Friends of the Earth Middle East

Towards a Living Jordan River:

An Environmental Flows Report on the Rehabilitation of the Lower Jordan River

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Dr. Sarig Gafny, Ruppin Academic Center, Israel
Dr. Samer Talozi, Jordan University of Science and Technology, Jordan
Banan Al Sheikh, Al Quds University, Palestine
Elizabeth Ya'ari, Editor, Friends of the Earth Middle East

EcoPeace / Friends of the Earth Middle East
Amman, Bethlehem, Tel Aviv
www.foeme.org

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EcoPeace / Friends of the Earth Middle East (FoEME) is a unique organization at the forefront of the environmental peacemaking movement. As a tri-lateral organization that brings together Jordanian, Palestinian, and Israeli environmentalists, our primary objective is the promotion of cooperative efforts to protect our shared environmental heritage. In so doing, we seek to advance both sustainable regional development and the creation of necessary conditions for lasting peace in our region. FoEME has offices in Amman, Bethlehem, and Tel-Aviv. FoEME is a member of Friends of the Earth International, the largest grassroots environmental organization in the world.

For more information on FoEME or to download any of our publications please visit:
www.foeme.org

Amman Office
Munqeth Mehyar, Jordanian Director
PO Box 840252 - Amman, Jordan, 11181
Tel: 962 6 5866602/3
Fax: 962 6 5866604
Email: info@foeme.org

Bethlehem Office
Nader Khateeb, Palestinian Director
PO Box 421 – Bethlehem, Palestine
Tel: 972 2 2747948
Fax: 972 2 2745968
Email: info@foeme.org

Tel Aviv Office
Gidon Bromberg, Israeli Director
8 Negev Street, Third Floor – Tel Aviv, 66186 Israel
Tel: 972 3 5605383
Fax: 972 3 5604693
Email: info@foeme.org

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Note of Gratitude

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The views expressed are those of EcoPeace/ FoEME and do not necessarily represent the views of our expert team, project advisors, participants in the project's National and Regional Advisory Committee meetings or our funders.

Expert Authors and Credits:

Dr. Sarig Gafny holds a Ph.D. in Limnology from Tel Aviv University in Israel followed by a Post Doc at the Center for Limnology at the University of Wisconsin-Madison in the United States. He is currently the Head of the Department for Marine Environment Sciences in the School of Marine Sciences at the Ruppin Academic Center in Israel. Dr. Gafny is an expert in the ecology and restoration of freshwater bodies with a special emphasis on Aquatic Conservation.

Dr. Samer Talozi holds a Ph.D. and MSc. in Water Resources and Irrigation Engineering from the University of California-Davis in the United States and a BSc. in Irrigation Engineering from the Jordan University of Science and Technology (JUST) in Irbid, Jordan. Currently he works as an Assistant Professor in the Civil Engineering Department at JUST. He has over 10 years of experience in water resources management.

Banan Al Sheikh holds a M.Sc. degree in Plant Taxonomy from Reading University in the United Kingdom. He currently works as a Plant Biodiversity Expert in the Department of Applied Earth and Environmental Sciences at Al Quds University and authored the Preliminary Checklist and Ecological Database of Plants of the West Bank.

Editor:

Elizabeth Ya'ari, Israeli Project Coordinator, Friends of the Earth Middle East

Editorial and Research Assistants:

Romy Zyngier, Editorial Assistant, Intern in the Tel Aviv office of FoEME
Nikki Hodgson, Research Assistant, Intern in the Bethlehem office of FoEME
Hadass Belitzky, Research Assistant, Student, Ruppin Academic Center, Israel

FoEME Jordan River Rehabilitation Project Team:

Munqeth Mehyar, Jordanian Director
Gidon Bromberg, Israeli Director
Nader Khateeb, Palestinian Director
Elizabeth Ya'ari, Israeli Project Coordinator
Baha Afaneh, Jordanian Project Coordinator
Mansour Bader, Palestinian Project Coordinator
Mira Edelstein, Resource Development
Chava Haber, Financial Management

Graphic Design, Maps and Layout:

Yehuda Hofshi, Visual Communication Department of Bezalel Academy of Art and Design, Jerusalem

National and Regional Advisory Committee Meeting Participants:

International Participants:

Shimon Anisfeld, Senior Lecturer and Research Scientist in Water Resources and Environmental Chemistry, School of Forestry and Environmental Studies, Yale University, USA
Udo Gattenlöhner, Executive Director, Global Nature Fund, Germany
Marion Hammerl, President, Lake Constance Foundation, Germany
Daniel Hillel, Professor, Columbia University, USA
Gene Lin, Senior Water Engineer, Water Resources and Infrastructure Office, USAID West Bank/ Gaza
Robert Parua, Program Specialist, UNESCO, Jordan
Juliette Rose, Project Officer, French Development Agency, French Embassy, Amman
Janna Shub, Graduate Student, School of Forestry and Environmental Studies, Yale University, USA
Rohan Titus, Deputy Head of Mission, Australian Embassy, Amman
Setta Tutundjian, Project Management Specialist, Policy Reform and Institutional Strengthening, Office of Water Resources and Environment, USAID, Amman
Eric Viala, Regional Water Advisor, Office of Middle East Programs, USAID, Cairo, Egypt
Julia Zieminska, Lake Constance Foundation, Germany

Palestinian Participants:

Alfred Abed Rabbo, Associate Professor, Chemistry Department, Water and Soil Environmental Research Unit, Bethlehem University
Iyad Aburdeineh, Deputy Director, FoEME
Akram Awawda, Deputy Minister Assistant, Ministry of Transportation
Taleb Harthi, Professor of Environmental and Earth Sciences, Palestinian Universities
Mohammed Said Hmeidi, Ph.d., Environmental Management, Director General, Palestinian Recycling Company
Mohammed Horani, Tourism expert
Qasem Abdul-Jaber, Ph.D., Department of Earth and Environmental Sciences, Faculty of Science and Technology, Al Quds University
Abdul-Salam A.A. Khalaf, Lecturer, Arab American University
Yousef Sadiq, Lecturer, Arab American University

Israeli Participants:

Youval Arbel, Deputy Director, FoEME
Ramon Ben Ari, Director, Lower Jordan River Drainage Authority
Raanan Boral, Environmental Consultant
Sarit Caspi, Adam Teva v'Din, NGO
Yaron Ergas, Ministry of Tourism
Hillel Glassman, Director, Stream Monitoring Department, Nature Parks Authority
Mordechai Karin, Lower Jordan River Drainage Authority
David Katz, Lecturer, Porter School for Environmental Studies, Tel Aviv University
Uri Mingelgrin, Institute of Soil, Water and Environmental Sciences, Ministry of Agriculture
Moshe Perlmutter, Water Coordinator, Society of Protection of Nature of Israel, NGO
Dror Pezner, Water and Streams Protection Division, Ministry of Environment
Gadi Rosenthal, Environmental Economist, Kivun Consulting
Eran Shostak, Water and Sewage Association, Water Authority
Yishay Sorek, Advisor to Minister, Ministry of Regional Cooperation
Dalia Tal, Zalul, NGO
Alon Zask, Director, Protection Water and Streams Division, Ministry of Environment

Jordanian Participants:

Ziad Ababneh, Ministry of Water
Nisreen Ahumoud, Royal Scientific Society
Leith Almughrabi, Royal Society for Conservation of Nature
Haitham Bani Hani, Ministry of Environment
Odeh Al-Jayyousi, Regional Director, IUCN – the World Conservation Union
Ahmad Al-Jazzar, Ministry of Planning and International Cooperation
Manar Fayad, Professor, Analytical and Inorganic Chemistry, Jordan University
Tatyana Gorskaya, Integrated Management and Information Consultants
Saleh Hlalat, Liaison Officer, Jordanian Military
Muna Hindiyeh, Assistant Professor, German Jordanian University, Chairwoman of Water and Environmental Engineering
Qais Owais, Director North and Middle Ghors, Jordan Valley Authority
Abdel Rahman Sultan, Deputy Director, FoEME
Raed Zureiqat, ENGICON

Regional Terminology and Abbreviations

The challenges of geo-historical terminology are particularly serious, since no single geographical name applies to all periods and to the same extent of land including the area of modern Israel, Palestine, and Jordan. Therefore, we have used the general term "region" when referring to the whole area of Israel, Palestine and Jordan. Where names have been used the local term in Arabic and/or Hebrew has been applied, while the English has acknowledged alternative names if they exist in different forms. In the case of the Lake Tiberias/Kinneret/Sea of Galilee we have utilized 'Sea of Galilee' for simplicity purposes as all three names are accepted in the scientific literature. Furthermore, in the case of English spellings of place names we have tried to select the most common spellings.

Abbreviations

BOD – Biochemical Oxygen Demand
Cl – Chloride
COD – Chemical Oxygen Demand
DO –Dissolved Oxygen
EC – Electrical Conductivity
EFS – Environmental Flows Study
EZ – Ein Feska/ Einot Zokim
FoEME – Friends of the Earth Middle East
INPA– Israeli Nature Parks Authority
JVA – Jordan Valley Authority
KAC – King Abdullah Canal
LJR – Lower Jordan River
m/sec – meters per second
m^3/sec – cubic meters per second
m^3/Y – cubic metres per year
mcm – million cubic metres
N – Nitrogen
NGO – Non Governmental Organization
NH_4 – Ammonium
NO_2 – Nitrite
NO_3 – Nitrate
ppm – parts per million
ppt – parts per thousand
TN – Total Nitrogen
TOC – Total Organic Carbon
TP – Total Phosphorus
TSS – Total Suspended Solids
UJR – Upper Jordan River
YA – Yarmouk River

Figures, Tables and Appendices Summary

1 Executive Summary

The Jordan River Rehabilitation Project's Environmental Flow study is the first of a two part study undertaken by EcoPeace/ Friends of the Earth Middle East (FoEME) to strengthen the knowledge base and enable political decision makers in Israel, Jordan and Palestine to act to rehabilitate the Lower Jordan River (LJR). The Environmental Flows study presented here answers the question – how much and what quality of water is required to rehabilitate the LJR? Complementing this study, FoEME undertook an analysis of the economic opportunities to save or produce fresh water resources from within the water economies of Israel, Jordan and Palestine which could potentially be returned to the Lower Jordan River as part of a river rehabilitation plan.

As the only regional environmental organization comprised of Israelis, Palestinians and Jordanians, FoEME is uniquely positioned to advance this study from a regional perspective. Having led efforts to date for the river's rehabilitation, FoEME understands that a regional approach that brings all sides to act together is a pre-requisite for gaining the political support for the flow of fresh water back to the river.

This study represents the first ever regional environmental flows study of the LJR prepared by experts from Palestine, Israel and Jordan and overseen by a Regional Advisory Committee involving key governmental representatives from each of the riparian countries. The findings are alarming and require urgent concrete action from all parties with support from the international community in order to breathe life into the dying Jordan River and preserve this important site of shared natural and cultural heritage.

This tri-lateral study has exposed several significant and previously unpublished findings including:

- The LJR today is a highly degraded system due to severe flow reduction and water quality decline.
- Over 98% of the historic flow of the LJR is diverted by Israel, Syria and Jordan for domestic and agricultural uses.
- The remaining flow consists primarily of sewage, fish pond waters, agricultural run-off, and saline water diverted into the LJR from salt springs around the Sea of Galilee.
- The river has lost over 50% of its biodiversity primarily due to a total loss of fast flow habitats and floods and the high salinity of the water.
- Long stretches of the LJR are expected to be completely dry unless urgent action is taken by the parties to return fresh water to the river.

This report concludes that the LJR requires 400 million cubic meters (mcm) annually, to be expanded to 600 mcm over time for the river to function as a healthy ecosystem. In addition, one minor flood event is required to take place annually, with the river's salinity level to be reduced to no more than 750 parts per million (ppm), meaning that primarily fresh water needs to be returned to the river with only the highest quality of effluents allowed (with effluents constituting no more than 25% of the LJR's base flow). Implementation of this strategy would remove most of the disturbances, restore the river's structure and function, allow the natural riparian plant community to recover and restore stable communities of flora and fauna and achieve a fair to high ecosystem integrity and health. With the historic flow of the river averaging 1.3 billion cubic meters the conclusion of this study recommends that approximately a third of the historic flow be returned. FoEME's economic study, written to complement this environmental flows study, determines that 400 mcm is an achievable quantity of water that must urgently be returned to the river.

Without concrete action the LJR is expected to run dry at the end of 2011. New waste water treatment plants, being built in Israel and Jordan, will remove the sewage and saline waters currently discharged into the LJR for treatment and use in agriculture. While the removal of these serious pollutants after years of advocacy efforts is an achievement, if the advancement is not coupled with the allocation of fresh water resources the LJR will run dry.

In early 2010 the Israeli Ministry of Environment released the Terms of Reference (ToR) for their proposal to rehabilitate the LJR from the Sea of Galilee to Bezeq Stream (the border with the Palestinian West Bank). The Israeli side presented the ToR to Jordanian and Palestinian stakeholders for comments during FoEME's February 14, 2010 Regional Advisory Committee. FoEME commends this first step towards rehabilitation and encourages the international community to support Jordan and Palestine in the development of their own ToRs as partners to the rehabilitation effort.

Friends of the Earth Middle East urgently calls upon our three governments, with the support of the international community, to partner together in a shared effort to rehabilitate the Lower Jordan River.

Background

The LJR and its tributaries are shared among the nations of Israel, Jordan, Syria and Palestine. It is the longest permanent river in the region, stretching along an aerial distance of 105 kilometers (km), with an actual stream channel length of 217 km from the Sea of Galilee to the Dead Sea. The river is gently sloped from an altitude of 212 meters (m) below sea level to an altitude of 422 m below sea level. The LJR flowed freely for thousands of years from the Sea of Galilee to the Dead Sea creating a lush wetland ecosystem, rich in biodiversity. This narrow corridor also serves as one of the most important migratory flyways on the planet with an estimated 500 million birds travelling its length twice annually (Turner et al., 2005).

This river has been immortalized in the holy books of Judaism, Christianity and Islam with references associating the river to prophets Moses and Elijah. Four of the Companions to the Prophet Mohammed are buried on the eastern banks of the river and for Christianity the river water is itself holy following the baptism of Jesus in the Jordan River. Unlike any other river on earth the LJR remains an important cultural anchor for half of the world's population. The Jordan River valley served as a pathway of early human migration out of Africa, as the site of early human settlement, hosted momentous battles, Roman cities and crusader and other castles. The rich history of the Jordan River valley warrants its inscription as a 'cultural landscape of universal significance' (Turner et al., 2005).

Politically, the LJR can today be divided into three sections; from the Sea of Galilee to the confluence with the Yarmouk River in which both sides of the LJR flow through Israel; from the entrance of the Yarmouk River into the LJR to Bezeq Stream in which the LJR serves as the border between Israel and Jordan; and from Bezeq Stream to the Dead Sea in which the LJR serves as the border between the Palestinian West Bank and Jordan (Figure 1). The rehabilitation of the river can in principal be addressed in stages; although a comprehensive approach adopted by the governments of Israel, Palestine and Jordan together would be the most beneficial and efficient strategy for the long-term management of the LJR. A regional approach to managing the LJR can further serve as an effective forum for peace building; enhancing dialogue, building confidence, exploring shared interests and broadening cooperation between the parties.

Descriptions from early explorers such as United States Naval Lieutenant Officer W.F. Lynch in his 1847 expedition down the Lower Jordan River to the Dead Sea, describe heroic navigations down cascading rapids and waterfalls. Likewise, until the second half of the 20th century the wild waters of the Jordan River turned the turbines at the hydroelectric power plant located at the confluence of the LJR and the Yarmouk – bringing power to thousands of residents on both sides of the river.

Though still unique in its natural and cultural wealth the "mighty Jordan" has been reduced to a trickle south of the Sea of Galilee-devastated by overexploitation, pollution, and a lack of regional management. According to recent studies conducted by Yale University, this important regional water resource carried an average of 1.3 billion cubic meters of fresh water from the Sea of Galilee to the Dead Sea every year until the 1930s (Anisfeld, 2009). Beginning in 1932 with the construction of Degania dam at the Jordan River's exit from the Sea of Galilee, the process of regulating the flow LJR began in earnest.

From 1946-1964 the river's flow regime was modified through interventions to prevent winter flooding, greatly reducing the flow variability of the LJR. In 1964 and 1966 Israel and Jordan undertook major national water infrastructure projects to divert the LJR and its tributaries for domestic and agriculture use through the construction of the Israeli National Water Carrier and the King Abdullah Canal respectively. Furthermore, the Israeli saline streams canal was constructed to improve water quality in the Sea of Galilee by diverting saline streams which once flowed into the Sea of Galilee into the LJR causing a large increase in the LJR's salinity. With the near complete blockage of fresh water flow into the LJR from the Sea of Galilee by Israel, the Yarmouk River, historically the LJR's second largest tributary, was from this period the LJR's main source of fresh water. As a final assault to the LJR's natural structure and function, Jordan and Syria completed the construction of the Unity Dam on the Yarmouk River in 2007, capturing the majority of the Yarmouk's flow and further reducing the LJR to 20-30 million cubic meters – just 2% of its natural flow.

All in all the average annual flows diverted by each country are estimated at 46.47% by Israel, 25.24% by Syria, 23.24% by Jordan and 5.05% by Palestine (Table 1). Compounding the drastic reduction of fresh water to the LJR, sewage from communities along both sides of the river has been discharged into the LJR continuously until recent years with dramatic affects on the river's health (Holtzman., 2003)..

In 1994, Jordan and Israel signed the Treaty of Peace committing their governments to work toward the "ecological rehabilitation" of the river and renewing hopes for a cross border effort to restore the Lower Jordan River through coordinated management. Despite this formidable commitment, neither government has taken concrete action to return any measure of fresh water to the river since the treaty was signed.

With regards to the discharge of waste into the LJR, the Israeli and Jordanian governments are currently taking steps to significantly reduce the flow of untreated sewage into the LJR including the upcoming activation of several new sewage treatment plants in the Jordan Valley. In Israel, a plant has recently been completed in the community of Beit Shean to treat the sewage of all of the residents of Beit Shean City, the Valley of Springs Regional Council and the Gilboa Regional Council. The Jordan Valley Regional Council, also in Israel, has broken ground on a new plant that will treat the sewage of Tiberias and other Sea of Galilee communities. Likewise, in Jordan, North Shuna, the largest community on the eastern side of the valley, has launched a project to collect sewage from cesspits for treatment rather than allowing it to seep into the ground and pollute the springs which flow into the Lower Jordan River. While these are indeed major achievements – they will also remove a large percentage of the effluent flowing in the LJR today making a coordinated regional effort to return fresh water resources to the Lower Jordan River ever more critical.

The equitable sharing of the Jordan River Basin water resources between people and nature and amongst all of the river's riparian stakeholders, including Palestinians presently denied from extracting any water directly from the river, is no-less an important issue. Palestine must get direct access to the river and is entitled to its fair share of Jordan Basin waters as a riparian to the river. This issue is specifically addressed in Friends of the Earth Middle East's Draft Agreement on Water Cooperation between The State of Israel and the Palestinian National Authority (FoEME, 2008).

The obligation to return water to the river must take into account the quantity of water each riparian extracted in addition to socio-economic differences between the parties. The government of Israel having diverted the largest share of LJR waters, together with Israel being a developed country, places responsibility on the Israeli Government, in the opinion of FoEME, to return proportionally a higher percentage of water towards the river's rehabilitation. The governments of Jordan and Syria also have a responsibility to return water back to the river. Israel, Jordan and Palestine, will in the future, need to work together to ensure that water returned to the river will not be illegally extracted by farmers and others along its banks.

A rehabilitated LJR offers residents on both sides of its banks significant opportunities to benefit from the area's rich cultural and natural heritage through the development of sustainable tourism. Tourism destinations including the proposed Jordan River Peace Park, the baptism sites and other numerous cultural heritage sites along both sides of the river have the potential to serve as leading attractions for hundreds of thousands of pilgrims and tourists every year, providing an important pillar for the region's economies.

The Lower Jordan River Today

To address the critical state of the Lower Jordan River, FoEME partnered with leading regional experts to undertake the first ever regional environmental flow study of the Lower Jordan River to identify a range of environmental flows necessary to rehabilitate the LJR. This multi-disciplinary study compared historical data, drawn from first hand testimonies from early explorers, to data collected by FoEME's expert team through sampling the Lower Jordan River over the course of one year. The new data was also compared to area reference sites and supplemented by water quality data including extensive chemical assessments provided courtesy of the Israeli Ministry for the Environment and the Nature and Parks Authority.

The sampling conditions along the Lower Jordan River proved far from ideal. Access to the river is extremely limited as a closed miliary zone is maintained on both sides of the river and landmines along the river's banks and within the channel provided a constant hazard to the sampling team.

The tri-lateral research team gathered new information on:

- Morphological and hydrological variables including cross sections, velocity and discharge
- Water quality indicators including temperature, transparency, electric conductivity, salinity, dissolved oxygen and percent oxygen saturation
- For the first time macroinvertebrates were sampled the length of the LJR creating an important baseline reference for future studies
- Botanical Survey

This study exposes several significant and previously unpublished findings including:

- The annual discharge of the LJR has been reduced from 1.3 billion cubic meters to an estimated 20-30 million cubic meters (mcm). This is a reduction of 98% of the river's historical flows.
- Increased salinity is the primary water quality challenge in the LJR. The dramatic reduction of freshwater inputs from the Sea of Galilee and the Yarmouk River coupled with the diversion of the saline springs into the LJR has created higher than natural saline conditions.
- Organic pollution is present in extremely high concentrations in the northern river segments and in levels that pose seasonal risks to public health in the southern segments – including at the southern baptism sites.

- Due to the high regulation of the river's flow the LJR has lost all fast flow habitats and floods, resulting in a dramatic reduction in the river's biodiversity.
- Biodiversity was found to be at least 50% lower than levels at comparable reference sites, primarily due to a loss of fast flow habitats and floods and the high salinity of the waters.
- The botanical survey revealed an overall reduction of biodiversity in the floral community of the LJR with shifts towards saline tolerant and invasive species. The loss of floods has caused a shift in the riparian belt from a wide and dense riparian belt to a much narrower belt with a lower abundance of woody trees and an increase in saline tolerant reeds along the river's banks – in some areas covering the channel completely.

Establishment of the Jordan River Rehabilitation Project's Regional Advisory Committee

In parallel to the ongoing study, FoEME established National and Regional Advisory Committees involving expert stakeholders and government representatives from Israel, Palestine and Jordan to provide feedback on the study at key stages in its development. FoEME's Regional Advisory Committee is today the only forum focused on the Lower Jordan River which brings Israeli, Palestinian and Jordanian representatives together and as such serves as an important medium for the region's experts to exchange information and discuss scenarios for the river's rehabilitation.

While initially established to give feedback on research undertaken by FoEME and proposals for the LJR's rehabilitation, the forum quickly expanded to an important meeting for the region's ministries to present and discuss cross border proposals related to rehabilitation and development initiatives in the Jordan River Valley.

Regional Strategy to Rehabilitate the Lower Jordan River

The research team developed a series of possible rehabilitation scenarios which were presented to the project's Regional Advisory Committee for discussion. The required flows, water quality, advantages and disadvantages were presented and discussed for each of the identified scenarios (these rehabilitation scenarios are presented in Tables 10 and 11).

This integrated regional stakeholder process resulted in FoEME's adoption of a regional rehabilitation strategy which requires 400-600 mcm of water annually, including one minor flood, a salinity level of no more than 750 (ppm) and primarily fresh water with only the highest quality of effluents allowed up to 25% of the LJR's base flow.

The adoption of this strategy will result in the removal of most of the disturbances in the LJR, restore the river's structure and function, allow the natural riparian plant community to recover and restore stable communities of flora and fauna and achieve a fair to high ecosystem integrity and health. Finally, this strategy requires high but achievable water resources; quantities of fresh water that FoEME has identified in its economic analysis of opportunities to return fresh water resources to the LJR from the water economies of the region.

Next Steps

To rehabilitate the LJR steps are necessary both to solve immediate crises and to lay the groundwork for long term regional management of the river.

FoEME recommends:

- **Israel to undertake an experimental flood of the LJR**. Because the LJR is highly regulated all flood waters are caught and stored. This has had a drastic effect on the entire ecology of the river and its floodplain and is one of the primary reasons the LJR has a 50% loss of biodiversity. Floods are essential to healthy river ecology to flush fine sediment and associated pollutants, reconnect the channel and floodplain, remove invasive plant and animal species, and provide biological cues for native migration and breeding. FoEME supports the implementation of the "experimental flood" proposal, developed by Yale University, which necessitates a flow of approximately 100 m^3/sec from the Alumot Dam for a 24 hour period (a total of less than 9 mcm of water total).
- **Jordanian and Palestinian government authorities to undertake the development of a master plan for the LJR** to complement the effort initiated by the Israeli Ministry of Environment in 2010.
- **400-600 mcm of fresh water resources must be allocated to the river** to halt its continuing deterioration as part of the national water plans of Jordan and Israel.
- **Palestine, as a riparian to the LJR, must receive a fair share of the river's water resources** as part of the Middle East peace negotiations.
- The Palestinian, Israeli and Jordanian Governments should **establish an International Commission** to manage the transboundary LJR basin.

In supporting the implementation of the recommendations contained in this report, FoEME seeks to partner with governmental institutions in Jordan, Israel and Palestine as well as other stakeholders to address the environmental needs of the LJR.

We invite the international community to partner with us in this initiative to transform the Jordan River into a thriving ecosystem bringing benefits to the communities alongside both of its banks and fostering peace and sustainable development in Palestine, Israel and Jordan.

2. Environmental flows for the rehabilitation of the Lower Jordan River

The primary goal of this environmental flow study is to propose a regional rehabilitation strategy for the LJR, creating a healthy ecosystem for each of the river's riparians.

River rehabilitation is the process of bringing a river system back to a healthy and balanced ecological state. It is an effort to artificially reintroduce the fundamental elements of the original stream, either by direct intervention or by hastening the recovery process. Understanding river hydrology is a key component for river restoration, rehabilitation, and water management. The hydrologic regime within a river will influence river physical attributes such as hydraulic conditions, shape of stream and as a result will influence river habitat and stream productivity. River hydrological status provides valuable information on the capacity of rivers to retain pollutants during low flow periods as well.

"*Ecosystem health*" is often the term used to describe the effect of human alteration on ecosystem ecological integrity (Angermeier and Karr, 1994). The terms "*river integrity*" and "*river health*" are applied to the assessment of river condition (Karr and Chu, 2000). River health is often seen as being analogous with human health (Norris and Thomas, 1999). Assessing the ecological health of rivers and streams is a fundamental and increasingly important water management issue worldwide (Bunn and Davies, 2000). This measure uses the status of different components of the ecosystem to assess how well the ecosystem is, just like we use body temperature to assess the health of a person. Traditionally the assessment of river health was based solely on abiotic attributes, such as hydrological and water quality characteristics of the river (Petts, 2000). While these measurements may be efficient for regulating effluent discharge into rivers they are not very useful for large-scale protection of river ecosystems (Norris and Thomas, 1999). Instead, biological monitoring approaches are essential to define river health (Karr, 1999; Council of Australian Governments, 1992, Bunn and Davies, 2000). Because biological communities integrate the effect of different stressors such as reduced oxygen, excess nutrients, toxic chemicals, change in temperatures, excess sediment loading and habitat degradation, the advent of bio-assessment in regulatory programs has provided scientists and stream managers with a more comprehensive and effective monitoring and assessment strategy (Barbour et al., 2000)

To assess river health we need to define how well these components did prior to the alteration (Gardiner, 1992; Galat and Lipkin, 2000) and thereafter to measure what is the current situation of the system. However, tracking complex systems requires measures that integrate multiple factors. Biological monitoring of the presence or absence of benthic macroinvertebrate (e.g. Wright, 1995) and fish (e.g. Karr, 1981; Jungwirth et al., 2000) are commonly used as attributes to define river ecosystem stability and health (Karr and Chu, 1999). The basic assumption is that the richer and diverse the system is in species, the more stable and healthy it is (Bunn and Davies, 2000). Thus, the presence or absence of indicative species (sensitive *vs.* tolerant) may provide important information on the river's health.

The LJR was historically rich in flowing water; the average multi-annual base flow averaged 1.3 billion cubic meters of fresh water per year, of which an average of 540 mcm flowed from the Upper Jordan River through the Sea of Galilee, an average of 480 mcm from the Yarmouk River and the remainder from smaller tributaries on both banks (Main, 1953, Farber et al, 2005, Hof, 1998, Holzman et al., 2005). The river can be characterized as a Mediterranean ecosystem (*sensu*: Gasith and Resh, 1999), historically typified by high flow variability resulting from inter-annual and intra-annual variability in precipitations, strong floods and frequent droughts along with relatively gentle slope and alluvial soil. Consequently, the LJR channel was very active and frequently changed its path. These factors largely affect the river's biodiversity; indeed, the LJR was historically characterized by rich biodiversity (Ortal and Por, 1978; Por and Ortal, 1985).

The diversion of over 98% of the LJR's historical discharge resulted in a dramatic decline in the LJR's biodiversity. Water was taken not only from the river's main channel, but also from most of its tributaries (the Yarmouk River and side wadis). On top of base flow withdrawal, most of the runoff to the LJR was captured and consequently, flood frequency and intensity declined severely. Since widespread diversion was initiated, the river ecosystem has dramatically changed its structure and function. For example, the base flow of the LJR in early 2000 ranged between 0.65-3 cubic meters/sec, a discharge which is hardly sufficient to maintain any habitats and biodiversity (McMahon and Finlayson, 2003; Magalhaes et al., 2007).

The LJR and its tributaries used to be highly rich in species of aquatic fauna (Ortal and Por, 1978; Por and Ortal, 1985). This high richness is also currently reflected in the less altered Upper Jordan River (UJR, Gafny, 2008) and tributaries of the LJR (Gafny, 1997) which are also characterized by relatively rich aquatic fauna (Gafny, 2008). The impacts of the human changes on the LJR are complex, but in general such impacts are usually reflected in the reduction of species richness and diversity of the river's aquatic fauna (Karr and Chu, 2000). Species with high habitat requirements such as rapid water velocities and high levels of oxygen cannot survive in the degraded river conditions and thus disappear. On the other hand, tolerant species that are well adapted to poor environmental conditions flourish and increase in abundance (Petts and Amoros, 1996).

3. Methodology

The Environmental Flows Study was undertaken in the 2009 hydrological year and examined the characteristics of the LJR in its current state and its original state before large-scale human intervention. The current river state was evaluated by undertaking hydrological, botanical and biological surveys at a number of selected sites over the winter and summer seasons of 2009, while the original state was investigated by reviewing historical records of river data.

3.1 Study sites

The habitat, plant assemblage and macroinvertebrate assemblage of the LJR were characterized for five sites along the LJR (Figure 1). Sampling sites were selected for close proximity to LJR bridges to ensure reasonably safe access to the river segment, as several regions of the LJR are considered hazardous due to the presence of landmines. All sampling was conducted on the eastern bank of the river in cooperation with the Jordan Valley Authority (JVA) and the Jordanian Military. The sampling locations were selected to include sites spanning from the north to the south of the river to ensure adequate representation of the LJR environment including:

Site 1: Gesher/ Jisr Al Majami Bridge (32°37'28.24"N 35°33'52.56"E) – A river segment where the wet channel changes from wide and deep to narrow and shallow with slow velocity (Figures 5a and 5b).

Site 2: Beit Shean/ Sheikh Hussein Bridge (32°29'48.97"N 35°34'32.08"E) – A river segment with a wide and deep channel, and slow water velocity (Figures 7a and 7b).

Site 3: Adam/ Damya Bridge (32° 6'9.45"N 35°32'6.19"E) – A segment with a split stream channel. The channel is relatively shallow with a slow water velocity (Figures 9a and 9b).

Site 4: Allenby/ King Hussein Bridge (31°52'27.00"N 35°32'27.00"E) – A river segment with narrow channel, relatively high stream slope and fast flow (Figure 11)

Site 5: King Abdullah Bridge (31°48'3.77"N 35°32'47.89"E) – A segment with relatively narrow stream channel and fast flow (Figures 13a and 13b).

Three relatively unimpaired reference sites were selected for comparison (Figure 1):

Ref. Site 1: Ein Fashka/ Einot Zokim (approximately 31°47'6.32"N 35°30'16.09"E), a site containing both running water and pool habitats near the northern shoreline of the Dead Sea.

Ref. Site 2: The Lower Yarmouk River (approximately 32°39'3.72"N 35°35'29.24"E), a tributary of the LJR located only a few kilometers from Site 1.

Ref. Site 3: The Upper Jordan River (approximately 32°54'19.70"N 35°36'59.85"E) from the Rosh Pina stream to the Sea of Galilee.

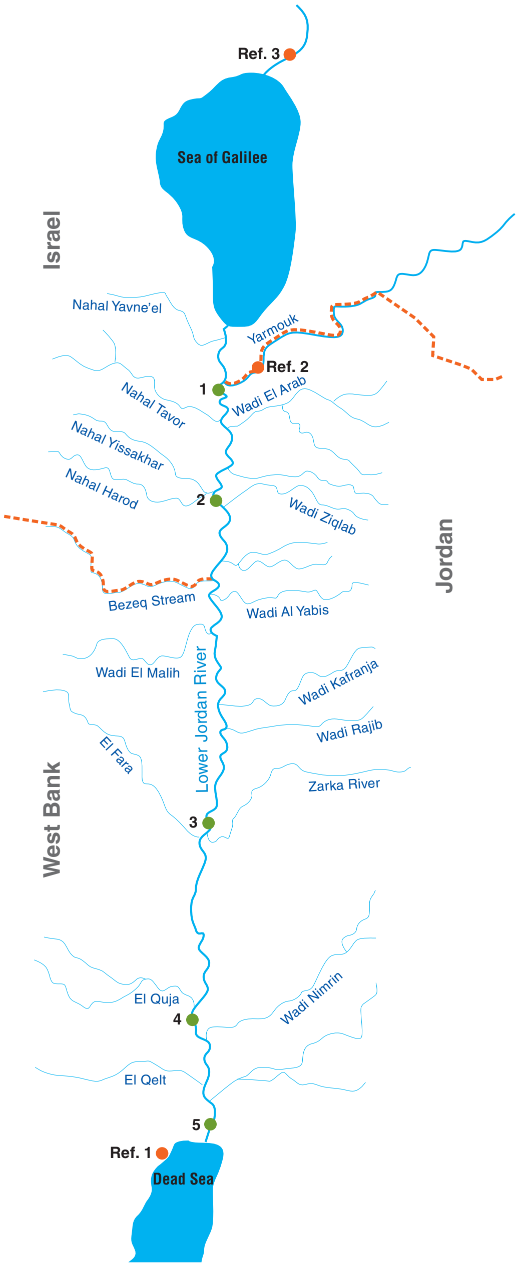

Figure 1. Map of the Lower Jordan River survey sites and reference sites. Site 1. Gesher/ Jisr Al Majami Bridge; Site 2. Beit Shean/ Sheikh Hussein Bridge; Site 3. Adam/ Damya Bridge; Site 4. Allenby/ King Hussein Bridge; Site 5. King Abdullah Bridge. Ref. Site 1. Ein Fashka/ Einot Zokim; Ref. Site 2. Lower Yarmouk River; Ref. Site 3. Upper Jordan River from Rosh Pina stream to the Sea of Galilee.

3.1.1 Historic characterization of the Lower Jordan River

During the last century the LJR has undergone severe alteration due to the impacts of industrialization, diversion of the fresh water and the continual expansion of agricultural and urban regions. These impacts have resulted in radical changes to the river's morphology and hydrology. The river's health has declined dramatically, with flow reduction of 98% and the water becoming increasingly saline with high pollutant levels. Consequently, the LJR in-stream and riparian habitat characteristics have changed dramatically.

The history of the LJR can be divided into the following four distinct periods (Ortal, 1976; Anisfeld, 2009):

1. **Undisturbed flows in the LJR - Prior to 1932:** During this period freshwater from the Sea of Galilee flowed uninterrupted into the LJR and onwards to the Dead Sea with the annual flow averaging 1.2 -1.4 billion cubic meters, with peak winter flows of 55 m^3/sec during the winter and minimal summer flows of 3 m^3/sec (Ben Ariyeh, 1965). According to Ben Ariyeh (1965), the level of the Sea of Galilee at the outflow of the LJR was at least one meter higher than the level of the LJR, which ensured constant freshwater flow from the lake into the river.

2. **Operation of the hydroelectric power plant at Naharyim – From 1932 to 1946:** During this period the location of the outflow from the Sea of Galilee was moved and dammed (Deganya dam constructed in 1932, controlling river inflow by dam discharge), and the water was diverted into the Naharyim Reservoir (Ben Ariyeh, 1965; Anisfeld and Shub, 2009). Together with the waters of the Yarmouk River, the LJR turned turbines which supplied electric power to both British Mandate Period Palestine and Jordan. The river waters were then released back into the LJR system. During this period winter flow rates were 6-7 m^3/sec whilst peak flows occurred during spring to fall at rates of 20-26 m^3/sec (Ben Ariyeh, 1965).

3. **Intermediate period – From 1946 to 1964:** Hydro-electrical plant operation at Naharyim ceased in 1947, however the Sea of Galilee continued to operate with the same minimum (-209 m) and maximum (-212 m) levels as in the preceding period. The main purpose of the Sea of Galilee during this period was to maintain fisheries and pump down-stream water stations for agricultural water application (Anisfeld and Shub, 2009). During this period the LJR flow regime was modified to prevent winter flooding and the flow variability was reduced to winter flows of 17-18 m^3/sec and summer flows of 10-15 m^3/sec (Ben Ariyeh, 1965). Furthermore, the Yarmouk River returned to flow through its original channel, resulting in the Naharyim Reservoir filling with sediment. The Yarmouk dam also remained open, enabling continuous downstream flow (Anisfeld and Shub, 2009).

   The Jordan Valley Unified Water Plan, commonly known as the "Johnston Plan", as it was negotiated and developed by US ambassador Eric Johnston between 1953 and 1955 drew upon the average annual stream flow data published in the 1953 study entitled, *The Unified Development of the Water Resources of the Jordan Valley Region* prepared by Chas T. Main of the Tennessee Valley Authority under direction of the United Nations Relief and Works Agency (Lowi, 1993). The Jordan Valley Unified Water Plan was subsequently approved by the technical water committees of all the regional riparian countries - Israel, Jordan, Lebanon and Syria (Shapland, 1997). Though the plan was rejected by the Arab League, both Israel and Jordan undertook to abide by their allocations under the plan. The US provided funding for Israel's National Water Carrier after receiving assurances from Israel that it would continue to abide by the plan's allocations (Sosland, 2007). Similar funding was provided for Jordan's King Abdullah Canal project after similar assurances were obtained from Jordan (Haddadin, 2006). The original findings of the 1953 survey on which the Johnston plan was negotiated are presented in Table 1 with additional information on water transfers between Jordan and Israel established in their 1994 Peace Treaty.

   While historical data, particularly for smaller tributaries of the LJR, is disputed this comprehensive 1953 survey provides the best basis available on which to estimate the quantities diverted by each country. These flow levels no longer exist on all sides of the LJR due to human intervention and less regional precipitation. FoEME's interest in this data set is to best estimate diversion responsibilities as a percentage of the historical average annual flow. FoEME acknowledges that these flow levels, controversial in 1953 certainly do not represent current flow levels.

Table 1. Estimated Average Annual Flow Data (mcm) for the Lower Jordan River and Estimated Average Annual Flows (mcm) diverted by Israel, Syria, Jordan and Palestine. *Source: The Unified Development of the Water Resources of the Jordan Valley Region prepared by Chas T. Main of the Tennessee Valley Authority under direction of the United Nations Relief and Works Agency, 1953*.

Lower Jordan River Surface Waters listed from North to South	Estimated Average Annual Flow (mcm) from Tennessee Valley Authority Survey, 1953	Estimated Average Annual Flows (mcm) diverted for use by:			
		Israel	Syria	Jordan	West Bank
Upper Jordan River at exit from Sea of Galilee	538	538			
Yarmouk	475		315	160	
Al Arab	15			15	
Harod (Jalud)	67	67			
Ziglab	8			8	
Jurm	11			11	
Yabis (Rayyan)	5			5	
Kufranja	6			6	
Rajib	5			5	
Zarqa	45			45	
El Far'a (Tirza)	45				45
El Auja (Yitav)	15				15
Wadi Nimrin (Sheib)	10			10	
El Qelt (Prat)	3				3
Transfers Specified in the 1994 Israeli-Jordanian Peace Treaty related to the Jordan River*		-50		50	
Transfers Specified in the 1994 Israeli-Jordanian Peace Treaty related to the Yarmouk River*		25		-25	
Totals	1248	580	315	290	63
Percentage of Total		46.47	25.24	23.24	5.05

** Source: "Treaty of Peace between the State of Israel and the Hashemite Kingdom of Jordan," October 26, 1994.*

4. **Intensified Diversion: Operation of Israel's National Water Carrier (NWC) in 1964 and Jordan's King Abdullah Canal (KAC) in 1966 to Present:** Israel's National Water Carrier diverts water from the Sea of Galilee to supply much of the country with fresh water. The Sea of Galilee's water levels are still controlled, preventing water from flowing into the lake and onwards into the LJR. Outflow from the Sea of Galilee into the LJR is dammed except for rainy years when the Sea of Galilee water levels exceed 209 m below sea level, or to store water at the Alumot Dam to deliver water for farmland irrigation in adjacent regions. In 1967 a by-pass to the Sea of Galilee was constructed to improve water quality by diverting saline springs and primary effluent to the LJR at Alumot Dam. These diversions have lead to the degradation of water quality downstream of Alumot Dam, with the water having high salinity, bacterial (effluent) and thermal (thermal springs) contamination (Anisfeld and Shub, 2009).

The King Abdullah Canal (KAC), running 110 km on the East bank of the Jordan River, was built in 3 phases, 1966, 1969 and 1987. It is considered the backbone of irrigated agriculture in the Jordan Valley. The northern section of the canal, 70 km long and completed in 1966, is fed by the Yarmouk River, some ground water wells, the Sea of Galilee (Jordan's water share according to the 1994 Treaty of Peace between the State of Israel and the Hashemite Kingdom of Jordan), and side valleys whenever water is available. The southern section, 45 km long and completed in 1987, is supplied with water from the access water in the northern section in winter and from the King Talal Dam and the Karama Dam in summer (Grawitz and Hassan, 2000). In 2007, Jordan and Syria completed the construction of the Unity Dam on the Yarmouk River. The capacity of this dam is 110 mcm and water stored is intended to be used for drinking and irrigation.

Until the beginning of the nineteenth century no research had been conducted on the LJR (Schattner, 1962). The first study on the LJR was carried out by United States Naval Lieutenant Officer W.F. Lynch and described in his reports "*Official Report of the United States' Expedition to Explore the Dead Sea and the Jordan River*" published in 1852 and the accompanying "*Narrative of the United States expedition to the Jordan River and the Dead Sea*" published in 1858. Lynch's 1858 report contains detailed information on the morphology and hydrology of the LJR as well as a comprehensive description of the flora and fauna composition in the river channel and on the river banks. Additional information on the aquatic habitats of the LJR prior to flow regulation can be found in studies by Eig, (1927: mainly on the aquatic flora), Ionides and Blake (1939: mainly on the rivers hydrology and geomorphology), Schattner (1962: mainly hydrology and geology), Anon (1964: hydrology) and Klein (1985: hydrology and geomorphology).

3.1.2 Historic records of macroinvertebrate biodiversity

Historic information on a river's macroinvertebrate species assemblage provides a useful tool to identify and characterize the pre-alteration condition of a currently disturbed river ecosystem (Schmutz et al., 2000). Unlike the relatively good historical data on the morphology, hydrology and vegetation of the LJR prior to the river regulation and flow alteration, there are no records on the river's macroinvertebrate assemblage prior to 1976. In fact, most of the LJR surveyed during this study was sampled for macroinvertebrates for the first time. Some useful information can be found in the studies of Ortal (1976) and Gasith and Hershkoviz, (2006), which took place in the Israeli section of the LJR, between the Sea of Galilee and Dalhamya Dam. Though Ortal's (1976) data was collected 10 years after the major decline in the LJR flow, this data may still serve as a good comparison to the current species assemblage of the LJR, as species elimination/exclusion following ecosystem perturbation can occur over a long period of time. The location overlap between Ortal's (1976) study and the more recent study by Gasith and Hershkoviz, (2006) may indicate the long term impact of the human alteration of the LJR.

3.1.3 Historic hydrology

The water quality and flow of the LJR has been negatively affected by a series of hydraulic projects conducted by Israel, Jordan and Syria over the past several decades. Currently, the water in the LJR is comprised of saline spring water, untreated sewage water, agricultural farm runoff, fish ponds outflows, ground water flow, and surface runoff during winter.

Historic records from the 1930's estimated the flow of the LJR at 1,200-1,400 mcm/year (Salameh and Naser, 1999). There are even records of very wet years with around 1800 mcm/year in 1930 and 1500 mcm/year in 1945 (Anisfeld and Shub, 2009). For the hydrological year of 2009, our study found that the current flow in the LJR is estimated to be 20-30 mcm.

The contribution from the two main tributaries, the Upper Jordan and the Yarmouk, has declined dramatically over the past several decades. Table 15, Appendix 5 summarizes the volumes of water diverted to the Jordan River from the Jordanian side from 2004 to 2008. Table 16, Appendix 5 summarizes the annual recorded stream flow in streams and valley on the Jordanian side of the LJR. Figure 2 illustrates the historical flow in the LJR at Deganya Dam where the Jordan River once exited the Sea of Galilee on its way to the Dead Sea but is today reduced to nearly zero due to damming, as seen in Figure 3.

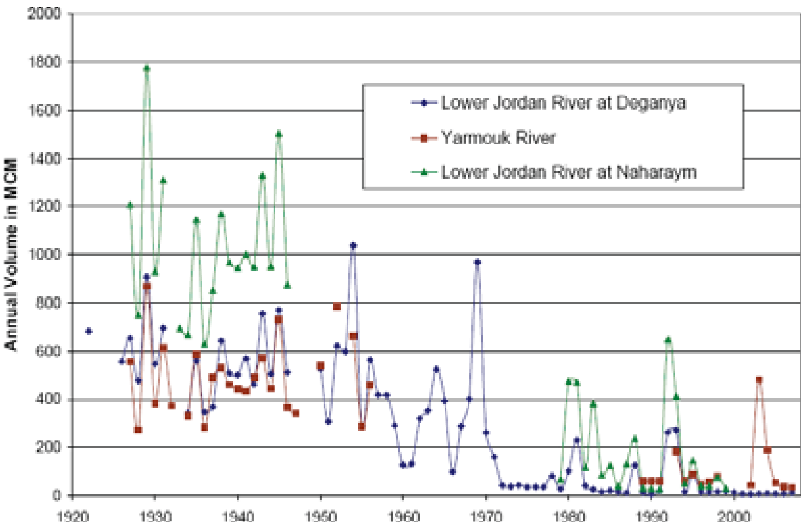

Figure 2: Annual flows in the Lower Jordan River and its tributaries from 1920's-2008. *Source: Anisfeld and Shub, 2009. Historical Flows in the Lower Jordan River.*

The Deganya Dam was built in the early 1930's by Israel for the purpose of regulating the water in the Sea of Galilee and for producing electricity in the Naharayim hydroelectric power plant. A second dam, Alumot Dam, was constructed in the early 1960's approximately 1.5 kilometres downstream from Deganya Dam as part of the saline water diversion project. The saline water canal was built as part of Israel's general National Water Carrier plan to divert saline streams away from the Sea of Galilee thus increasing the sweetness of the lake's fresh water and enabling its use as drinking water (Figure 3).

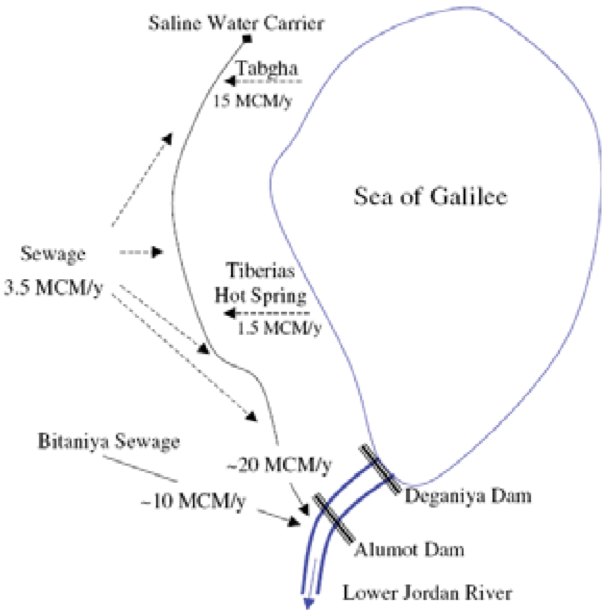

Figure 3: A schematic map showing the location of the two dams (Deganya and Alumot) which block the Lower Jordan River's exit from the Sea of Galilee. *Source: Farber et al. 2005.*

The cessation of flow from the Upper Jordan River via the Sea of Galilee to the LJR only reveals part of the story of the demise of the LJR. The situation with the Yarmouk River, the second largest tributary to the LJR, is similar. Figure 4 illustrates data collected by a hydrological station on the Yarmouk River; the reduction in the annual flow of the Yarmouk River is obvious, particularly since the 80's.

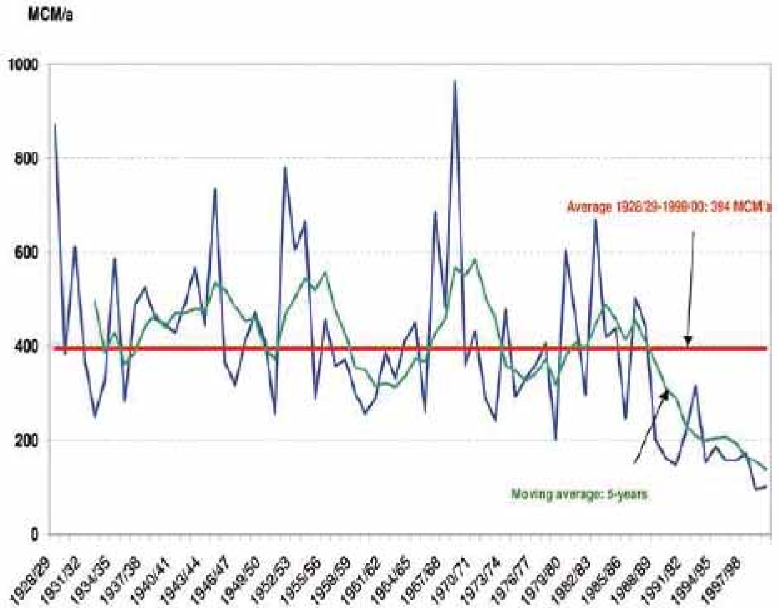

Figure 4. Annual flows and moving average of annual flow in the Yarmouk River from 1928-1998. *Source: Water Resources in Jordan. National Water Master Plan Directorate. Ministry of Water and Irrigation, Jordan. 2nd edition 2008.*

The long term (1928-29 to 1999-00) average of the Yarmouk River flow is 394 mcm per year, however prior to the 1970s the Yarmouk's input averaged 480 mcm per year (Farber et al, 2005, Hof, 1998, Holzman et al., 2005). From 1970-1980, the annual average flow decreased to 364 mcm per year; while from 1990-2000 it dropped to just 171 mcm per year (Water Resources in Jordan, 2008). In 2007, the Unity Dam was completed by Syria and Jordan with a total capacity of 110 mcm which aims to catch the remaining flood waters of the Yarmouk River.

In Jordan, six dams were constructed in the northern and middle parts of the Jordan Valley during the past five decades with a total storage capacity of 160 mcm (JVA, 2009). The six dams include: Wadi Arab, Ziglab, King Talal, Karamah, Shueib, and Kafrein. In addition, the Unity Dam on the Yarmouk River was completed in cooperation with Syria in 2007 with a total capacity of 110 mcm. All the above dams, except the Unity Dam, are built on the seasonal valleys leading to the LJR. These dams are used to store winter floods, regulate water and release it for irrigation during summer. The capacity of these dams and the water volumes they captured in 2008 and 2009 are summarized in Table 17, Appendix 5. Moreover, according to the water annex in the Treaty of Peace between the State of Israel and the Hashemite Kingdom of Jordan, a regulating dam was built on the Yarmouk River downstream of the diversion point of KAC (Fao/Aquastat, 2009).

Identifying the historical flows of the LJR is no simple task. Most hydrological recording stations were located upstream of Naharyim (the conflux of the Yarmouk River with the LJR). Several hydrologic stations have functioned at various locations on the Yarmouk River (Adasya, Gate 121, Um Butma, and Naharyim) as early as 1926. However, none of them functioned continuously throughout this period due to political instability resulting in discontinued hydrological records. On the LJR, a hydrologic station was located at Deganya (1921 – to date). Another station located at Naharyim operated between 1978 and 2000. Other stations on the LJR functioned in the 30's and 40's but all of these were upstream of Naharyim. No hydrological stations existed or currently exist on the LJR downstream of Naharyim.

Therefore, the closest estimates of the historical flows of the LJR are those of the station at Naharyim, because downstream of this point no major flow contribution exists. Minor contributions such as fish ponds outflows, agricultural runoff, ground water seepage, and rare floods that are not captured by the many dams in the Jordan Valley contribute to the flow of the LJR downstream of Naharyim. On the other hand, some farmers on both sides pump out directly from the river when possible and accessible for agriculture. Therefore, it is reasonable to assume that flow data from the Naharyim station is representative of the flow along the path of the LJR. Figure 2 shows the recorded annual flow volumes at Naharyim from the 1920's to 2008. Recording stopped at this station in 1948 and resumed again in the late 1970's.

Since the early 1990's the average annual flow in the LJR was estimated at less than 100 mcm/year, a dramatic drop from the volumes recorded in the 20's, 30's and 40's of the last century. Not only did the volume of flow drop, but also the variability in annual flows diminished. Due to the transformation of the Sea of Galilee into a reservoir, the variability of outflows from the lake has disappeared as can be seen in Figure 2 starting in the early 1970's. There is more variability from one year to another in the Yarmouk River flow; however this trend disappeared with the completion of the Unity Dam.

3.1.4 Historic flora

The Jordan River Valley is unlike any other geographic location; it acts as an ecological junction of three continents: Europe, Asia and Africa, resulting in a diverse and unique combination of habitats with origins to several bio-geographic climates or biomes (Turner *et al.*, 2005).

Historical biodiversity surveys focused on the LJR are rare with the exception of Lynch (1848), Eig (1927) and Zohary (1962). The pre-perturbation references describe the LJR's belt as wide and covered with dense vegetation including willows (*Salix sp.*), Poplar trees (*Populus euphratica*) and Tamarix (*Tamarix jordanensis*), which often shaded the river channel. Bank vegetation also included reeds (*Phragmites australis*), bulrush (*Typha sp.*), Oleander shrub (*Nerium oleander*) and various Cyperus species (Lynch, 1858). Furthermore, Lynch (1848) describes laurel trees as fringing the banks where the Yarmouk flows into the Jordan. This description was later supported by Eig (1927). Zohary (1962) describes the banks of the Jordan River as so densely populated with populus and tamarix that they formed dense and impenetrable woods with the populus growing along the river's banks and the tamarix in the back.

The active channel of the LJR also included rich diversity of submerged macrophytes which are currently totally absent from the river. The submerged macrophyte community included Eurasian milfoil (*Myriophyllom spicatum*), Sago pondweed (*Potamogeton pectinatus*), coontail (*Ceratophyllum demersum*) and Holly-leaves (*spiny*), and naiad (*Najas marina*) (Eig, 1927). Most of these species were later also described on the southern shores of the Sea of Galilee (e.g. Waisel, 1967; Gophen, 1982; Gafny, 1999).

3.2 Experiment design

In order to define the current situation of the LJR ecosystem, information on both abiotic and biotic habitat features are needed. To obtain this information the LJR was sampled twice during 2009, in April, when flow is high and in July when flow declined. However, data collection in the LJR is limited due to existence of minefields along the banks of the river as well as the danger of landmines that have been swept into the river corridor over the past few decades due to floods and water movement. Therefore, much of the river corridor is hard to approach and sampling was restricted to specific river segments. All bridges maintain heavy security with restricted access and mobility which affected our ability to collect detailed data especially relating to river cross-section depths, river width, and detailed current velocity profiles. Access to the river, survey, sampling, and measurements could only be conducted from one side at a time due to the river's function as a border. Stepping into the river is prohibited due to the possible existance of landmines. Under these circumstances, even simple river features such as a cross section area were difficult to define, especially in April, when visibility was significantly reduced due to higher turbidity and it was hard to see the stream bed. During the course of this study all sampling was conducted from the eastern bank in cooperation with the Jordan Valley Authority and under the escort of the Jordanian Army.

River water quality plays an important role in determining the physical and ecological character of a river system. A common tool to determine environmental flows is the Environmental Flows Decision Support System which uses five groups of hydrological descriptions; these are: flow magnitude, flow variability, rates of flow change, magnitude and frequency of extreme flows (floods and droughts), and seasonal predictability of flow (Young et. al, 1999).

The biota of a given watershed is the product of millions of years of geological change and biological evolution: the very existence of living organisms represents the integration of the environmental conditions around them (Karr and Chu, 2000). The best way to assess the current health of the LJR is to develop and implement an Index of Biological Integrity (IBI, e.g. Karr et al., 1986) for the river. This index assists in quantifying changes in ecosystem health resulting from habitat degradation, flow alteration, and poor water quality and requires a large scale regional study on the LJR biota. The development of an IBI is recommended for future studies of the LJR.

This study is focused on the structure of the macroinvertebrate assemblages of the LJR (the presence or absence of indicator species as well as some community structure characteristics) to determine the changes in ecosystem health and indicate the degree of habitat degradation (Barbour et al., 1999). For example, we examine whether the LJR macroinvertebrate assemblage includes Trichoptera or certain Ephameroptera larvae, which are typical to fast running water and can be used as an indicator of water quality and flow, to draw conclusion regarding the effect of flow reduction on the LJR's health.

3.3 Field sampling

At each of the five sampling sites information on the current hydrological and ecological status of the LJR ecosystem and its biologic components were collected. The main habitat characteristics of the LJR sampling sites are presented in Table 2. For a detailed description of the field methodology, please refer to Appendix 1.

The following parameters were recorded for each sampling site, where possible:

A. Morphology and hydrology:

The survey collected data on stream channel width, water depth, water velocity, discharge and information of stream substrata.

B. Water quality:

At each site water temperature, transparency, electrical conductivity, salinity, dissolved oxygen and percent oxygen saturation were measured. Additional water quality parameters for the LJR were obtained courtesy of Hillel Glassman, Director of the Stream Monitoring Department of the Israeli Nature Parks Authority (INPA) and the Israeli Ministry of the Environment including Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Chloride (Cl), Total Phosphorous (TP), Nitrate (NO_3), Nitrite (NO_2), Ammonium (NH_4), Total Organic Carbon (TOC), and Fecal Coliform. The results are summarized in Section 4.2.2 Water quality, Tables 4 and 5.

C. Macroinvertebrate assemblage:

During the two sampling periods (April and July 2009) composite samples of macroinvertebrates were collected to ensure adequate representation of the different substrates and habitat types found at each of the five sites. Macroinvertebrate assemblage information collected during these periods was compared with the available historical data to evaluate the change in macroinvertebrate assemblage as an indicator of stream health and biodiversity.

D. Botanical biodiversity:

A comparative analysis of vegetation distribution and abundance was undertaken to determine the current botanical biodiversity of the LJR as an indication of the river ecosystem health. At each of the five study sites along the LJR (Figure 1) a botanical inventory survey was conducted recording the plant species observed during the two sampling periods. An inventory survey was also conducted at a reference site on the Yarmouk (Reference site 2, Figure 1) during July when access was available.

4. Results

4.1 Historic data on habitat characteristics in the Lower Jordan River

The best description of the LJR habitat structure, prior to river regulation and alteration was provided by Naval Lieutenant Officer W.F. Lynch (1858). The results from the Lynch study serve as a good basis for perturbation comparison with our data as the spring sampling period for both the current study and that of Lynch occurred within the same sampling dates. According to Lynch's description, the width of the stream channel varied from 24-64 m. This stream channel width was recorded as relatively constant from the outlet of the Sea of Galilee down to the inlet of the Dead Sea. The river's maximum depth varied from 0.70 m (mainly at the northern section of the LJR) to approximately 4 m depth near the Dead Sea. The bottom substrate was dominated by boulders and stones and only in the southern section it became dominated by finer sediments. Water velocities ranged from 6 m/sec in the northern section (Sites 1 and 2 of our study) to 1-2 m/sec (Site 3 and 4) and back to 2-4 m/sec near the Dead Sea (Site 5). Table 2 fits site descriptions given by Lynch to our selected study sites.

Table 2. Selected morphological and hydrological characteristics of the sampling sites in the Lower Jordan River prior to flow regulation. *Source: Lynch 1858 pp: 99-171.*

	Site 1	Site 2	Site 3	Site 4	Site 5
Habitat type	Rapids, cascades & falls	Rapids, cascades & falls	Run	Rapids, cascades & falls	Rapids & cascades
Dominant bottom substrate	Boulders & stones	Boulders & stones	Pebbles, gravel & sand	Stones & pebbles	Mud
W - Width of the Wet Channel (m)	24.3	36.6	27.4-64	39.6	36.6
h - Depth (cm)	60	180	60-300	152	366
V - Velocity (m/sec)	6	2.5	1-3	3	2

Lynch describes runs, rapids and cascades as the dominant habitat types along the LJR. His description includes details on many waterfalls along the LJR, including in the northern section of the LJR, which is currently characterized as a pool habitat with near zero velocities. Islands were also recorded as a common component of the LJR habitat. Lynch describes the water quality as "high" and mentioned that fish could be easily observed through clear water. The banks of the LJR were covered with dense vegetation and submerged macrophytes were abundant in the water.

4.2 Characterizing the current in-stream habitat

In the truest sense, "habitat" incorporates all aspects of physical and chemical constituents along with the biotic interactions (Barbour et al., 1999). In-stream habitat refers to all the physical features of the stream, including the substrate (eg. rock, sand or mud), the depth and velocity of the water (pool versus run and riffle), the presence of vegetation in the stream (macrophytes) and around it (riparian vegetation), and any in-stream shelter, such as woody debris or large rocks. The floodplain is another important component of the aquatic habitat (billabongs or inundated vegetation can be important nursery areas for juvenile fish, for example). Streams that offer an array of different habitats are likely to support a greater diversity of organisms (Rutherfurd, 2000).

4.2.1 Morphology and hydrology of the river canal

The major flow reduction of the LJR has resulted in a dramatic change in the river habitat structure. Selected morphologic and hydrologic characteristics observed at the sampling sites in the LJR in April and July 2009 are presented in Table 3. Refer to Appendix 2 for the July sampling data in detail.

Table 3. Main morphological and hydrological characteristics of the sampling sites in the Lower Jordan River in April and July 2009.

	Site 1	Site 2	Site 3	Site 4	Site 5
Habitat type	Pool	Pool	Slow run	Run	Run
Dominant bottom substrate	Boulders & stones	Clay & sand	Clay & gravel	Stones & pebbles	Boulders & stones
W - Width of the Wet Channel – July (m)	25*	47	8	6.8	7.75
h_{max} - Maximum Depth - April (cm)	180*	230*	110*	55*	65*
h_{avg} - Average Depth – April (cm)		166**	69.8**	44.2**	50.4**
h_{max} - Maximum Depth – July (cm)	150	187	85	28	32
h_{avg} - Average Depth – July (cm)		119.0	47.6	18.9	16.4
Depth Variability – July (%)		48.9	74.2	63.8	62.8
A_{sum} –Cross Section Area (m^2) – July (m^2)		57.03	4.28	1.51	1.31
A_{spr} – Cross Section Area - April (m^2)		78.87**	6.16**	6.68**	7.65**
D – Hydraulic Depth – July (cm)		121	53.5	22.2	16.9
P – Wet Perimeter – July (m)		47.9	8.99	7.99	7.99
R- Hydraulic Radius – July (m)		1.19	0.48	0.19	0.164
V_{max} Maximum Velocity - July (m/sec)				0.52	0.46
V_{avg} Average Velocity - July (m/sec)		0*	0.075 (*Vsurf*)	0.293	0.291
Velocity Variability – July (%)				56.4	38.8
Q – Discharge - July (m^3/sec)			0.321	0.442	0.381
Annual Discharge –July (106*m^3/Y)			10.12*	13.9*	12.02*

* Estimated data ** Extrapolated data

The width of the stream channel (*W*) in the upper section of the river (from Alumot dam to the Beit Shean/ Sheikh Hussein Bridge) which was described by Lynch as relatively narrow is now the widest river section. The width of the LJR stream channel now ranges from 25 meters at the Gesher/ Jisr Al Majami Bridge (Site 1, Table 3, Figure 5a and 5b) to 47 meters at the Beit Shean/ Sheikh Hussein Bridge (Site 2, Table 3 and Figure 7a and 7b). This section, which was described by Lynch as the fastest flowing section of the LJR, with water velocities of 6 m/sec (Table 2) is now hardly moving and can be described as a pool habitat (Table 3). In contrast, changes in water depth for the northern section of the LJR were less pronounced (Tables 2 and 3).

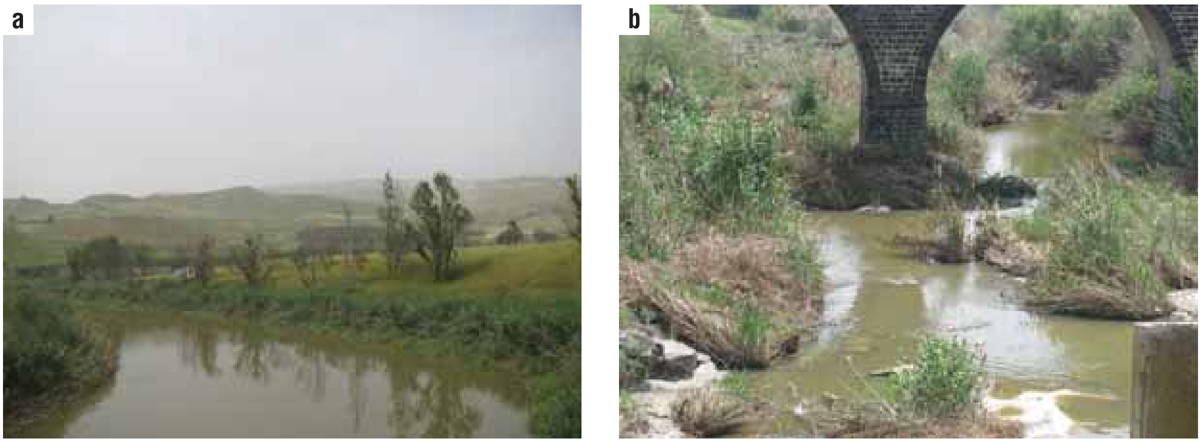

Figure 5. A general view of the river habitat at Site 1: Gesher/ Jisr Al Majami Bridge: a – upstream (north) of the bridge, b- downstream (south) of the bridge; April 2009. *Source: Sarig Gafny.*

Due to sampling difficulties (hazard of landmines) we could not characterize the morphology and hydrology of Site 1 in detail. However, the river channel changes at this site from wide and deep upstream of the bridge (Figure 5a) to split and shallow downstream of the bridge (Figure 5b).

A detailed cross section of the river channel in Site 2 is presented in Figure 6. A general view of the site in April (a) and July (b) are presented in Figure 7. The stream wet channel width and depth were the greatest at Site 2. The difference in water depth between April and July was approximately 40 cm. The cross section area of Site 2 was found to be one order of magnitude larger than the cross sections of all other sites. The seasonal difference in depth was reflected in a reduction of approximately 30% in the cross section area between spring and summer (Table 3). Despite the large cross section area, the LJR at Site 2 is almost completely stagnant with near zero velocity.

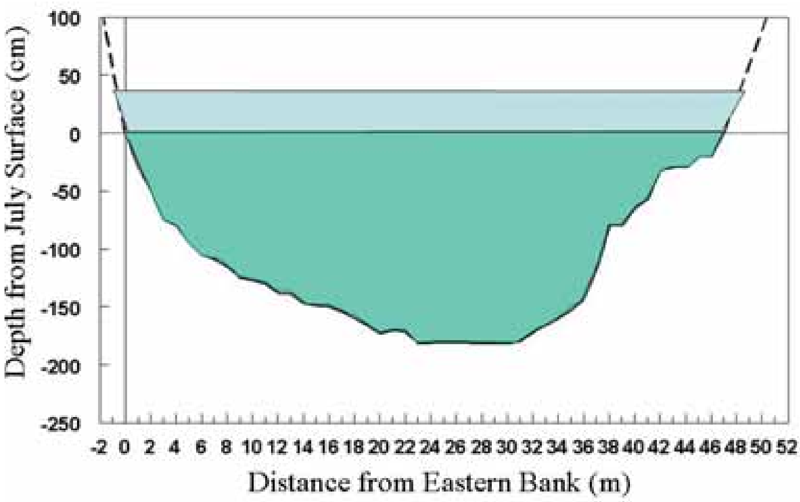

Figure 6. Cross section of the Lower Jordan River at Site 2: Beit Shean/ Sheikh Hussein Bridge; a (light blue) – extrapolated cross section in April, 2009; b (darker blue) – measured cross section in July 2009.

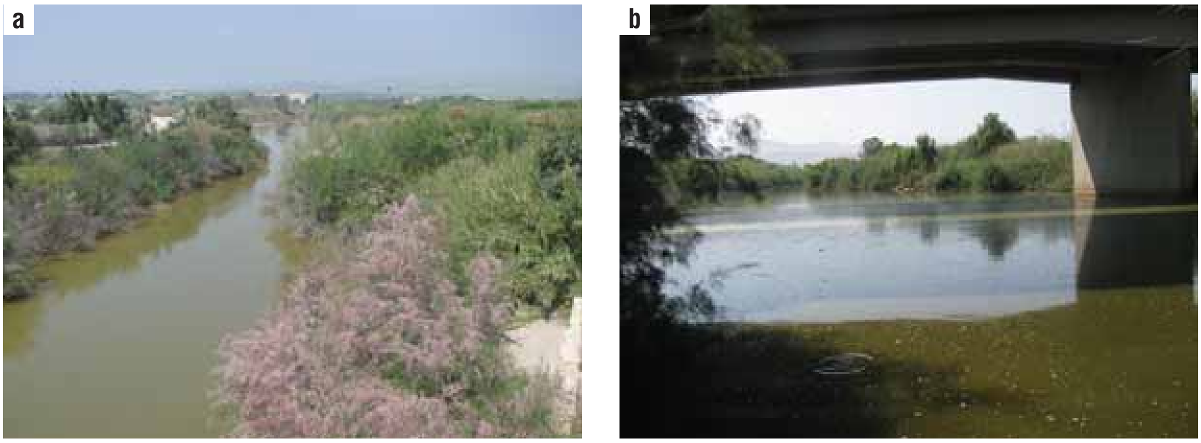

Figure 7. A general view of the river habitat at Site 2: Beit Shean/ Sheikh Hussein Bridge; a - April, 2009; b – July 2009. *Source: Sarig Gafny.*

A dramatic change in the river morphology was recorded for the southern LJR (Sites 3, 4 and 5). The wet channel at these sites is much narrower, ranging from 7-8 meters and shallower, ranging from 60-110 cm in April and 30-85 cm in July. These differences are also reflected in other morphological characteristics such as cross section area which was similar in all sites in April but differed significantly among sites in July (Table 3). The shape of the cross sections also differed from site to site (Figures 8, 10 and 12). With the difference in the shape of the LJR wet channel between the northern (Sites 1 and 2) and the southern (Sites 3-5) stream sections there is also a difference in the flow and substrate. Even under these conditions (narrow channel and small cross section area) the stream velocity ranges from less than 0.1 m/sec (Site 3, Table 3) to less than 0.3 m/sec (Sites 4 and 5, Table 3). Although the river's current appeared to be more turbulent (Figures 9, 11 and 13), these values are less then one tenth of the values reported by Lynch (1858) for Sites 3, 4, and 5 (Table 2).

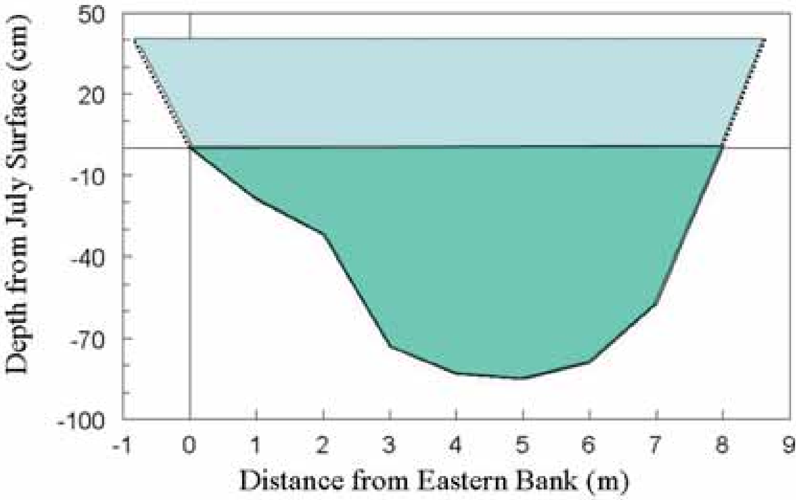

Figure 8. Cross section of the Lower Jordan River at Site 3: Adam/ Damya Bridge; a (light blue) – an extrapolated cross section in April, 2009; b (darker blue) – a measured cross section in July 2009.

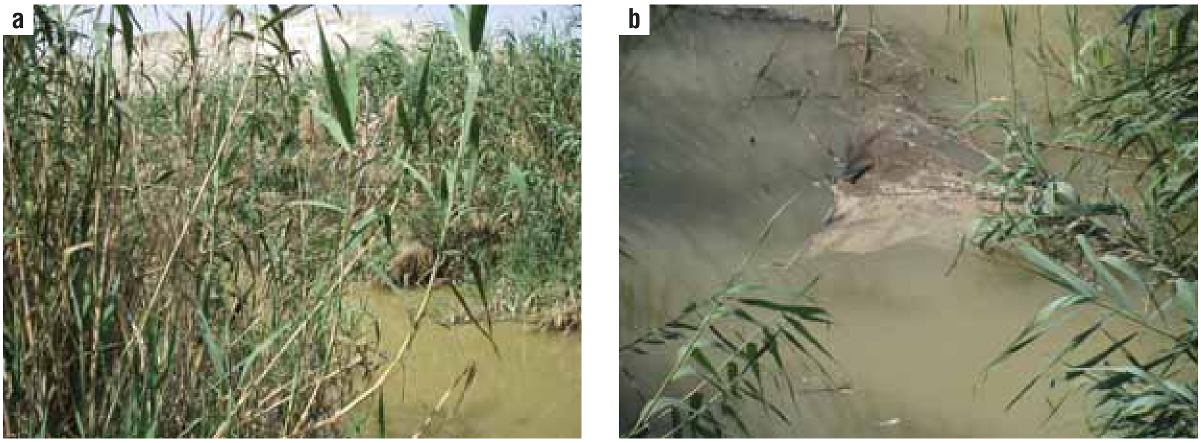

Figure 9. A general view of the river habitat at Site 3: Adam/ Damya Bridge; a - April, 2009; b – July 2009. *Source: Sarig Gafny.*

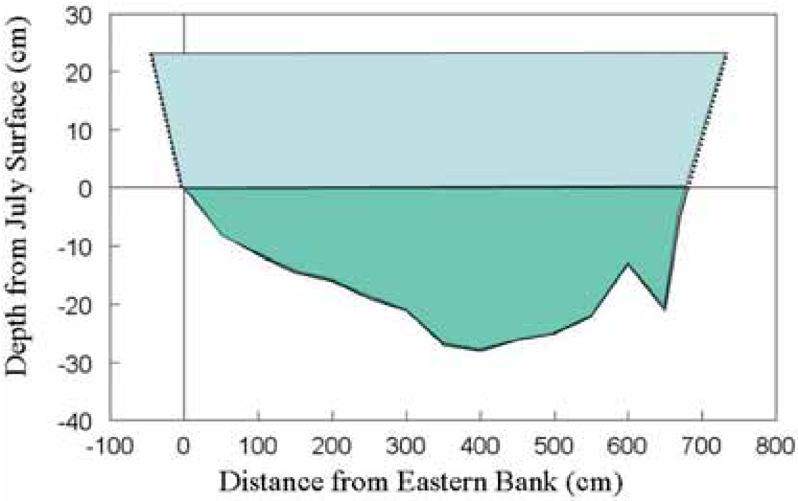

Figure 10. Cross section of the Lower Jordan River at Site 4: Allenby/ King Hussein Bridge; a (light blue) – an extrapolated cross section in April, 2009; b (darker blue) – a measured cross section in July 2009.

Figure 11. A general view of the river habitat at Site 4: Allenby/ King Hussein Bridge; April, 2009. *Source: Sarig Gafny.*

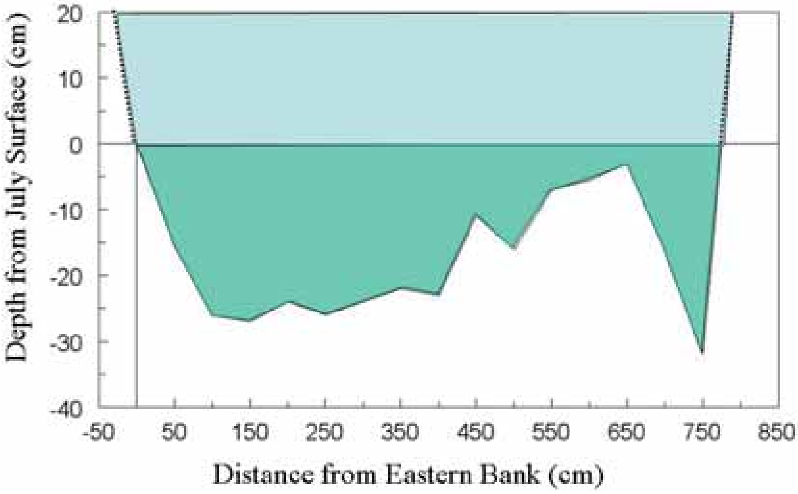

Figure 12. Cross section of the Lower Jordan River at Site 5. King Abdullah Bridge; a (light blue) – an extrapolated cross section in April, 2009; b (darker blue) – a measured cross section in July 2009.

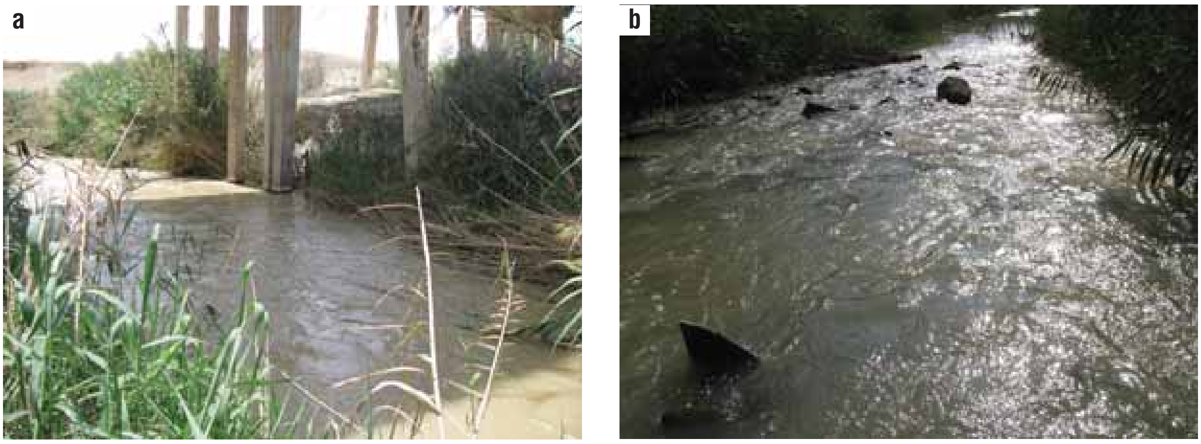

Figure 13. (Above) A general view of the river habitat at Site 5: King Abdullah Bridge; a –downstream (south) of the bridge from bank, b- downstream (south) of bridge from stream; April, 2009. *Source: Sarig Gafny.*

Based on July 2009 base flow measures, we estimated the annual discharge in 2009 between 10 and 15 mcm per year. These flows are in agreement with the findings of Holzman et al., (2003) which reported discharge of 16 - 35 mcm per year for the upper segment of the LJR, and 9.5 - 60 mcm per year for the lower segment of the LJR. We conclude that our estimate is rather conservative since the winter base flow was probably higher due to increased rainfall during the winter period. We consider 20 -30 mcm to be a reasonable estimation range for the 2009 annual discharge of the LJR. **This discharge is less than 2% of the discharge reported for the LJR prior to flow regulation**.

4.2.2 Water quality

To accurately characterize a stream habitat, the inclusion of water quality parameters into the study is essential. Water quality significantly affects the distribution of river biota (flora and fauna). Therefore, water quality impairment, such as the diversion of saline water and sewage into the LJR, may affect presence or absence of indicative species (e.g. Eherlich and Ortal, 1978). Similarly, high oxygen concentration may allow the presence of more sensitive species while low oxygen levels will only allow tolerant species to inhabit the river. Likewise, high water turbidity may result in a high sedimentation rate which may affect the distribution of species.

Despite the long north to south distance, which displays a strong gradient in the terrestrial vegetation change, water temperature was found to be uniform along the LJR. In April it ranged between 21.4 °C and 23.4 °C depending on the sampling hour. In July, the water temperature was 10 °C higher and ranged between 30.1 °C and 31.8 °C.

The water of the LJR is relatively turbid. Secchi depth ranged from 10 cm to 45 cm in April, and in most sites (except Site 1) it was less than 30 cm in July. The cause for the high turbidity differed between the northern and the southern sections of the LJR. While at the northern section (Sites 1 and 2) the low water clarity mainly evolved from algal blooms, the high turbidity in the southern section was mainly caused by inorganic suspended sediments. The algal bloom was most pronounced in Site 2 in July, when the color of the water was dark green (Figure 15) and the water was super saturated with oxygen.

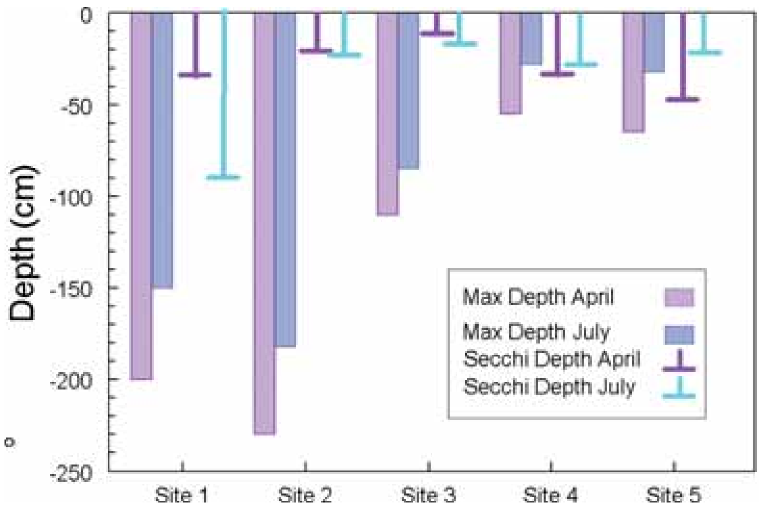

Figure 14. Water transparency using measures of maximum depth and Secchi depth in sites along the Lower Jordan River, April and July 2009.

Figure 15. Algal bloom in Beit Shean/ Sheikh Hussein Bridge, in July 2009. *Source: Sarig Gafny.*

The LJR water is characterized by relatively high salinity. The general pattern observed along the LJR was of an increase in both electrical conductivity (EC) and salinity from north (Site 1) to south (Site 5). However, EC and salinity in Site 2 were slightly lower than in Site 1 (Figure 16). During the April sampling period, EC (adjusted to 25 °C) varied from 5.9-10.63 mS and salinity from 3.4 ppt to 6.4 ppt. During the July sampling period, both EC and salinity levels were found to be higher than the values recorded during the April sampling period. Electrical conductivity values ranged from 6.46 to 19.67 mS, whilst salinity ranged from 3.5 ppt to 11.6 ppt.

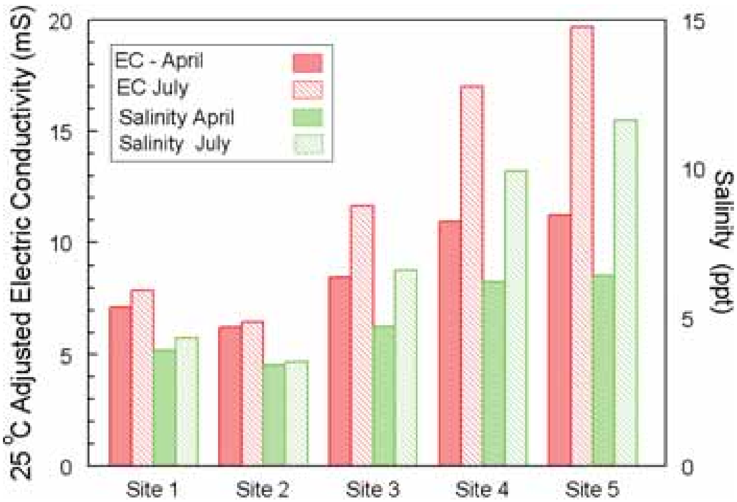

Figure 16. Electric conductivity (EC mS) and salinity (ppt) in sites along the Lower Jordan River, April and July 2009.

The summer increase in EC was small in the northern section ranging from 4% at Site 2 to 10% at Site 1. However the summer EC increase in the southern section was much higher. We recorded a 37% EC increase at Site 3, 55% EC increase in Site 4 and 76% increase at Site 5. The same pattern was observed for salinity value increases during the summer. We conclude that the northern segment of the LJR receives a stable input of fresh water that does not change seasonally. This is also reflected in the decrease in EC and salinity from Site 1 to Site 2 which indicates that a freshwater input between the two sites. This conclusion is supported by the study by Vengosh et al. (2001) that reported on fresh groundwater inputs into upper segments of the LJR.

A similar pattern of increase was also observed for dissolved oxygen concentration (DO). In April DO levels were lowest in the northern section, in sites with slow water flow and higher in the southern section. Saturation levels in April varied from 40-60% upstream, to 80-90% downstream (Figure 17).

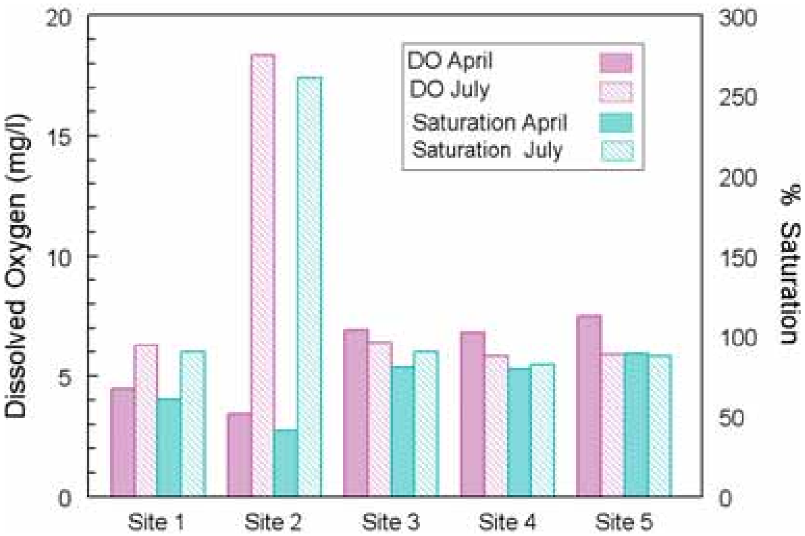

Figure 17. Dissolved Oxygen and Percent Saturation in sites along the Lower Jordan River in April and July 2009.

In July we observed a slight decrease in DO concentrations across most sites with the notable exception of Site 2. However, saturation data which takes into account the temperature increase from April to July indicates that the oxygen levels in the LJR during April and July were actually similar (Figure 17). Interestingly, July oxygen levels at Site 2 were unique. A high level of super saturation (271%) was recorded at this site. The high oxygen level reflected the algal bloom observed in Site 2 in July. This finding is typical to rivers polluted by organic inputs. Since Site 1 was not super saturated, this finding further supports our conclusion that fresh, but polluted water inputs enter into the LJR between Site 1 and Site 2.

Results from the April and July sampling periods for water temperature, Secchi depth, electrical conductivity, salinity and dissolved oxygen are summarized in Table 4.

Table 4. Water quality parameters for Sites 1-5 along the LJR. April and July 2009.

April	Site 1	Site 2	Site 3	Site 4	Site 5
Temperature (°C)	23.4	22.6	21.4	22.6	22.3
EC (m/S)	6.9	5.95	7.9	10.25	10.63
EC (25 °C m/S)	7.13	6.23	8.48	10.94	11.22
Salinity (ppt)	3.9	3.4	4.7	6.2	6.4
DO (mg/L)	4.47	3.44	6.92	6.82	7.52
DO (%)	60.4	41	80.9	80	89.3
Secchi depth (cm)	35	21	11	33	45

July	Site 1	Site 2	Site 3	Site 4	Site 5
Temperature (°C)	31.4	31.2	30.5	30.1	31.8
EC (m/S)	7.86	7.12	12.82	18.64	22.24
EC (25 °C m/S)	7.89	6.46	11.62	17.01	19.67
Salinity (ppt)	4.3	3.5	6.6	9.9	11.6
DO (mg/L)	6.28	18.34	6.4	5.84	5.9
DO (%)	90	261	90.4	82.2	87.5
Secchi depth (cm)	90	22	>10	27	19

The presence of dissolved oxygen (DO) is of fundamental importance in the maintenance of aquatic life and the aesthetic quality of rivers. The results obtained during April (Table 4) indicate the lowest DO values at Site 2 and the highest at Site 5. In April we can see strong correlation between the values of DO and water velocity. In July, DO levels along the LJR were almost similar except for super saturation in Site 2 resulting from an algal bloom. At Site 2 the water is stagnant while it is noticeably flowing at Sites 3, 4, and 5.

Table 5. Lower Jordan River water quality parameters in mg/l unless otherwise indicated. May and October 2009. Source: Israeli Nature Parks Authority (INPA). Jordanian Standards for Streams (Government of Jordan, 1995). Israeli Standards for Streams (Pareto, 2003).

Site #	Site Name	Date	BOD_t	COD_t	TSS105	Cl	TP	NO_3	NO_2	NH_4	ToC	Fecal coliform (cfu/100 ml)
Jordanian Standards for Streams			50	200	50	350	--	25	--	15	--	1000
Israeli Standards for Streams			10	70	10	400*	1	**	--	1.5	--	200
INPA1	Degania	25/5/09	0.35	68	5	252	0.1°	0.2	0.008	0.05	25.9	70
INPA 1	Degania	26/10/09	2.7	30	10	291	0.03	0.2	0.003	0.05	3	120
INPA 3	Alumot Upstream	25/5/09	0.35	70	5	312	0.04	0.2	0.007	0.05	27.2	60
INPA 3	Alumot Upstream	26/10/09	2.6	34	9	347	0.5	0.2	0.006	0.05	3.2	160000
INPA 3a	Alumot Downstream	25/5/09	15	140	30	1985	1.7	0.2	0.15	1.1	61.6	68000
INPA 3a	Alumot Downstream	26/10/09	9	52	33	2191	2	0.2	0.12	13	10.2	800
INPA 5	Kibbutz Beit Zerra	25/5/09	11.4	148	52	2169	1.2	0.2	0.17	1.2	51.4	5900
INPA 5	Kibbutz Beit Zerra	26/10/09	15	42	12	2234	2.4	0.3	0.13	5.5	7.5	78000
INPA7	Dalhamiya Bridge	25/5/09	23	150	77	2056	3.6	0.2	0.77	0.05	50.8	1100
INPA 7	Dalhamiya Bridge	26/10/09	16	44	71	2269	1	1.1	1.2	0.05	6.7	7200
INPA 8	Gesher	25/5/09	7.3	144	38	1773	2.3	3.1	1	0.05	52.4	1100
INPA 8	Gesher	26/10/09	18.6	56	20	2162	2	1.6	3.1	0.05	3.55	900
INPA8a	Sheikh Hussein Bridge	25/5/09	8	166	79	1489	1.4	2	0.24	0.05	62.9	100
INPA8a	Sheikh Hussein Bridge	26/10/09	24	52	68	1964	1.5	2	0.58	0.05	10.6	2300
INPA 9	Shifa Pumping Station	25/5/09	5	142	123	1978	0.5	0.2	0.04	0.05	47.3	270
INPA9	Shifa Pumping Station	26/10/09	16	58	70	2021	3	1	0.3	0.05	13.2	1100
INPA10	Adam/ Damya Bridge	25/5/09	1.2	135	33	2943	1.2	9.7	0.08	0.05	51.5	550
INPA10	Adam/ Damya Bridge	29/10/09	3	72	285	2163	5.3	3.9	0.03	0.05	18	1800
INPA11	King Hussein Bridge	25/5/09	1.6	120	14	3899	0.3	9.9	0.04	0.05	48.3	190
INPA11	King Hussein Bridge	29/10/09	3.3	60	93	2248	0.5	4	0.07	0.05	8.8	520
INPA12	Baptism Site	25/5/09	0.4	114	165	4041	0.16	9	0.03	0.05	48.5	80
INPA12	Baptism Site	29/10/09	4.5	68	87	2282	3	4.2	0.05	0.05	9.1	750

* Cl will change according to geographical area / stream basin ** Israeli standard for TN (total nitrogen) is 10 mg/lit

Further, water quality data was supplied to FoEME by the Israeli Nature Parks Autority (INPA) which undertakes sampling at 11 stations the length of the LJR twice annually. Water quality parameters for 2009 are presented in Table 5.

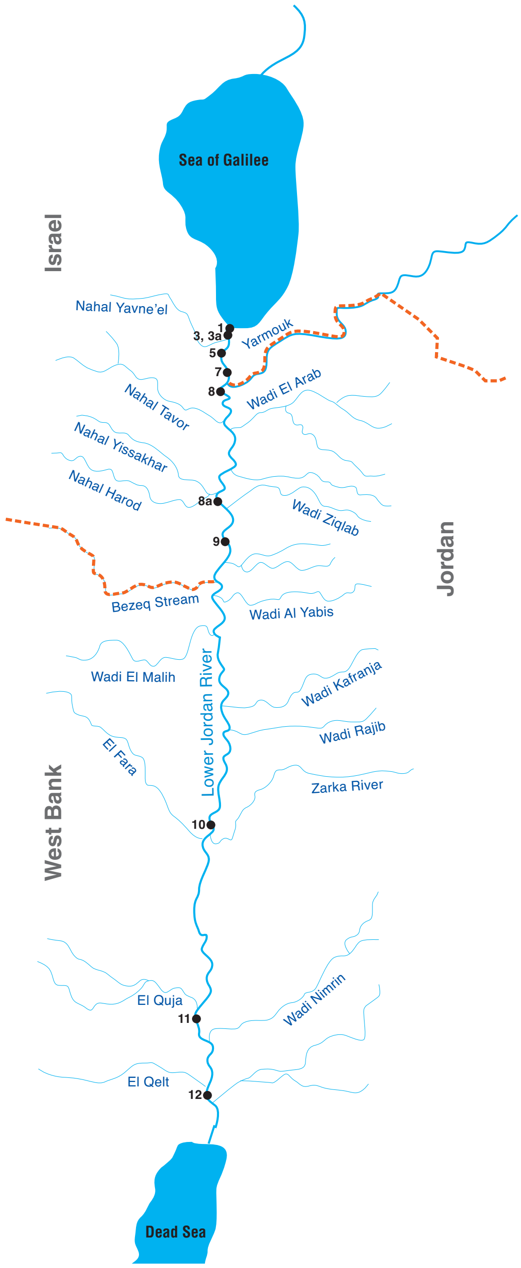

Figure 18. Map of the Israeli Nature Parks Authority's sampling points along the Lower Jordan River.

One distinctive feature in this data set is the effect of the Alumot dam (Figure 19), which is located approximately 1.5 km downstream of the Sea of Galilee and blocks the river's natural flow. Downstream of the dam partially treated sewage water (Figure 20) and saline spring water (Figure 21) is diverted into the river. Israel Nature Parks Authority (INPA) Station 3 and INPA Station 3a (Table 5) correspond to the points upstream and downstream of the Alumot dam respectively. The dramatic change in water quality upstream and downstream of the Alumot dam can be clearly seen in Table 5 and Figures 19 to 26.

Figure 19. Alumot Dam on Lower Jordan River. *Source: Jessica Griffin.*

Figure 20. Sewage flowing into the LJR downstream of Alumot dam. *Source: Jessica Griffin.*

Figure 21. Saline spring water being channeled into the LJR; a – channel parallel to LJR upstream of Alumot dam, b- saline waters flow into LJR downstream of Alumot dam. *Source 21 a: Elizabeth Ya'ari. Source 21 b: Jessica Griffin*.

As seen in Figure 22, BOD values start at 15 mg/L downstream of the Alumot dam and continue to decrease along the path of the river except at INPA Station 7 (Yarmouk convergence with the LJR) where the BOD jumps to a higher value than observed at the Alumot dam. As water approaches the Dead Sea, the BOD value drops down to levels similar to those observed upstream of the Alumot dam. Pristine rivers and moderately polluted rivers have BOD values that are below 1 mg/l and from 2 – 8 mg/l respectively; efficiently three-stage treated municipal sewage compared to untreated sewage have BOD values below 20 mg/l and from

200 – 600 mg/l respectively (Sawyer et. al, 2003). Based on these standards; the LJR upstream of Alumot dam (INPA Station 3) is considered a pristine river; downstream of Gesher/ Jisr Al Majami Bridge (Site 1/ INPA Station 8) is considered to be a moderately polluted river; and in between the two sites is considered to be a river polluted with municipal sewage.

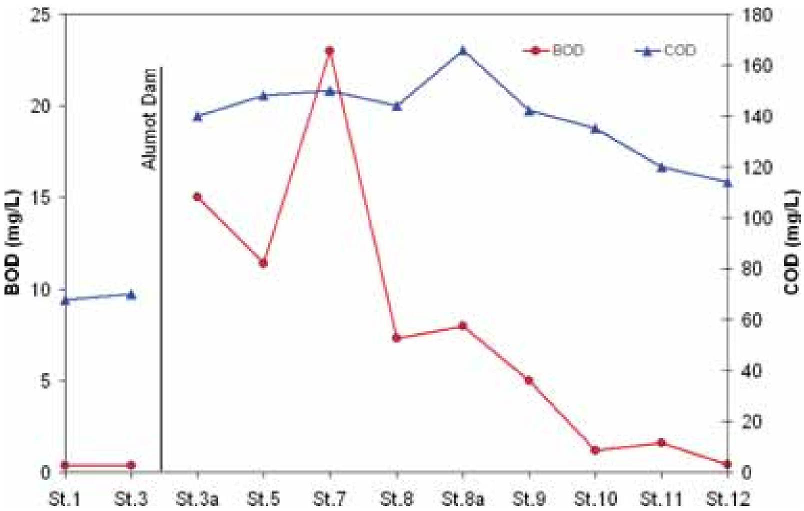

Figure 22. BOD and COD values along the LJR on May 25th, 2009*.*

Figure 23 shows the values of chloride (Cl) and total phosphorous (TP) obtained along the LJR. In general, the presence of chloride is an indication of saline water, while the presence of phosphorous is an indication of fertilizers or agricultural runoff and poorly treated sewage. The high levels of chloride at INPA Station 3a are a result of the saline spring waters diverted to the LJR at that point. The level of chloride after that point starts to drop until it reaches Beit Shean/ Sheikh Hussein Bridge (Site 3/ INPA Station 8a) after which it starts to increase steadily all the way to the Dead Sea. The gradual decrease in chloride concentration and the sharp rise in total phosphorous concentration upstream of INPA Station 7 are similar to the findings of Segal-Rozen et al., (2004) and are most likely attributed to a non-point pollution source, which enters the LJR through the local shallow groundwater aquifer and is influenced by agricultural return flows. The Segal-Rozen et al., (2004) study showed that the Yarmouk River acts as the non-point source for the LJR up to this point (INPA Station 7). As a result, the high chloride concentration at INPA Station 3a starts to be diluted as it flows past sites INPA Stations 5, 7, 8 and 8a. The decreasing concentrations of Cl cease downstream of INPA Station 8a and start to increase sharply all the way to INPA Station 12. This is an indication of a non-point source of chloride to the river; most likely saline or brackish ground water. The concentration of total phosphorous (TP), as seen in Figure 23, jumps sharply downstream of INPA Station 5, indicating the entrance of agricultural runoff into the river. The decrease of TP downstream is probably due to the up-take of phosphorus in the river by algae and other vegetation growth in the aquatic system.

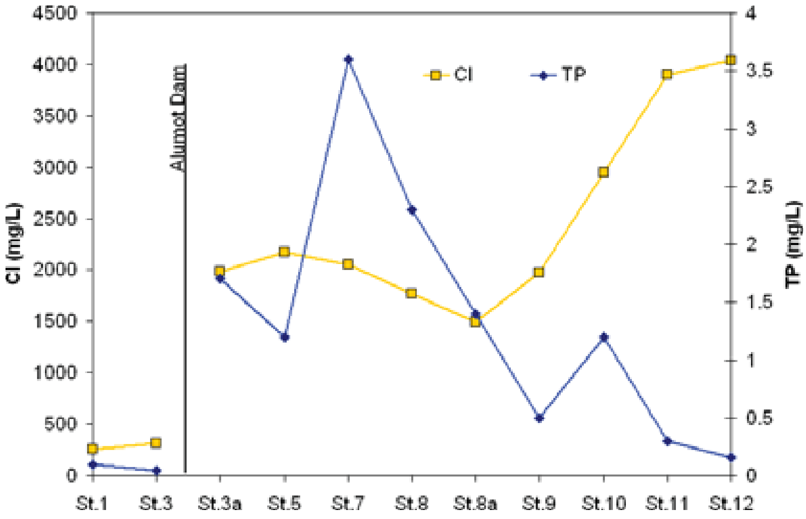

Figure 23: Chloride (Cl) and total phosphorus (TP) along the LJR on May 25th, 2009.

Figure 24 shows the concentration of the different nitrogen forms (N, NO_3, NO_2, NH_4, and TN) in the LJR. The Nitrate (NO_3) concentration increases while the Ammonium (NH_4) concentration decreases from INPA Station 3a to INPA Station 8. This indicates that nitrification is predominant in this reach of the river. Higher rates of nitrification can also be seen at INPA Station 10 and downstream.

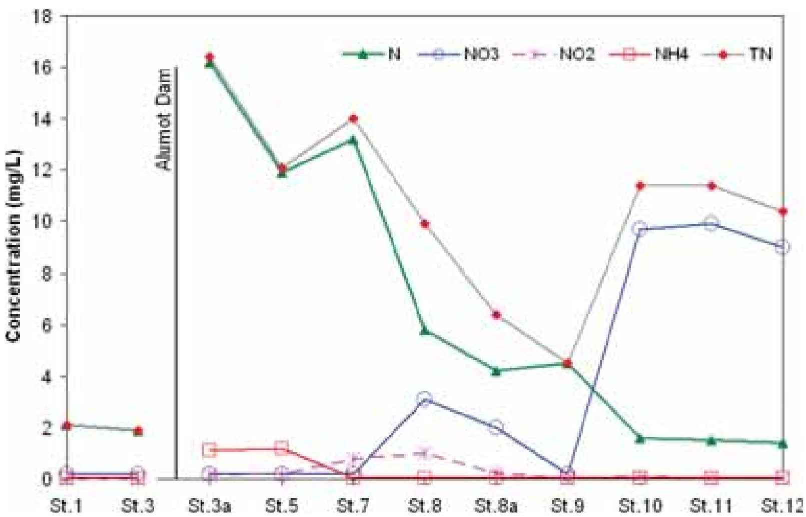

Figure 24. Nitrogen (N), Nitrate (NO_3), Nitrite (NO_2), Ammonium (NH4), and Total Nitrogen (TN) values along the LJR on May 25th, 2009.

Figure 25 shows the levels of fecal coliform (fecal bacteria) entering the LJR downstream of Alumot dam. In general, increased levels of fecal coliform provide a warning of failure in water treatment or possible contamination with pathogens. Fecal coliform can be harmful to the environment. Aerobic decomposition of this material can reduce dissolved oxygen levels if discharged into rivers or waterways. This may reduce the oxygen level enough to kill fish and other aquatic life. The current United States Environmental Protection Agency recommendation for fecal coliform levels in body-contact recreation is fewer than 100 colonies/100 mL; for fishing and boating, fewer than 1000 colonies/100 mL; and the drinking water standard requires less than 1 colony/ 100 ml.

Fecal coliform levels in the LJR (Figure 25) indicate that the LJR is not suitable for recreation, fishing or boating from INPA Stations 3a to 7. The fecal coliform count drops significantly (below 1000 count/100cc) by the time water reaches INPA Station 7 (Dalhamiya Bridge above the Yarmouk junction). A number of factors might be acting together and resulting in the fast reduction of bacteria count such as dilution, aeration, and/or microbial degradation. A closer look (Figure 26) at the values of fecal coliform downstream of INPA Station 7 indicates another source of pollution just downstream of Beit Shean/ Sheikh Hussein Bridge (Site 2/ INPA Station 8) of less significance.

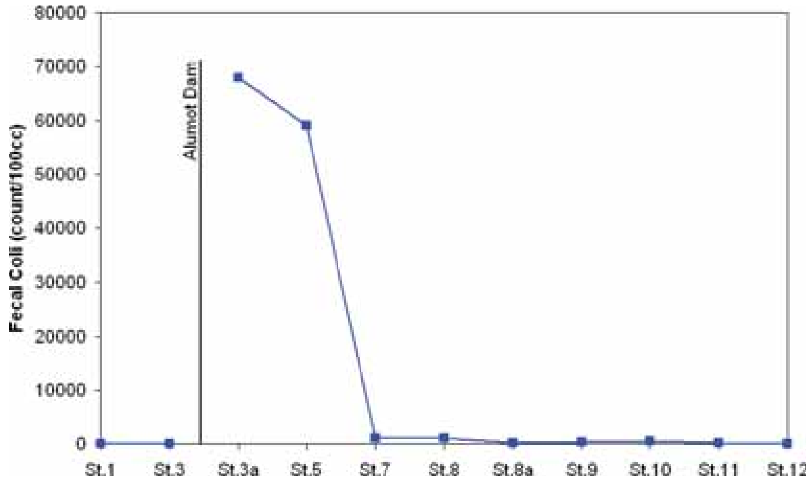

Figure 25. Fecal coliform values along the LJR on May 25th, 2009.

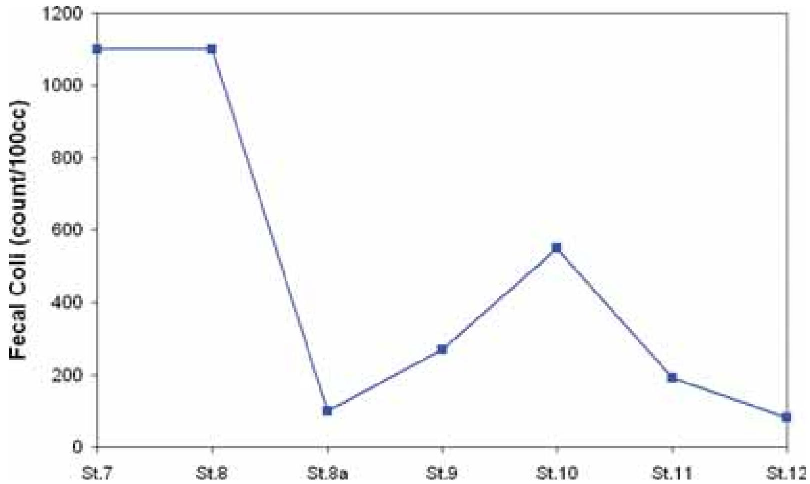

Figure 26. Fecal coliform values along the LJR on May 25th, 2009.

4.2.3 Macroinvertebrate assemblage

A summary of the macroinvertebrate assemblage data recorded in the Israeli segment of the LJR is presented in Table 6. The data indicates that 10 years after the dramatic reduction in LJR flow, the macroinvertebrate community of the river was still relatively rich. Ortal (1976) recorded 26 taxa in the river segment between Alumot Dam and Dalhamya Dam (Table 6, column a). From Dalhamya Dam to the mouth of the Yarmouk River, a river segment that borders Site 1 of our study, the macroinvertebrate species was even richer and included 33 taxa (Table 6, column b). Twenty two years later, Gasith and Hershkoviz recorded only 12 taxa at the same river segment (Table 6 column c). Furthermore, the 1976 macroinvertebrate community study included species that are characterized by higher habitat quality demands such as caddisflies (Trichoptera) and mayflies (Ephemeroptera). Today these two families have almost completely disappeared from the Israeli segment of the LJR.

Table 6. Comparison of macroinvertebrate taxa biodiversity at different sites (Site 1 to 5) along the LJR. a – From Alumot Dam to Dalhamya Dam (Ortal 1976); b – From Dalhamya Dam to the mouth of the Yarmouk River (Ortal, 1976); c – From Alumot Dam to Dalhamya Dam (Gasith and Hershkoviz, 2006). For a complete listing of species observed at each site and reference site, see Appendix 3, Table 12.

Site	a	b	c	1	2	3	4	5
Taxon richness	26	33	12	15	14	13	9	9

4.2.3.1 Current records of macroinvertebrate biodiversity

Taxa occurrence in the different sampling sites (April and July samples combined) is presented in Table 6. Taxa richness in all sites ranged from 9-15 taxa per site. Site 1 (Gesher/ Jisr Al Majami Bridge) was the richest in taxa while Sites 4 and 5 (Allenby/ King Hussein Bridge and King Abdullah Bridge respectively) were the poorest.

The amphipod *Echinogammarus veneri*s (Figure 27) was the only species found at all sites, while the snails *Melanoides tuberuculata* (Figure 28a) and *Theodoxus jordani* (Figure 28b) which are typical to the shores of the Sea of Galilee, and the dragonfly *Crocothemis erythrea* were found in 4 out of our 5 sampling sites. We should also mention hundreds of adult individuals of the dragonfly *Brachytemis teucostita* were recorded in Site 2 in July.

Figure 27. *Echinogammarus veneri*s, the only species found in all along the Lower Jordan River. *Source: Sarig Gafny.*

Overall we recorded 21 taxa along the LJR (all sites pooled together). This richness is slightly lower than the richness recorded by Ortal (1976) in a section of the LJR north of our survey's Site 1. However, the river sections that we studied were almost five times longer than the section studied by Ortal and included a much wider gradient of environmental conditions. Therefore we suggest that on a spatial scale, a comparison of the data reported by Ortal (1976), and by Gasith and Hershkoviz (2006) with individual sites included in our study is more relevant. Taxa richness per site recorded in our survey was similar to the richness recorded by Gasith and Hershkoviz, (2006) in the northern most section of the LJR but it was only 50% of the richness reported by Ortal during the seventies.

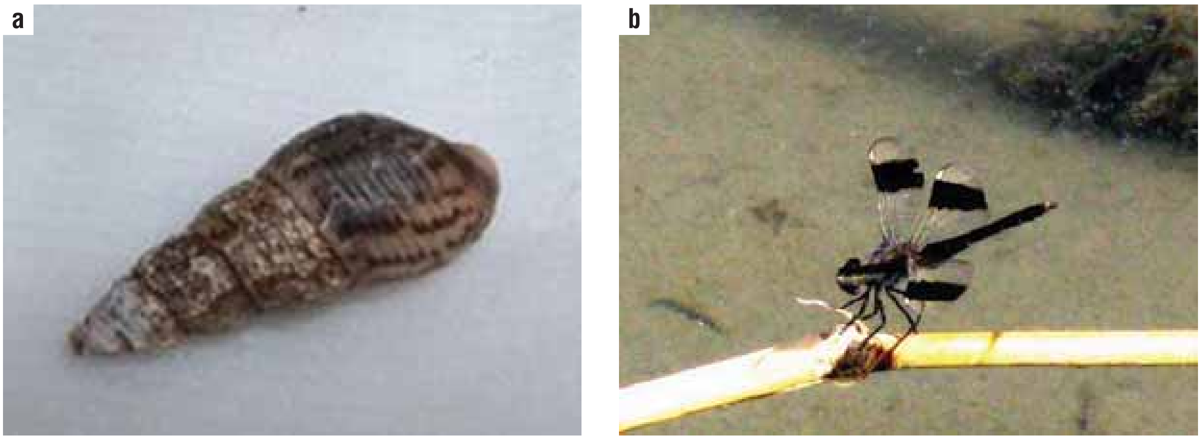

Figure 28 a. *Melanoides tuberuculata*, a snail found in Sites 1-4 along the Lower Jordan River. b. The dragonfly *Brachytemis teucostita* which was recorded in large numbers in Site 2 in July 2009. *Source: Sarig Gafny.*

Several taxa, such as *Tubifex* sp. and *Chironomus* sp. were found only in the upper slow running section of the LJR, while others such as the blue dragonfly *Orthetrum chrysostigms* were found only in faster running water sites.

4.2.3.2 Comparison of current macroinvertebrate records with reference sites

Reference conditions are a critical element of assessing the quality or health of the aquatic system (Barbour et al., 2000). However, whenever historical data is not available, the simplest approach is to use field data of reference sites along the same river (Hughes, 1995, Schmutz et al., 2000). The establishment of reference conditions is based on identification of minimally disturbed sites that represent the best physical, chemical and biological conditions attainable (Barbour et al., 2000). Two of the reference sites, selected for our study, are tributaries of the LJR. The Upper Jordan River (UJR, Table 7) currently fits Lynch's (1858) description of the LJR prior to its perturbation. The lower section of the Yarmouk River (YA, Table 7) located adjacent to Site 1 was sampled in 1997, when its flow was still relatively high (Water Resources in Jordan, 2008). These two reference sites are characterized by high velocities. However, the water salinity of these sites is considerably lower compared to the current salinity of the LJR thus a third reference site, Ein Faska/ Einot Zokim (EZ, Table 7), located adjacent to Site 5, was selected. The site is characterized by slower velocities and includes also pool habitats. This reference site was selected for inclusion because its water salinity is relatively high, though lower than the salinity of our southern sampling sites.

Table 7. Comparison of macroinvertebrate taxa composition for reference sites and at Sites 1-5 along the LJR. Reference sites: Upper Jordan River (UJR) from Benot Ya'akov Bridge to the Sea of Galilee (Gafny, 2008); the lower section of the Yarmouk River (YA) (Gafny, 1997); Ein Faska/ Einot Zokim (EZ) (Gafny, 2006). For a complete listing of species observed at each site and reference site, see Appendix 3, Table 13.

Site	UJR	YA	EZ	1	2	3	4	5
Taxa richness	33	45	34	15	14	13	9	9

Comparison of our sampling sites with the reference sites indicate that the macroinvertebrate taxa richness in the LJR is at least 50% lower than in the reference sites (Table 7). If we compare the reference sites with Sites 1 and 2 (the closest sites to UJR and YR) pooled together we detect a 45% - 65% reduction in the biodiversity of the LJR. If all LJR sites are pooled together, the current taxa richness is still less than 66% of the richness recorded in the reference sites.

Here again, sensitive taxonomic groups such as caddisflies (Trichoptera) and mayflies (Ephemeroptera), which were reasonably abundant in the reference sites and sites adjacent to the LJR (e.g. Eun Zafuah Sinai,

2005) were completely absent from the LJR itself. This absence is especially alarming since presence of these taxonomic groups often serve as indicators for good integrity and health of stream ecosystems (Bauernfeind and Moog, 2000). Another alarming finding of our observational study is that even less sensitive groups, such as water beetles (Coleopterans), which had a considerable representation at the reference sites, were completely absent from the LJR. The relatively high occurrence of dragonflies (Anisoptera) in the LJR was mainly of adult specimens, while larvae were rarer. The more sensitive damselflies (Zygoptera), which are very common in streams in Israel were hardly recorded. This may further indicate the poor condition of the LJR aquatic ecosystem.

4.2.4 Botanical biodiversity

A comparative analysis of vegetation distribution and abundance was undertaken to determine the current botanical biodiversity and degree of community structure change of the LJR as an indication of the river ecosystem health. Over the two sampling periods, April (spring) and July (summer) 2009, at each of the five study sites along the LJR (Figure 1) a botanical inventory survey was conducted recording the plant species observed. An inventory survey was also conducted at a reference site on the Yarmouk (Reference site 2, Figure 1) during July when access was available.

The observational survey study showed that there was a significant narrowing of the riparian belt and an overall reduction of biodiversity in the floral community of the LJR. The summary of plant species observed at the five sampling sites are indicated in Table 8 where Site 1 represents the highest number of species and Site 5 represents the poorest level of species richness. For a detailed list of species identified at each site as well as their abundance (Fragman, 1999) please see Appendix 4, Table 14.

Table 8. Plant species richness at Sites 1-5 along the LJR.

Sites	1	2	3	4	5
Species Richness	82	69	50	50	29

In comparing historical data with sampling undertaken in this study, it is clear that the reduced flow and flood frequency as well as the large increase in salinity levels have affected the presence or absence of indicative species (e.g. Eherlich and Ortal, 1978).

Today, the dominate species are primarily saline tolerant, resulting in the elimination of species sensitive to high salinity. For example willows were found to be extinct in the LJR, poplar trees which dominated the LJR riparian forest became rare while *Tamarix* sp., which is more resistant to salty conditions, became dominant (Figure 29). Similarly, the more saline tolerant reed took over the place of bulrush – in some areas covering the channel completely.

Figure 29. Resistant to the salty conditions, *Tamarix* sp. have become dominate in the LJR. *Source: Banan Al Sheikh*.

Many species previously identified along the LJR were found to be extinct along the banks of the LJR including *Nerium oleander*, *Laurus nobillis*, *Salvadora persica*, *Aciaca* sp., *Typha* and *Cyperus* and *Foeniculum vulgare*. Others including *Salix* sp., *Populus euphratica*, *Asparagus* sp., *Glycyrrhiza* sp., and *Cynanchum* sp. were found to be extremely rare. Furthermore, invasive species not identified in previous surveys were identified including *Acacia saligna*, *Prosopis juliflora* and *Parkinsonia aculeate* including large amounts of *Phragmites* sp. (Figure 30).

Figure 30. Large amounts of *Phragmites* sp., an invasive species, were identified in the LJR. *Source: Banan Al Sheikh*.

Several of the species found to be rare or extinct along the LJR remain common along the banks of the Yarmouk including *Salix* sp., *Populus euphratica* and *Nerium oleander* (Figure 31).

Figure 31. *Salix* sp. growing along the Yarmouk River. *Source: Banan Al Sheikh*.

5. Discussion

5.1 Defining the gaps between pre- and post perturbation conditions of the Lower Jordan River

The first step needed in order to define the water needs of the LJR is to define the gaps between pre- and post perturbation condition of the river's ecosystem. Table 9 summarizes some pre- and post- perturbation characteristics of the LJR.

Table 9. Comparison of selected pre- and post-perturbation habitat characteristics of the LJR

	Pre-perturbation	Post-perturbation (2009)
Annual Discharge mcm/year	1,200-1,400 (Ben Ariyeh,1965; Klein 1985; Salameh, 1996)	20-30 (Current study)
Width of the wet channel (m)	25-65 (Lynch 1858) 50-100 (Hassan and Klein, 2002)	7-25 (Current study) 10-30 (Hassan and Klein, 2002)
Water depth in base flow conditions (m)	0.6-3.7 (Lynch 1858)	0.3-2.5 (Current study)
Water Velocity in base flow conditions (m/sec)	1-6 (Lynch 1858)	0-0.5 (Current study)
Flood frequency	A minor flood (50 m3/sec) every year. A major flood (600-800 m3/sec) once in 6-12 years (Klein, 1985. Hassan and Klein, 2002)	Low
Dominant substrate	Boulders and rocks (Lynch 1858)	Stones – clay (Current study)
Sinuosity	High (Lynch 1858; Klein, 1985); 3.15 (Glick, 1946)	Decreasing (Klein, 1985); 2.07
Water salinity	More saline than UJR or the YR; freshwater inputs from the Sea of Galilee and the YR	4 ppt (northern section – spring) to 12 ppt (southern section summer) (Current study)
Organic pollution	None	BOD: 8 mg/l (northern section; 1.5 (southern section (INPA 2009)
Nutrient inputs	Natural	High NO_3 concentrations (up to 10 mg/l) in southern section (INPA 2009)
Dominant habitat type	Rapids, cascades & falls (Lynch, 1858)	Pools and runs (no rapids or falls) (Current study), with long sand bars (Hassan and Klein, 2002)

	Pre-perturbation	Post-perturbation (2009)
Riparian vegetation	Wide belt - dominated by willows, poplar trees, Tamarix, reed, bulrush (Lynch, 1858; Eig 1927)	Narrow belt - dominated by tamarix and reed (Current study)
Submerged vegetation	Eurasian milfoil, Sago pondweed, coontail, and spiny naiad (Eig, 1927).	None (Current study)
Macroinvertebrate taxa richness	26-33 taxa per site (Ortal, 1976) 33-45 taxa per site (reference sites; Gafny, 1997. 2006, 2008)	9-15 taxa per site (Current study)
Sensitive species (caddisflies and mayflies)	Many species	None (Current study)
Less sensitive species	Abundant	Rare (Current study)

Table 9 clearly indicates the major gaps between the non-regulated and regulated LJR. The pre-perturbation characteristics depict a healthy and self sustained river ecosystem which is reflected by the rich biodiversity and stable conditions, whilst the post-perturbation characteristics point towards a degraded and minimally persistent river ecosystem.

5.2 Ecological consequences of the gaps between pre- and post perturbation conditions and the effect on the structure and function of the Lower Jordan River ecosystem

The major decline of the LJR since it has become regulated has resulted in many direct and indirect consequences which dramatically changed the river habitat structure. Statzner and Higler (1986) suggest that physical characteristics of flow (i.e. stream hydraulics) are the most important environmental factor governing the zonation of stream benthic inhabitants (macroinvertebrates). Less water in the LJR has caused changes to the stream channel, resulting in a narrower and more canalized river ecosystem (Hassan and Klein, 2002). Less water has also resulted in much slower velocities. Fast flow habitats such as water falls, cascades, rapids and in most cases even riffles, have completely vanished and with them all species adapted to fast flow conditions (Statzner and Higler, 1986). The river is now dominated by medium (in the southern segment) or slow velocity (in the northern section) habitats.

The reduction in water flow resulted in a major change in the LJR sediment load. Slower velocities carry far less sediment, and the water velocity can only carry fine suspended sediments (Inbar and Schick 1979; Wiens, 2002) with a low settling velocity. Reduced water velocity results in a major reduction in erosive and depositional process, and in recent years the meandering activity of the LJR has been sharply reduced except for the region between King Abdullah Bridge and the Dead Sea (Hassan and Klein, 2002). The formation of streamside lentic water bodies (such as deserted meanders) has stopped, and such habitats have disappeared from the river's ecosystem. The seasonal connectivity between the river's main channel and these lentic habitats have been removed (Wiens, 2002; Woodward and Hildrew. 2002) resulting in the loss of unique community compositions of both plant and animal species specifically adapted to these habitats (Wiens, 2002).

The discharge reduction in the LJR is apparent not only in the decline in the river's base flow but also in the flow regime. Unfortunately, there is no data on the past and current occurrence of small scale floods. Large scale floods have occurred even after the river was regulated; in 1969, 1992 and 2003. River regulation has only a minor effect on the occurrence of large scale floods although it may affect the peak discharge during major floods (Petts and Gurnell, 1984). However, barrage building impoundment and diversion of many of the LJR tributaries has significantly reduced the occurrence of minor floods (Greenbaum, et al., 2006, Qtaishat, 2008). Since floods have a major effect on the structure and function of river ecosystems (e.g. Schumm, 1973), the reduction in minor flood frequency in the LJR clearly impaired the ecological integrity of the river.

The reduced flow and flood frequency affects not only the stream channel itself but also the riparian forests that develops along the LJR banks. In the past, the river was known for its wide and dense riparian forest which was fed by the stream water and flashfloods. Flow reduction has lead to a major reduction of the riparian vegetation belt width (Fisher et al., 1998). Additionally, the low frequency of spates allow reed to develop along the water line. Originally, when flood frequency was higher, the energy of the flood water allowed only woody trees (Populus, Tamarix) to develop near the river banks, while less woody plants such as reed have developed several meters above the water line.

Another effect of flow reduction was the deterioration of the LJR water quality. A negative linear relationship between river discharge and salinity was reported for the LJR (Klein 2005). The reduction of freshwater inputs from the two main water sources of the river, the Sea of Galilee and the Yarmouk River, sharply reduced the dilution effect of salty inputs into the LJR. The diversion of the Sea of Galilee's salty springs into the LJR, following the establishment of the Israeli National Water Carrier, further augmented this problem which resulted in the elimination of species sensitive to high salinity.

Increased salinity is without question the main water quality problem in the LJR (Farber et al., 2005); whereas nutrient (except Nitrate) and organic pollutants were found in concerning concentrations only in the northern river segments (Table 5). The combination of organic enrichment and very slow velocities lead to frequent planktonic algal blooms observed both in our spring and summer sampling. This in turn increases water turbidity and prevents the development of submerged aquatic plants, though other habitat conditions are suitable for their development.

5.3 Recommendations and proposals - rehabilitation scenarios

A growing consensus among water experts is that in order to maintain a healthy freshwater ecosystem it is important to restore natural flows around which the natural habitats and its inhabitants (flora and fauna) can develop (e.g. Poff et al., 1997; Bumm and Arthington, 2002). There are five fundamental components of a river's hydrological regimes (Richter et al., 1996):

(1) Magnitude of flow (discharge)
(2) Timing of flow (seasonality)
(3) Frequency of various flow events (floods and droughts)
(4) Duration of flow events
(5) Rate of change between types of flows (flow variability)

The results of this study, as summarized in section 5.2, indicate that all these components have been altered in the LJR and thus, should be addressed in any restoration program. Another important factor in any restoration program is water quality (United Sates National Research Council, 1992, Carr and Rickwood, 2008). In the case of the LJR this is important with regards to salinity and to organic pollution, both which have sharply increased in the last 50 years (Farber at al., 2005).

Water quantity and quality required for the rehabilitation of the LJR is largely dependent on the desired level of river restoration, which in turn, may vary from preserving the current situation to full ecological restoration. Different restoration alternatives require different flows and water qualities. These five scenarios present the range of rehabilitation/restoration options.

5.3.1 "Take No Action" scenario

Under the "*Take No Action*" scenario the average annual discharge to the LJR remains in its current level. The frequency of minor floods remains very low, giving the stream ecosystem little chance to "reset" itself. The main source for base-flow water flowing in the LJR will continue to be sewage, low quality effluents, agricultural and fishpond runoff and saline water. The dominant habitat in the northern section of the LJR will remain as a pool dominated river ecosystem, with very low velocities. The biodiversity in the LJR will remain very low and the ecosystem integrity and health will continue to be very poor.

5.3.2 "Full Restoration" scenario

On the opposite end of the spectrum of possible interventions, the "*Full Restoration*" scenario aims to produce a full recovery of the structure and function of the LJR ecosystem. Under this scenario the river is expected to fully return to its pre- perturbation state. The restoration project will achieve the following five objectives (modified from National Research Council, 1992):

1. **Restoration of the natural range of water quality:** In the LJR this indicates full removal of point and non-point pollution sources as well as dilution of the natural saline inputs of the LJR watershed by large inputs of freshwater from the Sea of Galilee and the Yarmouk River. Salinity of the northern segment of the LJR should not exceed 250 ppm in the winter and 350 ppm in summer and in the southern section it should not exceed 750 ppm. The saline water of the Sea of Galilee's salty springs, which are currently diverted into the LJR, should undergo desalinization and be returned to the lake, and the brine should be removed from the Jordan River system. Since the salinity of the Sea of Galilee is lower than it was prior to the establishment of the Israel National Water Carrier, the quantities of lake water needed to achieve water quality goals are smaller than the original pre-perturbation flow. Water clarity should be increased to a level that will allow the development of submerged vegetation in pool habitats. Under the "*Full Restoration*" scenario the use of high quality effluents, agricultural runoff or fishpond runoff is not acceptable.

2. **Restoration of the natural flow regime and sediment transport** (including the seasonal fluctuations, as well as the annual to decadal pattern of floods). This implies that approximately 700-750 mcm per year should be released from the Sea of Galilee into the LJR and approximately 500-600 mcm per year should be released from the Yarmouk River on average. The bottom line under the "*Full Restoration*" is that 100% of the original annual flow (i.e. 1,200 – 1,400 mcm per year) should be released into the LJR according to the original pre-perturbation monthly discharges. Under this scenario the original flood regime should also be restored. The "*Full Restoration*" scenario requires at least 3 minor floods (c.a. 20-50 m^3/sec) per year. This can be achieved by fully opening the dams for 24 hours, three times every winter and 1 major flood (c.a. 200 m^3/sec) every 3 years (Hassamn and Klein, 2002).

3. **Restoration of the natural channel geometry and stability** (if this is not achieved under 2.). In the LJR this implies that the original habitats of rapids, cascades and falls should be reconstructed in the river. If the original pre-perturbation flow is restored the original meandering activity of the LJR should also be naturally re-established. The stream channel should widen to 50-70m (including at the southern segments of the LJR). Riverside water bodies should be restored and the riparian zone should be frequently flooded during the winter following major flood events.

4. **Restoration of the structure and function of the original riparian plant community** (if this is not achieved under 2. and 3.) This includes reestablishment of the original width and nature of the vegetated belt of the Zohre area (Figure 32) including the replacement of Eucalyptus trees by *Populus cuphpratica* and *Salix acmopylla* which should dominate the riparian trees of the Zohre zone. The original frequency of appearance of bulrush and *Cyperus* should also be restored.

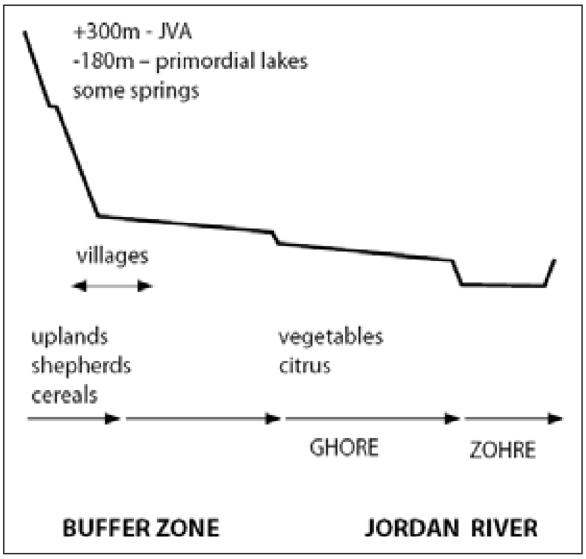

Figure 32. Ghore and Zohre of the LJR. *Source: Jordan Valley Authority*

5. **Restoration of native aquatic flora and fauna** including the original diversity of submerged macrophytes in slow running water. Restoring complex and diverse in-stream food webs to include all functional feeding groups and re-appearance of a high diversity of macro-zoobenthos, including sensitive taxa such as caddisflies and mayflies.

It is important to acknowledge that full restoration is seldom possible. Firstly, because of the on-going water shortage in the LJR region (Orthofer et al., 2007) the quantities and quality of the water required for full restoration are beyond the ability of the countries in the region. Secondly, our knowledge of what exactly the original pre-perturbation condition is limited. Thirdly, such restoration would mean modifying the physical and biological character of the reach (channel form, biological communities) so that they replicate the original state. This would involve changing all of the inputs and outputs (water quality and quantity, sediment, and organisms) from upstream, downstream and the riparian zone, to the pre-perturbation state. Because of the connections between the LJR and its catchment, in most situations this would only be possible if the entire river network, and most of the catchment surface, would also be restored. Clearly, this will probably not be possible. Even if the attempt was made, the changes that have occurred over the last 100 years may have been great enough to alter the river irreversibly.

5.3.3 “Partial Restoration” scenario

Under the “*Partial Restoration*” scenario the river is expected to return to most of its pre-perturbation state. This includes the following objectives:

1. **Significant improvement of the LJR water quality:** Full removal of point and non-point pollution sources. Decrease of the salinity in the northern segment of the LJR to less than 500 ppm in the winter and 750 ppm in summer. In the southern section of the LJR (Sites 4 and 5) it should not exceed 1,500 ppm. This could be achieved by partial dilution of the saline inputs by large quantities of freshwater, mainly from the Sea of Galilee and the Yarmouk River. The saline water of the Sea of Galilee’s salty springs which are currently diverted into the LJR should undergo desalinization and be returned to the lake, and the brine should be removed from the Jordan River system. The use of high quality effluents, agricultural runoff or fishpond runoff is not acceptable under this scenario.

2. **Partial restoration of the natural flow regime and enhancement of sediment transport** (including the seasonal fluctuations, as well as the annual to decadal pattern of floods). In the LJR the implication of this step is that at least 70% of the original annual flow (i.e. 600 – 800 mcm per year) should be released into the LJR. The "*Partial Restoration*" scenario requires at least 1 minor flood (c.a. 20-50 m^3/sec) per year. This can be achieved by fully opening the dams for 24 hours, once every winter.

3. **Partial restoration of the natural channel geometry and stability** (if this is not achieved under 2.). In the LJR this implies that in selected reaches of the river the width of the wet channel should reach 50-70 m in the northern section and 25-40 m in the southern section depending on the discharge. Some of the original habitat components such rapids, cascades and falls should be reconstructed in selected segments of the river while in other segments, the current pool habitat remain unchanged. The flow should be enhanced to a level that meandering activity of the LJR will be re-established, and the riparian zone will be flooded at least once a year during the winter following flood events.

4. **Restoration of the structure and function of the natural riparian plant** (if this is not achieved under 2. and 3.) This includes significant widening of the vegetated belt of the Zohre area including the replacement of Eucalyptus trees with *Populus cuphpratica* and *Salix acmopylla* which should dominate the riparian tree community of the Zohre zone. The frequency of appearance of bulrush and *Cyperus* should also be significant increased.

5. **Restoration of a stable aquatic flora and fauna** including presence of submerged macrophytes in pool habitats. Restore complex and diverse in-stream food webs to include all functional feeding groups and re-appearance of a highly diverse macro-zoobenthos community, including sensitive taxa such as, caddisflies and mayflies.

The implementation of the "*Partial Restoration*" scenario is possible; however the likelihood of this scenario being implemented is low. Firstly, because of the large amounts of high quality freshwater required for this scenario, which is higher from the annual water production of the Upper Jordan River. Secondly, because it requires major changes in the LJR watershed, including many land-use changes and the cooperation of other countries in addition to Israel, Jordan and Palestine.

5.3.4 "River Rehabilitation" scenario

Although restoration may be impossible, this does not leave a degraded LJR without hope. By improving the most important aspects of the LJR environment, we may create a river that, although only resembling the pre-perturbation condition, is nevertheless an improvement on the degraded river, and a valuable environment in its own right. Rehabilitation aims at creating a stable, functioning and healthy river ecosystem in the LJR. This includes the following objectives:

1. **Improvement of the LJR water quality:** Full removal of untreated point and non-point pollution sources. Only highly treated effluents, fish pond runoff and agricultural runoff, which comply with the Inbar water quality standard (Pareto, 2003) will be allowed into the river, providing that the total amount of effluents and fishpond releases will not exceed 25% of the total amount of base-flow running in the LJR. Decreasing the salinity of the northern section of the LJR to less than 1,000 ppm in the winter and 1,500 ppm in summer remains a basic objective of the "*River Rehabilitation*" scenario. In the southern segment, salinity levels of no more that 4,000 ppm should also remain a major objective. This could be achieved by partial dilution of the saline inputs by large quantities of freshwater, mainly from the Sea of Galilee and the Yarmouk River.

2. **Flow enhancement and restoration of the natural flow regime** (including seasonal fluctuations, as well as annual to decadal pattern of floods). To enhance flows and restore natural flow regimes in the LJR, at least 35% of the original annual flow (i.e. 300 – 400 mcm per year) should be released back into the LJR. The "*River Rehabilitation*" scenario requires at least one minor flood every other year. This can be achieved by fully opening the dams for 24 hours, once every two winters.

3. **Partial restoration of the natural channel geometry and stability** (if this is not achieved under 2.). In the LJR, this means that some of the original habitat components such rapids and cascades (but no waterfalls) should be reconstructed in the southern segments of the river while in the northern section, the current pool habitat remains unchanged. The flow should be improved to a level that some meandering activity of the LJR would also be reinstated. The stream channel should widen to 50-70 m at the northern section and 15-30 m in the southern segments of the LJR. The riparian zone should be flooded during the winter at least once every other year.

4. **Rehabilitation of the natural riparian plant community** (if this is not achieved under 2. and 3.) This includes the replacement of Eucalyptus trees by *Populus cuphpratica* and *Salix acmopylla* which should have a significant part of the Zohre riparian tree community. The frequency of appearance of bulrush and *Cyperus* should also be improved.

5. **Restoration of stable communities of aquatic flora and fauna** including presence of submerged macrophytes in pool habitats. Restoring complex and diverse in-stream food webs to include all functional feeding groups and reappearance of a diverse macro-zoobenthos community, including representatives of sensitive taxonomic groups such as caddisflies and mayflies.

5.3.5 "Flow Enhancement" scenario

The "*Flow Enhancement*" scenario aims at improving flow conditions without addressing water quality issues. This scenario is based on high quality effluent, as the main water source for the LJR. To achieve this goal the following objectives should be met:

1. **No change in the LJR water quality:** The main source for water in the LJR will remain as treated effluents which will be diverted into the river, as well as, fish pond runoff and agricultural runoff. The water salinity of the northern section of the LJR will remain at approximately 3,000 ppm in the winter and up to 4,000 ppm in summer. In the southern segment salinity should not exceed 10,000 ppm. This could be achieved by some dilution of the saline inputs by the treated effluents. The effluents should be treated to meet the Inbar quality standards for effluent release into stream.

2. **Flow enhancement and restoration of the natural flow regime** In the LJR, this would mean at least 35% of the original annual flow (i.e. 300 – 400 mcm per year) should be released into the LJR. Under this scenario the main source of water for the LJR will be treated effluents. This requires that high treated effluents will not be directed for agricultural use but rather will be diverted into the LJR. The flood frequency will remain in its current state.

3. **Partial restoration of the natural channel geometry and stability** (if this is not achieved under 2.). In the LJR this implies that some of the original habitat components such rapids and cascades (but no waterfalls) should be reconstructed in the southern segments of the river while in the northern section, the current pool habitat remains unchanged.

4. **Rehabilitation of the natural riparian plant community** (if this is not achieved under 2. and 3.) The width of the riparian belt should increase though the dominant species will remain *Tamarix* and reed. Eucalyptus trees in the northern and less salty section should be replaced by *Populus cuphpratica* and *Salix acmopylla*.

5. **Restoration of stable communities of aquatic flora and fauna.** Under this scenario a stable submerged macrophytes presence is not likely to develop in the LJR. In the northern, pool habitat, algal blooms are very likely. Taxa richness may include some fast flowing species but not species sensitive to high salinity.

5.4 Advantages and disadvantages for the rehabilitation scenarios

During the last hundred years, the situation of the LJR has deteriorated from bad to worse. The "*Take No Action*" scenario, describes the current attitude of the neighbouring countries to this unique natural resource. However, the implications of this attitude are severe (Bromberg, 2008) and this attitude can not be tolerated or accepted any longer.

The major obstacle towards the rehabilitation of the LJR is the availability of large enough resources of high quality water. A summary of the water quantities and qualities required for the different LJR rehabilitation scenarios is presented in Table 10.

Table 10. Summary of flow and water quality requirements in the different scenarios as presented in sections 5.3.1-5.3.5 (minor flood = 20-50 m^3/sec; major flood = 200 m3/sec).

Scenario	Required Flow	Required Quality
Take No Action	Less than 100 mcm/ year on average	Salinity: 3000-4000 ppm Mostly effluents, agricultural and fishpond runoff
Full Restoration	1,200 – 1,400 mcm/ year 3 minor flood/Y 1 major flood every 3 years	Salinity: 250-350 ppm No effluents, agricultural or fishpond runoff
Partial Restoration	600 – 800 mcm/ year 1 minor flood/Y	Salinity: 500-750 ppm No effluents, agricultural or fishpond runoff
River Rehabilitation	300 – 400 mcm/ year 1 minor flood/2Y	Salinity: 1000-1500 ppm High quality effluents, agricultural and fishpond runoff up to 25% of baseflow
Flow Enhancement	300 – 400 mcm/ year 1 minor flood/2Y	Salinity: 3000-4000 ppm Mostly effluents, agricultural and fishpond runoff

We conclude that although the highest ecological integrity and the best ecosystem health is achieved under the "*Full Restoration*", water quantities required for full restoration are beyond the ability of this water poor area. Thus, the likelihood that full restoration will indeed take place is very low. "*Partial Restoration*" is more feasible. It also requires large amount of water (at least 600 mcm per year, however, a common effort of all countries in the region, and maybe even an international effort, may make this scenario possible. The advantages of the "*Partial Restoration*" scenario are almost similar to those of "*Full Restoration*" (Table 10) but with 30 to 40% less water resources.

The highest likelihood is for the "*River Rehabilitation*" scenario. Under this scenario, many of the LJR rehabilitation objectives are fulfilled (Table 11). In this scenario, the current LJR flow is more than tripled. However, water quantities of 300 – 400 mcm per year, as are required in this scenario, are within the abilities of the adjacent countries. Based on the high self purification capability of the LJR the "*River Rehabilitation*" scenario allows inputs of up to 25% of the annual base-flow to be high quality effluents, agricultural runoff or fishpond runoff, providing that the salinity and water quality standards are met. This further reduces the pressure to provide scarce resources of high quality water (Venot et al., 2008). Although restoration of the ecosystem health and integrity is not fully achieved under the "*River Rehabilitation*" scenario, many disturbances are removed from the river ecosystem, and the level of ecological integrity and health expected is fair to high.

Table 11. Summary of the advantages and disadvantages of the different scenarios as presented in sections 4.3.1-4.3.5.

Scenario	Advantages	Disadvantages
Take No Action	1. No economic cost 2. No need to "give up" rare water resources 3. No need for major land-use changes in the LJR watershed	1. No removal of disturbances 2. No recovery of the LJR structure and function 3. Poor biodiversity 4. Poor ecosystem integrity and health
Full Restoration	1. Removal of all disturbances 2. Full recovery of the LJR structure and function 3. Recovery of biodiversity 4. High ecosystem integrity and good ecosystem health are acquired	1. Requires large quantities of high quality water resources, which are not readily available in the region 2. Requires major changes of land use practices in the LJR watershed and in the river corridor 3. Very costly 4. Feasibility is low
Partial Restoration	1. Removal of most of the disturbances 2. Most of the LJR structure and function is restored 3. Recovery of biodiversity 4. High ecosystem integrity and good ecosystem health are acquired 5. Requires high but achievable resources (both economic and water)	1. Requires large quantities of high quality water resources, which are not readily available in the region 2. Requires some changes of land use practices in the LJR watershed and in the river corridor 3. High cost
River Rehabilitation	1. Removal of many disturbances 2. Part of the LJR structure and function is restored 3. Recovery of biodiversity (but less than in restoration) 4. Fair to high ecosystem integrity and good ecosystem health are acquired 5. Less costly 6. Water needs are high but possible	1. Requires some high quality water resources, which are not readily available in the region 2. Requires some changes of land use practices in the river corridor 3. Restoration of the ecosystem health and integrity is not fully achieved
Flow Enhancement	1. Partial removal of disturbances 2. A small portion of the LJR structure and function is restored	1. Requires some water, which is not always readily available in the region 2. Requires some changes of land use practices in the river corridor 3. Restoration of the ecosystem health and integrity is not fully achieved

6. Conclusions

The evidence is clear that flow reduction and diversion have had devastating impacts on the aquatic ecosystem of the LJR. The results demonstrate a major reduction in water quality and quantity due to major alterations in the hydrology and morphology of the LJR, which in turn has negatively impacted other aspects of the river ecosystem causing the significant loss of both floristic and faunal biodiversity of this important river ecosystem. The recommendations provide well founded scenarios to advance rehabilitation goals and restore this extremely important river ecosystem.

Based on the expert recommendations as well as comments and feedback received by participants of the study's National and Regional Advisory Committee, FoEME recommends a flow release of approximately 100 cubic meters/ second from Alumot dam for a 24 hour period (less than 9 mcm) to cause an initial flood to make a significant ecological difference without flooding surrounding properties. The release should take place during the winter months to simulate natural seasonal flooding and would act to flush fine sediment and pollutants and provide significant habitat improvement in the short term. This "re-start" should then be followed by the allocation of fresh water resources to halt the river's continuing deterioration as part of the national water plans of Jordan and Israel.

Furthermore, FoEME encourages Israel to complete the development of a master plan for the northern stretch of the LJR, initiated by the Ministry of Environment in 2010, and for the Jordanian and Palestinian governments to develop complementary master plans. These master plans should aim to adopt FoEME's regional rehabilitation strategy which requires a water flow of 400-600 mcm annually, including one minor flood annually and a reduction of salinity levels to no more than 750 ppm. This can be achieved using primarily fresh water, with only the highest quality of effluents allowed for up to 25% of the LJR's base flow. This strategy would remove most of the disturbances, restore the river's structure and function, allow biodiversity to recover and achieve a fair to high ecosystem integrity and health. The development, implementation and monitoring of a unified regional master plan for the LJR Basin would be best achieved through the establishment of a Jordan River Basin Commission.

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8. Appendices

Appendix 1: Methodology in detail.

Here we outline in detail the measurements taken for each of the five sites along the LJR including: A- Hydrology and morphology; B- Water quality; C- Macroinvertebrate assemblage; D- Botanical diversity.

A - Hydrology and morphology

- Width of the stream channel (W)
- Water depth (h), for each transect: In April, we could only estimate maximum depth while in July, full transects where taken. Depth variability within each transect was calculated as the coefficient of variation (CV) between depth measurements.
- Reach cross-section area: The July cross-section areas were directly calculated from the depth measurements. To calculate the cross-sectional area of each transect, we first calculated the sub-areas (ai) between two adjacent measurements of water depth by using the formula:
  $a_i = [(h_i + h_{i+1})/2)$ * distance (d) between h_i and h_i+1].
  Total cross-sectional area for a given transect will be the sum of the sub-areas using the formula:
  $A = \sum a_i$.

April cross-section areas were extrapolated from April maximum water depth and July depth profile. For this extrapolation two basic assumptions were taken:

1. Since no flood events occurred between April and July the shape of the river channel was similar during the two sampling trips.
2. Since the river is canalized there was no major difference in the width of the stream channel.

The following parameters were also calculated from the depth information:

1. Hydraulic depth (***D***) was calculated by dividing the cross-sectional area (***A***) by the stream width (***W***).
2. Wet perimeter (***P***) was calculated by dividing the cross-sectional area (***A***) by the mean depth of water (h_{avg}) in that transect.

3. Hydraulic radius (***R***) was calculated by dividing the cross-sectional area by the wet perimeter (***P***) of the transect.
   - Qualitative information of different substrata types in the reach
   - Velocity (***V***) – with electronic flow meter
   - Discharge (***Q***) was calculated by multiplying average velocity (V_{avg}) by the cross section area (***A***).

B - Water quality

The variables measured at each site location include:

- Water temperature – using YSI model 85 SCT DO meter.
- Water transparency – using a standard Secchi disk.
- Electric Conductivity at ambient temperature and adjusted to 25°C – using YSI model 85 SCT DO meter. Electrical conductivity (EC) of water is used as an indicator of how salt-free, ion-free, or impurity-free the water is; the purer the water, the lower the conductivity. Conductivity measurements in water are often reported as "specific conductivity", which is the conductivity of the water when it is measured at 25°C.
- Water salinity – using YSI model 85 SCT DO meter.
- Dissolved Oxygen – using YSI model 85 SCT DO meter.
- Percent oxygen saturation – using YSI model 85 SCT DO meter.

C - Macroinvertebrate assemblage

Macroinvertebrates were collected using a 400μ mesh deep net. During the two sampling periods of this study, at each site three samples were taken to form a single composite sample. This was done to ensure adequate representation of the different substrates, velocities and bank vegetation cover. Different types of habitat were sampled in approximate proportion to their representation of surface area of the total macroinvertebrate habitat at the site (Barbour et al., 1999). Samples were preserved in 95% ethanol and taken to the Ruppin Academic Center laboratories for analysis, where macroinvertebrates were identified to the lowest possible taxon. Macroinvertebrate assemblage information was also compared to data previously recorded for each reference site. Following analysis, the samples were stored in the zoological collections at the Israeli National Collections of Natural History at Tel Aviv University.

D - Botanical diversity

Specimens of unknown plants were collected in plastic bags, pressed in paper and kept for identification back in the laboratory.

Appendix 2: Data Collected from July 2009 Sampling

1) Site 1: Gesher/ Jisr al Majami Bridge

Cross Section of Wider Section of Site 1: Gesher/ Jisr Al Majami Bridge	
Distance from Eastern Bank (m)	Depth (cm)
0-8.3	10-20
8.4-16.67	50
16.67-25	50-100
Estimated Total Width= 25 meters	Maximum Depth = 100 cm

Cross Section of Narrow Section of Site 1:Gesher/ Jisr Al Majami Bridge	
Distance from Eastern Bank (m)	Depth (cm)
Estimated Total Width = 6 meters	Maximum Depth = 150 cm

Additional Remarks:

Bottom substrate characterized by boulders, stones and mud. Rocks are covered with benthit algae. Gentle dragonflies, many black dragonflies, red dragonflies and blue dragonflies. Large tilapias up to 20 cm long were identified on site.

2) Site 2: Beit Shean/ Sheikh Hussein Bridge

Cross Section of Site 2: Beit Shean/ Sheikh Hussein Bridge		
Distance from Estimated Center (m)	Depth (cm)	Additional Comments:
- 21 m to the Left	0	
- 20 m to the Left	30	
- 19 m to the Left	49	
- 18 m to the Left	74	Less silt, more solid ground/ rockier from here to bank
- 17 m to the Left	80	
- 16 m to the Left	94	
- 15 m to the Left	105	
- 14 m to the Left	109	
- 13 m to the Left	115	
- 12 m to the Left	125	
- 11 m to the Left	127	
- 10 m to the Left	130	
- 9 m to the Left	138	
- 8 m to the Left	139	
- 7 m to the Left	147	
- 6 m to the Left	149	
- 5 m to the Left	150	
- 4 m to the Left	154	
- 3 m to the Left	160	

Cross Section of Site 2: Beit Shean/ Sheikh Hussein Bridge		
- 2 m to the Left	166	
- 1 m to the Left	173	
Estimated Center	**170**	
+ 1 m to the Right	172	
+ 2 m to the Right	182	
+ 3 m to the Right	181	
+ 4 m to the Right	181	
+ 5 m to the Right	181	
+ 6 m to the Right	181	
+ 7 m to the Right	182	
+ 8 m to the Right	182	
+ 9 m to the Right	182	
+ 10 m to the Right	180	
+ 11 m to the Right	172	
+ 12 m to the Right	166	
+ 13 m to the Right	160	
+ 14 m to the Right	153	
+ 15 m to the Right	143	
+ 16 m to the Right	117	
+ 17 m to the Right	80	
+ 18 m to the Right	80	
+ 19 m to the Right	65	Bottom substrate becomes rockier towards bank
+ 20 m to the Right	57	
+ 21 m to the Right	32	
+ 22 m to the Right	30	
+ 23 m to the Right	30	
+ 24 m to the Right	20	
+ 25 m to the Right	20	
+ 26 m to the Right	0	
Right indicates west; left indicates east; Total Width = 47 m	**Maximum depth = 182 cm**	**Bottom substrate is characterized by soft sediment; rockier towards banks**

Additional Remarks:

Velocity is estimated to be 0 (zero). Bottom substrate is characterized by soft sediment a bit rockier towards the banks. Many road dragonflies, wasps and hydrometra were identified on site.

3) Site 3: Adam/ Damya Bridge

Cross Section of Site 3: Adam/ Damya Bridge		
	Depth (cm)	Additional Comments:
- 4 m to the Left	0	
- 3 m to the Left	19	
- 2 m to the Left	32	
- 1 m to the Left	73	
Estimated Center	83	

Cross Section of Site 3: Adam/ Damya Bridge		
+ 1 m to the Right	85	
+ 2 m to the Right	79	
+ 3 m to the Right	57	
+ 4 m to the Right	0	
Right indicates west; left indicates east; Total width = 8 m	**Maximum Depth = 85 cm**	**Bottom substrate is characterized by rocks/ gravel**

Additional Remarks:

Average velocity estimated by stick test = 5-10 cm/sec. Bridge's width = 10.3 meters.

The bottom substrate is characterized by rocky gravel. Red dragonflies (*Crocothemis erythrea*), Jordan River sparrow (*Passer moabiticus*), white butterfly (*Madais fausta*), and *Acrocephalus* warbler were identified on site.

4) Site 4: Allenby/ King Hussein Bridge

Cross Section of Site 4: Allenby/ King Hussein Bridge		
Distance from Eastern Bank (cm)	Depth (cm)	Velocity (cm/sec)
0	0	0
50	8	2
100	11.5	4
150	14.5	52
200	16	32
250	19	28
300	21	24
350	27	30
400	28	40
450	26	46
500	25	52
550	22	42
600	13	32
650	21	14
670	5	12
680	0	0
Total width = 6.8 m	**Maximum depth = 28 cm**	**Bottom substrate is characterized by rocks/ gravel**

Additional Remarks:

Bottom substrate is characterized by rocky gravel. Red dragonflies, blue dragonflies, striped dragonflies and potamon (river crab) were identified on site.

5) Site 5: King Abdullah Bridge

Cross Section of Site 5: King Abdullah Bridge		
Distance from Eastern Bank (cm)	**Depth (cm)**	**Velocity (cm/sec)**
0	0	0
50	15.5	24
100	26	32
150	27	36
200	24	46
250	26	36
300	24	44
350	22	44
400	23	32
450	11	32
500	16	20
550	7	8
600	5.5	18
650	3	28
700	16	16
750	32	20
775	0	0
Total width = 7.75 m	**Maximum depth = 32 cm**	**Bottom substrate is characterized by stones, boulders up to 30 cm diameter**

Additional Remarks:

The bottom substrate is characterized by stones and boulders up to 30 cm in diameter. Blue dragonflies, little black beetle and tilapias were identified on site.

Floodplain description: Eastern stream (cross section above), smaller side stream – currently dry. Branches are seen caught on bridge an estimated 8-10 meters above the ground indicating peak flood. Estimated total width of floodplain 65-70 meters wide. A small side stream enters the Jordan River near this point; its volume is estimated at 30 m^3/ hour.

Appendix 3: Full macroinvertebrate taxa survey

Table 12. Comparison of macroinvertebrate taxa composition in different sites (Site 1 to 5) along the LJR. a – From Alumot Dam to Dalhamya Dam (Ortal 1976); b – From Dalhamya Dam to the mouth of the Yarmouk River (Ortal, 1976); c – From Alumot Dam to Dalhamya Dam (Gasith and Hershkoviz, 2006).

Taxon	a	b	c	1	2	3	4	5
Turbellaria								
Planaria sp.	+	+						
Dugesia sp.	+	+						
Nematoda								
Unidentified Nematoda	+	+		+	+			
Annelida								
Oligochaeta								
Tubificidae	+	+		+	+	+		
Hirudinea								
Dina sp.		+						
Placobdella sp.		+						
Crustacea								
Ostracoda								
Ostracoda unidentified		+	+	+				
Heterocypris salina				+	+	+		
Copepoda								
Eucyclops serrulatus	+	+						
Mesocyclops leuckarti	+	+		+	+			
Afrocyclops gibsoni	+	+						
Macrocyclops albidus	+							
Eudiaptomus gracilis	+							
Nitocra incerta	+	+						
Nitocra hibernica	+	+						
Onichocamptus mohammed	+	+						
Cletocamptus deitersi	+	+						
Ampipoda								
Echinogammarus veneris	+	+	+	+	+	+	+	+
Isopoda								
Proasellus coxalis		+						
Decapoda								
Atyaephyra desmarestii	+			+	+			+
Potamon potamios					+		+	
Insecta								
Amphibicorisae								
Gerris paludum				+	+	+		
Hydrometra stagnorum					+			
Hydrocorisae								
Sphaerodema urinator			+					
Micronecta sp.			+					
Ephemeroptera								
Batis sp.	+	+	+					
Caenis sp.	+	+						

Taxon	a	b	c	1	2	3	4	5
Odonata								
Anisoptera								
Crocothemis erythrea				+	+	+	+	
Orthetrum chrysostigms							+	+
Anax imperator			+					
Brachytemis teucostita				+		+		+
Zygoptera								
Pseudagrion sp.						+	+	+
Trichoptera								
Hydropsyche exocellata	+	+						
Hydropsyche jordanensis	+	+						
Hydroptilida sp.	+							
Diptera								
Culicidae	+	+	+		+			
Cricotopus silvestris	+	+						
Cricotopus vierriensis	+	+						
Chironomidae			+	+	+			
Chironominae sp.1		+						
Cladontanytarasus pseudomaneus		+						
Dicrotendipes pilosimanus		+						
Dicrotendipes fusconotatus	+	+						
Polypedilum tiberiadis	+	+						
Ephydridae			+					
Simulidae			+		+	+		
Tabanidae						+	+	+
Coleoptera								
Spercheus cerisyi			+					
Helochares sp.			+					
Unidentified species								+
Mollusca								
Gastropoda								
Melanoides tuberuculata	+	+	+	+	+	+	+	
Bithinella sp.	+	+						
Theodoxus jordani		+		+		+	+	+
Melanopsis costata		+		+		+		+
Falsipyrgula barroisi		+						
Bithynia badiella		+						
Physella acuta			+	+				
Bivalvia								
Corbicula fluminalis		+				+	+	
Taxa richness	26	33	12	15	14	13	9	9

Table 13. Comparison of macroinvertebrate taxa composition at reference sites and at Sites 1-5 along the LJR. UJR – Upper Jordan River from Benot Ya'akov bridge to the Sea of Galilee, Gafny 2008; YA the lower section of the Yarmouk River –Gafny, 1997; EZ – Einot Zokim (Ein Fashka) Gafny, 2006.

Taxon	UJR	YA	EZ	1	2	3	4	5
Porifera								
Coritspongilla	+							
Spongila lacustris		+						
Canidaria								
Hydra sp.	+	+						
Bryozoa								
Fredericella sultana	+							
Phylacotolaemata (statoblast)		+						
Turbellaria								
Dugesia golanical		+						
Nematoda								
Unidentified Nematoda		+		+	+			
Annelida								
Oligochaeta								
Tubifex sp	+	+	+	+	+	+		
Hirudinea								
Glossiphnia sp.		+						
Crustacea								
Cladocera								
Chydoridae		+						
Copepoda								
Cyclopoida	+	+						
Mesocyclops leuckarti				+	+			
Ostracoda								
Ostracoda unidentified			+	+				
Heterocypris salina	+			+	+	+		
Podocopa		+						
Ampipoda								
*Echinogammarus veneri*s	+			+	+	+	+	+
Orchestia sp.		+						
Isopoda								
Proasellus coxalis			+					
Asellus sp.		+						
Decapoda								
Atyeaphyra desmarestii	+	+		+	+			+
Potamon potamios	+	+	+		+		+	
Chelicerata								
Hidracarina		+	+					
Insecta								
Amphibicoriswae								
Gerris paludum		+	+	+	+	+		
Hydrometra stagnorum			+		+			
Hydrocorisae								
Rhagovelia nigricans		+	+					
Micronecta sp.		+						
Ephemeroptera								

Taxon	UJR	YA	EZ	1	2	3	4	5
Rhitrogena sp.	+							
Ecdyonurus galileae	+							
Oligoneuriella oronfensis	+							
Baetis sp.	+	+						
Caenis sp**.**		+						
Heptageniidae		+						
Leptophelebidae**?**		+						
Odonata								
Anisoptera								
Anax imperator	+							
Crocothemis erythrea			+	+	+	+	+	
Orthetrum chrysostigms	+		+				+	+
Brachythemis leucosticta	+			+		+		+
Libellulidae unidentified			+					
Hemianax ephippiger			+					
Gomphus davidi	+		+					
unidentified species		+						
Zygoptera								
Epallage fatime	+							
Ischnura elegans	+							
Calopterix syriaca	+							
Platycnemis dealbata	+							
Coenagrionidae			+					
Pseudagrion sp.	+		+			+	+	+
unidentified species	+	+						
Trichoptera								
Rhyacophila nubila	+							
Psychomyia sp.	+							
Policentropus hebraeus	+							
Ecnomus galilaeus	+							
Hydropsyche jordanensis	+	+						
Hydropsychidae		+						
Hydroptila sp.		+	+					
Orthotrichia sp		+						
Leptoceridae								
Chimarra sp.			+					
Neuroptera								
Sisyra sp.		+						
Coleoptera								
Laccobius levantinus		+	+					
Laccophilus sp.			+					
Dryops sulcipennis			+					
Hydrocyphon deflexicollis			+					
Limnius sp.		+						
Coelstoma sp.		+						
Limnebius sp.		+						

Taxon	UJR	YA	EZ	1	2	3	4	5
Sperchus sp.		+						
Uidentified species	+							+
Diptera								
Culex sp.			+		+			
Anopheles tenebrosus		+						
Chironomus sp.		+	+	+	+			
Rbeotanytarsus sp.	+		+					
Tanypodinae	+		+					
Stratiomyidae		+						
Tipulidae		+						
Dixa sp.			+					
Ceratopogonidae		+						
Tabanidae			+			+	+	+
Empididae			+					
Simuliidae	+	+	+		+	+		
Bezzia sp.			+					
Mollusca								
Gastropoda								
Theodoxus jordani	+	+	+	+		+	+	+
Melanopsis costata	+	+		+		+		+
Melanopsis buccinoidae			+					
Melanoides tuberculata			+	+	+	+	+	
Heleobia sp.			+					
Bithynia sp.		+						
Physella acuta				+				
Bivalvia								
Corbicula sp.	+	+				+	+	
Pisidium sp.		+						
Taxa richness	**33**	**45**	**34**	**15**	**14**	**13**	**9**	**9**

Appendix 4: Botanical Biodiversity Survey

Table 14. The occurrence of each species in sites along the LJV and the abundance (Fragman, 1999) of each species.

No.	Species	Site 1	Site 2	Site 3	Site 4	Site 5	Reference Site - Yarmouk	Abundance	No. of Sites
1	*Aaronsonia factorovskyi*	-	-	-	+	-	-	CC	1
2	*Acacia farenesnianan*	+	-	-	-	-	+	C	2
3	*Acacia saligna*	-	+	-	+	-	-	CC	2
4	*Aizoon hispanicum*	-	-	-	+	+	-	C	2
5	*Alhagi maroura*	+	+	+	-	-	-	C	3
6	*Allium neopolitanum*	+	-	-	-	-	-	C	1
7	*Alopecurus utriculatus*	+	-	-	-	-	-	C	1
8	*Ammi visnaga*	+	-	-	-	-	-	CC	1
9	*Anagalis arvensis*	-	+	+	-	-	-	CC	2
10	*Anthemis pseudocotula*	+	+	+	+	+	-	CC	5
11	*Antirrhinum orontium*	-	+	-	-	-	-	C	1
12	*Asparagus palaestinus*	-	-	+	+	+	-	R	3
13	*Asphodelus tenuifolius*	-	-	-	-	+	-	F	1
14	*Astoma sesilifolium*	+	-	-	-	-	-	F	1
15	*Astragalus hamosus*	+	-	-	-	-	-	C	1
16	*Atriplex halimus*	+	-	+	+	+	-	C	4
17	*Atriplex leucoclada*	-	-	-	+	-	-	C	1
18	*Avena sterilis*	+	+	-	+	-	-	CC	3
19	*Bassia eriophora*	-	-	-	-	+	-	F	1
20	*Bassia indica*	-	-	-	+	-	-	C	1
21	*Beta vulgaris*	-	+	+	+	-	-	C	3
22	*Brachypodium distachyon*	+	-	-	-	-	-	CC	1
23	*Bromus brachystachys*	-	-	-	+	-	-	R	1
24	*Bromus fasciculatus*	-	+	-	-	-	-	CC	1
25	*Bromus madritensis*	-	+	-	-	-	-	C	1
26	*Bromus scoparius*	-	-	-	+	-	-	C	1
27	*Bromus sterilis*	+	+	+	-	-	-	C	3
28	*Bryonia syriaca*	+	+	-	-	-	-	C	2
29	*Calendula arvensis*	+	-	-	-	-	-	CC	1
30	*Campanula erinus*	+	-	-	-	-	-	CC	1
31	*Capparis aegyptiaca*	-	-	+	+	-	-	F	2
32	*Capparis spinosa*	+	+	-	-	-	+	C	3
33	*Capsella bursa-pastoris*	-	-	+	-	-	-	CC	1
34	*Carthamus glaucus*	+	+	-	+	-	-	C	3
35	*Caylusea hexagyna*	-	-	-	+	-	-	C	1
36	*Centaurea hyalolepis*	-	+	+	+	-	-	CC	3
37	*Cetaurea iberica*	+	-	-	-	-	-	CC	1
38	*Chenopodium murale*	+	-	+	+	+	-	CC	4
39	*Chrysanthemum coronaria*	+	+	-	-	-	-	CC	2
40	*Cichorium pumilum*	+	+	-	-	-	-	CC	2
41	*Commicarpus africanus*	-	+	-	-	-	+	F	2
42	*Conium maculatum*	+	-	-	-	-	-	F	1
43	*Convolvulus arvensis*	-	+	-	-	-	-	CC	1
44	*Conyza canadensis*	-	+	-	-	-	-	C	1
45	*Crepis aspera*	+	+	+	-	+	-	CC	4

No.	Species	Site 1	Site 2	Site 3	Site 4	Site 5	Reference Site - Yarmouk	Abundance	No. of Sites
46	*Cuscuta* sp.	-	+	-	-	-	-		1
47	*Cynanchum acutum*	-	+	+	+	-	-	F	3
48	*Cynodon dactylon*	+	+	+	+	+	-	CC	5
49	*Cyperus* sp.	-	-	-	-	-	-		
50	*Datura innoxia*	-	-	+	+	-	-	-	2
51	*Desmostachya bipinnata*	-	-	+	-	-	-	F	1
52	*Echinops polyceras*	+	-	-	-	-	-	CC	1
53	*Echium judaeum*	+	-	-	-	-	-	CC	1
54	*Emex spinosa*	+	-	+	+	-	-	CC	3
55	*Erodium malacoides*	-	+	-	+	-	-	CC	2
56	*Erodium moschatum*	+	-	-	-	-	-	CC	`
57	*Eruca sativa*	-	-	+	-	-	-	C	`
58	*Erucaria hispanica*	+	-	+	-	-	-	C	2
59	*Eucalyptus camaludensis*	+	+	-	+	+	-	CC	4
60	*Euphorbia helioscopia*	+	-	-	-	-	-	C	1
61	*Euphorbia peplus*	+	-	-	-	-	-	CC	1
62	*Ferula communis*	-	+	-	-	-	-	C	1
63	*Ficus carica*	+	+	-	-	-	+	CC	3
64	*Galium aperine*	-	+	+	-	-	-	C	2
65	*Geranium molle*	+	-	-	-	-	-	C	1
66	*Glycerhiza glabra* *	+	-	+	-	-	-	RP	2
67	*Heliotropium* sp.	-	-	-	+	-	-		1
68	*Hordeum glaucum*	-	+	+	+	+	-	CC	4
69	*Hordeum spontaneum*	+	-	-	-	-	-	CC	1
70	*Hymenocarpus circinata*	+	+	-	-	-	-	CC	2
71	*Hyoscyamus aureus*	+	-	-	-	-	-	CC	1
72	*Hyparrhenia hirta*	+	-	-	-	-	-	CC	1
73	*Inula viscose*	+	+	-	-	-	-	CC	2
74	Juncus sp,	-	-	-	-	-	+		1
75	*Kickxia sieberi* ?	+	+	-	-	-	-	R	2
76	*Koelpinia linearis*	-	-	-	-	+	-	C	1
77	*Lactuca seriola*	-	+	+	-	-	-	CC	2
78	*Lamarckia aurea*	-	-	+	-	-	-	CC	1
79	*Launea nudicaulis*	-	-	-	+	-	-	CC	1
80	*Lavatera cretica*	+	+	+	+	+	-	C	5
81	*Limonium lobatum* *	-	-	-	-	+	-	C	1
82	*Limonium thouinii*	-	-	+	-	-	-	C	1
83	*Lolium rigidum*	-	+	-	+	-	-	CC	2
84	*Lotus peregrines*	+	+	-	-	-	-	CC	3
85	*Lycium shawii*	-	-	+	+	+	-	C	3
86	*Matricaria aurea* *	-	-	+	-	-	-	F	1
87	*Matthiola livida*	-	-	-	-	+	-	CC	1
88	*Matthiola parviflora*	-	-	-	-	+	-	F	1
89	*Medicago polymorpha*	+	+	-	-	-	-	CC	1
90	*Melia azderach,*	-	-	-	-	-	+		1
91	*Melilotus salcatus*	-	+	-	-	-	-	C	1
92	*Mentha longifolia,*	-	-	-	-	-	+		1
93	*Mercurialis annua*	+	+	-	+	-	-	F	3

No.	Species	Site 1	Site 2	Site 3	Site 4	Site 5	Reference Site - Yarmouk	Abundance	No. of Sites
94	*Morus species*	-	-	-	-	-	+		1
95	*Nerium oleander*	-	+	-	-	-	+	F	2
96	*Notobasis syriaca*	+	+	+	-	-	-	CC	3
97	*Ochradenus baccatus*	-	-	-	+	+	-	C	2
98	*Onobrychis squarrosa*	-	+	-	-	-	-	C	1
99	*Ononis spinosa*	+	+	-	-	-	-	C	2
100	*Opuntia ficus-indica*	-	-	-	-	-	+		1
101	*Pallenis spinosus*	+	-	-	-	-	-	C	1
102	*Papaver subpiriforme*	-	+	-	-	-	-	CC	1
103	*Parietaria judaica*	+	+	-	-	-	-	C	2
104	*Parkinsonia aculeata*	+	+	-	-	-	-	C	2
105	*Phagnalon rupestre*	+	-	-	+	-	-	C	1
106	*Phalaris bracystachys*	+	-	-	-	-	-	C	1
107	*Phalaris minor*	-	-	+	-	-	-	CC	1
108	*Phalaris paradoxa*	-	+	+	-	-	-	F	2
109	*Phoenix dactylifera* *	+	-	+	+	-	+	F	4
110	*Phragmitis australis*	+	+	+	+	+	+	CC	6
111	*Piptatherum miliaceum*	-	-	-	-	-	+		1
	Pistacia atlantica	-	-	-	-	-	+		1
112	*Plantago coronopus*	-	-	-	-	+	-	C	1
113	*Plantago lanceolata*	+	-	-	-	-	-	C	1
114	*Pluchea dioscoridis*	+	+	-	+	-	+	CC	4
115	*polygonum equisetiformis*	+	+	-	-	+	-	CC	3
116	*Polypogon monspeliensis*	-	-	-	+	-	-	C	1
117	*Populus euophratica* *	+	+	+	+	-	+	R	5
118	*Prosopis farcta*	+	+	+	+	-	+	C	5
119	*Prosopis juliflora*	-	+	-	-	-	-		1
120	*Pulicaria Arabica*	+	+	-	-	-	-	F	2
121	*Ricinus communis*	-	+	-	-	-	+	F	2
122	*Rubus sanguineus*	-	+	-	-	-	-	C	1
123	*Rumex cyprius*	-	-	-	+	+	-	CC	2
124	*Salix*? *	-	+	-	-	-	+	RP	2
125	*Salsola kali*	-	-	+	-	-	-	C	1
126	*Salsola volkensii*	-	-	+	+	+	-	F	3
127	*Scolymus macualtus*	-	+	-	-	-	-	CC	1
128	*Sedum palaestinum*	+	-	-	-	-	-	RR	1
129	*Senecio vernalis*	-	-	+	+	+	-	CC	3
130	*Silybum marianum*	+	+	+	-	-	-	CC	3
131	*Sinapis alba*	+	+	-	+	-	-	CC	3
132	*Sinapis arvensis*	+	-	-	-	-	-	CC	2
133	*Sisymbium irio*	+	-	+	+	+	-	C	4
134	*Solanum villosum*	-	-	+	-	-	-	C	1
135	*Sonchus oleraceus*	+	+	+	+	-	-	CC	4
136	*Spergula fallax*	-	-	+	-	+	-	C	2
137	*Stipa capensis*	+	-	+	-	-	-	C	2
138	*Suaeda aegyptiaca*	-	-	+	+	+	-	F	3
139	*Tamarix jordanis* *	+	+	+	+	+	+	C	6
140	*Tamarix nilotica* *	+	+	+	+	+	+	CC	6

No.	Species	Site 1	Site 2	Site 3	Site 4	Site 5	Reference Site - Yarmouk	Abundance	No. of Sites
141	*Theligonum cynocrambe*	+	-	-	-	-	-	CC	1
142	*Trifolium clusii*	+	-	-	-	-	-	F	1
143	*Trifolium purpureum*	+	+	-	-	-	-	CC	2
144	*Trigonella Arabica*	-	-	-	+	-	-	CC	1
145	*Urigenia maritime* *	+	-	-	-	-	-	CC	1
146	*Urospermum picroides*	+	+	+	+	-	-	CC	4
147	*Urtica pilulifera*	+	-	+	-	-	-	F	2
148	*Urtica urens*	+	-	-	-	-	-	C	1
149	*Verbascum fruticulosum*	-	+	-	-	-	-	C	1
150	*Verbascum jordanicum*	-	-	-	+	-	-	C	1
151	*Verbascum sinautum*	-	+	-	-	-	-	CC	1
152	*Verbina officinalis*	-	-	-	-	-	+		1
153	*Vicia hybrid*	+	+	-	-	-	-	C	2
154	*Vicia palaestina*	+	-	-	-	-	-	C	1
155	*Vitex agnus-castus*	+	-	-	-	-	-	F	1
156	*Water plant species*	-	-	-	-	-	+		1
157	*Withania somnifera*	+	-	-	-	-	-	C	1
158	*Zizyphus lotus* *	+	-	-	-	-	-	CC	1

(Note : CC: very common, C: common, F : Frequent, RP: potentially rare, R: Rare, RR: very rare, *: protected by law.)

Appendix 5: Annual water flows in side valleys, dam capacities, and volumes of water diverted to the LJR on the Jordanian side.

Table 15. Volume of water diverted to the Jordan River from the Jordanian side. *Source: Jordan Valley Authority, Amman, Jordan.*

Year	Water Volume (mcm)
2004	132.85
2005	12.78
2006	0.18
2007	3.17
2008	1.93

Table 16. Annual recorded stream flow in streams and valleys on the Jordanian side of the LJR. *Source: Jordan Valley Authority, Amman, Jordan.*

Stream Annual Flow (mcm)	2004	2005	2006	2007	2008
Yarmuk to KAC	68.61	42.55	14.25	15.99	14.9
Zeglab Valley	8.24	7.28	6.43	5.14	3.9
Jurm Valley	4.04	3.23	3.3	3.28	2.67
Kufranja Valley	4.18	6.52	4.15	4.28	2.2
Rajib Valley	2.79	3.12	2.34	2.6	1.6
Zarqa River	82.47	89.1	76.29	82.11	79.34
Shueib Valley	4.47	4.7	3.93	6.14	3.07
Kafrein Valley	8.52	11.62	7.39	10.85	6.94
Husban Valley	2.78	3.19	2.17	0.91	1.03
Tiberius carrier line	50.21	46.99	53.12	43.48	42.14
Additional minor valleys	2.33	4.81	2.53	1.76	1.65
Total	**238.63**	**223.1**	**175.91**	**176.54**	**159.43**

Table 17. The capacity of dams built on seasonal streams draining into the LJR with the volumes captured by February 22nd in 2008 and 2009. *Source: Jordan Valley Authority, Amman, Jordan*

	Capacity	**2009**		**2008**	
Dam	**(mcm)**	**Feb. 22nd**	**(%)**	**Feb. 22nd**	**(%)**
Al-Arab	16.79	6.02	35.84	8.31	49.49
Sharhabeel (Zegalb)	3.96	1.23	30.96	1.67	42.09
Talal	75	23.22	30.96	40.78	54.37
Al-Karama	55	17.25	31.37	15.18	27.61
Shueib	1.43	0.92	64.14	0.81	56.42

With the exception of the Shueib stream, which flows into the LJR year round despite the construction of the dam, these dams are used to store winter floods, used for irrigation during the summer months.