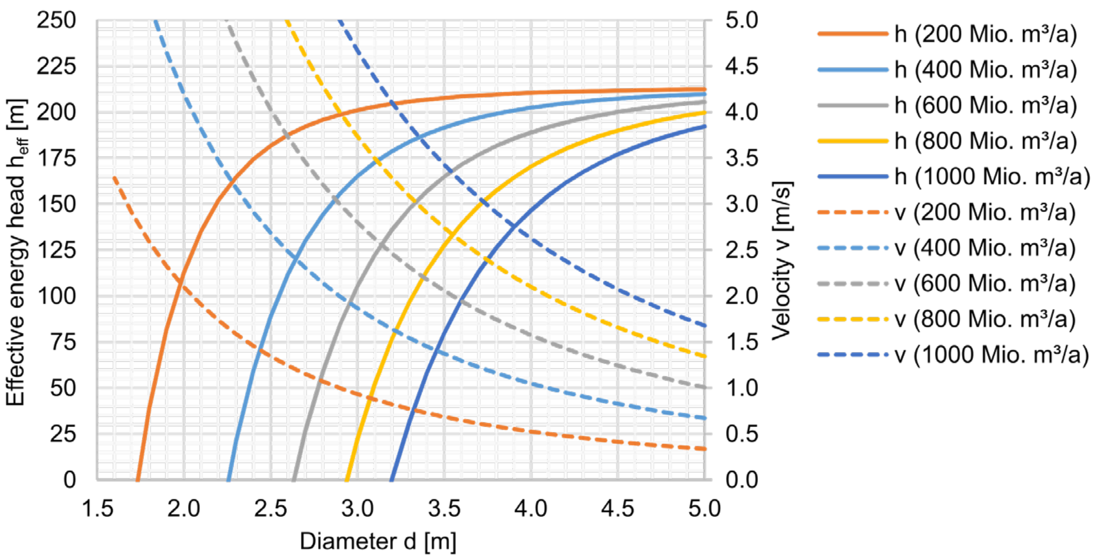

Figure 2: Effective energy head and flow velocity as a function of water production and diameter of the pressure pipe

the diameter. First example with a constant diameter of d = 4.4 m for all water production options and a second with a diameter determined individually for a target flow velocity of v = 2.5 m/s. To avoid disproportionately high energy losses for the water production options of 200 Mio. m^3/a and 400 Mio. m^3/a, a minimum diameter of d_{min} = 3.0 m is maintained.

The resulting power ranges, depending on the discharge system, between 9 MW and 47 MW, while the electricity generated ranges between 78 GWh/a and 400 GWh/a (Figure 3). The hydraulic system of a pressure pipe with constant diameter achieves highest energy output for all water production options. Considering an energy consumption of the desalination plant of about 3 kWh/m^3, the hydropower plant could recover, depending on the hydraulic system and the water production, 11 to 16% of the total electricity demand of the desalination plant. The results thus show that a hydropower plant at Lake Tiberias would be able to produce substantial quantities of electricity.

For a time-delayed energy production, desalinated water is stored during the day, while alternative energy sources such as solar power are used by the consumer. The reservoir required for temporary storage of the continuously flowing water should be located as close as possible to the pressure shaft. During the night, the hydropower plant would use the incoming and stored water to produce electricity. For the examples of 12 h/d and 15 h/d turbine operation, the resulting power is calculated between 15 and 95 MW (Figure 4).

An intermittent operation would thus lead to an increase in power of the hydropower plant for the same magnitude of electricity produced, with the consequence of increased investment and operating costs. However, synergies created by partially compensating the disadvantage of intermittent solar energy production could justify increased costs.

CONCLUSIONS

The above analysis shows that the elevation difference between the seawater desalination plant on the

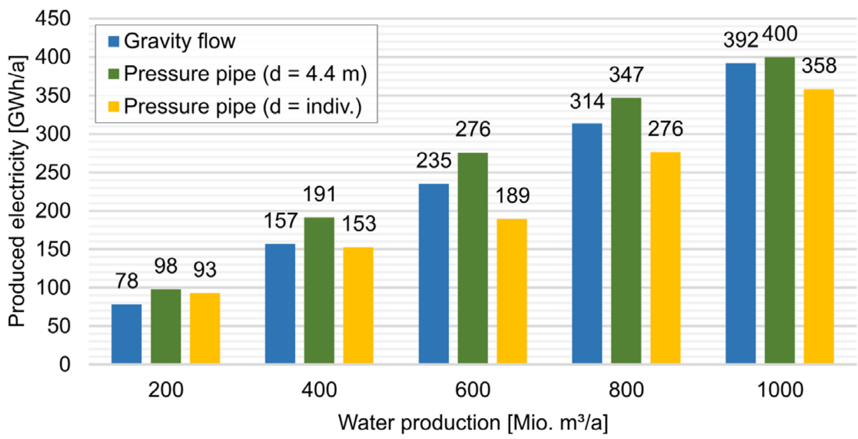

Figure 3: Comparison of produced electricity from gravity flow and pressure pipe for different water productions

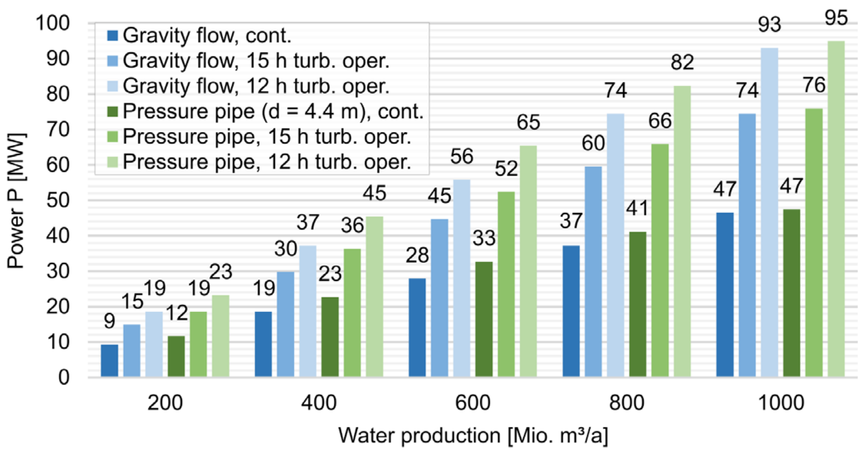

Figure 4: Comparison of generated power from gravity flow and pressure pipe for different water productions in continuous and intermittent turbine operation

Mediterranean coast and Lake Tiberias can be used to generate significant amounts of electricity. The relevance of the conducted analysis is emphasized by the agreement between Israel and Jordan related to the exchange of water and energy. Therefore, different capacities of desalination plants were investigated for hydropower generation. The resulting power ranges between 9 MW and 47 MW, depending on the water production and the hydraulic system of the supply tunnel. The magnitude of electricity produced ranges between 78 GWh/a and 400 GWh/a. A hydropower plant at Lake Tiberias could thus recover between 11 and 16% of the amount of electricity required by the desalination plant. A tunnel to supply the lake has to be constructed for storage purposes independent of the option of hydropower production, so, in economic terms, only investment cost of the power plant itself would have to be considered.

An additional storage option for intermittent operation of the hydropower plant could also achieve synergistic interactions with other energy sources such as solar energy. This would contribute to increasing grid stability and be in line with current Israeli energy policy.

HYDRAULIC CALCULATIONS

For the gravity flow option, a tunnel diameter was selected for a maximum water depth of 80% of the diameter, intended to prevent the pipe from hydraulic blocking. For the largest desalinated sea water production option of 1,000 million m^3, the resulting diameter is d = 4.4 m. This diameter was assumed for all water production options, since the profile then has no influence on the effective energy head.

Unlike the gravity flow, the diameter and the associated flow velocity are included in the calculation of energy losses for the pressure pipe. The individual defined diameters for a flow velocity of 2.5 m/s at production options 200 – 1,000 Mio. m^3/a are d = 3.0 m (d_{min}), d = 3.0 m (d_{min}), d = 3.2 m, d = 3.7 m, and d = 4.1 m. For the pressure pipe option with constant diameter for all water production options, the diameter of d = 4.4 m is determined according to the diameter of the gravity flow.

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Groundwater Models of the Lower Jordan Valley Aquifer

Julian Xanke[1], Muath Abu Sadah[2], Roman Hepp[3], Ola Barakat[2] Marc Ohmer[1], Tanja Liesch[1] , Martin Sauter[3]

KEY FINDINGS

The main input flow component of the Lower Jordan Valley alluvial aquifer is lateral groundwater inflow from the adjacent mountain flanks to the east (Jordan) and west (Palestine) of the Valley.

Abstraction by wells is the main flow component for the depletion of stored groundwater on both sides. A sharp decline in groundwater levels has been observed over the past 20 years in the central and southern parts of the valley on the Jordanian side as well as in Jericho and Auja areas on the Palestinian side.

There is potential for managed aquifer recharge (MAR) on both sides of the valley, which would increase groundwater resources availability and enhance managing the supply-demand in both areas.

MOTIVATION

Hydrogeological understanding of the aquifer system is a key aspect for sustainable groundwater management in the Lower Jordan Valley (LJV). The heterogeneous geological structure of the Quaternary sediments results from lacustrine and fluvial deposits, ranging from fine evaporite-bearing layers to coarse gravel. Groundwater quality ranges between freshwater and brackish water, the latter mainly due to groundwater overuse and leaching of evaporites. Two three-dimensional numerical groundwater models were developed to determine the groundwater fluxes and aquifer overuse in the past decades (Figure 1). The investigations include quantifying the groundwater balance, including lateral inflow from the mountain bedrocks and Lake Tiberias, while considering hydraulic exchange with the Jordan River and seepage to the Dead Sea. The models assess groundwater storage capacity and its change due to climate change and groundwater abstraction. Furthermore, the models can be employed to show the impact of different scenarios on the groundwater budget, e.g. increases or decreases in groundwater abstraction rates and/or through managed aquifer recharge (MAR). The eastern and western sides of the valley were investigated using two different groundwater models, as one model already existed on the Palestinian side and was further developed, and as the input data for calibration originated from different time spans. However, the models were created with similar parameters and boundary conditions to be comparable (see Table 1).

Model	Software package and numerical method	Number of layers	Model thickness [meter]	Hydraulic conductivity [m/d]	Boundary conditions			
					Jordan River	Dead Sea	Mountain range	Lake Tiberias
Jordanian	FEFLOW, finte element	10	200	1-2	Cauchy	Hydraulic head	Hydraulic head	Hydraulic head
Palestinian	MODFLOW, finite difference	9	200	0-8	Hydraulic head	Hydraulic head	Cauchy	-

Table 1: Comparison of the two model configurations.

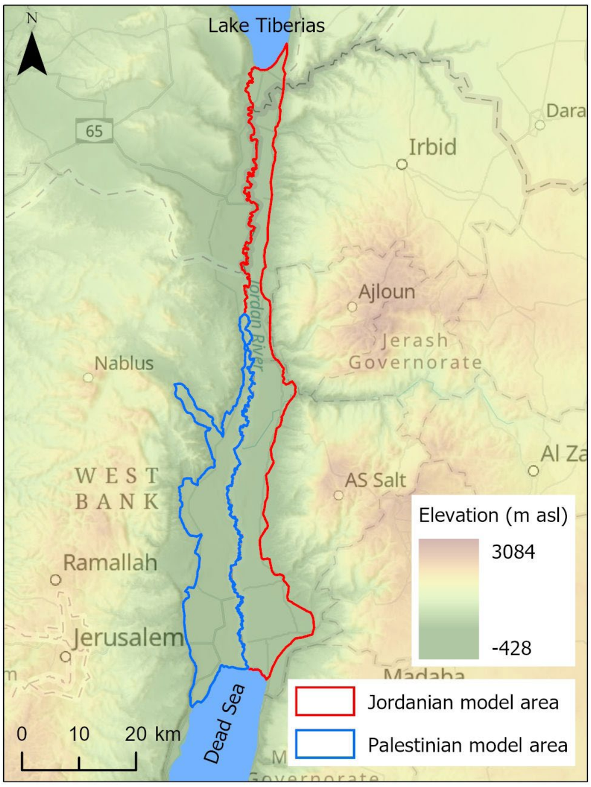

Figure 1: Location of the two model areas in the Lower Jordan Valley.

JORDANIAN SIDE

Methodology

Work steps included an evaluation of the lateral and vertical geometry of the upper unconsolidated aquifer, spatial analysis of hydraulic parameters, groundwater levels, and their regionalization, estimation of the inflow, and evaluation of available groundwater data from MWI (2019).

The model was implemented with FEFLOW software and covers the entire Jordanian part of the LJV with a length of 116 km and a width of up to 15 km (Figure 2). The model boundaries at Lake Tiberias (north), the Dead Sea (south), and the bedrock of the Jordan Highlands (east) were implemented as 1st kind/Dirichlet boundary condition. The Jordan River in the west was implemented as 3rd kind/Cauchy boundary condition. The model has an average thickness of 200 m.

The model was calibrated for steady-state conditions based on the groundwater levels of 1998 (best data coverage). For the calibration process, hydraulic conductivities of the Lisan-Formation, the Alluvium, and the interfingering area is estimated with PEST, an automatic parameter estimation software. Subsequently, the boundary conditions were adapted according to 2020 water levels from Lake Tiberias and the Dead Sea to represent the current groundwater conditions..

Results

Simulated groundwater levels show a very good correlation with observed groundwater levels from 1998 with a correlation coefficient of 0.95, which is satisfactory for a model of this size. Although, the simulated groundwater levels reproduce the observed groundwater levels well, in the southern area, the model indicates much lower groundwater levels compared to the contour map produced by

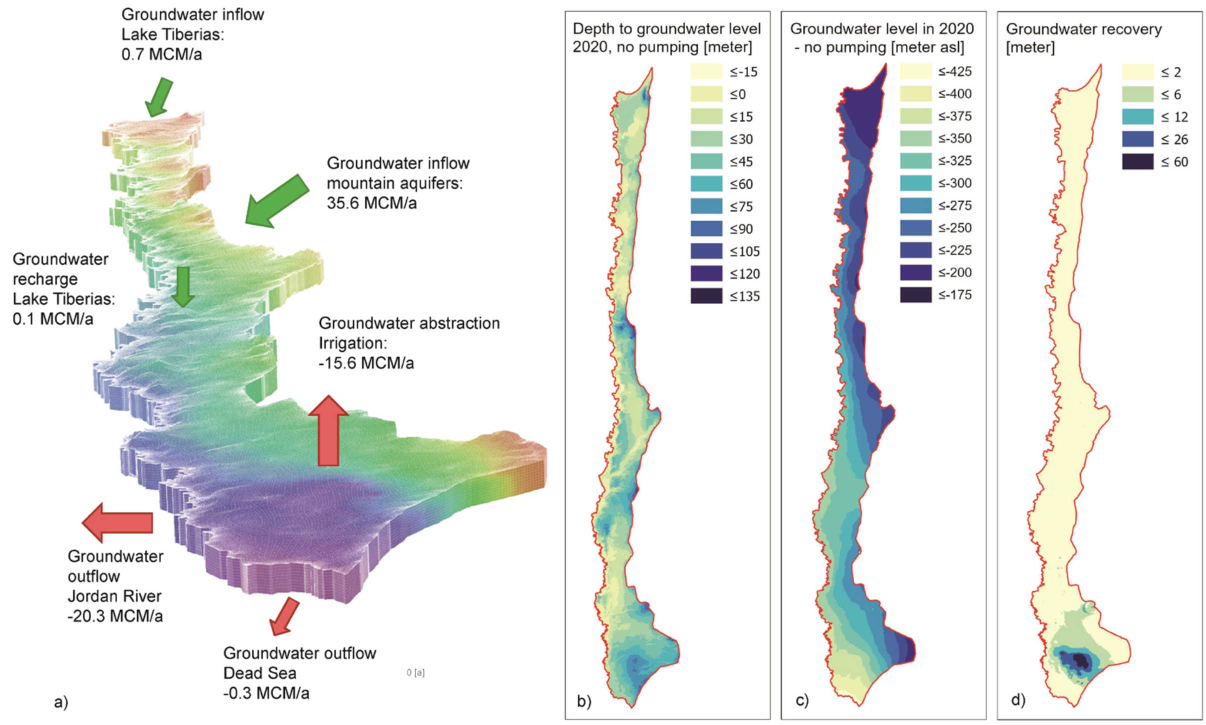

Figure 2: a) Numerical groundwater model of the Jordanian side with simulated in- and outflow components, b) depth to groundwater level and c) groundwater level in 2020 without pumping activities, and d) resulting groundwater recovery.

interpolation. It is assumed that excessive groundwater withdrawals cause local cones of depression not captured by the interpolated groundwater contour map.

A comparison of simulated groundwater levels with and without groundwater abstraction shows storage volume differences of 72 Mio. m^3/a. The results indicate that a combined groundwater management approach of reducing abstractions and increasing MAR would allow the aquifer long-term storage volume to increase significantly, positively affecting groundwater discharge to the Jordan River, favouring floodplain restoration and annual inflow to the Dead Sea.

PALESTINIAN SIDE

Methodology

A steady-state finite difference approach and inverse modeling were used to determine hydraulic conductivities, hydraulic heads, and groundwater budget on the Palestinian section of the Lower Jordan Valley Alluvial Aquifer (Figure 3). A geological map, a digital elevation model, precipitation data, and data from about 100 abstraction wells and 26 observation wells were used as input data. The simulation was performed using Aquaveo's GMS software, which includes the code of the finite-difference flow modeling program MODFLOW and a graphical user interface. As on the Jordanian side, model thickness is set at 200 m, assuming insignificant flow below this depth. The model is divided into 8 layers and extends about 60 km in the N-S direction and 10 km in the E-W direction. The hydraulic heads in the south and the east are defined as fixed-head boundaries at water levels of the Dead Sea and the Jordan River, respectively. In the west, towards the Eastern Mountain Aquifer, a variable general head boundary was implemented, controlled by measured groundwater levels in the adjacent carbonate aquifers.

Results

Trial and error calibration obtained a map of the spatial distribution of hydraulic conductivities in the model area (Figure 3a). Higher conductivities occur primarily in the west

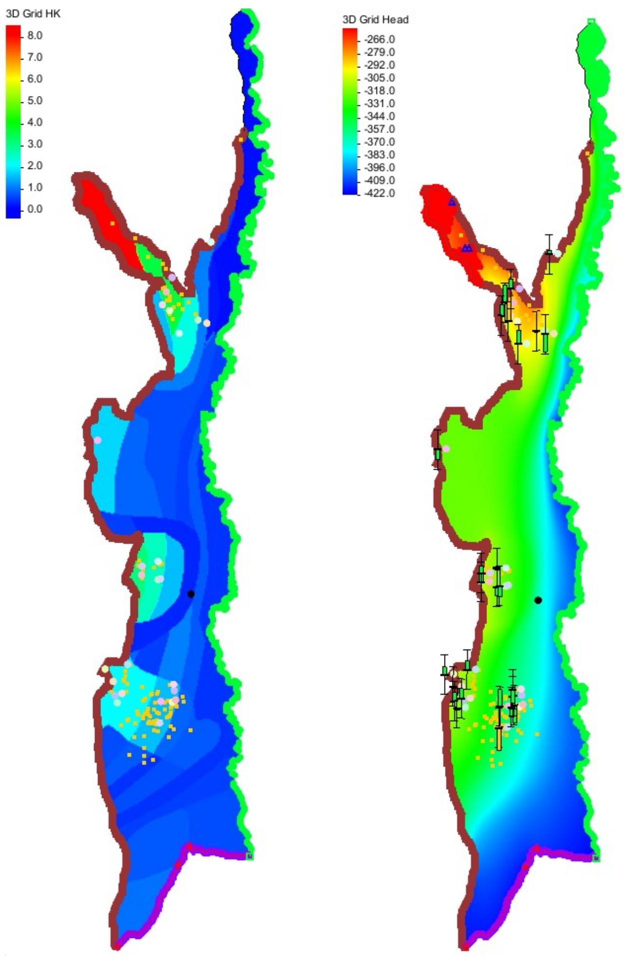

Figure 3: Hydraulic conductivities (left, in m/day) and hydraulic heads (right, in m asl) of the groundwater model at the Palestinian side.

and are concentrated around the major wadi exits to the LJV, consistent with the higher grain size expected in these areas. The hydraulic heads could be optimized to be within +/- 22 m compared to the observed heads, which appears large at first glance (Figure 3). More accurate calibration proved difficult because only a few observation wells are available. The available observation wells are located within a few clusters. The estimated hydraulic conductivities show a very heterogeneous distribution. A total of 11.3 Mio. m^3/a is withdrawn by wells, while 3.2 Mio. m^3/a discharges towards the Dead Sea. Recharge by precipitation is only 3.4 Mio. m^3/a. Inflow from the Eastern Mountain Aquifer can only be estimated by model calibration, thus implying some uncertainty. The final model can be used for forward modeling approaches to simulate the effect of MAR and the freshening process of brackish groundwater.

CONCLUSION AND NEXT STEPS

The large-scale groundwater models of the Lower Jordan Valley are well suited to simulate the inflowing and outflowing water volumes. Simple scenarios such as reservoir changes are feasible and allow conclusions about available groundwater volumes and groundwater management. For small-scale, local simulations, the model is rather unsuitable for drawing conclusions due to its size and generalized input parameters. Consequently, further numerical models are still needed to understand the flow dynamics between the mountain aquifers and the Lower Jordan Valley on both sides as well as the impact of climate change, pumping and managed aquifer recharge on the water quality in the aquifer systems.

MODELING SOFTWARE

Based on the hydrogeological conceptual models of the Lower Jordan Valley, two three-dimensional numerical groundwater models were created. The model for the Jordanian side was implemented using the FEFLOW software by DHY Wasy (Diersch, 2013). Model calibration was accomplished using FEPEST, which uses the Gauss-Levenberg-Marquardt algorithm (GLMA), which iteratively optimizes the model parameters to improve its fit to the observed data. The model for the Palestinian side was created using the GMS software by Aquaveo, which includes the code of the finite differences flow modeling tool 'MODFLOW' and a graphical user interface. Model calibration was done manually.

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Greenhouses in the Lower Jordan valley, Jordan ©Xanke

Management Strategies for the Reuse of Treated Wastewater in the Lower Jordan Valley

Julian Xanke[1], Muath Abu Sadah[2], Ola Barakat[2], Marc Ohmer[1], Tanja Liesch[1], Emad Al-Karablieh[3]

KEY FINDINGS

A large part of the treated wastewater can be reused for agricultural irrigation.

Managed aquifer recharge (MAR) using treated wastewater is a promising solution to regenerate depleted groundwater levels in the alluvial aquifer, mitigate droughts and freshen brackish groundwater to make them usable again for irrigation.

Discharging treated wastewater into the Jordan River would help to partially rehabilitate the Jordan River floodplains and slow down the water level decline of the Dead Sea.

MOTIVATION

The study identifies different variants for reusing treated wastewater (TWW) in the Lower Jordan Valley (LJV) in the conjunctive use with freshwater and brackish groundwater and develops different reuse alternatives to strengthen irrigation and ecosystem rehabilitation. The general water distribution and reuse concept are based on estimated wastewater volumes and their expected availability for 2050 [Regional Wastewater Infrastructure Development Strategies for Jordan and Palestine, p. 40], focusing on meeting future irrigation requirements and expanding agricultural land, assessing the potential for managed aquifer recharge (MAR) and evaluating existing approaches for the rehabilitation of the Jordan river (Gafny et al. 2010) and mitigating the water level decline of the Dead Sea (ICL 2020). All three reuse variants serve to create balanced reuse alternatives for the treated wastewater and groundwater from a technical and economic point of view, also considering ecological aspects. The reuse alternatives are developed and evaluated based on the combination of different criteria to provide decision support towards implementing an integrated reuse strategy to strengthen irrigation development and ecosystem rehabilitation [Multi-Criteria Assessment of Water Resources Planning Options, p. 80].

METHODOLOGY

The reuse alternatives show different combinations of three reuse variants, which are:

- Irrigation with prior mixing with freshwater or brackish groundwater.
- Managed aquifer recharge (MAR) into brackish groundwater zones
- Rehabilitation of the floodplains of the Jordan River

On the Jordanian side of the Jordan Valley, all reuse variants were investigated. On the Palestinian side, the analysis concentrated on MAR only. The reuse alternatives in Jordan are developed based on the volumes of TWW forecasted for 2050 of 445.1 Mio. m^3/a with centralized treatment solutions and 374.9 Mio. m^3/a with decentralized treatment solutions, averaging at 410 Mio. m^3/a.

The irrigation water requirement (IWR) was calculated based on the specific crop water requirement (CWR) for the average production of fruit, vegetables, and crop patterns from 2008 to 2017. The calculations consider an average irrigation efficiency of 70% (Al-Omari et al. 2015), an expansion of agriculture by 12% to the maximum usable area, and a 10% increase in IWR by 2050 due to climate change (Karablieh and Salman 2013).

The potential for **managed aquifer recharge** is assessed on a large scale. An assessment of the available storage space is made based on the hydrogeological conceptual model and results from the numerical groundwater models of the

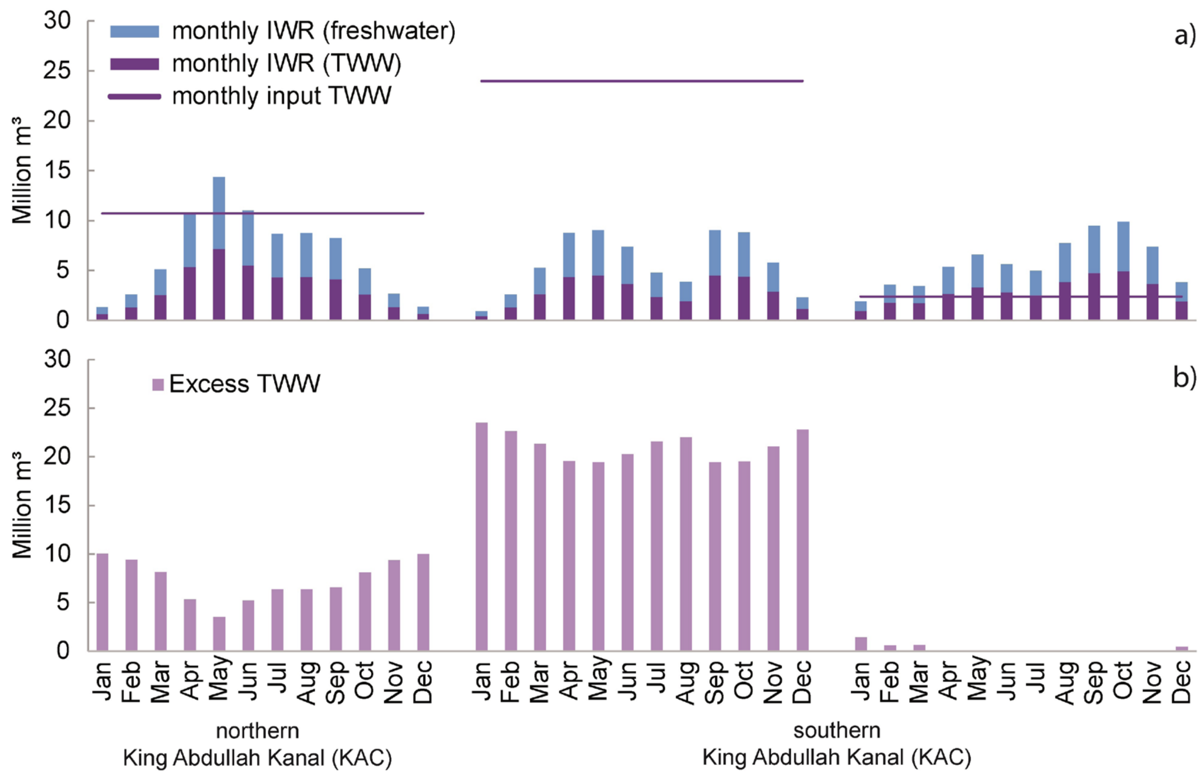

Figure 1 a) Monthly irrigation demand (IWR) in 2050 for the northern, central, and southern Lower Jordan Valley (Jordan), with the respective monthly inputs of treated wastewater from centralized solutions, and b) the monthly surplus of treated wastewater if the water is used for irrigation. The deficit of treated wastewater in the southern valley (March-November) must be covered with freshwater or treated wastewater from the central valley.

alluvial aquifer in the LJV [Groundwater Models of the Lower Jordan Valley Aquifer, p. 54]. On the Jordanian side, locations of potentially available storage volume in the subsurface are assessed, depending on the thickness of the unsaturated zone, effective porosity and the groundwater salinity, to avoid degradation of freshwater areas by infiltrated TWW. The conditions are transferred into a MAR potential with zones ranging from „none" to „high" potential. Furthermore, conceptual infiltration calculations by Xanke et al. (2019) are used to estimate the number and size of MAR plants to achieve a specific recharge volume.

The Palestinian side of the valley was divided into three zones (Jeftlek, Uja, and Jericho), to estimate the storage capacity per zone and the recovery rate for four injection/recovery scenarios illustrated as follows: SC1: Inject water informally to the demand areas, SC2 (based on SC1): abstract water (Recovery), SC3: Generate a hydraulic barrier to the east of the demand areas/Dead Sea, and SC4 (based on SC3): abstract water (Recovery). The storage capacity was computed considering the following constraints (1) no flow from the alluvial deposits to the mountain aquifer, and (2) no flooding allowed at the surface.

Jordan River floodplain rehabilitation is considered through the discharge of TWW using the river rehabilitation scenarios developed by Gafny et al. (2010). They developed five scenarios ranging from „Take No Action" to the „Full Restoration" scenario with intermediate steps of "Partial Restoration", "River Rehabilitation" and "Flow Enhancement". As one of the three reuse variants, the release of TWW into the floodplains of the Jordan River is evaluated from a quantitative perspective. Furthermore, the potential effect on the rehabilitation of ecosystems, river salinization, and declining Dead Sea water level is discussed. The latter is assessed with a water loss of up to 700 Mio. m³/a resulting in an average decline of more than 1 m in recent decades (ICL 2020).

RESULTS

Land use analysis revealed that ca. 12% of the area in the Jordanian section of the alluvial aquifer is unused grassland that could be converted into arable land. In this case, an average IWR of 261.3 Mio. m³/a could be reached by 2050. The volumes of TWW targeted for 2050 are sufficient to meet the IWR, except for some months of the year in the southern section (Figure 1a). The example for centralized solutions shows that IWR could be covered by using a 50:50 mixture of TWW and freshwater for irrigation with an excess of 314.5 Mio. m³/a, which is then available for managed aquifer recharge or the rehabilitation of the Jordan River and the Dead Sea.

Evaluation of the MAR map in Jordan (Figure 2c) shows four major sections in the alluvium of different MAR potential that differ in groundwater salinity, depth to groundwater, and aquifer porosity. Overall, most of the alluvial aquifer is

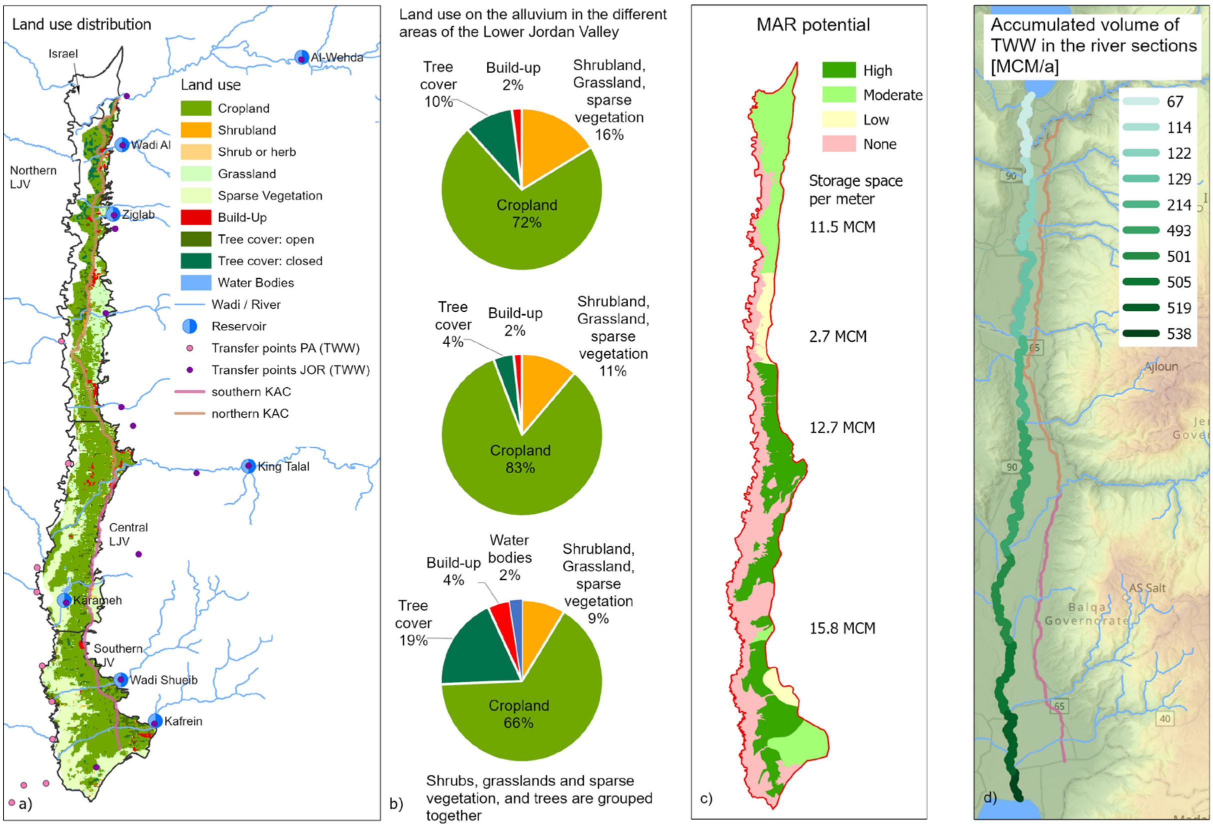

Figure 2 a) Land use in the Lower Jordan Valley (Jordan) with transfer points of treated wastewater from Jordan (JOR) and the Palestinian territories (PA), b) land use distribution, c) the derived potential map for managed aquifer recharge (MAR), d) accumulated volume of discharge in the different river sections if all of the treated wastewater is used for river rehabilitation (no base flow considered).

suitable for MAR using TWW, while zones of low permeability (red) are unsuitable. An increase in groundwater levels in the alluvial deposits by one meter would result in a storage volume increase of ca. 43 Mio. m^3 (Figure 2c). Using the approach presented by Xanke et al. (2019) showed that about 36 MAR plants with a size of 200 x 200 meters (40,000 m^2) would be required to infiltrate 43 Mio. m^3 per year. Surface infiltration is considered the most appropriate solution for the LJV. Experience for infiltration technology by infiltration ponds already exists (from Shafdan WWTP, close to Tel Aviv).

According to the numerical groundwater flow model of the Palestinian section of the Jordan valley alluvial aquifer, there is storage volume available for infiltration of treated wastewater to be recovered for irrigation of agricultural lands. Modelling results showed capacities for Jericho, Uja, and Jeftlek of 30, 8, and 15 Mio. m^3/a year , respectively. Should water be injected evenly across the respective demand areas (SC1), the maximum recommended water injection would be 30 Mio. m^3/a, with a recovery rate of 90% for the Jericho zone, while for SC3, maximum capacity would exceed 30 Mio. m^3/a, but only with a 70% recovery rate. Moreover, discharge to the Jordan River will increase by around 3 Mio. m^3/a for scenario SC3, which is twice as large as in scenario SC1.

Considering the rehabilitation of the Jordan River floodplains on the Jordanian side of the river, smaller volumes are transferred to the northern section and larger volumes to the central and southern sections (Figure 2d). The achievement level of the rehabilitation scenario (Gafny et al. 2010) would thus be up to about 34% in the northern part and

ALTERNATIVES WITH PRIORITIZATION	IRRIGATION	MAR	JORDAN RIVER	SUM TWW
Take no action	0	0	0	0
Irrigation before MAR and Jordan River	131	43	236	410
Irrigation before Jordan River and MAR	131	0	279	410

Table 1 Alternatives for treated effluent reuse on the Jordanian side of the LJV with the highest priority on irrigation and different priorities for MAR and Jordan River rehabilitation and the corresponding quantities of wastewater in [Mio. m^3/a].

fully reach it in the southern part with a significant dilution of the current salinity content in the Jordan River, which can reach about 11,000 ppm in the south (Gafny et al. 2010). Furthermore, a significant slowdown of the water-level decline in the Dead Sea (average loss of ~700 Mio. m^3/a) could be achieved, when all TWW is released into the Jordan River, and still be mitigated after subtracting irrigation use.

Table 1 summarizes the allocation of TWW for two reuse alternatives in Jordan considering the average amount of TWW of both treatment solutions, centralized and decentralized.

CONCLUSIONS

This study provides an overall analysis of reuse alternatives for treated wastewater in the Lower Jordan Valley as a key strategy for decision makers. Further detailed analysis would be required in a qualitative compatibility of each crop type with treated wastewater, an implementation of a test MAR pilot plant, as well as a meaningful water balance of the Jordan River with continuous monitoring of the water level and physicochemical parameters.

IRRIGATION WATER REQUIREMENT

For irrigation purposes, the IWR is determined, which is the sum of the individual Crop Water Requirement (CWR) according to:

$$\mathrm{CWR}_i = \sum_{t=0}^{T} \left(\mathrm{kc}_{i,t} \cdot \mathrm{ET}_o - P_{eff}\right)$$

where *kc* is the crop coefficient of crop *i* during the growth stage *t*, and *T* is the final growth stage. ET_0 is the reference evapotranspiration (ASCE Penman-Monteith), and P_{eff} is the effective precipitation (taken as 80% of the total precipitation). In a specific system, the irrigation water requirement is the sum of the individual crop water requirements CRW_i, multiplied by the area under cultivation for the respective crops S_i.

$$IWR = \sum_{i=i}^{n} (CWR_i \cdot S_i)$$

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Inventory of Fractured-Porous Rock Aquifers for Managed Aquifer Recharge with Desalinated Seawater

Tomy-Minh Trùòng[1], Martin Sauter[1]

KEY FINDINGS

The Coastal Aquifer in Israel and Palestine is suitable for seasonal water storage. Managed Aquifer Recharge (MAR) may also help to control seawater intrusion.

Despite being a karst system, the Western Mountain Aquifer has considerable potential for large scale, multi-annual water storage.

Due to low flow velocities, the Disi Aquifer is highly suitable for long-term storage of desalinated water. Additionally, MAR could reduce the rate of increasing salinity and radioactivity concomitant with the decreasing water table.

MOTIVATION

While desalination plants are designed to produce a constant flux of water, water demand fluctuates. This results in temporary water surpluses. Because the Middle-East relies more and more on desalination for its water supply, these surpluses will increase. Furthermore, the frequency of multi-annual droughts is expected to rise. Therefore, there is an increasing necessity for desalinated water storage to provide management flexibility. The utilization of natural aquifers presents an opportunity to store large volumes of water for extended periods of time at low cost, low evaporation loss, and low risk of contamination. Managed Aquifer Recharge (MAR) with desalinated water is therefore an important measure to balance freshwater supply and demand, increase the resilience of the system to droughts, and enhance the robustness of system management. An inventory is intended to provide criteria and procedures for the evaluation of fractured rock aquifers in Israel, Palestine and Jordan with respect to their suitability for MAR with desalinated seawater to allow for a pre-selection of potential aquifers to be further investigated.

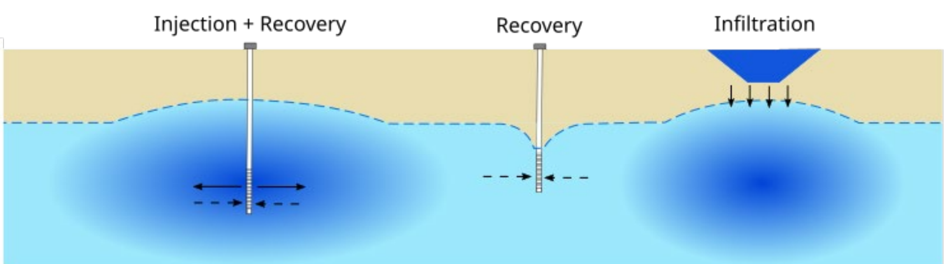

Figure 1: Functional principle of MAR

METHODOLOGY

For a comprehensive inventory, a holistic evaluation includes not only hydrological, hydrogeological, and water quality criteria, but also economic considerations as well as additional benefits (e.g., ecological benefits, improvements in aquifer management, etc.). These criteria (shown in Table 1) formed the basis in the assessment of different aquifer characteristics. First, available literature on MAR was processed, with a focus on criteria for MAR site selection. Then, aquifer characteristics were collected based on published material, GIS data and documents communicated by the regional project partners. The difference in groundwater levels of the water bearing formations of the aquifers between the times of pre-development and today

	criteria	WMA	EMA	Coastal Aquifer	Azraq	Disi
hydro-logical	terrain slope	-	-	+	+	-
	infiltration capacity	+	+	+	-	n.i.a.
	soil contamination	+	n.i.a.	+	-	n.i.a.
hydrogeological	Confinement	+	+	+	+	+
	hydraulic enclosure	+	-	-	+	+
	hydraulic gradient	-	-	+	+	+
	hydraulic conductivity	-	-	+	+/-	O
	water level depth	+	+	+	+	+
	aquifer thickness	+	+	+	+	+
	porosity/storage coefficient	O	O	+	O	+
	homogeneity/heterogeneity	-	-	+	-	+
	rock type (porous/fractured/karst)	-	-	+	O	+
quality	ambient groundwater salinity	+	+/-	+/-	+/-	+
	ambient groundwater quality	+	-	+/-	+	+
	aquifer matrix material (potential for geochemical interactions)	n.i.a.	n.i.a.	+	n.i.a.	+
	distance to pollution sources	+	-	+/-	+	+
economic	distance to source	-	-	+	-	+
	distance to user	+	+	+	-	+
	elevation differences	-	-	+	-	+
	available space/land prices	O	+	-	+	+
	preexisting infrastructure	+	+	+	-	+

Table 1: Evaluation criteria for Managed Aquifer Recharge (+ = high suitability, - = low suitability, O = moderate suitability, n.i.a. = no information available)

was integrated over the area to assess the available storage that resulted from groundwater development. The criteria partially depend on each other, making it difficult to provide a simple, single metric. The criteria were for this reason not converted into an equation, since this would lead to a loss of information, especially considering different stakeholders having different objectives. The inventory thus provides a semi-quantitative overview of different aquifer systems and evaluates their respective suitability for short- and long-term storage of desalinated seawater.

RESULTS

Table 1 gives a comprehensive summary of the results. While some aquifers show high storage potential, others are less suitable. The Coastal Aquifer and the Disi Aquifer have a considerable economic advantage, since they are located close to the production plants. Both aquifers also have favourable connectivity to demand centers. Due to the fossil nature of the Disi Aquifer, groundwater losses during MAR are much lower compared to those of the Coastal Aquifer.

In addition, the injection of desalinated water might be employed as hydraulic control to minimize seawater intrusion and, for the Disi Aquifer, to reduce salinization processes, both of which being related to an excessive drawdown of the groundwater level and the mobilization of brines. The Western Mountain Aquifer (WMA) shows great potential for short-term and even long-term storage, despite its karst aquifer characteristics. This is related to (1) discharge converging to a single spring, i.e., uncontrolled losses to the sea are low, (2) the aquifer being heavily exploited, and (3) the karst groundwater having good water quality. The above-mentioned characteristics are likely to ensure a high recovery efficiency. As the Eastern Mountain Aquifer (EMA) is part of the same geologic complex, but lacks the three advantages of its western counterpart, its suitability for MAR is considered low. The Azraq Aquifer is less suitable because of its low economic suitability. More details on the inventory can be found in (Truong et al., 2022).

CONCLUSION

The inventory is supposed to serve as a first but comprehensive overview for researchers, stakeholders, and decision-makers. It will be supplemented by input from regional partners with some alluvial aquifers. The results show that several aquifers are suitable for MAR. The storage volume is high: just from overexploitation a volume of up to 1.1 billion cubic meters of water was created. The inventory was used to select suitable aquifers for further investigations using modeling techniques. Modelling is imperative for the design of a management plan and to assess the associated losses. The modeling approach is explained in more detail in [Regional Models of Large-Scale Storage of Desalinated Seawater, p. 66].

MANAGED AQUIFER RECHARGE (MAR)

MAR makes use of natural aquifers for groundwater storage by usually using infiltration ponds or injection wells. Figure 1 shows the principle of MAR. The different recharge methods have their own requirements regarding aquifer characteristics and source water quality. As desalinated water usually fulfills all water quality requirements, the hydraulic properties of the aquifer as well as the native groundwater quality are from a technical point of view the main constraints for a successful MAR implementation.

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King Abdullah Canal, Jordan ©Al-Karablieh

Taninim Spring, Israel ©Bresinsky

Regional Models of Large-Scale Storage of Desalinated Seawater

Tomy-Minh Trùòng[1], Lysander Bresinsky[1], Martin Sauter[1]

KEY FINDINGS

Storage occurs in the vadose and phreatic zone at different temporal scales due to the contrast in hydraulic properties between the conduit network and the fractured rock matrix.

Model results show that hydraulic losses are below 10% for the first 14 years for the Western Mountain Aquifer. Cumulative hydraulic losses during that time are estimated at ca. 3%.

The regional water balance reveals that only a small fraction of the recharged water discharges to springs. Most of the groundwater is abstracted by wells.

MOTIVATION

Managed aquifer recharge (MAR) with desalinated seawater is a promising storage option in the Mediterranean region. Desalinated water being expensive and of very high quality, it is necessary to minimize water losses and prevent quality impairments during MAR. Numerical models provide quantitative support in the spatial optimization of MAR and the recovery of recharged water by simulating the storage system response to proposed MAR strategies. MAR applications can be examined a priori by employing process-based numerical models that provide quantitative measures of different injection/infiltration schemes, storage time, storage capacities, and potential losses because of quality impairment or uncontrolled discharge. Here, we assess the suitability of the Western Mountain Aquifer (WMA), shared by Israel and Palestine. The necessity of employing a numerical model is a result of the complex flow system of the WMA (i.e. duality of flow in karst), considering vadose and phreatic flow. Distributed numerical models allow to estimate the effects of the vadose zone on the storage and the residence time (and consequently the recovery efficiency) of the recharged water in the aquifer considering the rapid flow behavior of karst aquifers.

METHODOLOGY

The WMA is characterized by a vadose zone several hundred meters thick and its dual flow dynamics, i.e., diffuse matrix and rapid fracture/conduit flow. To account for these aspects, the WMA is represented as a variably saturated dual-continuum model (Bresinsky et al., n.d.) simulating the vadose and phreatic storage dynamics. The domain is discretized by two separate overlapping continua and coupled by a head-dependent exchange term representing flow through the rock matrix and all additional flow domains (i.e., conduits and fractures). The employed modeling software HydroGeoSphere (Brunner & Simons, 2012) uses the bulk-effective Richards' equation parameterized by the Van Genuchten material model to predict variably saturated conductivity. We heuristically approximate inertia-driven infiltration through the second continuum by employing a minimum relative conductivity at nearly dry conditions since capillary-driven approaches cannot resolve non-equilibrium infiltration. Net infiltration at the soil level is calculated by a soil-epikarst water balance model based on Schmidt et al. (2014). The serial model arrangement is shown in Figure 1. The methodology applied allows to predict spatiotemporally distributed storage at catchment scale and therefore enables to optimize the application of MAR.

RESULTS

The simulation of phreatic and vadose flow indicates that the WMA has considerable potential for long-term storage

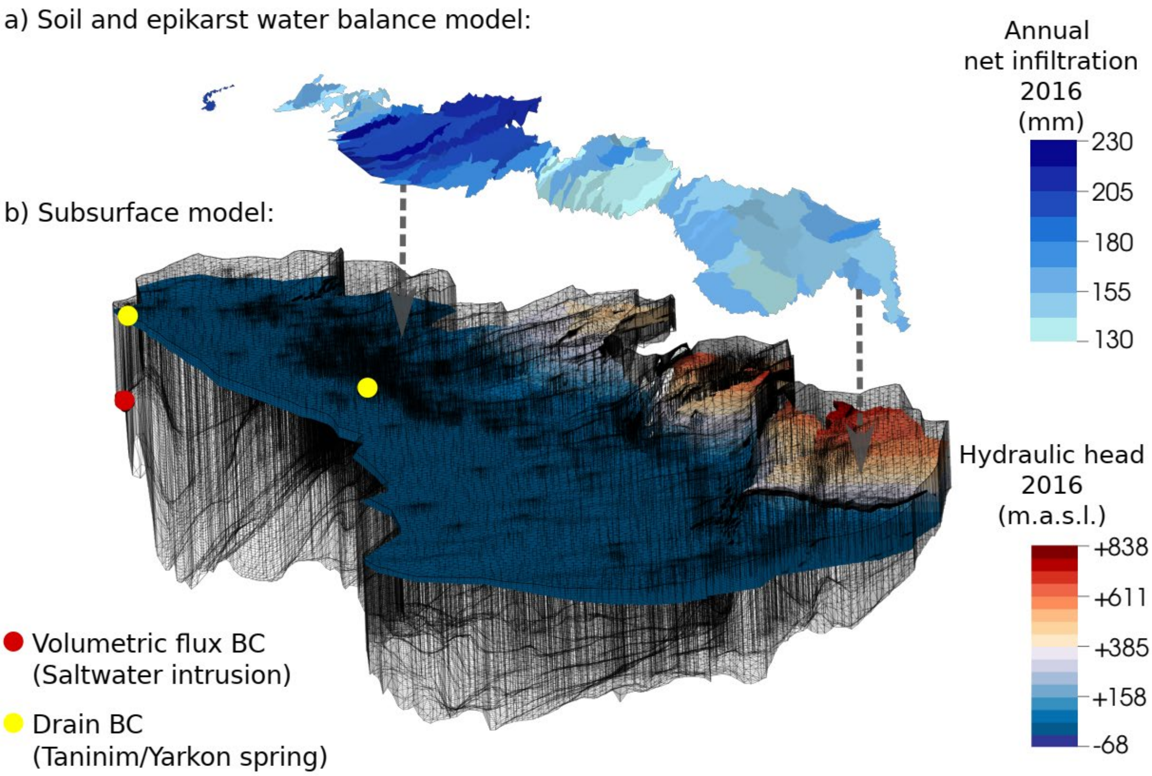

Figure 1: Recharge calculated by a soil-epikarst water balance model and variable saturated dual-continuum subsurface flow model for 15-09-2016.

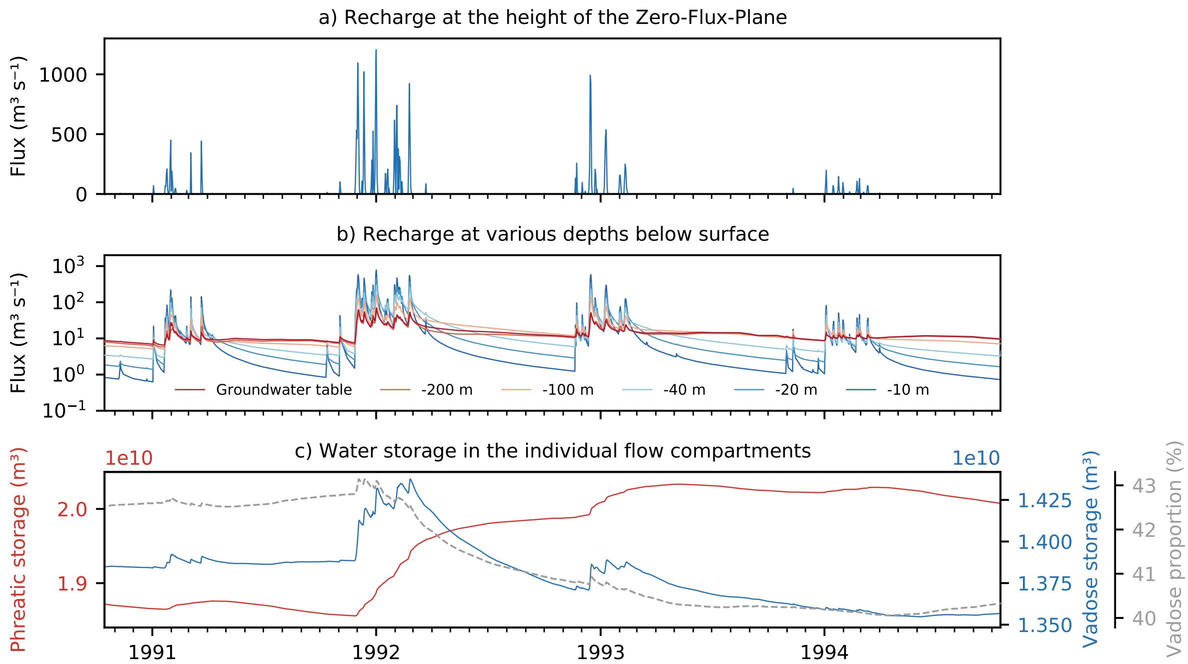

Figure 2: Simulation results for the Western Mountain Aquifer (WMA) of a) shallow recharge, b) deep recharge at various control planes below surface, and c) the change in water storage in the individual flow compartments following recharge events.

despite being a well-matured karst aquifer. This can be explained by the fact that the aquifer is enclosed largely by non-permeable geological units of the Talme Yafne Formation towards the Mediterranean, which prevent rapid discharge (i.e., dammed karst system). Natural groundwater discharge is confined to artesian discharge at the Taninim spring. However, due to heavy anthropogenic abstraction, only a small fraction of the recharged water discharges naturally, and ca. 90% of the water is abstracted at many production wells, inducing a regional cone of depression. Model simulations demonstrate that the thick vadose zone provides additional short-term storage. This is apparent from the delayed long-term recession of the hydraulic signal (spring discharge, groundwater levels) for ca. 600 days following the wet winter of 1991/1992 (Figure 2). Still, a large fraction of recharge reaches the groundwater table along preferential flow paths after circa 100 days. Natural recharge of the wet winter of 1991/1992 shows residence times of almost 1.5 years in the vadose zone and up to 7 years in the phreatic zone. Figure 3 shows how much water is lost per year if 100 Mio. m^3/a are artificially recharged in the upgradient Jerusalem district. As losses stay low (<10%) for up to 10 years, it highlights that the WMA can be used for long-term storage, while keeping the recovery efficiency high. Therefore, the combined storage capacity of the vadose and phreatic zones may be utilized for compensating increased water demands during multi-annual droughts.

CONCLUSIONS

This feasibility analysis shows that MAR can be used even in karst aquifers for long-term water storage while achieving high recovery efficiencies. However, the investigation of management scenarios for optimization remains an open task. Thus, this study may serve as a basis for future research dealing with optimization strategies, which in turn should be tested through field studies/experiments. A further study should consider substituting the soil-epikarst water balance model by a numerical model approach that discretely simulates surface runoff processes. It would allow to investigate the recharge potential of infiltration schemes along wadis, dolines and other infiltration hotspots. The model employed is particularly suited for coupling surface and subsurface processes, because the utilized spatial discretization method of mimetic finite differences was shown to be advantageous for such coupled simulation tasks (Coon et al., 2020).

MODELING TRADE-OFFS

Numerical models representing a natural flow system are subject to a trade-off between parametric ambiguity and structural uncertainty. When incorporating more physical processes into a numerical model, the number of unknown parameters increases, making it more difficult to obtain them via field measurements. In contrast, lumping physical processes carries the risk of having oversimplified model structures. Such oversimplified models do not account for relevant physical processes or the spatial variability of hydraulic parameters of carbonate aquifers, resulting in an overall low predictive power.

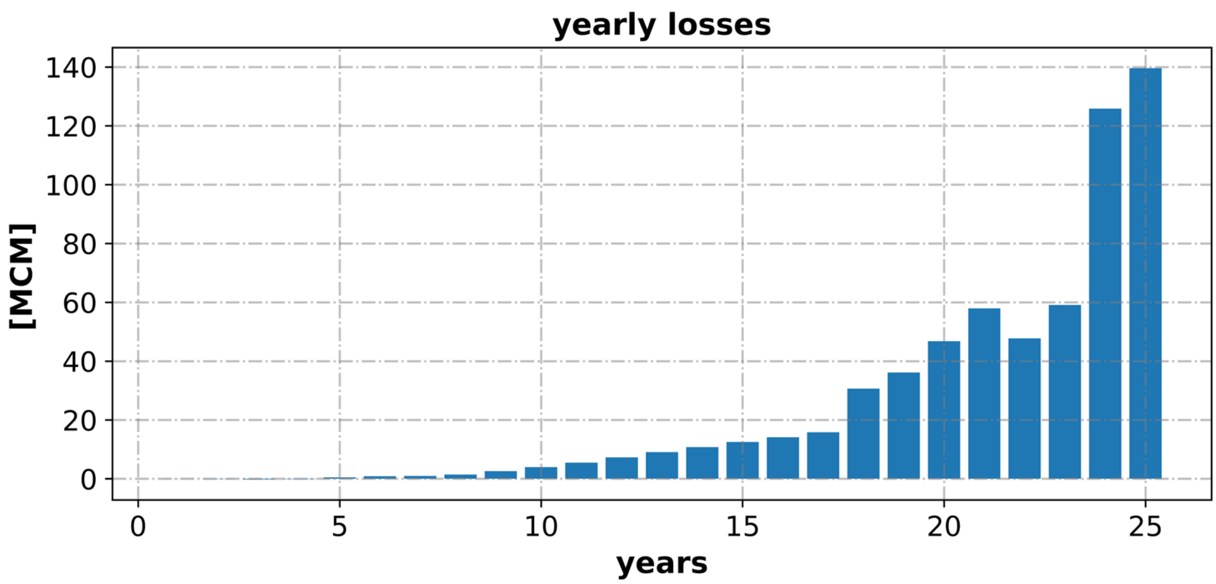

Figure 3: Annual losses in million cubic meters (Mio. m^3MCM) in case of an artificial recharge of 100 Mio. m^3/aMCM/a.

West Bank ©Bresinsky

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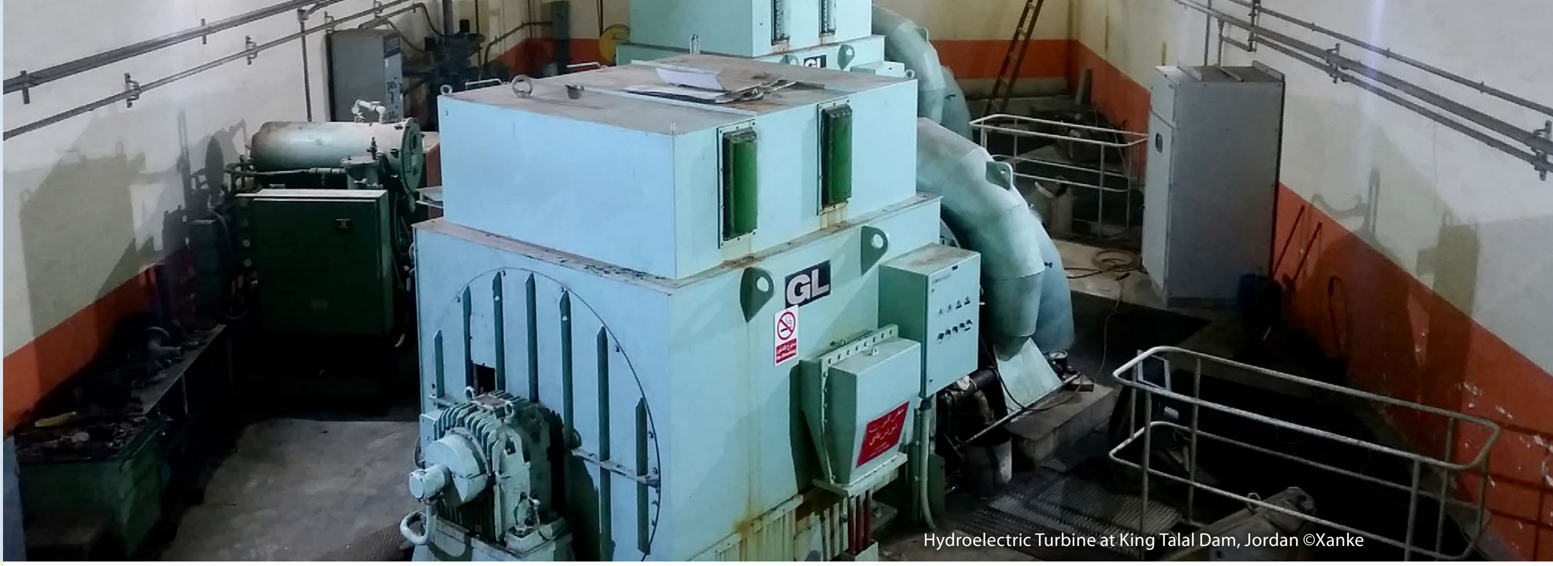
Strategy Evaluation and SALAM Expert System

> Techno-Economic Assessment of Water Infrastructure Projects

> Regional Macro-Model for Transboundary Water Resources Planning

> Multi-Criteria Analysis of Water Resources Planning Options

> SALAM Information and Expert System



Hydroelectric Turbine at King Talal Dam, Jordan ©Xanke

Techno-Economic Assessment of Water Infrastructure Projects

Sebastian Schär[1], Jutta Geldermann[1]

KEY FINDINGS

Specific water costs, which are the costs of providing one cubic metre of water at desired quality to the point of demand, are computed for all water infrastructure projects and are used to measure their relative economic efficiency.

In the infrastructure projects studied in SALAM, energy costs are the major cost drivers for seawater desalination and subsequent transfer.

From an economic point of view, it would be advantageous to supply water to the West Bank from desalination plants in Netanya and Ashdod. Desalination at Aqaba and Haifa and transfer to the Jordanian demand centers would be a cost-efficient solution to cover their water needs.

MOTIVATION

Due to the large set of possible technological solutions and the spatial extent of transboundary water infrastructure projects in the SALAM project region, the design of decision alternatives is a complex task. The water infrastructure system consists of seawater desalination plants and respective energy supply systems, water transfer pipelines and electromechanical equipment such as pumping stations. Furthermore, the topographic conditions in the region could favour hydropower generation. If a desalination site near Haifa in the north of Israel is chosen, the desalinated water could be transferred to the Lake Tiberias (Sea of Galilee) through a tunnel which would serve as a regional water storage reservoir, used for electricity generation before being transferred down the Jordan Valley and to the regional water demand centers [Large-Scale Hydropower Plant at Lake Tiberias in the Context of Transboundary Water Transfer, p. 50].

A techno-economic assessment is essential to identify, design and select possible projects. When upgrading or building new water infrastructure components, the associated costs are to be approximated at an early planning stage with reasonable effort in order to be able to differentiate between technical variants and evaluate them regarding their economic efficiency.

The objective of this Key Product is to assess the economic viability of water infrastructure projects considered within the scope of SALAM. We applied methods of fluid mechanics and cost estimation methods for the techno-economic assessment of integrated water resources management infrastructure projects. To judge and compare the projects economic viability, specific water costs were determined and used as a benchmark. Sensitivity analyses were conducted to cope with the inherent uncertainty due to the early planning stage and the underlying assumptions. Furthermore, Decision Support tools have been developed and are provided to the regional decision makers to provide support beyond the scope of the SALAM project.

METHODOLOGY

The specific water cost in US Dollar per unit of water ($/m^3) is used as a benchmark and defined as the cost of providing one unit of water to the point of demand at desired quality. It includes the cost of desalination and the cost of transfer with subcomponents as depicted in Figure 1.

The cost of desalination includes direct capital costs for materials and construction work as well as indirect costs, e.g. for insurance or project management, and operating costs with fixed and variable components. It is assumed that required capital is raised entirely through loans under a build-operate-transfer scheme (BOT), which means that capital costs are incurring as a constant annuity.

The transfer system's capacity was determined based on the expected water deficits per demand cluster in Jordan and Palestine by 2050 [Future Freshwater Deficits in Palestine and Jordan, p. 18]. The topography of the region was considered for the design of the transboundary freshwater transfer network from desalination plants at the Mediterranean and Red sea to the points of demand and the determination of the cost of water transfer. The topography impacts the required pumping power capacity as well as the design of routing and selection of pipeline types and diameters.

Within the cost assessment procedure, the power capacity required for a pumping station was determined for each section of the transfer network, taking elevation gains and head losses into account.

The resulting cost of water transfer therefore consists of pumping station installation, maintenance and operating costs, as well as pipeline installation and maintenance costs proportional to the total amount of supplied water.

Furthermore, desalinated water from Haifa could be used for electricity generation, which in return could be used for seawater desalination. To assess the economic benefit of incorporating hydropower into the network, a cost benefit analysis was conducted. The total cost of the hydropower plant includes annualized construction and installation cost, as well as operation and maintenance cost. In turn, benefit is obtained through energy proceeds. Energy generation capacity mainly depends on the inflow from desalination plants, as well as the effective head and energetic efficiency of the turbine. The net benefit of the hydropower plant was determined by relating the total annual costs and the estimated annual energy proceeds to the annual inflow of desalinated freshwater and would lower desalination cost. To account for uncertainty in the underlying assumptions, especially for the price of electricity, sensitivity analyses were conducted.

RESULTS

Five alternatives for covering the freshwater deficits up to the year 2050 in Jordan and Palestine were examined. Water production and transfer strategies were detailed in [Water Production and Transfer Strategies, p. 22].

Results, as summarized in Table 1, indicate that the cost of desalination is of minor importance when comparing alternatives. The specific transfer costs, on the other hand, vary considerably between alternatives. The most economical alternative for supplying the West Bank from Netanya and Ashdod is associated with specific transfer costs of 0.43 $/

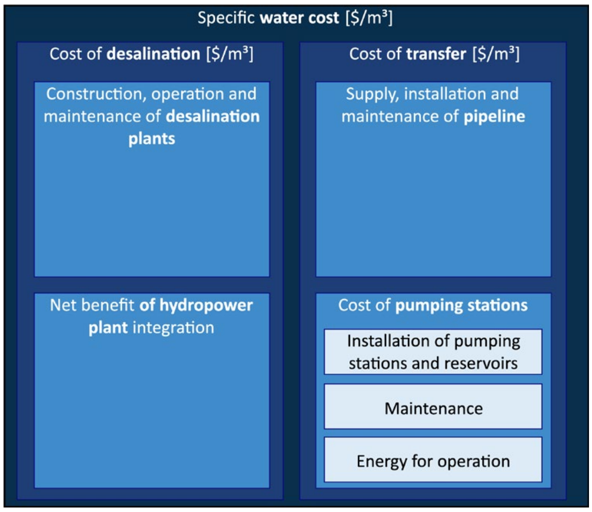


Figure 1: Cost components of the specific water cost. Specific water costs comprise the cost of desalination plant construction and operation, transfer cost and possible benefits of hydropower generation.

m^3, whereas exclusive supply via Haifa to the West Bank clusters incurs transfer costs of 0.89 $/m^3$. For demand clusters in Jordan, a combined supply via Haifa and Aqaba, as in Alternatives 3d and Cost Min, is the most economical solution. Given the higher share of supply from Haifa (563 million m^3/a) than from Aqaba, the Cost Min Alternative comes out to be slightly more advantageous than Alternative 3d (412 million m^3/a from Haifa). For alternatives with desalination in Haifa, a net benefit of 0.05 $/m^3$ through hydropower generation has been considered in the calculation of the specific water cost.

The higher transfer costs are mainly caused by energy requirements for transfer. At least two thirds of the transfer cost, depending on the alternative under consideration, are related to pumping stations and energy for operation, so that installation and maintenance of transfer pipelines represent the lesser cost factor. Additionally, transfer costs are highly sensitive to changes in energy prices, e.g. due to a different electricity generation mix or rising CO2 certificate costs.

The nominal power of the potential hydropower plant at Lake Tiberias ranges from 19.4 to 34.6 MW for considered flows. Thus, an annual flow of 412 million m^3 (Alternative 2b + 3e) yields an energy output of around 163 GWh/a. For alternatives with annual flows of up to 735 million m^3, the output increases up to 291 GWh/a.

Assumptions for the capital and operation expenditures were based on the global database of the International Renewable Energy Agency (IRENA 2021) and revenues from energy proceeds were assumed at 0.14 $/kWh. Since the costs of hydropower projects are highly dependent on specific local conditions, e.g. site access, extreme scenarios have been evaluated. Based on these assumptions, positive net present values ranging from 212 to 378 million $ were determined, which suggests that the project is economically advantageous. The resulting levelized cost of

ALTER-NATIVE	PRODUCTION POINT	SUPPLY [MILLION M³/A]	COST OF DESALI-NATION [$/M³]	COST OF TRANSFER PALESTINE [$/M³]	COST OF TRANSFER JORDAN [$/M³]	SPECIFIC WATER COST PALESTINE [$/M³]	SPECIFIC WATER COST JORDAN [$/M³]
1b	Netanya	735	0.64	0.53	1.09	1.17	1.86
	Aqaba	300	0.66	-	1.37		
2 + 4	Gaza	323	0.62	0.84	-	1.46	2.06
	Aqaba	712	0.66	-	1.41		
3d	Haifa	735	0.63	0.89	0.86	1.47	1.68
	Aqaba	300	0.66	-	1.35		
2b + 3e	Gaza	185	0.62	0.80	-	1.23	1.72
	Netanya	138	0.64	0.34	-		
	Haifa	412	0.63	-	0.91		
	Aqaba	300	0.66	-	1.37		
Cost Min	Netanya	138	0.64	0.34	-	1.07	1.63
	Ashdod	185	0.64	0.49	-		
	Haifa	563	0.63	-	0.92		
	Aqaba	149	0.66	-	1.46		

Table 1: Summarized results of the techno-economic assessment. If a region is supplied by multiple production points, the costs are allocated accordingly on the basis of the volume flow.

electricity (LCOE) range from 0.037 to 0.070 $/kWh and is comparable to the state of the art of other renewable energy generation projects as depicted in Figure 2.

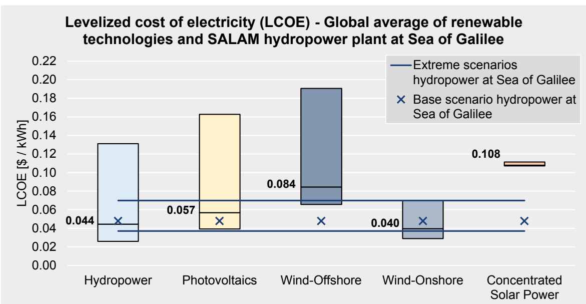


Figure 2: Levelized cost of electricity (LCOE) of the SALAM hydropower plant at Lake Tiberias compared with the global average LCOE of renewable technologies from the database of the International Renewable Energy Agency (IRENA).

CONCLUSION

The conducted techno-economic analysis provides decision support for the design of transboundary water infrastructure projects in Israel, Palestine and Jordan. The economic implications of different options for siting of seawater desalination plants and design of the water distribution network were highlighted and substantial differences between options became apparent. Due to the high flow volumes, the topographical conditions in the region and the long operating life of the infrastructure components, operational expenditures, especially for energy, have a stronger influence on the water cost than capital expenditures. This should be taken into account when planning water transfer routes, but also in the selection of energy technologies and sources.

Furthermore, results also show that the incorporation of a hydropower plant at Lake Tiberias can be economically advantageous in view of the large freshwater flows from desalination. Building on this study, the underlying assumptions for cost and revenue items can now be refined by including market specific data and tax effects within the framework of a detailed project study for selected alternatives.

The results of this study can be incorporated into the multi-criteria decision support procedure to rank the presented alternatives according to the preferences of the decision-makers. While the work presented here focuses on the economic performance of different water infrastructure projects, the methods of multi-criteria analysis furthermore allow to incorporate objectives from the social, political, ecological and technical domains to evaluate the performance of these alternatives.

SALAM ECONOMIC TOOL

The SALAM Economic Tool is a decision support tool that is linked to the SALAM IES with the goal to provide decision support for water resources planning and water management beyond the scope of the SALAM Initiative [SALAM Information and Expert System, p. 86].

The tool is organised in a modular approach that allows for an economic assessment of different types of hydroinfrastructure considered within SALAM. As of now, cost estimation for seawater desalination projects, determination of economic key data based on a reference project database and cost calculation for freshwater transfer networks are supported. Figure 3 illustrates the Graphical User Interface (GUI) and input scheme of the desalination module.

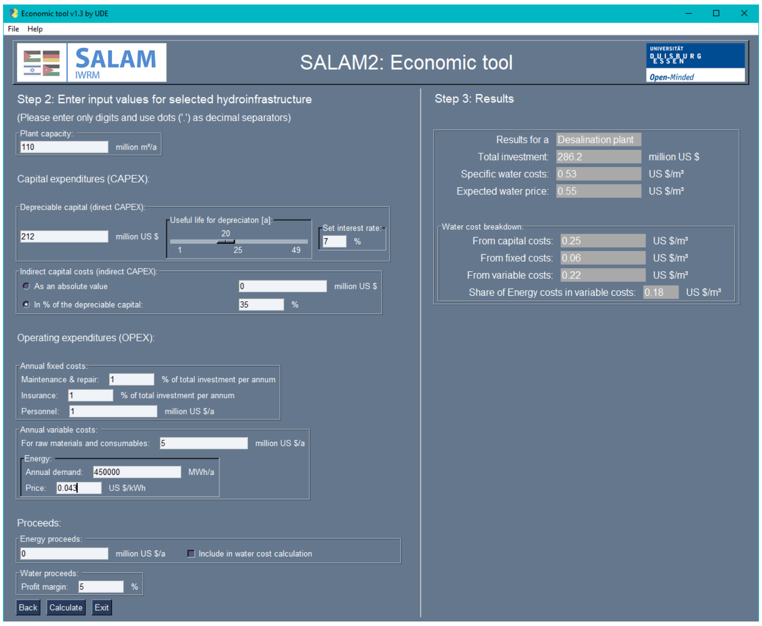


Figure 3: GUI and input scheme of the Economic Tool. Here, the desalination module is depicted.

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Regional Macro-Model for Transboundary Water Resources Planning

Jacob Bensabat[1], Bernd Rusteberg[2], Philippe de Bourgoing[3], Sebastian Schär[4]

KEY FINDINGS

The macro model identifies optimal pathways and sizing of infrastructure to allocate freshwater from different potential locations suitable for seawater desalination at the Mediterranean and the Red Sea to demand areas in Palestine and Jordan.

The macro model is formulated as a non-linear optimization problem where the objective function minimizes the combined cost of sea water desalination, infrastructure and energy.

Energy is the key component of the combined cost and its minimization leads to the most cost-effective solutions.

MOTIVATION

Freshwater production and allocation are a key challenge of the SALAM Initiative in view of the substantial freshwater deficits that are expected in the coming decades [Future Freshwater Deficits in Palestine and Jordan, p. 18]. It is clear that massive seawater desalination will be needed in order to match these deficits, as in the region there are no additional renewable freshwater resources that can be exploited. The selected locations for seawater desalination, denoted hereafter as Production Points (PP), are: 1) North of the city of Netanya, Israel (PP-1), 2) Extension of the plant in Gaza, Palestine (PP-2), 3) North of Haifa bay, Israel (PP-3), 4) Aqaba, Jordan (PP-4), 5) Extension of the plant near the city of Ashdod and/or new plant at Ashdod, Israel (PP-5) and 6) Extension of the plant in the city of Hedera, Israel (PP-6). Water supplied from Haifa would transit through a tunnel and released into Lake Tiberias. The elevation difference between the Mediterranean Sea and Lake Tiberias could be used for hydropower. This is presented in [Large-Scale Hydropower Plant at Lake Tiberias in the Context of Transboundary Water Transfer, p. 50]. The model focuses on the optimal distribution of the desalinated water to the Connection Points, which were defined for each demand cluster [Water Conveyance System for Freshwater Deficit Coverage in Jordan and Palestine, p. 37]. The distribution of the allocated water with each cluster is beyond the scope of work of the project and not addressed. Numerous demand clusters will face substantial freshwater deficits. There is a need to determine the capacity of each production point and to outline the water transportation infrastructure in such a way that the freshwater deficit at each connection point for the selected time horizon is covered. For the present study, the planning horizon 2050 has been considered.

The objective is to determine the best solution in terms of cost for a specified planning horizon. Any other solution under consideration by the regional decision makers could be compared to the “cost minimal solution”. In other words, the Macro-Model provides the means to estimate the economic implications of the decision makers preferences, e.g. with regard to location and productions capacities of SWD-plants, on the water allocation pathways, associated energy requirements, total cost and specific water cost.

METHODOLOGY

The macro model is formulated as a Mixed Integer Non-Linear Programming (MINLP) problem. The aim is to find the cost-optimal way to supply the connection points from the production points (desalination plants). The optimization relies on the network outlined in [Water Conveyance System for Freshwater Deficit Coverage in Jordan and Palestine, p. 37], and therefore, on the connections between

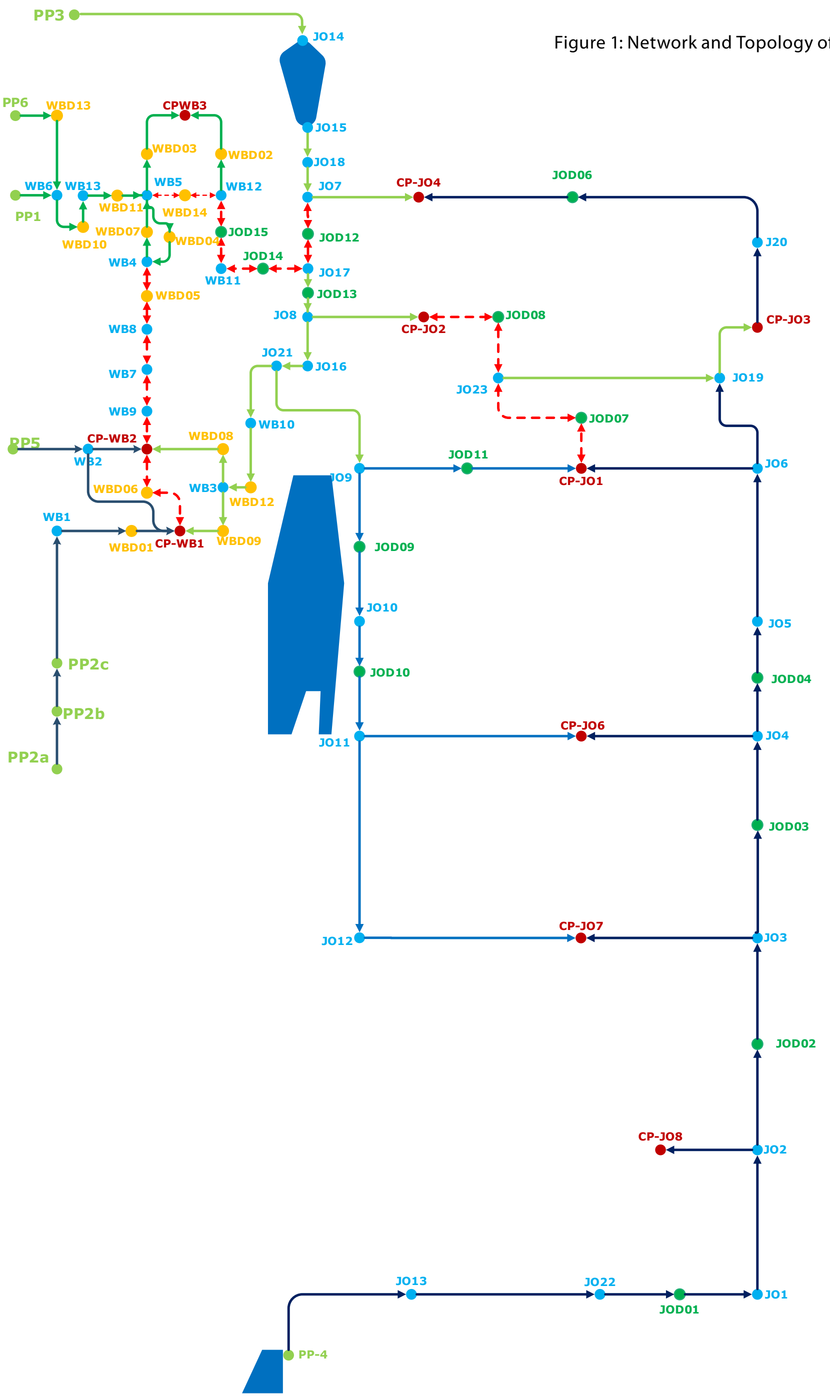

Figure 1: Network and Topology of the Macro-Model

potential production and demand areas [Water Production and Transfer Strategies, p. 22]. The complete network (Figure 1) is an overlay of all alternative water production and transfer strategies, comprising nodes and links. A node is a physical point at which mass must be conserved and also at which there could be a demand (a connection point is a node in the network). A link is a pipe connecting two nodes. The decision variables are: 1) The discharge along a link, between nodes *i* and *j*, Q_{ij} *(m^3/s)*; 2) The energy head needed to transfer water along a link , between nodes *i* and *j*, E_{ij} *(m)* and 3) The diameter of the pipe along the link, between nodes *i* and *j*, D_{ij} *(m)*.

The objective function is the sum of four terms: 1) cost of desalination; 2) cost of pipe installation and maintenance cost; 3) cost of power installation, its maintenance and energy cost for system operation; 4) the benefit from hydropower generated at Lake Tiberias via the transfer of water desalinated north of Haifa.

The starting network is presented in Figure 1. The pathways and the freshwater deficit values of each demand cluster in 2050 [Future Freshwater Deficits in Palestine and Jordan, p. 18] are inputs of the model. Constraints are set on the maximum desalination capacity of each plant. The AMPL community edition software was used for the coding of the optimization model (using the AMPL scripting language). The employed non-linear solver was the public domain open-source coin-or IPOPT.

NAME	SWD PLANT	CAPACITY (MIO. M³/A)	SHARE (%)
Netanya	PP-1	139.74	13.37
Gaza	PP-2	0.0	0.00
Haifa	PP-3	564.61	54.30
Aqaba	PP-4	154.14	14.75
Ashdod	PP-5	186.50	17.85
Hedera	PP-6	0.0	0.00

Table 1: Optimal Water Supply from the Desalination Plants (2050)

RESULTS & CONCLUSIONS

The results of the optimization for the time horizon 2050 are presented in terms of output from the desalination plants and discharges and diameters for the active links. The supply from the desalination plants is detailed in Table 1.

The routes identified by the optimization are presented in Figure 2. Haifa would supply central and northern Jordan. Aqaba would supply the south of Jordan. Netanya and Ashdod supply Northern and Southern West Bank respectively.

The optimum is dictated by the cost of the energy needed for transportation, as the desalination plants are neutral in the sense that they bear relatively similar costs. Haifa is by far the preferred desalination spot (54% of the total supply). The main advantage of Haifa compared to Aqaba is the shorter distances to demand centers in North and Central Jordan. The benefits generated by the hydropower plant at Lake Tiberias further lower the specific water cost. The optimization clearly identifies desalination in the Mediterranean coast as the preferred source of freshwater. Water production at Aqaba is hampered by the costs of energy required for the transportation.

Key outcomes of the study are summed up below:

> The procedure developed by the macro model provides a quantitative tool for the optimization of massive water supply allocation from desalination plants to demand areas.

> The cost of the optimal solution is considerably lower than other water production and transfer options [Techno-Economic Assessment of Water Infrastructure Projects, p. 72].

> The macro model suggests a solution that may not be the preferred one in Jordan and or in Palestine. It is beyond the scope of this work to recommend the preferred solution. However, the macro model provides to the stakeholders and decision-makers a tool that will allow them to evaluate the economic implications of their decisions (the extend of the additional investment required for the implementation, maintenance and operation of a different solution).

> The suggested approach (optimization of water allocation) is not new. What is new is its implementation to a complex transboundary water management challenge.

Figure 2: Optimal Transfer Route as Defined by the Model

> The optimal solution depends on the initial setting of the network. It is possible that a different layout of the network could result in a different optimal solution.

> The optimization assumes that there are no limitations on the pipe diameters, on the size of the power boosting stations and on the size of the temporary storage facilities. The cost of pipe installation per unit length (m) is assumed to be a linear function of the diameter (constants provided by Dorsch) with no limitation on the diameter size. Similarly, the cost of the power/temporary installation per kW is a linear function, as provided by Dorsch. Should there be limitations on the size of the diameter or the power boosting, this would have a an impact on installation costs (positive or negative, depending on other factors). Overall, the impact on the optimization would be negligible for the following reasons: 1) a small number of pipes and or power boosting facilities would be affected; 2) the factor dominating the cost is the energy consumption over the operation period.

The network comprises nodes connected to links for which the flow directions are determined as part of the optimization process. The first version of the script, which is presented in this paper, does not fully represent the mass balance at these „complex" nodes, which is why the script was further improved. The new outcome of the optimization further emphasizes the advantage, cost-wise, of seawater desalination in the Mediterranean Sea over seawater desalination in the Red Sea. In the new solution 98% of the demand is supplied by desalination in the Mediterranean Sea (Haifa: 67%, Ashdod: 18% and Netanya: 13%).

The Macro-Model is integrated to the [SALAM Information and Expert System, p. 86]. Users can visualize the path, the technical characteristics, and the specific water costs of the cost-optimal solution for a given set of freshwater deficits in the demand centers and capacity constraints of the desalination plants. Figure 3 shows the user-friendly interface of the tool.

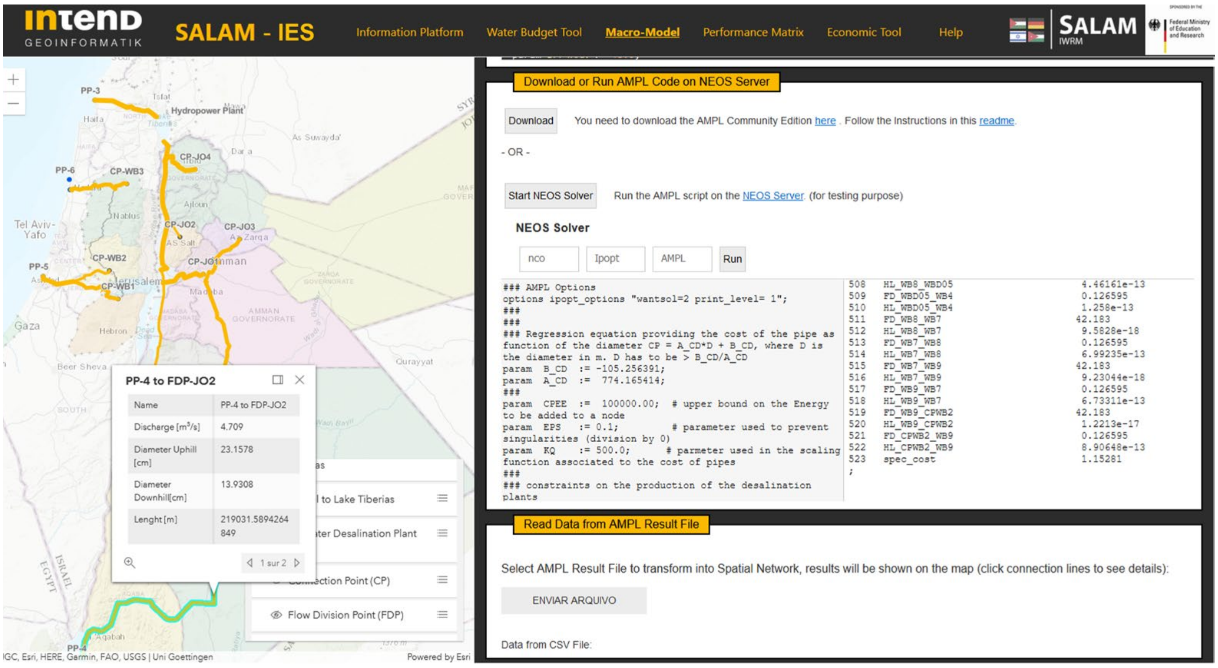

Figure 3: Interface of the Macro-Model in the SALAM Information and Expert System

THE MACRO-MODEL

The macro model developed in SALAM2 aims at finding an optimal solution of the water allocation problem from possible locations for the installation of desalination plants (on the Mediterranean Sea coast and on the Red Sea coast) to the demand points of the clusters in Jordan and in the West-Bank. The problem is formulated as Mixed Integer Non-Linear Program (MINLP) but solved as Non-linear program (NLP). The optimization problem consists of decision variables (the production at the desalination plants), discharges, energy head and diameters for link in the network (pipeline between two nodes). The objective function is composed of three costs items (infrastructure, desalination, and energy) and one benefit (hydropower related to the operation of a desalination plant at Haifa). Constraints include mass conservation, energy conservation, consistency, and bounds on the decision variables. The problem is solved using the AMPL Community edition version which can activate the Interior Point Non Linear Solver IPOPT.

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IPOPT - Interior Point Optimizer - Ipopt: Documentation (coin-or.github.io)

Workshop on the Simos Method, Jordan 2021 ©Nußbaum

Multi-Criteria Analysis of Water Resources Planning Options

Sebastian Schär[1], Jutta Geldermann[1]

KEY FINDINGS

Multi-Criteria Analysis (MCA) methods based on PROMETHEE can be applied for informed and transparent decision-making in water resources planning.

The analysis of water production and transfer strategies reflects Jordanian and Palestinian stakeholders' desire for water independency through seawater desalination at Gaza and Aqaba. Highly ranked were also combined options of Gaza/Netanya for the West Bank and Haifa/Aqaba for Jordan, which are more cost effective.

For desalination plant concepts at the Mediterranean Sea, alternatives in proximity to the shore are preferred due to lower capital requirements and costs. Offshore concepts perform better on environmental criteria while being less economical.

For Aqaba, desalination concepts with energy supply from photovoltaics and additional molten salt storage perform well overall. Weaknesses are the technical complexity, higher energy demand and impact of brine discharge.

A general preference for centralized wastewater systems has been identified. For decentralized systems, providing more funding opportunities might improve the political acceptance.

MOTIVATION

Palestine and Jordan, despite great efforts to use local water resources efficiently, suffer from considerable water shortages in all sectors. Over the coming years, this water shortage is expected to worsen so that effective countermeasures are urgently required. Due to the large set of possible technological solutions and the large spatial extent of the resulting water infrastructure solutions, the design and assessment of the water infrastructure system is a complex task. Water resources planning options consist of seawater desalination plants and their respective energy supply systems, water transfer pipelines and electro-mechanical equipment, such as pumping stations. Furthermore, a strategy for the expansion of wastewater systems is to be defined and associated infrastructure solutions are to be assessed.

Due to the broad temporal scope and the inherent complexity of the decision problem, multiple possible consequences must be considered simultaneously in the decision process, taking various criteria into account, such as the cost, environmental sustainability or public and political acceptance of a project. Therefore, the assessment of water resources planning options in SALAM is conducted via selected methods of Multi-Criteria Analysis (MCA) to allow for an informed and transparent decision.

The goal of this work is to structure the decision problem and elicit the preferences and objectives of the decision makers and stakeholders. Likewise, the performance of different water resources planning options on these objectives are determined and aggregated in the assessment to identify preferred options. Special emphasis is put on the consensus-building between the stakeholder groups involved. Strengths and weaknesses of water resources planning options are highlighted and uncertainty in the underlying assumptions is assessed by sensitivity analysis.

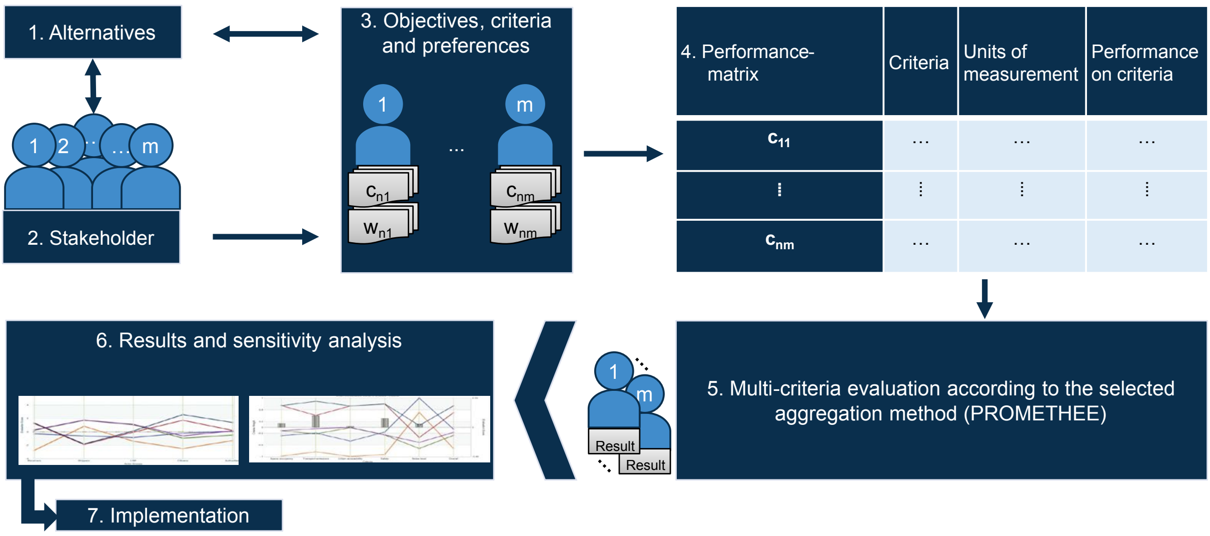

Figure 1: General framework of multi-criteria decision support in SALAM. The framework is adapted and extended from Macharis et al. (2009).

MCA provides a sound basis for the following strategy implementation. Since conducting an MCA can also facilitate the process of refining the current set of options, directions for future research are given. In more general terms, the results presented should not be viewed in a normative manner, but as an informed starting point to facilitate the decision process. This is achieved by increasing the transparency of the decision process and explicating the strengths and weaknesses of options to ultimately facilitate consensus building and actual implementation of options.

METHODOLOGY

Within this project, we applied selected MCA methods in close cooperation with project partners, decision-makers and stakeholders, in order to demonstrate the potential of MCA for decision makers in the project region. The framework is summarized in Figure 1. The aim of MCA methods is to support one or more decision-makers in evaluating different options, henceforth called alternatives, regarding multiple often conflicting criteria given in different units of measurement. Furthermore, this allows to manage the inherent complexity of a decision problem in a structured manner (Belton and Stewart 2002). The method has already been applied often in environmental management problems.

In the first step, we employed the strategy generation table method (Howard 1988) to structure the general and broad decision context of water resources planning options into manageable sub-decisions, and to iteratively screen for alternatives in each subset. Table 1 provides an overview on the decision problems and respective alternatives assessed during the SALAM Initiative. For a description of these alternatives we refer to the Policy Briefs of the corresponding partner institutions.

In the next steps, stakeholders' objective systems and preferences were elicited during multiple onsite workshops and online surveys. Elicitation was conducted according to the revised Simos method, also known as the method of cards (Figueira and Roy 2002). Based on the results, the objective systems were organized in a hierarchical manner, with overarching objectives from the technical, economic, environmental, social and political domain at higher hierarchy levels and more operational, measurable criteria at the lowest level of the hierarchy. Preferences map the relative importance a stakeholder allocates to the respective criteria. For each stakeholder group and each decision problem, a dedicated criteria hierarchy and preference modelling has been established.

The alternatives for each subset of the strategy generation table and their performance on the identified criteria has been determined in collaboration with the German and regional partner institutions from the project consortium. The collected information was then synthesized in performance matrices to conclude step four.

The ranking of alternatives in the following step five was conducted according to the Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) (Brans and de Smet 2016). PROMETHEE is an established outranking method, and we chose it for this particular case since comparison of alternatives on criteria with different units of measurement (e.g., kWh/m^3 and $\$/m^3$) is explicitly allowed. Furthermore, PROMETHEE allows for comprehensive sensitivity analysis as part of the results evaluation.

RESULTS

We applied the MCA procedure based on preliminary results elicited with SALAM project partners. It should be noted that MCA is an iterative process, and that the ranking yielded has to be rediscussed with the decision makers. In the following, selected and exemplary results are

DECISION PROBLEM	DECISION ALTERNATIVES FOR EACH DECISION PROBLEM IN THE SALAM INITIATIVE				
Desalination plant near Haifa	Land reclamation	1 km offshore at 12 m water depth	5 km offshore at 30 m water depth		
Desalination plant near Netanya	Onshore plant	1 km offshore at 12 m water depth	2.5 km offshore at 30 m water depth		
Desalination at the Red Sea	New plant at Aqaba Port combined with existing power plant	New plants at Wadi Araba & Aqaba	New plant at Aqaba with PV and molten salt storage	New plants at Dead Sea & Aqaba	
Wastewater Management System Expansion	Decentralized Expansion	Centralized Expansion	Mixed expansion (cost-efficient solution)		
Transboundary Water Production and Transfer Strategies	Supply via Netanya and Aqaba (Alternative 1b)	Supply via Gaza and Aqaba (Alternative 2 + 4)	Supply via Haifa and Aqaba (Alternative 3d)	Supply via Gaza, Netanya, Haifa and Aqaba (Alternative 2b + 3e)	Cost-minimal alternative (Alternative Cost Min)

Table 1: Overview on decision problems in the SALAM Initiative and identified sets of alternatives for each decision problem. The alternatives are detailed in [On- and Offshore Solutions for Large-Scale Seawater Desalination at the Mediterranean Coast, p. 26], [Renewable Energy for Seawater Desalination in the Middle East: Case Study Aqaba, Jordan, p. 30], [Water Production and Transfer Strategies, p. 22], [Regional Wastewater Infrastructure Development Strategies for Jordan and Palestine, p. 40]

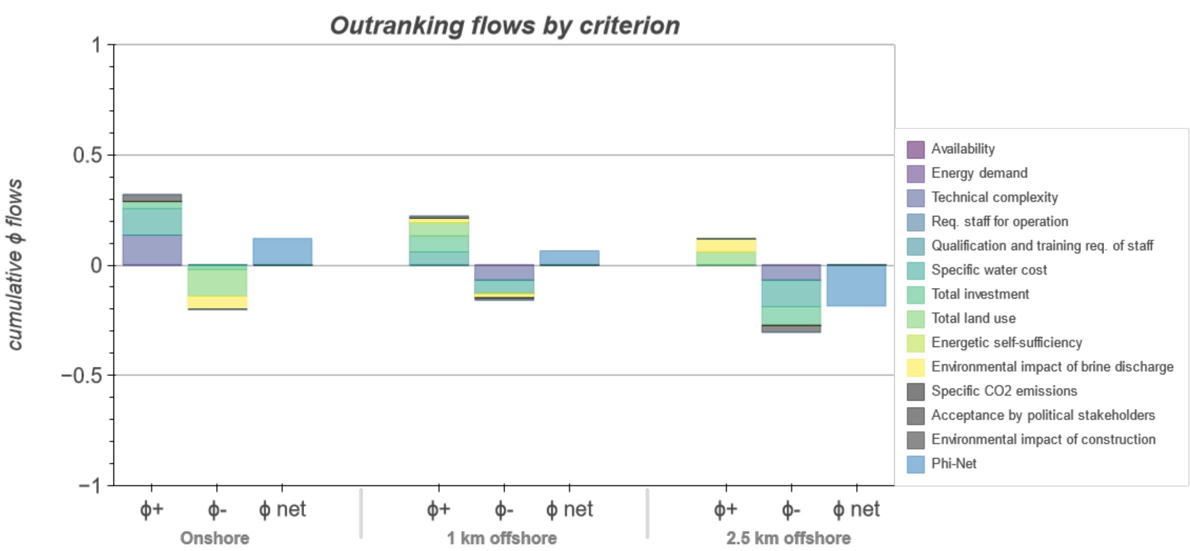

Figure 2: Evaluation of different seawater desalination concepts at the Mediterranean Sea according to PROMETHEE and performance on each of the criteria.

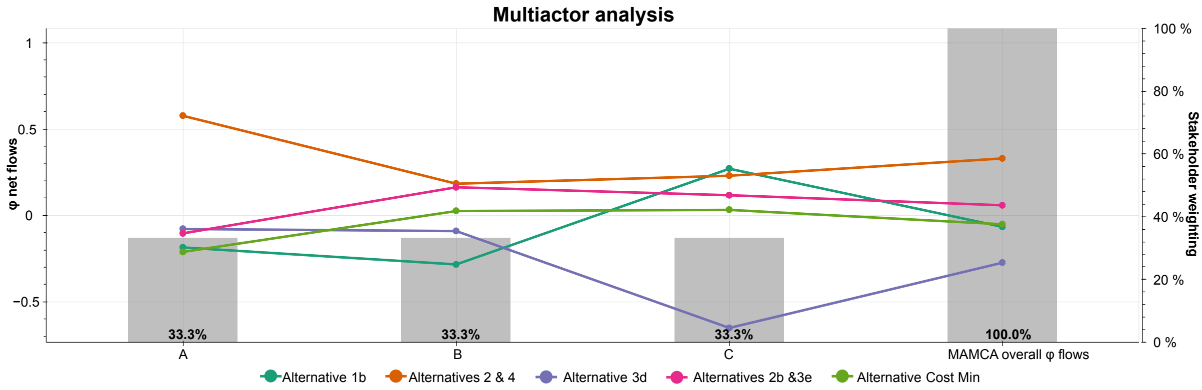

Figure 3: Multi-actor analysis across all stakeholders involved. It shows the net flows per stakeholder according to PROMETHEE and the overall ranking of alternatives.

presented. These results are based on the current state of the elicited data which may not be regarded as fully representative. Nevertheless, this does only affect the implications to be derived from the results, which may change with higher data accuracy, and not the general procedure and its usefulness in such decision contexts.

The PROMETHEE outranking flows express the strengths and weaknesses of each alternative. Positive outranking flows (Φ_+) indicate how much an alternative dominates other alternatives across the different criteria, and negative outranking flows (Φ_-) indicate how much it is dominated by other alternatives. Aggregating positive and negative outranking flows yields the net flow (Φ_{net}), which is also used to rank alternatives.

To showcase, for an assessment of three different desalination plant concepts at the Mediterranean Sea, alternatives in proximity to the shore are ranked highest, indicated by higher net flows as visualized in Figure 2. Furthermore, PROMETHEE allows the breakdown of outranking flow contributions on a criterion level. This provides insight into the performance of the alternatives on each criterion and is displayed by the colored bar sections in Figure 2, while Φ_+ contributions denote preference and Φ_- contributions indicate weakness of an alternative regarding the respective criterion. The main reasons for preference of near and onshore concepts in this case are the lower capital requirements and water costs. Offshore plants at high water depths perform better on the environmental criteria but are also associated with higher investments and costs.

For Transboundary Water Production and Transfer, five alternatives have been evaluated. In SALAM, three different stakeholder groups were considered. At first, evaluation was conducted for each stakeholder on an individual level, before results were aggregated across stakeholders for consensus evaluation. In Figure 3, the results of this MCA aggregation over all stakeholders are displayed as well as the individual evaluations. Each stakeholder group was granted an equal weight. Alternatives 2 & 4 (Gaza to supply West Bank/Aqaba to supply Jordan) and 2b & 3e (Gaza and Netanya to supply West Bank/ Haifa and Aqaba to supply Jordan) are preferred overall, while the Cost Min alternative (Netanya and Ashdod to supply West Bank/ Haifa and Aqaba to supply Jordan) performs consistent across all stakeholder groups.

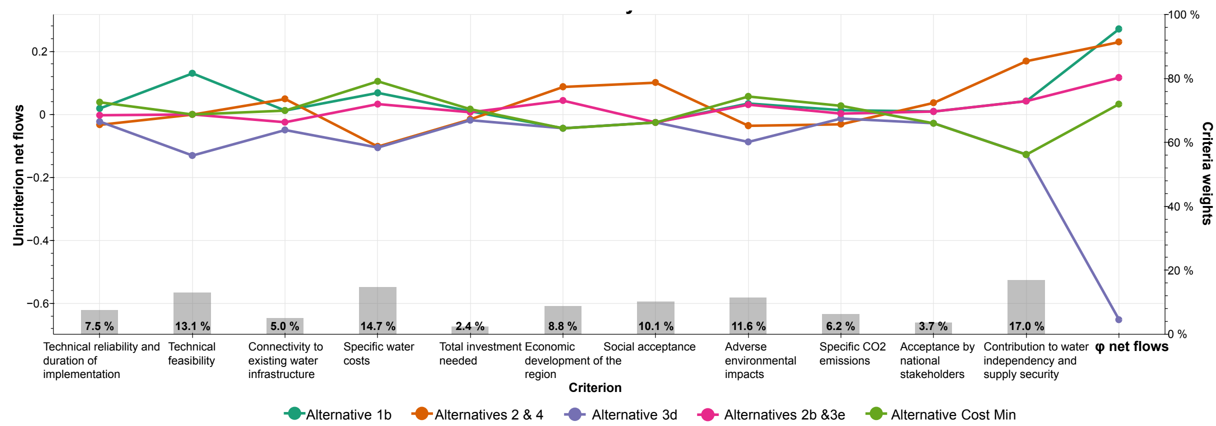

Figure 4: Intrastakeholder analysis for stakeholder C. The net flow contributions per criterion (unicriterion net flows) highlight the specific strengths and weaknesses of alternatives. Furthermore, elicited criteria weights are displayed.

Since reaching consensus is crucial for the transboundary alternatives considered in SALAM, the evaluation across all stakeholders is of particular importance. Noticeably, Alternative 1b is preferred by stakeholder C, while ranking low for stakeholders A and B in the above mentioned case. Therefore, an intrastakeholder analysis has been conducted. This additional analysis layer of the applied MCA framework may help in revealing each stakeholders' crucial trade-offs and indicates compromise options. Figure 4 depicts the intrastakeholder analysis for stakeholder C and shows that the strong performance on the technical and economic criteria leads to an overall preference, while the higher water costs for stakeholder C in Alternative 2 & 4 are responsible for the comparatively weaker preference of this alternative.

Moreover, three generic expansion alternatives for Wastewater Management in Jordan were examined. According to the preliminary results of the MCA, Jordanian stakeholders prefer a centralized expansion of the wastewater management system. Even if a decentralized expansion performs better on environmental criteria and requires fewer trunk lines, stakeholders associated it with a lower political acceptance and voiced difficulties to acquire funding.

CONCLUSIONS

The goal of our work was to provide a framework for decision support in water resources planning by structuring the decision problem, eliciting stakeholders' preferences and objectives and identifying potentially preferred alternatives. The framework should enable decision-makers to consider diverging objectives of different stakeholder groups and provide aid for consensus building. For this purpose, selected Multi-Criteria Analysis (MCA) methods based on PROMETHEE have been adopted to suit the context of SALAM and applied using preliminary project data to showcase the frameworks' contribution for informed and transparent decision-making. The MCA process developed in this work should help decision-makers and water planners to take informed decisions regarding water infrastructure planning.

Results highlighted how the framework can be used to reveal the alternatives' strengths and weaknesses across multiple stakeholders. This may facilitate the process of reaching consensus between all stakeholders and foster a decision's acceptance, like the evaluation of Transboundary Water Production and Transfer strategies demonstrated. The evaluation of different desalination plant sites and concepts at the Mediterranean and Red Sea revealed potential preference for novel concepts, incorporation of offshore solutions and renewable energy technologies and energy storage.

Nevertheless, some remarks have to be made. From a methodological point of view, preference elicitation procedures like the method of Simos are easy to apply and can lessen stakeholders' cognitive stress associated with translating preferences to numerical criteria weights. However, these interactive procedures can also lead to ambiguous preference mappings and an instable ranking of alternatives because of their design. For the decision problems addressed above, rank robustness analysis show that the evaluation is highly sensitive to slight changes in criteria weights and performance values. Since we applied the MCA procedure based on preliminary data from the current project phase, additional feedback by stakeholders is required to confirm or refine the preference model presented in this work before drawing further implications.

Besides, a more detailed design and techno-economic assessment of Wastewater System expansion variants is now required to advance decision-making in this context after the preliminary assessment in this project phase. In this sense, conducting the MCA allows to refine selected Water Resources Planning Options based on the elicited objectives and preferences of the stakeholders.

PROMETHEE CLOUD

The MCA evaluations have been carried out using the PROMETHEE-Cloud, a software tool developed by the University of Duisburg-Essen. PROMETHEE-Cloud is a web-based implementation of the PROMETHEE set of methods with comprehensive evaluation and sensitivity analysis features along with intuitive visual representations of the results. The tool is structured according to the general procedure of an MCA, starting with the creation of a performance matrix. Furthermore, it provides the opportunity to export the results and visualizations created, and contains elements of interactive guidance which makes it user-friendly. Using the tool allows decision makers to simultaneously take different objectives into account and get an overview of the strengths and weaknesses of the different alternatives under consideration. All visualizations provided by the PROMETHEE-Cloud can be exported in common graphics formats.

The PROMETHEE-Cloud can be accessed via the SALAM IES or directly on https://promethee.pom.uni-due.de/.

Yarmouk River, Jordan ©Klein

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SALAM Information and Expert System

Philippe de Bourgoing[1], Gerald Souza da Silva[2], Lukas Zintel[3], Bernd Rusteberg[4]

KEY FINDINGS

An information platform gathers the geographical data of the SALAM concepts.

The Water Budget Tool allows the user to compute future freshwater deficits and visualize the results in graphs.

Stakeholders can calculate the costs of a desalination plant using the SALAM Economic Tool.

The cost-minimal solution to cover the freshwater needs of the region is computed for a given set of constraints in the Macro-Model Tool.

The water production and transfer alternatives are compared on various criteria in the Performance Matrix.

Choosing between various planning alternatives is made easier using Multi-Criteria Analysis in the PROMETHEE-Cloud.

MOTIVATION

The methods and results developed in the SALAM Initiative should be easily accessible for decision-makers in the region. Knowledge transfer relies among other things on the establishment of a complete and well-organized database. The SALAM project partners produced geographical data at regional and national scale, which needs to be displayed and shared properly to enable the transboundary management of water resources. Decision Support (DS) tools can be of great help to facilitate short and long-term strategic planning. Developing these tools required a constant dialogue with the regional stakeholders to ensure transparency, interactivity and, therefore, participatory decision making on a multilateral level. The Information and Expert System (IES) developed during this project displays relevant geodata and gathers several DS Tools.

THE COMPONENTS OF THE SALAM IES

The SALAM IES stores geodata, hosts various web applications for water planners, and provides interfaces for data visualization. The ArcGIS Experience Builder was used to develop the web applications as it provides useful basic functionalities to build an Expert System. An information platform and five DS Tools are hosted in the SALAM IES. The system is accessible with an ArcGis Online license (https://salam2-dss.uni-goettingen.de/).

INFORMATION PLATFORM

Geodata is structured in thematic groups in the information platform (Figure 1). Data on the water and wastewater infrastructure and on the freshwater resources was gathered from the partner institutions in Israel, Palestine and Jordan. Project results, such as the freshwater deficits at cluster level, the water transfer pathways of the different transboundary water strategies, the suggested additional wastewater infrastructure or the wastewater reuse options in the Lower Jordan Valley are also displayed on the information platform. Clicking on a specific element allows the user to access technical information such as for example the freshwater deficits in a demand cluster or the capacity of a seawater desalination plant.

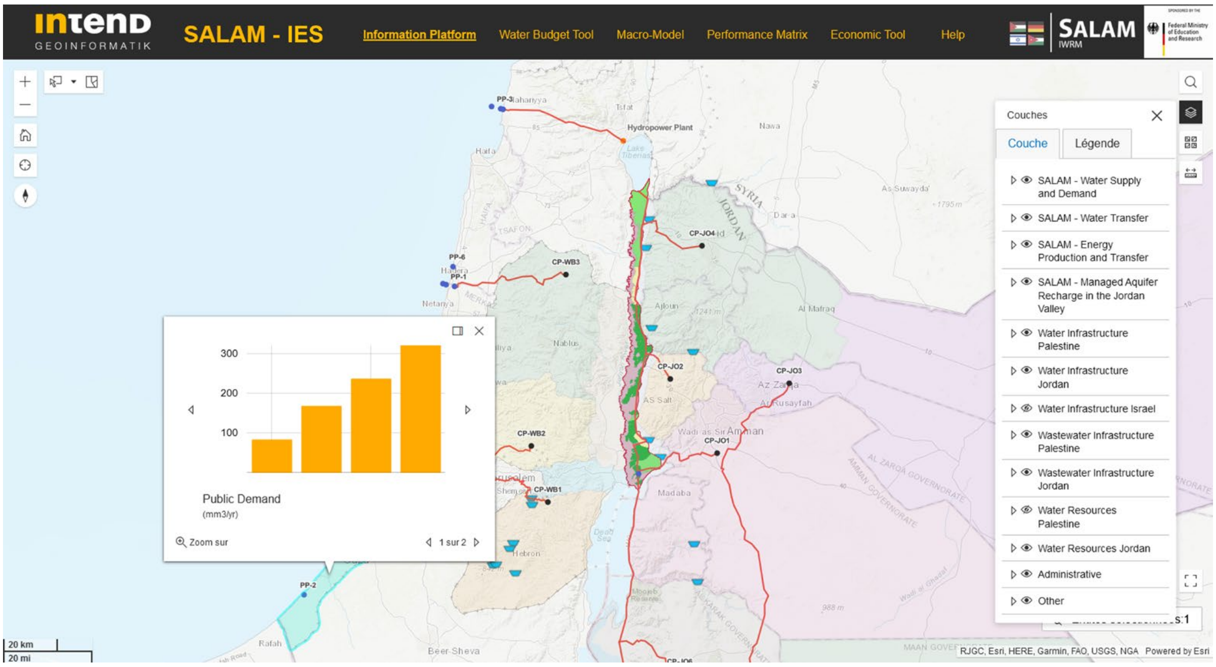

Figure 1: Information Platform

WATER BUDGET TOOL

The tool computes the projected freshwater budget from 2020 to 2050 in several economic sectors in Jordan and Palestine at the cluster or national level. A baseline scenario is defined in both countries. The computation mode of the freshwater budget and the underlying assumptions for the baseline scenarios are explained in [Future Freshwater Deficits in Palestine and Jordan, p. 18]. The user can choose to compute water supply and demand using the assumptions defined in the baseline scenarios or change these assumptions and define his own development scenario. Water demand, supply and budget are displayed in graphs (Figure 2). Inputs and outputs of the newly defined scenario can be saved and exported in a table.

SALAM ECONOMIC TOOL

The costs of a seawater desalination plant can be computed easily in the SALAM Economic Tool. Costs include capital expenditures (CAPEX) and operating expenditures (OPEX), divided between annual fixed and variable

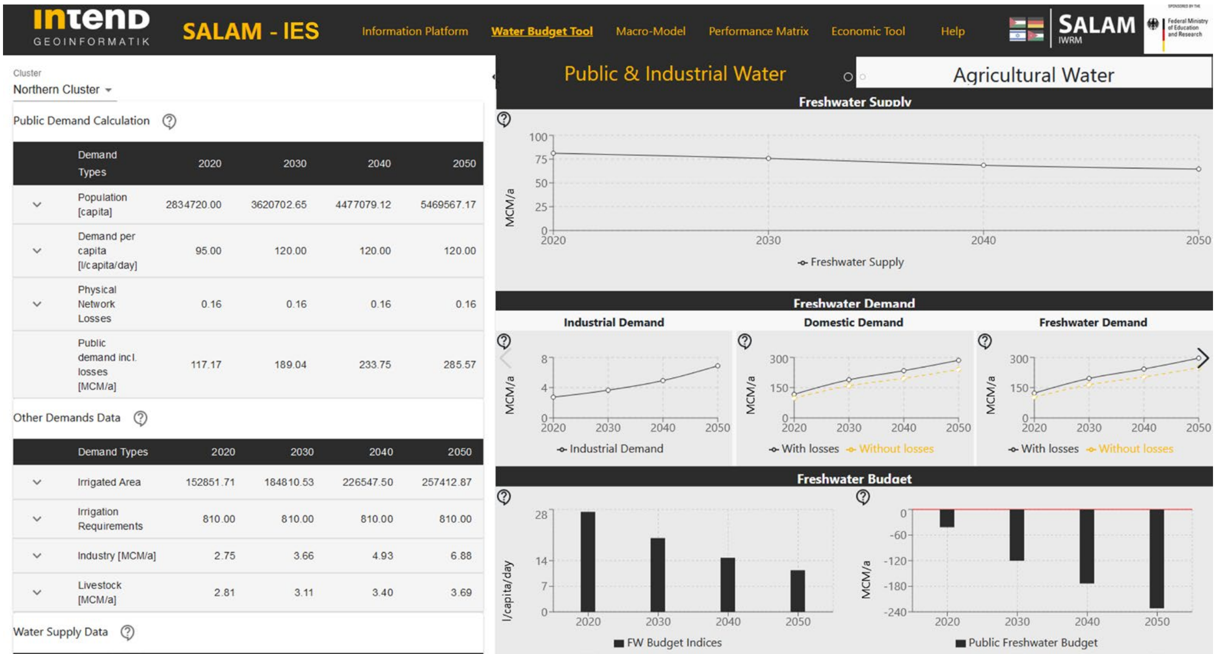

Figure 2: Water Budget Tool

costs. More details on the cost computation are provided in [Techno-Economic Assessment of Water Infrastructure Projects, p. 72]. The tool features a user-friendly Graphical User Interface. Outputs include the total investment and the specific desalination costs in €/m³. A cost breakdown allows the water planner to identify the main cost drivers, which is a prerequisite for developing effective cost-saving strategies.

MACRO-MODEL

TThe Macro-Model Tool is an optimization tool designed to identify the cost-minimal option to supply water from desalination plants at the Mediterranean and Red Sea to all demand clusters in Palestine and Jordan. The potential locations of the desalination plants and the potential water transfer network are defined. Details on the objective function and the optimization can be found in [Regional

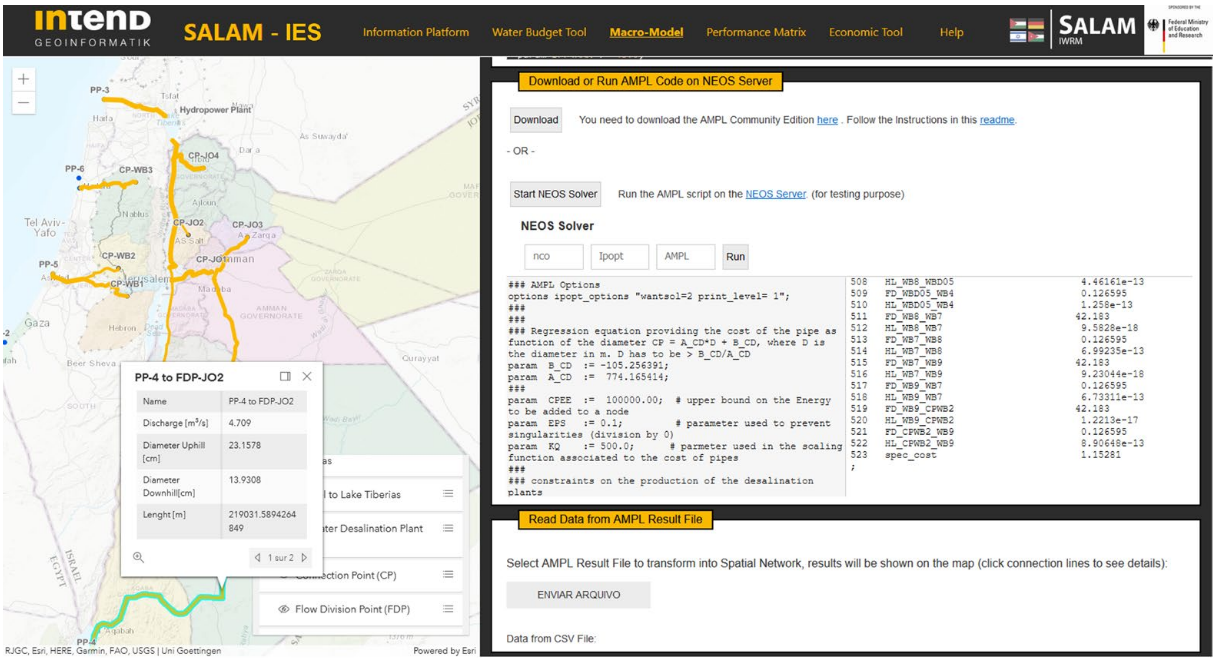

Figure 3: Macro-Model Tool

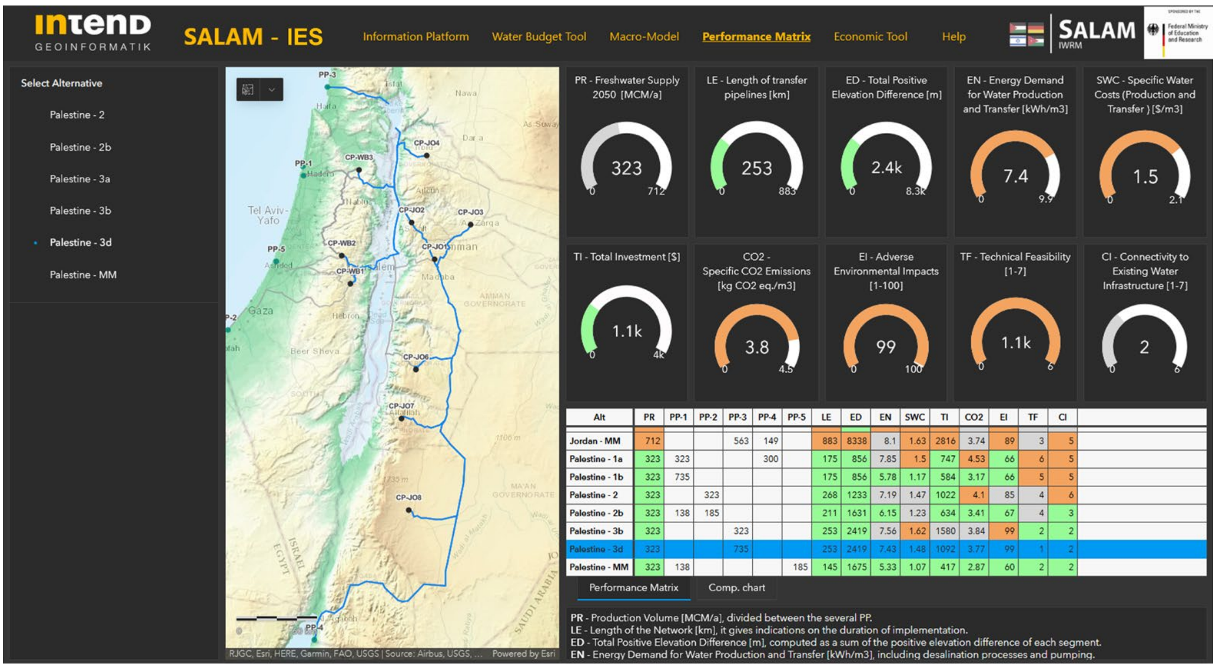

Figure 4: Performance Matrix

Macro-Model for Transboundary Water Resources Planning, p. 76]. The water-planner has the option to modify constraints regarding the capacity of the seawater desalination plants or even the possibility of not considering certain locations, to modify the planning horizon and, accordingly, the freshwater deficits of the demand clusters, and to compare the cost-minimal solutions obtained. The specific water production and transfer costs and the ideal transfer paths are determined and displayed by the system (Figure 3). Technical information regarding the discharge and diameter in each segment of the optimized network is given.

PERFORMANCE MATRIX

The water production and transfer strategies developed in the SALAM project are compared based on specific criteria, which are displayed in the Performance Matrix. Technical, economic and environmental criteria were evaluated for all strategies by the SALAM project partners. Their values are discussed in [Assessment of Freshwater Strategies and Recommendations for Implementation, p. 92]. The visualization tool allows the mapping of all strategies on the GIS platform and includes gauges with the performance of the strategy on all criteria and the whole performance matrix (Figure 4). Gauges and colours allow the user to assess the relative performance of a strategy against the others.

PROMETHEE-CLOUD

The tool aims at helping decision-makers to choose between various planning alternatives by means of Multi-Criteria Analysis (MCA). The planning alternatives should first be defined and evaluated on various decision-relevant criteria. The weight of a criterion illustrates its relative importance. The process and aim of the MCA are explained in detail in [Multi-Criteria Analysis of Water Resources Planning Options, p. 80]. The PROMETHEE-Cloud provides the user with graphs and tables and contains elements of interactive guidance which makes it user-friendly.

KNOWLEDGE TRANSFER AND NEXT STEPS

Decision-Support tools are successful if they are relevant to the user, reliable and intuitive. A user guide was elaborated for each tool and is accessible from the Help tab of the SALAM IES. A series of tutorials should be organized with decision-makers from Palestine and Jordan for technology transfer, ensuring that the potential of all tools can be fully exploited. The Water Budget Tool and Macro Model Tool could serve as basis for still more advanced and flexible water resources system planning tools in the context of SALAM follow-up projects. Desktop DS tools developed by other project partners during the project (e.g. UFZ and UK) could be adapted and integrated as online tools in the SALAM IES. The geodata gathered in the project is open-access and beneficial for any future research in the region.

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Tourism Facilities at the Dead Sea ©Nußbaum


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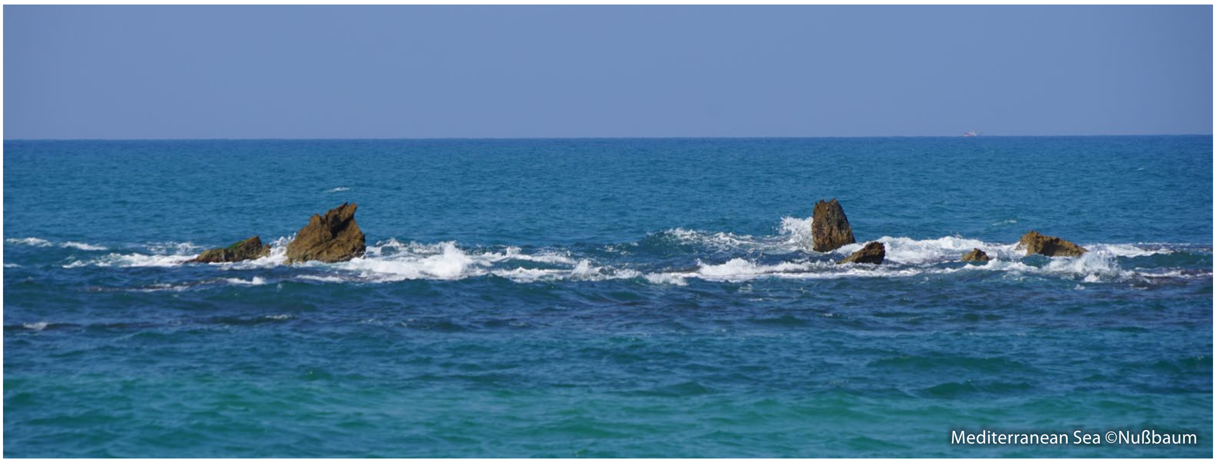
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Water Strategy Comparison and Implementation

> Assessment of Freshwater Strategies and Recommendations for Implementation


Desalination Plant in Hadera, Israel ©luciano

Assessment of Freshwater Strategies and Recommendations for Implementation

Bernd Rusteberg[1], Jacob Bensabat[2], Philippe de Bourgoing[3], Martin Sauter[3]

KEY FINDINGS

The most cost-effective water strategies consist of a combination of different water transfer projects and rely on seawater desalination at selected locations.

The assessment of alternative water strategies based on a performance matrix shows that there is a need for further improvement, e.g. with regard to the integration of renewable energies and environmental impact minimization.

Several issues still remain to be addressed before implementing a water strategy at the regional and national levels, including the issue of the resilience of water resources systems in facing the adverse effects of climate change and transboundary management of groundwater systems.

MOTIVATION

The purpose of this policy brief is to discuss the strengths and weaknesses of alternative water production and transfer strategies, as expansion options for the regional water resources system to match projected freshwater deficits until 2050. Thus, the focus is on the options developed under the SALAM initiative with respect to the positioning of seawater desalination (SWD) plants and distribution to demand centers in Jordan and Palestine, and the design of the required water infrastructure. Basic information was provided in the following specific policy briefs: [Future Freshwater Deficits in Palestine and Jordan, p. 18], [Water Production and Transfer Strategies, p. 22], [On- and Offshore Solutions for Large-Scale Seawater Desalination at the Mediterranean Coast, p. 26], [Renewable Energy for Seawater Desalination in the Middle East: Case Study Aqaba, Jordan, p. 30], [Water Conveyance System for Freshwater Deficit Coverage in Jordan and Palestine, p. 37], [Techno-Economic Assessment of Water Infrastructure Projects, p. 72], [Regional Macro-Model for Transboundary Water Resources Planning, p. 76], [Multi-Criteria Analysis of Water Resources Planning Options, p. 80]. Direct comparison of the project alternatives is intended to provide further decision support to regional decision makers and stakeholders with respect to the implementation of a regional water strategy. Finally, reference is made to the overall project, providing recommendations with regard to further studies to provide a sound decision-making basis for the implementation of water and wastewater reuse strategies on a national and regional level. Special attention should be given to the sustainable development of irrigated agriculture as well as the rehabilitation of regional ecosystems.

METHODOLOGY

A performance matrix is set up in order to better identify the strengths and weaknesses of the alternative water production and transfer strategies. The project alternatives are compared with the relevant decision criteria (indicators), including both quantitative and qualitative criteria. A comprehensive comparison of decision alternatives is achieved by considering economic, environmental and technical criteria.

The alternatives are characterized by the total length of the pipes of the transfer network, total positive elevation difference of the transfer pathways and energy demand. These indicators are not mutually independent as length and elevation difference directly impact the energy demand. The total length of the water allocation network of each option is a good indicator of the time needed to build the additional hydro-infrastructure. Qualitative technical indicators are the degree of connectivity with the existing water hydro-infrastructure and the technical feasibility of the water transfer strategy, based among others on the proximity to existing roads or power lines [Water Conveyance System

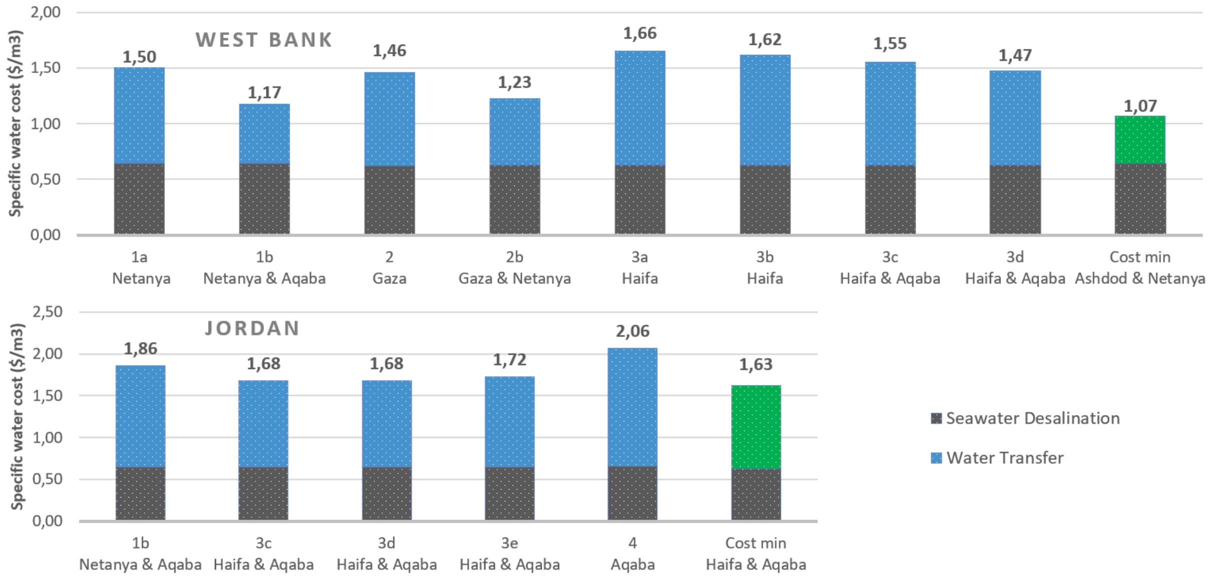

Figure 1: Specific water cost of the set of water production and transfer strategies

for Freshwater Deficit Coverage in Jordan and Palestine, p. 37]. Cost-effectiveness of the alternatives is assessed by the specific water production and transfer costs and the initial financial investment. The former criterion includes all costs including the energy for water production and transfer, which represents the largest share of the total costs [Techno-Economic Assessment of Water Infrastructure Projects, p. 72]. The environmental impact of the strategies is assessed by their CO2 emissions and by a combined criterion entitled adverse environmental impacts. The former is computed from the country-specific carbon footprint (International Energy Agency, 2022) and the energy demand of the strategy. The latter is qualitative and considers impacts during production (brine discharge, impact of construction, seawater intake) and transfer (risk of leakage, pipes productivity).

The set of alternative water production and transfer strategies is evaluated with respect to the relevant decision criteria, including their cost-effectiveness, in a participatory multilateral planning and decision-making process.

The performance matrix allows a direct comparison between the individual alternatives, here as potential expansion variants of the regional water resources system, with regard to their advantages and disadvantages and thus simplifies the decision-making process, especially in communication with political decision-makers.

RESULTS

Strengths and weaknesses of the alternatives, as expansion variants of the regional water resource system, are documented in Table 1.

Figure 1 shows the specific water production and transfer costs for each project alternative. In principle, cost-effective solutions of the regional freshwater deficit problem consist in a combination of several water transfer projects, with seawater desalination both in the Mediterranean Sea and the Red Sea. One option particularly economically attractive to Jordan involves the construction of a large-scale SWD plant at Shavei-Zion, north of Haifa Bay, the transfer of the desalinated water via a tunnel to Lake Tiberias, the construction of a hydropower plant at the lake, to generate renewable energy, and the transport of the water via the Lower Jordan Valley to demand centers in central and northern Jordan.

Option	Option	Freshwater Supply 2050 [MCM/a]	Freshwater Production	Length [km]	Total Positive Elevation Difference [m]	Energy Demand for Water Production and Transfer [kWh/m3]	Technical Feasibility [1-7]	Connectivity to Existing Water Infrastructure [1-7]	Specific Water Costs [$/m3]	Total Investment Needed [M$]	Adverse Environmental Impacts [1-100]	Specific CO2 Emissions [kg CO2 eq./m3]
Supply for West Bank	Alternative 1a	323	Netanya: 323 MCM/a	175	856	8	6	5	1,50	747	66	5
	Alternative 1b	323	Netanya: 735 MCM/a (412 to Jordan, 323 to the West Bank)	175	856	6	5	5	1,17	584	66	3
	Alternative 2	323	Gaza: 323 MCM/a	268	1233	7	4	6	1,47	1022	85	4
	Alternative 2b	323	Gaza: 185 MCM/a, Netanya: 138 MCM/a	211	1631	6	4	3	1,23	634	67	3
	Alternative 3b	323	Haifa: 323 MCM/a	253	2419	8	2	2	1,62	1580	99	4
	Alternative 3d	323	Haifa: 735 MCM/a (412 to Jordan, 323 to the West Bank)	253	2419	7	1	2	1,48	1092	99	4
	Cost-min Alternative - Palestine	323	Ashdod: 185 MCM/a, Netanya: 138 MCM/a	145	1675	5	4	5	1,07	417	60	3
Supply for Jordan	Alternative 1b	712	Netanya: 735 MCM/a (412 to Jordan, 323 to the West Bank)	762	5352	9	5	5	1,86	2980	72	4
	Alternative 3c	712	Haifa: 735 MCM/a (412 to Jordan, 323 to the West Bank)	744	4908	8	3	5	1,69	2965	81	4
	Alternative 3e	712	Haifa: 412 MCM/a, Aqaba: 300 MCM/a	744	4908	8	3	5	1,72	3331	81	4
	Alternative 4	712	Aqaba: 712 MCM/a	679	3214	10	4	4	2,07	3958	100	4
	Cost-min Alternative - Jordan	712	Haifa: 563 MCM/a, Aqaba: 149 MCM/a	883	8338	8	3	5	1,63	2816	89	4

Table 1: Performance Matrix for alternative water production and transfer strategies

By combining this option with a water transfer from a SWD plant near Aqaba, the projected 2050 freshwater deficits in Jordan can be met in a very cost-effective manner.

Regarding water transfer to the West Bank, water can be desalinated in Gaza and transported to the West Bank, which would provide Palestine control over water production. This alternative is favoured by the Palestinian stakeholders [Multi-Criteria Analysis of Water Resources Planning Options, p. 80]. A cost-effective solution combines water production near Netanya (new plant) and near Ashdod (expansion of the existing plant) [Regional Macro-Model for Transboundary Water Resources Planning, p. 76]. This latter solution is less expensive than the former given the shorter distance between the SWD plants and the demand centers. The freshwater deficits in the Gaza Strip are to be matched by a local SWD plant regardless of the transfer solution selected.

Significantly higher investment costs are associated with a system expansion on the Jordanian side than on the Palestinian side. This is reflected in the total length of the network of pipelines to be constructed as well as in the topographic height differences to be overcome and the associated energy requirements. It is thus likely that implementing the water production and transfer strategies will last longer in Jordan than in Palestine. However, the pipelines to supply the West Bank must cross Israeli territory, which can significantly delay or complicate implementation due to land property rights. In this regard, there is an advantage for water production near Haifa with water transfer through a tunnel to Lake Tiberias. On the other hand, the solutions involving water transfer from Haifa via Lake Tiberias to the West Bank seem to be significantly less cost-effective. Besides, the construction of the 47 km long tunnel to Lake Tiberias makes strategies supplying water from Haifa more technically complex. Some of the strategies supplying water to the West Bank include a pipeline connecting Jenin and Bethlehem through many Palestinian settlements. These strategies have a good connectivity to the local water distribution networks.

Table 1 shows that further improvement is required with respect to the design of the planning options, e.g. the integration of renewable energies and the minimization of environmental impacts. All strategies need to be further optimized in terms of CO2 emissions. The strategies with the lowest CO2 emissions are generally those with the lowest energy demand. However, as the carbon emission factor in Jordan is lower than in Israel, water transfer through Jordan results in less emissions. Sea water intake and brine discharge from offshore plants have fewer adverse environmental impacts than onshore plants. Longer water transfer routes are associated with a higher risk of leakage and lower pipe productivity. This basic environmental analysis should be completed in a future study by an extensive environmental impact assessment.

The performance matrix is integrated to the [SALAM Information and Expert System, p. 86]. Figure 2 shows the user-friendly interface of the tool.

CONCLUSIONS

A wide range of alternative strategies for solving the region's freshwater deficit problem have been delineated, investigated and evaluated by relevant decision criteria, including cost-effectiveness. For the first time, implementable and economically viable transboundary water production and transfer solutions are available to prevent an expansion of the emerging water crisis in the Middle East.

However, as detailed below, several issues need to be addressed before implementing a water strategy at regional and national levels, including the resilience of the alternative water resources systems after expansion to climate change and transboundary groundwater and system management. Special attention should be given to ecosystem rehabilitation via a combined management of conventional and nonconventional water resources. Furthermore, the comparison of alternative water strategies based on a performance matrix shows that there is a need for further optimization of system planning options, e.g. with regard to renewable energies integration and environmental impact minimization.

The methods, concepts and decision support tools developed in the SALAM initiative for sustainable planning of water resources systems based on seawater desalination and water transfer could be transferred to and used in neighbouring countries such as Egypt or comparable regions.

STEPS TOWARDS IMPLEMENTATION

The second phase of the SALAM project initiative focused on regional water resources system planning. Subsequently, different solutions were sought with respect to the necessary expansion of the regional water resources system to meet projected freshwater deficits until 2050. The decision-support tools developed for this purpose, such as the so-called regional macro model, are mostly based on a static (time invariant) approach.

With regard to the definition and implementation of a regional water strategy, it is now necessary to investigate how these system planning options have to be managed in order to ensure a sufficient degree of supply reliability, especially for drinking water supply. Intermediate storage of water should be studied to cope with the increasing climate change impacts. This requires a dynamic analysis of the system and its optimal control as well as detailed predictions on the effects of climate change on water resources and drought development and their impact on water availability and supply. The analyses show that in terms of climate neutrality, environmental impacts and cost effectiveness further efforts are necessary to optimize system solutions.

Rehabilitation of the Lower Jordan River and Dead Sea will only be possible through transboundary and conjunctive management of the region's renewable water resources, particularly groundwater, as well as non-conventional water

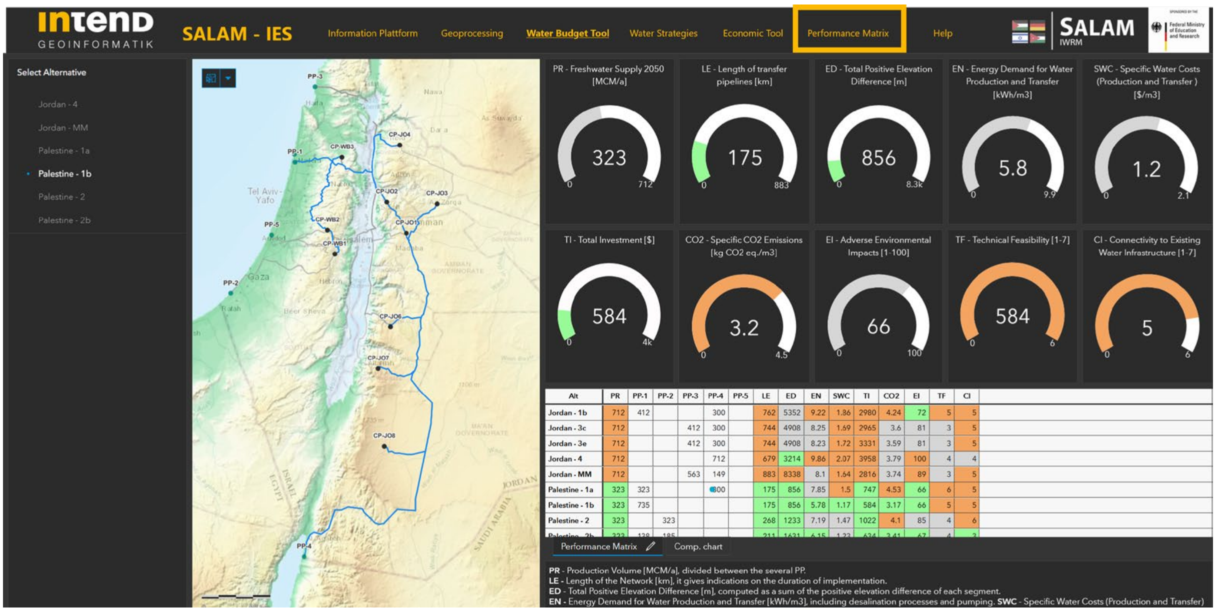

Figure 2: Interface of the Performance Matrix in the SALAM Information and Expert System. Gauges and colours allow the user to assess the relative performance of a strategy against the others.

resources. The latter include, first and foremost, wastewater resources, which must be appropriately treated for reuse. Once the water transfer is implemented, treated wastewater will represent a highly important non-conventional water budget component, together with brackish water resources, and, last but not least, water imports from seawater desalination. Dynamic system management studies and model calculations are also required to optimize the conjunctive management of conventional and non-conventional water resources on the national as well as transboundary level, both on a seasonal as well as interannual time-scale.

The irrigated agriculture sector and its sustainable development will require special attention in the future, not least because of the enormous sectoral water demand as well as the urgent need to meet food demand. In particular, it should be examined whether freshwater demand in agriculture can be further reduced by appropriate IWRM measures and how wastewater reuse for the expansion of irrigated agriculture can be implemented environmentally sound.

Water resources planning and system management are inextricably linked. Therefore, based on the studies on system dynamics and transboundary management of all water resources, important conclusions on system planning and thus on the definition and implementation of a regional water strategy can be expected.

In order to validate innovative SALAM concepts and strategies, including the integration of renewable energy into the process of seawater desalination as well as wastewater reuse, it is recommended to conduct pilot as well as feasibility studies. The latter applies in particular to the water-energy-SWAP concept between Jordan and Israel developed within SALAM.

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Transboundary Strategies for the Resolution of the Water Deficit Problem in the Middle East

This brochure summarizes the key products of the second project phase (2020-2022) of the SALAM initiative, a multi-lateral collaborative research project in the Middle East funded by the German Federal Ministry of Education and Research (BMBF). The research initiative aims at developing solutions to meet the region's increasing water needs and to halt the emerging regional water crisis. The project consortium consists of 19 partner organisations from Jordan, Israel, Palestine and Germany and includes universities, research centres, consulting companies, engineering firms, water utilities and the region's national water authorities.

The water budget calculations presented show rapidly increasing freshwater deficits in demand centres of Jordan and Palestine, expected to grow well over 1 billion m^3 per year by 2050. These large volumes of freshwater can only be produced by seawater desalination. The SALAM Initiative is the first project to present feasible and cost-effective transboundary strategies as system planning options to address the water deficit problem in the Middle East. All strategies are based on seawater desalination at the Mediterranean and Red Sea and a combination of transboundary water transfer projects. This brochure compiles the most important results as specific Policy Briefs, addressing the construction of offshore seawater desalination plants, the integration of renewable energy by hydropower, solar energy generation and innovative water-energy SWAP concepts, the techno-economic analysis of hydro-infrastructure projects, the temporary storage of desalinated seawater in regional aquifers, the optimal operation of surface water resources systems, as well as the expansion of wastewater infrastructure and wastewater reuse concepts towards sustainable irrigation development and ecosystem rehabilitation.

Die vorliegende Broschüre fasst die Schlüsselprodukte der zweiten Projektphase (2020-2022) der SALAM-Initiative zusammen, eines multi-lateralen internationalen Forschungsverbundvorhabens, gefördert vom Bundesministerium für Bildung und Forschung (BMBF), mit Partnern aus Deutschland und der Nahost-Region. Die Forschungsinitiative setzte sich zum Ziel, Lösungen zu entwickeln, den massiv steigenden Wasserbedarf der Region zu decken, um der absehbaren regionalen Wasserkrise Einhalt gebieten zu können. Das Projektkonsortium umfasst 19 Partnerorganisationen aus Jordanien, Israel, Palästina und Deutschland, bestehend aus Universitäten, Forschungszentren, beratenden Unternehmen, Wasserversorgern sowie nationalen Wasserbehörden aus der Region.

Bereits aus den Ergebnissen der BMBF-finanzierten SMART-Vorhaben (2006-2018) wurde deutlich, dass der Wasserbedarf nicht über die knappen erneuerbaren Wasserressourcen der Region gedeckt werden kann und dass die Region auf Wasserimporte angewiesen sein wird. Neue Wasserbilanzrechnungen zeigen schnell steigende Süßwasserdefizite in Jordanien und Palästina, die bis zum Jahr 2050 voraussichtlich auf mehr als 1 Milliarde m^3 pro Jahr anwachsen werden. Wie bereits im Rahmen der SALAM Pilotstudie festgestellt wurde, können diese großen Wasservolumina ausschließlich über Meerwasserentsalzung bereitgestellt werden. Als erstes Projekt stellt nun die SALAM Initiative alternative Lösungen vor, mit denen das prognostizierte Süßwasserdefizit gedeckt werden kann. Sämtliche Ausbauvarianten des regionalen Wasserressourcensystems basieren auf der Meerwasserentsalzung am Mittelmeer und Roten Meer und einer Kombination von grenzüberschreitenden Wassertransfervorhaben.

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