Restoration of the Besor-Hebron-Be'er Sheva Stream

A Transboundary Project Supported by the JNF Parsons Water Fund

Center for Transboundary Water Management,

Arava Institute for Environmental Studies

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Third Year Interim Report (March 1st, 2013-June 30th, 2014)

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Introduction

Figure 1: JNF CEO, Russell Robinson, explaining Blueprint: Negev to a group of Arizona water managers on Pipes Bridge, Be'er Sheva stream.

Fulfilling its dual mission of developing Israel and improving the environment, the JNF has worked tirelessly to restore the Besor-Hebron-Be'er Sheva watershed, a section of which runs through the center of Be’er Sheva. As a part of JNF's Blueprint Negev, the Be’er Sheva river parkway seeks to accomplish a service for a much larger region in the Negev that also relies on a safe and clean Besor-Hebron-Be'er Sheva watershed. This effort has the added feature of incorporating transboundary environmental protection, bringing together parties from both Israel and the Palestinian Authority. To fulfill these goals, the JNF Parsons Water Fund has joined with the Center for Transboundary Water Management at the Arava Institute for Environmental Studies, which has a long history in Israel of seeking practical solutions to environmental problems with diverse voices and a regional focus. While the JNF has made strides in community outreach and infrastructure projects within Be’er Sheva, the Center for Transboundary Water Management (CTWM) is researching the broader causes of pollution at a watershed level and using state-of-the-art hydrological monitors and Geographic Information Systems (GIS) to evaluate water quantity and quality throughout the watershed. This baseline data gathering activity is necessary before any restoration efforts can begin. By framing our research at a watershed level, our approach fulfills the goals of restoring the entire system from its source in the southern West Bank to its terminus at the Mediterranean Sea and establishing a viable and flourishing Be'er Sheva river park for which the stream is the lynchpin for success.

This document provides an update on the progress we have made for the period March 1st, 2013 – June 30th, 2014. To date, we have collected and compiled extensive data on water quantity and quality, environmental conditions, socio-economics, land use, and sources of pollution across the watershed. These data have been integrated in a database linked to GIS which allows for advanced visualization and analysis of the information on a watershed-scale. The results of analyses are presented herein.

Background

This research fits within JNF's wider development plan; Blueprint: Negev. The city of Be'er Sheva, the capital of the Negev, is a central focus of Blueprint: Negev. Any effort to bring more Israeli citizens to the region and to promote development of the Negev must focus on its largest city. Ten years into the project, the JNF has made significant headway in improving the infrastructure and physical outlook of the city, which has had a large impact on Be'er Sheva's image to both the region and the entire country. The centerpiece has been the beautification of the Be'er Sheva river parkway. Looking to San Antonio's river park as an example, the JNF has sought to make the park a hub for the city's residential and commercial development. Trash and debris have been removed, landscaping is in progress, and soon recycled water will flow within the stream year around.

Figure 2: Untreated sewage flowing in the stream at Umm Batin, a Bedouin village northeast of Be'er Sheva.

However, the Be'er Sheva stream does not operate in isolation. Water already does flow through the city permanently because upstream, untreated wastewater continuously pours into the section of the watershed originating in the West Bank near Hebron. This sewage flows through several Palestinian communities with limited wastewater infrastructure as well as active stone cutting and olive oil industries that do not treat the wastewater from these industries. This pollution crosses into Israel at the Green Line crossing north of Meitar, where it is partially treated. This treatment however, is minimal, as Israel cannot use this treated wastewater which legally belongs to the Palestinian Authority and therefore all Israel can do is return the wastewater to the stream. By the time the water enters Be'er Sheva it has picked up additional untreated wastewater from the surrounding Bedouin villages and towns, and by the time the water reaches Be'er Sheva it is a constant sewage flow that fails to match the beauty of the park that is being created around it.

Treating this wastewater effectively and efficiently is the impetus for this project, which takes the local conditions of the stream and expands the view to tackle the issue at the regional and watershed level, in order to find a more permanent solution for the entire stream's restoration and not just the section flowing through the Be'er Sheva river park. Our research looks at the entire Besor-Hebron-Be'er Sheva watershed, meaning the region where any flowing water ultimately ends up in the stream and, eventually, the Mediterranean Sea via Gaza. This region is roughly triangular, defined by Hebron in the northeast, Sde Boqer in the south, and Gaza in the west. While water flows freely across hostile political borders, the management of this transboundary watershed remains fractured. The diverse group of settlements and industry along the stream all contribute to its pollution, yet they blame each other and rarely coordinate, simply making the situation worse for all.

Figure 3: Besor-Hebron-Be'er Sheva watershed in Israel and the Palestinian Authority.

Both the JNF Parsons Water Fund and the Arava Institute have a commitment to transboundary solutions to regional environmental problems. This is why at CTWM we are approaching this project from a watershed and systems-level viewpoint. The water quality in Jewish communities in the Negev cannot be evaluated separately from the Bedouin and Palestinian communities upstream. The current body of research in the area often ignores this and looks at water quality from only one side of the Green Line, or considers only physical factors while overlooking the underlying political tensions which have led to the current situation. We seek to understand potential sources of pollution throughout the entire watershed from both a hydrologic and socio-economic perspective. This research will provide a platform to begin a transboundary dialogue about restoration strategies. Hopefully, this dialogue will help identify strategies that will be sustainable and beneficial for not only Be'er Sheva and the planned Be'er Sheva River Park, but also the Negev and the entire region.

Our Work

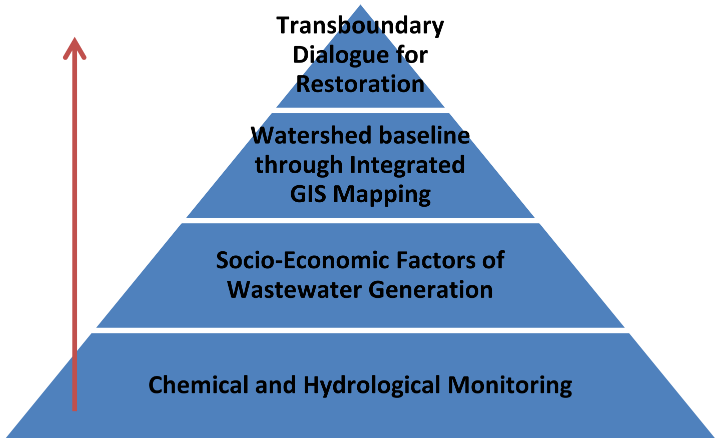

Figure 4: Model of data analysis for transboundary stream restoration.

Our research team is particularly well situated to handle this project. Dr. Clive Lipchin has worked as a water management expert in Israel for over fifteen years and acted as a senior editor for two books on regional transboundary water management in the Middle East. Shira Kronich is a native of the Negev region and has degrees in environmental engineering and development policy. Both currently live in and around Be'er Sheva. As respective director and associate director of CTWM, they have recruited a diverse group of students and interns, only possible at the Arava Institute, to work on the project and bring together all of its complex elements.

The Arava Institute is also working together on this project with the Department of Geography at Ben-Gurion University, the Zuckerburg Water Resources Institute at the Jacob Blaustein Institute for Desert Research, the Israel Water and Sewerage Authority and the Besor-Shiqma River Authority.

In collaboration with the Department of Geography at Ben-Gurion University and the Besor-Shiqma River Authority, we have begun to establish a joint effort to determine the water quantity and quality in the stream around Be'er Sheva. When completed, three advanced hydrological monitoring stations will collect data along the Hebron-Be'er Sheva stream. These stations will operate continuously, providing water quantiy and quality data in real time. The first station will be installed on the Hebron stream close to the Green Line at the outlet of the sewage treatment facility situated at the Metarim checkpoint.

In addition to our efforts to expand stream monitoring in the watershed, we are conducting a watershed characterization which combines physical and socio-economic information to establish a baseline status of the watershed and to better understand the extent of pollution. We are using geospatial information systems (GIS) as a tool to conduct scientific watershed analyses and to improve communication of management issues to stakeholders throughout the watershed. In 2014, the AIES brought on Tamee Albrecht, an American with an M.Sc. in hydrology and experience in watershed characterization and remediation plans for sites in the U.S. on the EPA's National Priorities List. Tamee's work at AIES has focused on data collection, database development, GIS and hydrologic analysis, and development of visualization tools for communicating with stakeholders. Data collected are from communities in the entire watershed, both Israeli and Palestinian communities. The AIES has recruited a Palestinian student from East Jerusalem, Leila Hashweh as the recipient of the JNF Parsons Scholarship for graduate studies in water management. Leila has begun her studies working on this project towards an M.Sc. in Hydrology and Water Resources at Ben-Gurion University. Her research will address the connection between surface water and groundwater in the upper Besor-Hebron-Be'er Sheva watershed which is crucial to understanding the potential pollution risk to important regional groundwater resources.

Watershed Approach to Integrated Management

Understanding the nature and extent of pollution is crucial to stream restoration. Pollution comes from point and non-point sources. Point sources have a distinct location of origin, such as a sewer discharge pipe or mine tailings pile discharging directly into a water body. Non-point sources are diffuse or distributed over a large area, and collectively become a source of pollution when aggregated. For example, runoff that flows over agricultural fields picks up nutrients from fertilizers and eventually carries these contaminants to streams. Non-point sources of pollution are more difficult to identify and regulate than point sources. Nevertheless, over the last 15 years non-point pollution loads to streams have decreased by 50-80% in Israel. Similarly, point source pollution sites have decreased from 130 sources to 80 sources. This is largely due to daily on-site supervision, inspection, and enforcement. The issue of pollution prevention in streams has gained great momentum over the last few years following the establishment of the Inbar effluent (wastewater) quality regulations.

The Inbar regulations are the new set of wastewater reuse standards containing 38 updated water quality parameters that was adopted by the Israel Ministry of Environmental Protection and the Ministry of Health in 2007. This policy requires that all future wastewater treatment plants would be designed to produce wastewater at a quality that allows for “unlimited irrigation or discharge to rivers” while existing wastewater treatment plants must be upgraded to abide by the new regulations. The purpose of the Inbar regulations is to protect public health, prevent pollution of water resources from sewage effluents, and enable the utilization of wastewater recovery for safe discharge back into streams whilst protecting the environmental factors, i.e. ecosystems, biodiversity, soils, and crops. These stringent standards place Israel as a leader among developed nations in terms of wastewater management for environmental protection and reuse. Israel's achievments in wastewater management were recognized by the UN World Water Development Report presented in 2010.

However, implementing these progressive policies is complicated by the fact that most of the major streams that flow westward to the Mediterranean Sea originate in the West Bank. The streams are therefore transboundary systems since they flow through both Israel and the Palestinian Authority. Israel does not have the jurisdiction to enforce the Inbar standards in the Palestinian Authority and the wastewater infrastructure in the Palestinian Authority is extremely inadequate. The result is that significant pollution that enters streams in the West Bank flows across the Green Line into Israel; a case in point being the Besor-Hebron-Be'er Sheva stream. Stream water flowing across the Green Line in the Besor-Hebron-Be'er Sheva stream is composed almost entirely of untreated wastewater (Tal, A., et al., 2007), and elevated concentrations of contaminants are observed downstream, even below Be'er Sheva.

Because downstream conditions are reliant on upstream activities and water quality regulations in Israel and the Palestinian Authority are severly imbalanced, the goal of stream restoration must be addressed at a watershed level. A watershed-level approach aims to develop a quantitative, scientific understanding of watershed dynamics and to investigate how local stream degradation relates to processes on a larger scale (Bohn, B.A. and J.L. Kershner 2002). Our approach integrates data collection (including monitoring), data analysis, communication of scientific information to stakeholders, stakeholder participation, and informed decision-making. The result is a dynamic, integrated water management regime.

This model of integrated watershed management focuses on a long-term methodology to serve the needs of the watershed's stakeholders over time. Stakeholders are not only recipients of the effects of a management plan, they are also key sources of the information needed to develop a workable plan. Often, stakeholders can provide data or help with watershed monitoring (FAO 2006). In addition, in order for a management plan to have a long-term impact, the recommendations of science and policy experts must be merged with stakeholders' preferences and interests (FAO 2006).

The watershed approach is an iterative process of data collection, centralized data management, and data analysis, leading to informed decision making and, ultimately, integrated watershed management practices, as represented in Figure 5. The first step in this approach is comprehensive data collection to help develop a baseline characterization of the condition of the watershed. A baseline characterization provides a starting point for evaluating how water quality and pollution in the watershed changes over time. Initially, data collection supports baseline characterization. In the iterative process, long-term monitoring programs are required to evaluate the effectiveness of management strategies. For the initial baseline characterization, we collected information about streamflow, climate, soils, lithology, surface water quality, groundwater, population, demographics, land use, wastewater treatment, and other potential sources of pollution. These data will be described in more detail in the next section. Since watershed processes operate at many spatial and temporal scales, it is important to obtain data from locations throughout the watershed and that both current and historic data were collected whenever available.

Figure 5: Schematic of integrated watershed management process

Compiling data into a centralized database is the next step. A centralized database is necessary to organize and manage data, integrate data from different sources, provide access to multiple users, and adapt dynamically to expanding datasets. To these ends, our model utilizes a geospatial information system (GIS). A GIS is not only a useful way to manage data, i.e. in a geographically-referenced database called a geodatabase, it provides the ability to analyze and visualize data in their spatial context. It also provides a platform for integrating scientific and socioeconomic data and investigating interactions between land use activities and the environment. In the previous stage of this project, we generated initial digital maps for certain hydrologic, socioeconomic, and geographic factors. In this phase of the project, we acquired, processed and uploaded numerous additional datasets into the geodatabase. These datasets and their sources are discussed in the following section.

GIS is also a powerful tool for data analysis to inform decision-making. Visualizing watershed information on maps and in other graphical representations, as quantitative results, and as explicit representations of potential scenarios can help stakeholders to better understand the implications of potential decisions and the interdependencies between watershed management and other sectors. Not only can datasets be overlaid on a map to explore their spatial interaction, GIS can assist in modeling potential future scenarios, such as changes in the watershed condition over time and the impact of different management interventions. GIS analysis also helps target priority areas. Scenario modeling using computer-based tools such as GIS has been extremely useful in supporting watershed decision-making (Carmona et al. 2013). Our hope is that through engaging stakeholders in the watershed approach, we will implement better informed decisions, and that the iteration and growth of this process will support integrated watershed management in the long-term.

Data Collection and Data Gaps

Since the Besor-Hebron-Be'er Sheva watershed is a transboundary system, one of the greatest challenges was the availability of and access to reliable data. Data were obtained from various Israeli sources, i.e. universities and government ministries however, data were sometimes not up to date or not freely shared. Although CTWM has strong connections with Palestinian partners, data are even more difficult to procure from Palestinian organizations either due to a lack of monitoring or hesitancy to share information with an Israeli counterpart. Our efforts to date have focused on obtaining data from Israel and the West Bank, since our partners are in these locations – we have not yet focused on data collection from locations in Gaza.

Fragmented data sources and the lack of a centralized system to access information were observed in both Israel and the West Bank. These problems have been described by many researchers in the region (Comair et al. 2014). Therefore, developing a database structure to organize, manage, and improve access to information is particularly important.

It was also challenging to assess the quality and accuracy of the data obtained. Data tables and GIS files were reviewed for internal consistency and spatial data were correlated to known locations where possible. Data quality persists as an issue inherent in relying on external sources of information.

Data Collected and Sources

The primary sources of data compiled thus far are universities, government ministries, NGOs, and international aid organizations. Since freely accessible GIS data are not easily available, data were often obtained from other researchers. Because of this, information regarding the origin of the data, date of data collection, and method used for compiling the GIS layers is often unknown. Data were collected about the physical environment, water quality, wastewater, and socioeconomics.

Table 1: Datasets compiled in the GIS database with the source are listed.

Dataset	Source
Physical Environment	
Soils for Israel and West Bank	Ben Gurion University
Lithology	Ben Gurion University
Land Cover for West Bank	Friends of the Earth Middle East (FOEME)
Land Use for Israel	Ben Gurion University
Watersheds	Ben Gurion University
Aquifers and Aquifer Recharge Areas	Digitized from Israel Hydrological Service
Rivers	Ben Gurion University
Rain	Ben Gurion University
WWT Plants and Collection Sites (Israel only)	Israel Water Authority and Mekorot (2006/07)
Digital Elevation Model (DEM)	Ben Gurion University
Water Quality	
Surface water quality	Israel Nature and Parks Authority, Nagouker Cohen, N. 2007, Ben Gurion University
Wastewater	
Type of Treatment Used by Municipality	Israel Water Authority, Arafeh 2012; House of Water & Environment (HWE); Hareuveni, E. 2009
Wastewater Treatment Facilities in Israel	Mekorot
Collection Sites and Reclamation Projects (Israel)	Mekorot
Stone Cutting Facility Locations	Al-Joulani, N. 2008
Socioeconomics	
Population areas	Israel Institute of Technology
Populations by Town/City	Israel Water Authority, Israel Central Bureau of Statistics, Palestinian Central Bureau of Statistics

Community Ethnicity	Israel Central Bureau of Statistics, Palestinian Central Bureau of Statistics, Israel Institute of Technology
Bedouin Community Status	Negev Coexistence Forum for Civil Equality and Rudnitzky, A. 2012
Israel District, Sub-Districts and Natural Regions	Israel Central Bureau of Statistics
West Bank Governorates	Ben Gurion University
West Bank Administrative Area	USAID
Jurisdiction and National Boundaries	Israel Central Bureau of Statistics
Data Created	
Hill slope layer	Calculated in ArcGIS from Digital Elevation Model

Data Processing and Integration

A preliminary geodatabase was constructed in ArcGIS during the previous stages of this project. The current phase of work has built upon the existing geodatabase structure by adding many new GIS layers, data tables, and lookup tables, and expanding the functionality of the geodatabase. This section describes the additions and modifications that were made.

The data collected were obtained as GIS files, Excel spreadsheets (or reports with data that could be transcribed into a spreadsheet), and image files. Each file and data type required varying amounts of pre-processing before it could be integrated into the geodatabase.

Geodatabase Functionality Upgrades

Another focus of this phase of the project was to increase the functionality of the geodatabase to serve as an analysis tool to investigate spatial relationships between varieties of data types. For example, in order to integrate socioeconomic data the data had to be linked to other data that are spatially referenced. To accomplish this, a master GIS layer showing all communities within the watershed was developed based on a compilation of many data sources. An initial file of community locations was obtained from the Israel Institute of Technology, however more than 45% of these locations were unnamed. Through research and investigation, names were added wherever possible, and in the final file only 25% of locations remained unnamed. The remaining unnamed locations typically have low populations and small areas. The English transliterated spelling of the name of each community was standardized throughout the geodatabase, so that these names could be used as a unique identifier to link the non-spatially referenced socioeconomic data to the locations of these communities. This linkage provided the ability to visualize many kinds of socioeconomic data on a map of the watershed, and explore the spatial relationship between these data and geographic and hydrologic information. Combining these data types in a spatial representation is extremely useful to increase the understanding of pollution sources, the upstream-downstream connection, and areas of greater risk to groundwater and surface water.

Results

This project is currently ongoing, and the research has not yet reached the stage where any conclusive results about the state of the watershed or specific recommendations about its restoration can be reported. That being said, we have made significant progress in investigating spatial and temporal trends in the data that have been compiled into the geodatabase thus far. This section presents the prepared maps, interpretations, and water quality results.

Spatial Analysis Results

The compiled data were mapped in order to better characterize the socioeconomic, hydrologic, and environmental condition of the watershed. These results are presented in a series of maps in Annex 1 and discussed below.

Boundaries and Demographics

Annex 1, Figure 1 shows the complexity of governance within the watershed. The Besor-Hebron-Be'er Sheva watershed overlies areas of Israel, the West Bank and Gaza. These areas of governance are further subdivided by different administrative areas. In Israel, the natural regions subdivide the Southern District. In the West Bank, Areas A and B denote important differences in civil and security administration. Additionally, boundaries of the over 200 municipalities within the watershed are shown.

Municipalities in this area typically have a dominant demographic. Annex 1, Figure 2 shows municipalities color-coded by demographic: Palestinian, Bedouin or Jewish Israeli. Bedouin communities are further subdivided based on the status of the community. Established Bedouin towns are recognized by the Israeli government and have access to infrastructure such as water and sewer networks and electricity. Unrecognized Bedouin villages are regarded as illegal by the Israeli government, and do not have access to infrastructure or services.[1] In 2003, Israel decided to recognize

[1] Negev Coexistence Forum for Civil Equality. Website accessed 01 June 2014. http://www.dukium.org/eng/

13 Bedouin villages in the Negev. Since 2003, improvements in infrastructure and access to services in these villages have been occurring, however slowly.

Seven Jewish communities are located in the West Bank within the Besor-Hebron-Be'er Sheva watershed. These include: Kiryat Arba, Otniel, Haggai, Tene, Shim'a, Mezodot Yehuda, and Suseya (separate from Palestinian Suseya).

Population data were compiled from the Israel Central Bureau of Statistics (2011), Palestinian Central Bureau of Statistics (2013) and the Israel Water Authority (2006-2007). Annex 1, Figure 3 shows the population of each community, where available. We have not yet been able to obtain reliable population data for some Bedouin communities, including Um Batin, Bir Hadaj, Al Sayyid, Abu Qureina, and others. Estimates for population areas in Gaza are even more uncertain, however the UNRWA suggests that approximately 124,000 people live in the area of Gaza within the Besor-Hebron-Be'er Sheva watershed. Figure 3 makes it easy to visualize and analyze the distribution of population throughout the watershed. Approximations suggest that about 900,000 people live within the watershed boundaries, 75% of which live in the northeastern quadrant. Estimations of demographic information compiled from surveys conducted between 2006 and 2013 suggest that approximately two thirds of the watershed population is Palestinian (including Gaza), one third is Jewish Israeli, and a small percentage (approximately 1%) is Bedouin living in Israel. Hebron is the largest population center in the southern West Bank, with a population of approximately 200,000 people.[2] Similarly, Be'er Sheva is the main population center of the Southern District of Israel with approximately also 200,000 people.[3]

Hydrologic Characterization

Drainages within the Besor-Hebron-Be'er Sheva watershed are naturally ephemeral. They do not support baseflow year-round, but instead flow in response to significant precipitation events that tend to occur six or seven times per year (Tal et al. 2007). However, the natural system has been altered by overallocation and overuse of surface water and releases of wastewater directly into the wadis. Releases of untreated, domestic and industrial wastewater from leather tanneries, stone cutting and olive presses in the urban area of Hebron have created a perennial baseflow in the Hebron drainage (also known as

[2] According to data from the Palestinian Central Bureau of Statistics for 2013. Website accessed 01 June 2014.
[3] According to data from the Israel Central Bureau of Statistics from 2011.

Wadi As Samen). The average annual streamflow varies from less than 5 to nearly 10 million cubic meters/year. The Hebron and Besor drainages are the basin's primary drainages (see Annex 1, Figure 4).

The climate in the Besor-Hebron-Be'er Sheva watershed varies from semi-arid to arid. Average annual rainfall in the south is less than 50 mm/yr, however in the north, can be as much as 550 mm/yr (see Annex 1, Figure 5).

The watershed is characterized by high topographic variability, rising from the Mediterranean Sea to over 1,000 meters above sea level in the northeast extent near Hebron (see Annex 1, Figure 6). The higher elevations in the northeast and southeast constitute the headwaters of the watershed. Drainages flow through the basin and eventually converge at the outlet to the Mediterranean Sea. The headwaters near Hebron are mountainous, with steep slopes, less soil cover, more permeable soils, and shallow bedrock. The headwaters overlie the southern extent of the surface expression of the anticline that forms the Judean hills. Bedrock in this area is generally Late Cretaceous limestone and dolomite of the Judea Group, which hosts the primary groundwater aquifer, the Mountain Aquifer. Groundwater is stored in a lower zone and a karstic upper zone separated by less permeable chalk and marl (GSI 2014). Groundwater flow in the upper zone is toward the south/southwest and toward the south in the lower zone (Livshitz et al. 2012). The Western Mountain Aquifer is bounded to the east partly by the crest of the anticline and partly by hydraulic controls. The Eastern Mountain Aquifer, composed of the same rocks units but with a flow direction to the northeast, underlies the most northeast corner of the watershed. Limestone also outcrops in the southeast of the watershed. Outcroppings of the Judea Group limestone in the southeast and northeast of the basin provide recharge areas for the groundwater aquifer. In these areas, there may be some seepage from the upper zone into the lower zone of the Mountain Aquifer (GSI 2014). The Israel Hydrologic Service identified groundwater recharge zones in the northeast and southeast of the basin, which corresponds to areas with shallow bedrock and thinner, more permeable soils (Livshitz 2012). Annex 1, Figure 7 shows the approximate areas where the basin overlies the Western Mountain Aquifer, the Eastern Mountain Aquifer, the Negev and Arava Aquifer, and the Coastal Aquifer. The Western and Eastern Mountain Aquifers are important sources of drinking water. The center of the basin is primarily chalk, chert of the Eocene Avedat Group, overlaid by conglomerate, sand, and alluvium (Annex 1, Figure 8; GSI 1998).

Soils vary from terra roasses, brown rendzinas and pale rendzinas in the northeast headwaters (see Annex 1, Figure 9). South of the Green Line, an east-west band of brown lithosols, loessial soils, and brown soils stretches across the basin. The southern quadrant of the basin can be characterized by loessial serozems and brown lithosols. Soil type affects infiltration to groundwater. Water infiltrates more easily through rendzinas than through loessial soils (Livshitz 1999). Areas of sand dunes, bare rocks and desert lithosols extend into the basin from the southwest.

Based on the geologic and hydrologic characteristics of the watershed, we can identify areas where surface water and/or groundwater are particularly vulnerable to pollution. Low flow in naturally ephemeral streams throughout the basin make these drainages susceptible to impact. Natural processes, such as self-purification, dilution, and sedimentation, can help to degrade pollutants, however without a substantial natural baseflow of clean water, these processes are reduced. Baseflow in the Hebron stream is almost entirely untreated wastewater. Although flood events typically increase pollutant loading by flushing pollutants from paved surfaces in runoff, in the Hebron stream, even runoff is a source of dilution to improve the extremely degraded streamflow (Nagouker Cohen 2007). Groundwater is most vulnerable in the headwaters in the northeast corner of the basin. Here, shallow groundwater and outcropping bedrock provides for recharge to the groundwater aquifer, which is facilitated by thin, permeable soils. In fact, previous studies have estimated that between 40 and 90% of surface water infiltrates into the subsurface within the first 8.5 km of measureable flow in the Hebron drainage (Tal et al. 2007). Recharge areas in the southeast are also vulnerable to pollution however cover of loessial soils may reduce infiltration rates.

Pollution Sources

The most problematic source of pollution in the Besor-Hebron-Be'er Sheva watershed is untreated domestic and industrial wastewater released in the upper catchment in and around the city of Hebron. This region is known for three main industries that all produce problematic wastewater. These industries are stone cutting, leather tanning and olive oil production. Due to the serious lack of an efficient wastewater treatment infrastructure these industrial wastewater streams drain into the Hebron drainage contributing significantly to its degradation. Currently between 22,730-25,150 m^3/day of wastewater is generated in the city of Hebron with most of this not being treated and eventaully ending up in the Besor-Hebron-Be'er Sheva watershed (Al-Zeer, I. and I. Al-Khatib 2008). Wide-spread agricultural land cultivation may constitute a non-point source of elevated nitrogen, phosphorus, and other nutrients from pesticide and fertilizer use.

The chemical characteristics of wastewater from these sources was described in detail in the 2nd Annual Report. The focus of this report is to use spatial analysis to better characterize the pollution sources as well as the nature and extent of their impact.

Based on the available data, the majority of the 3.5 million dunums of land within the Besor-Hebron-Be'er Sheva watershed is open land, forests or grasslands (approximately 64%) (see Annex 1, Figure 10). However, approximately 37% (1.3 million dunums) is used for agriculture or agriculture-related activities. An additional 1.4% (47,000 dunums) is covered by olive groves. Irrigated lands can be a source of increased nitrogen and phosphorus in surface water. Approximately 44,000 dunums of land (1.3% of the watershed) are zoned for industry or commercial use, which can be a highly concentrated source of contaminants. Mining areas are small (1,600 dunum) and restricted to the mountainous areas in the West Bank.

Annex 1, Figure 11 shows the primary wastewater treatment method used in each population area. This GIS layer was created by combining the available information. Wastewater treatment methods for Jewish Israeli communities in Israel and in the West Bank were tabulated by the Israel Water Authority in 2006/07. The main population center of Be'er Sheva and some nearby communities are serviced by the Mekorot's Be'er Sheva Wastewater Treatment facility, which treats 14.4 million cubic meters of wastewater per year (Mekorot 2014). Other regional wastewater treatment facilities serve additional communities. Less populous Jewish Israeli communities use cesspits, settlement ponds, or oxidation ponds. Settlement ponds and oxidation ponds are considered primary or secondary levels of treatment, and can be slow and inefficient. In settlement ponds, solids are allowed to settle out of the wastewater and in oxidation ponds, algae growth produces oxygen to fuel the breakdown of organic material by microorganisms. Cesspits are used to collect and store wastewater underground. In a porous cesspit, liquid waste percolates into the subsurface. The remaining solid waste needs to be cleaned out periodically. In a tight cesspit, a watertight liner is utilized to prevent infiltration, however emptying is required more often.

Over 80% of Hebron is connected to sewer pipes however the raw domestic wastewater collected in these pipes is discharged directly into the Hebron drainage south of the urban area (Hareuveni, E. 2009). Industrial wastewater is also discharged without treatment. Wastewater treatment in less populous Palestinian communities in the West Bank primarily use cesspits (HWE 2014), most of which are porous (PCBS 2014)which means that leakage of untreated wastewater into the subsurface is common. Arafeh

(2012) reports the use of some household septic tanks in Yatta, Bani Na'im, Dura, As Samu, and Ar Rihiya. In a septic tank, solids within the underground tank undergo some degradation and liquids are released into a drain field where they are dispersed. This allows septic tanks to be cleaned out less often than cesspits. In both septic tanks and cesspits, compromises to the construction integrity and lack of maintenance increase the risk to groundwater.

Wastewater treatment methods for many recognized and all unrecognized Bedouin villages are unknown, however are assumed to be rudimentary. Only two established Bedouin towns are connected to centralized WWTFs; these are Rahat and Segev Shalom. Laqye and Hura, which are also established towns, are documented as using cesspits for watewater as of 2006/07 (2008 et al. כהן, א.). Other established towns and recognized villages use cesspits or settlement ponds.

Annex 1, Figure 12 shows selected land uses that could be point sources of pollution and communities where the primary method of wastewater treatment may pose a threat to surface water or groundwater. General industrial and commercial areas are shown, as well as the specific locations of the industrial facility of Ramat Hovav and the stone cutting facilities in the Hebron Industrial zone. Direct discharge of untreated wastewater occurs exclusively in the northeastern headwaters of the watershed, from Hebron and Kiryat Arba. Other potential sources of pollution are spatially concentrated in the northeastern headwaters, including cesspits/septic tanks, mineral extraction sites, and industrial facilities, including many stone cutting facilities. Other industrial areas are found in the central part of the basin, particularly near Be'er Sheva and at the industrial complex of Ramat Hovav. Cesspit use in communities within Israel is dispersed in the north-central part of the basin.

An advantage of using GIS is the ability to overlie many different layers of information on the same map. Annex 1, Figure 13 shows the spatial interaction between potential pollution sources (as in Figure 12), streams, the groundwater aquifer, and groundwater recharge zones. This maps shows that multiple pollution sources tightly clustered in the headwaters in the northeastern corner of the watershed overly the natural recharge areas of the Western Mountain aquifer. Additionally, previous studies have estimated that infiltration from surface water to groundwater in the upper reaches of the Hebron stream is significant. Estimates suggest that 40-90% of water from the stream drainage infiltrates into the subsurface in the first 8.5 km of flow, and infiltration rates are high throughout the upper 40 km (Nagouker Cohen, N. 2007).

Industrial areas in the center of the basin tend to be located along streams, and may be potential sources of pollution to the surface water. Groundwater is less vulnerable in the center of the basin because the depth to groundwater is greater than in recharge areas, a thick alluvial unit covers the bedrock and is an unconfined aquifer in some areas, and soils are less permeable (loessial). Groundwater recharge areas in the southeast do not spatially overlap identified pollution sources.

Water Quality Monitoring Results

Water quality is a crucial part of a comprehensive baseline characterization. Understanding the current water quality helps us understand how pollution has affected the stream up to this point, and gives us a baseline from which to monitor for future impacts. Measuring the water quality at both upstream and downstream locations can shed light on the patterns and mechanisms of pollutant transport in the stream and the location of potential sources. This section reviews the water quality data that have been collected and analyzed thus far. First, a historical record from the Israel Nature and Parks Authority is presented. Next, samples that CTWM coordinated in 2013 are presented.

Historical Trends in Water Quality

A historical record of surface water quality was available for only four locations within the watershed, and only two locations along the Besor-Hebron-Be'er Sheva stream. These locations, the Shama Roadblock and the Southern Delivery Station, are useful in evaluating changes from upstream to downstream along this drainage. The Shama Roadblock station is located at the Green Line near Meitar, and the Southern Delivery Station is located downstream of Be'er Sheva. Surface water quality samples were taken by the Israel Nature and Parks Authority biannually since 2002. Data from 2002 through 2012 has been acquired to date. Samples were taken in the spring (April, May, or June) and fall (September, October, or November). Figures 6 through 10 show the time-series of concentrations for total suspended solids (TSS), biological oxygen demand (BOD), fecal coliforms, total nitrogen, and chloride along with their respective Inbar standards for these two stations.

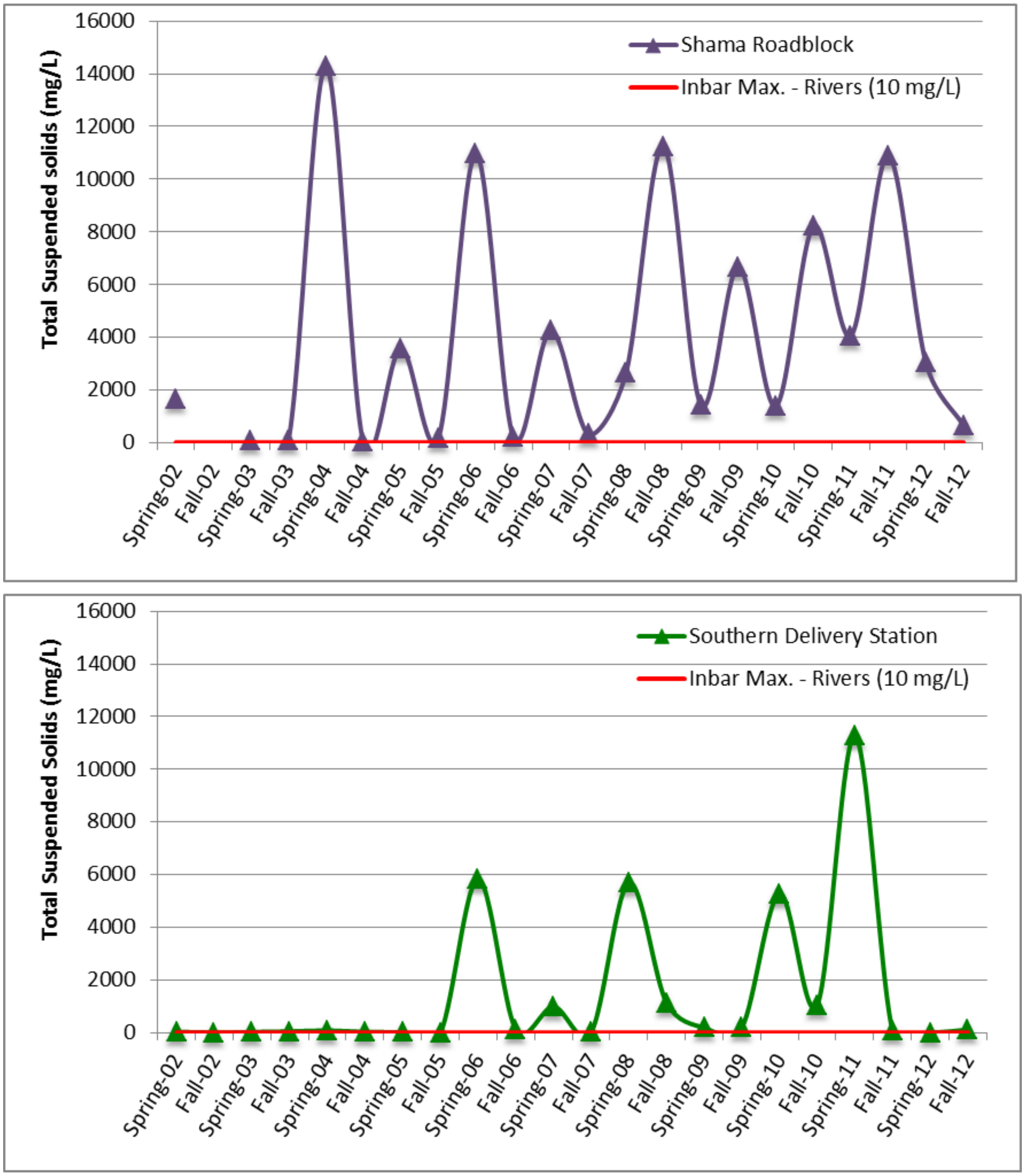

Figure 6: Total suspended solids (TSS) concentrations over time at the Shama Roadblock and Southern Delivery Stations.

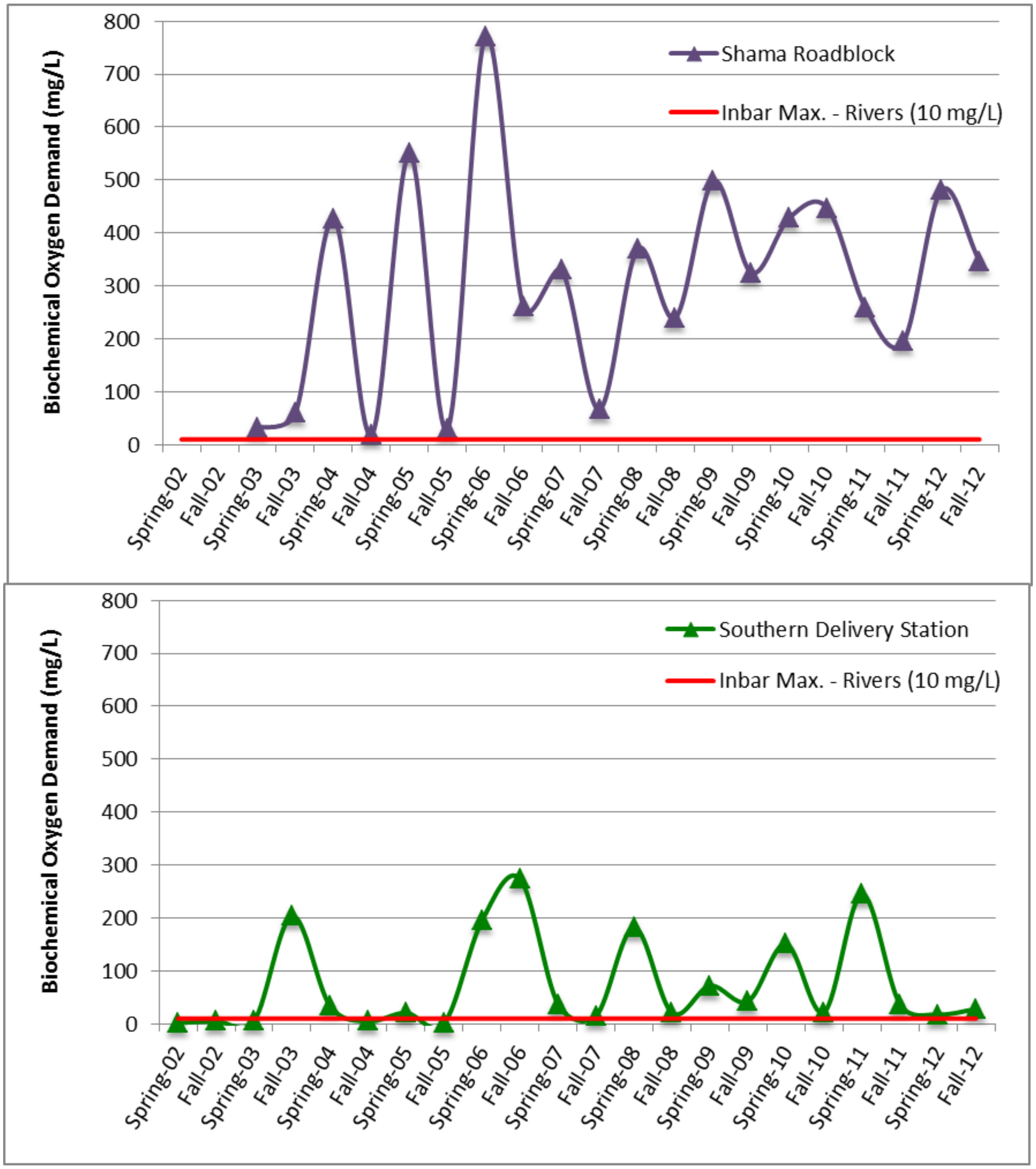

Figure 7: Biological oxygen demond (BOD) concentrations over time at the Shama Roadblock and Southern Delivery Stations.

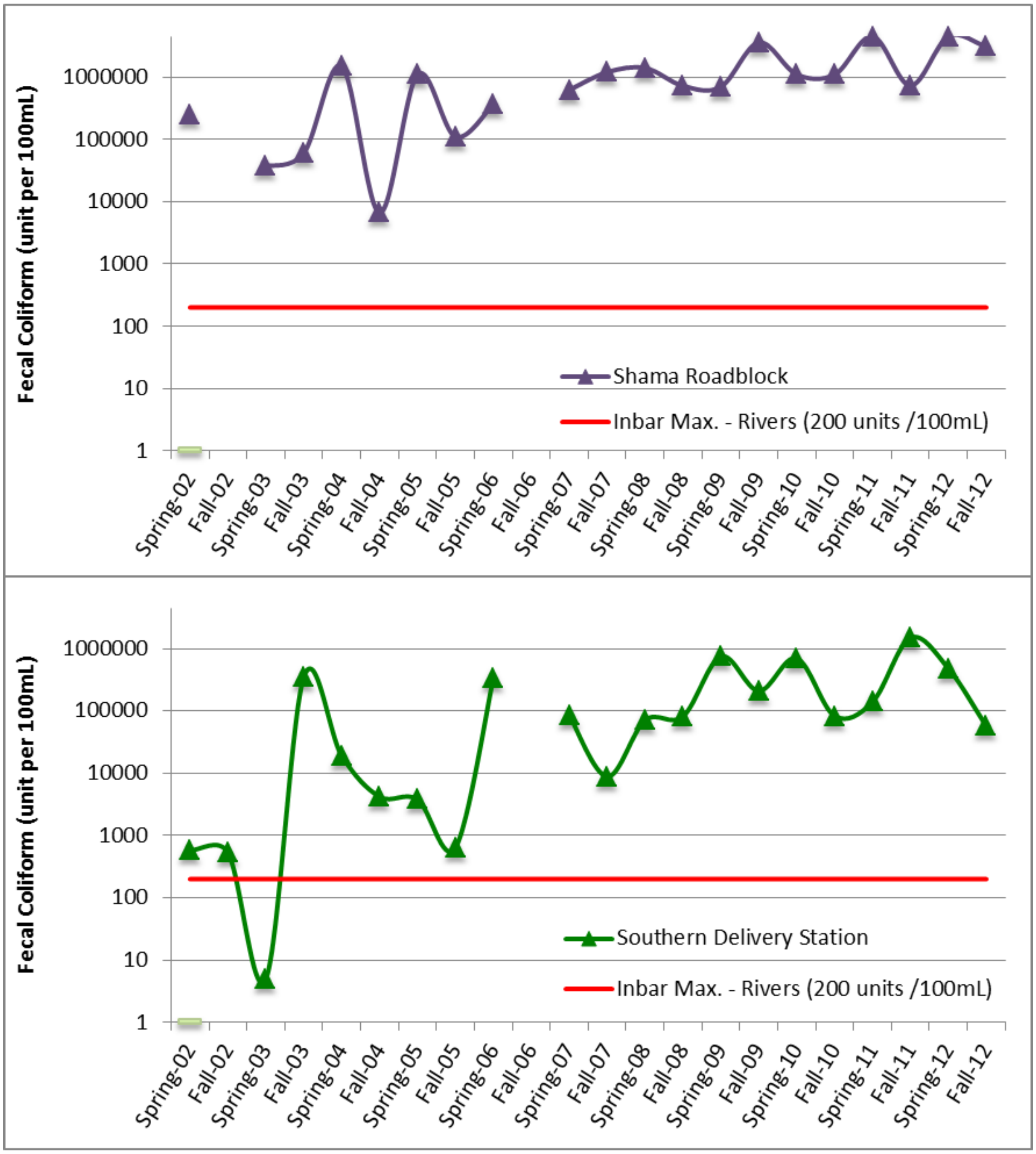

Figure 8: Fecal coliforms over time at the Shama Roadblock and Southern Delivery Stations.

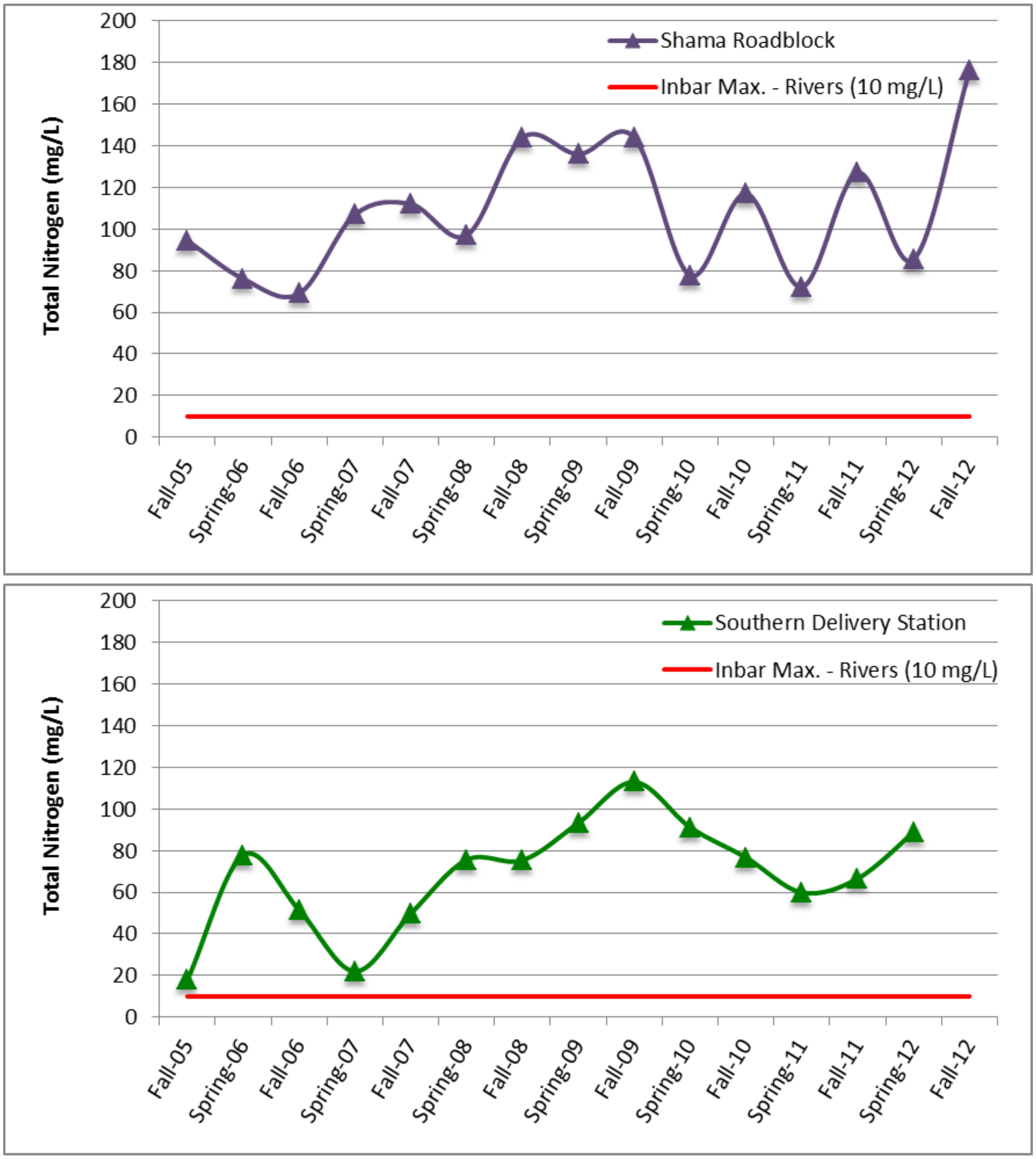

Figure 9: Total nitrogen concentrations over time at the Shama Roadblock and Southern Delivery Stations.

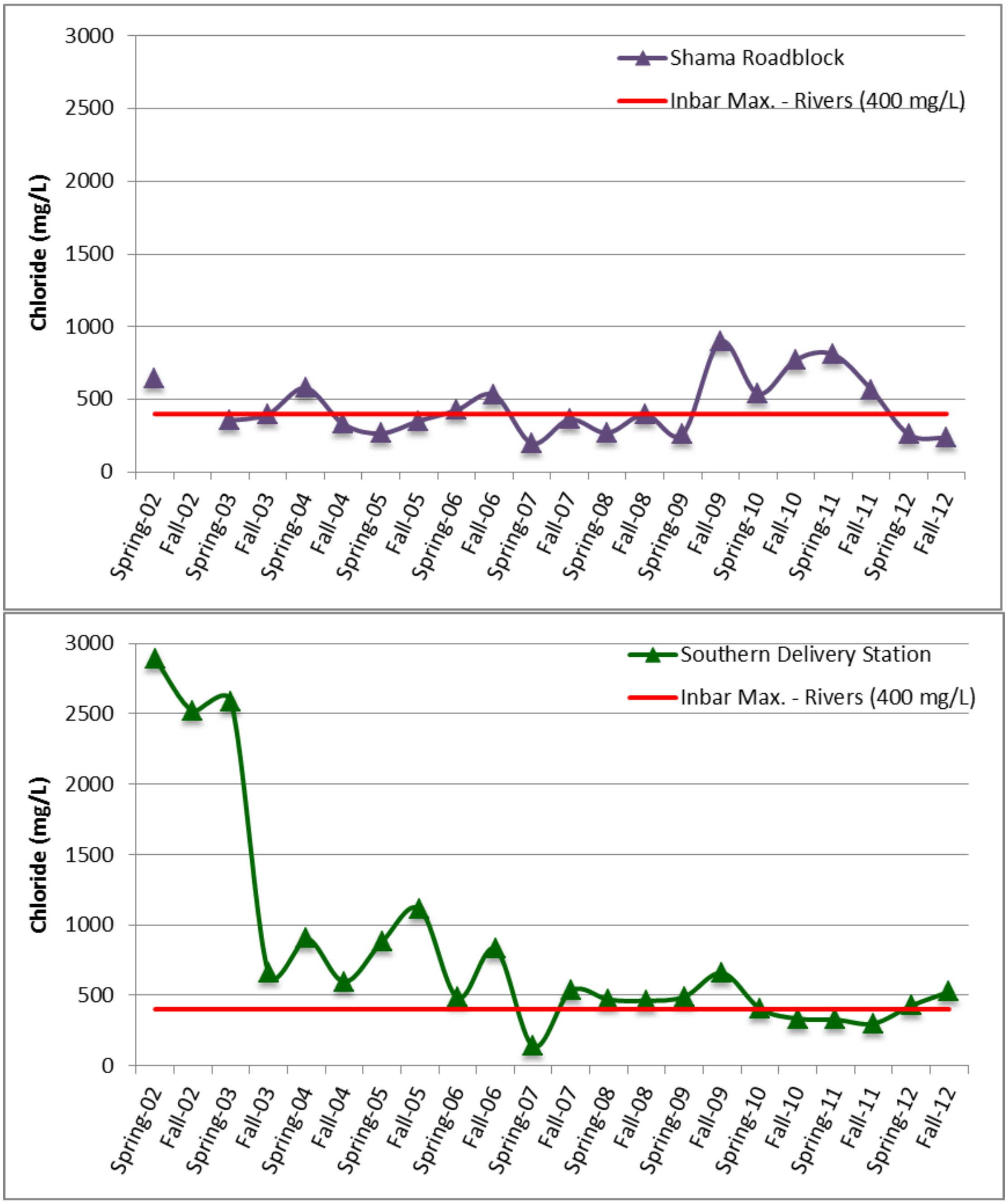

Figure 10: Chloride concentrations over time at the Shama Roadblock and Southern Delivery Stations.

The results plotted in Figures 6 through 10 show that concentrations of TSS, BOD, fecal coliforms, and total nitrogen are generally higher upstream than downstream (at the Shama Roadlock versus the Southern Delivery Station). Industrial wastewater from the stone cutting industry in the Hebron area of the West Bank is a major source of elevated TSS. The data show a seasonal variation in TSS concentrations, with peaks at the Shama Roadblock (upstream) occurring in spring before 2008, and in fall after 2008. This seasonal shift may reflect the installation of the Shoquet treatment facility at the Green Line near the Metarim checkpoint, just upstream of this sampling location. Wastewater treatment at the Shoquet plant is minimal, but some reduction in sediment and suspended solids could be expected from this process. At the Southern Delivery Station (downstream), elevated TSS typically occurs in the spring. Spring peaks suggest that flushing due to precipitation runoff increases the transport of TSS to the stream. Seasonal peaks both upstream and downstream exceed the Inbar standard of 10 mg/L by two or three orders of magnitude. Total Suspended Solids (TSS) is a measure of the amount of suspended particles in the water. Algae, suspended sediment, and organic matter particles can cloud the water making it more turbid. Suspended particles diffuse sunlight and absorb heat. This can increase temperature and reduce light available for algal photosynthesis. If the turbidity is caused by suspended sediment, it can be an indicator of erosion, either natural or man-made. Suspended sediments can clog the gills of fish. Once the sediment settles, it can foul gravel beds and smother fish eggs and benthic insects. The sediment can also carry pathogens, pollutants and nutrients.

BOD and fecal coliform are indicators of domestic wastewater pollution. BOD concentrations (Figure 7) are generally higher at the Shama Roadblock (upstream) than the Southern Delivery Station (downstream). Concentrations upstream peaked at nearly 800 mg/L in 2006, whereas downstream, concentrations have been below 300 mg/L between 2002 and 2012. Seasonal fluctuations are observed, both upstream and downstream, where peaks occur in the spring season. Fecal coliforms are plotted on a logarithmic scale, since their concentrations are extremely elevated compared to the Inbar standard of 200 units per 100 mL. Upstream concentrations were close to or above 1,000,000 units per 100 mL since 2007. Downstream, fecal coliforms vary more dramatically. This and the reduction in BOD downstream may suggest that some self-purification occurs within the Hebron stream. Elevated BOD and fecal coliforms confirm that domestic wastewater is a significant source of pollution to the Hebron stream, and that this is not a new problem and most likely relates to the minimal wastewater treatment infrastructure in the West Bank. Elevated concentrations were observed even in 2002. Additionally, since greatly elevated amounts of fecal coliforms persist downstream there are likely additional inputs of pollution south of the Green Line.

Agricultural uses can increase concentrations of nutrients (such as nitrogen and phosphorus) and salt in runoff that reaches surface water and groundwater (Causape et al, 2004 N Cohen). Total nitrogen concentrations are elevated far above the Inbar standard of 10 mg/L at both the Shama Roadblock (upstream) and Southern Delivery Station (downstream) since 2005. Upstream, concentrations vary between 60 and 160 mg/L, whereas downstream, concentrations are slight lower, and vary from less than 20 mg/L to almost 120 mg/L. Total nitrogen shows seasonal peaks in the fall since 2009, however seasonality is not apparent downstream. This is likely due to the self-purification capacity of the stream and the complex cycling of nitrogen in the environment. The meaning of seasonal fluctuations is difficult to diagnose in arid and semi-arid climates, since the first flood of a season can be responsible for washing 60-70% of the contaminants built up on the ground surface into the stream (Skipworth et al, 2000). It is unknown whether sampling events in the spring season were coordinated with the first flood. Chloride, a salt indicating irrigation of arid soils, is near the Inbar standard of 400 mg/L at the Shama Roadblock (upstream). At the downstream location, concentrations above 2,500 mg/L observed in 2002 and 2003 decreased dramatically in the fall of 2003, and in recent years have been at or near 400 mg/L. Seasonal variability downstream shows peaks in the fall of 2005, 2006, 2007, and 2009, and a peak in the spring in 2004.

These data show that historical records of water quality are helpful to gain a better understanding of the spatial and temporal variations, i.e. long-term changes and seasonal fluctuations that ultimately elucidate the sources of pollution and the magnitude of their impact. Having additional stations on the Hebron stream where a long-term record of water quality was available would help characterize the baseline condition of the watershed, clarify the upstream/downstream connection, and monitor the positive impacts due to changes in water management in the watershed. Our recommendations for further long-term monitoring are included in the section "Going Further".

Stream Sampling

One effort to address the data gaps is to collect additional water quality samples on the Hebron stream, specifically at locations that would show changes in water quality from upstream to downstream, and including locations in the West Bank, where data are sparse and potential pollution sources are nearby. To this goal, grab samples in the West Bank were collected by Leila Hashweh, a graduate student at Ben

Gurion University, at one location near Hebron, at the Green Line, and at two locations downstream on the Hebron stream. Two sampling events have been conducted, one in June 2013 and one in December 2013. During the second sampling event, an additional location on the Be'er Sheva stream, a tributary to the Hebron stream that enters the Hebron near the Bedouin town of Tel Sheva (upstream of Be'er Sheva), was sampled.

Results from the June 2013 sampling event were reported in the Second Year Interim Report. Here, we report the results from the December 2013 sampling event and compare it to the June 2013 sampling event (Table 2).

Table 2: Results of water quality from grab samples collected in June and December, 2013.

Parameter	Unit	Inbar Standards discharge to streams	Upper catchment – West Bank, outskirts of Hebron		Meitar Checkpoint – southern West Bank		Tel Sheva, east of Be'er Sheva		Near Kibbutz Hatzerim, west of Be'er Sheva		Be'er Sheva Stream, near Tel Sheva, upstream of Hebron Stream	
			Jun	Dec	Jun	Dec	Jun	Dec	Jun	Dec	Jun	Dec
Total suspended solids	mg/L	10	**1,260**	**96.7**	**2,721**	**18.0**	**62.0**	**14.0**	**63.0**	**28.0**	N/A	**100**
Chemical oxygen demand	mg/L	70	**1,210**	**320**	**1,230**	2.00	**186**	65.6	**170**	**72.0**	N/A	**420**
Total nitrogen	mg/L	10	**85.4**	6.18	**85.9**	1.86	**52.2**	**27.0**	**48.8**	3.15	N/A	6.00
Total phosphorus	mg/L	1	**9.35**	**13.3**	**11.7**	0.04	**12.2**	**8.48**	**10.3**	**4.23**	N/A	**15.9**
Chloride	mg/L	400	247	196	252	14.0	348	182	**411**	323	N/A	172
Sodium	mg/L	200	N/A	**246**	**208**	24.5	**287**	**218**	**285**	**272**	N/A	**244**
pH	mg/L	7.0 - 8.5	7.91	7.96	8.19	8.34	8.31	8.30	**8.67**	7.79	N/A	7.62

N/A = not applicable because not measured
Bold values exceed the Inbar standard for discharge to streams.

In Table 2, concentrations that exceed the Inbar standard for discharge to rivers (also included in the table) are listed in bold. In general, many values exceed the Inbar standards in both June and December. Total suspended solids (TSS) concentrations exceeded the Inbar standard in June and December for all stations, however, concentrations were lower at all stations in December versus June. More specifically, a decrease of two orders of magnitude was observed in TSS from June to December at the upper catchment stations near Hebron and the Meitar checkpoint in the West Bank. Total phosphorus and sodium concentrations exceeded the Inbar standards of 1 mg/L and 200 mg/L respectively in almost all samples. Chemical oxygen demand (COD) decreased from June to December in all locations that were sampled in both months. Decreases of between one and three orders of magnitude were observed, with the greatest magnitude of decrease occuring at station at the Meitar checkpoint. Sodium concentrations follow a different trend. Decreased sodium is observed in December only at the Meitar checkpoint station. At the Tel Sheva and Hatzerim stations, upstream and downstream of Be'er Sheva, respectively, sodium concentrations are consistenty elevated in both June and December with no significant seasonal change.

These results show that significant pollution is observed, specifically with regard to sodium, COD, and TSS. Elevated sodium is an indication of agricultural runoff from farms due to high rates of fertilizer and pesticide use. Since the topography in Israel is more conducive to agricultural use than the mountainous areas of the West Bank, it makes sense that more impact from agricultural runoff would be observed near Tel Sheva and Hatzerim. Additionally, non-point source pollution shows a different trend than point source pollution, such as wastewater treatment discharges. In general, water quality is worse in the summer, when flows are reduced and chemicals become more concentrated. For point source discharges, additional input from precipitation in the winter would be expected to cause a reduction in concentrations due to dilution. For non-point sources, however, increased precipitation causes an increase in runoff which mobilizes agricultural chemicals from fields.

Chemical oxygen demand (COD) is an indicator of the amount of organic compounds present in water. Wastewater effluent would cause COD levels to increase. COD concentrations vary by two orders of magnitude from upstream to downstream – concentrations are over 1,000 mg/L in the West Bank and less than 200 mg/L in Israel during the June sampling event. These show the effect of untreated wastewater discharge in the upper reaches of the Hebron stream.

Total Suspended Solids (TSS) is a measure of the amount of suspended particles in the water. As discussed in the Second Year Interim Report, approximately 100 stone cutting companies are located in Hebron and lie primarily within the industrial zone in the southern corner of the city (Kahrmann 2013). Stone cutting activities are a primary source of TSS in the Hebron stream. Water is used to cool rock saws, and the used water mixes with calcium carbonate dust. It is estimated that the stone cutting industry produces 3,300 metric tons/year of calcium carbonate solids (El-Hamouz 2010). TSS data are by orders of magnitude much higher in the West Bank further indicating that significant quantities of industrial wastewater are being discharged into the Hebron stream.

In summary the table indicates a complex situation of pollution with sources in both Israel and the West Bank, and illustrates the different transport mechanisms of point and non-point source pollution throughout the watershed. Very few of the parameters meet the Inbar standards reflecting a high level of pollution throughout the Besor-Hebron-Be'er Sheva stream, including the section of the stream flowing through the Be'er Sheva River park. In some cases the data are orders of magnitude above what the Inbar standards require. The sampling locations included in this sampling effort begin to address an important data gap of water quality information from locations in the upper reaches of the Hebron stream in the West Bank.

A comprehensive dataset that covers both the upstream and downstream areas of a polluted watershed is necessary in order to develop a clear baseline understanding of the water quality. Upstream and downstream sampling locations help clarify the nature and extent of pollution, and elucidate potential sources of pollution. Collecting samples in both dry and wet seasons can be useful to understand the mechanisms of pollutant transport as well as the seasonal variations caused in part by natural fluctuations, chemical transport mechanisms, and variations in loading from the sources of pollution.

A baseline characterization is crucial, however long-term monitoring is also required to evaluate the effectiveness of any stream restoration. Seasonal variability and other natural fluctuations will only be apparent in an extended record of sampling. Long-term monitoring can also elucidate the fate and transport of pollution in the watershed. For example, what is the self-purification capacity of the stream? And, is the groundwater vulnerable to impact from polluted surface water? In addition, long-term trends can help evaluate and quantify improvements in water quality caused by changes in water management or point source control. Continuation of stream monitoring that is proposed for the the Besor-Hebron-Be'er Sheva watershed is discussed in the section "Going Further".

Meeting with Stakeholders

The Arava Institute's experience working with cross border organizations and extensive network of researchs puts it in a unique position to address transboundary water management challenges. CTWM regularly connects with researchers from across the region during workshops, conferences, and trainings held in the region. On June 26th 2014, CTWM had the opportunity to present the current research on the Besor-Hebron-Be'er Sheva watershed to a group of this watershed's stakeholders during a workshop co-sponsored by international aid agencies and NGOs from Israel and the Palestinian Authority.[4] The workshop participants are listed in Table 3. Out of over 30 participants, approximately 37% were Palestinian, 37% were Israeli (including Israeli-Arabs), and 25% were internationals. The benefit of this workshop was twofold – by sharing research results we can begin to increase the stakeholders' understanding of the watershed and we can develop new relationships with researchers and stakeholders.

By presenting the results of preliminary research in the Besor-Hebron-Be'er Sheva watershed, stakeholders can learn about the scientific aspects of watershed management and increase their knowledge of the specific challenges faced in this watershed (Carmona, G. et al. 2013). Likewise, stakeholders can participate in the data collection process, as engaging in discussion about active research may make them more likely to share their existing knowledge. More specifically, data visualizations, such as maps and graphs are especially effective in promoting a holistic understanding of watershed processes (Carmona, G. et al. 2013). For example, seeing a map of water quality samples on a map can clearly show how upstream activities can impact the water quality downstream.

Table 3: Participant affiliations from the 26 June 2014 stakeholder meeting in Beit Jala.

Participant Affiliations
Al Quds University
Arava Institute for Environmental Studies
Ben Gurion University
Bethlehem Western Southern Joint Council
Black and Veatch Consulting
Colorado State University
Friends of the Earth Middle East

[4] The workshop was co-sponsored by USAID, the Arava Institute for Environmental Studies, Ben Gurion University, the Water and Environmental Development Organization (WEDO), and House of Water & Environment.

GIZ Ramallah
Hebrew University
Independent
Israel/Palestine Center for Research and Information (IPCRI)
United Nations Development Programme, Ramallah
US Agency for International Development (USAID)
Water and Environmental Development Organization (WEDO)
Yarkon River Authority

Since the watershed is interconnected, so to should the research and data collection throughout the watershed by collaborating with scientists and researchers from Israel and the West Bank. At the workshop in June, CTWM was able to make connections with other researchers, both Israeli and Palestinian who are working in the watershed. Our hope is that these relationships become productive avenues to share data and knowledge and increase the potential to arrive at collaborative solutions that address water quality challenges. Unilateral solutions have been attempted by Israel to reduce the impact of polluted streamwater. A wastewater treatment facility was constructed on the Hebron stream at the Green Line to treat sewage from the West Bank as it flows into Israel (Hareuveni, E. 2009). Although political conflict and economic asymmetries between the governing bodies of Israel and the Palestinian Authority can make unilateral solution more viable, treating wastewater so far from its source is problematic (Fischhendler, I. et al. 2011; Tal, A. et al. 2010). Research has shown that over the 40 km that sewage flows in wadis before entering Israel, between 40 and 90% may seep into the groundwater aquifer causing additional pollution to this important resource (Nagouker Cohen, N. 2007). Since the solutions with the least resistance are often servely deficient in addressing the source of pollution, we believe that collaboration is key in minimizing the impact on the environment throughout the watershed.

Going Further

Figure 11: The Be'er Sheva River Parkway as it is today with untreated sewage flowing in the stream.

With the ultimate goal of improving the health of the Besor-Hebron-Be'er Sheva stream to support the development of a viable river park in Be'er Sheva, the focus of our continued work is twofold - to further our scientific understanding and promote cooperation among stakeholders - both on a watershed level. Specifically, our next tasks will include furthering our baseline understanding of pollution, establish a long-term monitoring program, and promote stakeholder engagement so as to develop feasible recommendations for restoration of the watershed.

The importance of building and maintaining a comprehensive database in GIS has been demonstrated herein. Currently, we are able to conduct some analyses with the information that has been collected up to this point. Gaps in the database should be addressed. We have received groundwater depth and quality information that needs to be integrated into the database. In addition, the preliminary analysis has identified areas where additional water quality (surface water and/or groundwater) are needed, specifically in the West Bank and in Gaza. Our analyses also showed that understanding the connection between surface water and groundwater is critical to quantifying the potential risk to water resources. This is a questions that Leila Hashweh is currently investigating in her Master's research. She will also continue water quality monitoring for 2014.

However, a long-term monitoring plan is needed. Grab samples in wet and dry seasons should be conducted annually in order to understand how rainfall and flooding impact the quality of wastewater in the stream. This schedule will be coordinated and supported in part by the Israeli Water and Sewerage Authority. In addition, automatic sampling stations, proposed in the First Year Interim Report,and now in the process of implementation would add important real-time information about water quantity and quality and would constitute a significant contribution to our understanding of flow and chemical transport in the stream.

Arriving at viable solutions to improve the water quality in the watershed depends not only on science, but also on establishing cooperative relationships with stakeholders. We believe that engaging stakeholders in the process of data collection and analysis will set the stage for cooperative relationships to develop. Through sharing information and learning about the watershed, stakeholders are more likely to consider watershed-wide solutions that positively benefit multiple parties (Carmona, G. et al. 2013). Following the stakeholder workshop in June 2014, we plan to build upon relationships started here, by engaging with researchers working in the Besor-Hebron-Be'er Sheva watershed to share information about water quality and pollution. This workshop was also an example of how GIS can be used as a visual tool for communicating complex information to stakeholders from different professional backgrounds (i.e. scientists and decision-makers). Our next steps are to continue to develop the capacity of GIS as a tool for engaging and educating stakeholders and for conducting analysis for decision support. The GIS database that we have developed is the first step toward conducting quantitative modeling of scenarios that reflect different management options for watershed restoration. For example, we could model the effect that removing the point source discharge of untreated wastewater in Hebron would have on the flow and stream water quality downstream, such as near Be'er Sheva. Visual representations of quantitative results derived from observed data would be an extremely effective tool in helping decision-makers understand the effect of different decisions, and therefore choose the most beneficial decision for the entire watershed.

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Annex One

This section includes maps of the spatial data for the Besor-Hebron-Be'er Sheva watershed.