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BMBF IWRM R&D Programme

SMART – IWRM

Integrated Water Resources Management in the Lower Jordan Rift Valley

Final Report Phase II

Jochen Klinger, Nico Goldscheider, Heinz Hötzl (eds.)

Scientific Publishing

SMART – Sustainable Management of Available
Water Resources with Innovative Technologies

IWRM – Integrated Water Resources Management
in the Lower Jordan Rift Valley

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Part A: Kurzfassung
Part B: Executive Summary
Part C: Final Report

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Karlsruhe, 2015

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Pictures title page

1st row from left to right: Demonstration site for DWWT&R in Fuheis, Jordan; Desalination plant in Karameh, Jordan; MAR site Wala Dam, Jordan (Photos by J. Klinger);
2nd row from left to right: Teaching material for schools (provided by UFZ); SMART group, November 2012 in Karlsruhe; Geological profile and aquifer systems in Auja / Jericho, Palestinian Territories (S. Schmidt, 2014)

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Lead Editors

Dr. Jochen Klinger,
Karlsruhe Institute of Technology, Institute of Applied Geosciences,
Division of Hydrogeology
email: Jochen.Klinger@kit.edu

Prof. Dr. Nico Goldscheider,
Karlsruhe Institute of Technology, Institute of Applied Geosciences,
Division of Hydrogeology
email: goldscheider@kit.edu

Prof. Dr. Heinz Hötzl (em.),
Karlsruhe Institute of Technology, Institute of Applied Geosciences,
Division of Hydrogeology
email: Heinz.Hötzl@kit.edu

Disclaimer

Overall, the SMART project involved more than 70 researchers. This report is compiled chiefly from reporting requirements of each institution and in many cases only the responsible activity leaders are cited as authors since they submitted the input to this report. For a complete overview of involved researchers and their individual contributions in SMARTII please consult the SMART list of publication in chapter 9.1 at the end of this report.

Hinweis

Das diesem Bericht zugrunde liegende Verbundprojekt wurde mit Mitteln des Bundesministeriums für Bildung und Forschung unter den Förderkennzeichen 02WM1079-1086 und 02WM1211-1212 gefördert. Die Verantwortung für den Inhalt dieser Veröffentlichung liegt bei den Autoren.

Executive Editing & Layout Team

Felix Grimmeisen, Julian Xanke, Paulina Alfaro, David Riepl

Photo of cover: View from upper Wadi Naur above Jordan Valley (Photo taken by J. Klinger)

Authors who contributed to the Final Report

Name	Prename	Institution	Country
Abassi	Bassim	Al'Balqa Applied University	Jordan
Abbt-Braun	Gudrun	Engler Bunte Institute	Germany
Alhejoj	Ikhlas	Karlsruhe Institute of Technology	Germany
Ali	Wasim	Karlsruhe Institute of Technology	Germany
Alkhoury	William	Göttingen University	Germany
Al-Zoubi	Abdallah	Al'Balqa Applied University	Jordan
Bandel	Klaus	Consultant	Germany
Bensabat	Jakob	Environmental & Water Resources Engineering	Israel
Flexer	Akiva	Tel Aviv University	Israel
Frimmel	Fritz	Engler Bunte Institute	Germany
Fuchs	Stephan	Karlsruhe Institute of Technology	Germany
Geyer	Stefan	Helmholtz Centre for Environmental Research	Germany
Ghanem	Marwan	Palestine Hydrology Group	Palestine
Goldscheider	Nico	Karlsruhe Institute of Technology	Germany
Grimmeisen	Felix	Karlsruhe Institute of Technology	Germany
Guttman	Joseph	Mekorot, Israel National Water Co.	Israel
Haaken	Klaus	University of Bonn	Germany
Hameideh	Arwa	Jordan University Amman	Jordan
Heinz	Ingo	Consultant	Germany
Hötzl	Heinz	Karlsruhe Institute of Technology	Germany
Jarra †	Ayman	Palestinian Water Authority	Palestine
Jawad	Hasan	Al-Quds University	Palestine
Kaempgen	Benedikt	Karlsruhe Institute of Technology	Germany
Karablie	Emad	Arab Technologist for Economical and Environmental Consultation	Jordan
Kemna	Andreas	University of Bonn	Germany
Klinger	Jochen	Karlsruhe Institute of Technology	Germany
Lee	Mi-Yong	Helmholtz Centre for Environmental Research	Germany
Leicht	Miriam	Karlsruhe Institute of Technology	Germany
Lienhoop	Nele	Helmholtz Centre for Environmental Research	Palestine
Marei	Amer	Al-Quds University	Palestine
Momani	Thair	Ministry of Water and Irrigation	Jordan
Müller	Roland	Helmholtz Centre for Environmental Research	Germany
Rahman	Azizu	Göttingen University	Germany
Riepl	David	Digitale Informationssysteme GmbH	Germany
Ries	Fabian	University of Freiburg	Germany
Rödiger	Tino	Helmholtz Centre for Environmental Research	Germany
Rusteberg	Bernd	Göttingen University	Germany
Sahwneh	Julia	Jordan University Amman	Jordan
Salameh	Elias	Jordan University Amman	Jordan
Salman	Amer	Arab Technologist for Economical and Environmental Consultation	Jordan
Saravia	Florencia	Engler Bunte Institute	Germany
Samhan	Subhi	Palestinian Water Authority	Palestine
Sauter	Martin	Göttingen University	Germany
Sawarieh	Ali	Karlsruhe Institute of Technology	Germany
Schmidt	Sebastian	Göttingen University	Germany
Schmidt	Natalie	Technologiezentrum Wasser	Germany

Name	Prename	Institution	Country
Schweder	Christine	Stulz-Plan Aqua	Germany
Seder	Nayef	Ministry of Water and Irrigation	Jordan
Shomar	Basem	Birzeit University	Palestine
Siebert	Christian	Helmholtz Centre for Environmental Research	Germany
Studenroth	Sabine	University of Heidelberg	Germany
Subah	Ali	Ministry of Water and Irrigation	Jordan
Tamimi	Abed	Palestinian Hydrology Group	Palestine
Tiehm	Andreas	Technologiezentrum Wasser	Germany
V. Afferden	Manfred	Helmholtz Centre for Environmental Research	Germany
Wolf	Leif	Karlsruhe Institute of Technology	Germany
Wolff	Heinz-Peter	Quasir	Germany
Xanke	Julian	Karlsruhe Institute of Technology	Germany
Yahya	Alfred	University of Heidelberg	Germany
Yellin-Dror	Annat	Tel Aviv University	Israel
Zemann	Moritz	Karlsruhe Institute of Technology	Germany

SMARTII Project Coordination

Main Coordinator	Deputy Coordinators	
Prof. Dr. Nico Goldscheider Karlsruhe Institute of Technology Institute of Applied Geosciences, Adenauerring 20b 76131 Karlsruhe, Germany Phone: +49 (0) 721 608 45465 Fax: +49 (0) 721 606 279	Prof. Dr. Martin Sauter Department of Applied Geology Göttingen University Goldschmidtstrasse 3 37077 Göttingen, Germany Phone: +49 (0)551 39 79 11 Fax: +49 (0)551 39 93 79	Prof. Dr. Roland Mueller Helmholtz Centre for Environmental Research (UFZ) Permoserstr. 15 04318 Leipzig, Germany Phone: +49 (0)341 235 30 00 Fax: +49 (0)341 235 2885

SMARTII CONSORTIUM

Germany

- Karlsruhe Institute of Technology (KIT), Institute of Applied Geosciences, Division of Hydrogeology
- Helmholtz Centre for Environmental Research – (UFZ)
  - Centre for Environmental Biotechnology
  - Department Catchment Hydrology
  - Department of Economics
- University of Göttingen, Geoscience Centre, Department Applied Geology (GU)
- DVGW - Research Center at the Engler-Bunte-Institut (EBI), Karlsruhe Institute of Technology (KIT)
- DVWG- Water Technology Center (TZW), Karlsruhe,
- Heidelberg University, Institute of Earth Sciences (UH)
- Training and Demonstration Centre for Decentralized Sewage Treatment (BDZ)
- ATB Umwelttechnologien GmbH, Porta Westfalica (ATB)
- Huber SE, Berching (HUBER)
- Stulz-Planaqua GmbH, Bremen (SPA)

Israel

- Tel Aviv University, Department of Geophysics and Planetary Sciences (TAU)
- Ben-Gurion University of the Negev, J. Blaustein Institute for Desert Research, Beer Sheba (BGU)
- Mekorot Water Company Ltd., Tel Aviv (MEK)
- Environmental & Water Resources Engineering, Haifa (EWRE)

Jordan

- Ministry of Water and Irrigation, Amman (MWI)
- Jordan University, Amman (JUA)
- Al-Balqa’ University, Salt (BALQ)
- Arab Technologist for Economical and Environmental Consultation, Amman (ATEEC)
- ECO-Consult, Amman (ECO)
- NAW - Nabil Ayoub Wakileh & Co., Amman (NAW)

Palestinian Territiories

- Palestinian Water Authority, Ramallah (PWA)
- Al-Quds University, Department of Earth & Environmental Sciences, Jerusalem (QUDS)
- Palestinian Hydrology Group, Ramallah (PHG)

SUB-PROJECTS THAT CONSTITUTED THE SMART INITIATIVE SPONSORED BY THE FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF)

Cooperative Research Project: IWRM Israel (ISR), Jordan (JOR), Palestine (PAL): Integrated Water Resources Management in the Lower Jordan Rift Valley: SMART – Sustainable Management of Available Water Resources with Innovative Technologies – 2nd Project Phase

- Sub-project 1: Coordination, capacity building, aquifer recharge; Karlsruhe Institute of Technology (KIT), Institute of Applied Geosciences, Division of Hydrogeology; grant number: 02WM1079
- Sub-project 2: Data base, waste water treatment and reuse, socio-economy; Helmholtz Centre for Environmental Research - UFZ, Centre for Environmental Biotechnology (UbZ); grant number: 02WM1080
- Sub-project 3: Water resources assessment, aquifer recharge; University of Göttingen, Faculty for Geoscience and Geography, Geoscience Centre, Department Applied Geology; grant number: 02WM1081
- Sub-project 4: Elimination of emerging pollutants by membrane bioreactor and groundwater recharge processes, DVGW German Technical and Scientific Association for Gas and Water - Water Technology Center (TZW); grant number: 02WM1082
- Sub-project 5: Technologies - Brackish water; DVGW German Technical and Scientific Association for Gas and Water at the Engler-Bunte-Institute, Chair of Water Chemistry and Water Technology, Karlsruhe Institute of Technology (KIT); grant number: 02WM1083
- Sub-project 6: Membrane bioreactor; Huber SE, Berching; grant number: 02WM1084
- Sub-project 7: Decentralized sewage treatment systems by SBR technologies, ATB Umwelttechnologien GmbH, Porta Westfalica; grant number: 02WM1085
- Sub-project 8: Gaza, assessment of waste water treatment and reuse, Heidelberg University - Faculty of Chemistry and Earth Sciences - Institute of Earth Sciences; grant number: 02WM1086
- Sub-project 9: Membrane pilot plant for brackish water treatment and desalination, STULZ-PLANAQUA GmbH, Bremen; grant number: 02WM1211
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On behalf of the whole SMART group we want to thank the language service at the Public Relations and Marketing Department (PKM) of the KIT, namely Maike Schröder for her excellent work at reviewing this report.

PART A

KURZFASSUNG

Edited by: Jochen Klinger, Nico Goldscheider

Einführung

Die Jordanregion zählt weltweit zu den Regionen mit der geringsten Wasserverfügbarkeit und es herrscht allgmeiner Wassermangel. Die angestrebte wirtschaftliche Entwicklung, das überdurchschnittliche Bevölkerungswachstum in der Region und die Folgen des Klimawandels werden die vorhandenen Wasserressourcen in den kommenden Jahren noch stärker unter Druck setzen. Die Aufnahme und Versorgung von Flüchtlingen aus Krisengebieten wie z. B. Syrien stellen für die Jordananrainer weitere Herausforderungen dar. Die Umsetzung eines Integrierten Wasserressourcen Managements wird als mögliche Handlungsstrategie zur Lösung dieser Aufgaben angesehen.

Das Bundesministerium für Bildung und Forschung (BMBF) finanziert unter Bezugnahme auf die von den Vereinten Nationen ausgerufene Dekade „Water for Life“ (Resolution 58/217 vom Dezember 2000) sowie der vereinbarten „Millenniumsziele“ eine Fördermaßnahme zum Integrierten Wasserressourcenmanagement (IWRM) in Problemregionen (siehe:

http://www.bmbf.wasserressourcen-management.de/).

In diesem Rahmen wurde das gemeinsam von den deutschen Hauptpartnern, dem Karlsruher Institut für Technologie (KIT), dem Umweltforschungszentrum Leipzig – Halle (UFZ) sowie der Georg-August Universität Göttingen (GU) eingereichte Forschungsprojekt SMART (Sustainable Management of Available Water Resources with Innovative Technologies) mit der Projektregion Unteres Jordantal durchgeführt.

SMART steht für Sustainable Management of Available Water Resources with Innovative Technologies und ist ein multilaterales interdisziplinäres Forschungs- und Entwicklungsprojekt mit 25 Partnern aus Universitäten, Forschungszentren, Wasserbehörden, entscheidungstragenden Ministerien, externen Experten aus dem Wassersektor und Partnern aus der Industrie aus Deutschland, Israel, Jordanien und den palästinensischen Autonomiegebieten.

Die übergeordnete Zielsetzung von SMARTII war die Entwicklung eines IWRM Konzepts für die Wassermangelregion Unteres Jordantal (siehe Figure KI), um eine optimierte und nachhaltige Nutzung der verfügbaren Wasserressourcen der Region zu gewährleisten. Die hierbei entwickelten, angewendeten und validierten Modellansätze sollten im Idealfall auch auf andere wasserarme Regionen übertragbar sein. Neben konventionellen Wasserressourcen wurden auch Klärwasser, künstlich im Untergrund gespeichertes Oberflächenwasser und entsalztes Brackwasser berücksichtigt. Um eine nachhaltige Exploration und Nutzung sicherzustellen, war es eine grundlegende Anforderungen an das Projekt, entscheidungstragende Interessengruppen von Anfang an mit einzubeziehen.

Kartengrundlage: Israeli Touring Map (Survey of Israel), 1997

Figure KI: Unteres Jordantal mit der SMART Projektregion (Layout: H. Neukum / J. Klinger 2012, KIT)

Projektstruktur

Aufgrund der Größe und der breiten Ausrichtung der Forschungen wurde das Projekt in Arbeitspakete, sogenannte Workpackages, strukturiert, die jeweils Schwerpunkte des IWRM beinhalteten. Die Vernetzung der jeweiligen Workpackages untereinander demonstrierte bereits den integrierten Charakter des Projekts (siehe Figure KII)

Auf den ersten Blick scheint SMART von der Demonstration von Wasseraufbereitungstechnologien dominiert gewesen zu sein. Auf den zweiten Blick werden jedoch die IWRM relevanten Beiträge aus den Bereichen der Wasserforschung, Ausbildung von technischem und akademischen Personal, Wissenverbreitung und -verwertung deutlich.

Eine der übergeordneten Zielsetzungen von SMART war es, den zuständigen Behörden und Ministerien alle relevanten Information bereitzustellen, um den Entscheidungsprozess im Wassersektor zu unterstützen.

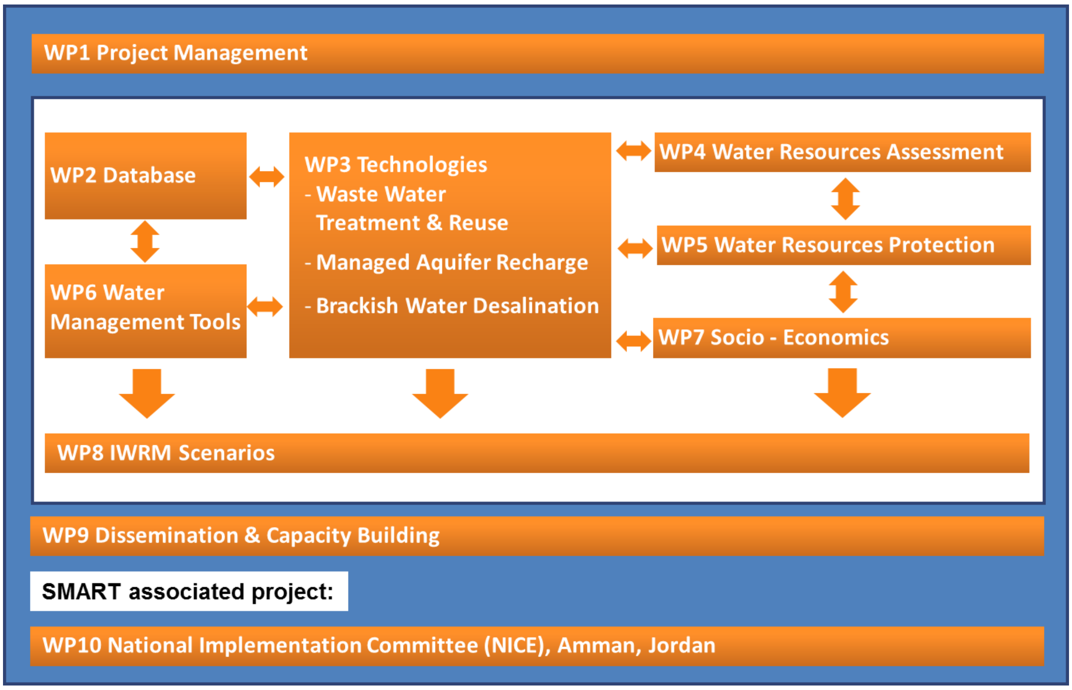

Figure KII: SMART Projektstruktur

Folgend werden die wichtigsten Aktivitäten des jeweiligen Workpackages, die Ziele und die erreichten Ergebnisse zusammengefasst.

WP1: Project Management

Neben der wissenschaftlichen Koordination als Hauptaufgabe kümmerte sich die Projektkoordination weiterhin um die administrative und operative Koordination. Kooperationen mit thematisch nahestehenden Projekten wurden kontinuierlich gefördert z.B. in Form gemeinsamer Workshops. Nach dem Kickoff in Amman 2010, wurde der wissenschaftliche Fortschritt in sechs weiteren Projekttreffen diskutiert und dokumentiert. Um die Ergebnisse in der Wissenschaft publik zu machen, waren drei der Treffen an internationale IWRM Tagungen in Dresden und Karlsruhe angebunden. Die erfolgreiche Durchführung von Detailstudien vor Ort wurde durch die jährlich übermittelten Zwischenberichte dokumentiert.

WP2: Datenbank-Management

Um die knappen Wasserressourcen für künftige Generationen zu bewahren, umfasste der IWRM Ansatz im Rahmen des SMART Projekts unter Berücksichtigung der regionalen Wasserverfügbarkeit und des Wasserbedarfs sowohl Umwelt- und ökologische Belange als auch sozio-ökonomische Aspekte,. Eine umfassende Datenbasis aller verfügbaren Parameter und Messdaten ist dabei für eine belastbare Entscheidungsunterstützung hinsichtlich eines Ressourcenmanagement unerlässlich. Das Daten- und Informationsmanagement bildet daher einen zentralen Aspekt von IWRM.

In SMART wurde ein umfassendes Datenbank Managementsystem (DBMS) mit dem Namen DAISY (Data and Information System) eingerichtet, über das Projektpartner Zugang zu verfügbaren Daten der Jordanregion, z.B. für Modellierungen oder Weiterverarbeitung mit Geoinformationssystemen, haben. So diente DAISY einerseits dazu, erhobene Daten einzupflegen, zu speichern und zwischen den Partnern auszutauschen, bot aber darüber hinaus auch eine Plattform, schnell und effizient erforderliche Daten für verschiedene Arbeitsschritte abzufragen.

Am Umweltforschungszentrum Halle-Leipzig (UFZ) wurden dazu die bei den Behörden akquirierten und die im Laufe des Projekts erhobenen Daten in eine relationale Oracle-Datenbank integriert. Über eine web-basierte graphische Benutzeroberfläche können daraus vom Benutzer Daten nach thematischen oder räumlichen Kriterien abgefragt werden. Mit Abschluss der zweiten Projektphase (Stand Juni 2014) enthielt die Datenbank etwa 2,75 Millionen Datensätze. Die Zahl der angemeldeten Benutzer und der Datenbank-Zugriffe auf DAISY steigt immer noch stetig, was eine wachsende Akzeptanz von DAISY als zentrale SMART-Datenplattform zeigt. Die Datenbank wird über die Projektlaufzeit hinaus weiterbetrieben und freigebene Datensätze sind auch für externe Interessensgruppen abrufbar (siehe: https://www.ufz.de/daisy_harvester/).

WP3-1 Dezentrale Abwasseranlagen

Mit dem Ziel eine belastbare Infrastruktur unter den Bedingungen des herrschenden Wassermangels zu schaffen, wurde im SMART Projekt die Implementierung von Forschungsergebnissen als eine Strategie für ein integriertes Wasserressourcenmanagement entwickelt. Diese interdisziplinäre Forschungsstrategie basiert auf drei Säulen:

a) Adaption von Technologien an lokale Bedürfnisse,

b) die auf Entscheidungsunterstützung ausgerichtete ökonomische Effizienz und

c) Wissenstransfer auf verschiedenen Ausbildungsebenen und Disziplinen.

Die Zielsetzung des WP3-1 im SMART Projekt war dabei auf die Entwicklung, Demonstration und Implementierung innovativer Technologien gerichtet. Im Bereich der dezentralen Abwasserbehandlung wurden dabei folgende Ergebnisse erzielt:

- Errichtung eines Forschungs- und Demonstrationsstandorts einer dezentralen Abwasserbehandlungsanlage in Fuheis, Jordanien.
  Hinweis: Die Tatsache, dass die Infrastruktur dabei speziell auf die lokalen Bedürfnisse zugeschnitten wurde, war ein wichtiger Aspekt beim Implementierungsprozess. Der aufgebaute Demonstrationsstandort entwickelte sich als Ort, an dem Kooperationen von Forschern angeregt und damit interdisziplinäre Synergien geschaffen wurden. Weiterhin bot er einen Rahmen für Wissenstransfer im technologischen Bereich, diente Ausbildungszwecken und stellte eine effektive Maßnahme für die Bewusstseinsschaffung der Öffentlichkeit in Bezug auf die Abwasserproblematik dar.
- Entwicklung und Anpassung von neun verschiedenen Technologien zur dezentralen Abwasserbehandlung für den ländlichen Raum hinsichtlich einer Aufbereitung, die dem Jordanischen Standard (JS 893-2006) zur Wiederverwendung behandelten Abwassers entspricht.
- Implementierung von sieben dezentralen Abwasserbehandlungsanlagen im Real-Maßstab für einzelne oder mehrere Haushalte.
- Einführung einer kompakten biologischen Reinigungsstufe (Sequencing Batch Reactor, sogenannte SBR-Technologie) mit einer Pflanzenkläranlage auf dem jordanischen Markt durch Industriepartner.
- Entwicklung eines Entscheidungshilfe Werkzeugs (Decision Support Tool) zur Sicherung ökonomischer Effizienz.

Die Implementierung der entwickelten Technologien auf regionalem Maßstab erforderte darüber hinaus ein einfach anzuwendendes Hilfsmittel zur Entscheidungsunterstützung, die Anwender (z.B. lokale Behörden, beratende Ingenieurbüros etc.) in die Lage versetzt, verschiedene Szenarien von dezentraler und zentraler Abwasserbehandlung miteinander zu vergleichen und die beste Lösung unter den lokal gegebenen Bedingungen zu identifizieren. Es wurde eine neue innovative Methodik zur Standortanalyse entwickelt, die erlaubt, hochgradig unterschiedliche, z.B. sozio-ökonomische, physische, topographische oder institutionelle Daten zusammen mit Satellitenbildern und digitalen Geländemodellen zu verarbeiten. Damit können nun die Anwendungsmöglichkeiten von dezentralen Abwasserbehandlungslösungen unter den lokalen Randbedingungen effizient eingeschätzt werden. Auf dieser Methodik wurde ein GIS-basiertes Decision Support Tool entwickelt, mit dem Szenarien und Machbarkeitsanalysen, angepasst an lokale Gegebenheiten, durchgeführt werden können. In enger Zusammenarbeit mit offiziellen Behörden- und Interessenvertretern, Industrie und Geldgebern wurden Abwasserbehandlungs-Szenarien auf regionalem Maßstab in Jordanien entwickelt sowie ökonomisch und technologisch evaluiert. Die Anwendung dieses Werkzeugs hat großes Potential, deutschen Unternehmen Zugang zu neuen Märkten im Wassersektor zu gewähren.

- Um gesellschaftliche und politische Grenzen, die eine Implementierung erschweren, zu überwinden und Impulse für eine nachhaltige Entwicklung zu geben, wurden Maßnahmen für einen Wissenstransfer, ausgerichtet auf verschiedenen Interessengruppen, umgesetzt.

WP3-2: Managed Aquifer Recharge

Managed Aquifer Recharge (MAR) bzw. die sogenannte kontrollierte Grundwasseranreicherung ist eine Schlüsseltechnologie, um die Wasserknappheit in Gebieten mit hohem Frischwasserbedarf, sowie begrenzter Wasserverfügbarkeit, die häufig zeitlich hoher Variabilität unterliegt, abzuschwächen. Der Ansatz ist, überschüssiges Wasser, wie Regenwasser oder gereinigtes Abwasser, in Grundwasserleitern zwischenzuspeichern und es in Zeiten begrenzter Wasserverfügbarkeit wieder zu und zur Verfügung zu stellen. In SMARTII wurden in der Projektregion verschiedene Methoden zur künstlichen Grundwasseranreicherung demonstriert und weiterentwickelt. Die Untersuchungen im WP3-2 beinhalteten umsetzungsorientierte Forschungen in ausgewählten Testgebieten, die Bewertung der relevanten biogeochemischen Prozesse bei der Bodenpassage, sowie sozio-ökonomische Bewertungen zur Durchführbarkeit von MAR Maßnahmen. In den folgenden sechs Testgebiete wurden MAR Maßnahmen getestet und demonstriert untersucht: Wadi Wala (Infiltration in Karstaquifer), Deir Alla (alluvialer Schwemmfächer als Grundwasserspeicher), Wadi Eshe künstlich erstellter Speicherraum entlang eines Flusslaufs und Wadi Kafrein (flächenhafte Infiltration für Schotterfeld) in Jordanien und Wadi Auja (Bohrlochinfiltration) und Beni Zeid (Versickerung von aufbereitetem Abwasser) in der Westbank.

WP3-3: Brackwasserentsalzung

Das Untere Jordantal verfügt über eine relativ große Menge an Brackwasser, das nicht genutzt, aber aufbereitet werden könnte, um dieses als Frischwasser für Bewässerungszwecke oder als Trinkwasser zu nutzen. Es wird in flachen und tiefen Grundwasserleitern angetroffen, meist in unmittelbarer Nähe zu nicht oder nur gering salinarem Frischwasser.

Auf Grundlage früherer Studien der ersten SMART Phase und der Erkundung von geeigneten Standorten zur Brackwasserentsalzung, wurden detaillierte Studien zu den Brackwasservorkommen und den Aufbereitungstechnologien in Jordanien und den Palästinensischen Autonomiegebieten durchgeführt. Die Untersuchungen umfassten u. a. die Lokalisierung von Gebieten mit unterschiedlichen Brackwasservorkommen (Grundwasser, Quellen) in Bezug auf Qualität und Quantität.

In den Palästinensischen Autonomiegebieten wurde sich auf zwei Hauptstandorte im westlichen Teil des Jordantals konzentriert (Jericho und Auja): Insgesamt wurden mehr als 50 Wasserproben labortechnische analysiert. Auf Grundlage der Wasserqualitätsdaten wurde die Anwendung der Nanofiltration (NF)-Membranen zur Brackwasserbehandlung untersucht. Die verfügbaren Brackwassermengen westlich des Jordans werden auf etwa 45 MCM / a geschätzt.

Auf jordanischer Seite wurde in Karameh im Jordantal eine Entsalzungsanlage mit innovativer energieschonender Membrantechnologie (Niedrig-Druck-Umkehrkehrosmose, LPRO) von dem deutschen Industriepartner STULZ-PLANQUA (SPA) in Kooperation mit dem Engler-Bunte-Institut (EBI) und dem Ministerium für Wasser und Bewässerung Jordanien (MWI) ausgelegt und gebaut. Die Anlage wurde im März 2014 erfolgreich in Betrieb genommen und förderte unter Spitzenlast 16 m^3/h brackisches Grundwasser. Mit einer Ausbeute von 50 % wurden etwa 8 m^3/h Frischwasser (Permeat) und ca. 8 m^3/h Konzentrat produziert. Das entsalzte Frischwasser wurde dem Wasserversorger zur Versorgung der umliegenden Dörfer zur Verfügung gestellt. Somit wurde die Anlage direkt in den Wasserversorgungkreislauf implementiert. Nach der Ausbildung des technischen Personals wurde die Anlage an das Jordanische Ministerium für Wasser und Bewässerung (MWI) übergeben.

WP 4: Wasser Resources Assessment

Die Bewertung der Oberflächengewässer und Grundwasserressourcen ist die wichtigste Komponente in der langfristigen wasserwirtschaftlichen Planung im Kontext des integrierten Wassermanagements. Diese erforderliche Bewertung gibt Aufschluss über die durchschnittlich verfügbaren Wassermengen auf der Angebotsseite, deren hydrochemische Eigenschaften sowie die zeitliche Variabilität in Bezug auf Wasserdargebot und -nachfrage. Grundsätzlich gibt es zwei Hauptmethoden zur quantitativen Bestimmung vorhandener Wasserressourcen. Diese sind direkte Messung der Abflusskomponenten (Oberflächen-, Grund- und Abwasser), die Wasser Budgetierung sowie die Berechnung der Wasserhaushaltgrößen mit hydrogeologischen Modellen.

Im WP4 wurde eine integrierte Strategie verfolgt, die das Spektrum der oben genannten Methoden umfasst. Detaillierte physikalische Modelle wurden für die Einzugsgebiete herangezogen, für die günstige Randbedingungen in Bezug auf Gebietseigenschaften und Mess- und Monitoringlogistik existieren.

Für die meisten Einzugsgebiete wurden flächendifferenzierte, vorwärtsgewandte hydrologische Modelle angewandt: J2000g für die Teileinzugsgebiete Al-Arab (Jordanien) und Qilt (Westbank), TRAIN-ZIN für Teileinzugsgebiete und Auja (Westbank) und Wadi Kafrein (Jordanien). Diese Modelle wurden vor allem mit Zeitreihen vom jeweiligen Oberflächenabfluss kalibriert. Die Wasserbilanz des Teileinzugsgebietes Wadi Shueib, Jordanien wurde unter Verwendung eines konzeptionellen Wasser Auswertungs-und Planungsmodells (WEAP21) bewertet. Der Wasserhaushalt des Einzugsgebietes der Auja Quelle (Palästinensiche Autonomiegebiete) wurde durch Berechnung der langfristigen durchschnittlichen Grundwasserneubildung anhand einer Chlorid –Massenbilanz, durch eine langfristige Zeitreihe der täglichen Neubildung, einer Kombination von flächenkonzentriertem Bodenwasserhaushalts-Modell und einem Reservoir-Modell bestimmt.

Die berechneten Wasserhaushaltsgrößen zeigen erhebliche Unterschiede zwischen den einzelnen Teileinzugsgebieten auf. Während der Langzeitniederschlag relativ gleichmäßig ist (ca. 400 - 550 mm / a), weisen Oberflächenabfluss und Grundwasserneubildung deutlich größere Unterschiede auf. Der niedrigste Anteil des Oberflächenabflusses wurde bei ca. 1 % für das Oberflächenwassereinzugsgebiet Wadi Auja für die hydrologischen Jahre 2011 bis 2013 gemessen. Im Gegensatz dazu, weisen die anderen Einzugsgebiete Oberflächenabflussanteile zwischen 3 – 7 % auf. Die Grundwasserneubildung deckt einen Bereich zwischen 13 % und 33 % für die untersuchten Einzugsgebiete ab.

WP5: Grundwasserschutz

Der Schutz von Frischwasser für die Nutzung durch den Menschen und in Ökosystemen benötigt einen ganzheitlichen Ansatz des Oberflächen- und Grundwassers sowohl in qualitativer als auch quantitativer Hinsicht. Auch wenn in der Landwirtschaft das meiste Wasser benötigt wird, hat gerade die Trinkwasserversorgung höchste Ansprüche an die Wasserqualität und sollte darum oberste Priorität genießen. Dies gilt insbesondere für aride und semiaride Gegenden mit hoher Bevölkerungsdichte und intensiver Landwirtschaft wie das untere Jordantal. Um eine sichere Trinkwasserversorgung zu gewährleisten, ist ein Multibarrierenansatz erforderlich, der folgende Elemente enthält:

- Verringerung von Verschmutzungsaktivitäten
- Implementierung von Schutzzonen
- Kontinuierliches Qualitätsmonitoring insbesondere bei Verschmutzungsproblemen
- Angepasste Wasseraufbereitung

Unter Berücksichtigung dieser Elemente befasste sich WP5 daher mit den folgenden Aspekten:

- Detaillierte Erfassung der Wasserqualität und auftretenden organischen Spurenstoffen im unteren Jordantal und einigen Seitentälern. Der Fokus lag bei der Abschätzung des Einflusses von Klärwasser auf das Grundwasser (qualitativ und quantitativ).
- Die biologische und chemische Erfassung der Oberflächenwassserqualität unter Entwicklung eines an die Region angepassten Bioindikatoransatzes für aquatische Invertebraten.
- Die Entwicklung und initiale Implementierung eines Monitorings mit hoher zeitlicher Auflösung an einer Karstquelle in Jordanien die zur Trinkwasserversorgung genutzt wird.
- Die Weiterentwicklung von Grundwasserschutzzonenkonzepten sowie die erstmalige Implementierung in Palästina unter Berücksichtigung sozio-ökonomischer Aspekte.

WP6: Werkzeuge für das Wassermanagement

Der Fokus im WP6 lag auf der Entwicklung, der Erstellung und der Anwendung von modernen (Software-) Werkzeugen als Kernelemente des IWRMs, die folgend aufgelistet werden:

- Aufbau einer webbasierte Programmumgebung mit modularem Aufbau; diese Werkzeuge, die über SMARTII hinaus verfügbar sind, dienen der Visualisierung und Analyse von relevanten Daten im Kontext des Wasserressourcenmanagements (sogenanntes Decision Support System, DSS)
- Programmierung einer Plattform zur Risikoabschätzung
- Programmierung eines webbasierten, semantischen Wissensmanagements (DROPEDIA)

Die spezifische web-basierte DSS Anwendung besteht dabei aus verschiedenen Unter-Programmen zur Entscheidungsunterstützung und Berichtserzeugung, die die Erstellung von Wasserwirtschaftsplänen erleichtern sollen. Es beinhaltet folgende Anwendungen:

- Speicherung von relevanten Daten und Informationen zu unterschiedlichen Wasserressourcen und -qualitäten auf beliebigen räumlichen Maßstäben (HYDROBUDGETS).
- Werkzeuge zur Entscheidungsunterstützung wie AHP (Analytischer Hierarchieprozess) und ELECTRE-III – Diese Verfahren sind Teil einer Multikriterienoptimierung und bestehen aus Ableitungen des Pareto Sets und einem Szenariengenerator für eine optimierte Erstellung von Wasserwirtschaftsplänen.
- Die Anwendungen wurden im Wadi Nueima, Kalya und Auja angewendet und getestet.

Das DSS ist über das Internet zugänglich unter: www.ewre.com/smartdss/publish.htm

DROPEDIA (http://dropedia.iwrm-smart2.org/index.php/Main_Page) ist ein webbasiertes Wissensmanagementsytem, dass dem WIKI Vorbild folgt. Es ermöglicht die Integrierung von erhobenen von Daten und Informationen auf unterschiedlichen Detailebenen (informative Daten, Modelldaten über WEAP, etc.). DROPEDIA ist mit der DAISY Datenbank (siehe WP2) verbunden. Daten können direkt gesucht und für weitere Analysen genutzt werden.

WP 7: Sozio-ökonomische Analysen

Sozio-ökonomische Wassermanagementstudien decken ein breites Spektrum von Fragen in Bezug auf die wirtschaftliche Effizienz, die finanzielle Erschwinglichkeit, soziale Gerechtigkeit und Beteiligung verschiedener Wassernutzer ab. Probleme in Bezug auf Wasserknappheit und die häufig schlechte Qualität verfügbarer Wasserressourcen können ernsthafte negative Auswirkungen auf das Wohlbefinden der Gesellschaften haben. Derartige Bedingungen herrschen derzeit in Palästina und Jordanien und rufen nach einer schnellen effektiven und nachhaltigen Verbesserung der Wassernutzung. Die sozio-ökonomischen Studien in SMARTII umfassten eine Wirtschaftlichkeitsbewertung verschiedener Wasser-Management-Optionen sowie die Überprüfung der institutionellen Rahmenbedingungen für deren Umsetzung. Die Ergebnisse der Fallstudien, insbesondere in Palästina in Unteren Jordantal, zeigten deutlich die Abhängigkeit von den örtlichen Gegebenheiten. Hier dient das Beispiel der Entsalzung von Brackwasser zusammen mit der Wiederverwendung von gereinigtem Abwasser-und Regenwassernutzung in Jericho im östlichen Teilgebiet. Durch die Maßnahmen kann der Anstieg des Wasserbedarfs zur Bewässerung in den nächsten 20 Jahren gedeckt werden. Mit Kosten-Nutzen-Analysen (KNA) wurden effektive Maßnahmen abgeleitet und die zeitlichen Abfolgen zur Umsetzung dieser Projekte abgeschätzt. Die KNA stellt ein wichtiges Werkzeug zur Identifizierung der effizientesten und wirtschaftlichsten IWRM Strategie dar. Doch vor allem in Palästina sind viele institutionelle Barrieren für die Etablierung eines effizienteres Wasser-und Abwassermanagement zu überwinden.

WP8: IWRM Szenarien

WP8 fokussierte sich auf die Bereitstellung von Planungskriterien auf der Teileinzugsgebietsebene und die Integration der Ergebnisse aus anderen Arbeitspaketen in kombinierte IWRM-Ansätze. Nationale- und regionale Szenarien, die das Ergebnis von mehreren internationalen Forschungsprojekten sind, boten den Ausgangspunkt für die Prognosen zur Entwicklung im Wassersektor der SMART Untersuchungsgebiete.

Die Reduzierung der zusammengeführten Szenarien, zeigte aufgrund der ausgeprägten Heterogenität der ausgewählten Untersuchungsgebiete, die Notwendigkeit zusätzlicher lokaler Informationen. Die endgültig festgelegten, quantitativen und qualitativen lokalen Szenarien, kombinieren unter Berücksichtigung der jeweiligen Wasserstrategie, die nationalen Annahmen auf dem Wassersektor und die spezifischen Einschränkungen der ausgewählten Gebiete. Die Ergebnisse zeigten, dass die Ausgangslage und die Schlüsselfaktoren des Wassersektors in der Westbank und Jordanien sich deutlich in den Teileinzugsgebieten unterscheiden. Anhand der Szenarien wurde zudem gezeigt, dass die Unterschiede in Zukunft noch deutlicher werden. Szenario Annahmen und quantitative Ergebnisse wurden in dem öffentlich zugänglichen SMART IWRM-Wiki DROPEDIA eingefügt.

Ein Gesamtbericht über IWRM Strategien auf lokaler Teileinzugsgebietsebene konzentriert sich auf zwei unterschiedliche Ansätze. Die Ansätze dienen der Identifikation von vorrangigen Wasserbewirtschaftungsmaßnahmen in Bezug auf die Wasserinfrastruktur und -technologien auf der lokalen Fallstudienebene, um den steigenden Wasserbedarf auf beiden Seiten des Jordans zu decken. Alternative IWRM-Strategien, als kombinierte Maßnahmen, werden anhand von Leistungsindikatoren miteinander verglichen.

Der SMART-Ansatz im Wadi Shueib basierte vor allem auf dynamischen Wasserhaushalteinschätzungen, die mit Hilfe von WEAP für verschiedene Entwicklungsszenarien durchgeführt wurden. Die Bewertung alternativer Wasserbewirtschaftungsansätze, die angepasste Bewirtschaftungsoptionen beinhalteten, erfolgte unter Berücksichtigung von Schlüsselindikatoren, die auf der Jordanischen Wasserentwicklungspolitik basieren.

Für die palästinensischen Untersuchungsgebiete wurde ein allgemeiner konzeptioneller Ansatz entwickelt und in beispielhafter Weise im Wadi Auja angewendet.

WP9: Wissensverbreitung und Aufbau von technischen und institutionellen Kapazitäten

Wissensverbreitung: Im SMART-Projekt wurde von Anfang an ein Augenmerk auf den Aufbau und die Pflege von forschungsstrategisch erforderlichen Netzwerken gelegt. Dies wurde unter anderem durch ein projektbezogenes Doktorandenprogramm, in dem insgesamt 26 Doktoranden aus Israel, Jordanien, Palästina und Deutschland teilgenommen haben, umgesetzt. Die Einrichtung und Betreuung dieses Netzwerks stellt den nachhaltigsten Effekt des SMART-Projekts dar, da viele der ehemaligen Doktoranden mittlerweile Entscheidungs- und Führungspositionen in Behörden und Ministerien bekleiden.

Darüber hinaus wurde ein wissenschaftliches Austauschprogramm zum fortlaufenden wissenschaftlichen Austausch zwischen den Partnern aus der Region und Deutschland gefördert. So nahmen allein in SMARTII zehn Wissenschaftler aus Israel, Jordanien und Palästina an diesem Programm teilweise bis zu 3 Monate teil.

Die Veröffentlichung und Verbreitung der Ergebnisse sind in mehr als 55 Veröffentlichungen in internationalen ISI - Fachzeitschriften dokumentiert. Darüber hinaus kann SMART auf mehr als 110 Beiträge bei internationalen Konferenzen zurückblicken und fungierte zum Beispiel bei der IWRM Konferenz in Dresden und Karlsruhe als Co-Organisator.

Capacity Development: Zur Überwindung von gesellschaftlichen und politischen Barrieren, die eine nachhaltige Implementierung behindern, und um Impulse zur nachhaltigen Entwicklung in den verschiedenen sozialen Schichten zu setzten, wurden konzentriert Aktivitäten zur Bildung von technischen und institutionellen Kapazitäten für wichtige Stakeholder-Gruppen umgesetzt. Diese umfassten

- im schulischen Bereich, die Entwicklung einer Unterrichtseinheit für Grundschulen: "WATER FUN – hands, minds and hearts on WATER FOR LIFE!", die die Kernaspekte der Wasserqualität, des Wasserverbrauchs, der Abwasserbehandlung und -wiederverwendung in Jordanien und Palästina thematisieren.

  Die Unterrichtseinheit wurde bei 118 Lehrern und Schulen aus Jordanien und den Palästinensischen Autonomiegebieten eingeführt. An den Unterrichtseinheiten nahmen annähernd 5.000 Schüler teil.
- Am Ministerium für Wasser- und Bewässerung Amman, Jordanien wurde ein Implementierungsbüro eingerichtet. Die Hauptaufgabe bestand darin, einen interministeriellen Ausschuss zu etablieren (National Implementation Committee for Decentralized Wastewater Management – NICE), in dem die rechtlichen und institutionellen Rahmenbedingungen für die flächendeckende Implementierung von dezentralen Abwasseraufbereitungsanlagen in Jordanien entwickelt wurde.
- Basierend auf diesem Dialog und dem Feedback aus dem Workpackage WP3-1 wurde die Implementierung von dezentralen Abwasseraufbereitungsanlagen in "Jordaniens Wasserstrategie 2009-2022" integriert und der dazugehörende "Aktionsplan“ angepasst.

PART B

EXECUTIVE SUMMARY

Edited by: Jochen Klinger, Nico Goldscheider

Introduction

SMART is a multilateral and interdisciplinary research project of 25 partners from universities, research centers, water authorities, decision relevant institutions, external experts as well as industry partners from Germany, Israel, the Palestinian Territories and Jordan. The SMART initiative is in its second project phase while the investigations of SMART I from 2006 to 2010 are documented in the project report phase 1 (Wolf & Hötzl, 2011). The SMART project itself was built upon the German-Israeli-Jordanian-Palestinian (GIJP) project which was also funded by the BMBF from 1997 – 2004 and concentrated on a regional hydrological, hydrogeological and hydrochemical database as well as on exemplary detailed studies along a section from Jerusalem to Amman crossing the Jordan rift valley (see Figure I and Hötzl, Möller & Rosenthal 2009).

Figure I: The Lower Jordan Valley - overview of the SMART project area. (Layout: H. Neukum / J. Klinger 2012, KIT)

In SMARTII, which was initiated in 2010, the overall goal is to develop an IWRM concept for the Lower Jordan Valley to ensure an optimized and sustainable use of all water resources in the region (DoW, 2010). Ideally, the developed, applied and validated concepts should be transferable to other regions suffering under natural and/or manmade water scarcity. Besides conventional water resources, unconventional water resources are taken into account, such as treated wastewater, temporally stored surface water and desalinated brackish groundwater. To ensure a sustainable exploitation and use of the results gained through the research investigations, the involvement of decision-making stakeholders was one of the basic requirement in planning the project.

Structure and objectives of the SMART project

Due to its size and the wide field of research activities SMART was divided into subprojects or more specifically into work packages addressing IWRM relevant issues. The IWRM character of SMART is illustrated in the structure of the project (Figure II) showing the all work packages and their interdependencies.

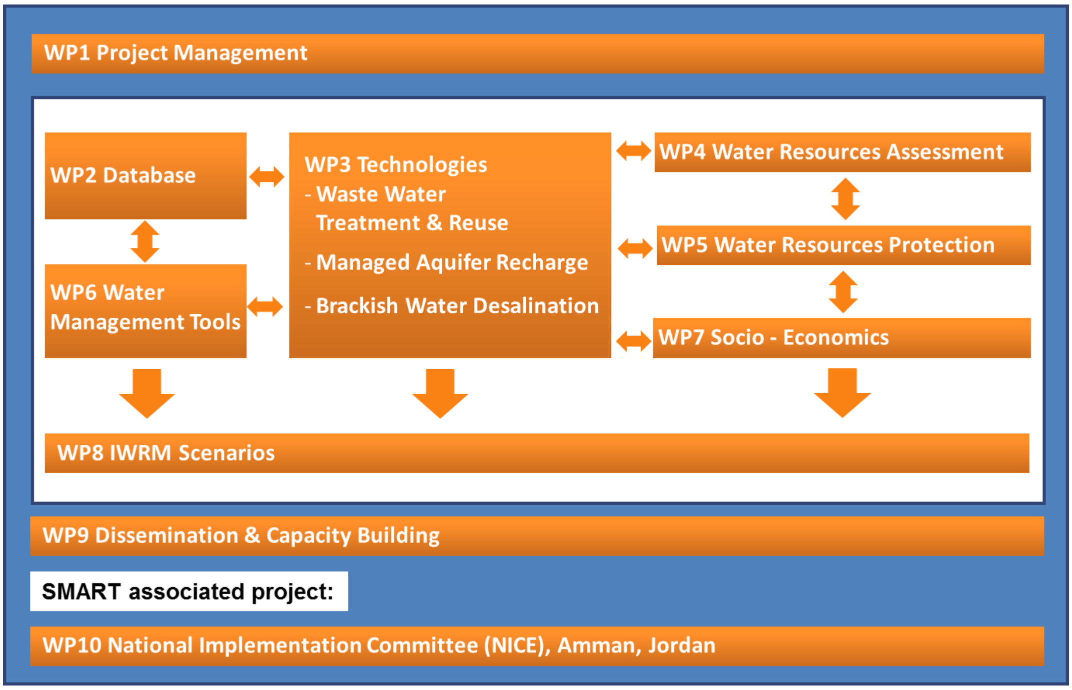

Figure II: Project structure of SMART

Even though the project is dominated by technology demonstration and implementation it has substantial components of research and development, education, dissemination and capacity building. It is one of the overall goals of the project, that the stakeholders and the local authorities are provided all necessary information and data needed for a sustainable decision making process.

The executive summary lists the goals and key achievements which were obtained in the respective workpackages.

WP1: Project coordination

The project coordination included the administrative, operational and, as the most important task, the scientific coordination of the works of SMARTII. The cooperation with thematically associated projects was continuously promoted and could be nicely demonstrated in mutually performed workshops. The progress of the scientific works was presented and discussed at in total seven scientific coordination meetings (SCM), including the Kick-off meeting in Amman, which took place in 2010. To reach a wider scientific community, in particular the projects funded also within the funding priority of the Federal Ministry for Education and Research on Integrated Water Resources Management (IWRM), three of SCMs were tied to the international IWRM conferences in Karlsruhe and Dresden. Furthermore the successful development of site specific studies was additionally examined by controlling the annually submitted interim reports. Both of them main proposers and subcontractors were obliged to submit these reports in February each year.

WP2: Data base management

The Integrated Water Resources Management (IWRM) of SMART accounts for environmental, eco-systems, socio-economy, water provision and demand management to conserve the water resources for future generations. For a decision-making in natural resources management a profound database of all available variables and measurements is essential. The data and information management are a key issue for an IWRM. In SMART a comprehensive database management system (DBMS) called DAISY (Data and Information System) was set up to efficiently supply all partners with input-data for establishing systems and system (Modeling, Geographical information systems - GIS). The DBMS is designed to be a data platform for assembling, storing data and its sharing between partners, in lodge to ensure proper, effective and quick supply of data and info required for the implementation of the various project tasks. All implemented data are incorporated into the integrated relational DBMS which is based on an Oracle-system at the Helmholtz-Centre for Environmental Research - UFZ. The DBMS makes them available via a personal internet-portal and an interface of a GIS platform. A web based graphical user interface (GUI) for data queries was established. In the meanwhile a sum of 2 million data of the region is available in the information base. The number of users and daily access counts are rising permanently as the consciousness of the DAISY data gets more and more recognized.

WP3-1 Decentralized Wastewater Systems

Within the SMART-project, the research strategy “Implementation Research” was developed with the goal to establish resilient infrastructure for managing water resources under scarcity conditions and within an integrated water resources management approach. This interdisciplinary research strategy is based on three pillars: a) technology adaptation to local requirements, b) decision support focusing on economic efficiency and c) capacity development for different educational levels and academic fields. The core element of the SMART project is “innovative technologies”. In the area of decentralized wastewater management the following results have been achieved:

Establishment of a research and demonstration site for DWWM systems in Jordan: The fact that infrastructures are tailored to local conditions makes them important modules in the implementation process. Furthermore, the site has been established not only as a research platform stimulating cooperation between researchers, thus generating cross-disciplinary synergies but also a location for technical and educational capacity development as well as measures to enhance public awareness on wastewater issues.

Development and adaptation of 5 different DWWM technologies towards a treatment performance that complies with the Jordanian Standard (JS 893-2006) for the reuse of wastewater. Implementation of 7 DWWM systems at real scale for individual households and group solutions. Introduction of the Wetland- and SBR-technology on the Jordanian market by our industrial partners. Development of a decision support tool to secure economic efficiency. A new and innovative methodology for site analysis was developed which allows to integrate highly diverse data, i.e. economic, social, physical, topographic, institutional data along with satellite imaging and a digital land elevation model in order to effectively asses DWWM system solutions under local conditions.

Based on this methodology, a GIS-based decision support tool was developed, with which scenario and feasibility analyses can be performed fitted to local conditions. In close cooperation with government officials, stakeholders, industry, and development banks GIS-based wastewater management scenarios at regional scale in Jordan were generated and assessed, both economically and technologically.

In order to overcome further societal and political barriers that impede implementation and to set impulses towards sustainable development on different social strata, capacity development activities that targeted different and essential stakeholder groups were realized.

WP3-2 Managed Aquifer Recharge (MAR)

MAR is seen as a key technology to mitigate water shortage in areas characterized by high freshwater demand, limited water availability and high temporal variability. The basic idea is to store excess water, such as storm water or treated wastewater, in aquifers and use it in periods of limited water availability. Diverse technologies were tested and further developed in the SMARTII project region. Activities in WP3-2 included studies of implementation-oriented research in selected test sites, an evaluation of relevant biogeochemical processes during the soil passage, as well as socio-economic considerations concerning the feasibility of MAR implementation. The following six test sites were studied during SMART: Wadi Wala, Deir Alla, Wadi Kafrein and Wadi Eshe in Jordan and Wadi Auja and Beni Zeid in the Palestinian Territories.

WP3-3: Brackish Water Usage

The Lower Jordan Rift Valley has relatively high quantities of non-exploited brackish water sources which can be treated to generate fresh water. They can be found in the shallow and deep aquifers, mostly coexisting with fresh water. A detailed study was carried out to integrate the amount, locations and quality of brackish water resources in the study area based on previous studies as well as exploration of sites for brackish water utilization. Efforts were made to locate sites for utilization of brackish water from the various sources in order to produce preliminary forecast and recommendation of the volume and salinity of water that can be explored from each site. Accurate endorsements can be achieved only by future detail survey.

In the Palestinian Territories two main areas were focused (Jericho and Uja) in the western part of the Jordan valley. From these two areas more than 50 water samples were characterized. According to the water data the application of nanofiltration (NF) membranes to treat the brackish water sources was investigated. Furthermore the potential of brackish water that may be desalinated was assessed to be approximately 45 MCM/a.

In the framework of SMARTII an innovative water treatment plant, which uses elaborated cutting-edge techniques to treat the challenging ground water from the test site (Karameh) in Jordan, was built by STULZ-PLANQUA (SPA) in cooperation with the Engler-Bunte-Institute (EBI). The plant can generate about 10 m^3/h of treated water – enough to irrigate a large area or to supply a small village. The input of well water will be 16 m^3/h. In March 2014, the water treatment plant was taken into operation. After the training of the technical staff the plant was handed over to Jordanian Ministry of Water and Irrigation.

WP 4: Water Resources Assessment

The assessment of surface water and groundwater resources is the most important component in the long-term planning of an integrated water management scheme since it provides information on the sustainable average available input on the supply side, its hydro-chemical properties as well as its temporal variability. Generally, there are two main methodologies employed to quantitatively determine available water resources. These are Direct Measurement of discharge (surface / groundwater / wastewater) components and water budgeting and forward modelling with hydrological models. In SMART, an integrated strategy was followed that includes the spectrum of the above listed methodologies. Detailed catchment based physical models were built for those catchments, where favorable conditions with respect to catchment characteristics and measurement logistics existed. For most catchments distributed hydrological forward models were applied: J2000g for sub-basins Al-Arab and Qilt, TRAIN-ZIN for sub-basins Auja and Kafrein. These models were mainly calibrated using time series of surface runoff. The water balance of sub-basin Shueib was assessed employing a conceptual water evaluation and planning model (WEAP21). Water balance of the Auja spring catchment was assessed by calculating long-term average recharge by a chloride mass balance and a long-term time series of daily recharge could be derived by a combined lumped soil water balance and reservoir model.

The calculated water balance components display considerable differences among the sub-basins. Whereas mean long-term precipitation is relatively uniform (ca. 400–550 mm/a), surface runoff and groundwater recharge exhibit larger differences. The lowest fraction of surface runoff was measured at ca. 1 % for the surface catchment of Wadi Auja for the hydrological years of 2011–2013. In contrast, for the other catchments surface runoff fractions between 3–7 % were assessed. Groundwater recharge displays a range between 13 % and 33 % for the analyzed catchments.

WP 5: Water resources protection

The protection of freshwater for human use and ecosystems requires a holistic approach, encompassing surface water and groundwater resources in terms of both quality and quantity. Agriculture is often the largest freshwater consumer, while drinking water requires the safest quality and should be assigned first priority. This applies particularly to arid and semiarid regions with high population density and intense agriculture, such as the Lower Jordan Valley (LJV). The provision of safe drinking water requires a multi-barrier approach, including the following elements: General reduction of polluting activities, implementation and enforcement of appropriate protection zones, continuous monitoring of water quality and contamination problems and adapted drinking water treatment.

Within WP5 following main aspect were addressed: A detailed evaluation of water quality and trace contaminants in the Lower Jordan Valley and side Wadis, with a focus on wastewater impacts on groundwater resources. An evaluation of chemical and biological surface water quality, including the development of a bioindicator approach using aquatic invertebrates, specifically adapted to the LJV region. The development and initial implementation of continuous monitoring techniques at a karst spring in Jordan that is connected to the regional drinking water network. The advancement of groundwater protection zoning concepts, with initial implementation in the Palestine territories, including a socio-economic assessment.

WP6: Water management tools

The focus within WP IWRM tools was put on the development, deployment and application of state of the art tools for IWRM, including: 1) a web-based, set of visual tools for water resources management – the SMARTDSS platform developed by EWRE; 2) a web-based visual platform for knowledge management – the DROPEDIA application (developed by KIT); 3) a platform for risk assessment (developed by EWRE) and 4) comparative analysis of the performance and applicability of software applications for the simulation of variably saturated flow and reactive transport (prepared by EWRE).

The SMART DSS application: These web-based applications consist in a number of decision making and reporting tools aimed at facilitating the derivation of water plans. It comprises following tools: An application for storing data and information relevant to the inventory of water resources of various qualities at any spatial aggregation scale (HYDROBUDGETS), Decision making tools such as the implementation of the AHP and ELECTRE-III, a procedure for Multi-criteria optimization based on the derivation of the Pareto set and a scenario Generator, implementing an approach for the derivation of optimal water plans. The tools have been extensively applied and demonstrated to the Wadi Nueima, Kalya, and Wadi Auja basins.

The DSS can be deployed from the internet (www.ewre.com/smartdss/publish.htm).

DROPEDIA (http://dropedia.iwrm-smart2.org/index.php/Main_Page) is a web-based knowledge management system based on the WIKI paradigm. It enables integrating collected data and information at various levels of refinement (informative data, modeling data through WEAP, etc.).

DROPEDIA is linked to the DAISY database platform developed by UFZ and can mine the data and information required subsequent analysis.

WP 7: Socio economics

Socio-economic studies on water management address a broad spectrum of issues related to different performance goals, such as economic efficiency, financial affordability, social equity and participation. Water problems in terms of shortage and poor quality can have serious adverse impacts on the welfare of communities and societies. Such a situation prevails currently in Palestine and Jordan calling for improvements in water utilization. Subject of the socio-economic studies prepared for SMARTII is the economic efficiency of various water management options and the institutional prerequisites for their implementation. In Palestine, particularly at the West Bank, and at the lower Jordan River Valley priority is given to the following technical solutions

The results of the case studies clearly showed it depends on the local conditions. E. g. at the Jericho east sub-basin, for instance, the desalination of brackish groundwater together with the reuse of treated wastewater and storm water harvesting should be short-listed. By these measures, the increase in water demand of irrigated agriculture can be met in the next 20 years. By applying the cost benefit analysis (CBA) advises can be derived, in which temporal sequence these projects should be realized in order to implement the most economically efficient IWRM strategy. However, especially in Palestine, many institutional barriers for a more efficient water and wastewater management are to be overcome. As a prerequisite, the reforms of the water governance need to be done.

WP 8: IWRM Scenarios

WP8 focused on the provision of planning criteria on the sub-basin level and the integration of results from other work packages into combined IWRM approaches. Nation- and region wide scenarios, which were the result of several international research projects, provided the starting point for prognoses on the water sector development in the research areas of SMART.

Downscaling of these aggregated scenarios by regression analysis highlighted the necessity of additional local information due to the distinct heterogeneity of the selected research regions. The finally established, quantitative and qualitative local scenarios combined the framework of national assumptions on the water sector with the specific constraints in the selected locations. Results show, that the situation and key aspects of the water sector of the West Bank and Jordan differ significantly between the basins. The scenarios indicate that such differences will become even more distinct in the future. Scenario assumptions and quantitative results were inserted in SMARTs public IWRM-wiki DROPEDIA.

An aggregated report on IWRM strategies at Local Sub-Basin Level, Sensitivity analysis and performance assessment focused on two different SMART engineering and scientific approaches to identify priority interventions (measures) in terms of new hydro-infrastructure and water technologies on local case study level in order to cover increasing water demands on both sides of the Jordan river. Alternative IWRM-strategies, as combined measures, are compared to each other based on performance indicators. For the Palestinian study area a generalized conceptual approach has been developed and applied in an exemplary manner to Wadi Auja. The SMART approach applied at Wadi Shueib is based on dynamic water budget assessments by WEAP for different development scenarios and alternative sets of interventions, taking performance indicators into account which rely on the Jordan water development policy.

WP 9: Dissemination and Capacity building

Knowledge Transfer: In the SMART-project, a focus was placed on building strategic network from the start. This was done inter alia through a project-related program in which a total of 26 doctoral students from Israel, Jordan, Palestine and Germany participated. The setting and the care of this network represents a sustainable use of the SMART project, as many of the former graduate students now work in decision-making leadership positions in government agencies and ministries.

In addition, a scientific exchange program (Scientific Advanced Training) has been promoted to the ongoing scientific exchange between partners from the region and Germany. This program took alone in SMARTII ten scientists from the three countries.

The publication and dissemination of the results are documented in more than 35 papers in international journals. Furthermore, SMART can look back on more than 80 contributions to international conferences and worked for example in the IWRM conference in Dresden and Karlsruhe, as co-organizer.

Capacity Development: To overcome further societal and political barriers that impede implementation and to set impulses towards sustainable development on different social strata, capacity development activities that targeted different and essential stakeholder groups were realized.

These included

- In schools: the development of a lesson for primary schools: "WATER FUN - hands, minds and hearts on Water For Life!" which focuses on the core aspects of water quality, water consumption, wastewater treatment and reuse in Jordan and the Palestinian Territories. The lesson was introduced to 118 teachers and at schools from Jordan and the Palestinian Territories. The lessons attended nearly 5,000 pupils.
- At the Ministry of Water and Irrigation Amman, Jordan (MWI), an implemtation office was established. The main task was to establish an interministerial board (National Implementation Committee for Decentralized Wastewater Management - NICE), in which the legal and institutional framework for the widespread implementation of decentralized wastewater treatment plants in Jordan has been developed.
- Based on this dialogue and feedback from the WP3-1 the implementation of decentralized wastewater treatment plants was integrated in "Jordan's water strategy 2009-2022" and the corresponding "Action Plan" adapted.

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ABBREVIATIONS AND ACRONYMS

AHP	analytical hierarchy process
BALQ	Al Balqa Applied University, Jordan
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources, Germany)
BGU	Ben Gurion University, Israel
BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research, Germany)
BMBR	biofilm membrane bioreactor
CB	capacity building
CBA	cost benefit analysis
CBS	Central Bureau of Statistics, Israel
CBL	capillary break layer
CBS	capillary break system
CEA	cost-effectiveness analyses
CL	capillary layer
CN	curve number method
DAISY	data information system
DBMS	database management system
DEM	digital elevation model
DGMS	dialog generation and management system
DI	on-surface drip irrigation
DO	dissolved oxygen
DOS	Jordanian Department of Statistics, Jordan
DPSIR	driving forces, pressures, states, impacts and responses – model
DSS	decision support system
DTS	demonstration and training site
DWWSS	decentralized wastewater systems solutions
EC	electrical conductivity
EM	Eigenvector method
EPS	extra cellular polymeric substances
ERM	earth resistivity meter
ESI	electrospray interface
EWRE	Environmental and Water Resources Engineering Inc, Israel
Fm	formation
GIJP	German – Israeli – Jordanian – Palestinian joint research project
GIS	geographic information system
GJU	German - Jordanian University, Jordan
GSC	grain size curve method
GTZ	Gesellschaft für Technische Zusammenarbeit (international cooperation enterprise for sustainable development with worldwide operations, Germany)
GUI	graphical user interface

gw	groundwater
HPC	high performance computing
HPLC-MS/MS	high performance liquid chromatography with tandem mass spectrometric detection
hr	hour
HRD	human resource development
HRU	hydrological response units
IWRM	Integrated Water Resources Management
JAMS	Jena Adaptable Modelling System
JD	Jordanian Dinar
JICA	Japan International Cooperation Agency
JRV	Jordan River Valley
JVA	Jordan Valley Authority
KfW	Kreditanstalt für Wiederaufbau
LDAP	lightweight directory access protocol
LJRB	Lower Jordan River Basin
LJRV	Lower Jordan Rift Valley
LJV	Lower Jordan Valley
LLSM	logarithm least squares method
LOQ	limits of quantification
MBMS	model-base management system
MBR	membrane bioreactor
MCDM	multi criteria decision making
MCM	million cubic meters
MEK	MEKOROT, Israel
MLSS	mixed liquor suspended solids
MPI	message passing interface
MWI	Ministry of Water and Irrigation, Jordan
O&M	operation and maintenance
OMS	operations & management support
PAPA	Palestinian Agribusiness Participatory Approach
pe	person equivalent
PHG	Palestinian Hydrological Group, Palestine
PME	Palestinian Ministry of Education, Palestine
PWA	Palestinian Water Authority, Palestine
QUDS	Al Quds University, Palestine
RDBMS	relational database management system
RO	reverse osmosis
RSCH	Ramallah Schools
SAR	sodium absorption ratio
SCS	United States soil conservation service method
SDI	sub-surface drip irrigation

SER	secondary effluent from reservoir (reservoir effluent)
SEP	secondary effluent from ponds (waste stabilization ponds)
SPE	solid phase extraction
SPSS	statistical program for social sciences
SQL	structured query language
SRT	sludge retention time
sw	sea water
T	temperature
TAU	Tel Aviv University, Israel
UF	ultra filtration
UFZ	Helmholtz Zentrum für Umweltforschung (Centre for Environmental Research), Leipzig/Halle, Germany
UG	University of Göttingen, Germany
UH	unit hydrograph
UJ	University of Jordan
UKA	University of Karlsruhe, Germany
UT	University of Tübingen, Germany
VES	vertical electrical sounding
WAJ	Water Authority Jordan
WP	work package
WRS	water resources system
WTF	groundwater table fluctuation method
WW	wastewater
WWT	wastewater treatment
WWTP	wastewater treatment plant
WWT&R	wastewater treatment and reuse

PART C

FINAL REPORT

1 INTRODUCTION

Author: J. Klinger (KIT)

The Lower Jordan Valley (LJV) (Figure 1) comprises parts of Israel, Jordan and the Palestinian Territories and is in terms of per capita freshwater availability among the water scarcest regions worldwide. The current overexploitation of the natural surface and groundwater resources already shows severe impacts on environment and society. According to the observed trends of population growth and demand, the conditions are likely to be aggravated in the coming years.

On a regional scale, capacious seawater desalination and import schemes are presently discussed as potential solutions. However, even if political and economic constraints and environmental concerns over such mega-projects can be overcome, the effective management and protection of the basins internal resources still remains a key requirement for the future water security in the LJV.

Figure 1: The Lower Jordan Valley (picture taken from the eastern escarpment in Jordan with view to the West Bank, photo J. Klinger).

In response to this situation, the responsible governments have already stated their commitment to foster IWRM as well as the required major water sector reforms. However, each of the riparian states is vastly different in terms of institutional setting and capacity, awareness, economics and water policy. Therefore, at present, there is no universally applicable basin-wide IWRM implementation concept for the Lower Jordan Valley. In spite of this, there are common denominators that unite the different riparian states. Aside from the need for reliable and comprehensive information on the temporal and spatial availability of the regions' conventional water resources, the understanding of treated wastewater, brackish groundwater and storm runoff as genuine parts of the water management cycle that induces the importance for IWRM in such water stressed regions. The critical challenges in this regard are the establishment of measures that are technically adapted to local physical conditions as well as conceptually adapted to the respective socio-economic realities.

The multilateral SMART (**S**ustainable **M**anagement of **A**vailable **R**esources with Innovative **T**echnologies) research initiative has investigated these topics in a series of local pilot studies and demonstration sites in sub-catchments in Israel, the Palestinian Territories and in Jordan. The focus within these studies was placed on decentralized wastewater treatment, brackish water desalination, managed aquifer recharge, and groundwater protection. Central objectives were the investigation of feasibility, costs and effectiveness of adapted solutions as well as the provision of necessary decision support tools and institutional capacity building initiatives. Finally, the local findings were up-scaled to a basin-wide framework by means of a regional trans-boundary water budget model and a regional data- and knowledgebase.

2 WATER RESOURCES IN THE LOWER JORDAN VALLEY

Involved Institutions: GU, UFZ, KIT, JUA, TAU, MEK, QUDS, EWRE, BALQ

Spokesmen: M. Sauter (GU), Y. Guttman (MEK)

Compiled by: M. Sauter (GU)

2.1 Introduction

Author: M. Sauter

The assessment of surface water and groundwater resources is the most important component in the long-term planning of an integrated water management scheme, since it provides information on the sustainable average available input on the supply side as well as on its temporal variability.

Generally, there are two main methodologies to quantitatively determine available water resources. These are:

a) *Direct measurement* of discharge (surface / groundwater / wastewater) components and water budgeting.

b) *Forward modeling* with

    a. Hydrological models

    b. Runoff (hydrological response unit-based) and groundwater recharge (soil moisture balance) calculations.

While the *direct measurement* provides the most detailed information and data on the water budget of a local catchment and, hence, represents the optimal basis for local planning, the results mostly cannot be generalized to a larger region because of the generally large variability of natural catchment characteristics and local catchment precipitation and evapotranspiration patterns. Furthermore, usually long-term measurements of the water budget components of precipitation, evapotranspiration, as well as surface and groundwater discharge are required. Especially in *semi-arid areas*, such as the Lower Jordan Valley, the required detailed spatially distributed long-term records are not available. A main reason is the characteristic episodic nature of precipitation and discharge. Although large efforts have been made since the 1960s to set up hydrological and climatological networks, the long-term spatially detailed data base is limited in the region because of massive floods, technical challenges, and the uncertain political situation.

Forward modeling with process models is a powerful tool for the determination of surface water and groundwater discharge since, once calibrated and validated, they allow for the prediction of the temporal and spatial variability of the discharge components. They do, however, require a large amount of detailed spatially distributed data on the catchment, e.g. hydrological soil and vegetation characteristics, relief, etc. that are not readily available. Furthermore, the above large climatological and hydrological variability, the episodic nature of precipitation events, as well as the extreme heterogeneity and contrasts in catchment characteristics (hill slope, thin soils, and bare rock, spotty vegetation) do not allow for the application of forward models.

The general answer under such conditions is to expand the region of investigation to a larger spatial and temporal scale in order to be able to obtain quantitative information for water resources assessment purposes. While this type of approach compromises on the detailed information, it can still provide the basis for long-term regional assessment. However, a prerequisite for the spatial-temporal large-scale approach is the availability of spatially and temporally integrating signals, i.e. continuous discharge via perennial rivers. In semi-arid regions this large-scale approach unfortunately reaches its limitations because of the above natural episodic climatological patterns and the extreme spatial variability of the catchment characteristics in the Lower Jordan Valley with discrete short-lived winter surface runoff via wadis and groundwater discharge at individual springs.

In SMART, an integrated strategy was followed, which covered the complete spectrum of methodologies described above. Detailed catchment-based physical models were built for those catchments, where favorable conditions with respect to catchment characteristics and measurement logistics existed. Furthermore, massive effort was made during the last six years to set up a detailed climatological and hydrological measurement network to cover seasonal as well as event variability in order to be able to evaluate long-term fragmentary records with long measurement intervals with respect to their short-term information content. These detailed long-term records were the basis for the setup of hydrological and hydrogeological models of the Jericho-Auja catchments, the Wadi Kafrein and Wadi Al-Arab areas.

2.2 Water resources components and challenges

Authors: F. Ries, S. Schmidt, J. Klinger

The basis for the assessment of water resources and long-term planning based on an integrated water resources management approach is the quantification of the individual components of the water balance. It allows the analysis of the long-term average sustainable volume of surface and groundwater discharge and provides information on the seasonal and event variability. The latter is critical for the analysis of the uncertainty of water availability, particularly for the highly variable climatic conditions, prevailing in the region of the Lower Jordan Valley.

Precipitation

In the Eastern Mediterranean, precipitation is a highly variable component of the water balance (Figure 3 and Figure 3). Most of the annual rainfall occurs between the period of October and April when barometric pressure lows arrive from the Mediterranean Sea. In addition to the pronounced seasonality and the high interannual variations of rainfall, there are strong rainfall gradients due to topographic differences. As a result, some areas (e.g. the Lower Jordan Valley) receive much less precipitation than the nearby mountainous areas. Under such conditions, a dense monitoring network is required in order to adequately measure the heterogeneous nature of rainfall. Rainfall data sets over long time periods allow for the analysis of rainfall variability over years and decades. Such networks and data sets are partly lacking in the Eastern Mediterranean, making it difficult to provide reliable information about intensity, amount, and distribution of rainfall in certain areas.

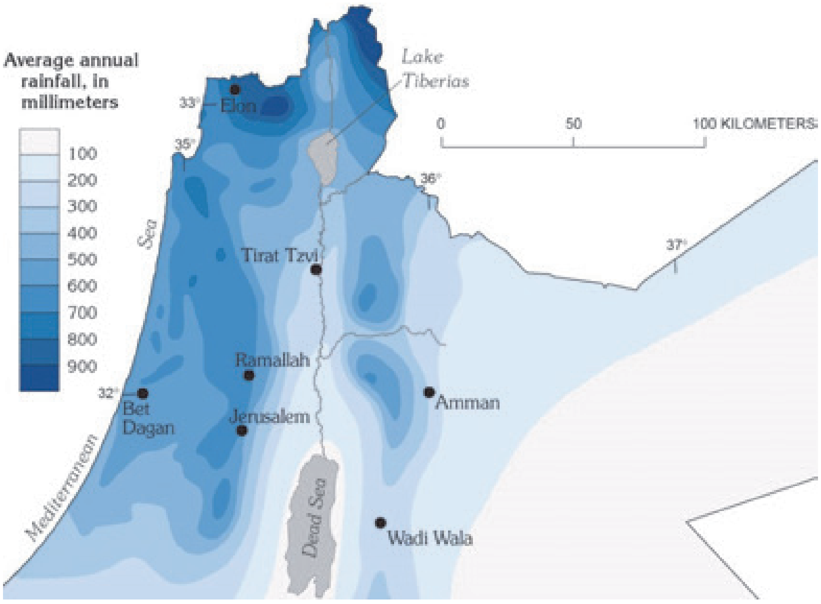


Figure 2: Long-term mean aerial precipitation distribution in the study area (from Assaf et al., 1998, modified).

The use of collected rainwater for domestic purposes is an old practice in the Eastern Mediterranean. Although the overall amount of harvested rainwater is too low to play a significant role in water supply, it could contribute to local solutions for non-potable water supply in some regions.

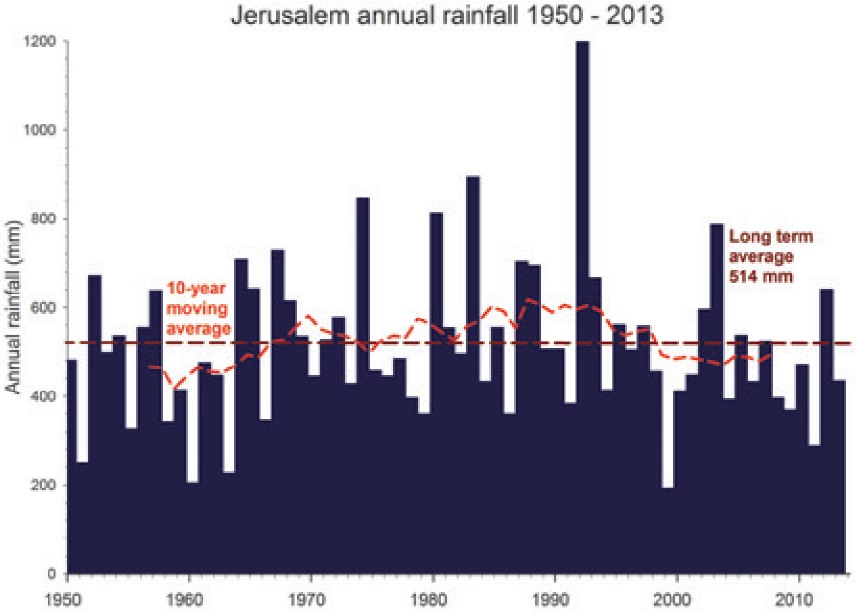


Figure 3: Long-term annual precipitation for Jerusalem central meteorological station (data source: Klein Tank et al., 2002 and IMS-Database – http://data.gov.il/ims).

Evapotranspiration

Under arid and semi-arid climatic conditions, evapotranspiration represents the largest output term in the water balance. Its components are evaporation of water from the soil surface and water transpired by plants. Despite its importance, there is no practical way to measure actual evapotranspiration routinely in the field. Therefore, potential evapotranspiration is calculated from meteorological data using empirical or physically based equations with varying data requirements. The potential evapotranspiration rates are often reduced by water availability in the soil and plant physiological processes. Hence, a term converting potential into actual evapotranspiration is required. Due to the high dependence of evapotranspiration on water availability, plant cover characteristics, and physical properties of the soil, a reliable estimation of spatial evapotranspiration taking into account the temporal variability is very challenging.

Surface Runoff

Surface runoff events (flash floods) constitute water resources in arid and semi-arid regions, which are available for a very short time periods only. They are generated when high precipitation intensity exceeds the infiltration rate of the soil surface or when rainfall amounts are higher than the water storage capacity of the unsaturated soil zone. Since rainfall amounts and intensities are strongly variable in time and space, the occurrence of surface runoff and runoff volumes are extremely variable even for hydrological years with similar rainfall totals. Due to the short duration, high intensity, and high sediment load, the accurate measurement of surface runoff is very difficult. Use of surface runoff as a water resource usually requires major civil engineering structures. Due to the high intensities, they may also be a threat to infrastructure and life. An example from Wadi Qilt is displayed in Figure 4. To date, the storage and subsequent use of surface runoff has been applied in the western part of the study area only, whereas a number of large-capacity reservoirs were constructed in the eastern part.

Figure 4: Flash flood event in Wadi Qilt on March 1, 2012 (Picture: courtesy of Palestinian Water Authority). The runoff at time the picture was taken was about 23 m³ s^{-1}.

Groundwater recharge

Since groundwater is the most important water resource component in the project region, the assessment of groundwater recharge is of primary importance to a sustainable management of the water resources, i.e. to avoid overexploitation caused by groundwater abstraction. However, in arid and semi-arid environments, the assessment of groundwater recharge is a difficult task due to the high temporal and spatial variability and the usually low recharge rates (Simmers, 1990). In the karst aquifer regions of the Middle East, the assessment of groundwater recharge is further aggravated by the presence of thick unsaturated zones which limit the observation of the water table by monitoring wells. Moreover, the presence of preferable flow pathways in the unsaturated zone prevents the application of a variety of unsaturated zone methods (e.g. Scanlon et al., 2002) that are widely applied for groundwater recharge estimations in arid environments.

As in many karst regions around the world, karst aquifer discharge in the Middle East often occurs via large springs. Karst groundwater plays a very important role in the supply of drinking water in the region. For example, the oasis of Jericho is fully dependent on the discharge of the Sultan (alternatively: Elisha) spring. 50 % of the water supply of the city of Salt is provided by local spring discharge.

Discharge of karst springs is often characterized by large fluctuations because of large variations in precipitation and, hence, in groundwater recharge. A prominent spring displaying a highly variable discharge is Auja spring, the largest freshwater spring in the West Bank (Nuseibeh and Nasser Eddin, 1995). The observed range of annual discharge is from 0.5 to 18 million cubic meter/a (MCM/a) (see Figure 5). This high variability has severe impacts on agricultural practices at the Auja village, where farming is the main type of employment (e.g. planning of seed time and general irrigation water availability).

Due to the rapid transport of pollutants in carbonate aquifers, karst springs are commonly very sensitive to anthropogenic activities. Strong urbanization and often inappropriate waste management schemes (e.g. regarding effluent and domestic waste disposal) in the recharge areas of the carbonate aquifer systems are expected to cause widespread groundwater contamination.

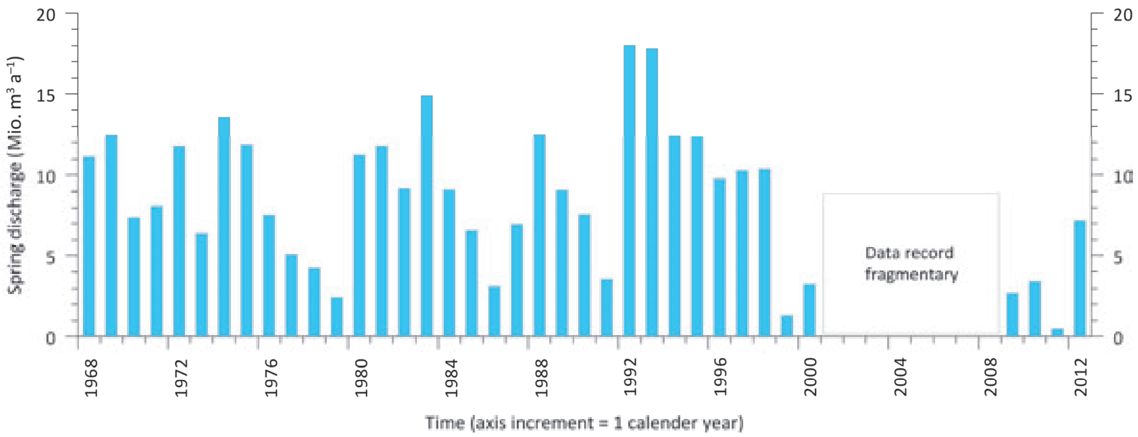


Figure 5: Annual discharge of Auja spring from 1968 to 2000 (Palestinian Water Authority database) and from 2009 to 2012 (Schmidt et al., 2014).

Water Import, Wastewater

On both flanks of the Jordan Valley, considerable amounts of water are imported from outside of the study area. On the western side, the large cities, such as Jerusalem or Ramallah, are supplied with water originating from different sources/aquifers located outside of the study area (e.g. surface water from Lake Tiberias and desalinated water produced in plants on the Mediterranean Sea shore). The reuse of treated wastewater is only partly implemented in the study area. For example, blending of treated wastewater and brackish water is applied to irrigate palm trees in the Jordan Valley (e.g. Kalya area).

2.3 Groundwater-related Conceptual Models

Authors: Y. Guttman, J. Klinger, H. Hötzl, E. Salameh

This chapter summarizes the groundwater-related conceptual models for the regional aquifers on both sides of the Rift Valley. The conceptual model may be a basis for the construction and calibration of flow and transport models and for the identification of favorable sites for the further development of groundwater resources. The study area consists of three topographic regions: The western side of the rift, the eastern side of the rift, and the rift valley itself. Geological and hydrogeological conditions (tight valley fill materials) make it extremely unlikely that direct groundwater flow occurs between the western and the eastern sides. On the other hand, groundwater of the western and the eastern regions partly drains into the valley fill sediments, if the geological conditions permit this. Therefore, the following description is divided into two sub-chapters: The western side and the eastern side.

The Western Side

The chapter below focuses on the hydrogeology of the area between Wadi Faria in the north, the southern Judean Desert in the south, the mountain crests in the west, and the Jordan River in the east. Some of the geological and hydrogeological characteristics are repeated under the sections of the individual catchment to account for the local specificities.

The Judea Group layers constitute the regional aquifer in this area with a total thickness of about 800–850 m. The aquifer is mainly composed of limestone and dolomite and some interbedded layers of marls and clays. In most of the study area, the aquifer is divided into two sub-aquifers (upper and lower). These two sub-aquifers are present throughout the study area and therefore called the "regional aquifers". An additional local aquifer exists in the vicinity of Jericho and Wadi Al-Qilt, known as the “uppermost sub-aquifer” in the Bina (Jerusalem) formation. In principle, the entire area can be divided into two regional sub-basins, each of which drains to a different outlet (see Figure 6). The borders of the northern sub-basin are the southern fault of Wadi Faria in the north, the Faria anticlinal axes in the west, the structural elements that run from the Jericho fault towards Taybeh village in the south, and the western rift valley fault in the east. In this sub-basin the two sub-aquifers (upper and lower) are separated. The outlet of the upper sub-aquifer is via springs, such as Ein Samia, Ein Auja, and Ein Fazael. Close to these springs, a few wells were drilled into the lower sub-aquifer. The water level of the lower sub-aquifer is about 200 meter deeper than the spring outlets, which makes it unlikely that groundwater in the spring catchment areas is in hydraulic contact with the two sub-aquifers, i.e. the karst springs are unlikely fed by groundwater from the lower sub-aquifer.

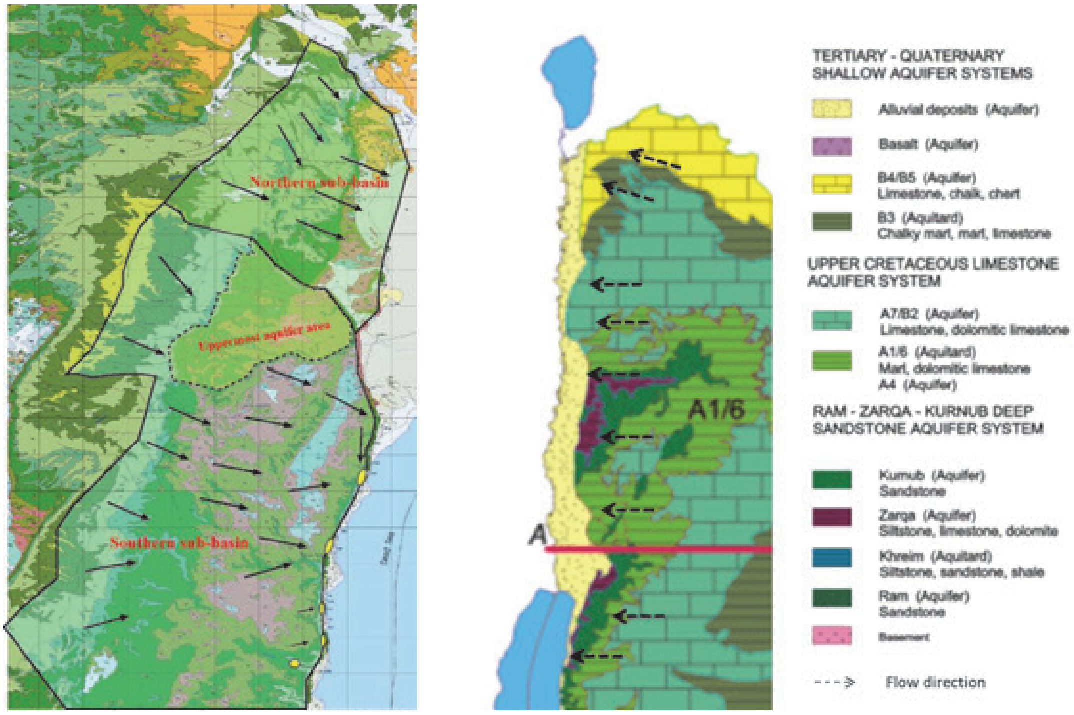


Figure 6: Overview maps of the investigated groundwater basins and groundwater flow direchtions. Left: Sub-division of the western side groundwater basin into sub-basins (map: Sneh et al., 1998); Right: Simplified hydrogeological map of Jordan, showing the spatial distribution of aquifers and aquitards (map: MWI, 2004).

The springs Ein Samia and Ein Auja are characterized by quick responses to precipitation variation caused by droughts or heavy rainy periods, which is typical of highly developed karst systems. On the other hand, the flow velocity in the lower sub-aquifer is much slower. The gradient from the recharge area to the Auja–Gitit well field located along the foothill is very steep, up to 7 % in some places. Such an unusual gradient can be explained by hydraulic barriers. The geological cross sections of the area indicate that the fault systems create places where the base of the lower sub-aquifer is above the regional water table. Those places act as a local hydraulic barrier to the groundwater flow. Groundwater flow is induced to bypass them and to flow down the gradient via discrete individual flow paths. Figure 6 displays the relationship between the geology, the tectonic pattern, the flow direction, and the recharge areas to the aquifer.

The outlet of the lower sub-aquifer is to the Rift Valley. Groundwater flow crosses the foothill, the predominant structural element in the basin. The foothill is a steep monoclinal flexure associated with the Auja–Sartaba syncline that is located east of the flexure. The groundwater flows eastwards in the Judea Group layers beneath the Auja–Sartaba syncline until it reaches the western rift fault. The groundwater crosses the fault and enters the Pleistocene formations of the rift valley fill. Well data strongly support the assumption that the flexure acts as a low permeability area, a dynamic barrier between the freshwater and saline water bodies. The freshwater body is located on the western side of the flexure, while the saline water body is situated beneath the syncline. Wells that are located along the foothill and abstract water from the same formations exhibit different total salinities and temporal variations. In some wells the salinity is stable and low and in others the salinity is characterized by seasonal fluctuations or a rising trend. The reason for the different types of behavior of the wells still remains to be found.

The second sub-basin extends from the southern border of the first sub-basin in the north to the Ramallah–Hebron anticlinal axes in the west to the southern part of the Judea Desert in the south to the Dead Sea shore in the east. This is the largest and most important sub-basin. Most of the future development programs for utilizing additional groundwater for drinking water production are based on this sub-basin. The two regional sub-aquifers mentioned above also exist in this sub-basin. The outlet of the two regional sub-aquifers is in the springs that are located along the western shore of the Dead Sea.

In the northern part of this sub-basin there is a third and local sub-aquifer, called the uppermost sub-aquifer. This sub-aquifer is located above the upper sub-aquifer. The area of the uppermost sub-aquifer extends from the southern border of the first sub-basin in the north to the southern bank of Wadi Al-Qilt in the south and from East Jerusalem in the west to the Jericho fault in the east (Figure 6). The outlets of the uppermost sub-aquifer are the springs that emerge in Wadi Al-Qilt and along the Jericho fault. Below the uppermost sub-aquifer, the "regional aquifers" are located.

In most of the second sub-basin area, the two regional sub-aquifers are hydraulically separated. But the outlets (the springs) are common to both. Therefore, a hydraulic connection between these two sub-aquifers is supposed to exist somewhere in the region. The results from the Mizpe Jericho wells, together with other hydrogeological analyses, allow the conclusion to be drawn that the hydraulic connection between the two sub-aquifers is located a few kilometers west of the spring outlets.

According to the IHS (Israel Hydrology Survey) reports, the total discharge of the springs along the western shore of the Dead Sea is between 90–95 Mm^3/a. There is a large difference in groundwater levels between the recharge area in the west and the outlets in the springs on the Dead Sea shore (750–850 meters across a distance of about 25 km). The only plausible hydrogeological explanation of the extremely steep gradient is to assume a combination of structurally tight fault elements and flow parallel to fault strike. The structural elements build a cascade that acts as a hydraulic barrier. Cross-flow of groundwater towards the springs is permitted via certain paths only.

The Eastern Side

The hydrogeological description of the eastern side of the River Jordan focuses on the area between Wadi Wala in the southern part, Wadi Shueib and Deir Alla in the center, and Wadi Al-Arab in the northern part of the SMART region.

In Jordan, especially along the escarpment of the Rift Valley, the A7/B2 aquifer (Wadi Sir-Amman Aquifer System) is the most important aquifer system, in particular in the SMART study area. The A7/B2 aquifer which is included into the Upper Cretaceous Limestone Aquifer System consists of the Upper Turonian to Campanian-Maastrichtian sedimentary sequence with the Wadi As Sir Limestone Formation (A7), the Wadi Umm Ghudran Formation (B1), and the Amman Silicified Limestone and Al Hisa Phosphorite formations (B2). It consists of limestone, dolomitic limestone, and dolomite with intercalated beds of sandy limestone, chalk, marl, gypsum, chert, and phosphorite. The aquifer can be characterized as a karstified fractured bedrock aquifer. Even though these formations have a very wide extent, thickness distribution varies significantly due to high tectonic activity. Their thickness ranges from only 40 m in Risha (close to the Dead Sea) to a maximum of 3,000 m in Fuluq (approx. 250 km east of Amman). In Wadi Wala the A7/B2 reaches a thickness of approximately 250 m, in Wadi Shueib 80–150 m. In the catchment of Wadi Al-Arab in the northern part of the study area, the sequences of A7/B2 and B4 build a multi-aquifer system. The fractured and karstified Upper Cretaceous (A7-B2) reaches thicknesses of 200 m in the outcrop areas (middle and SE' part) to more than 700 m in the NW. Above, Cenozoic deposits of the Umm Rijam Fmt. (B4), around 300 m thick, make up the uppermost sequence of the study area in Wadi Al-Arab. B4 consists of chert-rich limestones and builds a locally productive aquifer in the northwestern part of the study area (Margane et al., 2002; Sahawneh, 2011).

The springs of the Upper Cretaceous limestone are generally karst springs with appreciable discharge, examples being Hazzir, Fuheis, and Mahis in Wadi Shueib. The discharge of these springs ranges from a few cubic meters per hour (Hummar spring) up to more than a hundred cubic meters per hour (e. g. Fuheis, Azraq spring). The springs may show an immediate reaction to precipitation events in the recharge area or their reaction takes up to several days (Hötzl et al., 2009). In Wadi Shueib the response of the spring systems takes between one and two days (Grimmeisen, 2014). The chloride concentration in Wadi Shueib ranges from as low as 270 mg l^{-1} in Fuheis spring to 650 mg l^{-1} in the Hazzir spring (Guttman, 2009). However, the groundwater which feeds these springs in their respective catchments is affected by human activities and urbanization to different degrees. In some cases, leakage from water supplies and sewage systems as well as irrigation return flow lead to induced infiltration of water in the aquifers feeding the springs.

The aquifer systems in the Jordan Valley, e.g. in the area around Deir Alla in the middle part of the Jordan Valley, consist of recent alluvial fan deposits of gravels and sands interlayered with fine silt and clays. These sediments are incised in the form of wadi channels into the Young-Pleistocene Lisan Formation consisting of alternating marl, clay, chalk, silt, and gypsum layers of about 30 m in thickness (Toll et al., 2009; Salameh, 2011). Below the Lisan Formation, a Plio-Pleistocene sequence (Samra-, Aramshi -, and Al Quarn Formations in the northern Jordan Valley (Alhejoj, 2013) and Al-Ghor –Formation in the southern Jordan Valley (Al-Amoush, 2012)) of mainly clastic sediments of more than two hundred meters in thickness follows. On the Jordan side, it forms the main aquifer below the whole Jordan Valley. The water in this aquifer still is of good quality along the eastern margin, where recharge from the tributary wadis as well as from the Cretaceous aquifers occurs, but becomes more and more saline towards the central part of the Jordan Valley. Below depths of hundred meters, highly saline waters are prevailing.

2.4 Water Resources Quality

Authors: H. Hötzl, E. Salameh, J. Sahawneh

2.4.1 General Remarks

Though the lower Jordan Valley is an area of extreme water scarcity, this does not necessarily imply a low variability with respect to different water quality types. Due to the geological situation with a great variety of rocks starting igneous basalts to the whole sedimentary sequence from clastic to chemical deposits as well as due to the morphotectonic development, especially during the last 15 million years with the formation of closed deep depressions, in which thick sequences of evaporates were deposited to later generate different types of brine, a large spectrum of different water types from low to highly mineralized water with a great diversity of chemical components occurs in the region. In the past, people suffered from bad water quality. While the main water problem all around the world today is anthropogenic pollution, the dominant problem in these arid or semi-arid areas has always been the high salinity. It limited the usage of water for drinking purposes, for agricultural irrigation, or for animal feeding.

It is not surprising that the first main scientific interest in water quality in this region focused on salinization in general and on the source and origin of the salt as well as on the relevant geochemical processes, which led to such an enrichment of salt in the Dead Sea water as well as in different brines of the Jordan Valley (Hötzl et al., 2009). During several major phases of the geologic history, brines were formed, which now endanger the groundwater reservoirs in the Jordan Valley. Though evaporates occurred in the Mesozoic sequence already, the main important development for this region started with the beginning of the Dead Sea -Transform -System and the resulting formation of the deep pull-apart-basins in the Upper Miocene about 12 million years ago (Bayer et al., 1988). It continued up to recent time. These deep depressions formed marine estuaries partly by ingression of the Mediterranean Sea, lagoons, or closed basins, which under the changing tectonic pressure and climatic changes were desiccated repeatedly and filled several times (Rosenthal et al., 2006; Horowitz, 2001). Figure 7 shows the extension of the assumed three most important sea or lake phases in the JordanValley of the Sdom-Estuar, the Samara- and the Lisan-Lake.

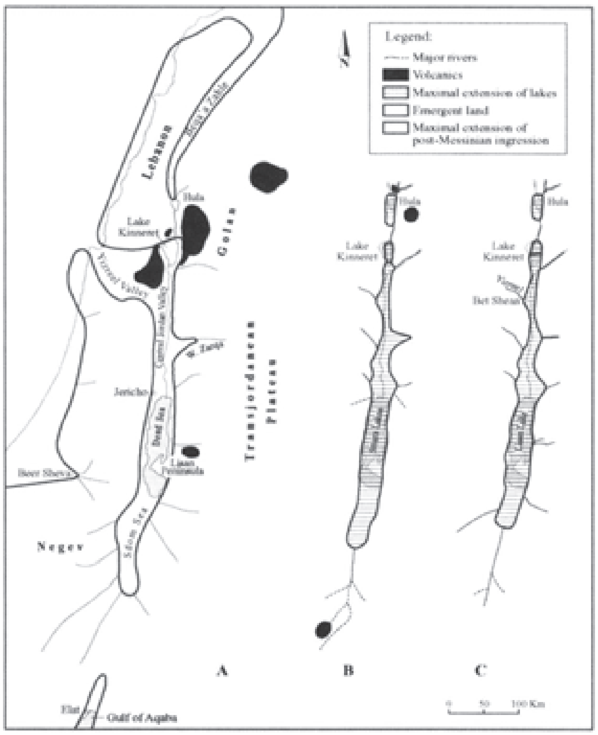


Figure 7: Schematic extensions of the former lakes in the Jordan Valley; A: Sdom Sea of Pliocene, B: Samara Lake of Mid-Pleistocene; C: Lisan Lake of Young Pleistocene (70–11 ka) (according to Horowitz, 2001).

According to Möller et al. (2012), the following generations of brines can be identifed by chemical and isotopic means:

- Primary evaporation brines of the Dead Sea type Mg>Ca.
- Primary evaporation brines of the Sodom Sea period Mg>Ca.

- Secondary ablation brines high in Na+K.
- Tertiary brines with Ca>Mg of different periods.

Together, these brines are the sources of the salinization of the groundwater in the Jordan Valley. On the other hand, the infiltration of precipitation into the underground, in contact with the soil and rocks, causes a quite different enrichment of chemical components. The mixing of these two components, the freshwater as well as the remnants of brines, finally results in the large spectrum of natural water quality types observed in the Jordan Valley.

2.4.2 Water Classification

As regards the suitability of the different water types for usage by humans, water quality is an important issue. It considers the total content of dissolved compounds, the specific dominance and relationship of the main elements, the occurrence of inorganic and organic trace substances, the bacteriological conditions, and other aspects. Regarding practical usability, the water in the Jordan Valley might be classified simply into (1) water which can be used for the domestic sector (including industry), (2) water for the agricultural sector, and (3) water which can be used for neither domestic nor agricultural purposes without previous treatment.

Surface Water

Surface water generally is a mixture of different sources, including direct precipitation surface runoff and groundwater. Nowadays, it is frequently mixed with different amounts of wastewater. Accordingly, surface water quality varies over a wide range. The main source of surface water in the Lower Jordan Valley is the Jordan River itself. Except for the Yarmouk River, most of the other tributary wadis, especially on the eastern side, hardly contribute to the Jordan River with their temporary flow.

Jordan River

The Lower Jordan River originally resulted from the outflow of Lake Tiberias with an average discharge of about 20 $m^3 s^{-1}$ with a concentration of about 600 to 700 mg l^{-1} TDS. After damming the Lake Tiberias between 1955 and 1960 and the diversion of the water to the Israel National Water Carrier, the lower Jordan River mainly contains water diverted from salt springs and sewage effluents. An additional adverse impact on the water quality resulted from the diversion of most of the water from the main tributary, the Yarmouk River, via the King Abdallah Canal, i.e. the Jordan River lost most of its freshwater component. Other water sources which now discharge to the Jordan include drainage from fish pools, wastewater, fresh and saline spring water, exfiltrating groundwater as well as agricultural return flow. This resulted in a dramatic degradation of the river water quality. While Neev & Emery (1967) mentioned chloride contents of the river waters immediately before discharging into the Dead Sea of around 350 mg l^{-1} till 1947, these concentrations amount to more than 5,000 mg l^{-1} today.

After a sampling campaign in 1996, Howari & Banat (2002) described the predominant water type of the Jordan river as earth-alkaline with increasing proportions of alkalis and prevailing chloride and a high TDS value ranging from 2,900 to 3,200 mg l^{-1}. The last detailed sampling campaign along the Jordan River was carried out between 1999 and 2001 by Faber et al. (2004). In general, the total content of the dissolved solutes close to the Lake Tiberias was about 4,500 mg l^{-1}. After a short distance, it decreased to 3,500 mg l^{-1} due to some inflow from the Yarmouk and a few springs. Then, it increased gradually to 7,000 mg l^{-1}, in extreme cases even up to about 10,000 mg l^{-1} and more at the Baptism site close to the Dead Sea (Faber et al., 2004; Geyer et al., 2013). Due to this high mineralization, the water of the Lower Jordan is used neither for domestic nor for agricultural purposes now. Partial treatment is considered, but not implemented.

Tributary Rivers and Wadis

The main tributary of the Jordan River is the Yarmouk River coming from Syria and Northeastern Jordan. Its annual average flow amounts to about 500 Mm³. Of this total amount, about 100 Mm³ are diverted to the Lake Tiberias and the Israel Water National Carrier and about 350 Mm³ per year are led towards the King Abdallah Canal in Jordan. The water samples of the Yarmouk River taken by Howari & Banat (2002) revealed predominantly alkaline water with sodium and chloride, with the TDS values ranging between 570 and 800 mg l^{-1}. Down to Deir Alla, the Canal conveys mainly the Yarmouk water with a relatively good water quality, which is pumped from Deir Alla over an elevation of about 1,200 m to the mountain plateau for water supply of Amman and surrounding cities. South of Deir Alla, discharges from the Wadi Zarqa, Wadi Shueib, and Wadi Kafrein are added to the King Abdallah Canal. These blended waters consist of the natural wadi flow, flood water, spring discharge, as well as treated and untreated wastewater. Downstream of Deir Allah, the water from the King Abdallah Canal can only be used for agricultural irrigation purposes.

The water of the tributary wadis shows a wide range of water qualities. The TDS varies between 500 and 2,500 mg l^{-1}, earth-alkaline or alkaline components and carbonates, sulfates, or even chloride may predominate depending on the rock types in their catchment and the density of settlements. Besides the normal anthropogenic pollutions, also organic emerging trace components occur (Tiehm et al., 2011). On the western side of the Jordan River, there are mainly wadis with intermittent flow conditions. During the rainy season and especially after floods, low mineralized surface water with TDS values of less than 500 mg l^{-1} are observed. During the drier periods, the share of spring water becomes dominant. These springs discharge mainly from the thick karst aquifers with dominating earth-alkali-hydrogen carbonate waters and TDS values of 400 to 800 mg l^{-1}.Due to the increasing population and numbers of settlements, where hardly any sewer systems or wastewater treatment plants exist, pollution increases with a significant rise in the sulfate, nitrate, and chloride rates. In addition a rise of trace elements, including heavy metals (Samhan et al., 2014) as well as organic emerging pollutants (Tiehm et al., 2011), was observed over the last twenty years.

Groundwater

Upper Cretaceous and Eocene Aquifers

The most important mountain aquifers on both sides of the Jordan Valley consist of the carbonatic rock sequence of the Middle and Upper Cretaceous, including the Eocene limestones especially in the northern part. The karst springs of these rocks typically discharge earthalkali-hydrogencarbonate waters with a relatively low mineralization. Most of these waters are still under-saturated with respect to calcite and dolomite (Salameh, 2002; Sawaneh, 2011). The residence time and the intensity of recharge play an important role in controlling the chemical composition of spring water. Two groups may be distinguished: On the western side, the springs in higher areas connected to faults or intercalations of less permeable chalks and marls and on the eastern side, nearly all karst springs due to the outcropping of the karst base above base level of the Jordan Valley. They are fed directly through the infiltration of meteoric water and surface runoff from the mountains with little groundwater residence time and high flow rate. The second group mainly includes the springs near the foothills of the western mountains, which are fed by the deep groundwater flow of the karst aquifers. Flow circulation in these aquifers reaches deep below the Jordan Valley base level. This group exhibits a longer groundwater residence time and, hence, a higher mineralization of sulfate and chloride, which partly results from leaching of evaporitic inclusions. However, several of these springs along the western foothills show an extreme increase in salinity, which is due to ascending brines or entrapped brines from the precursors of the Dead Sea flushed into adjacent sedimentary rocks. These karst springs are the basis of the water supply in the region and are still in use today, but most of the used water is now supplied by numerous wells, which are the reason for the overexploitation of these karst aquifers.

Triassic, Jurassic and Lower Cretaceous Aquifers

These aquifers are only important on the Jordanian side in the southern parts adjacent to the Dead Sea, where these sequences have outcrops or are present at depths of a few hundred meters. The sequence consists mainly of sandy silty rock formations with some evaporitic intercalations in the lower parts of the Triassic. Due to the low permeability of these rocks, the sequence can be considered an aquitard. Recharge occurs mainly through leakage from the Upper Cretaceous aquifers (Salameh, 2001). Only in areas where these sediments display outcrops, is the water quality characterized by low mineralization. In confined aquifers, the waters are highly mineralized and usually of brackish or even saline character due to the long residence time and probably long migration distances. They can be dominated on the cationic side by alkaline or earthalkaline components and on the anionic side by sulfate, carbonate or chloride. Due to the high salt content, these groundwaters were used neither for domestic nor for irrigation purposes. However, about ten years ago, the first brackish water desalination plants were installed in the Jordan Valley to also use this water for irrigation purposes and to apply smaller amounts as potable water.

Quaternary aquifers

The young sediments of the Quaternary are primarily restricted to the Jordan Valley itself, where they were deposited as fluvial, lacustrine or even marine sediments which filled the depression of the Jordan rift system by about 200 to 300 meters during the last 2.5 million years. The rift depression is much deeper, but in the lower part salts and other evaporates dominate, with mainly brines. Only the sandy and gravelly sediments can be classified as important aquifers. They were transported into the rift valley by the Jordan River and the numerous tributary wadis, together with silty and clayey materials, between the Mid-Pleistocene (Samara) and the Young-Pleistocene (Lisan) lake phases. These aquifers are covered over wide areas by the more or less impermeable Lisan marls with an average thickness of about 30 m. Due to this cover and the low precipitation rates of less than 200 mm a^{-1} in the Jordan Valley, the recharge to the aquifer is primarily generated by lateral inflow from the mountain fractured and karstified rock aquifers. This inflow primarily determines the groundwater quality and chemical properties. In the marginal areas of the Valley, an incoming groundwater flux of high-quality freshwater from the mountain karst aquifers can be observed at depth. This groundwater contribution varies over the long distances on the western side as well as in the northern part of the Jordanian side. In the middle and southern parts of the Jordanian side, an additional inflow of brackish water from the Lower Cretaceous and Triassic aquifers takes place. Groundwater discharge in the Quaternary aquifer is directed from both sides towards the central part of the valley, where the Jordan forms the actual base level. Along the flow path, groundwater becomes more and more saline. Reasons are irrigation backflow, seepage from the partially evaporitic Lisan, wastewater influx as well as locally ascending brines from the depth. Consequently, the water in the Quaternary aquifers shows a large spectrum of chemical compositions: From low mineralized carbonate water with less than 1,000 mg l^{-1} to brackish water with changing alkali or earth alkali dominance and TDS of 3,000 to 20,000 mg l^{-1} to highly saline water with sodium and chloride dominance due to mixture with brines with all transitions. The lower mineralized part of this groundwater is utilized to a large extent for irrigation purposes.

2.5 Hydrology and hydrogeology of selected catchments (sub-basins)

2.5.1 General remarks

As described in the introduction, surface runoff and groundwater flow can only be analyzed properly and quantified on a catchment basis, because this type of approach allows for the calculation of a water budget, i.e. it allows to check any type of model for availability of the respective data. Furthermore, catchments integrate all discharge components in space and time, provided that the respective climatological and hydrological records are available. Favorable conditions (with some restrictions) to conduct detailed investigations prevail in a number of catchments draining towards the Jordan Valley (Figure 8).

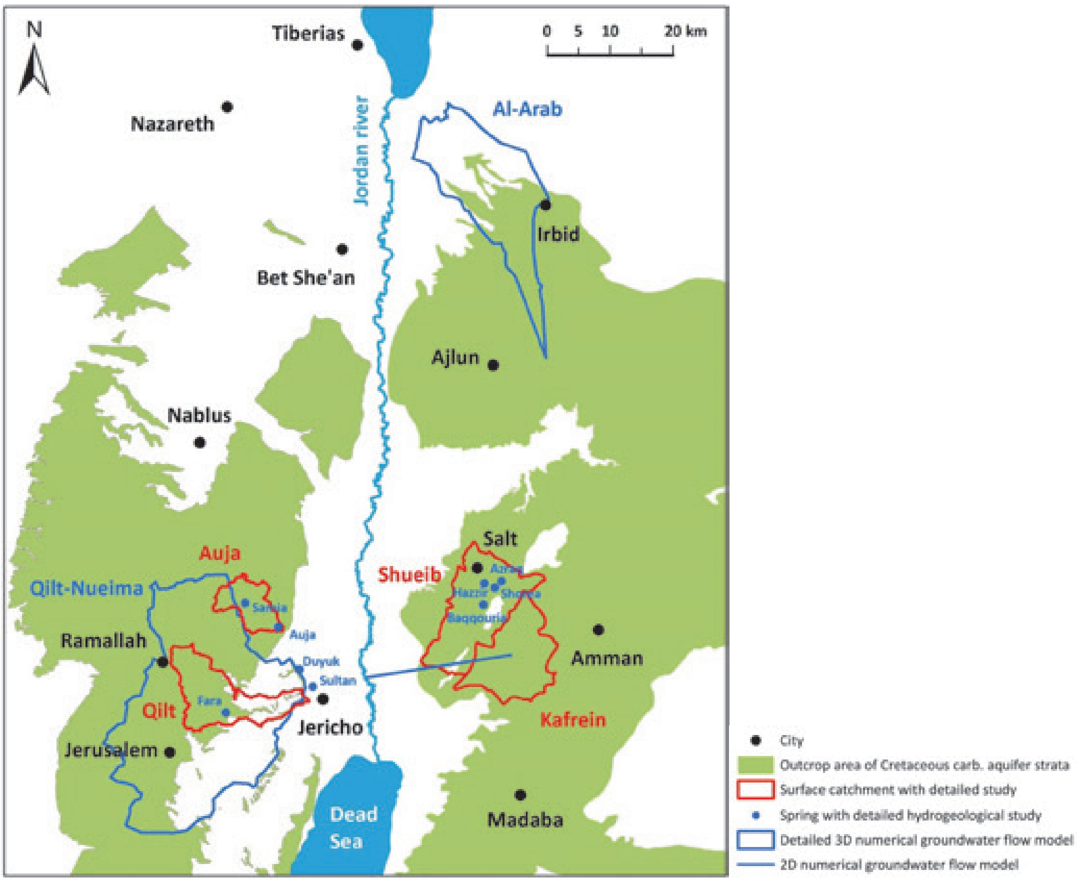


Figure 8: Overview map of the study area with the locations of the sub-basins and detailed hydrogeological studies.

2.5.2 Wadi Auja catchment

Authors: S. Schmidt, F. Ries, K. Haaken, A. Kemna, M. Sauter

2.5.2.1 Study Area and Water Resources Challenges

Sub-basin Auja is located on the western margin of the Lower Jordan Valley (Figure 8). The surface water catchment consists of three main ephemeral stream (wadi) branches. Detailed hydrological investigations focus on the middle wadi branch, where also Auja spring is located. There are two main aquifer systems in the area, the regional fractured/karstified aquifer system in Cretaceous carbonate rocks in the hilly region and a porous alluvial aquifer in the largely unconsolidated Quaternary sediments in the Jordan Valley. The groundwater catchment area of the carbonate aquifer system extends beyond the surface water divide of Wadi Auja to the North and to the West (“Northern sub-basin”, compare Figure 6 and Figure 8 (Schmidt, 2013).

Water demand comprises drinking water supply for villages (both in the hilly region and in the Jordan Valley) and for irrigated agriculture in the arid Jordan Valley. The water users are supplied from three main sources: (1) Spring water, predominantly from Auja spring, as well as water from smaller springs (Ein Samia and Ein Fazael springs), (2) abstraction from deep wells in the carbonate aquifer (depth 250–750 m), (3) abstraction from shallow wells (depth 40–100 m) in the Jordan Valley alluvial aquifer, for irrigation purposes exclusively. The main issues studied for the assessment of water resources in the sub-basin are: (1) Unknown gradient and spatial pattern of precipitation depth in the slopes from the hilly region towards the Jordan Valley (ANTEA, 1998). (2) Unknown quantity and intensity variation of surface runoff, a potential untapped water resource. (3)Unknown catchment boundaries, groundwater recharge rates, and flow systems of the different carbonate aquifer sections discharging via springs and abstracted by wells. (4) The high discharge variability of the Auja spring. (5) Groundwater contamination due to strong urbanization and inappropriate waste management schemes in the recharge areas of the carbonate aquifer system. Furthermore, the knowledge of the thickness and the hydrogeological properties of the alluvial aquifer system is essential for the use of the western alluvial basin for managed aquifer recharge as an underground water resource.

2.5.2.2 Methodology

For the determination of meteorological and hydrological parameters necessary for the system analysis and the calculation of water balance components during the two project phases and in the future, an extensive high-resolution hydrometric monitoring network was implemented (Schmidt et al, 2012; Ries, 2013). It consists of 45 stations for the continuous measurement of (number of stations in brackets): Precipitation quantity (15), environmental tracers in precipitation (3), meteorological parameters (4), soil moisture depth profiles (6), surface runoff (9), groundwater level in wells (4), spring discharge, and/or physicochemical parameters (4). To assess the long-term hydrologic system behavior, representative hydrometric and hydrochemical time series of the larger study region were measured and analyzed.

The Train-Zin hydrological model was used to simulate the temporal and spatial variability of the water balance components of surface runoff, evapotranspiration, and deep percolation in the Wadi Auja study area (Ries, 2013). Train-Zin is a combination of the soil-vegetation-atmosphere model TRAIN (Menzel, 1997) for modeling vertical water flux and the rainfall-runoff model ZIN (Lange, 1999) to simulate horizontal water transport and channel routing. The model was applied with a five-minute resolution to the winter seasons of 2010–2013.

The aquifer system of Auja spring was investigated by a hydrogeological analysis, e.g. by conducting recession and event analysis of spring flow data as well as a water balance assessment (Schmidt et al., 2014). From the results, a conceptual model of the flow system was built. The spring flow system was modeled by a combination of a lumped soil water balance model and a reservoir model. The high-resolution monitoring data of the springs Sultan, Duyuk, Auja, and Samia, together with precipitation environmental tracer data, were analyzed to evaluate spring source vulnerability and to determine recharge processes (Schmidt, 2014).

The thickness and lithology of the alluvial materials in the western alluvial aquifer basin were investigated using high-resolution 2D refraction seismics and electrical resistivity tomography as well as exploration boreholes (Haaken and Kemna, 2012). To assess the infiltration processes and possible rates, infiltration tests monitored by time-lapse electrical resistivity tomography were conducted.

2.5.2.3 Results

The precipitation quantity in the previously ungauged mid- and downslope sections of the main wadis is lower than estimated by a linear interpolation. For the first time, the accurate areal precipitation for the surface water catchments was assessed (Table 1). The results of the Train-Zin model (Table 1) show that all water balance components are highly variable depending mainly on the rainfall amount and spatial distribution, climatic conditions, and physical properties of the soil. Most surface runoff in Wadi Auja is generated by soil saturation in the upper catchment area due to excessive rainfall for short time periods during intense storm events. Surface runoff accounts for only 1 % of the total water balance. Actual evapotranspiration ranges from 63 % to 92 % and deep percolation from 8 % to 35 % of annual rainfall. Further analysis of longer time series of rainfall under different meteorological conditions could provide more insights into the variability of the system and its reaction to the expected changing climate in the Mediterranean in the coming decades.

Table 1: Modelled water balance components for three hydrological years (October to September) for the Wadi Auja surface catchment. Measured and modeled cumulative surface runoff for the entire measurement period 2010–2013 is 12.9 mm and 13.4 mm, respectively.

	2010/2011	2011/2012	2012/2013	Mean 2010–2013
Precipitation	290 mm	486 mm	400 mm	392 mm
Actual evapotranspiration	268 mm	308 mm	259 mm	278 mm
	(92 %)	(63 %)	(65 %)	(71 %)
Deep percolation (≈ recharge)	22 mm	170 mm	135 mm	109 mm
	(8 %)	(35 %)	(34 %)	(28 %)
Surface runoff	0 mm	6 mm	6.9 mm	4 mm
	(0 %)	(1.2 %)	(1.7 %)	(1 %)

The analysis of the long-term data of spring water chloride concentration allowed for the determination of the fraction of spring discharge from wastewater infiltration in the recharge area (Schmidt et al., 2013). It ranges from 0 % to about 10 % for individual spring catchments, documenting a considerable impact of anthropogenic activities on natural water quality. The mean long-term groundwater recharge fraction of precipitation of individual spring catchments could be estimated by the chloride mass balance method. It is about 34 % for the catchment of Auja spring and 25 % for the catchment of Fazael spring (Schmidt et al., 2013). With these results and the mean spring discharge, the size of the recharge area of the Auja spring was calculated to be about 50 km^2, independently of knowledge of the spatial delineation of the catchment boundaries (Schmidt et al., 2014). This value is an important input component for the water balance calculations and lumped parameter modeling.

Auja spring displays a rather unusual discharge behavior compared to many other karst springs throughout the world (Schmidt et al., 2014). It is characterized by a limited flow capacity of the karst conduit network and, hence, by an upper limit of discharge around 0.5 m^3 s^{-1}. The lumped parameter model of the Auja spring aquifer system was used to refine the conceptual model and to derive a daily time series of groundwater recharge (deep percolation). For the 45-year time series analyzed, the annual recharge rate is highly dependent on the annual precipitation sum and on the distribution of precipitation and potential evapotranspiration over the winter season. The bulk of recharge originates from high-precipitation years, whereas only small amounts of recharge are calculated during average and lower-than-average precipitation years (Figure 9 and Table 2). The model can be used to predict spring discharge and, hence, irrigation water availability after the winter season.

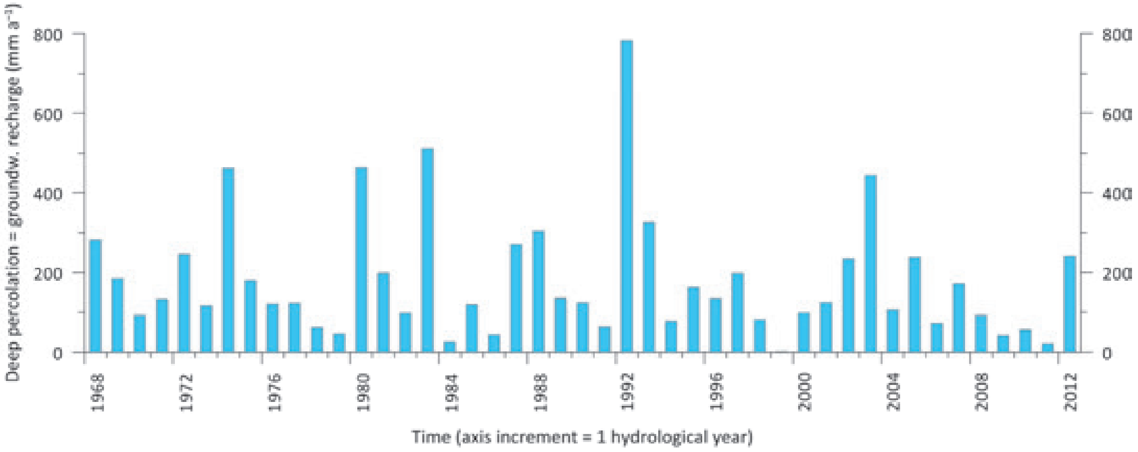


Figure 9: Time series of annual groundwater recharge in the catchment of Auja spring calculated by the reservoir model.

Table 2: Modelled water balance components for the period of 1968–2012 for the Auja spring catchment (ca. 50 km²).

Precipitation (mm a^{-1})	actual Evapotranspiration (mm a^{-1})	GW recharge (mm a^{-1})	Surface runoff (mm a^{-1})
544	364	180	neglected

High-resolution monitoring for the Samia, Auja, Duyuk, and Sultan springs reveals that (1) the springs Sultan and Duyuk are connected to a common conduit system and, hence, catchment area, (2) the spring flow systems display similar time lags and event breakthrough behaviors that are largely independent of the event magnitude, which allows for the prediction of the arrival time and breakthrough duration of the potentially polluted fast event water component at the springs (Figure 10), and (3) processes in the epikarst and rapid transfer through the vadose zone are important rapid groundwater recharge mechanisms in the study area (see also Schmidt, 2014 and Schmidt et al., 2014).

Samia and Auja time series based on electrical conductivity data converted into chloride concentration, Sultan time series based on corrected chloride-sensitive electrode data with a moving average filter of 0.5 d filter width applied (modified from Schmidt, 2014).

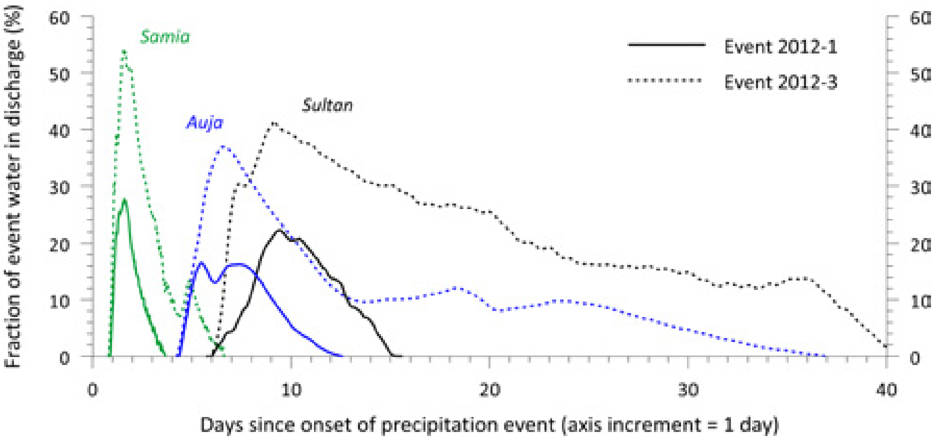


Figure 10: Comparison of the event water fractions observed at the springs, with the recharge events 2012-1 (moderate event) and 2012-3 (very large event) being used as examples.

Refraction seismics and electrical imaging were carried out along several arrays in the central and northern parts of the western alluvial aquifer basin. Based on the geophysical measurements, the thickness of the quaternary sediments was evaluated to be up to 30 m in the central part and around 20 m towards the north-eastern basin section, where the hydrological basin outlet is located (Haaken and Kemna, 2012). The tomograms also show variations in thickness, which are related to a paleo-relief (Figure 11). Exploration boreholes drilled in the area of the basin outlet confirm the thickness estimated by the geophysical measurements. The (heterogeneous) sediments are mainly composed of gravel and sand, containing also fine material (mostly silt).

Infiltration experiments were carried out in the alluvial sediments and were monitored using time-lapse electrical imaging. The imaging results reveal the infiltration pattern in the subsurface (Haaken and Kemna, 2012). Along with classical hydrological investigations, hydraulic conductivities in the range of 4* 10^{-6} to 2*10^{-4} m s^{-1} were measured for the alluvial sediments.For water infiltration, the hydraulic conductivity is low, but reasonable. Using an undisturbed soil specimen, a mean porosity of 35 % was measured.

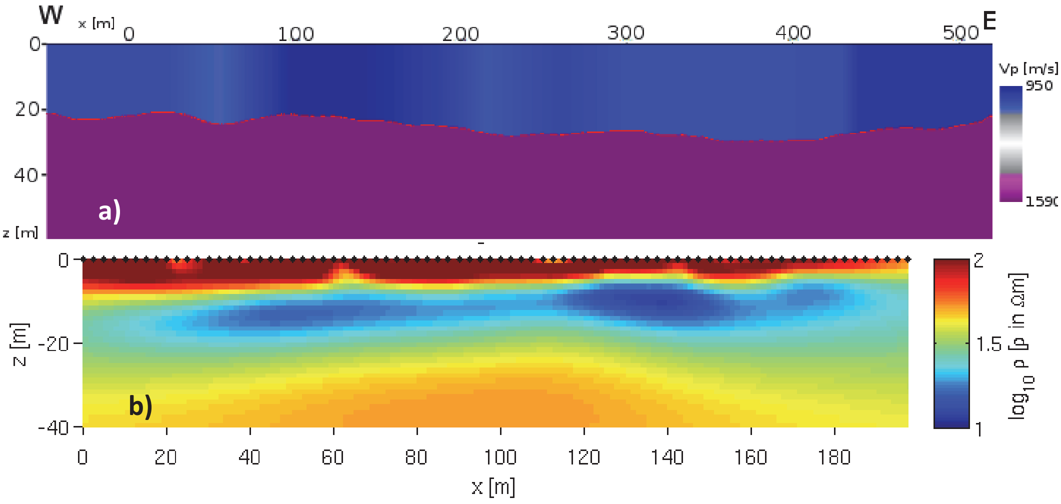


Figure 11: Results of the geophysical surveys in the western alluvial aquifer basin.

In Figure 11 (a) shows the seismic P-wave velocity in the northern part of the basin. The upper (blue) layer is correlated with the unconsolidated, alluvial sediments and the lower (purple) layer with the bedrock. (b) shows an electrical tomogram near the hydrological basin outlet in the north-eastern part of the basin. The bedrock is represented by the high resistive layer below about 20 m depth.

2.5.3 Qilt–Nueima catchments

Authors: T. Rödiger, C. Siebert

2.5.3.1 Study Area and Hydrogeological Background

Wadi Qilt-Nueima is located in the central mountainous area of the West Bank. The about 200 km² large surface catchment extends from Jerusalem to the east through the Judean Mountains into the plain of Jericho. The subsurface groundwater basin is nearly 760 km² large (Figure 8). The irregular distribution of annual precipitation ranges from more than 600 mm at the top of the Judean Mountains to 50 mm and less in the Jordan Valley itself. Hence, the recharge area is strongly limited to the highly elevated outcrop areas of the aquifers.

Groundwater is the main source of drinking water supply, which is reflected by an array of groundwater production wells and strong utilization of the few springs in the area. Lack of information about precipitation depths, groundwater recharge processes, groundwater fluctuation, etc. prevents the sustainable planning of groundwater resources. Hence, the main objective of the investigations was the estimation of the individual water balance components with a focus on the assessment of groundwater resources.

The main groundwater systems of the study area are the aquifers of the Lower (Lower Cenomanian) and the Upper Judea Group (Upper Cenomanian–Turonian). The highest elevated region in the west and the entire western water divide is dominated by a large N–S directed anticline. From there, the strata dip generally towards the east. Towards the Lower Jordan Valley, the layers of the Upper Judea Group Aquifer cover the Lower Judea Group Aquifer. Close to the Jordan Valley, the base of the Senonian Mount Scopus Group is preserved on the top of the Upper Judea Group Aquifer. Fractured bedrock and variable karstified rocks represent the Judea Group. In the outcrop area both aquifers are unconfined. Local confined conditions occur, where clayey or marly formations are intercalated.

The groundwater level decreases in both aquifers along the dip of the strata to the east. The hydraulic heads drop from above 650 m msl to 50 m msl and regional flow directions tend to be eastwards. The groundwater flow patterns generally show no hydraulic connection to the course of the surface wadis.

Subsurface outlet of the catchment area is the discharge of the Lower and Upper Judea Group aquifer to the Jordan Valley. Continuous base flow (groundwater flow) only exists for the En Perrat, Ein Dyouk, and Ein Qilt spring system. Groundwater recharge is only derived from annual infiltration processes.

2.5.3.2 Methodology

The water budget is based on the analysis of climatic data, discharge, and groundwater level records. Hence, a specific monitoring instrument network was installed in cooperation with ME-

KOROT (Israel National Water Company), the Palestine Water Authority, the Hydrological Survey Israel, the Israel Nature and Park Authority, and UFZ to produce reliable background data for the water budget estimation. The strategic focus was put on adding new long-term information to the few available sporadic data. The monitoring network consists of 20 stations on the scale of the subsurface catchment area. The continuous measurement instruments are 10 rain gauges, 2 climate stations, 4 flow meters for discharge measurements, and 4 groundwater divers.

The following methods were applied to obtain a reliable estimate of water resources: I) Direct and indirect measurement of discharge, II) chloride mass balancing methods, and III) development of the hydrological model J2000g (Krause and Hanisch, 2009; Krause et al. 2010) to simulate the temporal and spatial variability of the water balance components of flash floods, evaporation, and groundwater recharge. Actual evapotranspiration and groundwater recharge were obtained with a soil moisture balance approach at a monthly timestep for the time period 1978–2010. All methods are described in detail in Rödiger & Siebert (2009; 2012; 2013). A description of the J2000g model is given in Rödiger et al. (2014).

2.5.3.3 Results

The main focus was put on the estimation of the water budget components of Wadi Qilt on the scale of the subsurface catchment area using the hydrological model J2000. The model was calibrated against measured values. However, calibration was hampered by the lack of high-quality catchment-based data records. The spatial distributions (number of stations, equal spatial distribution) of the precipitation stations in the start phase of the hydrological model are likely to affect simulation results.

The simulation results show a strong relationship to the precipitation pattern. Hence, accurate mapping of the decrease in precipitation from Jerusalem down to the Jordan Valley was required. During the different model calibration phases, a stepwise implementation of rain stations occurred. Due to data scarcity, we used a nested multi-response calibration approach for a semi-distributed J2000g hydrological model with sparsely available runoff data. The calibration was accomplished by a nested strategy, i.e. sub-parts of the model were calibrated to various observation data types first. Then, the data source was used to calibrate the respective subset of model parameters, while the remaining model parameters were unchanged. The gauged spring discharge method, flash flood observations, and data relating the chloride mass balance were used to derive plausible parameter ranges for the conceptual hydrological model J2000g.

The analysis of the discharge records of En Perrat shows that the spring discharge mainly consists of a base flow component. The direct runoff component can be neglected. The integral of curves of spring discharge equates the base flow discharge of both spring systems. Analysis of the spring discharge of En Perrat yields an annual groundwater recharge rate varying between 95 mm a^{-1} and 113 mm a^{-1}. An annual groundwater recharge rate of 122 mm a^{-1} can be calculated for the spring of Ein Dyouk (Rödiger & Siebert, 2009; 2012).

The chloride mass balance method was used for the recharge assessment of the Ein Perrat catchment. The results of the chloride mass balance method are based on the average chloride concentrations in precipitation and groundwater, which are also given in Rödiger & Siebert (2009). With an average annual amount of 534 mm a^{-1} precipitation obtained from eight climate stations in the surrounding area of Jerusalem during the time period 1967–2009, an average groundwater recharge of 119 mm a^{-1} was calculated using the chloride mass balance method for the Ein Perrat catchment.

The groundwater recharge rate was used in the nested multi-response approach for the hydrological model of Wadi Qilt (Rödiger & Siebert, 2013). By exploiting all available information, a coherent simulation of the water components by J2000g was possible despite the limited data. The model simulation period was set for a time series from 1978–2010. The simulation results are summarized in Table 3.

Table 3: Results of water budget simulated by J2000g depend on the catchment scale

Catchment (km^2)	**Precipitation (P) (mm/yr)**	**actual Evaporation (E) (mm/yr)**	**GW recharge (R) (mm/yr)**	**Direct runoff (RD) (mm/yr)**
Qilt surface (163)	403	311	77	15
Qilt subsurface (761)	481	345	112	24
Perrat system (23)	466	340	105	21

Figure 12 shows the regionalized annual precipitation, the simulated annual groundwater recharge, the actual evaporation, and the direct runoff by the separated response units for the modeling period. The rain stations used for the simulation are shown in the precipitation plot. The precipitation map reveals the W-E decrease in rainfall, with higher values > 600 mm a^{-1} in the western mountain area and lower values of 135 mm a^{-1} close to the Jordan Valley. The recharge plot illustrates the relationship between annual precipitation and annual groundwater recharge rates and patterns in the study area. Groundwater recharge follows the same gradient as precipitation. High values of 225 mm a^{-1} groundwater recharge are associated with the high precipitation rates on the hilly parts of the catchment. In the Lower Jordan Valley groundwater recharge decreases to less than 25 mm a^{-1}. The simulated results of actual evaporation also reflect the relationship with precipitation. High values are calculated for the mountain areas, low values of less than 25 mm a^{-1} are associated with the Jordan Valley itself. Simulated components are shown in Figure 13. Both diagrams illustrate the dynamics of precipitation with wet and dry seasons during the period of 1978–2010. The years of 1998 and 1999 were the driest years and the years 1983, 1992, and 2003 were the wettest years during the simulated period. Figure 13a and b demonstrate the dynamics of groundwater recharge (black line) and of surface runoff (flash flood) events (black line). Precipitation depths of higher than 100 mm/month are required to generate groundwater recharge. In contrast to this, Figure 13b shows that a precipitation depth of 115 mm/month is the lower limit for generating flash flood events.

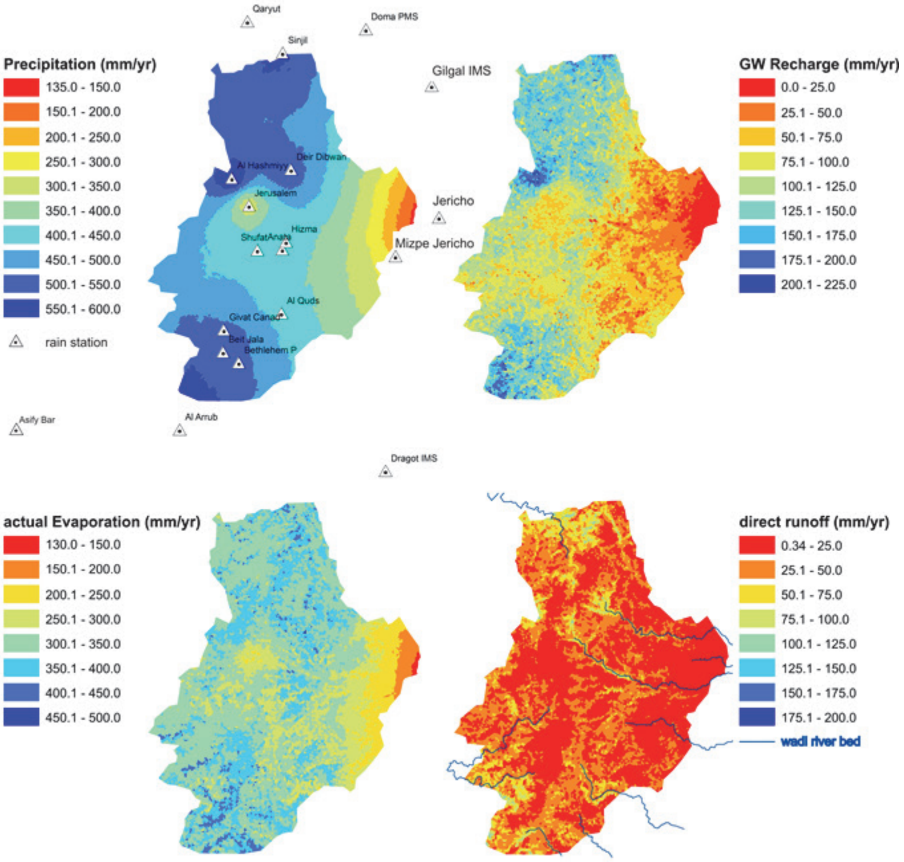


Figure 12: Regionalized precipitation, simulated groundwater recharge, actual evaporation, and direct runoff obtained by J2000g for the Wadi Qilt catchment (from Rödiger & Siebert, 2013).

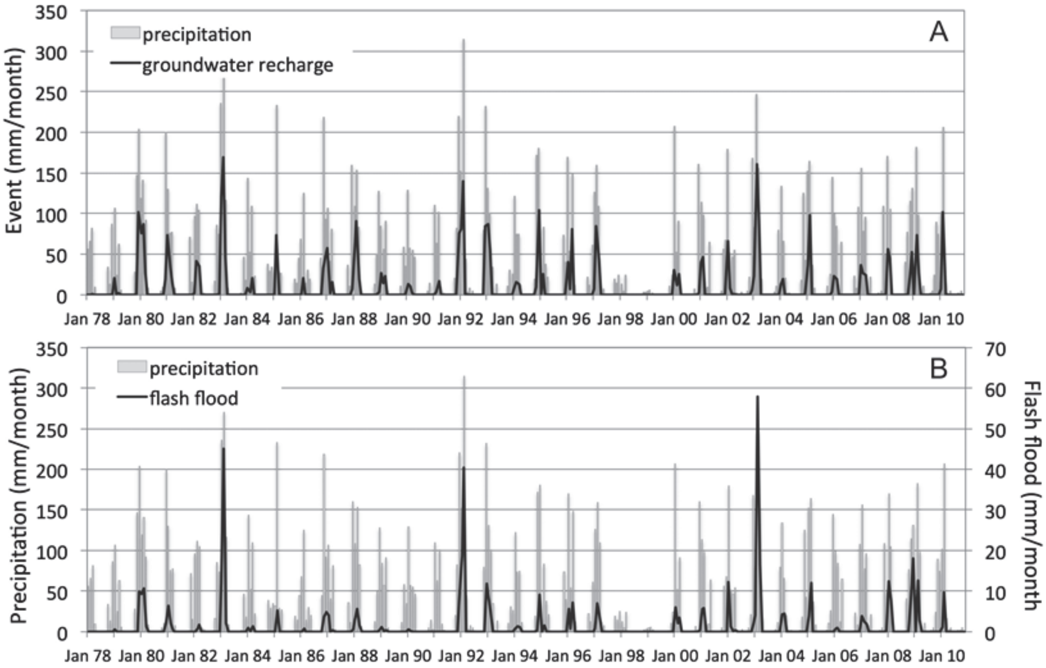


Figure 13: Final simulated precipitation (grey column A,B), groundwater recharge (black line A) and flash flood (black line B) by J2000g for the Wadi Qilt catchment (Year 1978 – 2010) (from Rödiger & Siebert, 2013).

2.5.4 Wadi Al-Arab catchment

Authors: T. Rödiger, C. Siebert

2.5.4.1 Study area and hydrogeological background

The study area of Wadi al Arab is situated in the northwestern region of the Jordan Valley (Figure 8, Figure 14). The catchment is bordered by the Yarmouk valley in the north and by the Jordan Valley in the west. To the SE and E, it extends into the foothills of the Ajlun Dome and the branch of the Azraq plain, respectively. Altitudes vary between −200 m msl in the Jordan River Valley and more than 1100 m msl in the mountain ranges of the Ajlun. The surface catchment area covers about 200 km^2, whereas the subsurface catchment covers an estimated area of about 300 km^2.

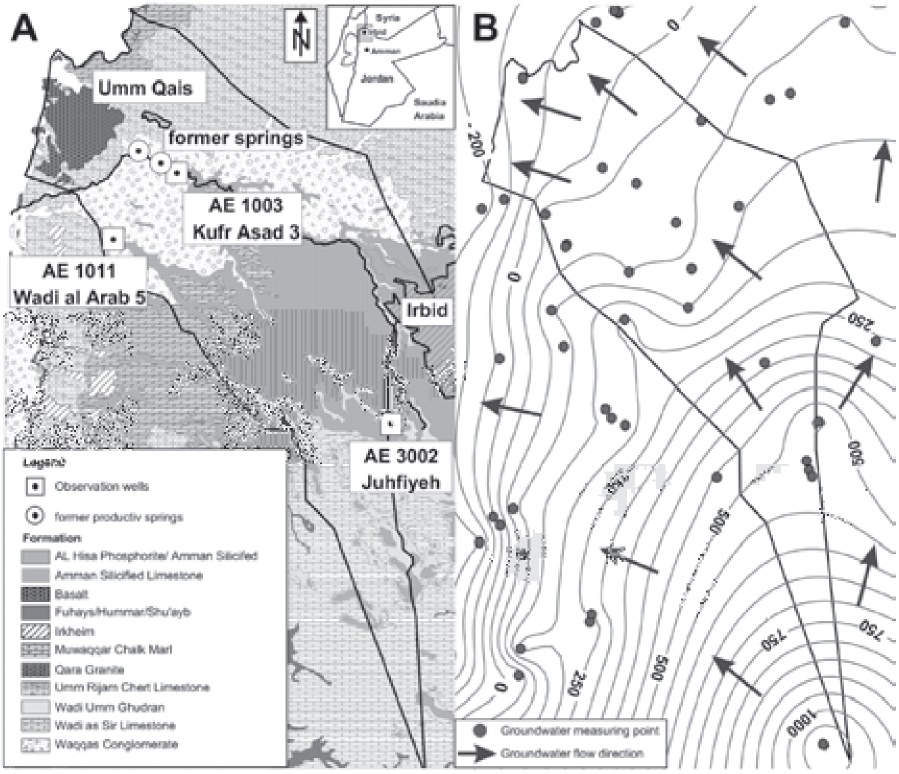


Figure 14: a) Geological map of the Wadi al Arab catchment. Urban areas, observation wells, and former springs (originating from A7-B2) are indicated. b) Map of the catchment with water table isohypses, groundwater flow directions, and the watershed of aquifer A7-B2, respectively.

The annual precipitation ranges from less than 200 mm to approx. 500 mm, with the wet season extending from October to April. About 80 % of the wet season rainfall is concentrated on the period between December and February. Since the entire annual precipitation very often occurs within a single day, the intensities of single precipitation events often are extremely high. The average daily temperature is 12.4°C during the winter season (November to April) and 23.0 °C during the summer season (May to October).

The multi-aquifer system of the catchment consists of fractured and karstified Upper Cretaceous (A7-B2) and Tertiary (B4) deposits. Its basement is formed by the marly limestone aquitard of the Upper-Cenomanian Shueib formation. (A6). Within the catchment, thickness of the A7-B2 aquifer ranges between 200 m in the outcrop areas (middle and SE' parts) and more than 700 m in the NW. The uppermost Cretaceous formation on top of A7-B2 is represented by the Muwaqqar aquitard (B3). Above, Cenozoic deposits of the Umm Rujm Fmt. (B4), around 300 m thick, build the uppermost sequence of the study area. The A7-B2 aquifer is hydraulically separated from the B4 aquifer by the B3 aquitard.

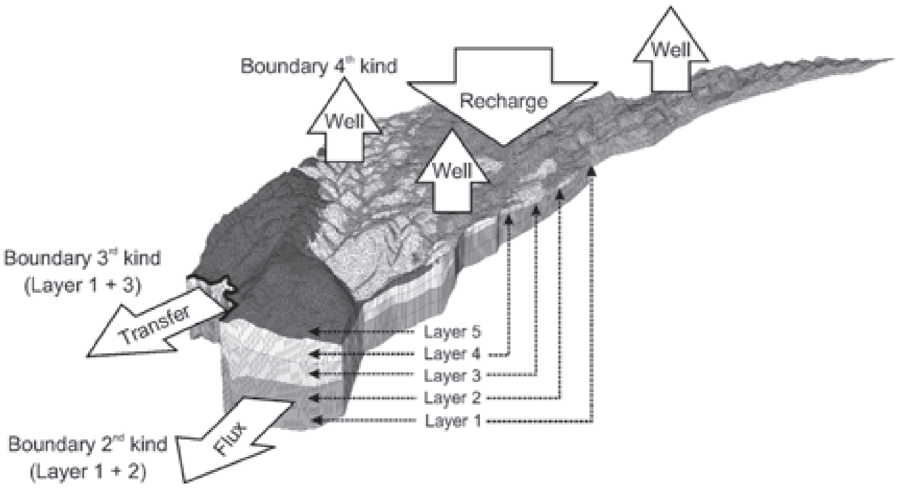


Figure 15: The conceptual model and the set boundary conditions of the study area are shown.

The conceptual model of Figure 15 illustrates the structure and flow system of the Al-Arab catchment. The catchment drains towards the Yarmouk gorge in the NW and the discharge of the A7-B2 aquifer to the Jordan Valley. Groundwater recharge occurs via seasonal infiltration processes. Furthermore, the A7-B2 aquifer is heavily developed by abstractions from deep wells.

The entire complex dips northwestwards. The hydraulic conditions of A7-B2 change from unconfined to confined in the presence of the B3 aquitard. Groundwater flow in aquifer A7-B2 is structurally dictated and is directed from the southeast down to the Yarmouk gorge and the Lower Jordan Valley in the northwest (Figure 14 b). On the southern edge, close to the foothills of the Ajlun Dome, hydraulic heads range between 1000 m msl and 250 m msl. Further towards the northwest, the hydraulic heads decrease to −150 m msl in the Yarmouk and to -200 m msl along the eastern flank of the Lower Jordan Valley. In the entire area, groundwater flow is hydraulically autonomous from the surface morphology (e.g. wadi network). The recharge zones of the aquifers are located in the outcrop areas of the A7-B2 and B4 units.

Groundwater is the main source of drinking water supply and abstracted in a number of well fields. Groundwater resources are limited due to the prevailing semi-arid climatic conditions. Significant overdevelopment is the main reason for the continuous decline of groundwater levels and the drying up of springs in the region. To evaluate the water budget of the study area, a hydrological J2000g model and a numerical finite element groundwater flow model based on FEFLOW were set up. The predictive power of model calculations, however, is somewhat limited due to the lack of long-term and spatially distributed data records.

2.5.4.2 Methodology

A detailed monitoring network with a total of 9 stations was installed in the groundwater catchment. These include 2 rain gauges, 1 climate station, 5 flow meters for discharge measurements, and 1 groundwater level recorder. Furthermore, sampling was accomplished to determine the hydrochemical composition of precipitation, surface runoff, and groundwater for both spring discharge and abstracted well water.

The results of the following methods were compared in order to obtain a reliable estimate of the available water resources: I) Direct and indirect measurement of discharge, II) chloride mass balance method, III) water table fluctuation method, IV) hydrological model with J2000g to simulate the temporal and spatial variability of the water balance components of flash floods, evaporation, and groundwater recharge, and V) development of a numerical groundwater model based on the FEFLOW code. The soil moisture model of J2000g was run with a monthly time step for the time period 1980-2008. The results of J2000g are used as input functions for groundwater recharge in the numerical model. All methods are described in Rödiger & Siebert (2009; 2012; 2013). The J2000g model is presented in Rödiger et al. (2014).

2.5.4.3 Results

Multi-criteria analysis, such as the gauged spring discharge (GSD) method, flash flood observations, and data from the chloride mass balance (CMB) and water table fluctuation (WTF) method are used to derive plausible water budget components. Using these methods, groundwater recharge for the A7/B2 aquifer was calculated to be about 63 mm a^{-1}. Furthermore, the estimated components are used for a nested multi-response calibration and validation of a hydrological model. A detailed description of that hydrological model is given in Rödiger et al. (2014). The model simulation period was set for a time series from 1980–2008. The simulation results are summarized in Table 4.

Table 4: Results budget results simulated by J2000g for the Al-Arab catchment for the period 1980 - 2008

Catchment (km^2)	Precipitation (P) (mm/yr)	actual Evaporation (E) (mm/yr)	GW recharge (R) (mm/yr)	Direct runoff (RD) (mm/yr)
Wadi al Arab (subsurface (300)	489	413	61	15

Figure 16 illustrates the dynamics of precipitation with wet and dry years during 1980–2008. It is obvious that the dynamics of groundwater recharge (black line) is strongly related to the temporal variability of precipitation depths. A threshold of precipitation depths of less 100 mm per month does not generate any groundwater recharge. Groundwater recharge was simulated by J2000g and used as an input function for the numerical groundwater model of Wadi al Arab.

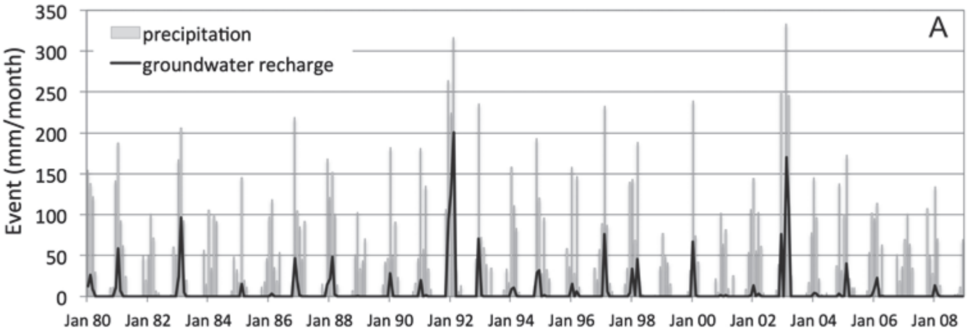


Figure 16: Precipitation (grey column) and groundwater recharge (black line) from model simulations of Wadi al Arab (Rödiger et al., 2013)

Figure 17 illustrates the dynamics of precipitation with wet and dry years during 1980–2008. It is obvious that the dynamics of groundwater recharge (black line) is strongly related to the temporal variability of precipitation depths. A threshold of precipitation depths of less 100 mm per month does not generate any groundwater recharge. Groundwater recharge was simulated by J2000g and used as an input function for the numerical groundwater model of Wadi al Arab.

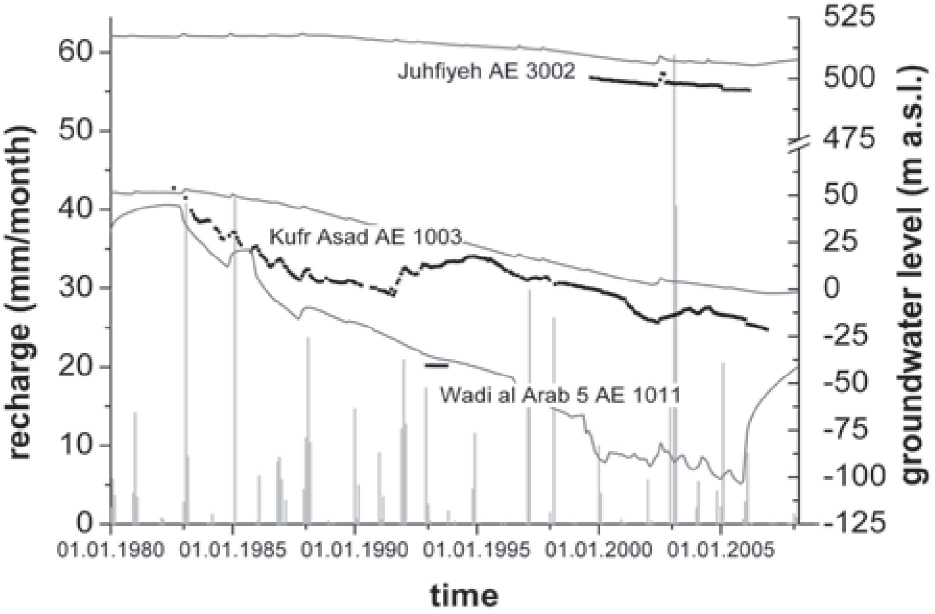


Figure 17: First simulation results of the transient model. Measured (black dotted line) and simulated (gray line) groundwater levels and average recharge curves (grey column) are shown

Figure 17 shows a first comparison of simulated and measured groundwater levels. The simulated and measured transient water levels match well, especially when considering the data availability. Similar ranges and trends could be modeled. The differences between observed and simulated groundwater levels likely are a result of unknown groundwater abstraction. Particularly in the well field of Kufr Asad, the groundwater level cannot be reproduced without detailed abstraction rates, which currently are not available. To overcome this deficiency, abstraction rates similar to the Al Arab well field (10,000 m^3 d^{-1}) were assumed for wells in Kufr Asad in a simulation phase between 01/1983–4/1992 and 11/2001–07/2003. The new results show that after adaptation, the simulated groundwater level reproduces the measured values much more closely (Figure 18)

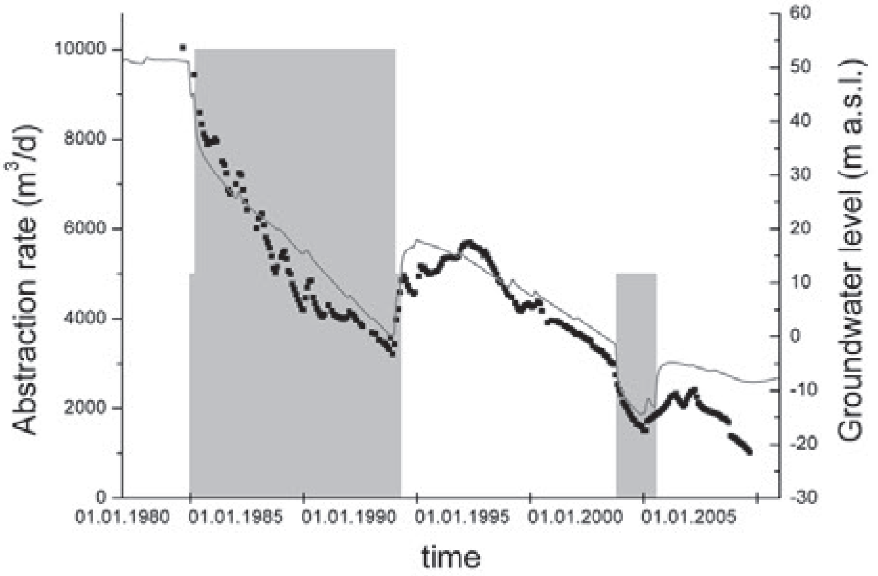


Figure 18: Simulated (grey line) and measured (black dotted line) groundwater heads of observation well Kufr Asad after assuming abstraction rates (grey column) for the Kufr Asad well field similar to those of the Al Arab.

In summary, the water budget analysis by FEFLOW is shown in Table 5 for the time period 1980–2008. The analyses of the water budget reveal an imbalance for the simulation period 1980–2008. The outflow exceeds the inflow by about 18 %, which is a result of the overexploitation of the system.

Table 5: The result of the water budget analysis by FEFLOW in the time period 1980 – 2008 in Mm^3.

Water budget	**Inflow (Mm^3)**	**Outflow (Mm^3)**
Flux boundary (2nd kind)	0	223.4
Transfer boundary (3rd. kind)	215.3	267.5
Well boundary (4th kind)	-	440.7
Groundwater recharge	548.6	-
Sum	763.9	931.5

2.5.5 Wadi Shueib catchment, Jordan

Authors: D. Riepl, F. Grimmeisen, M. Zemann, J. Klinger

2.5.5.1 Study area and water resources challenges

The Wadi Shueib is a catchment of the Lower Jordan River Basin in the Balqa governorate west of the capital Amman. The catchment covers an area of 198 km² upstream of the Wadi Shueib dam. The relief increases from −200 m msl in the southwest up to above 1,250 m msl in the northeast. The most populated area as well as most of the agricultural and industrial activities are concentrated at the higher altitudes in the north-eastern part of Wadi Shueib. The area comprises 5 larger municipalities (i.e. Salt, Fuheis, Mahis, Yarka, Ira) and several smaller hamlets. It has a total population of currently 131,000 inhabitants.

In the study area the near-surface formations consist of sedimentary carbonate rocks and with a karstic aquifer system of variable hydraulic conductivities. The Ajlun Group is divided into sub-unit aquifer complexes with a lower aquifer complex in the lower part Cenomanian) of the Ajlun Group in the Hummar Formation (A4) and Naur Formation (A1/2). The uppermost unit of the Ajlun Group and the lower part of Belqa Group (Upper Turonian to the Campanian-Maastrichtian) is part of the aquifer complex (A7/B2) forming the most important aquifer in Jordan due to its vast extent and its relatively high permeability. The Shueib Formation (A 5/6) is composed of calcareous siltstones, mudstones, and shales which act as main aquicludes separating the two sub-aquifer complexes (Margane et al., 2002). According to Werz (2006), the average thickness of the unsaturated zone in the study area is assumed to range from 50 m (Hummar) to 60 m (Naur) and 75 m (Wadi As-Sir). Thus, direct evapotranspiration losses from the groundwater table are negligible.

The water supply system in the Wadi Shueib includes the capture of spring water, groundwater wells, and water imports as well as a distribution network to the municipalities. The four main springs Azzraqqu, Baqqouria, Hazzir, and Shoreia provide the basis for water supply of the largest cities As Salt and Fuheis. The water of all five springs is processed at the Shoreia spring treatment plant before being distributed to the customers (Margane et al., 2009). However, water supply is intermittent and the municipalities receive pumped water from the water authority for a limited number of days each week, varying (reportedly) from 1 to 3 days per week. The water is then stored in tanks either on the roof of the property or below ground. The investigated area is drained by a dense wadi stream network, whereas the Wadi Shueib course acts as a receiving stream for the entire area and discharges in the Wadi Shueib dam reservoir in the southwestern part of the area (Werz, 2006).

The most pressing challenges to the water sector in the Wadi Shueib catchment are pollution problems as well as water supply network losses and intermittent supply.

2.5.5.2 Methodology

The assessment of the water resources in Wadi Shueib was based on a comprehensive monitoring of both water quantity and quality. Acquired and collected data were fed into a model for the holistic evaluation of the water balance.

Meteorological and hydrogeological parameters were recorded by a detailed monitoring network. It included a total of 16 devices measuring the climatic data (precipitation, air temperature, etc.) as well as the groundwater and spring values (discharge, water level, water temperature, electric conductivity, pH, and nitrate) at high temporal resolution (see Grimmeisen, 2014 and Alfaro, 2014). Furthermore, major ions, pharmaceutical compounds, X-ray contrast media, as well as microbiological parameters were determined to assess water quality within more than 10 sampling campaigns (Zemann, 2014; Grimmeisen, 2014).

The water balance model was built based on WEAP21 Water Evaluation and Planning (WEAP). The structure was specified before the modeling runs were made, and some of the model parameters had to be estimated by calibration (Wagener & Wheater, 2006).

2.5.5.3 Results

There are 27 registered springs emerging in the Wadi Shueib catchment area, of which 21 showed discharges for the period from 2000–2010 (Figure 19), while the remaining springs fell dry. All of the springs drain the Upper Cretaceous Aquifer Complex, the majority in number and discharge volume emerge from the limestone of the A7/B2 and the A1/2 Formation, while the A4 aquifer appears to be less relevant (Figure 19). It is assumed, however, that due to the intensive faulting in the area, the A4 aquifer is often in direct hydraulic contact with the underlying aquifer and, thus, its water is mainly discharged through the springs in the A1/2 aquifer (BGR & MWI, 2010). The majority of springs in the area show patterns of intermittent discharge with annual peak flows below 100 m^3 h^{-1} mainly during March and April. All of these smaller springs are used by the local land owners, mostly for agricultural purposes.

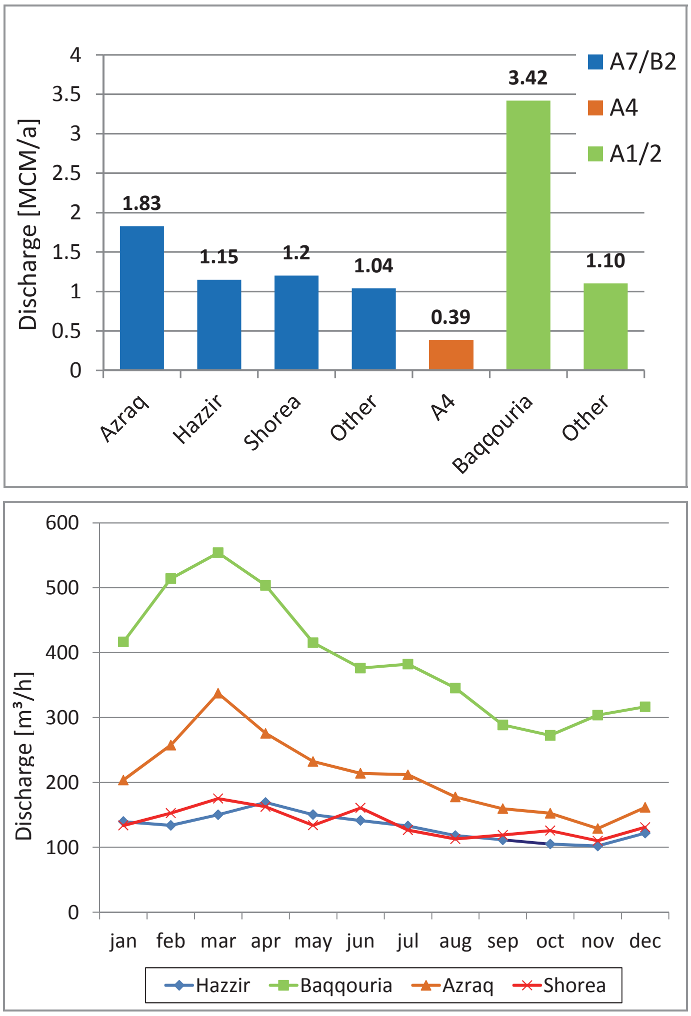


Figure 19: Average annual and monthly discharges of the Wadi Shueib springs during the period 1980–2010 (based on data records from the MWI, Figures Riepl, 2013). a: Average annual discharge of the Shueib springs in relation to their aquifer of origin. b: Average monthly discharge pattern of the main springs in Wadi Shueib.

The four most productive springs in Wadi Shueib are the perennial discharging Azzraqqu -Fuheis (A7/B2), Baqqouria (A1/2), Hazzir (A7/B2), and Shoreia (A7/B2) with average annual discharges between 1.15 MCM/a (Hazzir) and 3.42 MCM/a (Baqqouria).

The WEAP model for Wadi Shueib provided the most conclusive groundwater recharge apart from other parameters, such as the unintended recharge and change in storage. Table 6 shows the resulting recharge balance for the Wadi Shueib springs groundwater contribution zones for the years 1995/96 until 2008/2009. According to the annual balance, the mean groundwater recharge volume in the area is 9.9 MCM/a or 21 % of the areal precipitation over the groundwater contribution zones. The estimated yearly recharge volumes range from 8.1 MCM/a in the very dry winter 1998/99 to 11.9 MCM/a in the wet winter of 2002/03. The fraction of precipitation contributing to groundwater recharge ranges from 16 % to 37 %. Furthermore, the estimated annual recharge rates show a good agreement with the recharge figures used in the regional groundwater modeling by the Ministry of Water and Irrigation (MWI, 2004), but are considerably higher than the average estimates of Zagana et al. (2007) and Ta'any (1992). Possible errors are due to the assumptions concerning catchment boundaries and further subsurface groundwater outflows from the groundwater contribution zone. When taken into account, average recharge fractions could well reach up to 30 % of annual recharge, as was found by Alkhoury (2011) for the adjacent Wadi Kafrein area.

Table 6: Annual recharge balance for the Wadi Shueib springs groundwater contribution zones for the period from 1995/96 to 2008/09 (see Riepl 2013).

Water year	Areal rainfall	Spring discharge O_s	Well abstraction O_w	Unintended recharge R_{UR}	Change in storage ΔS	Recharge from precipitation R_p	
	[MCM]	[MCM]	[MCM]	[MCM]	[MCM]	[MCM]	[%]
1995/96	46.5	10.2	2	1.4	-0.7	10.8	23
1996/97	53.4	10.3	2	1.4	0.2	10.9	20
1997/98	50.4	10.4	1.8	1.4	0	10.8	21
1998/99	22.1	7.1	1.9	0.9	-3.6	8.1	37
1999/00	33.6	8	2.2	1	-1.4	9.2	27
2000/01	37.8	8.1	2.1	0.9	-0.7	9.3	25
2001/02	63.1	11.2	1.3	1.2	1.7	11.3	18
2002/03	74.8	11.9	1.4	1.4	3.6	11.9	16
2003/04	38.7	9.8	1.5	1.4	-2.9	9.9	26
2004/05	56.3	9.7	1.7	1.4	2.1	10	18
2005/06	46.3	9.1	1.6	1.4	0.5	9.3	20
2006/07	53.9	9	1.4	1.4	0.5	9	17
2007/08	34.5	8.1	1.4	1.3	-1.3	8.2	24
2008/09	62.2	9.6	1	1.3	2.4	9.3	15
Avg.	48.1	9.5	1.7	1.3	0	9.9	21

2.5.6 Wadi Kafrein catchment, Jordan

Authors: W. Alkhoury, A. Rahman

2.5.6.1 Study Area and Water Resources Challenges

The arid to semi-arid catchment of Wadi Kafrein (161 km²) is located on the eastern margin of the Lower Jordan Valley. The catchment is characterized by large differences in climate, topography, and land use. The investigations focused on the quantification of the water balance of the study area with special emphasis on (1) identification of runoff generation mechanisms and (2) quantification of the transmission losses in the ephemeral stream channels.

During SMART I, a 3D groundwater model was developed to simulate the unconsolidated aquifer in the region north of the Dead Sea extending from Wadi Hisban in the south up to Wadi Shueib in the North (Toll, 2007). Wu et al. (2011) simulated the groundwater flow in the consolidated aquifer of Wadi Kafrein. During the current project, the assessment of the variability of recharge and surface runoff was the main objective of the investigations. Furthermore, quantification of the unknown discharge from the bedrock aquifer into the unconsolidated valley fill system was in the center of the study.

2.5.6.2 Methodology

Investigations in the Wadi Kafrein catchment comprised (1) detailed hydrological field investigations, (2) the construction of a physically based spatially distributed rainfall-runoff model, and (3) the construction of a numerical groundwater flow model.

Due to the large variability of hydrological parameters of the catchment area, a physically based and spatially distributed rainfall-runoff model was selected (TRAIN-ZIN model). Field data of high spatial and temporal resolution were obtained for model input and a comprehensive hydrological database was prepared. A digital elevation model (DEM) was generated for the catchment using Cartosat-1 satellite images with a resolution of 5 m. Variations in land use and soils were spatially mapped by using multi-temporal ASTER satellite images. In order to calibrate the model, runoff measurements were performed. For this purpose, the topography of the Kafrein dam surface water reservoir was surveyed during a dry period by high-resolution differential GPS measurements. From the resulting digital elevation model, a rating curve for the surface water reservoir was derived. It allowed for the quantification of surface runoff by water height determination. The water height in the reservoir was measured continuously using pressure transducers and data loggers. Several sub-wadis with catchment areas of 0.3 km^2 to 7 km^2 were instrumented for rainfall and runoff measurements of high temporal resolution. The monitoring period extended from November 2007 until December 2009. The model was parameterized with the measured data and calibrated and validated using the differential split sample test approach (Figure 20). The water components of the two consecutive hydrological years were quantified and spatial distribution maps were plotted for every water component on an event basis.

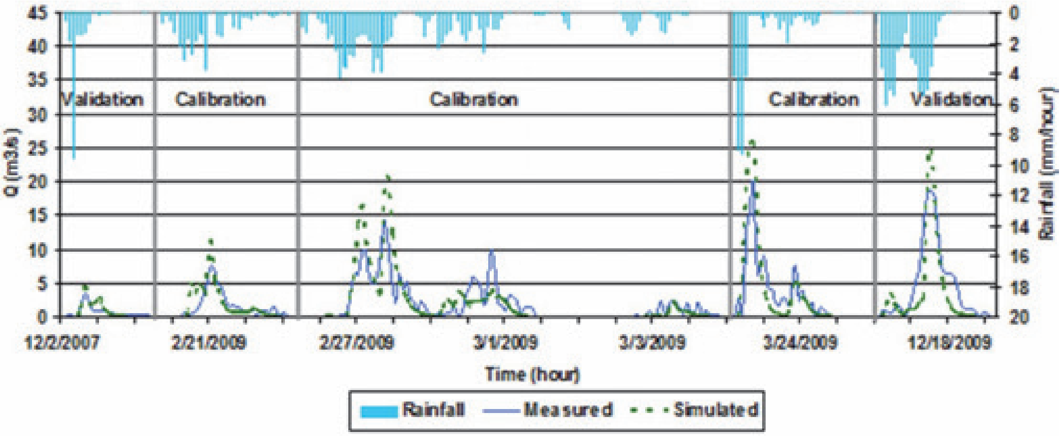


Figure 20: Comparison of measured and simulated surface runoff for the model calibration and validation periods (Alkhoury, 2011).

In order to predict the impact of climatic variations and the impact of urban expansion and land use changes on the water balance components of Wadi Kafrein, a new approach was developed. This new approach takes into consideration precipitation characteristics and temperature increases, including the wettest and driest years of the available records. In total, 24 climatic scenarios were developed and continuous modeling was performed for the hydrological years from 2002 until 2007.

A groundwater flow model of the study area was set up employing Visual Modflow software (v.2009; SWS, 2009). Visual Modflow uses the finite difference code MODFLOW (Harbaugh and McDonald, 1996) to simulate groundwater flow. Due to the lack of a complete subsurface characterization and properties, the model has the character of a schematic model which includes original data as far as available. The study area was delineated based on the structural maps of a previous study of Toll, 2008. The study area includes the catchments of Wadi Hisban, Wadi Kafrein, and Wadi Shueib in the north when considering the hydrogeological system of the region. The groundwater model involves a two-dimensional vertical cross-sectional domain. The cross section extends 23 km from the Jordan River towards the east in the high lands with the horizontal grid size ranging between 10 m and 100 m and grid refinement around the fault zones (Figure 6). The geometry and the thicknesses of the vertical layers are taken from the data available for the different hydrogeological units in published articles and reports (e.g., Alkhoury, 2011). Five geological layers of variable thickness were defined and included in the model. The five hydrogeological units are: Amman and Wadi As Sir (layer 1), Shueib & Hummer (layer 2), Fuheis (layer 3), Na’ur (layer 4), Kurnub (layer 5). Three major faults were identified and incorporated into the flow model.

For model simulation, the water requirement and abstraction data from the years 2002 to 2009 were used. There are five abstraction wells within the model domain, which are AB 1292, AB 1276, AB1221, AB1042, and AB 1190. The abstraction data were obtained from MWI (2012). Recharge was estimated from the results of the Wadi Kafrein hydrological model for 2002–2009 (Alkhoury, 2011).

2.5.6.3 Results

Runoff generation mechanisms were investigated in detail for the monitored runoff events. Based on the number of observed events, infiltration excess overland flow (IEOF) is the dominant runoff mechanism in the study area, which is also known to be the dominant mechanism in other arid and semi-arid regions.Although fewer events were generated by saturation excess overland flow (SEOF), the bulk runoff quantity results from SEOF. For similar amounts of rainfall measured in two different storm events, the volume of the generated runoff with SEOF as the dominant runoff generation mechanism was ten times as large runoff due to IEOF. This observation may be attributed to the rainfall intensity, the antecedent soil moisture, and the lag time between the storm events. Transmission losses were also quantified on an event basis and on an annual basis. Transmission losses ranged from 18 to 44 % of the generated runoff on an event basis, while the average transmission losses were 24 % and 26 % of the generated runoff in 2007/2008 and in 2008/2009, respectively. The maximum runoff coefficient was 4 % in 2007/2008 and 11 % in 2008/2009. Recharge was higher when SEOF was the dominant mechanism and lower when IEOF was the dominant mechanism. The results of a sensitivity analysis indicate an important effect of soil depth and soil infiltration rates on the generated runoff amounts, while transmission losses are mainly affected by channel length, channel width, and the depth of the active alluvium.

The results of the climatic scenarios show that runoff coefficients range from 4 % for very dry years to 21 % in very wet years. Furthermore, an increase in temperature of 1 to 3 °C will slightly decrease recharge and runoff. Urbanization expansion in Wadi Kafrein will mainly increase the volume of generated runoff and decrease the recharged water.

Previous estimations of runoff and recharge in the Wadi Kafrein were too low and evapotranspiration was estimated too high. The results from this study indicate that during an average year, runoff is approximately 6.4 MCM/a and recharge is about 21 MCM/a. Recharge equations were developed to estimate recharge based on annual rainfall.

Table 7: Modelled water balance components for the period of 2003–2009 for the Kafrein catchment (161 km²).

Precipitation (mm a^{-1})	actual Evapotranspiration (mm a^{-1})	GW recharge (mm a^{-1})	Surface runoff (mm a^{-1})
336	221	93	23

The calibration of the groundwater model was performed by trial-and-error based on hydrogeological knowledge, considering the information from reports and personal experience. The model was calibrated against groundwater levels observed at the South Shuna monitoring well (AB 1340). As the model setup considers the two-dimensional vertical cross section only, calibration was made for transient conditions only. Steady-state simulation was made to construct the initial condition for the transient model. The time resolution of the transient model was one month. Every time period was divided into 10 equal time steps. The model was simulated for 2617 days in total. Besides the aquifer properties, annual recharge played an important role in model calibration. As recharge was estimated based on a 3D hydrological model, the reduction to a 2D groundwater flow model implied considerable averaging and simplifications. Hence, some secondary readjustments to recharge values were also made to improve model calibration. The modeling period extended from October 2002 to February 2010. The calibration of the groundwater model was satisfactory. As the calibration procedure could only be accomplished for one observation well, located at the uppermost aquifer and no other information for other aquifers was available, the error in the mass balance could not be reduced below 5 %. Extensive efforts, personal experience, and available secondary information were required to minimize the error.

Sensitivity analyses were carried out with respect to the aquifer properties K_h, K_v, S_y, and S_s. From the analysis, it became obvious that the model was highly sensitive to a change in the K_h value. S_y was the second most sensitive parameter. K_v and S_s showed only little sensitivity to the model.

The estimated average groundwater flux to the unconsolidated aquifer is about 1,000 m^3 d^{-1} per 1 km width of the aquifer. Its seasonal variation ranges between about 1,200 m^3 d^{-1} per 1 km length of the aquifer and 700 m^3 d^{-1} per 1 km length of the aquifer (Figure 21). The results also show that groundwater flux to the unconfined aquifer from the mountain aquifer, in general, started to increase in 2008. This is due to high groundwater abstraction in the lower part of the valley. Wu et al. (2011) also mentioned the increasing flux to the downstream Dead Sea.

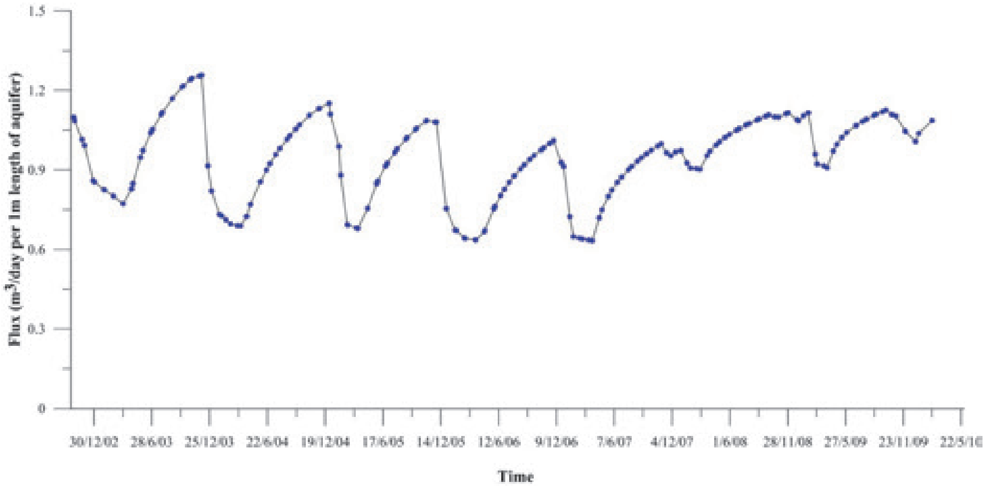


Figure 21: Groundwater flux entering the unconsolidated aquifer from the mountain consolidated aquifer in the 2D aquifer system.

2.5.7 Comparison of Catchment

Authors: S. Schmidt, M. Sauter

Various methods were used to assess the water balances of the sub-basins. For most surface water catchments, distributed hydrological forward models were applied: J2000g for sub-basins Al-Arab and Qilt, TRAIN-ZIN for sub-basins Auja and Kafrein. These models were mainly calibrated using time series of surface runoff. Recharge was calculated as a residual component in those models, next to the output of the extremely temporally and spatially variable runoff. The latter is a real challenge to simulate for the semi-arid and highly heterogeneous physical catchment characteristics of the Lower Jordan Valley. Regarding the assessment of recharge as a water balance residual by forward hydrological models, uncertainties of the estimates have to be taken into account.

On the other hand, groundwater recharge estimates for catchment-scale investigations based on groundwater discharge data (e.g. measured at springs) are subject to the uncertainty of the position and the size of the catchments, since the surface catchment cannot be expected to match the subsurface groundwater catchment due to the specific geological geometry and karstification processes. Apart from hydrological models, alternative methods were applied for the assessment of recharge, such as the chloride mass balance method, to reduce ambiguity in recharge assessment. The water balance of the Auja spring catchment was assessed by calculating long-term mean recharge by a chloride mass balance and deriving a time series of daily recharge by a combined lumped soil water balance and reservoir model. The water balance of sub-basin Shueib was assessed employing a conceptual water evaluation and planning model (WEAP21).

The calculated water balance components differ considerably between the sub-basins (Table 8).

Table 8: Modelled water balance components for the different sub-basins.

	Auja spring	**Auja surface**	**Qilt surface**	**Qilt subsurface**	**Arab**	**Shueib**	**Kafrein**
Period (hydr. years)	1968–2012	2011–2013	1978–2000	1978–2000	1980–2008	1996–2009	2003–2009
Method[a]	CMB+M	DHM	DHM	DHM	DHM	WEAP	DHM
Reference	Schmidt et al. (2014)	Ries (2013)	Rödiger and Siebert (2012)	Rödiger and Siebert (2012)	Rödiger et al. (2014)	Riepl (2013)	Alkhoury (2011)
Area (km²)	49	55	163	761	300	198	161
Precipitation (mm)	544	392	403	481	489	442	336
ETa (mm)	364	278	311	345	413	382	221
ETa (%)	67	71	77	72	84.5	86	66
Surface runoff (mm)	neglected	4	15	24	15	16	23
Surface runoff (%)	neglected	1	4	5	3	4	7
Recharge (mm)	180	109	77	112	61	70	93
Recharge (%)	33	28	19	23	12.5	16	28

[a] Methods: CMB+M: chloride mass balance and lumped soil water balance and reservoir model; DHM: Distributed hydrological model; WEAP: conceptual water evaluation and planning tool/model

However, due to the limited availability of hydrological data, different periods were used for hydrological water balance modeling. A short modeling period can be highly biased by the dominance of either dry or wet hydrometeorological conditions. In semi-arid environments long-term time series of observation data are therefore mandatory for hydrological modeling and water balance assessment. Whereas mean long-term precipitation is relatively uniform (about 400–550 mm a^{-1}), surface runoff and groundwater recharge exhibit larger differences. The lowest fraction of surface runoff was measured to be about 1 % for the surface catchment of Wadi Auja for the hydrological years of 2011–2013. However, this period did not cover a very rainy year. The main reason for the low volume of surface runoff possibly is the high infiltration capacity of the karstified limestone and dolomite outcrops in the catchment. In contrast to the other catchments, surface runoff fractions between 3–7 % were determined. These higher values are partly due to catchments comprising a relatively high fraction of impermeable rocks at the surface (e.g. Upper Cretaceous chalk).

Groundwater recharge ranges between 13 and 33 % for the analyzed catchments. Comparatively low recharge was estimated for catchment Al-Arab, whereas for most other catchments, long-term recharge is in the range of 23 to 33 %. However, the water budget calculations can also be influenced by the different reference periods, with longer periods being considered to provide more reliable estimates compared to shorter ones.

The above compilation represents the first long-term assessment of groundwater recharge and surface runoff for highly dynamic catchments in (semi-)arid regions of the Middle East and still provides event-based recharge patterns/information. To control resources assessment, a chloride mass balance is highly recommended for long terms, since it is independent of the catchment size (e.g. Schmidt et al., 2013). However, it requires considerable effort to correct for external sources of chloride. Combined with methods based on discharge events, a suitable technique to reliably assess water resources in semi-arid regions is available. Future efforts should concentrate on the assessment of the transient effect of storage within the vadose and phreatic compartments of the aquifer systems.

2.6 Transboundary model of the Lower Jordan Valley

Authors: J. Bensabat, Y. Guttman, A. Flexer, A. Yellin-Dror, J. Sawahneh, E. Salameh, H. Hötzl, A. Al-Zoubi

2.6.1 Background

A regional computational model capable of reproducing the groundwater flow pattern within the project area is one of the key products expected to result from the SMART project phases. The logical steps required for the generation of such a model capable of reliably predicting flow behavior included: (1) The definition of a conceptual, static model; (2) Translating the model into a computational model; (3) Assigning values of the hydraulic and replenishment properties; (4) Determining conditions and the model border; (5) Identifying and representing outlets, and (6) Conducting actual simulations under pristine conditions and later simulation of active well fields within the model area.

A necessary prerequisite for proceeding was the construction of a conceptual model. This critical phase included a number of tasks:

1. Delineating the model dimensions in the west and east;
2. Determining the geological layers (essentially the layers bearing water that could be utilized);
3. Producing a digital elevation model (elevation and thickness of the layers) of the area;
4. Identifying and representing the key geological features having a potential impact on the groundwater flow pattern (faults and flexures);
5. Suggesting a practical approach to connecting the fractured rock aquifers in the west and the east with the alluvium of the Valley;
6. Preparing the digital data needed for the construction of the model.

2.6.2 The Conceptual Model

The area was divided into three parts:

1. The hard rock aquifers in the west;
2. The alluvium in the Valley;
3. The hard rock aquifers in the east.

The stratigraphical profile of the study area ranges between the Jurassic age and much younger formations of Holocene age. Table 9below describes the geological layers that were taken into consideration in both parts of the model. The Judea group is the main aquifer on the western side of the study area. The thickness of the Judea Group is about 800–850 m and mainly composed of thick limestone and dolomite sequences with interbedded marly, shaly, and chalky horizons.

Table 9: The layers included in the trans-boundary model.

Layer	Israel	Jordan
12	Neogene	Sediment filling
11	Avedat Gr.	Eocene - Balqa Group B4-B5
10	Mount Scopus	B3 Aquiclude -
9	No equivalent in Israel	B1, B2 Aquifer
8	Turonian	Turonian (A7, WSL)
7	Upper Cenomanian	A56
6	Upper Cenomanian	A4-A6
5	Middle Cenomanian (Moza, Bet Meir)	A3
4	Lower Cenomanian (Kesalon – Kefira)	A1-A2
3	Aptian	Kurnub
2	Lower Cretaceous	Kurnub
1	Jurassic	Azab - ZM

The model was constructed with EWRE-VASP software, which can create the computational mesh and incorporate digital elevation data of the various layers. The western side of the model was constructed using the Bottom Judea (Kfira formation) structural map (Guttman, 2000). It was chosen as a reference layer, since it extends over a major part of the model and represents the bottom layer of the main aquifer. Part of this map is illustrated in Figure 22. The Eastern side was constructed using top Kurnub as a reference level.

A series of West–East cross sections and sampling wells, combined with layer thickness data, was used to estimate the layer thickness above and below the geological reference level. Cross sections were digitized to create a digital elevation/thickness (*xyz*) data set which was then interpolated, creating representative surfaces of geological formations. The surface was then merged, generating a 3D geological model with its upper level truncated with the surface topography. The model was validated by comparing the exposed geological formation with the geological map created by the Geological Survey of Israel. The matching between the rock aquifers and the alluvium in the west and in the east was achieved by mapping the main faults that cross the model area from north to south.

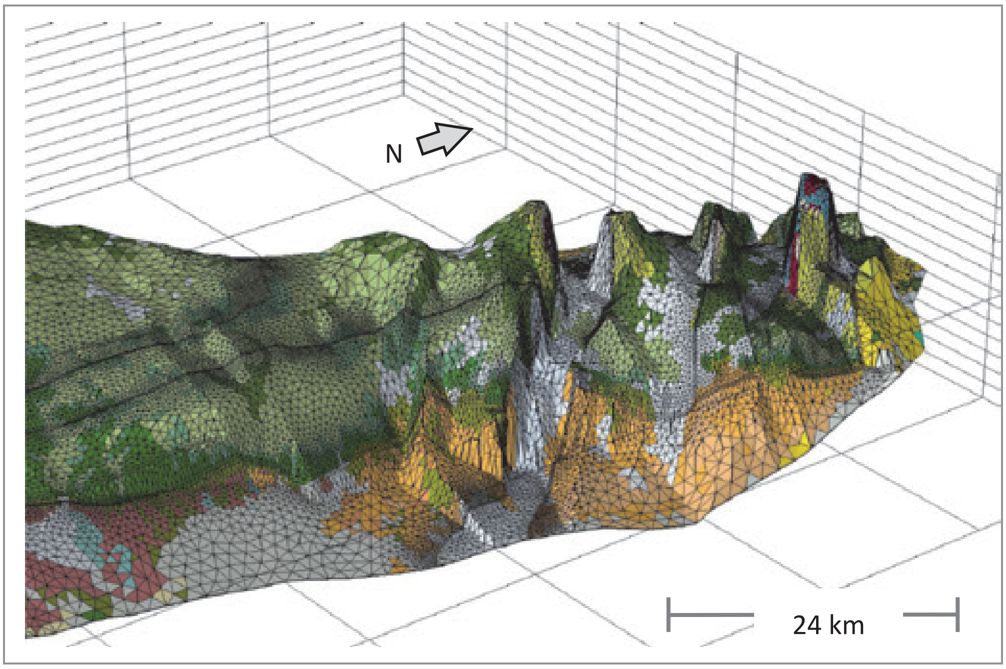


Figure 22: Part of the bottom Judea structural map.

2.6.3 The Computational Model

The resulting computational model was created by snapping the models in the west and in the east to the mesh of the alluvial system. The model comprises 57,408 nodes and 114,129 (triangles) elements in the plane as well as 746,303 nodes and 1,369,548 elements (triangular prisms) in 3D. The model mesh and boundary conditions are illustrated in Figure 23.

The western and eastern boundaries of the model are assumed to match the groundwater divide that separates flows from the western and eastern parts of the mountain aquifer in Israel and Jordan. The northern and southern boundaries are assumed to be streamlines through which no flow takes place. The Dead Sea boundary deserves a much finer treatment. The subsoil along this segment is filled with brines. A precise representation of this boundary would have required consideration of density-dependent flow and salt transport. However, since this approach is beyond the scope of the project that deals with the flow processes only, a boundary condition of type III (mixed type) was assumed, and the cross-sectional flow was artificially limited in order to represent the presence of the brines (through which no freshwater flow occurs). This type of condition allows for a better control of the fluxes crossing the boundary. The model structure is illustrated by means of the cross section presented in Figure 24.

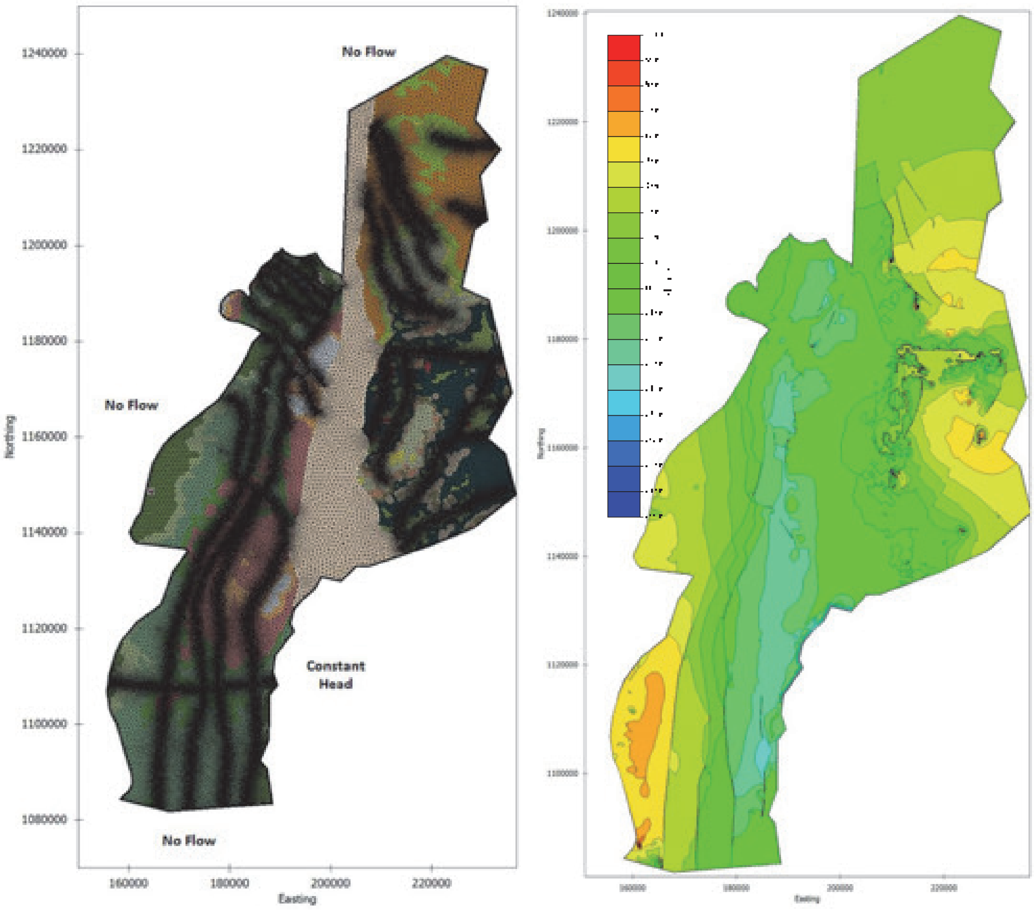


Figure 23: Left: Model mesh and boundary condition. The finer mesh represents geological faults. Right: Model of the piezometric head elevation in the upper Cenomanian (West) and corresponding aquifers in the East.

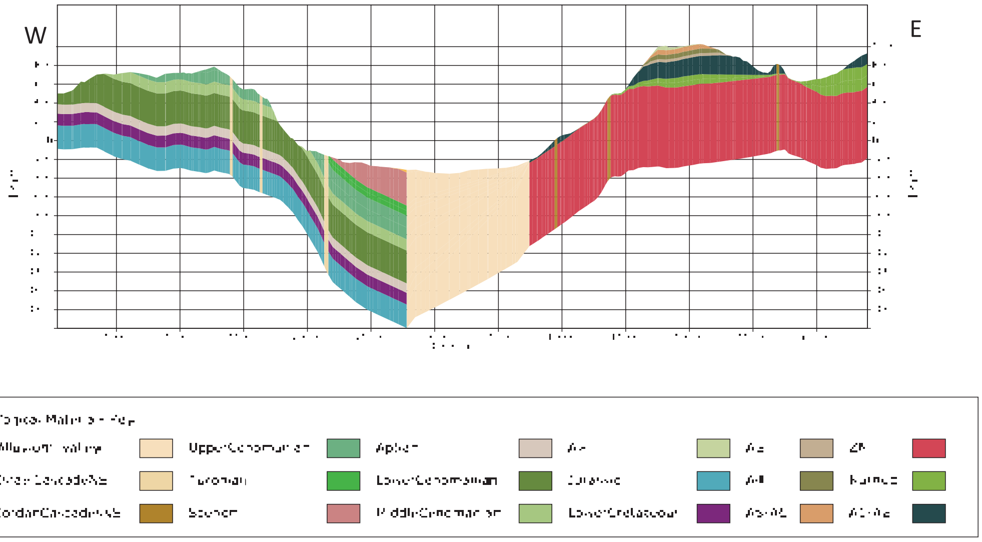


Figure 24: Cross section through the model.

2.6.4 Initial Model Results

The constructed model was run under pristine, i.e. not developed, conditions (prior to any pumping development). The reasons are that we first wanted to create basic information on the regional groundwater flow patterns. Additionally, little information is available on pumping wells on the Jordanian side (their locations, depths, and pumping rates).We therefore plan to run the model until it produces sound groundwater flow patterns and sound piezometric head values at locations where these are known. The hydraulic parameters (porosity, hydraulic conductivity, and storativity) were calibrated to achieve a relatively good agreement between calculated and observed groundwater levels. Table 10below summarizes the preliminary results obtained with respect to the hydraulic properties.

Table 10: Preliminary calibrated values of the hydraulic properties of the model formations.

Formation	**Hydraulic conductivity in the plane (m day^{-1})**	**Anisotropy**	**Effective porosity**	**Storativity (m^{-1})**
Neogene	< 1	10–100	5 %	10^{-7}
Avedat Gr.	< 1	10–100	5 %	10^{-7}
Mount Scopus	< 1	10–100	5 %	10^{-7}
Turonian	10–20	10–100	5 %	10^{-7}
Upper Cenomanian	5–10	10–100	5 %	10^{-7}
Middle Cenomanian (Moza, Bet Meir)	0.1–1	10–100	5 %	10^{-7}
Lower Cenomanian (Kesalon –Kefira)	1–5	10–100	5 %	10^{-7}
Aptian	0.1–1	10–100	5 %	10^{-7}
Lower Cretaceous	0.1–1	10–100	10–20 %	10^{-7}
Jurassic	0. 1–1.0	10–100	5 %	10^{-7}
Balqa Group B4-B5	5	10–100	5 %	10^{-7}
Balqa Group B3	0.00001	10–100	5 %	10^{-7}
Balqa group B1-B2	2	10–100	5 %	10^{-7}
A7 (NA)	2	10–100	5 %	10^{-7}
A56	0.0001	10–100	5 %	10^{-7}
A4	2	10–100	5 %	10^{-7}
A3	0.0001	10–100	5 %	10^{-7}
A1_2	1	10–100	5 %	10^{-7}
Kurnub	3	10–100	5–10 %	10^{-7}
Azab	3	10–100	3 %	10^{-7}

In the west three major outlets are located: 1) The Dead Sea; 2) the Marsaba-Feshcha springs; and 3) the Kane and Samar springs. We were not able to gather information on the outlets in the east. In agreement with the partners, we decided to do without incorporating them. Possible consequences may be higher than predictable piezometric heads in the various aquifers, including the alluvium. The total discharge of the Marsaba-Feshcha springs in the model is equal to 70 MCM/a. This is the last estimate of the springs discharge. The discharge of the Kane and Samar springs is 30 MCM/a.

The model was run for a period of 10 years using time steps of 1 month. However, the groundwater heads stabilized before that (after about 5 years), thus yielding a sort of quasi-steady state situation.

The resulting groundwater piezometric head elevation for the upper Cenomanian is presented in Figure 23. The piezometric head in a vertical section stretching from west to east is presented in Figure 25. It is found that the model produces groundwater head elevations in the west that are consistent with the measurements, i.e., about +400 m on the western edges and about −300 m in the east, near the Jericho area. On the Jordanian side, a general groundwater flow pattern from east to west is obtained, but also an accumulation of water in the west due to the lack of groundwater outlets. In our opinion, the groundwater head elevation in the alluvium near the Jordan side is too high, which once again is due to the lack of outlets on this side.

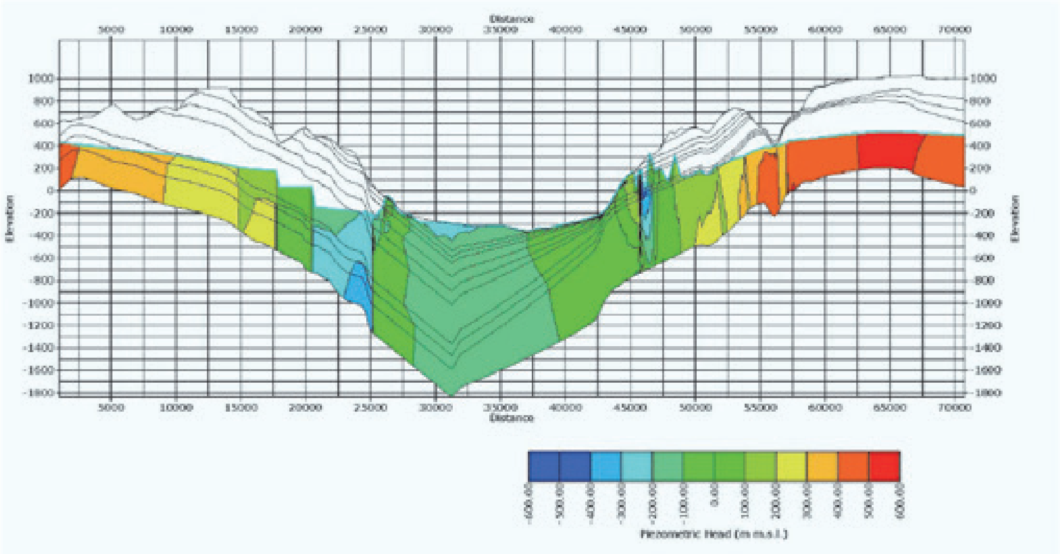


Figure 25: Piezometric head elevation in a vertical cross section from West to East.

Replenishment from rainfall is about 260 MCM/a. The total amount of water flowing to the Dead Sea is about 420 MCM/a. The latter value must be treated with caution, because the real conditions are not truly represented at the Dead Sea interface. In fact, the presence of brine in the Dead Sea prevents the flow of freshwater and probably limits it to a very small portion of the cross section. Additional work has to be done in properly suggesting a surrogate for the hydraulic conditions prevailing at the Dead Sea. The most satisfactory way would have been to run a coupled model of groundwater flow and density-dependent brine transport. However, the size of the model makes this task difficult to achieve. Another possibility would be to mimic the brine intrusion into the Dead Sea and to represent the part of the cross section that is open to flow.

Despite its limitations, the model is very near to be operational and can provide valuable information on the regional trends of the groundwater flow patterns on the basin scale, regional scale, and transboundary scale. Of notable importance is the fact that we were able to properly represent the groundwater table elevation in the Jericho area, without any kind of special boundary conditions. It is very well-known that the vast majority of models constructed in this area produce groundwater head elevations that are far higher than those actually measured.

The cross section in Figure 25 also illustrates the impact of the cascades of hydraulic obstacles on breaking the steep hydraulic gradient in a stepwise manner.

2.7 Summary

Author: Martin Sauter

The assessment of water resources in arid and semi-arid areas for integrated water resouces management purposes is a challenging task, particularly in areas characterized by data scarcity, such as the Lower Jordan Valley. Considerable effort was made within SMART I and SMARTII during the last years to provide original data (geological, climatological, hydrological, hydrogeological) to lay the basis for the quantitative characterization of selected catchments. Effective methodologies for the water resources components, such as groundwater recharge and surface runoff, were developed and applied, including different types of recharge assessment techniques, such as the chloride mass balance, the spatially distributed soil moisture balance technique JAMS, and reverse hydrological methods. Surface runoff was measured at a high temporal resolution in order to be able to record the heavy short-duration flash-floods. Thanks to the extensive instrumentation, it was possible for the first time to document the distribution of the infiltration and runoff processes, to determine the available water resources, as well as to obtain an initial idea of their high temporal and spatial variability.

The catchment-based approach proved to be a viable approach for the assessment of total groundwater recharge, in particular when it was combined with water balance control. It also provides information on the catchment characteristics and totals of the highly dynamic surface runoff. The assessment of the individual catchments allowed for the investigation of the spatial variability of these main flow components and for highlighting and quantifying the assumed effect of the hydrogeological charcteristics, i.e. the difference in surface runoff between Eastern and Western Wadis and the differences in groundwater recharge resulting from differences in the hydrogeological properties of the geological materials. Surface runoff in the west is about 1 to 5 % of precipitation. It corresponds to about half of surface runoff in the east (3 to 10 %). This effect is mainly due to the less permeable sandstones and their larger proportion of surface exposure on the Jordanian side. Consequently, groundwater recharge is considerably higher in the karst limestone areas of the West Bank than in the Jordanian catchments. Regarding the above figures, attention has to be paid to the fact that the individual observation periods are considerably different (length and time periods).For this reason, it is difficult to specify absolute figures for all the catchments. Nevertheless, for a number of catchments, these recharge depths can form a solid input for catchment-scale groundwater flow models developed for individual groundwater basins.

The large scale transboundary model integrates over a large spatial scale, while still providing detailed local hydrological and hydrogeological information. The transboundary model considerably reduces the frequent problem of the unknown catchment size and location. However, it cannot simulate local spring discharge on a detailed event basis, because it does not include the specific karst characteristics. Nor does the transboundary model calculate surface runoff. Hence, both transboundary models and local catchment models are necessary for the assessment of water resources for the semi-arid conditions and the physical catchment characteristics in the Lower Jordan Valley.

The hydrochemical quality of the aquifers in the Lower Jordan Valley is affected by the presence of evaporites and brines originating from the precursors of the Dead Sea. This affects the alluvial aquifers as well as the carbonate aquifers in parts of the Lower Jordan Valley floor. In contrast to this, the groundwater of the carbonate aquifer in the mountain region is fresh, but increasingly affected by anthropogenic pollution sources, such as infiltration of treated and untreated wastewater.

3 TECHNOLOGIES / OPTIONS

3.1 Decentralised Wastewater Systems

Involved Institutions: UFZ, BALQ, ATB, HUB, BDZ, ECO, MWI, NAW

Spokesmen WP3-1: R. Müller (UFZ), B. Abassi (BALQ)

Authors: R. Müller (UFZ), M. v. Afferden (UFZ)

3.1.1 Introduction: The SMART Story

Since 1978, the Jordanian government has gradually implemented the reuse of treated wastewater (Haddadin and Shteiwi 2006) by the country's 27 wastewater treatment plants, which presently serve about 68 % of Jordan's households and capture around 118 MCM sewage per year, of which nearly 90 % are reused mainly in agriculture in the Jordan Valley (Seder and Abdel-Jabbar 2011, WAJ 2011).

However, the quantitative potential of wastewater treatment and reuse has not yet been exploited to the full extent. As stated in "Jordan's Water Strategy 2009-2022" that was prepared with feedback of the SMART team, the Ministry of Water and Irrigation (MWI) aims at reusing 200 MCM of treated wastewater by 2022. The Strategy defines implementing decentralized wastewater treatment infrastructure as a measure to alleviate Jordan's permanent and growing water scarcity and to significantly improve sanitation (MWI 2009).

Previous research activities therefore focused on the development and implementation of innovative Decentralized Wastewater Treatment and Reuse (DWWT&R) systems as a flexible tool for Integrated Water Resources Management (IWRM). Within the SMART project, the research strategy of "Integrated Implementation Research" was developed for setting up DWWT&R systems as a resilient infrastructure for managing water resources under the conditions of scarcity and it was applied in the context of IWRM. This multilateral and interdisciplinary research strategy is based on three interacting pillars: "Technologies“ (Headley et al. 2012, Nivala et al. 2013a, Nivala et al. 2012), "Decision Support + Economic Efficiency" (Müller et al. 2013, Van Afferden and Müller 2011, Van Afferden et al. 2010), and "Capacity Development".

By applying the strategy, we developed an IWRMtool that already reached the implementation level in Jordan.

The core element of the SMART project is defined by innovative technologies. We achieved:

- The establishment of a research and demonstration site for DWWT&R systems (Figure 26).
- The fact that these research infrastructures are tailored to local conditions makes them important modules in the transfer and implementation process. Furthermore, they are also established as a research platform stimulating cooperation between researchers and generating cross-disciplinary synergies.
- The development /adaptation of five different DWWT&R technologies with a treatment performance complying with the Jordanian standard for reusing wastewater in agriculture.

- The implementation of seven DWWT&R systems on real scale for individual households and group solutions
- The introduction of the Wetland- and SBR-technology on the Jordanian market by our industrial partners.

Figure 26: Fuheis research and demonstration site for DWWT&R systems. (Photo: M. v. Afferden)

Implementation of the developed technologies on the regional scale requires a transparent "Decision Support" to compare economic efficiencies of different scenarios of DWWT&R clusters with alternatives, such as centralized wastewater treatment systems. The project produced the following results:

- GIS-based decision support tools were developed and in close cooperation with government officials, stakeholders, industry, and development banks, GIS-based implementation scenarios for DWWT&R systems were generated and assessed both economically and technologically.
- A methodology was developed, which can be used as an innovative service for assessing the feasibility of DWWT&R systems on the regional scale and has the potential of opening up new markets for German consulting companies in the water sector.

To overcome further barriers that still impede change and for improving the implementation process, capacity development activities addressing different stakeholder groups were conducted on different levels.

- We developed the teaching unit “Water Fun – Hands, Minds, and Hearts on Water for Life?” for primary schools. It addresses central aspects of water quality, water consumption, wastewater treatment and reuse in Jordan and Palestine (see WP 9 report).
- “Water Fun” was introduced to 118 teachers/schools from North, Central, and South Jordan and Palestine. School projects were organized for nearly 5000 students (see WP 9 report).
- An «Implementation Office» was established in the Jordanian Ministry of Water and Irrigation. Its main tasks are to facilitate and support work of the inter-ministerial and multi-stakeholder “National Implementation Committee for Decentralized Wastewater Management” that has set out to develop a regulatory and institutional framework for the implementation of such systems in Jordan.
- We succeeded in integrating DWWT&R systems into “Jordan´s Water Strategy 2009-2022” and the associated “Action Plan”.

3.1.2 Technology Development

One objective of the SMART I project was to select and install decentralized wastewater treatment technologies under controlled conditions in order to demonstrate their suitability for use in Jordan. Within the SMARTII project, these technologies were monitored and their performance assessed in order to optimize them for implementation in the Jordanian context.

One objective of this report is to analyze the performance of the various wastewater treatment technologies installed at the Fuheis research and demonstration site. The performance of the systems is analyzed in terms of compliance with the Jordanian standards for the reuse of treated wastewater (JS 893/2006) (Table 11). This report will outline how decentralized wastewater treatment systems can be implemented in order to provide an additional water resource for Jordan.

3.1.2.1 Technology and Performance Monitoring

The Research and Demonstration Site at Fuheis, Jordan

Within the SMARTII project, selected technologies were monitored and their performance assessed in order to demonstrate and then optimize them for implementation under real decentralized conditions in Jordan. The performance of the systems was analyzed in terms of compliance with the Jordanian standards for the reuse of treated wastewater (JS 893/2006). Figure 27 shows the location of the different technologies at the research and demonstration site at Fuheis, Jordan.

The parameters given in the standards are in the focus of the monitoring program at Fuheis, but for research purposes, some other parameters are monitored as well. Table 12 presents the parameters and the analytical methods used.

Table 11: Jordanian standards for irrigation water (JS 893/2006).

Allowable limits per end use		**Irrigation**			Groundwater recharge	Discharge to wadis, streams or water bodies
Parameter	Unit	Cooked Vegetables, Parks, Playgrounds and Sides of Roads within city limits	Fruit Trees, Sides of Roads outside city limits, and landscape	Field Crops, Industrial Crops and Forest Trees		
Class of water		**A**	**B**	**C**		
Biological Oxygen Demand	mg/L	30	200	300	15	60*
Chemical Oxygen Demand	mg/L	100	500	500	50	150**
Dissolved Oxygen	mg/L	> 2	-	-	> 2	> 1
Total suspended solids	mg/L	50	150	150	50	60**
pH	unit	6 - 9	6 - 9	6 - 9	6 - 9	6 - 9
Turbidity	NTU	10	-	-	2	-
Nitrate	mg/L	30	45	45	30	45
Ammonium	mg/L	-	-	-	5.0	
Total Nitrogen	mg/l	45	70	70	45	70
Escherichia Coli	MPN or cfu/100 mL	100	1000	-	<2.2	1000
Intestinal Helminth Eggs	Egg/L	< or = 1	< or = 1	< or = 1	< or = 1	< or = 1
Fats Oils Grease	mg/L	-	-	-	8.0	8.0

* For biological WWTP or WWTP with polishing ponds BOD$_5$ is considered as the filtered BOD.

** For biological WWTP or WWTP with polishing ponds the allowable limit is twice this number.

Table 12: Parameters monitored at the Fuheis research and demonstration site.

	Parameter	**Unit**	**Method**	**Place of analysis**
Field analysis	pH	SU	Probe	Fuheis (site lab)
	Dissolved Oxygen	mg/L	Probe	Fuheis (site lab)
	Field Water Temp.	°C	Probe	Fuheis (site lab)
	Redox Potential	mV	Probe	Fuheis (site lab)
	Electrical Conductivity	µS/cm	Probe	Fuheis (site lab)
Lab analysis	Lab Water Temp.	°C	Probe	Fuheis (site lab)
	COD	mg/L	Test kit	Fuheis (site lab)
	CBOD$_5$	mg/L	Respirometer	Fuheis (site lab)
	TSS	mg/L	Filtration	Fuheis (WWTP lab)
	Turbidity	NTU	Turbidimeter	Fuheis (site lab)
	TN	mg/L	Test kit	Fuheis (site lab)
	NH$_4$-N	mg/L	Test kit	Fuheis (site lab)
	NO$_3$-N	mg/L	Test kit	Fuheis (site lab)
	NO$_2$-N	mg/L	Test kit	Fuheis (site lab)
	E. coli.	MPN/100 mL	IDEXX	Fuheis (site lab)

Helminth eggs are not covered by the regular monitoring program due to the fact that our laboratory facilities are not equipped to carry out these analyses.

Total phosphorus (TP) and PO_4-P were monitored from 1/2011 – 1/2012. After a basic performance for TP and PO_4-P was achieved, monitoring was stopped, because phosphorus is not included in the Jordanian reuse standards. Starting in 2012, the focus of laboratory analysis was shifted towards a better characterization of TN and E. coli removal.

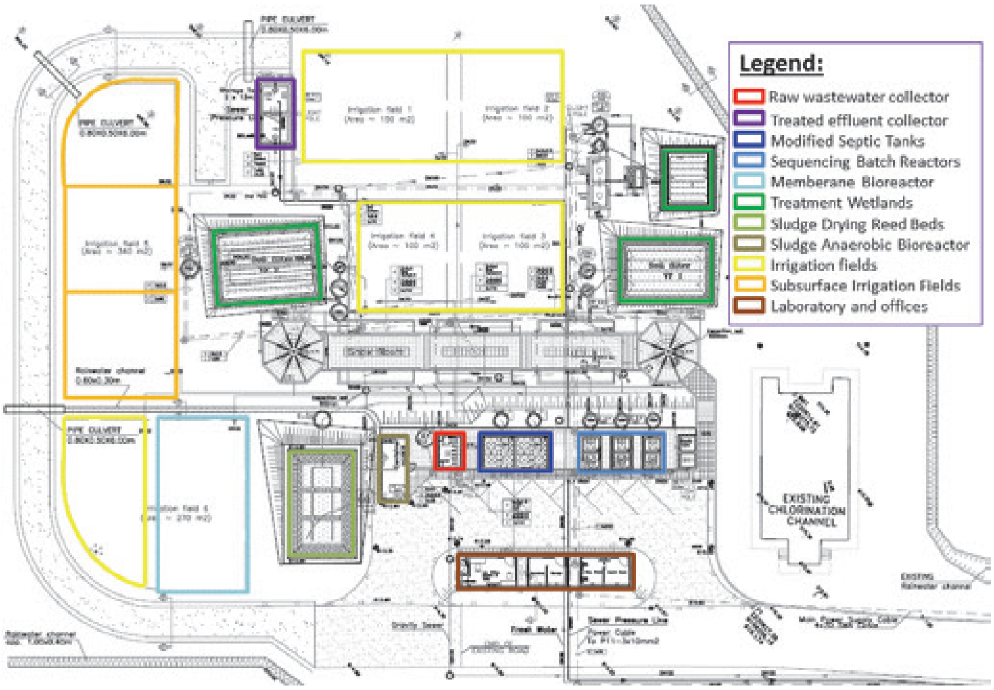


Figure 27: Layout of the research and demonstration site at Fuheis.

The Membrane Bioreactor

A containerized MBR pilot plant (Figure 28) was installed at Fuheis. It consists of a mechanical pretreatment system with a screening screw and an aeration tank with separately mounted ultrafiltration membrane modules for the treatment of about 10 m³ of wastewater per day.

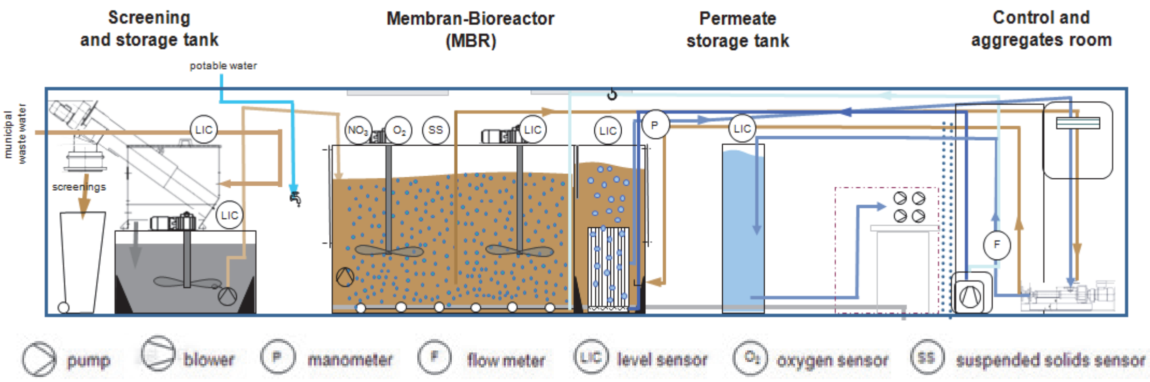


Figure 28 Flow diagram of the containerized MBR pilot plant at Fuheis

The results of two months of testing are presented in Table 13. The biological process reached a high N elimination rate with complete nitrification (99.8 %) and advanced denitrification. COD reduction was very high (97.1 %) and E. coli results were below the detection limits. During the whole test period, permeate quality complied with the chemico-physical and bacteriological requirements for the utilization of treated wastewater for groundwater recharge according to the Jordanian standards (JS 893/2006).

Table 13: Performance of the MBR pilot plant (01/06/2012 to 27/07/2012).

Parameter	Limit for aquifer recharge	Raw wastewater quality (avg.)	Effluent quality			Elimination [%]
			Min.	Max.	Average	
COD (mg/L)	50	991	20.1	33.8	27.4	97.1
TSS (mg/L)	50					100
pH	6 - 9	7.7	7.4	8.3	7.8	-
NO_3-N (mg/L)	6.8		4.5	6.7	5.8	-
NH_4-N (mg/L)	3.9	68.4	0.0	0.5	0.1	99.8
TN (mg/L)	45	104	5.4	14.9	8.3	89.9
PO_4-P (mg/L)	4.9	8.7	1.4	7.4	4.5	60.4
E. coli (MPN/100 mL)	< 2.2		0 3)	(1.0) 3)	0 3)	100 3)

The combination of aeration and membrane ultrafiltration proved to be a suitable solution for wastewater treatment and its reuse for groundwater recharge. The treated wastewater can be stored in the aquifer after soil passage without impairing the quality of the natural groundwater; it can also be reused for irrigation without any restrictions (Class A).

Sequencing Batch Reactors

The research and demonstration site at Fuheis was equipped with three commercially available add-on kits from ATB Umwelttechnologien GmbH, namely, two SBR plants (one conventional SBR and one SBR with UV light for disinfection) and one innovative continuous batch reactor (CBR) technology. The treatment processes are based on ill-and-draw activated sludge processes, where various phases (biological oxidation, sedimentation, nitrification, and anoxic processes) occur in a sequence within the same reactor. The results obtained from using the different systems are shown in Figure 29, Figure 30 and Figure 31.

Remark: It is important to mention that sampling and analysis were missed in the periods when the plants were prone to overflow, electricity cut, or mechanical malfunction. In addition, that the malfunction of the feeding system (flowmeters) of all SBR plants has tremendously resulted in distortion of sampling frequency as well as in the analysis results of the samples.

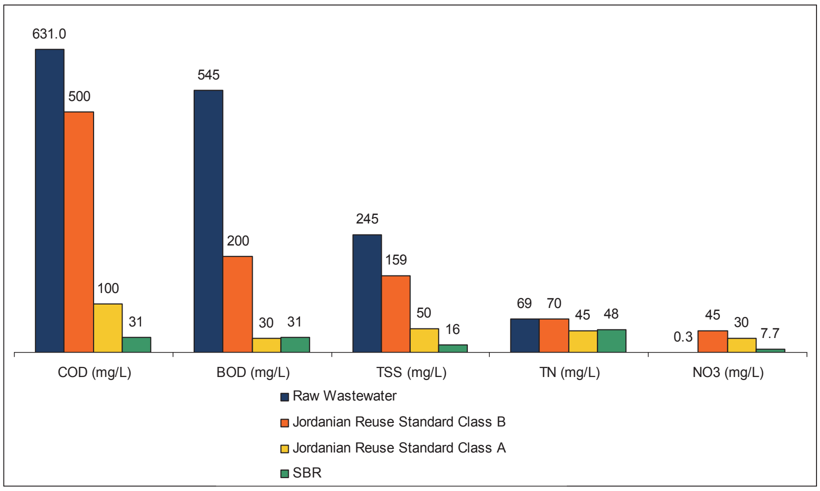


Figure 29: Mean values of monitored parameters for the conventional SBR plant

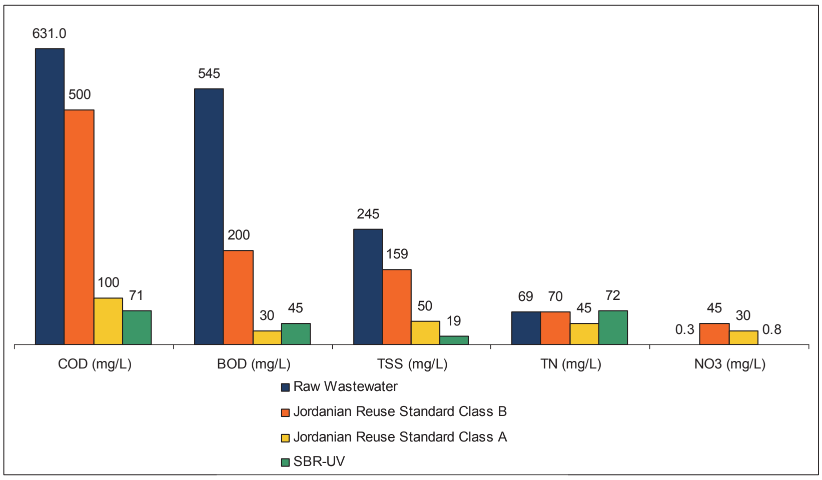


Figure 30: Mean values of monitored parameters for the SBR-UV plant

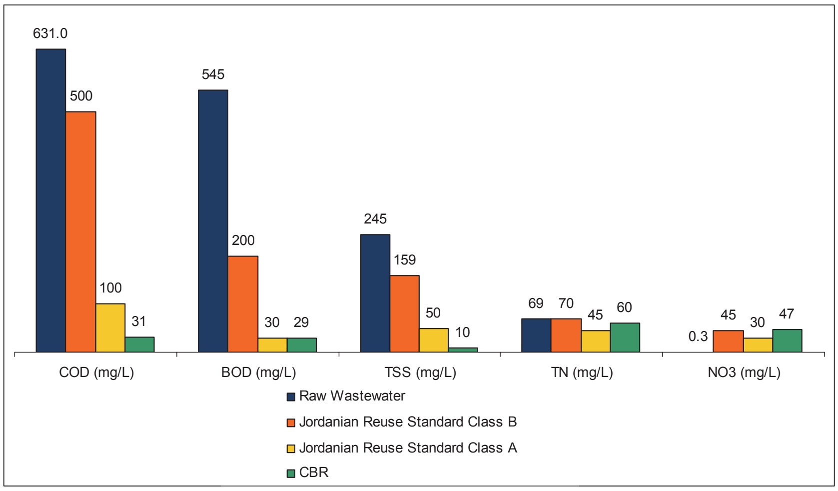


Figure 31: Mean values of monitored parameters for the CBR

Modified Septic Tanks

Each modified septic tank technology is designed to be a one-tank system that entails series of anaerobic treatment chambers, followed by one aerobic section. The anaerobic section is similar to the traditional septic tank, where treated water flows to the aerobic chamber by gravity for further treatment. One pilot plant is filled with fixed-bed media (plastic media) in both sections (anaerobic & aerobic) in order to compare the attached growth system (effect of fixed film) to the conventional suspended growth system. The results obtained from using the suspended growth system (BS) and attached growth system (BA) are shown in Figure 32 and Figure 33.

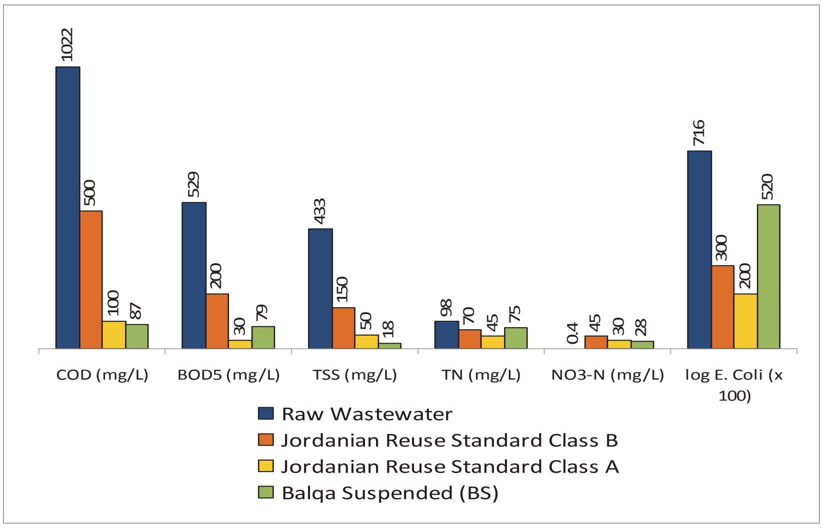


Figure 32: Mean values of monitored parameters for the suspended growth system.

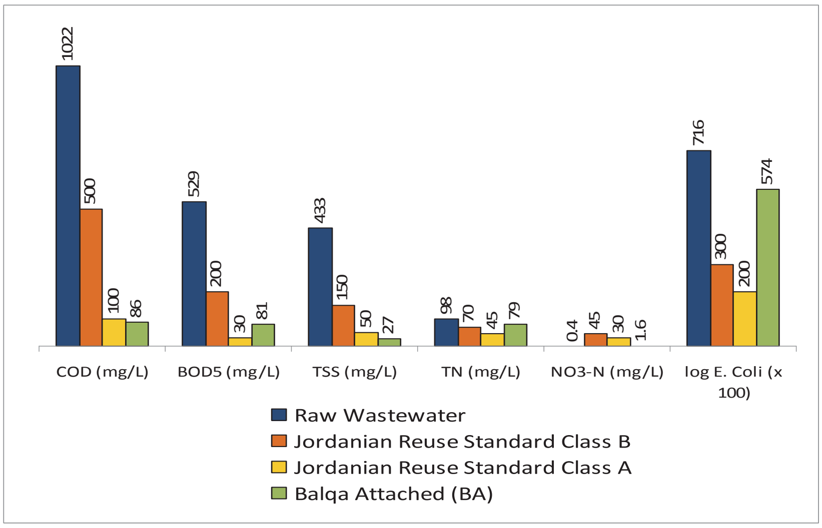


Figure 33: Mean values of monitored parameters for the attached growth system.

Eco-technologies

Eco-technology refers to treatment systems whose design is based on ecological principles. The fundamental aim of these technologies is to reproduce natural processes in order to minimize the use of additional energy, mechanical or chemical inputs. Eco-technologies are robust systems, provide good treatment performance, require only simple maintenance and have low operating costs. Hence, they are ideal for decentralized and remote applications. The two ecotechnologies at the Fuheis research and demonstration site include a single-stage unsaturated vertical flow system with recirculation (ECO-1), as well as a two-stage unsaturated vertical flow system (ECO-2). The results from the two systems are shown in Figure 34 and Figure 35.

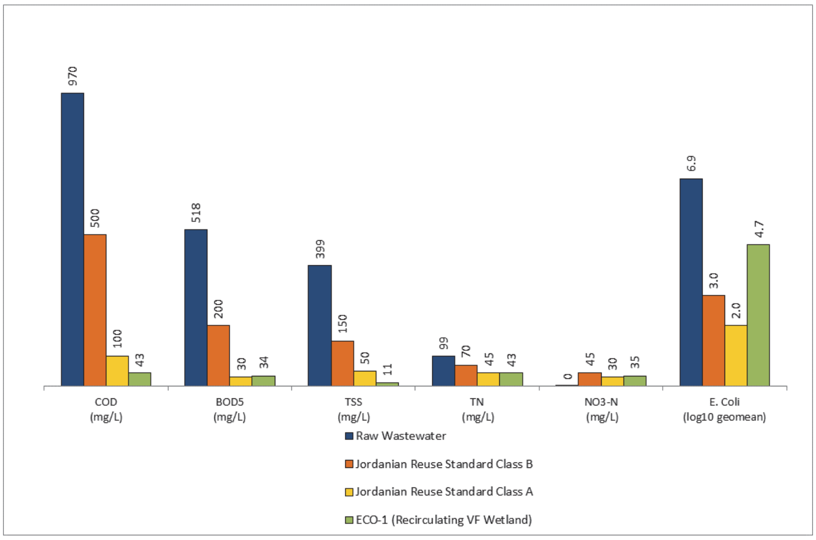


Figure 34: Average performance of ECO-1 compared to the Jordanian Standards.

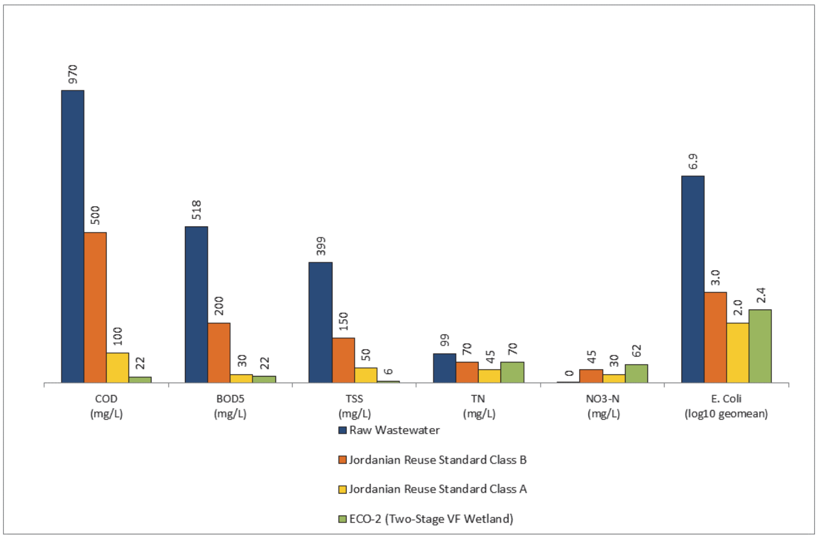


Figure 35: Performance of ECO-2 compared to the Jordanian Standards.

The technologies installed at Fuheis provide for an effective wastewater treatment and in many cases, they are able to meet the Jordanian Class A standards for the reuse of treated wastewater. At the Fuheis research and demonstration facility, the recirculating vertical filter (ECO-1) reaches high BOD, COD, TSS, and TN removal values, but has a rather limited performance in terms of E. coli removal. The single-pass vertical filter (ECO-2), by contrast, is able to reach high BOD, COD, TSS, and E. coli removal values, but has a limited performance in terms of nitrogen removal (TN and NO_3-N). Ongoing research activities at Fuheis aim at meeting all Class A reuse standards by a single treatment wetland system.

3.1.2.1.1 The Research Site at Langenreichenbach, Germany

Located approximately 50 km northeast of Leipzig, the UFZ Ecotechnology Research Facility at Langenreichenbach contains traditional and innovative treatment wetland designs in order to compare the relative benefits of various systems in terms of treatment performance and nutrient cycling, the role of plants, water use efficiency, and energy efficiency.

The research facility is unique, as it is located adjacent to the wastewater treatment plant for the nearby villages, enabling all of the pilot-scale systems to receive the same domestic wastewater with no industrial wastewater inputs. Raw wastewater for the research site is subjected to primary treatment in a large septic tank before it is fed into the wetland systems.

A SCADA system is used to control influent metering into the pilot-scale treatment systems and to measure inflow and outflow rates on both an hourly and a daily basis. Remote access allows for a limited control of the facility from Leipzig. The research facility has its own onsite weather station measuring every ten minutes air temperature, humidity, rainfall, air pressure, wind speed and direction, as well as solar radiation.

The eco-technologies are operated and monitored throughout the year. Field parameters, such as water temperature, dissolved oxygen, redox potential, electrical conductivity, and pH, are measured at the onsite laboratory. All other water quality parameters are measured at the laboratories on the UFZ-Leipzig campus.

Description of the Treatment Systems

The Langenreichenbach eco-technology research facility contains 15 pilot-scale treatment systems of eight different designs or operational variants (Figure 36). The designs differ in terms of flow direction, degree of media saturation, media type, loading regime, and aeration mechanism.

The characteristics defining each design are provided in Table 14 and illustrated in Figure 37 and Figure 38. As obvious from Figure 36 there are two pairs of horizontal flow systems (H25p/H25 and H50p/H50), three pairs of vertical flow beds (VS1p/VS1, VS2p/VS2, and VGp/VG), two pairs of systems with aeration (VAp/VA and HAp/HA), and one reciprocating system (R). Due to the continued debate about the role of plants in treatment wetlands, seven of the designs at Langenreichenbach were constructed with and without plants in order to further investigate the role of plants (*P. australis*) with respect to treatment performance and water treatment efficiency. The designation “p” in the system name is used to denote the planted system of each pair. Moreover, intensified systems (VAp/VA, Hap/HA, and R) can be studied, where typically a higher power consumption (pumping and aeration) is compensated by an improved treatment performance and/or reduced footprint.

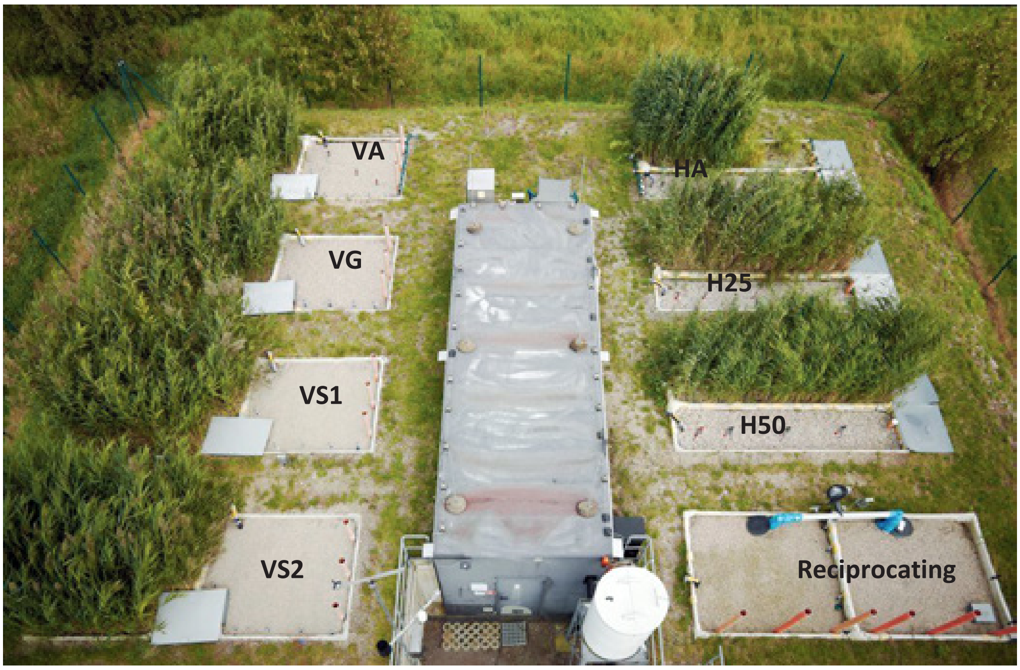


Figure 36: Layout of the research site at Langenreichenbach.

Table 14: Design and operational details of the 15 treatment systems (Nivala et al. 2013b).

System abbreviation[a]	System type	Depth of main media (m)	Saturation status	Main media type	Dosing interval (h)	Surface area (m^2)	Hydraulic loading rate[b] (L/m^2 d)
Horizontal flow							
H25, H25p	HF	0.25	Saturated	Medium gravel	0.5	5.64	18 (3)
H50, H50p	HF	0.50	Saturated	Medium gravel	0.5	5.64	36 (4)
Vertical Flow							
VS1, VS1p	VF	0.85	Unsaturated	Coarse sand	1.0	6.20	95 (4)
VS2, VS2p	VF	0.85	Unsaturated	Coarse sand	2.0	6.20	95 (4)
VG, VGp	VF	0.85	Unsaturated	Fine gravel	1.0	6.20	95 (4)
Intensified							
VA, VAp	VF + Aeration	0.85	Saturated	Medium gravel	1.0	6.20	95 (3)
HA, HAp	HF + Aeration	1.00	Saturated	Medium gravel	0.5	5.64	130 (12)
R	Reciprocating	0.85	Alternating	Medium gravel	1.0	13.2	160 (27)

Standard deviations are given in parenthesis.

[a] Systems planted with *P. australis* are denoted with "p" in the system abbreviation, other systems are unplanted.

[b] Average values for August 2010–December 2011.

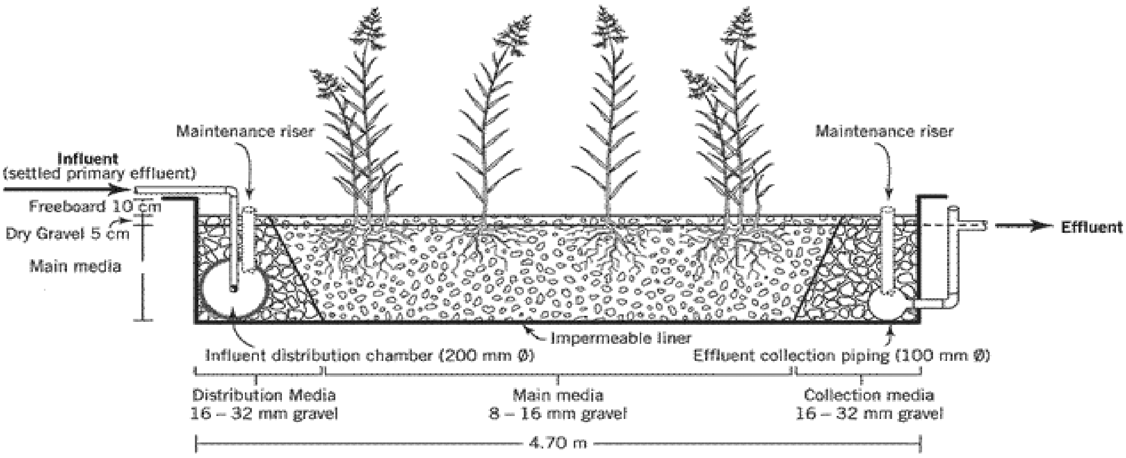


Figure 37: Typical design of a horizontal flow treatment wetland at Langenreichenbach (Nivala et al. 2013b).

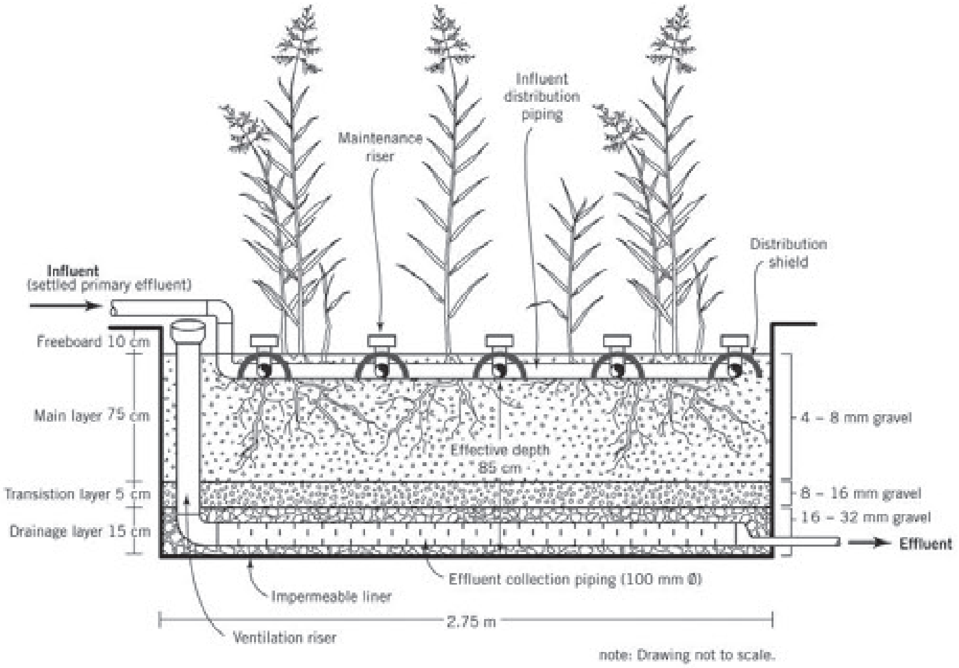


Figure 38: Typical design of a vertical flow treatment wetland at Langenreichenbach (Nivala et al. 2013b).

Treatment Performance and Comparison

The rebuilt facility at Langenreichenbach went into operation in June 2010, and the treatment systems have been monitored on a weekly basis since then.

Table 15 presents period-of-record (POR) data covering approximately 75 data points over 2.5 years for H25/H25p, H50/H50p, VG/VGp, VAp, and HAp. POR for VS1/VS1p, VS2/VS2p, VA, HA, and R systems contain approximately 50 data points over 1.5 years. Flow data were rounded to the nearest five-liter increment.

Overall, the eco-technology systems are capable of providing for a secondary treatment of domestic wastewater as regards the main parameters, such as $CBOD_5$ and TSS. Total nitrogen (TN) is removed to a smaller extent in horizontal flow systems than in vertical flow systems and to a much greater extent in the intensified systems. Intensification by pumping water or air through a system results in a higher treatment performance, but at the expense of energy costs. The intensified systems, however, can treat much higher pollutant loads and wastewater flows than the typical passive systems.

The removal of E. coli is one requirement made in the Jordanian standards for reuse of treated wastewater. The eco-technologies at Langenreichenbach were effective in reducing E. coli concentrations, with horizontal flow systems demonstrating approximately 1 – 2 $\log_{10}$ reduction; vertical flow systems reaching 1 – 3 $\log_{10}$ reduction, and intensified systems 2 – 5 $\log_{10}$ reduction.

Table 15: Typical design of a vertical flow treatment wetland at Langenreichenbach (Nivala et al. 2013b).

System	Inflow (L/d)	Outflow (L/d)	CBOD5 (mg/L)	TSS (mg/L)	TN (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	DO (mg/L)
Influent			257	145	77	61	0.3	0.4
Horizontal Flow								
H50	200	200	62	7	65	65	0.3	1.6
H50p	200	190	62	6	63	63	0.2	1.7
H25	100	100	55	9	64	64	0.2	2.3
H25p	100	90	47	6	57	57	0.3	2.9
Vertical Flow								
VS1	600	600	7	8	53	11	40	6.0
VS1p	600	570	4	3	50	6	41	6.5
VS2	600	600	5	5	57	10	42	4.9
VS2p	600	570	4	3	54	6	45	5.5
VG	590	590	20	18	47	18	25	4.3
VGp	590	570	28	42	50	18	28	4.2
Intensified								
VA	590	590	4	9	36	1.1	31	5.3
VAp	590	570	5	14	45	0.7	40	5.8
HA	730	730	3	10	43	1.2	38	8.1
HAp	730	710	2	2	42	0.6	40	7.9
R	1,770	1,770	4	3	22	11	10	3.2

Current E. coli results are shown in Figure 39. The black circles represent average concentrations over the period of record (POR) for each system described in the table above. Boxes represent the upper and lower quartiles; whiskers represent the maximum (upper) and minimum (lower) values. For typical HF and VF designs, planted systems perform slightly better than unplanted systems. The unplanted horizontal flow system with aeration reaches an average E. coli concentration below 1,000 MPN per 100 mL, indicating that this technology has the potential to meet the Jordanian Class A standard for reuse of treated wastewater.

The research site in Langenreichenbach compares eight different eco-technology designs, both with and without plants. Work conducted at this site in Germany clearly showed that the intensified treatment wetland systems are able to reach high levels of both total nitrogen removal and E. coli removal, while minimizing water loss during treatment. Hence, this eco-technology option may be well-suited for Jordanian conditions.

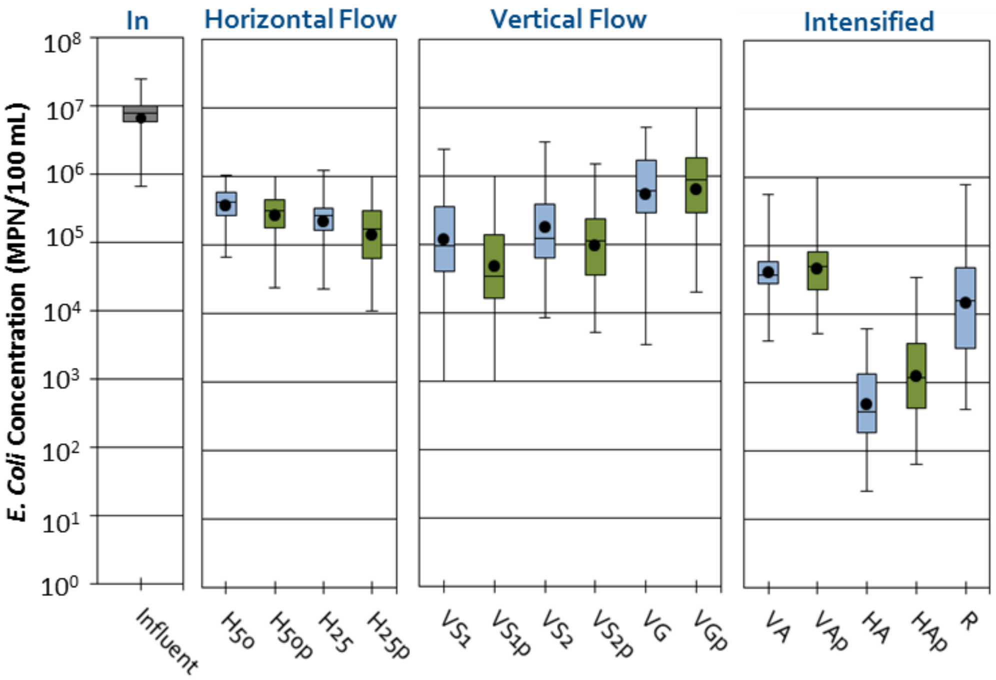


Figure 39: Typical design of a vertical flow treatment wetland at Langenreichenbach (Nivala et al. 2013b).

3.1.2.1.2 Recommendations

In Jordan, decentralized wastewater treatment and reuse is an option to optimize the use of water and provide for additional water resources. However, the existing Jordanian standards for the reuse of treated wastewater make it very difficult to implement small and decentralized wastewater treatment technologies. This difficulty results from the fact that the required performance of a treatment system does not depend on its size (e.g., how many people are served), but on the expected reuse of the treated effluents (independently of the reuse technology applied).

It is interesting to note that the WHO guidelines for E. coli are not as strict as their Jordanian equivalent. The 1989 revision of the WHO guidelines resulted in a recommended E. coli limit of 1,000 CFU per 100 mL. This decision was based on the consensus that the actual risk associated with the reuse of treated water for irrigation was much lower than previously thought. The World Health Organization stated that the previous standards were unjustifiably restrictive, particularly concerning pathogenic organisms.

In addition to the requirements concerning pathogen removal, the Jordanian standards require nutrient removal. This is an important point the WHO does not consider, as some nutrients (especially nitrogen and phosphorus) are highly valuable in agriculture (in rural and suburban areas). Although these requirements make sense in the centralized context (e.g. mass balance of pollutants), they are highly challenging for decentralized systems and cannot be complied with in a cost-effective manner.

As a result, it is difficult to identify a single technology that can meet every requirement of the Jordanian Class A standard for reuse of treated wastewater. The treatment requirements for individual households should not be identical to those of larger neighborhoods ormunicipalities. Stricter water quality regulations can be applied, as the size of the serviced municipality increases. It is not possible to envisage full-scale implementation of the decentralized scenario in Jordan, unless new reuse standards that fit the specific local context are formulated. These concerns have been raised by various stakeholders of the wastewater management sector in Jordan (private companies, development organizations, and ministries) and are subject to discussions that are expected to bring about changes of the current regulations.

It would not be surprising, if new standards adapted to the decentralized context were developed in Jordan in the near future. These revised standards would ideally allow for the successful implementation of eco-technologies and other decentralized wastewater treatment systems in order to meet the Jordanian Water Strategy goal of 100 % reuse of treated wastewater by 2022. The development of new Jordanian standards in particular for small and decentralized treatment plants would be in line with the approach adopted and implemented in other parts of the world, namely, Europe and North America.

3.1.3 Reuse of Treated Wastewater

In Jordan, the safe reuse of treated wastewater has become an integral part of the country's water management program. To ensure the reduction of pollutants, appropriate wastewater treatment is required. Yet, treatment always is a challenging task, as it requires to take into consideration aspects like technical possibilities, expected treatment targets, land available, O&M requirements, local support, and budget available. As the risks of system failure cannot be avoided, the implementation of a multi-stage barrier in the form of sub-surface trench irrigation was evaluated for the reuse of treated wastewater to reduce the risks of exposure for humans and the environment.

Sub-surface trench irrigation consists of a water distribution pipe installed in a trench and covered by a chamber that provides a large volume of underground void space. Treated effluent is spread along the entire length of the trench. The trench is filled with a layer of gravel to facilitate effluent transfer into the trench and the surrounding soil. When dosed into the chamber, the effluent is exposed to the air, stimulating the soil's bioactivity. This provides for an additional treatment if the wastewater treatment system has failed. Irrigation efficiency is also enhanced through oxygen transfer to the soil.

The size of the irrigation field depends on the local soil's hydraulic conductivity and on provisions for normal precipitations. The trench's depth depends on the use of the field, the type of soil, and the depth of the bed rock. Plants can be grown on top or on the side of the system. Sub-surface trench irrigation requires a certain amount of installation work and is a permanent unmovable system.

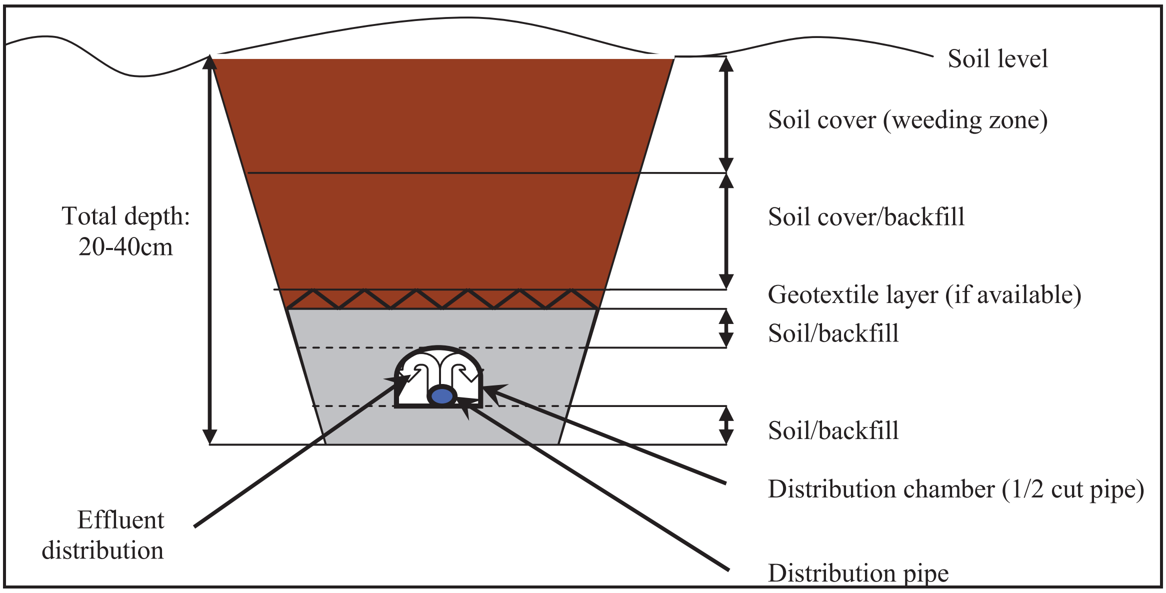


Figure 40: Subsurface irrigation trench

Research into trench irrigation systems has now been conducted for one year at Fuheis (see Figure 40 and location on Figure 27). Three different fields were installed and fed with treated effluent from ECO-1, ECO-2, and tap water as a control, respectively. Each field is subdivided into two plots receiving 120 L/d and 220 L/d of water. On each plot, five lemon trees (*Citrus sp.*) are planted. The purpose of the experiment is to assess the sustainability of such an irrigation system under local conditions. Since planting (Figure 41), the trees have grown well and some of them even started to produce fruits. Table 16 presents the results of the trees' growth since plantation.

Figure 41: Photos of an irrigation field just after plantation (left) and after 1 year of operation (right).

Table 16: Measurement of the trees' growth since plantation.

		Plot					
	Time	**P1.1**	**P1.2**	**P2.1**	**P2.2**	**P3.1**	**P3.2**
Average height (cm)	**T+0**	80.0	65.0	82.0	82.0	91.0	68.0
	T+1	81.5	65.9	81.5	85.7	92.4	68.9
	T+2	83.0	74.0	85.0	87.0	94.0	76.0
	T+3	86.2	83.0	89.0	88.4	95.1	80.2
	T+4	114.2	119.0	102.0	112.0	100.6	107.0
	T+12*	134.0	133.0	150.0	109.0	140.0	94.0
	T+13	140.0	139.0	152.0	111.0	141.0	95.0

T+0: Beginning of observation test (May 2012), one month after planting.

**: Pruning of the trees happened at T+11*

In parallel to the plants' growth measurements, the evolution of the soil characteristics was evaluated. Early results (Table 17) reveal an improvement of the SAR (sodicity), while the electrical conductivity tends to improve, especially in summer. These results are part of an ongoing PhD study that will be concluded in 2015.

Table 17: Variation of electrical conductivity and SAR in the irrigation fields.

			Field and depth (cm)								
			P1			P2			P3		
Parameter	**Plot**	**Time**	**0-20**	**20-40**	**40-60**	**0-20**	**20-40**	**40-60**	**0-20**	**20-40**	**40-60**
EC (µS/cm)	1	T+0(winter)	1460	1730	1570	1360	1860	2290	1350	1780	1780
		T+6 (summer)		1900	2200	2500	2100	2100	2520	1900	2100
		T+12 (winter)	2070	2260	1780	1751	2000	1782	2010	1950	1790
	2	T+0(winter)	1460	1730	1570	1360	1860	2290	1350	1780	1780
		T+6 (summer)	2200	2230	2200	2800	3100	3200	2300	2000	2100
		T+12 (winter)	2010	1960	1555	1640	1810	2731	1951	2582	2311
SAR	1	T+0(winter)	1	0.9	0.9	0.9	0.9	1.3	1.1	0.9	0.9
		T+6 (summer)		1.6	2.1	2	0.6	0.8	2.2	1.8	0.4
		T+12 (winter)	3.9	3.4	4.4	4.4	4.3	3.4	3.8	4.2	3.7
	2	T+0(winter)	1	0.9	0.9	0.9	0.9	1.3	1.1	0.9	0.9
		T+6 (summer)	1.2	1.9	1.7	1.5	1.4	1.2	2	1.9	1.1
		T+12 (winter)	5.1	4.2	2.8	3.6	3.6	4.1	0.4	0.5	0.3

T+0: first soil analysis (January 2012) before starting irrigation (March 2012).

3.1.4 Sludge Treatment

Sludge management has become a key issue for municipal wastewater treatment plants (WWTPs) in Jordan. About 300,000 m³ of liquid sludge as well as 11,000 m³ of dewatered biosolids are generated annually (Al-Hmoud, 2008). This situation is particularly critical in the decentralized context, where the transport of sludge to larger WWTPs may be required. Biosolids generated at municipal WWTPs are usually dewatered using drying beds and then hauled to a landfill or stored onsite, but not reused.

The objectives of research in Jordan consist in demonstrating that the technology works on the pilot scale, in using sludge from the Fuheis WWTP (total solids (TS) content of 0.5 % to 3 %), and in proposing operational recommendations.

3.1.4.1 Anaerobic Bioreactor

Anaerobic treatment (AT) processes are able to transform C-containing substrate into biogas. AT aims at stabilizing the sludge and at producing fermentation residues (biogas). HUBER SE, Germany, supplied a containerized AT plant that was installed at Fuheis. The primary goal of the investigation was to determine the biogas yield from secondary sludge under stable operating conditions. The bioreactor was fed four times a day. After a long startup phase, the reactor was able to operate under stable conditions with a hydraulic retention time of 25 days. Biogas production was continuously monitored by a gas counter. Figure 42 shows the gas production rate during 2 years of operation.

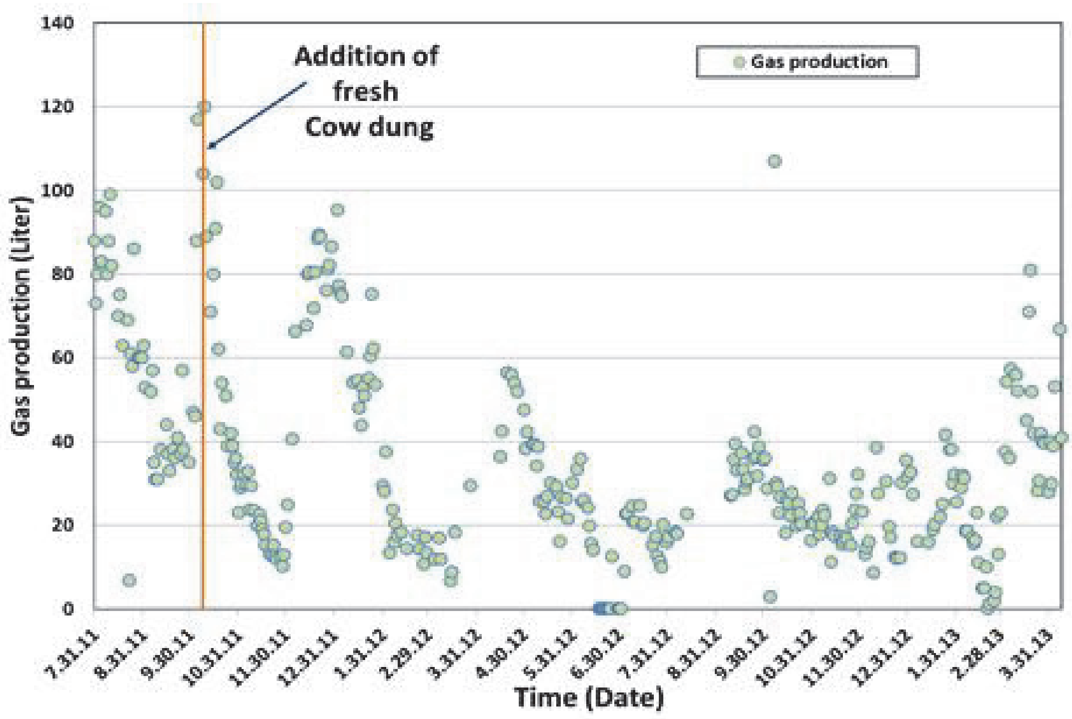


Figure 42: Gas production rate in the bioreactor during the 2 years of operation.

The results obtained from the two years of stable operation can be summarized as follows:

- Gas production rate from the bioreactor fluctuated with a mean value of 38.3 ± 23 L/d.
- About 55 % of the gas produced was methane (CH_4).
- The increase of the TS content suggests volume reduction and mineralization of sludge under the operating conditions of the bioreactor.
- The outlet sample showed about 90 % reduction of organic acids, 85 % of TOC, 70 % of COD, and almost 2-log reduction of E. coli compared to inlet samples.
- The produced biogas can be collected and used for energy/heat production, while the effluent of the bioreactor can be dried, composted, or reused directly as a soil amendment.
- A methane production yield of about 60 % was obtained in a laboratory experiment using a combination of olive-mill sludge and secondary sludge.

3.1.4.2 Sludge-drying Reed Beds

In sludge-drying reed beds (SDRBs), sludge is dewatered and mineralized/composted by reeds during resting time between each loading process. Fresh sludge is regularly applied on top of the previously mineralized layer. Unlike common sand-drying beds, biosolids in SDRBs are removed after 7 to 10 years of operation when the compost layer reaches 1 to 1.5 m in height. At Fuheis, the investigations focus on potential volume reduction and mineralization. Three 10 m³ SDRBs were built in July 2009. Research started in November 2010 when the sludge was supplied on a regular basis. The sludge loading rates (SLR) were 50, 100, and 150 kg TS/m^2.y. Biosolid samples were collected from the conventional sludge-drying bed (control) and SDRBs to analyze heavy metal concentrations and assess the quality according to different standards (Jordan and EU) (see Table 18).

Table 18: Concentration of heavy metals within the biosolids collected from different depths of the SDRBs.

Heavy metal	Unit	Samples							Jordanian standard (JS 1145/2006)			EU Directive (86/278/EEC)	
		Control	SDRB 1		SDRB 2		SDRB 3		Concentrations/Biosloids Class			Concentrations	
		SDB	0 - 5 cm	5 -10 cm	0 - 5 cm	5 - 10 cm	0 - 5 cm	5 - 10 cm	First class	Second class	Third class	If pH < 7.0	If pH > 7.0
Cr	[mg/kg]	28	60	43	30	28	34	39	900	900	3000		
Ni	[mg/kg]	26	40	33	27	24	27	32	300	400	420	300	400
Cu	[mg/kg]	162	193	198	158	156	167	215	1500	3000	4300	1000	1750
Zn	[mg/kg]	1723	2008	2127	1587	1648	1736	2215	2800	4000	7500	2500	4000
Se	[mg/kg]	5	4	4	3	3	4	4	100	100	100		
As	[mg/kg]	<2	<2	<2	<2	<2	<2	<2	41	75	75		
Pb	[mg/kg]	31	37	41	28	27	32	40	300	840	840	750	1200
Mo	[mg/kg]	16	14	16	12	13	13	21	75	75	75		
Cd	[mg/kg]	3	2	2	<2	<2	<2	<2	40	40	85	20	40
Hg	[mg/kg]	3	2	<2	<2	<2	<2	2	17	57	57	16	25

The experience gained from the ongoing SDRB pilot-scale experiments can be summarized as follows:

- Results show a sludge volume reduction of up to 95 % and final dry matter content varies between 40-60 % depending on the applied SLR.
- Mineralization of the sludge took place. In general, the volatile solids (VS) content of the SDRB units decreased by 10-15 %, while nutrient concentration was also reduced.
- The low level of NH_4-N (<1 mg/L) and high level of NO_3-N (>900 mg/L) clearly indicate stable aerobic conditions and high oxygen transport within the SDRBs.
- The top biosolids layer of the beds is a stabilized (non-smelling), humus-like residue, while the deeper layer (5-10 cm) is aerobic and brown. Biosolids in SDB are anaerobic and black.
- Concentrations of heavy metals, such as Cr, Cu, Ni, Zn, Se, As, Pb, Mo, Cd, Hg, Sb within the accumulated layers of biosolids are well below the Jordanian and EU standards.
- Although long-term monitoring is required, first results are encouraging.

3.1.4.3 Recommendations

The use of anaerobic reactors in Jordan showed some promising results, but requires further investigations to optimize the production of biogas. Addition of co-substrate to the WWTP sludge to stimulate methane production seems to be a good option to follow, but turned out to be difficult to implement due to the limited sources of renewable carbon-based substrate (straw, wood chips, etc.). Olive-mill sludge showed a great potential as a co-substrate for anaerobic bioreactor operation, but needs to be further studied.

Based on the experience gained from sludge treatment with pilot-scale SDRBs at the Fuheis site in Jordan, the following issues are recommended for further consideration:

- Long-term operation and monitoring (minimum 5-6 years) are required to assess the performance of the existing pilot-scale SDRBs (Fuheis) under local climatic conditions.
- Real-scale implementation in a controlled environment (Fuheis) is required to validate the early results and derive design and operation recommendations for SDRB in Jordan.
- The monitoring plan for raw sludge, leachate, and biosolids from the SDRBs installed (retrofitted) at the As-Salt WWTP (BAUER Umwelt GmbH) should be optimized.
- Development of an operation manual/procedure for sampling and testing biosolids according to the Jordanian standard.
- As the concentrations of heavy metals within the biosolids layers are below the standard limits, agricultural reuse should be studied (soil amendments) when sufficient biosolids will have been generated (another 3 to 5 years). A long-term monitoring program (for biosolids and soil) should be implemented (rate of heavy metal accumulation in soils, etc.).
- Transfer of knowledge (capacity building activities) to the local universities and stakeholders should be initiated to deal with and assess the specifics of biosolids reuse in Jordan.
- Alternative eco-technologies for simultaneous wastewater and sludge management (French system) should be studied in a real situation (Fuheis) and adapted to local conditions.
- SDRB is widely recognized as an economically interesting technology for sludge management. However, a complete cost analysis under the Jordanian conditions (land requirement, investment cost, O&M, monitoring, etc.) is required for regional implementation.

3.1.5 Technology Demonstration

To adapt the decentralized wastewater treatment and reuse concept to the situation in Jordan, a technology implementation chapter has been integrated into the SMARTII project in order to:

- Demonstrate that the technologies installed at Fuheis are operating properly in real situations.

- Solve existing wastewater-related problems.

- Demonstrate that private owners and municipalities can benefit from reusing treated wastewater.

- Assess the process of implementing DWWT&R in Jordan.

The following map (Figure 43) shows the locations of the ten sites selected for technology implementation in relation to the Fuheis research and demonstration site.

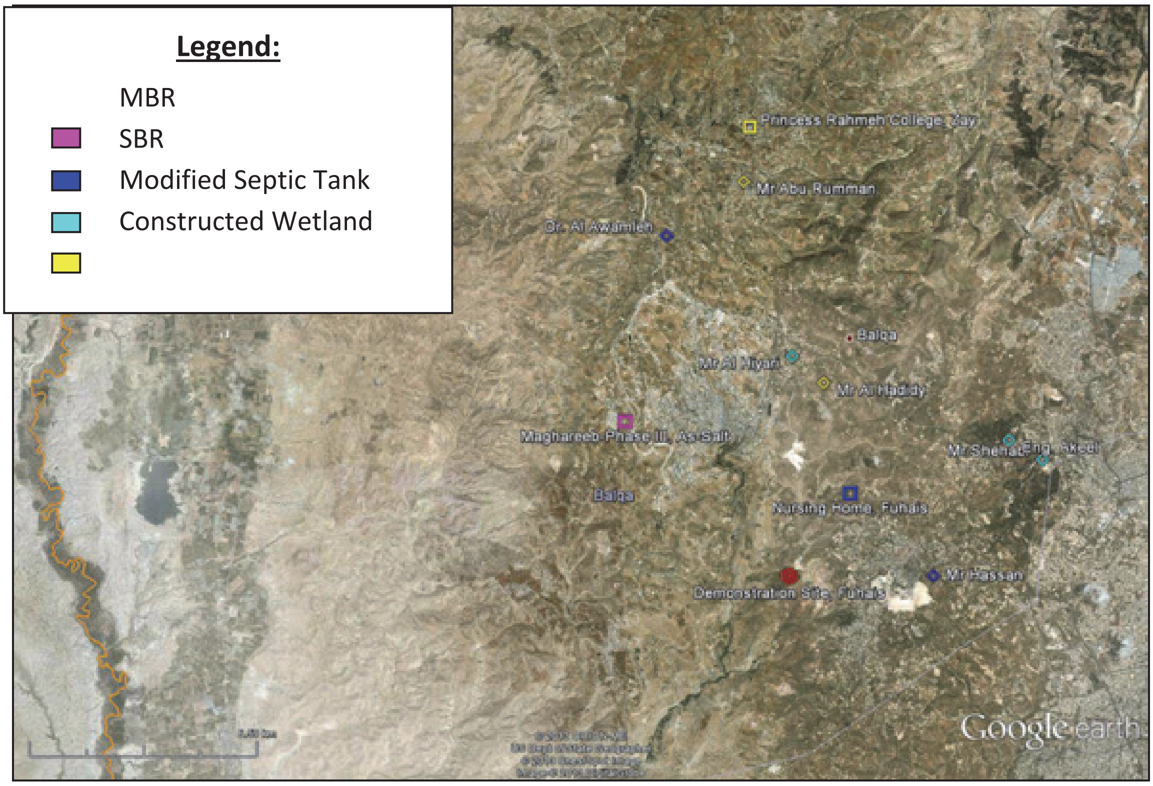


Figure 43: Map of the sites selected for technology implementation.

3.1.5.1 Presentation of the Individual Sites

3.1.5.1.1 Modified Septic Tanks

Mr Al Hiyari (see Figure 44)

The site is located in an area north of As-Salt. The house was not connected to the sewer network. The wastewater was drained from the building into a sealed underground tank located under the car park area. The site includes a garden of about 1000 m², where a sub-surface reuse system is to be installed. The modified septic tank treatment system was judged to be the best treatment solution due to the space limitations. The system is aimed at producing class B effluent (Class C for E. coli).

The wastewater was first diverted from the existing collection tank into the modified septic tank on March 25, 2012. Due to the dimensioning of the system (expected population of 20 PE and a peak flow of about 25 PE), it took about 6 days to fill the modified septic tank. The modified septic tank required about 3-4 months to build up its microbiology and is now operating under steady-state conditions.

Figure 44: Modified septic tank of Mr Al Hiyari

Mr Shehabi (see Figure 45)

The site is located between Fuheis and Sweileh, near the main road. The site was not connected to the sewer network and the wastewater was collected in an infiltration pit located underneath the car park area. The site includes a garden of about 580 m² to install a sub-surface reuse system. The modified septic tank treatment system was judged to be the best treatment solution due to the space limitations. The system is aimed at producing class B effluent (Class C for E. coli).

The wastewater was first diverted from the existing cesspit into the modified septic tank on May 6, 2012. Due to the system's dimensions (expected population of 16 PE and a peak flow of about 20 PE), it took about 6 days to fill the modified septic tank. The modified septic tanks required about 3-4 months to build up their microbiology and are now operating under steady-state conditions.

Figure 45: Modified septic tank of MR SHEHABI

Eng. Akeel (see Figure 46)

The site is located between As-Salt and Sweileh, near the main road. The building was originally under construction with no possibility to be connected to the sewer network. A decentralized wastewater management system had to be installed and the owner was really interested in the reuse possibilities (thus excluding a cesspit scenario). The site includes a garden of about 350 m² planted with lawn and ornamental plants. The owner requested a surface reuse system with disinfection. The modified septic tank treatment system was judged to be the best treatment solution due to the space limitations. The system is aimed at producing class A effluent (chemical disinfection takes place in the reuse tank).

The wastewater first flowed into the modified septic tank on November 19, 2010. Due to the system's dimensions (population of 8 PE and a peak flow of about 12 PE), it took about 6 days to fill the modified septic tank. The modified septic tank requires about 3-4 months to build up its microbiology and is now operating under steady-state conditions.

Figure 46: Modified septic tank of Eng. Akeel

3.1.5.1.2 Sequencing Batch Reactors

Mr Hassan (see Figure 47)

The site is located east of Fuheis. The site was not connected to the Fuheis sewer network. The wastewater was collected and drained from the building and sent to a percolating pit located in the garden. The site includes a garden of about 3,400 m² to install a sub-surface reuse system. The sequencing batch reactor treatment system was judged to be the best treatment solution due to the population concerned. The system is aimed at producing class B effluent (Class C for E. coli).

The wastewater was first diverted from the existing cesspit into the SBR system in May, 2013. The delay was due to some uncertainties in the customs clearance procedure for the mechanical parts of the systems. It took about six months to conclude all clearance processes. The system is currently in a build-up phase. The tanks and the irrigation lines were water-tested in fall 2012.

Mr Al Awamleh (see Figure 48)

The site is located north of As-Salt. The site was not connected to a sewer network. Wastewater was collected, then drained from the building and sent to a percolating pit located in the garden. The site includes a garden of about 3,000 m² allowing for the installation of a sub-surface reuse system. The sequencing batch reactor treatment system was judged to be the best treatment solution due to the topography of the site (limited flat area). The system is aimed at producing class B effluent (Class C for E. coli).

The wastewater was first diverted from the existing cesspit into the SBR system in May 2013. The delay was due to some uncertainties in the customs clearance procedure for the mechanical parts of the systems. It took about six months to conclude all clearance processes. The system is currently in a build-up phase. The tanks and the irrigation lines were water-tested in fall 2012.

Figure 47: Sequencing Batch reactors of Mr Hassan

Figure 48: Sequencing Batch reactors of Mr Al Awamleh

3.1.5.1.3 Treatment Wetlands

Mr Al Hadidi (see Figure 49)

The site is located east of As-Salt in a remote area. The site was not connected to a sewer collection system. The wastewater was drained from the house into a percolating pit located in the garden. The site includes a garden of about 15,000 m² to install a sub-surface reuse system. The sequencing batch reactor treatment system was judged to be the best treatment solution due to the population concerned. The system is aimed at producing class C effluent.

The wastewater was first diverted from the existing cesspit to the septic tank on March 25, 2012. Due to the system's dimensions (expected population of 14 PE and a peak flow of about 20 PE), it took about 6 days to fill the septic tank. Accordingly, it took about 15 days to fill the wetland. The treatment wetlands and the septic tank required about 3-4 months to build up their microbiology and are now operating under steady-state conditions.

Mr Abu Rumman (see Figure 50)

The site is located in the Zay – Um Jouzeh area, north of As-Salt. The site was not connected to the sewer network. The wastewater was collected from the building and sent to two cesspits located in the garden. The second cesspit was installed in series with the first one and received the effluent that the "partly clogged" first cesspit could not infiltrate. The site includes a garden of about 3,100 m² to install a sub-surface reuse system. A constructed wetland was judged to be the best treatment solution due to the population concerned and the reuse potential.

The installation of the treatment wetland and its septic tank was delayed by about 6 months due to material supply issues (the same material was required for the Princess Rahmeh College). It started in operation in summer 2013. The system has been designed for 35 PE to consider the future extension of the family (currently 19 people). The treatment wetland and the septic tank require about 3-4 months for building up their microbiology and operating under steady-state conditions.

Figure 49: Sequencing batch reactors of Mr Al Hadidi.

Figure 50: Sequencing batch reactors of Mr Abu Rumman.

3.1.5.2 Presentation of the Collective Sites

3.1.5.2.1 Sequencing Batch Reactor at the Nursing Home, Fuheis

The nursing home is located on the west side of Fuheis, in an area not connected to the sewer collection system. It had a problem with its sewage disposal system, requiring the pumping out of 10-15 m³ of wastewater every 2 to 3 days. In 2011-2012, the problem was worsening, costs were rising, and the construction of an extension (increased capacity) was planned. Besides, potable water consumption was an issue, as some of it was used in the property's garden, increasing the price of the water bill.

The property covers 45,000 m² of land, on which a 3-storied building was constructed in 2000. The building's ground floor accommodates central facilities (reception, office, visitors' hall, kitchen, laundry, etc.). The residents are living on the 1st floor (women) and 2nd floor (men). Each floor comprises several rooms of different size and shape (single-bed, 2-bed, and up to 5-bed rooms). Each room has its own toilet. However, bathrooms are provided for common use on each floor. The building represents the first phase of a complex housing concept for old people. The existing building currently is only occupied to 50 % of its capacity, but the construction of an additional edifice started in late 2012 to house retired priests. The current occupancy of about 50 PE (including the staff) is planned to rise to about 70 PE together with the priests' building having a total capacity of about 100 PE.

The buildings are surrounded by a large garden planted with olive and fruits trees that will be watered with the treated wastewater. The vegetable garden and a picnic area are excluded from the reuse scheme for hygienic reasons.

An SBR was judged to be the best treatment solution due to the space limitations. The wastewater is collected in the existing 46 m³ 3-chamber septic tank/buffer tank. Adjacent to the septic/buffer tank, a new 11.3 m³ underground tank was built to accommodate the biological reactor (AQUAmax®Professional XL1-100). The wastewater is then pumped into a storage tank, while passing a disk filter and a UV disinfection unit (Figure 51).

Figure 51: The Sequencing batch reactor at the nursing home, Fuheis.

The storage tank is located 200 m away in the garden and feeds an energy-free, gravity-fed drip irrigation system. Drip irrigation is used to improve water efficiency and dispose of the excess water in winter.

The backup solution (power failure, etc.) consists in storing the wastewater in the existing treatment tanks (1.4 days of storage at full capacity). The tanks can be emptied by pumping to prevent overflow.

3.1.5.2.2 The Treatment Wetland at Princess Rahmeh College, Zay

The Princess Rahmeh College is a decentralized campus of Al-Balqa University located in Zay, As-Salt (Figure 52). It was not connected to a centralized sewer collection system and had recurrent problems with its sewage disposal system. About 1300 students and staff are present on the campus during school days. The existing wastewater management system was not able to appropriately and safely handle the load of wastewater produced and the high concentration of pollutants (TN, NO_x-N, NH4-N, and BOD_5/COD). It created health and environmental risks. Moreover, potable water instead of treated wastewater was used for irrigation on the campus. Due to the site's specific activity, the wastewater production varies on a daily and weekly basis (day or night, school day or weekend, holidays, etc.). The average water consumption was estimated to be 9 m^3 per working day, which corresponds to about 7 L/PE/day. The high concentrations of BOD_5/COD and nitrogen observed are typical of school effluents.

Figure 52: The treatment Wetland at Princess Rahmeh College, Zay

The site accommodates three groups of buildings (a chancellery/administration, a small clinic, and the classrooms) surrounded by a small park. The total area of the site is about 63,000 m^2, including about 2,500 m^2 of buildings and 60,000 m^2 of service land. Due to the location of the site on the side of a hill, only about 500 m^2 have been identified to be available for the installation of a treatment wetland. This area is located outside the fenced area of the campus (buildings plus gardens) and required enclosure to prevent access by people and animals.

The treatment systems received the wastewater from 7 different locations on the campus that are already fitted with septic tanks or cesspits. The effluent (raw or from septic tank) is collected in a chamber, from where it is fed into a horizontal flow aerated wetland by gravity. The effluent is recirculated into the first chamber to maximize denitrification (carbon-deficient effluent) or collected in an outside tank, from where it can be reused on the campus. The treated effluent will not be disinfected for practical reasons (cost, O&M, etc.), but reused in a sub-surface way to minimize risks. The existing septic tanks and cesspits remain available as backup solutions in case of maintenance or system malfunction.

The installation of the treatment system was delayed by about 6 months due to material supply issues (the same material was required at Mr Abu Rumman's site).

3.1.5.2.3 The Membrane Bioreactor at Maghareeb-Phase III, As-Salt (Figure 53)

Maghareeb, a village of As-Salt, which is divided into four separate neighborhoods, has recurrent problems with its wastewater management system. Each neighborhood individually manages its wastewater: Three neighborhoods are connected to collective cesspits; the fourth is equipped with an onsite wastewater management system (septic tank/cesspit). One neighborhood (Phase III, 31 lots)) was selected for installation of a Huber membrane bioreactor (MBR), as the number of people connected to the existing cesspit (currently, 130 PE, but expected to rise to a maximum of 300 PE) and the type of wastewater (domestic wastewater, no industries connected) match the project's requirements. Within this neighborhood, the existing cesspit lot (about 375 m^2) was rehabilitated to install a MBR able to treat up to 30 m^3 of domestic wastewater per day in order to achieve class A quality according to the Jordanian standards.

Figure 53: The Membrane Bio Reactor at Maghareeb-Phase III, As-Salt

The wastewater is pre-treated directly upon arrival at the site by a Ro9E sieve pre-treatment system located in an above-ground building. A separate room of this building accommodates the control panel of the entire wastewater treatment plant. From the pre-treatment building, the wastewater is collected in a nearby underground buffer tank and stirred to reduce flocculation. The wastewater is then pumped into an aeration tank fitted with stirrers and aeration membranes. From the aeration tank, the wastewater is pumped into the filtration tank, where the Huber "BioMem" membrane filtration module is located. The permeate is finally collected in a dedicated storage tank located directly underneath the above-ground building until its reuse.

Three different connection points will be installed to reuse the permeate water on nearby agricultural fields or green areas (public service water usage).

The existing wastewater treatment system (septic tank + cesspit) remains on the site in order to be used as a backup system, if a problem occurs. The cesspit will also be considered as a backup for the disposal of permeate that cannot be used by the local partners (e.g. winter, etc.).

3.1.5.3 Difficulties Encountered during the Implementation Process

Due to space requirements, selection of the individual and of the collective sites differed completely. Direct interaction with the house owners and their ability to take responsibility for the systems installed made the selection of individual sites a very straightforward process. The only difficulty experienced was related to the fact that two site owners decided to withdraw from the project a few days before signing their contract. To avoid the related drawbacks (delay due to the need to find new sites, to proceed with the new surveys, and to realize new designs), signature of a "memorandum of understanding" expressing the interest of the house owners in the project should have been required. Responsibility of the house owner (reimbursement of the costs in case of withdrawal, etc.) would have prevented unnecessary costs and waste of time.

For the big sites, however, the task was a lot more complex. The following difficulties were encountered:

- One selected site (SBR, treatment wetland) had to be rejected in the design phase due to complaints of a few, but influential local land owners, although the majority of the population, the Ministry of Water and Irrigation, and the municipality were supporting the project.
- Most of the identified settlements and clusters of houses (suburban and rural) identified were larger than the 250 inhabitants defined in the project proposal. Such sites had to be excluded, which led to budget constraints.
- The limited possibilities of building infrastructures, especially sewer networks, led to the exclusion of many potential sites. It had not been expected that so many villages were lacking a sewer system.
- Limited land was available (public land) for the construction of decentralized treatment system.
- Currently, Jordan is moving towards decentralization, where responsibilities are delegated to local governments (i.e. municipalities). The decentralized concept of wastewater management might be impeded by the fact that these new competences require knowledge and resources that are not necessarily available on the local or municipal levels.
- On some sites, the land owner differed from the potential future owner of the treatment plant. This caused contractual problems and an unclear responsibility/ownership situation.
- Unclear responsibilities for future operation and maintenance of the treatment systems led to a low readiness to take over the ownership of the treatment system from the project partners.
- Unclear administrative and regulatory framework conditions on all levels for implementing decentralized wastewater treatment and reuse systems slowed down the site selection and construction processes.

3.1.6 Decision Support and Economic Efficiency

3.1.6.1 Introduction

The main financing instruments for wastewater infrastructure in Jordan are loans or funds provided by development banks or donor organizations. Due to the size of the DWWT&R systems, such projects generally are of low priority for these organizations. Other barriers for implementing DWWT&R systems are the uncertainties relating to responsibilities and cost recovery for the O&M of such systems. Research therefore focused on providing a GIS-based decision support methodology to support decision-making for successful site selection, cost allocation, and financial assessment of potential wastewater treatment solutions.

3.1.6.2 Approach

The decentralized wastewater management support (DEWAMS) methodology developed considers the population, connection degree, groundwater vulnerability, topography, required sewer connections, reuse possibilities, technology selection, and associated costs as the main criteria for decision-making relating to decentralized wastewater treatment solutions (Figure 54). As a main output, the DEWAMS analysis produces a comparative cost analysis of the different DWWT&R scenarios and generates relevant financial indicators.

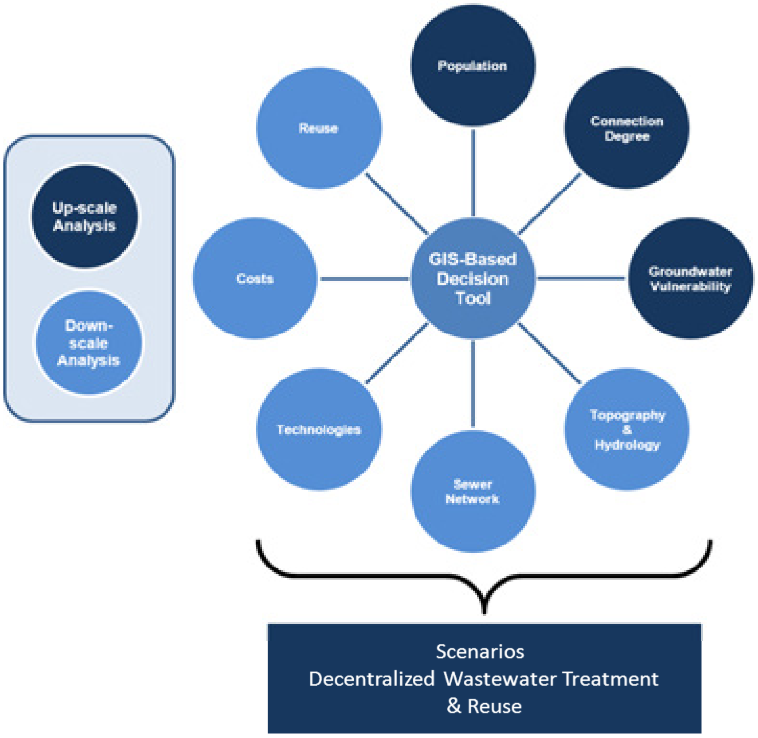


Figure 54: Decentralized wastewater management support “DEWAMS”

The tool provides a geo-database, including geographical, socio-economic, and statistical data of the area of interest, and allows to:

- Estimate the required treatment capacity (m^3/d) for DWWT&R solutions using the population statistics and parcel index for future building construction.

- Identify catchment areas for sites with highest potential for the future implementation of DWWT&R systems without pumping stations using satellite imaging and digital elevation models.
- Design gravity flow sewer networks for the selected catchment areas that are defined to favor the natural drainage of the area.
- Estimate costs for construction, operation, and maintenance (O&M) as well as required reinvestments for DWWT&R.
- Generate annualized costs and determine the cost efficiency of different scenarios of DWWT&R systems.
- Optimize O&M schemes of DWWT&R systems.
- Identify reuse potentials based on satellite imagery of potential reuse areas near the selected sites for constructing decentralized wastewater treatment plants.

3.1.6.3 Results

A regional analysis covered the Jordanian Wadi Shueib. It evaluates DWWT&R scenarios using the core technologies of sequential batch reactors (SBR) and recirculation vertical flow constructed wetlands (RVFCW). Two case studies were made; one in the rural area of the municipalities of Ira and Yarqa, and a second one in a suburban area of the municipality of As-Salt. The methodology was implemented with the intention of evaluating DWWTS&R systems from an economic perspective. The scenarios were analyzed and compared in terms of total project value (TPV) and specific treatment costs (STC) in Jordanian Dinar JOD per m^3 treated wastewater (JOD/m^3). Additionally, a cost comparison between the TPV of the decentralized solutions and the TPV of connecting the municipalities to a centralized wastewater treatment plant was carried out in order to reveal the competitiveness of the decentralized solutions versus a centralized approach.

In the case of the rural area of Ira and Yarqa, the analysis favors the implementation of DWWT&R approaches instead of centralized wastewater treatment solutions.

Using the DEWAMS methodology, nine potentially appropriate decentralized treatment plants were identified and their respective costs in terms of TPV were compared with the projected costs of a new centralized wastewater treatment plant. The costs of constructing a new centralized wastewater treatment plant (activated sludge technology) were estimated based on the costs of existing activated sludge treatment plants in Jordan. As a result, the DWWT&R option, including benefits generated by selling treated wastewater for irrigation to the farmers, was identified to be more attractive than constructing a centralized treatment plant, with the STC being 2.64 JOD/m^3 for the DWWT&R option compared to 4.43 JOD/m^3 for a new centralized wastewater treatment plants.

In the case of the suburban region of As-Salt, the specific treatment costs of applying DWWT&R systems are more attractive than the costs incurred by connecting the municipality to the nearest existing centralized treatment plant. Thus, decentralized wastewater treatment and reuse solutions are more competitive, with specific treatment costs being 0.86 JOD/m^3 compared to 1.32 JOD/m^3 for a centralized solution. Additionally, it was found that the costs of operation and maintenance (0.6 JOD/m^3) are nearly compensated by the benefits from the reuse and sale of treated wastewater to farmers.

3.1.6.4 Case study "Rural Areas": Ira and Yarqa

Ira (Figure 55) and Yarqa are located in the Wadi Shueib which covers a total area of 185 km^2 and includes the suburban areas of the municipality of Salt and the sub-districts of the municipalities of Ira, Yarqa, Fuheis, Shooneh Janoobiyeh, Shooneh Jadeedeh, Yazeediyeh, and Wadi Ennahq in the governorates of Amman and Al-Balqa. Projections for the region show a significant population growth as well as a significant deterioration of the existing groundwater conditions mainly due to cesspit infiltration into groundwater.

Figure 55: Panoramic view of Ira settlement (Photo: Cardona 2012).

The climate in Ira and Yarqa is arid and, thus, it is characterized by a constant lack of water. Both villages are surrounded by agricultural land that is mainly planted with olive trees in addition to seasonal crops, such as wheat, barley, lentils, and chick peas. Forests also exist in the region and are used as recreational areas, especially in spring.

Connection Degree: Key elements of the analysis are the identification and geo-referencing of existing central wastewater treatment plants, the connection to public sewer networks, and existing on-site solutions, i.e. cesspits in the area. Based on information from the Ministry of Water and Irrigation and local surveys, two central treatment plants serving the study area were identified. Based on data of the Jordanian census of 2004 (DOS), the connection degree of each settlement as well as existing on-site solutions, i.e. cesspits, were identified. The survey was performed on the local level to reflect local conditions in the municipalities of interest and showed a connection degree of 0 % for Ira and Yarqa.

Population: For the selected area of Ira-Yarqa (20 km^2), a population analysis was made based on the interpretation of GeoEye satellite images captured in April 2011. As a result, we identified a total of 1,710 buildings, equivalent to 10,218 people, assuming an equivalent dwelling unit (EDU) of 6 people per building. Using the projection estimations for the Al-Balqa governorate according to the DOS, a 30 years' population projection was made. This population will result in an estimated wastewater flow of 1,103 m^3/d assuming a wastewater production of 74 L/c d.

Topography and Hydrology: Based on the interpretation of the digital elevation model and topography maps in ArcGIS (ArcHydro tool box), local catchment areas were identified in order to determine flow directions for the design of collection systems. Additionally, the natural drainage streams were determined and final catchment points defined (Figure 56).

15 catchment areas were identified on the local level, which include a total of 2743 buildings.

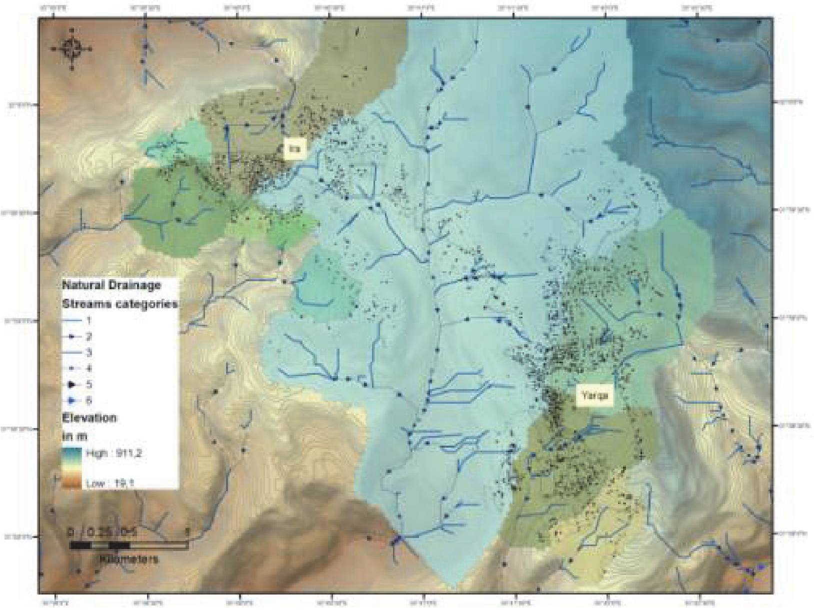


Figure 56: Identification of catchments areas related to the localities Iran and Yarqa.

Technologies: The decentralized wastewater treatment technologies were defined to meet the quality category A of the Jordanian standard for reclaimed domestic wastewater (JS893) from 2006. This target quality is mainly required in suburban areas, where space limitations exist and direct human contact with the treated wastewater should be restricted. Since the limit concentrations established especially for nitrate and E. coli are very low, they cannot be reached in one treatment step. Therefore, a tertiary treatment step and disinfection were added to the biological core treatment.

The cost estimations for the construction and operation of the DWWT&R systems were made for treatment plants of 50, 500, and 5000 PE in capacity (Figure 57).

Two main technologies were considered, namely, recirculating vertical flow constructed wetlands (RVFCW) and sequential batch reactors (SBR). For the DWWT&R solutions, every system includes pre-treatment, primary treatment, secondary (biological) treatment, denitrification, UV disinfection, as well as sludge-drying beds (only units of 500 and 5000 PE).

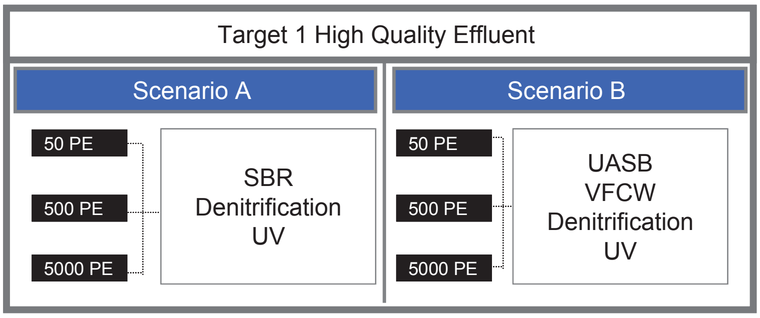


Figure 57: Proposed decentralized wastewater treatment technologies

Since the construction area is limited in some regions of Jordan, compact technologies with a small footprint, such as SBR, represent a suitable option. Moreover, vast operating experience is available for SBR in arid countries, such as in Oman (As Sauwwaiq 1999; Sulyok 2009). For the design of the SBR plants, we followed the German standards (ATV 1997). The excess sludge storage was designed to cope with a storage time of at least two months. In the cost calculations it is assumed that all SBR reactors are covered and that evaporation of the wastewater is avoided. It is assumed that the raw wastewater has a COD concentration of around 1,000 mg/L and it is expected that effluent values may reach concentrations of Category A of the Jordanian standard JS893. The dimensioning of SBR technologies for 50, 500, and 5000 PE was done by ATB in 2009/2010.

Constructed wetlands were identified to be an advantageous wastewater treatment solution for rural or less densely populated areas. Advantages of this technology include low operation and maintenance costs and reduced energy demands (Galvao et al. 2005; Kadlec & Wallace 2009; Alfranca et al. 2011). Preliminary designs of RVFCW for 50, 500, and 5000 PE were made by UFZ in 2009. For the RVFCW systems bigger than 500 PE, a UASB reactor as primary treatment step was added. This combination is an excellent alternative for Jordanian conditions, where high levels of BOD prevail (Elmitwalli et al. 2003; Wendland et al. 2006).

Groundwater Vulnerability: Werz & Hötzl (2007) developed groundwater vulnerability maps for Wadi Shueib based on geological and land use data. This information was combined with the connection degree map and digitized buildings in order to identify settlements that were not connected to sewer lines and, hence, are associated with high and extreme groundwater vulnerability. Most areas that are not connected to sewer lines were found to be located in zones with high or extreme groundwater vulnerability, indicating that an improvement of wastewater infrastructure would significantly reduce groundwater pollution in Ira and Yarqa.

Sewer Network: It is the goal of decentralized wastewater treatment scenarios to allow for the conveyance of wastewater by natural gravity flow wherever and whenever possible to avoid pumping. Within the catchment areas identified on the local level, layers of settlements, including buildings, streets, manholes, and sewer lines, were produced in ArcGIS (see Figure 58, satellite images from April 2011). Finally, the estimated total network length and the number of manholes were used to estimate the costs of the sewer network for the different catchment areas and scenarios.

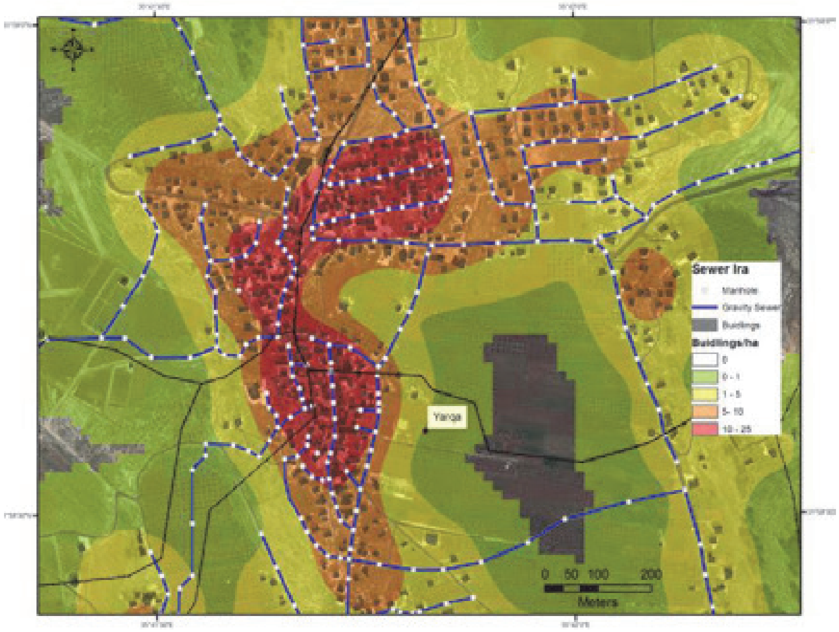


Figure 58: Identified areas for irrigations in Ira and Yarqa.

Based on satellite imagery and the respective referenced building data, a kernel density analysis was made using ArcGis 9.3 and the distribution of buildings per km^2 was identified. For DWWT&R solutions, the kernel density of buildings with less than 1 building per hectare was excluded for sewer construction, because the required sewer length of around 19 meters per inhabitant is associated with extremely high costs (see Table 19).

Table 19: Sewer analysis of the study area.

Density Buildings/ha	*Nr. Buildings*	*Percentage of total Buildings*	*Sewer length (m)*	*Estimated Population*	*Sewer/person (m/c)*
<1	90	4.56 %	10,498	540	19.44
1 to 3	409	20.72 %	11,779	2,454	4.80
3 to 6	658	33.33 %	15,543	4,310	3.61
6 to 10	518	26.24 %	6,869	3,108	2.21
10 to 25	299	15.15 %	2,997	1,794	1.67
Total	**1,974**	**100 %**	**47,686**	**12,206**	**Average 6.35**

Reuse: In order to identify suitable areas for reuse of treated wastewater, the land use of each catchment area was analyzed. The analysis identified spots for potential irrigation to cover a total area of 4.5 km^2 within the perimeters of the settlements (Figure 59). The total potential of reclaimed wastewater generated by the DWWT&R system was calculated to be 371,587 m^3/year. This water can be used for irrigation purposes within the municipalities in the identified agricultural area surrounding the treatment plants.

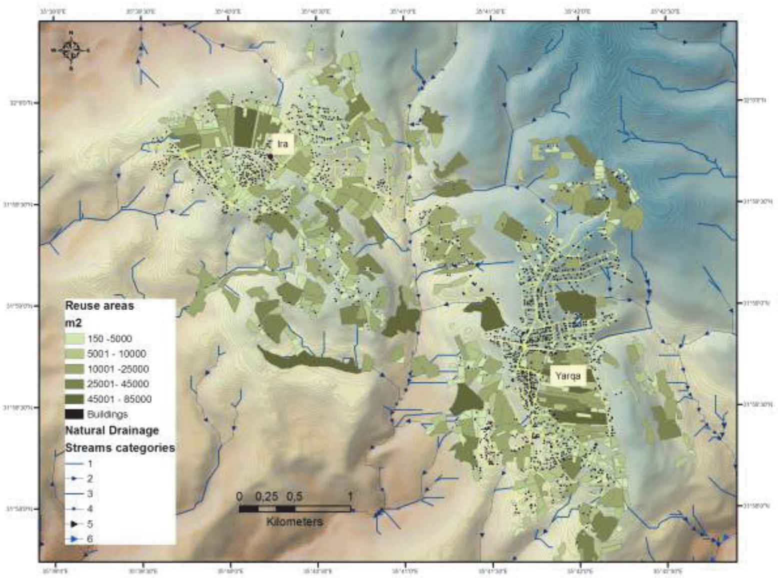


Figure 59: Identified areas for irrigations in Ira and Yarqa.

Costs: As a main output, DEWAMS analysis produced a comparative cost evaluation of the different DWWT&R scenarios. Relevant criteria for the financial assessment are the total costs incurred during the complete time frame of the project. Usually, wastewater infrastructure projects are evaluated over 25 years for wastewater treatment plants and 50 years for collection systems (LAWA 2005). Within these periods, different costs occur, and it is essential to use a robust methodology to analyze the financial data. Therefore, DWWT&R scenarios are compared using the total project value (TPV) methodology elaborated by LAWA (2005) as a guideline for costs comparison of wastewater infrastructure projects. Applying TPV methodology for DWWT&R scenarios, the costs for the entire project in terms of total capital costs (TCC), reinvestment costs (RIC), as well as operation and maintenance sosts (OMC) were calculated. A discount rate of 3 % and 5 %, respectively, and a 30 years' evaluation period were assumed to reflect the total sum of money needed for financing the complete project (Figure 60).

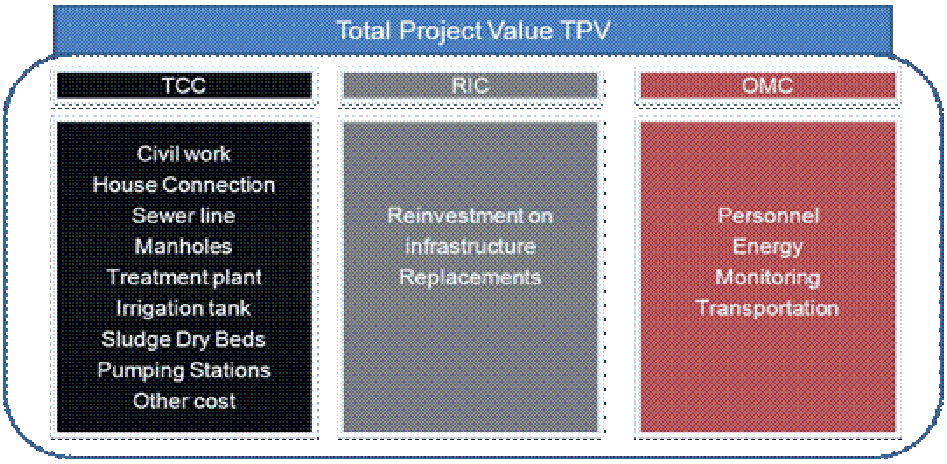


Figure 60: Cost components of the total project value methodology

Total Capital Costs represent all the infrastructure components required to build the treatment solution. This includes the mechanical and electrical components of the plants as well as the associated civil work. For the TCC estimation, a robust data base, including the local unit prices for components, such as excavation, labor, pipes, pumps, cabling, etc., was obtained by interviews with local companies and a direct survey of the Jordanian market. For converting historical costs into present values, historical and present consumer prices of the urban consumables index from the U.S Department of Labor Bureau was used (U.S. BLS 2012). Present values for historical costs were updated using the equation presented by Friedler and Pisanty (2006). Expenses that are not directly associated with the construction of treatment plants were included as “other costs” and include land costs, buildings for offices, engineering design costs, overheads, profits, and contingencies.

For the two main technologies of RVFCW and SBR (pre-treatment, primary and secondary treatment, denitrification, disinfection (UV), sludge-drying beds), two cost functions were developed (Figure 61).

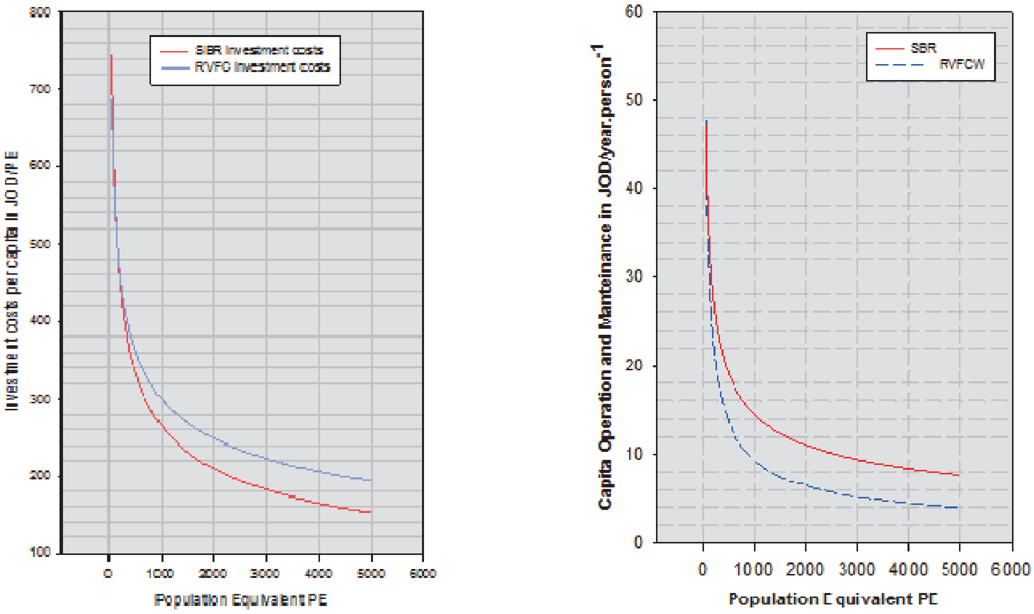


Figure 61: Costs functions for SBR and RVFCW for Total Capital Costs and Operation and Maintenance Costs.

The use of cost functions allows to model different possible wastewater treatment plants and has been used extensively for the estimation of costs of wastewater treatment infrastructures (Soderqvist 2002; Tsagarakis et al. 2003; Friedler & Pisanty 2006; Nogueira et al. 2007; Kadlec & Wallace 2009).

Operation and maintenance costs of DWWTS&R systems were estimated considering personnel costs, energy consumed by electrical devices (pumps, aerators, and ultraviolet lamps), laboratory costs as well as costs for sludge treatment. Costs of personnel were calculated in JOD/month. O&M costs were calculated based on current (2011/2012) Jordanian salaries and energy prices (0.05 JOD/kWh). Additionally, spare parts were included, assuming 9 % of the total O&M costs per year (Tsagarakis et al. 2003).

Reinvestment costs were calculated based on LAWA 2005, considering 40 % of the construction costs for replacements in year 12 and 25 and 60 % of the construction costs for reconstructions after 25 years.

Annualized Costs: In order to compare the economic efficiencies of different technologies and scenarios, the calculated TPVs were annualized and the costs expressed as annual cash flow over the 30 years' evaluation period. The annualized costs (AC) indicator allows for a comparison of the DWWT&R technologies and scenarios by calculating specific treatment costs (STC) that reflect the costs per m^3 of treated wastewater in JOD/m^3.

Scenarios: The developed methodology allows defining different scenarios by varying the sewer network design and type, size and locations of the decentralized wastewater treatment plants.

For Ira and Yarqa, a first wastewater management scenario was defined with a central wastewater treatment plant that serves the population of both villages (Figure 62).

- Scenario I: Central solution, where the wastewater is collected and transported to a central wastewater treatment plant using trunk lines and lift stations. For this study, the historical costs of activated sludge treatment plants were used for estimating the construction and O&M costs. It is assumed that the treatment plant, lift stations as well as trunk lines will be operated and maintained by WAJ.

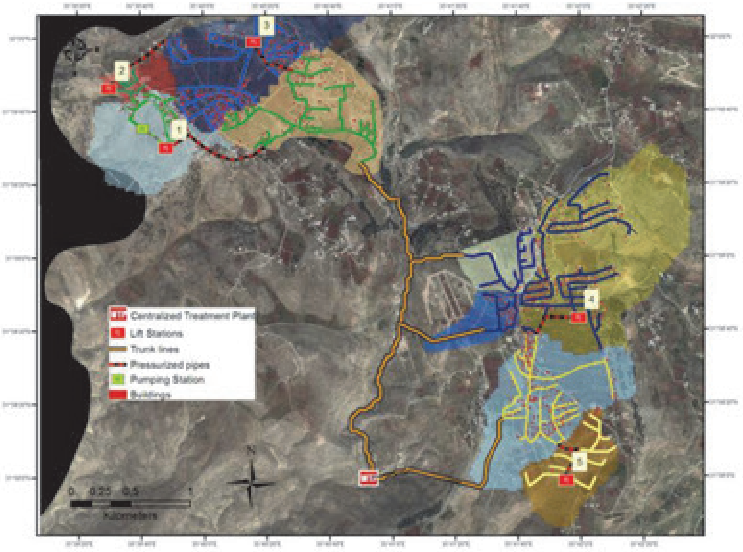


Figure 62: Central wastewater treatment scenario for Ira and Yarqa

The group of scenarios for implementing decentralized wastewater management is based on a cluster of 9 different decentralized treatment plants and 9 corresponding gravity-driven sewer networks (Figure 63). Since O&M is a central criterion for cost efficiency and sustainability of such decentralized systems, three sub-scenarios have been defined with varying O&M schemes.

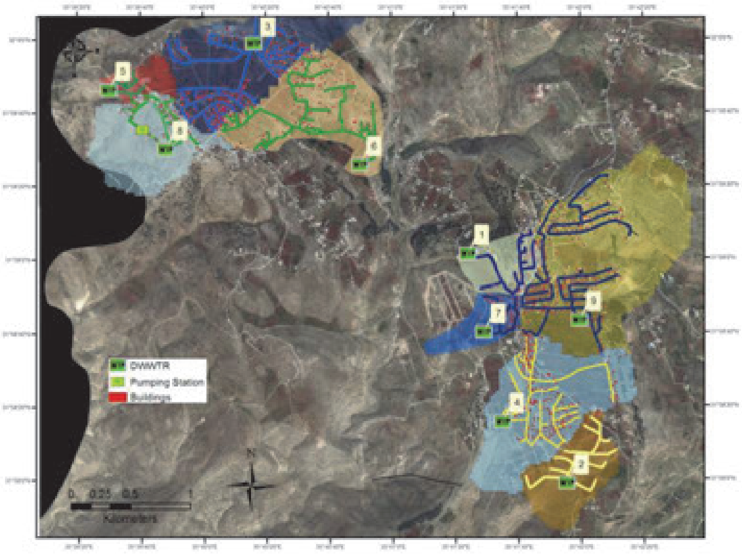


Figure 63: Decentralized wastewater treatment scenario for Ira and Yarqa

The Water Authority of Jordan is responsible for water delivery, but can assign this duty to the private sector in principle. Several service companies exist in Jordan that operate, maintain, and monitor water supply, central wastewater treatment plants, and collection systems. However, no experience has been gathered from the operation of decentralized systems.

- Scenario II: Cluster of decentralized wastewater treatment plants operated by the private sector: In this scenario a private operator will be in charge of the operation and maintenance of the DWWT&R systems. The sewer network will be maintained by the Water Authority of Jordan (WAJ).

- Scenario III: Cluster of decentralized wastewater treatment plants operated by the public sector. In this scenario the treatment plants as well as the sewer networks will be operated by WAJ. The private company will be in charge of the maintenance of the treatment plants. The sewer network will be maintained by the Water Authority of Jordan (WAJ).

- Scenario IV: Cluster of decentralized wastewater treatment plants with reuse benefits. This scenario was generated based on Scenario III, including reuse benefits of the produced reclaimed wastewater.

- Economic efficiency: summarizes the analysis of the economic efficiencies of the different wastewater management scenarios. Comparison of the specific treatment costs (JOD/m3) for each scenario clearly indicates that the construction of a new central treatment plant will be significantly more cost-intensive than a decentralized solution. This is mainly due to the high construction costs for trunk lines and lift stations. Comparing the different operation and maintenance options for the decentralized solution, the most favorable option is scenario IV, with a public-private partnership model and the consideration of potential benefits derived from the reclaimed wastewater. In this scenario WAJ will be in charge of the operation of the DWWT&R cluster, while a private company will maintain the treatment systems.

- Table 20 summarizes the analysis of the economic efficiencies of the different wastewater management scenarios. Comparison of the specific treatment costs (JOD/m^3) for each scenario clearly indicates that the construction of a new central treatment plant will be significantly more cost-intensive than a decentralized solution. This is mainly due to the high construction costs for trunk lines and lift stations. Comparing the different operation and maintenance options for the decentralized solution, the most favorable option is scenario IV, with a public-private partnership model and the consideration of potential benefits derived from the reclaimed wastewater. In this scenario WAJ will be in charge of the operation of the DWWT&R cluster, while a private company will maintain the treatment systems.

Table 20: Total Project Value Summary for the Scenarios for Ira and Yarqa.

Scenario	**I**	**II**	**III**	**IV**
Total Investment (JOD)	19,840,354	10,741,188	10,741,188	10,741,188
Total Reinvestment (JOD)	4,604,938	2,582,440	2,582,440	2,582,440
Reuse benefits (JOD / year)	0	0	0	37,170
Total O&M (JOD / year)	245,871	364,835	243,635	206,476
TOTAL PROJECT VALUE (JOD) (30 years, 5 % discount rate)	25,324,000	17,498,000	15,635,000	15,063,000
Annualized Cost (JOD / year)	1,647,362	1,138,270	1,017,079	979,870
O&M (JOD/m^3)	0.66	0.98	0.66	0.56
Specific treatment costs (JOD/m^3)	**4.43**	**3.06**	**2.74**	**2.64**

All cost estimations are presented in Jordanian Dinars JOD (2011: 1 JOD = 0,94 Euro)

3.1.6.5 Case Study “Semi-urban Areas”: Maghareeb

The Maghareeb community shown in Figure 64 belongs to the municipality of As-Salt. The region urgently requires wastewater treatment solutions. The municipality has been growing significantly over the last years. According to a previous analysis made in 2010, the municipality already has primary wastewater treatment systems that utilize gravity sewer networks and septic tanks. The diagnosis revealed the location of septic tanks, sewer networks, and the associated buildings served. It was found that in the northern part of the municipality one septic tank works outside of the design capacity and wastewater is discharged into the environment. This northern zone collects the wastewater for around 96 buildings and shows a clear need for promoting the construction of new and appropriate wastewater treatment facilities.

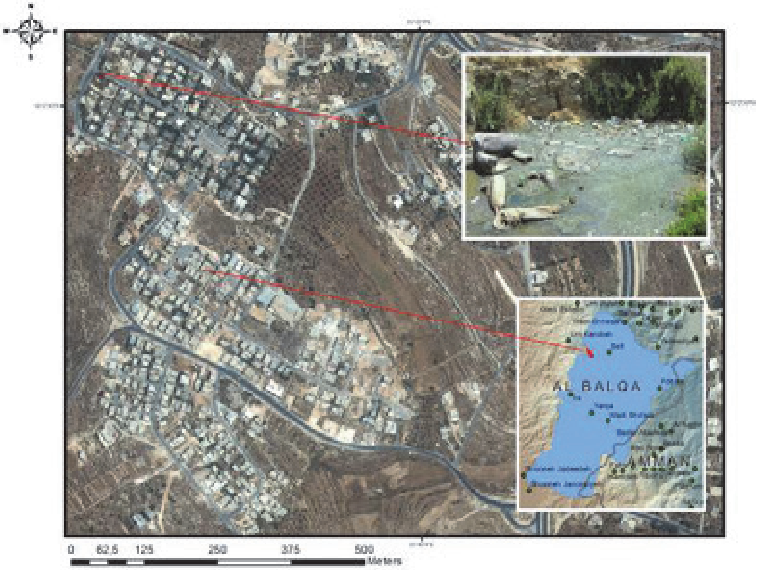


Figure 64: General view of the settlement Maghareeb in As-Salt.

For Maghareeb, a population analysis was performed based on the interpretation of GeoEye satellite images captured in April 2011. A total of 330 buildings, equivalent to a population of 3960 people, was estimated, assuming an eEquivalent dwelling unit (EDU) according to Wakileh (2012) of 12 people per building. The types of buildings identified consisted of mostly 3-storied constructions. Using the parcel index developed by the Department of Land and Survey of Jordan, a future population of 7416 was calculated for the selected buildings.

Topography and Hydrology: The topography for Maghareeb was developed using the digital elevation model DEM and raster relation tools in ArcGIS 9.3 ® to illustrate the elevation values within the municipality. The deepest level is at 612 m, while the highest is at 1082 m.

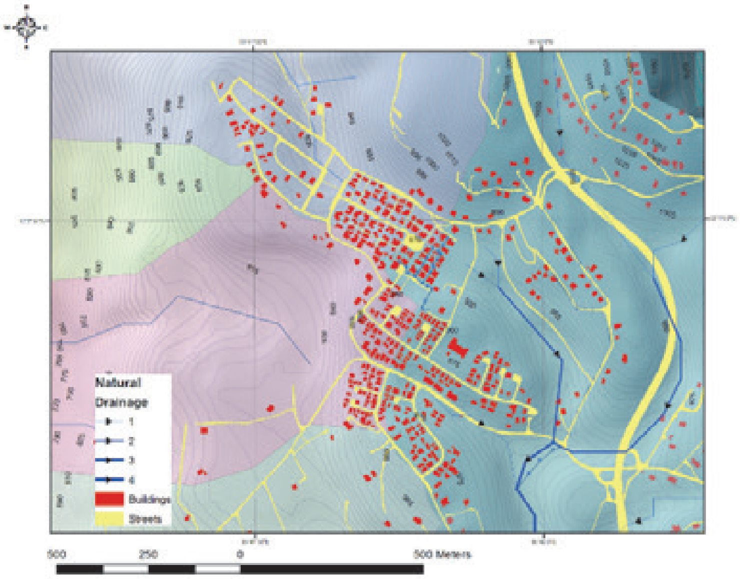


Figure 65: Catchment areas in Maghareeb.

The current situation benefits from the existence of a gravity flow collection system. The identified catchment areas are associated with the already existing collection zones of the gravity flow sewer networks. Figure 65 illustrates the DEM used for the construction of the catchment areas associated with Maghareeb. Additionally, the natural drainage streams were determined for defining the water flow direction and final catchment points.

DWWT&R Scenarios for Maghareeb

The following scenarios were developed were Maghaareeb:

Scenario I: The first scenario is a cluster of decentralized wastewater treatment plants. For this scenario, a decentralized wastewater treatment solution is constructed in every identified treatment zone. RVFCW is considered as a wastewater treatment technology for this scenario. Figure 66 shows the farthest treatment plant site proposed by the municipality of As-Salt for the settlement of Maghareeb.

Figure 66: Decentralized wastewater treatment scenario for Maghareeb.

Scenario II consists in the wastewater management scheme of Scenario I, but also includes potential economic benefits derived from the reclaimed wastewater produced by the DWWT&R system. For the calculation, we assumed a price for treated wastewater of 0.10 JOD/m^3.

Scenario III refers to a tanker solution for the existing septic tanks. In this scenario, the existing septic tanks will be upgraded to provide a primary treatment for every single treatment zone. The operation and maintenance costs a result from periodic emptying of tanks and the transportation and external treatment of sludge. This process will be controlled by the WAJ, assuming costs of 2.30 JOD/m^3 of pumped sludge. For this scenario, we additionally assumed up-grading costs per tank of 10,000 JOD.

Scenario IV assumes that the wastewater of all buildings of the settlement is collected in adequate (no seeping) septic tanks which are emptied by a tank vehicle. The operation and maintenance will consist in biweekly emptying of the units and disposal of the pumped wastewater at the nearest wastewater treatment plant. The operation and maintenance costs for this scenario were calculated based on local Jordanian costs.

Scenario V was defined as an alternative to the decentralized wastewater management systems by connecting the settlement to the nearest existing central treatment plant. Using the GIS methodology, the distance to the nearest existing centralized treatment plant and the costs for the required pressure lines and pumping stations were calculated. The analysis revealed that the As-Salt treatment plant is the nearest alternative for wastewater treatment. A general overview of the scenario is presented in Figure 67.

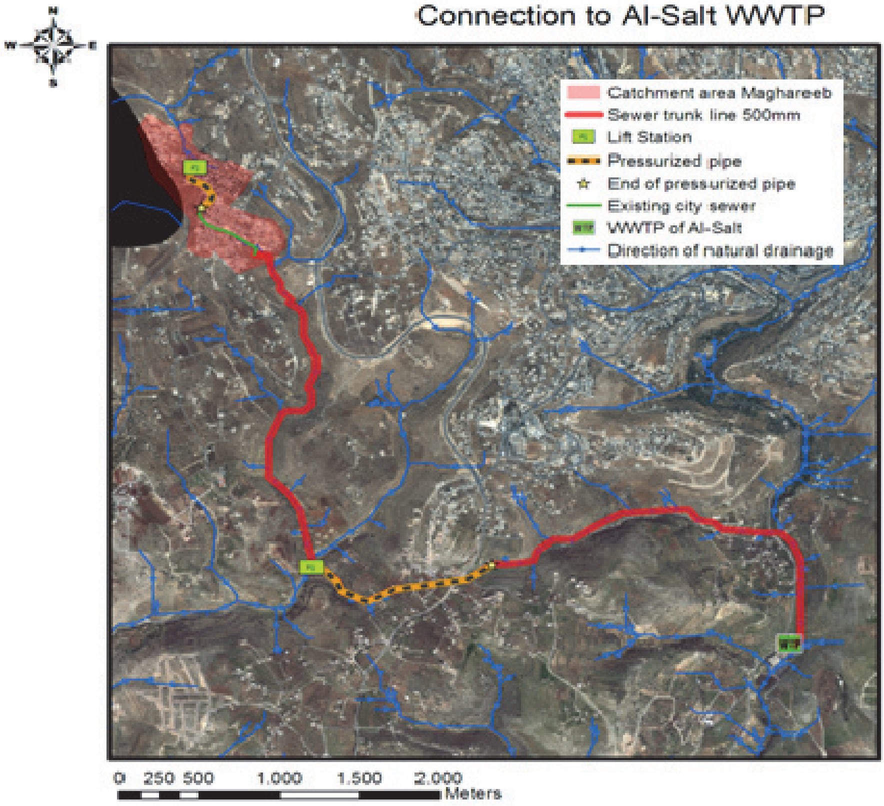


Figure 67: Scenario V, connection to a central treatment plant

Economic Efficiency: The TPC analysis favored the decentralized wastewater management scheme of scenario II (including reuse benefits), followed by scenario I (see Table 21). The central management scheme by connecting the settlement to the existing As-Salt treatment plant clearly is more cost-intensive, which is basically due to the high investments in trunk lines and lift stations.

The DEWAMS methodology developed allows for a comparison of different central and decentralized wastewater management options in terms of total project costs over the complete lifetime of the project. The results show that decentralized solutions can be competitive and less costly than conventional central wastewater treatment approaches.

The DEWAM methodology is principally applicable to any existing suburban and rural conglomeration before implementing (new) wastewater infrastructure and management schemes. The methodology might be useful in particular for new developments when uncontrolled population growth makes it impossible to draft a long-term capital investment plan for central wastewater treatment plants, sewage networks, and related facilities. The recommendations for actions mainly address national (regional) wastewater utilities and international donor organizations. The approach is aimed at promoting alternative investment plans for DWWT&R systems for sustainable changes in rural and urban development.

Table 21: Total project value summary for the scenarios for Maghareeb.

Scenario	I	II	III	IV	V
Total Investment (JOD)	2,042,153	2,042,153	90,000	927,000	3,494,329
Total Reinvestment (JOD)	1,350,607	1,350,607	0	0	0
Reuse benefits (JOD / year)		21,655			0
Total O&M (JOD/year)	31,372	13,534	498,059	789,495	56,860
PRESENT VALUE 30 years, 5 % discount rate (JOD)	3,184,000	2,851,000	7,746,381	13,063,473	4,386,000
O&M JOD/m^3	0.16	0.06	4.49	3.65	0.26
Annualized Cost (JOD)	207,124	185,462	503,913	849,798	285,316
Annualized JOD/m^3	**0.96**	**0.86**	**2.33**	**3.92**	**1.32**

3.1.6.6 Work Package Appraisal

Decentralized wastewater treatment and reuse (DWWT&R) systems can play a significant role in the alleviation of water scarcity and pollution. This SMART concept is also reflected in Jordan’s Water Strategy 2009-2022. In addition to the objective of an adequate wastewater collection and treatment in major cities, the strategy specifies that DWWT&R shall be built to serve semi-urban and rural municipalities and that DWWT&R approaches shall also be explored for new urban settlements.

- For the two case studies presented, the innovative DEWAMS tool proved that the decentralized solutions are much more cost-effective than central solutions.
- The developed DEWAMS methodology provides decision–makers with an enhanced understanding of existing onsite conditions and the potential financial impacts of different wastewater treatment and management schemes.
- Central management of decentralized clusters of treatment plants is required.

3.1.7 National Implementation Office Amman (NICE)

3.1.7.1 Introduction

In the context of the BMBF research project ”Integrated Water Resources Management in the Lower Jordan Rift Valley: SMART – Sustainable Management of Available Water Resources with Innovative Technologies, phase 2“, the BMBF sponsors the sub-project 10 ”Implementation Office Amman“ for the period from 01 June 2012 to 31 May 2015. The present report reports the progress of sub-project 10 until the end of the project period of the SMART II-consortium (30 June 2014).

One of the main objectives of the sub-project "Implementation Office Amman" is to develop a proposal for a national strategy for implementing decentralized wastewater management (DWWM) systems in Jordan. Furthermore, the office promotes cooperation among German researchers and decision-makers in the Jordanian water sector and supports the transfer of SMART research results to Jordan.

3.1.7.2 Official Opening of the Implemtation Office

The Implementation Office in the Ministry of Water and Irrigation (MWI) was officially opened in 2012 by Federal Minister Annette Schavan (BMBF, Figure 68). The visit of Annette Schavan to the Jordanian Ministry of Water and Irrigation as well as the opening of the Implementation Office were reported by the most important Jordanian newspapers, among others Al-Rai, Ad-Dustour, and the Jordan Times.

Figure 68: Official opening of the Implementation Office on 22 October 2012.

From right to left: Ambassador of the Federal Republic of Germany to the Hashemite Kingdom of Jordan Ralph Tarraf, Minister-President of the federal state of Saxony-Anhalt Dr. Reiner Haseloff, Manager of the NICE Office Dr. Mi-Yong Lee (UFZ), German Federal Minister of Education and Research Annette Schavan, Jordanian Minister of Water and Irrigation Maher Abu Al-Samin, Secretary General of the Jordanian Ministry of Water and Irrigation Basem Telfah.

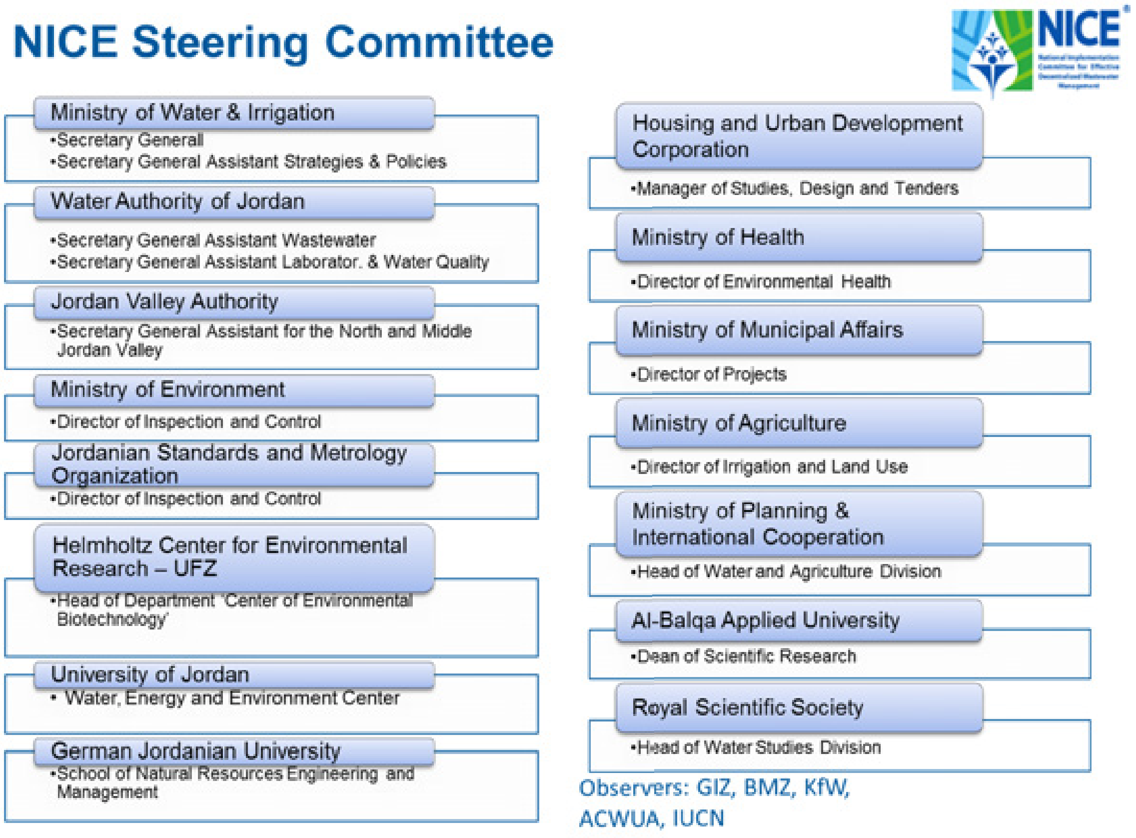
Al Rai is a political newspaper of the Jordan Press Foundation that is read in all provinces of Jordan. Al-Rai published an article in print as well as online on 22 October 2012. Ad-Dustour is an independent Arabic newspaper, which is also read nationwide. Ad-Dustour published its article on the visit of the federal minister and the opening of the "NICE" Office on 22 October 2012 in print and online. The Jordan Times is the most widely read Jordanian newspaper in English. The newspaper reported the visit and the opening in print and online in their local news section. The website of MWI provided the press release of the visit of the Federal Minister for one month starting on 22 October 2012.

3.1.7.3 Establishment of the National Implementation Committee for Effective Decentralized Wastewater Management in Jordan (NICE)

In November 2012, the Minister of Water and Irrigation, Maher Abu Al-Samin, issued invitations to all ministries relevant to wastewater management to participate in the ”National Implementation Committee for Effective Decentralized Wastewater Management in Jordan (NICE)“. NICE is an inter-sectoral committee that comprises eight (8) ministries and subordinated authorities and five (5) science and research institutions.

The main objective of NICE is to develop a strategy for implementation of decentralized wastewater management in Jordan.

The following persons have been delegated to represent their respective organisation in the NICE Steering Group. In addition, some institutions have been invited as observers in NICE (Figure 69).



NICE Steering Committee

Ministry of Water & Irrigation
- Secretary General
- Secretary General Assistant Strategies & Policies

Water Authority of Jordan
- Secretary General Assistant Wastewater
- Secretary General Assistant Laborator. & Water Quality

Jordan Valley Authority
- Secretary General Assistant for the North and Middle Jordan Valley

Ministry of Environment
- Director of Inspection and Control

Jordanian Standards and Metrology Organization
- Director of Inspection and Control

Helmholtz Center for Environmental Research – UFZ
- Head of Department 'Center of Environmental Biotechnology'

University of Jordan
- Water, Energy and Environment Center

German Jordanian University
- School of Natural Resources Engineering and Management

Housing and Urban Development Corporation
- Manager of Studies, Design and Tenders

Ministry of Health
- Director of Environmental Health

Ministry of Municipal Affairs
- Director of Projects

Ministry of Agriculture
- Director of Irrigation and Land Use

Ministry of Planning & International Cooperation
- Head of Water and Agriculture Division

Al-Balqa Applied University
- Dean of Scientific Research

Royal Scientific Society
- Head of Water Studies Division

Observers: GIZ, BMZ, KfW, ACWUA, IUCN

Figure 69: Members and observers in the NICE Steering Group.

The Helmholtz Center for Environmental Research - UFZ is a regular member of NICE and the only German institution with voting rights in the committee.

The NICE Kick-Off Meeting took place on 3 March 2013.

3.1.7.4 Establishing the Committee, Discussing Core Issues of DWWM in Jordan and Identifying Nice Core Themes and Priorities

Fundamental issues of DWWM in Jordan were discussed and the statutes of NICE were developed in the NICE Kick-Off Workshop on April 29th and 30th, 2013 (Figure 70). The committee adopted the statutes on May 29th, 2013 during the 2nd NICE Steering Group Meeting. The statutes define the following items: Committee purpose and objectives of the committee work, organisational and working structure of the committee, decision-making structure of the committee, role of the Implementation Office.

Figure 70: Steering Committee Meeting, 29.05.2013, Amman, Jordan

3.1.7.5 Developing the Nice Work Programme and Schedule

The NICE work programme and schedule were defined during the 3rd meeting of the NICE Steering Group. Furthermore, the framework and framework chapter composition and structure were decided upon (Figure 71).

Figure 71: NICE Steering and Technical Group Workshop, 29 and 3 April 2013, Amman, Jordan.

And finally, drafts of the NICE logo and the NICE website were presented and discussed (Figure 72).

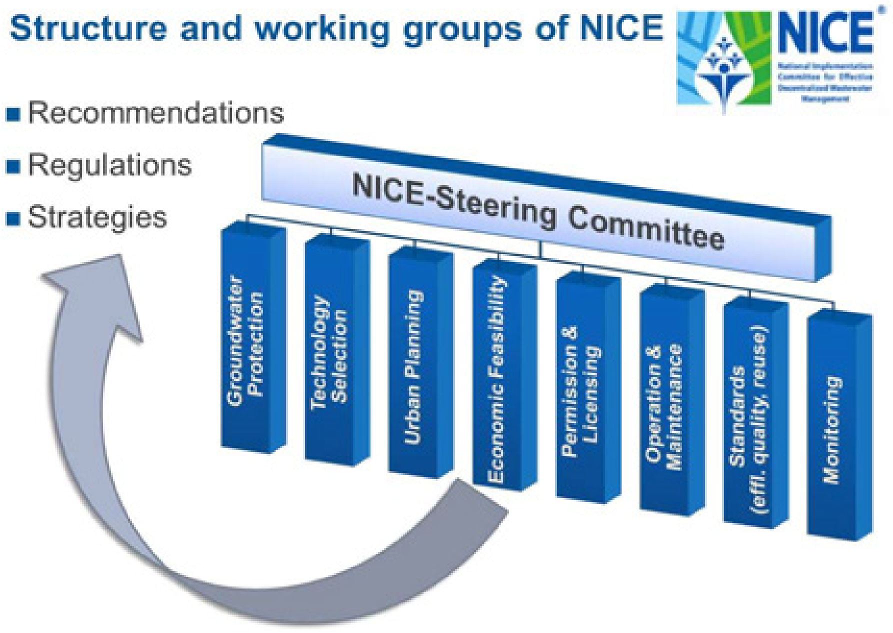


Figure 72: Thematic structure and working groups of NICE

3.1.7.6 Implementing the Nice Work Programme

3.1.7.6.1 4th Nice Steering and Technical Group Meeting (Workshop), 5 December 2013

- Presentation ”Groundwater Protection and Decentralized Wastewater Management".
- Discussion and decision on objectives and tasks of the working group ”Groundwater Protection and Decentralized Wastewater Management“.
- Establishment of the working group ”Groundwater Protection and Decentralized Wastewater Management“.
- Presentation ”Decentralized Wastewater Technology“ and ”Technology Selection for Decentralized Wastewater Management“.
- Discussion of and decision on objectives and tasks of the working group “Technology Selection for Decentralized Wastewater Management“.
- Establishment of the working group ”Technology Selection for Decentralized Wastewater Management“.

3.1.7.6.2 5th NICE STEERING GROUP MEETING, 15 MARCH 2014 (see Figure 73)

- Presentation of the feasibility study on regional implementation of DWWM in the Governorate of Ajloun, Jordan.
- Presentation and discussion of the results of the working group "Groundwater Protection and Decentralized Wastewater Management“.
- Presentation and discussion of the results of the working group ”Technology Selection for Decentralized Wastewater Management“.

3.1.7.6.3 6th NCE Steering Group Meeting, 13th May 2014

- Establishment of the working group ”Standards & Monitoring for DWWM“.

Establishment of the working group ”Urban Planning and DWWM“.

Figure 73: 5th NICE Steering Group Meeting with Dr. Helmut Löwe (BMBF), Dr. Verena Höckele (PTKA WTE), and Dr. Leif Wolf (PTKA WTE) , Marriott Hotel, Amman, Jordan.

3.1.7.7 Implementing the NICE Work Programme on Working Group Level

3.1.7.7.1 Working Group “Groundwater Protection and Decentralized Wastewater Management“

- Implementation of groundwater protection zones with DWWM – procedures and measures.
- Provisions for wastewater treatment near groundwater protection zones and analysis of Jordanian standards and guidelines relevant to groundwater protection.
- Survey of hot spots to identify DWWM priority areas for groundwater protection (GIS mapping).
- Handling of cesspools and septic tanks with respect to groundwater protection.
- Recommendations for implementing groundwater protection by means of DWWM.
- Meetings/workshops within the SMART II report period: 11 December 2013, 13 January 2014, and 18 March 2014.

3.1.7.7.2 Working Group “Technology Selection for Decentralized Wastewater Management“

- Definition of the target group for recommendations regarding technology selection for DWWM.
- Design criteria for DWWM technologies.
- Methods of DWWM technology selection.
- Selection criteria and ranking criteria for DWWM technology selection.
- DWWM technology selection based on three scenarios typical of Jordan.
- Recommendations for implementing DWWM technology selection procedures.
- Meetings/workshops within the SMART II report period: 05 January 2014 and 19 March 2014.

3.1.7.7.3 Working Group “Urban Planning and DWWM“

- Assessment of the current wastewater situation in new settlements.
- Assessment of the institutional landscape concerning wastewater management infrastructure for new settlements.
- Identification of measures for improvement of wastewater infrastructure planning.
- Introduction to urban planning in Jordan, including legal frameworks, i.e. organizational and legislative aspects.
- Definition and classification of settlements (problems and practical issues).
- Urban planning for new and existing settlements and identification of applicable instructions or guidelines.
- Considerations and criteria for implementation of decentralized wastewater treatment plants (orientations, instructions, technical standards, and suggested control guideline) for urban planning.
- Meetings/workshops within the SMART II report period: 17 June 2014.

3.1.7.7.4 Working Group “Standards and Monitoring for DWWM“

- Assessment of knowledge base on standards and monitoring for DWWM in Jordan.
- Reuse standards in Jordan.
- Different approaches to safe reuse (WHO, GIZ) and their principles.
- Development of Jordanian approach.
- Recommendations for implementing standards and monitoring procedures for effective DWWM.
- Meetings/workshops within the SMART II report period: 02 June 2014 and 11 June 2014.

3.1.7.8 Collateral Measures to Promote DWWM in Jordan

3.1.7.8.1 Implementation Research - Institutional Efficiency Study

- Study of the legal and administrative framework: Comprehensive survey and analysis of legal provisions relevant to DWWM in order to identify gaps and bottlenecks for implementing DWWM in Jordan and to develop recommendations towards enhancing legal efficiency.
- Qualitative study based on interviews with main decision-makers in the Jordan Water Sector in order to assess the administrative readiness for and capability of implementing DWWM in Jordan

Interview Schedule

Interview partner	Institution	Position	Datum	Beginn
H.E. Eng.Basem Telfah	Ministry of Water & Irrigation	Secretary General	29/04/2014	10:00 a.m.
H.E. Eng. Sa'ad Abu Hammour	Jordan Valley Authority	Secretary General	05/06/2014	9:30 a.m.
H.E. Eng. Tawfiq Al-Habashneh	Water Authority	Secretary General	14/07/2014	1:00 p.m.
Eng. Iyad Dihyat	Program Management Unit	Director	06/03/2014	11:00 a.m.
Eng. Malek Al-Rawashdeh	Water Authority	Secretary General Assistant for Technical Affairs	06/02/2014	3:00 p.m.
Eng. Qais Owais	Jordan Valley Authority	Secretary General Assistant for the Northern and Middle Governorates	14/04/2014	1:00 p.m.
Eng. Ali Subah	Ministry of Water & Irrigation	Secretary General Assistant for Technical Affairs	15/12/2012	4:00 p.m.
Eng. Huda Qumoq	Water Authority	Director Studies & Designs	05/01/2014	11:30 a.m.
Eng. Majed Joudeh	Water Authority	Head of Technical Support for Treatment Plants Section	19/11/2013	9:30 a.m.

3.1.7.8.2 Networking and Collaboration

- Agreement (”Agreed Minutes“) on the collaboration of UFZ and GIZ in the area of DWWM in Jordan.
- NICE office manager is Steering Committee member of the Project EU SWIM Water MED. Within this project, GIZ implements a decentralized wastewater treatment solution at the National Public Security Directorate in Muqabeleen near Amman.
- Presentation of a potential investment project "DWWM Cluster in Ajloun“ for the Director of the Program Management Unit (PMU) Iyad Dihayat and the Secretary General Assistant Technical Affairs, Malek Al-Rawashdeh (WAJ) together with KfW representatives (Dr. Stefan Gramel, Beate Richter, Isabel Hoffmann), 27 February 2014.
- Participation in the GIZ appraisal mission DWWM in Jordan for developing a GIZ Project financed by the BMZ energy and climate fund, 22 and 28 January 2014.

3.1.7.8.3 Conferences and Meetings

- Participation in 7th SMART II coordination meeting in Lanarca. Presentation on NICE project status and progress.
- Participation and presentation at the Arab Water Week, January 27 - 31, 2013, Amman, Jordan.
- Presentation of the sub project "Implementation Office Amman" at the EU SWIM Water Med stakeholder meeting, Amman, Jordan.
- Participation in Jour Fixe of the German Ambassador in Jordan: 31 January 2014, 10 March 2014, 18 June 2014 and a one-on-one meeting with the German Ambassador in Jordan, Ralph Tarraf, on 09 March 2014.
- Participation in GIZ-CAWR Workshop at UFZ, presentation of GIZ (in lieu of GIZ water portfolio manager in Jordan, Daniel Busche) und UFZ activities in the Jordanian water sector, 19 May 2014.
- Participation in 3rd Workshop of the Global Water Partnership in the context of the ”Jordanian Policy Dialogue“ and the official publication of the OECD Report “Water Governance in Jordan: Overcoming the Challenges to Private Sector Participation”, 04 June 2014.

- Participation in planning workshop ”Water Governance MENA - Humboldt University Cooperation and Development Initiative“, led by Humboldt University, Prof. Dr. Matthias Weiter, 05 February 2014.

3.1.7.9 SMART II Support

The Implementation Office supported the site selection for the SMART II pilot plants. It contributed to the transfer of SMART II specific topics in the field of IWRM, among others pilot plant for brackish water desalination, groundwater tracer testing, community involvement for DWWM, introduction of MYWAS at MWI, private sector participation in DWWM implementation, etc. to the Ministry of Water and Irrigation, the Water Authority of Jordan, and other important stakeholders. Furthermore, the office supported SMART II-associated students and researchers during their field activities in Jordan and organized meetings with local stakeholders.

3.1.7.10 UFZ-financed Feasibility Study for Regional implementation of DWWM in Ajloun, Jordan

A feasibility study for the regional development in Jordan was commissioned in September 2013 to the company of Dorsch International Consultants. The study was financed by the UFZ with own funds of EUR 75,000.00 plus 13.71% overhead. The study results were presented at the 5th Meeting of the NICE Steering Group in the presence of PTKA WTE (Dr. Verena Höckele, Dr. Leif Wolf) as well as Dr. Helmut Löwe (BMBF).

3.1.7.11 Launch of NICE Project Website

The NICE website has been available at www.nice-jordan.org since March 2014:

http://nice-jordan.org/EN/NICE.aspx

3.1.8 Conclusions and Recommendations

The achievements made so far in developing and advancing an integrated decentralized wastewater management system in Jordan allow for linking this tool more closely to other components of IWRM, such as groundwater protection and managed aquifer recharge (MAR), thereby completing and deepening the SMART approach.

Challenges in implementing DWWT&R technologies in Jordan are the abundance of marketable and internationally available technologies and the difficulties decision-makers face in assessing and maintaining the sustainability of technologies for a given local context. In Jordan there are yet any regulations and standards for DWWT&R technologies. Hence, there is a need for defining these regulations and standards in order to ensure that solutions will be implemented, which are technically suitable and economically feasible. This also provides opportunity for developing a certification protocol that is based on the European standard for small wastewater treatment plants (EN 12566-3). By way of example, a pre-certification of marketable German wastewater treatment technologies under Jordanian conditions may be accomplished.

Continuing our activities in the area of decentralized wastewater management in Jordan would provide the great opportunity to complete our model of “implementation research”. This means the integration of research, government, and donor organizations (development banks) on the project level in order to jointly prepare a roll-out investment project for constructing clusters of decentralized wastewater technologies on the regional scale in Jordan.

The successful and sustainable implementation of the main outcomes of these proposed research activities also require a well-thought-out capacity development (CD) concept and program tailored to the local conditions, which is to take into account the needs of the counterparts and stakeholders involved.

The following central recommendations are made:

- Groundwater protection: Further development of the decentralized wastewater management tool as an instrument for water resources (groundwater) protection.
- Managed aquifer recharge: Adapting decentralized wastewater technologies to managed aquifer recharge.
- Investment project: Applying the developed GIS-based decision support tool for decentralized wastewater management and preparation (technologies, sites, financing, O&M) of an implementation project on the country scale.

Considering the results, future perspectives for the implementation of DWWT&R in Jordan may be attractive for economic investments in the water and sanitation sector. Based on Jordan's Water Strategy 2009-2022, it is reasonable to assume that the Jordan Ministry of Water and Irrigation (MWI) is considering the introduction of decentralized wastewater treatment and reuse (DWWT&R) infrastructure on a regional scale. The Jordanian government is pursuing the strategic aim of realizing a key step in the sustainable use of its water resources.

3.2 Managed Aquifer Recharge

Involved Institutions: TZW, UKA, UFZ, GU, JUA, MWI, PHG, QUDS, TAU, MEK

Spokesmen WP3-2: A. Tiehm (TZW), A. Marei (QUDS)

Compiled by: N. Schmidt (TZW)

3.2.1 Introduction

Author: N. Schmidt

Water resources in the Lower Jordan Valley (LJV) consist of groundwater, surface water and recently treated wastewater. After diversion of the tributaries of the Upper Jordan River through Israel, Jordan and Syria, a huge stress is still applying on the local aquifer systems. This causes lowering of the water table and a rise in salinity due to over-pumping. In the eastern part of the Valley many storage dams are constructed in the Wadis to collect flood surface water. This causes limitations for the use of surface stored water for irrigation purposes, where the demand for domestic water increases rapidly.

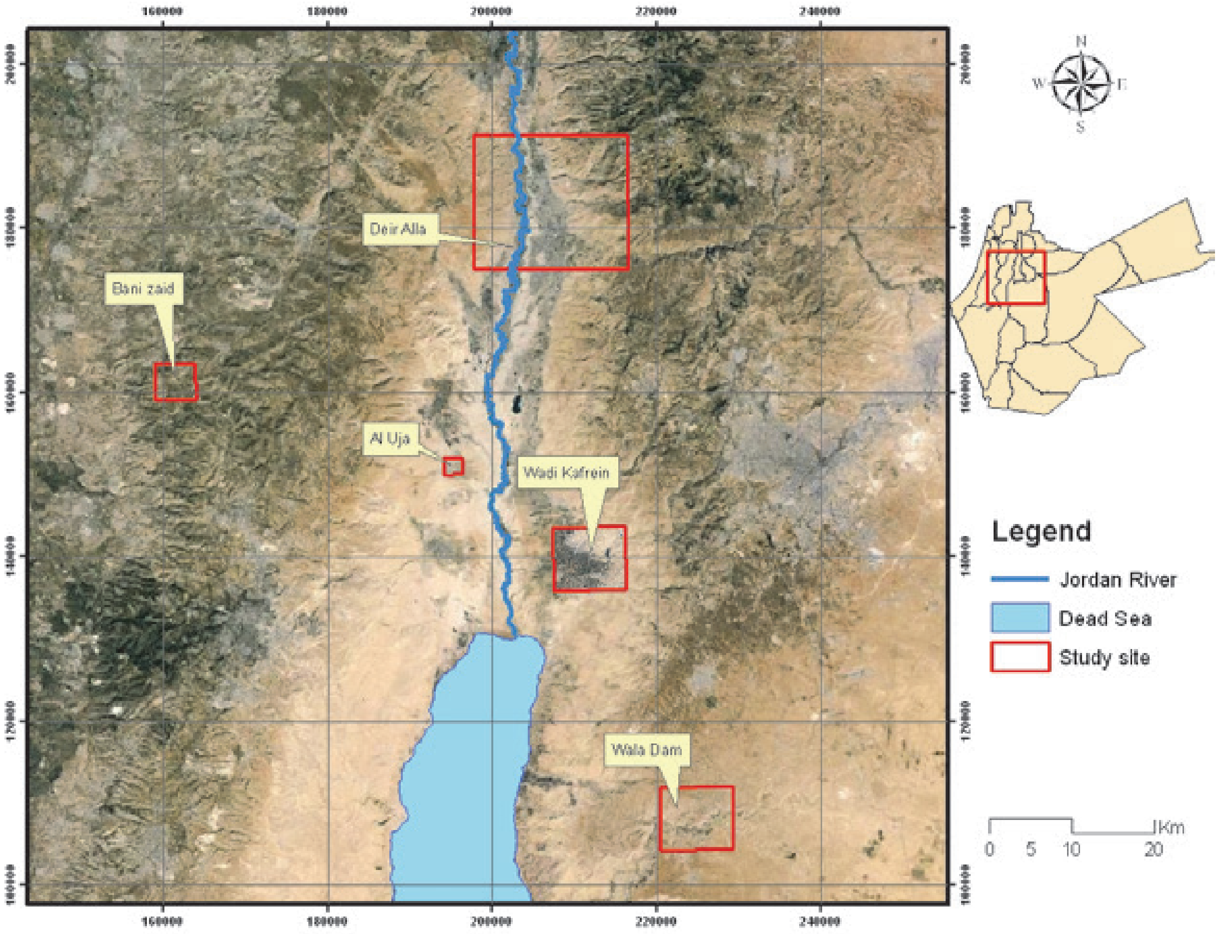


Figure 74: Locations of artificial recharge test sites in Jordan and the West Bank

In the western part of the LJV, groundwater still is the only source for all uses, while flood surface water is not utilized. In a semi-arid/arid climatic region like the LJV storing of surface water in open reservoirs is affected by a high evaporation rate as well as by a number of existing pollution sources. On the other hand, the sustainable use of water resources in the LJV is crucial to the economic development of Jordan and the West Bank. Undeveloped water resources or their degradation could be reflected easily on the fragile political situation in the form of political conflicts. Storing excess water (spring or river overflow, treated wastewater, or floodwater) in the underground is one option to overcome water quality degradation. Managed aquifer recharge (MAR) depends on many factors, including climate, geology, hydrogeology, water quality, and water uses. These factors were tested at four artificial recharge sites in Jordan (Wala dam, Deir Alla ,Wadi Kafrein, and Wadi Ishe) and at two sites in the West Bank (Al Uja and Bani Zaid area) (Figure 74). At these sites, different sources of water were used for artificial recharge. These included spring water, river water, floodwater, and treated wastewater. Also different artificial recharge techniques were used, such as infiltration ponds, injection wells, and dam water. Results of these techniques are summarized in the following deliverables.Study sites and main results

3.2.2 Study sites for Managed Aquifer Recharge

3.2.2.1 Wala Dam, Jordan

Authors: A. Sawarieh, J. Xanke

Introduction

The Wala-Haidan well field supplies domestic water to the cities of Madaba and Amman. During the last three decades, the well field was overexploited and yearly averages (1997-2012) of about 11.5 MCM were continuously pumped for drinking purposes, whereof about 0.5 MCM on the average were used for irrigation purposes (JVA, 2012).Since the natural recharge was not sufficient to replenish the groundwater system, a major part of the base flow in Wadi Wala dried out and the groundwater level dropped. As a consequence, water salinity increased and deteriorated the groundwater quality. Managed aquifer recharge (MAR) was an option to boost the natural seasonal recharge process.

The aim of this study was to investigate the impact of Wala Reservoir stored water on the downstream groundwater system. The long-term monitoring data of the groundwater level and the reservoir storage records were used to evaluate the quantitative effect of the infiltrated water on the Wala-Haidan well field. The main problems associated with Wala Reservoir operation, such as sedimentation and turbidity, were also examined.

Water Quality

The results of the chemical analyses of the reservoir and some selected wells in the study area during the last ten years (MWI 2012) show that the total dissolved solids (TDS) concentration ranges from 600 to 900 mg/l. This range of salinity is typical of groundwater from carbonate aquifers with a long mean residence time. The yearly average electrical conductivity (Ec) values of the reservoir water are highly variable and range from 380 to 700 µs/cm. The highest values were recorded during 2008 and 2009; when the reservoir dried out, lower Ec values are always related to flood events. A general decreasing trend in Ec values was observed in the groundwater after the first impoundment into the reservoir. Furthermore, a relatively small regional increase in salinity was observed during the period from December 2003 to April 2004, which was explained by the flushing of the cavities and rock matrix during the period of first infiltration from the reservoir (Sawarieh et.al 2010). Nitrate concentrations in the groundwater ranged from 3 to 42 mg/l. Higher values were attributed to agricultural activities in the vicinity of some wells.

The reservoir water revealed an isotopic signature, similar to regional rainfall. The content of heavy stable isotopes of the reservoir water ranges between -5.5 ‰ and -7.4 ‰ for oxygen-18 (δ18O) and between -25 ‰ and -32 ‰ for deuterium (δ2H). In the summer, the reservoir water became enriched with heavy isotopes by evaporation. The relationship between δ2H and δ18O, for the reservoir and four wells downstream, shows that the water originated from regional vapor. The wells nearest to the reservoir were more depleted in δ2H than the wells further away, which indicates a mix of different waters in the aquifer.

Intensive agricultural activities and housing along the Wadi Wala and Wadi Haidan cause high contamination of the surface waters. Periodical pollution with coliform bacteria and turbidity were detected in the Haidan and Wala wells during the rainy season in the past years, especially at the beginning of the winter season during major flood events. Several water samples from

Wala and Haidan wells were analyzed for E. coli and compared to rainfall events. The conclusion is that Haidan wells are much more affected by E. coli than the Wala wells. This might be due to the presence of swallow holes, which enhance the infiltration of surface water.

Geology

The Wala reservoir catchment extends from Amman in the north to Wadi Mujib in the south on a total area of about 18,000 km^2 (Figure 75). It is covered by thick soil, especially in the northern and eastern parts. A sequence of more than 400 m thick sedimentary rocks is cropping out in the catchment area and ranging from Torunian to recent age. This sequence belongs to the Ajlun and Belqa groups that are subdivided into a number of geological formations, as is described in the geological maps of Ma'in, Madaba, Khan Ez Zabib, Sahab, and Amman. The geological formations, in descending order, include alluvium and soil, Pleistocene gravels, Umm Rijam Chert Formation (B4), Muwaqqar Chalk Marl Formation (B3), Al Hisa Phosphorite (B2b) and Amman Silicified Limestone (B2a) formations, Wadi Umm Ghudran (B1) and Wadi As Sir Limestone (A7).

Hydrogeology

The Wadi Wala catchment drains westwards to the Dead Sea through Wadi Wala and its three major tributaries, Nitl, Rumail, and Ammuriya wadis (Figure 75). These tributaries are dry, except for a short period after rainfall. The mean annual precipitation in the catchment area is about 218 mm, with a mean temperature of 15°C. The evaporation is around 92 % and the groundwater recharge is estimated to be 3 % of the total precipitation.

The B2/A7 is the most important carbonate aquifer system in Jordan and also represents the main aquifer in the Wala catchment, whereas the upper part of the aquifer (B2) is mainly unsaturated at the reservoir site. Meanwhile, it has become a major permeable formation and may provide for a significant leakage path, especially when the reservoir approaches its full capacity. The lower part of the aquifer (A7) forms the major aquifer in the vicinity of the Wala and Haidan wadies with a thickness of about 150 m. The main recharge to the B2/A7 aquifer takes place at outcrops in the catchment.

The groundwater flow pattern in the B2/A7 aquifer within the Wadi Wala catchment is strongly influenced by the recharge mounds, the geological structural setting, and the presence of Wadi Wala and the Dead Sea. From the recharge mound in the north (Amman-Madaba), the major part of the groundwater flows southwards to Jiza region, then southwest along the main drainage system of Wadi Wala, passing the Wala-Haidan well field towards the Dead Sea. Other recharge enters the aquifer in the catchment from Karak recharge mound in the south and flows first north and then to the west towards Wadi Wala (Sawarieh 2005, Xanke, et al. 2015).

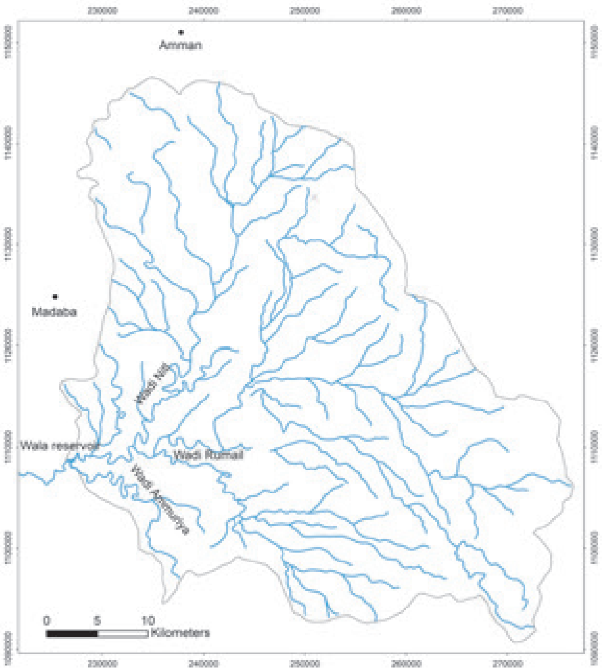


Figure 75: Wadi Wala catchment.

Method of Recharge

The Wala Reservoir is the biggest artificial recharge construction in Jordan. It was built to store the flood water of Wadi Wala and recharge it to the karstic limestone aquifer below using 8 recharge wells that were drilled downstream of the reservoir. The Wala dam was constructed on the Wadi Wala, 8 km upstream of the well field, with a maximum storage capacity of 9.3 MCM (live storage: 7.7 MCM). The mean annual inflow into the reservoir was estimated to be 17.7 MCM and was believed to constitute the annual safe yield from the Wala-Haidan well field. The reservoir was designed to artificially recharge 5 MCM/Y of water to the aquifer through injection into the recharge wells. Most of the stored water, however, was naturally seeped into the aquifer. Therefore, these wells were used as monitoring wells in addition to the two observation wells in the Wala-Haidan well field. The first injection through the recharge wells was conducted in 2011. The impoundment in the reservoir started in winter 2002/03, when it received about 15.3 MCM of water. Most of the inflow seeped naturally from the reservoir into the aquifer. The static water level (SWL) records of the monitoring wells show that the reservoir lake and the groundwater are hydraulically connected and that the aquifer system downstream is supplied by recharge from the reservoir lake.

Implementation and Results

Wala Reservoir storage

The storage records (2002-2012) of the Wala Reservoir (JVA, 2012) show that the reservoir was almost dry in November 2003, when the amount of storage was only 0.369 MCM. The records also reveal that the maximum storage capacity (9.3 MCM) was reached in the wet years 2004 and 2006, whereas total storage was lowest in the year 2008. In this year, the reservoir was dry for six months and the elevation of the bottom was at 498.6 m a.s.l., while its original base had been at 485 m a.s.l. This means a loss of about 1.124 MCM from its maximum capacity due to sediments accumulation. Its new maximum capacity of around 8.176 MCM has been taken as a basis of the water balance calculations since then. The records show that the reservoir storage reached its new maximum capacity in the years 2009 and 2010 (Figure 76). Total inflow into the reservoir during 2002–2012 was calculated to be 125 MCM. Of this inflow, about 44 MCM were lost as spillover, about 8 MCM were evaporated, and about 73 MCM were recharged to the aquifer.

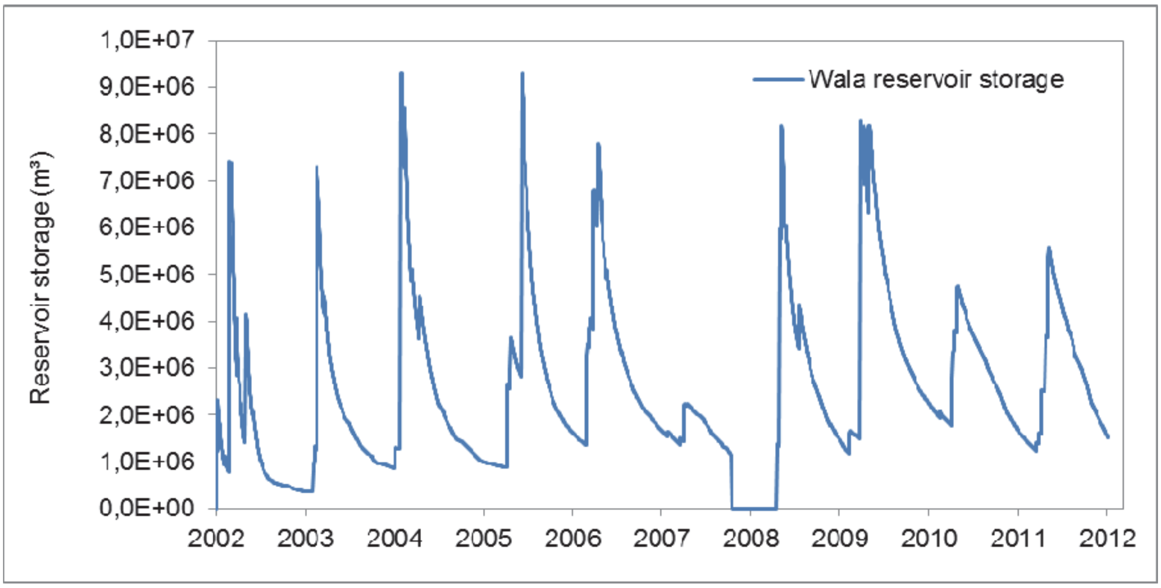


Figure 76: Wala reservoir storage fluctuations from 2002 to 2012.

Recharge Wells (RW1-8)

The 8 recharge wells are distributed along the wadi downstream of the Wala reservoir at a distance of around 2 km, their depth being 175 m (Figure 77). The filter section starts around 80 m below surface level, down to the bottom of the well. Due to the fact that most of the water has been infiltrating the aquifer naturally from the reservoir since 2002, the recharge wells were never used until 2011. The static water level records of the recharge wells before and after reservoir impoundment show that the SWL in the recharge wells was raised by 20 m to 32.5 m after the first year of operation. Records also reveal a sharp decrease of SWL in these wells in the year 2008 when the reservoir was dry. The water level fluctuations in the recharge wells depend strongly on the reservoir storage and infiltration.

Observation Wells (CD 1097 and CD 3133)

The observation wells, CD 1097 and CD 3133, were drilled and equipped with water level recorders to monitor groundwater level fluctuations in the Wala-Haidan well field (Figure 5). The SWL data of these wells recorded for the period 1994-2012 (MWI, 2012) were used to evaluate the impact of the Wala reservoir on the Wala-Haidan well field. The fluctuations of the SWL in wells CD 3133 and CD 1097 are shown in Figure 4. It can be seen that the water level in both wells decreased until winter 2002/2003, when the impoundment in the reservoir was started. The SWL in these wells then increased until the year 2008, afterwards it decreased sharply, because the reservoir was dry (August 2008 to February 2009). It started to rise again in 2009 and 2010, when the reservoir reached its new maximum storage capacity in 2010 (Sawarieh et al., 2011). This confirms that the SWL of these wells is directly influenced by the reservoir storage.

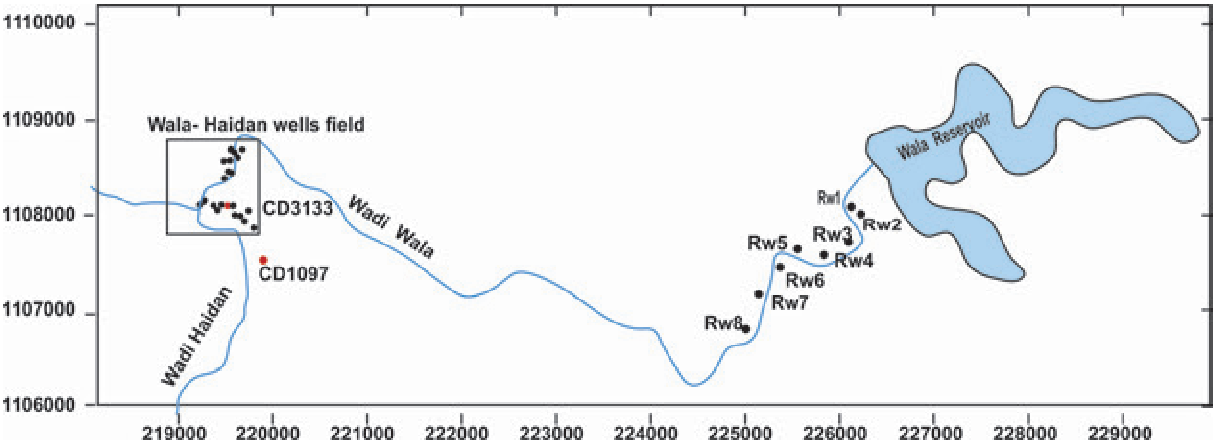


Figure 77: Location of the recharge and observation wells (Xanke et al., 2015)

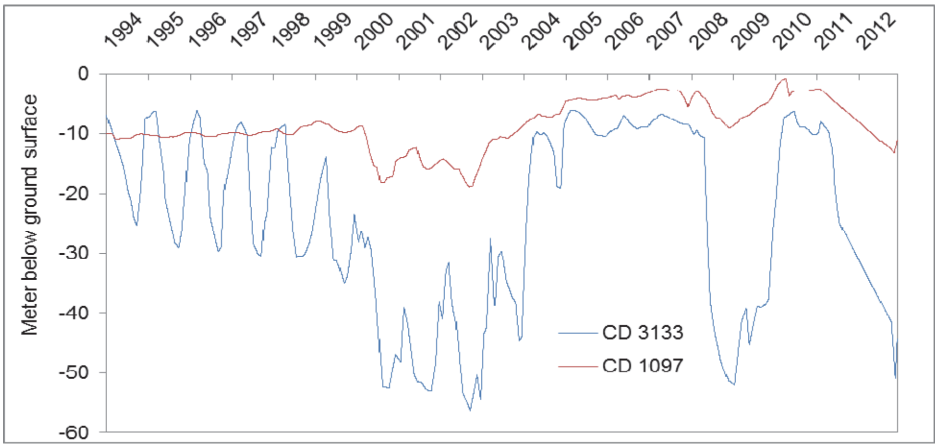


Figure 78: Static water level fluctuation of the observation wells

Sediment Accumulation

Due to sediment accumulation in the reservoir, the bottom of the reservoir has risen considerably since reservoir completion. It can be seen from the reservoir records that the bottom of the reservoir rose by 5.81 m in the first year (2003), which means a loss of about 0.369 MCM of the reservoir capacity. In the year 2008, the reservoir bottom rose by about 13.62 m and decreased the reservoir capacity by about 1.124 MCM. In February 2010, the gates were opened and about 0.4 MCM of sediments were flushed from the reservoir. The sediment continued to accumulate in the reservoir and the elevation of the sediments reached 501.33 m a.s.l in Oct. 2012. This means that the current maximum storage capacity of the reservoir is about 7.7 MCM. The flushed sediments and the major flood events increased the turbidity in the Wala-Haidan well field. Well field production was stopped several times in the last years. Based on the known reservoir floor and sediment elevations recorded in 2002, 2003, 2008, and 2012 (JVA, 2012), an attempt is made to calculate the sedimentation rate for the three periods. The mean sedimentation rate was calculated by dividing the total volume of sediments by the total volume of stored water in the periods 2002-2003, 2003-2008, and 2008 -2012. A mean sedimentation rate of 29 liters of sediments per 1000 liters of water inflow was obtained.

To characterize the sediments in the reservoir, three soil samples were taken in February 2012. The samples were analyzed for grain size distribution, polycyclic aromatic hydrocarbons (PAH), and carbonate content. The results show that the main components of the reservoir sediments are silt and clay and the carbonate content ranges between 25 and 28 %. The analysis of 16 polycyclic aromatic hydrocarbons (PAH) reveals a total content of 208.4 µg/kg in sample 1 (at the dam site), 1436.7 µg/kg in sample 2 (at the lakeside), and 63.7 µg/kg in sample 3 (at the lakeside), with naphthalene being the main component (40-170 µg/kg). Smaller amounts (4-38 µg/kg) of acenaphthene, fluorine, phenanthrene, anthracene, fluoroanthracene, pyrene, and benzo anthracene were detected in samples 2 and 3. All other PAH's lay below the detectable limit (2 µg/kg). The higher amounts were found in the sediments at the reservoir inlet.

Recharge from the Reservoir

The reservoir records show the daily recharge quantities of the stored water into the aquifer (Figure 79). It is obvious that there was a continuous decrease in recharged quantities with time. The accumulated sediment in the reservoir not only reduced the reservoir capacity, but also decreased the infiltration rate through the reservoir floor and edges.

Total abstraction from the Wala-Haidan well field during the operation period of the reservoir 2002-2012 was about 125 MCM. In August 2010, 66 % of the total production were provided by recharged water. This amount decreased to 60 % by December 2011 and to 58 % by August 2012 (Sawarieh et al., 2012).

The first artificial recharge test through the recharge wells was carried out on June 9th, 2011 when 48311 m^3 of the reservoir water were injected into RW1, RW3, and RW4. The second operation was carried out on July 25th of the same year, when 89177 m^3 were injected into all recharge wells (RW1-8). As a result of these injection operations, the water level was increased by 0.1 to 0.4 m. From November 30th, 2011, an injection campaign was run until the end of the year by injecting 1000 m^3 per day into six recharge wells (RW2-7). This resulted in a water level rise in the recharge wells of up to 0.5 m. The total amount of water injected into the aquifer through recharge wells in 2011 was 0.6 MCM. Injection was continued in 2012, and about 0.3 MCM of water were recharged through the wells.

Six sensors (WL, T, Ec) were installed in the Wala reservoir and in certain wells downstream to ensure constant recording of the reservoir and groundwater levels on a daily basis. The measurements show the aquifer response to the natural infiltration from the reservoir as well as to the artificial recharge through the recharge wells (Xanke et al., 2012).

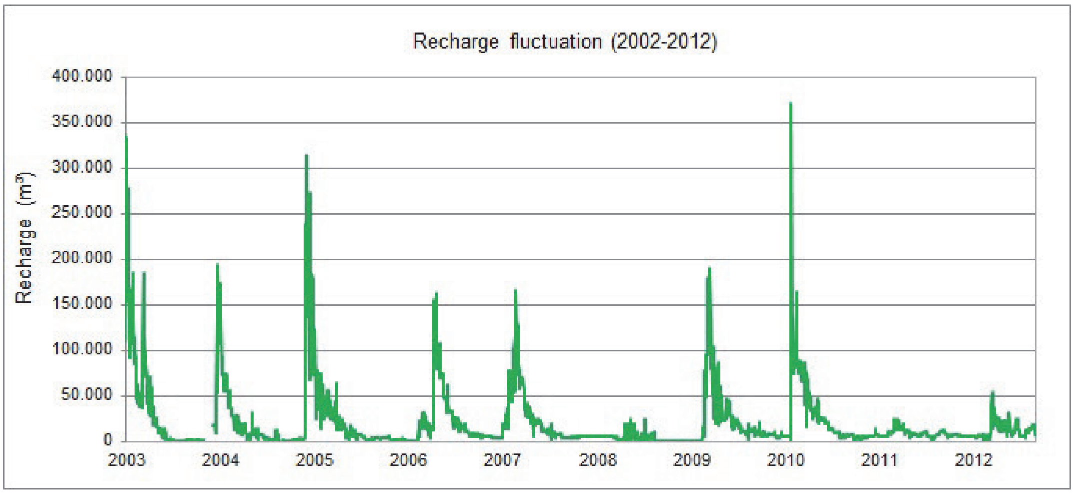


Figure 79: Daily recharge fluctuation from the reservoir into the aquifer

Suggested Actions

To overcome the problem of sediment accumulation in the reservoir, which affected its storage capacity, the JVA recently proposed to raise the dam by 15 m. This would result in a live storage of 26.3 MCM, but will not prevent continuous sedimentation in the reservoir. The remaining permeable parts of the reservoir floor and edges will be covered with time and the natural infiltration rate will be reduced to about zero. To maintain the current infiltration rate, it is therefore proposed to build check dams upstream - even if the reservoir is raised - on the major tributaries of Wadi Wala (Wadi Rumil and Wadi Ammuriya) to minimize sediment inflow into the reservoir. Two areas along these wadis were selected (Figure 80) after studying the geology. Their construction will be based on an elevation of around 535 m a.s.l.

The Wadi Rumil sub-catchment is mostly covered by thick soil and drains about 50 % of the Wadi Wala catchment (12.5 MCM as yearly average of 2002 - 2012). This means that most of the sediment in the Wala reservoir was brought in by Wadi Rumil floods. Hence, a check dam along this wadi will reduce sediment accumulation in the reservoir and will help to keep the current natural infiltration rate. A site for the proposed check dam is selected at location 1108585 N and 230805 E of Palestine Belt 1923. The maximum capacity of the dam would be about 4.5 MCM, with a maximum height of 22m to keep the dam lake elevation at 560 m a.s.l., so Rumil Bridge will not be affected. The estimated cost is about 7 million JD (about 9.8 million US Dollars). The geological cross section of the site is shown in Figure 81.

The second check dam proposed can be constructed on Wadi Ammuriya, which drains about 30 % of the Wala catchment. The selected site is located at the coordinates 1107199 N and 228644 E of Palestine Belt 1923 and at an elevation about 538 m a.s.l.. A dam height of 20 m would result in a maximum capacity of about 3.5 MCM and estimated costs of about 5 million JD (about 7 million US Dollars).

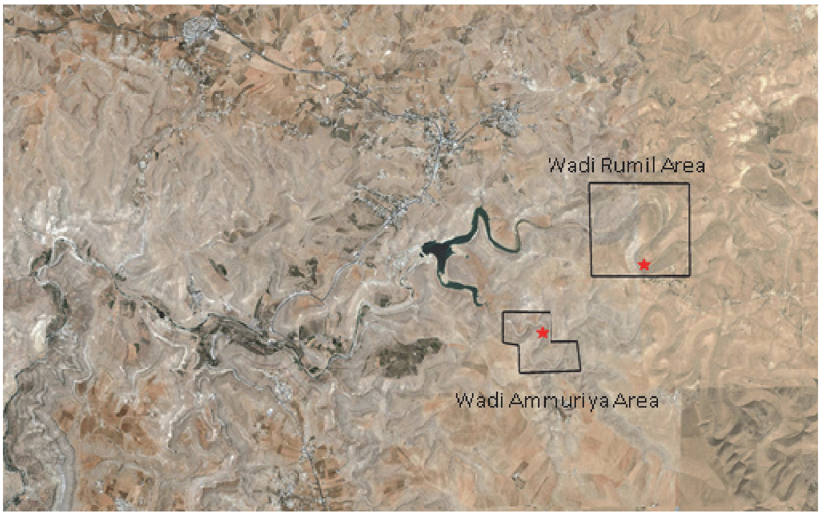


Figure 80: The two studied areas and the proposed check dams (Red stars)

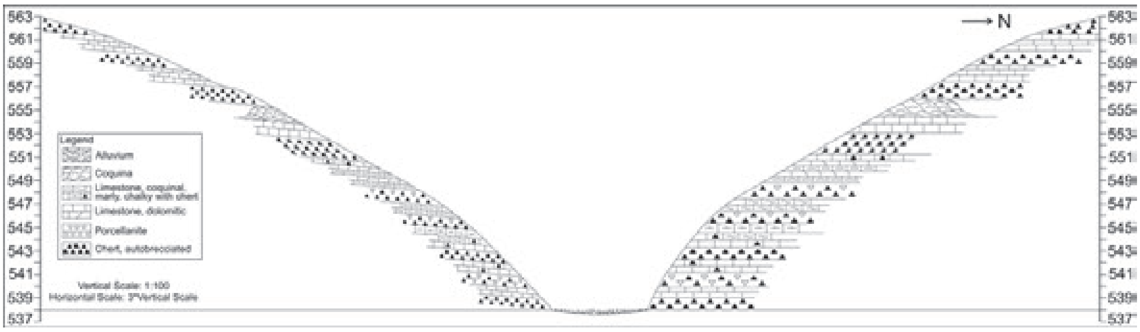


Figure 81: Geological cross section of the proposed dam on Wadi Rumil

Site-specific Conclusions and Recommendations

Although the reservoir has turned out to be very effective in recharging the downstream aquifer during the period of operation, it is facing the problem of sediments accumulation with a resulting decrease of the capacity and infiltration rate from the reservoir floor into the aquifer. The sediments accumulation was increasing year after year. Based on the known reservoir volume, the sediment elevations of different years, and the amount of flushed sediments (0.4 MCM in 2010), an attempt was made to calculate the mean sedimentation rate, with a value of 29 liters sediments per 1000 liters water inflow being obtained. According to the sediment elevation in the reservoir in Oct. 2012, the capacity of the reservoir decreased to 7.7 MCM.

The increasing amount of sediments in the reservoir not only reduced its capacity, but also decreased the infiltration rate. The daily recharge quantities show a continuous decrease with the years, which is reflected by the recharge percentage of total abstraction from 66 % in 2010 to 58 % in 2012.

The flushed sediments and the major flood events increased the turbidity in the Wala-Haidan well field and, consequently, pumping was stopped several times in the last years.

The JVA recently proposed to raise the Wala dam to around 15 m to increase the storage capacity of about 26.3 MCM. This will help prevent spilling of the reservoir in the future and it is expected to increase the infiltration rate, but sedimentation will continue. Therefore, it is recommended to construct check dams upstream on the major tributaries of Wadi Wala to minimize the sediments inflow into the reservoir.

Additional work was done to examine the possibility of constructing check dams on Wadi Rumil and Wadi Ammurriya. One check dam is proposed on Wadi Rumil, with a maximum capacity of 4.5 MCM and estimated cost of about 7 million JD (about 9.8 million US Dollars). Another check dam is proposed to be built on Wadi Ammuriya, with a maximum capacity of 3.5 MCM and 5 million JD cost (about 7 million US Dollars).

The work on the check dams, drilling more injection wells, and installations of large sand filters as well as several management actions remain to be done in the future.

It may be concluded that the Wadi Wala Reservoir is a very successfully managed aquifer recharge construction in Jordan and it is highly recommended to copy and apply this approach to other places in Jordan and the region.

3.2.2.2 Al Uja, Westbank

Author: A. Marei

Introduction

The Al Uja area is located in the western part of the LJV. This area is characterized by its dry climate, where the annual precipitation does not exceed 300 mm. Hence, cultivating crops without additional water is not possible. Water sources in this area are limited to the karstic spring (Al Uja) that drains fresh water from the upper carbonate mountain aquifer and to a limited number of groundwater shallow boreholes. Due to the karstic condition of the aquifer, the spring discharge is not stable and depends on the amount of rainfall in the mountain area, which varies from one year to another. Due to this fact, many groundwater boreholes were drilled in the Plio-Plistocene shallow aquifer system. At that time, the average depth of these boreholes was 40 meters, currently, the average depth is 90 m.

In the seventies of the last century, about 12 000 dunums were under irrigation, with banana trees being the major crop. Currently, only half of this area still is under irrigation and no banana tree farms exist. Only salt-tolerant vegetables and date trees are the dominant crops. This is due to the fact that the spring discharge decreases as a result of drilling 5 groundwater boreholes in the upper mountain aquifer system (Ein Samia well field). Continued pumping and limited knowledge about the hydrogeological setting of the area cause a lowering of the groundwater table and increase groundwater salinity. The salinity problem is the major obstacle affecting the economic development of the area. This problem caused a shift in the cropping pattern during the last 30 years, monoculture crops are becoming dominant in the area.

The aim of this study was to investigate different artificial recharge methods that could be applied to improve the water resources in terms of quality and quantity.

Water Quality

Salinity of spring water ranges between 700 and 1000 µS/cm, which is typical of the upper mountain aquifer system. This water was used in an artificial recharge test. Salinity of the borehole water tapped from the shallow aquifer system ranges between 2,500 µS/cm in the western part and 6,000 µS/cm in the eastern part of the aquifer. Vertical measurement of water salinity in boreholes revealed an increase of salinity from 3,000 µS/cm at a depth of 45 meters to

8,000 µS/cm at a depth of 80 meters, which means that the salinity process takes place in the lower part of the aquifer system.

Geology

The Jordan Valley-Dead Sea fault system that extends south–north is the major structural feature in the study area, where carbonate rocks of Upper Cretesouse age bound this fault from the western part and alluvial deposits of Plio-Plistocene ages from the eastern part. The carbonate rocks consist of limestone, dolomite, marl, chalk, and chert layers. Formations of Torunina age that consist of limestone, dolomite, and marl make up the upper mountain aquifer system, these formations are overlayn with chalk and chert beds of Senonian age. The Plio-Pleistocene sediments were deposited mainly east of the fault under two environmental conditions, freshwater of Samra lake where gravel, sand, and silt layers were deposited and saline to hypersaline conditions of Lisan lake where evaporates were deposited. The structural setting of the area and the lithology of the sediments govern the salinity of the groundwater in the shallow aquifer system.

Hydrogeology of the Plio-Pleistocene Aquifer System

This system consists of gravel, sand, and silt layers. The silt content increases eastwards and partly forms a barrier for eastward groundwater flow. This system is bounded by the major fault system in the west and the Jordan River in the east. The Jordan River is considered the base flow of this system. The water table is located at 60 m below the surface in the west and decreases to 38 m 3 km west of the fault. Direct recharge through rainfall is negligible due to high evaporation. Indirect underground lateral recharge takes place along the fault system. Additional recharge of about 0.25 MCM/year takes place through wadi flooding.

Method of Recharge

Improvement of groundwater water quality depends on introducing new techniques of artificial recharge. A team from the Al-Quds University applied and investigated four artificial recharge methods. Two water sources were used in this area: Spring water and floodwater. The objectives of the artificial recharge experiments were to identify the best method to be applied to use these two sources. Major challenges were to store the excess of freshwater in an efficient way and where to store it without influencing its quality. The annual spring discharge ranges between 0.5 and 8 MCM. Most of the spring water is stored in 53 agricultural surface ponds (Figure 82). The storage capacity ranges between 1,500-25,000 m^3/pond (Figure 83). The total storage capacity of these ponds is about 10 MCM and, hence, exceeds the spring discharge. Due to the fluctuation of the spring discharge, however, many of these ponds are in bad condition. One of these ponds was used for infiltration tests. The depth of these ponds ranges between 3 and 5 m, where the upper radius surface area ranges at 295-12,000 m^2.

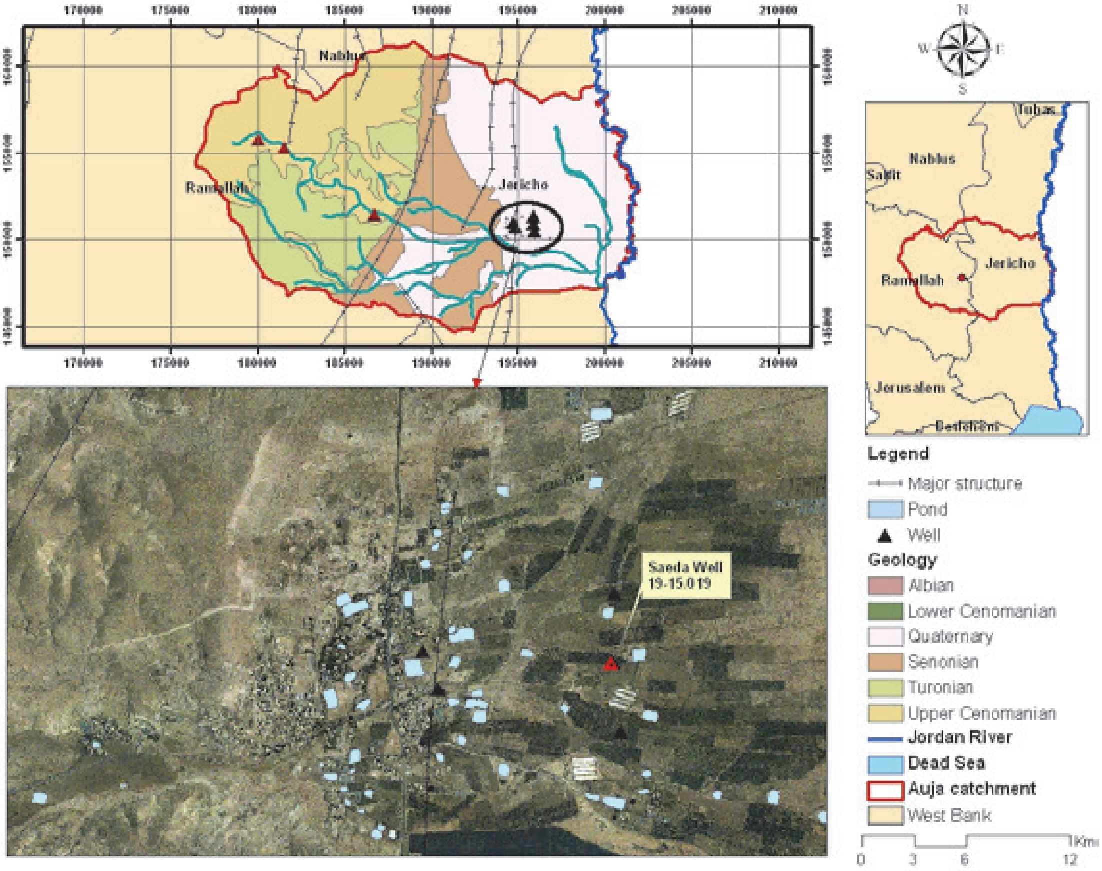


Figure 82: Distribution of surface collection ponds along Al Uja area

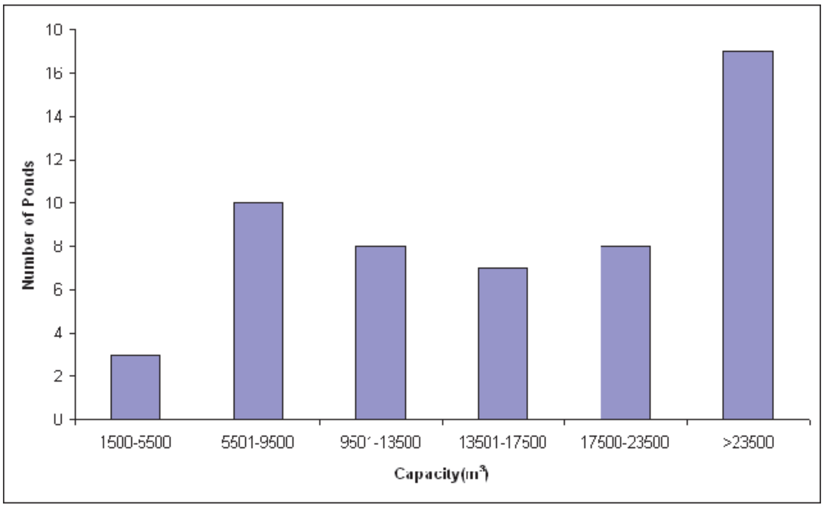


Figure 83: Distribution of collection ponds storage capacity in the Al Uja area

Infiltration Pond Test

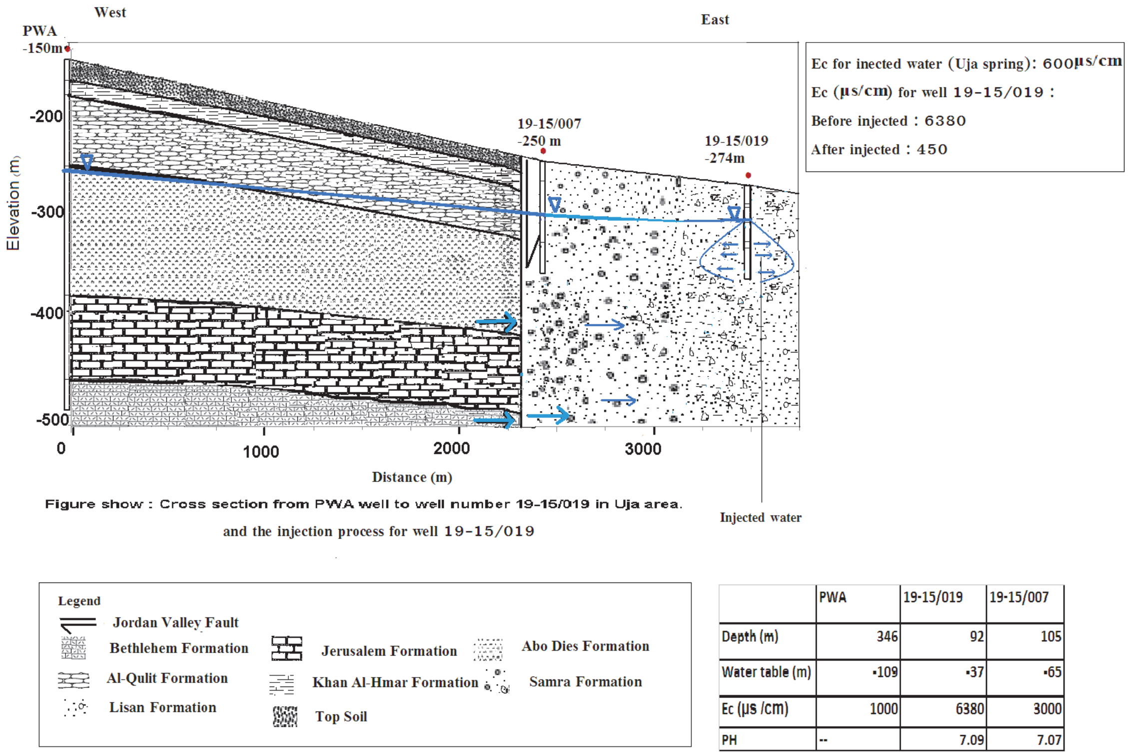
The objective of this test was to find out whether it is possible to use the existing infrastructure in artificial recharge. The material of these ponds is a soft Lisan formation that consists of evaporates and clastic material (22 % sand, 23 % clay, and 45 % silt). The sieve analysis shows that the average hydraulic conductivity coefficient of the pond material is $2.6*10^{-2}$ cm/s (Hazen equation). Results of surface infiltration measurement in addition to geo-electrical investigations revealed that the average water infiltration velocity is $9.6*10^{-4}$ cm/s. The depth to groundwater table is about 40 m, so that the infiltrated water can reach the groundwater body after 50 days of infiltration. Having this result, this method cannot be recommended due to the high evaporation rate, and these storage ponds can only be used for managing water sources.

Injection Borehole

The objective of this experiment was to investigate possible artificial recharge through available production boreholes. For this purpose, a pumping test was conducted and the physical properties of the aquifer were determined. The average hydraulic conductivity is $1.6*10^{-2}$ m/sec with an effective porosity of 27 %, the aquifer transmissivity is 0.8 m^2/sec. Different volumes of water (106.86 and 100 m^3/h) were injected. The static water table rose from 37 m to 34 meters below the ground surface, and after one hour, the static water table fell to the original level. The results of this method show that it is possible to use the nine production boreholes available as injection boreholes, provided that the injected water is of high quality. By using these boreholes as injection wells, it could be possible to store 900 m^3/h from the spring overflow or from other sources meeting the injected water standard. Recovery tests show that water salinity decreased significantly from 8,000 to 3,000 µS/cm.

Lateral Recharge of the Plio-Plistocene Aquifer System

A lithological cross section was built from different well logs and from the geophysical profiles recorded (Figure 84 and Figure 85). The western boundary of the Al Uja aquifer system is 1,000 m long from north to south along the major fault system and 3,000 m wide (from west to east), namely, from the fault system to the Jordan River drainage system. The saturated thickness of the aquifer is 120 m. The effective porosity of the aquifer is 27 %, so the storage capacity of the aquifer system is about 97 MCM. The available stored water was estimated to be about 61 MCM. The groundwater gradient between the mountain aquifer and the shallow aquifer is 0.02. The calculated lateral flow is 1.8 MCM/year, this water flows from the upper mountain aquifer across the fault system into the shallow aquifer. The current abstraction from all boreholes is 3 MCM/year, so there is an annual deficit in the water budget of 1.2 MCM/year. This causes lowering of the water table and an increase in water salinity.



	PWA	19-15/019	19-15/007
Depth (m)	346	92	105
Water table (m)	-109	-37	-65
Ec (µs /cm)	1000	6380	3000
PH	--	7.09	7.07

Figure 84: Lithological cross section between the mountain and shallow aquifer

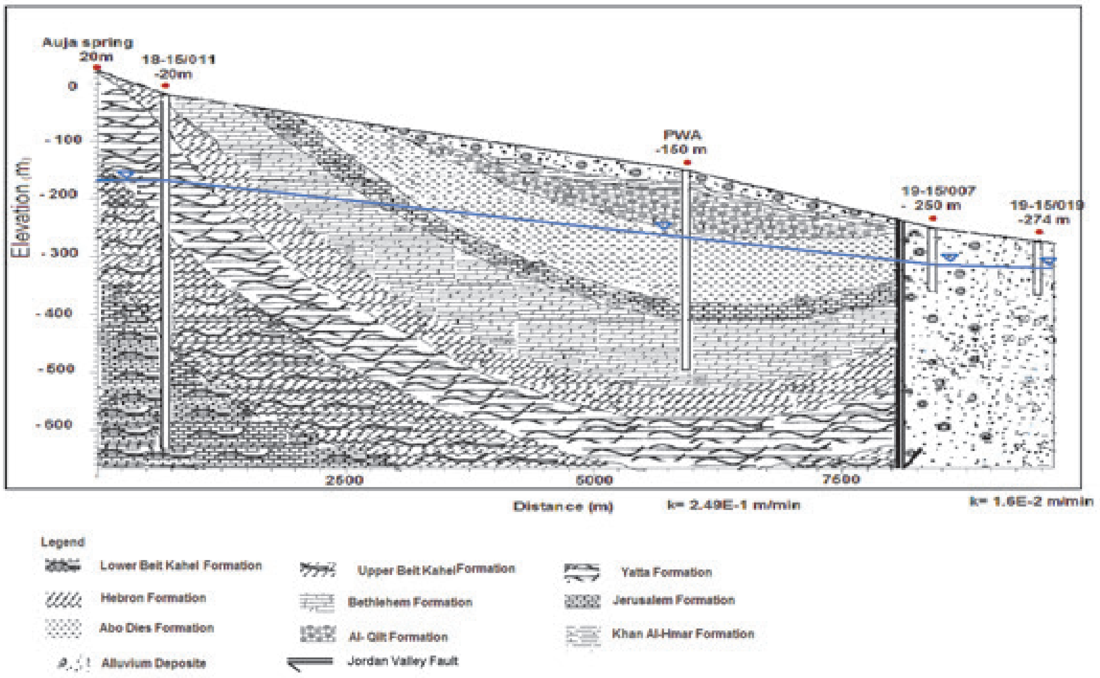


Figure 85: Deep boreholes in the mountain and in the shallow aquifer systems with a static water table

Implementation and results

The new findings for the first time explain the recharge mechanism of the shallow aquifer system by underground lateral flow in the Al Uja area. Artificial recharge in the mountain area can improve groundwater in the shallow aquifer system. On the other hand, tapping water from the upper mountain aquifer system can negatively influence the groundwater quantity in the shallow aquifer**.**

Artificial recharge through wadi sediments

The new hydrogeological knowledge about the connection between the mountain and the shallow aquifer in the Al Uja area raise the issue of possible indirect natural recharge along the wadi drainage system. To verify this hypothesis, salt tracer tests were conducted to investigate the amount of surface water infiltrated into the mountain aquifer through the wadi sediment. In our opinion, the section between the spring niche and the concrete canal tunnel is an important recharge zone. Results of the above tests show that about 15 % of the total spring discharge can be considered recharge for the shallow system. Of the average spring discharge of 8 MCM/year, about 1.2 MCM were infiltrated into the underground. This volume of water flows eastwards and crosses the fault system before flowing into the shallow system. Then, it is from the 9 boreholes. The new PWA (Palestine Water Authority) borehole will tap part of this volume before the latter will cross the fault system. It is expected that the high pumping rate of this borehole will have a negative impact on the shallow system, such as a lowering of the groundwater table and rise of salinity.

According to the new knowledge, surface water retention walls crossing the wadi towards the west of the spring niche will increase the recharge rate and improve the groundwater quality of the aquifer system significantly.

Artificial recharge infiltration earth dam

In 2011, the Palestinian Ministry of Agriculture constructed the Al Uja earth dam with a maximum storage capacity of 500,000 m³. The objective of this dam is to store surface excess water during flooding time and to use this water during water shortage periods. The dam was constructed west of the fault system, where chalk and chert of Senonian age crop up at the surface and form the bottom of the dam. The related catchment area of the dam is 50 km². The chalk layer is considered an impermeable layer in literature. The monitoring program of the two hydrological years 2011/2012 and 2012/2013 shows that 250,000 and 200,000 m³ of water were stored in the dam, respectively, and that this water was partly infiltrated into the upper mountain aquifer system. The average storage duration of water in the dam was 3.5 months. All water infiltrated into the underground before the end of June. This important finding indicates that the chalk unit of Senonian age in this area cannot be considered an impermeable layer and that surface flooding water also infiltrates through this layer. After two years of monitoring, the Al Uja earth dam can be considered an artificial recharge dam for the upper mountain and also for the shallow Plio-Pleistocene aquifer systems.

Site-specific Conclusions and Recommendations

- The borehole injection method is the best option for direct artificial recharge in the Al Uja area within the boundary of the Plio-Pleistocene shallow aquifer system. Surface infiltration ponds are not recommended.
- The mountain and the shallow aquifer system are hydraulically connected. Where underground lateral flow from west to east crosses the major fault system. 1.8 MCM/year continuously flows in this direction while about 3 MCM/year are abstracted from the aquifer. The management of both aquifer systems as one hydrological unit is strongly recommended.
- 15 % of the Al Uja spring discharge infiltrate into the upper mountain aquifer system and flow eastwards into the shallow system. Retention walls across the wadi will increase the recharge rate.
- The chalky unit of Senonian age is not considered impermeable rock and stored water infiltrates into the underground within relatively short periods of time. Additional earth dams for collecting flood water can improve the recharge rate as well as the quality of the groundwater.

3.2.2.3 Deir Alla, Jordan

Author: E. Salameh, J. Klinger

Introduction

The study area extends from Deir Alla in the south to Suleikhat in the north and from the Jordan River in the west to the mountain foothills in the east, between the coordinates N: 180 to 195 and E: 204 to 209 PG, or E; 350 34' 1500" to 350 35' 3300", and N: 320 18" 0000" to 320 19' 4640" (see Figure 87).

Aims of the Study

The study aims at finding underground storage aquifers for the surface water of King Abdullah Canal (KAC) to serve the following purposes:

1. Storage of several million cubic meters of surface water in underground reservoirs.
2. In emergency cases, such as water pollution or low flows in KAC, the water supply from KAC via Zai will not be interrupted, because the water stored in the underground reservoirs will be used to supply the Zai treatment plant with water.
3. Water recharged into underground reservoirs undergoes self-purification processes and, hence, it is superior to surface water storage.
4. In cases of draught or decreases in the water flow of KAC, stored groundwater can be exploited to cover the immediate needs of water supply. The groundwater will then be replenished when surface water becomes available for that purpose again.

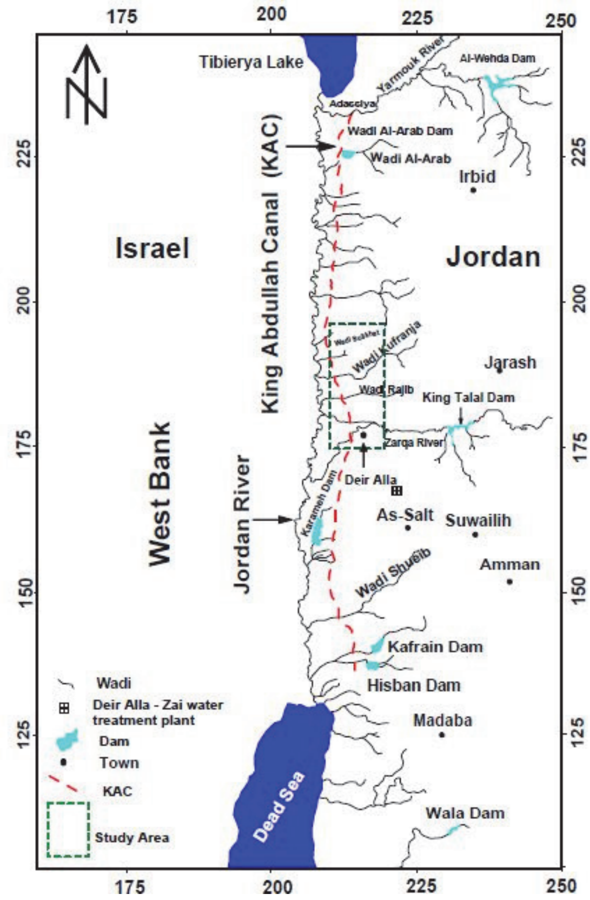


Figure 86: Overview and location of MAR site Deir Alla (Al-Omoush et al. 2012)

Climate

The climate in the Jordan Valley is classified to be of semi-arid type. The average annual rainfall in the study area is 235 mm. The relative humidity ranges between 30 % during hot summer days and 70 % on cold winter days.

Geology

The Jordan Valley Group thickly fills the rift valley and forms the wide valley floor. This Group can be divided into three main units, which are from older to younger: Consolidated/cemented conglomerate layers of about 100 m in thickness, conglomerates and alternating marl, sand, gravel layers of about 350 m in thickness and alternating marl, clay, chalk, silt, and gypsum layer of about 300 m in thickness (Lisan Formation, JV3). The intermediate aquifer in the Jordan Valley is formed by the middle unit intercalated with sand and gravel layer (Sand/Gravel Aquifer). Along the eastern part of the valley floor, these sediments are overlain by recent alluvial fan deposits consisting of gravels and sands which fine up to silt and clays closer to the Jordan River course (Figure 87). The recent sediments inter-finger with the salty, clayey deposits of the ancestors of the Dead Sea, like the Lisan Lake which, tens of thousands of years ago, extended northward beyond the present shores of Lake Tiberias. The shallow alluvial fan aquifer has a good potential with rather good water quality. However, it deteriorates towards the west due to the presence of Lisan beds responsible for an increase of the salinity in an order of about 1,500 to 2,500 µS/cm. The permeability of the shallow aquifer ranges between 6.5×10^{-4} to 1.3×10^{-2} m/s with an average value of 6.6×10^{-3} m/s.

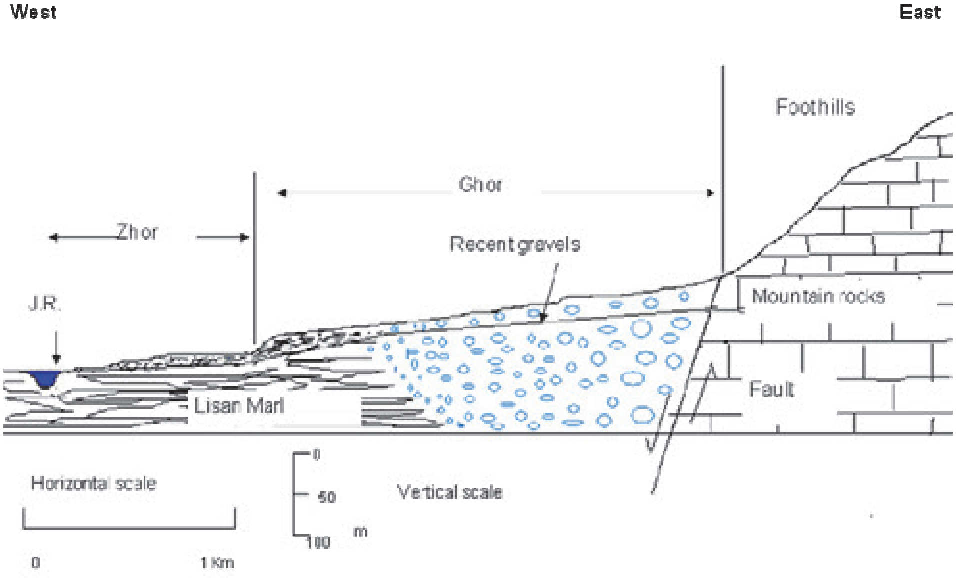


Figure 87: Geologic cross section in the Northern Jordan Valley (Suleikhat area)

Geo-electric Soundings

Vertical Electrical Resistivity Soundings (VES) were conducted in the area of study along N-S and E-W profiles. The selection of soundings locations was governed by the geological findings, the site conditions, free - geophysical noise area, accessibility through cultivated farms, and road availability (Figure 88). The interpretation was based on available information from surface geology and from the few wells drilled in the area and its surroundings.

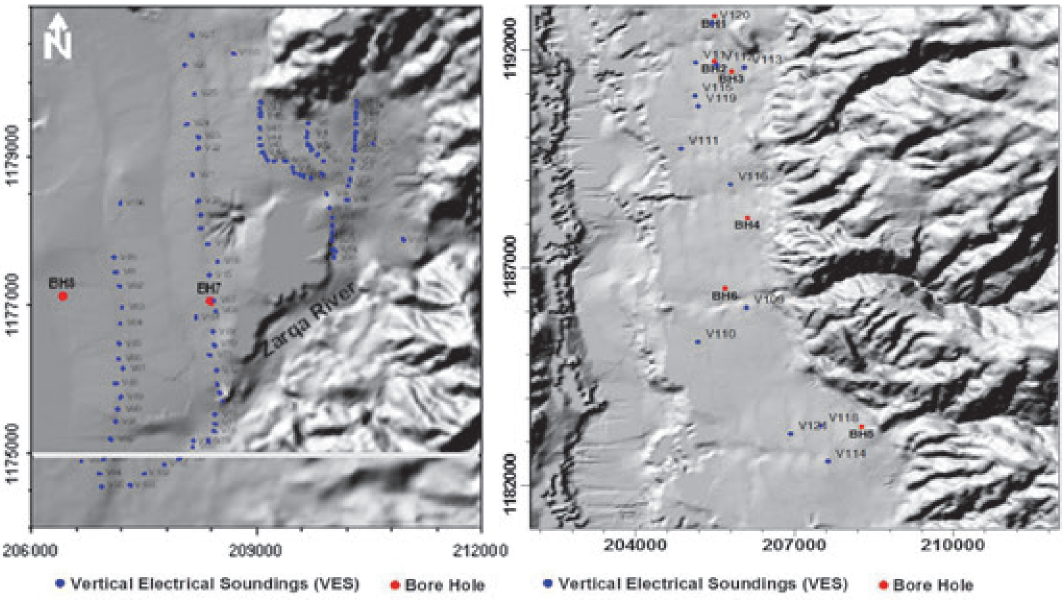


Figure 88: Location map of VES and boreholes in the southern part (left) and northern part (right) of the study area

Method of Recharge

Recharge and extraction schemes

Recharge to the aquifer is suggested to be implemented by utilizing the abandoned gravel quarry in the Suleikhat area with an N-S extension of about 800 m, an E-W extension of 150 to 300 m, and a depth of 10 to 20 m (Figure 89).

Figure 89: View on the gravel pit suggested to be used for surface water infiltration and groundwater recharge (Photo: J. Klinger, 2013)

The recharge scheme foresees diverting water from King Abdullah Canal into the abandoned gravel quarry and allowing that water to infiltrate and recharge the groundwater. The groundwater will then be extracted from wells drilled for that purpose in the down-gradient areas further west of the recharge site (Figure 90).

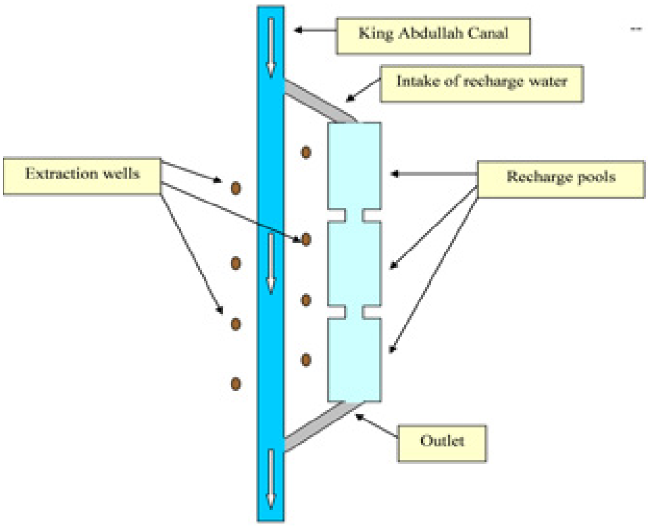


Figure 90: Recharge and extraction scheme in Suleikhat area.

In addition to geological, hydrological, hydrochemical, and geoelectric surveys, the investigations included the drilling of 9 investigation boreholes (Figure 91) to obtain geologic information about the rocks in the underground, water levels, and groundwater chemistry. The obtained information is presently being evaluated.

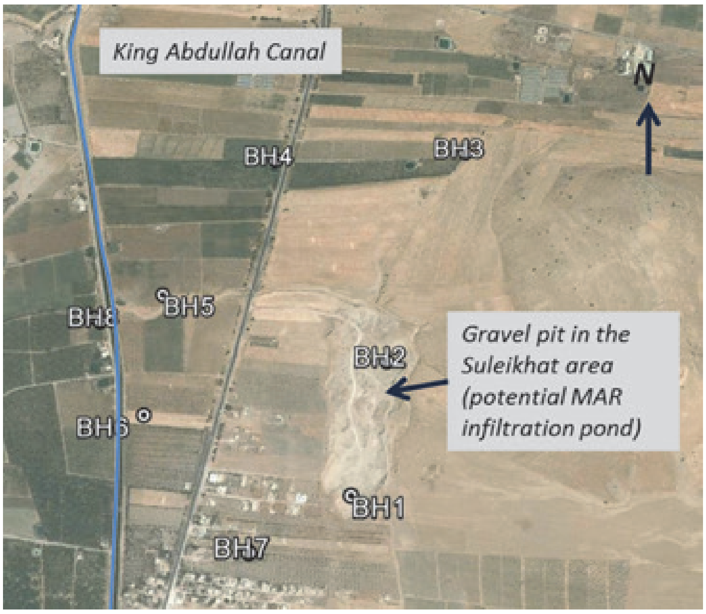


Figure 91: Locations of boreholes drilled in the course of the SMARTII project (Fig. J. Klinger)

Site-specific Conclusions and Recommendations

The geological, geomorphologic, and geo-electrical studies of the area show that an aquifer is present in the area north of the Zarqa River course (Latitude 175000N) to the Suleikhat area, 194000 N, and between longitudes E 206.000 and 209.500. Its thickness, as revealed from geoelectric soundings, is about 80 m in the east, decreasing gradually to the east due to fining up of grain sizes, and diminishing at longitude 206.000. Nevertheless, at latitude 178.000 to 179.000 and longitude 206.000-207.000, an underground flow channel was found by geoelectric soundings, with a resistivity of 60-220 Ωm indicating a freshwater body in this channel.

This aquifer extending between 175.000-193.000 N and 206.000 to 209.500 E contains fresh to slightly brackish (1500 µS/cm) groundwater. The aquifer is not filled and possesses a potential to be recharged.

The study concludes that between coordinates N: 170.000 to 195.000 and E: 205.000 to 210.000, a fine to coarse grained gravelly sand aquifer extends underneath the area. It has a wedge shape in its vertical cross section with a thickness of around 80 m at the mountain foothills along longitude 209.500 E decreasing westwards to inter-finger with the Lisan marls along longitude 206.000 E east of the Jordan River. In its north-south extension this aquifer starts at the northern bank of Zarqa River at latitude 175 N to about 185 N. Further north, alluvial fan deposits are found.

The aquifer in the Jordan Valley is saturated at depth with freshwater in its eastern parts in the mountains foothills. The salt content along the flow path increases to the west especially when coming closer to the Jordan River course. The middle reaches, 207-208 E, show groundwater salinities of 1,500-2,500 µS/cm. In its western parts, the salinity of the groundwater increases further due to the effects of the salty Lisan marls.

The porosity of the aquifer resembles that of fine sand with some silt components of around 15 % having a drainable porosity of about 7 %. The permeability in the eastern part is around 10^{-5} m/s, decreasing westwards to about 10^{-6} m/s.

The geological setup will allow to store up to 10 MCM of reclaimed water in addition to the stored quantities in the aquifer of some 15 MCM.

Temporarily, water/water and water/rock interaction may cause a slight increase in water salinity from an average of 950 µS/cm in KAC water, when that water is used for recharge, to about 1050-1100 µS/cm. However, the water will still comply with the Jordanian standards for drinking water. With time of operation, the salinity will stabilize and the salinity of the recharged water will not increase, but will remain at its original salinity. Nonetheless, the water quality itself will improve due to self-purification during infiltration and recharge.

Most probably, winter flood water in KAC will be recharged into the aquifer. That water has a salinity of 500 to 600 µS/cm (mixture of flood and base flows). Therefore, the salinity of that water after recharge will most probably increase to 600-750 µS/cm. This means that the groundwater salinity will be lower than that of KAC water during the dry periods, i.e. about 950µS/cm.

Figure 92 illustrates a conceptual model of the MAR site in Deir Alla.

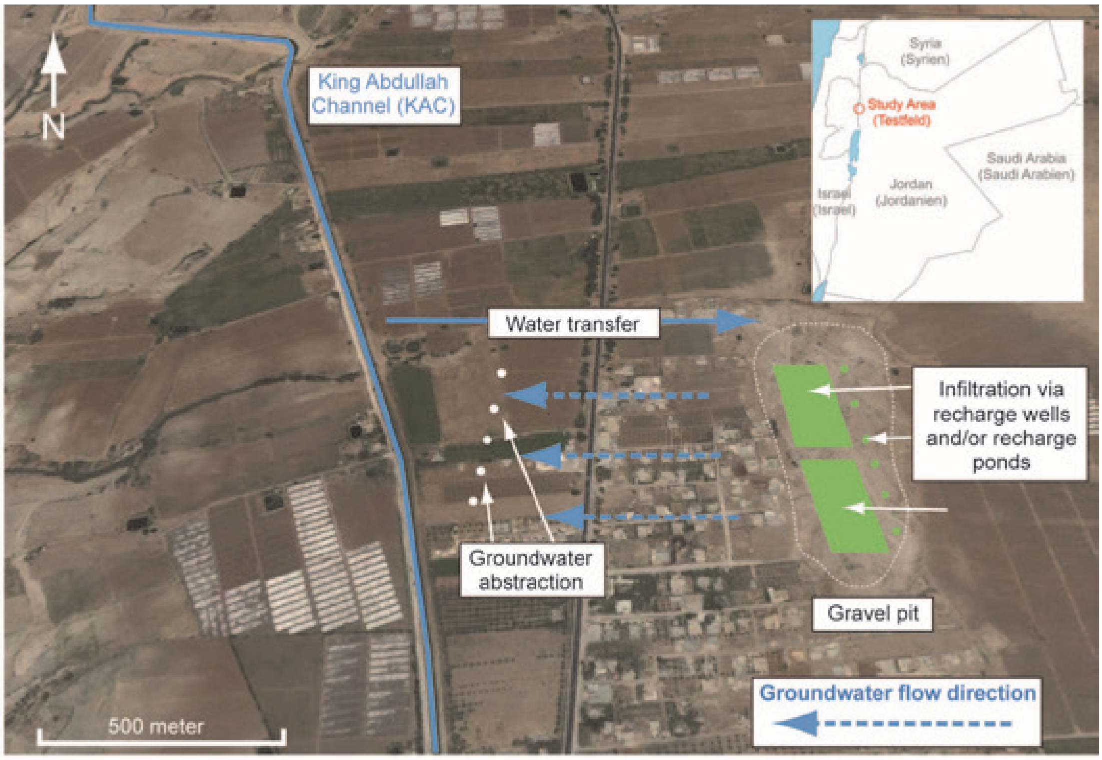


Figure 92: Conceptual model for MAR measrues in Deir Alla (Figure Xanke, 2014)

Storing KAC water in the delineated aquifer as groundwater has the following advantages:

- Guaranteed additional stored amount of up to 10 MCM of water in the aquifer.
- The stored water will have a superior quality compared to KAC water during summer times.
- In the case of diminishing flows in KAC, the water supply of Zai to Amman will not be interrupted, because the stored groundwater will then be used for that purpose.
- In the case when the canal water becomes highly eutrophic (as in 1987 and 1998) or contaminated (as for example in 2007 and 2009), the stored groundwater will be used to supply Zai with the required amounts of water, without interruptions.

3.2.2.4 Bani Zaid/Jeftlik, Westbank - Artificial Recharge of Wastewater

Author: M. Ghanem

Introduction

Two artificial recharge test sites were selected in the West Bank, Jeftlik and Bani Zaid. The Jeftlik area is located within the eastern catchments of the Westbank in the footprints of the Faria basin in the Upper Jordan Rift Valley. Bani Zaid test site is situated within the western catchments northwest of Ramallah city. It represents the wastewater artificial recharge site, while Jeftlik represents the artificial recharge of floods.

Socio-economic Study of the Bani Zaid Test Site, Artificial Recharge of Wastewater

A socio-economic study was made to determine the people’s acceptance of of using treated wastewater of the Bani Zaid treatment plant. Fifty questionnaires were distributed to the people of Beit Rima, a village near the Bani Zaid wastewater treatment plan. Agricultural activities are carried out by 58 % of the respondents, who are land owners as well as people working in the field. Their agricultural areas range from 1 to more than 10 dunums, while half of them have an area of irrigated land of less than one dunum. Sixty percent of them perform agricultural activities depending on the rainfall, while only 24 % have irrigated agricultural areas. Their irrigation sources are the water network or rain-fed cisterns. The irrigated agricultural products are vegetables (30 %), fruits (24 %), seeds (12 %), and olive trees (34 %). The majority of respondents (82 %) agree that the untreated flowing wastewater will cause health problems to the people and appreciate the treatment facilities at Bani Zaid. The people are afraid of the spreading of diseases like cholera and diarrhea around the station, if the treatment will not improve its wastewater. In this respect, 90 % agree with the importance of the treatment in the nearby Bani Zaid region. Sixty eight percent agree to use the treated wastewater for their gardens and irrigated crops. An artificial recharge option will help the area inform the environmental point of view and will provide an additional water source for the people in the area and protect the springs in the nearby areas from wastewater pollution.

Jeftlik, artificial recharge of flood water

In the Upper Jordan Rift Valley the hydrogeological and hydrochemical integration parameters as well as the physical characteristics of allocated water bodies were tested. The major objective was to determine the potentiality of the aquifer system in the area.

An artificial pond infiltration type of 26 m diameter and 3 m depth with a hyperbolic form of 500 m^3 volume was used. The test site area lies within the shallow alluvial aquifer of 30-50 meters in saturated thickness. One groundwater well of 19 m distance and two groundwater wells of 1 km distance were used for system monitoring. The filled water in the test system comes from the wadi water floods brought by 1.5 km of open canal. The sub-catchment covers an area of 3 km^2. The first stage focused on the feasibility study of the site and determination of its potentiality, followed by drilling one monitoring well of 40 meters depth in order to check the results of SMART I for inclusion in this experiment.

3.2.2.5 Wadi Kafrein/Hisban, Jordan

Author: T. Momani

Introduction

The study area is located in the southern part of the Jordan valley extending from the northern shore of the Dead Sea to the north Wadi Shueib area with an area of approximately 300 km^2 (see Figure 93). The elevation ranges between 333 m above mean sea level to -429 m below mean sea level on the shore of the Dead Sea. The average maximum and minimum temperatures are 35°C and 20°C according to the daily metrological station in South Shuneh. The average annual rainfall ranges from about 165 mm in the study area and reaches up to about 550 mm near Salt city in the eastern high mountains.

Geology

The study area within the Jordan Valley is covered by quaternary sediment and consists of Lisan marl formations made of grey-green clay alternating with white aragonite marls and small gypsum crystals and superficial deposits differentiated into fluviatile and lacustrine gravels, alluvial fans, and soil. The eastern part of the study area consists of a different group of outcrops from older sediments belonging to the Zarqa group of Triassic sediment (Suwayma sandstone-limestone shale formation), kurnub sandstone group (Cretaceous), Ajloun Group of Upper Cretaceous age, which consists of a thick sequence of carbonate platform sediment, and Balqa Group which consists of chalk, marl, chert, phosphate, and limestone.

Water Availability

The Soil Conservation Service (SCS) Curve Number Method was used to compute the runoff depths and volumes for the water years 1989/1990 up to 2011/2012. The estimated runoff coefficient of rainfall over the 23 year’ period of analysis is equivalent to 5.71 %, 8.71 %, and 5.91 % for the Kafrein, Shueib, and Hisban catchment, respectively.

Hydrochemistry

Twenty samples were collected from the study area twice in September 2012 and March 2013 to determine the total anions and cations, trace elements, and isotopes (deuterium and O18). The electrical conductivity of the samples ranged between 700 and 10,700 µS/cm.

Implementation and Results

In October 2012, 19 infiltration tests were carried out in the study area to investigate the infiltration capacity into the soil. Double ring infiltrometers with 30 cm inner and 60 cm outer diameter were used and 14 tests were performed with clean water. Five sites were basin infiltration test sites with an area of 3 m*2 m and 30 cm depth. The infiltration rates were high in the apex of the wadies and decreased downwards as well as in between the wadies due to the increases in the Lisan formation and high thickness of impermeable soils. The results showed that the infiltration rate ranges between 43.5 and 57.7 cm/day in the apex of Wadi Hisban and Shueib dam and between 3 and 7.2 cm/day at the ends of the wadies and in the westernmost parts of the study area towards the Jordan River.

Site specific Conclusion and Recommendation

The Shueib and Kafrein reservoirs are very effective in recharging the alluvial aquifer downstream during the rainy season. The Shueib Dam does not have enough capacity to store all the runoff coming from the Wadi Shueib catchment.

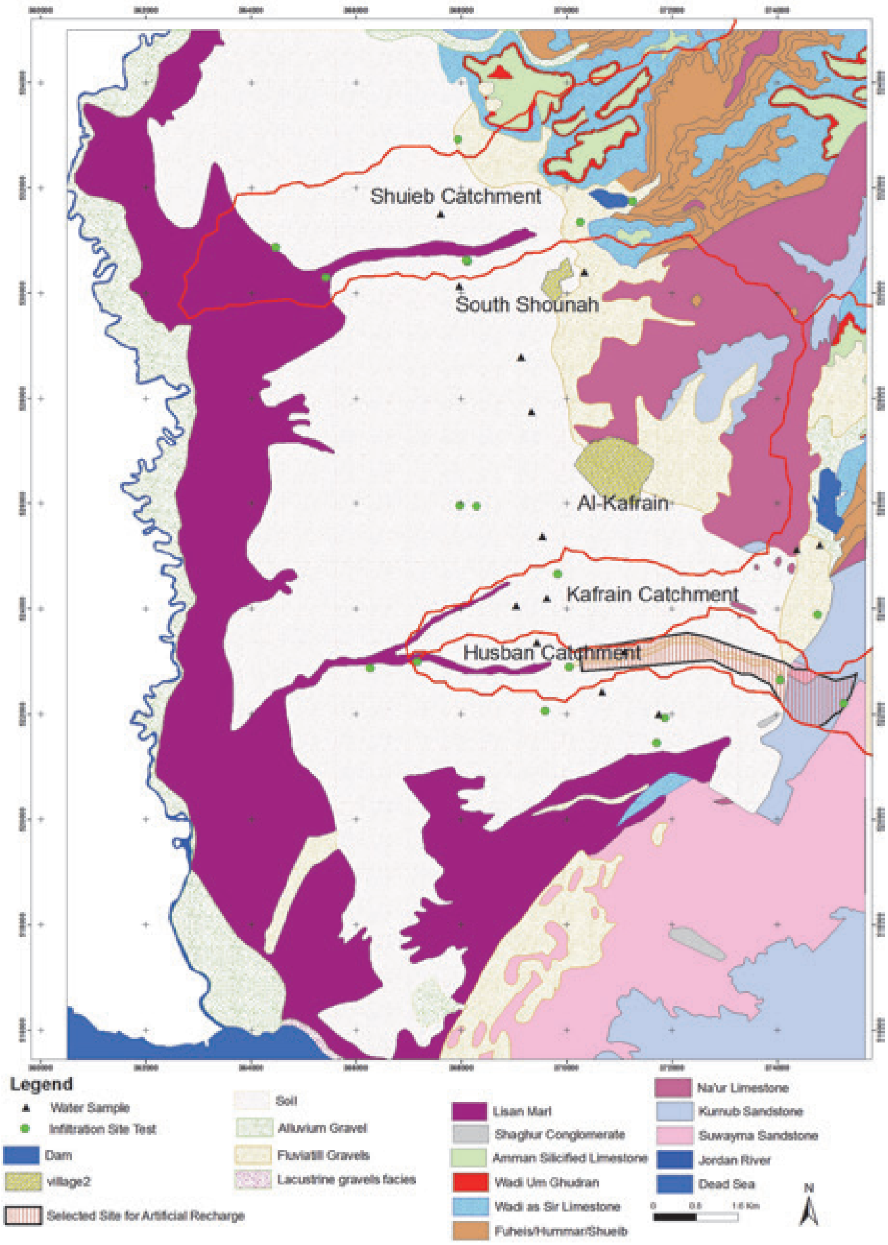


Figure 93: Study area Wadi Kafrein/Hisban

On the average, approximately 65 % of runoff are passed to the Dead Sea and lost. Consequently, increasing the capacity of the dam is highly recommended. The apex of Wadi Hisban is considered suitable for artificial recharge by using infiltration basins with rock gabions. The wadi bed can be used to infiltrate more than 1 million cubic meters during the rainy season. The wadi is suitable for this kind of recharge, since it has a length of 1.5 km and width of 35-50 m with a slope of less than 2 % and consists of fluviatile gravels.

3.2.2.6 Wadi Ishe, Jordan

Author: A. Hameideh

Introduction

The Wadi Ishe pilot project is an attempt to illustrate the benefits of runoff storage in a groundwater reservoir as an alternative water supply for rural arid areas of Jordan. With growing water demand and water scarcity, coupled with flood hazards due to high rainfall intensity and rainfall events of short duration, groundwater dams can be an option for water harvesting and mitigating flood effects in the Wadi Ishe basin. The Wadi Ishe site, also known as Wadi Madoneh, is located approximately nine kilometers away from the city of Zarqa. Zarqa governorate is about 15 km east of Amman.

Land use and topography

The Wadi Ishe catchment has been classified as bush land/range land. Some industries, such as a battery recycling plant and a sulfo-chemical plant, are located downstream of the site at a distance of around 10 km.

Wadi Ishe slopes range up to 0 %. The general topography becomes hilly towards the northern downstream area. From the wadi bed, the topography rises steeply over a short distance and slopes range up to 25 %.

Geological Formations and Soils

The geological study of the groundwater storage reservoir resulted in assessing the rock sequence from the upper part to the downstream area. According to the geological cross sections, the upper part is covered by fluviatile and lucustrine gravels of Pleistocene age. For the geological description in general: AI (Alluvium) and s (sand/ soil) are of holocene age and Plg (fluviatile and lacustrine gravels) is of pleistocene age. WSL (Wadi as Sir Limestone) belongs to the Ajloun Group, while the others (ASL, MCM, URC, WG) belong to the Belqa Group.

The formation, types, and properties of soils in Jordan are determined by parent material, topography, and climate. There are soils associated with the East Jordan Limestone Plateau, which include limestone, chalk, calcareous sands, gypsum, marls, and Tertiary cherts.

Climate

The climate of the Wadi Ishe area is characterized by hot summers and mild winters. The precipitation data from 2000 to 2010 indicate that average annual precipitation in the vicinity of the pilot site and in the upstream basin ranges from approximately 120 to 150 mm. The annual average potential evaporation is approximately 1,075 mm.

Method of Recharge

The principle of a subsurface dam is to dig a trench across the valley reaching down to the solid, impervious layer at a suitable location. In the trench an impermeable wall or barrier is constructed and the trench is refilled with excavated material. A subsurface reservoir created in this way retains water during the wet season and can be used as a water resource throughout the dry periods.

The suitability of an underground dam is highly site-specific and depends on aquifer properties, hydrological conditions, and the geological setting of the basin. A thorough hydrogeological investigation, coupled with a model analysis, was therefore carried out for the Wadi Ishe site.

Implementation and Results

Construction of the Wadi Ishe Pilot Subsurface Reservoir

Construction started with trench excavations of 90 m length, 4 m and 3 m width. The trench across the course of the wadi dispelled the young wadi sediments completely, so that the marly rock layers form the ground of the trench from one side to the other side. Afterwards, the trench was filled with natural sediments and the well pipe was installed.

Rainfall Runoff and Surface Runoff Models

At the Wadi Ishe pilot site, a hydrologic model was generated to estimate the runoff potential by using the Hydrologic Modelling System of the Hydrologic Engineering Center (HEC).

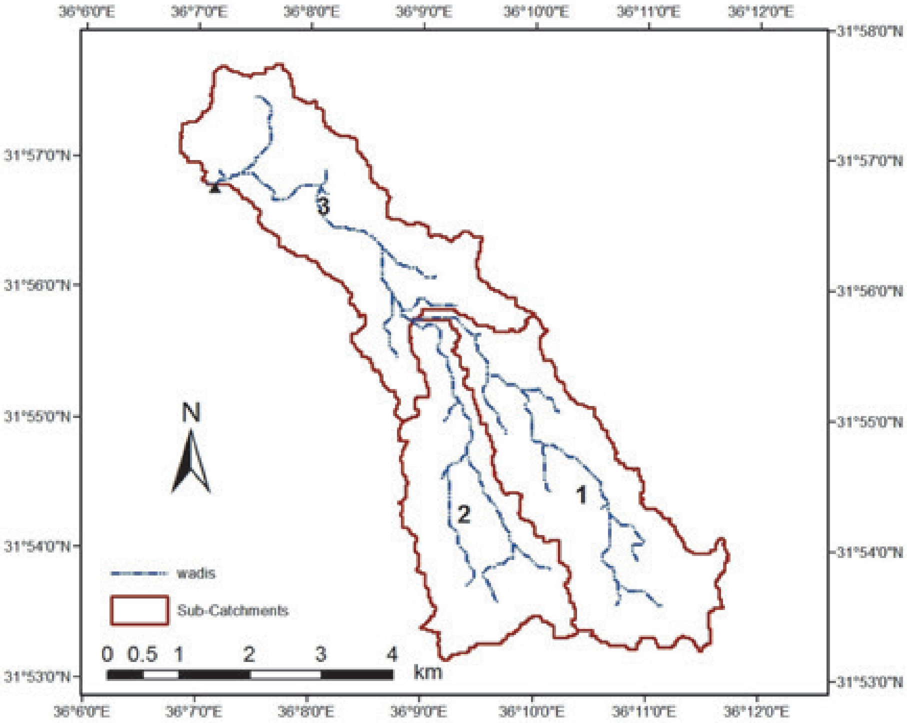


Figure 94: Wadi Ishe catchment and its sub-basins

The HEC-HMS model covers a variety of options for simulating precipitation runoff processes. However, the study area is an ungauged basin. Consequently, HEC-HMS models with GIS were used to simulate rainfall runoff using the SCS curve number. The hydrographs, the runoff volume, peak discharge, and percentage loss for the 10 years' return period were determined. The total precipitation was 44 mm, the total loss 35.3 mm, the total runoff was 8.7 mm. The total precipitation volume for the years 2000-2010 within the catchment area was approximately 36.14 MCM. For this analysis, the catchment which has an area of 22.256 km^2 was divided into three sub-basins as shown in Figure 94 and Table 22.

Table 22: Summary of the modeling parameters for the sub-basins using NRCS-CN and NRCS-UH methods.

Sub-Basin	Area (km^2)	Slope (%)	Main Wadi Length (km)	Initial Abstraction (mm)	Lag Time (min)
1	7.954	1.26	6.623	14.3	212
2	6.176	2.25	5.305	14.3	133
3	8.126	1.58	5.315	14.3	159
Catchment Area	**22.256**				

The 24-hrs and 10-years return period storm is used to model the catchment's outflow (Table 23). The modeling storm was found in three references for the study area. The first storm is derived using daily rainfall for the stations Ruseifa and El-Muwaqqar for the years 2000 to 2010. The data were analyzed using extreme value distribution and the 10 years return period. Daily (24-hrs) storms are calculated for both stations, as shown in Figure 95. Thiessen polygons are derived for those stations to find the 24-hrs and 10-years storm for the study area. The 24-hrs storm is distributed using National Resources Conservation Services (NRCS) (formally known as Soil Conservation Service (SCS)) Type II storm. Table 23 lists the 24-hrs and 10-years storms used in the modeling and the reference for these storms.

Table 23: The 24-hrs and 10-years storms used in the modeling of Wadi Ishe catchment and the reference for these storms

Rainfall Depth Estimation Reference	Storm depth (mm)
From daily rainfall for two stations	44.00
Consulting Engineering Center [1]	45.60
Hammouri and El Naqa [1]	42.58

Table 24: The three storm depths and the peak discharge and outflow volume used to model the catchment

Storm Depth (mm)	Peak Discharge (m^3/s)	Outflow Volume (1,000 m^3)
44.00	5.7	193.3
45.60	6.2	210.3
42.58	5.2	177.8

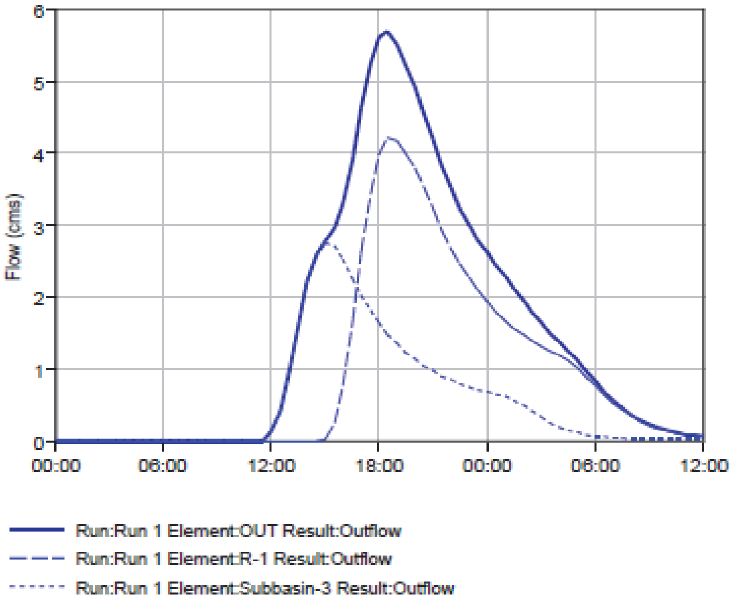


Figure 95: Hydrograph for the Wadi Ishe basin for a basin's 24-hour storm and 10 years return period and its sub-basins

The reservoir porosity was calculated according to the porosity of the three structure sections based on reservoir geometry and weighting evaluation. Extracting this information, the reservoir porosity was calculated to be 20-23 %. Considering the total volume of the reservoir (945 m^3), the total water volume available for storage within this reservoir is around 200 m^3.

Site-specific Conclusions and Recommendations

A subsurface storage reservoir in arid and semi-arid countries like Jordan offers an attractive solution of the water shortage problem. Moreover, the development of the groundwater basin and the concept of storing water in subsurface terrain have relatively low social and environmental impacts and have a tremendous potential.

3.2.3 Water Quality: Elimination of Emerging Pollutants

Authors: N. Schmidt, A. Tiehm

Introduction

In the European Union (EU), about 3000 different substances are used in human medicine. Some drugs are documented regularly within the most frequently applied range, such as the class of non-steroidal anti-inflammatory drugs (NSAID) of ibuprofen and diclofenac, as well as the antiepileptic carbamazepine (Fent et al., 2006). Due to the high persistency of some of these compounds, accumulation in the environment through constant input is supposed. These substances are therefore also referred to as Emerging Pollutants (EPs). Additionally, xenobiotics with endocrine-disrupting effects, such as bisphenol A used in plasticizers or trialkyl phosphates with a carcinogenic potential used as flame retardants, belong to the group of EPs. Concentrations of EPs are in the range of ng/L up to µg/L in surface waters, e.g. diclofenac 1.4 – 54 ng/L, ibuprofen 0.3 – 1215 ng/L, gemfibrozil 2.3 – 1105 ng/L, carbamazepine 56.3 – 900 ng/L, or naproxen 9.1 – 790 ng/L (Hoppe-Jones et al., 2010, Rabiet et al., 2006). Up to 590 ng/L of diclofenac and 900 ng/L of carbamazepine were found in groundwater samples in Germany, for instance (Sacher et al., 2001). Environmental concern arises, if environmental persistence and a harmful biological activity are exhibited by EPs. As exemplified by the synthetic steroid hormone 17α-ethinylestradiol (EE2) in contraceptive pills, the annual production amounts to a couple of hundred kilograms per year in the EU, yet it is extremely potent, quite persistent in the environment, and shows estrogenic activity in fish at 1–4 ng/L or lower (Fent et al., 2006).

Material and Methods

Column and batch experiments were performed in order to understand the processes involved in the elimination of emerging pollutants during wastewater treatment and aquifer recharge through the unsaturated zone.

For simulation of biodegradation processes during soil passage, column experiments under unsaturated conditions were conducted with treated wastewater as feed over almost three years. Four columns of stainless steel, filled with natural vadose zone sediment, were irrigated with treated wastewater from the municipal WWTP Neureut/Karlsruhe (Figure 96). Every two weeks, reservoir bottles containing effluent of the WWTP were renewed and stored in a refrigerator at 2°C. Hydraulic retention time in the columns was 5 days. By comparing leachate concentrations of the 2 biologically inhibited (cooled down to 2°C) and the 2 bioactive columns (20°C), biodegradation of the trace organics during soil passage was assessed. Temperature and water content in the columns were controlled by temperature sensors and tensiometers. 5 µg/L of each substance were spiked into the reservoir bottles for one of the cooled and one of the 20°C columns, respectively. Thus, the influence of concentration on the elimination behavior of the emerging pollutants was assessed by comparing the performance of the columns with spiked wastewater with the performance of the columns fed with original wastewater.

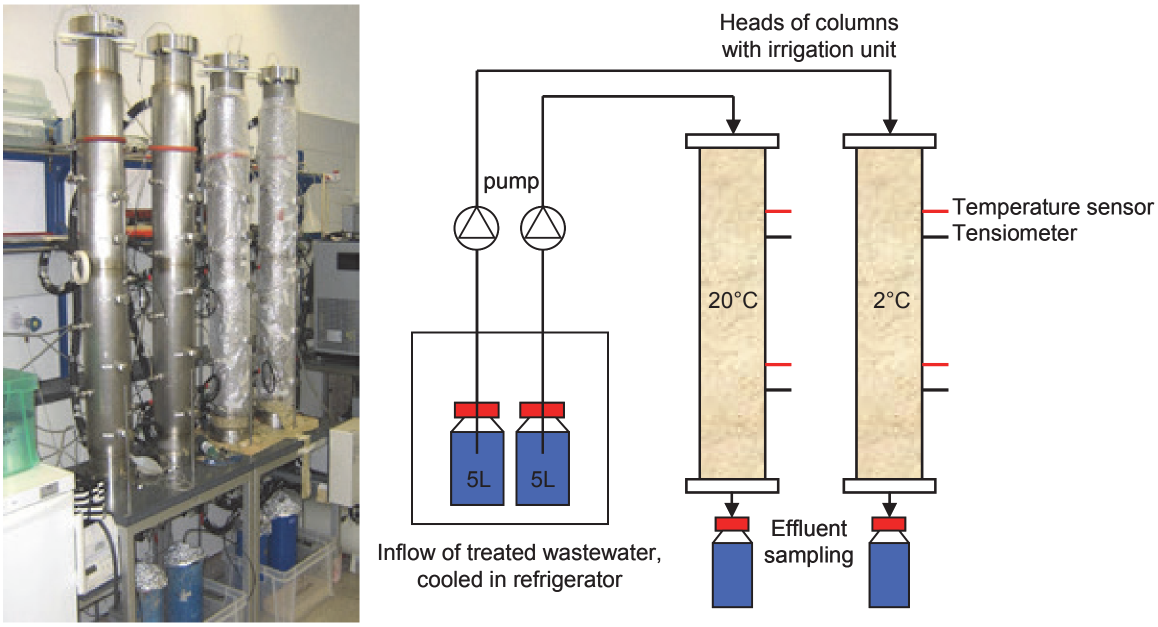


Figure 96: Laboratory setup and scheme of the column experiments

The fate of emerging pollutants was further examined in long-term batch studies to assess their behavior during aquifer storage under different redox conditions. For this purpose, original river bank filtrate without the addition of auxiliary substrates was used. Thus, the direct degradation of the substances could be studied in a mixture with a whole range of emerging pollutants. The experiments were conducted without the addition of easily degradable organic matter (auxiliary substrates), which allowed for studying degradation processes under environmentally relevant conditions.

At two different concentrations, microbial degradation of the compounds was investigated. It is a process characterized by the use of a substance as a substrate, namely, a carbon and/or energy source, and is linked to enzyme production and biomass growth. A growth substrate is an electron donor, while oxygen serves as the electron acceptor under aerobic conditions. Anaerobic conditions provide other electron acceptors like nitrate, manganese (Mn(IV)), iron (Fe(III)), and sulfate. A mix of the pharmaceuticals with 10 µg/L of each substance was added to the assays. After analyzing their behavior for at least 15 months, another 100 µg/L of each of the pharmaceutical substances were added and their fate was examined for another ten months. The anaerobic batch assays were incubated under different redox conditions with the addition of different terminal electron acceptors (TEA) (NO_3^-, Mn(IV), Fe(III), SO_4^{2-}). Next to pharmaceutical compounds, the natural estrogens, 17α ethinylestradiol and bisphenol A, were analyzed.

Results and Discussion

Table 25 summarizes the results for the batch experiments under aerobic and different anaerobic conditions. Of 27 substances tested, 16 were either completely or to more than 50 % removed. This is indicated by the letter ‘b’ under the column named ‘classification’. All 16 substances were removed under aerobic conditions, while naproxen, pentoxifylline, atenolol, propranolol, and the natural estrogens estrone, 17β-estradiol, and estriol showed distinct removal under anaerobic and/or anoxic conditions as well. Letter ‘a’ stands for substances that either did not show any elimination, were only eliminated partly (< 50 %), or that showed a distinctly different behavior in the two phases of the experiment (at 10 µg/L and 100 µg/L).This was the case with phenazone, which was completely degraded at 10 µg/L, but showed only 21 % elimination at 100 µg/L under aerobic conditions. Also diatrizoic acid exhibited nearly 80 % degradation in the first phase, but less than 50 % in the second phase in the aerobic assays and is therefore classified under ‘a’. However, in the same assay, the elimination of sotalol increased from 48 % to 78 % and it was therefore ranked into group b.

Bisphenol A was not detected within the first phase, presumably due to its rapid degradation within the first hours after the spiking of 10 µg/L to the aerobic assay. However, degradation of 100 µg/L within the first four weeks was detected in the second phase, which classifies it under ‘b’. With less than 50 % elimination in any of the assays during the whole experiment, diclofenac, ibuprofen, bezafibrate, clofibric acid, carbamazepine, iopamidol, and the synthetic estrogen 17α-ethinylestradiol all belong to group a. The two ionic X-ray contrast agents iothalamic acid and diatrizoic acid behaved similarly under Mn(IV)-reducing conditions. While more than 50 % removal was measured in the first phase, elimination decreased substantially in the second phase, ranking these two substances under ‘a’ as well.

Table 25: Summary of the results of batch experiments with riverbank filtrate under anaerobic and aerobic conditions with 10 µg/L and 100 µg/L start concentration of each of the substances

(elimination <10 % = -, 10 % – <50 % = +, 50 % – 90 % = ++, >90 % = +++; ‘a’ = removal <50 %, ‘b’ = removal >50 %)

		O_2		NO_3^-		Mn(IV)		Fe(III)		SO_4^{2-}		Classification
		10 µg/L	100 µg/L	10 µg/L	100 µg/L	10 µg/L	100 µg/L	10 µg/L	100 µg/L	10 µg/L	100 µg/L	
Analgesics	Diclofenac	-	+	-	+	-	+	-	+	+	-	a
	Ibuprofen	+	-	+	+	+	-	-	-	+	-	a
	Naproxen	+	+++	+	-	+++	+++	+++	+++	+++	+++	b
	Phenazone	+++	+	-	+	+	-	-	+	-	-	a
	Pentoxifylline	+++	++	+	++	-	+	+	+	+	-	b
Lipid-lowering agents	Bezafibrate	-	-	-	-	-	+	-	-	-	-	a
	Clofibric acid	-	-	-	-	-	-	-	-	-	-	a
	Etofibrate	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	b
	Fenofibric acid	-	-	-	-	+	-	+	-	+	-	a
	Fenofibrate	+++	-/-	++	-/-	+	+++	+	-	+	-	b
	Gemfibrozil	+++	++	+	-	+	-	+	-	++	-	b
Antiepileptic	Carbamazepine	-	-	-	-	-	-	-	-	-	-	a
Beta blockers	Atenolol	++	+++	++	+++	+	+	+	++	-	+	b
	Metoprolol	++	+++	-	+	-	+	-	-	-	-	b
	Propranolol	++	+++	+	++	-	+	-	+	-	-	b
	Sotalol	+	++	-	+	-	+	-	-	-	-	b
X-ray contrast media	Diatrizoic acid	++	+	+	+	++	-	+	-	-	-	a
	Iohexol	+++	+++	-	-	+	-	-	-	-	+	b
	Iomeprol	+++	+++	+	-	+	-	-	-	-	-	b
	Iopamidol	+	+	+	+	+	+	+	+	+	-	a
	Iopromide	+++	+++	+	-	+	-	-	-	+	-	b
	Iothalamic acid	+	+	+	+	++	+	+	+	+	-	a
Estrogens and Bisphenol A	17α-Ethinylestradiol	+	-	+	-	-	-	+	-	+	-	a
	17β-Estradiol	+++	+++	+++	+++	+	+	+++	+++	+++	+++	b
	Estriol	+++	+++	+++	+++	-	+	-	+	+	-	b
	Estrone	+++	+++	+++	+++	-	-	-	-	+	+++	b
	Bisphenol A	-/-	+++	+	+	-	-	-	+	-	+	b

Addressing the issue of risk assessment for managed aquifer recharge, the table illustrates the importance of redox conditions for the elimination of the tested substances. Even naproxen, which showed a good biodegradability, behaved in a recalcitrant way under nitrate-reducing conditions. Similarly, 17β-estradiol exhibited an overall good removal except under Mn(IV)-

reducing conditions. Other substances behaved even more specifically and were only degraded under aerobic and nitrate-reducing (pentoxifylline and propranolol) and sometimes only under aerobic conditions (e.g. gemfibrozil, iohexol). Next to the redox conditions present in the recharged aquifer, the composition of the microbial community is an important factor for the degradation of the trace organic chemicals. It depends on the redox condition, but also on the water quality that the microorganisms are adapted to, basically a low or high organic content and the specific mixture of organic substances. If the biological community of the aquifer is not adapted to water containing a certain composition of micropollutants, it will take up to several months to adapt. This was shown in the batch experiments running for over 2 ½ years. The degradation of the beta blockers, for example, increased from the first phase to the second phase in both the anoxic and aerobic assays. For atenolol, such an increase was also detected under Fe(III)-reducing conditions. However, the elimination rate of other substances like the ionic X-ray contrast agents and iopamidol did not increase. Furthermore, due to their high persistency and the frequency with which they were detected in the environment, the recalcitrant substances clofibric acid and carbamazepine are rather unlikely to be degraded during underground storage, even after long time spans (Heberer, 2002, Scheytt et al., 2004, Arye et al., 2011).

Another aspect which has to be considered in managed aquifer recharge is the hydraulic retention time of the recharged water needed to reach considerable degradation rates. As an example, Figure 97 shows the degradation of 17β-estradiol under the different redox conditions over time. The natural estrogen is completely degraded within four weeks under aerobic conditions.

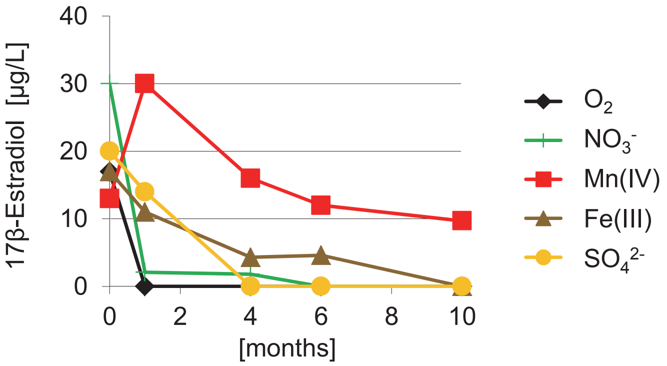


Figure 97: Overview of 17β-estradiol degradation under different redox conditions with 100 µg/L start concentration

Complete degradation under sulfate- and nitrate-reducing conditions occurred within four to six months. Finally, complete degradation is reached under Fe(III)-reducing conditions within ten months, while under Mn(IV)-reducing conditions, a removal of 20 µg/L was measured within eight months after an increased concentration within the first two months due to delayed dissolution.

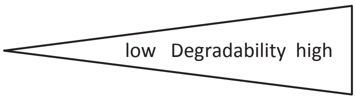
Aerobic conditions often accounted for the fastest degradation. Other substances like the beta blockers atenolol, metoprolol, and propranolol needed between six and ten months for a complete degradation. Pentoxifylline, gemfibrozil, sotalol, and the X-ray contrast agents still exhibited final concentrations of 38 %, 31 %, 22 %, 6 %, 7 %, 1 %, respectively, after ten months under aerobic conditions. For pentoxifylline, atenolol, propranolol, and estrone, final concentrations under the respective anaerobic and anoxic conditions were 40 %, 48 %, 34 %, and 2 %. It can be summarized that the estrogens and Bisphenol A as well as the analgesic naproxen showed the fastest elimination rates, depending on the redox potential. Subsequently, atenolol, metoprolol, and propranolol showed complete elimination under aerobic and anoxic conditions, respectively. At the same time, considerable degradation took place for e.g. pentoxifylline with 51 µg/L and 67 µg/L removal under aerobic and nitrate-reducing conditions, respectively.

Pharmaceuticals in the environment are generally detected in the ng/L and low µg/L range, which is the tenth part of the experimental concentration. It needs to be considered that in general threshold values for substances serving as carbon and energy source for microorganisms exist, covering a range of 2 µg/L up to 790 µg/l for substrates like glucose and starch or 2,4 dichlorophenol, benzoate, and quinoline (Alexander 1999). It cannot be ruled out that a complete degradation of e.g. atenolol under aerobic conditions only occurred in the second phase of the experiment due to an increase in biomass, favored by a higher substrate concentration. In contrast to that, it was suggested recently that due to the low concentrations observed for these kinds of pollutants, microorganisms adapted to oligotrophic environments are able to sustain growth within such low concentration ranges (Egli, 2010, Rauch Williams et al., 2010). Biologically available carbon compounds are usually in the range of 10 – 100 µg/L in groundwater. The simultaneous utilization of many different carbon/energy sources is thought to be the mechanism by which heterotrophic microorganisms maintain sufficient nutrient uptake and growth in oligotrophic environments (Egli, 2010).

Since soil passage and aquifer storage are subsequent processes Table 26 combines the classification derived from the batch experiments with the ranking drawn from the column experiments.

The substances tested in the column experiments can be ranked into three different groups. Group I with the substances eliminated to less than 50 %, group II with substances eliminated to more than 90 % under certain conditions, and group III with substances that show a removal rate above 90 % regardless of any conditions. Substances of group I mostly showed no removal at all and were not eliminated in the batch experiments. Therefore, they are classified under Ia and, consequently, no class Ib exists. Bezafibrate is one example of the class IIa category. It is eliminated completely in the columns, but with a dependence on temperature and substance concentration. In the batch experiments, however, its concentration remained unchanged. Naproxen, on the other hand, showed a good degradability in most of the batch assays and was also degradable in the columns, depending on temperature and time. It is therefore ranked in IIb. Ibuprofen showed very good removal in the column tests irrespective of any influencing parameters, but remained unchanged in the batch assays, which puts it into class IIIa. Bisphenol A and the natural estrogens belong to the substances ranked in class IIIb. Like ibuprofen, they were always completely eliminated under any condition. Furthermore, their behavior during the batch experiments indicated easy degradability under aerobic and anaerobic conditions.

Table 26: Classification of emerging pollutants by their biodegradation behavior during soil passage through the laboratory columns and in the batch studies with riverbank filtrate under aerobic and anaerobic conditions



		Ia	IIa	IIb	IIIa	IIIb
Analgesics	Diclofenac		•			
	Ibuprofen				•	
	Naproxen			•		
	Pentoxifylline					•
	Phenazone		•			
Lipid-lowering agents	Bezafibrate		•			
	Etofibrate					•
	Clofibric acid	•				
	Fenofibrate				•	
	Fenofibric acid		•			
	Gemfibrozil			•		
Antiepileptic	Carbamazepine	•				
Beta blockers	Atenolol					•
	Metoprolol			•		
	Propranolol					•
	Sotalol			•		
Hormones and Bisphenol A	Bisphenol A					•
	17β-Estradiol					•
	Estriol					•
	Estrone					•
	17α-Ethinylestradiol				•	
X-ray contrast media	Diatrizoic acid	•				
	Iohexol			•		
	Iomeprol			•		
	Iopamidol	•				
	Iopromide			•		
	Iothalamic acid	•				

Table 27 shows substances that were not assessed during the batch experiments. For this reason, they were grouped into one of the three main classes derived from the column experiments. Three of the trialkyl phosphates showed a dependence on time, temperature or the substance concentration, which ranks them under group II. The compounds listed in group III of Table 26 show a high degradability during soil passage.

Table 27: Classification of the substances not measured in the batch experiments

		II	III
Alkylphenols	4-*iso*-Nonylphenol		•
	4-*tert*-Octylphenol		•
Trialkylphosphates	Triethyl phosphate	•	
	Trikresyl phosphate (o-, m-, p-isomers)		•
	Tri-n-butyl phosphate		•
	Triphenyl phosphate		•
	Tris-(2-chloroethyl) phosphate	•	
	Tris-(2-chloropropyl) phosphate	•	
	Tris-(2-ethylhexyl) phosphate		•

On the other hand, substances like diatrizoic acid and carbamazepine are expected to be eliminated neither during soil passage nor during storage in the aquifer. As conventional wastewater treatment does not remove these substances sufficiently, they will be contained in the treated wastewater used for recharge. Utilization of diatrizoic acid as a tracer for anthropogenic pollution in the water cycle might be beneficial, since it is thought to have no therapeutic activity. It needs to be considered, however, that the composition of wastewater can differ depending on the pharmaceuticals prescribed in each country. Not all substances mentioned here necessarily have to be contained in a certain WWTP effluent. This needs to be analyzed on a case by case basis. Still, the possibility to find some of the substances listed under Ia is high, as the usage of carbamazepine and the X-ray contrast agents is widely spread (Kümmerer et al., 2004). Advanced wastewater treatment by reverse osmosis, nanofiltration or the application of powdered activated carbon has turned out to eliminate these recalcitrant substances (Drewes et al., 2002, Ternes & Joss 2006). An easy and economically more efficient step, however, would be to change the usage of pharmaceuticals and switch to substances of category II, using e.g. iohexol instead of diatrizoic acid. Together with the substances of class III, they pose less a risk to the groundwater due to their high degradability during soil passage. In fact, the usage of fibrates, with clofibric acid being one of the active transformation products, ceased over recent years in Europe, while its prescription in the US always was of minor importance (Sedlak et al., 2004). Due to reports of either low or contradictory effects of fibrates on high blood lipid levels, statins were prescribed as alternative drugs. The main advantage of a statin over a fibrate is the effective dose of mg compared to g (Mutschler, 2008). However, the high stability of clofibric acid in nature, which was confirmed by the current experiments, shows the urgency for action in this field.

Furthermore, the boundary conditions during soil passage have to be known (e.g. temperature, retention time, redox conditions). Since the column experiments were run under unsaturated conditions and no distinct nitrate reduction occurred, it can be deduced that aerobic conditions prevailed along the 1.10 m passage through the columns. The results of the tests of degradability of the emerging pollutants in the columns supposedly were obtained under aerobic conditions. If other than aerobic conditions predominate the soil passage, the elimination rate resulting for the emerging pollutants might be different.

Conclusions

It can be concluded that the tentative classification is a first step towards risk assessment of emerging pollutants for groundwater recharge with treated wastewater. The substances were ranked into three main classes and subdivided into two categories according to their behavior in the column and batch experiments. The rate at which a substance is degraded and the hydraulic retention time needed for this degradation mainly depend on the composition of the microbial community and its affinity to trace organic compounds. Furthermore, different hydrodynamics and biochemical boundary conditions of aquifers may result in different outcomes with respect to the elimination behavior of the trace organics. These are variables that have to be identified by either studying the respective aquifer in the field or taking soil and water samples for laboratory tests (e.g. batch assays or column tests). The present experiments were conducted with water only in order to avoid sorption onto sediments. Degradation in natural environments that also contain sediment with biofilms is estimated to be even faster.

3.2.4 Economics Assessment of MAR

Author: N. Lienhoop, I. Heinz, N. Schmidt

A cost / effectiveness analysis of alternative technologies for the mobilization of additional water was made. Among other technologies, managed aquifer recharge was evaluated, considering treated wastewater as resource.

As an example of the costs of the pre-treatment step in treated wastewater infiltration, data were taken from the Deir Alla wastewater treatment plant located in the Balqa Governorate (input = 400 m^3/day). For further calculations, the number of person equivalents (pe) supplied by aquifer recharge was considered to be 5000 pe. The treatment includes a screen, an equalization tank, a trickling filter, aeration tanks, a clarifier, and UV disinfection right before the distribution to the users. This technology is exchangeable, but a treatment to a specific water quality is crucial (B or C, JS 893-2006). Only then can the treated wastewater be infiltrated into the soil for further treatment (quality A) and storage, which requires a reservoir or well to drain the water.

Due to the lack of a field site for managed aquifer recharge, assumptions were made for the construction of the infiltration basin. Assuming an infiltration rate of 2 $m^3/(m^2*d)$ and a minimum storage depth of 1 m, an infiltration area of at least 200 m^2 turned out to be necessary. Thus, two basins of 100 m^2 each were found to be sufficient, if solely volume is considered. To ensure safe and robust operation of the aquifer recharge, however, more than two basins are recommended for backup, because sedimentation, clogging, and vegetal invasion may reduce or stop infiltration. This makes three basins of 100 m^2 each that are recommended to fulfill these requirements.

Summing up the investment costs and operation and maintenance costs, total project costs for an MAR option with three basins amount to 91,800 JD, considering the lowest interest rate of 0.03. However, including the installation of a full wastewater treatment as a suitable pre-treatment step clearly raised the costs to 3,420,000. Through annualization of the total project costs and division by annual flow rates, the unit treatment costs were determined to be 0.03 JD/m^3 and 1.19 JD/m^3, respectively.

The two MAR options differed considerably from other technologies (decentralized and brackish water treatment). The least cost-effective option was MAR (treatment + infiltration, 1.19 JD/m^3), while the most cost-effective option was MAR (only infiltration, 0.03 JD/m^3).

The high specific treatment costs for MAR (treatment + infiltration) can be attributed to the treatment costs of the central wastewater treatment plant Deir Alla that was selected as an example of providing a water quality that would be suitable for infiltration purposes. However, pre-treatment in a centralized treatment plant before infiltration can be substituted by smaller decentralized low-tech treatment plants. Combining such plants with infiltration basins would result in water quality A at a lower cost (e.g. SBR technology = 0.53 JD/m^3). MAR (only infiltration) turned out to be the most cost-effective option, because it assumes that a treatment plant already is in place. Thus, solely an addition of the infiltration basins is necessary and the additional investment costs arise from the infiltration step.

3.2.5 MAR Executive Summary and Conclusions

Authors: N. Schmidt, A. Tiehm

Water shortage in the study area led to over-pumping and, consequently, to the lowering of the water table and rise in salinity. To minimize further depletion and deterioration of groundwater resources as well as evaporation losses during surface storage and to efficiently use the available water resources (groundwater, surface water, and treated wastewater), different managed aquifer recharge techniques were applied at different test sites in Jordan and the West Bank. Infiltration was conducted by using ponds, injection wells or dams.

Wala Dam has been successfully operated for a period of 10 years already for effectively recharging the downstream aquifer with the Wala-Haidan well field for provision of domestic water to Madaba and Amman. Nowadays, it is facing the problem of sedimentation which reduces the overall capacity and decreases the infiltration rate. Furthermore, turbidity in the Wala-Haidan well field increases so that production from the well field had to be shut down several times in the last years. In order to enhance the capacity again, the reservoir shall be raised by 15 m and check dams are supposed to minimize the sediments inflow into the reservoir. Further down the valley, close to the north end of the Dead Sea, the Shueib and Kafrein reservoirs were investigated. As a result, it turned out that a large amount of the runoff water is going directly into the Dead Sea, since the capacity of the Shueib Dam is not sufficient. Therefore, it is proposed to heighten the dam in order to use the water from the Wadi Shueib catchment for additional recharge of the alluvial aquifer. On the western side of the Jordan Valley in the Al Uja area, an earth dam was built in 2011 for the infiltration of excess water into the Upper Mountain and Shallow Plio-Plistocene aquifer system. Under a two years' monitoring program, partial infiltration in relatively short periods was measured, with the chalky unit of Senonian age found to be a permeable layer.

Borehole injection for direct artificial recharge of spring water is the recommended method in the Al Uja area, while surface infiltration ponds are not recommended due to high evaporation losses. From the geophysical, hydrochemical, and hydrological analyses in the area, it can be concluded that the mountain and the shallow aquifer systems are hydraulically connected. For a stable water balance, it is recommended to manage both aquifer systems as one hydrological unit and to build retention walls across the wadi in order to increase the recharge rate from the Al Uja spring into the aquifers.

An aquifer for recharge via infiltration ponds was identified through geological and geomorphological studies and geoelectric soundings in the area between Deir Alla in the south and Suleikhat in the north. The aquifer contains fresh to slightly brackish groundwater, but is not completely filled and will allow to store up to 10 MCM of reclaimed water in addition to the already available 15 MCM. The method of recharge foresees to take water diverted from the King Abdullah Canal for infiltration into an abandoned gravel quarry and extraction through wells down-gradient to the recharge sites. Self-purification during infiltration and the additional storage volume are the two major advantages of this managed aquifer recharge project. Within the apex of Wadi Hisban, another suitable area for artificial recharge via infiltration basins was identified. More than 1 MCM are estimated to be infiltrated into the wadi floor with its fluviatile gravels during the rainy season.

Next to the different test sites, the water quality during managed aquifer recharge processes was investigated. In column and batch studies a high potential for the elimination of emerging pollutants due to natural degradation processes within the unsaturated zone and during storage in the underground was found. The combination of the redox condition, adaptation time, and concentration of the respective substances was identified to be crucial to the effective removal of trace substances. Some compounds showed a high recalcitrance to natural degradation and are expected to prevail and accumulate in the water cycle. However, since the X-ray contrast agents are thought to have no therapeutic activity, the presence of diatrizoic acid might be of advantage, if it is used as a possible anthropogenic tracer for hydrogeological investigations. From the results of the batch and column experiments, a classification scheme was deduced that can support the planning, implementation, and monitoring of managed aquifer recharge systems in terms of water quality aspects.

Cost-effectiveness analyses showed that the combination of decentralized treatment units for wastewater with subsequent surface infiltration and storage in the underground is the most beneficial option from the economic point of view. Due to the high remediation potential of the soil passage for trace pollutants and the advantage of storage in the underground (minimizing evaporation losses and additional enhancement of water quality), especially decentralized treatment options, together with aquifer recharge systems operating via surface infiltration, are recommended to be fostered in the study region.

3.3 Brackish Water Usage

Involved Institutions: EBI, BALQ, TAU, MEK, JUA, GU ,BGU ,UKA, MWI,WAJ, PHG, PWA, QUDS, SPA

Spokesmen WP3-3: F. Frimmel (EBI); A. Flexer (TAU)

Compiled by: Florencia Saravia

3.3.1 Introduction

The main goal of the SMARTII project is to increase the total amount of water for domestic and agriculture usages in the area of the Lower Jordan Rift Valley (LJRV). The major and most important local water resources are freshwater from shallow and deep aquifers. However, due to lack of freshwater resources in the region, secondary origins of brackish and saline water have been taken into consideration for local usage. Relatively large amounts of these potential water reservoirs are found in the shallow and deep aquifers, mostly coexisting with freshwater.

The current report illustrates the occurrence of the brackish water in the LJRV. Furthermore, it recommends (from the engineering and water supply points of view) preferred locations of sites for local desalination plants and facilities. Additionally, the report gives a general overview of the innovative desalination plant constructed within the framework of SMART2 and its operation at the demonstration site in Karameh, Jordan.

3.3.2 Desalination

3.3.2.1 Introduction

The quantity and availability of freshwater is one of the important issues the world is facing today. The overexploitation of aquifers and the subsequent lowering of their levels is a problem in many areas in the world, including the ones in the Near East. In many countries in the near East, unsustainable withdrawal exceeds recharge rates and the water bodies are overexploited. The overexploitation leads to the intrusion of seawater and/or the upward diffusion of deeper saline water into the groundwater, as a result of which the groundwater quality is deteriorated. The depletion of water resources may have a negative impact on the aquatic ecosystems and, at the same time, underline the importance of socio-economic development (F.A.O.Water 2009).

Different alternatives can be used to improve the situation of water resources in the world. This includes rational use of water resources, optimization of water use (e.g. appropriate irrigation technologies), sustainable protection of water sources, the application of innovative technologies to treat low-quality water sources, such as municipal and industrial wastewater and saline waters.

Desalination of seawater is the most important process used to reduce the water scarcity problems in coastal zones in the world. The application of desalination technologies (principally thermal and membrane-based desalination) accounts for a worldwide production capacity of 24.5 MCM/d (Lattemann and Höpner 2008). The emerging treatment of brackish water shows further promising potential for inland matter and for its reuse.

3.3.2.2 Desalination Technologies

A lot of different desalination technologies for water treatment exist, ranging from very old processes, such as multi-effect distillation (MED) which dates back to the middle of the 19th century (Al-Shammiri and Safar 1999) to the application of forward osmosis (FO) (Cath et al. 2006, Lee et al. 2010).

In 1999, the reverse osmosis (RO) worldwide desalination capacity was about 10 %. The main desalination process was multi-stage flash distillation (MSF) with 78 % of the total desalination (Escwa 2009). Nowadays, membrane-based desalination (RO and electrodialysis (ED)) reaches more than 56 % of the total desalination capacity, while thermal desalination technologies (MED and MSF) account for 33 %.

In the countries of the Western Asia Region MSF is the principal desalination technology with 53 % of the total treatment capacity. RO accounts for approx. 28 % and MED for approx. 9 % (Escwa 2009).

Differences between desalination capacities in the world and in the Western Asia Region are due to the specific energy sources available in this region. Countries with no or low availability of fossil energy sources mostly use membrane technologies which require electrical power as the only source of energy. Where energy prices are low, thermal technologies are used (Escwa 2009).

3.3.2.3 The Brine Issue

One of the most important environmental issues of desalination is the generation of the saline "by-product" brine. The concentrate has not only a high concentration of salts, but also contains residual chemicals, such as antiscalants and cleaning chemicals. The magnitude of brine discharge can be understood better when considering that the global desalination capacity is 109,646,353 m^3/d (van der Merwe et al. 2012) and the recovery rate of a desalination plant typically varies between 40 and 50 % for seawater desalination and reaches up to 95 % for brackish and low-saline water treatment. Most countries have no regulations or environmental constraints for brine disposal. Desalination plants located in coastal areas usually discharge brine without any treatment directly into the sea. This is associated with the risk of damaging or influencing the marine environment (Hoepner and Lattemann 2003, Roberts et al. 2010). Desalination plants of inland brackish water that are located far away from the coast are obliged to find low cost alternatives for the disposal of brine.

For brine treatment, various environmentally friendly and relatively low-cost options for the LJRV region can be suggested:

a) Disposal (no treatment) of brine, thus minimizing the risk of environmental impacts: One of the problems of brine discharge is the high concentration of salts. The Dead Sea is an adequate alternative with a low risk of an environmental impact.

b) Use of evaporation ponds is a brine treatment method which is limited to small desalination plants (Mickley 2006) and could be effective only in regions with a dry climate and high evaporation rates. The high quantities of solid waste to be disposed of are easier to handle and can be always reused for commercial applications.

c) Disposal of brine into fish ponds: Once brackish water desalination technologies will be operated on a large scale, agricultural options, such as use by fish and sea food industries, can be implemented in the area.

d) Selective precipitation: Through a combination of evaporation and crystallization technologies (Hajbi et al. 2010) or by the treatment of brine with the patented SAL-PROC technology (Ahmed et al. 2003), valuable salts can be recovered.

3.3.2.4 Why Desalinate?

The southern LJRV is an arid zone with precipitations of 50 to 150 mm/a and potential evaporation of up to 2,600 mm/a. The main sources of freshwater are the relatively deep aquifers which are naturally replenished by precipitation on both sides of the valley, the Jordanian highland in the east and the Judean Mountains in the west (Israel and Palestine). The main economic activity in the region is agriculture which depends on local water resources. The water supply system in the LJRV (on its western side) is a separate system disconnected from the national network. Import of additional water from other areas is impractical due to cost/value issues and engineering problems. Consequently, the present and future development depends and will depend significantly on the availability of water (freshwater and brackish water) in the region.

3.3.2.5 Which Percentage of the Water Problem Is Solved by Desalination?

Israel

The national water system provides approximately 1150 Mm^3/a of freshwater. The desalination capacity presently amounts to a total of about 300 Mm^3/desalinated water per year, which is about 24 % of the freshwater consumption per year. According to the Water Authority's future master plans, the desalinated water production will reach 505 Mm^3/a by 2013. This amount constitutes about 44 % of the yearly freshwater consumption. This desalination capacity will allow for a beginning restoration of aquifers and refilling of The Sea of Galilee.

Palestine

The shallow Plio-Plistocene aquifer system still is the main water source in the western part of the LJV groundwater, with the annual abstraction being about 22 Mm^3 (in 2011/2012). Of this volume, 7 Mm^3 (about 30 %) have a salinity of more than 5 mS/cm. Desalination of this volume is essential to sustain the current status of the agricultural sector. Currently, one desalination treatment plant with a capacity of 150 m^3/h is operating. Operation started one year ago in the Al Zbedat area. The operation cost of this plant is 0.4 kW/m^3 in addition to 8 US$/kg.day for anti-scaling material. The water inflow has an electrical conductivity of around 7 mS/cm, while the water outflow has about 1 mS/cm. The treated water is used for the cultivation of vegetables at the Al Zbedat site. Brine residuals flow directly into the Jordan River.

Jordan

According to the information available, there are 20 desalination plants in Jordan, the capacity totaling 86 Mm^3/a. Most of the plants are of small size and provide less than 50 Mm^3/a. Three desalination systems are applied in Jordan. These are evaporation, reverse osmosis (RO), and electrodialysis. The RO technique is the main one used in the desalination plants. Jordan plans to increase the volume of treated water up to 150 Mm^3/a in the near future. The plan envisages 70 Mm^3/a from the Gulf of Aqaba, 8 Mm^3/y for the Husban area, up to 3 Mm^3/y in Tabkat Fahel, Jordan Valley, and 10 Mm^3/y for other areas.

3.3.3 Review of Desalination, Infrastructure in the Region

The objectives facing the water authorities in the region in developing desalination plants are to achieve (1) reliable and regular sustainable water management, (2) improve the water quality for drinking as well as agricultural use, (3) compensate water shortage in natural reservoirs during the dry years, and (4) restore overexploited aquifers.

Israel

After the outbreak of the severe water crisis in Israel, the government initiated an emergency master plan to increase the amount of desalinated water. The master plan of desalination water supply for the year 2050 is based on approximately 1750 Mm^3/a freshwater. The desalination production now reaches a total of about 300 Mm^3/a which is about 24 % of the national freshwater consumption per year. According to future master plans, the desalinated water production is to reach 750 Mm^3/a by 2020. This amount constitutes about 44 % of the yearly freshwater consumption. This capacity of desalination will allow for a beginning restoration of aquifers and preserve The Sea of Galilee.

The desalination technology selected in Israel is RO. It is associated with tremendous savings of energy (having the largest share in the production cost of a desalination facility) compared to conventional evaporation technologies used in the past.

There are three active mega-plants for seawater desalination in Israel, another two are under construction: The Ashkelon plant with a production of 120 Mm^3/a; the Hadera plant with a production of 127 Mm^3/a; and the Palmahim plant with a production of 45 Mm^3/a. The Ashdod plant already produces approx. 100 Mm^3/a; the Sorek plant will produce 150 Mm^3/a by 2013 and is planned to be the largest of its kind.

Several small brackish water desalination facilities in Israel are located in Eilat, Arava, Negev, and the Coastal Plain. The total capacity of brackish water desalination now is about 35 Mm^3/a. It will increase to an output of up to 80 Mm^3/a by the end of 2020.

Palestine

Water resources in the western part of the LJV mainly consist of springs and groundwater. For historic reasons, these two sources are owned by private persons. Centralized institutions as in Jordan and Israel are still lacking in Palestine. Each groundwater borehole is owned by many farmers or farmers' associations. Due to this fact, small desalination units are more practical than central plants. The Ministry of Agriculture (MoA), in cooperation with the Islamic Investment Bank, built the first RO plant, which has been operated for one year now in the Al Zbedat area (Marj Najah). In addition, eight RO treatment plants are in the process of tendering. These plants are expected to be in operation by the next 12 months. In general, the factor limiting the introduction of desalination technology in the LJV is the weak financial status. Disposal of brine outflow still is an open question for many funding agencies that are interested in the technology of desalination.

Jordan

Water scarcity is the most important natural constraint to Jordan's economic growth and development. Rapid increases in population and industrial development have resulted in unprecedented demands on water resources. Total demand is approaching one and a half billion cubic meters per year, which is far away from the limit of Jordan's renewable and economically developable water resources.

New resources, such as desalination of brackish water, are a viable alternative when all other options of resources as well as demand issues are resolved. It is with this spirit and background that we approach desalination.

The desalination capacity in Jordan (for drinking water purposes is 86 Mm^3/a (10 Mm^3/a from Abu Zeighan wells, 50 Mm^3/a from Zara, 6 Mm^3/a from Zarqa wells, and 20 Mm^3/a from other small desalination plants).

With an investment in the region of 8 to 10 billion JD, Jordan is planning a mega-project to provide desalinated water to Jordan and refill the Dead Sea. It should be noted that two similar projects were proposed to connect the Red Sea with the Dead Sea: The Red-Dead Project, a regional project in collaboration with Israel and the Palestinian authorities; and the Jordan Red Sea Project (JRSP), a Jordanian version of the project. The JRSP's project goals are to:

- Convey approximately 2,000 Mm^3/a of seawater from the Red Sea to the Dead Sea.
- Provide 930 Mm^3/a of desalinated freshwater to Jordan.

- Refill the Dead Sea with the remaining brine.
- Use JRSP as a basis for further economic development in the region (for example, new urban centers, resort areas, and gated communities).

3.3.4 Hydrochemistry and Geohydrology

3.3.4.1 Main Goals

The main goal of the brackish water study is to calculate the total amounts of water for domestic and agricultural usages in the study area.

For that purpose, a detailed hydrochemical and geohydrological study was prepared with the following objectives:

1. Examine the hydrochemistry of the study area in order to determine the brackish water chemical potential suitable for desalination.
2. Study the geohydrology of the area in order to evaluate the location of potential additional brackish water that can be used for desalination.
3. Evaluate the sources and volume of potential additional brackish water that can be used for desalination.
4. Suggest precise locations for drillings for brackish water exploration.
5. Suggest potential sites for future desalination facilities.

3.3.4.2 Israel and Palestine

The study area extends between the crest of the Hebron-Ramallah (Judea) and Fariah anticlines in the east and the western margins of the Rift Valley, which are partly defined by faults. It covers parts of eastern Judea and Samaria and is part of the eastern drainage basin.

Four aquifer units are discerned in the study area. Two of them form part of the Judea Group and are known as:

1. The Albian-Lower Cenomanian Lower Judea Group aquifer.
2. The Cenomanian-Turonian Upper Judea Group aquifer.

The two other aquifers are:

1. The Lower-Middle Eocene Avedat (Jenin) Group aquifer.
2. Permeable beds within the Quaternary Dead Sea Group occurring mainly within the Rift Valley.

Judea Group Aquifer

The lower aquifer of the Judea Group comprises highly permeable karstic beds (320 m thick) related to the Kefira, Giveat Yearim, Soreq, and Kesalon formations (lower and upper Beit-Kahil formations). The upper aquifer of the Judea Group is also built of highly permeable and karstic beds of the Aminadav, Weradim, Shivta, and Nezer formations or Hebron, Beit-Lehem, and Jerusalem formations, which attain a total thickness of 250 to 280 m.

Groundwater levels in the Lower Judea Group aquifer are between 450 m mean sea level (MSL) in the west and below - 350 m MSL near the borders of the Rift. Groundwater flow is generally eastwards. Water levels in the Upper Judea Group aquifer vary between + 450 m MSL and - 320 m MSL and the flow is generally eastwards.

In the Judea Group aquifers the longitudinal and parallel isochlorine lines indicate that the increase in salinity in both aquifers closely follows groundwater flow. The Cl^- concentrations are in the 26 to 12200 mg/L range (Figure 98).

In the lower aquifer (Albian–Lower Cenomanian) the average Cl content is 39 ± 14 mg/L, whereas in the overlying aquifer (Mid-Cenomanian-Turonian) it is slightly higher, 56 ± 28 mg/L. Such concentrations are characteristic of most parts of the two aquifers. The freshwaters in the lower aquifer reach as far as 10 km west of the Rift boundary. Northwards in the Auja area, these freshwaters reach the rim of the Rift. Judging by the shapes of isochlore lines of the upper aquifer, two preferred flow paths appear to exist, one heading from the boreholes in the outskirts of Jerusalem eastwards to the Rift and another one in the northeastern part of the aquifer is directed towards the Atara-Masua-Beqaot wells.

The location and chemical concentration maps in both aquifers (Upper Judea and Lower Judea), showing the distribution of water wells, the water levels, and the chemical composition of the water.

In the lower aquifer brackish water with average chloride concentrations of 6,000 mg/L was encountered exclusively in the Mitzpe Jericho wells (# 3 and 5 deep) and Jericho 2 well. In the upper aquifer such brackish groundwater attains salinities in the range of 430 to 2100 mg/L Cl^- and is encountered in Mitzpe Jericho and Jericho wells as well as at two additionalplaces, in the Qaliya 2 and Fazael 11 wells. The waters of both aquifers of the Judea Group are generally characterized by low SO_4^{2-} concentrations (av. 17 ± 8.5 and 19 ± 11 mg/L, respectively). Higher concentration (but not exceeding 45 mg/L) is encountered in the lower aquifer in the northeastern part of the study area, i.e. in the Fazael-Beqaot area.

The brackish water found close to the margins of the Rift in the wells of Mitzpe Jericho, Jericho, and Fazael have high concentrations of sulfate. In the lower aquifer they reach up to 870 mg/L and stand out as a separate group. In the upper aquifer the concentrations are in the 40 to 260 mg/L range.

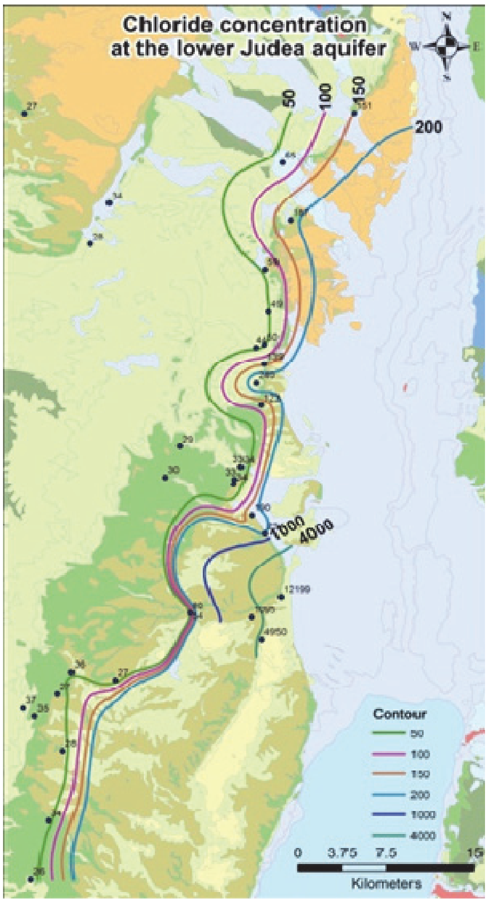


Figure 98: Chloride concentration map of the Judea Lower Aquifer.

Avdat Group Aquifer

The Eocene Avedat Group is located in the northeastern part of the study area, in the vicinity of Fariya and of Argaman-Beqaot (Marj-Naja) in the core of the regional syncline of Sartaba, which is diagonally incised by the Fariya Graben. It uncomformably overlies the impervious sequence of the Senonian-Paleocene Mt.Scopus Group, the thickness of which varies in the range of 0 to 380 m.

The aquifer beds of the Avedat Group are directly recharged by local rainfall which attains 250 to 300 mm/a in the western parts of the study area and ± 100 mm/y in the Rift and its vicinity. In the Beqaot-Argaman area (Marj-Naja) the thickness of the Mt.Scopus aquiclude is strongly reduced or even entirely absent due to non-deposition. This local geological feature facilitates interflow between the Judea and Avedat aquifers. It is further enhanced by the intensive faulting along the western margins of the Rift (mostly obscured by the alluvial fill).

Groundwater levels in the Avedat aquifer are between 100 m to 300 m MSL (Mean Sea Level) and the flow is generally directed to the east and south-east.

In the Avedat Group aquifer the isochlorine lines indicate that salinity increases east-south-eastwards. Chloride concentrations are in the 37 to 1300 mg/L range. The lowermost concentrations (37 to 82 mg/L) were encountered close to the western margins of the study area and represent groundwater replenished in the southern part of the Shekhem-Nablus syncline. In the central part of the study area the groundwater has an average chloride content of 520 mg/L, whereas close to the western margins of the Rift, the concentrations are in the 800 to 1300 mg/L range (av. 1000 mg/L). The shapes of the isochlorine lines reflect preferential groundwater flow. In the Avedat Group aquifer the fresh groundwater in the western parts of the study area are characterized by low sulfate concentrations (av. 20 mg/L), which are quite similar to the concentrations encountered in the Judea Group aquifer.

Dead Sea Group (Shallow) Aquifer

The Quaternary Dead Sea Group sediments outcrop mainly in the flatlands east of the western fault escarpment of the Rift. This Group is divided into several formations which contain permeable horizons:

The Samra Formation (Plio-Pleistocene) crops out along the western part of the Jordan Valley floor. It consists mainly of detrital material, such as conglomerates, sandstone, and silt and is subdivided into two members: the Silt Member and the Coarse Clastic member. The Silt Member (up to 20 m thick) interfingers with the Lisan formation.

The Lisan formation (Plio-Pleistocene) is found in wide parts of the Jordan Valley and often penetrates the mouths of wadis. The highest outcrops are found at - 180 m. The 35 m thick formation essentially consists of chemical and detrital deposits, such as laminated aragonite-chalk, gypsum and sulfur, clay with some sandstone and pebble beds. Algal tufa occurs at a constant elevation of - 240 m MSL. Alluvial deposits contain debris from all formations bordering the Rift. The total thickness of these beds is unknown and may certainly reach very high figures in the central parts of the Rift, thinning out towards the edges.

The present study revealed that all permeable horizons are interconnected in the Valley and that hydrological and hydrochemical continuity prevails. Groundwater levels in the aquiferous horizons of the Dead Sea Group are between - 280 m MSL to - 340 m MSL and the flow generally is directed to the east.

Figure 99 presents the location and chemical concentration maps of the Dead Sea (Shallow) Aquifer, showing the distribution of water wells, the water levels, and the chemical composition of the water.

In permeable horizons of the Dead Sea Group Aquifer Cl^- concentrations are in the 50 to 2200 mg/L range. The pattern of isochlorine lines clearly reflects recharge of the Dead Sea Group aquifers by inflow of fresh groundwater from the major wadis draining the East Judea Mountain range. The lowest Cl^- concentrations occur close to the outlet of the wadis Qelt, Auja, and Fari’a to the Central Jordan Valley. Salinities evolve with the further flow of groundwater eastwards. The salinization rate in the Dead Sea Group aquifers is quite high. Groundwater of < 200 mg/L Cl^- at the outlet of W. Qelt reaches concentrations of > 1200 mg/L after subsurface flow of about 5 km. The same phenomenon occurs in W. Fariya, though at a slightly lower rate. A prominent salinity high (>1200 mg/L Cl^-) occurs east of Jericho, in the vicinity of the Alami wells.

In the permeable horizons within the Dead Sea Group subsurface inflow of waters originating from the mountain wadis is characterized by sulfate concentrations of up to 100 mg/L. These concentrations increase to much higher values (> 200 and up to 900 mg/L) near and east of Jericho in particular.

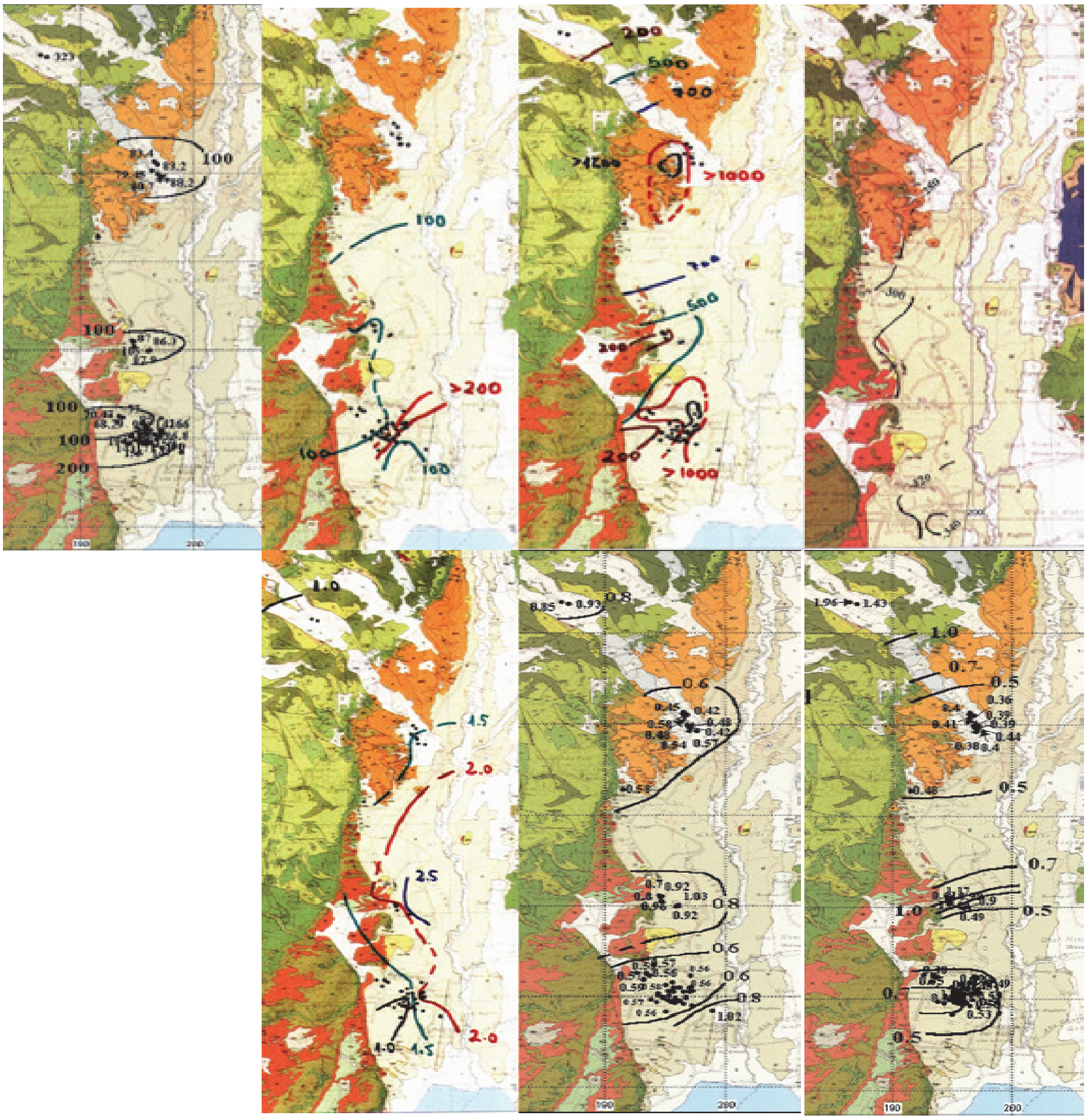


Figure 99: Location and chemical concentration maps of the Dead Sea Group Shallow Aquifer, showing the distribution of water wells in the aquifer, the water levels, and the chemical composition of the water.

Summary of the Evolution of Ion Concentrations versus Salinity in the Three Aquifers

In the three main aquifers the concentrations of the main cations versus salinity are quite similar. The concentrations of Ca^{2+}, Mg^{2+}, and Na^{+} generally exhibit a direct linear dependence on the Cl^{-} concentrations. In all cases SO_4^{2-} increases in the vicinity of the western rim of the Rift. Scattering of Ca^{2+} and Na^{+} around the function line is due to exchange reactions on argillaceous rock components.

3.3.4.3 Jordan

On the eastern side of the Jordan Valley area, a variety of groundwater chemistries are found, reflecting different sources of chemical constituents. Analyses of common water constituents, O18 and D isotopes, bromide concentration, ionic ratios, and chemical clustering were used to characterize the groundwater types and to understand their genesis.

The findings show the compositions of the different water types and their evolution as they pass from precipitation to infiltration to down-percolation into the different geologic formations and from one formation into the other.

Salt water bodies in the underground of the Jordan Valley, Lisan formation, and Triassic-Jurassic rocks are found to be the main sources of salinity and chemical species in the groundwater of the area.

3.3.5 Hydrogeology

3.3.5.1 Major Sources and Volume of Brackish Water on the Western Side of the LJRV

The reports of Hasan and Guttman (2011), Marei and Saravia (2011), and Flexer et al. (2011) summarized the brackish resources within the study area.

Unfortunately, only few of the sites suggested can be used as sustainable sources for direct irrigation and/or desalination. Two sources of brackish water were found suitable in the regional aquifer (Judea/Ajlun Group Aquifer) and two other suitable sources are located in the alluvial aquifer of the valley fill. In addition, the surface water of the Jordan River itself can be an additional source of sustainable brackish water in the area (today, there are few pumping stations along the river banks).

Brackish Water in Feshcha Springs (Marsaba- Feshcha Basin)

The Ein-Feshcha spring group located on the upper north-western shore of the Dead Sea is the major outlet of the calcareous regional aquifer (the Judea/Ajlun Group Aquifer). The spring discharge towards the Dead Sea is estimated to range between 62 and 67 Mm^3/a (measured by the Israeli Hydrology Survey). The springs have a large storage capacity. Over the years, the discharge rate was rather stable with small annual fluctuations only. The springs cover a relatively large area of 3 to 4 km along the Dead Sea shore. The water emerges from the alluvial deposits which are directly connected to the major aquifer.

The spring water maintains the local natural reserve. After crossing the natural reserve, the brackish water flows to the Dead Sea and is lost there. Our recommendation is to select the pumping points between the eastern border of the natural reserve and the Dead Sea shore. We believe that capturing the brackish water after it has crossed the natural reserve and before it flows into the Dead Sea will not damage the natural reserve.

Hasan and Guttman (2011) assumed that an annual amount of 30 Mm^3 can be used as raw water for desalination facilities. Their recommendation is to focus on the northern part of the Feshcha springs. The salinity in this section is between 1,500 to 2,000 mg/L Cl^-. The desalinated water will be transferred to the local customers in an equitable manner (Table 28).

The analyzed hydrochemical data reveal that Ein-Feshcha water quality varies over short distances, implying a flow through a heterogeneous fractured system with respect to both hydrogeology and mineral reactivity. Consequently, it can be concluded that spring salinization differences are due to several factors and lead to various types of water quality of the spring group with different chemical compositions over short distances Figure 100.

Table 28: Concentration (in mg/L) of the main ions in the brackish water of the Feshcha springs (Marsaba-Feshcha basin).

	Cl^-	Na^+	K^+	HCO_3^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	T [°C]
β [mg/L]	1.500-2.500	380-860	43-90	170-470	48-82	94-420	150-400	23-31

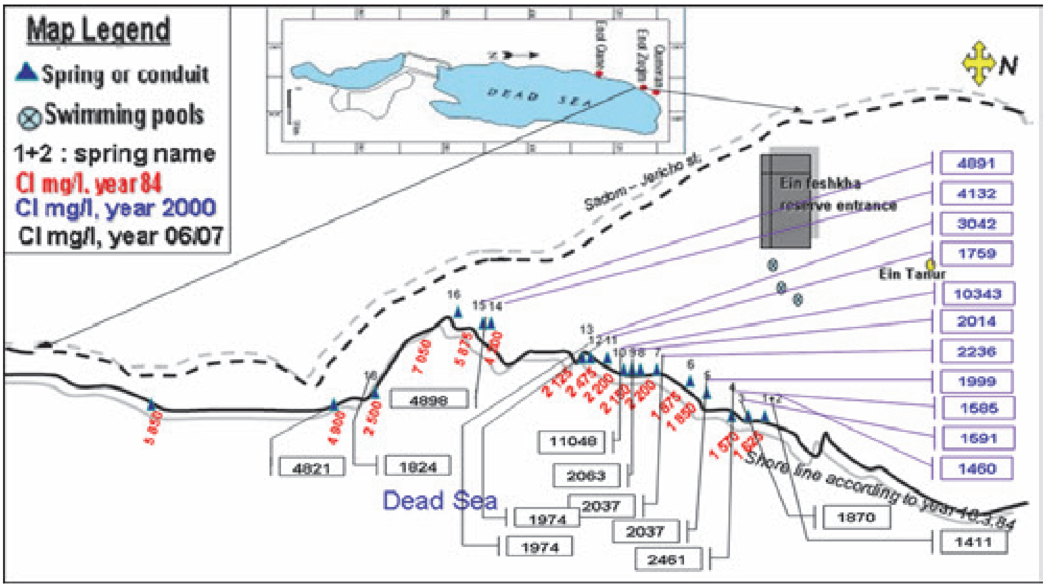


Figure 100: Site map of the Ein-Feshacha springs with the Cl^- concentrations for the years 1984 and 2000 as well as current research data (Hasan and Guttman 2011).

Brackish Water in the Fazael Area

Most of the pumping wells in the LJRV are located inside the eastern monocline flexure that runs along the foothill to the west of the Jordan Valley. The Fazael-1 borehole located a few hundred meters east of the monocline flexure was the first deep well drilled in the Jordan Valley, which penetrated the Judea/Ajlun Group Aquifer. The water in this well was saline (up to 4500 mg/L Cl^- in the lower part of the well). For this reason, the well was abandoned and followed by the Fazael 2 borehole which was drilled closer to the wadi aperture that crosses and cuts the monocline flexure. The water in this well was found to be fresh and stable in salinity (about 45 mg/l Cl^-). This salinity difference between the two wells is explained by the fact that the monocline flexure acts as a hydraulic barrier between the fresh and the saline water bodies. All pumping wells, such as the Fazael, Gitit, and Uja boreholes drilled into the Judea/Ajlun Group Aquifer in the Fazael-Uja region, are situated within the monocline and are aimed at pumping the freshwater before it flows and is lost within the deep basin-fill sediments of the Jordan Valley.

The sources of salinization in the LJRV are residual deep-seated brines as well as salt layers and bodies that were deposited during various sea transgression events and penetrate deep formations inside the valley. The cause of salinity rise in several pumping wells is the hydraulic connection between formations containing freshwater and deep formations containing saline water. As the current knowledge available is rather limited, the absence of deep investigation wells inside the valley makes it difficult to delineate the exact location and nature (fault, wedge-out, inter-fingering, etc.) of contact zones between the freshwater and the saline water. The Judea/Ajlun Group Aquifer in the Jordan Valley east of the foothills is situated at a depth of a few hundred meters and covered by younger formations (from Mt. Scopus/Belqa up to the Dead Sea/Lisan Groups).

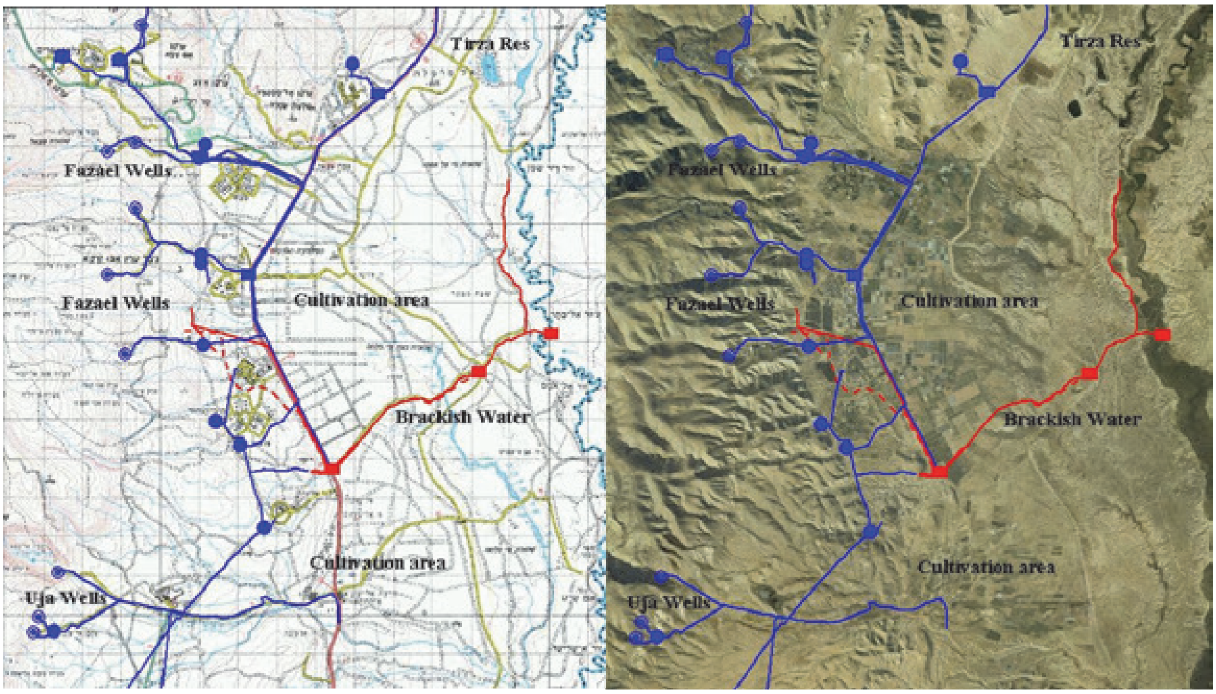


Figure 101: Locations of three boreholes proposed for brackish water exploration in the Fazael-Uja basin presented on Mekorot's pipeline system map.

Interpretation of seismic lines within the framework of SMART-I revealed that within the Jordan Valley there are areas where the Judea/Ajlun Group Aquifer is located at a shallow depth (Ankar 2007). These sites are favorable places for prospecting and drillings for brackish water reservoirs in the upper part of the Judea/Ajlun Group Aquifer. Applying these data with the hydrogeological conceptual model and the strategic planning program of the region, Mekorot (The Israel National Water Company) identified three new sites for drilling within the valley (Figure 101). Each of the future wells is planned to pump about 1 Mm^3/a of brackish water with a salinity of 2000 to 2500 mg/L Cl^-. This water can be used as an additional supply for irrigation of palm plantations either directly or by mixing with treated wastewater. Some portion can be used for local desalination facilities. The new drilling program is combined with a program for transferring and distributing the pumped water through the network in the study area. The expected chemical composition of the raw water is shown in Table 29

Table 29: Expected chemical composition of brackish water in the Fazael area (based on Fazael 1)

	Cl^-	Na^+	K^+	HCO_3^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	T [°C]
β [mg/L]	2,000-2,500	800-900	70-80	230-240	75-85	290-310	250-270	25

Brackish Water in the Alluvial Deposits of the Jericho and Uja Areas

The shallow aquifer in the Jericho and Uja areas consists mainly of alluvial deposits, i.e. clay, silts, conglomerate, chalk, marl, and gypsum layers of the Lisan formation. In these areas unsustainable withdrawal due to the high water demand and high groundwater extraction exceeds recharge rates and the water bodies are overexploited. The amount of freshwater that recharges into the alluvial aquifer is limited and unable to push the saline water back from the well fields. During pumping, the saline water moves towards the wells and the salinity rises. This suggests that the shallow formations that contain freshwater and the deep formations that contain the saline water are hydraulically connected.

The freshwater acts as a lens or a thin layer that is overlaying the saline water body. In many wells the perforated section provides for an artificial connection between the freshwater horizon and the saline water layers. Furthermore, the permeability in many wells is low, resulting in large dynamic drawdown. Those conditions (upconing and lateral movement of saline water) are the reasons of salinity rise in this aquifer.

According to the preliminary design of the study, it is recommended to install 5 to 6 new wells in the eastern part of the Jericho area as well as 2 to 3 wells in the eastern part of Uja village. The hourly discharge of each well is expected to be around 100 to 120 m^3/h and the calculated yearly amount is estimated to be between 0.8 to 1.0 Mm^3/a per well.

The salinity is expected to be between 1600 to 2000 mg/L Cl^- and might increase during pumping either due to the inflow of higher amounts of saline water from the east or the depression cone reaching the saline waters at the bottom of the wells.

Brackish Water from the Jordan River

The water in the Lower Jordan River is mainly saline. Few pumping stations are located on both sides of the river and pump brackish water from the river for use in agriculture. Some portion is used for direct irrigation and another portion is used to dilute the secondary effluent. The total brackish water of the area is used solely to irrigate palm plantations.

The exact amount of water pumped from the stations is unknown. According to the pump capacities and the usage, it is assumed that the total pumping volume of brackish water from the southern part of the Lower Jordan River varies between 3 to 10 Mm^3/a.

The salinity measured at Mekorot's pumping station (Gilgal station) exhibits a low chloride concentration during winter when the flow is high and the river receives freshwater from side wadis and higher chloride concentrations during summer when the flow is low and the contribution of salty water from the shallow aquifers predominates. A maximum concentration of about 6000 mg/L Cl^- was measured in summer 2008. Since then, Mekorot has stopped pumping from the river.

Turbidity varies considerably between winter and summer. During winter, a value of about 2000 NTU was measured. A low turbidity value of 150 NTU was measured during summer time. The variation in turbidity is connected to the flow discharge. Due to the high turbidity values, pre-treatment is needed in order to use the river water for desalination facilities.

As mentioned above, the potential resources of brackish water are as follows: The regional Judea/Ajlun Group aquifer in the area of the Feshcha springs as well as the Fazael area; the alluvial shallow basin-fill sediments in the Jordan Valley (Jericho and Uja region); direct pumping from the Jordan River (Figure 102).

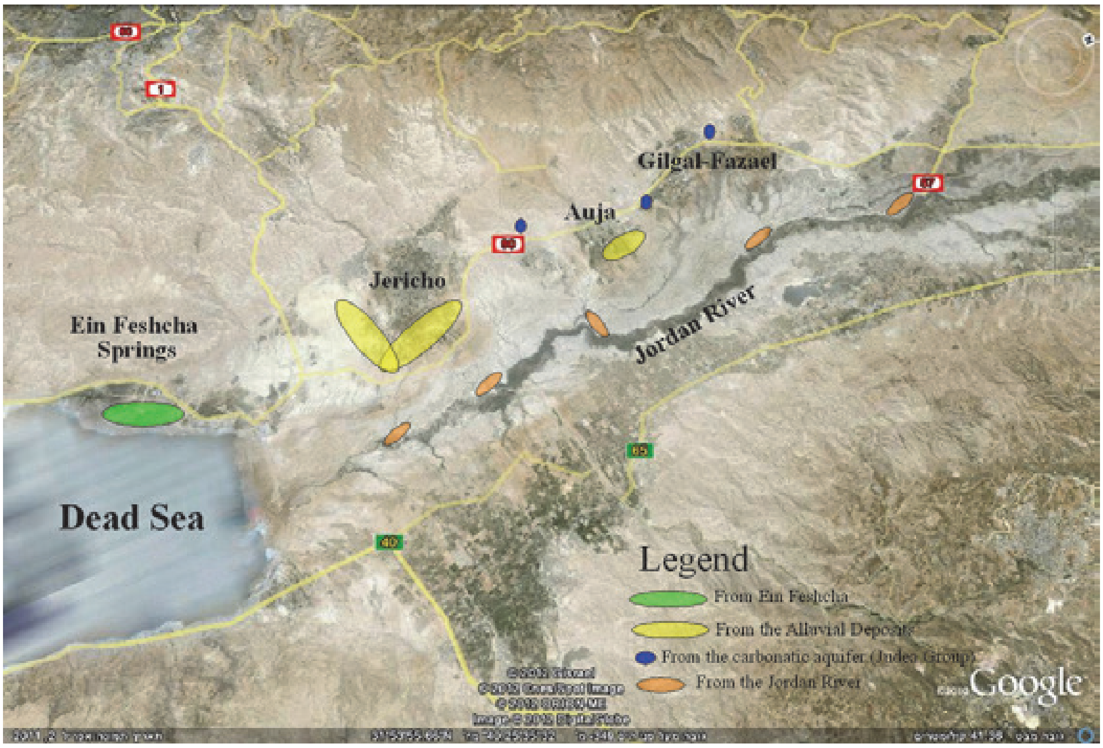


Figure 102: Location map presenting the various potential sites for utilization of the brackish water in the LJRV.

Table 30 summarizes the potential volume that can be abstracted from the suggested sources as well as preliminary recommendations for each source.

Table 30: Potential brackish water volume from the different sources.

Site	Well/station	Yearly pumping Mm³	Expected salinity mg/L
Feshcha Sp.	2	30	1,500-2,000
Jericho	5-6	4-5	1,600-2,000
Uja	2-3	1.5-2	1,600-2,000
Fazael	3	3	2,000-2,500
Jordan River	3-5	5	1,000-6,000

3.3.5.2 Major Sources and Volume of Brackish Water on the Eastern Side of the LJRV

3.3.5.2.1 Surface Water

Figure 103 shows the drainage patterns of the surface water of the JV. These drainage systems were determined by using the ARC-Hydro GIS software. The escarpments to the east and west are cut by wadis (valleys and semi-dry river basins) created by the flows which drain from the highlands into the valley floor. Wide and dramatic alluvial fans have been formed at the mouths of these wadis.

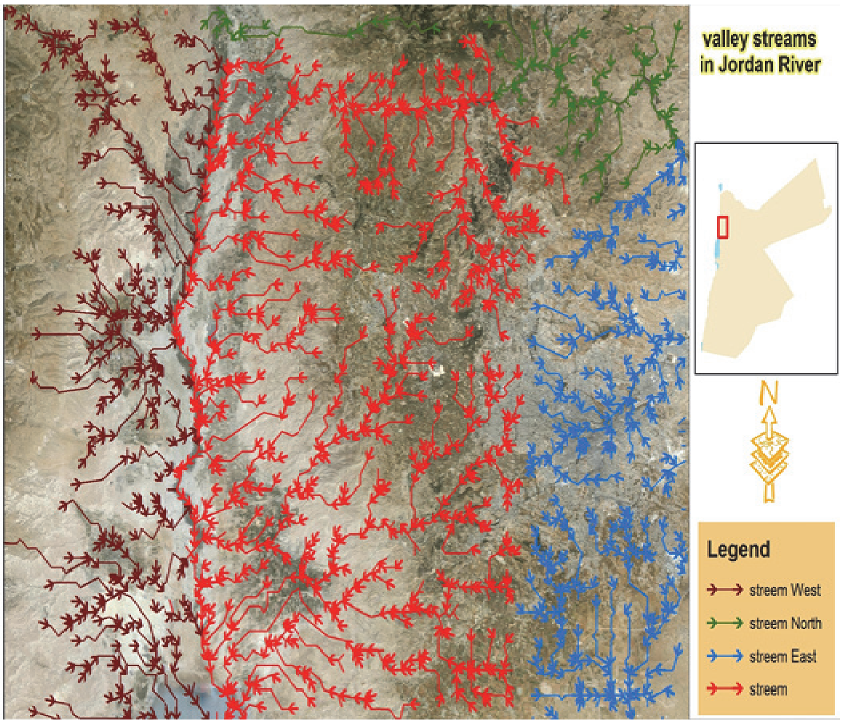


Figure 103: The drainage pattern and the catchment area along the Jordan Valley.

3.3.5.2.2 Geophysical Studies

Author: A. Al-Zoubi

Vertical Electrical Sounding

Forty five vertical electrical sounding (VES) stations were built during the last 4 years with a maximum AB/2 separation of 400 m. The collected data were interpreted with the help of partial curve matching techniques using theoretically calculated master curves. This information (layer parameters) was used to interpret the sounding data by means of a 1D inversion technique (i.e. RESIX-IP, Interpex Limited, Golden, Co.). The RESIX-IP inversion technique is an interactive, graphically oriented, forward and inverse modeling program.

An example of the interpretation of the CVES profiles is presented in Figure 104. The section clearly shows some of buried wadies, channels, faults, and saturated zones.

To study the subsurface resistivity distribution of the area, iso-resistivity maps were determined at different depths from the earth's surface. Three depth levels, i.e. 25 m, 75 m, and 100 m, were selected. Zones of different resistivity values are grouped in terms of relatively high (>80 Ohm.m), moderately high (40 to 80 Ohm.m), moderately low (15 to 40 Ohm.m), low (1 to 15 Ohm.m), and very low resistivity (< 1 Ohm.m).

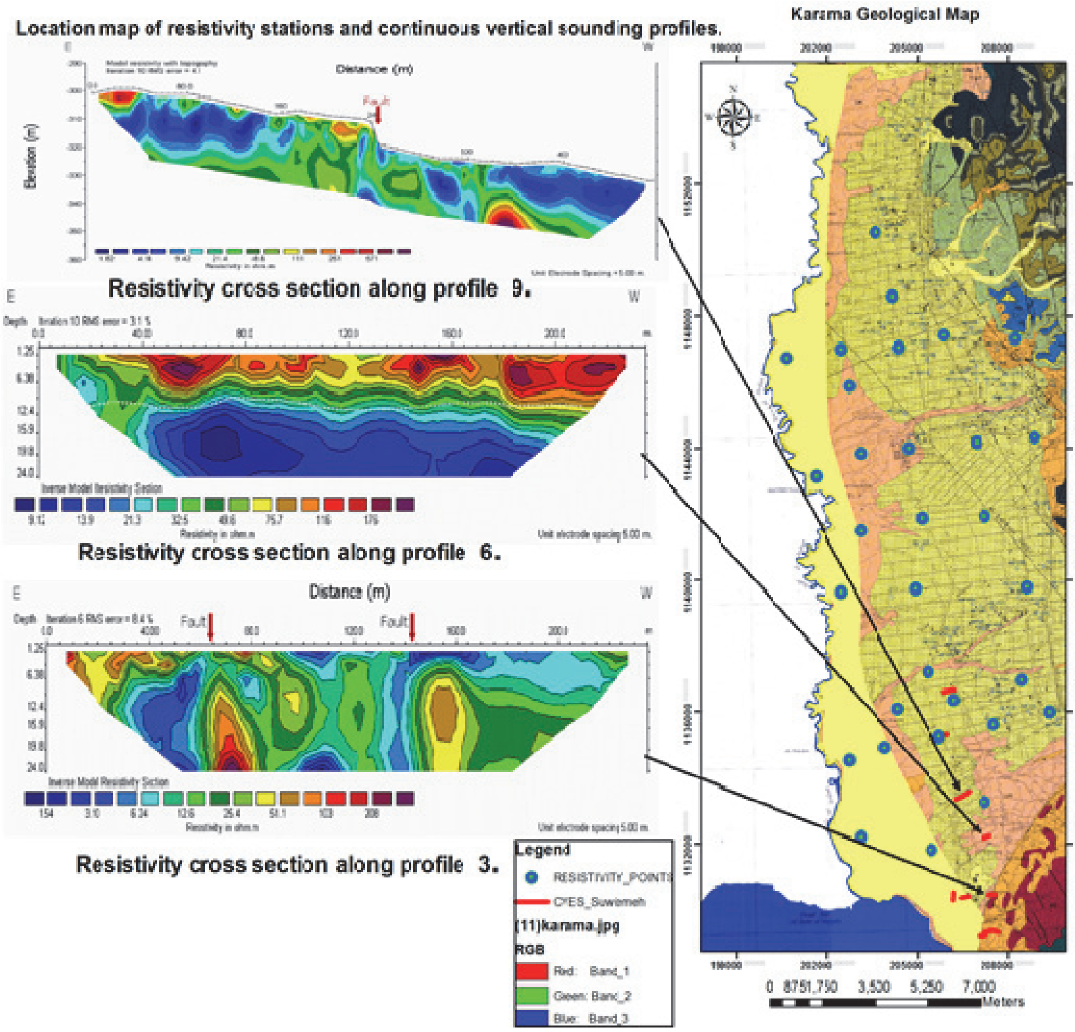


Figure 104: The CVES location map in the southern part of the JV and CVES sections.

In order to make a meaningful interpretation of conditions pertaining to the resistivity characteristics of the study areas, the relatively high resistivity was found on the eastern side of the study area along the rift shoulder. It is worth noting that in some places this zone was wider, especially in the southeastern part of the JV basin. This zone narrowed with depth. The zones of moderately high resistivity and moderately low resistivity covered the central part of the rift (Jordan side). These two zones have a width of about 6 km in the southern part of the study area and less than 2 km in central part of the JV. The wider part of these zones might be related to water seepage from Wadi Kafrein and Wadi Shueib.

The low resistivity zone and very low resistivity zone were proceeding from the northern end of the Dead Sea northwards along the Jordan River, covering the central part of the rift (Figure 105). The boundary of the above zones generally agreed with the faults cutting the study area (the area occupied by these zones became wider with depth.

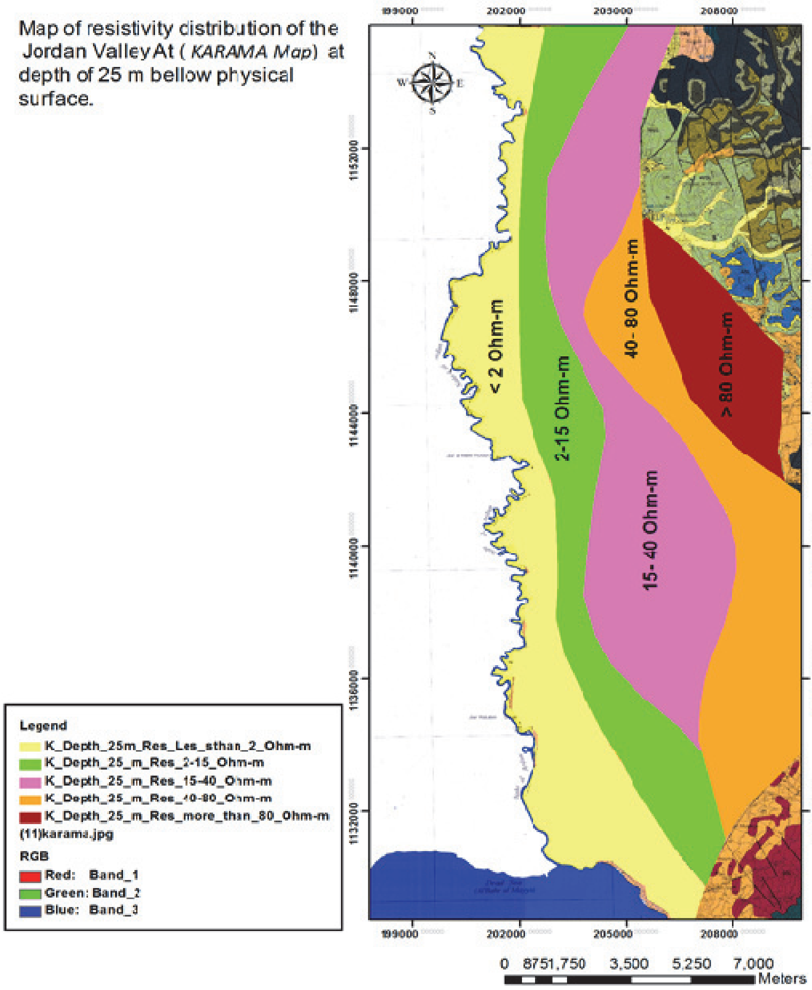


Figure 105: Resistivity distribution map at a depth of 25 m.

Ground-penetrating Radar (GPR) Results

The results of three GPR in several profiles are illustrated in Figure 106. The cross section along the profile shows an excellent example of buried channels. Figure 106 displays the water-saturated zone and the water table in the southern part of the JV basin.

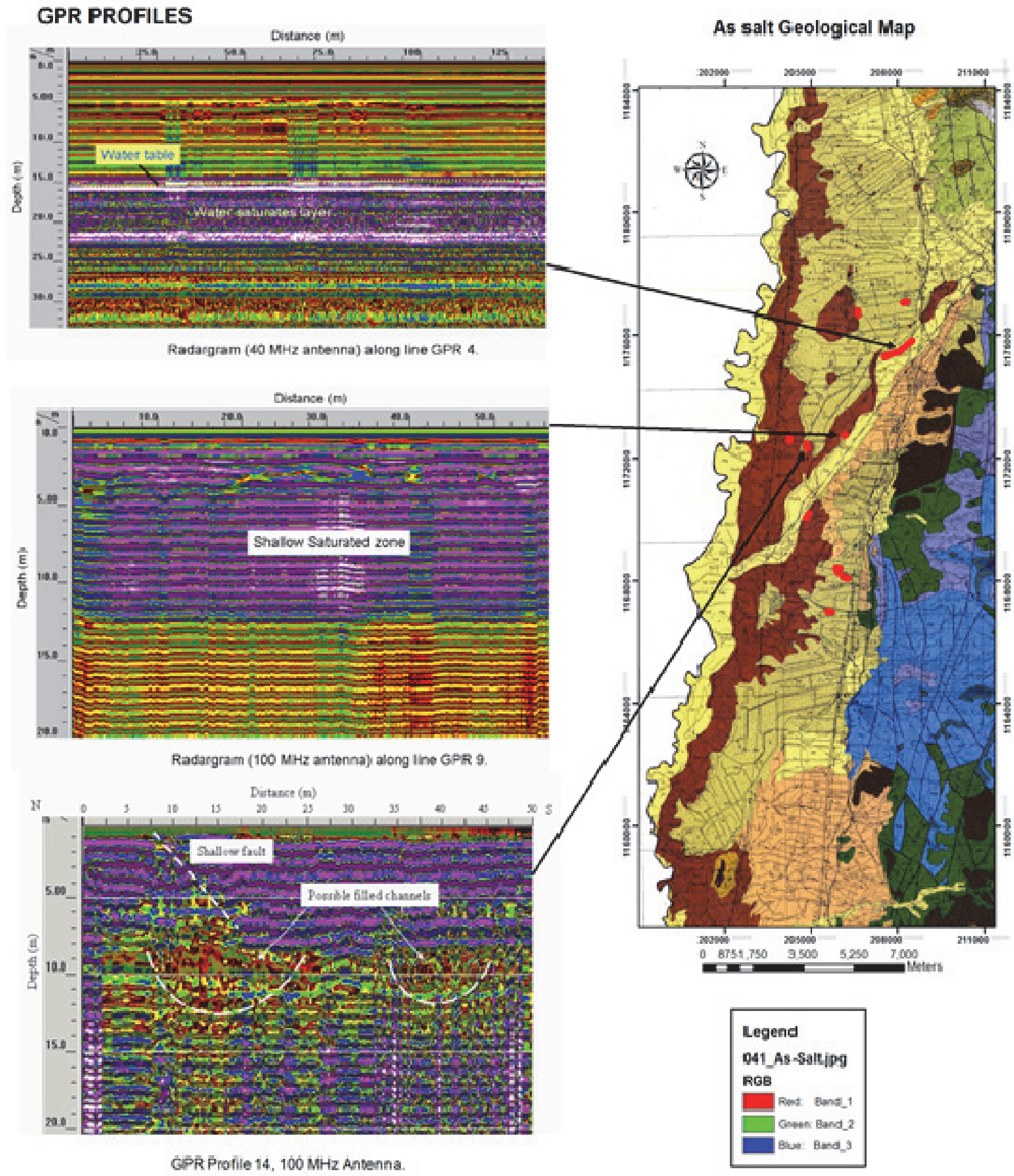


Figure 106: Location map of the GPR and three GPR profiles on the right side.

3.3.5.2.3 Locations and Estimations of Brackish Water

Two predicted locations of brackish water are shown in Figure 107. The first predicted location is located in the lower part of the Jordan valley. The area of this location is about 80,000,000 m^2 (80 km^2). saturated thickness of the aquifer ranges from 25 m depth up to 100 m, the average being about 40 m. Porosity is about 12 % (average), recovery about 1/10, and transmissivity around 100 m^2/d. The estimated quantity of brackish groundwater is about 35 to 40 Mm^3. The second predicted area is located in the middle part of the Jordan Valley in the Deir Alla area. The area of this location is about 31.5 km^2, the thickness of the saturated zone of the aquifers is about 30 m on the average. The porosity of the aquifer is around 12 %, the recovery is about 1/7 to 1/8, transmissivity 6000 (High) to 100 m^2/d (JVA). The quantity of the brackish water at this location is estimated to be about 14 to 15 Mm^3.

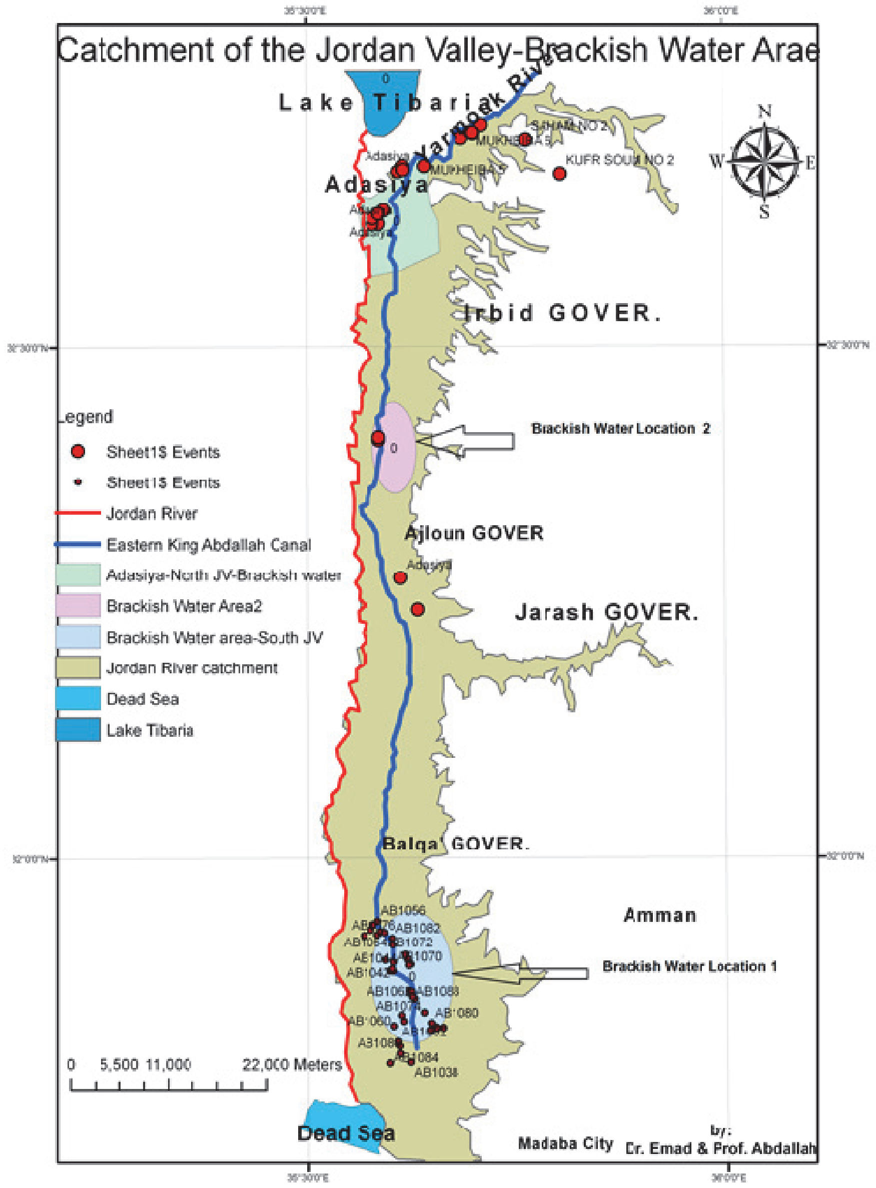


Figure 107: The locations of brackish water along the Jordan Valley.

3.3.6 Demonstration Plant (Karameh, Jordan)

3.3.6.1 Raw Water Analysis

The pilot plant experiments were to be carried out at three different sites in the LRJV. In order to select the best suitable sites, four different sampling campaigns were performed and the samples were characterized. Table 31 summarizes the main results of the water characterization.

Deir Alla

The brackish water from the sampling site "Deir Alla" represents the normal shallow aquifer water of the Twal-area region. Electrical conductivity reaches values between 5 and 8 mS/cm, principally because of the high NaCl concentration present in the samples. The brackish water samples showed fairly high silicon, strontium, and sulfate concentrations (Table 31). Severe scaling problems can be expected to result from the membrane filtration of this water. Additionally, the seasonal variation of the water quality is an important aspect to be considered for the desalination plant design.

Table 31: Water characteristics of the pre-selected sites for brackish water treatment.

Parameter		Jordan river	Deir Alla	Sweimeh	Karameh
El. conductivity	mS/cm	2.3 - 18.3	3.9-8.0	3.9 - 13.8	6.5
pH value (25 °C)		7.0 - 8.2	6.8-7.9	7.2–8.2	7.0
Ba^{2+}	mg/L	0.10 - 0.17	0.04 - 0.07	0.10	0.05
Ca^{2+}	mg/L	82 - 330	98 - 344	117 - 440	287
K^{+}	mg/L	25 - 167	61 - 94	51 - 220	78
Mg^{2+}	mg/L	79 - 490	157 - 229	78 - 444	200
Na^{+}	mg/L	345 – 1,380	456 – 1,058	475 – 1,593	767
Sr^{2+}	mg/L	2.5 - 8.6	9.2 - 25	3.6 - 5.7	3.7
Cl^{-}	mg/L	345 – 4,904	739 – 1,598	825 – 4,689	1,757
NO_3^{-}	mg/L	12 - 40.5	136 - 244	0.1 - 15.5	4.5
SO_4^{2-}	mg/L	254 – 2,085	399 – 1,388	108 - 678	336
HCO_3^{-}	mg/L	240 - 334	382 - 465	243 - 395	494
CO_3^{2-}	mg/L	0.1 - 3	0.7 - 1.9	0.5 - 1.7	0.3
Br^{-}	mg/L	20 - 48	0.5 - 4.6	2.8 - 30	24
F^{-}	mg/L	0.29 - 1.9	0.75 - 1.8	1.1 - 1.3	2.9
DOC	mg/L	5 - 7	0.9 - 1.6	0.6 - 1.1	0.7
TOC	mg/L	6 - 37	1.6 - 1.8	0.7 - 1.3	-

Karameh

The brackish water from Karameh represents anoxic shallow aquifer water, which can be influenced by (infiltrated) surface water (e.g. water used for irrigation) and untreated or poorly treated wastewater. The site was sampled only once (in January 2012, see 3.3.6.2 Site Selection). The samples showed high iron, manganese, and gases (e.g. radon, H_2S) contents. H_2S levels as low as 0.1 mg/L can adversely affect the performance of desalination systems (Dow Liquid 2005). In addition, the water in Karameh is high in divalent ions which form scaling with carbonate, sulfate, and fluoride, depending on the recovery of the system.

Jordan River (Baptism Site of Jesus)

The water from the Jordan River represents saline surface water in the Jordan Valley. Water composition shows extremely high seasonal variations. Electrical conductivity (EC) values are in the range between 2 and 20 mS/cm. As expected, the samples from the Jordan River had high DOC (Dissolved Organic Carbon) concentrations (Table 31). The treatment of Jordan River water is highly complex. Main challenges are the seasonal variation of the water quality, the anthropogenic contamination, the suspended solids, and the DOC concentration.

Sweimeh Area (Northeastern Shoreline of the Dead Sea)

The water at the „Sweimeh“ site is deep aquifer water with iron and manganese and the gases H_2S, CO_2, and radon. For membrane filtration, an extensive pre-treatment (oxidation/ aeration and flocculation) must be considered due to reductive conditions. An advantage of Sweimeh as a potential site of the pilot plant is its location near the Dead Sea. The Dead Sea can be considered an environmentally friendly alternative for high-saline brine disposal.

3.3.6.2 Site Selection

For the selection of potential sites for the brackish water treatment experiment, the following criteria were considered (Papadakis 2007):

- Freshwater scarcity (drinking water, irrigation, groundwater recharge);
- Availability and quality of brackish water sources (availability of data);
- (Basic) water infrastructure (wells, water distribution systems);
- Building/space infrastructure (accessibility);
- Electricity infrastructure (availability);
- Environmental aspects (brine treatment/discharge);
- Accessibility of the site;
- Existence of renewable energy potential.

After several discussions, the Ministry for Water and Irrigation in Amman (MWI) chose a well in Karameh in the lower Jordan Valley in December 2011. Selection of only one site allows for a long-term study to optimize the operating conditions of the plant. In the region the produced permeate water can be used best, mainly for drinking water purposes, and the concentrate can be discharged into a wadi. The raw water for the pilot plant consists of groundwater (see Table 31) and, during rainy seasons, it is a mix of groundwater, well water, and surface water. A raw water quality with low seasonal variations would be best for operating the plant.

3.3.6.3 Pilot Plant

Authors: F. Saravia (EBI), C. Schweder (SPA)

One main goal of this work package was the implementation of the desalination techniques evaluated by the Engler-Bunte Institute (EBI, KIT) in a pilot plant. The purpose was to demonstrate the feasibility of desalination of brackish water in the Lower Jordan Valley and to test modern techniques. An innovative plant which uses elaborated cutting-edge techniques to treat the challenging groundwater from the test site in Jordan was built by STULZ-PLANAQUA (SPA) in cooperation with the Engler-Bunte Institute. The plant produces about 10 m^3/h of treated water – enough to irrigate a large area or to supply a small village with drinking water. The input of well water is 16 m^3/h. Hence, the plant has a recovery rate of over 60 %.

As described in the previous chapter, the water from the well in Karameh requires special treatment. It contains relatively high concentrations of iron and manganese as well as of calcium and therefore has a high scaling potential. In addition, it contains rather low amounts of radon and hydrogen sulfide, which are still too high for a safe and comfortable usage of the water. Moreover, the bacterial load is fairly high for groundwater, which has to be taken into account as regards biofouling and hygienic issues. The concept of the water treatment plant accounted for these issues and was therefore much more elaborated than a simple desalination device. It was designed especially for the conditions at Karameh.

The final concept differed from the idea presented in the project application due to political decisions taken during the project in coordination with the Funding Agency. Only one instead of three test fields was tackled. The plant remained at the test field of Karameh for the rest of the project and probably beyond.

Apart from technical issues regarding the water treatment, the additional challenge when designing the layout was the limited space of the container-based plant and, of course, also the limited budget. This was not only due to the restricted budget of the SMARTII project. It was also aimed at showing that desalination can be economically attractive.

As energy shortage and climate change are vital issues today, special attention was paid to the energy balance of the plant. According to reports of the MWI, cost for energy is one of the main obstacles for farmers who plan to desalinate water. Hence, the components of the plant were chosen with regard to their energy consumption and a special energy recovery system as well as a solar power plant were installed. The solar power plant has an area of 42 m^2 and a nominal power of 10 kW. The expected maximum output of the energy recovery system is 3.0 kW. The average energy consumption of the plant is estimated to be 44 kW.

The Technical Concept

The core of the desalination plant is a reverse osmosis unit. It reduces the content of dissolved salts in the water and it is also a barrier for microorganisms and even viruses. However, the water from the well in Karameh needs ingenious pretreatment to guarantee the quality of the output and to reduce scaling in the reverse osmosis step. Figure 108 gives an overview of the plant's layout design. The important process steps will be discussed in more detail below.

The first step covers the elimination of radon (poisonous and radioactive) and hydrogen sulfide (poisonous). Both radon and hydrogen sulfide are gaseous at room temperature, have a higher density than air, and are a danger to human health. The concentrations in the raw water are low and the gases will be eliminated by aeration. The flat bed aerator was designed and built specially for the requirements at Karameh. To take into account the limited space of the container, it was constructed with three layers. The first two are for aeration and the last one is a settling chamber. It has a throughput of 16 m^3/h of raw water and 170 m^3/h of air.

The high concentrations of iron (14 mg/L) and manganese (0.4 mg/L) are problematic in terms of scaling in particular. In order to flocculate iron and manganese, the ions have to be oxidized. For the SMARTII water treatment plant, an innovative process was chosen: Iron and manganese are partly oxidized in the aerator, which is needed anyway for the reasons named above. Additional oxidization is carried out chemically with sodium hypochlorite. After this oxidation, the iron and manganese will mostly be precipitated. More of these ions will be flocculated with a flocculant (aluminum hydroxide solution). The remaining iron and manganese ions will be kept in solution by an antiscalant. This innovative technique with a sophisticated combination of oxidation, ultrafiltration, and antiscalant is competitive both regarding costs and space requirements.

The precipitated ions as well as particles contained in the raw water are eliminated by an ultrafiltration step (UF). The UF consists of five multi-bore dizzer modules with a 40 m^2 membrane each. The pore size is 20 nm. The filtration mode is in-out. Expected recovery is approximately 92 %.

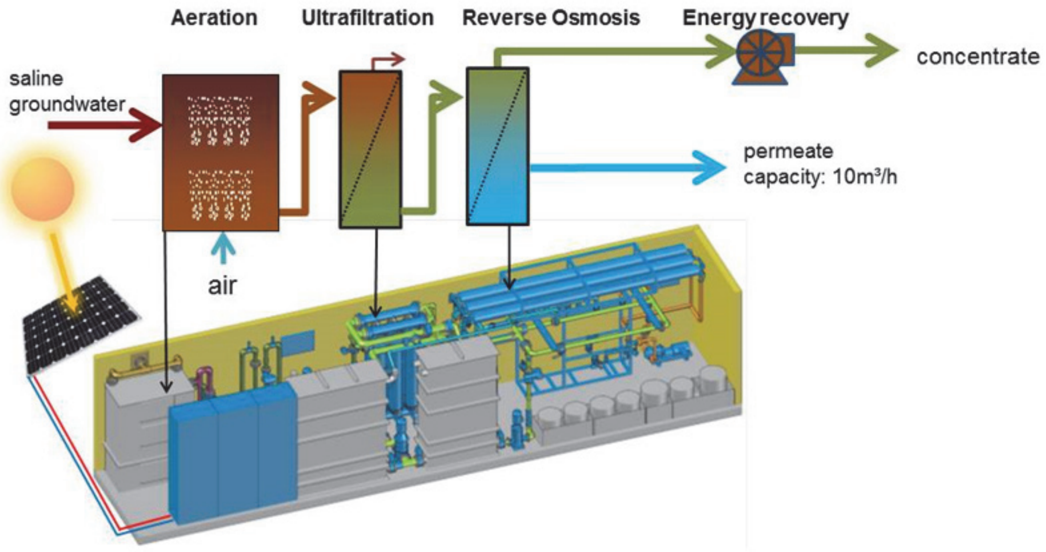


Figure 108: Layout design of the water treatment plant and 3D scheme.

The reverse osmosis unit is responsible for desalination. It contains 12 modules in 3 pressure vessels with a total membrane area of 444 m^2. The feed pressure is 13 bar and the expected recovery is 65 %. For the unit to fit into the container, the pressure vessels are installed underneath the ceiling, while the pump, valves, and measurement devices are installed on a rack at the wall.

3.3.6.4 Delivery of the Pilot Plant to Karameh and Challenges Associated with the Karameh 2 Well

In May 2013, after a test run in Bremen, the container-based water treatment plant was shipped to Jordan. Together with a second container with additional equipment. Both containers were set up in Karameh on June 16, 2013.

In July, the solar power plant was installed, which had been transported there after a test run in Bremen (Figure 109).

After finishing the construction of the infrastructure and power supply facilities and the delivery of the pump, pumping started at the end of August 2013. The pump was installed at a depth of 180 m, as this was considered to be the hydrogeologically optimal depth. However, it turned out that the quality of the well water differed significantly from the water analysis made during the pump test in January 2012, which had been used for the layout design of the water treatment plant (Table 31). The salt concentrations of the well water were up to 5 times higher than expected according to data of the year 2012. Further problems arose due to unexpected power blackouts on site, which happens fairly often. Salt concentration of the well water increased when pumping was stopped for some time. After these incidents, the clear well water was silty and brownish (Figure 110). It typically took about 30 to 60 minutes until the water was clear again.

Figure 109: Installation of the solar power plant in Karameh (photo: SPA).

Figure 110: Well water after stop and restart of the well pump (photo: SPA).

At the same time, the performance of the well pump decreased. After several weeks of troubleshooting, the Water Authority Jordan (WAJ) brought the pump up for inspection. It turned out that the pump was broken and blocked by material (sand, stones, silt) from the bottom of the well. The pump was cleaned and repaired.

In the following months work was dedicated to finding the cause of the striking difference in water quality compared to the pump test in 2012. Additional pump tests showed that the EC values were lower at 126 m depth than at 150 m depth. It was suggested that the upper aquifer has the lower salinity and, hence, the greatest potential for operation of the desalination plant.

To stop the flux from the lower, highly saline aquifer, the well was cemented at a depth of 147 m by the MWI in December 2013. Additional video scans were carried out. After the cementation, new pump tests were performed by the MWI with pump rates of 30 m^3/h and 18 m^3/h.

The results still show an influence of the pump rate, which probably means that the two aquifers are still not completely separated and the pump may suck water from the deeper aquifer as well.

However, water quality improved a little at a lower pumping rate (Table 32). This water quality was considered sufficient for the plant to go into operation, although the yield of the desalination plant would be reduced to approximately 50 %. As the chloride concentration was very high, the risk of corrosion remained. After discussion with all partners and the project coordinators, it was decided to take this risk and try the commissioning.

Table 32: Water analysis after cementation (analysis by MWI).

Parameter (unit)	Unit	Pump test on January 06, 2014, depth 126 m, pumping rate 18 m^3/h
EC	mS/cm	11.6
Temperature	°C	30
pH	-	6.5
HCO_3^-	mg/L	350
Cl^-	mg/L	3,807
SO_4^{2-}	mg/L	216
Na^+	mg/L	1,478
Mg^{2+}	mg/L	382
Ca^{2+}	mg/L	505
$Fe^{2+/3+}$	mg/L	1.4
Mn^{2+}	mg/L	0.05
Ba^{2+}	mg/L	0.08
Sr^{2+}	mg/L	9.71
SiO_2	mg/L	16
Br^-	mg/L	61.4
F^-	mg/L	1.1

3.3.6.5 Commissioning

In March 2014 the plant successfully went into operation (Figure 111). The yield was approximately 50 %. After ultrafiltration, the contents of iron and manganese were below the detection limit of the field tests. So far, all treatment steps have worked very well.

The quality of the well water still varies strongly, especially after pump stops. This issue needs to be solved for a stable operation of the plant.

The staff of the WAJ was trained extensively and was instructed how to run the plant and how to do troubleshooting.

After 4 weeks of operation, no major signs of corrosion were found. The plant was handed over to officially the WAJ on April 6, 2014.

Figure 111: Pilot plant (interior of the container) in Karameh.

3.3.6.6 Remarks

Although the plant was designed for 24 hours of operation, there is usually no need for a full-time operator. Reverse osmosis plants similar to the plant in Karameh are not made to be turned on/off frequently. If the plant is turned off for several hours or longer, it must be rinsed with freshwater or treated water. Otherwise, the brine remains in the membrane modules and in the pipes. Salt crystals and fouling layers will be formed and will block the plant components. For this reason, it is highly recommended to operate the plant on a 24 h per day basis and switch it off for maintenance, etc. only.

One of the most important environmental issues of desalination is the generation of the saline “by-product” brine. The concentrate has not only a high content of salts, but also contains residual chemicals (such as antiscalants and cleaning chemicals). The treatment or disposal of brine is one of the drawbacks of the application of membranes in inland desalination, but it was beyond the scope of the project. This topic will have to be investigated in in future studies to reach environmentally acceptable solutions.

3.3.7 Application of Nanofiltration in Palestine

The studies in Palestine focused on two main areas (Jericho and Uja) in the western part of the JV. From these two areas, more than 50 water samples were characterized. According to the water data, application of nanofiltration (NF) membranes to treat the brackish water sources appeared possible and was investigated. NF represents an interesting alternative to RO. NF membranes can be used for a partial demineralization of the brackish water sources (water production without the need of re-mineralization) at relatively low pressures and high water fluxes. The main interest in NF applications is to achieve a partial demineralization of the brackish water at low cost.

The characterization of the brackish water samples revealed a range of electrical conductivity values between 0.9 and 8 mS/cm with an average of about 3.2 mS/cm. Sodium concentration showed an average value of 413 mg/L, with a maximum of 1324 mg/L and a minimum of 300 mg/L. Organic matter concentration measured as TOC was low, ranging from < 0.1 to 0.9 mg/L. Considering the concentration of salts and the organic concentration, NF was found to be an option for the treatment of this raw water.

3.4.1.1 Application of Nanofiltration

On the basis of the water characterization data, 5 commercially available NF membranes were chosen for the membrane experiments: NF90 and NF270 (Filmtech, Dow Chemicals), UTC60 (Toray), DL-NF, and DK-NF (Desal, GE).

Experiments with the different NF membranes showed huge differences in their rejection properties. As expected, all NF membranes offered high rejection for divalent ions: Calcium rejection was between 75 and 99 % and sulfate rejection ranged between 96 and 99.5 %. The main difference between the membranes was observed in the rejection of monovalent ions (see Figure 112). The NF90 membranes showed the highest sodium and chloride rejection (70 % and 80 %, respectively). The other membranes reached Na+ rejection values smaller than 25 % and Cl- rejection values smaller than 45 %.

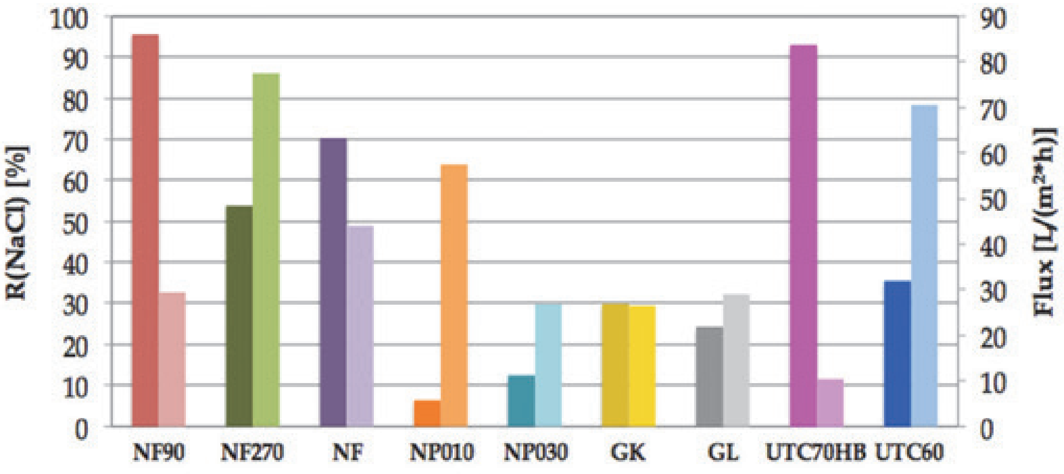


Figure 112: NaCl rejection (dark) and flux (light) of all membranes tested (p = 10 bar, T = 25 °C, c_0 (NaCl) = 50 mmol/L).

Most NF membranes are charged and the retentions of the NF membranes are influenced by the interaction between the membrane surface charge and the charged components of the raw water, the size, and the diffusivity of the solutes.

Comparison of the permeabilities of the membranes showed that NF270 has the highest clean water permeability (13 L/(hm^{2}bar), water flux (10 bar) = 75 L/(hm^2)). The membrane with the highest rejection performance (NF90) has a relatively high clean water permeability of about 6.8 L/(hm^{2}bar) (water flux (10 bar) = 30 L/(hm^2). The main advantage of high water permeability is that the required feed pressure to achieve a specific flux is lower and, thus, energy can be saved.

3.3.7.1 Salt Retention in the Treatment of Natural Water

Experiments with natural brackish water were carried out using natural water from a highly mineralized thermal well in Baden-Baden (Germany).

Concentrations of different ion species in natural brackish water, in membrane permeates of NF90, NF270, and NF, and in tap water from Karlsruhe (Germany) are summarized in Table 33. The tap water serves as a standard for potable water for subsequent comparison with the permeates. NF90 retains all ions by more than 95 %, which is similar to reverse osmosis membranes. The produced water contains slightly more monovalent ions than tap water, but concentrations are below the limit values given in the German Drinking Water Directive (GDWD) (TrinkwV 2001). It also complies with guidelines for desalinated water in Jordan, limiting TDS to 200 mg/L (Batarseh 2006). Nearly complete removal of monovalent and especially divalent ion species makes remineralization of the product water necessary.

NF270 and NF membranes lowered the divalent ion concentrations to a larger extent. By both membranes, about 98 % of sulfate was removed from the raw water, whereas a medium calcium and magnesium retention was reached, as is visible in Table 5. Retentions of sodium, potassium, and chloride by NF range between 40 % and 50 %. Although the resulting concentrations are far higher than the concentrations in tap water, the permeate conductivity (2515 µS/cm) is below the GDWD limit value of 2790 µS/cm. NF270 allows for a monovalent ion retention between 18 % and 26 %. Permeate conductivity is 3465 µS/cm, which is higher than allowed in GDWD. With a TDS of 1301 mg/L, it still complies with Jordanian limit values for tap water (TDS = 500 to 1500 mg/L) (Batarseh 2006).

Table 33: Salt concentrations in brackish water (Baden-Baden, BB), in membrane permeates (MP), and in tap water (Karlsruhe).

Ion species mg/L	Feed 5 (BB)	NF90 (MP)	NF270 (MP)	NF (MP)	Tap water
Na^+	775.6	35.2	615.5	439.7	11.4
K^+	70.5	3.4	52.6	37.2	2.0
Ca^{2+}	110.0	1.9	65.5	36.8	118.0
Mg^{2+}	3.5	0.1	1.3	0.7	10.5
Cl^-	1,350.5	58.8	1,099.3	782.5	22.7
SO_4^{2-}	202.6	1.8	4.7	4.1	55.1

3.3.7.2 Conclusions

The use of NF filtration for desalination of low-salinity brackish water sources has two main advantages: High permeability and, thus, lower operating costs in comparison to RO. Commercially available NF membranes had very different retention properties and permeability values. The NF90 membrane reached the highest rejection and a relatively high permeability and seems to be appropriate for desalination processes of low-salinity waters (salt concentration < 3 g/L, also dependent on the concentration of the individual ions) similar to the raw water sources characterized by this study.

Main disadvantages to be considered when applying NF membranes are the influence of the water matrix on the rejection properties of the membranes and the limitation of the total recovery of the desalination plant.

3.3.8 Legal Situation

Israel

In Israel the Ministry of Environmental Protection encourages the construction of desalination plants, as desalination is considered an important national goal and a suitable solution for protecting and preserving the marine and coastal environment.

The marine environmental policy and regulations are based on the requirements of the Ministry of Environmental Protection (2002), fehlt in der Lit.Liste the National Master Plan for Desalination of Seawater, 34B3 (2004) fehlt in der Lit._Liste, the precautionary principle, and the acquired experience during the last years since the start of operation of the first and the largest desalination plant in Ashkelon (Safrai and Zask 2006).

Brackish water desalination plants produce different types of discharge: a. Concentrated brine and additives, such as antiscalants, coagulants, membrane preservative (sodium bi-sulfite), b. Pretreatment and post-treatment backwash water: Concentrated wastes (suspended solids, turbidity, iron oxides), c. Cleaning solutions for membranes and pretreatment.

The environmental requirements to be met by desalination plants are based on the legislation and the environmental policy of the year 2002. It was outlined that the construction of seawater desalination plants will be accompanied by an environmental document prepared on the basis of the National Master Plan 34B3 (Appendix 1) and specific guidelines of the Marine and Coastal Environment Division. In case of brackish water desalination plants with a new constructed outfall, preparation of an environmental document will be required. The main marine environmental aspects that need to be considered are (Safrai and Zask 2006) marine outfall, the marine monitoring program, and discharge composition.

Jordan

In Jordan regulations about brackish water can be found in the “Instructions and terms of use of treated wastewater, salt water, brackish water for agricultural uses No. 4 for the year 2004”. Article 2 classifies brackish water into two groups according to salt concentration:

- Intermediate-salinity water (2,000 to 7,000) mg/L;
- High-salinity water (7,000 to 10,000) mg/L.

The transfer of brackish water from one area to another for crop irrigation purposes must be avoided. However, transfer to fish, animals, or poultry farming or for the purposes of scientific research and experiments by official scientific institutions is permitted.

3.4.2 Summary, Conclusions, and Recommendations

Access to freshwater is becoming a critical issue in many areas of the world. Contributions to solving the freshwater problem, to reducing over-exploitation of water sources (such as groundwater), and to decreasing the impacts of climate change and extreme weather need to consider alternative water sources, such as wastewater and brackish water.

The Low Jordan Rift Valley has relatively high quantities of non-exploited brackish water sources, which can be treated to generate freshwater. They can be found in the shallow and deep aquifers, mostly coexisting with freshwater.

From the technical point of view, membrane filtration is a promising option for brackish water treatment and freshwater supply. Reverse osmosis systems were improved during the last decade, resulting in the development of high-performance membranes which require less pressure and less energy. Modern membranes also have better rejection properties and larger fluxes, longer lifetimes, and lower cost. Additionally, the application of energy recovery systems and the use of renewable energy sources contribute to the propagation of membrane technologies in countries with non-fossil energy sources.

The calculation of “desalination costs” must not only consider membrane and water pre-treatment costs, but also the costs for the water post-treatment as permeate water. The permeate normally has a low ion content and can be aggressive to water distribution systems. In addition, general water supply issues, water transport, (raw) water production, proximity to existing water pretreatment infrastructure, environmental issues (noise, air pollution), and waste disposal and/or treatment (e.g. brine) have to be considered.

The application of membranes for desalination involves many important issues that must be taken into account:

1. Investment and operation costs: Although membranes and membrane systems were improved in the past years, the high pressure required for reverse osmosis desalination implies higher energy and capital costs.
2. Requirement of maintenance and trained operators: Reverse osmosis is an advanced technology. Maintenance and correct operation are key factor for ensuring the good performance of the desalination system.
3. Scaling and fouling: Membranes for desalination purposes are subject to fouling and scaling processes, which lead to a reduction of the membrane performance, decrease of membrane module lifetime, and increase of energyconsumption. Adequate saline water pre-treatment minimizes this problem.
4. Brine and waste disposal from brackish water treatment plants: One of the most important environmental issues of desalination is the generation of the saline “by-product” brine. The concentrate contains not only a high concentration of salts, but also residual chemicals (such as antiscalants and cleaning chemicals). The treatment or disposal of brine is one of the drawbacks of the application of membranes for inland desalination, and it requires innovative approaches.

Although membrane technologies nowadays are the best choice for desalination due to the lower energy consumption, thermal desalination systems that use the waste heat from power stations represent a potential option for the desalination of saline water sources at competitive costs. However, membrane systems generally are the best option when waste energy is not available.

The scarcity of freshwater, the availability of large volumes of unused brackish water resources, the existence of renewable energy sources, and the geographical location makes the LJRV a high-potential region for cost-efficient membrane-based desalination technologies. However, the application of membrane technologies should not be considered a separate solution, but be part of an IWRM (Integrated Water Resources Management) approach, which includes freshwater use and availability, wastewater treatment, and water reuse. Education, socio-economic evaluation, quantification of a regional water balance, and last, but not least, the acceptance of the new concepts by the broad population must be achieved to guarantee sustainability.

3.4 Water Resources Protection

Involved Institutions: KIT, MEK, GU, JUA, ATEEC, MWI, PHG, PWA, QUDS, TAU, MEK, BALQ, TZW

Spokesmen WP5: N. Goldscheider (KIT), Y. Guttman (MEK)

Compiled by: M. Zemann, F. Grimmeisen, N. Goldscheider, Y. Guttman

3.4.1 Introduction

Author: N. Goldscheider

The protection of freshwater for human use and ecosystems requires a holistic approach, encompassing surface water and groundwater resources in terms of both quality and quantity. Agriculture often is the largest freshwater consumer, while drinking water requires the safest quality and should be assigned first priority. This applies particularly to arid and semi-arid regions with a high population density and extensive agriculture, such as the Lower Jordan Valley (LJV). In this and many other regions of the world, groundwater is the most important freshwater resource by volume and the preferred source of drinking water, with several advantages compared to surface water. The provision of safe drinking water requires a multi-barrier approach, including the following elements:

- General reduction of polluting activities;
- Implementation and enforcement of appropriate protection zones;
- Continuous monitoring of water quality and contamination problems;
- Adapted drinking water treatment.

All of these elements were addressed within the framework of the SMART project. For instance, decentralized wastewater treatment (WP 3.1) contributes to the general reduction of contaminant releases into the environment. WP 5 addressed the following main activities:

- A detailed evaluation of water quality and trace contaminants in the Lower Jordan Valley and side wadis, with a focus on wastewater impacts on groundwater resources.
- Evaluation of chemical and biological surface water quality, including the development of a bioindicator approach using aquatic invertebrates, which is specifically adapted to the LJV region.
- The development and initial implementation of continuous monitoring techniques at a karst spring in Jordan that is connected to the regional drinking water network.
- The advancement of groundwater protection zoning concepts, with initial implementation in the Palestine territories, including a socio-economic assessment.

3.4.2 Evaluation of Contamination Problems in the Eastern Jordan Valley based on Pharmaceuticals in the Water Cycle

Authors: M. Zemann, L. Wolf, A. Sawarieh, N. Seder, A. Tiehm

3.4.2.1 Occurrence, Pathways, and Risks of Xenobiotics in the Environment

Occurrence of pharmaceuticals in the environment gained scientific and public attention in the last years, as their residues and metabolites had been detected in all aquatic compartments. Although those substances appear in trace concentrations, there are concerns that they may have effects on long-term low dosage or that mixtures of different substances may possibly be toxic and have interactive or synergetic effects (Jekel et al. 2006). Their uptake in plants (Herklotz et al. 2010) and aquatic organisms (Meredith-Williams et al. 2012) has already been verified. Negative effects on different animals have been reported, such as vulture disease by diclofenac in India (Taggart et al. 2007) and Africa (Naidoo et al. 2009) or changes in the social behavior of perches by psychotropic drugs (Brodin et al. 2013).

Most pharmaceuticals were, after consumption or disposal, released into the sewer system or into septic tanks. As a lot of those substances are rather persistent to microbiological degradation, they are not reduced when passing a WWTP and later released into streams and further into the groundwater after bank infiltration. Infiltration of treated wastewater in agriculture during irrigation as well as leaking sewers might introduce them directly into the groundwater (Klinger 2007; Wolf et al. 2012). Independent of their entry pathway, all those substances bear the same characteristic of not occurring naturally. Hence, any detection of a single substance can be related directly to an anthropogenic impact. Due to this uniqueness and the special entry pathways into the aquatic environment, they can be used both as tracers and indicators of water quality.

The occurrence of several organic trace substances, such as emerging pollutants or pharmaceuticals, in the local water sources is a well-known fact and was first described for the Lower Jordan Valley by different authors like Tiehm et al. (2012) or Wolf et al. (2009). The removal capacity from 3 local WWTP and the release concentrations from 2 hospitals in Amman were described for 4 pharmaceuticals by Alahmad et al. (2010). The effluent concentrations were reported to range between 36 – 44 µg/l for diclofenac and 30 – 49 µg/l for Ibuprofen at Al Seir WWTP, from which water is released into the Kafrein dam (Alahmad et al. 2010).

3.4.2.2 Water Quality Assessment

The water quality in groundwater, surface water, and wastewater treatment effluents was assessed by 4 sampling campaigns between 2008 and 2012. The main focus was placed on 25 xenobiotics, including 16 pharmaceuticals and 9 iodinated X-ray contrast media, but also on physicochemical parameters (EC, redox, temperature, oxygen). In addition, ions and coliforms were measured. A total of 127 individual samples were taken from representative locations, reflecting the flow paths of contamination from source to sink. In the Wadi Shueib a total of 10 different sites were selected together with three sites in Wadi Kafrein and 21 sites in the Jordan Valley. The number of detected substances at each location from 2008 until 2012 is given in Figure 113. As the contamination composition is highly variable in time and pharmaceutical compounds especially in the surface water and the effluent of the local WWTPs, the number of detected substances (detections) at each sampling location was considered to be an indicator of the degree of pollution.

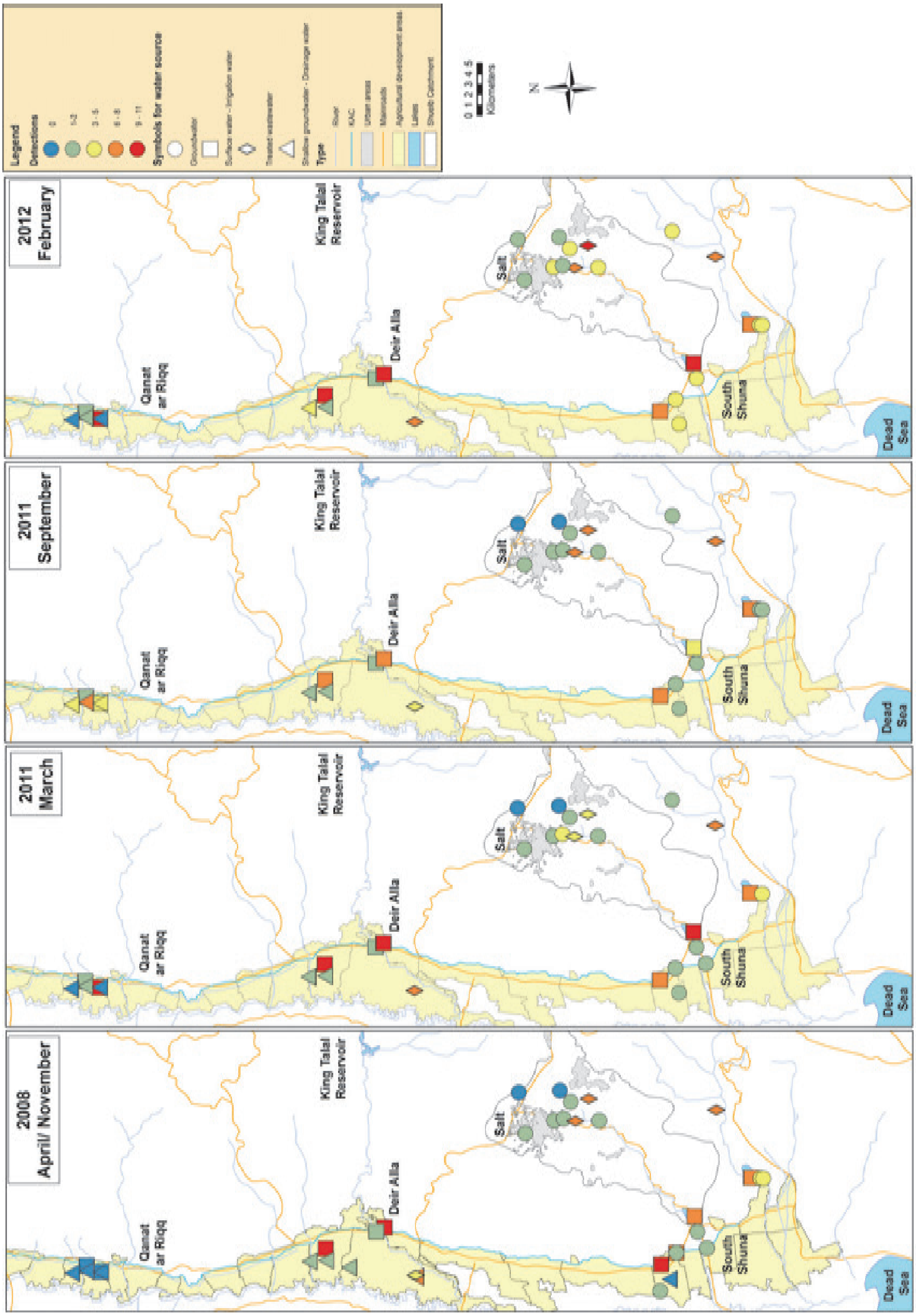


Figure 113: Number of pharmaceutical substances detected during water quality analysis between 2008 and 2012 (Zemann et al., 2014).

3.4.2.2.1 Pharmaceutical Groundwater Contamination in Urban-influenced Areas: Case Study of Wadi Shueib/Kafrein

3.4.2.2.2 Local introduction

Around 130,000 inhabitants are living mainly in the upper part of the Wadi Shueib in the cities of As Salt and Fuheis. Four springs (Azraq, Baqqouria, Hazzir, and Shoreia) and two wells (Yesidia, Um Attija) are the basis of water supply in the cities and villages in the Wadi Shueib. All water is purified at the Shoreia spring treatment plant before it supplied to the customers (Margane et al. 2009). Additional water is supplied by transfer and treatment from the Jordan Valley. The investigated area is drained by a dense stream net, with the Wadi Shueib acting as a receiving stream for the entire area and discharging in the Wadi Shueib dam reservoir at the southwestern outlet of the Wadi area towards the Jordan Valley (Werz 2006). Two wastewater treatment plants in Fuheis and As Salt release their effluents into the stream as well. The geological condition in the whole area mainly is determined by outcropping karstified limestone. The groundwater in the whole area is therefore highly vulnerable to anthropogenic hazards (Werz 2006). The main catchment of the Hazzir and Shoreia spring groundwater contribution zone lies directly within the urban areas of the city As Salt. The zone for Baqqouria is located downstream of the city. The zone of Azraq spring is located upstream of Fuheis. Yesidia well is located upstream of and Um Attija well inside the city of As Salt. Although the sewer network inside the city is in good conditions with few breakages and leakages, a lot of people still use septic tanks to avoid paying the costs of a sewage connection. As costs for suction trucks are expensive as well, permeable bottoms and overflowing pits are common rather than an exception (Margane et al. 2009). Consequently, a lot of wastewater enters the underground untreated.

Wadi Kafrein is adjacent to Wadi Shueib in the south with similar geographic conditions. A suburb of the capital Amman conveys its wastewater to the Es Sir WWTP, from where it is discharged into the Wadi stream and later stored in the Kafrein reservoir until irrigation in the JV. A medical center in the area is discharging its wastewater to this WWTP as well.

3.4.2.2.3 Water Quality in the Wadi Shueib/Kafrein

While the effluents of the WWTP and the reservoir showed a wider range of different substances (up to 11 different), the two X-ray contrast media diatrizoic acid and iopamidol were the only substances which could be detected regularly in the springs and wells (see Table 34). Compared to other studies in urban areas (Wolf et al. 2012), those concentrations are much more frequent. Detections rates for iopamidol were higher by a factor of ten. Ibuprofen and fenofibrate only occurred in February 2012. Chlofibric acid, fenoprofene, fenofibric acid, etofibrate, indomethacin, pentoxifyllin, phenacetin, iodipamid, iothalamic acid, ioxaglic acid, and ioxithalamic acid were never detected in GW, SW, or TWW.

Table 34: Occurrence of pharmaceuticals and x-ray contrast media in groundwater (GW), surface water (SW) and treated wastewater (TWW) in the Wadi Shueib/Kafrein. The LOD for ground- and surface water is 10 ng/l for x-ray contrast media and 50 ng/l for the pharmaceuticals, and 50 ng/l each in TWW.

Substance	Samples above LOD			Median concentration of samples above LOD			Maximum Concentrations		
	GW	SW	TWW	GW	SW	TWW	GW	SW	TWW
	[%]	[%]	[%]	[ng/l]	[ng/l]	[ng/l]	[ng/l]	[ng/l]	[ng/l]
Amidotrizoesäure	74	75	25	51	110	115	220	270	300
Iopamidol	39	88	100	69	1600	2275	1900	78000	680000
Ibuprofen	17	38	67	56	250	168	65	430	750
Fenofibrat	8	0	0	110			130		
Iohexol	6	63	67	19	95	163	27	1600	9000
Carbamazepin	0	100	83		275	2050		1200	7900
Gemfibrozil	0	100	67		225	408		510	4800
Iopromid	0	88	92		130	155		4500	280000
Iomeprol	0	63	75		170	290	0	5300	360000
Bezafibrat	0	25	58		56	87		89	480
Diclofenac	0	25	17		117	218		140	240
Naproxen	0	13	8		69	95		69	95
Ketoprofen	0	0	17			63			64
Diazepam	0	0	8			720			720
total number of samples	24	8	12	24	8	12	24	8	12

The total number of substances detected in Wadi Shueib each year (Table 35) shows no significant trends for TWW and SW. the values remain on a high level between 6 and eight pharmaceuticals per sample. This might reflect the highly variable composition of these water sources. The substances in SW mostly reflect the same spectrum than the TWW. In contrast to this, detection rates in GW increased from 2008 until 2012, which was mostly due to increasing iopamidol findings (see Zemann et al. 2015).

Table 35: Number of detected pharmaceuticals in Wadi Shueib water resources

	number of samples	2008 Nov	2011 May	2011 Nov	2012 Feb
TWW	3	21	18	19	24
SW	2	12	14	11	17
GW	8 (7*)	6	10	10	18

A comparison of pharmaceutical detections (Figure 114) with other typical contaminants occurring in wastewater (nitrate or E. coli) reveals the correlation between rising nitrate and E. coli concentrations and increasing (2-3) pharmaceutical detections. The blue and yellow points are mainly related to springs and wells located upstream of and sideways to the cities, while the orange and red ones are mainly inside and downstream of the city areas.

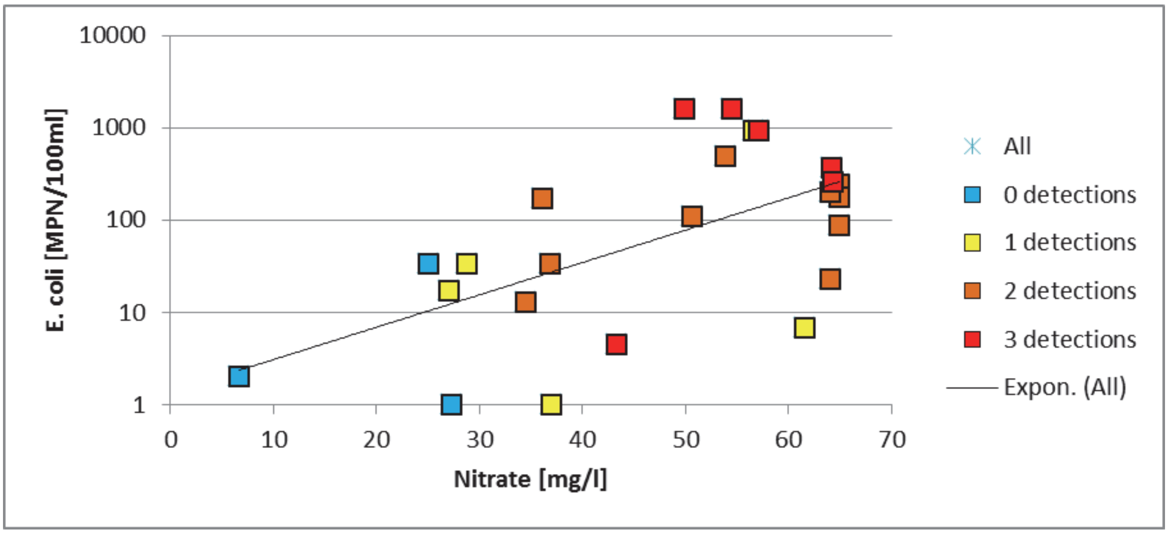


Figure 114: Correlation of nitrate, E. coli, and number of pharmaceutical detections for all GW samples from 2011 – 2012 (Zemann et al., 2015)

3.4.2.2.4 Conclusions

All springs and wells downstream of or inside the city area are contaminated with pharmaceuticals. The rates were found to increase from 2008 – 2012, especially for iopamidol. Total numbers of detected substances (e.g. X-ray contrast media) were high compared to other studies. The occurrence of pharmaceuticals is obviously linked to other wastewater contaminants like nitrate and E. coli, the detection numbers correlating strongly with the spring location and its position in the Wadi. The results, on the one hand, reflect the benefit of pharmaceuticals as contamination indicators, but, on the other hand, they also show the increasing influence of the urban area on the aquifer and the deterioration of the water quality. However, it must be stated that drinking water quality in the area is sufficient. Due to mixing of different springs and UV treatment, the limits for nitrate and E. coli in drinking water according to the Jordanian standard (JS 286) were met.

3.4.2.3 Pharmaceutical Groundwater Contamination in Agriculturally Influenced Areas: Case Study of the Eastern Part of the Lower Jordan Valley

3.4.2.3.1 Local Introduction

The local water cycle in the Jordan Valley is driven by high temperatures, high evaporation rates, use of treated wastewater for irrigation, and a very short-circuited reuse of the local groundwater. The irrigation water is brought by the King Abdallah Channel (KAC) starting from the river Yarmouk close to the Syrian border in the north to the Dead Sea (DS) in the south. The KAC runs parallel to the Jordan River with a total length of 110 km. Along the KAC, the water is pumped at several turnout stations (T.O.) into the development areas (DA), where it is diverted to the single farm units (FU) for irrigation on the agriculture areas. Water from several dams, catching treated wastewater from the highland settlements, the base flow, and flash floods of the Wadis along the eastern escarpment, is led into the channel (see Figure 115). As a result, water quality decreases continuously until Deir Allah (Alkhoury et al. 2010). The main share of TWW enters the middle part of the Channel from the King Talal Reservoir (KTR), into which the wastewater of the capital Amman is released after treatment. Shortly before this inflow, around 90 MCM/y of water are pumped back to Amman, where it is treated and then used to cover the demand for drinking water. After this diversion, the share of TWW in the channel ranges between 50 – 70 % (JVA) and is qualified as “blended water”. The groundwater in the lower Jordan Valley is mostly found in the quaternary deposits. As there is hardly any precipitation, especially in the southern parts, the main share of groundwater recharge is supposed to originate from irrigation water. In addition, a lot of farmers operate their own, mostly illegal wells in the shallow aquifer to extract extra groundwater for irrigation. They recycle the replenished TWW, which may keep any contaminant longer in the system or even leads to accumulation due to the high evaporation losses in agriculture.

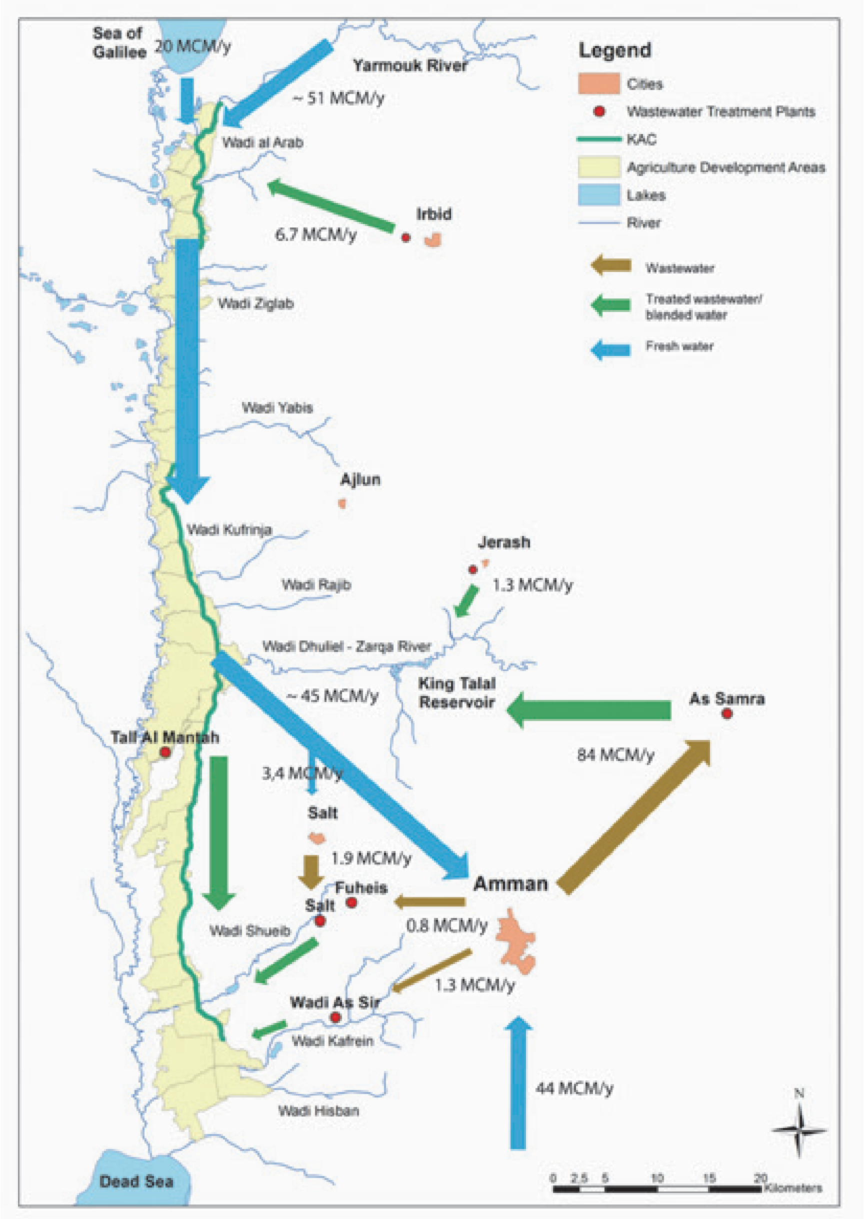


Figure 115: Main water fluxes in the Lower Jordan Valley 2010 (data source: MWI)

3.4.2.3.2 Water Quality in the Lower Jordan Valley

Nine substances were detected in the GW of the JV (compare Table 36) with most frequent detection of diatrizoic acid (74 %) and iopamidol (42 %). These findings are similar to the findings in

Wadi Shueib. Compared to a study of 105 wells in Germany (Sacher et al. 2001), where diatrizoic acid was found in 20 % and iopamidol was found in 4.7 % of the samples, the detection rates of X-ray contrast media were more frequent. Of all substances found in the JV, only carbamacepine, ibuprofen, and fenoprofene do not belong to the class of X-ray contrast media. Except for diatrizoic acid and fenofibrate, all other substances occurred more often in surface water than in groundwater.

Table 36: Occurrence of pharmaceuticals and X-ray contrast media in groundwater (GW), surface water (SW), and treated wastewater (TWW) in the Jordan Valley. The LOD for groundwater and surface water is 10 ng/l for X-ray contrast media, 50 ng/l for the pharmaceuticals, and 50 ng/l each in TWW.

Substances	Samples above LOD			Median concentration of samples above LOD			Maximum concentration		
	GW	SW	TWW	GW	SW	TWW	GW	SW	TWW
	[%]	[%]	[%]	[ng/l]	[ng/l]	[ng/l]	[ng/l]	[ng/l]	[ng/l]
Diatricoic acid	75	42	0	120	140		940	850	
Iopamidol	42	79	100	59	1,300	3,950	36,000	78,000	33,000
Iopromide	19	67	75	24	660	876	250	4,500	1,700
Iomeprol	11	58	0	39	2,700		790	6,900	
Carbamazepine	8	58	75	74	900	7150	500	2,100	17,000
Iohexol	8	67	25	31	620	130	180	1600	130
Ibuprofen	6	38	75	56	80	280	59	430	340
Fenofibrate	3	0	0	74		260	74		260
Iotalaminc acid	3	8	25	10	21	42	10	23	42
Bezafibrate	0	13	25		89	91		120	91
Clofibric acid	0	8	0		32			33	
Diclofenac	0	8	50		78	350		140	430
Etofibrate	0	0	25						0
Gemfibrozil	0	50	25		270	100		2,100	100
Naproxen	0	13	0		70			82	
Ioxaglic acid	0	0	25			28			28
Ioxithalamic acid	0	17	0		19			51	
total number of samples	36	24	4	36	24	4	36	24	4

The temporal analysis of the distribution and dispersion of pharmaceuticals showed two main trends:

- Increasing detection numbers in the groundwater from north to south (Figure 113)
- Increasing detection numbers in groundwater over the investigated period (Table 36)

Table 37: Temporal evolution of detected pharmaceuticals in the LJV

	total substances in groundwater	total number of samples	average per sampling site
Apr 2008	16	13	1,2
Mar 2011	14	10	1,4
Sep 2011	27	10	2,7
Feb 2012	27	10	2,7

Nitrate and electric conductivity (EC) generally were found to increase from north to south (compare Table 38). The EC in the KAC remained stable until the inflow of saline water from the KTR. All concentrations in the southern JV were higher than those in the contributing flows from KAC and the reservoirs. This might already indicate accumulation processes due to intense short-cycled reuse. The high nitrate concentrations in the middle JV might be due to the application of nitrate fertilizers.

Table 38: Mean values between 2008 and 2012 for nitrate [mg/l] and the electric conductivity [µS/cm] along the Jordan Valley

	nitrate				electric conductivity			
	GW	KAC	KTR	reservoirs	GW	KAC	KTR	reservoirs
Northern JV	16,5	4,7	x	x	1,640	1,105	x	x
Middle JV	124,9	3,3	30,2	x	2,579	1,032	2,750	x
Southern JV	59,8	38,5	x	28,4	3,542	2,160	x	1,036

Table 39: Number of substances above the local thresholds according to the Jordanian Standard for reuse of reclaimed water

	2012 Feb	Nb. of samples	2011 Sept	Nb. of samples	2011 March	Nb. of samples	2008 Apr	Nb. of samples	total number of substances above the threshold
Northern JV	4	5	6	5	0	4	2	5	12
Middle JV	14	6	16	6	15	6	8	5	53
Southern JV	12	4	13	4	15	5	26	7	66
Totals	30	15	35	15	30	15	36	17	

The ions concentrations were evaluated according to the Jordanian standard for reuse of reclaimed water (JS 893:2002) by counting the limits exceeded for all main ions (potassium, sodium, magnesium, calcium, sulfate, phosphate, nitrate, hydrocarbon, chloride) and physiochemical parameters (EC, dissolved. O2, pH, redox). From 2008 until 2012 (see), the values were not found to increase. However, the spatial analyses again show an increase of thresholds from north to south.

3.4.2.3.3 Conclusions

Relating the water quality in the Lower Jordan Valley with the detection rates of pharmaceutical substances, the increasing amounts over the investigated period clearly indicate the influence of irrigation with treated wastewater on the shallow water resources. Increasing rates of detected substances reflect ongoing and increasing contamination. The hydrochemical and hydrophysical parameters, especially indicators for wastewater, such as nitrate and electric conductivity, or the increasing number of limits exceeded according to the Jordanian standards, show the same trend from north to south. Both pharmaceuticals and common hydrochemical and physical parameters reflect the use of freshwater quality in the northern parts of the Lower Jordan and increasing pollution towards the south (compare Figure 113), accompanied by massive reuse of treated wastewater for irrigation. This increase especially results from the inflow of water from the KTD into the area. According to the Jordanian standard for reuse in irrigation, the limits for quality parameters were exceeded several times, e.g. in the middle and southern parts of the Jordan Valley. This indicates that the amount of TWW for irrigation exceeded a sustainable level.

3.4.3 Biological Water Quality Indicators

3.4.3.1 Biological Methods to Characterize Surface Water Quality: Biofilms, Macroinvertebrates - Status of Biological Water Quality at Different Test Sites

Biological methods are a good means to describe the quality and pollution of surface water bodies and are an excellent instrument to evaluate the overall ecological quality. Their advantage is that they allow for an integrated assessment of surface water quality, considering several parameters, such as organic load, discharge, bottom substrates, and pollutants. To supply all necessary information regarding water quality, physical and chemical measurements should be conducted in addition to the determination of biological parameters. As the aquatic environment may be affected by both natural and anthropogenic impacts and organisms living in a water body are sensitive to any changes in their environment, the response of an organism to those changes can be used to determine the water quality in terms of the organism’s ability of living there (Friedrich, G. et al., 1992).

3.4.3.2 Macro fauna and flora as indicators of water quality in Jordan

Authors: I. Alhejoj, K. Bandel, E. Salameh, H. Hötzl

Many different species of aquatic fauna and flora were found in Jordan and can be utilized in characterizing the water quality. The idea to use animals as biological indicators to assess the Jordanian water quality was first proposed in 1981 by Bandel and Salameh for creeks, rivers, and springs in the Amman-Zarqa area. The authors were able to assign degrees of pollution to the different sources, ranging from 1 for the best water quality to 10 for heavily polluted water. In the new study, this frame was utilized and improved by including additional organisms and data on flora as well as more creeks and springs. The aim of the research activities presented here was to study the occurrences of aquatic organisms in springs, creeks, rivers, and ponds to determine the correlations between their occurrence and the various water quality parameters, such as temperature, pH (acidity), conductivity, nitrate, phosphate, hardness of water (calcium, magnesium, total hardness), trace elements (e.g. copper, iron, zinc, boron), BOD, and COD. The study covered water creeks and rivers extending from the Zarqa River in the north to the Mujib River in the south. Samples of animals and plants were collected from 24 sites at 8 locations from December 2011 to April 2013. The organisms were isolated and determined with respect to their place in the taxonomic system as far as possible. Plants were documented by photos. The freshly collected organisms were studied in the laboratory of the University of Jordan with a stereomicroscope. Most of them were documented by pictures as well. The sampling of macro-organisms in this study is summarized in Figure 116.

The animals chosen for the analysis predominantly represent invertebrates, such as flat worms (Turbellaria), annelid worms (including Tubifex (Oligochaeta)), and leeches (Hirudimea). Important are the larvae of insects (e.g., mayflies, caddisflies, black flies, true bugs and beetles, mosquitoes, shore flies, and chironomids). Gastropods of the mollusks were found to be useful as indicator species, especially the species of the genera Theodoxus, Melanopsis, Melanoides, Prosostenia, and Physa (Figure 117). The occurrence of crustaceans (crabs, ostracods, amphipods, and isopods) was documented as well. Other species, like sponges, fish, and algae were used as biological indicators. This research also highlighted the existing plants, especially flowering seed plants growing in and next to the water, indicating pollution and salinity. The selected size of the animals in most cases was larger than about 0.5 mm. They could be seen without a microscope (macro-organisms). The quality of open water in Jordan was defined by means of the biological indicator method which is based on organisms indicating water quality. Animals which can be used as bio-indicators were recognized successfully. Among them were the gastropods, aquatic worms, and insect larvae. As a result of the present study, a “Jordanian Biomonitoring System for Water Courses (JBSW)”, with water qualities of 12 categories from very good water quality to very bad water quality, was suggested. This report deals with the living organisms as bio-indicators of water quality from selected localities at Wadi Shueib and River Muijb. In addition, several other water bodies, such as Zarqa River, Wadi Hisban, Wadi Sir, Wadi Shita, Wadi Atun, Wadi Mukheiris, and the area around Karama Reservoir, were studied and included in the overall work. The transition from clean water to polluted water within the course of a single creek can be exemplified by Wadi Shueib. The disturbance of intolerant organisms (Theodoxus and Melanopsis) disappeared with increasing pollution along the creek of Wadi Shueib. Clean spring water enters the creek coming from the town with household sewage added to it. Further downstream, the water of the As-Salt WWTP is discharged into it as well. From here on, it flows further over stony beds bordered by Nerium oleander bushes towards the JV, with the Physa occurring as the only gastropod. Elevated phosphorus and nitrate concentrations in this creek due to the treated wastewater are reflected by a strong growth of cyanobacteria on surfaces and in the water as phytoplankton. These bacteria support reproduction and growth of the sewage worm Tubifex and the red larvae of Chironomidae which settle in the organic sludge. These two organisms are clear indicators of the poor water quality. Both organisms can tolerate water with almost no dissolved oxygen. In Wadi Shueib, floods caused by winter rains may flush out all muddy bottom sediments and, together with them, the habitat of Tubifex. With the return of more moderate flow conditions, the sludge is rapidly deposited again and red worms and red larvae colonize in it. The amount of winter floods therefore determines the living conditions in the Shueib reservoir at the outlet of the valley. Water there may be polluted to different degrees, e.g. strongly in 2012 with only dipteran larvae occurrence in near shore puddles and moderately in 2013 with a high population of daphnia in the shallow parts of the lake.

The study allows the conclusion to be drawn that aquatic biota (fauna and flora) can be used effectively as bio-indicators of water quality in the studied area. Certain groups of organisms show high bio-indicator values for different water situations, such as clean water, polluted water, mineral water, warm water, and salty water. Gastropod organisms are considered very good bio-indicator candidates of water quality in Jordan. Fossilization or preservation of the gastropods in recent sediments provided clues to historical environmental changes and can also be used to analyze improvements or deterioration of water quality along wadis after certain time periods.

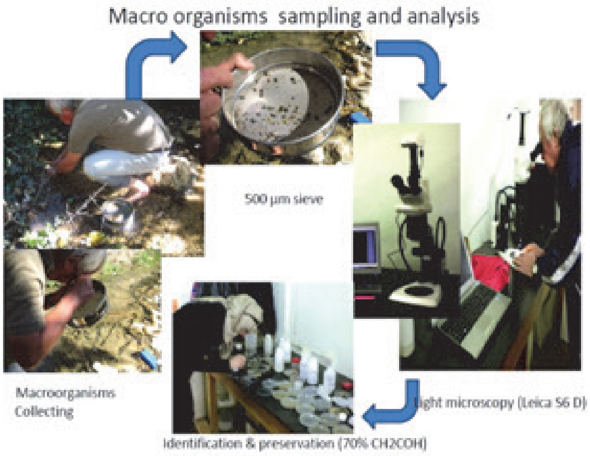


Figure 116: Collecting of aquatic macro organisms

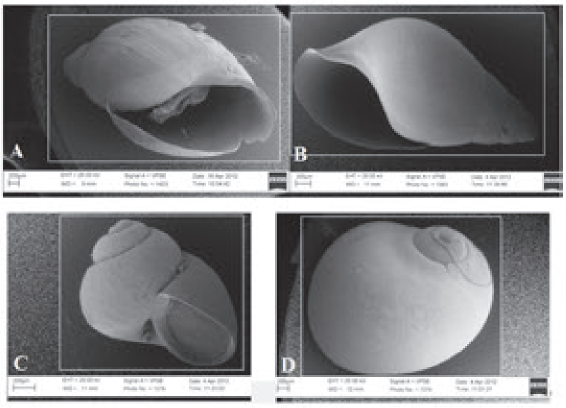


Figure 117: Gastrpods organisms were collected from Jordanian water bodies; A: Physa; B: Melanopsis; C: Pseudamnicola; D: Theodoxus

3.4.3.3 Monitoring of Surface Water Pollution Based on Biological Indicators

Authors: S. Fuchs, M. Leicht

Biological monitoring is used to determine the condition of the environment by using living organisms. Compared to physical or chemical monitoring, biological monitoring has several advantages, such as ecological compatibility (physical, chemical, and biological). It is an integrated way of measuring environmental conditions by integrating stresses over time (Barbour, M.T., 1999). Within the scope of this project, two biological methods were tested and applied in the area of the King Talal Dam (KTD) reservoir:

- Biofilm monitoring for the assessment of water pollution, e.g. heavy metals.
- Macro-invertebrate survey to evaluate the overall ecological status.

The project area is located north of Amman, in the area of “The Royal Botanic Garden of Jordan (RBG)”. The location was highly suited for this study, as it provides a protected environment to place samplers for monitoring and easy access to laboratories (RBG, Jordan University, Royal Scientific Society (RSS)). Moreover, it covers inflow of TWW from As Samra WWTP through Zarqa River and use of the KTD surface water for irrigation purposes in the Jordan Valley (JV). In addition, RBG wished to have a demonstration site showcasing sustainable water management.

The monitoring method is based on aquatic biofilms and is used to monitor surface water pollution (Table 40). Biofilms can be found on any surface exposed to water. They represent a microbial community with various inhabitants, such as sessile bacteria, protozoa, fungi, and algae (Fuchs et al., 1996). Thanks to their structure, they are able to incorporate and adsorb contaminants, to grow rapidly, and they can be sampled easily (Fuchs et al., 1996). Consequently, these aquatic microbial communities can be used as a pollutant monitor (Fuchs et al., 1996). Due to its low cost, easy handling, and low site-specific requirements, the method reaches a high spatial resolution of monitoring. Furthermore, the analysis of the biofilm will deliver reliable and time-integrated results with respect to the sources and state of surface water pollution. The biofilm samplers were exposed at different sites within the surface water system for about 14 days, depending on the organic load of the water. During this time, a biofilm grows on the surface of the collector and incorporates any particulate and dissolved pollution passing through. Afterwards, the biofilm was transferred to a lab for subsequent analysis of five heavy metals: Iron, lead, copper, zinc, and cadmium. Using those measurements, a geochemical index (Igeo) was calculated according to Müller`s (1981) formula (Muzungaire, L., 2012):

$$I_{geo} = \log_2 C_n \cdot 1.5\, B_n^{-1}$$

Cn = trace element concentration in the sediment at the particular station

Bn = geochemical background of the element (Turekian and Wedepohl, 1961)

Table 40: Mean values of the geochemical index of Zarqa River and KTD reservoir (Feb. to Sep. 2012).

Metal	I_{geo} value	I_{geo} class	Pollution intensity
Iron	4.29	5	Highly polluted
Lead	0.88	1	Unpolluted
Copper	0.81	1	Unpolluted
Zinc	1.74	2	Unpolluted to moderately polluted
Cadmium	2.48	3	Moderately polluted

To compare the biological findings with chemical analyses, three water samples were taken at Zarqa River, KTD, and at the RBG and analyzed for nitrogen, hydrogen carbonate, carbon trioxide, iron, COD, nitrate, sulfate, and total phosphorus. The samples had a differing iron content ranging from 1.30 mg/l at Zarqa river to 0.490 mg/l at the KTD reservoir to 1.55 mg/l at the KTD reservoir within the area of the RBG. Still, the maximum limit of 5 mg/l (given in the Jordanian standard 893/2006) was not reached.

Within the macro-invertebrate survey, organisms are being used to determine the water quality. In the last century, the Saprobien Index was developed by Kolkowitz and Marsson. It is based on the observation that the biocenosis of a water body varies in a predictable way with the organic load (Chorus et al., 1999). While some residents are more resistant to organic water pollution, others can survive unpolluted or slightly polluted water only, as their range of tolerance is very limited. These observations can be explained by the biology of the organisms, as for example some species need oxygen-rich waters and will die with decreasing oxygen content. Other species require a high supply of nutrients, but they may be able to tolerate very low oxygen levels (Friedrich, G. et al., 1992). The occurrence and frequency of those organisms which react to organic pollution can be used to determine the grade of pollution, if the tolerance ranges for each species are known.

Aquatic insects were sampled at selected sites in the project area and order, family and, if possible, the genus or species were identified. A total of 6 orders and 26 families were found, orders being: Diptera, Ephemeroptera, Hemiptera, Odonata, Trichoptera, and Coleoptera. The organisms were given values from 0 to 10 according to their tolerance to the water quality. Organisms rated with 1 or 2 are intolerant organisms which will not survive waters with poor conditions, while organisms rated with values 9 or 10 are tolerant and will survive in waters of poor quality. The tolerance values of the organisms found ranged from 2 (Dixidae) to 9 (Libellulidae). In the KTD Reservoir as well as in the Zarqa River, the tolerance values ranged from 4 to 9, with a high percentage around a tolerance value of 6 and no species with a low pollution tolerance. This is an indicator of moderate to polluted water quality, as organisms which settle here have a higher tolerance to pollution. Within the area of the RBG, species with a tolerance value of 2 were found, indicating “good” to “moderate” water quality, even if some species also showed a value of 6. Based on this result, no indicators of organic pollution were identified, whereas Al Zarqa River showed a reduced invertebrate community indicating organic loading of the water.

3.4.4 Improved Monitoring Concepts

Authors: F. Grimmeisen, M. Zemann

3.4.4.1 Introduction

In Jordan the urban water systems are not sufficiently managed and provide ample potential for improvements towards sustainability. This applies to both sanitation systems as well as industrial point sources. Within the SMART project study area, substantial amounts of raw sewage and treated wastewater are discharged into the wadis contributing to the Lower Jordan Valley. Due to the high vulnerability of mostly karst aquifers along the wadis (Werz 2006), the groundwater is frequently contaminated by these effluents. As mentioned in Chapter 3.5.2, the upper part of Wadi Shueib with its cities As Salt and Fuheis was chosen as test site to investigate groundwater contamination problems caused by an urban area.

Modern groundwater protection covers the four main components, namely, water protection zoning (1), the reduction of polluting activities (2), water quality monitoring (3), and drinking water treatment (4; Goldscheider 2008). Whilst the importance of all of these measures is equal, the focus of the case study of the Wadi Shueib springs (Hazzir, Baqqouria, and Shoreia) was directed to water quality monitoring. The development of a new monitoring system included the implementation of high-resolution sensor technologies, combined with up-to-date analytical methods. This monitoring system was then applied to improve the data availability.

The basin of the monitored karst springs is located in the region of Jordan’s great Upper Cretaceous limestone aquifer system with the Amman/Wadi As Sir aquifer (Upper Turonian to Campanian-Maastrichtian) as most important sequence (Margane et al. 2002; see Figure 118). The city Salt is located in the middle of the spring’s catchment area. It is the central problem and a main objective of the investigations (see Figure 120)

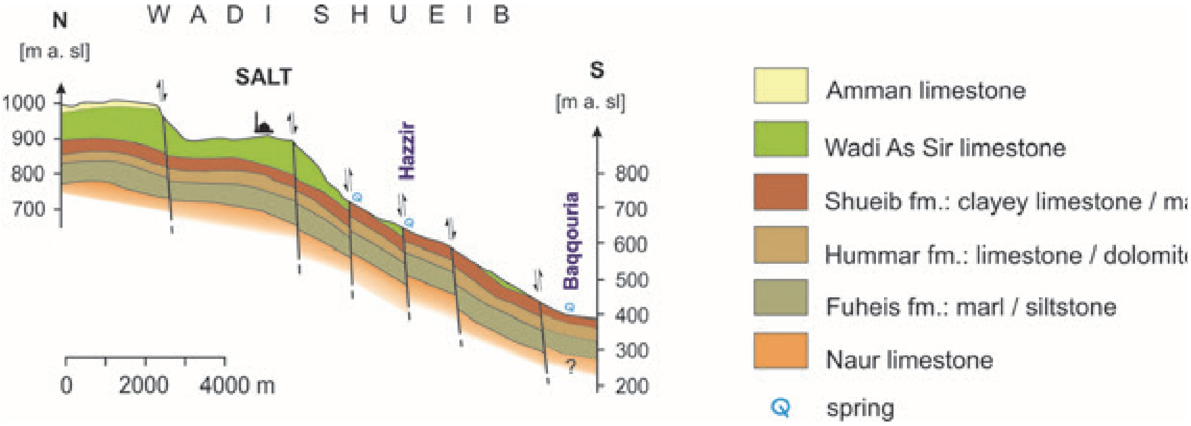


Figure 118: Simplified geological N-S cross section at the upper Wadi Shueib with Baqqouria and Hazzir springs. The geological formations date from Upper Turonian to Campanian-Maastrichtian.

Figure 119: Quarry of Wadi As Sir Limestone in Salt

Figure 120: Center of the old city of Salt

Historical data of the Wadi Shueib springs' water quality showed increasing concentrations of nitrate, organic matter, and impacts of fecal bacteria during the last decades. Due to the frequent contamination problems, the total discharge of all springs summing up to 5.65 MCM/a (Margane et al. 2010) cannot be fed completely into the drinking water supply system.

3.4.4.2 Methodology

The aim of this study was the development of groundwater monitoring concepts and the improvement of the scientific basis taking into account local limitations. For example, innovative analytical parameters, such as pharmaceuticals or $\delta^{18}O$ /$\delta^{2}H$ isotopes, were evaluated for their suitability as anthropogenic tracers to characterize the catchment. To obtain a better understanding of the hydrochemical variability on a detailed level, new technologies, such as a spectrometric sensor (UV-Vis) and an ion-sensitive electrode (ISE), both for nitrate measurements, were used to measure time series with a high resolution (up to 1 minute intervals). By analyzing time series of parameters like electric conductivity (EC), nitrate, and spring discharge, statistics relating to pollution frequency and appropriate sampling strategies were developed. The most critical problem of the Wadi Shueib springs and a main challenge for water quality monitoring is the detection of fecal bacteria with a high time resolution. Within this study, the test method Colilert® (IDEXX) was established on a convenient time scale to improve early warning. The increased nitrate concentrations and the frequency of bacteriological impacts were in the focus of the investigations.

3.4.4.3 Technical Implementations and Analysis

Beginning in May 2011, monitoring devices with the following components were installed at the Wadi Shueib springs (cf. Figure 121 a-e).

Hazzir spring:

- UV-Vis spectrometer probe for NO_3-N, turbidity, DOC, and TOC.
- V-weir and ultrasonic flow device for discharge.
- Climate station for hourly measurement of rainfall, air humidity, and air temperature.
- Multi-parameter probe for electric conductivity (EC) and temperature.

Shoreia spring:

- Multi-parameter probe for EC and temperature.

Baqqouria spring:

- Multi-parameter probe for of EC, redox, turbidity, salinity, nitrate (ISE), and temperature.

Furthermore, between May 2011 and April 2012, more than 50 water samples were collected weekly from the Hazzir spring for nitrate and E. coli analysis. In addition, 4 sampling campaigns (March & Sept. 2012, March & June 2013) were performed at all Wadi Shueib springs for the determination of other hydrochemical parameters. For spring monitoring, the main parameters, such as EC, were measured first to obtain a rudimentary idea of the hydrochemistry and the basic hydraulic characteristics of the aquifer system during the year. Measurements of EC show variations of the total mineralization, but also can be used for a better control of the relative amount of pollution.

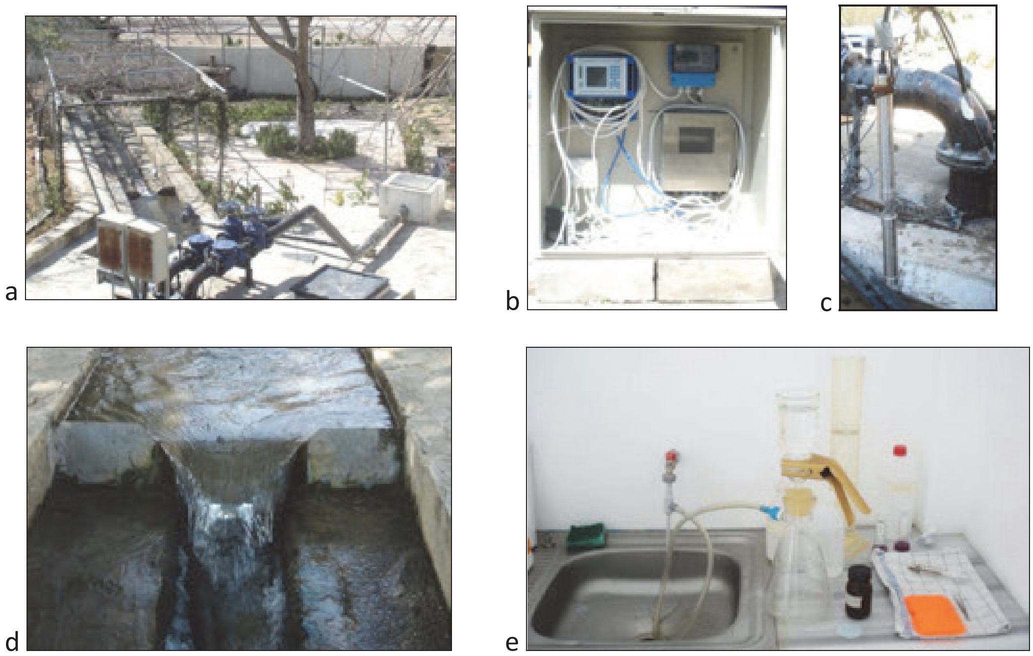


Figure 121: Hazzir spring reservoir with overflow channel and water main. b Sensor devices installed at Hazzir spring. c Spectrometer probe (UV-Vis). d V-weir at Hazzir spring. e Field laboratory with water filtration device

3.4.4.4 Results and Conclusions

Within the research a special focus was laid on the Hazzir spring, due to its important role in the water supply of the area on the one hand and its persisting pollution problems on the other (see Figure 122, Figure 123 and Figure 124). A special focus of research was placed on the Hazzir spring due to its important role in the water supply of the area and its persisting pollution problems (Figure 122 and Figure 124). By the spectrometer probe, an almost complete time series of nitrate concentration at Hazzir spring for about 2.5 years at 15 minutes' time interval was provided. Additionally, the 4 sampling campaigns with detailed studies of bacteriological pollution enhanced understanding of contamination under low and high flow conditions. For example, during a heavy rainfall event, E. coli tests revealed the quick response of increasing discharge, accompanied by a strong bacteriological impact, which is a typical hydraulic effect of karst aquifers. As a general result of monitoring, most time series and water analyses showed a strong anthropogenic impact in particular at Hazzir spring and temporarily at Baqqouria and Shoreia springs. While high vulnerability (e.g. of leaking sewers) and high groundwater flow velocities in karstic systems after major rain events are two well-known phenomena , monitoring at the Wadi Shueib springs provides strong evidence of anthropogenic activities in the catchment area. Furthermore, the comparison of time series with different temporal resolutions clearly shows the benefits of this high-resolution monitoring concept (see Figure 123). While single event samplings can only give a rough idea about the level of contamination, the short measurement intervals are helpful to interpret contamination dynamics e.g. based on multiple parameters. Water quality and quantity data help to manage so far unused water resources (due to contamination) on a sustainable level and can improve both the water quality and the available water amount. An important part of this research was to show what future monitoring measures may be like and to demonstrate their transferability to other comparable areas. In addition, activities were aimed at developing a method for the scientific assessment and evaluation of the various monitoring parameters using appropriate criteria. In this context the efforts and costs of implementing the various technologies or advantages and disadvantages of the analytical methods must be considered.

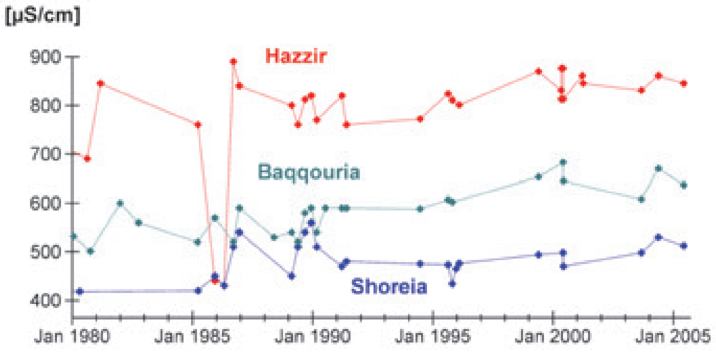


Figure 122: Historical measurements of electric conductivity (EC) at the Wadi Shueib springs. The orders of the EC levels at all springs have remained the same until today, but, in general, they are all rising slowly (cf. next Figure 123).

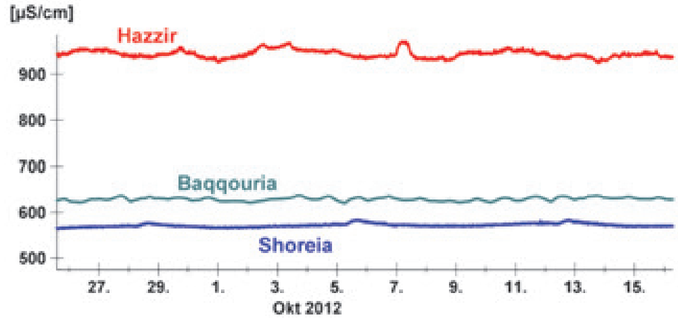


Figure 123: Time series with 15-min interval of EC at the Wadi Shueib springs in autumn 2012. Whilst the values of Baqqouria and Shoreia springs are still at a low level, the EC at Hazzir spring is significantly higher.

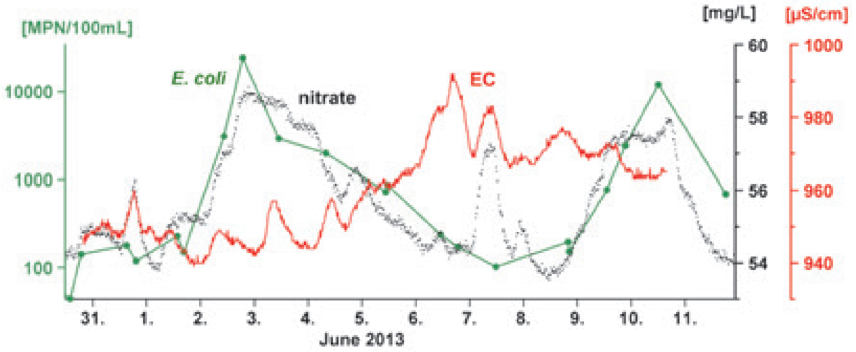


Figure 124: EC, *E. coli,* and nitrate monitoring at Hazzir spring in summer 2013. Due to the high-resolution time series, a clear correlation between *E. coli* detections and nitrate variations can be found.

Table 41 summarizes all parameters monitored at the Wadi Shueib springs from 2011-2013 and gives a simplified evaluation of their suitability for developing and improving a genuine monitoring concept for karst springs in semi-arid climate in highly urbanized catchments. These studies confirmed the great benefits of high-resolution nitrate measurements, e.g. the correlation of quantitative E. coli detections with the nitrate time series at Hazzir spring. However, it needs to be considered that this single parameter cannot be recommended for use as standard monitoring method for all other springs due to its high costs and the high expertise requirements. In the case of Wadi Shueib, it makes no sense to install nitrate probes at all other springs despite the great benefits at Hazzir spring. The UV-Vis spectrometer at Hazzir spring was specifically adapted to the characteristics of karst aquifers as well as to the pollution problem. The simplified comparison of parameters demonstrates (EC bold, nitrate not bold in Figure 124) that the easy-to-conduct EC measurements were preferable to an expensive nitrate sensor, although the effectiveness and significance of both parameters were rated to be quite similar. Nevertheless, the highest possible resolution of monitoring always provides an optimum knowledge, on the basis of which further protection measures, such as water treatment, protection zoning, and especially the detection of the pollution source, can be taken. Finally, improved monitoring concepts have to end up in water quality management strategies, including sewer and cesspit construction and maintenance, general groundwater protection measures, and end-of-pipe vs. source control approaches. Due to the better knowledge of pollution events, improved monitoring concepts can help the Jordan water management to cope with its highly vulnerable karst aquifers, economic limitations, inadequate sewage treatment plants and sewer systems, and the lack of groundwater protection measures over the past decades.

Table 41: Overview of monitored parameters at the Wadi Shueib springs with a simplified evaluation of timing & resolution effectiveness and indicator significance (most convenient parameters are bold)

parameter	timing & resolution effectiveness	indicator significance
electric conductivity	**+++**	**++**
discharge / water level / pumping rate	**+++**	**+++**
NO_3	+++	++
pharmaceuticals	o	+++
E. coli [1]**/ total coliforms**[1]	**+(+)**	**+++**
turbidity	+++	(+++)
$\delta^{18}O$ /$\delta^{2}D$ isotopes	+	++
pH	+	+
Cl^{-} & SO_4^{2-}	++	+
major cations	++	+
TOC / DOC	++(+)	++(+)
viruses	o	+++
temperature	+++	+
oxygen demand / redox	+++	+(+)

+++ very convenient ++ convenient + partly convenient

o hardly convenient ( ) evaluation not finished yet

3.4.5 Groundwater Protection Zoning

3.4.5.1 Groundwater Protection Zones in the Legislations of the Participating Countries

3.4.5.1.1 The Israeli Case

Author: Y. Guttman

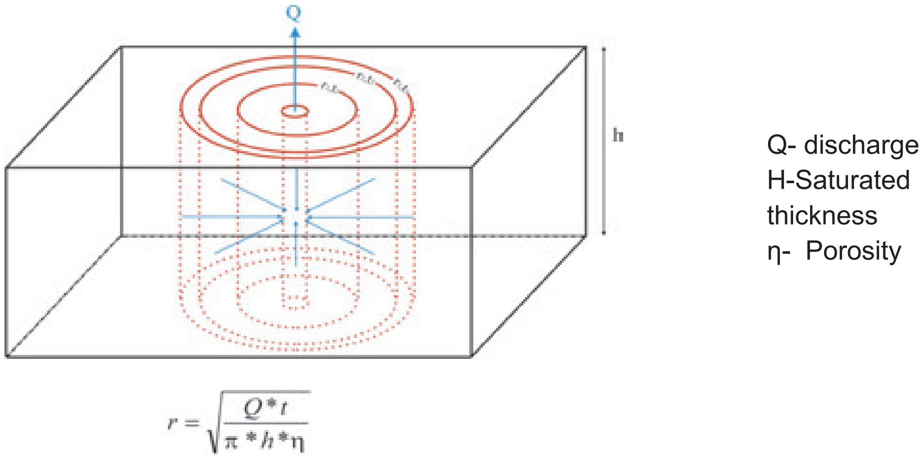
According to the Israeli law, water is a public property. So there is no private ownership of the water source. However, each person has the right to get water according to the law. Any supplier, like Mekorot Water Company, must ensure that the water sources will be protected from any contamination sources. The Health Ministry is responsible for the drinking water quality and without their approval the water supplier cannot supply drinking water to his customers. The legislator defined three protection zones around any drinking well. These protection zones are statutory by several laws:

- In Radius A (20 m around the borehole) it is allowed to have only buildings and other structures that are directly related to the borehole itself.

---

[1] testing method Colilert®-18 (IDEXX)

- In Radius B it is forbidden to have any building or structure that can be a contamination hazard to the borehole. It is calculated for a travel time of 50 days.
- In Radius C it is forbidden to have buildings or structures that can be a source of a significant contamination (major effluent pipelines, wastewater treatment plants, irrigation with treated effluent, etc.). It is calculated for a travel time of 200 days.



$$r = \sqrt{\frac{Q*t}{\pi * h * \eta}}$$

Figure 125: Protection zones and distance formula used in Israel

The formula that is used to calculate the radius of the protection zone is simplistic and does not consider pumping from deeper formations, confined aquifers, and the effect of anisotropy. The formula is built on a constant that reflects the porosity and the travel time of bacteria (Figure 125). The Health Ministry can approve of smaller radii B and C, if they think that the hydrogeology conditions allow it. In addition, the Health Ministry publishes rules and guidelines that deal with the duties of the water supplier to protect the water sources. These duties include periodic chemical and bacteriological analyses and environmental monitoring within the protection zones as well as actions for the removal of any contamination hazard from these zones. In case of a parameter (chemical and/or bacterial) exceeding the limit given in the standard, the water supplier must inform the authorities and, in parallel, re-analyze the water to detect and remove the source of contamination.

3.4.5.1.2 The Palestine case

Author: S. Samhan

According to the Palestinian legislation, water is a public property based on the Water Law (No. 3/2002). The objective is to “develop, manage, and protect water resources, all water resources are considered public property”. The Palestinian Water Authority (PWA) is the regulatory body for Palestine, its main goal being to ensure equitable utilization and sustainable management and development of Palestinian water resources. Within the framework of SMARTII, the PWA assumed the responsibility of developing a new legislation for water resources protection. In 2010, the PWA established a consortium, including decision makers from all relevant Ministries, NGOs, and academic university staff, to issue new guidelines for the protection of water resources in Palestine. The consortium agreed on several points:

- Groundwater is the only available source of freshwater and needs to be protected.
- Diffuse water pollution is a serious problem in Palestine.
- The establishment of water protection zones (WPZs) is a main activity to protect water resources.
- Every water source should be protected by three main zones (inner, outer, and total catchment) and a fourth zone of special interest.

Five criteria were identified to form the basis for WPZ delineation: Radius (distance), drawdown, travel time, flow boundaries (discharge area), and assimilative capacity. Three steps were defined for developing a wellhead protection plan:

- Phase I defines the protected and managed area for wellhead protection. This is the subsurface area surrounding a well, through which contaminants are likely to move through and reach the well. The boundaries are scientifically calculated.
- Phase II is to create a contaminant source inventory with the purpose to identify potential sources of contamination which may influence the public water supply well.
- Phase III is the actual zoning and land use management.

It was agreed on testing two methods to determine the wellhead zoning areas. These methods mainly depend on the time it takes for the groundwater to travel a specified horizontal distance:

Calculated Fixed-Radius Method (CFR) (Figure 125: The Israel case)

Wellhead Analytic Element Model (WhAEM2000): The advantages are the hydrological computer model of groundwater flow and a more accurate delineation of the WPZ. The method accounts for variation in hydraulic parameters and boundary conditions. It often produces a smaller area to manage than other methods. However, the disadvantages are high costs, the requirement for sufficient data, and a high level of expertise to set up the model grid. The magnitude of the uniform flow was denoted by Qo (m2/day) and estimated from the hydraulic gradient i and the aquifer transmissivity kH (hydraulic conductivity k times saturated aquifer thickness H) (m2/day).

$$Qo = kHi$$

Application to the Karst Aquifer in the Wadi Qilt Area

Author: J. Hasan

The Wadi Al-Qilt and Jericho areas are located east of the cities of Ramallah and Jerusalem. More than 65,000 people from Palestinian communities (PCBS 2007) and six Israel villages totaling about 15,000 people (PCBS 2007) live in the Al-Qilt catchment. Of the wastewater discharged into the catchment, less than 10% are treated efficiently. Most of the wastewater enters the nearest wadis untreated (ARIJ 2007). The wastewater discharge in the Al-Qilt catchment is estimated to amount to about 9500 m3/day from the Palestinian communities and to about 4500 m3/day from the Israeli colonies. The wastewater treated at the Al-Bireh wastewater treatment plant is subsequently mixed with raw wastewater from Qalandiah and runs downstream. The springs in the upper part of Wadi Al-Qilt (Ein Fawwar, Ein Fara, and Ein Qilt) emerge from the limestone layers of the "uppermost aquifer". The spring system has a young water age and fast flow indicating the existence of a well-developed (fossil) karstic system.

Wadi Al-Qilt and its tributaries cut into the limestone rocks that are part of the outcrops of the springs. Effluents of the main cities’ wastewater treatment plants flow on the limestone layers and reach the springs via the karst fissures. Due to their small storage capacity and the fast flow mechanism, the effluents reach the spring very quickly and within a short period of time that enables the bacteria to persist. In contrast to the springs in the upper part of Wadi Al-Qilt, the Jericho springs located in the lower part of Wadi Al-Qilt and also emerging from the "uppermost aquifer", are "clean" from anthropogenic contamination most of the time. The reason is that the Jericho springs have a larger catchment area than the upper springs, which leaves enough time for "self-purification". Contamination events in the Jericho springs are most probably a result of local contamination sources near the springs. The wells that are located in this area are pumping from a deeper, "regional” aquifer. This regional aquifer is characterized by slow flow and, hence, better protected from contamination. Only wells that are pumping from an unconfined aquifer and located close to the wadi’s bank may receive a small amount of WWTP effluents that flow in those wadis and penetrate through karst fissures into the deep aquifer system. The amount is quite small and after short pumping, the "contaminated lens" disappears. Wells that are located far from the wadi bank are not contaminated. The situation at well Mizpe Jericho 2 located far away from the wadi bank is different. Near the well yard, a sewage pipe is passing and sometimes, because of maintenance problems, a small amount of effluents leaks into the ground. This occurs quite rarely and the amount is small. Short pumping removes this contamination. In most of the cases, the contamination appears randomly. It is impossible to predict when and at which intensity the contamination will appear in the springs and in some wells. A hydrogeology study and the understanding of the flow pattern helped rank the water sources according to their vulnerability to contamination and also map the places that might contaminate the springs and wells. The result of the study showed that the primary vulnerable places are inside Wadi Al-Qilt and the secondary places are some points along the sewage pipeline passing near the Jerusalem-Jericho road. The least contaminated wells are those wells that are far from the wadi bank and pumping from a deep confined aquifer.

The resulting vulnerability map (Figure 126) shows that the most vulnerable area is concentrated on the Wadi Al-Qilt and its tributaries that cut into the limestone rocks. Treating the cities’ effluents to the tertiary level before releasing the effluents into the wadis is an essential action to reduce the contamination hazard of the water sources (springs and wells).

Another study, done between 2008 and 2009, assessed the sediment quality regarding anthropogenic pollution by heavy metals and arsenic. Overall 36 sediment samples were taken from the catchment and evaluated by using the average shale values of Turekian and Wedepohl (1961) and soil samples from Al-Qilt as references. The soils from Al-Bireh, Fawwar, Ras Al-Qilt, and Murashahat were taken as representative reference values, since these regions are located far away from human activities and considered to be pristine areas within the catchment. By calculating the contamination factor (CF) for the “aqua regia” fraction, the extent and distribution of metal pollution were assessed. Moreover, the elemental background of soil from pristine sites was compared to the continental crust values. The contamination factor was classified into four groups according to Hokanson (1980) and Pekey et al. (2004). They used the following terminology: $CF < 1$ for low contamination; $1 \leq CF < 3$ for moderate contamination; $3 \leq CF < 6$ for considerable contamination; $CF \geq 6$ for very high contamination.

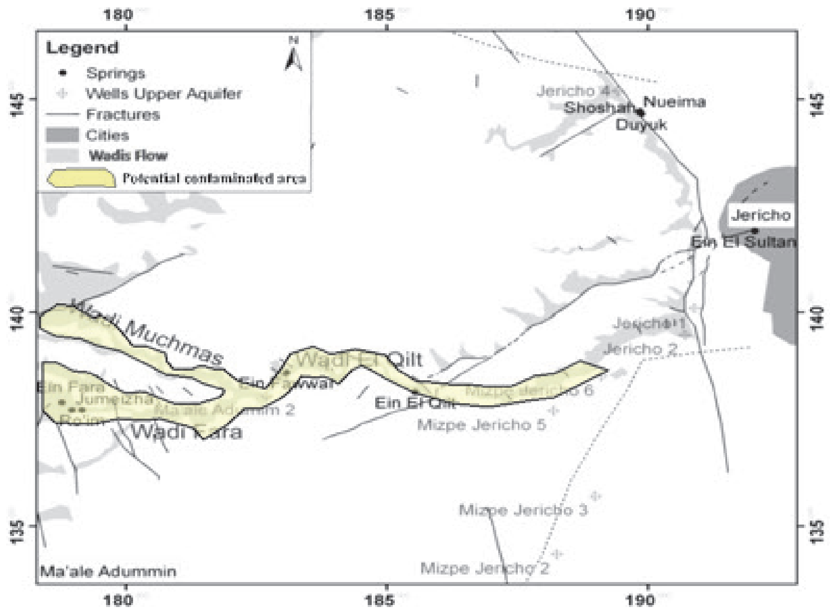


Figure 126: Vulnerability map oft the Wadi Al Quilt and Jericho area

On the basis of the CF, sediments appear to be particularly contaminated with Zn, Cu, Ag, Sn, Cd, Hg, Bi, and B. Three regions, Wadi Sweanit, Ras Al-Qilt, and Qalnadiah, were identified to be critical points of contamination. According to the contamination factor classifications done by Hokanson (1980) and Pekey et al. (2004) and by determining the total contents of Cr, Co Ni, As, Sr, Mo, Cd, and Ba, scattered pollution points were found in sediments. For As, Cd, and Mo, these values are lower than the continental crust reference values (Samhan, 2013). The very high CFs for Ag, Hg, Bi, and B are encountered at Al-Bireh and at Mukhmas, since the TWW coming from Al-Bireh WWTP is mixed with raw wastewater from Qalandiah and Stone Cut at Mukhmas again. Although the distance from Mukhmas to Sweanit is about 4-5 km, these parameters still reach high contamination factors at Sweanit. This might indicate an additional contamination source (Samhan, 2013). The surface sediment samples of the Al-Qilt catchment are characterized by trace element contents that are typical of aquatic environments located in industrial and densely populated areas. Zn, Ag, Cd, Hg, Bi, and B have CF values higher than six, classifying them as highly polluted. When applying the calculation of CF to single steps of the BCR sequential extraction scheme, a more realistic view of the potential impact of the trace metals on the environment is obtained. Considering the first two steps of the BCR scheme (exchangeable, reducible) and the most relevant fractions of metals released into the environment, Cu, Pb, Zn, Ag, Sb, and Bi exhibit CFs higher than six. This can be seen as a hint for the high risk of pollution by these traces of metals.

Summing up, trace metal inputs into the Al-Qilt catchment need to be kept under strict control in the future, since Ras Al-Qilt is considered one of the important springs in the area and is used for domestic purposes. Moreover, it will be susceptible to pollution, if no action will be taken to decrease the pollution upstream of Al-Qilt (Samhan, 2013).

3.4.6 Socio-economic Aspects

Author: I. Heinz

3.4.6.1 Introduction

Water resources protection requires measures to prevent or reduce pollution and other hazards. Beyond the hydrogeological, toxicological, and technical challenges, socio-economic aspects are to be taken into consideration as well. Doing so, the effectiveness of water resources protection can be enhanced substantially. Socioeconomics deals with a broad range of societal factors influencing the utilization of water resources. They include, amongst others, the wealth of people, economic and financial constraints, political structures, and regulatory frameworks. In low-income areas or in countries with poor regulatory settings, for instance, the possibilities for water resources protection are usually limited.

There is a wide spectrum of potential actions to protect water resources. One of them is the designation of water protection zones (WPZ). Hereinafter, the focus will be placed especially on this powerful intervention. As obvious from the study 506 of SMARTII of examples in Palestine and Jordan, WPZ can lead to considerable economic benefits for domestic, commercial, and agricultural users. The aim of these case studies was to show that WPZ do not only protect water resources, but can lead to gains in societal welfare as well.

3.4.6.2 Methodology

WPZ can be assessed by applying the cost - benefit analysis (CBA). For instance, the cost of connecting houses to sewage networks and water reuse may be lower than the economic value of additional crop yields due to the additional reclaimed water for irrigation purposes. In such a case, the increase in farmers' income would exceed the annual capital and running cost of sewage collection and wastewater treatment. Moreover, high-quality drinking water maintained by WPZ has a high economic value for domestic, commercial, and industrial users. CBA studies investigate to what an extent measures to reduce or prevent water pollution can produce economic benefits that are higher than the costs.

Some CBA studies focus on the economic losses due to diseases and premature death that could have been reduced or prevented (e.g. diarrhea, fatal illness of children, etc.). Examples are expenses for medical treatment and losses in incomes due to inability to work. But these approaches are questionable, because it is extremely difficult to evaluate health damages and loss of life in monetary units. Therefore, it is assumed that water protection measures should not be made dependent on the expenses in the health sector and losses in manpower due to diseases. Water authorities rather have to ensure that any harmful effects will be prevented as far as possible by precautionary measures. An equally disputable methodology is to assess the health costs, which could be prevented, if drinking water standards were met. Again, it is extremely difficult to determine the economic losses that would occur, if water protection measures were not taken properly.

A more promising approach is to estimate the economic benefit of WPZ by considering the amounts users are willing to pay for safe drinking water. Here, it is assumed that water prices reflect the economic value of one cubic meter. This approach was used in the case studies in Palestine and Jordan mentioned above. The idea is that without precautionary measures, the water will sooner or later cease to be suitable for drinking purposes or complex treatment techniques will be required to eliminate contaminations, for instance, nitrate or pesticides. But the estimated benefits will represent lower bounds, if tariffs do not fully reflect the water value.

Moreover, if houses will be connected to sewage networks to prevent water pollution, cesspits and the expenses for operating them will not be needed anymore. These cost savings represent economic benefits of WPZ. Further benefits are the extra incomes for farmers, if the treated sewage can be used as an additional water resource for irrigation purposes.

3.4.6.3 Results

In the Jericho area in Palestine, springs are the main natural water resources. The Ein Sultan spring with an annual discharge of about 5.5 MCM represents the main supplier of water for domestic, commercial, and public use in the Jericho city central area. Today, Jericho city is considered an important place for tourism activities. Deterioration of water quality would require costly treatment and may adversely affect various economic activities in Jericho area. For instance, the expenses needed for water purification, such as elimination of nitrate in potable water, are usually unreasonably high, so that potential customers (e.g. hotels, manufactures, etc.) may be charged with excessive water cost. Moreover, the quality of drinking water is often a decisive factor for determining the location of companies and households.

Current contamination sources upstream of the Ein Sultan spring are the domestic wastewater cesspits in Ein Sultan Camp. To avoid this pollution, the cesspits should be made inoperative and a sewer network with treatment facilities should be constructed. Currently, there are around 750 cesspits. Moreover, several farms using pesticides and fertilizers exist upstream of the Ein Sultan spring.

The cost of a sewage collection network for Ein Sultan Camp is about 1.345 million USD. The corresponding annualized capital cost amounts to 113,910 USD/yr (useful lifetime of 30 years; discount rate of 7.5 % (cf. study D506 of SMARTII). The wastewater collected by the planned sewage network can be treated at the projected treatment plant (WWTP) of Jericho city. The effluents could be used for agricultural irrigation purposes. Restrictions for using fertilizers and pesticides in the area above En Sultan Spring would reduce crop yields and consequently lead to losses in farmers' income. However, no data are available. Therefore, it is assumed that agricultural production would decrease by 20 % (minimum value) to 50 % (maximum value). Table 42 summarizes the CBA results for the WPZ of Ein Sultan spring, assuming 20 % losses in agricultural production due to land use restrictions (rounded numbers). Supposing that the precautionary measures will be implemented soon, a surplus of benefits over costs (value added) of about 590,000 USD/yr can be expected.

Table 42: Costs, benefits, and added value of a water protection zone for the Ein Sultan spring

	USD/yr
Costs Sign post 100 Operation, monitoring quality & hazards 18,750 Wastewater network for Ein Sultan Camp 113,910 Economic losses due to agricultural restrictions 336,409 *)	**500,000**
Benefits	**1,090,000**
Economic value of water supplied to municipal users 1,070,000 **)	
Cost savings due to shutting down cesspits 20,000	
Value added (rounded)	**590,000**

* Under the assumption of 20 % income losses

**) 2.788 Mm^3/yr represents the water volume currently supplied to municipal users. The average water value (tariff) is 0.384 USD/m^3.

3.4.6.4 Conclusions

As confirmed by the studies of water resources protection in the Jericho area and the Jordan Valley, a surplus of economic benefits over the costs can be expected in most cases (cf. study 506 of the SMARTII project). The implementation of water protection zones contributes to safe drinking water supply and reduction of water pollution resulting from poor sanitation (e.g. bottomless cesspits and leaking sewage systems) and use of agro-chemicals. Under special conditions, however, restrictions particularly in agricultural land use (e.g. ban of pesticides) can cause considerable income losses, so that the costs of delineated water protection zones may exceed the economic benefits. Nevertheless, there are often significant positive environmental impacts, such as less pollution of groundwater.

The maintenance of high-quality water resources represents the major advantage of protection measures, resulting in considerable gains in welfare. The reason is the great importance the society attaches to not contaminated drinking water.

Further investigations are needed with regard to the impacts of safe drinking water supply on the economic development of communities. Who pays the costs of restrictions in land use? To which extent should farmers get compensation payments and from which financial means can water resources protection be funded? More information on the financial implications of protection zones would be useful to enhance the sustainability of natural water resources.

3.4.7 Conclusion and Outlook

Author: N. Goldscheider

Groundwater protection requires a multi-barrier approach (or security chain) consisting of four elements: The reduction of polluting activities, the delineation and enforcement of protection zones, continuous monitoring of water quality, and adapted water treatment technologies. The combined implementation of these measures can ensure safe drinking water and contribute to improved living conditions. However, in many cases, not all four elements can be realized. In the region of the Lower Jordan Valley, the situation concerning groundwater protection often is not satisfactory and there are widespread and serious water quality problems.

The SMART project has addressed this problem using the described multi-barrier approach. Major accomplishments include a detailed regional assessment of water quality and contaminants with a focus on wastewater impacts on groundwater; an evaluation of chemical and biological surface water quality, including the development of a regionally adapted invertebrate bioindicator approach; the implementation of continuous monitoring techniques at selected springs; and the conceptual advancement of groundwater protection zoning, including a socio-economic assessment.

However, many problems still exist and further research efforts and implementation measures are required. In many cases, not all elements of the multi-barrier approach described above can be realized due to the general water shortage and the high population density with the associated widespread contamination sources, such as untreated wastewater releases. The extreme hydrologic variability represents another challenge that needs to be addressed. The problems are so numerous and widespread that they cannot be solved within a short time and need to be prioritized.

Priority measures include the proper delineation of catchment areas of springs and wells used for water supply using hydrogeological methods, because the precise knowledge of catchments is the precondition for the delineation of appropriate protection zones. In many catchments in the region, untreated or insufficiently treated wastewater represents the most severe threat to groundwater quality. Therefore, the fields of wastewater treatment and groundwater protection should be better linked to each other. Implementation of decentralized wastewater treatment plants should have priority in recharge zones of aquifers used for drinking water supply. Furthermore, better monitoring devices should be installed in order to capture the variations of water quality and short-term contamination events related to the extreme hydrologic variability.

3.5 Socio-economic issues

Involved Institutions: UFZ, JUA, ECO, MWI, PHG, EWRE

Spokesmen WP7: I. Heinz, A. Tamimi (PHG), N. Lienhoop (UFZ)

Compiled by: Ingo Heinz

Preamble: This chapter summarizes the results of studies made by the SMARTII members I. Heinz, A. Salman, E. Al-Karablieh, N. Korff, N. Lienhoop, M. Lee, T. Milgrom, and A. Tamimi. Editorial integration: I. Heinz

3.5.1 Introduction

Socio-economic studies under SMARTII focus on the economic efficiency, financial affordability, social equity as well as on the institutional and participatory requirements of IWRM strategies. IWRM should enhance the welfare of communities or the society. In most of the studies, the values added generated by water projects were identified to be an important performance goal. Values added emerge wherever the benefits exceed the costs. If the overall cost exceeds the total economic benefits, an IWRM strategy is inferior, even though other benefits (for instance, sustainable use of aquifers) arise. In such a situation, the stakeholders may weigh these benefits and the economic losses (trade-offs).

While the studies 701 & 704, 702, and 703 focus mainly on economic advantages of wastewater treatment & reuse in irrigated agriculture, studies 706 & 707 deal with IWRM strategies that combine different projects, such as brackish water desalination, water reuse, stormwater harvesting, rehabilitation of wells and networks, interregional water transfer, and others.

Study 705 deals with the cost-effectiveness of water projects. Improvements in water supply are related to the costs of different technologies, such as decentralized wastewater treatment and water reuse (DWWT & reuse), managed aquifer recharge and brackish water use. The benefits are not evaluated in economic terms, but in physical performance units (for instance, improvement of water supply).

Study 708 provides a comprehensive overview of the socio-economic and political conditions, the present and future water situations, and discusses alternative IWRM technologies, their impacts on water availability, and their costs, particularly in the West Bank. Based on these investigations, study 709 explores the social implications of amendments in water management. Water tariffs and the affordability of water supplied for domestic and agricultural users play a major role. Study 710 highlights the institutional structures needed to achieve an effective and equitable governance of water problems, particularly in Palestine.

Study 711 presents a decision tool based on the Analytic Hierarchy Process (AHP) approach, by means of which IWRM strategies can be prioritized when conflicting objectives are to be met, such as sustainable utilization of aquifers, reliability of water supply, natural environment preservation, and economic profits.

Finally, study 712 points out the participatory requirements for implementing IWRM. It develops a participatory planning framework for implementing DWWT & reuse projects on the pilot scale in particular.

3.5.2 Case-specific Water Problems, Socio-economic Issues

Case studies were carried out in the West Bank and the lower Jordan River Valley. A common feature is water shortage due to declining precipitation and increasing water demand. But also quality problems caused by cesspits, leakages of sewage networks, missing wastewater treatment plants, and salinization (brackish water) reduce the availability of usable water resources.

Water-related Problems in Palestine

In Palestine (West Bank and Gaza) the annual wastewater volume amounts to 66 MC. Only 30 % of this water was collected in a public sewer network and less than 7 % are passed on to a water treatment plant. The virtual lack of a household wastewater collection network and, hence, of any pollution treatment, especially in the West Bank, forces each household to store its wastewater in cesspools holding both blackwater and greywater. Some major cities (e.g. Jericho) have no centralized wastewater collection. Regarding wastewater treatment, the currently existing treatment plants in the West Bank are clearly inadequate to handle the amount of wastewater collected. In the West Bank, 93 % (33.5 MCM/y) of the produced wastewater are discharged into the environment untreated.

The situation is additionally characterized by high unemployment rates (average 19 %), low family incomes, water shortage, and poor water management. The availability of water per capita particularly in the West Bank ranges from 29 to 150 liters per day, but is mostly below 100 liters. Widespread are seasonal water cut-offs, mainly during dry summers. 30 % of the communities or 700,000 people are currently not served by any water network. There, purchasing water from trucks and hauling water from standpipes are typical. In the West Bank, the gap between supply and demand will increase dramatically in the coming years.

A high percentage of Palestinian families in the villages, especially in the far-off ones, live in poverty with low incomes. Most of these families depend on farming to ensure their basic needs of life. Due to the lack of water, many use untreated grey wastewater to irrigate their farms and gardens without taking into consideration health and environmental risks especially to the children and women who are direct users of this kind of water. In addition, social problems with neighbors arise because of the foul odors and insects, which ultimately affect social coherence. Grey wastewater treatment and reuse in the irrigation of gardens and farms is acceptable for the Palestinian families. It is considered a good and durable source of water for agricultural use, ensuring their basic needs for vegetables which are planted in the house garden having an area of 150 to 200 square meters. However, the pollution and sanitary problems caused by untreated grey wastewater can be reduced. The Palestinian Hydrological Group (PHG) established many grey wastewater treatment units in Palestinian communities, the families were provided with irrigation networks.

Still, reuse in Palestine remains very primitive and requires development mainly due to the lack of large-scale infrastructure, social obstacles, and public non-acceptance. Furthermore, there are insufficient economic incentives to encourage farmers. Farmers and households must be fully aware of the importance of reuse and of how they can benefit from the treated wastewater by increased production and saved costs that would otherwise be spent on fertilizers and freshwater (study 702 of SMARTII).

Case Studies in Palestine

In the Jericho area groundwater wells are concentrated and only inefficient agriculture exists in the east sub-basin. Most of the wells are not working due to the poor water quality and insufficient water levels. Salinity is the main problem and salinity increases with falling water levels causing sea water intrusion from the Dead Sea. In the Jericho central sub-area with the city of Jericho, there are domestic, agricultural, commercial, and public water users. Currently, this area is supplied with water from the Ein Sultan Spring that produces about 5.5 Mm^3/yr. Population is expected to grow rapidly in the next decades, so that the water demand will increase. The arable land currently is not fully used and the expansion of agriculture would only be possible, if additional water resources were available. Thus, the total water deficit will rise in the future. In the Jericho northern sub-area, there are villages that depend on agriculture as their main source of income. The water sources are the three adjacent Shosa, Nueimah, and Duyuk springs. The major water use is the irrigation for agricultural purposes. The yearly discharge of the springs varies due to different climate conditions. The projected water demand will grow. Together with the declining spring water availability, this will lead to water deficits in the future (studies 706 & 707 of SMARTII). Consequently, there is a need for expanding the use of non-conventional water and for integrated water management options.

Water-related Problems in the Jordan Valley

As the result of growing urbanization, the lower Jordan River valley is facing a continuous decrease in water supply. As regards agriculture, this situation aggravates due to the increasing water demand for irrigation. Further influencing factors are the unfavorable climatic conditions, such as high temperatures and declining precipitations. The river valley is a ‘food basket’ for Jordan and a major source of drinking water supply of the city of Amman and other municipalities. The river basin receives its water from the upstream Jordan river, the Yarmouk river, and the Zarqa river that flow into the Dead Sea. Due to water shortage, use of treated wastewater plays an important role. A prominent example can be found downstream of the King Abdullah Canal (KAC), where the effluents of the As-Samra treatment plant of Amman are stored in the King Talal Dam (KTD) and then mixed with the KAC freshwater. The blended treated wastewater (BTWW) is utilized for agricultural irrigation in the middle and southern parts of the Jordan Valley. The upstream KAC freshwater is diverted partly for domestic users (mainly the city of Amman), partly for agricultural irrigation in the northern part of the Jordan Valley (study 703 of SMARTII).

In the lower Jordan River Valley, water consumption will be relatively stable from 2012 to 2030 and will range approximately between 280 MCM/yr and 300 MCM/yr. The reason is the water scarcity, which does not allow for growing activities particularly of agriculture – the main user in this basin. Due to the yearly changes in precipitation and increasing water needs, including the citizens in Amman and neighboring municipalities, there is a permanent water deficit, which varies from 80 MCM/yr to 140 MCM/yr.

Case Studies in the Lower Jordan Valley

As obvious from the case study of Israeli municipalities in the lower Jordan River Valley, treated wastewater is considered an important agricultural resource and its utilization is recognized to be economically beneficial. Freshwater for irrigation is limited. The Jordan Valley is the major producer of dates and 80 % of the yield are exported. The water demand for this branch in the northern part during the first 6 years is 300-400 CM/yr per dunam, while mature trees demand 1,600-1,800 CM/yr per dunam. In the southern part, mature trees consume 2,200 CM/yr per dunam. Only palms are irrigated with reclaimed wastewater and they can tolerate a high salinity and 60/90 mg/l BOD/TSS.

There are 4,600 dunam of table grapes. In the past, this crop suffered from ongoing crises, but now it is expanding from year to year. 70 % of the yield are exported, corresponding to half of the grape export of the State of Israel. The main water consumption region is Fazael-Naaran, because it is the largest cultivation area. In the northern part of the lower Jordan River valley, brackish water for use in agriculture is provided from the Jordan River, which has a high saline level (1,200-3,200 mg Cl- per liter) and can only be applied to irrigate date palms. Along the Dead Sea shore, there are two spring clusters (Feshkha springs). Their salinity varies between 600 and 6,000 mg/l Cl- and the total discharge is approximately 90-95 MCM per year. Most of the spring’s water flows to the Dead Sea without being used.

Mekorot (a governmental authority) is the main freshwater supplier for the lower Jordan River consumers. It supplies the water by a local distribution network, mainly from drilling water from the mountain aquifer. This system is isolated from the main Israeli national water systems. Therefore water cannot be transferred from other sources of freshwater available in the state (study 711 of SMARTII).

In Jordan, the construction of decentralized treatment plants is planned to serve rural communities that have a poor sanitation infrastructure. Examples are two villages: Ma’addi in the Middle Jordan Valley and Maghareeb, a suburb of the city Al-Salt. Both villages have a sewage system in place and wastewater is collected in several shared cesspits that are owned and emptied by the respective municipalities. Both villages face problems of overflowing cesspits causing odor, groundwater contamination, and diseases. Agricultural production in Ma’addi primarily takes place in greenhouses, where a range of vegetables are grown. Agricultural activities in Maghareeb are dominated by olive tree plantations and fruit trees. With respect to health problems, 19 % of the surveyed households in Maghareeb and 13 % in Ma’addi state that household members sometimes face health problems associated with wastewater. The most common diseases are: Skin problems (increase in mosquito bites), diarrhea, and asthma (as a result of odors) (studies 701 & 704 of SMARTII).

Several authors criticized the way IWRM was interpreted and implemented as a relatively standardized 'package' of reforms regardless of the context. A major point of criticism relating to IWRM approaches in 'developing' and 'transitional' countries is the impression of IWRM being externally imposed or adopted to please donors. Especially with regard to the implementation of decentralized wastewater treatment and reuse (DWWT & reuse) in Jordan, there is a need for establishing a participatory framework. An example is the project for a pilot treatment plant in a suburban community of Al-Salt that strongly suffers from dysfunctional wastewater disposal (wastewater overflow, insects, diseases, smell, etc.) (details see study D7012 of SMARTII).

3.5.3 Case-specific Technical Solutions and Water Management Options

Authors: I. Heinz, A. Tamimi & N. Lienhoop

Water Management Options in Palestine

As mentioned above, groundwater & spring water are the main resources in *Jericho* (around 20,000 inhabitants). Potential water resources are flood flows from the valleys of Wadi Qilt and Wadi Nuwei'meh. Currently, Jericho has no wastewater collection system and treatment, only cesspits exist. Irrigated agriculture plays a major role, as this area is the 'food basket' of the West Bank. The total water deficit (unmet demand) will presumably increase from 0.44 MCM/yr in 2010 to 3.28 MCM/yr in 2040, if no measures will be undertaken.

Within the next 10 years, it is intended to improve water sanitation in Palestine by constructing huge municipal wastewater treatment facilities, financially supported by international donors, such as USAID and KfW. In 2000, about 73 % of the households in the West Bank had cesspit sanitation. Several small-scaled treatment plants were constructed recently in the rural areas to replace cesspits.

There are several water management options in Palestine to tackle the water problems:

- Rehabilitation of wells
- drilling of new groundwater well
- purchasing water use rights
- construction of graywater treatment plants
- demand management
- network maintenance
- construction of a wastewater treatment plant
- stormwater harvesting
- construction of brackish water treatment plants

From the regional perspective, several future large-scaled water projects are under consideration, such as the desalination of seawater and brackish water (Israeli plants; Mediterranean and Red Sea projects), the Red-Dead Sea Canal, more water from the lake Tiberius and the West-Ghor canal. As far as the Jericho area is concerned, the recommendations focus on better governance of water management, improvements in spring water conveyance systems, implementation of stormwater harvesting and artificial recharge, promotion of wastewater treatment and reuse, and more cash crops in irrigated agriculture (study 708 of SMARTII).

The IWRM approach, however, needs adequate institutional structures to achieve an effective and equitable governance of water problems. The SMARTII study 7010 provides an overview of the historical development of water regulations in Palestine. In particular, it shows what happened before and after the Oslo Agreement II of 1995. Moreover, the state institutions and non-governmental organizations in the West Bank are described. The progresses and the constraints in improving the governance are outlined as well.

Even though a Palestinian Water Law and several ministries exist, there are problems in enforcing the current legislation. The lack of investments in improving the water infrastructure, the scattered nature of the water sector and management bodies are hampering the responsible decision makers, particularly at the PWA, in adopting adequate rules, regulations, and water tariff systems. Another problem is that the Palestinians have not the full control of their resources. They are partly dependent on the water supplies from Israel and often need the approval of Israeli Water Authorities. These and other factors have led to an inefficient and uncoordinated water management.

The fundamental principles for reforming the current governance in the water sector include inter alia: a) Assigning clear responsibilities to central governmental institutions and local water management bodies; b) Public participation in water management at all levels, and c) Integrated water resources management (IWRM) to ensure efficient and sustainable water utilization.

Case Studies in Palestine

The desalination of brackish water would improve the water situation mainly in the east agricultural area of Jericho. But further measures are to be considered, such as wastewater reuse and rainwater harvesting. In the Jericho central sub-area the rapid increase of unmet demands due to declining spring water discharge and growing population calls for a better water management, including the rehabilitation of groundwater wells, intersectoral / interregional water transfer (the municipality buys the farmers’ water rights from Duyuk spring), rainwater harvesting from Al Qilt watershed, demand management, rehabilitation of water distribution networks, and water protection zones.

Different options are proposed also to decrease water shortage in the Shosa / Duyuk and Nueimah areas in the Jericho north sub-basin: Rainwater harvesting from Nueimah watershed and decrease of network losses by replacing the open channel with closed pipeline distribution networks. In studies 706 & 707 of SMARTII, the impacts of each of these options were evaluated in terms of improved water supply, costs, and economic benefits.

Water Management Options in the Jordan Valley

In the lower Jordan River Valley, water consumption will be relatively stable from 2012 – 2030 and will range approximately between 280 MCM/yr and 300 MCM/yr, as was mentioned above. The reason is water scarcity that does not allow for any growing activities particularly in agriculture – the main user in this basin. Due to the yearly changes in precipitation and increasing water needs of agricultural and municipal users, including the citizens in Amman and neighboring municipalities, there is a permanent water deficit, which varies from 80 MCM/yr to 140 MCM/yr.

The purpose of the Disi conveyer project is to pump water from Disi fossil aquifer to Amman and other governorates over a distance of about 300 km. The aquifer lies beneath the desert in southern Jordan and north-western Saudi Arabia. The project will be finished by the end of 2013. The additional water supply will amount to around 100 Mm^3/yr. It will mitigate water shortage for Amman, but not completely resolve the water deficit. However, it will play a crucial role in water reallocation on the basin level. For instance, the water volume of about 40 Mm^3/yr currently pumped from the Jordan Valley basin via the King Abdullah Canal (KAC) to Amman can be reduced. The water released by that, approximately 20 Mm^3/yr, can be used for agricultural irrigation in the lower Jordan valley. Furthermore, it will positively affect the overexploited groundwater resources by slowing down the dramatic decline of their water levels.

Another measure is the construction of the Kufranjeh dam to utilize the runoffs flowing into the Jordan Valley and Dead Sea. The dam will be located south of wadi Shueib with a storage capacity of 5 Mm^3, operation will start presumably in 2015. The water will be used mainly for agricultural irrigation in the southern Jordan Valley. Further options are more use of reclaimed water by construction of three further wastewater treatment plants and enhancing the efficiency in agricultural irrigation (studies 706 & 707 of SMARTII).

Case Studies in Jordan

As mentioned above, reuse of treated wastewater for irrigation purposes in agriculture plays an important role in Jordan. The objective of the SMARTII 703 study was to assess the economic impacts of using treated wastewater (TWW) compared to freshwater in the Jordan Valley. The analysis addressed two basins in the Jordan Valley using two different water qualities: a) TWW comes from King Talal Dam (KTD) and is blended with freshwater in the first basin (Basin 20) and b) freshwater that originates from the Yarmouk River in the northern part of Jordan flows through the King Abdullah Canal (KAC) and is used in the second basin (Basin 10).

As evident from the case study SMARTII 711 dealing with the Israeli municipalities in the lower Jordan River Valley, there are substantial sources of residual waters, such as brackish water of various degrees of salinity and treated effluents. A proper mixing of these waters can be applied for the irrigation of different crops. Agriculturally used freshwater can be released for other uses (domestic, tourism, industry, and water-sensitive crops).

Apart from water shortage, poor sanitation can be found in Jordan, especially in rural areas. As mentioned above, the water problems were highlighted and two alternative technologies for wastewater treatment and reuse (DWWT & reuse) were assessed in a case study covering the Eastern part of Ma’addi, an agricultural village in the Middle Jordan Valley, and the Maghareeb village, a suburb of the city Al-Salt. The DWWT & reuse technologies were: 1. Sequencing batch reactors and 2. constructed wetlands. In particular, the socio-economic impacts on different water users, such as households and farmers, were evaluated in terms of costs and benefits (studies 701 & 704 of SMARTII).

As mentioned above, there is a need for establishing a participatory framework especially with regard to the implementation of DWWT & reuse projects in Jordan. To assess the impacts of DWWT & reuse in Jordan, the SMARTII project covered the construction of three treatment facilities on the pilot scale, which serve between 50 and 300 population equivalents. All three facilities are located in Wadi Shueib in the Balqa Governorate, near the city of Al-Salt. The technologies implemented are membrane bioreactor technology, sequencing batch reactor technology, and constructed wetland technology. The treated effluents from the pilot plants will be reused locally for agricultural or landscaping purposes.

While reuse practices as well as decentralized wastewater treatment have already been introduced separately in Jordan, their combination in small to mid-sized rural and suburban municipalities is a novelty. The introduction of such community-based DWWT & reuse infrastructure requires some decentralization of institutional and managerial arrangements concerning budgeting, planning, and operation & maintenance responsibilities. Consequently, participatory planning will play an essential role in preparing municipalities for the implementation and operation of such systems. It will help to resolve problems, such as dysfunctional local wastewater disposal, which affects villagers by causing health risks, odor, and comparatively high sanitation cost (study 7012 of SMARTII).

3.5.4 Summary and Conclusions

Socio-economic studies on water management address a broad spectrum of issues relating to different performance goals, such as economic efficiency, financial affordability, social equity, and participation. Water problems in terms of shortage and poor quality can have serious adverse impacts on the welfare of communities and societies. Such a situation currently exists in Palestine and Jordan, calling for improvements of water utilization. Subject of the socio-economic studies prepared for SMARTII is the economic efficiency of various water management options and the institutional prerequisites for their implementation. In Palestine, particularly in the West Bank, and in the lower Jordan River Valley priority is given to the following technical solutions:

Water Management Options in the West Bank

- Rehabilitation of wells.
- Drilling of new groundwater well.
- Purchasing water use rights.
- Construction of graywater treatment plants.
- Demand management.
- Network maintenance.
- Construction of wastewater treatment plants.
- Reuse of treated wastewater.
- Stormwater harvesting.
- Construction of brackish water treatment plants.

Water Management Options in the Lower Jordan River Valley

- Regional water transfer.
- Construction of wastewater treatment plants.
- Reuse of treated wastewater.
- Construction of dams.
- Improvement of irrigation efficiency.

As shown by the case studies, it depends on the local conditions, which of these options can be considered. In the Jericho east sub-basin, for instance, the desalination of brackish groundwater, together with the reuse of treated wastewater and stormwater harvesting, should be short-listed. By these measures, the increase in water demand of irrigated agriculture can be met in the next 20 years. By applying the cost-benefit analysis (CBA), recommendations relating to the temporal sequence of these projects to implement the economically most efficient IWRM strategy can be derived (cf. chapter 6 below).

In the Jericho north sub-basin, replacing open channels with a pipeline system and stormwater harvesting are the only feasible options. However, even if both will be implemented, there will still be a water supply deficit in the future due to the water needs of irrigated agriculture - the main user in the Shosa / Duyuk and Nueimah areas. Consequently, both projects should be realized soon – no temporal sequence is needed. A similar situation can be found in the lower Jordan River valley, where all the options mentioned above (e.g. reallocation of Disi water, Kufranjeh dam, etc.) and further projects are required simultaneously in order to mitigate the ongoing water shortage.

Especially in Palestine, many institutional barriers for a more efficient water and wastewater management are to be overcome. As a prerequisite, the following reforms of the water governance scheme are needed:

- Review of the contradictory laws and regulations causing the fragmentation of water management institutions. This aim can be achieved by amending the Water Law and the Local Government Law to accommodate the management and regulatory functions of utilities, municipal corporations, and water source owners.
- Creation of a body to facilitate communication and sharing of knowledge by the three countries Jordan, Palestine, and Israel regardless of the future political agreements.
- To recognize the necessity to promote Public Private Partnerships (PPP) on the local and regional levels.
- Enhancing the capacity of organizations managing the reuse of wastewater and encouraging farmers to use different water qualities for more profitable crops (such as palm and cash crops).

In general, water sector has to be reformed as a starting point of the entire socio-economic development on the local and regional levels.

3.6 Capacity Building and Dissemination

Involved Institutions: UKA, UFZ, BDZ, ECO, MWI, PHG, PWA, BALQ

Spokesmen WP9: W. Ali, M. v. Afferden

Authors: M. v. Afferden, W. Ali

3.6.1 SMART Capacity Development Program

The successful and sustainable implementation of an operational Integrated Water Resources Management requires an elaborate capacity development (CD) concept and program. The complexity of (sustainable) water management requires equally complex solutions; the knowledge and capacity generated in this problem solution process “has to be deeply rooted within the originating region” (Leidel et al. 2011), in which everyone is a stakeholder (GWP 2000). Only an accompanying CD concept opens up the possibility to systematically identify existing knowledge and capacities as well as to expand and enhance them in order to implement advanced technological and organizational innovations that lead to comprehensive and sustainable water management.

IWRM and CD processes are interdependent and cannot exist independently. For both IWRM & CD, neither a blueprint nor one universally valid, unambiguous definition exists. Still, basic principles have been conceived for these interdependent processes – first agreed upon at the Dublin and Rio conferences – independently of natural, hydrological, economic, and societal factors and characteristics, which vary considerably from country to country (GWP 2000). The second of the four Dublin principles requires a participatory approach to water management, “involving [all] users, planners, and policy makers at all levels” (GWP 2000), and has to be addressed in particular by a CD program.

Against this background and inspired by the definition of Alaerts (2009) and UNDP (2005), CD should be understood to be the process that strengthens and expands existing skills and capabilities of individuals, organizations, and the society to resolve identified (water) problems targeted, to learn from this experience, and to generate new problem-solving knowledge.

Such a CD program must be developed to the extent possible in close cooperation with all project partners, involving stakeholders, including ministries, local authorities, NGO's, professionals, and community members to adequately take into account holistic solutions and to ensure sustainable implementation in the corresponding region.

Figure 127 shows the individual steps of the CD development process. It has to be understood as an iteration process cycle in order to be able to make adjustments, to include modifications, and to adequately accompany the ongoing IWRM cycle.

The fundamental goal is to tackle (water) problems in close relation to politics and methods of development, while considering the potential, limits, and needs of the people in the region. In this context international research, inter alia the UNDP (2005), outlines that CD programs, measures, and activities take place on three different, but not uniquely separable levels; this concept is commonly referred to as the "multi-level approach" and consists of the following levels:

Individual level: Predominantly addressed by training and education activities, allowing individual participants to enhance existing and build up new knowledge. This adapting to change process through individual learning requires the meaningful and direct integration of the participants' learning prerequisites: Knowledge, capabilities & abilities, attitudes & behavior.

Organizational level: Includes activities to support and improve processes within organizations, i.e. defining a strategy. This level is strongly linked to the individual level; measures address improved institutional performance (Leidel 2011).

System level: Addresses the framework conditions that influence the performance of the individual and organizational levels and, thus, sustainable development; it is often called "enabling environment".

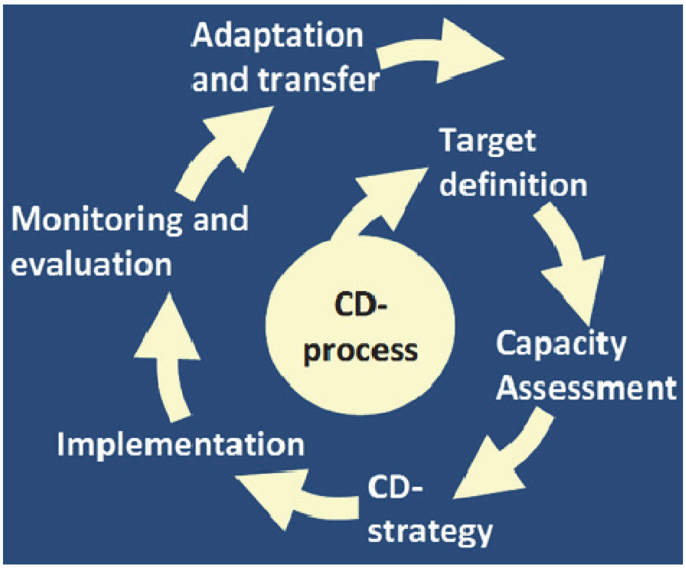


Figure 127: Individual steps of CD development processes

Within the framework of the SMART project, these general guidelines and principles for a supporting CD program have been considered as far as possible. A region- and problem-specific CD strategy was developed systematically and implemented. The fundamental objective can be summarized as: “Reducing vulnerabilities and increasing capacities” or even more pointedly: “Strengthen strengths, weaken weaknesses” by means of targeted and tailor-made CD measures and activities either directly or indirectly on all levels, if possible. This fundamental objective was complemented by more differentiated targets. SMART CD measures and activities are defined to:

- Improve the availability of information as well as the communication and action ability of all project partners, stakeholders, and end users;
- Improve human resources development through school education, university education, vocational education, and institution development (Figure 128)
- Support and facilitate the implementation of the IWRM tools and technologies developed in SMART I and II.

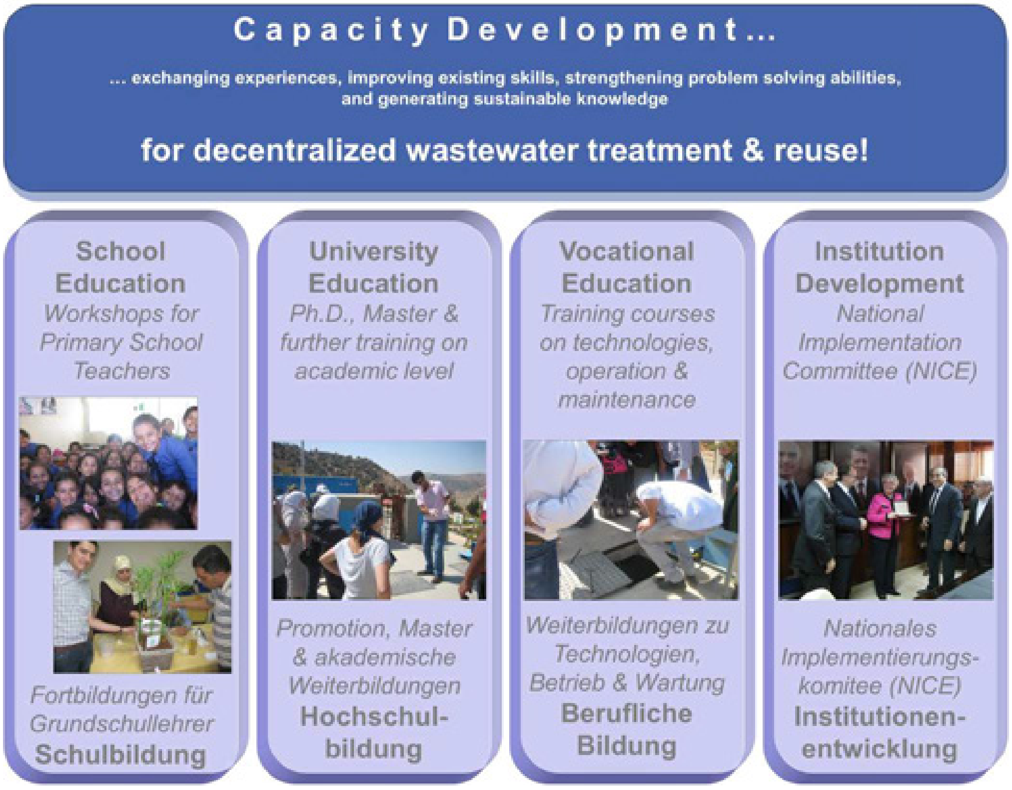


Figure 128: Overview of the target groups for CD measures to support the implementation of decentralized wastewater management in Jordan.

This report describes all CD measures taken within the SMART project, provides a selective evaluation, and formulates some recommendations for future activities. Furthermore, the report contains a small selection of literature and an annex with single project development areas for superordinate activities.

3.6.2 School Education

The Sustainable Management of Available Water Resources with Innovative Technologies (SMART) research project supports the Jordanian and Palestinian governments in adopting policies towards a sustainable water use. One key element of this approach is the effective treatment and adequate reuse of wastewater.

Treating and reusing wastewater requires new technologies, specific regulatory framework conditions, and adequate operation and maintenance structures. In addition to these “technical” aspects, effective implementation also needs the acceptance of this treatment & reuse concept by the population and the understanding of human behavior and its impact on the sustainable reuse of treated wastewater.

To address this issue, we designed and developed a capacity development program for primary/ basic school teachers and students, which was entitled: “WATER FUN – hands, minds, and hearts on Water for Life!" (Figure 129 shows the cover of the teacher’s handbook). This country-specific program effectively delivers the message and aims of the Jordanian and Palestinian strategic master plans for wastewater management through a didactic reduction for basic/ primary school students (5th/ 6th grades).

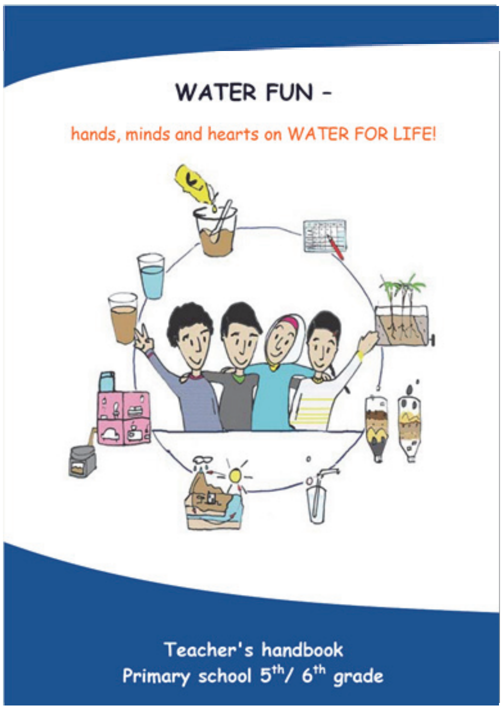


Figure 129: Cover of the teacher’s handbook.

In Palestine the program is supported by the Palestinian Water Authority (PWA), the Palestinian Hydrology Group (PHG), and the Ministry of Education (MOE), the objective being to facilitate the implementation of new water management approaches (e.g. decentralized wastewater treatment, reuse technologies).

The Palestinian National Authority established the Palestinian Water Authority (PWA, founded in 1996) following the signing of the Oslo Agreement in 1995. The PWA prepared the National Water Plan of 2000, which sets the direction until 2020 and proposes specific actions to achieve its goals.

It describes the role of service providers and shifts the functions of the PWA to regional utilities for operations, maintenance, repairs, wastewater collection and treatment, bulk water supply, water reuse, and allocation for industrial and agriculture use. The PWA strategic wastewater management plan focuses on the long-term objective of connecting 75 % of the population in municipalities and 50 % of the population in rural areas to the water network by 2020. In 2002, the PWA issued the Water Law (3/ 2002). This law aims at developing and managing the water resources, increasing their capacity, improving their quality, and preserving and protecting them from pollution and depletion.

In Jordan the program is supported by the Jordanian Ministry of Water and Irrigation (MWI), the Water Authority of Jordan, and the Ministry of Education (MOE). In 2008, the “Royal Commission on Water” prepared a new water strategy entitled “Water for Life, Jordan’s Water Strategy 2008 - 2022” that was adopted in February 2009. This new strategy reflects the policy of Jordan for the whole water sector and includes wastewater treatment in semi-urban and rural areas by decentralized treatment technologies. The strategy specifically focuses on wastewater treatment and reuse and defines concrete aims and requirements (MWI 2009):

- All the major cities and small towns in Jordan will be provided with adequate wastewater collection and treatment facilities.
- Decentralized treatment plants shall be built to serve new urban settlements, semi-urban and rural communities.
- In terms of wastewater reuse, the 2009 strategy states that treated wastewater shall be fully reused by 2022.
- Treated effluent complies with recently established national standards (JS893-2006) and all treatment units meet the quality required for use in agricultural activities and other non-domestic purposes, including groundwater recharge.
- And last but not least, this water strategy calls for the introduction of water awareness programs in the form of events and curricula at all school grades. In this connection, the CD program or teaching unit "Water Fun ... Water for Life” was developed and will be presented and explained below.

3.6.2.1 Pedagogical Concept and Objective of the Teaching Unit

The pedagogical concept primarily considers the special needs of Jordan and Palestine concerning water resources, water management, and treated wastewater reuse possibilities. The research performed in other working packages of SMART are made available for teachers and consequently for their primary/ basic school students after a didactic reduction, which addresses the countries strategic water policy aims.

The teaching unit is designed to enhance the reflection process regarding wastewater components and provides teachers and students with information to understand the possibilities of wastewater treatment and its reuse purposes in decentralized systems. In addition, classroom experiments and activities are described, by means of which students and teachers are to understand and accept wastewater as a valuable resource, particularly in regions with water shortages.

The main objective of the Water Awareness Program "Water Fun … Water for Life" is to support human resources development (HRD), which represents one of the cross-section elements to accomplish economic and social development in all primary/ basic schools, to reach all young people regardless of their socioeconomic situation and to strengthen their willingness to take water conservation actions. Diverse class behaviors, water problem perceptions, awareness levels related to the water situation, and scarceness problems will be integrated: We "pick up" the students (and the teachers) there on their way, where they are at this moment and they should have the opportunity to develop the analytical, social-emotional, and behavioral skills they need to face consciously and in a reflected manner real-life problems as well as challenges and solutions now and in the future.

The teaching unit title is program, and the title elements represent the concept:

Water Fun - Students (and teachers) should have fun during the teaching units and have the opportunity to bring in their creativity, live their curiosity, and exercise and deepen critical thinking processes. Because, what is fun will be liked and what people like, they will protect. This pedagogical concept is far away from any kind of disaster education, which attempts to impart lesson contents with a moralizing finger. Students should not be blamed for the current (water) situation in their country. They should not becriticized, but develop awareness, strength, and courage to take responsibility for water protection. – *Disaster education is avoided!*

hands, minds and hearts on - The progressive education triad addresses and integrates in a balanced and holistic way the active and critical coverage of the teaching topic and its elements. Each unit of this education triad stands for a certain kind of skills/ disposition, which already exists and has to be further developed:

hands ⇨ life skills ⇨ actions
minds ⇨ cognitive skills ⇨ awareness & knowledge
hearts ⇨ values ⇨ attitudes and behavior

Specifically chosen methods structure learning processes in order to convey knowledge, to raise awareness, and to support attitude and, hopefully, behavior and action changes.

Hands-on learning processes replace teacher-centered teaching processes!

Water for life! - Water is not just a resource, but a source of life. This title element reflects the country's strong orientation towards sustainable water management, the Jordanian Water Strategy (2009-2022), and the international UN Water Decade (2005-2015) with the same title element. - *Education for sustainable development is education for sustainable water management!*

3.6.2.2 Didactic – Methodical Principles

Natural science and environmental education at primary/ basic schools should focus on the development of the following skills and capabilities of students:

They should develop interest in and joy…

- … thinking about the phenomena of nature and technology.
- … asking questions.
- … developing self-confidence.
- … finding out and understanding something.
- …adopting a research-based thinking.
- … taking challenges in thinking processes.
- … learning to experiment.

The following characteristics of school education are essential to support these learning processes:

The teaching content should originate from the real life of the students. The artificial wastewater produced by the students contains ingredients, which they can also find in the wastewater at home.

The ideas and observations of students should be considered. Students already have certain and individual experience with respect to wastewater, which they can contribute during wastewater production, analysis, water filtering processes, final assessment, and action. This will expand their knowledge and learning can take place.

The independent thinking and action must be encouraged. During their group work, the students need time and space to express and discuss what they know and think. The teacher should leave his/ her teacher-centered teaching position; she/ he is a partner, who makes learning in this way possible.

The teacher should act restrained in order to give students a chance to learn how to discover, investigate, and explain. No student learns discovering, investigating, explaining through lectures and explanations from the teacher. This has to be done by the students themselves, supported by e.g. open questions or nonverbal learning impulses by the teacher.

Students must have the opportunity to discuss and to learn about the statements of others. In this way, students develop, according to their individual knowledge level, an understanding for new contents and cooperative learning and working processes.

In summary: Our conception of (school) education has to enable students to learn in a problem-based manner and has to be student-centered, competence- and experience-based in this respect.

The international perspective of sustainable environmental education goes a step further:

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (United Nations, 1987).

One of the goals of education for sustainable development is to provide the individuals with skills that will enable them to shape their future activities and responsibilities. To be responsible means to consider that future generations have the same right to natural resources as we do today. These skills can already be conveyed on the primary school level, if appropriate methods are selected. The methods of pure knowledge transfer (for example, ex-cathedra teaching) do not achieve this goal. Already in the classroom must the students have the possibility to develop their own ideas and the opportunity to exchange these ideas, to reflect on them, and to put them directly into practice. The targeted students' skills need to address all areas of development of a primary school child: Practical (hands-on), cognitive (minds-on), and emotional (hearts-on). Students as learners are seen holistically.

An investigation led by the USAID Jordan (2010) supports this perspective. The interviewed Jordanian adolescents, for example, prefer hands-on experience as the most useful source of information for developing their awareness and influencing their actions. It was found that those young people who had actively participated in environmental activities had a better understanding of practical issues of conservation and protection.

In order to guarantee that students are capable of reflecting and acting sustainably, the following methods and action forms have been chosen: Contemplating about drawings, thinking and studying, dialog, discussion and presentation, practical experiments, practical work, compilation, planning, action development, etc. The media and materials used for these purposes are given below.

3.6.2.3 Description of Main Media and Materials

"Water Fun - hands, minds and hearts on Water for Life!" is a didactic-methodical package that currently contains the following media and materials for use by each participating teacher and transmission to students and interested colleagues:

1. The student's workbook contains artistic and child-friendly drawings to support the work process of the entire teaching unit. We have carefully selected the steps that are presented in detail so that students can work largely independently in their groups after an explanation and/ or demonstration by the teacher. The student's workbook contains no text, except for the unit titles. Students are to focus more on their group work and tasks. In addition, students can identify with the illustrated children, landscape, houses, and activities in groups. Each teacher receives five student's workbooks: One for himself and four for the group work activities. Teachers can reuse the set of 5 books by laminating the page of the book, on which students enter their names. When students enter their names with a non-permanent marker, they can easily be wiped away after the completion of the project.

Figure 130: Teacher's handbook (excerpt from the Arabic version).

2. Each participating teacher receives a teacher's handbook (Arabic & English; Figure 142 shows an excerpt from the Arabic version), which explains the individual unit in detail, formulates learning objectives and key questions, indicates required materials, and outlines the unit. Transitions between the units are not described explicitly, because this depends on the implementation possibilities (single lessons, project days, project week,…). The transitions result logically from the conceptual association. Thematic or methodological extensions are not specified, because these depend mostly on the learning groups, their knowledge and capabilities, which teachers may assess far better. The intention of this handbook is to provide an orientation and a basis for the pilot trainings as well as for the discussions and evaluations. Necessary adjustments of the school curriculum and assignments are lacking, since we have

neither the Palestinian and Jordanian school curriculum nor school books in English from both countries.

3. The didactic-methodological package also includes all materials required for the classroom experiments. These are common household objects that are easily available, and most of them are reusable. Consequently, they do not strain the school budget, if they need to be replaced.

3.6.2.4 Teaching Unit Overview

Table 43: Overview of the teaching units

Unit title	Learning content	Action form	Time (min)
1. Water cycle - water in nature	The students are invited to listen to the "water music" and the "story" of the water cycle illustrated in their workbook. Students can/ may recapitulate their knowledge about the water cycle and its basic mechanisms.	Group formation Making assumptions Summing up knowledge	30' to 45'
2. Household water consumption in Palestinian National Authority/ Jordan – water in our life	Students learn where and how in their homes water becomes polluted from use. They can realize where it goes when it leaves their homes and that it has to be cleaned to prevent environmental contamination.	Identifying Estimating Calculating	30' to 45'
3. Water pollution – artificial wastewater production and analysis	Students produce wastewater with simple, safe ingredients and they can observe how the water changes gradually. They learn how to define the term “clean water” and “quality guidelines”. They understand the principles of water analysis and learn how to measure different substances in water.	Experimenting Comparing Evaluating	45' + 60'
4. Wastewater treatment I – constructing a filter	Students construct filters for cleaning (their) wastewater by building layers from different materials and comparing the filter results. They discover that different filter materials produce different filter results. They discuss functionalities of each filter and reflect on which material or mechanism is best suitable for what kind of wastewater component.	Holistic material experience Experience transfer into practical work Comparison and dialog	90'
5. Wastewater treatment II – constructing a wetland	Students learn that constructed wetlands are a modern ecological technology, where principles of nature are used to clean wastewater. The students build the wetland model themselves and handle technical equipment. Thus, they will get an insight into the practical work of engineers and scientists.	Experience transfer into practical work Comparison and dialog	90'
6. Treated wastewater – reuse possibilities	Students learn about water quality guidelines and compare these with their "pollution points" from the wastewater analysis. Students discuss treated wastewater reuse possibilities in their daily life as a means to conserve drinking water. They apply their acquired experience and knowledge.	Presentation, comparison and discussion Recording, structuring, processing, and evaluating information Developing, presenting, and implementing ideas	90'

3.6.2.5 Implementation Strategy

Since as many students as possible are to participate in the lessons in the course of the SMART project, 50 teachers in Jordan and 50 teachers in Palestine were trained in workshops of several days duration to use the media and materials for the students. After the workshops, the materials stored at Al-Balqa Applied University, Salt, in Jordan and

at the Palestinian Water Authority, Ramallah, in Palestine were distributed to the schools by the representatives of these institutions (SMART project counterparts). Then, the teachers started to implement the teaching unit.

Each workshop comprises an opening session, usually in the evening before the first workshop day, two days of theoretical and practical introduction to the teaching unit, pedagogical concept, didactic-methodological principles, the media, and materials, and during the last (3rd) workshop day, an excursion to the SMART Research, Demonstration, and Training Facility for Decentralized Wastewater Treatment and Reuse in Fuheis, Jordan. Figure 131 shows photos taken during one of the last visits in 10/ 2012.

Figure 131: Excursion to the SMART Research, Demonstration and Training Facility for Decentralized Wastewater Treatment and Reuse in Fuheis, Jordan

3.6.2.6 “Water Fun – Water for Life” in Jordan

In Amman, Jordan, 3 workshops were conducted in April 2011 and in October 2012 for a total of 54 teachers from Central, North, and South Jordan. The following figures show the participants and the distribution of the 54 trained teachers/ schools in Jordan (see Figure 132).

Figure 132: Participants and the distribution of the 54 trained teachers / schools in Jordan

3.6.2.7 Feedback from the Jordan Teachers Regarding Their Implementation Experience

The teachers reported their project implementation mainly by means of pictures and videos, even though feedback sheets were made available. Some pictures and a few comments are presented below (Figure 133).

Figure 133: Impressions of the implementation in South Jordan

Mr. Qublan from South Jordan sent the pictures shown below. As he had no plants for the wetland model, he and his students used two plastic roses as a symbol (Figure 134). The Water Fun project leaves space for creative solutions. As one of a few teachers, he had the opportunity to make a field trip with his students to the treatment plant in Wadi Musa (Figure 134).

The pictures speak for themselves: They reflect joy, creativity, and enthusiasm for learning: Simply “Water Fun”!

Mrs. Momani from North Jordan sent the following pictures:

Figure 134: Impressions of the implementation in North Jordan

3.6.2.8 “Water Fun – Water for Life” for Palestine

In December 2011, a workshop for six Palestinian trainers from PWA, MOE, and PHG took place in Amman, Jordan. Some impressions of this workshop are given below (Figure 135 to Figure 139):

Figure 135: The six trainers from Ramallah, the Palestinian National Authority, and one teacher from Amman, Jordan, perform student experiments on the production, analysis, and purification of artificial sewage.

Figure 136: “Hands-on learning”: Artificial sewage analysis and assessment.

Figure 137: Teamwork: constructing a wetland.

Figure 138: Excursion to the SMART – Research, Demonstration and Training Facility for Decentralised wastewater treatment and reuse

Figure 139: Good “work”: after handed over the Certificates by BDZ.

The PWA/ Water Fun team provided various action plans in order to report the workshop preparations for Palestine. Due to the political situation in the country, the workshops had to be postponed several times. The last action plan is shown below. It agrees with the data and activities reported later.

Team:

- Subhi Samhan, Shahd Tibi, and Ghaleb Bader (PWA);
- Manar Nazzal & Shireen Zidan (PHG);
- Ayed Asfour, Murad Abdulghani, and Majdi Muammar (MoE).

The group re-set the original timeframe due to the unclear situation in the area and the strike that took several months and limited the possibility of moving around in the country (Table 44).

Table 44: Overview of the action plan for implementing "WATER FUN - hands, minds and hearts on WATER for LIFE!"

Activity	Comments	Time Frame
Selection of school teachers (trainees)	The 64 schools are distributed over three groups covering all the area of the West Bank. The priority in selecting the 64 schools lay on the active schools that participated in previous trainings with PWA and showed the needed discipline and commitment. In addition, the schools to be selected must have a laboratory or an environmental club, among other things. Each session took two training days.	Done
Receipt of material	The material was checked by the team, and it had been distributed over the three areas where the training sessions will be held. Each area had confirmed receipt of the material.	Distribution to areas Sept. 27, 2012
First training session	This session will target the South: This area includes Hebron and Bethlehem.	Sept. 29, 2012
Second training session	This session will target the central area: This area includes Ramallah and Al Bireh, Jericho, Jerusalem, and Salfit.	Oct. 6, 2012
Final training session	This session targets the North: This area includes Nablus, Jenin, Tulkarem, Qalqilya, and Tubas.	Oct. 14, 2012
Preparing the training program	The training session program was prepared by the team members to cover the two-day period.	Done
Preparing the training presentation	The training presentation was prepared by the team members.	Done
Follow-up	Following up the implementation steps, preparing the material, the logistics arrangements.	Sept. 1, 2012

It was agreed that the implementation of the program by the teachers at the schools and the submission of the final report by each teacher were to be finalized by Nov. 15, 2012." The training events and the training program are summarized below (Table 45):

Table 45: Summary of the training events in Palestine

Area	Governorates	Place	Date	Number of participating schools
Southern area	Bethlehem, Hebron	Al Hussein training center, Hebron	9/29 - 30/2012	20
Central area	Ramallah, Jerusalem, Jericho, Salfit	Caesar Hotel, Ramallah	10/6-7/2012	20
Northern area	Jenin, Tulkarem, Tubas, Qalqilya, Nablus	Training center, Nablus	10/13-14/2012	25

The training course focused on the use of institutional mechanisms to transfer knowledge to next generations to strengthen the capabilities of civil society of participating in environmental sustainability efforts. The participants were divided into four groups, each group had the chance to work jointly during the training. This helped raise the teamwork spirit and enabled the participants to compare their work with each other.

Figure 140: During the formation of groups

Figure 141: Calculating water consumption

Figure 142: Comparison between samples

Figure 143: During analysis of the samples.

The team trained 65 schools covering all Governorates according to the following program (Table 46):

Table 46: Training program and topics of the training sessions in Palestine.

	Session summary	Comments and action points
Day One		
Introduction to the training program	Introduction to the program, objectives, and overview of units. This was backed up with an introduction of the content to be discussed within the following two days.	This day was not educational, but more of an introduction to the program and its expected outcomes. This introductory meeting was followed by a coffee break to break the ice between the trainers and the participants.
Water cycle and water pollution	This session was spent on discussing four main activities: Activity/ Unit 1: Water cycle, water in nature. Activity/ Unit 2: Household water consumption in Palestine. Activity/ Unit 3.1: Water pollution, artificial wastewater production. Activity/ Unit 3.2: Water pollution, artificial wastewater analysis.	These units provoked discussion; the participants were introduced to the principles of wastewater treatment and reuse. The vertical filter was prepared at the end of the day by the participants as a trial without discussing the results obtained from the constructed filter. This step was discussed on the following day and the filter was re-constructed again by the participants.
Day Two		
Wastewater Treatment and Reuse	This day was spent on discussing the rest of the 6 activities: Activity/ Unit 4: Wastewater treatment I, constructing a filter. Activity/Unit 5: Wastewater treatment II, constructing a wetland. Activity/ Unit 6: Treated wastewater, reuse possibilities.	This day started by reviewing the previous day's input and evaluating the training material and program. Closing meeting: Certificate hand-over, workshop resume and evaluation, implementation strategy discussion, follow-up options.

3.6.3 University Education

3.6.3.1 SMART – PhD Program

Capacity development of young scientists coming from all participating countries of the SMART project is an important activity. One element is the multinational and interdisciplinary PhD program associated with the SMARTII project. 15 PhD students were selected in the partner countries. Their PhD theses were integrated into the SMART project and fit to the SMART objectives. The SMARTII - PhD program was designed for students from Jordan, Palestine, Israel, and Germany to promote their intercultural abilities and widen their scientific horizon by studying and working within an international project team at universities or research institutions of the four partner countries.

The aims of the PhD program in the SMARTII project were:

- Formation of specialists in IWRM-related research areas.
- Integration of young scientists into an international research project.
- Scientific exchange on the interdisciplinary and multinational level.
- Strengthening of intercultural competences.
- Long-term network building.

Table 47: PhD candidates of the SMART project

No	Family and first names	Country	Title of the thesis
01	ALFARO, Paulina	Germany	IWRM approach for Wadi Shueib
02	AL-HEJOJ, Ikhlas	Jordan	Macro fauna and flora as indicators for water quality in the lower Jordan River catchment- Eastern side
03	Al-MOMANI, Thair	Jordan	Potential of managed groundwater recharge in the lower Jordan valley and its side wadis
04	GHANEM, Issam	Palestine	Preliminary: Integration of alternative energy into the water sector
05	GRIMMEISEN, Felix	Germany	Groundwater protection in karstic aquifers influenced by urban areas in semi-arid regions
06	LEICHT, Miriam	Germany	Correlation of water quality and agronomic risks and benefits for irrigated agriculture in Jordan
07	MUSALLAM, Shadha	Palestine	Application of xenobiotics as indicators for groundwater flow in a carbonate aquifer system
O8	RIES, Fabian	Germany	Hydrological modelling of catchment scale runoff-recharge processes under a strong, semi-arid, climatic gradient
09	SAGIV, Yair	Israel	Preliminary: Reuse of wastewater
10	SCHMIDT Natalie	Germany	Elimination of anthropogenic trace organics during soil passage
11	SHATNAWI, Nawras	Jordan	Evaluation of brackish water resources in the Jordan Valley
12	SHAWAHNA,, Ayman	Palestine	Preliminary: Groundwater modelling and IWRM of the Uja-Jericho area
13	WEISS, Hila	Israel	Preliminary: Hydrogeology and hydrochemistry of brackish water occurrence
14	XANKE, Julian	Germany	Preliminary: Managed aquifer recharge
15	WILSKE, Cornelia	Germany	Application of a combined REE, stable isotopes, and organic components approach to evaluating the groundwater flow system between Jerusalem/Ramallah and the Dead Sea

In addition to the PhD program, many master's theses were supported by the SMART project.

The PhD program is different for every participating institution and country, allowing for meeting the different demands of each partner. With their work and enthusiasm, the young scientists contributed to the overall success of the SMARTII project.

The SMARTII - PhD program was based on similar PhD programs of the GIJP and the SMART I projects. All these PhD programs were evaluated to be very successful capacity building tools. The above table (Table 47) shows the names and the countries of the participants of the PhD program of the SMARTII project.

3.6.3.2 SMART Advanced Training for Scientists – SAT Program

The SAT program focuses mainly on WWT&R management, water protection zones, water quality, and training on newly developed software dealing with groundwater management. This program is designed to facilitate the sustainable implementation of the developed IWRM tools and technologies.

The major target groups addressed by this program consist of professionals and stakeholders. The training covers both technical and management issues to strengthen the local expertise on a short-term basis.

The following table lists all participants in the SAT program during the SMARTII phase (see Table 48).

Table 48: Participants on the SAT program during SMARTII phase

Name of the participants	Institution	Cooperation in GER with	Objective/ work area
Prof. B. Abbassi	Al-Balqa Applied University, Jordan	Prof. A. Nassour, University Rostock, Germany	Wastewater, Biogas
Dr. Hani Omoush	Co-worker of Prof. E. Salameh, Al-Bayt University, Jordan	University of Bonn, University Göttingen, Karlsruhe Institute of Technology, Germany	Interpretation of geophysical profiles
Dr. Jawad Hasan	Al Quds University, Palestinian Territories	Karlsruhe Institute of Technology , Water Technology Center, Karlsruhe, Helmholtz Centre for Environmental Research, Germany	Tracer and isotopes, publication Ein Feshka

Table 48 Part2: Participants on the SAT program during SMARTII phase

Name of the participants	Institution	Cooperation in GER with	Objective/ work area
Dr .Marwan Ghanem	Bir Zeit University, PHG, Palestinian Territories	Karlsruhe Institute of Technology, Water Technology Center , Karlsruhe, University of Aachen, University of Freiburg, Germany	Chemical analysis
Dr. Amer Marei	Al Quds University, Palestinian Territories	Karlsruhe Institute of Technology, Germany, University of Göttingen, Germany, Helmholtz Centre for Environmental Research, Germany,	Isotopes, MAR
Dr. Ali Sawarieh	National Ressource Authority (NRA), Jordan	Karlsruhe Institute of Technology, Germany	Geological mapping
Ali Omar Hamad Al-Brezat	Ministry of Water and Irrigation, Jordan	Karlsruhe Institute of Technology, Germany	Advanced WEAP training
Hadeel Al-Smadi	Ministry of Water and Irrigation, Jordan	Karlsruhe Institute of Technology, Germany	Advanced WEAP training
Ma'moon Yousef Naser Ismail	Ministry of Water and Irrigation, Jordan	Karlsruhe Institute of Technology, Germany	Finite Element Groundwater Modeling
Dr. Emad Akawwi	Al-Balqa Applied University, Jordan	Karlsruhe Institute of Technology, Germany	Tracer

3.6.4 Vocational Training

On the level of professionals from government, industry, and university, the project activities were supported by specialized workshops. On this level of CD within the SMART project, local as well as international experts were consulted to identify and increase the existing capacity. The CD activities contributed to improving existing skills in the fields of analytical and monitoring methods, practical training on technologies, and management concepts as well as to identifying the specific country needs and priorities in terms of an integrated water resources management. The main workshops and training activities are summarized below.

3.6.4.1 Water Quality IWRM Workshop: Managed Aquifer Recharge

The SMART set of innovative technologies for a sustainable management of water resources includes “Managed Aquifer Recharge” (MAR). Specifically in arid regions, MAR provides for water storage and supply of an additional water source e.g. for irrigation.

The SMART workshop on “Managed Aquifer Recharge”, which was held in Jericho on February 29, 2012, focused on hydrogeological, chemical, technological, environmental, and socio-economic aspects of MAR in the Jericho sub-basin (Palestine) (see Figure 144).

The workshop addressed representatives of the local farmer association, Jericho municipality, Ein Sultan water user association, Environmental Protection Authority, Palestinian Ministry of Agriculture, and students from the Al-Quds University and other universities. Approximately 70 participants attended the workshop. It was organized by Al-Quds University, the Governorate of Jericho and the Jordan Valley, and the Ministry of Agriculture. The lecture program was developed by the spokespersons of the work package “Managed Aquifer Recharge”.

Figure 144: Opening session, from left to right: Eng. Isam Nofal (Ministry of Agriculture, Director of Water Department), Eng. Qasem Ado (Deputy Minister of Agriculture, President of Department Soil and Agriculture), Eng. Majed Al Fityane (Governor of Jericho and Jordan Valley), Dr. Amer Marei (Al Quds Universtiy).

Al-Quds University and the Ministry of Agriculture agreed to produce and publish the outcome of the work package, including water quality information and groundwater salinity maps. The booklet had been published in Arabic and English.

The background of the workshop was reported in newspapers and the Palestinian TV. The Ministry of Agriculture evaluated the workshop as successful and is interested in organizing additional workshops.

3.6.4.2 Decentralized Wastewater Management in Jordan

In order to contribute to the development and implementation of decentralized wastewater management solutions for Jordan, the Helmholtz Centre for Environmental Research – UFZ, in association with the Training and Demonstration Centre for Decentralized Sewage Treatment – BDZ e.V., organized the workshop “Decentralized Wastewater Management in Jordan”. The workshop was held in Amman on April 29 and 30, 2013.

The workshop was developed for representatives of Jordanian institutions that will mainly be involved in the implementation of decentralized wastewater management. The 38 participants represented the Jordanian Ministry of Water & Irrigation, Water Authority of Jordan, Jordan Valley Authority, Ministry of Agriculture, Ministry of Planning & International Cooperation, Ministry of Municipal Affairs, Ministry of Environment, Ministry of Health, Housing & Urban Development Corporation, Al-Balqa’ Applied University, the Royal Scientific Society, and the Jordanian Institute for Standards and Metrology.

Figure 145: Technical field trip to the SMART-Research and Demonstration site in Fuheis

The objective of the workshop was to assist the “National Implementation Committee for Effective Decentralized Wastewater Management in Jordan” (NICE) by developing managerial and technical issues associated with the implementation of decentralized wastewater solutions.

The two days’ workshop aimed at laying the basis for a common understanding of the actual state of discussion for implementing decentralized wastewater management concepts in Jordan. The three modules of the workshop provided information on the definition of decentralized wastewater management, treatment and reuse technologies, site selection, operation and maintenance schemes, planning, development, and financing of infrastructure projects. One main outcome of the workshop was that the participants identified the main bottlenecks in the existing regulatory framework and potential roles of different stakeholders in the planning process for a sustainable implementation of decentralized wastewater systems. Figure 145 shows the participants of the workshop at the demonstration site in Fuheis.

3.6.4.3 Groundwater protection zones and tracer techniques

For supporting the SMART project activities relating to groundwater resources in Jordan, a specific workshop on “Groundwater Protection and Tracing Techniques” was held onFebruary 28 and 29, 2012 at Al-Balqa’ Applied University in Salt, Jordan (Figure 146). The workshop was organized by the Karlsruhe Institute of Technology and the Al-Balqa’ Applied University and was mainly directed to participants from universities and hydrogeologists from governmental institutions. The workshop covered the areas of tracing techniques in hydrogeology, groundwater protection zones, and potential groundwater contamination by leaking sewage pipes. A total of 23 representatives participated.

Figure 146: Participants of the Workshop on Groundwater Protection and Tracing Techniques

The main intention of the workshop was to inform the participants from the Ministry of Water and Irrigation and the Msc. and PhD students of the Al-Balqa Applied University about new tracer techniques for groundwater movement tests and methods for delineating groundwater protection zones.

3.6.4.4 Protection zones regulation

A second workshop on groundwater protection was held in Ramallah on March 06, 2012 (Figure 147). Members of the SMART Project Coordination Team Karlsruhe participated in the workshop that was organized by the Palestinian Water Authority and the Al Quds University. The main topic of the workshop was to support the Palestinian Water Authority in preparing a draft of a new regulation for protecting springs and wells in the West Bank.

Figure 147: Participants of the workshop “Protection Zones Regulation”

Two outcomes of this workshop could be achieved:

Two outcomes of this workshop were achieved:

A- More coordination between the Palestinian Water Authority and the Palestinian Universities.

B- Exchange of experience gathered under the SMART project with the participants from the Palestinian Authority and Palestinian Universities and research centers.

3.6.4.5 Practical Training Activities

Most of the practical training activities were performed as bilateral CD wastewater measures between an industry partner or research institute and the user of the technologies and methods. The following training events were conducted in Germany as well as in the partner countries.

- The design and implementation of a monitoring program.
- On-site analytical methods at the SMART Research and Demonstration Site in Fuheis.
- Operation of wastewater treatment plants in Germany and Jordan.
- Installation and maintenance of wastewater treatment plants.
- Operation of analytical laboratory equipment and analysis of results.

3.6.5 Conclusion and Recommendation

CD is a complex, iterative, and dynamic process that requires flexibility, time, trained staff that knows how to cooperatively engage in multilateral and intercultural work contexts. To achieve long-lasting outcomes, some recommendations are made below.

3.6.5.1 Recommendations Relating to School Education

Based on targeted observations during the preparation and implementation of this CD activity, targeted surveys of trained teachers, and permanent contact via mail, the following selected recommendations can be given:

- It is recommendable to ensure the compliance of teacher selection criteria during the preparation process and the invitation of the teachers. The idea is not to get absolutely homogeneous groups, but to carefully control the composition of groups.
    - In order to focus the target groups, particularly in rural areas, the community-based approach (extracurricular) has to be preferred taking into account the advantages of strong family and neighborhood orientation.
    - It is imperative to consider the gender balance, because of the absence of co-education! The women’s quota has to be increased, because women are more affected by water problems/ scarcity due to their responsibility for household management, food preparation, personal hygiene of children among others.
- As Education for Sustainable Development (ESD) principles and objectives cannot be supposed to be known and practiced, expanding of the workshop content and duration is advisable. ESD principles must be practiced and not only learned in theory. However, this process requires time, financial resources, and expert advice. Furthermore, many teachers asked for repetitions and/ or extensions of the workshops. One extension

possibility might be to provide teachers with qualified and reliable support during the implementation of the project at their schools.

- From the beginning of the process, all stakeholders should be involved in the planning and implementation process. Responsibilities have to be clarified very early.

The Palestinian trainers reported the following recommendations:

- Organization of a field visit for the participants to a constructed wetland treatment plant.
- Concentration on and organization of further awareness campaigns for schools to educate teachers and students about the crucial role of wastewater treatment to environmental sustainability.
- Providing local schools with needed financial support and scientific staff to consolidate the existence of on-site treatment plants at local schools around the West Bank.
- Governmental institutions are to increase the involvement of the local municipalities to achieve the applied goals of environmental sustainability.

It is worth mentioning that the educational system in Palestine is moving towards a new era that includes the transition from the memorization and indoctrination dilemma to innovation and applied involvement of schools. This will support the personality of the students and increase their self-esteem.

3.6.6 Annex

Author: W. Ali

3.6.6.1 SMART Project Coordination Meetings

The SMART Project Phase II Kick off Meeting took place between March 16 and 18, 2010 in Amman, Jordan. The 2nd Scientific Coordination Meeting (SCM) took place on November 22 and 23, 2010 in Karlsruhe, Germany, in connection with the IWRM Conference on November 24 and 25, 2010, in Karlsruhe. Two SMART coordination meetings took place in 2011. The 3rd coordination meeting (Specific Strategy Meeting) took place in Malta from May 08 to 12, 2011. The members of the steering committee, the work package spokespersons, and several representatives of partner institutions of the SMART project were invited. The 4th SCM took place in Dresden from October 10 to 11, 2011 in connection with the BMBF IWRM Conference Dresden on October 12 and 13, 2011. The 5th SCM took place in Istanbul, Turkey, from March 26 to 29, 2012 and the 6th SCM took place in Karlsruhe from November 18 to 20, 2012 in connection with the IWRM International Conference Karlsruhe on November 21 and 22, 2011 in Karlsruhe. The 7th SCM took place between 13. and 15. April 2013 in Larnaca, Cyprus.

3.6.6.2 SMART internet presence and newsletter

An internet presence has been established since the beginning of the SMARTII phase to show all activities during the 3 years of the SMART project. For more information see http://iwrm-smart2.org/. A regular newsletter is issued every 6 months to report all news and activities of the project. The newsletters are also documented on the website of the SMARTII Project.

4 IWRM APPROACH TOWARDS STRATEGY DEVELOPMENT

Involved Institutions: UKA, UFZ, GU, JUA, MWI, PHG, QUDS, TAU, MEK, EWRE

Spokesmen: A. Subah, Y. Guttman, A. Jarrar

Compiled by: J. Klinger, H.-P. Wolff

4.1 Introduction / Overview

Authors: J. Klinger, H.-P. Wolff

The most quoted definition of IWRM was formulated by the Global Water Partnership as a process which promotes the coordinated development and management of water, land, and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2004). And the principles of the Global Water Partnership postulate that integrated water resources management is built upon a clear understanding of the river basin processes (GWP 2009, FAO 2012). The Lower Jordan River basin is shared by Israel, Palestine, and Jordan, and the water resources are scarce. For the management of theses scarce water resources, a generalized IWRM approach, here called IWRM implementation concept, is required in order to develop IWRM strategies in a standardized way as a basis for further negotiations of Israel, Palestine, and Jordan towards trans-boundary water resources management. A clear stepwise approach improves the transparency of the water resources planning and decision-making process and ensures a high level of acceptance of the water development and management strategies developed.

In the context of the SMARTII project, different IWRM implementation concepts have been developed and applied in Jordan and Palestine. In the following sections, both concepts will be presented, while chapter 1 will summarize the results of applying these concepts to selected SMARTII case study areas.

The main characteristics reflecting the integrated approach are displayed in Table 49. However, due to the significant differences in water strategies and the economic and social development within each state, a common IWRM concept has not yet been formulated. Three different approaches have been applied and socio-economic as well as the environmental impacts were assessed. Each of the approaches allows for an evaluation of the current water balance, water management in the respective sub-basin, water management options in the context of population growth and climate change, and recommendations can be derived with regard to adapted water management options.

In the following sections, the concepts for Wadi Shueib (Jordan) and the Wadi Cluster Auja, Nuema, and Quilt will be presented, while chapter 2 will summarize the results of applying these concepts to selected SMARTII case study areas.

Table 49: Overview of the case studies and their main characteristics in the LJV (see Klinger et al. 2015)

Properties	Wadi Cluster Auja / Nuema / Quilt	Kalya	Wadi Al-Arab	Wadi Shueib,
Location of sub-basin / study area	West bank	West bank	Jordan	Jordan
Area [km²]	577	< 10 km	300	190
Time line: current status	2010	2010	1980 – 2008	1994-2009
Time line scenario	2050	No scenarios defined	No scenarios defined	2010-2025
IWRM measures rely on	Participative approach, definition through water experts and stakeholder	Participative approach, interaction of water experts and stakeholders	Hydrological assessment – artificial recharge as key technology	Jordan's Water strategy water for Life
Ranking of measures, setting of priorities and definition of scenarios	Analytical Hierarchy Process (AHP), Multi-Criteria analysis; Local IWRM strategies as combined water management measures	Analytical Hierarchy Process (AHP), Definition of alternative water management options using multi-criteria decision procedure	Multi-response calibration Scenario: recharge of TWW and storm water	Jordan's Water strategy water for Life and Action Plan
Scenario modelling / optimise strategy	Multi-Objective Optimization / Pareto-Frontier	-	J2000g; FEFLOW	WEAP21
Involved stakeholder, decision maker	PWA, PHG, MoA, Mek	MEK	MWI, WAJ, JVA	MWI, WAJ, JVA

Abbreviations used: MWI: Ministry of Water and Irrigation (including Water Authority of Jordan and Jordan Valley Authority), PWA: Palestinian Water Authority, PHG: Palestinian Hydrology Group, MoA: Palestinian Ministry of Agriculture, Mek: Mekorot: Israel National Water Company, WEAP21: Water Evaluation and Planning System

4.2 IWRM Indicators for IWRM assessment

Authors: I. Heinz, H.-P. Wolff

4.2.1 Hydrological / Environmental indicators

Suitable indicators of the performance of IWRM in general depend on their contributions to the strategic objectives of the superordinate national water sector strategies. Another recommendation, if not requirement, is their compliance with and coverage of the DAC evaluation criteria stipulated by the Development Assistance Committee of the Organization for Economic Co-operation and Development (cf. OECD, 2012), which focus on the five basic fields "relevance", "effectiveness", "efficiency", "impact", and "sustainability". The DAC criteria do not only provide a professional framework for evaluations, they are also relevant to requests for support and funding by European donors at least. The third constraint that determines the suitability of indicators is the required costs for collecting information about the indicators, which may force monitoring and evaluation (M&E) to find a compromise between ideal and feasible analyses.

Comparatively easy-to-grasp performance indicators, such as e.g. the provision of water quantities of a given quality at a certain point in time with minimal costs, are typical project and operational process measurements. Such indicators help in the isolated judgment on technical and managerial components, but can only constitute one component in the evaluation of comprehensive IWRM strategies (Wolff et al., 2012). Due to the third constraint, i.e. the costs of information gathering and measurements, however, an equally comprehensive set of suitable indicators is rarely practicable for continuous M&E systems.

The research under SMART led to the definition of three IWRM-specific areas of indicators (Wolff et al., 2012, p. 1412), which had their equivalents in the national water strategies of all three riparian states and in the DAC criteria. Discussions among the participating scientists in a second step allowed for the identification of the most meaningful, even if by far not comprehensive, individual indicator of each of these three sets. The recording of these indicators was rated the central first step in the judgment on the success of IWRM approaches and the selection among alternative IWRM strategies.

- Indicator 1: Closure of gaps in municipal water demand. IWRM-specific area: Potential additional water supply, DAC criteria: "Relevance", "effectiveness", and "impact".
- Indicator 2: Recuperation of total costs for water services (supply and sanitation). IWRM-specific area: Costs of additional water through improved technologies, DAC criteria: "Efficiency" and "sustainability".
- Indicator 3: Environmental water stress (EWS). IWRM-specific area: Controlled mass flows, pollutants in water and land, DAC criteria: "Relevance", "effectiveness", and "sustainability".

The case studies presented below show that the outcomes of alternative IWRM strategies can be assessed by using most of the above-mentioned performance indicators.

4.2.2 Socio-economic indicators

Authors: I. Heinz, A. Tamimi

4.2.2.1 Introduction

For the determination of IWRM strategies that can provide appropriate solutions of water problems, socio-economic indicators are indispensable. The following indicators are distinguished:

1. Economic efficiency.
2. Financial affordability.
3. Social equity.
4. Institutional feasibility.

Economic Efficiency

The cost of water projects is an essential decision criterion. Costs mean consumption of raw materials, commodities, water, energy, and manpower. They can be assessed in a common economic unit (e.g. dollars), so that the total value of resources consumed can be determined easily. Moreover, it can be found out whether the use of resources is economically efficient or not. Here, it is important to compare the cost of water projects with performance criteria, such as improvements in water supply, sanitation, or flood control. Projects are preferable, if their costs are low and their performance is high. This relationship can be measured by using the cost-effectiveness analysis (CEA). Physical units are used, such as water availability, water contamination, and other environmental pressure indicators. The cost-effectiveness ratio (CER) is calculated as follows:

$$CER = \frac{\mathrm{C}}{\mathrm{E}}$$

where C means the cost and E the effective yield of a water project in physical units. Since the investments in water infrastructure generally are of long-term nature (covering often more than 20 years), the costs can be calculated in terms of present values by using a discount rate. Another calculation method refers to the cost per year: The annual capital cost is computed by multiplying the initial investment by the capital recovery factor; the yearly operating costs are to be added.

Study 705 of SMARTII employed the CEA approach for comparing the economic efficiencies of alternative technologies, such as decentralized wastewater treatment, managed aquifer recharge, and brackish water treatment to mobilize additional water resources. The water volumes generated per year are related to the total annual cost. In this way, the different technologies can be compared in terms of cost per cubic meter. The economically most efficient technology is the one with the lowest unit cost.

Another approach, cost-benefit analysis (CBA), evaluates the performance of water projects in economic units. By means of this analysis, it is possible to find out whether costs exceed the benefits. This indicator is essential to determine the values added resulting from alternative IWRM strategies. Values added mean an access to wealth for communities or entire societies. The unit value added v of a project (e.g. wastewater reuse) can be calculated as follows:

$$v = \frac{\mathrm{B} - \mathrm{C}}{\mathrm{Q}}$$

where B means the economic benefit per year, C the cost per year, and Q the increase in water supply per year. B can be estimated by multiplying the extra water either by the average water tariff for municipal users or by water profitability for agricultural users (explained below). C represents the sum of the annualized capital cost and operating cost per year – as mentioned above. Another CBA method refers to the difference between the benefits and costs, where both are discounted over the economic lifetime of a project (present value of net benefit). The CBA uses discount rates to consider the opportunity cost of capital investment.

The CBA approach was applied in several SMARTII studies. In the Jericho east sub-basin in Palestine, for example, declining groundwater availability and increasing water demand will lead to growing water deficits in the near future. The options of desalination of brackish water, wastewater reuse, and rainwater harvesting were considered to be possible solutions. Each of them was evaluated in terms of unit added values, defined as annual surplus of the benefits over the costs per cubic meter extra water. The CBA revealed that the wastewater reuse option is the best one, followed by rainwater harvesting and desalination of brackish water.

In the Jericho east sub-area, a maximum additional water supply of 6.3 Mm^3/yr can be provided by the three projects, whereas the projected water deficit will increase from 1.2 MCM/yr in 2016 to approximately 4.0 MCM/yr in 2030. This means that not all the management options considered for this sub-area should be implemented now. Based on the CBA results, the different options can be prioritized and their temporal sequence of implementation can be scheduled according to their relative economic efficiencies (studies 706 & 707 of SMARTII).

Another socio-economic indicator addressing especially water utilization in irrigated agriculture is water profitability. It expresses the gains in the farmers' income per cubic meter extra water supply. By using this indicator, it can be shown that treated wastewater is preferable to freshwater for irrigating most of the crops in the Jordan valley (study 703 of SMARTII).

Financial Affordability

The implementation of economically efficient IWRM strategies can fail, if there are no sufficient financial resources. Water projects are financed usually by charging the water users, such as farmers, citizens, and entrepreneurs. In special cases, however, they cannot fully afford the costs. Other funds are required, such as governmental, private or international donations (e.g. World Bank, USAID, KfW). Otherwise, water services cannot be provided properly. The following criteria may be considered when selecting the method of financing (studies 706 & 707 of SMARTII):

- **True cost principle:** All the costs of water services are to be taken into account and allotted to the water project. However, the cost of the water reuse option consists of the incremental expenses for providing the reclaimed water only rather than of the total cost of wastewater treatment plants (WWTP).
- **Water user and polluter pays principle:** The costs of both water supply and sanitation are to be paid by the beneficiaries as far as possible. However, the total cost of WWTP should not be charged to farmers, who use the effluents for irrigation purposes; other financial sources are required, such as the revenues from municipal water tariffs or donors. The same applies to water projects, where the beneficiaries cannot afford the full cost. This is always justified, if considerable values added can be expected from the project – as demonstrated in the SMARTII studies.
- **Cost recovery:** The cost of water projects should be recovered fully in any case regardless of the available financial resources. Otherwise, the infrastructure will not be operated properly and cannot be replaced after its useful time. Examples of water projects in the Jericho area show that even when the costs first exceed the economic benefits, the costs can often be recovered from increasing revenues in later years.

Social Equity

- **Connection to water networks:** Supplied from the Ein al Sultan spring, almost all of the households in Jericho City are connected to a water network. However, more than 85 % of the consumers complain about seasonal water cutoffs mainly during the summer in the nights. This problem is further aggravated by the lack of storage facilities, as 11.5 % of the households do not have any tanks. The main obstacles to a proper connection are: a) Historic water ownership rights of farmers imposing restrictions on municipalities in providing domestic users with water, b) poor water management, c) unfair water allocation, d) insufficient financial resources, and e) rapid development of the entire region.
- **Connection of households to sewage systems and wastewater treatment plants:** In Palestine (West Bank and Gaza), only 30 % of the wastewater are collected in a public sewer network and less than 7 % are connected to a water treatment plant. The virtual lack of a household wastewater collection network and, hence, of any pollution treatment, especially in the West Bank, forces each household to store its wastewater in cesspools holding both blackwater and greywater. Some major cities (e.g. Jericho) remain without centralized wastewater collection. In the West Bank, 93 % (33.5 MCM/year) of the produced

wastewater are discharged untreated into the environment. The lack of effective wastewater treatment has adverse impacts on nature, biodiversity, and groundwater quality and endangers public health. The reasons for that are, amongst others, disagreements between Palestinians and Israelis concerning the trans-boundary wastewater infrastructure and poor governance of the Palestinian water authority regarding interventions, institutional arrangement, and pricing of treated wastewater.

- **Water prices:** A survey carried out by the Palestinian Hydrology Group (PHG) in Jericho City reveals that approximately 92 % of the people do not pay their water bills on a regular basis. According to the UN Millennium Declaration of 2000, water prices must be affordable and the proportion of water charges in the household income should not exceed an upper limit. Consequently, the current tariff structure needs to be revised according to the special economic status of households. The major difficulties in creating efficient water tariff and pricing systems are: a) Insufficient knowledge about the socio-economic status of the water users, b) the historic water rights of farmers, and c) scattered institutions and fragmented decision processes in water pricing.

Institutional Feasibility

- **Effectiveness of governments:** Even though a Palestinian Water Law and several ministries exist, there are problems in enforcing the current legislation. The lack of investments in improving the water infrastructure, the scattered nature of the water sector and management bodies are hampering the responsible decision-makers, particularly at the Palestinian Water Authority (PWA), to set up adequate rules, regulations, and water tariff systems. Another problem is that the Palestinians do not have the full control over their resources. They are partly dependent on water supplies from Israel and often need the approval of Israeli Water Authorities. These and other factors have led to uncoordinated water management and poor governance in tackling water problems. The Palestinian Water Authority (PWA) recently initiated a reform program to deal with all these issues. It includes the establishment of 1) an Institutional Water Sector Review (IWSR) panel which shall propose a concept for better institutional arrangements; 2) a Legislative Review (LR) board which will submit the proposal to the Council of Ministers for revising the water law, and 3) a Technical Planning Advisory Team (TPAT) which aims at providing capacity building and technical assistance to the PWA.
- **Participatory requirements:** Participatory planning is an important prerequisite for successful implementation of water management measures, especially those involving the reuse of treated wastewater. At present, households in Jordan are yet not closely involved in water management planning processes. However, close cooperation with the people concerned throughout the entire planning process is important in order to attain acceptance and an enabling environment. In other words, participatory framework conditions should be in place, which set the requirements for implementation, performance, and management of decentralized wastewater projects in particular. Such requirements include, amongst others, legal provisions, technical, health, and environmental standards, the assessment of socio-economic impacts, and feasibility studies.

4.2.2.2 Summary

Important units of measurement of the indicators discussed above are summarized in Table 50:

Table 50: Units of measurement for socio-economic indicators

Indicator	Examples
Economic efficiency	
Cost effectiveness (m^3/USD)	Extra water supply / cost of wastewater reuse
Added value (USD/yr)	Benefit of extra water supply – cost of wastewater reuse
Water profitability (USD/ m^3)	Income increase / extra water for irrigation purposes
Financial feasibility	
True cost (%)	Cost of wastewater reuse / cost of wastewater treatment
Cost recovery (%)	Revenue from extra water supply / cost of water transfer
Water user / polluter pays (%)	Charges paid / cost of water supply and sanitation
Social equity	
Connection to water supply networks (%)	Number of households connected / total households
Connection to sewage networks (%)	Number of households connected / total households
Water pricing (%)	Expenses for water services / household income

The purpose of the indicators presented is to assess and enhance the performance of alternative IWRM strategies. The indicators are to help quantify the socio-economic impacts of water management projects.

4.3 IWRM Strategy for Jordan – Wadi Shueib

Authors: D. Riepl (KIT, Disy), J. Klinger (KIT)

4.3.1 Introduction

The conceptual development and application of a sub-basin-scale approach to Integrated Water Resources Management and scenario planning are represented for the Wadi Shueib case in this chapter. The conceptual modeling framework employed for this purpose is illustrated in Figure 148. The IWRM theory usually promotes the basin as an adequate management unit. While basin-scale scenarios are useful for setting broad national water management strategy goals, they frequently lack reliability due to the non-validated assumptions regarding their local implementation. The approach pursued here starts from a detailed water system model of the Jordanian Wadi Shueib sub-catchment, which was developed based on the current state of knowledge of the responsible water sector institutions.

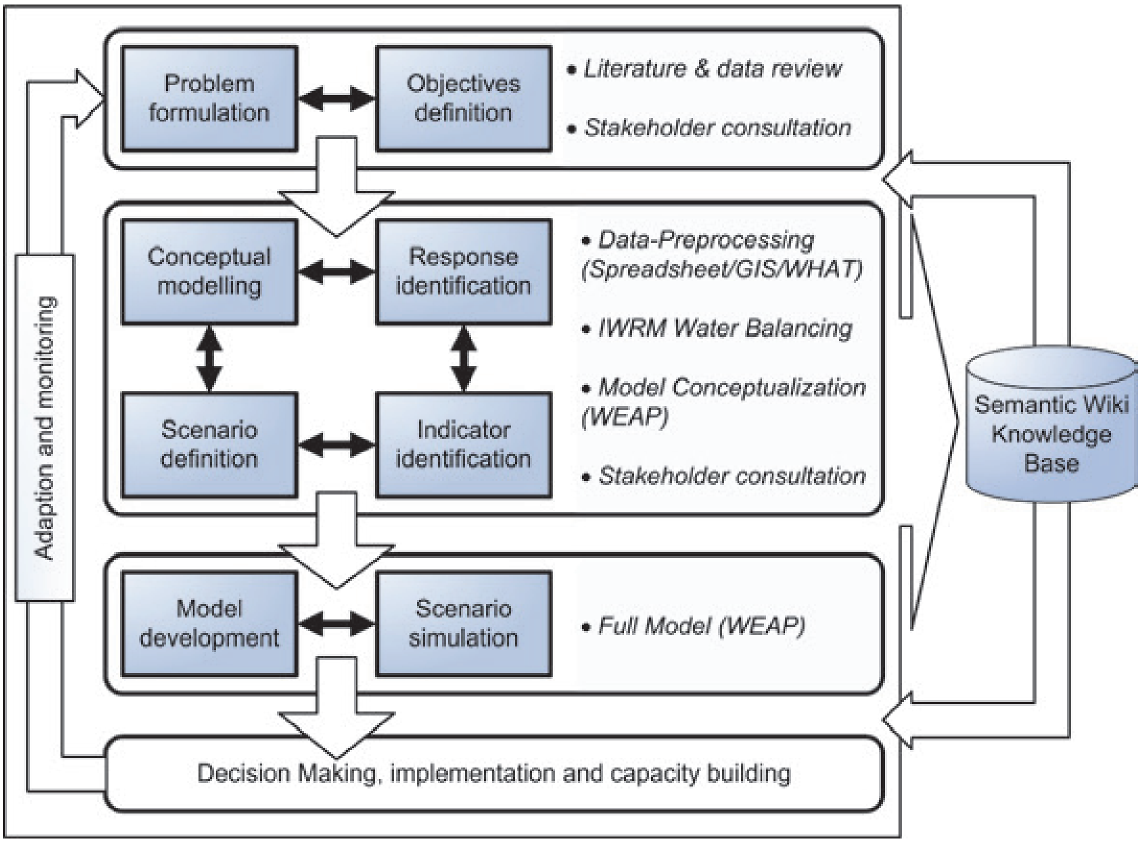


Figure 148: Conceptual framework of the IWRM modeling and scenario planning approach developed for the Wadi Shueib case. Blue marks the steps performed within the framework of this work.

Study Area and Water Resources

The Wadi Shueib (also: Wadi Shu'aib) is a Jordanian sub-catchment of the Lower Jordan River Basin in the Balqa governorate west of the capital Amman (Figure 149). The catchment, as defined in this study, features an area of 198 km² upstream of the Wadi Shueib Dam, with a steep relief ascending from -200 m bmsl in the southwest part up to above 1250 m amsl in the northeast. The average temperature shows an opposite trend with daily means rising about 5-10 °C towards the Jordan Valley, where the temperature ranges from around 12°C average daily minimum in January up to above 40 °C average daily maximum in July.

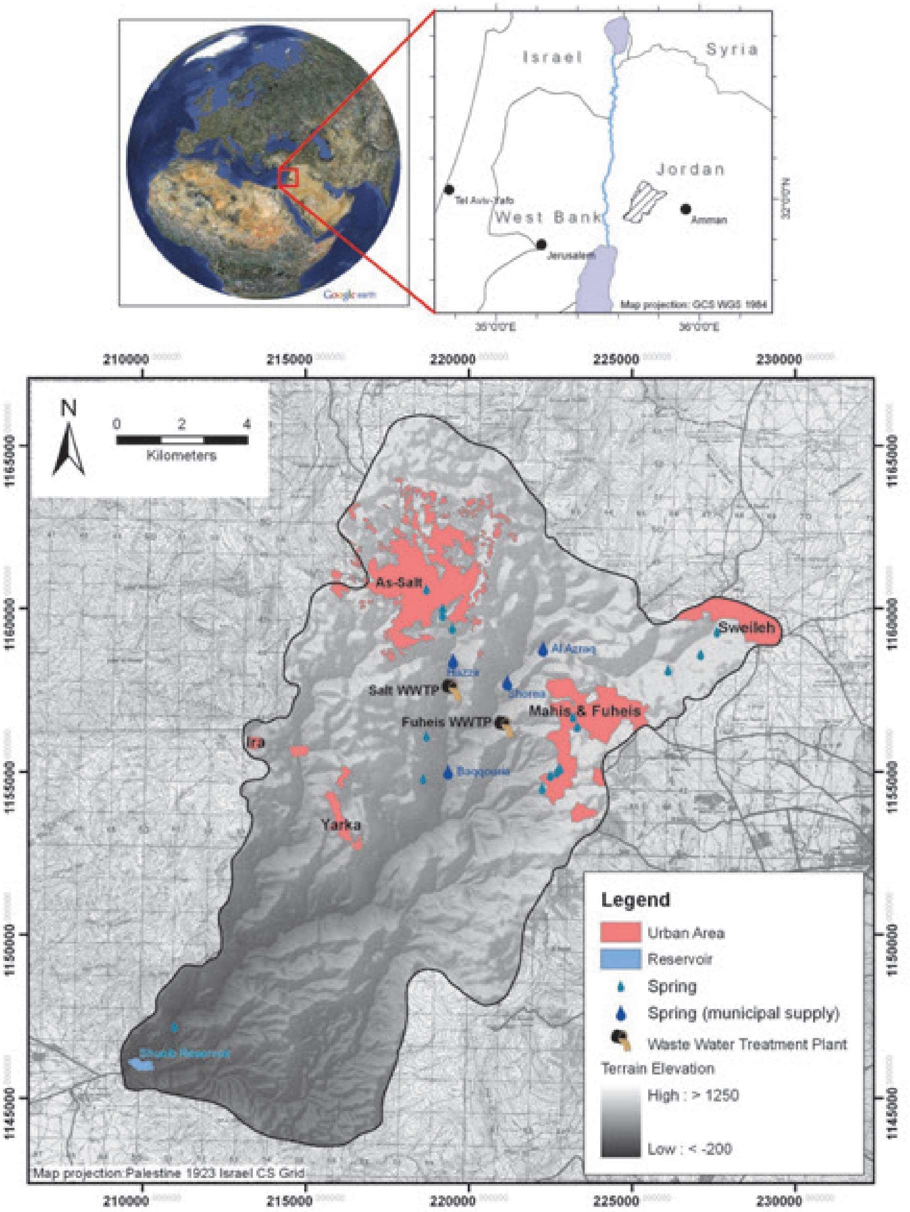


Figure 149: The major amount of rainfall occurs in the winter month from October to March in the higher altitudes to the northeast with annual precipitation amounts often exceeding 600 mm (in 44 % of recorded years) and is decreasing considerably towards the Jordan Valley where annual amounts are usually below 200 mm (in 67 % of recorded years).

The rainfall flush floods are stored at the wadi outlet in the Wadi Shueib Reservoir with a capacity of 1.4 MCM (million cubic meters). The karstified Upper Cretaceous Aquifer Complex is the primary source of freshwater and feeds several springs with a combined average discharge of about 10 MCM/a.

However, the aquifer also receives unintentional recharges and has turned out to be particularly vulnerable to pollution by the abundant domestic sewage leakages (Abu-Jaber et al., 1997; BGR & MWI, 2010; Werz, 2006). Thus, growing demand is opposed by pollution-induced yield reduction and high physical losses (28 %) in the supply infrastructure (MWI, 2004). As a consequence, the necessary water imports increased considerably during the last years, although the quantity of local freshwater would still be sufficient to cover the officially anticipated supply of 100 l/c/d for the approximately 120,000 domestic users.

Projecting this situation into a future that follows the official demographic scenarios (HPC, 2009) would result in almost 50 % imported water for drinking water supply until 2025, if no actions would be taken to enhance and protect local freshwater quality or to reduce current supply losses. However, increased imports would compete with neighboring demand sites, particularly the nearby Jordanian capital Amman. Downstream farms in the Jordan Valley receive irrigation water from the Shueib Reservoir, and any alteration of the allocation system has to consider the impact on these communities.

Due to the topography and the climatic conditions, the population as well as most agricultural and industrial activities are concentrated at the higher altitudes in the north-eastern part of Wadi Shueib. The area comprises 5 larger municipalities (Salt, Fuheis, Mahis, Yarka, Ira, see Table 51) and several smaller hamlets.

Table 51: Demographic development in Wadi Shueib between 1994 and 2004

	As-Salt (Sub-District)	**Mahis**	**Fuheis**	**Ira & Yarqa**	**Wadi Shueib total**	**Jordan**
1994	56,458	8,000	10,098	6,319	**80,875**	4,139,458
2004	77,441	10,649	11,641	8,654	**108,385**	5,350,000
yearly growth	3.21 %	2.90 %	1.43 %	3.19 %	**2.97 %**	2.60 %

Modelling Approach

The modeling approach applied follows widely accepted standards of good modeling practice (Refsgaard et al., 1997), with the understanding of the actual state and the urgent challenges of the observed environmental system being perceived as a crucial starting point. This first stage comprises the formulation and identification of specific focus problems, particularly of objectives and possible response options through a review of all available information and strong stakeholder participation. The subsequent workflow after this initial phase is illustrated in Figure 150.

Data: The majority of data time series were received directly from responsible water sector institutions in Jordan and their respective monitoring programs. A considerable amount of data quality control and pre-processing of the original time series was necessary in order to prepare a consistent database appropriate for model application.

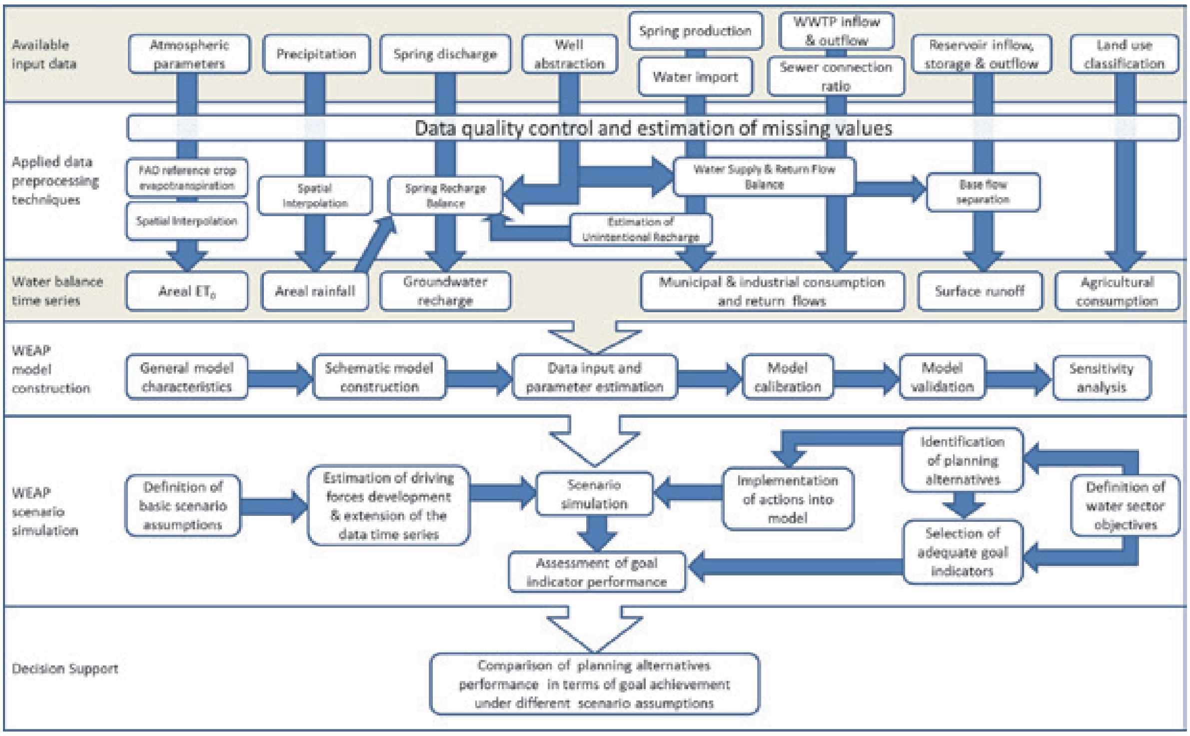


Figure 150: Detailed workflow of the Wadi Shueib IWRM modeling and scenario planning study

4.3.1.1 Set-up of the Modeling Approach

For model construction, the WEAP21 Water Evaluation and Planning (WEAP) tool was used. The approach applied in this study can be understood to be conceptual modeling, as the structure was specified before the modeling runs weremade, and some of the model parameters had to be estimated through calibration against observed data (Wagener & Wheater, 2006).

After the model had been satisfactorily conceptualized, calibrated, and validated, it was employed in an exemplary scenario planning exercise. For the latter, national water strategy objectives and action plans were analyzed and used as normative guideline to draft a set of planning alternatives with direct relation to the local challenges.

Model Characteristics:

Spatial scale: The spatial boundaries chosen for the IWRM model are based on the Wadi Shueib Dam surface water catchment.

Temporal scale: Taking into account the available data and the objectives, a monthly time step was chosen for the Wadi Shueib WEAP model, with a calibration and validation period from 2001 until 2009. For the planning scenario simulations, the time frame was expanded until 2025 in agreement with the actual MWI water planning horizon.

Table 52: Overview of temporal and spatial scales of the data available for water balance modeling in the Wadi Shueib catchment area (UFW stands for "Unaccounted for Water").

Data available for year:	1990	91	92	93	94	95	96	97	98	99	2000	01	02	03	04	05	06	07	08	09	2010
General:																					
Landuse											🟫	🟫			🟫					🟫	
Population					🟫										🟫						
Water Balance:																					
Rainfall	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Climatic parameters						🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Spring Discharge	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Dam Water Level	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Dam in- & outflow													🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Demand:																					
- Municipal							🟫	🟫	🟫	🟫	🟫	🟫									
- Agricultural							🟥	🟥	🟥	🟥	🟥	🟥			🟥						
- Industrial															🟥						
Supply:																					
Spring Production						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Well Production					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Water Import						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
UFW assessment							🟥	🟥	🟥	🟥	🟥	🟥									
Return Flows:																					
Sewer connections														🟫	🟫			🟫			
WWTP in- & outflow	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Legend: 🟧 daily values 🟩 monthly values 🟫 yearly values 🟥 values on regional or national scale

Schematic WEAP Model

The conceptual model of the Wadi Shueib water resources and supply structure is represented in the WEAP model schematic representation (Figure 151). The modeled components are represented as set of interconnected nodes of catchment areas, aquifers, supply and demand sites, wastewater treatment, and water storage facilities. During model simulation, the nodes act as one-dimensional lumped parameter elements, wherein the water budget calculations for each time step are performed. The linking vectors between the nodes represent runoff or infiltration allocations, natural stream flows, and intentional water transmissions and return flows. Stream flows and diversions can be modeled as two-dimensional features for some calculations, given the reach lengths and related parameter variance.

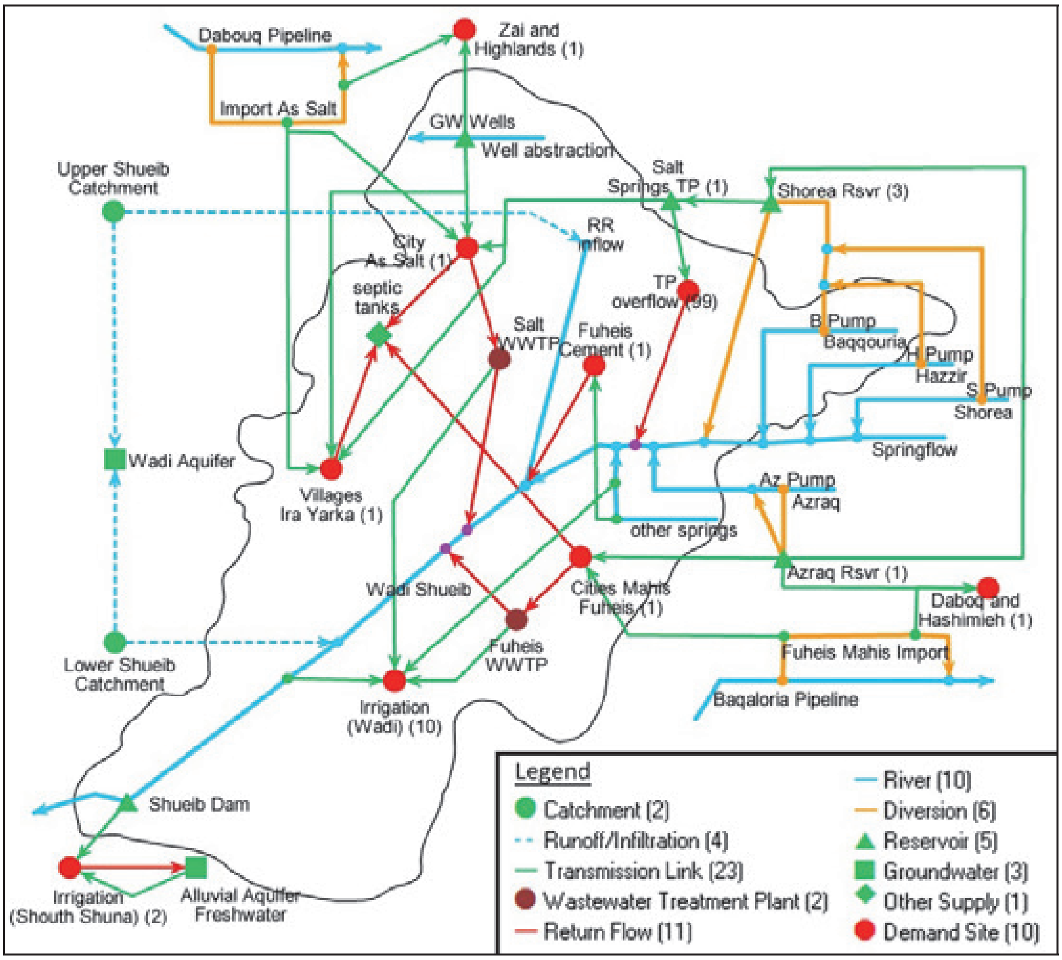


Figure 151: Schematic representation of the Wadi Shueib WEAP model. In order to provide a better overview, some nodes are shifted from their true geographical location.

4.3.1.2 Scenarios for Wadi Shueib

In order to define the distinct objectives for the planning scenarios in the Wadi Shueib case study, a distilled and reorganized version of the Jordan Water Strategy was prepared on the basis of the published strategy documents and personal interviews with stakeholders from the policy- and decision-making institutions. The schematic representation in Figure 152 depicts the main topics and their primary objectives and interactions resulting from this analysis.

Not the complete range of objectives and implementations as stated in the National Water Strategy appears to be relevant to the situation in the Wadi Shueib catchment. Hence, a subset of appropriate and applicable goals and measures was extracted, which is listed in Table 53 and the stated general implementation approaches were compared with respect to their possible effect within the Wadi Shueib water system.

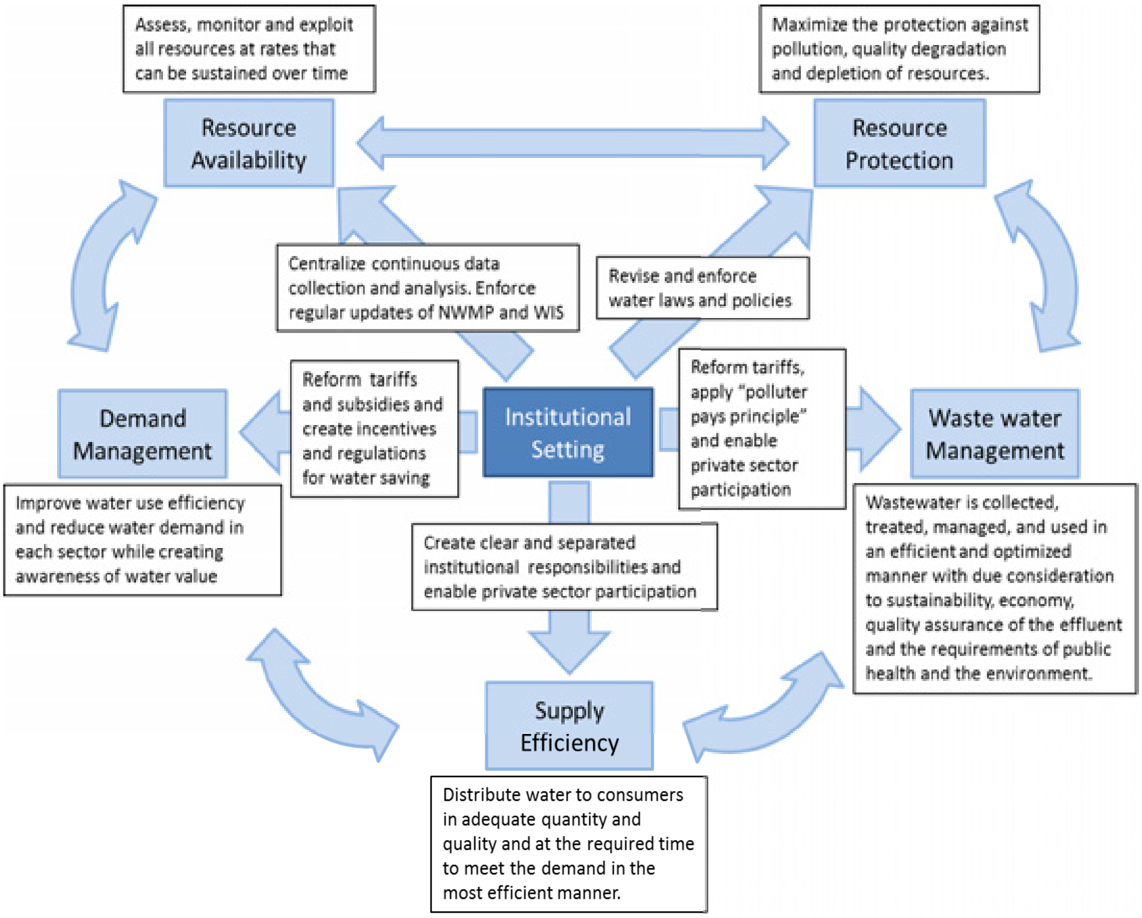


Figure 152: Schematic representation of the topics addressed in Jordan's Water Strategy and the respective primary objective statements

Table 53: Strategic objectives and implementation approaches of the Jordanian Water Strategy and their possible impacts in the Wadi Shueib area

Objective	Ind.	General implementation approach	Possible impacts in the Wadi Shueib
O.1: Increase volume of captured and treated wastewater	I.1a I.1b	Connect all households in urban areas to a treatment facility	**Increase the sewer connection ratio in As Salt**, Fuheis, and Mahis
		Rehabilitate all sewerage pipes which are over 10 years old	Decrease the leakages from sewer pipes in As Salt, Fuheis, and Mahis
		Install decentralized treatment to serve semi-urban and rural communities	Installation of DWWT units for Ira and Yarka
		Establish and enforce standards for the use of septic tanks in rural areas	Decrease the losses from septic tanks
O.2: Maximize Resources Availability	I.2	Use treated effluent in agriculture, industry, landscapes, and aquifer recharge	The amount of treated wastewater directly allocated to agriculture is increased
		Implement rainwater harvesting in new buildings and industry compounds	Fuheis Cement builds a rainwater harvesting pool
O.3: Secure constant drinking water supply	I.3	Expand production and supply networks to required capacities in all regions	Increase the treatment capacity of the Salt Springs water microfiltration plant to meet future water needs
	I.4	Rehabilitate old and damaged supply sources and network components	**Reduction of the physical supply network losses**
O.4: Establish demand management		Conduct national programs for water education and conservation	The per capita domestic consumption does not rise above the targeted 120 l/c/d
O.5: Improve cost efficiency of supply and sanitation services	I.5	Improve meter reading and billing accuracy to reduce administrative losses	Increases of revenue per supplied m^3 from the water treatment plants and the water imports
O.6: Protect water resources and environment	I.6	Establish protection zones for recharge areas of drinking water supply resources	Implementation of spring protection zones for the Azraq, Baqqouria, Hazzir, and Shoreia springs
		Consider environmental quality and quantity demands in sensitive habitats when designing water allocation plans	Establish and monitor a minimum flow requirement for the perennial wadi stream

4.3.2 IWRM Performance Indicators

In order to compare and evaluate the planning alternatives within the scenario simulations, a set of suitable indicators has to be selected. The indicator set selected for this study has to be understood as a minimum set having the purpose to directly and efficiently assess the objectives of the water strategy. Following the full IWRM principles, several additional indicators would be needed.

Indicator: I.1a/b: Municipal Wastewater Treatment / Recharge Ratio

According to the stated objective of increasing the volume of captured and treated wastewater, this indicator comprises the assumed volume of total wastewater produced with the amount of municipal wastewater treated at centralized and decentralized treatment facilities, including the volumes pumped from the septic tanks and cesspits in urban and rural areas with

$$TR_{MWW} = 100 \times \left[\frac{WW_{TP} + WW_{DTP} + WW_{CPpumped}}{WW_{cap} \times Pop_{total}}\right]$$

where TR_{MWW} is the municipal wastewater treatment ratio [%], $WW_{TP+DTP+CPpumped}$ are the inflow volumes of centralized and decentralized wastewater treatment plants and the pumped sewage from cesspits [m^3], WW_{cap} is the average volume of generated wastewater per capita [m^3/capita/month], and Pop_{total} is the total population in the catchment area [capita].

Indicator: I.2: Available Renewable Water for Internal Use

For this study, the available resources were considered to be the total sum of water volumes produced from renewable sources, including surface runoff, groundwater, reclaimed water, and harvested rainwater. With regard to the sources and the resulting quality types, the indicator comprises sub-indicators for groundwater, stored runoff, and reclaimed water and is applied in the Wadi Shueib case study by

$$ARW_{intern} = \frac{1}{Pop_{total}} \sum_{QT=1}^{3} P_{QT} + I_{QT} - E_{QT}$$

where ARW_{intern} is the internal renewable water available per capita [m^3/capita/year], Pop_{total} is the total population in the catchment area [capita], QT is the quality type (groundwater, surface runoff, reclaimed water), P_{QT} is the total annual production of the respective quality type [m^3], I_{QT} is the total annual import [m^3], and E_{QT} is the respective total annual export [m^3].

Indicator: I.3: Water Supply Shortage Index

To assess the unmet demand for water, it is important to consider the quantity as well as the frequency of supply shortages. The water supply shortage index was originally developed for dam operations to assess annual shortages over multiyear periods (Srdjevic, 1987). It is also convenient for assessing monthly shortages of any other supply framework, as it acts as an indicator of both frequency and quantity of shortages. It is given by

$$WSS_{DS} = \frac{100}{n} \sum_{i=1}^{n} \left(\frac{S_i}{D_i}\right)^2$$

where WSS_{DS} is the water supply shortage index of a certain demand site or sector [dimensionless], n is the number of time steps in the assessed period [e.g. months], S_i is the total quantity of unmet demand in the time step i [m^3], and D_i is the total demand in the time step i [m^3].

Indicator: I.4: Water Supply Requirement

The water supply requirement (WSR) is given by

$$WSR = \frac{(D_{au} \times A_{au} \times (1 - W_{reuse}) - W_{alternative})}{(1 - Loss_{supply})}$$

where WSR is the water supply requirement for a certain demand site or sector [m^3/time step], D_{au} is the actual demand per activity unit (e.g. per capita, production unit or agricultural area) [e.g. m^3/capita/time step, m^3/ha/time step or m^3/production unit], A_{au} is the total activity [e.g. capita, ha or production/time step], W_{reuse} is the process water reuse or recycling ratio [%], $W_{alternativr}$ is the volume of water from alternative sources (e.g. from water harvesting) [m^3], and $Loss_{supply}$ is the ratio of internal or supply system water losses [%].

Indicator: I.5: Full Water Service Cost

The unit costs for supply and sanitation of a water commodity (e.g. drinking water) is then given by

$$FSC_{UC} = \frac{1}{Q_D} \times \sum_{i \in I} [ACI_i + O\&M_{fix_i} + O_{var_i} \times Q_{T/P_i}]$$

where FSC_{UC} is full service cost as unit cost [JD/m^3], Q_D is the volume delivered at the demand site [m^3], I is the complete set of supply and sanitation infrastructures used for delivering the commodity, ACI is the annualized capital investment cost for an infrastructure element [JD], $O\&M_{fix}$ is the fixed operation and maintenance cost [JD], O_{var} are the variable operation costs [JD/m^3], and $Q_{T/P}$ is the production, flow or treatment volume at the respective infrastructure element [m^3]. The full service costs can be split up easily into sub-indicators for water supply and sanitation costs by considering particular infrastructures only.

It is important to note that the proposed cost indicator can only be understood as a relative measure reflecting the influence of investment decisions on the direct water service costs within the boundaries of a self-sustained system. In order to achieve a full economic cost assessment as well as an understanding of the economic value of the water resources, it would also be necessary to include the opportunity costs of alternative supply options as well as potential economic and environmental externalities (Rogers et al., 1998).

Indicator: I.6: Environmental Water Stress (with Return Flows)

The environmental water stress indicator (WIS) is given by

$$WSI = \frac{total\ withdrawals}{MAR_n - EWR}$$

where WSI is the environmental water stress indicator of the catchment [dimensionless], MAR_n is the (natural) mean annual runoff [m^3], and EWR is the environmental water requirement [m^3].

The categories of the resulting WSI are proposed by (Smakhtin et al., 2004)

$$WSI = \begin{cases} > 1 & \rightarrow \quad Overexploited\ and\ environmentally\ water - scarce \\ 0.6 < WSI > 1 & \rightarrow \quad Environmentally\ water\ -\ stressed \\ 0.6 < & \rightarrow \quad No\ water\ stress \end{cases}$$

In the presented form the WSI accounts for total withdrawals, but neglects return flows, which may be satisfactory for systems with predominantly agricultural consumption. In the Wadi Shueib catchment, the return flows of treated wastewater add up to a significant proportion of the dry weather flow. Also, the primary withdrawals (from springs) and return flows (from treatment plants) occur in a relatively close range in the catchment area. Thus, to consider the return flow volumes for this study, the WSI was adjusted to be used in the form of

$$WSI_{RF} = \frac{MAR_n - AR_o}{MAR_n - EWR}$$

where WSI_{RF} is the adjusted WSI to consider return flows [dimensionless], MAR_n is the natural mean annual runoff [m^3], AR_o is the actual observed (or simulated) runoff [m^3], and EWR is the environmental water requirement [m^3].

The WSI or WSI_{RF} is a relatively easy-to-assess environmental indicator convenient for this study, but some important shortcomings have to be kept in mind. The WSI is based on annual mean runoff and does not consider the amount and frequency of monthly or seasonal water shortages. Furthermore, it exclusively is an indicator of quantitative shortages, but does not consider environmental water quality requirements. Smakhtin et al. (2004) also mention that the WSI does not specify a desired conservation status in which an ecosystem needs to be maintained. In order to address these issues, it would be necessary to employ additional environmental indicators that should best be adapted to the actual local ecosystem conditions.

4.3.3 Driving Forces

To account for these uncertainties in the planning process, the key driving forces identified were used to basically define two thinkable development outlines for both the external as well as the internal drivers. The basic development narratives are as follows:

The **High Resource Pressure (HRP)** development is characterized by a relatively dry period over the coming 15 years with an above-average frequency of dry water years.

The **Low Resource Pressure (LRP)** development is characterized by a climatic period in the range of the long-term average observed in the area.

In the **Business as Usual (BAU)** development the national water strategy in the Wadi Shueib area is implemented by the already active projects and their current performance as reported in the annual MWI reports (MWI, 2010).

The Full Implementation (FI) development line assumes that all obstacles are overcome and the full range of stated implementation approaches is realized in the Wadi Shueib area until 2025 (the complete third column).

The development outlines were eventually grouped in a set of four planning scenarios as depicted in Figure 153. The combinations, even though reasonable, are arbitrary, of course, and the scenarios have to be understood as a not necessarily mutually exclusive and exhaustive set of future states. It is often emphasized that scenarios have to be perceived as equally valid (although not necessarily equally likely to occur) and that therefore a truly robust strategy must allow for the objectives to be achieved under all of them (e.g. IPCC, 2007; van der Heijden, 1996).

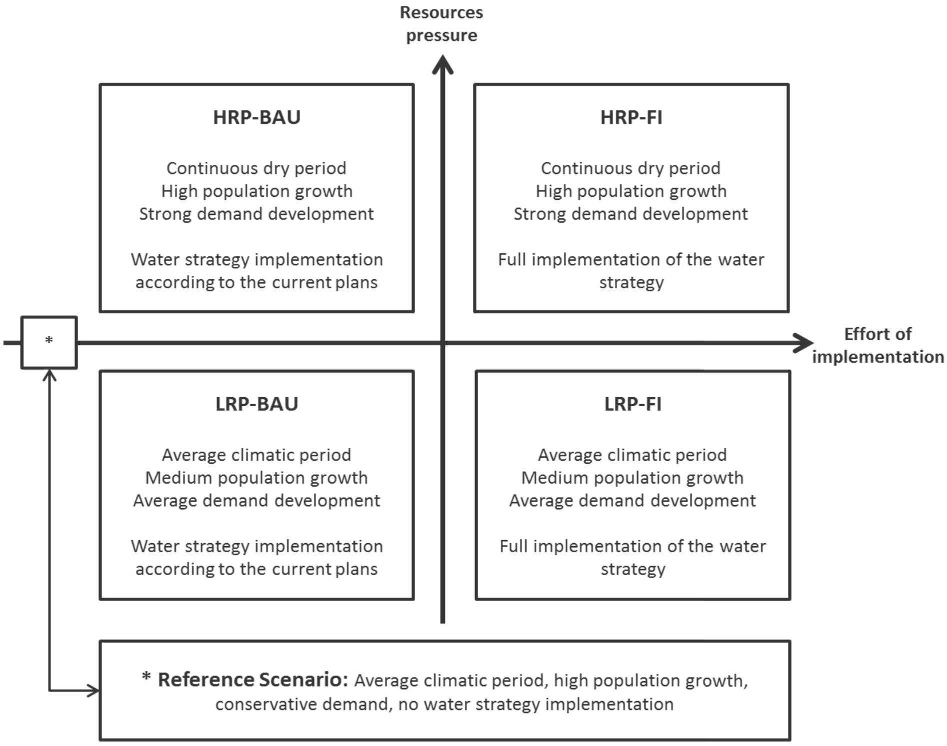


Figure 153: Alternative development scenarios for the case study with a planning horizon of 2025.The scenarios are characterized by the development of the external and internal drivers towards a future of high or low resources pressure (HRP or LRP) and towards a business as usual or a full implementation of the water strategy objectives (BAU or FI)

4.4 IWRM Strategy for Palestine

Author: B. Rusteberg

4.4.1 Introduction

The building blocks of the suggested IWRM implementation concept are illustrated in the chart of the following Figure 154. The approach has been developed in the context of the SMART project in order to support the elaboration of an integrated water resources development and management plan (WATER PLAN). Below, the main elements of the approach and the rationale of the procedure itself will be explained in more detail:

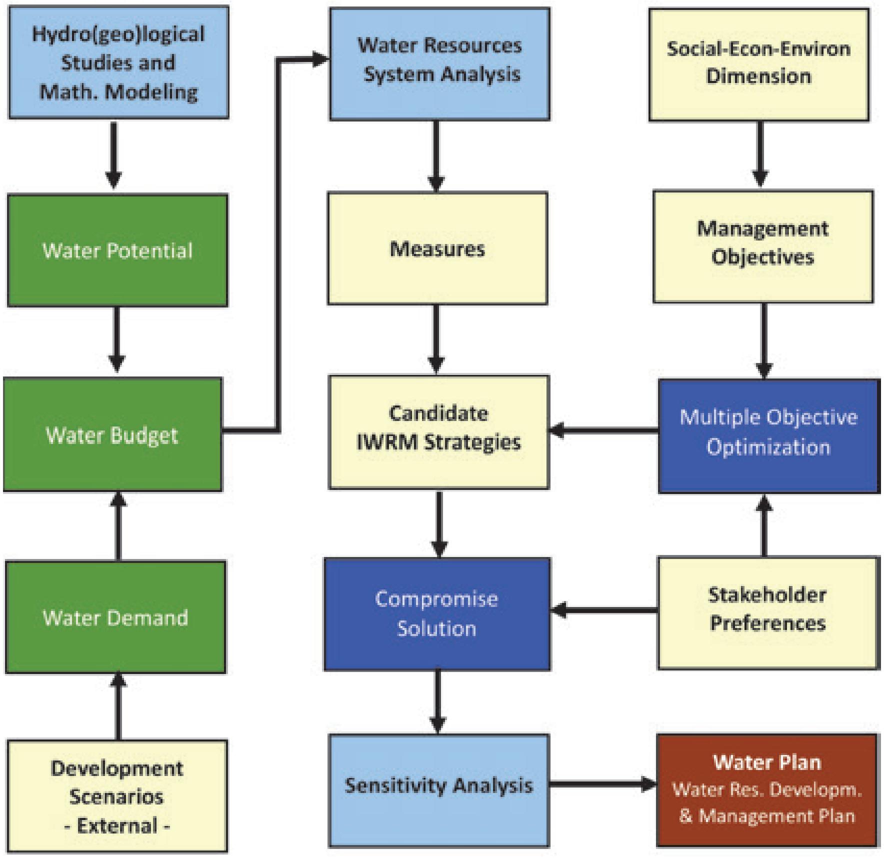


Figure 154: SMART IWRM approach to the development of an integrated water resources development and management plan

4.4.2 Hydrogeological Studies, Modelling and Water Resources Inventory

This is a fundamental step in the IWRM strategy preparation. It deals with the evaluation and inventory of the available water resources. In the case of the LJV, every single source of water, be it freshwater, saline – brackish water, treated or raw effluent, is regarded a valuable source of water. This step requires a careful characterization of the relevant aquifer systems, quantification of natural groundwater recharge, and sustainable yields. Managed aquifer recharge implementation is an compulsory measure in the Lower Jordan Valley (Rusteberg et al.; 2014) to adapt the high water resources variability to the water demand structure, which requires adequate groundwater monitoring and modeling tools. These evaluations may be supported by macro-hydrologic (cell models) and numerical groundwater models on the local level.

4.4.3 Water Potential

The water potential refers to the amount of water of a specific source (spring, shallow groundwater, surface runoff, etc.) that could be produced/abstracted with a certain degree of reliability. The water potential differs from the water availability, which considers just that water which has been made available for usage and, therefore, depends on the type of existing hydro-infrastructure and related losses. The estimation of the water potential requires an understanding of the relevant hydro(geo)logical processes. For example, the quantification of the surface runoff potential requires the understanding of the precipitation runoff process in the basin and estimating that amount which annually may be retained by adequate hydro-infrastructure taking unavoidable losses into account. In case of flash floods and missing water retention structures, the availability of surface runoff for later usage may be near to zero. Climate change impacts on the water potential should be quantified in this context.

4.4.4 Development Scenarios

The future water demand, as an important component of the water budget, depends on the expected development within the river catchment with regard to the different water sectors (users). In order to cope with related uncertainties, different development scenarios may be considered. This is of particular importance to the agricultural sector as the main water consumer in the Lower Jordan Valley. The future water needs of the agricultural sector in terms of quantity and quality significantly depend on decisions relating to agricultural development, e.g. the extension of irrigated land, selected crops or new irrigation technologies, such as greenhouses. Certain development options may be politically supported by economic incentives. Future development, therefore, relies on considerable uncertainties. Due to the political instability of the LJV, the population growth rate is above the historical trends as a result of immigration from neighboring countries. The development scenarios are considered external forces influencing the water demands and, hence, the future water budgets and related needs.

4.4.5 Water Demand

The assessment of the water budget requires the quantification of the present water consumption and future water demands for all water sectors in the river catchment in terms of both qualities and quantities. While the quantification of the present water consumption captures the current situation taking the existing hydro-infrastructure and related losses into account, the future water demand is quantified based on the development scenarios and upgrades of the water resources system.

4.4.6 Water Budget

The water budget compares the water potential and water availability with the present water consumption and future water demand. The water budget assessment considers both water quantity and water quality, since water sector demands are intimately connected to water quality standards. Actual losses in the water distribution network or at the consumers' need to be quantified in this context. The water budget assessment will provide information about the existing water deficit or currently untapped water resources as a basis for decisions on water resources system planning and management.

4.4.7 Water Resources System Analysis

This block deals with the in-depth analysis of the water resources system. A new analysis and planning approach is presented, which relates the water potential of each type of water source to present and future water demands. The water resources system analysis obtains most important input from the water budget assessment. It is aimed at identifying those components of the water potential, which require further activation by means of new hydro-infrastructure.

4.4.8 IWRM Measures

IWRM measures are required to activate the remaining water potential and manage the water resources system towards the achievement of the socio-economic and environmental development goals. Since the approach focuses on sustainable water resources development and management, main interventions refer to the implementation of new hydro-infrastructure and water technologies for water production, water trade, water treatment, and storage, taking different agricultural development options into account. For the LJV, a set of priority IWRM measures has been developed. The implementation of demand management measures at consumer points (e.g. high-efficiency irrigation systems) is considered to be compulsory under the prevailing conditions.

4.4.9 IWRM Strategy

According to the UNESCO (2005), an IWRM strategy consists in the combination of structural and non-structural measures towards the integrated management of water resources. The suggested approach to IWRM implementation in the LJV focuses on technological and hydro-infrastructural interventions and gives special attention to sustainable agricultural development and the extension of irrigated lands. The implementation of collateral measures, such as institutional development or capacity building, is considered compulsory and is not in the focus of the present study.

4.4.10 Socio, Economic and Environmental Considerations

This step leads to a better understanding about the correlation and competition of social, economic, and environmental interests, the selection of representative indicators as well as the definition of priority water development goals and related constraints.

4.4.11 Water Management and Development Objectives

The objectives are related to social, economic, and environmental development goals, which are partially conflicting with each other due to their nature, independent of any water scarcity situation. This means that improving one objective automatically induces a deterioration of one or more of the other objectives.

4.4.12 Multi- objective Optimization

In the context of the present study, a water resources planning and sectorial water allocation tool has been developed, which relies on Multi-objective Optimization (MOO) and allows for the consideration of partly conflicting social, economic, and environmental development goals. The application of the tool leads to a PARETO set of alternative (candidate) IWRM strategies as optimized (non-dominated or superior) solutions of the MOO problem. For the generation of PARETO solutions, the (1) Normal Boundary Intersection and the (2) Normalized Normal Constraint Method are being applied. The mathematical background is explained by Das & Dennis (1996) and

Messac et al. (2003). In the case of three objective functions representing the priority goals with regard to social, economic, and environmental development, the PARETO set may be presented graphically by means of a `surface´ in the 3-dimensional objective space.

4.4.13 Compromise IWRM Strategy

For the selection of a compromise strategy among social, environmental, and economic interests from the PARETO set of candidate IWRM strategies, different procedures are available. In the present case study, the Goal approach is applied, which requires the definition of a goal point outside of the set of feasible IWRM strategies, which represents the stakeholder preferences with regard to the achievement of the different water development goals. Alternatively, a subset of alternative solutions may be selected from the PARETO set and ranked based on the Multi-criteria Analysis (MCA) based on the most relevant decision criteria (indicators) and stakeholder preferences. If qualitative criteria are included, an appropriate MCA approach, such as the Analytical Hierarchy Process – AHP (Saaty, 1980) may be selected.

4.4.14 Stakeholder Preferences

The entire IWRM approach is strictly participative and relies on the active participation of the relevant stakeholders and decision-makers in the water resources planning and decision making process. This especially applies to the identification of candidate IWRM strategies and the selection of the final compromise solution. By means of the Goal approach or alternative MCA procedures, the stakeholders provide weights with regard to the achievement of development goals or the set of decision criteria. Their input is mainly driven by political and more subjective considerations. Together with the expert representatives, objective functions, constraints, and indicators are formulated.

4.4.15 Sensitivity and Scenario Analysis.

Sensitivity and scenario analysis are required in order to cope with uncertainties which may be relating to the prevailing physical and political conditions. Uncertainties relating to agricultural development or stakeholder preferences should be analyzed in this context to study the robustness of the identified solutions. Their impact on the candidate and compromise IWRM strategies is discussed.

4.4.16 WATER Resources Development and Management PLAN (WP)

Based on the results of the sensitivity and scenario analysis, a final IWRM strategy is selected, which may be considered a preferred WATER PLAN for the sustainable development and integrated management of the water resources in the river catchment under study. The application of the suggested IWRM implementation concept should be concluded by recommendations regarding the upgrade of the water resources system, implementation of new water technologies, and system management.

4.5 Scenarios

Author: H.-P. Wolff

4.5.1 Objectives

The objective of the scenario development group was to provide a baseline for quantitative impact assessments of IWRM measures and strategies at the research locations of SMART. The scenarios were to quantify the development of the water sector under the "most likely" assumptions of future developments as well as under potential variations. Basic specifications of the scenario development process included the request for:

- **Local congruence**: The validity of the scenario results was to coincide as far as possible with the research locations of SMART. Results from already existing scenario exercises of other organizations and projects (cf. DROPEDIA, 2013a) as well as administrative records at central authorities in all partner countries focus on larger geographical entities. Such entities are determined by political and administrative boundaries, which rarely coincide with basins or watersheds.

- **Water coherence**: The scenarios in the water sector were to consider developments and dependencies in other sectors, which influence water-related parameters. The term "water coherence" was coined by the water program of the OECD and focuses on nexuses with other sectors, where "*… the water sector is not always the master of its own fate*" (OECD, 2012, p. 130). Within the framework of SMART, this includes *(1)* the compliance with the expected developments, assumptions, and planning by the national decision-makers and *(2)* the interdependencies of SMART's research locations with the regional water systems. Basin- or watershed-based water economies are closely intertwined with the national water infrastructure and superordinate policies in all participating countries.

- **Cost efficiency**: The development of scenarios for SMART research locations was to make use of already available administrative records and results from existing scenario exercises in order to avoid the substantial costs of full-scaled basic scenario exercises. This excluded funding of participatory approaches with decision-makers and stakeholders as well as of data collection below the level of the central national authorities. Instead, the scenario development team combined experts, who were involved and participated in relevant positions in earlier scenario development and planning processes by the national authorities as well as by other organizations and projects.

  This requirement also applied to the planning constraints of IWRM implementations outside of the SMART research locations and added the research task of analyzing the suitability of quantitative downscaling approaches of nationwide and regional scenarios towards scenario development on the scale of sub-basins or even communities (*cf.* e.g. Wilby et al., 1997).

4.5.2 Materials and Methods

Several projects with international funding came up with scenarios of regional development of the Lower Jordan Valley over the last decade. Most of these scenario exercises centered on different major topics, such as e.g. effects of the regional peace process (*e.g.* The Millennium Project, 2009) and climate change (e.g. GLOWA, 2011), but all of them considered developments in water availability and water resources management crucial elements in their reflections.

The initial intention of SMARTII was to use these regional scenario exercises, which were based on substantial funding over three to nine years, as the basis for downscaling of results to the basin-based research regions of SMARTII. However, this approach turned out to be not feasible due to the following reasons:

1) The considered regional scenarios used either information about aggregated, national developments in the water sector or extrapolations of findings from selected areas. However, the representativeness of the latter was not proven in any of the existing scenario analyses. Individual analyses of regions in Jordan by the scenario developers in SMARTII gave a strong indication that the extrapolations are not justified and downscaling or transfer of the results from the respective scenarios would lead to uncontrollable bias and errors (*cf.* SMART Deliverable D801, annex 1).

2) Downscaling from aggregated, national developments in the water sector failed due to the significant heterogeneity of basins and administrative districts in the Lower Jordan Valley (*cf.* SMART Deliverable D801, annex 1).

3) None of the regional scenarios was considered realistic or a guideline by the decision-makers in the water authorities of the participating countries, despite the participation of at least some members from these authorities in the scenario exercises (pers. comm. at MWI and PWA, check of policy documents from MWI, PWA, and IWA).

A repetition of full-scaled scenario exercises in the SMART research basins and the related collection of local primary data were not budgeted. However, this scientifically desirable alternative would not correspond to the conditions expected for the transfer and implementation of SMART's technical findings in other than the current research areas. The choice of the finally applied methodological alternative resulted from the simultaneous involvement of SMART partners in scenario exercises and planning processes of the Jordanian and Palestinian water authorities, which were funded by the French development cooperation. This involvement offered three advantages:

- The scenario exercises took place on behalf of the national water authorities concerned, which gave their results a high relevance to further national planning and secured their acceptance by the client,

- Detailed data and information collected and created during these exercises were made available to the SMART scenario developers. The responsible water administrations authorized the use of the data and information for SMART research areas.

- The adoption of national assessments about *(1)* driving forces of developments in the water sector and *(2)* linkages and interdependencies between elements in the water economies facilitated the calibration between local and national prognoses.

However, the most disaggregated level of data from the national accounting systems and statistical offices - in the case of Jordan and Palestine – results from the governorates. The boundaries of these administrative entities do not coincide with hydrological basins. This "problem of fit", which was also reported from other BMBF-funded IWRM projects (*cf.* e.g. Horlemann et al., 2010), required another step in downscaling water consumption. The applied downscaling routines varied according to the sector of water use (*cf.* SMART Deliverable D801, annex 1).

The specific situation of the Israeli settlement Kalya required a different approach to scenario development. Work package 9 of the preceding phase of SMART provided initial data, and information and updates during SMARTII were provided by Mekorot. Estimations of possible developments were based on references of the Israeli Water Authority (IWA), the Israeli Central Bureau of Statistics (CBS), and other organizations (*cf.* SMART Deliverable D801, chapter 4). The sequential results of the scenario development process were cross-checked with Israeli partners in SMART during the biannual scientific committee meetings.

As expected, water sector planning in the partner countries was subject to significant and rapid developments during the term of SMARTII. The scenario developers met this challenge by updates of the scenarios through incorporation of information from new reports, studies, and references. The scenarios presented in this report are the latest version of spring 2013.

However, the regional process of changes in assumptions and driving forces still continues. This holds in particular for areas which are affected by changes in the political situation, e.g. through the influx of refugees and changes in access to resources, or which may experience abrupt, significant changes in water infrastructure. Such potential changes include the prospective catchment areas of water mega projects - i.e. the planned Red Sea-Dead Sea channel, the alternative Jordan Red Sea project, and the West-East conveyors of desalinated water from the Mediterranean Sea – as well as comparatively smaller projects, such as e.g. local desalination plants. The specific dynamics of the region, the international interest in its developments, and the related funding mechanisms showed in the past that such changes may be planned and realized on short notice. This results in a temporally limited validity of the calculated figures and underlines the necessity of continuous cross-checks and updates of the underlying scenario assumptions.

4.5.2.1 Assessment of Approaches to Scenario Downscaling

The assessment of downscaling tools also covered regression methods and limited-area models, i.e. modeling based on local empirical data and local assumptions. Normative and stochastic modeling was not considered due to the extensive requirements of research and development. Such models were supposed to exceed the requirements and funding of SMART's overall research program.

- ***Regression Methods:***

The suitability of downscaling by regression was tested for the case of municipal water consumption as a function of population size and income per capita for areas in Jordan, where relevant data on the national (superordinate scenario) and governorate (subordinate units) level could be obtained at the beginning of the SMART scenario development already. The hypothesis of the test read: "*Municipal water consumption as a function of population size and income per capita develops in a comparable manner in all sub-regions*".

The calculations yielded three regression models with different functional forms, which provided results with a sufficient precision (i.e. a coefficient of determination close to 1). However, only the variations of the explanatory variables considered in two models showed sufficiently significant impacts in more than 50 % of the cases and only one model yielded significantly precise results for all governorates. In addition, two models suffered from violations of the methodological preconditions of regression analyses, i.e. estimations by these models may contain uncontrollable bias. Consequently, the remaining model was the best choice for downscaling by regression analysis. The model which yielded the best results on the level of governorates was calculated for the national level, where it showed the same quality.

Still, comparison between the results from regression estimation by the governmental models and those from the combined models with national coefficients and governmental parameters revealed strong discrepancies. The rural character of the examined governorates explains these differences. Governorates with distinctive urban areas, e.g. Amman and Aqaba, which were not part of the analysis, distort the coefficients of the national model in a way, which does not allow for downscaling, i.e. the drawing of conclusions with respect to individual governorates from the national average situation.

The results of the analysis did not support the initial hypothesis. Regions in Jordan are not homogeneous enough for regression downscaling. Consequently, the regression approach to scenario downscaling was rejected (*cf*. Deliverable D801, annex 1).

- ***Limited Area Approach:***

The application of limited area models became possible due to the access to detailed data and information about the subordinate areas. The chapters on the different research areas below explain the sources and type of this information. However, the most disaggregated level of data from the national accounting systems and statistical offices - in the case of Jordan and Palestine – is that of the governorates. The boundaries of these administrative entities do not coincide with hydrological basins. This required further downscaling of water consumption to the basin level.

Downscaling in those cases relied on relationships between different types of water consumption and land use (*cf*. Deliverable D801, annex 1).

4.5.3 Scenarios for Regions in Jordan

Data and information for scenario development relating to research locations in Jordan were obtained from MWI, WAJ, JVA, and DOS. The involvement of the Jordanian and German team members in former and ongoing scenario exercises of the MWI allowed for access to the relevant databases as well as for the incorporation of opinions and directives of the Ministry and the Jordanian utilities. It was also possible to provide the other partners in SMART with guidelines about sources of information on Jordan's water sector (*cf*. Deliverable D801).

For the local scenarios for Jordan, "economic development" and "demographic development" were assumed to be major drivers (i.e. overall conditions that determine the general shape of the potential future). This corresponds to the approaches *(a)* the MWI’s water demand management scenarios (*cf.* MWI/AFD, 2011) and *(b)* the downscaling of the IPCC Special Report on Emissions Scenarios (IPCC, 2000). Three of the five scenarios considered by MWI yielded sufficient differences in relevant indicators for IWRM strategies. Results from the other two scenarios differed slightly from those of the three major scenarios only, which did not justify the additional input for separate calculations. Figure 155 displays the drivers and the classification of the considered three major scenarios.

The authoritative guidelines for planned developments under all scenarios were Jordan's official Water Strategy (MWI, 2009) and the goals defined therein. Contributions to these goals are the yardstick for the evaluation of alternative strategies within the different scenarios.

Scenarios were developed for the research regions of *Wadi Shueib* and *Wadi Arab*. Figures on the development of individual components in the water sector, e.g. water demand for domestic, industrial, agricultural, and touristic purposes, are compiled in Deliverable 801, appendix 2 (2013). All figures may also be found on the webpages of DAISY and DROPEDIA.

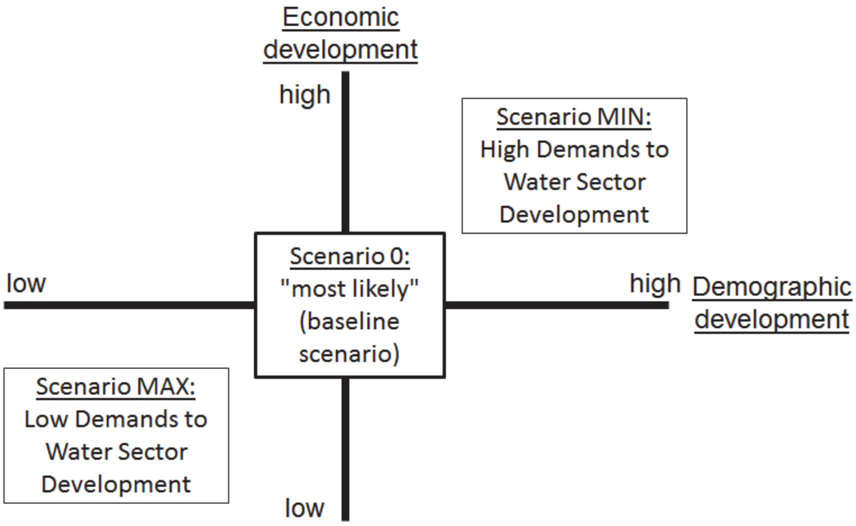


Figure 155: Drivers and scenarios for research areas in Jordan

- ***Scenario Zero (0): "Most Likely", Baseline Scenario***

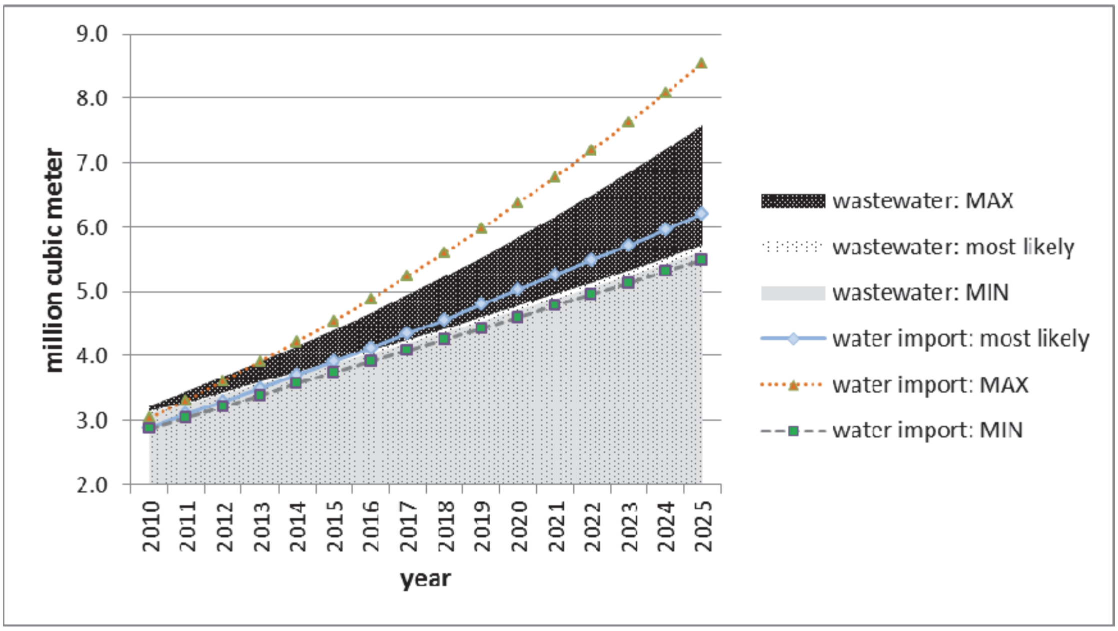
Scenario narrative: Water consumption, demand, and supply develop according to the estimates of Jordan's water authorities. Responses of supply to additional demands rely on the development of new water resources (desalinization, wastewater treatment, water imports), the reduction of water losses in conveyance systems, and caps of water provision to agriculture. Investments in the reduction of current UFW allow for success according to the estimations by the utilities, which are lower than the stipulated rate in Jordan's water strategy (MWI, 2009). The stated goal, i.e. to provide all cities and small towns with adequate wastewater collection and treatment facilities, will happen with or without inclusion of SMART technologies.

Water demand: Water demand includes water for urban areas (domestic demand), industries, agriculture, tourism, maintained landscapes, and expected physical and administrative water losses. Agriculture is assumed to be constant over the years with 2.835 MCM/year in Wadi Shueib and 10.125 MCM/year in Wadi Arab. Additional water supply that exceeds this demand can be transferred to economically effective use in this sector, with the water for agriculture being treated wastewater, too.

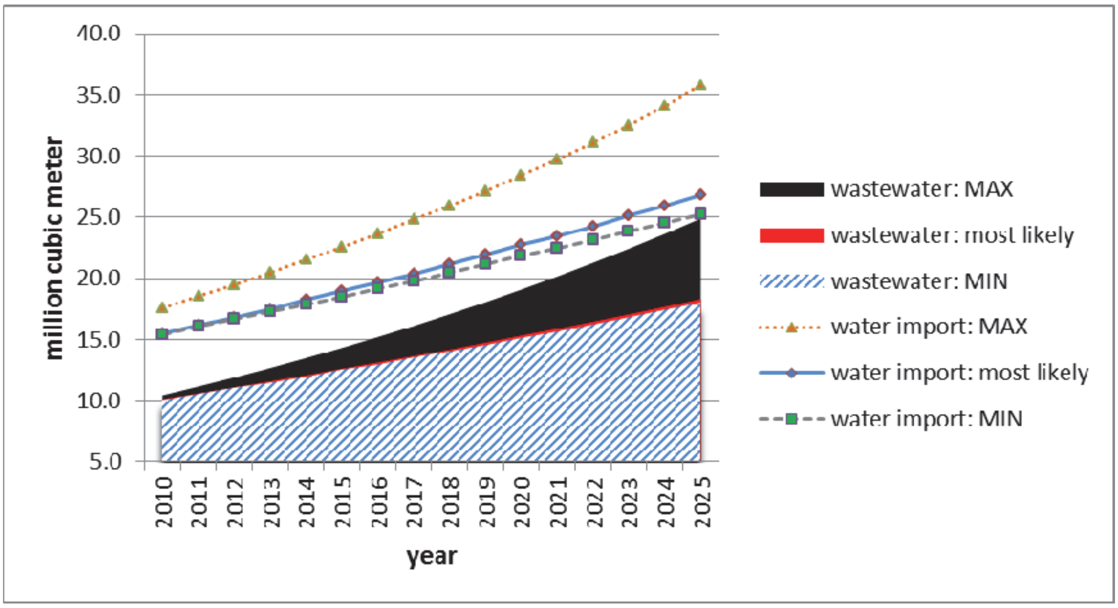
Water supply: Water supply comes from local freshwater resources, local water recycling, and water imports through Jordan's nationwide freshwater conveyor system. Local freshwater resources include springs and wells, with the latter tapping the groundwater base flow. The expected amounts are valid for all scenarios, i.e. they do not vary under different demographic and economic developments. The MWI assumes that a maximum of 20 % of water from these resources is used for domestic water supply. The rest goes to other sectors, i.e. agriculture and industry, or remains unused.

Wastewater: The contribution of local water recycling to the planned water supply depends on the recycling capacities. However, also untreated wastewater adds to the water balance, either by uncontrolled use in agriculture or infiltration to soils and groundwater (see Figure 156).

Water imports: Differences between freshwater from local sources and the expected water consumption require water imports through Jordan's freshwater conveyor system. This holds for the consumption in all sectors, except for agriculture and landscape. Freshwater used in irrigated agriculture comes from local freshwater sources only, this results in a difference of 80 % between the estimated water capacity of local springs and wells and the use of water from these springs and wells for domestic, industrial, and touristic water demands (see Figure 156).



2a: Wadi Shueib



2b: Wadi Arab:

Figure 156: Water imports and wastewater in different scenarios, research regions in Jordan

- ***Scenario MAX: High Demands for Water Sector Development***

Scenario narrative: Water consumption in the domestic sector increases more than expected due to higher population growth, combined with a higher water demand per capita as a result of better household incomes. Industrial and touristic water demand also develops along the upper limit of estimations. This leads to correspondingly higher amounts of wastewater and the related requirement of treatment capacities. Strategies to cope with the additional demands for water supply and wastewater treatment may assume a favorable situation for fund raising and may also count on a higher coverage of total water costs by water users. This may shift compromises between financial reflections and goal achievement towards the latter. The improved economic development also allows for a more efficient reduction of UFW, which will reach the anticipated level of 25 % in 2025 according to Jordan's water strategy (MWI, 2009).

The explanation of assumptions about the specific developments in water demand, water supply, and wastewater with regard to water demand corresponds to that in the description of scenario Zero.

- ***Scenario MIN: Low Demands for Water Sector Development***

Scenario narrative: The lower than expected demographic growth and the economic stress on household incomes lead to the lowest increase in domestic and municipal water demand compared to all other scenarios. Also water demand by industry and tourism develops along the lower limit of estimations. The leeway for water tariffs for water consumers remains limited and may require divergences from the goal of full cost coverage. Economic aspects in compromises between financial reflections and goal achievement are given a stronger weight. Investments in the reduction of current UFW still reach the rate of success according to the estimations by the utilities.

The explanation of assumptions about the specific developments in water demand, water supply, and wastewater with regard to water demand corresponds to that in the description of scenario Zero.

- ***Preliminary Indications from the Scenario Results in Jordan***

The major intention of the scenario exercise was to provide SMART experts with an evaluation framework for impact analyses based on "with-without" comparisons for their specific field of innovation development. The comparison of the three scenarios themselves allowed for some conclusions, which help estimate the potentials of changes in water resources management. More detailed analyses are possible, but go beyond the current assignment of the working group on scenario development in SMART.

Initial observations:

- The potential of wastewater recycling would cover the current agricultural water demand in Wadi Shueib as well as in Wadi Arab already nowadays. However, it is likely that the availability of more water would lead to an extension of irrigation areas. An evaluation of these effects and interdependencies would require an analysis of farming systems and enterprises, e.g. their potentials for investments and spatial expansion. The amount of treated wastewater, which may alternatively go to aquifer recharge, depends at least as much on the aforementioned capacities of farming systems as on its quality.

- Observations in the area indicated that at least a part of the untreated wastewater is used for irrigated agriculture. The interdependencies between growing and more expensive amounts in treated wastewater and the reduced availability of cheap wastewater will need closer analysis in order to minimize local resistance against innovations in water treatment.

- The increasing amounts of wastewater are the result of increasing water imports in both areas. Potentials of wastewater treatment will thus depend on the overall development of Jordan's freshwater conveyor infrastructure and water production in other regions. Any sustainable planning of local wastewater treatment coverage will crucially rely on the inclusion of these supra-regional interdependencies in the planning process.

4.5.4 Scenarios for Regions in Palestine / West Bank

Data and information for scenario development at research locations in Palestine were obtained from PHG, PWA, the Community of Jericho, and different international donors under the umbrella of the Local Aid Coordination Secretariat of the international donor community (LACS). The involvement of the Palestinian team members in municipal scenario exercises provided access to the relevant databases and ensured the incorporation of opinions and directives of the local stakeholders. This also allowed for the provision of guidelines about sources of information on the Palestinian water sector to the other partners in SMART (*cf*. Deliverable D801).

Existing results from regional scenario exercises are too highly aggregated for deriving meaningful results by direct downscaling due to the distinct diversity of situations in the areas in the Palestinian West Bank. However, scenario development for Jericho used data, agreed-upon assumptions, and findings from the recent design of the Water Master Plan for Jericho City (AFD *et al*., 2011), which was organized and implemented by PHG. The development of scenarios for Wadi Auja as the second SMART research location in Palestine was not possible under the given research approach, as it would require a full-scaled basic scenario exercise, i.e. the funding of primary data collection and specific stakeholder workshops.

The stakeholders in Jericho identified "management and coordination among stakeholders" and "resource availability under climate change" as the two most significant factors for future developments in the water sector (see Figure 157). Assumptions were that *(a)* a further deterioration of the drivers themselves is not likely and *(b)* variations in demographic growth may arise due to immigration, but not due to changes in the natural growth within the governorate. However, migration due to external causes was considered as a non-quantifiable event in terms of size and timing under the given political situation. This excluded demographic growth as a suitable driver of framework conditions for water sector scenarios.

The scenario exercise boiled down the vast amount of potential developments to 2 most probable scenarios, which represent

- The worst case scenario without progress in water resources management and coordination among actors with a limited resource availability and

- the best case scenario, which reflects a competent management, an improved coordination and the availability of additional water resources (without additional, potential contributions from SMART developments).

The water-related results from all other scenarios ranged between these two extremes. All figures may also be found on the webpages of DAISY and DROPEDIA.

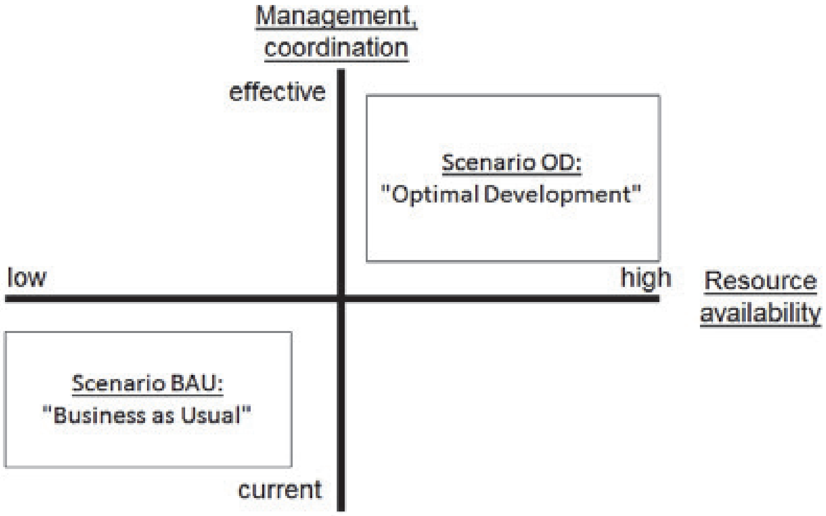


Figure 157: Scenario drivers, Jericho

- ***Scenario BAU: "Business as Usual"***

Scenario narrative: Negotiations with holders of private water rights and wells fail and investments in water infrastructure other than the preservation of existing tanks, conveyance, and meters do not take place. The current water supply system remains unchanged with two separate setups of both major water resources *(1)* Ein As Sultan springs and *(2)* groundwater wells east of Jericho. Poor household incomes and a lack of donor-supported promotion of water-saving devices and techniques leave domestic water demand unchanged at the current level of 250 l/c/d. However, this demand can only be partly satisfied with the available water supplies. The same factors lead to a lack of improved irrigation infrastructure and the lacking applicability of irrigation methods in agriculture. Results are increasing water demands by agriculture under a decreasing supply of water for irrigation. Another reason for this increase in the demand of water for irrigation is the lack of alternative employment for citizens in the area. The creation of new job opportunities, such as the expected construction of the agro-industrial park and substantial increases of business in tourism, fails in this scenario. Established, but inefficient structures in municipal water management do not change under the given situation which lacks incentives for administrative improvements.

Water demand: Water demand rises in all sectors, but cannot be met by the available water supply. Table 14 displays the realizable water use. Water use is the sum of water consumption and remaining wastewater. Water use rises in particular due to the increase in domestic, public, and commercial water demand by demographic growth. Agricultural freshwater use decreases in all areas with the decreasing water supply through Jericho's conveyor infrastructure for water from the Ein As Sultan springs. However, agricultural use of treated wastewater overcompensates this effect, but agriculture in the eastern part of Jericho relies on the pumping of increasingly saline water from private groundwater wells in this area. Water supply to the refugee camps Ein As Sultan Camp and Aqbat Jaber remains constant on the current level.

Water supply: Water from the Ein As Sultan springs and water from groundwater wells and their distribution networks remain separated under the conditions of the scenario BAU. Treated wastewater from the new treatment plant provides additional water for agricultural purposes, but increases in its potential through blending with saline water are not possible due to the missing network link. Figure 158 shows the assumed supply from these sources. Differences between supply and demand, i.e. unmet demand, will have to be covered either by water purchase or by reducing water consumption. The latter holds in particular for agriculture, where unmet demand most likely results in reduced production due to decreasing cultivated areas.

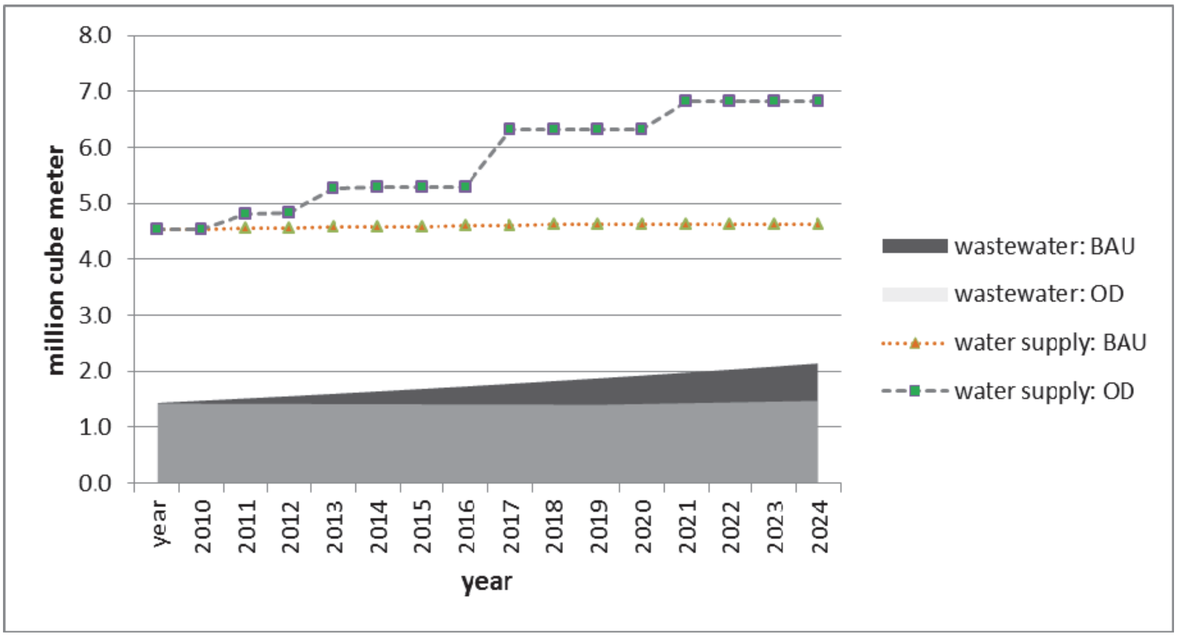


Figure 158: Water supply and wastewater under different scenarios, research region Jericho: *Scenario OD: "Optimal Development"*

Scenario narrative: Negotiations with owners of private water rights and wells succeed and new investments in water infrastructure, such as well rehabilitation, new tanks, and conveyance infrastructure, take place. The hitherto separated water structures of the Ein As Sultan springs and groundwater wells east of Jericho are connected and allow for a joint management of all available water resources. The development of job opportunities leads to increasing water demands by the industrial and touristic sectors, but simultaneously creates higher household incomes, too. This and extended donor-supported propagation of water-saving techniques and devices allow for investments by households, which leads to decreasing water demands per capita. The overall domestic water demand consequently decreases until about 2020. Afterwards, impacts of the more sensitive use of water in households will be fully compensated by demographic growth and restart to increase.

Water from new and rehabilitated wells is used for agriculture with more sophisticated irrigation technologies and approaches. Additional water for agriculture comes from stormwater harvesting in earth pools and a new tank for blending treated wastewater with brackish water from the groundwater wells. This allows for a stronger increase of cultivated areas with smaller additional demands for water supply. The creation of job opportunities in industry and tourism results in additional demands for freshwater supply. The municipalities' water network will supply the planned agro-industrial park with 100,000 m³/year of water during its installation phase from 2012 until the end of the scenario horizon. Additional water for tourism increases the amount of required commercial water within Jericho city.

Water demand: Total water demand from urban areas decreases until 2020 due to the successful introduction of water demand management measures. It reaches and exceeds the current level of total water demand again after 2020 due to demographic growth. The development in water consumption by agriculture corresponds to the BAU scenario, but reflects a higher coverage of water demands due to the use of improved irrigation techniques and the respective cropping patterns. This becomes possible due to the better quality, i.e. lower salinity, of water provided to agriculture. Water supply to the refugee camps Ein As Sultan Camp and Aqbat Jaber remains constant on the current level.

Water supply: The distribution networks for water from the Ein As Sultan springs and water from groundwater wells will be linked and allow for an optimization of water allocation in terms of quantity and quality. Improvements in the infrastructure, such as pumps and tanks, allow for increases in the amount and reliability of water supply from these sources. Treated wastewater from the new treatment plant provides not only directly additional water for agricultural purposes, but is also available for blending with otherwise unsuitable saline water.

Additional freshwater comes from the mobilization of new water resources, such as new and rehabilitated wells and stormwater harvesting, as well as from the institutionalization of trading contracts with well owners outside of Wadi Quilt.

- *3. Preliminary Indications from Scenario Results*

The governorate of Jericho is not ridden by natural water scarcity per se. Water consumption in urban areas is significantly higher than in comparable municipalities in the East Bank, but also significantly lower than in Israeli settlements. However, water availability restricts the potential of agricultural production and forces Palestinian farmers to leave large areas of cultivated land fallow.

The start of operations of the large-scale wastewater treatment plant in Jericho East, which is in its final phase of construction, will provide sufficient capacity for the full sanitation of the Jericho governorate even beyond the scenario period until 2025. Current planning foresees the connection of Jericho City to this treatment plant only, but this will still leave some capacity for the potential connection of water users in adjacent areas. However, plans for the extension of the wastewater collection infrastructure beyond Jericho City do not yet exist.

Water demand management (WDM) and the success of the foreseen WDM measures will be a significant factor in obtaining a neutral water balance. However, the success will strongly depend on the investment capacities of individual commercial enterprises as well as of private and public households.

Water purchases from the Ed Dyuke At Tihta Spring, which is located in Wadi Nuweima, play a role for covering gaps between demand and supply in both scenarios. Any water planning in Wadi Nuweima will not have to consider these water exports to Jericho City only, but also the implications for local water trade. Potential implications include e.g. water pricing in Wadi Nuweima as well as competition between sectors of local water use and water exports.

The current estimations of the stakeholders in Jericho indicate that desalination of groundwater from wells in Jericho East will become a potential contributor to local water supply after 2025 only. This estimation relies on the current state of the art of desalination plants and may change, if technical innovation leads to economically sound solutions before that date.

4.5.5 Scenarios for Kalya, Westbank

Data and information for scenario development for Kalya were obtained from MEKOROT, the preceding work of EWRE during the first phase of SMART, and the policy papers relating to the currently ongoing formulation of Israel's new water master plan. The Israeli team members are members of the planning teams in the stated organizations (*cf*. Deliverable D801).

The situation of Kalya suggests "water resources mobilization" and "economic development" as the major drivers of the development of the local water sector until 2025. However, the choice of these drivers depends on an "educated guess" of the scenario developers only. Recent local scenario exercises were not available. Figure 159 displays the resulting scenarios.

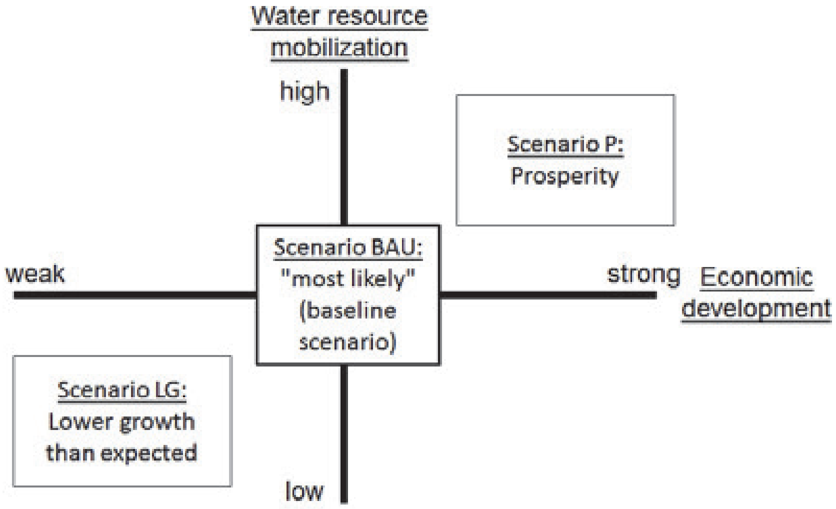


Figure 159: Scenario drivers, Kalya: ***Scenario BAU: "Business as Usual"***

The scenarios "Prosperity" and "Lower growth than expected" combine the extreme developments in water resources mobilization and economic development. All other combinations yield results between the outcomes of both extreme scenarios. Scenario "Business as usual" considers the current prognoses of water demands and assumes the realization of already decided changes in water resources mobilization.

Figures relating to the development of the individual components were compiled in appendix 4 of Deliverable 801 (2013). All figures may also be found on the webpages of DAISY and DROPEDIA.

Scenario narrative: The demographic and economic development of the Kalya area continues according to available prognoses and expectations. Demographic growth corresponds to the expected annual rate of 7.9 %, and tourism increases by about 1 % per year (estimation based on average development of tourism in Israel, CBS, 2012). In addition to natural growth, this is linked to an arrangement between the Israel Nature and Parks Authority and Mekorot, which allows for replenishing natural pools in the Ain Feshkha nature reserve by an additional well in the area. The agricultural cooperative reaches arrangements with Mekorot which allow for the successive reduction of water scarcity during peak days and a moderate, but continuous extension of agricultural production.

Water demand: The water consumption per capita stays at the current 548 l/c/d, which includes domestic consumption as well as additional water consumption in the municipalities. Water demand by visit sites remains constant, while water demand by tourism increases by annually 1 %. The development of water supply capacities for irrigation allows for an increase in water consumption of 1 % p.a. by agriculture.

Water supply: Local freshwater production from the existing Mizpe Jericho wells will continue on the current level (extrapolated based on moving average over three years). A new well at Mizpe Jericho will contribute an additional amount of 2 MCM/year from 2014.

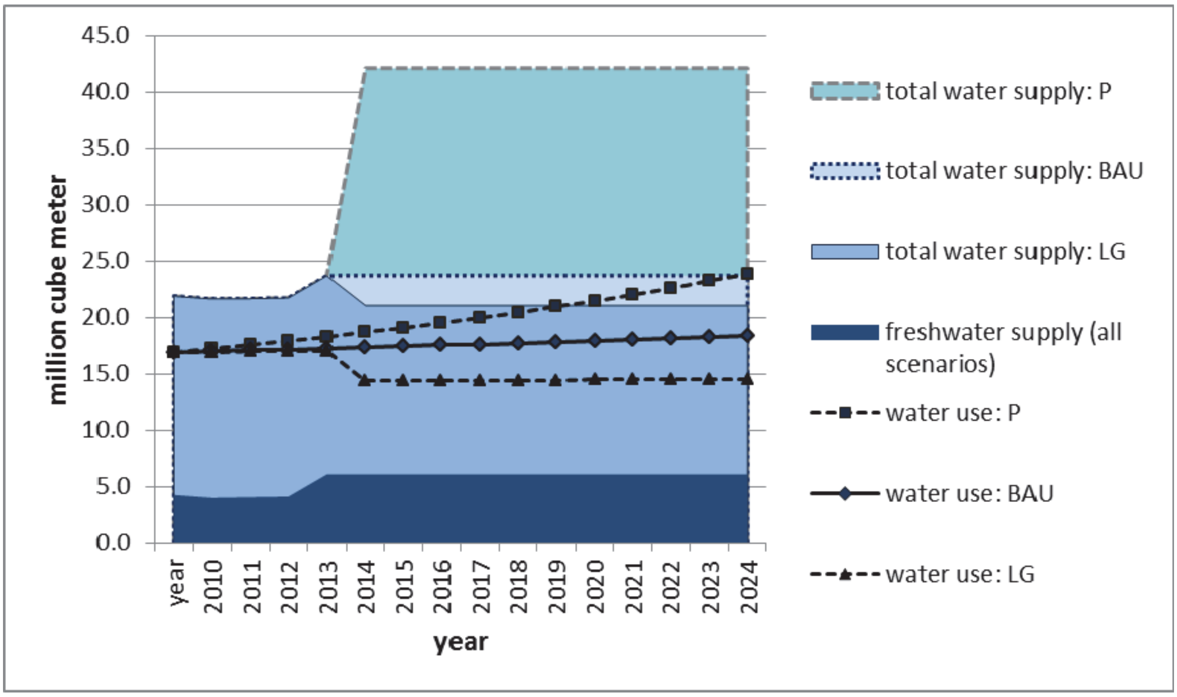


Figure 160: Water supply and water use under different scenarios, research region Kalya:
Scenario P: "Prosperity"

Saline water supply remains constant from the existing Feshka wells and the Kane and Samar springs (Kane and Samar wells extrapolated based on moving average over three years). The National Nature and Parks Authority drills a new well in 2015 with a capacity of 2,400 m³/h, but extracts only 600 m³/h 12 hours per day, which is required for replenishment of the pools. Agreements with prospective clients on the potential surplus water, i.e. the agricultural cooperative or the Palestinian water authorities in Jericho, fail. The amounts of treated wastewater from the Og reservoir remain on the current level (see Figure 160)

Scenario narrative: Development of tourism significantly exceeds the growth rate of the last 5 years and increases by 2 % annually. The related direct and indirect job opportunities attract more residents to the area and lead to a demographic growth of 8.9 % per year. As under the BAU scenario, the Israel Nature and Parks Authority and Mekorot reach an agreement, which allows for replenishing natural pools in the Ain Feshkha nature reserve by an additional well in the area. The increased economic activities also stimulate further investments in agriculture (e.g. installation of private desalination plants, extension of cultivated areas, changes in cropping patterns, and greenhouse installations) and induce the agricultural cooperative to invest in additional water supply.

Water demand: The water consumption per capita stays at the current 548 l/c/d, which includes domestic consumption as well as additional water consumption by the municipalities. Water demand by visit sites remains constant, while water demand by tourism increases by annually 2 %. The development of water supply capacities for irrigation allows for an increase in water consumption of 5 % p.a. by agriculture.

Water supply: The development of local freshwater production corresponds to the development under the BAU scenario. Supply from the existing Mizpe Jericho wells will continue on the current level and the new well will contribute an additional amount of 2 MCM/year from 2014. Saline water supply remains constant from the existing Feshka wells and the Kane and Samar springs.

The National Nature and Parks Authority does not only conclude an agreement with Mekorot on the planned new well at Feshkha, but also with clients for the surplus water. The amounts of treated wastewater from the Og reservoir remain on the current level.

- ***Scenario LG: "Lower growth than expected"***

Scenario narrative: Regional developments cause a decline in international tourism and lead to a decrease in tourism at Kalya by annually 1 %. The impacts on job opportunities decelerate demographic growth down to 5 % per year. Analyses of effects and consequences of the contemplated new well at Feshkha yield disadvantageous results and the Nature and Parks Authority refrains from the construction. The agricultural cooperative continues production on the current level and water demand remains constant.

Water demand: The water consumption per capita stays at the current 548 l/c/d, which includes domestic consumption as well as additional water consumption by the municipalities. Water demand by tourism decreases by annually 1 %. Water demand by visit sites remains constant, but supply and consumption decrease by 2,628 MCM/year from 2015 due to reductions in the discharge of the existing pumping station at Feshkha. The water consumption by agriculture remains on the current level.

Water supply: The development of local freshwater production corresponds to the development under the BAU scenario. Supply from the existing Mizpe Jericho wells will continue on the current level and the new well will contribute an additional amount of 2 MCM/year from 2014.

Saline water supply from the Kane and Samar springs remains constant. Supply from the Feshka wells decreases due to the lower discharge of the existing pumping station. In reality the drop of discharge most probably is a continuous process. In the scenario calculations, however, it is considered a discrete event in 2015 due to the lack of more precise information on the process. The amounts of treated wastewater from the Og reservoir remain on the current level.

4.5.6 Summary and Conclusions

- Downscaling of aggregated regional or national scenarios requires additional information on the subordinate areas. The individual sub-regions in the Lower Jordan Valley are too heterogeneous for downscaling by regression. The possibility of direct transfers of findings to sub-regions other than the examined ones is limited.
- The calculated scenarios represent the closest estimation for the examined basins that can be achieved by the aggregated information available on the sub-regional level. Improvements in the underlying database are possible by primary data collection, as was proven by Riepl (2013) for Wadi Shueib, Jordan, but would also be more expensive. Justification of such additional costs will require a problem analysis in each individual case.
- The presented scenarios correspond to the national guidelines and assessments, i.e. match the assumptions of national decision-makers regarding further developments on the national level.
- The specific dynamics of the region, the international interest in its developments, and the related funding mechanisms may lead to changes in assumptions and implementations on short notice. This indicates the temporally limited validity of the calculated figures and underlines the necessity of continuous cross-checks and updates of local scenarios.
- The situation and key aspects of the water sector in the examined regions of the West Bank and Jordan differ significantly between the basins. The scenarios indicate that such differences will become even more pronounced in the future.
- Water availability from local resources is one of the major parameters that differs among the research locations of SMARTII. The scenarios indicate that water from local sources cannot cover the future water demand of the SMART research regions in Jordan, but might or already does so for the regions west of the Jordan River. However, a generalization of this finding for all regions on the respective side of the Jordan River would be incorrect, since representativeness of the selected region is not proven.

5 IWRM TOOLBOX

Involved Institutions: EWRE, UKA, UFZ, GU, JUA, MWI, PHG, QUDS, TAU, MEK

Spokesman WP6: J. Bensabat (EWRE)

Compiled by: J. Bensabat, D. Riepl, S. Geyer, B. Kaempgen, I. Heinz

5.1 Definition of the IWRM Tools and Their Purposes

Authors: D. Riepl, S. Geyer, B. Kaempgen, I. Heinz, J. Bensabat

WP06 is solely devoted to the development and deployment of tools aimed at supporting the IWRM process. These include:

1. **A comprehensive database management system (DBMS) DAISY** hosted at UFZ and integrating data collected from a various large number of sources, (MWI – Jordan, PWA – Palestinian authority, and IWA – Israel as well as data collected under the SMART/I and SMART/II projects).
2. **A knowledge management system, (DROPEDIA)**, based on the WIKI paradigm. It can collect and integrate data and information from various levels of refinement (informative general data, modeling data through WEAP, etc.). DROPEDIA has been developed and deployed from SMART resources.
3. **Generic models for supporting various activities undertaken in the project:** 1) model for the evaluation of natural replenishment; 2) models for the simulation of groundwater flow and reactive solute transport on various space and time scales; 3) models for the simulation of surface flow and others. Most of these models have been developed outside of SMART.
4. **Quantitative tools for socio-economic analysis, such as cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), multi-criteria analysis (MCA), social acceptance analysis, inter-seasonal agricultural water allocation system (SAWAS), water evaluation and planning system (WEAP), and the multi-year water allocation system (MYWAS).** These tools have been developed outside of SMART, but have been extensively used for socio-economic evaluation within the project (with the exception of MYWAS).
5. T**ools for decision-making relating to IWRM, including the evaluation of hydrological budgets (HYDROBUDGETS), multi-criteria decision-making (MCDS), including ELECTRE-III and the analytical hierarchy process (AHP), multi-criteria optimization (MCO),** including the weighted sum (WS), the normal boundary intersection method (NBI), and the normalized normal constraint method (NNC). The purpose of the MCO module is to determine the set of non-dominated solutions of the MCO problem or the pareto set. In order words, this procedure allows to create a set of candidate solutions, from which the preferred solution will be chosen. The last module is the scenario generator (SG), a tool that supports the formulation and ranking of optimal IWRM alternatives. All these tools are integrated into the SMART-DSS software platform.

Altogether, three software platforms were developed. They have been loosely integrated so far: DAISY (http://www.ufz.de/daisy); SMART-DSS (www.ewre.com/smartdss/publish.htm); and DROPEDIA (http://dropedia.iwrm-smart2.org/index.php?title=Main_Page).

Access to DAISY is restricted to registered users, partial access to DROPEDIA is free, and full access is restricted to registered users. Finally, access to SMART-DSS is free.

5.2 Database and Information management

Authors: D. Riepl, S. Geyer, B. Kaempgen, J. Bensabat

5.2.1 Introduction

The exchange and integration of information between participants and or stakeholders is a prerequisite of any IWRM implementation. Realization of the required communication flow is associated with two major challenges. From a technical point of view, the attempt is made to provide an efficient infrastructure adapted to the dissimilar requirements of the multitude of stakeholders, processes, and tools involved. On the administrative level, the challenge lies in overcoming the obstacles of trans-border information flow, both across sectors and across countries.

The administrative challenge of sharing information among multinational partners is an acute issue, particularly in the Lower Jordan Valley. Within SMART, this issue was given consideration by locating most of the data management infrastructure on what is perceived as “neutral ground” in Germany, while granting all partners equal access rights and data protection options.

Within SMART, the necessary technical infrastructure was built upon a tripartite combination of data, information, and knowledge management instruments. The first pillar (data level) is a centralized IWRM database (DAISY) with web-based query interfaces (see 5.2.2). The second pillar (information level) is addressed by the DAISY WebGIS (Chap. 5.2.2.3) and the Hydrobudgets tool (see chapter 5.2.3). The third pillar (knowledge level) is the wiki-based online knowledge management platform Dropedia (see chapter 5.2.4). The primary objective of this structure is to enable an efficient information exchange between project partners and stakeholders for water resources assessment and decision-making.

5.2.2 Daisy

Author: S. Geyer

5.2.2.1 Objective

A project database was developed to supply all partners with a common and efficient data-sharing platform for their project tasks and modeling efforts. The interdisciplinary and complex nature of data and information gathered during the SMART project as well as the input from related previous and parallel projects called for a comprehensive and robust database management system (DBMS) capable of efficiently handling spatially distributed, temporally varying data and geo-referenced data (polygons and points). Functional querying and visualization capabilities were other basic requirements. For this purpose, the Helmholtz Centre for Environmental Research (UFZ) technologically developed a tool called DAISY (**Da**ta and **I**nformation **Sy**stem) which builds upon an Oracle database and DBMS hosted at the UFZ.

5.2.2.2 Desgin

In order to design the logical data structure (variables, units, parameters, etc.) and to avoid redundancy, all data stored during previous activities and those supplied by project partners were reviewed and classified according to database regulations and their relevance to the project. Persisting information gaps that needed to be bridged in order to meet the project objectives were detected in cooperation with the project partners. The conceptual design of DAISY is depicted in Figure 161.

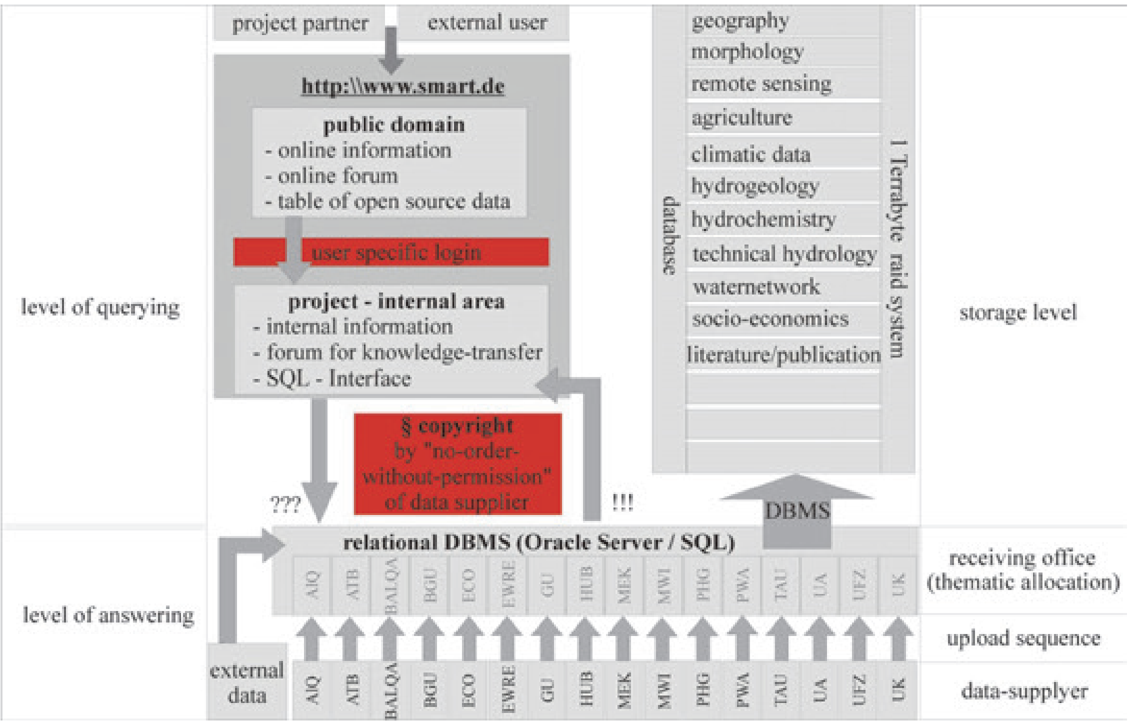


Figure 161: Conceptual flowchart of the SMART relational database management system DAISY.

In order to provide comprehensive historical and contemporary data, an integral part of the data management working package was to gather, compile, and organize all the available data on the LJV relevant to the project, including:

- **Geography**: Maps (up to 1:50,000), aerial and/or satellite photography/images from different periods.
- **Morphology**: Digital elevation models on GIS-readable base (e.g., grd, img) from different sources (e.g. Israel Geological Survey or from aerially corrected ASTER stereography).
- **Climate**: Station characteristics and time series (precipitation, temperature, air moisture, solar radiation, wind speed, etc.).
- **Agriculture**: Crops, irrigation practices and applied technologies, irrigation schedules, efficiency, agricultural development (temporary and long-term crop rotation/changes regarding the necessary amount of irrigation, changes in recharge, soil erosion).
- **Socio-economics**: Cities and villages (population and growth trends, water consumption and water demand trends, wastewater output and utilization.
- **Wells**: Well characteristics (location, depth, casing, lithology, static water level, etc.) and time series of piezometric heads and quality.

- **Spring**s: Characteristics (location, elevation, type, aquifer, etc.), time series of discharge and quality.
- **Water infrastructure**: Layout and characteristics (pipe diameter, discharges, treatment facilities, capacities, etc.) of water supply, sewage networks, and retaining and storing facilities.

Data input is designed to be performed exclusively via the UFZ data management group. Experience of the group showed that an automatic input via the internet is not reasonable, because data have to be reliably checked for consistency. A second important issue is related to the variety of names for e.g. sampling locations due to the use of Hebrew and Arabic names and their transcription. Thus, alphanumerical data (ASCII or Excel files) and raster/vector data (images or ESRI-shape files) have to be checked by the administrator before incorporating them into the database.

Data retrieval was designed in DAISY to offer access via portals with a WEB-GIS interface and a web-based data query interface (harvester), with the actual level of access being granted by the owner of the data.

5.2.2.3 Implementation

In order to enable the required functionality, DAISY incorporates several modules:

- **Oracle DBMS:** Alphanumerical data
- **ArcSDE:** Raster and vector data
- **Transfer drives:** Secure platform for storing and exchanging files between project members and institutions
- **ArcIMS/UMN:** Interactive Web-GIS to plot raster and vector data and design maps
- **DAISY-Harvester:** GUI to request alphanumerical data of Oracle

The entry point is provided online under http://www.ufz.de/daisy. From there, the different user interfaces can be accessed.

The data security policy of DAISY allows for separating published data sets unlocked for public domain access from sensitive data. The metadata (e.g. type of data, location, owner) of the latter are visible to everybody. However, the owner is able to define the level of visibility, e.g. no numbers, just locations). Thus, the availability of data can be investigated by user-generated thematic queries and maps for the SMART region under the Web-GIS interface http://www.ufz.de/webgis-daisy (Figure 162).

The database is updated frequently and mirrored daily to the de-coupled storage core of the Helmholtz Centre for Environmental Research –UFZ. A secure long-term access to the data is guaranteed to all partners, also after regional projects expire. A large amount of data from former projects, such as GIJP, GLOWA, from literature and from the internet, from local and foreign databases were screened, selected, evaluated, and compiled. Data from project partners, such as the Jordanian Ministry of Water and Irrigation, Mekorot, Tel Aviv University, etc., and of foreign partners, such as the BGR, were integrated as well. By making all these information items and data available, the data and information system assisted project partners in determining the need for additional investigations (including field work) that are necessary to achieve the strategic objectives of the project.

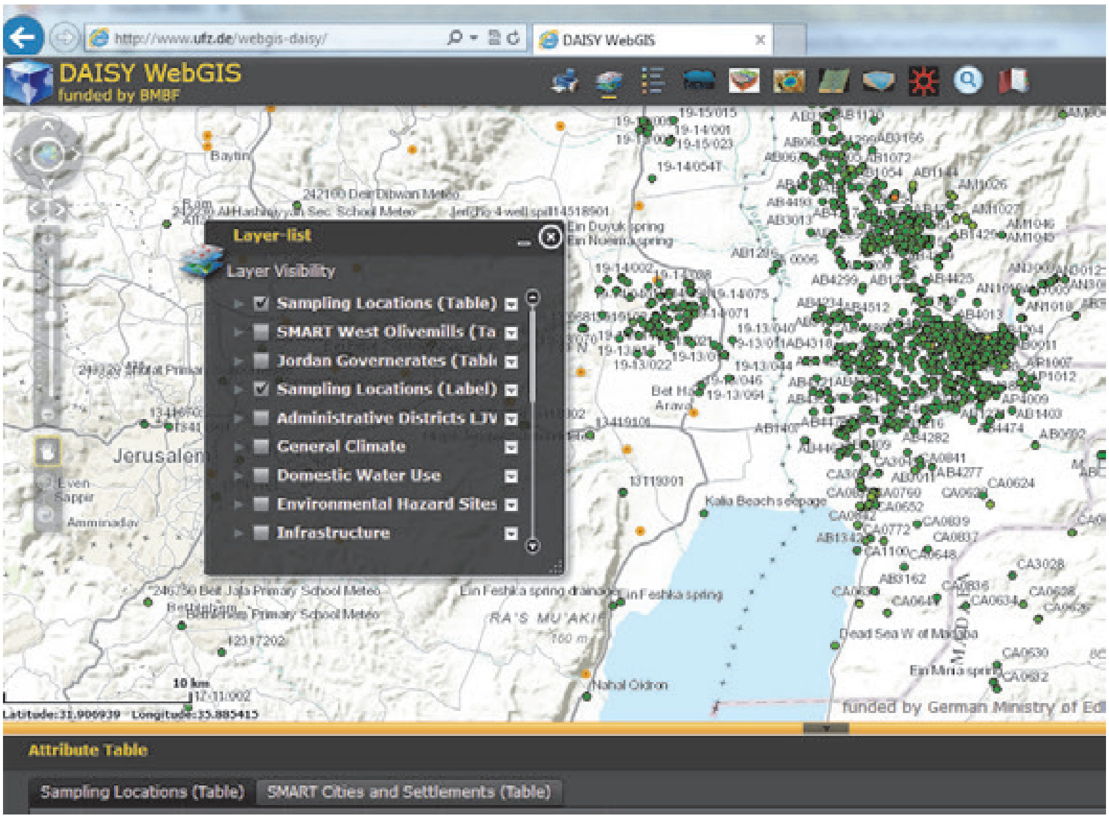


Figure 162: Public-domain DAISY WebGis start-up page.

5.2.3 Hydrobudgets

5.2.3.1 Objective

Hydrobudgets (HB) is one of the modules developed within the web-based SMART-DSS application. It is to allow for the evaluation of the water yield or the inventory of available water resources on the regional scale or on the basin scale. The water yield, or the water potential, is the amount of water that can be utilized with a certain degree of sustainability (a number of years or permanently). The application does not generate data. It relies on data and information from other investigations and integrates them into a single platform that allows for flexible querying and aggregation.

5.2.3.2 Design

Hydrobudgets comprises a database management engine (of generic type though OLEDB providers) for integrating point data, such as wells, springs, and rain stations, similar to the DAYSY system. These point data cover two types of tables: Catalog or static data tables and time series. Static data tables include static information on location, such as an id (which must be unique) and other relevant data specific of the nature of the data under consideration. For a well, for instance, the depth, the reference point elevation, the perforated aquifer, the drilling year, etc., are stored in addition to the coordinates and the id. Moreover, HB can integrate and display vector data (maps in a number of GIS formats) and geo-referenced raster maps (of a large number of formats).

The water yield is evaluated first on the scale of the hydrological reporting unit (HRU). Several types of reporting units exist:

1. Groundwater reporting units (GWHRU): This can be a groundwater sub-basin with known physical boundaries or a portion of a sub-basin with arbitrary boundaries set for administrative purposes. Within such a GWHRU, we evaluate the components of the water balance to be detailed later on.
2. Surface water reporting unit (SWHRU): Usually, this is a surface water catchment or a sub-catchment. Here, the components of the water balance are gathered, too.
3. Sewage/effluent reporting unit (RWHRU): In this case, the reporting unit is purely administrative.

All the data and information in HB are gathered and assembled on the basis of previous investigations. It is therefore suggested that the data and information are input into HB by an expert exclusively. Access to data modification/addition should be restricted, as the quality of the output largely depends on the quality of the input and on the reliability of the expert feeding the system.

5.2.3.3 Implementation

An HB application always starts by the definition of a workspace or project, very similar to the workspaces that are defined in GIS applications, such ArcView (Figure 163). HB first integrates a number of data layers, such as maps (vector and raster) and point data stored in databases.

Building a Hydrobudgets project:

1. Add vector maps that depict the various groundwater basins and define their vertical order in the case of overlapping geological layers.
2. Add vector maps that depict basins and/or lakes.
3. Optionally add a raster map for the background.
4. Optionally add databases.
5. Create the project Hydrobudgets database.
6. Define every HRU.
7. Prepare the project for publishing (deployment).
8. Guidance on how to create a workspace with HYDROBUDGETS is provided in deliverable D602.

A number of layers of information can be integrated: 1) Vector maps (in a comprehensive variety of formats) from hydrological reporting (HRU) units can be defined; 2) Raster maps (with geo-referencing); 3) Relational databases (using a wide variety of formats) by means of OLEDB connection protocols. The hydrological budget is built on the level of the HRU first, which can be surface water, groundwater (of various qualities) and/or treated effluent. The hydrological budget of the project area is then formed by aggregating the individual budgets of the HRU. The components of the budget include: 1) Characteristics of the HRU; 2) Utilization by quality thresholds; 3) Water inflows from adjacent HRUs; 4) Outflows to adjacent HRUs; 5) Outflow control policy. From this information, it possible to derive a water budget or water yield for the HRU (Yield = Inflows-outflows-utilization). Controlling the outflow and the utilization provides means to develop water resources management strategies. HYDROBUDGETS provides a number of facilities for visualization and data analysis.

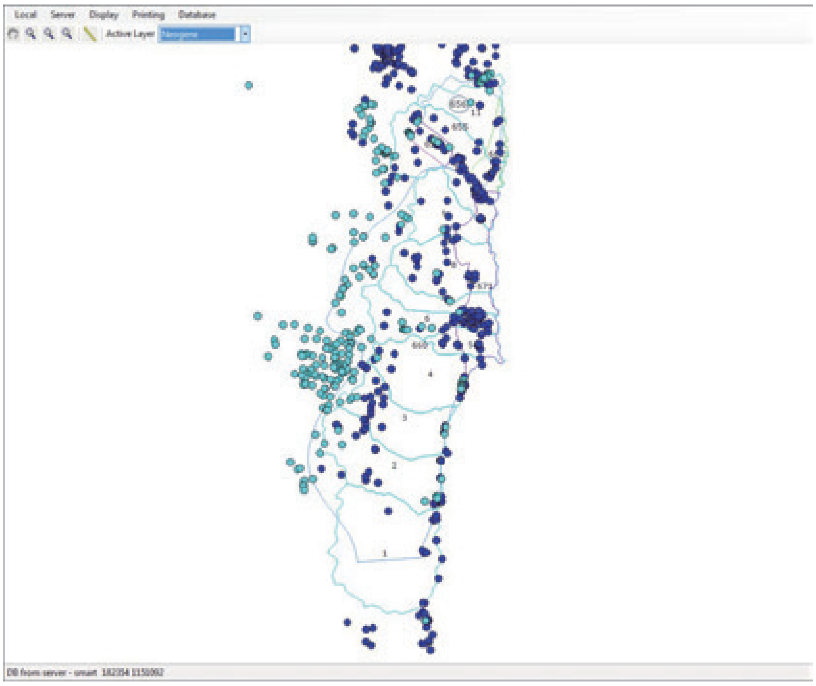


Figure 163: General view of a HYDROBUDGETS graphical user interface.

5.2.4 Dropedia

Author: D. Riepl

5.2.4.1 Objectives

SMART has embarked on the realization of a knowledge management system for collaborative documentation and sharing of planning- and decision-making-relevant knowledge for integrated water resources management in the Lower Jordan Valley. For this purpose, the potentials of different knowledge management approaches were investigated to eventually choose a technology with strong collaborative functionalities: The semantic wiki. This led to the implementation of the DROPEDIA online platform for collaborative knowledge management for the participants and stakeholders of the SMART project (Riepl, 2013).

5.2.4.2 Design

Following the experience from the Wadi Shueib IWRM modeling exercise (Riepl, 2013) as well as discussions in the community of the SMART project, it was agreed that a beneficial knowledge management process would enable the channeling of expert knowledge and the decision–makers' objectives towards the IWRM planning process.

The general approach of the SMART knowledge management system is to offer an instrument that enables domain experts to formulate their analyses and structure them by linking to the respective interrelated entities (IWRM objects) which represent the IWRM system. Acknowledgement of these requirements led to the broad design decision as illustrated in (Figure 164). Members of the IWRM domain (IWRM analysts), on the other hand, are enabled to identify and select from the information available to formally document their decision and planning processes (IWRM processes). Formal linking between a database and the entities in the knowledge base (mostly with the IWRM objects) integrates the knowledge management instrument into an overarching information system. The ultimate goal is to develop a well-structured IWRM knowledge base that provides rich application-level information from experts for experts, IWRM analysts, and decision-makers and can be integrated smoothly into a holistic planning and decision practice.

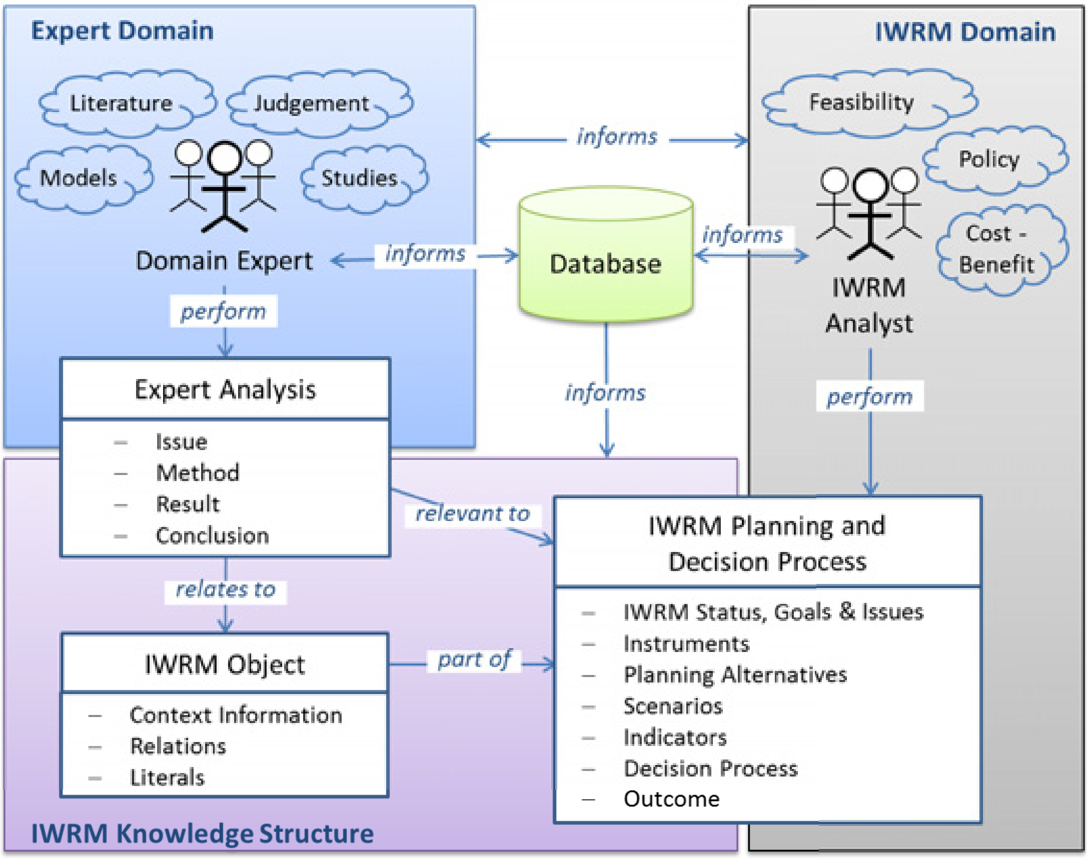


Figure 164: Fundamental concepts and user roles in the IWRM knowledge process.

In knowledge management research wikis are widely perceived as potent knowledge management instruments (e.g. O'Leary, 2008, Wagner, 2006) and also in the IWRM domain, some organizations recently started wiki initiatives (WaterWiki, 2012)(IWAWaterWiki, 2012).

In order to compose an a-priori knowledge representation structure that suits these fundamental concepts as well as the exemplary use cases identified by the Wadi Shueib IWRM study, a semi-formal class structure of IWRM entities was developed (Riepl, 2013), as is illustrated in Figure 165.

Exchange format protocols allow 1) queries to the knowledge base to be made by third parties, e.g., application developers (e.g., data analysis and visualizations tools) and 2) the knowledge base to be extended by data from other parties, e.g., other IWRM-related projects (e.g., SMART-DB, but possibly also GLOWA, EXACT, SUMAR). Full integration requires a user interface to access several data sources, a unique identification of data source content as well as the possibility to relate content from different data sources to each other (e.g., creating a canonical identifier for groups of identical elements).

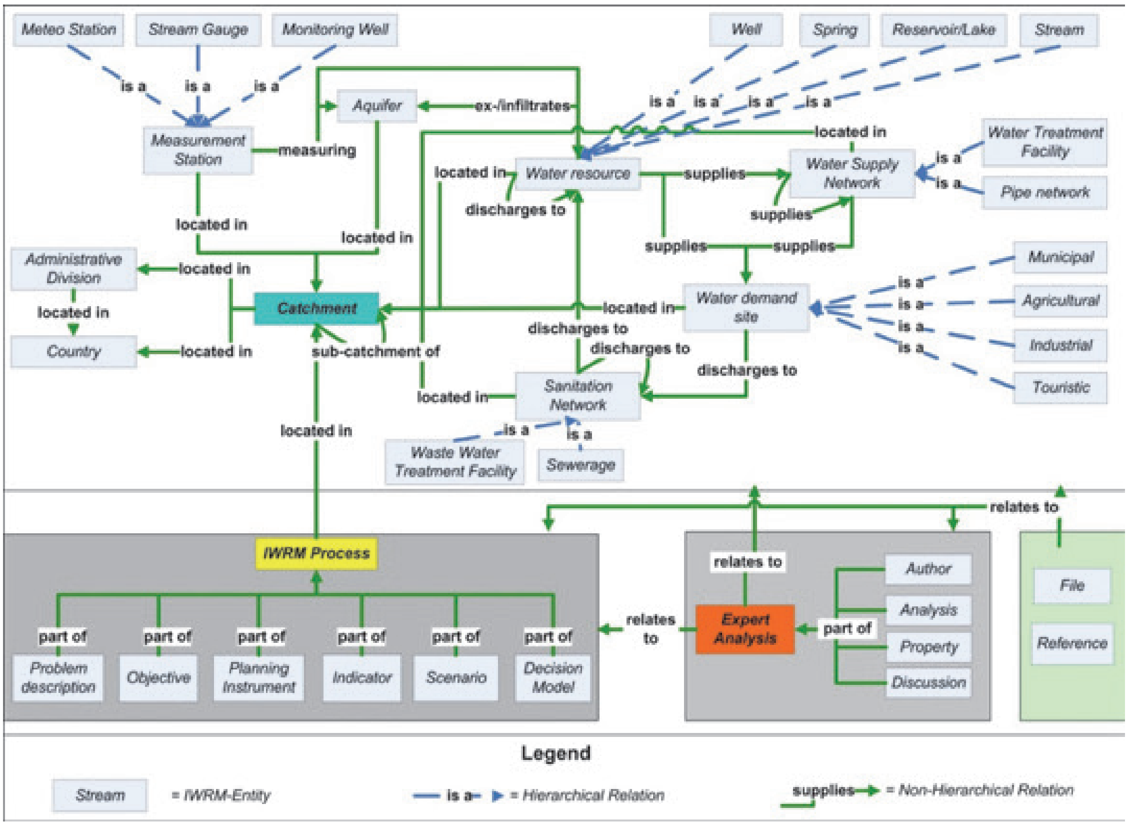


Figure 165: Class structure of the semi-formal IWRM ontology designed for the SMART IWRM knowledge base DROPEDIA.

See Figure 166 for an overview of the architecture of an integrated SMART knowledge base. Here, we use the Linked Data principles (Berners-Lee, Linked Data, 2006) as a suitable exchange format protocol for publishing and consuming IWRM data. Human or machine agents query the integrated SMART knowledge base that, in turn, retrieves and integrates data from several data sources.

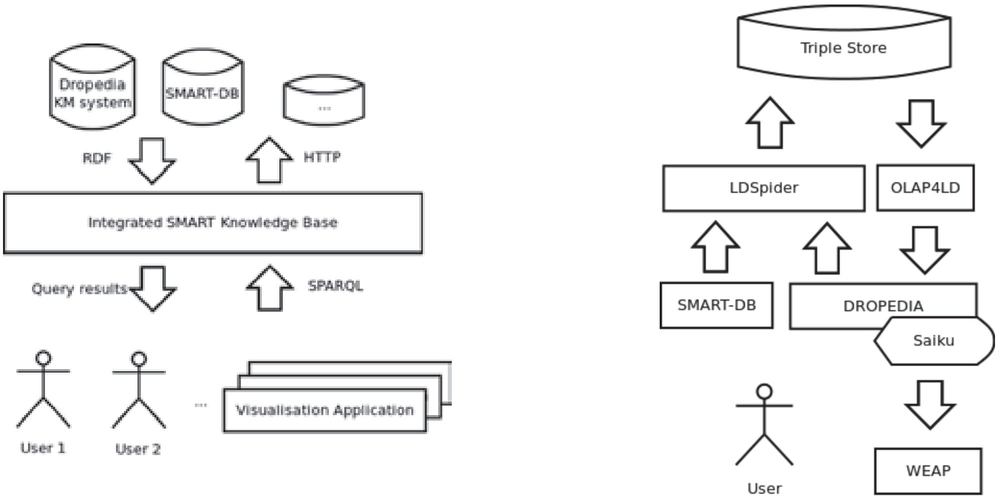
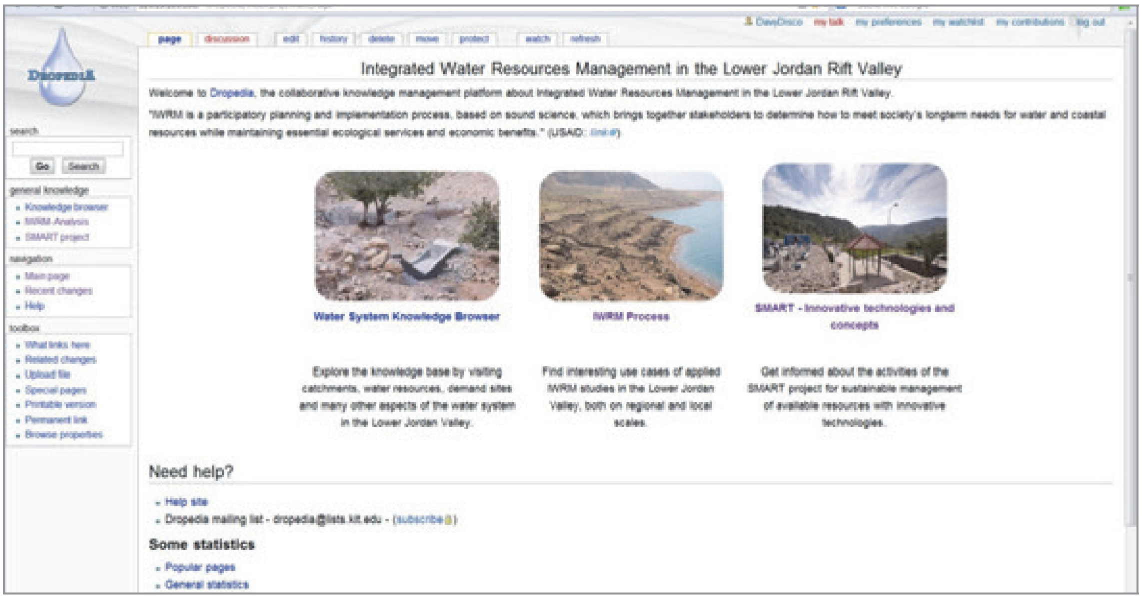


Figure 166: Architecture of Integrated IWRM Knowledge Base

5.2.4.3 Implementation

IWRM planning and decision support has been implemented within the scope of the SMART project. After an initial closed development phase, the platform was opened with online access to the SMART project partners (full access) and the public (read only) under http://dropedia.iwrm-smart2.org (see Figure 167).The following sections provide an overview of essential elements that were implemented to meet the identified requirements.

Based on the classical web-based wiki concept, the DROPEDIA platform is hosted as a client-server model. DROPEDIA is based on Open Source software distributed under the GNU General Public License in versions 2.0, 3.0 or under compatible licenses approved by the Open Source Initiative (OSI). The wiki itself is running on a MediaWiki installation with a number of extensions that are mostly related to the Semantic MediaWiki project.



Integrated Water Resources Management in the Lower Jordan Rift Valley

Welcome to Dropedia, the collaborative knowledge management platform about Integrated Water Resources Management in the Lower Jordan Rift Valley.

"IWRM is a participatory planning and implementation process, based on sound science, which brings together stakeholders to determine how to meet society's longterm needs for water and coastal resources while maintaining essential ecological services and economic benefits." (USAID: link#)

Water System Knowledge Browser

Explore the knowledge base by visiting catchments, water resources, demand sites and many other aspects of the water system in the Lower Jordan Valley.

IWRM Process

Find interesting use cases of applied IWRM studies in the Lower Jordan Valley, both on regional and local scales.

SMART - Innovative technologies and concepts

Get informed about the activities of the SMART project for sustainable management of available resources with innovative technologies.

Need help?

- Help site
- Dropedia mailing list - dropedia@lists.kit.edu - (subscribe)

Some statistics

- Popular pages
- General statistics

Figure 167: DROPEDIA welcome page.

Some typical workflows in DROPEDIA are illustrated in Figure 168.

Users may start on the welcome page or on the permanent left-side navigation and search panel (1) to open to the DROPEDIA knowledge browser page (2) which offers an overview of the knowledge base content. Since the overview is created automatically with inline queries when the page loads, it always presents an up-to-date view on the content. Query results are organized as IWRM objects in sections corresponding to the ontology and are displayed in table as well as in map format.

To add a new IWRM entity to the knowledge base, every section offers an "Add [IWRM object]"-link (3) that opens the respective input form (4) with fields for the categories' metadata. Helpful features extend the semantic forms: Auto-completion, file uploads, map navigation for geographic locations and geocoding of addresses. Saving the form (5) creates the article page (6) that displays metadata properties, attached files, and a series of sections that represent primary topics of the subject (e.g. a spring page shows sections for water discharge, water quality, etc.).

Figure 168: DROPEDIA workflow for IWRM-Object and Analysis contribution.

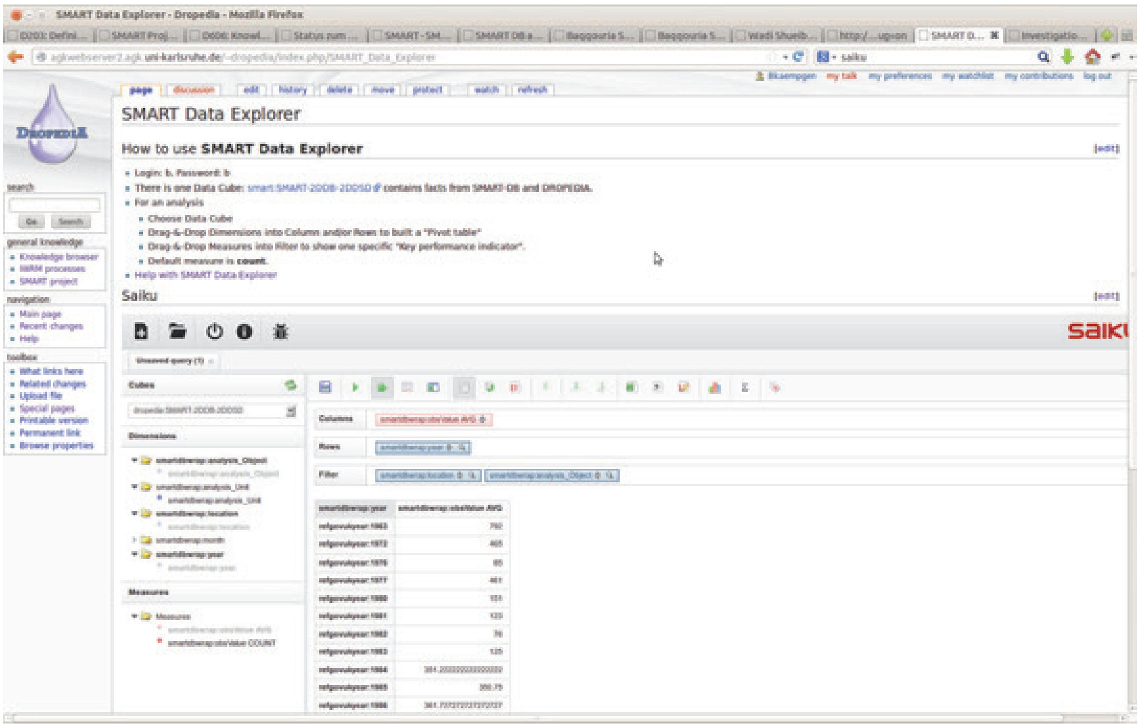
Every section can be edited by a logged-in user by following the displayed “Add/Edit [Section]” links that lead to a corresponding form input (7). Generally, every IWRM object, analysis or IWRM process page offers such links, thus allowing updating and commenting of the knowledge base.

Article pages also present a graph view (8) on the data available in the SMART database, which is created by an embedded SPARQL query at every page load.

Full integration of the database with the knowledge base into an integrated SMART knowledge base for simultaneous queries to both data sources was achieved by implementing an RDF data warehouse – a triple store (Open Virtuoso, see http://www.openlinksw.com/wiki/main/) – that is automatically and regularly filled with up-to-date data from SMART-relevant data sources.

The triple store provides a query interface (Virtuoso SPARQL Query Editor, see: http://agkwebserver2.agk.uni-karlsruhe.de:8890/sparql) for structured queries using SPARQL (Working Group W. S., 2013), which does not only allow returning the results as HTML or RDF, but also as CSV, a suitable format for import into most modeling tools.

Another interface between the triple store and DROPEDIA is the SMART Data Explorer which allows interactive and user-friendly exploration and export of such data. The basic idea behind the SMART Data Explorer is to apply common OLAP and Data Warehousing concepts and technologies to enable scientists and decision-makers to analyze numerical data from the SMART knowledge base. For that, all observations from the IWRM ontology reusing the RDF Data Cube Vocabulary (Cyganiak et al., 2013) are modeled as one single data cube on which OLAP operations, such as slice and dice, can be issued (Kämpgen & Harth, 2011). See Figure 169 for an example of using the SMART Data Explorer for querying the time series of the mean discharge of Baqqouria Spring. Data can be visualized in diagrams (naturally resembling the line chart on the DROPEDIA page except for the observations integrated from DROPEDIA), see Figure 170 and be exported to Microsoft Excel and CSV for import into WEAP.



SMART Data Explorer

How to use **SMART Data Explorer**

- Login: b, Password: b
- There is one Data Cube: smart:SMART-2DDB-2DDSD contains facts from SMART-DB and DROPEDIA.
- For an analysis
  - Choose Data Cube
  - Drag-&-Drop Dimensions into Column and/or Rows to built a "Pivot table"
  - Drag-&-Drop Measures into Filter to show one specific "Key performance indicator".
  - Default measure is **count**.
- Help with SMART Data Explorer

smartdbwrap:year	smartdbwrap:obsValue AVG
refgovukyear:1963	792
refgovukyear:1972	465
refgovukyear:1976	85
refgovukyear:1977	461
refgovukyear:1980	151
refgovukyear:1981	123
refgovukyear:1982	76
refgovukyear:1983	125
refgovukyear:1984	351.20333333333333
refgovukyear:1985	350.75
refgovukyear:1986	361.72727272727272

Figure 169: Screenshot of SMART Data Explorer with query for time series of Mean Discharge of Baqqouria Spring

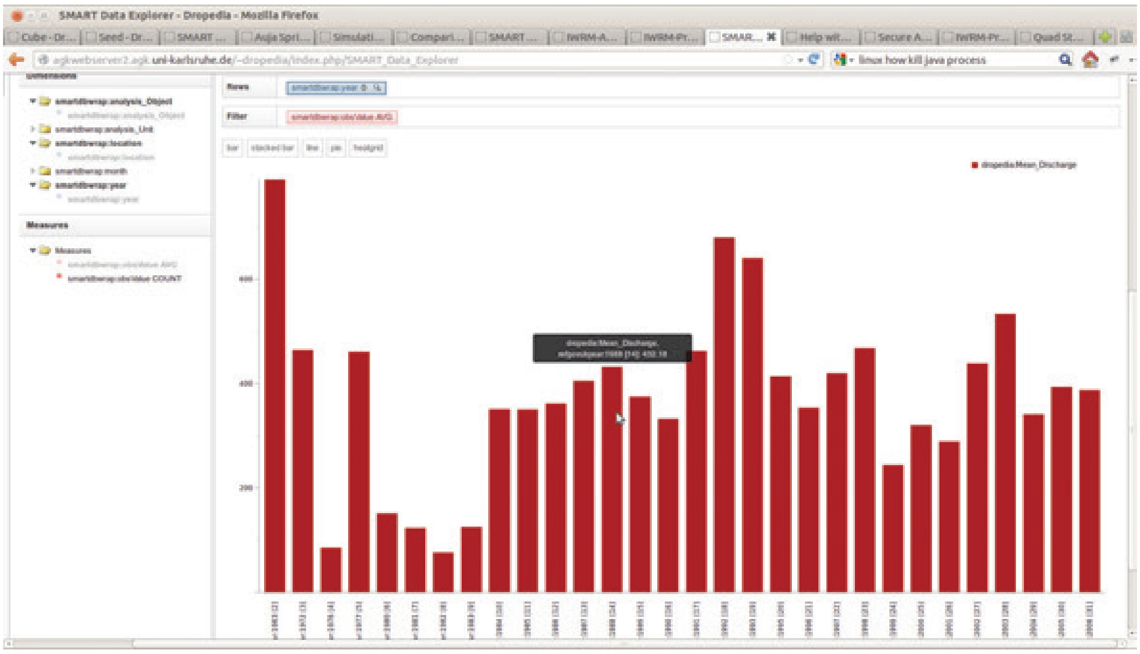


Figure 170: Bar chart of Baqqouria Spring Mean Discharge

5.3 Quantitative tools

Authors: D. Riepl, S. Geyer, I. Heinz, J. Bensabat.

5.3.1 Introduction

Quantitative descriptions of hydrologic processes are important IWRM tools to understand the relationship among precipitation, evaporation, water yield, stormwater runoff, flood routing, groundwater flow, and water quality. Detailed knowledge about the space-time development of water resources in arid regions is necessary for an adequate assessment of impacts and the associated water resources management. Our research focused on the development of generic methods for water resources management on a regional, cross-border scale in the context of strong climate gradients.

5.3.2 Generic IWRM models

Author: D. Riepl

5.3.2.1 Background

IWRM models were developed to provide an integrative platform to address the different subsystems of the IWRM domain. In most cases they emerged as river basin simulation models from a hydrological basis with a focus on water allocation and water balancing. Typical application objectives are to manage river basin operation and development, to address conflicts in water uses, or to evaluate socio-economic and environmental impacts of alternative management strategies. A classical distinction is made between simulation and optimization models, although state-of-the-art models often contain elements of both (Wurbs, 2005). The general approach is to simulate the movement of water through a system of river reaches and nodes that represent reservoirs, diversions, and abstractions, demand sites, and other network elements in order to simulate and optimize different allocation scenarios. For this purpose, most applications adopt some form of linear programming solvers, but other optimization algorithms have also been proposed (e.g. dynamic programming, gradient search, genetic algorithms, and others). The river basin model often provides a more or less interactive link to other model components, e.g. the above-mentioned specialized domain models, in order to meet the objective of IWRM modeling. Hundreds of IWRM river basin models can be found in the published literature, of which prominent and elaborate examples are the models developed by the Hydrologic Engineering Center (HEC) of the USACE (HEC-HMS, HEC-RAS, HEC-ResSim), the MIKE model family (MIKE SHE, MIKE BASIN) from the Danish Hydraulic Institute (DHI), the MODSIM model (Labadie, 2005), RiverWare (Zagona et al., 2001), RIBASIM by Delft Hydraulics as well as the WEAP model by the Stockholm Environmental Institute (SEI) (Yates et al., 2005).

5.3.2.2 Water Evaluation and Planning model (WEAP21)

The Water Evaluation and Planning (WEAP) software tool was initially developed in 1988 in cooperation with the United States branch of the Stockholm Environment Institute (SEI-US), where it is still being further developed and maintained today. Stated design objectives of WEAP21 are to provide a water resources planning tool with hydrologic modeling as well as management elements and a scenario planning environment (Yates et al., 2005).

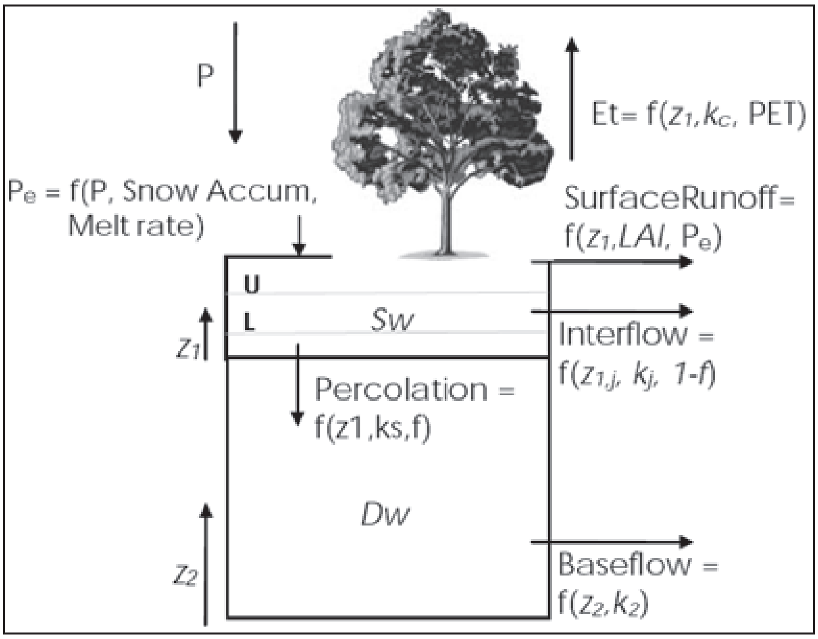


Figure 171: WEAP21 conceptual water balance elements. The two-bucket model tracks the storage volumes Zi by dividing forced rainfall into evapotranspiration (Et), runoff, interflow, percolation, and base flow for each defined fractional land use area with optional parameters for crop coefficients (kc), leaf area index (LAI), water holding capacities (Sw&Dw), hydraulic conductivities (ks&j), and infiltration/runoff partitioning fraction (f) (Yates et al., 2005).

The workflow in a WEAP21 application clearly follows a conceptual modeling approach by defining the model structure as “model schematics” prior to any model simulations. The basic structure is composed of a system of water resources, demand sites, and operational network elements as model nodes that are connected by flow vectors of various types (e.g. streams, canals, transmission links, return flows). Water balances are computed for every time step as linear programmed mass balance within lumped catchment nodes and the resultant fluxes are passed towards connected groundwater or river elements. The conceptual model used for the balancing algorithm employs empirical functions to calculate evapotranspiration, surface runoff, interflow, and deep percolation (Yates et al., 2005). By defining sub-catchments with differential parameterizations, WEAP21 can also be employed to build at least semi-distributed catchment models (Yates & Strzepek, 1998). Figure 171 shows the input and output terms of the conceptual catchment node balance in WEAP21.

Groundwater can be modeled as a simple aquifer bucket element with optional parameterizations of hydraulic conductivity, specific yield, and river-aquifer interconnectivity. Within a sub-module, WEAP21 also provides the possibility to link to a MODFLOW model as well as to a Qual2K (water quality) and a MABIA (crop water requirements and irrigation planning) model (Yates et al., 2005).

The WEAP21 model was applied frequently in studies at various sites and on various spatial and temporal scales. The majority of studies used the software as an instrument to assess the effects of changes in water infrastructure and water management under variable scenario assumptions, for example climate change or development scenarios (e.g. (Groves et al., 2008; Levite et al., 2003; Yates et al., 2009), or specifically for the Lower Jordan Valley region (Al-Omari et al., 2009;

Hoff et al., 2011)). Within the framework of the SMART project, WEAP was applied in several local case studies and with different degrees of model detailing (Riepl, 2013, Alfarra et al., 2011, Heinz et al., 2014).

Within these SMART studies, WEAP was found to be a flexible and ample tool, generally appropriate for water resources system modeling in the applied use cases. I In the Jordanian Wadi Shueib, for example, a detailed WEAP model was successfully constructed to represent all elements of the holistic sub-catchment water balance. The final model displayed good performance for the assessment of the monthly integrated catchment water balance (Riepl, 2013).

WEAP contains a component, by which the economic impacts of different IWRM strategies can be estimated. It allows to assess the annual capital and running costs of improvements in water demand coverage, for instance, by new conveyance systems, dams, and water reuse projects. The benefits of domestic, commercial, and public users are calculated by multiplying the increases in water supply by water tariffs. See SMART studies 706 & 707.

5.3.3 Specialized models

Author: *S. Geyer*

5.3.3.1 Background

Hydrological models and groundwater flow models are common tools for the assessment and prediction of water quality and quantity in the region of Jordan and Israel (e.g. Al-Abed et al., 2005; Al-Assa'D and Abdulla, 2006; Wu et al., 2011; Gräbe et al., 2012). In this case the hydrological models calculate the hydrological cycle and its water balance components, such as groundwater recharge, which will then serve as an input for groundwater flow models. Process-oriented, distributed hydrological models use spatial data sets describing topography, land cover, and soils along with hydro-meteorological time series describing climate conditions. Since the required data and information are usually insufficient, many models are developed on the basis of a-priori start parameters. Current model operators look for a new and better estimation of a-priori start parameters of models or describe combination methodologies for reducing lacking parameters.

SMART demonstrates opportunities to develop a hydrological model in the data-scarce regions with the semi-arid conditions of Wadi al Arab (NW Jordan) and Wadi Quilt / Nueima (east of Jerusalem). For the simulation, we used the hydrological model J2000g implemented in the JAVA framework system JAMS (Jena Adaptable Modeling System). A multi-response technique was used to reduce the impact of data scarcity. The multi-response calibration is based on multivariable measurements (flash flood, groundwater level, spring discharge, groundwater chemistry, etc.). Depending on the data available, chloride mass balance (CMB), water table fluctuation (WTF), and gauged spring discharge (GSD) methods are used to produce calibration and validation data. During the calibration process, the different calibration coefficients are adapted to the results of the independent method. The strategy was to upscale data from the local spring catchment to the wadi surface catchment to the wadi groundwater catchment. Different catchments sizes are chosen to fix typical hydrological conditions. The optimized calibration coefficients are set constant in the next upscaling process.

5.3.3.2 GSD – Gauged spring discharge method

The measurable discharge of springs by the gauged spring discharge method is assumed to represent the base flow of the corresponding catchment areas. Assuming that the individual integrated spring discharge equals the simulated groundwater recharge of the hydrological model, further groundwater storage modules of the hydrological model were implemented to adapt the temporally varying groundwater flow in a double porosity aquifer system.

5.3.3.3 CMB – Chloride mass balance method

The result of the chloride mass balance is assumed to represent the mean groundwater recharge of a corresponding catchment area simulated by the hydrological model. The chloride mass balance method is a simple method to estimate groundwater recharge in arid and semi-arid areas (Bazuhair et al., 1996; Sharda et al., 2006). It is based on the temporal and spatial distribution of groundwater recharge using the conservative chloride (Cl) concentration in groundwater, which is assumed to stem solely from air deposits by precipitation. Hence, recharge R is calculated according to the equation below (Wood and Sanford, 1995) by taking into account the average annual amount of precipitation P (mm) and the average chloride concentration in precipitation (Clrain) and in groundwater (ClGW) of the investigated aquifer:

$$R = P * Cl_{rain} / Cl_{GW}$$

5.3.3.4 WTF – Water table fluctuation method Rainfall-Recharge models

The water table fluctuation (WTF) method is another calibration / validation technique for simulating groundwater recharge by hydrological models. Based on the WTF method, changes of the groundwater table can be observed over time. The method follows the assumption that rising groundwater levels are related to groundwater recharge and is described in detail by Healy and Cook (2002). The groundwater recharge R is calculated according to the equation below, where S is the storage coefficient (effective porosity in an unconfined area), Delta h the change of groundwater table in the period δt, and A is the extension of the watershed. For a proper estimation, highly resolved time series for the groundwater table have to be available.

$$R= S * \text{Delta } h/\text{Delta } t * A$$

5.3.3.5 Hydrological model J200g

The hydrological model J2000g is a process-oriented distributed rainfall-runoff model to estimate spatially distributed hydrological water balance components (Krause and Hanisch, 2009, Krause et al., 2010). J2000g is implemented within the modular JAVA framework system JAMS (Jena Adaptable Modelling System) (Kralisch and Krause, 2006). Figure 172 illustrates the model input requirements in addition to the simulated processes and the related output data.

The model requires daily or monthly meteorological input data (rainfall, temperature, sunshine duration, relative humidity, wind speed) and spatially distributed information about the topography, soil types, and land cover to describe the physico-geographical conditions of the study area. The catchment is divided into hydrologically homogeneous entities, so-called Hydrological Response Units (HRU). HRU are delineated by GIS overlay analysis of the relevant spatially distributed information. Based on GIS-derived information, each HRU is described by its elevation, slope, aspect, land cover, and soil type.

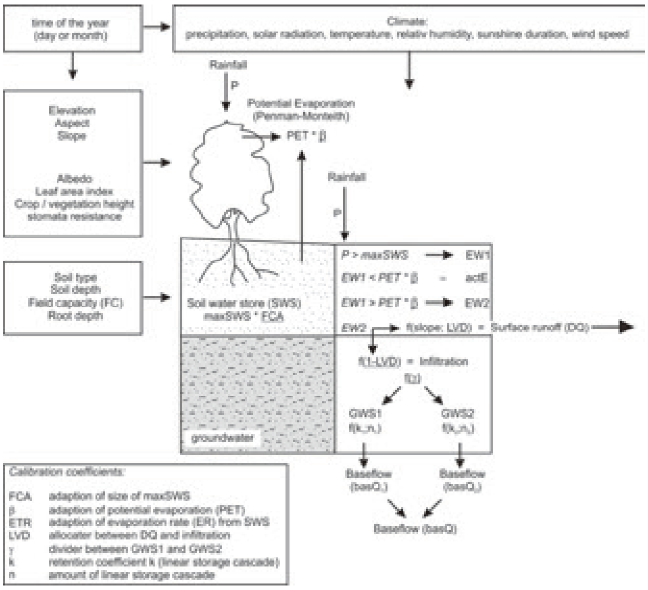


Figure 172: Schematic diagram illustrating the J2000g model input requirements, the simulated processes and the related output data.

For each HRU and each time step, water balance components, i.e. evaporation, are calculated according to the climatological input data, which are regionalized by spatial interpolation using inverse distance weighting and optional elevation correction. Potential evapotranspiration (PET) is calculated with the Penman-Monteith formula as described in Allen et al. (1998). To account for uncertain input data, a multiplicative calibration parameter can be used to increase or decrease the potential evapotranspiration for all HRU by the same relative amount.

The central element of the J2000g water balance is the soil water storage capacity (SWS). The SWS determines distribution between input (i.e. precipitation) and output (evaporation, direct runoff, groundwater recharge, and base flow.) The maximum soil water storage capacity (maxSWS) is parameterized using the effective field capacity FC of the soil horizons within the rooting zone (depth) RD. With the calibration parameter FCA, the maximum soil water storage capacity (maxSWS) can be increased or decreased by the same relative amount for all HRU. The input, i.e. precipitation P, is used until the complete saturation of maxSWS. After the saturation, the surplus water EW1 will be allocated to evaporation. If the potential evaporation is reached, the excess water EW2 is used for the generation of direct runoff and groundwater recharge. In EW1 is smaller than the potential evaporation PET, an evaporation deficit exists, which is balanced partly by SWS. The maximum evaporation rate (ER) from the SWS is therefore calculated by the ratio of a linear calibration coefficient ETR to the relative saturation of soil water storage. The excess water (EW2) is passed into a direct runoff component (DQ) and groundwater recharge (GR) based on the slope (α) and a calibration coefficient LVD. Within the framework of the groundwater module, the generated GR is divided into two groundwater reservoirs (GWS1, GWS2) by the calibration coefficient ⍰. The two groundwater reservoirs allow for the simulation of a fast and slow groundwater component (double continuum aquifer). The outflow (base flow) from GWS1 and GWS2 is computed with single linear storage cascades (Nash, 1958) that are parameterized by n linear reservoirs and the retention coefficient k.

5.3.3.6 Combining the Surface Flow Model J2000 with the 3D Groundwater Flow Model FEFLOW

Hydrological models and groundwater flow models are common tools for the assessment and prediction of water quality and quantity. Linking of both models is supposed to result in better reproductions of hydrological and hydrogeological processes. Both models are combined via the parameter of groundwater recharge.

As numerical groundwater flow model, the “Finite element subsurface FLOW system“ FEFLOW (WASY, 2006) was used in the catchments of Wadi al Arab and Wadi Qilt. FEFLOW is an advanced modeling system with an extensive list of functionalities, including variably saturated flow, variable fluid density mass and heat transport, and multispecies reactive transport (WASY, 2006). It is a proprietary code and not freely available.

5.3.3.7 Models for the simulation of subsurface flow and reactive transport

Author: J. Bensabat

Artificial replenishment is one of the key IWRM tools envisaged in the SMART project. Artificial replenishment can be carried out with freshwater, storm water and/or treated effluents in shallow aquifers, which are mostly of saline/brackish nature. Artificial replenishment can be achieved with injection wells and/or infiltration ponds. Using wells has the advantage of a small footprint (less need of land), but is associated with the disadvantages of well clogging and injection discharges declining with time. On the other hand, infiltration ponds have the disadvantage of having a much larger footprint, but they are more efficient and robust and they allow for an additional treatment of the water by flow through an unsaturated zone (SAT – Soil Aquifer Treatment). The design of such kind of plants is far more complex than a purely hydraulic problem and requires tools for simulating saturated-unsaturated flow and reactive solute transport. We reviewed a number of models capable of performing the task, such as Hydrus, TOUGHREACT (LBNL), and PLFOTRAN (LLNL). Hydrus had the most user-friendly interface by far, but lacked the ability to the handle the chemical complexity of the problem. TOUGHREACT is the most complete model for handling the chemical behavior, but is extremely inefficient from the computational point of view. Finally, PFLOTRAN, which is a native parallel software, proved to have high capabilities with regard to chemistry and a high efficiency, as the speed is almost linearly reduced with the number of involved processors.

5.3.4 Risk Assessment

Author: J. Bensabat

The Risk-based Corrective Action (RBCA) is a consistent decision-making process for the management of remediation of contaminated sites. This process includes a tiered (hierarchical) approach that integrates site assessment and response actions with human health and ecological risk assessment to determine the need for remedial actions and to tailor corrective action activities to site-specific conditions and risk.

RBCA values are determined using mathematical models which assess the fate and transport of chemicals in the environment, estimate chemical uptake that results from environmental exposure and interpret, interpolate, and extrapolate toxicological site information. Models are categorized as analytical (direct solution of the governing equation), numerical (use of finite differences or element methods) or a hybrid of both.

The purpose of the project work was to evaluate some of the more widely used software platforms in the RBCA process. For that purpose, seven commonly used computer software packages were evaluated. The packages are divided in: (1) Programs which model migration of the constituent: VLEACH, BIOSCREEN, Tier2 Analyzer and (2) programs which combine both migration models and risk and target level assessments: RBCA tool kit, RISC5, Johnson & Ettinger (EPA), and IRBCA (the Israeli implementation of the RBCA paradigm).

The software programs were run under three scenarios:

1. Source of contamination located in the vadose zone, leaching towards the groundwater, and volatilizing into buildings.
2. Source of contamination in the saturated zone, transporting with groundwater to a drinking water well.
3. Percolation of contaminant in the gaseous phase from the saturated zone through the vadose zone to buildings.

The programs require 4 types of input data in order to calculate the risk assessments:

1. Exposure parameters and toxicological properties of the constituent;
2. Physical and chemical properties of the constituent;
3. Physical, chemical, and biological properties of the media through which migration occurs;
4. Structure of the building through which vapor intrusion occurs;

The three main output types of the programs for each scenario include:

1. Calculated concentrations at the point of exposure, which are given in some of the programs as a function of time and in others as a function of location along the center line of the plume;
2. Risk levels which define whether a contaminated site poses a risk to human beings and whether a target level for remediation needs to be calculated for the site. In some programs the risk levels are the sum of all risks from all exposure routes. Another methodology claims that summation of risks is not possible and that the highest risks from one exposure route should be chosen.
3. Target levels for remediation of the site, based on target risks or on a maximum contaminant level.

The study provided an evaluation of RBCA-based software platforms. The risk and target level results were compared and the influence of input parameters on the final result was examined. A calculation technique was developed for each pathway in the different programs.

The results obtained reveal different values of the programs in some of the scenarios and a good agreement in others.

Decision making tools

Author: J. Bensabat

5.3.5 Multi-criteria Decision Support (MCDS)

5.3.5.1 Introduction

Multi-criteria decision support (MCDS) tools are essential in IWRM, as they allow for a decision-making process with the participation of the decision-maker, the stakeholder, and the expert. Additionally, IWRM requires taking into consideration a number of, often conflicting, objectives and/or criteria. For example, the most appropriate economic solution for an IWRM problem may not be the best when considering either or both environmental and social aspects. In such cases MCDS provides tools for finding compromise solutions and/or solutions that are better suited to the preferences of the decision-maker and/or the interests of the stakeholders.

Two well-known MCDS procedures were implemented in SMART: AHP (Analytical Hierarchy Process) suggested by Saaty and ELECTRE suggested by Roy (1968) and later investigators. These two procedures are basically subjective, i.e., they heavily depend on the preferences (not always consistent) of the decision-maker /the stakeholder / the expert. The AHP is simple to set, but depends on the subjective choices of the decision-maker, while the ELECTRE procedure seems to be more robust and less dependent on the possibly inconsistent choices of the decision-maker. In SMART-DSS both approaches were implemented.

5.3.5.2 The Analytical Hierarchy Process (AHP)

The AHP is a systematic procedure to construct and represent the elements of a problem in a hierarchy format. The basic rationale of AHP is to break down the problem into smaller constituent parts on different levels. An AHP model typically consists of an overall **goal**, a set of **criteria** to specify the overall goal, which is decomposed into sub-criteria, and finally, on the lowest level of the hierarchy, the decision **alternatives** to be evaluated. In AHP each element in the hierarchy is considered to be independent of all the others. The hierarchy can be visualized as a diagram like the one shown below (Figure 173).

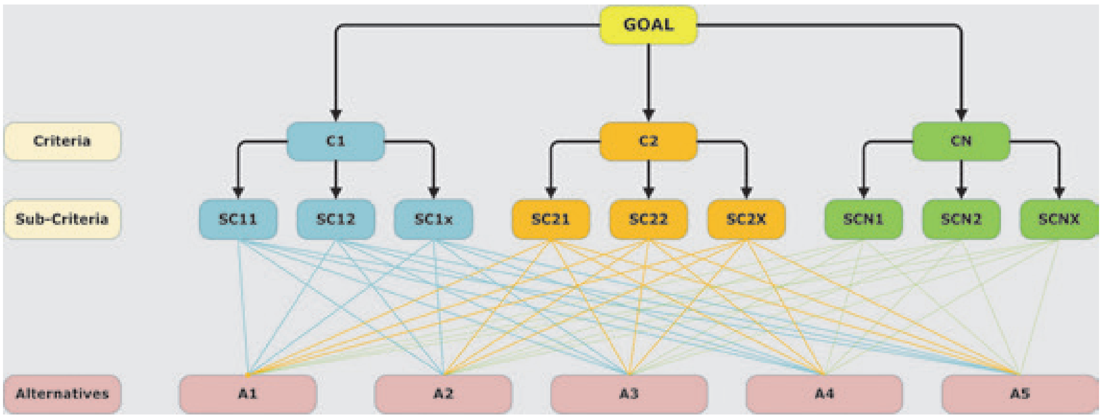


Figure 173: Illustration of the analytical hierarchy process.

Apart from the decomposition principle, the AHP is based on pairwise comparisons of elements in a decision hierarchy with the parent element on the next higher hierarchical level (i.e., between criteria and lower level elements). The pairwise comparison is aimed at providing a cardinal scale to evaluate objects according to some subjective preference criteria. Pairwise comparisons are made on a scale of relative importance (see Table 54), where the decision-maker has the option to express the preferences between two elements on a ratio scale from equally important (i.e., equivalent to a numerical value of one) to absolute preference (i.e., equivalent to a numerical value of nine) of one element to another.

Ratings of decision-makers are arranged as numerical numbers in a comparison matrix. Based on this matrix, relative weights for all elements of the hierarchy are calculated with the eigenvector method (**EVM**), indicating the priority level for each element in the hierarchy (Saaty, 2001). Accordingly, priorities for the alternatives are obtained by judgments with respect to each above-level element of the hierarchy. Their performances are weighted with the relative weights of criteria and sub-criteria and added to an overall priority for each alternative (i.e. how the alternative contributes to the goal), which allows for a cardinal ranking of the alternatives (Saaty, 2006).

Table 54: A nine point scale for pair-wise comparison

Intensity of Importance	Definition	Explanation
1	Equal Important	Two elements contribute equally to the objective.
3	Weak Importance	Experience and judgment slightly favor one element over another.
5	Strong Importance	Experience and judgment strongly favor one element over another.
7	Very Strong Importance	One element is favored over another; its dominance is demonstrated in practice.
9	Absolute Importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intermediate values used to interpolate between adjacent scale values		

AHP was applied extensively within the framework of SMART (Wadi Kelt, Wadi Nueima, Kalya). Although it is of subjective nature, it allows to fully incorporate the inputs from the many stakeholders (decision-makers, technical experts, and interested parties).

5.3.5.3 Electre

The ELECTRE tool goal is to divide a set of decision alternatives into a small number of hierarchical categories – from “best” to “worst”. This process of categorization is being made in two stages: Learning and implementing.

Learning Stage

In the learning stage, the user provides a set of already categorized references that will be used as the learning sequence by ELECTRE. Every reference is described by a set of criteria, such that a given reference is a vector composed of the marks of the specific reference over each criterion. For example, a Mercedes car can be compared to other vehicles by using the criteria of its speed, design, comfort, and safety. The resulting vector can be: ["Very Fast", "Beautiful", "Cozy", "Very Safe"]. While each of these criteria can be mapped to a different numerical scale on a level from 1 (worst) to 5 (best) for all criteria, our Mercedes can then be described as: [4,5,5,5]. If our task is to categorize new cars compared to the cars we already know, then the set of references should contain some of the cars we know along with the grades assigned to every criterion. The set of categories also is hierarchical on a scale of 1 (worst) to 5 (best). This scale is where we place each of our references.

5.3.6 MCO (Multi-criteria optimization)

Author: J. Bensabat

While the MCDS procedures heavily rely on subjective judgments with regard to alternatives / scenarios, multi-criteria optimization (MCO) is a far more elaborate technique, much less subjective, but also much more rigid. The concept is to formulate the IWRM problem in a problem of mathematical programming, i.e., an optimization problem consisting in the minimization of the number of objective functions subject to bound and general constraints:

$$\begin{aligned} &\min_x \mu(x) \\ &s.t. \qquad g(x) \leq 0 \\ &\qquad\qquad h(x) = 0 \\ &\qquad\qquad x_l \leq x \leq x_u \end{aligned}$$

Here μ denotes the vector of the objective functions $\mu = (\mu_1, \mu_2, \ldots.., \mu_m)$, where m is the number of objective functions and $x = (x_1, x_2, \ldots.. x_n)$ denotes vector decision variables (of size n). Examples of decision variables may be the amount of freshwater, brackish water or treated effluents that could be allocated to irrigation, the size of arable land for specific crops, the size of greenhouses, the amount of freshwater to be allocated to industrial activity, etc. The objective function vector μ covers mathematical functions expressing objectives (such as maximum profit, minimum investment, minimum impact on groundwater resources, minimum adverse socio-economic impact, etc.). The objective functions must be independent for the problem to be truly multi-objective and, hence, they often conflict with each other. The vectors $g(x)$ and $h(x)$ represent inequality and equality constraints. Finally, x_l and x_u denote the vectors of lower and upper bounds on the decision variables vector x. The objective functions and the constraints can be either linear or non-linear. The formulation of such a problem requires substantial effort and expertise. However, it helps the planner identify the key components (in the form of the general constraints) of the IWRM system and bounds of the various variables (box constraints) and to formulate the relevant objectives. The objectives are usually conflicting, meaning that there is no possibility to find a single optimal solution. Instead, the purpose of MCO is to find the non-dominated solutions or the Pareto surface. From a mathematical point of view, a solution $x^{(1)}$ is said to dominate a solution $x^{(2)}$, if the following conditions hold:

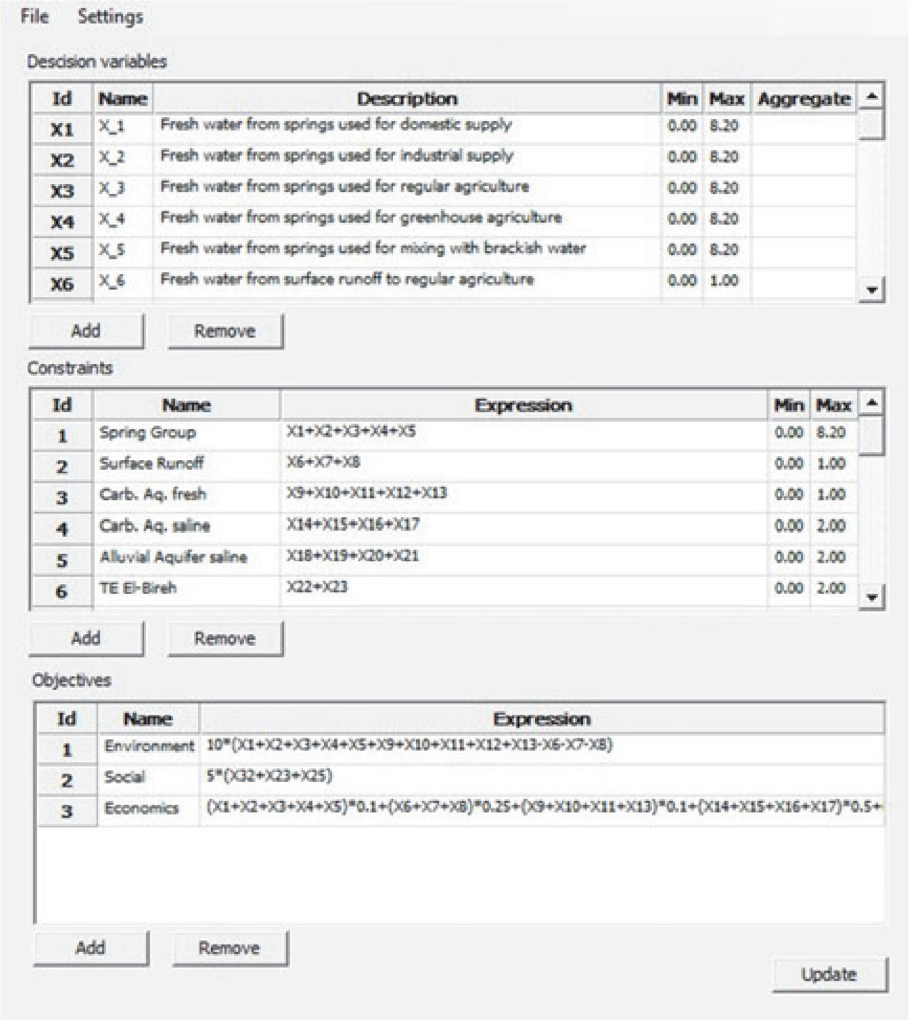
$$\mu_i\left(x^{(1)}\right) \leq \mu_i\left(x^{(2)}\right) \quad \text{for all } i \in \{1,2,3,4,.,.,.,.,.\ m\}$$

and

$$\mu_j\left(x^{(1)}\right) < \mu_j\left(x^{(2)}\right) \quad \text{for at least one } j \in \{1,2,3,4,.,.,.,.m\}$$

In simple words, a non-dominated (or a Pareto-optimal) solution is achieved, when we reach the situation in which the improvement of one objective function automatically results in the deterioration of one or more other objective functions. Finding such non-**dominated** solutions and quantifying the trade-offs in satisfying the different objectives are the goals when setting up and solving a multi-objective optimization problem.

The MCO application is based on the multi-objective part of the "ACADO" toolkit, which has a robust MCO solver. The problem is usually defined by a set of decision variables, optional general constraints, and two or three objective functions .The solution is a Pareto surface or curve represented by a set of points (discretization) , in which each point corresponds to an alternative. The application form is used to define the problem (see Figure 174). It is divided into 3 parts for the definition of the variables, constraints, and objectives. In every list an element can be added or removed.



Descision variables

Id	Name	Description	Min	Max	Aggregate
X1	X_1	Fresh water from springs used for domestic supply	0.00	8.20	
X2	X_2	Fresh water from springs used for industrial supply	0.00	8.20	
X3	X_3	Fresh water from springs used for regular agriculture	0.00	8.20	
X4	X_4	Fresh water from springs used for greenhouse agriculture	0.00	8.20	
X5	X_5	Fresh water from springs used for mixing with brackish water	0.00	8.20	
X6	X_6	Fresh water from surface runoff to regular agriculture	0.00	1.00	

Constraints

Id	Name	Expression	Min	Max
1	Spring Group	X1+X2+X3+X4+X5	0.00	8.20
2	Surface Runoff	X6+X7+X8	0.00	1.00
3	Carb. Aq. fresh	X9+X10+X11+X12+X13	0.00	1.00
4	Carb. Aq. saline	X14+X15+X16+X17	0.00	2.00
5	Alluvial Aquifer saline	X18+X19+X20+X21	0.00	2.00
6	TE El-Bireh	X22+X23	0.00	2.00

Objectives

Id	Name	Expression
1	Environment	10*(X1+X2+X3+X4+X5+X9+X10+X11+X12+X13-X6-X7-X8)
2	Social	5*(X32+X23+X25)
3	Economics	(X1+X2+X3+X4+X5)*0.1+(X6+X7+X8)*0.25+(X9+X10+X11+X13)*0.1+(X14+X15+X16+X17)*0.5+

Figure 174: Problem definition

5.3.7 Scenario Generator - SG

Author: J. Bensabat

The Scenario Generator is one of the most integrating modules of the SMART-DSS platform. Generally speaking, an IWRM project includes a number of logical stages that need to be completed, as is illustrated in the chart below (Figure 175).

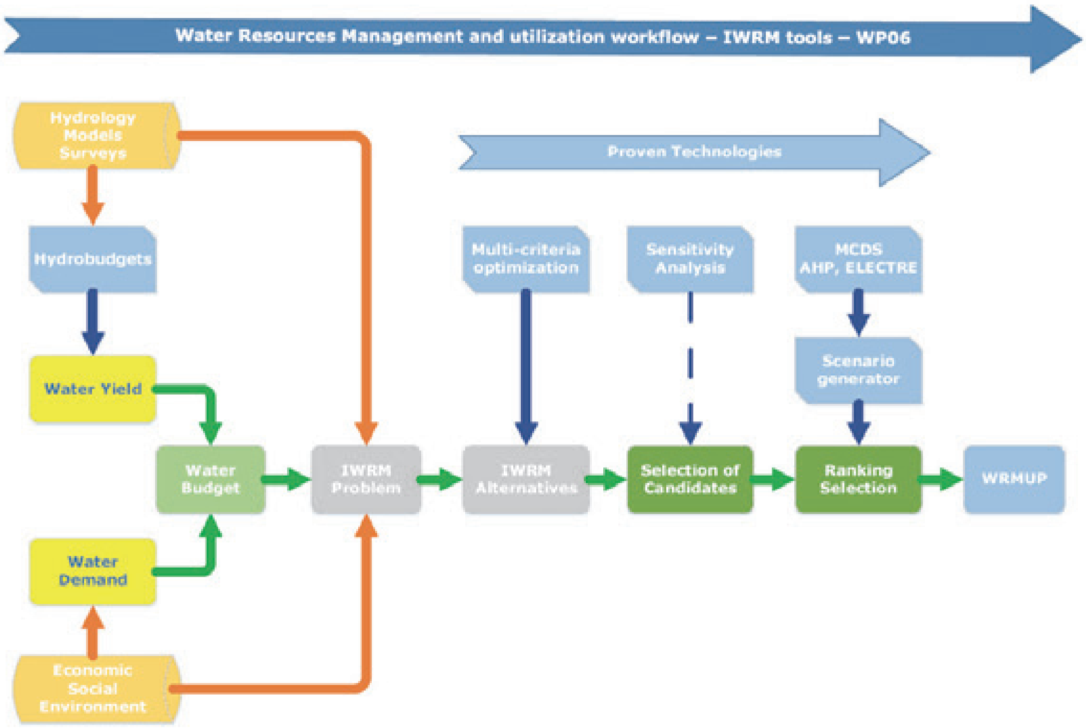


Figure 175: Chart of the scenario generator

An IWRM project must always start from a definition of the problem, a characterization of the water resources (both those utilized and the potential ones), and information on the water demand that is driven by economic, social, and environmental constraints. The part of the water demand is determined outside of this work package, but its outcome and values are integral parts of it. Data and information on the available and potential water resources are evaluated outside of the work packages (by means of hydrogeological modeling and surveys). The output is fed into the HYDROBUDGET Sapplication (or an equivalent one) and the aim is to determine the water yield or the amount of water per quality categories that can be produced in a region in an either sustainable or risk–qualified way. Water yield and water demand make up the water budget that is the root of the of IWRM problem definition. The scenario generator module, SG, is the module that transforms the IWRM problem into a set of IWRM alternatives that have the capability of resolving the problem.

The logical sequence followed by SG comprises the following steps:

1. Translate the IWRM problem into a multi-criteria optimization problem, i.e., 1) objective functions representing the, usually conflicting, interests of economic, social, and environmental factors and 2) a set constraints that fully define the limitations and physical properties of the system.

2. The solution of the MCO problem is not unique. It rather has the form of a surface (or hypersurface in higher dimensions) of non-dominated solutions or the Pareto surface. Any solution belonging to this surface or set is characterized by the fact that one of the objective functions cannot be improved without altering one or more of the others. This set can be large and represent the set of preferred solutions for a wide range of interests, and it needs to be further analyzed.

3. The suggested step here is to use MCDM (either AHP or ELECTRE) to further reduce the set of preferred solutions and obtain the one that corresponds best to the objectives of the decision-makers and/or stakeholders.

Hence, the role of the SG is to limit the space of the IWRM alternatives to a smaller set of “good” solutions, thus limiting margins of error and/or the impact of subjective and inconsistent decision-making. Of course, the quality and suitability of the Pareto set heavily depend on how we represent the IWRM problem specific of a region by an MCO problem. It is usually suggested and recommended to use the simplest possible formulation. However, the tools that have been developed allow for a full non-linear MCO problem.

A practical implementation is presented in the project report Deliverable D803.

5.4 Tools for socio-economic evaluation

Author: I. Heinz, E. Al-Karablieh, A. Salman

5.4.1 Introduction

This overview will focus on the following tools: Cost benefit analysis (CBA), cost-effectiveness analysis (CEA), multi-criteria analysis (MCA), financial feasibility analysis, social acceptance analysis, and hydro-economic models. Most of these tools aim at increasing the economic efficiency of water management projects on the basin level. Financial tools are to ensure the realization of projects by providing sufficient funds. Sometimes, economically efficient projects can fail due to lacking economic resources.

From the economic point of view, efficient water projects result when the difference between the benefits and costs (net benefits or value added) is high. However, determining these values is not easy. In many cases, they are not properly calculated and often understated. For instance, over-exploitation of aquifers is not taken into account sufficiently and the scarcity value of water is ignored (Dinar and Zilbermann 2002, Griffin 2006, Raucher et al. 2005, Young 2005). It is widely argued that IWRM strategies considering the true costs and values could prevent excessive use of resources.

5.4.2 Cost-Benefit Analysis (CBA)

The CBA involves the translation of all benefits and costs of water projects into monetary terms as far as possible. If the total benefit of a project exceeds the total cost, values added emerge. Values added represent increases in economic welfare for a community or a society as a whole.

The CBA methodology can be used either to decide whether a project is economically efficient in order to justify the investment or to select that alternative with the highest net benefit or values added. Water operators usually use a set of CBA indicators. A prominent example is the net present value (NPV). It indicates the present value of the stream of net returns (benefits minus costs) of a project during its economic life. The NPV is determined by discounting the expected future net returns at a rate, which reflects the cost of borrowing funds (interest rate), or another time preference, which is expressed by the 'social discount rate' (often applied for public infrastructures). A positive NPV shows that the project is economically efficient. Another CBA indicator is the difference between the total benefit and total cost per year, where the initial investments are transformed into annualized capital cost by using a discount rate and added to the running cost (Heinz 2011). The CBA methodology was employed in the SMART studies D701 & D704, D702, D703, and D706 & D707.

5.4.3 Cost-Effectiveness Analysis (CEA)

The CEA can be used to compare available alternatives that have the same objective (for instance, reaching a water quality standard). It selects either the least expensive alternative that can attain the intended objective or the alternative that yields the maximum degree of target achievement with a fixed budget (for instance, better coverage of water demand) (Veeren van der 2002). As mentioned, the objectives are not expressed in economic terms, but in hydrological, technical or environmental units. CEA is less ambitious than CBA. However, it relates costs directly to the performance indicators of water projects – see SMART study D705.

5.4.4 Multi-criteria Analysis (MCA)

The MCA is a decision tool, by which IWRM strategies to achieve competitive objectives (e.g. sustainable utilization of aquifers, reliability of water supply, economic benefits, etc.) can be ranked. It can facilitate complex decisions in situations with several conflicting goals. Such situations are encountered often in integrated water management. Different management options, such as the use of treated wastewater, desalinated brackish water, and harvested storm water, usually have both positive and adverse impacts, so that a multi-criteria evaluation process can help find the best IWRM strategy. In particular, the trade-offs between economic gains and other objectives, such as aquifer sustainability and reliability of water supply, can be pointed out – see SMART study D711.

5.4.5 Financial Feasibility Analysis

As mentioned, financial feasibility is different from economic efficiency. The implementation of economically efficient IWRM strategies can fail, if there are no sufficient funds. Usually, water projects are to be financed by charging water users, such as farmers, citizens and entrepreneurs. In special cases, however, the users cannot fully afford the costs. Other funds are required, such as governmental, private or international donors (e.g. World Bank, USAID, and KfW).

It is important to know the wide range of financial tools and sources available (Asano et al. 2006, Lens et al. 2001, Rouse 2007). This knowledge is a basic requirement for a successful planning of IWRM strategies. Financial feasibility analyses address cost recovery from users, loans from banks, external grants from international funds, subsidies from governments, Build-Operate-Transfer schemes (BOT), where projects are funded both by private concessionaires and state institutions, and last not least, cost sharing agreements between different beneficiaries of water reuse projects (Heinz 2011) – SMART study D706 & D707.

5.4.6 Social Acceptance Analysis

The social acceptance of IWRM strategies is also to be taken into account. Water pricing is one of the tools to facilitate the realization of water projects. Major roles play the charges on using treated wastewater, particularly in irrigated agriculture (Steenburgen van et al. 2007). Farmers will refuse to join water reuse projects, if there are no economic incentives. A similar behavior can be expected if the difference between these charges and the cost or prices of freshwater as an alternative resource is negligible. With respect to the water tariffs for municipal users, the block rate settings may be revised in order to align it with the actual water consumptions, to encourage water saving and to ensure social equity and cost recovery – SMART study D709.

5.4.7 Hydro-economic models

5.4.7.1 Inter-Seasonal Agricultural Water Allocation System (SAWAS)

SAWAS deals with the inter-seasonal allocation of irrigation water and their impact on agricultural production and incomes at the Jordan Valley (Salman et al. 2001). The model is designed to serve as a decision making tool for agricultural planners in both district and regional level. It generates an optimal mix of water supply activities that maximizes the agricultural income of the districts. It also provides the planner with tools to simulate and optimize water allocations with different qualities. Hence, the model is a tool to bridge the gap between the limited water resources and increasing agricultural production at an area with severe water scarcity – SMART study D703.

5.4.7.2 Multi-Year Water Allocation System (MYWAS)

MYWAS (Multi-Year Water Allocation System) is a model that maximizes the economic benefits of IWRM strategies at regional level (Fisher and Huber-Lee 2005, Fisher and Huber-Lee 2011a, Fisher and Huber-Lee 2011b). MYWAS is based on the WAS approach (Water Allocation System), developed jointly by water experts in Israel, Jordan and Palestine between 1992 and the beginning of 2000. It employs the model configuration of WEAP, but incorporates more complex economic procedures. It is designed to be applied in Palestine and later in Jordan in the near future.

The model aims to suggest ways how to use scarce water resources as efficiently as possible. A key role is played by the scarcity value of water, which is seldom considered in the tariffs. It is influenced by both the production cost and the water demands. Where resources are abundant, no water scarcity values and scarcity rents exist. The latter represent the extra revenues from higher water tariffs, which include the scarcity values. From these revenues the costs for alleviating water shortage can be financed. MYWAS determines the water prices and true water values ("shadow values") within a water allocation optimization model (GAMS). It analyses for confined areas with a given water infrastructure the system-wide impacts of new projects (e.g. a projected conveyance system) and deals many variables as determined endogenously within the model, such as costs, water prices, shadow values and scarcity rents. Currently, MYWAS is being tested at selected areas in the West Bank, It can be considered as a further promising economic tool for appraising alternative IWRM strategies at water shed level.

5.4.8 Application / Implementation Cases

Authors: I. Heinz, A. Salman, E. Karablieh, N. Lienhoop

By using examples, in the following it will be illustrated how the CBA, CEA and MCA tools have been applied in the SMARTII research project.

Cost Benefit Analysis (CBA) of decentralized wastewater treatment and reuse in Jordan (study D701 & D704)

Two local cases of decentralized wastewater treatment technologies and re-use (DWWT & Reuse) will be assessed by using the CBA methodology. In Jordan, the construction of DWWT is planned to serve rural communities that do not have an adequate sanitation infrastructure. Two technologies are investigated: 1. Wastewater treatment and re-use through Sequencing Batch Reactors (SBR) and 2. Wastewater treatment and re-use through Constructed Wetlands (CW).

The villages under investigations are: The Eastern part of Ma'addi, an agricultural village in the Middle Jordan Valley and the Maghareeb village, a suburb of the city Al-Salt. Both villages have a sewage system in place and wastewater is collected in several shared cesspits that are owned and emptied by the respective municipalities. Both face problems with overflowing cesspits causing odor, groundwater contamination and diseases. Agricultural production in Ma'addi takes primarily place in greenhouses where a range of vegetables are grown. Agricultural activities in Maghareeb are dominated by olive tree plantations that do not require irrigation and fruit trees.

Applying the CBA methodology provides the opportunity to make a comparison between alternative projects. Since the investments in water infrastructure are generally of long-term nature, both the costs and benefits will be calculated in terms of present values. By using the present value analysis the time streams of the future costs and benefits can be diverted ('discounted') to single numbers. The difference between both values is the net present value (NPV): if greater than 0, the investment would be worthwhile. If there are several optional projects, the one with the highest net present value should be chosen.

Where costs and benefits cannot be quantified directly in economic terms (e.g. health risks for children), surrogates are used. A commonly applied method is the willingness-to-pay approach or the Contingent Valuation (CV) method to estimate the amount of money the people are ready to pay for improving the sanitation situation.

As the results show, in Ma'addi the net present value of the both wastewater treatment technologies is larger than zero. This means that values added from the wastewater treatment can be expected, i.e. both options would be cost-beneficiary for the villagers in economic terms. In Maghareeb, however, the net present values of SBR are mostly negative. This can be explained by the relatively low economic benefit in agriculture and the high costs of wastewater treatment due the requirements for the quality of reclaimed water in Jordan.

Assessing the impacts of different water qualities and quantities on farmer income and their economic situation in the Jordan Valley (study D703)

The economic impacts of different water types, such as freshwater (FW) and treated wastewater (TW) for agricultural irrigation will be assessed by using the CBA methodology. Water reuse is one of the major options to tackle exhaustion of natural resources and overuse of aquifers particularly at the Jordan Valley.

A prominent example can be found downstream of the King Abdullah Canal (KAC), where the effluents of the As-Samra treatment plant are stored in the King Talal Dam (KTD) and then mixed with the KAC freshwater. The blended treated wastewater (BTWW) is utilized for agricultural irrigation in the middle and southern part of the Jordan Valley. The upstream KAC freshwater is diverted in part for domestic users (mainly the city of Amman), in part for agricultural irrigation in the northern part of the Jordan Valley. The study aims to assess the economic impacts of water use for irrigation purposes at two sites: The upstream basin 10 (Northern Jordan Valley - NJV) and the downstream basin 22 (Middle Jordan Valley - MJV) provided with FW and BTWW, respectively. The key question is as to which of the two different water types are more cost-beneficial.

A linear programming model was used with the total gross margin as objective function and the availability of water with different qualities (BTWW and FW), land, labor and fertilizer as constraints. The main outcomes of the investigation are:

Generally, it can be observed that the productivity of vegetable crops (kg/du) is higher if BTWW is used instead of FW. However, in the case of fruits, the yields of all kinds of citrus irrigated with FW, were much higher than those irrigated with BTWW.

The average values for the profitability of water were in the area irrigated with BTWW higher (0.518 JD/m^3) than in the area irrigated with FW (0.477 JD/m^3). It should be kept in mind that the water prices together with the water volumes used for irrigation determine the total water cost and consequently the net profits per dunum (1 dunum=1000 m^2) (JD/du) and water profitability (JD/m^3). However, in the Jordan Valley there are the same prices for FW and BTWW used for irrigation. The difference in water profitability between FW and BTWW may be interpreted as a proxy of the value added of reuse, assuming that the costs of these two types of water are the same.

Costs and benefits and the financial feasibility of alternative IWRM strategies at selected areas in Palestine and Jordan (study D706 & D707)

The basin of Jericho in Palestine is divided into three sub-areas with different utilization of water resources, infrastructures and water demands: east sub-area, central sub-area with the Jericho City and north sub-area. As a further area under investigation, the eastern lower Jordan valley was selected. At each of these areas the specific problems were highlighted and various water management options were identified and evaluated by using the CBA methodology. The initial investments were annualized in capital cost per year by using different discount rates.

Jericho sub-areas: Desalination of brackish water; wastewater reuse; storm water harvesting, rehabilitation of groundwater wells; transfer of Duyuk spring water rights from agriculture to the municipal users; demand management; rehabilitation of water distribution networks and replacement of open channel with closed pipe distribution networks.

Lower Jordan valley: Reallocation of Disi water, new Kufranjeh dam, further WWTP & water reuse and enhancing the efficiency in agricultural irrigation.

In the most cases, the economic benefits exceed the costs. For instance, at the Jericho east sub-area a maximum of additional water supply of 6.3 Mm^3/yr can be provided, whereas the projected water deficit will increase from 1.2 MCM/yr in 2016 to approximately 4.0 MCM/yr in 2030. This means, that not all the possible management options for this sub-area should be realised at the same time. Thus, these options are to be prioritized within the planning period according to their economic values added. As the CBA showed, the water reuse option is the best one (2.06

USD/m³), followed by rainwater harvesting (1.11 USD/m³) and desalination of brackish water (0.76 USD/m³).

In case of the Lower Jordan valley, WWTP & water reuse is the most cost-beneficial option (1.2 USD/m³). With respect to the high annual value added, reallocating of Disi water to the agriculture for irrigation purposes (0.64 USD/m³) and constructing the Kufranjeh dam (0.84 USD/m³) appear to be promising options as well.

Cost effectiveness (CEA) of alternative technologies (study D705)

The study addresses the following technologies to recharge existing water resources in the Lower Jordan River Basin: 1) Decentralized wastewater treatment (DWWT), 2) Managed aquifer recharge (MAR) and 3) Brackish water treatment (BRA).

These technologies aim to providing a water quality, which is suitable for reuse in agri-cultural irrigation. Water quality A is defined by the Jordanian Standard 893-2006 for the irrigation of cooked vegetables and playgrounds. By applying CEA, the three different technologies will be ranked.

As the results show, the decentralized treatment technologies VFCW (Vertical Flow Constructed Wetlands), SBR (Sequencing Batch Reactor) and BRA differ only slightly in terms of their cost-effectiveness. The specific treatment costs to produce one cubic meter of water quality a range from 0.53 JD/m³ (SBR) and 0.59 JD/m³ (BRA) to 0.62 JD/m³ (VFCW). The two MAR alternatives, however, differ considerably from the other technologies. The least cost-effective option is MAR (treatment & infiltration) with 1.19 JD/m³ and the most cost-effective option is MAR (infiltration) with 0.03 JD/m³.

Multi-criteria analysis (MCA) of multiple water qualities in Israeli municipalities (study D711)

The study deals with various options of using resources with different qualities, such as freshwater, treated wastewater, saline water and flooding water. In trying to determine the best management strategy to tackle water shortage, priorities for the allocation of different resources are needed. The impacts of each action on different objectives are to be investigated and evaluated. This is done by using the Multi-Criteria Analysis (MCA) and the Analytical Hierarchy Process (AHP) based on a case study at Israeli localities in the Lower Jordan River Valley. These methods allow ranking different IWRM strategies.

The main objectives as decision criteria for implementing IWRM are: a) Aquifer sustain-ability, b) Natural environmental preservation, c) Maximizing the economic profit and d) Reliability of water supply.

According to the results of the case study, utilizing the Tirza and Og reservoirs capacity and adding marginal water to the water budget at Lower Jordan valley (A3) has a significantly higher preference rather than adding new wells (A2) or desalinating the brackish water from the springs (A4). In other words, the application of reclaimed effluents is much more favorable than the exploitation of more fresh or spring water.

6 RESULTS: IWRM ASSESSMENT

Compiled by: D. Riepl (KIT), B. Rusteberg (GU), H.-P. Wolff (Quasir)

6.1 Local Case Study: Wadi Shueib, Jordan

Author: D. Riepl (KIT, Disy)

6.1.1 Wadi Shueib Water Balance

In order to combine and review the results of the systematic pre-processing steps, the resultant system understanding was expressed in holistic water balances for different water year conditions. The conceptual balancing approach was straightforward in defining different compartments and their inflows and outflows. It is inevitable that certain flow paths or storage components stay highly uncertain. Elements without any available measurement data or directly related studies and elements which cannot be balanced properly from other components have to be estimated from the experience of experts or international literature. In the case of the Wadi Shueib water balance, this primarily concerns several components of the groundwater flow and here especially the sewer leakages and the resultant unintentional recharge as well as potential lateral groundwater flows. Furthermore, the irrigation-related evapotranspiration and return flows as well as the amount of private water imports have to be estimated. International literature provides a multitude of examples where even highly uncertain water balancing approaches were applied for water resources studies on catchment scales (e.g. Fleischbein et al. 2006, McCartney 2000). A final result of these balance schemes is illustrated in Figure 176, which exemplarily summarizes the knowledge acquired with respect to the Wadi Shueib water budget for the water year 2008/09. Within the SMART project, the structured visualization of the current state of knowledge could also be used to delineate areas with critical knowledge gaps and to help streamline further research activities.

All values in Figure 176 are given in MCM for the water year 2008/09. The color of the flow arrows indicates the confidence in data quality: Blue = good (measured); yellow = medium (balance derived); red = poor (expert or literature estimates or no data). Transmission losses (base flow) are an outflow component.

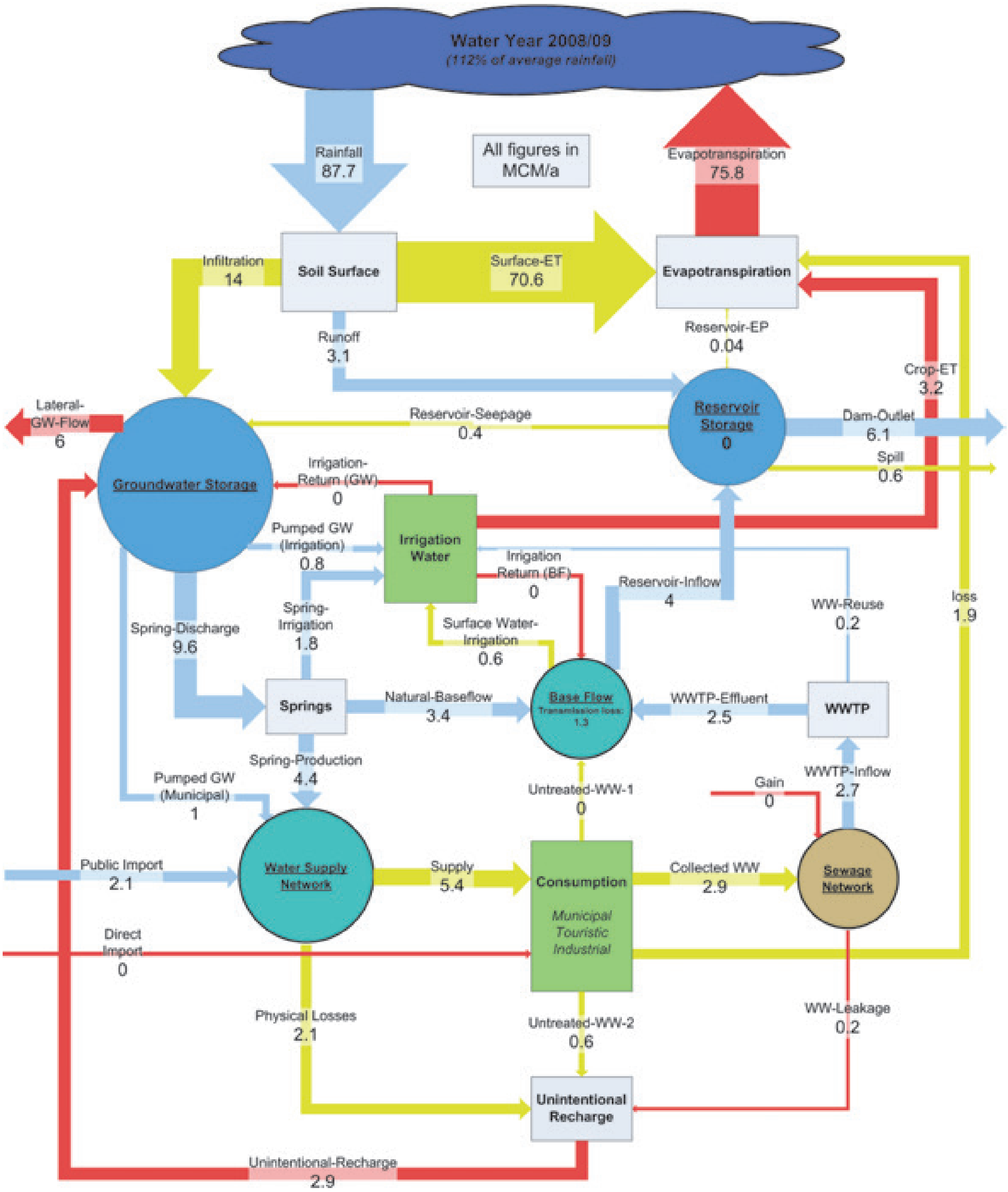


Figure 176: Balance for Wadi Shueib compiled from the pre-processed data.

6.1.2 Scenario assessement for Wadi Shueib

In order to facilitate a direct comparison of the scenarios, it is necessary to standardize the simulated indicator values to a common scale. For this purpose, different standardization techniques are proposed in the multi-criteria decision analysis literature, which either use linear or non-linear transformation or value/utility functions to transform the decision criteria to a common scale (see e.g. Malczewski, 1999). The selection of a suitable transformation procedure depends on the general decision process, the distribution of the criterion data, and other factors and can result in different rankings of the decision alternatives (e.g. Young et al., 2010).

For a comparative summary of the scenario simulation results, a simple maximum score procedure transformation was considered useful. In order to achieve a common scale, benefit criteria (where maximizing the criterion value is desirable) and cost criteria (where lower criterion values are desirable) have to be distinguished. The performance indicators selected in this study are all cost indicators except for I.1a: Municipal wastewater treatment ratio and I.2: Available renewable water for internal use, where maximization obviously is desired. In order to have scores with a common basis at 0.0 (the scenario with the worst performance always has a score of zero for an indicator), the indicator score for the cost type indicators is given by

$$x'_{ij} = 1 - \frac{x_{ij}}{x_i^{max}}$$

where x'_{ij} is the standardized score for the i-th indicator and the j-th scenario, x_{ij} is the original value, and x_i^{max} is the maximum value for the respective indicator.

In the case of benefit-type indicators, the indicator score is given by

$$x'_{ij} = \frac{x_{ij}}{x_i^{max}} - \frac{x_i^{min}}{x_i^{max}}$$

where x'_{ij}, x_{ij}, x_i^{max} are as defined above and x_i^{min} is the minimum value for the respective indicator. Table 55 shows the resultant standardized indicator scores in the evaluation matrix. The score range of the Reference, BAU, and FI scenarios defines the maximum and minimum of each indicator within the respective LRP and HRP scenario sets and within the period from 2023-2025 (dry, wet, and average water years).

Table 55: Evaluation matrix of standardized indicator scores.

Indicator	**Sub-indicator**	**Reference**		**BAU**		**FI**	
		score range		*score range*		*score range*	
I.1	I.1a: WW treatment ratio	0.00	0.00	0.08	0.08	0.23	0.23
	I.1b: WW recharge ratio	0.20	0.40	0.00	0.53	0.80	0.93
I.2	I.2a: available groundwater	0.00	0.08	0.05	0.18	0.27	0.45
	I.2b: available surface water	0.26	0.30	0.24	0.59	0.00	0.41
	I.2c: available reclaimed water	0.00	0.03	0.07	0.10	0.63	0.83
I.3	I.3a: municipal shortage	0.13	0.21	0.00	0.40	0.56	0. 94
	I.3b: agriculture shortage	0.00	0.76	0. 24	0.88	0. 32	0.88
I.4	I.4a: municipal supply requirement	0.21	0.21	0.00	0.29	0. 17	0.42
I.5	I.5: unit cost	0.38	0.38	0.27	0.29	0.00	0.09
I.6	I.6: environmental water stress	0.08	0.08	0.03	0.06	0.00	0.02
	Total:	**1.26**	**2.45**	**0.72**	**3.40**	**2.49**	**4.26**

As expected, the FI alternative reaches the best performance for most of the selected indicators and a total score in the range from 2.49 to 4.26 points. Under favorable conditions (LRP), the BAU alternative beats the Reference and the HRP-FI scenarios with a total score of 3.40. In the case of

HRP conditions, however, it shows the worst performance for most of the indicators and a total score of 0.72 points. It has to be kept in mind that for the Reference scenario, the external driving forces were assumed to develop on an intermediate path between the LRP and the HRP assumptions. Comparison and interpretation have to take this bias into account. Due to the standardization procedure, the indicator score range between 0.0 and 1.0 does not mean that a value of 1.0 represents an absolute optimum, but rather a scenario with an indicator performance that is significantly higher in comparison to the scenario with the minimum performance. The performance scores for the most significant indicators of the planning scenarios are plotted for comparison.

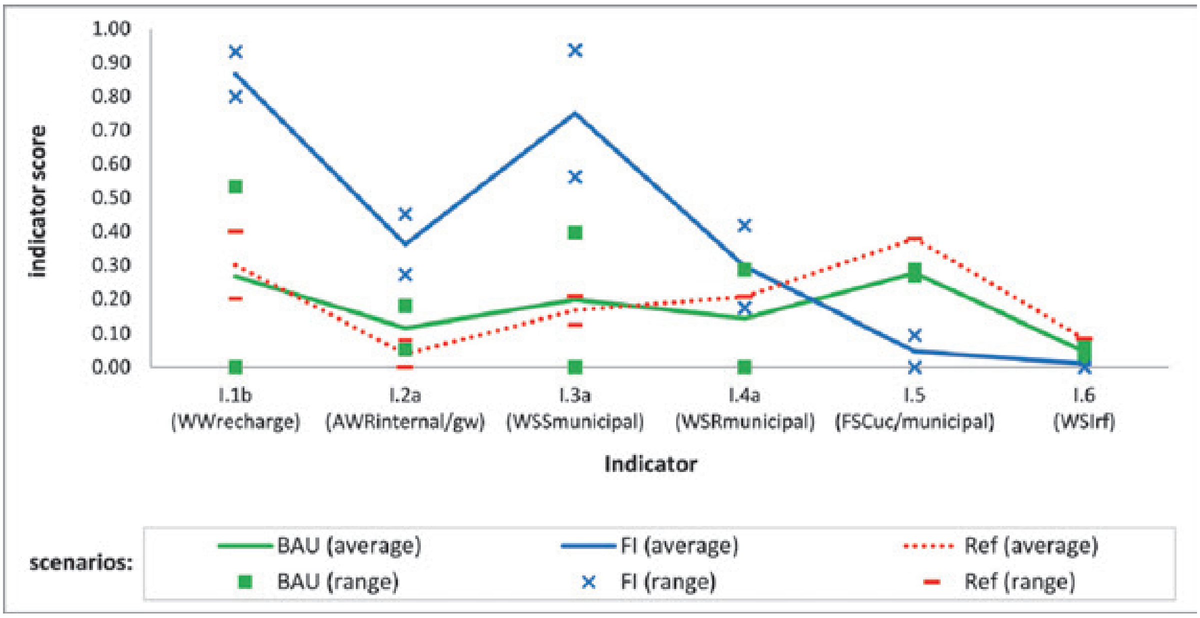


Figure 177: Summary of the standardized scenario simulation results. A higher score means a better performance, while the range expresses the sensitivity to the external scenario-driving forces (LRP/HRP).

Especially in untreated wastewater recharge (I.1b) and municipal water supply shortages (I.3a) the FI scenarios outperform the BAU alternatives significantly for both the LRP and HRP assumptions. As regards the untreated wastewater recharge ratio (I.1b), the BAU scenario shows a comparatively wide range between LRP and HRP conditions, whereas the FI performs more stably. It has to be stated that apart from the regularly recorded coliforms in the Wadi Shueib springs, the processes and the amounts of discharged wastewater recharging the groundwater resources in the study area are not yet understood clearly. Nonetheless, the simulated high volumes of untreated wastewater in relation to the groundwater recharge estimates can certainly be considered an important and warning groundwater vulnerability factor, especially when taking into account the karstified environment of the Wadi Shueib area.

As regards the readily available and utilizable freshwater (groundwater) within the catchment (I.2a), the investment in water production as well as the anticipated strong improvements of groundwater protection make the FI values exceed those of the BAU scenarios. For the latter alternatives, improvements of groundwater quality were also expected, but to a lesser extent. The scores for this criterion display a smaller magnitude of improvement for the FI scenarios. Although the possibility of developing new or maximizing available water resources in the study area is limited, this, of course, does not mean that the improvements are less substantial for the water sector in the study area. Surface water uses change slightly in the scenarios, but in relation to the amounts stored and used downstream, the scenario implementations have no strong effect on internal or external surface water availability.

The total municipal water supply requirement (I.4a) is expected to rise in all scenarios, but the magnitude is strongly dependent on the driving forces of population growth and demand development. According to the simulations, it appears likely that increased water imports become necessary, if the supply objectives of the national water strategy are to be met. In this connection, considerable investments in demand management, water infrastructure, and the efficient reduction of water losses appear urgently necessary when these impacts are to be mitigated in the Jordanian water future. Similar recommendations are made in current studies on the status and future of the Jordanian water sector (McIlwaine, 2009; Rosenberg & Lund, 2009; Sommaripa, 2011).

With regard to the simulations of environmental water stress (I.6), all scenarios show a relatively similar performance in the category of water stressed by fluctuations that are mainly dependent on the water year conditions. With a slight offset, the FI scenario shows the worst performance under both LRP and HRP conditions, due to the high abstraction of the wadi base flow (spring discharge). It has to be kept in mind that the environmental water stress as discussed here merely addresses water quantity. Quality concerns and possible impacts on ecosystem functions due to the continuously increasing share of treated effluents in the wadi runoff would need a separate assessment that could not be undertaken within this study.

6.1.3 Conclusions in the context of the Jordanian Water Strategy

The scenario simulations allow the conclusion to be drawn that only an increased effort (FI scenarios) can enable progress towards the goals of the national water strategy and a successful IWRM process in the Wadi Shueib area. The projects currently undertaken in the area, even when prolonged into the near future (BAU scenarios), do not appear to be able to relieve the pressure on the water situation. Furthermore, the rate of success in meeting future water requirements is strongly dependent on the uncertain development of near-to-mid-future climatic conditions, population growth, and water demands for all implementation strategies addressed.

The major drawback of the FI alternative is, of course, related to the considerable investment costs involved and the resultant rise of the water service costs. Due to the reduction of expensive water import volumes and decreasing water losses, the unit cost of water services does not rise linearly with the anticipated investments. Yet, it was still simulated to significantly increase from the current 0.595 JD/m^3 to 0.958 JD/m^3 in the LRP-FI scenario in 2025. However, in the light of the estimated water sector expenditures (including MWI, WAJ, JVA, Aqaba Water Company, and Miyahuna) of approximately JD 500 million in 2010 (Sommaripa, 2011), the anticipated investment costs for the FI scenarios (~JD 94 million over 15 years in a region with 2-3 % of the country's population) do not appear overambitious. This even more applies when considering mega-projects like the Red-Sea-Dead-Sea canal with currently estimated costs of approximately JD 4 – 8 billion (World Bank, 2009).

In any way, it is expected that another water tariff reform will be necessary in order to progress towards the objective of cost recovery in the water sector, since the revenues of the WAJ and the public companies today do not cover their annual expenditures (Segura/IP3 Partners LLC, 2009).

The bottom line of the simulation results in the Wadi Shueib area might also reflect the general Jordanian situation. During the last decade, the water sector mostly focused on the maximization of available and the development of new resources (e.g. use of reclaimed water, brackish water desalination) as well as on the extension of sanitation services. And even though remarkable accomplishments have been achieved in these segments, the water situation has not been eased. On the other hand, the reduction of the tremendous water losses and the execution of efficient demand management and water awareness campaigns have been of minor importance so far.

Of course, the scenarios may only be used as a basic framework. For further application in planning and strategy decisions, the development of additional scenarios is recommended. They may certain aspects of the FI options only or other combinations of driving forces. The model presented in this study is flexible enough to implement such changes within a relatively short time.

6.1.3.1 The Wadi Shueib WEAP Model as an IWRM Modelling Tool

WEAP has a clear focus on basin-scale water balancing and allocation scenarios. Rather generic modeling options allow for the implementation of elements that are not directly provided by the user interface (e.g. springs and water treatment plants) and ensure some scale independence. WEAP has therefore been found to be a flexible and ample tool that is generally appropriate for water resources systems modeling in the applied case study. Despite the complexity of the assessed IWRM system and the detail of the sub-catchment scale, the Wadi Shueib WEAP model successfully represents all elements of the preliminary holistic water balance schemes (see chapter 6.1.1). However, it also has to be kept in mind that the groundwater component in the catchment was represented by a relatively simple bucket model of a single cretaceous aquifer complex (A1-A7). Although WEAP can link to a MODFLOW model component, use of a numerical groundwater model did not appear to be feasible due to the difficult and largely unknown geological situation in the study area and the absence of a suitable observation wells network. Furthermore, a set of general assumptions had to be made in the effort to find best model estimates for the IWRM complexity. Additionally, calibration had to be conducted manually by iterative adjustment of the monthly parameter values after model runs, because the stepwise hydro-balance algorithm in WEAP does not cope with interdependent parameters within one time step, such as the simulated water volume in reservoir and reservoir seepage.

Eventually, the final model is good in assessing the monthly integrated catchment water balance. The peak storage volumes of the Wadi Shueib Reservoir appear to be simulated well for all years except 2005/06. The calibrated transmission loss parameter, by contrast, might aggregate various other estimation errors although it is in the range of comparable literature estimates. More reliable logging of dam operation habits and discharge records could help to significantly reduce remaining uncertainties here. For the intended model use for long-term IWRM scenario planning, however, these uncertainties were accepted.

Overall, it was found that WEAP can contribute an important part to IWRM planning processes with a focus on water balance and allocation, especially when it is embedded well in a comprehensive and soundly constructed IWRM scenario planning framework as demonstrated in this study. An important strength of WEAP was the integrated scenario management that allowed for a straightforward and suitable modeling of the scenario assumptions made here. The final WEAP model is documented well in this report as well as in the developed knowledge platform Dropedia. It is ready to be employed and extended by the Jordanian decision-making institutions. Free licensing for developing countries, the intuitive usability, and the flexible nature are essential benefits of the WEAP approach. Thanks to these advantages, several water sector institutions in the Lower Jordan Valley have already begun to apply and adapt WEAP at their strategic planning directorates.

6.1.3.2 IWRM Planning in the Wadi Shueib

The current Jordanian Water Strategy (RCW & MWI, 2009) is an ambitious policy that comprehensively addresses the critical issues. During the last decade, tremendous efforts were undertaken in the water sector by the Jordanian government as well as the international community. So far, however, these efforts often have not been streamlined and sometimes, they have been mismanaged (Humpal et al., 2012). This frequently leads to the situation that important and intricately obtained information gets lost after projects are finished. In better cases, results are summarized in a report. But often, the documentation is incomplete and the knowledge leaves the region with the project or the worker. In any case, it appears very difficult to keep this large pool of knowledge alive in the IWRM process.

The work presented here demonstrated that the actual planning practice considers a small subset of the comprehensive national goals and implementation objectives only. Detailed analysis of the objectives given in the standards with regard to necessary implementation options and suitable performance measures (indicators) is another important contribution to the IWRM planning endeavors in the Wadi Shueib area. In this regard, the study offers a proof of concept and a methodological framework for application in other sub-basin-scale IWRM planning activities.

The combined modeling and scenario planning approach also shows a potential path towards an operational realization of the ambitious IWRM hypothesis on the sub-basin scale and, thus, represents a step further towards IWRM. The modular and flexible nature of the presented framework appears applicable for expansion and continuous development.

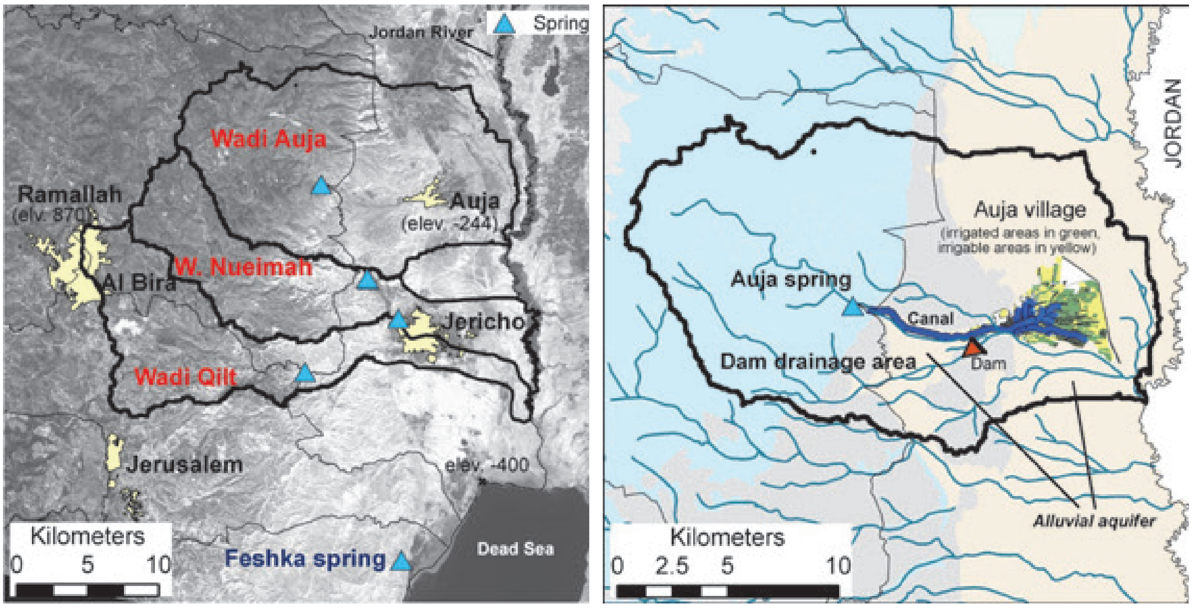
6.2 Local Case Study: Wadi Nuema, Westbank

Author: B. Rusteberg

6.2.1 Introduction to the Study Area

The Wadi Auja case study follows the IWRM approach presented in the previous chapter. A certain focus lies on the application of the innovative water resources planning model based on multi-objective optimization (MOO), which leads to the identification of candidate IWRM strategies and the selection of a compromise solution.

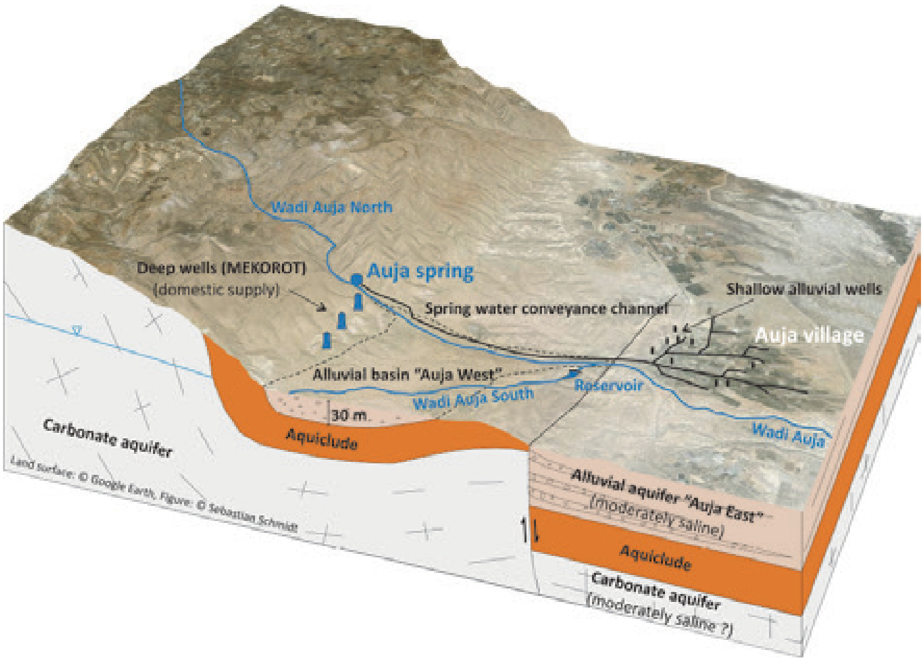
The study region in the Israeli-Palestinian territory comprises 3 watersheds, namely, Al Qilt (189 km^2), Al Nuemah (128 km^2), and Al Auja (260 km^2), which are located in the south-eastern part of the West Bank. They extend from the central mountains of the West Bank in the west to the Jordan River in the east (Figure 178). Due to the suitable climate and land fertility, the lower valley has a good agricultural potential and, therefore, is of major importance to Palestinian crop production (JICA, 2007). Jericho city with around 25,000 habitants is the major urban center. The difference in elevation between the lower and upper parts is around 1,000 m. The climate is arid to semi-arid with an average annual rainfall from less than 100 mm to 700 mm and high evaporation of 2,120 mm/a in the LJV (Arij, 1998). The Eastern groundwater basin of the West Bank is bounded by the major groundwater divide in the west and the Jordan valley major fault in the east.



a) b)

Figure 178: Study region (a) and case study area Wadi Auja (b)

A deep carbonate aquifer system is present in the mountain areas and located below the shallow aquifer system in the valley. The aquifers are recharged by the seasonal rainfall through outcropping area in the West Bank mountains. The shallow alluvial aquifer in the valley is recharged by direct infiltrations from the surface runoff or by lateral flow from the mountain aquifers. Both the phreatic alluvial aquifer with partly high salt concentrations as well as the deeper fractured carbonate system suffer from groundwater level decreases during dry years due to over-exploitation (Abdel-Ghafour, 2005). Figure 179 presents the local aquifer systems in a schematic and simplified way as required for later water resources systems analysis.



Land surface: © Google Earth, Figure: © Sebastian Schmidt

Figure 179: Geological profile and aquifer systems in the case study area (Schmidt, 2014)

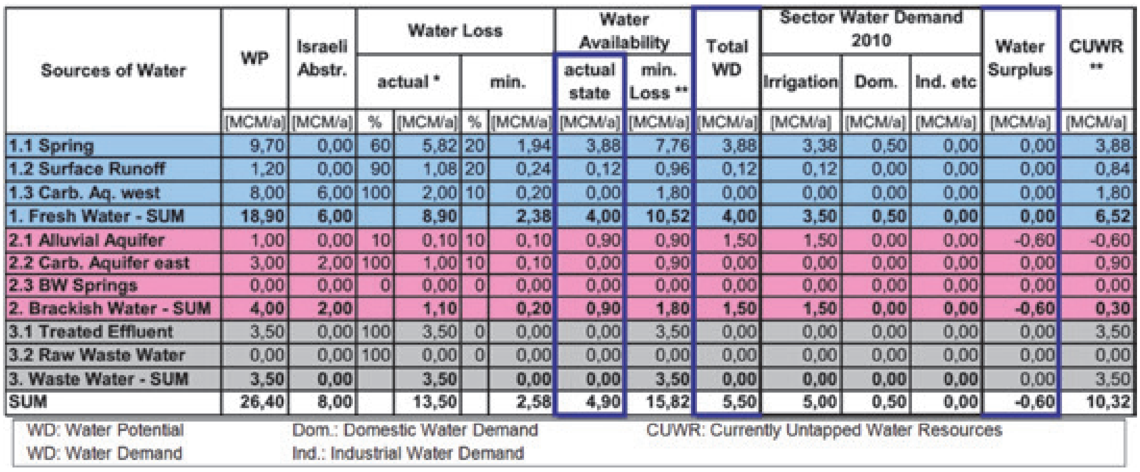
6.2.2 Water Budget Assessment

Table 56 presents the results of a water budget assessment for Wadi Auja, revealing currently untapped water resources that may be activated. According to the water qualities, the available water resources have been divided into freshwater (blue), brackish water (red), and wastewater resources (gray). The freshwater resources in the Wadi consist of discharge of the local spring, surface runoff, mainly in the form of flashfloods, and groundwater of the deep carbonate aquifer east of the geological fault. The shallow alluvial aquifer and the deep carbonate system between the geological fault and the Jordan River mainly consist of moderately saline brackish water with salinities above 2000 mg/l.

The deep carbonate aquifer in the valley may provide a sustainable amount of 8 MCM/a of freshwater. Due to Israeli abstraction of about 6 MCM/a from the aquifer, there are only 2 MCM/a available for Palestinian use.

Another 3 MCM/a could be abstracted sustainably from the brackish carbonate aquifer east of the fault. Israeli authorities already claim 2 MCM/a of this water, leaving another 1 MCM/a for potential Palestinian use. Additionally to local water sources, a total of 3.5 MCM/a of treated effluents may be imported from the wastewater treatment plants of El Bireh and Jericho. The water potential of Lower Wadi Auja is around 14.9 MCM/a from local water sources. Considering modernized hydro-infrastructure and minimized water losses, at least 12.3 MCM/a remain for direct allocation. In addition, 3.5 MCM/a of treated effluents from Jericho and El-Bireh could be imported, resulting in a total water availability of at least 15.8 MCM/a in Lower Wadi Auja. Taking 0.5 MCM/a for the coverage of future domestic water demand leads to a total amount of 15.3 MCM per year, which is available for agricultural purposes (seeTable 56). Under the present conditions of high water losses and non-activated sources of water, no water surplus is available. The untapped water resources taking minimized losses and treated effluents import into account amount to 10.3 MCM/a. According to MEKOROT, another 3 MCM/a may be extractable from the deep carbonate aquifer in the mountain areas. Due to the related uncertainties, this value has yet not been considered in the water budget analysis. In general, the local groundwater potential has been estimated roughly for the time being and requires further studies on aquifer system characterization and groundwater modeling in the area.

Table 56: Currently untapped water resources for Lower Wadi Auja



Sources of Water	WP	Israeli Abstr.	Water Loss				Water Availability		Total WD	Sector Water Demand 2010			Water Surplus	CUWR **
			actual *		min.		actual state	min. Loss **		Irrigation	Dom.	Ind. etc		
	[MCM/a]	[MCM/a]	%	[MCM/a]	%	[MCM/a]	[MCM/a]	[MCM/a]	[MCM/a]	[MCM/a]	[MCM/a]	[MCM/a]	[MCM/a]	[MCM/a]
1.1 Spring	9,70	0,00	60	5,82	20	1,94	3,88	7,76	3,88	3,38	0,50	0,00	0,00	3,88
1.2 Surface Runoff	1,20	0,00	90	1,08	20	0,24	0,12	0,96	0,12	0,12	0,00	0,00	0,00	0,84
1.3 Carb. Aq. west	8,00	6,00	100	2,00	10	0,20	0,00	1,80	0,00	0,00	0,00	0,00	0,00	1,80
1. Fresh Water - SUM	**18,90**	**6,00**		**8,90**		**2,38**	**4,00**	**10,52**	**4,00**	**3,50**	**0,50**	**0,00**	**0,00**	**6,52**
2.1 Alluvial Aquifer	1,00	0,00	10	0,10	10	0,10	0,90	0,90	1,50	1,50	0,00	0,00	-0,60	-0,60
2.2 Carb. Aquifer east	3,00	2,00	100	1,00	10	0,10	0,00	0,90	0,00	0,00	0,00	0,00	0,00	0,90
2.3 BW Springs	0,00	0,00	0	0,00	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2. Brackish Water - SUM	**4,00**	**2,00**		**1,10**		**0,20**	**0,90**	**1,80**	**1,50**	**1,50**	**0,00**	**0,00**	**-0,60**	**0,30**
3.1 Treated Effluent	3,50	0,00	100	3,50	0	0,00	0,00	3,50	0,00	0,00	0,00	0,00	0,00	3,50
3.2 Raw Waste Water	0,00	0,00	100	0,00	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3. Waste Water - SUM	**3,50**	**0,00**		**3,50**		**0,00**	**0,00**	**3,50**	**0,00**	**0,00**	**0,00**	**0,00**	0,00	3,50
SUM	**26,40**	**8,00**		**13,50**		**2,58**	**4,90**	**15,82**	**5,50**	**5,00**	**0,50**	**0,00**	**-0,60**	**10,32**

WD: Water Potential
WD: Water Demand
Dom.: Domestic Water Demand
Ind.: Industrial Water Demand
CUWR: Currently Untapped Water Resources

*with loss rate equal to 100 % for non-activated water sources

**assuming the activation of the remaining water potential by hydro-infrastructure taking a minimum loss rate into account

6.2.3 Water Resources System Analysis

The dam with a designed capacity of 1.2 MCM and 45 km^2 drainage area was constructed recently. The water of the Auja spring is passed via an open canal to the irrigated areas around Auja village (PCBS, 2010). Poor canal maintenance results in water losses of about 60 % of the mean spring discharge (Sadah & Tamimi, 2011, Aliewi et al., 2007). The present domestic water demand of around 0.3 MCM/a of Auja village is being supplied from deep wells in the carbonate aquifer, which are operated by the Israeli water supply company MEKOROT.

Figure 180 presents the results of the WRS analysis for Lower Wadi Auja and the water budget assessment (Table 56) The available water resources, their water potential in MCM/a, the existing and required hydro-infrastructure (dotted lines) for water potential activation as well as relevant water users and demand between 2010-2030 are given (Sadah & Tamimi, 2011). Freshwater, brackish water, and treated effluent resources are presented as blue, red, and gray boxes, respectively. The domestic demand of Auja village over the planning horizon may be covered from deep wells in the carbonate aquifer. A considerable water potential will remain for irrigation.

Auja spring provides a high water potential of about 9.7 MCM/a. The above-mentioned high water losses in the old canal need to be reduced by rehabilitation measures or a new pipeline (PL). Auja spring discharge is supplied directly to the irrigated areas, but due to the highly variable discharge behavior of the spring, storage of spring water surplus will be required over the year.

According to Figure 180, this requires the implementation of managed aquifer recharge (MAR) and underground storage of water in the shallow alluvial aquifer. The porous aquifer system would permit the controlled recovery of the recharged water by well groups (WG) during dry periods for irrigation purposes (Rusteberg et al.; 2014).

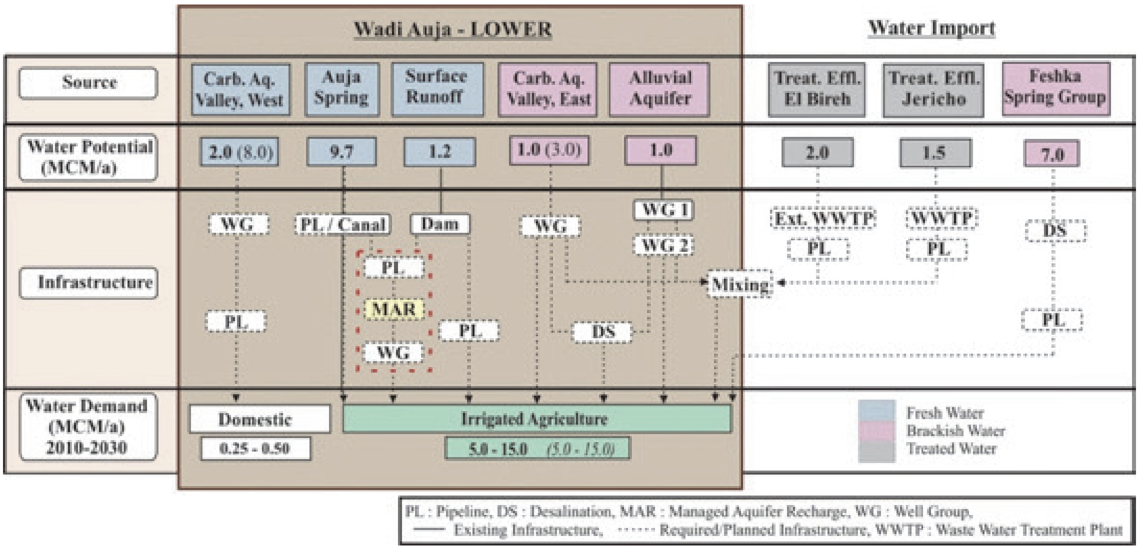


Figure 180: Water Resources System Analysis - Case study Auja

Surface runoff is stored in the new dam and should be supplied for irrigation with high priority in order to reduce evaporation and infiltration losses. It is recommended to install a pipeline between the dam and the irrigated lands, taking advantage of the improved hydro-infrastructure (canal or PL) between Auja spring and the agricultural land under irrigation. Due to the high temporal variability of surface runoff, the corresponding water potential is difficult to quantify (Moe et al., 1998). Based on precipitation runoff studies (Abadi, 2006), it has been estimated that a mean runoff of 1.2 MCM/a may be stored in the dam. After covering the immediate irrigation demand, the remaining surface water surplus retained by the dam should be stored in the alluvial aquifer by MAR in order to prevent evaporation and infiltration losses at the dam and to maintain control of the surface water surplus. Therefore, MAR is being considered an obligatory measure for the study region (Rusteberg et al.; 2014).

Brackish groundwater (see Figure 180) from shallow wells in the alluvial aquifer (1 MCM/a) and deep wells in the deep carbonate aquifer near Auja village (1 MCM/a) may be used for direct irrigation of salt-resistant crops or it may be desalinated by small solar facilities and used for high-quality crops and intensive protected agriculture (greenhouses). This would require the installation of new wells in both aquifer systems. Optionally, brackish groundwater may be mixed with treated effluents to reduce salt concentrations and applied directly for the irrigation of salt-resistant crops, such as palm trees. Due to insignificant effluent production at Auja village (0.15 MCM/a), additional effluents of up to 2 MCM/a could be imported from the El Bira wastewater treatment plant via a gravity pipeline or Jericho WWTP (< 1.5 MCM/a). Extraction of surface water from the Jordan river is not considered due to political restrictions.

In addition, desalinated water from the Feshka spring at 20 km distance may be imported via a pipeline. This option is not covered by the work presented here. It is solely relied on the local water resources potential and wastewater reuse to strengthen agricultural development at Auja.

6.2.4 Components of Local IWRM Strategies

According to UNESCO (2005), an IWRM strategy consists in the combination of structural and non-structural measures towards the integrated management of water resources. The suggested IWRM implementation concept focuses on technological and hydro-infrastructural interventions and gives special attention to the sustainable agricultural development and the extension of irrigated lands. Taking the already existing hydro-infrastructure and the results of the WRS analysis into account, the following 17 key measures (M1 to M17) have been identified in the Palestinian case study areas for developing an integrated water resources management strategy Table 57. They are classified based on the criteria of (a) additional water production, (b) water import, (c) brackish water desalination, water management, and (d) agricultural development.

Table 57: IWRM measures as potential strategy components

No.	Description of IWRM Measures	
M1	Implementation and renewal of water service network	Water Production
M2	Retention of flash floods	
M3	Deep wells in the carbonate aquifer – Fresh Water	
M4	Deep wells in the carbonate aquifer – Brackish	
M5	Shallow wells in the alluvium aquifer - Brackish	
M6	Import of treated effluents from El Bireh WWTP	Water Import
M7	Import of treated effluent from Jericho WWTP	
M8	Water import from Feshka (spring)	
M9	Fresh water import from Palestinian National Water Carrier	
M10	Export of surplus water	
M11	Groundwater desalination	Desalination & Management
M12	Mixing of brackish water and fresh water resources	
M13	Mixing of brackish water and treated effluent	
M14	Managed Aquifer Recharge (MAR) – spring discharge & surface runoff	
M15	Extension of regular irrigated agriculture	Agric. Develop.
M16	Greenhouse technology implementation	
M17	Palm tree production (salt-resistant high revenue crops)	

6.2.5 Agricultural Development Options

Irrigated agriculture is the dominating water user in the valley and the main factor for social development. The main source of income is local agriculture. According to the Palestinian Ministry of Agriculture (MoA), the irrigated area around Auja village is about 5,000 dunam (dn; 1 dn = 0.1 ha), while the additional area with reasonable agricultural potential for the extension of the irrigated land amounts to approximately 10,000 dn. The main constraint results from the existing Israeli occupation of the surrounding lands. Some areas at Auja village are possessed by private companies which produce medical crops (herbs) for export using greenhouse technology. Local farmers and inhabitants of Auja village are partly employed by these firms to work on the land.

Besides medical crops, palm trees, vegetables, and grain, grapes and other citrus fruits are cultivated. Vegetables are cultivated in a traditional way by open drip irrigation schemes as well as in low-tech greenhouses by intensive protected agriculture. On approximately 40 % of the irrigated area (≈ 2000 dn), palm trees are cultivated due to their robustness to brackish water irrigation from shallow wells and the economic value of dates. Figure 181 presents a map of the currently irrigated areas around Auja village, together with areas available for the extension of irrigated land, classified into 3 zones according to the results of comprehensive field surveys conducted by Shawahna (2014).

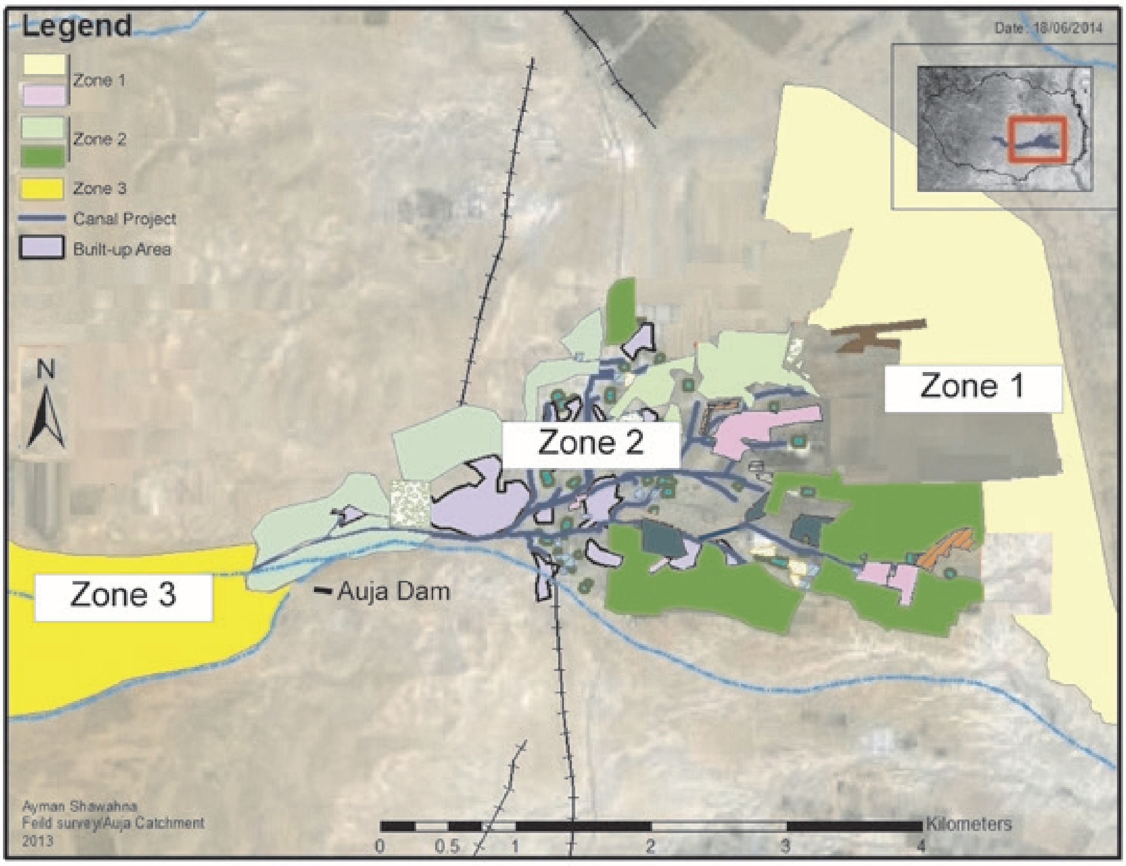


Figure 181: Irrigated area around Auja village and available irrigable land (modified, Shawahna, 2014)

The soils of these 3 zones are sandy clay to sandy loam silts with a potential for agricultural production. Zone 1 comprises an area of about 3600 dn (360 ha) and is characterized by a higher risk of soil salinization. The area would be adequate for palm tree irrigation due to the salt resistance of these crops. Zone 2 is located around the already existing irrigated area, directly at Auja village. According to Shawahna (2014), zone 2 (3400 dn) is characterized by a low risk of soil salinization and, therefore, adequate for the planting of traditional, already irrigated crops, such as vegetables, corn, banana, and grapes. As zone 3 (3000 dn = 300 ha) is partly located in the flood risk area, citrus fruits, such as grapes, or palm trees could be considered for the extension of the irrigated land to the west of Auja village. According to Shawahna (2014), zone 3 may even be extended to about 5000 dn, but requires further studies with regard to the flood risk and recommended cropping pattern. For the present study, it is assumed that around 1500 dn in zone 3 are applicable for irrigated agriculture.

Table 58 summarizes revenues (NIS/dn), water demand (m^3/dn), present irrigated area (dn), and the zones for the extension of irrigated lands, with (a) regular irrigated agriculture, (b) intensive protected agriculture (greenhouses), and (c) palm tree irrigation being distinguished. For vegetables under regular irrigation, 2 growing periods per year with a water demand of 875 m^3/dn/season are being considered. The revenue values are based on good water supply conditions taking into consideration that the current production benefits at Auja are inferior due to water scarcity impacts. These values require further consolidation. Further details about the collected data and underlying assumptions are provided by Rusteberg et al. (2014) and Shawahna (2014).

Table 58: Irrigated agriculture and potential for extension of irrigated lands in the Lower Wadi Auja (modified, Shawahna, 2014).

Agricultural Sector	**Crops**	**Revenue** [NIS/dn]	**Water Demand** [m^3/dn]	**Present Area** [dn]	**Corresponding Extension Zone (New Land)** [-]
Regular Irrigated Agriculture (RA)	Vegetables	2,000	1,750	300	2 and 3
	Corn	2,100	954	400	2 and 3
	Banana	4,400	1,565	70	2 and 3
	Grapes	3,300	1,040	30	2 and 3
	Average/Total	**2,033**	**1,309**	**800**	**-**
Greenhouses (GH)	Vegetables	**8,100**	2,000	1,200	2
	Herbs	2,500	395	1,000	2
	Average/Total	**5,500**	**1,270**	**2,200**	**-**
Palm Trees (PT)	Dates	**3,100**	**1,200**	**2,000**	**1 and 3**
SUM (dunam)				**5,000**	**10,000**

6.2.6 Water Development and Management Objectives

The mathematical model for multi-objective optimization (MOO) requires the definition of a set of objective functions, which represent the water development and management goals, together with a set of constraints (Das and Dennis, 1996; Messac et al.; 2003). For the definition of an environmental and social objective function, it was studied, whether the allocation of the available water resources, represented by decision variables Xi, should be maximized or minimized by the corresponding objective function or whether there is an indifference to the allocation of the corresponding source. The same refers to water management actions (e.g. mixing, desalination) and source allocation to different agricultural development options. The economic objective function basically represents a cost-benefit assessment, where revenues are maximized and water productions minimized. Due to the fact that the capital costs for land preparation and installation of low-tech irrigation systems are expected to be low in comparison with the water production costs, the former have not been considered in this exemplary assessment. Table 59 summarizes the nature of the objective functions. A more comprehensive assessment is presented by Rusteberg et al. (2014).

The social objective function focuses on the maximization of regular, traditional irrigated agriculture and reflects the low social acceptance of treated effluents reuse in irrigation as well as more sophisticated irrigation technologies. Local farmers prefer freshwater from springs, surface runoff or deep wells for irrigation and, therefore, support the desalination of brackish groundwater.

Table 59: Water Development and Management Objectives

	Environmental Objective	Economic Objective	Social Objective
Fresh water use	+		+
Mixing fresh water / brackish water			-
Brackish water use	-		+
Desalination of brackish water	-		+
Treated effluent use	+		-
Mixing brackish water / treated effluent	+		-
Expand Regular Agriculture			+
Expand Greenhouses			-
Expand Palm Trees			
Water allocation revenues		+	
Water production costs		-	

Legend: [**+**] : favourable [**-**] : unfavourable [ ] : indifferent

The environmental objective function rejects the direct application of brackish groundwater for irrigation due to the related risk of soil salinization as well as the use of desalination techniques due to the unsolved problem of brine disposal. Treatment of effluents and reuse in irrigated agriculture are being supported due to their contribution to environmental protection. The mixing of treated effluents with brackish groundwater and use in restricted agriculture should be maximized, since wastewater reuse is enhanced and the risk of soil salinization reduced. Since the environmental and social objective functions refer directly to water allocation, the unit is MCM/a, while the economic objective function is quantified in NIS/a.

6.2.7 Water Allocation Problem, Decision Variables and Constraints

Figure 182 provides a graphical representation of the water allocation problem which is the basis for the mathematical description of the problem constraints. Based on the water resources systems (WRS) analysis (Figure 180), the colors blue, red, and gray refer to the source water quality, differentiating between freshwater and brackish water resources as well as treated effluents, which may be imported from El Bireh and/or Jericho wastewater treatment plants.

The water management measures refer to water quality improvements by brackish water desalination and brackish water mixing either with treated effluents or freshwater. The water quality and related costs to achieve a certain quality standard are relevant to decisions relating to the agricultural sector development, since regular agriculture and greenhouse irrigation would require a high water quality, while salt-resistant, high-value crops, such as palm trees, should not be irrigated with freshwater.

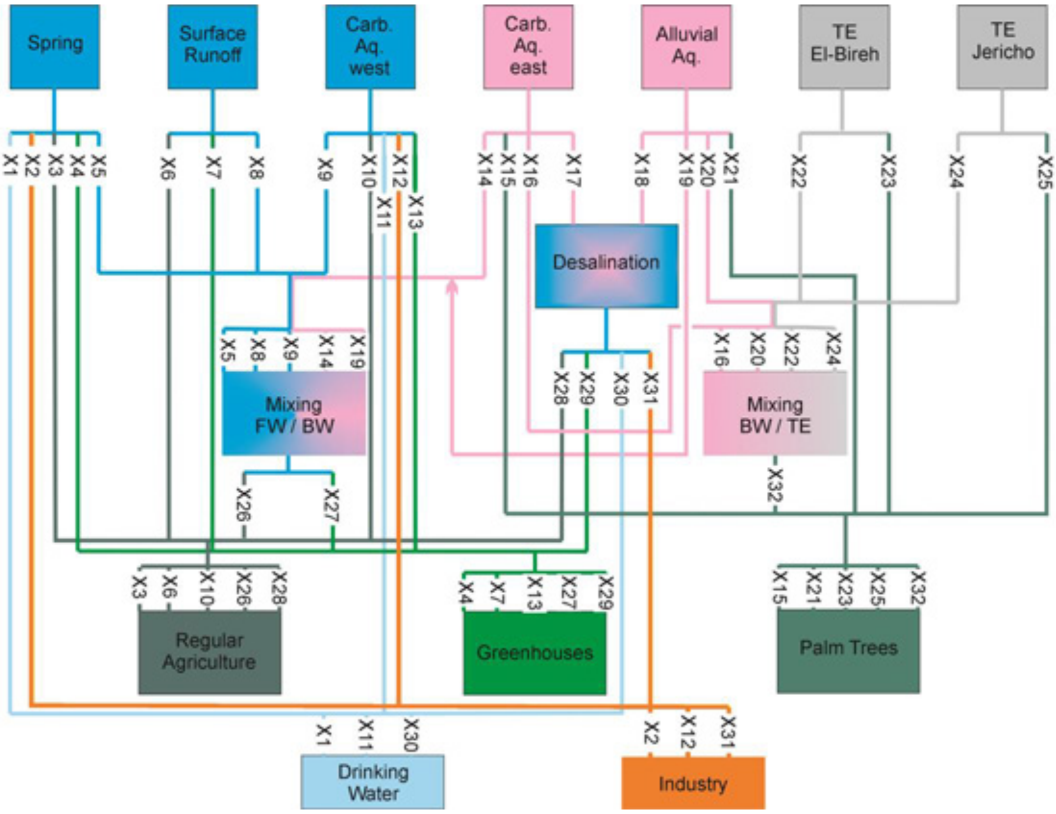


Figure 182: Water allocation structure referring to decision variables X1 to X32 (MCM/a)

The underground storage of surface water surpluses, consisting of spring discharge and surface
The underground storage of surface water surpluses, consisting of spring discharge and surface runoff, by means of managed aquifer recharge is obligatory in the case study area for any IWRM strategy in order to adapt water availability fluctuation to the demand structure and ensure a high reliability in water supply (Rusteberg et al., 2014).Consequently, this technological measure has not been considered explicitly in the water resources planning model. According to Figure 182, a total of 32 decision variables (X1 to X32) have been defined for water allocation to different water sectors taking different options for agricultural development as the main water user into consideration. Since this is a typical water resources planning task, the decision variables refer to the annual water allocation and water sector demands in MCM/a.

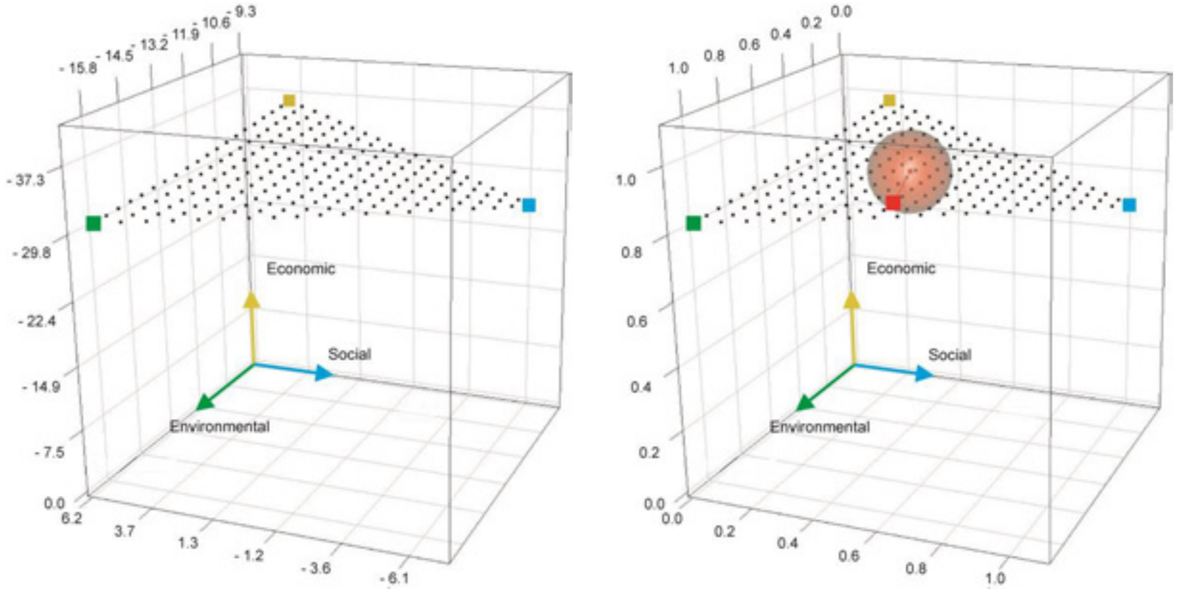
The multi-objective optimization problem and feasible solutions are constrained by the water potential of the different water sources, with minimized losses being taken into account, the corresponding source water qualities, the available area (zones 1, 2, and 3) for the extension of irrigated lands, the suitability of the different areas for irrigating different crops, and sector water demands. Further constraints refer to the mixing of freshwater and brackish water resources, brackish water desalination, and brackish water mixing with treated effluents. In total, 35 problem constraints have been defined for the Auja case study. For the definition of the mathematical model for the water resources planning and water allocation task, numerous parameters had to be quantified:

- Cost of water production options (incl.water transfer) in NIS/m3;
- cost of management options and (wastewater) water treatment in NIS/m3;
- benefits of water allocation in NIS/m3 and NIS/dn;
- water demand for regular agriculture, palm trees, & greenhouses in mm/dn;
- salinity thresholds of mixed water (mg/l);
- salinity threshold & parameters for overpumping of carbonate aquifer (mg/l).

A list of all parameters, decision variables, and problem constraints is given in Rusteberg et al. (2014).

6.2.8 Candidate IWRM Strategies and Compromise Solution

The results of the multi-objective optimization (MOO) are presented in the Figure 183 below using a 3-dimensional objective space, consisting of 3 axes to plot the achievements with regard to the environmental, social, and economic objective functions. Since the model has been defined as a minimization problem, the given values are negative (Rusteberg et al., 2014). Therefore, the lowest value reflects the best performance. The PARETO surface of non-dominated, candidate IWRM strategies as solutions of the MOO problem shows the conflicting nature of the selected water development and management objectives. This especially refers to the environmental and social objectives and their values at the corner points of the surface, which are `extreme´ solutions of the MOO problem. The best environmental performance is achieved at the green corner point, when social performance is low (blue point) and vice versa. The yellow corner point refers to the economic optimum as an `extreme´ strategy for best economic performance. For this IWRM strategy, annual benefits from water allocation (revenues minus production costs) amount to 37.3 million NIS. Each point of the PARETO surface refers to a specific water resources planning and allocation strategy with different values for the 32 decision variables in Figure 182 and different results regarding the extension of irrigated land and most appropriate cropping pattern. Figure 183shows in an exemplary way how a compromise solution can be achieved by means of a goal point. For this approach, the absolute values are normalized and percentage values for the achievement level of each water management objective have to be provided by local stakeholders and decision-makers.



a) Pareto surface and extreme solutions *b) Compromise solution with normalized values*

Figure 183: Candidate IWRM Strategies

For an exemplary application, goal achievement levels of 90 % for the economic, 60 % for the environmental, and 50 % for the social optimum have been assumed. This leads to a goal point, which is located above the PARETO surface (Figure 183 b). That point of the PARETO surface with the shortest distance to the goal point corresponds to the selected compromise IWRM strategy. Further details on the procedure are provided by Rusteberg et al. (2014).

Figure 184 and Table 60 show how the extreme solutions differ with respect to the total irrigated land, with regular irrigated agriculture (RA), greenhouse (GH), and palm tree irrigation (PT) being distinguished, and compare them to the selected compromise solution. The results include the already existing irrigated area.

The social (blue) strategy just maintains the already existing irrigation areas with greenhouses and palm trees, but extends traditional agriculture to cover the entire zone 2 and one third of zone 3, depending on the freshwater availability. Due to high water demand of RA, the total irrigable land is limited to around 10,000 dn. Just a small amount of treated effluents from Jericho is imported for palm tree irrigation. The economic benefit is reduced to 25.3 million NIS/a.

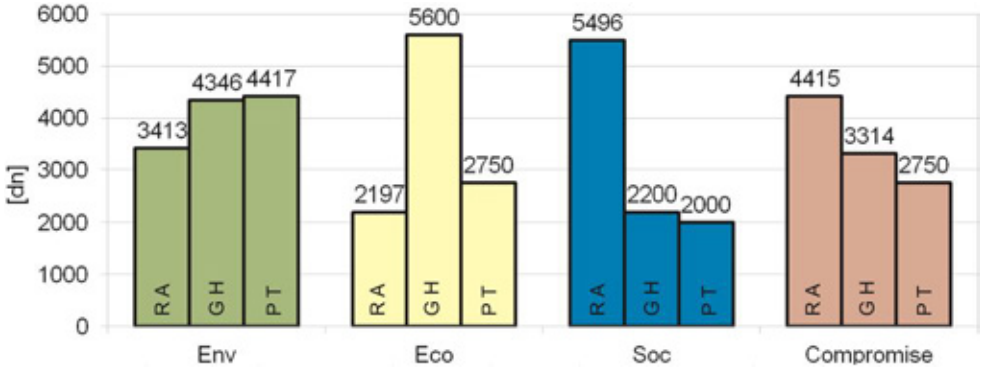


Figure 184: Compromise agricultural development strategy in comparison to extreme solutions

The economic (yellow) strategy with a maximum benefit focuses on greenhouse technology, extending the existing 2,200 dn to the entire zone 2 (3,400 dn). Palm tree irrigation is restricted due to the limited treated effluents import from Jericho (1.5 MCM/a). Mixing with brackish groundwater is taken into consideration. Treated effluents import from El-Bireh (2 MCM/a) is not economically efficient given the revenues for palm tree irrigation (2.6 NIS/m^3) and water production cost (4 NIS/m^3). These values require further study and consolidation.

The environmental (green) strategy exploits the entire potential of treated effluents import from Jericho and El-Bireh (3.5 MCM/a) due to environmental considerations. The effluents are mixed with brackish groundwater and applied for palm tree irrigation on around 4,400 dn. As for all other strategies, the availability of local water resources and treated effluents for agricultural development are the limiting factors.

Table 60: Agricultural development options, water trade and water requirements for extreme and compromise strategy

	Water Allocation in Agriculture			**Water Trade**	**Water Requirements**		**Irrigated Area**
	RA	GH	PT	Import	Local	**Total**	Total
Allocation (Area)	MCM/a (dunam)	MCM/a (dunam)	MCM/a (dunam)	MCM/a	MCM/a	**MCM/a**	(dunam)
Env. Extreme	4.5 F 3,413	5.5 F 4,346	1.8B+3.5E 4,417	3.5 E	11.8	**15.3**	**12,176**
Econ. Extreme	2.9 F 2,197	7.1 F 5,600	1.8B+1.5E 2,750	1.5 E	11.8	**13.3**	**10,547**
Soc. Extreme	7.2 F 5,496	2.8 F 2,200	1.8B+0.6E 2,000	0.6 E	11.8	**12.4**	**9,696**
Compromise Strategy	5.8 F 4,415	4.2 F 3,314	1.8B+1.5E 2,750	1.5 E	11.8	**13.3**	**10,479**

Legend: *F: Fresh water; B: Brackish water; E: Treated Effluent*

The compromise (red) strategy still provides an economic benefit of about 30 million NIS per year, but, nevertheless, strengthens traditional agriculture by increasing the area from today's 800 dn to around 4,400 dn. The area for greenhouse irrigation is nearly doubled. Wastewater reuse is restricted to treated effluents import from Jericho. According to Table 60, 5.8 MCM/a and 4.2 MCM/a of freshwater resources from Auja spring, surface runoff, and deep wells in the carbonate aquifer are applied for regular agriculture (RA) and greenhouse irrigation (GH), respectively. Palm tree irrigation is covered by treated effluents and brackish groundwater. Brackish water desalination is not considered, since the brackish water potential is applied for palm tree irrigation. The implementation of the compromise IWRM strategy would double today's irrigated area around Auja of around 5,000 dn to approximately 10,500 dn. This would require the implementation of the IWRM measures listed in Table 57, but not water import from Feshka (M8) and the Palestinian water carrier still under study (M9) as well as brackish groundwater desalination (M11). The evaluation of measures M8 and M9 will require further investigations on regional and catchment cluster levels. The rehabilitation of the old canal between Auja spring and the irrigated lands or installation of a new pipeline instead to reduce the high water losses of about 60 % of the water potential to at least 20 % may be considered most important structural interventions.

Based on the suggested IWRM implementation concept (Figure 178), Rusteberg et al. (2014) analyzed the uncertainties of the agricultural development, stakeholder preferences, and water pricing at Auja by means of a sensitivity and scenario analysis and discussed the impact on candidate and compromise IWRM strategies.

6.2.9 Summary of the local case study Palestine

Based on IWRM studies in the western sub-catchment cluster, comprising the Wadis Auja, Nueimah, and Qilt, a clear methodological approach (concept) has been developed, which leads to an integrated water resources development and management plan (WATER PLAN). The IWRM implementation concept may be characterized as a water resources planning procedure from an engineering point of view. The concept is strictly participative, involving all relevant stakeholders. The final water resources development plan indicates clearly how priority interventions in terms of structural measures (e.g. pipelines, surface water retention structures, shallow and deep wells) and management measures (e.g. water mixing, desalination, water import) should be combined. The WATER PLAN is to be understood as a compromise IWRM strategy and represents the best compromise solution between the most relevant social, environmental, and economic water management objectives and stakeholder preferences, taking the relevant water development policies into account. Several software tools have been developed to support the decision-making process, e.g. with regard to the identification of pareto-optimal alternative IWRM strategies.

The approach was applied in an exemplary manner to the typical rural LJV sub-catchment of Wadi Auja, involving local stakeholders, such as the Palestinian Water Authority (PWA), the Palestinian Ministry of Agriculture (MoA), the Israeli Water Supply Company (MEKOROT), the Palestinian Hydrology Group (PHG), and Al-Quds University. According to Figure 178, the approach is based on detailed hydro(geo)logical investigations and mathematical modeling, assessment of the present and future water demands based on socio-economic development scenarios, water budget studies, and an innovative method for water resources systems analysis. The study considers alternative development scenarios for the extension of the irrigated area, taking into account the integration of salt-resistant crops, greenhouses technology, high-value crops, and regular agriculture. In the case study, the impact of the different water pricing policies, stakeholder preferences, and agricultural development scenarios on the selection of priority interventions has been analyzed, too. The optimized IWRM strategies reach a high economic efficiency under different preference structures of the decision-making group with regard to social and environmental aspects. For the identification of the final water development plan from alternative sets of optimized IWRM strategies, different procedures are available. Details about the case study of the approach suggested for water resources planning and IWRM strategy development are presented by Rusteberg et al. (2014).

6.3 Socio - economic assessment of IWRM

Author: I. Heinz

Socio-economic issues are to be taken into consideration when assessing alternative IWRM strategies in terms of economic efficiency, financial affordability, social equity, and institutional feasibility. In the following sections, key results from case studies will be presented, showing that appropriate technical solutions to tackle water problems should be determined by using socio-economic performance criteria and tools (see chapter 4.3.2 and chapter 5.4).

Case Study of the Jericho Area, Palestine

The area of investigation can be divided into three sub-areas with different utilizations of water resources, infrastructures, and water demands: a) Jericho east sub-area, b) central sub-area with Jericho city, and c) Jericho north sub-area. For each area with its specific problems, water management options have been identified for improving the water situation. In the near future, the water supply problems will aggravate, if no measures will be undertaken. In sub-areas, where agriculturally used land can be expanded, more water will be required. In other areas, growing population and additional commercial activities will raise the municipal water demand (Table 61). Of special relevance is the fact that in the Jericho area the sanitary infrastructure is poor, as currently no wastewater treatment plants (WWTP) exist. Cesspits are in use, by which the water bodies (groundwater, wadis) are seriously endangered.

Table 61: Water demands and deficits in the Jericho sub-basins.

Jericho areas	Water demand (MCM/yr) 2012 – 2030	Water deficit (MCM/yr) 2016 - 2030
Sub-area east	2.6 – 5.0	1.2 – 4.0
Sub-area central	3.7 – 7.0	0.6 – 4.0
Sub-area north		
▪ Shosa / Duyuk site	2.5 – 7.0	1.2 – 5.0
▪ Nueimah site	1.4 – 4.0	0.8 – 3.0

In the Jericho area, the water deficits can be resolved by means of the proposed water management options. In most cases, the economic benefits exceed the costs. In the Jericho east sub-area, for instance, a maximum additional water supply of 6.3 MCM/yr can be provided, whereas the projected water deficit will increase from 1.2 MCM/yr in 2016 to approximately 4.0 MCM/yr in 2030 (Table 61). This means that not all the management options considered for this sub-area are to be implemented at the same time. The different options are to be prioritized according to their economic efficiency and social acceptance. In Table 62 the economic efficiencies of the three options are compared in terms of their unit added values – defined as the annual surplus of the benefits over the costs per cubic meter extra water. It shows that the water reuse option is the best one, followed by rainwater harvesting and desalination of brackish water.

Table 62: The economic efficiencies of water management options in the Jericho east sub-area.

Water management option	Unit values added [USD/m³]*)
Desalination of brackish water	0.76
Rainwater harvesting from Al Qilt	1.11
Water reuse	2.06 **)

*) Values at 100 % use of capacity; water losses in the networks not considered

**) Indirect benefits are included, such as cost savings due to replacing cesspits. This unit value would be higher, if only the costs of upgrading the treatment technology to comply with the quality requirements for agricultural irrigation, together with the additional conveyance facilities, will be taken into account.

In the Jericho central sub-area, the ranking was as follows: The options rehabilitation of water networks (0.42), demand management (0.37), and intersectoral water transfer (0.23) have the highest values, while rainwater harvesting (0.164) has the lowest. Similar to the Jericho east sub-area, possible water supply will exceed the water demand, if all options would be implemented. Again, all the alternatives have to be prioritized and to be implemented one after the other.

In the Jericho north sub-basin, the value added from replacing open channels by a pipeline network (1.06) is higher than from stormwater harvesting (0.66). However, even if both options would be implemented, the water deficit in irrigated agriculture - the main user in the Shosa / Duyuk and Nueimah areas – will continue to increase each year within the planning period 2012 - 2030. Consequently, both measures should be undertaken simultaneously, i.e. a ranking is not needed. More water for the irrigated agriculture in both areas could lead to additional values added, if further projects would be realized, such as regional water transfer and artificial groundwater recharge.

As mentioned, a prioritization of different water management options is needed in cases where the water supply will exceed the demand, if all options would be implemented as of now and at the same time. Obviously, such a plan would lead to economic losses, because unnecessary expenses would incur. Provided that a continued growth in water demand can be expected, a temporal sequence is to be defined in accordance with the relative economic efficiencies of the options, i.e. the project with the maximum value added will be selected first. In the Jericho east sub-area, this is the wastewater reuse option, followed by rainwater harvesting and desalination of brackish water. This order indicates the years in which different water projects should be realized and which combinations, called IWRM strategies, are to be preferred Table 63.

Table 63: IWRM strategies at the Jericho eastern sub-basin

IWRM strategy	Combination of water management options	Time interval
A	Water reuse	2012 - 2031
B	Water reuse + rainwater harvesting	2018 - 2031
C	Water reuse + rainwater harvesting + desalination of brackish water	2026 - 2031

Such a temporal sequence ensures that no unnecessary costs incur and that the values added of the IWRM strategies will be as high as possible. Figure 185 displays the yearly development of the total values added (in million USD/yr) for the Jericho east sub-area.

The drops of the curve in 2015, 2018, and 2026 result from the fact that the capacities of the facilities are not fully utilized in these years, so that temporarily the costs are higher than the benefits.

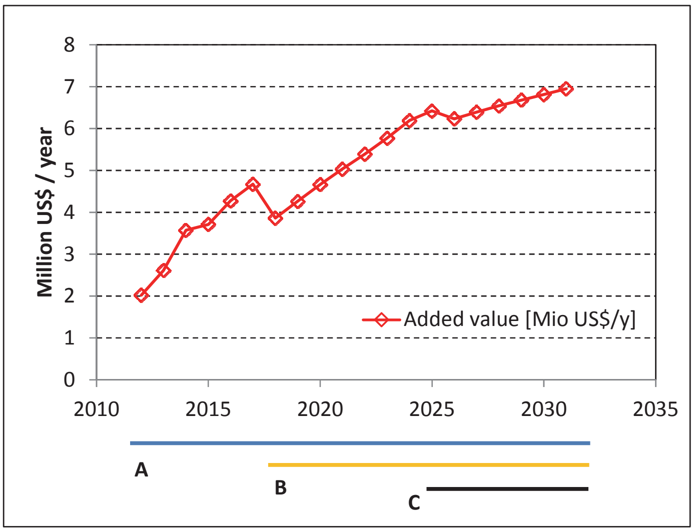


Figure 185: Value added of IWRM strategies from 2012 to 2031 in the Jericho east sub-area.

Such a time-referenced CBA of IWRM provides a guideline for water managers, who have to decide when water projects should be constructed and which capacity they should have.

Key influencing factors are:

- Growth rate of water demands;
- Variations in water availability (affected by changes in precipitation and others);
- Costs of water projects, crop prices, and the economic benefits, such as water profitability in agriculture and water tariffs;
- Capacity limits of the constructions;
- Size of lands available for cultivation.

Note: If the rate of agricultural production rises, the curve may move upwards. This means that each of the water projects is to be realized earlier and other way around: At a lower growth rate, the facilities can be installed later.

The example of the Jericho east sub-area represents a relatively simple approach, as irrigated agriculture is the only water user. In case of more types of users – as in the Jericho central sub-basin –, this approach is feasible as well, but more complicated (studies 706 & 707 of SMARTII).

Lower Jordan River Valley

Decentralized wastewater treatment and reuse projects (DWWT & reuse) are needed to improve sanitation and to enhance agricultural productivity in rural areas and small municipalities in Jordan. The *net present value calculations* of the SMARTII studies 701 & 704 address all major costs and benefits associated with DWWT & reuse at two villages. A range of valuation methods were used to monetize the benefits associated with the environment, health, and irrigation in agriculture (see chapter 5.4 ‘Tools for socio-economic evaluation’). As evident from the results for the village of Ma’addi, the average net present value of both wastewater treatment options - sequencing batch reactors (SBR) and constructed wetlands (CW) - is higher than zero (Table 64). This means that values added will result from DWWT & reuse. In the village of Maghareeb, however, the average net present value of the SBR technology is negative. This can be explained by the relatively low economic benefit in agriculture and the high costs of wastewater treatment due the high demands on the quality of reclaimed water in Jordan.

Table 64: Present values of costs and benefits and net present values of two DWWT & reuse technologies at the discount rate of 3 %.

	PV COSTS Million JD	PV BENEFITS Million JD		NPV Million JD	
		Maghareeb	Ma’addi	Maghareeb	Ma’addi
OPTION 1: SBR	1.68	1.26	1.93	-0.42	0.25
OPTION 2: CW	0.98	1.24	1.78	0.26	0.80

In the Jordan Valley, the reuse of treated wastewater in irrigated agriculture is widespread. A prominent example can be found downstream of the King Abdullah Canal (KAC), where the effluents of the As-Samra treatment plant of Amman are stored in the King Talal Dam (KTD) and then mixed with the KAC freshwater. The blended treated wastewater (BTWW) is utilized for agricultural irrigation in the middle and southern parts of the Jordan Valley. The upstream KAC freshwater is diverted for domestic users (mainly the city of Amman) and agricultural irrigation in the northern part of the Jordan Valley.

SMARTII study 703 covers the economic impacts of water reuse for irrigations at two agricultural sites: The upstream basin 10 (Northern Jordan Valley - NJV) and the downstream basin 22 (Middle Jordan Valley - MJV) supplied with freshwater (FW) and blended treated wastewater BTWW, respectively. The question is which of the two different types of water resources are more cost-beneficial.

As obvious from Figure 186 the average values for the profitability of water were higher in the area irrigated with BTWW (0.518 JD/m³) than in the area irrigated with FW (0.477 JD/m³). The profitability of blended treated wastewater for winter vegetables (1.040 JD/m³ and 0.942 JD/m³, respectively) and summer vegetables (0.835 JD/m³ and 0.642 JD/m³, respectively) is significantly higher, but lower for citrus (0.158 JD/m³ and 0.241 JD/m³, respectively) and other fruit.

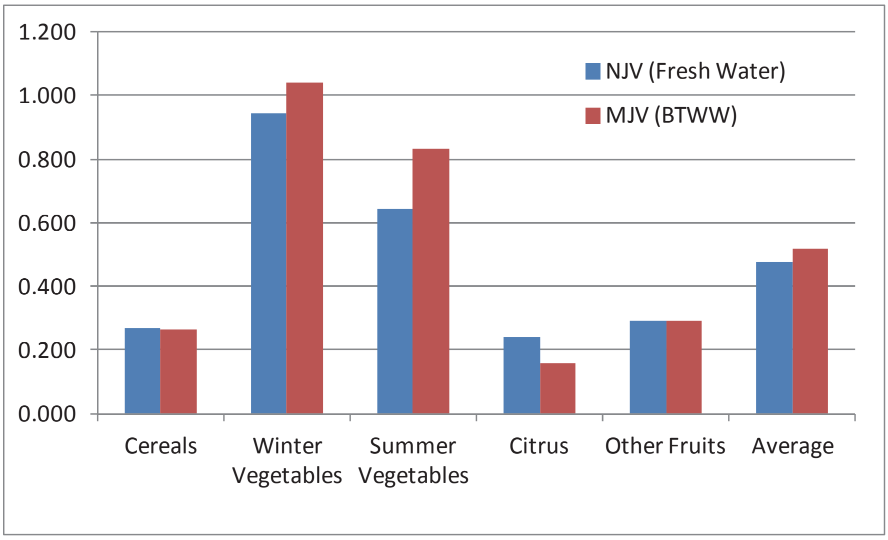


Figure 186: Water profitability in agriculture for freshwater and blended treated wastewater in the northern and middle Jordan Valley (JD/m m³).

Since there is no information about the true cost of BTWW, the difference between the farmers' incomes generated by the two types of water may be assumed as a proxy for the value added from treated wastewater reuse.

Another case study addresses a comprehensive IWRM concept at Israeli locations in the western Jordan river valley (study 711 of SMARTII). The analysis focuses on alternative water management options for irrigating farmlands with different qualities, such as freshwater (FW), treated wastewater, saline water, and flooding water. In trying to determine the best management strategy to tackle water shortage, priorities for the allocation of different resources are needed. The impacts of each action on different objectives or performance criteria are to be investigated (Table 65).

Table 65: Decision criteria for IWRM

Decision criteria	Objectives
C1	Aquifer sustainability - preserving water levels and its quality in order to minimize the impact on the fresh water resource
C2	Natural environment preservation
C3	Maximisation the economical profit
C4	Reliability of water supply, including minimizing the gap between water demand and supply especially on peak demands

By applying the multi-criteria analysis (MCA) and the analytical hierarchy process (AHP), various alternatives can be ranked in order to determine the most favorable IWRM strategy (see chapter 5.4 'Tools for socio-economic evaluation'; studies 706 & 707 of SMARTII). The following 4 alternative options for different plants, such as vegetables, fruits, grapes and date palms, are considered.

A1: FW and marginal water,

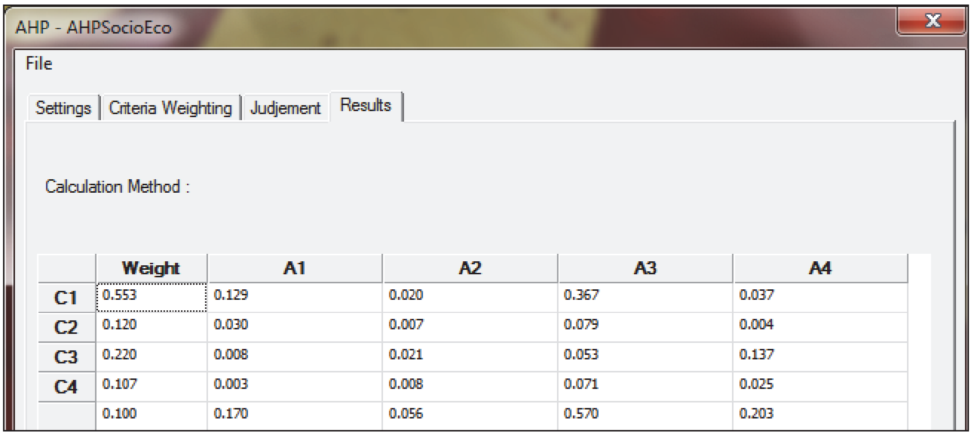
A2: FW, marginal water, and additional FW from new wells,

A3: FW, marginal water, and additional marginal water,

A4: FW, marginal water, and spring saline water.

The source “marginal water" is a mixture of different types, has inferior water quality, and can therefore be used to irrigate date palms only: Winter floodwater that flows from the Nablus region to the Tirza reservoir, saline water from the Jordan River, and re-claimed wastewater from the Og and Kidron streams.

For prioritization, a pair-wise comparison of the criteria is needed, which provides the relative weights for the four criteria. In the case study, the criteria hierarchy resulted as: C1 > C3 > C2 > C4 (Figure 187, 1st column).



Calculation Method :

	Weight	A1	A2	A3	A4
C1	0.553	0.129	0.020	0.367	0.037
C2	0.120	0.030	0.007	0.079	0.004
C3	0.220	0.008	0.021	0.053	0.137
C4	0.107	0.003	0.008	0.071	0.025
	0.100	0.170	0.056	0.570	0.203

Figure 187: The outcomes of the comparison of water resources alternatives for all policy criteria.

This result indicates that aquifer sustainability has the highest priority in order to preserve the only freshwater source in the study area, i.e. criterion 1 is considered to be more important than the other criteria due to the high significance of the mountain aquifer.

In the second step, a pair-wise comparison of the 4 alternatives is needed to obtain the weights for each of the alternatives and each of the four performance criteria. For instance, when analyzing criterion C1, the weight of alternative A3 is 0.6636 and of alternative A2 is 0.036. This means that alternative A3 is superior to alternative A2 with respect to the objective C1 ‘aquifer sustainability’.

Finally, in step 3, these weights will be multiplied by the respective weights of the four criteria given above. The outcomes for each of the criteria will be added to the overall weights for each of the four alternatives. The sums indicate their priorities, as is obvious from the last line in Figure 187. As mentioned, C1 is the most important criterion with the weight of 0.553 according to the 1st column of Figure 187. The other columns show the weights provided by step 3. For instance, the value of 0.367 in the 4th column represents the outcome of multiplying the weight of criterion C1 (0.553) by the weight of alternative A3 (0.6636), thus indicating its performance in this respect. The last line of Figure 187 contains the overall weights of each of the four alternatives, which yields the following hierarchy: A3 > A4 > A1 > A2. The option ‘FW, marginal water, and additional marginal water’ is the best one, whereas the option ‘FW, marginal water, and additional FW from new wells’ ranks fourth.

As study 712 of SMARTII reveals, participatory planning processes are complex, time-intensive, and require financial and human resources and developed skills (facilitation, moderation, negotiation, and communication with the stakeholders and water managers). Where implemented successfully, however, participation generates local ownership of the solution and, hence, sustainability. The latter is indispensable for cost-efficient and environmentally sound IWRM strategies. In Jordan, where centralized treatment is not always the most cost-efficient option, decentralized solutions should be explored and - where feasible and socially accepted - be implemented. Their sustainability and effectiveness, however, will be out of the hands of the central government and will depend on the local and regional actors. Thus, participatory planning will be one of the keys to successful implementation of IWRM. It is recommended to have this participatory planning process discussed and, if deemed appropriate, applied by the recently established National Implementation Committee for Decentralized Wastewater Management in Jordan (NICE).

6.4 Summary and Conclusions

The preceding chapters documented an exemplary modeling and scenario planning exercise for sub-basin-scale integrated water resources management with applications to the Jordanian Wadi Shueib catchment as well as to the Wadi cluster of Nuema, Quilt, and Auja in the West Bank.

6.4.1 IWRM at the Wadi Shueib, Jordan

Author: D. Riepl, J. Klinger

Modeling was purposefully based on the data and information basis as it would currently be available for fully informed planning personnel and decision-makers in the Jordanian water sector institutions. The data were subjected to a thorough data quality control and several pre-processing steps in order to generate consistent water balance time series, which allowed for the estimation of important hydrological and resources engineering model assumptions. The Water Evaluation and Planning (WEAP) model was used to represent the water system of the study area and serve as an IWRM planning tool. National water strategy objectives and action plans were used as a normative guideline to draft a set of planning alternatives directly related to the local challenges. The systematic selection and development of IWRM performance indicators was organized in direct reference to the stated objectives and the constraints inherent in the WEAP framework. For the scenario approach, the identified alternatives were combined in two action plans for the Wadi Shueib area: The Business as Usual (BAU) strategy assumed the currently active projects to be continued and finished until 2025 and the Full Implementation (FI) development line assumed that the full range of all implementation approaches is realized until 2025. External driving forces were modeled to agree with the official projections for climatic conditions, demographic growth, and water demand development. Internal drivers were modeled as a rate of change and cost figures based on a review of past performances and the respective current planning status of the Jordanian water sector institutions. The scenarios were simulated for the performance indicators identified, discussed for a range of 3 consecutive water years with dry (84 % of average rainfall), average (101 %), and wet (120 %) year conditions, and compared to the current situation in the water year 2008/09.

6.4.2 IWRM in Palestine

Author: Bernd Rusteberg

Based on IWRM studies in the western sub-catchment cluster, comprising the Wadis Auja, Nueimah, and Qilt, a clear methodological approach (concept) has been developed, which leads to an integrated water resources development and management plan (WATER PLAN). The IWRM implementation concept may be characterized as a water resources planning procedure from an engineering point of view. The concept is strictly participative, involving all relevant stakeholders. The final water resources development plan indicates clearly how priority interventions in terms of structural measures (e.g. pipelines, surface water retention structures, shallow and deep wells) and management measures (e.g. water mixing, desalination, water import) should be combined. The WATER PLAN is to be understood as a compromise IWRM strategy and represents the best compromise solution between the most relevant social, environmental, and economic water management objectives and stakeholder preferences, taking the relevant water development policies into account. Several software tools have been developed to support the decision-making process, e.g. with regard to the identification of pareto-optimal alternative IWRM strategies.

The approach has been applied in an exemplary manner to the typical rural LJV sub-catchment of Wadi Auja, involving local stakeholders, such as the Palestinian Water Authority (PWA), the Palestinian Ministry of Agriculture (MoA), the Israeli Water Supply Company (MEKOROT), the Palestinian Hydrology Group (PHG), and Al-Quds University. According to Figure 178, the approach is based on detailed hydro(geo)logical investigations and mathematical modeling, assessment of the present and future water demands based on socio-economic development scenarios, water budget studies, and an innovative method for water resources systems analysis. The study considers alternative development scenarios for the extension of the irrigated area, taking into account the integration of salt-resistant crops, greenhouses technology, high-value crops, and regular agriculture. In the case study, the impact of the different water pricing policies, stakeholder preferences, and agricultural development scenarios on the selection of priority interventions has been analyzed, too. The optimized IWRM strategies reach high economic efficiencies under different preference structures of the decision-making group with regard to social and environmental aspects. For the identification of the final water development plan from alternative sets of optimized IWRM strategies, different procedures are available. Details about the case study of the approach suggested for water resources planning and IWRM strategy development are presented by Rusteberg et al. (2014).

Conclusions Concerning IWRM in Palestine

- The development goals of the agricultural sector as the main water user significantly influence the future water needs of the Palestinian territories in the Lower Jordan Valley.
- Wastewater treatment, reuse in agriculture, and mixing with brackish groundwater for irrigation of salt-resistant, high-revenue crops, such as palm trees, meet with a low social acceptance, but should be part of a compromise IWRM strategy due to their economic, environmental, and social benefits and their positive impact on water supply reliability.
- The extension of the irrigated areas beyond the local water potential, with treated effluents reuse being taken into account already, would require further water import into the area in order to prevent over-exploitation of local groundwater resources. This requires water management studies on the regional and even trans-border levels to define bound-

ary conditions for local water resources development. Water import from Feshka or by a Palestinian water carrier in the valley should be studied in this context.

- Reliable groundwater budget studies are required to improve the groundwater potential estimation. Especially the alluvial aquifer system requires better investigation with regard to long-term storage of spring water surpluses in the context of managed aquifer recharge (MAR). MAR implementation is an obligatory IWRM measure for the region in order to activate the surface water potential and to improve water supply reliability.

Conclusions with Respect to IWRM in the Lower Jordan Valley

- A commonly accepted IWRM implementation concept for the entire Lower Jordan Valley is required in order to derive transparent compromise solutions for water resources development and management as a basis for further negotiations of the partner countries. The IWRM implementation concepts developed under SMARTII on both sides of the Jordan river should be merged for this purpose and consolidated together with stakeholders and decision-makers of the region in a participative process.
- Water trade and transfer of local water resources between neighboring sub-catchments of the LJV is an important IWRM component, especially under extreme hydrological conditions. This requires IWRM strategy development on the level of sub-catchment clusters. For this water resources planning and management task, a comprehensive assessment of water production costs and related benefits is needed.
- To meet the future water demands in the LJV, additional water imports into the region are urgently required. Therefore, sustainable strategies for the supraregional, transborder management of water resources are needed to providing the area with significant water impulses and, at the same time, to define the boundary conditions for local water resources development.
- The high variability of water resources availability and the impacts of extreme events, such as droughts and flashfloods, on water resources systems planning and management require further studies in the area.

7 SMART-RELATED PROJECT: ASSESSMENT OF WASTEWATER / SLUDGE REUSE IN THE GAZA STRIP AND WEST BANK AND THE IMPLICATION ON GROUNDWATER

Involved institutions: University of Heidelberg, Birzeit University

Spokesman: A. Yahya (UH)

Authors: S. Studenroth, B. Shomar, A. Yahya

7.1 Project structure

The Gaza III project is entitled "Assessment of Wastewater/Sludge Reuse in the Gaza Strip and West Bank and the Implication on Groundwater Quality – 2010 to 2013 FKZ 02WM1086 and it represents a project associated with the SMART project. The Gaza III project integrates the outcomes of the previous two project phases covering the monitoring and the geochemical characterization of groundwater, soil pollution levels as well as the potential reuse of sludge and treated wastewater in the Gaza Strip. This final report presents and briefly summarizes the work and results of the years 2010 to 2013.

7.2 Introduction

For more than a century, the Gaza Strip has been considered one of the most volatile areas in the world, both politically and environmentally (Shomar, 2007b, 2011). The Gaza Strip is part of the coastal zone in a transitional area between a temperate Mediterranean climate in the East and North and an arid climate of the Negev and Sinai deserts in the East and South. It extends more than 40 km along the south-eastern corner of the Mediterranean Sea (Figure 188). As a result, the Gaza Strip has a characteristic semi-arid climate.

The Gaza Strip is one of the most densely populated areas in the world (4,138 inhabitants per km^2) (PCBS, 2007). With limited and deteriorated resources, it has already started to suffer the outcomes of environmental quality deterioration. Shortage and pollution of resources, coupled with high population growth and insufficient job opportunities, have created many environmental hazards. The shortage of water and the decline of water quality represent factors limiting the economic development of Palestine (MEnA, 1999).

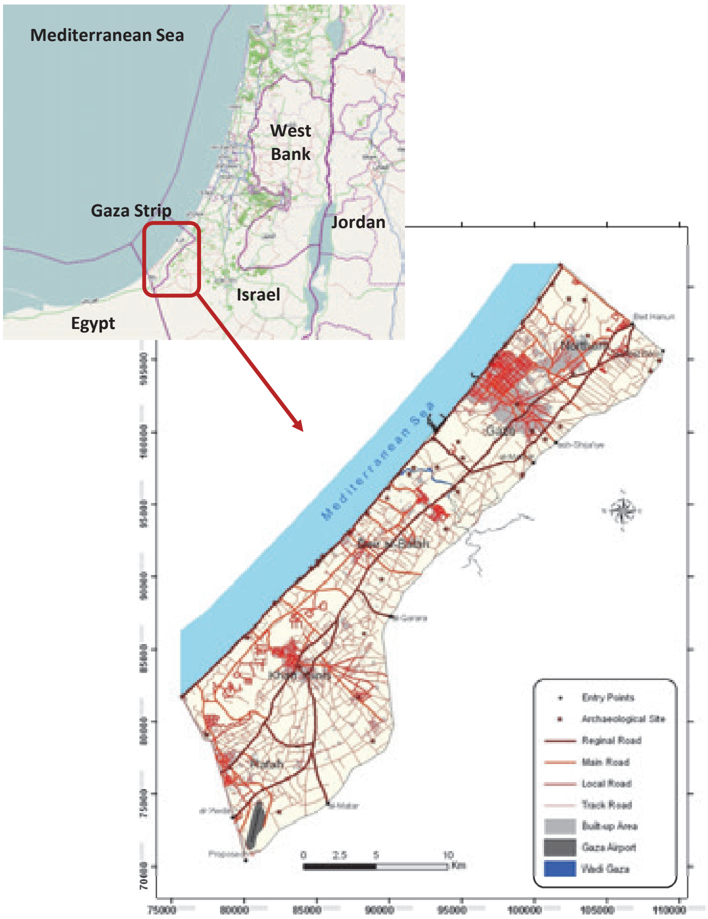


Figure 188: Gaza base map (map: © OpenStreetmap contributors) (OpenStreetMap).

7.3 Groundwater Monitoring in Gaza

7.3.1 Introduction

Groundwater is the most precious natural resource in the Gaza Strip, as it is the only source of water for the population. Groundwater contamination may therefore pose serious health and economic threats to the population that relies on this water for drinking, agriculture, and industry uses. The groundwater aquifer of Gaza is extremely susceptible to surface-derived contamination because of the high permeability of sands and gravels. It has already deteriorated in terms of quantity and quality as a result of over-exploitation and direct and indirect contamination (GCMEPMP, 2001; Shomar, 2006a; Alsharif et al., 2008; Amr and Yassin, 2008; Hamdan et al., 2008). Approximately 85 % of the population of the Gaza Strip drink from municipal groundwater wells and 15 %, mostly in agricultural areas, use private wells to supply themselves with drinking water (Shomar, 2006a).

7.3.2 Assessment of Groundwater Quality in the Gaza Strip Using GIS Mapping

A geographical information system (GIS) tool was used to generate thematic maps for groundwater quality in the Gaza Strip (Shomar et al., 2010). The data used for the water quality maps and other supporting maps were derived from the results of an eight-year monitoring program for major anions, cations, and heavy metals (Shomar et al., 2004a; Shomar et al., 2004b; Shomar, 2005; Shomar et al., 2005a, b; Shomar et al., 2005c; Shomar, 2006a, b; Shomar et al., 2006; Shomar, 2007b, a; Shomar et al., 2008; Shomar, 2009). The thematic maps used for the study included digitized data sets originally developed by the Ministry of Planning, the Water Authority, and the Environmental Quality Authority in Palestine. The integrated spatial maps helped to refine information on land use, soil types, depth to groundwater table, environmental "hot spots", and contaminant concentrations of the Gaza Strip.

7.3.3 Results

The "land use" data were obtained from the analysis of aerial photographs taken in 2008. About 40 % of the land is used for agriculture; most of it is located in the eastern half of Gaza, where population densities are low. About 80 % of the population lives in the built-up areas shown on the map (Figure 189). In addition to the major pollution point sources of overloaded wastewater treatment plants, unprotected solid waste dumping sites, and Wadi Gaza, hot spots appear sporadically at many locations due to Gaza's inability to maintain adequate infrastructure. For example, frequent electricity outage disrupts wastewater pumping stations and results in untreated wastewater infiltrating homes and streets. The lack of gasoline and diesel causes solid waste to accumulate in the streets without transportation to the dumping sites (Shomar, 2009).

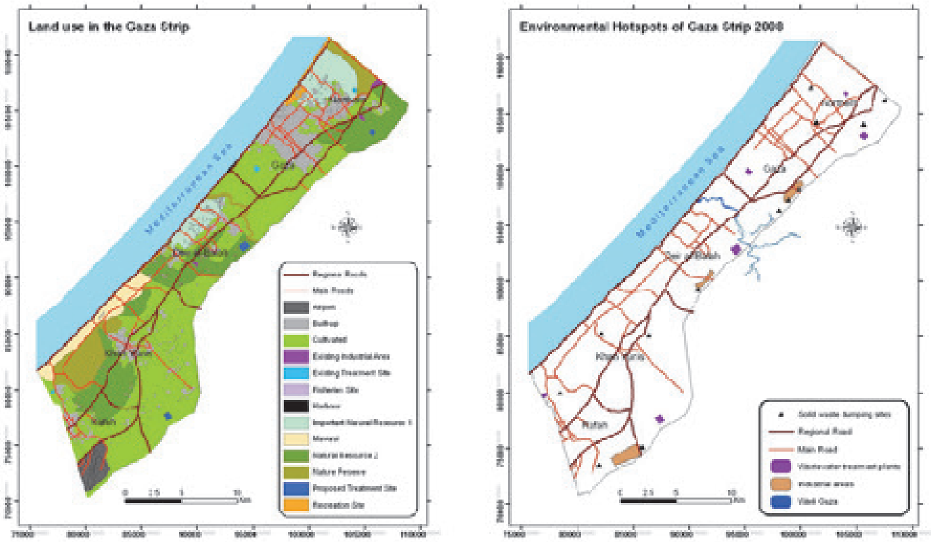


Figure 189: left – Land use in the Gaza Strip; right – Environmental Hot Spots (Shomar et al., 2010).

All wells investigated in Gaza have at least one parameter of Cl-, NO_3^-, F- or SO_4^{2-} exceeding the WHO standards of 250, 50, 1.5 or 250 mg/L, respectively (WHO, 1998). The nitrate map (Figure 190) for the year 2008 confirms previous findings of almost 90 % of the groundwater wells having NO_3^- concentrations that are 2 to 8 times higher than the WHO standards. Except for the northern area, the average concentration of F- in the groundwater is higher than the WHO standards (Figure 190). Furthermore, the F- concentration increases from North to South.

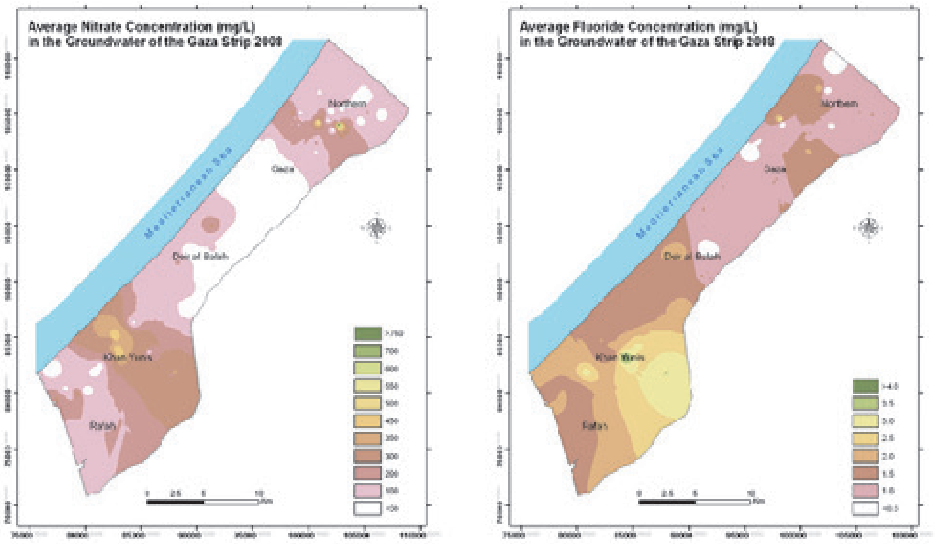


Figure 190: Left – average nitrate concentration; right – average fluoride concentration in the groundwater of the Gaza Strip in 2008 (Shomar et al., 2010). (Areas marked in white are either areas which have not been measured so far or the data were below the detection limit).

The most F- contaminated areas are Khan Younis with an average of 2.7 mg/L and Rafah with an average of 2 mg/L. Beside several cations the concentrations of some trace elements like Fe, Cr and Zn were also detected in all wells of the Gaza Strip and most of them exceed the WHO standards.

7.3.4 Conclusions

The GIS maps revealed that the water in Gaza currently is not suitable as drinking water, since most of the wells do not meet all the WHO standards (WHO, 1998). Areas of high nitrate concentrations are found in the vicinity of wastewater discharge areas, solid waste dumping sites, and Wadi Gaza. Chloride concentration is elevated in the coastal areas as a result of seawater intrusion and in the eastern areas as a result of upcoming and over pumping. The accelerating rate of salt-water intrusion (Al-Agha, 2005) alone could make the Gaza aquifer unusable for agriculture, industrial, and domestic non-drinking water uses within 2 or 3 decades. Areas naturally contaminated with high concentrations of F^-, Ca^{2+}, Mg^{2+} and SO_4^{3-} exist, as was expected due to the underlying soil chemistry, geology, and hydrogeology. The aquifer is also contaminated with a lot of pollutants from Gaza's sewage and agriculture (Shomar et al., 2005b; USCB, 2008). Given the large numbers of groundwater pollutants, an integrated approach to managing water resources is essential, including conservation, land use regulation, and control of human waste and agricultural and industrial pollutants.

Groundwater Sampling

7.3.4.1 Introduction

To update the data of municipal groundwater wells und to cover new areas, two sampling campaigns were conducted in the Gaza Strip in 2010 and 2011 (Figure 191). The main task of the sampling campaigns was to assess the groundwater quality in the whole area of the Gaza Strip using the GIS (Geographical Information System) tools and to update the groundwater quality maps from 2008 (Shomar et al., 2010). The municipal wells that have been selected for the monitoring program since 2001 have always been the same. Additionally, new wells have been constructed and sampled in full cooperation with the local authorities.

Figure 191: **Sampling of groundwater in Gaza.**

For the first time, 50 samples were collected from the Al Mawasi area, because this area had been under Israeli occupations since 2005. A third sampling campaign was conducted in March/April 2012. Due to a delay during shipment and subsequent extended storage without cooling, the results of these groundwater samples are not considered and rejected.

7.3.4.2 Results

The results of the anion and cation analysis revealed no major changes between the results of the year 2010 and the previous years (see e.g., Figure 192). More than 90 % of the groundwater wells are not suitable for drinking purposes because of high concentrations of NO^{3-}, Cl^-, and F^-, and some trace metals which exceed the WHO standards by a factor of 2-7. Some wells have a permissible concentration of NO_3^-, but high amounts of Cl^- or F^-, and vice versa. Trace elements in the groundwater generally do not pose any health or environmental hazard in the Gaza Strip. Private wells exposed to contamination sources of solid waste dumping sites, wastewater, and manure disposal sites showed high concentrations of Zn, Pb, As, and Cd.

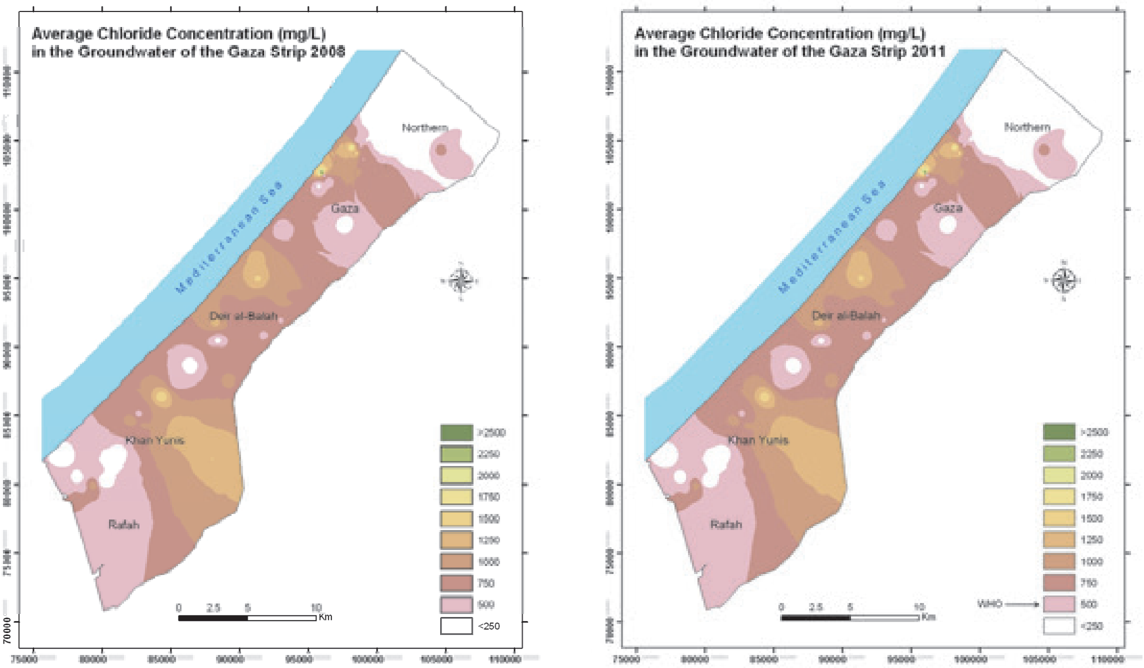


Figure 192: Average chloride concentration in the groundwater of the Gaza Strip in 2008 (left) and 2011 (right). (Areas marked in white show either areas which are not determined so far or the data were under the detection limit).

Similar results were obtained for the anion concentration of 50 groundwater wells in the Al Mawasi area. At least one parameter of Cl^-, NO_3^-, F^- or SO_4^{2-} exceeds the WHO standards. Only 5 wells are below the WHO standards (WHO, 1998) (see Figure 193).

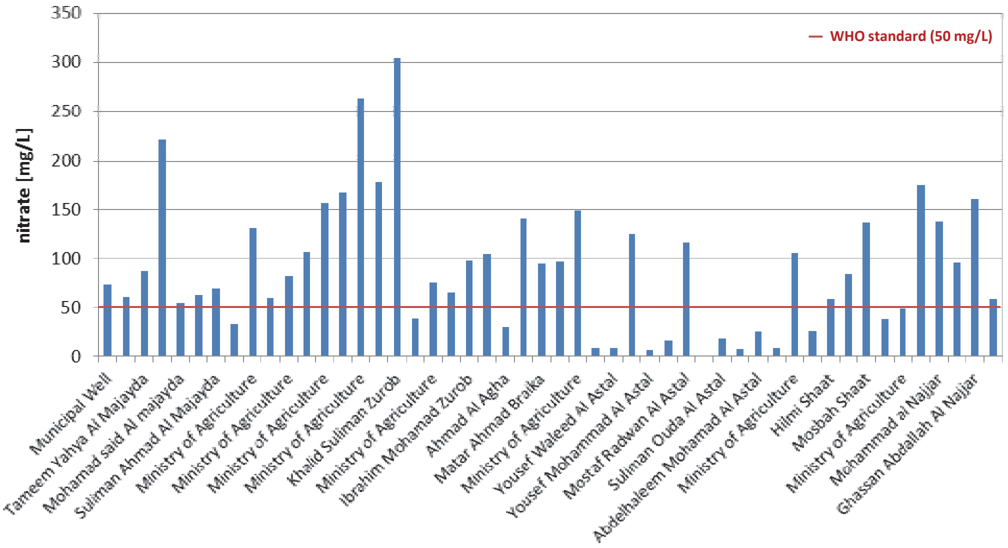


Figure 193: Nitrate concentrations in groundwater wells in the Al Mawasi area in January 2011.

7.4 Investigation of Treated Wastewater and Sludge in Gaza

7.4.1 Introduction

Lack of wastewater management has a direct impact on public health, marine and coastal pollution, deterioration of nature and biodiversity, as well as landscape and aesthetic distortion in the Gaza Strip. About 60 to 80 % of the domestic wastewater is discharged into the environment without treatment, either directly at the source after collection from cesspits or through the effluent of the sewer system or overloaded treatment plants. Approximately 40 % of the wastewater that is generated in Gaza is currently discharged into the sea and a minor part infiltrates into the soil and contaminates the groundwater (Shomar et al., 2004b).

Up to now, there has been very little production of sludge, as all existing wastewater treatment plants in Gaza are deficient and operate with old technologies. Furthermore, sludge treatment facilities are frequently lacking. For this reason, the sludge is removed from the ponds and left for drying close to the treatment plant, depending on the season and the available area (PWA, 1999).

7.4.2 Sampling campaign

Until March 2014 two wastewater treatment plants are operating, while another two wastewater treatment plants are planned or under construction (Stulz-Planaqua). The operating plants are the Beit Lahia wastewater treatment plant in the northern part of the Gaza Strip and the Gaza wastewater treatment plant in the region of Gaza city, but none is working properly (Figure 194).

Figure 194: Gaza wastewater treatment plant: Left – aerobic pond; right – sludge holding pond/drying lagoon.

The wastewater monitoring program of the two treatment plants is executed by the Palestinian Water Authority and only a few parameters like pH, solids, BOD, and COD are recorded on a regular basis.

Wastewater, sludge, and soil samples were collected from the Gaza and Beit Lahia wastewater treatment plants for analysis of heavy metal and anion concentrations (Figure 195). This study was aimed at checking the performance of the wastewater treatment plants by comparing the heavy metal contents of the influent and effluent with the heavy metal contents from earlier studies made about 10 years ago as well as with the heavy metal concentration in sludge and soil samples collected around the wastewater treatment plants. Furthermore, the results were compared with standard values, if the samples collected were suited for reuse experiments as alternative irrigation and fertilizer resource.

Figure 195: Collection of sludge, soil, and wastewater samples in September 2012.

7.4.3 Results

Table 66 presents the current heavy metal and arsenic contents of the influent and effluent of the Gaza and Beit Lahia wastewater treatment plants in comparison with heavy metal concentrations from earlier studies of 2000, 2001, and 2002 (Shomar et al., 2004b).

Regarding the heavy metal contents in general, most influent concentrations of both wastewater treatment plants in 2012 are lower compared to earlier measurements. This is probably related to a decline of the industrial sector in Gaza over the last ten years. The performance of the Beit Lahia wastewater treatment plant seems to be good. A heavy metal decrease from influent to effluent was observed for most of the heavy metals, expect for Cu and Pb. While the current concentrations of Ag, As, Cd, Co, Ni, and Pb are below the detection limit (< 1 to 10 µg/L) in the influent and effluent of the Gaza wastewater treatment plant, the concentrations of Al, Cr, Cu, Mn, and Zn in the effluent are higher than in the influent. This suggests that the removal of these heavy metals might not be working well compared to the measurements of 2000, 2001, and 2002, where these heavy metals showed a decrease from influent to effluent, except for Al in 2002. Presumably, these elements are dissolved from the sludge, which leads to an increase of their concentrations in the effluent.

Despite some irregularities regarding the performance of the Gaza wastewater treatment plant, however, both effluents have good heavy metal characteristics close to the guidelines and standards of many developed countries and are recommended for irrigation in agriculture.

The heavy metal and arsenic concentrations in the sludge samples of each pond predominantly are in similar concentration ranges for each measured element, with some fluctuations (Table 67). In addition, there are no significant differences between the two wastewater treatment plants. The lowest heavy metal concentrations are measured in the sludge samples of the anaerobic pond of the Beit Lahia wastewater treatment plant. As all samples were taken only once, another sampling campaign should be performed to guarantee that the anaerobic pond works well. However, the heavy metal concentrations are below the limit values (AbfKlärV, 15.04.1992). Hence, the sludge might be used as alternative fertilizer in reuse experiments. The mobility of heavy metals for potential plant uptake and the accumulation in the soil should be monitored and recorded.

Table 66: Heavy metal and arsenic concentrations in the influent and effluent of the Gaza and Beit Lahia wastewater treatment plants.

	2000*		2001*		2002*		2012	
	influent	effluent	influent	effluent	influent	effluent	influent	effluent
Gaza wastewater treatment plant								
Ag [µg/L]	0.8	0.8	n.m.	n.m.	0.7	1	< 5	< 5
Al [µg/L]	71	61	n.m.	n.m.	89	278	< 10	60
As [µg/L]	6.6	7	0.4	1.1	7.8	8.4	< 10	< 10
Cd [µg/L]	0.5	< 0.5	0.1	0.1	0.5	< 0.5	< 1	< 1
Co [µg/L]	0.4	0.7	n.m.	n.m.	0.5	0.9	< 5	< 5
Cr [µg/L]	11.3	4.8	7.0	2.6	11.3	5.9	5.72	6.96
Cu [µg/L]	7	7	4.3	3.2	6.9	7.5	2.25	3.11
Fe [µg/L]	137	132	163	121	198	202	83.5	83.7
Mn [µg/L]	76	68	303	103	70	52	41.1	71.1
Ni [µg/L]	5.5	6.8	n.m.	n.m.	5.4	7.1	< 5	< 5
Pb [µg/L]	2.6	2.6	2.5	< 2.5	3.3	< 2.5	< 5	< 5
Zn [µg/L]	75	54	61	41	92	56	34.1	61.4
Beit Lahia wastewater treatment plant								
Ag [µg/L]	0.7	0.6	n.m.	n.m.	7.3	1.3	< 5	< 5
Al [µg/L]	73	39	n.m.	n.m.	138	44	69.3	67.8
As [µg/L]	5.6	5.1	0.7	0.6	5.5	5.4	<10	<10
Cd [µg/L]	< 0.5	0.8	0.1	< 0.5	< 0.5	1.3	< 1	< 1
Co [µg/L]	0.3	0.8	n.m.	n.m.	0.6	0.8	< 5	< 5
Cr [µg/L]	38.9	7.6	25.3	2.9	25.2	8.4	7.33	3.83
Cu [µg/L]	6	6.7	2.5	2.7	8.5	5.1	7.96	17.8
Fe [µg/L]	373	114	344	76	356	347	167	114
Mn [µg/L]	120	96	116	47	142	139	71.2	70.5
Ni [µg/L]	21.9	11.8	n.m.	n.m.	13.1	12.1	< 5	< 5
Pb [µg/L]	2.6	< 2.5	2.9	< 2.5	2.7	< 2.5	< 5	6.37
Zn [µg/L]	120	35	105	29	87	59	110	69.6

n.m. = not measured; * (Shomar et al., 2004b)

Table 67: Average heavy metal concentrations in sludge samples from the Gaza wastewater treatment plant.

	2000	2001	2002	2012
Gaza wastewater treatment plant				
As [mg/kg]	18.2	21.2	4.1	7.4
Cd [mg/kg]	0.9	1.3	1.8	0.9
Co [mg/kg]	4.1	5.3	2.5	5.8
Cr [mg/kg]	50	82	93	98.2
Cu [mg/kg]	110	251	276	185.0
Mn [mg/kg]	206	235	244	158.5
Ni [mg/kg]	24	25	25	19.5
Pb [mg/kg]	49	121	140	82.3
Zn [mg/kg]	897	1,909	2,281	983.8

The soil samples were collected near the plant influent and effluent of both plants and, in addition, near the sludge drying beds of the Gaza wastewater treatment plant and near infiltration into the ground at the Beit Lahia wastewater treatment plant. Compared to the sludge samples, the heavy metal and arsenic concentrations of the soil samples are low. Consequently, the area around the wastewater treatment plants does not seem to be influenced by the plant activities and exhibits the normal topsoil composition (Shomar et al., 2005a).

7.5 Reuse Experiments in the West Bank

7.5.1 Background

In various districts in the Palestinian Territories (PTs), farmers are forced to use marginal-quality water, often because they have no alternative; PTs suffer from a severe scarcity of freshwater. The available resources include reclaimed wastewater from urban and peri-urban areas, saline and sodic agricultural drainage water, and groundwater.

Around cities in developing countries, farmers use wastewater from residential, commercial, and industrial sources, sometimes diluted, but often without any treatment at all.

Reclaimed wastewater contains considerable amounts of nutrients, mainly N and P, which can substitute proportional quantities of mineral fertilizers. However, reclaimed wastewater often contains a variety of pollutants, such as salts, metals, metalloids, pathogens, residual drugs, organic compounds, endocrine disruptor compounds, and active residues of personal care products. Furthermore, farmers may suffer harmful health effects from contact with wastewater, while consumers are at risk from eating vegetables and cereals irrigated with wastewater. Accordingly, application of wastewater has to be managed carefully for effective use. In the PTs, several wastewater treatment plants are in the planning stage, while only one central treatment plant already is in service at Al-Bireh, West Bank. These wastewater treatment plants will produce considerable quantities of treated wastewater that must be managed in a sound way from both the economic and the environmental points of view. However, research related to the use of wastewater for irrigation and its impacts in Palestine is rather limited. Accordingly, the purpose of this study was to investigate the suitability of wastewater produced by the Al-Bireh wastewater treatment plant for irrigation of corn as a partial substitution of mineral fertilizers (Amer, 2012) Additionally, sludge produced by the Al-Bireh wastewater treatment plant was used as alternative fertilizer resource.

7.5.2 Study area

The reuse experiments were conducted at the new Campus of Birzeit University (Figure 196). It is located 26 km northwest of Jerusalem and is characterized by a mild climate, as it is located at an altitude of 770 m above sea level.

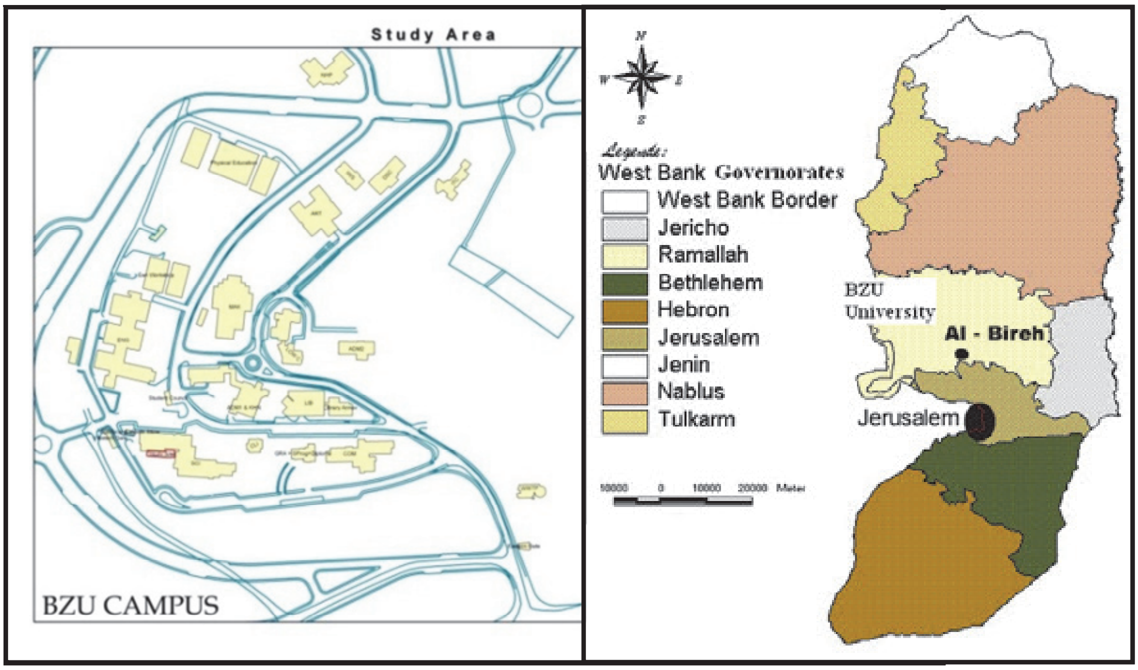


Figure 196: Base map of the West Bank and the approximate location of Birzeit University (Amer, 2012).

7.5.3 Construction and preparation of the greenhouse

The Civil Engineering department and the administration of the University agreed to build a greenhouse and to use an open area of 200 m^2 for the experiments for a period of two years (Figure 197). The greenhouse was cleaned and maintenance activities were performed before running the experiments. The area of the greenhouse is 75 m^2, it is 5 m wide and 15 m long. It was kept clean from all weeds and a pest control program was employed to control insects and fungi for a long time before the reuse project.

Figure 197: Greenhouse at Birzeit University, Palestine.

7.5.4 Setup of Reuse Experiments

Treatments

The reuse experiments were conducted to study the impact of wastewater, mineral fertilizers, and sludge on corn and tomato plants. The plants were grown with different replicates and were irrigated with wastewater or freshwater as control. Additionally, the plants were fertilized systematically with complete or partial amounts of mineral fertilizer or sludge (5 %, 25 %, and 50 %).

Soil: Transport and Application

The soil used in the projects was from the local agricultural areas of Qalqilia, north of the West Bank, an area, in which corn is produced commercially. It was applied for corn and tomatoes in all reuse experiments. To characterize the soil texture, the grain size was determined based on international definitions.

Plantation

The experiments were carried out using 45 L plastic pots made of plastics (PE), which are used widely by Palestinian farmers (see Figure 198). According to the local experience and market availability, corn seeds were obtained from a certified source, namely, the SYNGENTA company. This company is said to sell good-quality corn seeds. The seeds were planted and subjected to the standard cultivation procedures as regards pest management.

Figure 198: left - soil transportation; right - preparation of plastic pots.

Fresh water and Treated Wastewater

Freshwater was the tap water of Birzeit University and it was used for irrigation using the procedures explained below.

The source of wastewater was treated wastewater from the Al-Bireh wastewater treatment plant. This plant receives its sewage from Al-Bireh City. The Al-Bireh wastewater treatment plant is located 2 km east of the city in Wadi El-Ein and covers an area of 22,000 m^2, including an area reserved for later extension. The treatment system is based on extended aeration. The process comprises a mechanical treatment, followed by extended aeration with simultaneous aerobic sludge stabilization and sludge drying by a filter press. The water used for irrigation was transported and stored in barrels of 1 m^3 in size.

Fertilizer

a) Mineral Fertilizer

The mineral fertilizer known as NPK 13-13-13 is certified and bought from local markets with the following chemical structure: Total N: 13 %; P2O5: 13 %; K2O - 13 %;

Micronutrients: Fe: 500 ppm; Mn: 250 ppm; Zn: 75 ppm; Cu: 55 ppm; Mo: 35 ppm.

b) Sludge

The sludge was obtained from the Al-Bireh wastewater treatment plant with secondary treatment quality (activated sludge system).

Table 68: Results of sludge used for fertilization.

Parameter		Sludge	Limit*
Cd	[mg/kg]	0.9	10
Co	[mg/kg]	3.8	
Cr	[mg/kg]	27.7	900
Cu	[mg/kg]	201.2	800
Hg	[mg/kg]	2.1	8
Mn	[mg/kg]	121.9	
Ni	[mg/kg]	16.1	200
Pb	[mg/kg]	23.3	900
Zn	[mg/kg]	1080.3	2500

* sewage sludge regulation (AbfKlärV, Germany)(AbfKlärV, 15.04.1992)

Figure 199: left - storage of treated wastewater used for irrigation; right – application of mineral fertilizer.

Experiment One by Ahmad Sameeh Amer (M.Sc. Student)

"Reuse of reclaimed wastewater to irrigate corns designated for animal feeding." (Amer, 2012)

The first reuse experiment was designed to target the following objectives:

- Study of the physico-chemical characteristics of all components used in this reuse project, including treated wastewater, freshwater, soil, mineral fertilizer, and corn seeds.
- Identifying the impact of treated wastewater on plant morphology, growth rate, and number of leaves, fruits, appearance, and chlorophyll contents.
- Tracking the transport of some parameters from the source to the outputs, including the chemo-dynamics of some toxic elements within the food chain.

Figure 200: Experiment one - field measurements and sample preparation.

Experiment Two by Samya Sehweil (M.Sc. Student)

"Wastewater and sludge reuse for corn production and the impact on morphology, protein contents, and gene expression."

The second reuse experiment targeted the following objectives:

- Studying the possibility of using treated wastewater of the Al-Bireh wastewater treatment plant for corn irrigation.
- Using the final product of wastewater treatment (sludge) as alternative fertilizer material.
- Investigating the soil quality before plantation and after the experiment in order to study the effect of reclaimed wastewater and sludge for agricultural purposes.

Figure 201: Experiment two - growth steps of corn plants.

Experiment Three by Muhannad Al Khatib (M.Sc. Student)

"Wastewater reuse for tomatoes production and the impact on morphology, chemistry, and gene expression."

Figure 202: Experiment three – growth steps of tomatoes.

The experiment was conducted to reach the following objectives:

- Studying the physico-chemical characteristics of all components used in this reuse experiment, including treated wastewater, freshwater, soil, mineral fertilizer, and seeds.
- Tracking the transport of toxic elements from source to output by analyzing all plant parts.
- Studying the impact of the reuse experiment on protein and nutrient contents of the produced tomatoes with emphasis on total protein, phosphorus, and nitrogen contents.
- Investigating the impact of treated wastewater reuse on plant genotoxicity through the identification of the gene structure of the original Processing Tomatoes Trans-Plants (PTTP), before application of treated wastewater, after plantation, and after harvesting.

Experiment Four by Birzeit University

"Impact of fertilization with treated wastewater and sludge on maize plants."

The final reuse experiment was aimed at reaching the following objectives:

- Studying the physico-chemical characteristics of all components used in the reuse project, including freshwater, wastewater, soil, mineral fertilizer, and sludge, and their impact on maize plants.

- Identifying the impact of treated wastewater on plant morphology, growth rate, number of leaves and fruits, appearance, and chlorophyll contents.
- Studying the impact of heavy metal soil pollution under the effect of various sludge levels.
- Investigating the mobility of heavy metals and possible plant uptake by conducting sequential extractions of soil samples "after harvesting".
- Comparing the heavy metal concentrations from sequential extractions with standard guidelines.

Figure 203: Experiment four – pots before and after plantation.

7.5.5 Results

During the growth process, daily monitoring was performed according to international rules and protocols. Several parameters related to plant morphology were obtained from each experiment, including plant height, growth rate, number of leaves and fruits. After harvesting, samples were taken from roots, stems, leaves, and fruits for analysis of heavy metal contents. Additionally, soil samples were taken from each pot before plantation and after harvesting.

The following results are obtained and conclusions can be drawn from the reuse experiments:

- Treated wastewater taken from the effluent of the Al-Bireh wastewater treatment plant was safe when used for irrigation and does not cause any significant heavy metal pollution to soils.
- No obvious heavy metal uptake in fruits was observed due to the treatment with treated wastewater, mineral fertilizer, and sludge.
- Concentrations of Ag, As, Cd, Co, Cr, Ni, and Pb in fruits were below the detection limit.
- Treated wastewater and the addition of mineral fertilizer stimulated the synthesis of chlorophyll and proline in corn leaves.
- The morphology of corn is highly affected by fertigation with treated wastewater and mineral fertilizer and the experimental work showed that the major growth parameters of corn (e.g., height, number of leaves, weight of cobs, etc.) were almost doubled compared to the plants irrigated with freshwater.
- The increase in the proline content found in plants treated with fertilizer is a symptom of stress. However, the low salinity of soil, tap water, and wastewater used for irrigation as well as low concentrations of heavy metals in wastewater did not influence proline accumulation in corn leaves.

- Elevated concentrations of chlorophyll were observed in the leaves of the plants irrigated with treated wastewater and mineral fertilizer in case of a high nitrogen content that might be the factor limiting the chlorophyll composition.
- As regards health problems, the drip irrigation systems led to a minimum contact between the treated wastewater used for irrigation and the aerial parts of the corn plants → total and fecal coliforms were not detected in the harvested cobs, although high coliforms were present in the treated wastewater.
- A positive and significant relation between the applied sludge levels and the Mn and Zn concentrations of leave dry matter was found.
- Sludge supplementation increased the heavy metal concentration in soils.
- The use of sludge as alternative fertilizer had a positive effect on plant growth and fruit number.

→ Treated wastewater should be considered an important resource of water to be used for irrigation alternatively to freshwater.

→ Sludge supplementation increased the heavy metal concentration in soil, but can also be used as alternative fertilizer.

Sequential extractions

The mobility of heavy metals in soils and sediments depends on their chemical form and on how they are integrated into the soils and sediments (Peula-López, 1995). The BCR scheme (Ure et al., 1993) (BCR, European Community Bureau of References, today European Standards, Measurements and Testing Program, SM&T) is a standardized method for the specification of Cd, Cr, Cu, Co, Mn, Ni, Pb, and Zn in sediments and soils. A small sample is successively shaken with different extraction solutions, which are specified for certain phases (Figure 204). As a result, the heavy metals are released from these phases or together with the phases and are then quantified. Ideally, each extraction step simulates changes in soil or sediment, which may occur naturally.

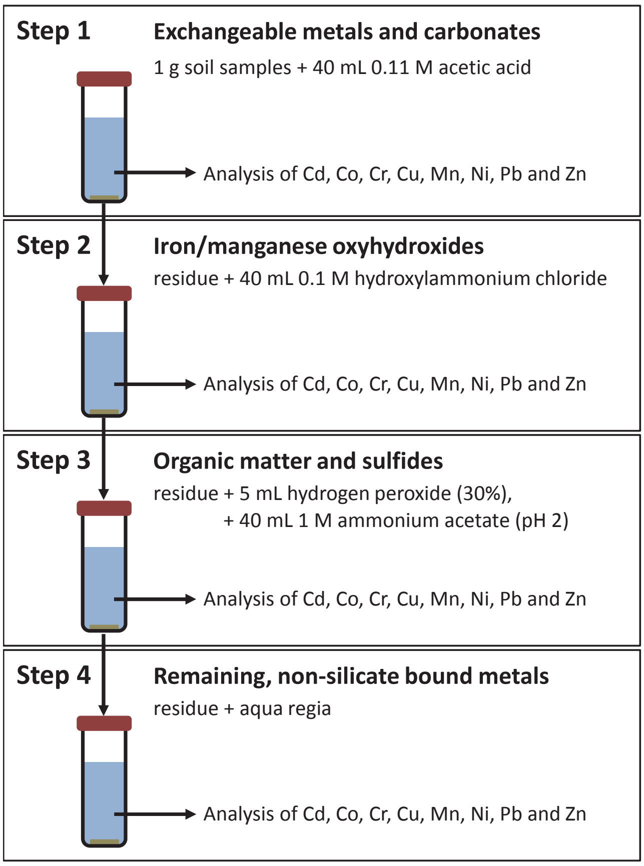


Figure 204: BRC scheme (Ure et al., 1993).

The sequential extractions were carried out with the soil samples “after harvesting” and the sludge of Experiment four. The samples were subjected to the following treatments:

T1 → No mineral fertilizer, irrigation with freshwater (control).
T2 → Complete mineral fertilization, irrigation with freshwater.
T3 → No mineral fertilizer, irrigation with treated wastewater.
T4 → Partial mineral fertilization, irrigation with treated wastewater.
T5 → Complete mineral fertilization, irrigation with treated wastewater.
T6 → 5 % sludge (w/w), irrigation with freshwater.
T7 → 25 % sludge (w/w), irrigation with freshwater.
T8 → 50 % sludge (w/w), irrigation with freshwater.
T9 → 5 % sludge (w/w), irrigation with treated wastewater.
T10 → 25 % sludge (w/w), irrigation with treated wastewater.
T11 → 50 % sludge (w/w), irrigation with treated wastewater.

Results of the Sequential Extractions

The sequential extractions showed highest heavy metal concentrations in Step 4, i.e. in the remaining and non-silicate bound metals which are hardly mobilized for plant uptake. The highest amounts of Co and Mn were measured in Step 2, the iron/manganese oxyhydroxides phase. Apart from Mn and Zn, no further organically or sulfide-bound metal was detected in Step 3. Step 1 comprises heavy metals which are exchangeable metals, including sulfates, carbonates, and phosphates. Hence, this group includes heavy metals which most likely might be absorbed by plants.

Cd, Co, Cr, and Pb were below the detection limit in Step 1, which is also reflected by the results of the corn cobs (< 2.5 mg/kg). Figure 205 presents the Ni concentrations extracted in Step 1, the exchangeable metals and carbonate phase. Here, the irrigation with treated wastewater and fertilization with mineral fertilizer seem to have no obvious influence on the Ni concentration in the soil samples "after harvesting" compared to the control (T1).

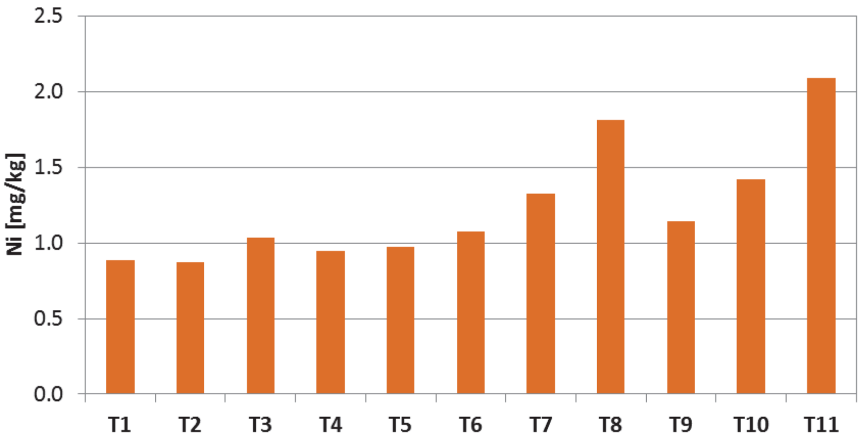


Figure 205: Ni concentrations extracted from soil samples "after harvesting" in Step 1.

With increasing sludge addition, Ni concentrations increased. In experiments T9 to T11 samples treated with wastewater and sludge showed higher Ni concentrations than samples in experiments T6 to T8, which were treated with freshwater and sludge. Despite an obvious influence of the sludge treatments on the Ni concentrations in Step 1, all Ni concentrations determined in the corn cobs were below the detection limit of 2.5 mg/kg.

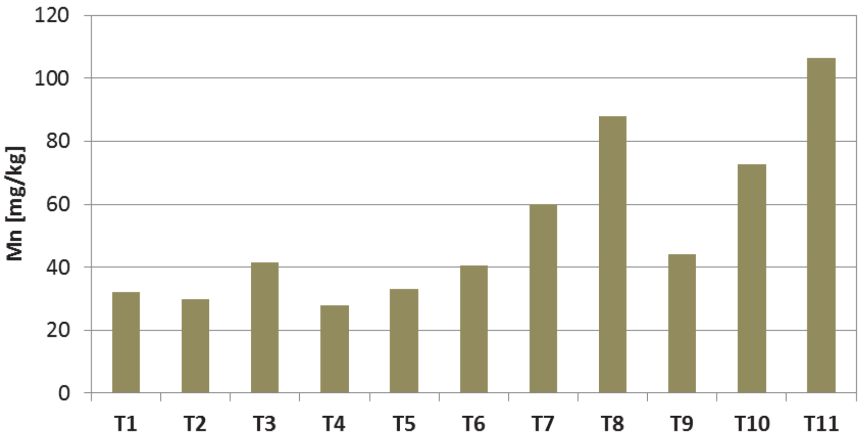


Figure 206: Mn concentrations extracted from soil samples "after harvesting" in Step 1.

Regarding the Mn concentrations extracted in Step 1, experiment T3 showed a small increase, which reflects an influence of irrigation with treated wastewater (Figure 206). The addition of sludge produced an increase of Mn concentration, whereas higher Mn concentrations were measured in the experiments T9 to T11, in which samples were treated with wastewater and sludge.

An influence on the Mn concentrations in corn cobs was observed only in corn cob samples treated with 50 % sludge (Figure 207). Here, a slight increase of the Mn concentrations of the corn cobs from treatments T8 and T11 was observed.

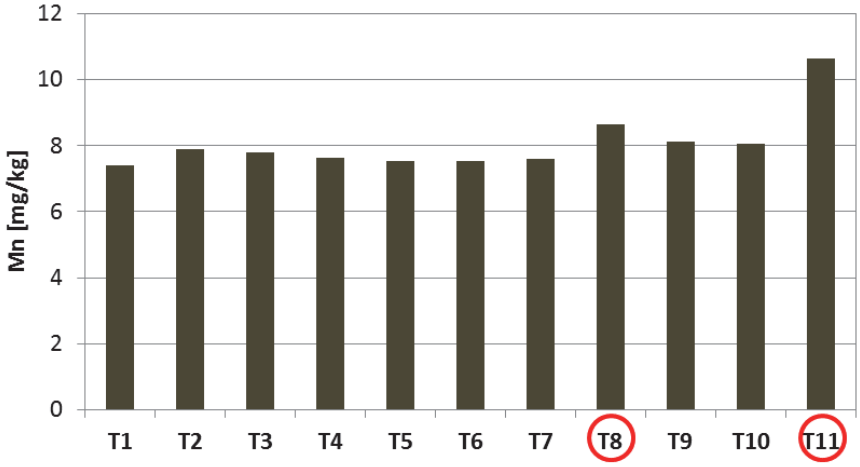


Figure 207: Mn concentrations in corn cobs “after harvesting”.

The measurements of Cu extracted in Step 1 showed a small increase in treatments T8 (0.27 mg/kg) and T11 (0.32 mg/kg) with 50 % sludge addition. A higher Cu concentration was measured in sample T11 that was treated with wastewater and sludge. The other investigated soil samples were below the detection limit of 0.25 mg/kg. An influence of the Cu concentrations of the sludge and wastewater on the Cu concentrations in corn cobs was not observed. The soil samples treated with sludge (T6 to T11) showed an increase of Zn concentrations in Step 1 (Figure 208). The treatments T2 to T5 did not reveal any obvious influence of irrigation with treated wastewater and mineral fertilizer on Zn concentrations.

Despite varying Zn concentrations in the soil samples “after harvesting”, no obvious changes were observed in the corn cobs treated with wastewater, mineral fertilizer, and sludge compared to the control T1. Only a slight increase was observed in corn cob samples T8 and T11 treated with 50 % sludge.

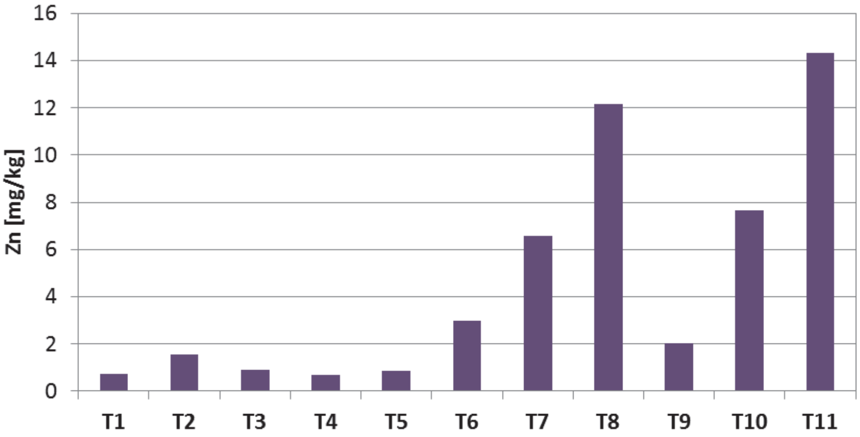


Figure 208: Zn concentrations extracted from soil samples “after harvesting” in Step 1.

7.5.6 Summary

In summary, the results of the sequential extractions showed that most of the measured heavy metals are remaining. Non-silicate bound metals are hardly mobilized for plant uptake. It is expected that exchangeable metals and carbonates which are extracted in Step 1 are easily mobilized and absorbed by plants. This is also reflected by the results obtained. Heavy metals which are not extracted in Step 1 are not detected in corn cobs. Soils treated with 50 % sludge seem to influence most corn cobs, as higher heavy metal concentrations are measured in corn cobs after treatments T8 and T11.

However, even if the used soils were influenced by the different treatments with wastewater and sludge, the heavy metal concentrations in soil samples “after harvesting” still allow for agricultural production. No guidance and limit values were exceeded in spite of the different treatments. Although the total Co values for treatments T3, T4, and T6 to T11 were above the upper limit value (Kloke-Liste, 1980), the Co concentrations of corn cobs were not influenced. Here, these Co concentrations were below the detection limit.

7.6 Capacity Building

7.6.1 Workshops in Gaza City

Held by Dr. Ahmed Mughari (Environmental analytical methodology expert) and Dr. Abed el Majeed Nassar (lecture)

Workshop in July 2012: “Reed beds in water and sludge treatment”.

- Aim: Training the participants through lecturing about the use of reed beds in water and sludge treatment, especially for reuse purposes.
- Participants: 26 students from different geographic areas of the Gaza Strip → most of the students are specialized in environmental engineering and environmental sciences.
- According to a general discussion of important recommendations and major needs for further training and workshops, the following issues were found to be of particular interest to the participants:

- Practical training on environmental analytical methodology.
- Desalination technologies for water treatment (i.e. nanofiltration).
- Pesticide pollution of groundwater.
- Roof using in water harvesting and planting.
- Heavy metals in water.
- Water quality management.

Workshop in December 2012: "Secondary treated wastewater for agricultural reuse" (Figure 209, left)

Workshop in January 2013: "Reed beds in water and sludge treatment" (Figure 209, right)

Figure 209: Workshop "Reed beds in water and sludge treatment" in Gaza City, Palestine.

7.6.2 Lab Training in Gaza by Dr. Ahmed Mughari

"Analysis of water and soil"

Figure 210: Lab training.

Training: Sampling campaign

Training of collecting soil, sludge, sediment, and water samples at the Gaza and Beit Lahia wastewater treatment plants in September 2012.

Figure 211: Collection of samples at and around wastewater treatment plants.

7.6.3 Exchange of scientists between Gaza and Heidelberg

- 2010: Visit of Dr. Ahmed Mughari to Heidelberg for 2 months: Lab training in analysis.

- 2010: Visit of Raghid Nidal Sabri and Kamal Zurba: Practical training in collecting samples from wastewater treatment plants and lab training for 2 months → both are now PhD students at the University of Freiberg.

Figure 212: Collection of wastewater and sludge samples from a wastewater treatment plant in Bammental/Germany.

November 2012: Visit of Dr. Ahmed Mughari to Heidelberg: Participation in the SMART Meeting in Karlsruhe and IWRM (Integrated Water Resource Management) conference in Karlsruhe.

May/June 2013: Visit of Dr. Alfred Yahya to Cairo/Egypt and Gaza/Palestine: Meetings and discussions with Gaza partners.

8 SUMMARY

Author: H. Hötzl

After eight years of a very constructive cooperation with the partners from Israel, Jordan and Palestine the SMART consortium can look back proudly on very successful results regarding the adoption of the IWRM concepts in the target-oriented regional planning in the Lower Jordan Rift system. The manifold requirements of a sustainable water management were taken not only with respect to the availability of the resources but also with regard to the socio-economic conditions in order to satisfy the demands of the diverging groups of the society. The reorganization from a sectoral projection to an integrated approach of water development needs longtime. Within SMART new scientific models for sub- catchments could be developed, which improved the entire understanding of regional water systems and the connected land use, which can solve and secure locally the water situation. These concepts can be transferred step by step to the whole region. On the base of the strong connection with the governments and stakeholders certain elements of the new concepts are already integrated in the current state water programs like the approaches for groundwater protection in Palestine or the conversion of the main IWRM concepts in the new water strategy plan for Jordan. In addition improved technologies, like the decentralized wastewater treatment or the desalinization of brackish water, could be adapted, tested in pilot and demonstration plants and partially are now already implemented locally. The large involvement of all responsible groups starting from the government with the appropriate ministries, the water and environmental authorities, stakeholders and local consultants and companies together with the scientists from universities and other scientific organizations finally formed a huge corporation which initiated and supported the rethinking of the previous reckless water utilization. This was in addition supported by a gradual capacity development program beginning with specific water curricula for pupils in school, including training programs for technicians or specific scientific programs for PhD students. We are proud that many of our former students now in important positions of the water domain in their country. Last not least the close cooperation between the partners from different countries of this political instable region confirmed that water resources are not restricted to political boundaries, but needs the joint efforts from all riparian owners. Such a fruitful cooperation as was demonstrated in the SMART Project between all partners could contribute to a peaceful understanding between the involved countries.

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9.1.4 SMART at the IWRM Conferences: Dresden 2011

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9.1.5 Doctoral Theses

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Laster, Y. (2010): Transborder Water Governance: Investigating New Tools for Conflict Management, Hebrew University.

Nivala, Jaime (2013): Effect of design on treatment performance, plant nutrition and clogging in subsurface flow treatment wetlands.

Riepl, D. (2012): Knowledge-Based Decision Support for Integrated Water Resources Management with an application for Wadi Shueib, Jordan. Dissertation at the Department of Civil Engineering, Geo and Environmental Sciences - Karlsruhe Institute of Technology (KIT), 241 p.

Sahawneh, J. (2010): Structural control of Hydrology, Hydrogeology and Hydrochemistry along the eastern escarpment of the Jordan Rift Valley.

Samhan, S.: Preliminary Title: Tracing The Fate And Transport Of Bio-Contaminates And Organics due to wastewater effluent in Al-Qilt catchments

Schmidt, Sebastian (2014): Hydrogeological characterisation of karst aquifers in semi-arid environments at the catchment scale – Example of the Western Lower Jordan Valley. Dissertation at the Chair of Applied Geology, University of Göttingen, 116 p.

Shatnawi, N. (2014): Assessment and Mapping of Groundwater Potential Zones in the Lower Jordan Valley Using Remote Sensing Approach, PhD at theInstitut für Photogrammetrie und Fernerkundung (IPF), Karlsruhe Institute of Technology

Sorge, S.: preliminary title: Operational and financial models for decentralized wastewater treatment plants in the Lower Jordan Valley.

Toll, M. (2007): An integrated approach for the investigation of unconsolidated aquifers in a brackish environment – A case study on the Jordanian side of the lower Jordan Valley. Dissertation at the Chair of Applied Geology, University of Göttingen, 222 p.

9.1.5.2 PhD thesis in progress

Abdallat, Ghida: The fate of nitrogen and E. coli in vertical flow wetlands (VFWs) and subsurface irrigation areas used for decentralized wastewater treatment and reuse.

Ghanem, Issam: Using solar driven evaporation as an integrated method for increasing the efficiency of desalination plants

Grimmeisen, Felix: Groundwater protection in karstic aquifers influenced by urban areas in semi-arid regions

Leicht, Miriam: Preliminary: Correlation of water quality and agronomic risks and benefits for irrigated agriculture in Jordan

Mahmou, Ayman Ameen: Preliminary: Groundwater modeling and IWRM of Uja-Jericho area

Momani, Thair: Potential of Managed groundwater recharge in the lower Jordan valley and its side wadis

Mussalam Shadha: Thema von Prof. Sauter noch definiert aber im Bereich Mikroorganismen

Navon, Hila: Preliminary: Hydrogeology and hydrochemistry of brackish water occurrence

Ries, Fabian: Preliminary title: Water balance of karst aquifers

Sagiv, Yair: Treatment, storage, transportation and Optimal Use for Diverse and Unrestricted Purposes Treatment and Reuse

Wilske, Cornelia: Preliminary title: Application of a combined REE, stable isotopes and organic components approach to evaluate the groundwater flow system between Jerusalem/Ramallah and the Dead Sea

Xanke, Julian: Managed Aquifer Recharge at the Wala Dam, Jordan

9.1.5.3 PhD thesis not funded by SMART program, but related to the SMART project

Abueladas, A: Proposed geophysical methods for hydrogeological exploration at the lower Jordan Valley, Al-Balqa Applied University

Alfaro, Paulina: preliminary title: IWRM approach for Wadi Shueib

Zemann, Moritz: preliminary title: potential for accumulation of pharmaceutical in arid environment

9.1.5.4 Bachelor-, Master and Diplomthesis in SMART I and II Project

Bastian, D. (2008): Groundwater vulnerability mapping in the eastern aquifer basin of the West Bank. Diploma Thesis at the Geological Institute, University of Karlsruhe (TH), 86 p.

Gabi, M. (2012): Assessment of suitable test sites for artificial groundwater recharge in the Lower Jordan Valley; Institut für Angewandte Geowissenschaften, Abteilung Hydrogeologie, Karlsruher Institut für Technologie (KIT)

Huttenlocher, L. (2012): Entwicklung und Beurteilung der Hydrochemie im Jordantal und im Wadi Shueib, Jordanien, Institut für Angewandte Geowissenschaften, Abteilung Hydrogeologie, Karlsruher Institut für Technologie (KIT)

Leicht, M. (2008): Numerical groundwater modeling of the Wadi Shueib Dam and the downstream alluvial aquifer to support water management decisions in the Lower Jordan Valley, Jordan. Diploma Thesis at the Geological Institute, University of Karlsruhe (TH), 118 p.

Modic, D. (2012): Application of a water evaluation and planning program for a planning exercise in an agricultural dominated area in the lower Jordan Valley, Institut für Angewandte Geowissenschaften, Abteilung Hydrogeologie, Karlsruher Institut für Technologie (KIT)

Mrinski, A. (2011): Comparison of techniques and methods for artificial recharge of groundwater in Australia, Israel and India; Institut für Angewandte Geowissenschaften, Abteilung Hydrogeologie, Karlsruher Institut für Technologie (KIT)

Pöschko, A. (2008): Long-term effects of treated /blended wastewater used for irrigation in agriculture on groundwater and soils in the Jordan Valley area, Jordan. Diploma Thesis at the Geological Institute, University of Karlsruhe (TH), 120 p.

Rapp, M. (2008): Evaluation of potential sites for managed aquifer recharge via surface infiltration in NW-Jordan. Diploma Thesis at the Geological Institute, University of Karlsruhe (TH), 99 p.

Roth, A. (2012): Variabilität der Wasserqualität des Karstgrundwasserleiters unterhalb des Wala-Stausees, Jordanien; Institut für Angewandte Geowissenschaften, Abteilung Hydrogeologie, Karlsruher Institut für Technologie (KIT)

Schneider, M. (2012): Quantifizierung von Abwassereinflüssen an der Hazzir-Quelle anhand hydrochemischer ParameterMasterarbeiten, Institut für Angewandte Geowissenschaften, Abteilung Hydrogeologie, Karlsruher Institut für Technologie (KIT)

Walter, M. (2012): Hydrogeologisches Konzeptmodell der Region Deir Alla, Jordanien, Institut für Angewandte Geowissenschaften, Abteilung Hydrogeologie, Karlsruher Institut für Technologie (KIT)

Xanke, J. (2010): Groundwater protection in Palestine, Diploma Thesis at the Geological Institute, University of Karlsruhe (TH), 94 p.

Zemann, M. (2008): Artificial recharge tests at an infiltration basin in the Wadi Kafrein, Jordan. Diploma Thesis at the Geological Institute, University of Karlsruhe (TH), 94 p.

Diploma thesis at Engler-Bunte-Institut

(2011): Einsatz von Antiscalants und induktiven Systemen zur Minimierung von Scaling bei der Filtration mit LPRO (Low Pressure Reverse Osmosis)

(2011): Ion Rejection properties of low pressure reverse osmosis (LPRO) membranes: comparison of experimental data with calculated data

(2012) Einfluss von Magnetfeldern auf die Bildung von Scaling bei der Filtration mit Niederdruckumkehrosmose und Nanofiltration Membranen

(2012): Einsatz von Magnetfeldern für die Minimierung von Scaling bei der Membranfiltration: Untersuchungen im kontinuierlichen Betrieb

9.1.6 Deliverables

The works and results of the main activities are documented in the project reports (so called deliverables). The list below represents the available reports of the respective workpackage (wp) that may be downloaded from the project homepage (www.iwrm-smart2.org).

WP2 - Data Base Management (Spokesmen: S. Geyer, UFZ)

Deliverable	Content	Editor
201	Maintenance and improvement reported in an updated handbook of DBMS (Note: Deliverable 201, 204 and 206 are summarized in one report: Handbooks SMART-Daisy and SMART-Webgis)	UFZ-G
202	Incorporation of SMART I datasets and continuous data acquisition (no report – this was a continuous process)	UFZ-G
203	Definition of exchange format protocols for the connection with SMART-DSS	UFZ-G
204	Improvement of DAISY data harvester in respect to data selection, output, presentation and export from DBMS	UFZ-G
206	WebGIS Thematic Map Generation	UFZ-G

WP3-1 - Technologies - Decentralised Wastewater Systems (Spokesmen: R. Müller (UFZ), B. Abassi (Balqa)

Deliverable	Content	Editor
301	Delivery of sites/Model Village with an existing sewer system for approx. 650 (three plants)	MWI
302	General Design of the wastewater treatment and reuse (WWT&R) units in the villages and/or suburban community	UFZ-U
303	Construction of the vertical soil filter WWT&R system for 250 pe. and six on-site systems (vertical soil filter, extended sludge) for 10-20 pe each.	NAW
304	Construction of the SBR-WWT&R system (250 pe.) and three SBR on- site –WWT&R systems (Note: 304 and 307 are compiled within one report)	ATB
305	Construction of the MBR-WWT&R system (150 pe.)	HUB, MWI
306	Report on the technical and economic evaluation of the WWT&R units	BALQ, ECO
307	Tested and approved remote control systems for WWT&R units that allows to detect and inform maintenance personnel about system failure and preventive information (Note: 304 and 307 are compiled within one report)	BALQ
308	Report on the potential of the an- aerob-reactor and sludge bed eco- technology for treating concentrated sludge fractions	UFZ-U
309	Optimized ecotechnology system (e.g. Recirculating Vertical Flow Filter) designed specifically to achieve the nitrogen removal targets of the Jordanian Effluent Reuse Guidelines	UFZ-U
310	Optimized financing and maintenance model for the implementation	BDZ, MWI

WP3-2 - Technologies - Managed Aquifer Recharge (Spokesmen: A. Tiehm (TZW), A. Marei (Quds)

Deliverable	Content	Editor
311	Identification of biodegradation processes contributing to emerging pollut- ant elimination (summary of D311/D315 & D317/D503)	TZW, HUB
312_1	Demonstration of artificial recharge of flash floods	QUDS
312_2	Impacts of Wala Reservoir stored Storm Waters on Wala-Haidan Well Field, Jordan	KIT
313	Demonstration of artificial recharge of treated wastewater (Beni Zaid, Palestinian Territories)	KIT, PHG
314	Demonstration of the efficiency of a capillarity break system for water harvesting	KIT-HAM
315	Assessment of water quality during soil infiltration, aquifer storage and recharge (included in D311/D315 & D317/D503)	TZW
316	Report on Operation of MBR/soil columns pilot plant at Fuheis test site	HUB
317	Water quality analysis in waste water and recharged groundwater (included in D311/D315 & D317/D503)	TZW
318	Identification of the most suitable areas for the implementation of groundwater artificial recharge (AR) in the LJV (Compiled with D320 including the eastern part of the Jordan River)	TAU, JUA, GU
318_2	Identification of the most suitable areas for the implementation of groundwater artificial recharge (AR) in the LJV (➔ Wadi Quilt and Bensaid, preliminary report, available), WESTERN PART	SUB MG
319	Economic assessment of artificial recharge (summary of D 319 + 327 + 705)	UFZ-Ö
320	Development, evaluation, comparison and ranking of AR-planning options (Compiled with D318 including the eastern part of the Jordan River)	GU

WP3-3 - Technologies - Brackish Water Usage (Spokesmen: A. Flexer (TAU), F. H. Frimmel (EBI)

Deliverable	Content	Editor
321_1	Inventory and characterization of avail- able brackish water resources in the study area - WESTERN PART	TAU
321_2	Inventory and characterization of avail- able brackish water resources in the study area - EASTERN PART	BALQ
322	Technology review addressing specific requirements of the LJV	EBI
323	Selection of a suitable brackish water desalination processes for the LJV	EBI, TAU
324	Report on potential sites for brackish water usage (eastern part is included inD328 and the status report)	BALQ, MEK
325	Demonstration of desalination combined with aquifer storage and recovery technology	EBI
326	Environmental impact assessment for desalination technologies	EBI,

	in the LJV	KIT
327	Cost analysis (summary of D 319 + 327 + 705)	UFZ-Ö
328	IWRM concept of regional deployment of desalination units	EBI, MWI

WP4 - Water Resources Assessment (Spokesmen: M. Sauter (GU), Y. Guttman (MEK)

Deliverable	Content	Editor
401	Data acquisition report for the input parameter of JAMS	UFZ-G
402	Geological and hydrogeological conceptual models incl. water budget of each sub-basin	GU, TAU
403	Geophysical surveys at selected hot spots	GU
404	Intersection of JAMS parameter in GIS applications to build up hydrological unites (HRU's)	UFZ-G
405	Definition of runoff formation and - energy (development) specified to catchment and wadi course specifications	UFZ-G
406	Quantification and spatial delineation of currently untapped water resources (fresh and saline groundwater, runoff, wastewater)	GU
407	Assessment of temporal evolution of water quality in selected wadis	UFZ-G, JUA
408	Development of an water quality im- pact matrix	UFZ-G
409	Individual numerical transient flow models for each sub-basin	GU
410	Refined trans-boundary numerical groundwater model	EWRE
411	Report on JAMS modelling in the scale of the trans-boundary groundwater mode l	UFZ-G
412	Report on regional/transboundary water budgets	EWRE
413	Reports on impact of climate change on local and regional IWRM (models from GLOWA project)	GU
414	Report on implementation of SMART I/II recommendations on new drill sites	MEK TAU

WP5 - Water Resources Protection (Spokesmen: N. Goldscheider (KIT), Y. Guttman (MEK)

Deliverable	Content	Editor
501	Report on water resources pollution from urban areas in the LJV	KIT, TZW, QUDS, UKA
502	Assessment whether biological methods for water quality determination are applicable under the given boundary condition. Recommendation for further developments.	KIT-IWG TZW, UKA
503	Assessment of groundwater risk by treated wastewater	TZW, KIT, TAU, BALQ, QUDS, JUA
504	Delineation of protection zones in selected areas to demonstrate feasibility	QUDS-JH
505	Documentation on Workshop with decision makers to discuss implementation barriers	PWA, MEK
506	Economic implications of water protection zones	SUB-IH, PHG

	(results appear also in D706 / D707)	TAU
507	Improved monitoring concepts for groundwater quality	TZW, UKA, PHG, UFZ-UBZ
508	Guideline document on integrated management of sanitation systems and groundwater protection	KIT, PWA UKA

WP6 – IWRM Tools (Spokesmen: J. Bensabat)

Deliverable	Content	Editor
601	Step 1 of DSS development (web app + GUI + GIS + DBMS + visual tools)	EWRE, KIT
602	MCDM module	EWRE, GU
603	MCO module	EWRE, GU
604	Platform for Risk Assessment	EWRE
605	Further development of decision support tools for AR-Systems: planning and management	GU
606	Knowledge management system	KIT
607	Computational model for the simulation of sat-unsat flow and transport	GU, EWRE
608	Step 2 of DSS development (step 1 + MCDM + MCO + scenario generator)	EWRE, KIT

WP7 – Socio-Economics (Spokesmen: I. Heinz, A. Tamimi, N. Lienhoop)

Deliverable	Content	Editor
701	Report on quantifying environmental, health & social benefits of DWWT in JOR	UFZ-Ö
702	Report on quantifying environmental, health & social benefits of DWWT in PAL	PHG
703	Report on assessing the impacts of dif ferent water qualities and quantities on farmer income and their economic situation	PHG, ATEEC
704	Report on cost-benefit analysis for de- centralized WWT&R	UFZ-Ö, ATEEC
705	Report on cost effectiveness analysis (least cost option) for the provision of additional water through DWWT&R, MAR & BRA (summary of D 319 + 327 + 705)	SUB-IH, ECO
706 & 707	Report on cost-benefit analysis of alternative IWRM strategies at watershed level Report on cost-benefit analysis of alternative IWRM strategies at watershed level	SUB-IH
708	Report on investment and O&M costs of alternative IWRM technology lines in the Palestinian IWRM pilot area	PHG
709	Report on social acceptability of alternative IWRM technologies in the West Bank	PHG
710	Report on institutional feasibility of alternative IWRM technologies in the West Bank	PHG
711	Report on socio-economic assessment of using multiple water qualities in Israeli municipalities	EWRE

712	Report on methodology and evaluation of the participatory planning process	UFZ-Ö

WP8 – IWRM Scenarios (Spokesmen: H.-P. Wolff, J. Klinger)

Deliverable	Content	Editor
801	Report on downscaling of nationwide and regional scenarios to local / sub-basin level	HP Wolff
803 804 805	Report on IWRM strategies for each sub-basin and the representation in SMART Knowledge Management Sensitivity analysis of local IWRM Strategies Reports on performance, impact assessment and ranking of local IWRM strategies	GU, KIT, UFZ-G, H. Wolff
803 & 805	Report on IWRM strategy for Wadi Shueib, Jordan and its representation in SMART Knowledge Management and Reports on performance , impact assessment and ranking of local IWRM strategies	KIT
806 & 807	Report on IWRM Strategies for the Jordan River Valley as a single basin and Guidelines on IWRM strategy implementation	SUB-HW, KIT, SUB-IH

WP9 – Dissemination & Capacity Building (Spokesmen: W. Ali, M. v. Afferden)

Deliverable	Content	Editor
901	Upgraded SMART-website No report available: see launched website: www.iwrm-smart2.org	KIT
902	Technical reports on the general SMART-workshops for all partners on an annual basis	KIT
903	Water quality IWRM workshop	BDZ, TZW
904	Large scale international IWRM conference	KIT
905	Quarterly SMART-Newsletter	KIT
906 907 909	906: Delivery of the Teaching Unit didactical set 907: Elaboration of didactical material in Arabic language 909: Technical report on the training courses for teachers on decentralized WWT&R technologies and management in Jordan and Palestine	BDZ
908	Technical report on the training courses for professionals on decentralized WWT&R technologies and management	BDZ, MWI
910	Evaluation report on the effectiveness of the training and dissemination activities (WP 9) (BDZ+ KIT)	MWI

9.2 Literature Cited in the Final Report

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