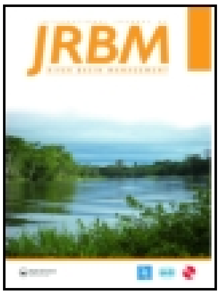

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Chemical and biological monitoring in ephemeral and intermittent streams: a study of two transboundary Palestinian-Israeli watersheds

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Research paper

Chemical and biological monitoring in ephemeral and intermittent streams: a study of two transboundary Palestinian–Israeli watersheds

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ABSTRACT
Although ephemeral streams constitute critical natural resources in dryland environments, water regulations and monitoring protocols typically focus on perennial streams, and may not always be appropriate for characterizing intermittent systems. The article presents findings from a comprehensive evaluation of environmental conditions in two ephemeral transboundary streams: the Hebron/Besor and Zomar/Alexander. The streams are representative of numerous watersheds which originate in Palestinian land and flow into Israel. Transboundary streams in the region exhibit high concentrations of point and non-point sources of pollution. Many of the region's streams that in the past had no flow except for isolated storm incidents have emerged as perennial streams, channelling raw or partially treated industrial or municipal wastes. Management of these natural resources constitutes a unique challenge because of the complex local political circumstances. The article presents chemical and biological monitoring results, identifying high levels of non-point source nutrient runoff during rainfall events and high percolation of contaminated stream water during its flow that should be addressed in future restoration strategies. The practical challenges associated with the monitoring of ephemeral streams are also discussed with suggestions for future studies and management efforts.

Keywords: Rivers; streams; non-point source runoff; water management; monitoring; surface water hydrology; transmission loss

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1 Introduction

Because they lack the recreational appeal of perennial rivers and offer a different aesthetic, ephemeral streams, with their seasonal flow are among the more neglected water resources in the world. Existing water and environmental regulations and standards are invariably driven by perennial streams (US Clean Water Act, sec. 303d, (33 US § 1313), EU Directive 75/440/EEC), as are priorities for restoration projects, preservation initiatives, etc. Yet, particularly in Mediterranean climates with semi-arid and dry sub-humid climatic regions, ephemeral streams constitute an important natural resource with enormous significance as a habitat and an open space. They also play a critical role in drainage and flood control within their regions. Understanding their temporal dynamics is important as their potential as recreational resources is increasingly recognized. Given the anticipated climate induced in both rainfall patterns and general hydrologic conditions many dryland regions are expected to see more extreme rainfall events, with implications both for flooding and for non-point source water pollution (Clarke and Rendell 2006).

In their natural state, ephemeral streams lie in watersheds in which the channel is hydrologically active for less than 2% of the time or about 7 days per year (Reid *et al.* 1998). These watersheds are also characterized by flash floods, which make it difficult to monitor and understand the process and the behaviour of the stream, the ecological systems it supports, its sediment content and pollutants. The hydrograph for semi-arid settings is different from humid areas; it is characterized by a rapidly ascending climb in flow which is subsequently followed by a rapid decline that can last for only a few hours (Reid and Frostick 1997). Such streams can also be characterized by multi-peak hydrographs (Reid *et al.* 1998). In addition the flow from different tributaries may reach the main channels at different times, sometimes when the main channel is dry either before or after a flow has passed through (Abrahams and Parsons 1994).

Reductions in flow volume between upstream and downstream points in a semi-arid channel system are caused by evapotranspiration and infiltration into the bed, the banks, and possibly the flood plain. These 'transmission losses' reduce both the volume of the hydrograph, and the peak discharge. Transmission losses not only cause reductions in discharge but also can dry up the channel completely (Cataldo *et al.* 2004). Transmission losses through the bed of ephemeral rivers in arid and semi-arid regions can account for a large proportion of the total amount of runoff generated upstream (Hughes and Sami 1992) and are often reflected in groundwater recharge and contamination. Even though the channel in these areas is dry most of the year, when active, ephemeral streams can transport large amounts of sediment (Reid *et al.* 1998). Flow in ephemeral channels is characterized by high sediment concentration and large sediment yields (Abrahams and Parsons 1994).

With regard to their pollution profiles, ephemeral stream basins are similar to the watersheds in perennial streams which are characterized by a heterogeneous variety of sources. These include point sources and non-point sources. Point source pollution includes industrial effluents, treated water, or raw sewage from a discrete source discharging and contaminating the water. Yet, the fate and impact of point source pollutants is fundamentally different in ephemeral streams than perennial streams. As waste treatment practices in semi-arid communities shift from septic tanks and cesspools to central sewage systems, ephemeral steams have increasingly come to serve as conduits to collected treated effluents and to raw wastewater with impacts on both the water quality and stream morphology (Hassan and Egozi 2001).

Wastewater discharge into the stream has considerable impact on channel bed morphology and functionality by transforming a dry ephemeral stream with intermittent flow events to one of continuous flow (Hassan and Egozi 2001). The environmental conditions in such streams are extremely poor, because effluent being discharged into these streams does not get diluted by a cleaner water body. The high concentrations of biological oxygen demand (BOD), nutrients and bacteria frequently have a more direct and severe impact on the ecosystem than in naturally perennial streams. Effluent concentrations produced by municipal wastewater treatment are typically set with the full dilution associated with perennial streams in mind, while the flow conditions in ephemeral streams present completely different hydrological and ultimately ecological requirements (Tal 2006).

In addition, the effluent discharge introduces a continuous input of water into an ecosystem which is mostly dry. This shift affects the vegetation cover, bank and bed stability, sediment transport and storage. The associated hazards of mosquitoes, odours and of course groundwater contamination can be substantial. The natural vegetation and fauna are often replaced by invasive species that are better adapted to contaminated wet environments.

Environmental conditions in ephemeral streams in general are more difficult to characterize than perennial streams. Hughes (2005) cites two primary reasons for this:

(1) the difficulty of representing spatially variable inputs (especially rainfall) in arid areas that are notorious for variability and lack of observations; and
(2) the dominance of in-channel processes that are either difficult to quantify or simply not understood sufficiently to incorporate into models.

We would add to these the difficulty in conducting biological monitoring as well as the higher relative impact of 'first flush' events on ephemeral streams along with the higher degree of variability in pollution concentrations in both non-point source and point source discharges during flood events (Stein and Ackerman 2007).

A variety of biological criteria have been available for some time to assess the health of perennial streams such as fish species, invertebrates, etc. (Karr 1991, Gasith and Resh 1999). These can only be partially applied in ephemeral streams and only if there are places along the streams that contain water for sufficiently long periods for species to develop. As a result, in the past, past water quality studies tend to ignore biological monitoring in ephemeral watersheds.

The logistic implications from the perspective of stream monitoring can be daunting. The researcher must adapt sampling schedules to actual stream conditions which are driven by stochastic rainfall events, and hence be available for sampling at short notices at disparate hours. Predicting which rainfall events will be significant for stream flow is not always self-evident. It is also possible that notwithstanding monitoring plans, precipitation will not be sufficient for runoff to reach the stream or tributaries for an entire sampling season. In short, conducting a systematic study, that relies on sampling at particular time intervals under the same conditions is not a possibility. Hence, a combination of hydrometric stations and field grab sampling during and following storm events is required.

Relatively few research efforts have been conducted to monitor the full pollution loadings into ephemeral streams. This article considers the major findings to emerge from a 3 year study that for the first time characterized environmental conditions in transboundary watersheds that cross the Palestinian Authority into Israel: the Hebron/Besor and the Zomar/Alexander (Figures 1 and 2). These 2 stream systems are representative of over 10 ephemeral streams that originate in-land under the Palestinian Authority in the West Bank and that flow into Israel (Kaplan 2004). The current of course goes both ways. In a few watersheds, such as the Kidron stream which begins with sewage from East Jerusalem and reaches the Dead Sea in the east, the roles are reversed, with the downstream - Palestinians receiving Israeli discharges (Shapira and Mazor 2004, Israel Ministry of Environmental Protection 2007).

Historically, many of the region's streams were fed by high quality spring water. Owing to decades of diversions, for agriculture and drinking water, streams have become dry. Beyond direct diversions, historic flow often is reduced due to a drop in ground water levels from the aquifers that feed the streams (Juanico and Friedler 1999). Alternatively, wadis (dry, arid riverbeds) that for generations served as ephemeral streams with no flow except for occasional storm incidents have emerged as perennial streams, channelling raw or partially treated industrial or municipal wastes (Ramat-Hovav Local Industrial Council 2004, Tal 2002).

Between 2004 and 2007, research was conducted by Palestinian and Israeli researchers to characterize the pollution loadings in the Hebron/Besor and Zomar/Alexander Streams and to consider rehabilitation strategies. Water sampled throughout the watershed was analysed for its chemical components, with the goal of identifying the relative contribution of point and non-point discharges. In addition, biological (macroinvertebrates) sampling was conducted in order to assess the ecological health of the streams, providing important insights into actual stream health and the relationship between chemical and biological monitoring in ephemeral conditions.

The findings suggest that the inherent obstacles to monitoring ephemeral streams can be overcome. Practical dilemmas faced by the research team will be described along with recommendations for effective monitoring of ephemeral watersheds. The results also suggest that non-point sources contribute to a higher proportion of pollution loadings to such streams than was previously anticipated and confirmed the magnitude of stream water infiltration into ground water. A companion editorial piece highlights the ramifications of these findings for transboundary management strategies for stream restoration.

2 Study sites

The two watersheds studied were selected because of their relative size, their significance for local recreation and future development and because they offered contrasting example of ephemeral and intermittent streams. The Hebron/Besor watershed lies completely in a semi-arid region with its natural flow representing a standard ephemeral surface water body, occurring only during the aftermath of rainfall events. Until recently, parts of the Alexander/Zomar stream year enjoyed year-round flow. Owing to diversions and drawdown of groundwater, with the exception of the estuarine area, segments of the streams are now either intermittent or ephemeral, with flow dominated by effluent discharges.

2.1 *The Hebron/Besor watershed*

The Hebron/Besor drainage basin covers 3500 km^2, extending from the Hebron Hills in the Palestinian Authority, where the Hebron stream crosses the border and flows into the Israeli city of Beer Sheva. Once the flow reaches Israel it is called the Beer Sheva stream, and it serves as the main channel in the Besor watershed, where it receives water from other tributaries in Israel's northern Negev, and ends in the Gaza Strip on the Mediterranean coast (Figure 1). The basin is the largest of the area's coastal streams, and is characterized by many land uses: urban, rural, industrial, and agricultural (both crop and livestock), grazing, firing ranges, open spaces, and nature reserves.

Located in a semi-arid and arid region, most of the streams in the Hebron/Besor watershed naturally are ephemeral, except for small local springs in the lower part of the basin. The northern 'mountain' part of the basin has a mean annual precipitation of 500 mm, the western 'Mediterranean coastal' section receives on average 300 mm, while the southern 'desert' part has only 70 mm. During a rainy year, water may flow in the main stream channel six to seven times a year (Kahana *et al.* 2002), during the course of the study, rainfall was far below past annual averages, with only one major rainfall event taking place (Goldreich 2009). Similar to other dryland regions, this was manifested in the large variation in stream flow between drought and wet years in semi-arid and arid regions (Knowles and Cayan 2002). This serves to accentuate the predominant

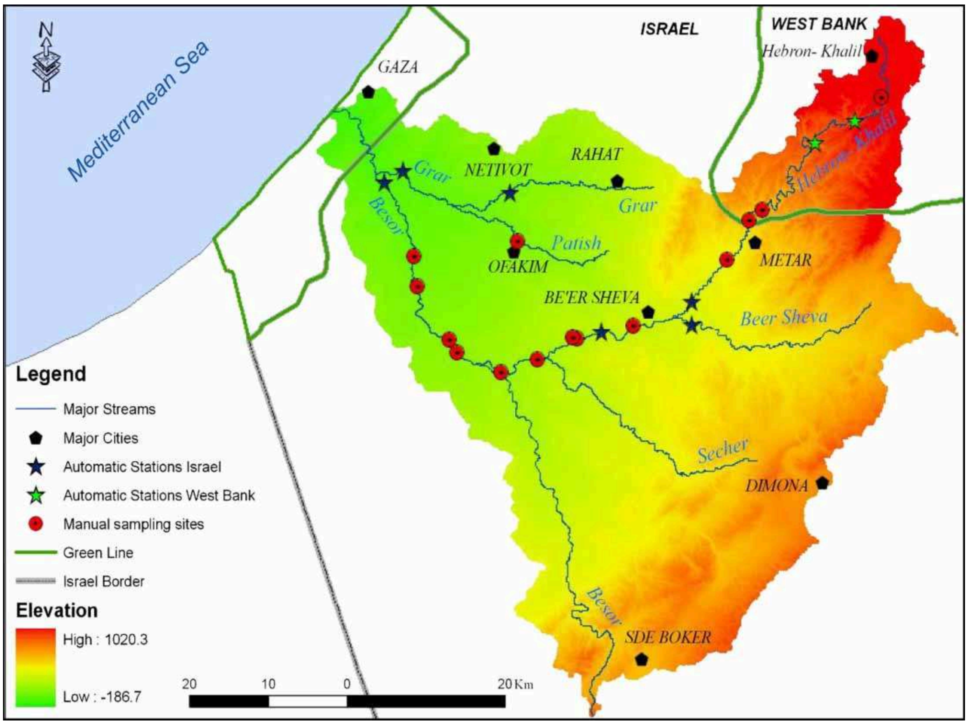

Figure 1 Hebron/Besor basin and water quality monitoring network.

role of wastewater in creating a permanent base flow that has changed the nature of the stream.

Since the 1990s, the Hebron/ Beer Sheva stream drains the untreated wastewater of the city of Hebron and the Jewish settlement of Qiryat Arba (Hassan and Egozi 2001), home to approximately 200,000 residents. In addition to the domestic sewage of the city, the stream also drains the wastewater of almost 100 industrial facilities (Morris *et al.* 1998).

Recently, a plan was drafted for the transformation of the Beer Sheva stream into a major recreational venue for the city (JNF Blueprint Negev 2006). Like the role of the San Antonio River in reinvigorating development in San Antonio Texas, new residential and commercial developments are to be built in order to take advantage of the anticipated free-flowing, meandering green strip through the desert city, with its anticipated parks, sports facilities and artificial lakes (Christensen *et al.* 2001, Eckhardt 2005). To realize this urban renewal initiative, water quality in the stream must improve dramatically. Consequently, Israel has elected to construct a sewage treatment facility, just inside its border at the Shoqet Junction, just north of Beer Sheva (Figure 1) which essentially is designed to provide secondary treatment for the raw Palestinian sewage that flows through the city of Beer Sheva. While such monolithic efforts by Israel may ameliorate the problem, the study results suggest that a more comprehensive solution is required.

2.2 *The Zomar/Alexander watershed*

The second watershed assessed in this research drains into the Zomar/Alexander stream. The watershed is far smaller than the Hebron/Besor, covering ca. 650 km^2, from the Samaria Mountains in the east, through Israel's rural Hefer Valley, flowing in a westerly direction until reaching the Mediterranean (Figure 2). The dry-subhumid climate in this basin is typical Mediterranean. It is characterized by mild temperatures and precipitation, which falls mostly during the coldest half of the year (October–April) with mean annual precipitation ranges between 500 and 650 mm based on geographical and topographical variations. The main channel – the 'Zomar' – in Arabic or 'Alexander' as it is known in Israel has a total length of 44 km, 17 of which are naturally perennial. The western segment of the stream reaches the Mediterranean Sea and is relatively wide (ca. 10–15 m), holding water all year round. This estuarial section supports one of the region's only populations of soft-back turtles, for which the stream has become famous.

The basin shows the effects of decades of continuous contamination, associated with the accelerated development and increase in the sewage discharges from the Palestinian cities of Nablus (population, 135,000) and Tulkarem (54,200) as well as several Israeli municipalities, most notably the city of Netanya (population 173,000 and Taibeh, 33,000). The quantity of the effluents discharged into the stream is estimated to be roughly 5 million cubic metres (MCM)/year (Volvendo Consulting 2005). Some 70 point sources of pollution continue to flow into the stream (Israel Ministry of the Environment 2000). Of particular concern is the seasonal discharge from 26 olive oil mills, via the Nablus stream, a Zomar tributary during the October/November harvesting period. The residues contain extremely heavy organic loadings that do not undergo meaningful pretreatment and then fail to respond to

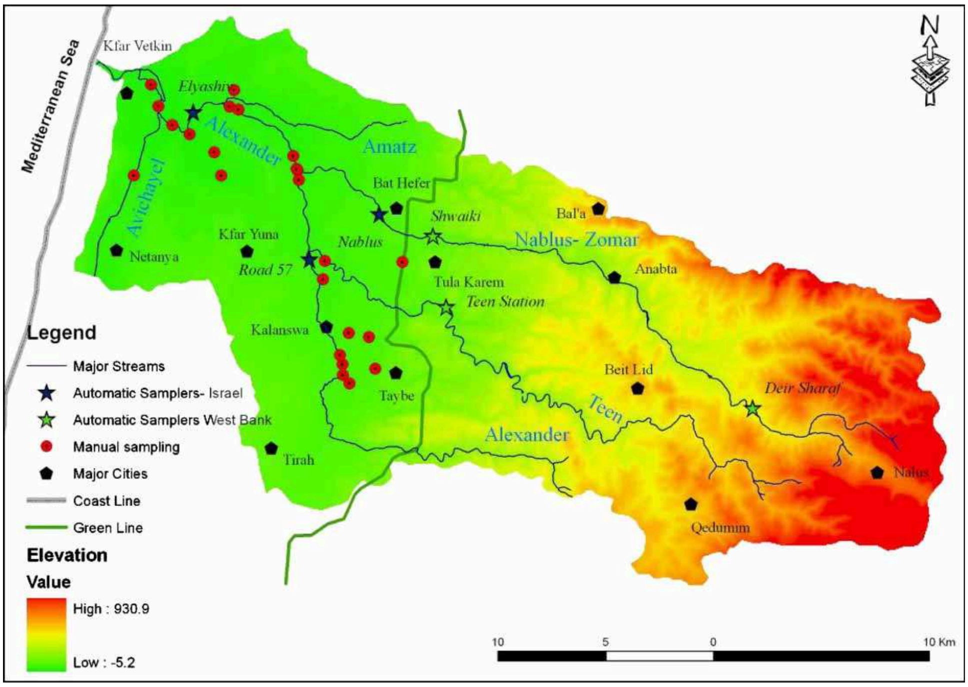

Figure 2 Zomar/Alexander basin and monitoring network.

conventional municipal treatment at the Yad Hanah plant, posing an enormous burden on the ecological systems of the stream (Brandeis 2003).

The ongoing discharge from production processes in Palestinian stone mills, and a mix of pollutants in the streams caused by leaching from solid waste sites, garage oil, etc. cause additional contamination. Runoff from Israeli industrial and agricultural operations also contributes non-point pollution sources which the study revealed to be of considerable cumulative impact.

The poor conditions in the stream triggered the establishment of a comprehensive restoration plan in the 1990s that has gained both nationwide and international recognition. The plan was jointly adopted and implemented by Palestinian and Israeli local governments. Sewage treatment for the Netanya municipal sewage was upgraded and the treated wastewater transported to farmers for irrigation. Several additional initiatives included scenic rehabilitation, bank stabilization, cleanup campaigns, reduction of several point sources through pre-treatment, parks and recreation areas in which stretches are set aside as 'showpieces' – along with myriad public campaigns to raise awareness about stream rehabilitation efforts (Brandeis 2003).

In 2002, as part of this rehabilitation endeavour, an emergency waste purification facility was built adjacent to Kibbutz Yad Hanah on the edge of the Israeli border that intercepts the sewage discharges coming from the Nablus and Tulkarem regions. Through assistance from the German Government, the city of Tulkarem also installed a primary treatment facility for its municipal waste. In 2007, three pilot projects were established on the Yad Hanah site to provide advanced treatment through a variety of biology techniques as preparation for the ultimate upgrading of the facility. Unlike the Shoqet plant, the wastewater facility at Yad Hanah was not built unilaterally, but was the outgrowth of ostensibly successful cooperation between the Hefer Valley Regional Council and the city of Tulkarem. Stream conditions improved as a result (Israel Ministry of the Environment 2007). While the effluents released into the stream are monitored closely, no study prior to the present one has considered the overall pollution loadings into the stream and the long-term prospects for restoration of aquatic ecosystems and recreation. Beyond development of a comprehensive monitoring program to characterize non-point source and point source loadings, the study, also sought to assess the lessons learned from restoration efforts thus far in these two watersheds, given their new character as 'perennial streams'. Broader implications for the facilitating environmental cooperation in stream monitoring and restoration efforts of other ephemeral and intermittent streams in semi-arid regions emerge from the findings.

3 Methodology

3.1 *Hydrology*

A network of automatic hydrometric monitoring stations was set up for sampling of storm events in the two basins. Four stations were set up in the Palestinian Authority, and 10 in Israel (Figures 1 and 2). Monitoring the base flow was an important preliminary step for quantifying the dominant wastewater 'point source' inputs in both streams. Measurements of the quantity of base flow water discharge (Q) was undertaken at several stations along the Wadis of Hebron/Besor and in the Alexander stream during winter and spring 2006 using the velocity-area method. Discharge was calculated using the equation:

$$Q = Au, \tag{1}$$

where A is the cross section area of the stream (m^2) and u is the mean stream flow velocity (m/s).

The measurements in the Besor stream were performed in seven sites along the stream from upstream to downstream during summer 2005, winter 2006 and spring 2006 (Table 2 and Figure 3), and in the Alexander stream in additional eight sites during summer 2006. At each chosen location, the cross-sectional topography was measured to determine the flow surface area. The average water velocity of 0.20 m-increment water columns was measured at 60% of the depth (from the water surface) using an electromagnetic current meter (Marsh-McBirney Inc. Flow-mate model 2002). The total discharge is a summation of the partial discharges of all water increments in the cross section. This method assumed that the velocity at each vertical point represents the mean velocity in the segment.

For the estimation of losses or gains in the channel, a water balance approach was used. Several assumptions have been made accordingly: since there are additions of water along the stream that change the water balance, losses were only taken into account for Wadi Hebron. Water loss is caused by three main processes: infiltration into the ground, evaporation and evapotranspiration. The evaporation rate value is an average for the entire basin, but it varies between seasons. Direct evaporation from the stream appears to be approximately 7 mm/day in the summer months, 3 mm/day in the winter months and 5.5 mm/day in the spring months (The Ministry of Agriculture and Rural Development, Gilat station data). An average value of 3 m was used for the channel width. Since this study did not attempt to evaluate evapotranspiration, measurements were not made; yet, it cannot be ignored. In desert ephemeral streams which lack continuous vegetation cover, evaporation plays a greater role than transpiration (Cataldo *et al.* 2004). Therefore, transmission losses include those from evapotranspiration. As Wadi Hebron has minor vegetation cover that is occasionally grazed by livestock, these losses are minimal.

3.2 *Water quality sampling*

In addition to the automated samples and measurements made at the hydrometric monitoring stations to define base flow during winter, spring and summer 2006, pollution loadings were characterized by flood events during the 2005/2006, 2006/2007 winter seasons as well as 289 water samples in the Hebron/Besor streams and 488 samples in the Alexander/Zomar basin. The samples were taken from various locations at different time intervals in the two watersheds, either collected manually from various sampling points along the stream, or by automatic samplers at the permanent stations. The samplers in the stations were programmed to take samples every 15 min during the first hour of a rain event and every two hours at later stages, to allow for better characterization of the 'first flush effect' where higher concentrations of pollutants are typically found (Thornton and Saul 1986, Skipworth *et al.* 2000, Lee *et al.* 2002).

All water samples were collected manually or automatically in 1-litre bottles. The bottles were cleaned by first soaking in phosphate-free detergent and then in nitric acid and finally rinsed with deionized water several times. In the field, the bottles were washed again with water from the stream before sampling. The samples were stored in thermally isolated cases filled with ice until they reached the laboratory for analysis and were stored in the lab in refrigerators at 4°C. *In situ* measurements of water temperature, pH, dissolved oxygen, and electrical conductivity (EC) were taken using the portable field multi-parameter kit (MultiCal®) at every site.

3.3 *Chemical analysis*

The analysis of major ions was carried out at the analytical laboratories of the Zuckerberg Institute for Water Research at Ben-Gurion University of the Negev. Following the determination of bicarbonate (by acid-base titration, ±5 mg/l), all samples were filtered through a 0.45 μm filter. Calcium, magnesium, sodium and potassium were measured using atomic adsorption (Perkin Elmer, ±1%). Chloride, sulphate, nitrate and bromide were measured using ion chromatography (Dionex, ±1%). Ammonia was measured spectrophotometrically (Hitachi-U2000, ±0.05 mg/l with a detection limit of 0.03 mg/l).

The analysis of trace elements was carried out at the Interdepartmental Laboratory of the Faculty of Agricultural, Food and Environmental Quality Sciences of The Hebrew University of Jerusalem in Rehovoth. Analyses for trace elements were carried out using inductively coupled plasma-atomic emission spectrometry according to the US Environmental Protection Agency (EPA) method 6010B. An acid base digestion (HNO_3) was carried out for Total Recoverable Metals according to the standard method 3030 E. Effluent parameters including BOD, total organic carbon (TOC) and dissolved organic carbon, microbial analyses (general count of cells, coliform bacteria, and fecal coliform bacteria), and nutrients (organic nitrogen and organic phosphorus) were analysed according to standard methods and procedures.

3.4 *Fluxes from point and non-point sources*

To determine the nutrient fluxes during base flow, data from the base-flow measurement and the base-flow grab sampling were used in the following formula:

$$F_B = \int Ct^* Qt, \tag{2}$$

where F_B is the integration pollutant flux in base flow (kg/day), Ct the pollutant concentration in the water sample (mg/l), Qt the water discharge (m^3/s).

For the storm event fluxes nutrient concentrations in the water samples were measured along with the continuous water discharge data to characterize the nutrient fluxes that appeared during the measured flow events. The calculation was made using the equation:

$$F_S = \int Ct^* Qt, \qquad (3)$$

where F_S is the integration pollutant flux in storm (kg/event), Ct the concentration of pollutant (mg/l), t the time of flow, Q the discharge of flood water (m^3/s).

3.4.1 *'Biological health' assessment*

In addition to the chemical parameters, the study included biological monitoring, relying on the integrity of the macroinvertebrate community as a proxy for stream health. This requires comparing the community structure of the studied stream/site with that of an undisturbed situation (reference stream/site). For the Hebron/Besor stream in the semi-arid and arid regions no reference situation was available. Therefore, an alternative approach was applied which assesses stream health according to the relative value of sensitivity of the assemblage to pollution (assemblage sensitivity index = ASI, modified after Chessman (1995, 2004)). ASI aggregates the multiplication of the proportion of each taxon in the macroinvertebrate assemblage by its relative sensitivity score (from lowest = 1 to highest= 10). The ASI of an assemblage varies on a scale of 1 (lowest) to 10 (highest). Stream health is expressed as follows: >7 = 'very good'; 5.1–7 = 'good'; 4.1–5 = 'fair'; 3.1–4 = 'fairly poor'; 3–2.1 = 'poor'; ≤ 2 = 'very poor'.

For the Zomar/Alexander coastal stream a multi-metric procedure was used for calculating the Benthic-Index of Biological Integrity (B-IBI, modified after Barbour *et al.* (1996)). A relatively undisturbed section of a comparable coastal stream (the nearby Yarkon Stream) was used as a reference. This information formed the basis for a community structure analysis. Six community attributes that were significantly correlated with pollution variables (degradable organic matter – BOD, total ammonia-NH_4-N) were used in the analysis and are referred to as metrics (Hershkovitz 2002). These included macroinvertebrate taxa richness, the proportion of non-biting midges (family Chironomidae), mayflies (order Ephemeroptera) and of dragon and damsel flies (order Odonata) and indices of evenness and of sensitivity of the macroinvertebrate assemblage to pollution (ASI). The value of each of the selected metrics was scored on a scale of 1, 3 and 5. For metrics whose values decrease with increasing disturbance, the score of 5 was given when the value was equal or higher than the median value of this metric in the reference situation. The score of '1' was given when the value of metrics was equal or lower than the minimum value of this metric in the reference situation. The score of '3' was given to intermediate values. For non-biting midges whose proportion in the assemblage increases with organic pollution, the scoring was reversed. The sum of scores of all six metrics was divided by the maximum possible value ('30') and expressed as percent biological integrity (B-IBI_6). 'Stream health' was expressed on a relative scale as follows: $\geq$87% = 'very good'; 75–86% = 'good'; 61–74% = 'fair'; 47–60% = 'fairly poor'; 35–46% = 'poor'; $<$35% = 'very poor'.

In each sampling site macroinvertebrates were collected using semi-quantitative sampling by net jabbing (hand-net, 0.42 mm pore size) along a constant distance (10 m) usually in vegetated habitats. Samples were preserved in a 70% ethanol solution and transported to the laboratory where the organisms were sorted, identified and counted.

4 Findings

The following presents the most significant findings from the study, summarized according to watershed boundaries. After characterization of discharge and stream flow, water quality is described, with an emphasis on the key indicators of municipal sewage. Water quality variations in time and space are identified and evaluated. The biological health of each watershed is then assessed. The implications of the finding for future monitoring effort of ephemeral and intermittent streams will then be discussed.

4.1 *Hebron/Besor watershed*

4.1.1 *Flow and infiltration to groundwater*

In the Hebron/Besor watershed, the predominant initial source of pollution in the watershed is the effluent and raw sewage leaving the urban Hebron and Qiryat Arba areas. Measurements suggest that ca. 15,000 m^3/day of sewage, mostly untreated, flow over approximately 120 km downstream until reaching Israel's Besor Reserve near the Negev village of Tze'elim. This steady baseflow fundamentally alters the character of the stream, transforming it from a seasonal stream where historically high quality storm water flowed for only a few days a year throughout a largely semi-arid watershed, to one with a constant flow of sewage throughout the year.

It is important to note that a significant portion of the water in the Hebron/Besor, however, does not reach the Israeli border. Measurements of flow taken from the different monitoring stations along the length of the stream in various seasons indicate that along the stream's first 60 km between 40% and 90% of the wastewater discharged (8000–11,000 m^3) percolates into ground water before it reaches the green line and the Beer Sheva stream (Table 1). This is consistent with comparable hydrological research in Israel (Melloul and Azmon 1997) and in other regions (Triska *et al.* 1989, Zaramella *et al.* 2003, Ryan and Boufadel 2007).

These values represent high transmission losses in the channel during the flow and infiltration into the ground water, far beyond the potential water lost by evaporation and transpiration by plants

Table 1 Percent losses of stream flow from Hebron to Shoqet according to seasonal measurements

Seasons	Total loss (%)	Evaporation (%)	Infiltration (%)	Infiltration (m^3)
Summer 2005	60	7	53	8000
Winter 2006	76	4	72	11,000
Spring 2006	43	6	37	6000
Summer 2006	82	6	76	11,000

Source: Field measurements, 2004–2006.

and vegetation cover from the streambed. The rate of percolation appears to be seasonal as reflected in Table 1. The quality of the water that infiltrates the surrounding aquifer in the upper reach is extremely poor – and is in fact raw sewage (Table 2).

4.1.2 *Water quality*

Water quality in the stream varies dramatically along its flow as a process of biological purification clearly emerges from sampling results (Table 2). Table 2, which presents measurements of samples taken along a north-south gradient, shows a dramatic contrast between average parameters measured in the upper reaches of the watershed near Hebron and those in the lower Israeli stretches. In particular, the drop in nutrient concentrations for total phosphorus and NO_3 is on average an order of magnitude reflecting the general reduction in the concentration of organic material flowing in the stream. The declining gradient in the level of pollution along the sampling route between the top and the bottom segments of the stream is further reflected in the drop of 91.7% in biological oxygen consumption (BOD), 87.7% in chemical oxygen consumption (COD), 73.9% in overall nitrate levels, and 72.8% in overall ammonia levels (yearly average). The results suggest that water quality improvement is not as predictable nor as linear as anticipated. Figure 3 shows unanticipated increases in BOD levels in the lower stretches of the stream. The possibility of additional, local contamination by small point source discharges in Israel cannot be ruled out. For example, local ‘contributions’ of pollutants to the base flow were observed from a few points along the Besor basin. This is consistent with previous research in the area (Hatukai 1996). These appear to be primarily derived from inadequate treatment levels in the sewage systems of the Israeli communities of Beer Sheva, Ofakim, Rahat, and Meitar. In addition, raw sewage was observed flowing into Beer Sheva stream during light rainfalls from Beer Sheva’s southern sewage pumping station.

Specifically, in the summer of 2005, an increase in flow was observed in the vicinity of the city of Beer Sheva (about 60–70 km from the Hebron Outlet) and downstream of the Hipushit site, 94 km from Hebron. During the winter of 2006, additional flow was measured in Israel, close to Tel Sheva until Sh’hunot and an even greater addition of flow was observed as well at the Quarry Site, peaking at the Secher Site at 7590 $m^3/$day. In comparison with other seasons, during the spring of 2006 higher discharges were measured at most of the sites (12,110 $m^3/$day at the Metar Forest Site). A considerable increase in discharge began at the Hazerim Site and reached a peak (10,900 $m^3/$day) at the Secher Site. In the summer of 2006 the downstream Hebron reached a lower discharge of 2770 $m^3/$day. Mass balance calculations and geo-chemical profiling of the stream’s water and underlying groundwater also show that in certain stretches of the stream (downstream towards Beer Sheva) there was an increment of growing nitrate and sodium levels that can be associated with the entry of contaminated groundwater flow from the local shallow alluvium aquifer (Figure 4).

Sewage, of course, is not the sole source of contamination. Heavy metal levels of chrome, copper, titanium, barium, and zinc were measured in the upstream segments, but generally decline in the down-stream segments of the stream. Two cases of high mercury (Hg) levels (0.071 mg/l and 0.081 relative to the proposed local standard of 0.0005 mg/l) were measured in lower reaches. Cr concentrations of 0.126 mg/l were also detected. For the adsorbed phase trace elements, high concentrations of Cr and Cd were found in all sites (34–27,500 and 0–630 mg/kg, respectively) and Cu was also measured at most of the sites (34–3,200 mg/kg). This suggests that industrial waste discharged from Hebron’s leather and tanning industry reaches the stream year-round.

Overall, the water quality in the lower reaches of the stream remains low, and the levels of pollutants exceed recently proposed Israeli standards (Lawhon and Schwartz 2006) which require tertiary treatment before the release of effluents into streams. Self-purification processes do occur, and the warm climate expedites this oxidation process. Yet, the likely reappearance of wastewater from the urban area of Beer Sheva, as it follows the stream in a subsurface flow, contributes to the generally poor quality of water in the lower reaches.

4.2 *Fluxes from point and non-point sources*

Because of the modest rainfall during 2004–2005 in the Besor basin, the flood fluxes could be calculated only during the 27.12.06 event, which was the largest event of preceding 3 years. On the basis of historic data, it can be assumed that the event represents typical conditions during large winter storms (Israel Hydrological Service 2008).

In Table 3, the total yearly base flow fluxes vs. the 27.12.06 event fluxes for different solutes and nutrients for the Hazerim station is presented. It is clear that for TDS, chloride,

Table 2 Range and average of base flow pollutant concentrations (mg\L) in the Besor stream

Element	Hebron *PA*	Metar + Taneh	Shokuet	Tel Sheva	Sh'hunot	Hazerim	Mifsam	Secher	Hipusit	Ze'elim	Grar Sharsheret
pH		7.53	7.71	7.56	7.72	7.62	7.61	7.88	7.77	7.83	8.05
		7.34–7.84	7.468–0.08	7.06–7.81	7.63–7.86	7.43–7.76	7.35–7.89	7.47–8.34	7.32–8.35	7.46–8.19	7.83–8.28
EC (mS/cm)	1.87	2.48	3.03	2.13	2.72	2.84	3.14	2.78	2.56	2.37	11.42
	1.25–3.49	1.99–3.46	2.80–3.21	1.78–2.7	2.44–3.2	2.37–3.40	2.45–3.88	2.03–3.35	1.90–3.17	1.94–2.79	3.48–17.7
TDS (mg/l)	1200	1700	1990	1470	1960	1853	2050	1760	1650	1500	6880
	800–2230	1280–2210	1820–2120	1330–1730	1660–2190	1516–2274	1570–2490	1300–2000	1220–2060	1270–1740	1970–10,100
NO_3 (mg/l)	11	0.82	2.02	0.87	13.4	9.69	6.2	7.32	9.3	13.28	3.10
	9–140	0.087–1.2	0–6.55	0–2.54	0–31.87	0–29.98	0.181–23.5	0–18.2	0–19.59	7.352–19.2	0–8.52
NH_4 (mg/l)	75	92	125	88	74	76	84	58	48	31	0.41
	55–105	66–120	107–156	73–113	66–86	56–108	64–127	26–87	28–80	25–36	0–1.485
NO_2 (mg/l)		0.1	0.01	0.11	0.13	0.07	0.18	2.6	2.96	2.98	0.10
		0–0.292	0–0.05	0–0.406	0–0.38	0–0.266	0–0.713	0–5.725	0.174–6.755	1.35–4.605	0–0.455
TSS (mg/l)	713	6178	5440	6480	2440	1340	212	53	43	119	45
	42–3506	2918–10020	134–11900	436–13200	35–7240	33–4530	35–716	22–101	11–112	40–199	18–88
COD (mg/l)	654	829	733	692	391	193	159	108	50	61	94.53
	240–1190	381–1176	196–1262	160–1610	177–606	130–316	98–261	68–139	26–74	14–107	22–224
BOD (mg/l)	498	290	337	239	128	89	49	33	15	15	0.97
	82–1050	137–399	104–480	98–567	110–164	43–121	24–63	17–64	3.6–30.8	6–24	0–3.29
Total *N* (mg/l)	64	115	98	84	60	69	77	56	48.1	28	1.5
	75–89	64–160	10–175	32–116	23–98	0.4–92	47–101	28–75	37.8–59.4	16–14	0–3.2
Total *P* (mg/l)	8.5	19	72	32	41	20	16	12.5	3.8	5	0.04
	1.8–14.5	4–34	37–107	24–39	25–75	15–25	10–22	5–20	3.8–3.8	4–6	0–0.18

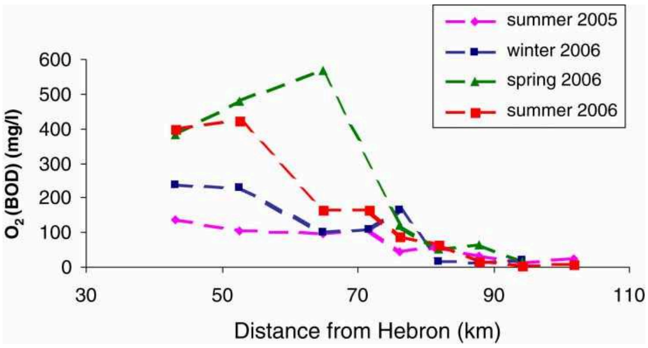

Figure 3 BOD variation along the main Hebron-Beer Sheva channel

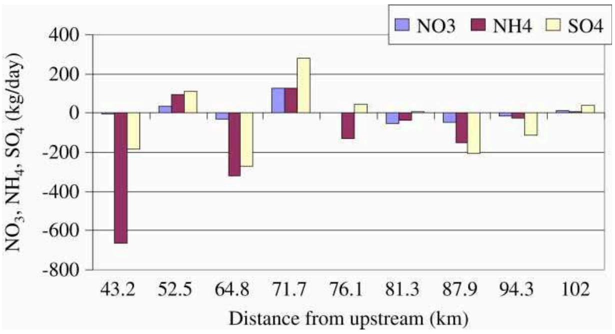

Figure 4 Loss and addition of NO_3, NH_4 and SO_4 fluxes between sites during summer 2005 along the Besor basin

ammonia, and for total *N* most of the loads are associated with the base flow, while total suspended solids (TSS) has higher loads during floods. Total P loads are relatively high during flood events and it may be connected to the contribution from agriculture land uses. The fluxes are associated with non-point sources which tend to be considerably higher during years with larger storm flows because of the higher loads of suspended meter.

4.2.1 *Biological health*

The prevalence of sewage in the Hebron/Besor watershed is not only apparent from the chemical parameters measured (e.g. BOD levels close to 500 mg/l when present standards are set at 10 mg/l) but also in the make-up of the macroinvertebrate community of the streams (Table 4). The relatively poor macroinvertebrates biodiversity (overall 28 taxa and less than 10 taxa in each assemblage), and the dominance of a single or a few taxa (evenness <0.64), along with the overall poor stream health ('very poor–fairly poor') confirm the environmental impacts of these discharges on the entire basin.

The state of the macroinvertebrate community in the upper tributary (Hebron stream) was even worse than that of in the lower parts of the basin. Only four taxa were found at the two sampling sites ('Rihiya' and 'Thahariya'), all of which midge larva (order Diptera). Two families: hover-flies (Syrphidae) and moth-flies (Psychodidae), were the most dominant ($>99\%$), representing macroinvertebrate with highest tolerance to organic pollution (sensitivity value $= 1$). The extremely low biodiversity and the nature of the macroinvertebrates found are consistent with the very poor water quality at these sites.

4.3 *Zomar/Alexander watershed*

4.3.1 *Flow and infiltration to groundwater*

Similar to the situation in the Hebron/Besor watershed, discharge measurements revealed that in all of the Palestinian and Israeli sections of the Zomar/Alexander watershed, the predominant source of water and pollution in base-flow were sewage effluents. Figure 5 shows the flow along with the annual rain data from the nearest rain station (Maberot). While in years of particularly high rainfall, there are associated peaks in stream flow, the general trend in the data reflects a steady increase in base flow and summer flow from 1995. Before 1995 there was no flow during summer time and during the last years the summer flow reach up to 4.4 MCM about 20–30% of the overall annual flow. This change is due to the increase in discharge of effluents from the area's growing population as well as direct management action by the local Alexander Drainage Authority (remove of soil dams and restoration activities).

The Nablus tributary contributes to the majority of the water flowing in the stream, first comprised of raw sewage and industrial effluents, which are partially treated immediately upon entry into Israel (chemical treatment without nutrient reduction). Notwithstanding general legal prohibitions against pollution and specific plant level permit stipulations, several additional point sources continue to discharge into the stream. These are largely intermittent depending on seasonal factors. Sampling suggests that their influence on stream water quality is minimal. For example, a fruit juice factory (Tnuvot) typically diverts all its effluents for reuse by agriculture. On rare occasions, when there is no demand by farmers, treated effluents will be discharged into the stream. Fish ponds periodically will

Table 3 Annual base flow and flood fluxes (ton/year)

		TDS	Cl	SO_4	NH_4	Total *N*	Total *P*	TSS
Hazerim-event	Ton/event	574	170	45	0.28	36.7	16.8	11,297
Hazerim base	Ton/year	3835	1110	95.0	190.9	161.6	21.1	4054
Total		4410	1279	140	191	198	38	15,351
Base flow (%)		87	87	68	99.9	81	56	26
Floods (%)		13	13	32	0.1	19	44	74

Table 4 Range of values of macroinvertebrate taxa richness, evenness, ASI and respective stream health in selected stream sited in the Besor watershed (n = number of samples in each site).

Stream	Hebron	Beer Sheva			Grar		Besor		
Site	Sh-Brd	T-S	Hip-Dn	Qu[a]	P-HaSh	Re-Brd	E-B[a]	E-S[a]	Hav-Brd
Samples (n)	1	1	1	1	2	1	2	2	1
Taxa richness	4	3	10	3	6	2	9–11	7–10	10
Evenness	0.46	0.21	0.56	0.1	0.21	0.1	0.26–0.65	0.08–0.46	0.64
ASI	1	1.9	2.1	2	1.9–2.1	2	2.8–4.4	2–3	3.1
Stream health	Very poor	Very poor	Poor	Very poor	Very poor – poor	Very poor	Poor – fairly poor	Very poor – poor	Fairly poor

Notes: Sh-Brd, Shoqet bridge; T-S, Tel Sheva; Hip-Dn, Hipushit down; Qu, Quarry site; P-HaSh, Park Ha'Sharsheret; Re-Brd., Re'yim bridge; E-B, Ein HabEsor; E-S, Ein Sarohan; and Hav-Brd, Havalim bridge.
[a]Sites located outside the main channel.

release waters as well but relative to the present quality of the water in the stream it is not expected to have a deleterious effect on the overall ambient water quality.

4.3.2 *Water quality*

Average base flow data for the stream are listed in Table 5 revealing the broad range of conditions along the stream with as much as a twenty-fold differential for some parameters (e.g. NH4). This reflects the presence of sewage treatment, dilution levels, natural in-stream purification processes and the estuarial conditions that begin to emerge as the stream reaches the sea. Total P concentrations, however, deviated little during the course of the stream's flow (from 3.5 to 15.9 mg/l).

In all cases, concentrations were far above new recommended Israeli levels for phosphorus concentrations from waste water treatment plant discharges of 1 mg/l. One explanation for these exceedances is the sewage treatment technologies in use in the discharging Israeli facilities. Present secondary (biological) treatment reduces organic loadings with moderate efficacy, but its treatment does not remove phosphorus as effectively.

Sampling was also carried out during several storm events. Results indicate that overall solute and major ion concentrations are much lower for in-stream concentrations during flood events than in the base flow. Lower levels of BOD, COD, NH_4, and total N were also recorded during storm events. Dilution, however, is more pronounced downstream, with somewhat higher in-stream concentrations in the Zomar stream appearing storms relative to the Alexander stream. As seen in previous studies, water quality was influenced by the hydrological characteristics of the watershed and by the chemical inputs of natural or anthropogenic

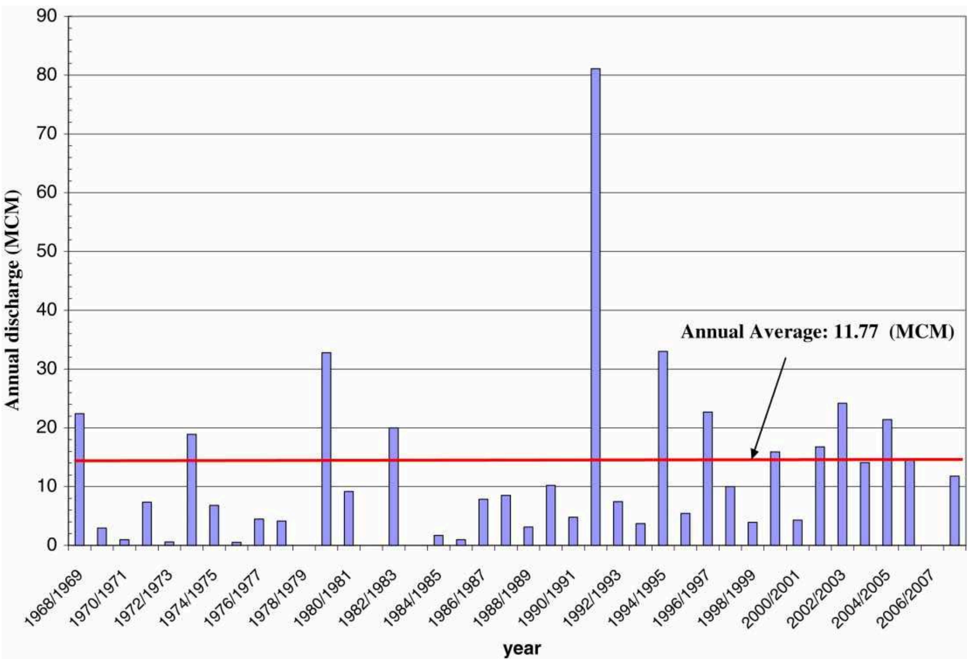

Figure 5 Alexander stream annual average flow at Elyashiv station

Table 5 Range and average of base flow concentrations (mg\l) in the Alexander catchment

	Kalanswa landfill st (3)	Alexander stream road-57 (4)	Up stream Zomar stream (3)	Down stream Zomar stream (4)	Park G. Hayim (2)	Maabarot-fish pond (2)	Elyashiv (5)	Maabarot (5)	Nablus/Zomar stream station (9)
NH_4	20.2	20.1	1.1	18.7	9.7	17.5	13.8	7.6	43.2
	13.4–24.9	1.479–30.4	0.518–2.276	7.3–32.4	2.478–16.9	17.01–18	2.27–35.8	4.352–11.43	22.3–72.4
NO_2	2.0	1.8	0.5	8.6	1.0	5.1	5.6	4.9	4.7
	0.1–5.1	0.64–4.56	0.14–0.8	0.76–20	0.77–1.18	1.08–9.058	0.71–11.8	1.14–6.942	0.2–14.364
TSS	20.8	30.5	60.7	79.8	58.0	94.0	63.8	106.5	62.7
	20–21.4	12–46	52–70	42–142	50–66	58–130	36–106	80–134	20–150
COD	75.5	48.2	38.1	72.9	48.6	48.0	63.2	58.7	97.5
	65–89.3	15.68–79.8	6.7–77.8	61.8–98.2	46.08–51.2	35.2–60.8	49.6–75.4	51.8–64.96	50.21–172
BOD	16.1	13.5	9.5	28.8	29.3	28.4	22.7	20.7	28.3
	10.5–25.1	4.4–23.2	1.7–21	19.4–36.7	22.3–36.2	22–34.7	4.83–36.7	6–43.1	10.6–58.9
TN	19.3	5.9	6.0	24.3	15.3	24.6	16.5	18.0	43.2
	14.8–23.4	4.191–8.513	5.3–6.7	12.9–40.3	8.298–22.3	24.08–25.1	8.24–23.838	13.8–22.606	30.4–65.06
TP	5.1	7.7	3.4	5.4	6.2	7.6	4.6	6.6	7.2
	3.03–6.87	3.5–15.9	2.1–6	1.66–7.65	4.14–8.18	5.6–9.6	2.01–5.8	4.9–10.4	3.68–12.9

origin, in the watershed (Baker and Richards 2000). These observations from the Alexander stream are also in agreement with data reported by Caporali *et al.* (1981) regarding an agricultural watershed in Tuscany, and Behrendt (1993) for the river Rhine. As expected, dilution was correlated with higher water discharges. In some cases there is an increase in concentration during high flow in spring time with connection to specific agricultural practice (Lapp 1996) or a change in flow condition during the event. Variations in the concentration in rivers during storms often result in a hysteresis effect with different concentration measured during the rising and falling limb of the hydrograph (Bowes *et al.* 2005).

Pollution concentrations during rainfall events show dramatic temporal shifts, reflecting the so-called 'first flush' effect in the stream. For example, COD and BOD levels dropped from 104 and 33 mg/l, to less than 27 and 4.3, respectively in the later stages of the storm events. The event of 9–10 February 2006 was the largest rainfall event recorded during the study, with discharges exceeding 10 m^3/s for more than 24 h. Under such conditions, a strong 'dilution effect' was anticipated which should have been reflected in measurements of major ions and other compounds. Results, however, were unexpected, revealing relatively high concentrations throughout the event rather than a dilution effect. Based on other studies, it would appear that during the duration of major storm events, soil erosion increases steadily, with the mixing zone of rainfall–runoff interaction containing an increasing portion of the subsoil material. The ongoing erosion continuously exposes and mobilizes nutrients in the flow path, resulting in the initial portion of the runoff hydrograph showing a relatively low concentration of nutrients that steadily increases as water travel time increases (Steinheimer and Scoggin 1998).

These results can be attributed to the high contribution of pollution from non-point sources. The overall mass of nitrogen and phosphorus was ~23,000 and 5100 kg, respectively, during the 9–10 February event (mean total *N*) compared with1700 kg and 1100 in the 16–17 December 2005 event (Table 5). In the base flow, the daily contribution appears to be less than 500 kg of nitrogen and less than 100 kg of phosphorus. The nutrient loadings during large events appear to be a full two orders of magnitudes higher, highlighting the contributions of non-point sources.

Moreover, pollution loads during storm events seem to be much higher in comparison with the pollution loads in base flow. Furthermore, the data show that the larger the discharge of the storm, the larger the pollution loads of the event. Accordingly, the highest quantities of nutrients discharged into the stream correspond to the storm of 24–27 December 2005. This event had both the largest overall discharge and the highest peak discharge. These results can be explained by the fact that water flowing in the stream already contains nutrients. The levels of these nutrient levels differ between storm events. At the same time, results consistently indicate that the greater the amount of water flowing in the stream, the higher the nutrient loads. This would support the existence of a 'cumulative effect', meaning that even if concentration is lower, the overall load may be higher, since more water flows through the stream.

Measurements suggest that during storm events between 59–92% of the TN and 81–95% from the TP could be attributed to non-point sources. These values present the upper limit of the possible contribution from non-point sources, and do not take into account additional possible sewage inputs. One should take into consideration that some of the loads could be attributed to re-suspended material and sediments accumulating in base flow. But the low concentration of sediments (25 and 34 mg/l of TSS, respectively) measured in June 2006 from the outlet of the Yad-Hanna waste treatment plant suggest a relatively minor contribution from these alternative sources for sediments.

As can be seen in Table 6, overall nutrient loads in storm events are much higher than those loads in base flow, at least by an order of magnitude. The results are similar to the trend appearing at the downstream 'Elyashiv' monitoring station. During rainfall events, it is plausible to assume that almost all of the sources of nutrients originate from non-point sources, in particular, agricultural runoff (99.7–99.8%, Table 7).

4.3.3 *Biological health*

Bio-assessment of base flow stream health also revealed considerable contrasts in stream conditions. Except for the lowest site on the Zomar/Alexander ('M-up' site), all other sites showed little variation in community attributes and biological integrity and were assessed as having 'very poor' to 'fairly poor' health condition (Table 8). The 'M-up' site was assessed as 'very poor' on one occasion and as 'good' on another. This is an indication of the variation in water quality conditions and a demonstration of the instability of effluent discharges in the Zomar/Alexander stream. As in the Hebron/Besor watershed the macroinvertebrate community of the upper tributaries of the Zomar/Alexander (Nablus/Shekhem stream) was also in very poor condition. The only taxa found in these sites were diptera larvae which are tolerant to the raw sewage conditions. Accordingly these sites were clearly dissimilar from the other sites in the watershed.

5 Conclusions: contrasting conditions in the two watersheds

Estimates by Israel's Ministry of Environmental Protection of pollutant discharges from point sources within each of the watersheds suggests that since 1994, upgraded sewage treatment has contributed to a substantial drop in phosphorus loadings in the Alexander and the Besor watersheds, even as nitrate concentrations have only improved in the former. Table 9 compiles official projections from over a 14-year period. Yet, stream conditions remain very poor and TOC loadings have remained constant in the Alexander and actually worsened in the Besor,

Table 6 Nutrient concentrations in different storm events as calculated for the Elyashiv station.

			Average concentration (mg/l)		Average load (kg/event)		
Storm event	Cumulative/average discharge (m^3)	Peak discharge (m^3/s)	TN	TP	TN	TP	Number of samples
16–19 December 2005	426,308	6.25	5.3	3.1	2265 (82%)	1323 (92.8%)	7
24–26 December 2005	1,104,303	15.03	6.22	2.72	6871 (94.2%)	3006 (96.8%)	18
14–16 January 2006	389,090	6.6	3.71	1.91	1441 (72.2%)	741 (87.2%)	7
25–29 January 2005	581,857	6.875	4.1	3.46	2411 (83.4%)	2012 (95.3%)	13
8–11 February 2006	3,252,166	61.4	5.4	1.7	17,562 (97.7%)	5529 (98%)	[b]
Baseflow	20,400[a]	0.34	19.6	4.65	400	95	5

Note: Percentages of relative contributions of non-point sources for storm events given in parenthesis.

[a]Average of baseflow of 27.8.05–27.8.06 from hydrological service data.

[b]No samples were taken at this station at this event; average concentrations were extrapolated from concentrations in Nablus tributary and station 57.

Table 7 Nutrient concentrations as calculated for road 57 stations.

Storm event	Cumulative/average discharge (m^3)	Peak discharge (m^3/s)	Average (mg/l)		Average load (kg)		Number of samples
			TN	TP	TN	TP	
16–19 December 2005	743,972	7.67	4.2	3.81	3122 (99.7%)	2822 (99.7%)	17
24–26 December 2005	1,152,282	20.42	3.33	1.78	3841 (99.7%)	2045 (99.6%)	18
8–10 February 2006	1,450,000	160	3.2	1.8	4630 (99.8%)	2660 (99.7%)	
Baseflow	1000	0.01	11.4	8.3	11.4 (99.8%)	8.3 (99.7%)	4

Note: Percentages of the relative contributions of non-point sources in the various events are given in parenthesis.

Table 8 Range values of macroinvertebrate metrics, calculated B-IBI and respective stream health of the Zomar/Alexander stream (n = number of samples in each site).

Site	B-Dn	AS-Up	AS-Dn	H-Can[a]	H-IBrd	Ely.	M-Up
Samples (n)	2	3	3	2	2	3	3
Chironomidae (%)	20–99%	38–63%	35–97%	2–50%	47–82%	4–79%	9–73%
Odonata (%)	0–2%	7–14%	0.7–12%	0–4%	0.1–2%	0.3–14%	2–18%
Ephemeroptera (%)	0–4%	0.2–0.9%	0.0–0.1%	0–33%	0.00%	0.4–1%	0–13%
Taxa richness	4–9	11–19	10–24	9–13	11–18	10–17	4–13
TSI	2.1–3	2.4–3.2	2.0–2.4	3.0–4.3	2.2–2.8	2.7–3.0	2.4–3.0
Eveness (J)	0.03–0.5	0.37–0.54	0.07–0.55	0.34–0.63	0.28–0.48	0.23–0.60	0.48–0.73
Calculated B-IBI 6	27–60%	53–60%	40–47%	47–80%	40–47%	47–60%	33–83%
Stream health	Very poor – fairly poor	Fairly poor	Poor – fairly poor	Fairly poor – good	Poor – fairly poor	Fairly poor	Very poor – good

Notes: B-Dn, Buregeta down; AS-Up, Alexander-Shekhem up; AS-Dn, Alexander-Shekhem down; H-Can, Ha'Ogen channel; H-IBrd, Ha'Ogen Irish bridge; Ely., Elyashiv; M-Up, Maabarot up.
[a]Springs located outside the main channel.

Table 9 Trends in total pollution loads from point sources of TOC, total nitrogen and total phosphorous at the Besor and Alexander watershed (ton/year) 1994–2008.

Total phosphorous	Total nitrogen	TOC	
Besor basin (ton/year)			
205	520	1350	1994
275	830	2290	2000
290	585	1985	2001
77	324	1451	2003
81	527	1337	2005
81	392	787	2006
81	748	1408	2008
Alexander basin (ton/year)			
205	273	850	1994
200	424	1930	2000
161	416	1856	2001
70	168	600	2003
44	167	224	2005
32	266	349	2006
44	143	800	2008

Source: Dr Dekel Amir – Shapira Israeli Ministry of Environmental Protection, 2008: *Pollution loads in Israel streams, comparison.*

presumably as a result of the continued contribution to pollution loadings from non-point sources.

The habitat and ecological systems of both streams pay a heavy toll for the many years of pollution and dramatic modification of the natural hydrological regime. This is evident in the relatively poor macroinvertebrate biodiversity, dominance of a single or a few taxa (low evenness index), and overall poor stream health (low percent biological integrity or low value of ASI).

The ubiquitous dipterans, with their tolerance for extreme environmental conditions suggest that large sections of the stream remain inappropriate for a range of recreational and other uses. Many dipterans are tolerant of extreme environmental conditions and their presence reflects high levels of wastewater contamination. This proved to be true also in the present study. Two dipterans groups are especially good bioindicators for the degree of organic pollution. The first one includes moth-flies (family Psychodidae) and hover-flies (family Syrphidae) that were found only in the grossly polluted (raw sewage) tributaries of both the Alexander (Shekhem/Zomar) and of Hebron/Besor. The other group includes the non-biting midge larvae (Chironomidae, mostly *Chironomus* sp.) that were frequently dominant reflecting the enrichment by organic matter (mostly municipal effluent). The clear relationship between percent dipteranslarva and organic pollution (represented as total ammonia concentration) indicates a threshold of 40 mg/l ammonia, from which the community is totally dominated by tolerant dipteranslarva (Figure 6).

On the basis of water quality, community and health variables, the Alexander stream (from 'Buregeta' site down) is

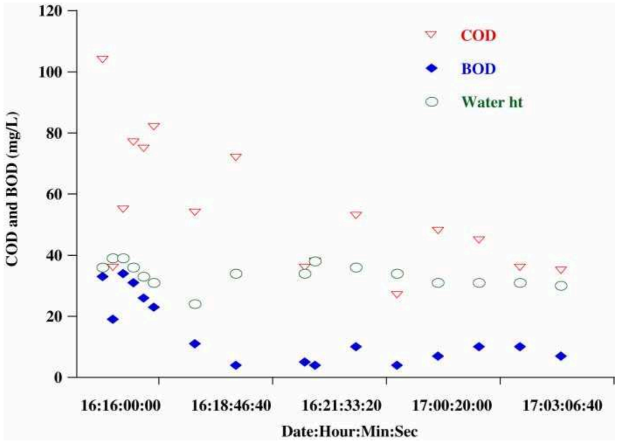

Figure 6 Relationship between the proportion of diptera larvae in the assemblage and the concentration of total ammonia (NH_4-N) in Alexander and Besor streams and their tributaries.

better off ecologically than the Besor stream. This is clearly evident when the different sampling sites in the two watersheds are contrasted according to a common scale of ASI (Table 10).

The median value of the ASI for all sites in Table 9 along the Alexander stream (2.8, 'poor' health) is ca. 30% higher than that of all sites (excluding upper tributaries) along the Besor stream (2, 'very poor' health). There is a single site at each stream basin that stands out by its highest ASI value. In Alexander stream it is the side channel that drains a natural wetland area ('Ha'Ogen channel', ASI = 4.3) and in the Besor stream it is the spring area ('Ha'Besor springs', ASI = 4.4). In the absence of a true undisturbed reference site, the above sites may be considered as a realistic alternative. Although the geomorphology of the two streams differs greatly as do their climatic setting and conditions, the ecological state of their upper tributaries is 'very poor' (reflected by the ASI). Man-made alteration is so extreme (perennial flow and heavy pollution) that none of the site specific attributes is being expressed biologically.

As both watersheds receive no rain during the summer and have trivial spring flow, their water quality is dominated by sewage discharges. The greater precipitation during the rainy season and associated dilution in the Zomar/Alexander basin do not affect this dynamic. Nor does a decade of efforts to reduce point sources and partially treat sewage from the West Bank. Both streams are heavily polluted as reflected in water quality variables and by the biological health category. This is especially noteworthy given the steady growth in the number of residents living in the watershed, particularly among the Palestinian population (The Palestinian Central Bureau of Statistics 2008). Although the geomorphology of the two streams differs greatly as does their climatic setting and conditions, the ecological state of their upper tributaries (reflected by the ASI) are also 'very poor'.

Regardless of reductions in point source discharges as well as the self-purification processes that reduce the pollution loads,

Table 10 Comparison of ASI (range and median) and 'health assessment' at different sites along the Alexander and Besor streams and their upper tributaries (Zomar and Hebron, respectively).

Stream	Site	*n*	ASI range	ASI median value	'Health assessment'
Alexander	Burgata dn.	2	2.1–3.0	2.8	'Poor'
	Alexander-Shekhem-up	3	2.4–3.2		
	Alexander-Shekhem-dn	3	2.0–2.4		
	Ha'Ogen cannal	2	3.0–4.3		
	Ha'Ogen bridge	2	2.2–2.8		
	Elyashiv	3	2.7–3.0		
	Ma'abarot up	3	2.4–3.0		
Zomar	Deir Sharaf-up	2	1	1	'Very poor'
	Deir Sharaf-dn	2	1		
Besor	Tel Sheva	1	1.9	2	'Very poor'
	Re'yim bridge	1	2		
	Ein Sarohan	2	2–3		
	Ha'Sharsheret park	2	1.9–2.1		
	Ein Ha'Besor	2	2.8–4.4		
	Shoket Brd	1	1		
	Rope Bridge	1	3.1		
	Sekher Dn	1	2		
	Hipushit	1	2.1		
	Quarry	1	2		
Hebron	Rihiya	2	1	1	'Very poor'
	Thaharyia	2	1		

water quality did not attain the required level even at the stream's distant downstream reach (102 km from the source at the Besor stream). Annual averages of COD and BOD and NH_4 were 73, 21 and 47 mg/l respectively are considerably higher than the recommended Israeli effluent standards of 70 and 10 and 1.5 mg/l. The high percentage of the contaminated stream flow that percolates into groundwater should be another source of concern for water managers.

Water quality during storm events, in terms of pollutant concentration, is of better quality than that found in base flow. However, during storm events, significant amounts of nutrients (total nitrogen and total phosphorous) flow through the stream. Thus, NPS both from the many agricultural fields surrounding the stream, and urban runoff from the adjacent towns, are the most plausible source to account for these nutrients.

While neither Palestinian nor Israeli regulators have set formal water quality standards for these two streams, a reduction of 45–74% in TP is needed in order to meet a phosphorus concentration of 1 mg/l that is presently considered appropriate by the Israel Ministry of Environmental Protection for reasonable wastewater quality in streams (Tal *et al.* 2005). To meet this ambitious objective, all pollution sources must be considered in a management strategy. Ongoing disregard for non-point phenomena is likely to lead to a continued failure in stream restoration efforts and ineffective investment of public resources. Moreover, it is likely that the release of pollution sources from the sediment will continue into the water column and the high concentrations of pollutants carried from the watershed into the stream during flood events will continue to contribute high nutrient concentrations. Even before formal common water quality standards are set and a coordinated management strategy for restoring transboundary streams crafted, controlling non-point source pollution can and should be integrated into present management programmes.

6 Implications for future monitoring studies

The research confirms the importance of an extended monitoring programme for characterizing ephemeral and intermittent streams that combines a network of automatic hydrometric monitoring stations with manual grab water quality sampling prior to, during and after flood events. As establishing an automatic station costs roughly 10,000 dollars and laboratory costs quickly mount, especially for non-conventional pollutants, researchers seeking information about ephemeral streams are faced with several practical dilemmas in finding an optimal balance for their monitoring strategy. Sufficient funds should also remain for assessment of sediments which often have a meaningful effect on long-term aquatic conditions.

Manual 'grab' samples are able to overcome gaps in the data collection at relatively low costs. But it is very difficult if not impossible for field staff to predict when and how streams will react to a given storm, its anticipated duration, etc. Consequently, determining optimal intervals for sampling in the field during storm events often remains an imprecise 'guesstimate' which presumably improves over time as the field researchers become more familiar with the watershed.

As 'first flush' contributions to pollution loadings appear to be particularly significant in ephemeral and intermittent streams, sufficient manpower must be in place and ready to capture this event and identify the relative contribution of different pollution sources. In the present study, given the participation of numerous graduate students, technicians and researchers it was possible to establish a protocol and stock equipment on site which allowed for a nimble response to rain events. Generally, weather reports allowed for anticipation of rain events prior to their inception, with lags never less then 2 h between the start of precipitation and the first in-stream measurements. If a research team or government agency cannot field a large research team for these seasonal events or if large sections of the streams are not accessible to vehicles at short notice or at night, then greater reliance on permanent stations is required.

The nature of watershed monitoring is that there are rarely if ever adequate funds to fully characterize a watershed, especially a large one, so limited resources must be optimized by taking advantage of pre-study surveys. This can help prioritize the pollutants that are particularly relevant to human or ecological health in order to reach a concise list that will be measured, as well as establish key junctures where permanent monitoring stations should be located. In the present study, an adjusted biotic index proved to be applicable, even in highly ephemeral tributaries. This appears to offer a relatively inexpensive approach for assessing the health of heavily polluted streams. Yet, it also requires a high level of expertise and familiarity with the biological assemblage and proven associations with different water qualities.

In summary, the data collected in this study are highly relevant and should inform future stream restoration strategies in both watersheds. The findings suggest that monitoring ephemeral streams, while more complicated than perennial waters, can generate information which is critical for decisions regarding management and restoration efforts. As most surface water assessments and protocols are based on perennial streams, clearer methods of analysis ecological assumptions and standards should be developed for ephemeral and intermittent flows.

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