A Dual-mode Biofilter System: Case study in Kfar Sava, Israel

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ABSTRACT
Despite experiencing recent drought conditions, Israel is expected to discharge more than 150 GL of urban runoff to sea due to extensive urbanization along the coastal plains. The underlying aquifer, a vital water resource, has become contaminated mainly by nitrate. Stormwater biofilters, have been demonstrated to be effective for stormwater treatment. A dual-mode biofiltration system has been constructed in Kfar-Sava to combine stormwater harvesting and treatment during the wet season, while being used to treat polluted aquifer groundwater (aquifer recovery) during the dry season. In addition to demonstrating treatment effectiveness, direct and infiltration recharge options of the treated water were tested to determine their relative efficiency. The preliminary results show that the system was able to effectively treat a range of pollutants in urban runoff (heavy metals, nutrients and pathogens) and meet Israeli and Australian guidelines for irrigation, aquifer recharge and streams health. Initial aquifer recovery tests show up to 73% nitrate removal of aquifer polluted water at low biofiltration rates. The Kfar-Sava biofilter marked an important milestone for implementing Water Sensitive Urban Design (WSUD) principles in the Israel and in the next two years Israel will gain at least two pilot systems across the country, with the aim being to establish policies and process to underpin widespread adoption.

KEYWORDS: Biofilter; stormwater; aquifer recovery; water sensitive urban design

INTRODUCTION
Stormwater treatment and harvesting is becoming widely adopted in many cities around the world to build a diversity of water sources in response to population growth and increased vulnerability in water security. The first blueprint on how to harness the potential of stormwater to overcome water shortages, reduce urban heat and improve waterway health in Water Sensitive Cities has just been published in Australia (Wong *et al*., 2011), focusing mainly on capture and treatment of stormwater for non-potable uses (such as garden irrigation or toilet flushing). Many other countries around the world are also exploring the potential for stormwater to overcome water shortages. For example, Israel, although under constant water shortages and with cities experiencing around 400-600 mm/year of rainfall, has only recently starting to explore this option. In fact, Israel coastal aquifer is under ongoing stress of being irreversibly contaminated by intrusion of sea water due to over pumping and diminished natural aquifer refill. This is expected to accelerate due to enhanced urbanization of the recharge areas of the coastal aquifer.

It is anticipated that by the year 2020, Israel will discharge more than 150GL per annum of urban runoff to the sea (Shamir and Carmon, 2007). The management of stormwater as a resource in Israel is in its infancy and more research is needed in treatment and storage technologies that can be implemented within limitations of tight urban spaces. Some of the most promising treatment technologies are stormwater biofilters, while Aquifer Storage and Recovery has been identified as the most cost-effective storage method (Wong *et al*., 2011).

Stormwater biofilters, also known as bioretention systems, have been used extensively and effectively for stormwater treatment for waterways health protection (e.g. Bratieres *et al.*, 2008, Davis *et al.,* 2009, Lucas *et al.,* 2007, FAWB 2009). They are usually built as trenches or basins filled with carefully engineered fast-draining filter material that is effective in removing sediment, metals and nutrients (Hatt *et al*., 2009) from stormwater. Biofilters are planted with species that can tolerate both drained and waterlogged conditions and effective in removal of nitrogen and its species (Read *et al*., 2008, Zinger *et al*., 2007a). These systems can include a saturated zone (SAZ) at the base and are usually gravity fed by stormwater. They can be scaled to fit any type of urban landscape (Zinger et al, 2007b) ranging from 'pods' of only a few square metres to large regional-scale biofiltration basins that may cover several thousand square metres. However, the full potential of biofilters for removal of pollutants that are of interest for stormwater harvesting is yet to be recognised. More data on removal of heavy metals (e.g. Fe or Al) and pathogens (only one field study reports on pathogen indicators; Hunt *et al*., 2008) that can cause problems to water supply is required.

Apart from effective treatment, stormwater harvesting systems require a cost-effective storage, especially where supply and demands are highly seasonal. A variety of storages have been used, but where geology is suitable, aquifer storage is found to be the best way of storing the treated stormwater. Conventional Aquifer Storage and Recovery (ASR) schemes often involve large scale stormwater treatment and extensive and expensive injection wells. What is needed is development of small gravity fed injection and infiltration wells that can support decentralised recharge of locally harvested and treated stormwater if a surface aquifer is available. Many such aquifers in Israel are already polluted and thus themselves in great need of remediation. Stormwater harvesting could therefore support recovery of such underground water systems, especially if the treatment system that harvest stormwater during wet months (e.g. biofilters) can also be used to clean the polluted groundwater during dry months (by extracting, filtering and re-injecting the aquifer water).

To test the viability of this concept, a stormwater biofiltration system with groundwater injection wells has been recently built in Kfar-Sava on the outskirts of Tel Aviv, Israel. The system, that was designed in accordance to Australian stormwater biofiltration guidelines (FAWB, 2009), has been tested for treatment and capture of stormwater during wet winter months, as well as for treatment of polluted groundwater during dry months. This system is unique in its dual operational regime: it is tested as the hybrid system for both stormwater harvesting and groundwater remediation. If proven, the stormwater biofiltration technology could be applied on a widely distributed scale in Israeli cities and towns to (i) provide an extensive new source of water through harvesting of urban stormwater; (ii) treat polluted groundwater, and over time recover the groundwater quality; (iii) prevent degradation of waterways and beaches due to polluted stormwater; and (iv) assist in greening Israeli cities, reducing the urban heat island effect, and creating a more pleasant city environment.

METHODS

Location and overall design: the pilot site was located within a future public park in the "Green Neighbourhood" of Kfar-Sava city (17km north east from Tel-Aviv). The system receives (1) gravity fed stormwater by a 315mm diameter diversion stormwater pipe installed off a main drainage culvert that drains a catchment of 300 ha (approximately one third of city area), and (2) polluted groundwater (with concentrations of nitrate of up to 150 mg/l) from a pressurised pipeline that connects three nearby extraction wells. The system consists of a stormwater biofilter and two types of recharging wells (deep and shallow) as outlined in Figure 1.

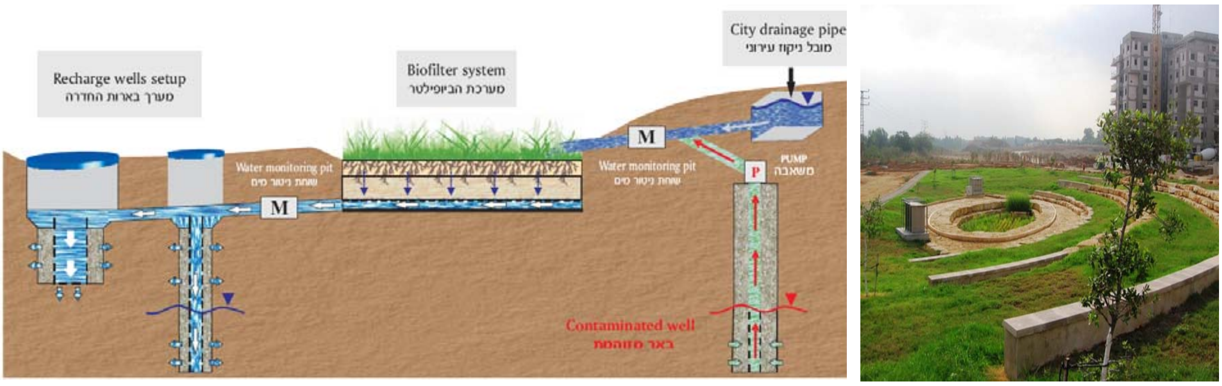

Figure 1. The dual operation stormwater biofilter, Kfar-Sava, Israel.

Biofilter design: Biofilter design was based on local rainfall data and Australian stormwater biofiltration guidelines (FAWB, 2009). The total size of the biofilter is 85 m^2. It is fully lined and has a five-layer filter media of a total depth of 1.2m (Figure 2). The bottom layer was permanently submerged (SAZ) and contains a cellulose-base carbon source designed as an electron donor to enhance the denitrification process. The top layer of the biofilter is free-draining and supports plants growth and aerobic processes (such as nitrification). The pilot biofilter was planted six months prior to testing, with twelve different plants, including three species of sedges (*Carex appresa* , *C. flacca and C. secta*, Vetiver grass (*Vetiveria zizaniodes*) and *Goodenia ovate*) and three species of *Melaleuca* tree (*M. ericifolia, M. Green doom, M. snow storm*). The biofilter upper layer was supplemented with a six-month control released fertiliser with trace elements (Haifa Chemicals-Multicote 6) and chicken compact compost (Givat Ada) to accelerate the vegetation establishment period.

Aquifer recharge design: Two types of wells were constructed: (1) the deep recharge well that extends to the most conductive (gravel) layer of the aquifer (87m deep and 8” in diameter with treated water conveyed using a 3” pipe); and (2) three shallow wells (24m deep and 1m in diameter with treated water conveyed using a 12” pipe) that are one metre above the aquifer water table. This allows for testing of different recharge applications.

Monitoring: Two monitoring pits were installed at the inlet and outlet of the biofilter, each including a Siemens Magflow-8000 flow meter and a Sigma SD900 auto-sampler (M at Figure 1). The flow data was recorded by Campbell Scientific CR-800 data logger while flow-weighted water samples were collected. Two monitoring campaigns were conducted so far:

(1) ***Stormwater treatment during wet weather season***: Inflow into and outflow from the biofilter was monitored during nine storm events (December 2010 to February 2011), and event mean concentration (EMC) were measured by a certified lab for: Heavy metals (26 elements), TSS, TOC, TKN, NO_3, NO_2, NH_3, TP, PO_4, pH, EC and pathogen indicators (*E.coli*, Faecal coliforms, and total coliforms). Data are now available for 6 more events, but they were not included in this paper.

(2) ***Groundwater treatment during dry weather season - Groundwater recovery***: Only preliminary testing was carried out so far using the groundwater from nearby wells as inflows. The system performance was monitored under low flow rates (2-3 m^3/day) for a period of six weeks, followed by three experiments when 50m^3 of groundwater were

conveyed to the biofilter at three different inflows rates (i.e 8.0, 17, and 40 m^3/hr). In these experiments, outflow samples were collected at hourly intervals to investigate the breakthrough of pollutants. The water samples were initially analysed for a number of parameters, which was subsequently narrowed down to nitrate due to its high concentration (up to 150 mg/l) and critical role in groundwater.

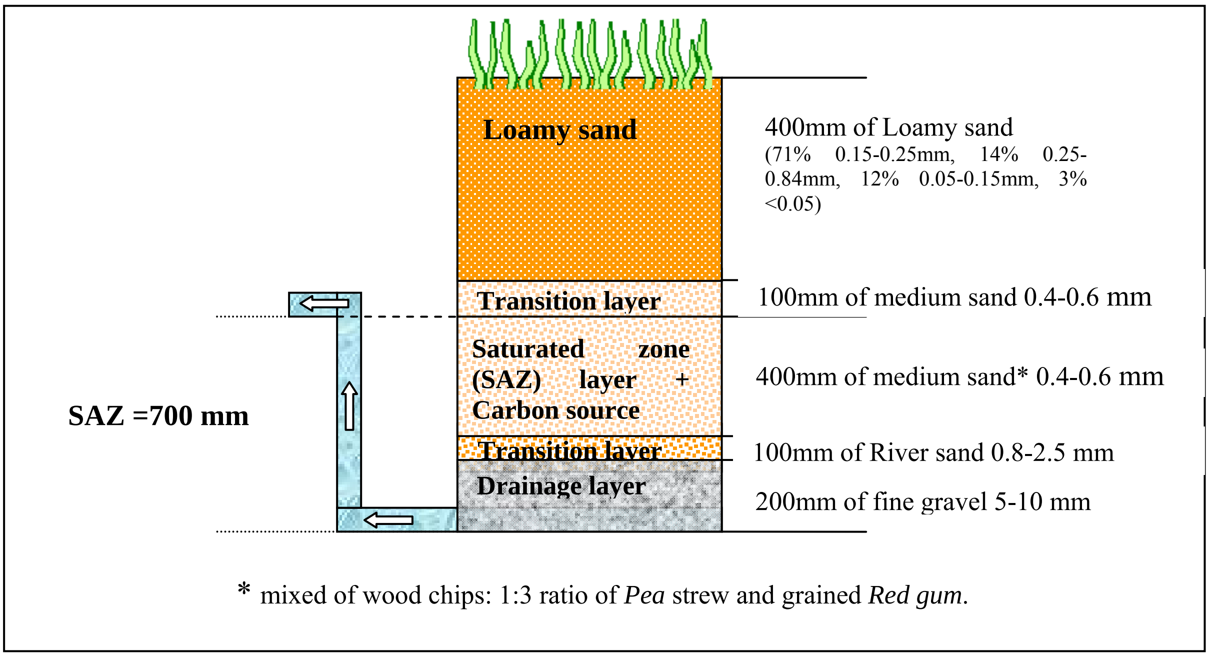

Figure 2. Biofilter filter media setup of five layers by total including extensive SAZ.

Data analysis: The outflow concentrations recorded in both cases were analysed for their mean, and 90%ile values. They were compared to "Inbar committee guidelines" for irrigation and groundwater recharge and against Israel water drinking guidelines. The removal percentages were also determined for all studied pollutants and both monitoring campaigns. Breakthrough curves were constructed for nitrate concentrations in order to determine how far the system could be pushed before it stops being effective.

RESULTS AND DISCUSSION

Stormwater Treatment

The rainfall depth of the nine monitored event ranged from 1.7 to 63 mm with the median being 11.4 mm. The composition of stormwater in Israel is rarely reported (only a couple of studies exist in the open literature; Nativ *et al*., 2006, PWR 2011 cite). This study found Kfar-Sava stormwater to be rather polluted (Figures 3 and 4) in comparison to the 'typical' stormwater as found in several worldwide studies (Duncan, 1999, Fuchs *et al*., 2004). For example, median EMCs of TSS, TN and TP concentrations were around 600, 3.27 and 0.89 mg/l respectively which are all well above the log-mean values of 150, 2.1 and 0.35 mg/l but still within the expected range reported by Duncan (1999). The *E.coli* levels are within expected range (McCarthy *et al*., 2007) and metal concentrations are also usually higher than typical values with Fe and Al being exceptionally high and well above irrigation guidelines (Figure 3). The presence of Fe of 16 to 52 mg/l (with median of 27.5 mg/l) is of particular concern if water is to be injected into the groundwater aquifer and recovered for subsequent use for non-potable purposes. It could be concluded that the presence of high concentrations of TSS, pathogens and some metals make the untreated stormwater in Kfar-Sava unsuitable for direct recharge or non-potable use. The biofilter was found to be able to treat the stormwater to the required standards for irrigation (Inbar committee, 2010) for all prescribed water quality parameters (Figures 4 and 5).

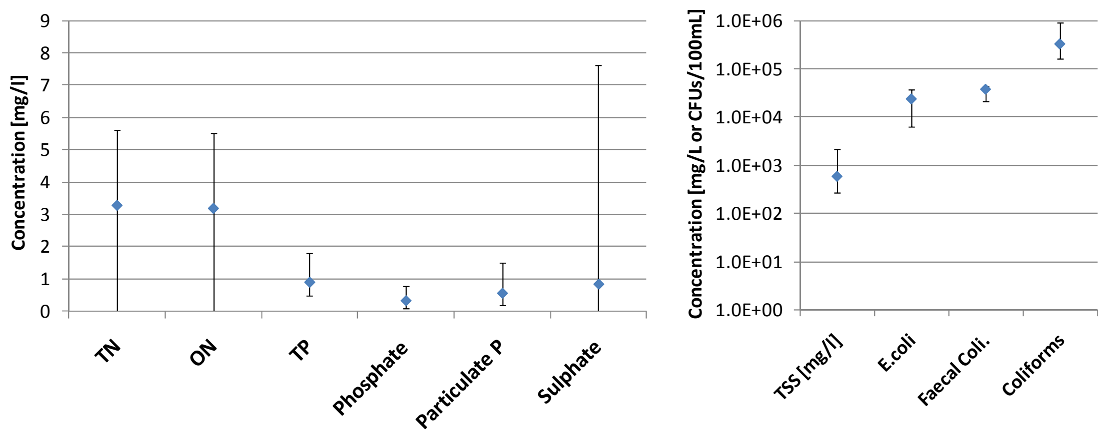

Figure 3: Median and 90-procentail of EMCs of key pollutants in Kfar-Sava untreated stormwater (based on nine monitored events).

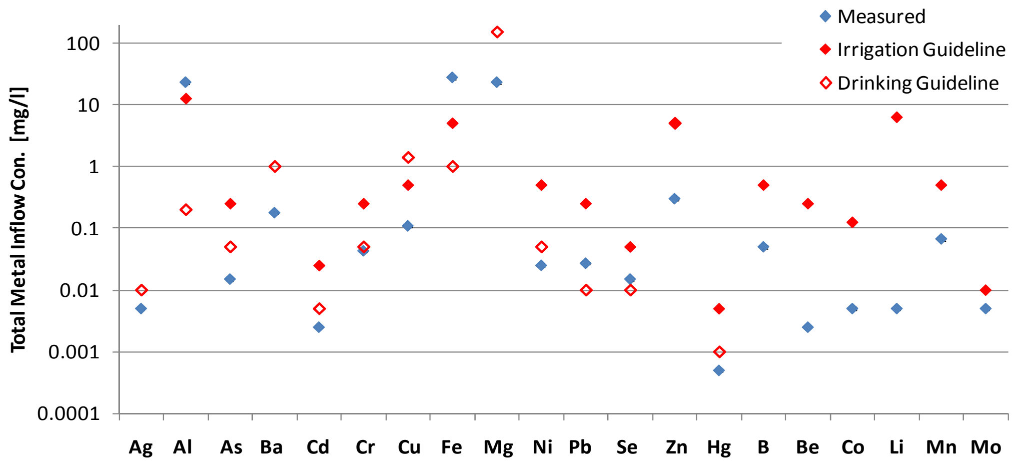

Figure 4: Median heavy metal EMCs in Kfar-Sava untreated stormwater (based on nine monitored events) compared to guideline values.

Figures 5 and 6 show the measured quality of the outflow from the biofilter and apart from *E-coli* and TSS, all other parameters met Israel's drinking water guidelines (Ministry of Health, 2000). It is noteworthy that even TSS and *E.-coli* met the irrigation guidelines most of the time with the biofilter achieving 3-log reductions of *E.coli* levels. We hypothesise that this level of *E.coli* reduction is partly due to the presence of the saturated layer at the bottom of the biofilter. However, it is necessary to do far more work to understand how this high level of *E.-coli* removal translates to the removal of spectrum pathogens. The good results achieved does not mean that the water can be directly used for potable purposes, but it does give us lots of confidence to investigate the potential of stormwater for drinking purposes. A range of micro-pollutants such as PAHs, pesticides, and endocrine disruptors should be monitored in treated stormwater to determine if the harvested stormwater is suitable for direct exportation for potable purposes. Between Nov 2011 and Feb 2011, the system treated and injected into the groundwater around 64% of the total inflow of 1009 m^3, with the rest bypassing as overflow. As a pilot biofilter, the system was under-designed relative to its catchment so this degree of overflow was expected. Another factor causing the overflow was the initial reduction in the hydraulic conductivity of the media as shown in Figure 7. This is similar behaviour to that recorded for other stormwater biofilters (Hatt *et al*., 2009) and is attributed to sediment accretion which is overcome later by the development of plant roots throughout the media profile. The system's hydraulic conductivity is expected to recover with time (which appears to have already commenced) when roots get established and commence their natural cycle of die-off creating macrospores in the soil (Hatt *et al*., 2009).

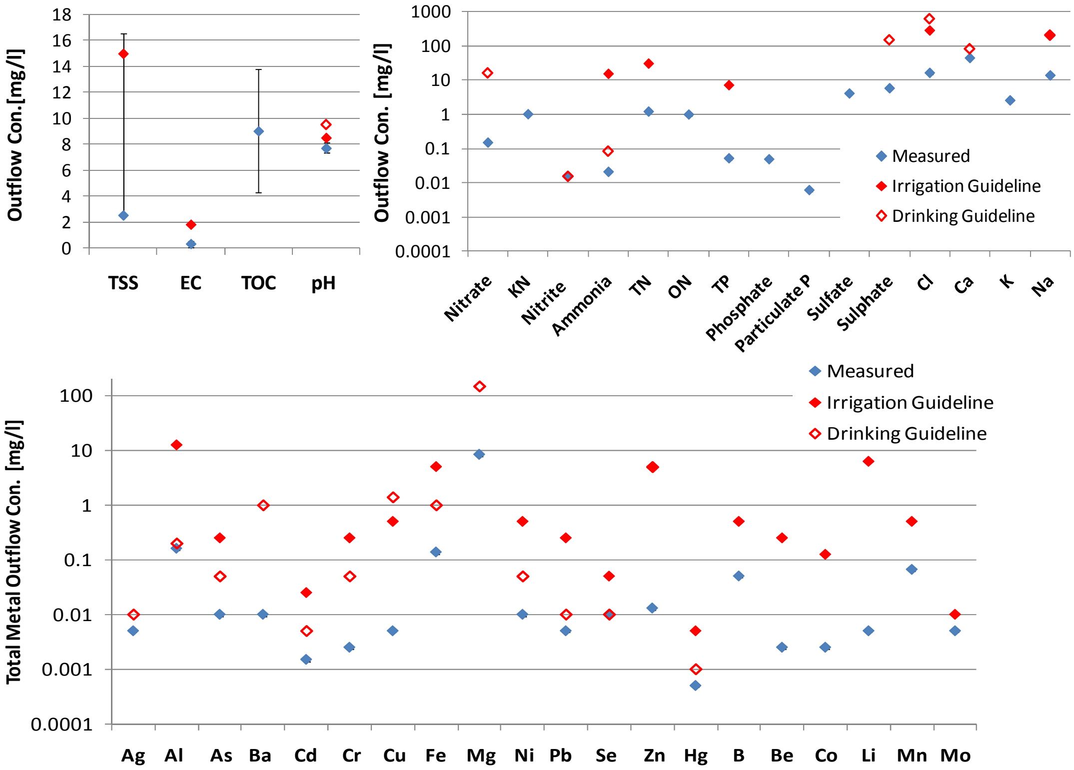

Figure 5: Median EMCs of measured pollutants in the outflow from Kfar-Sava biofilter for nine monitored stormwater events compared to guideline values (the TSS, EC, pH and TOC graph also includes 90-procentai intervals). Note: nitrogen species are given in a form of N concentration (X-N).

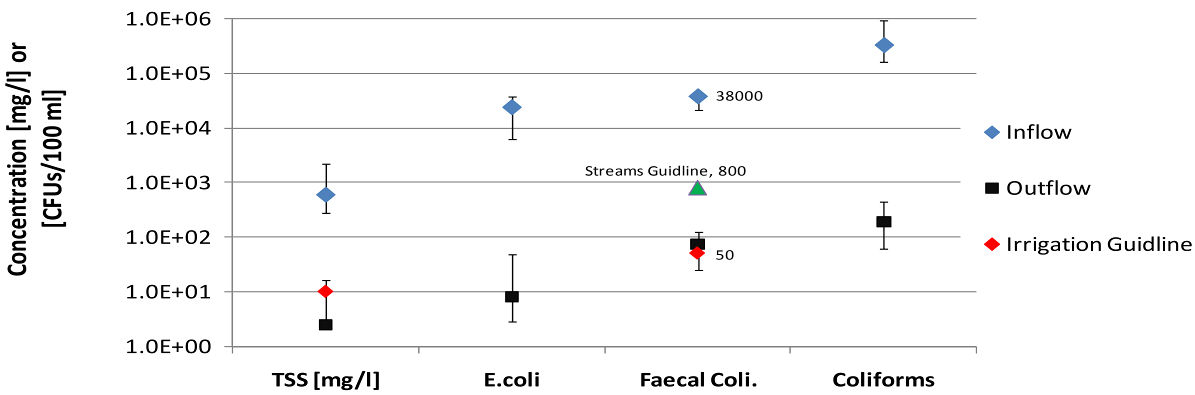

Figure 6: Inflows and outflows of TSS and pathogen indicators during stormwater events (median and 90-procetail of EMCs of nine monitored events) and irrigation guideline values.

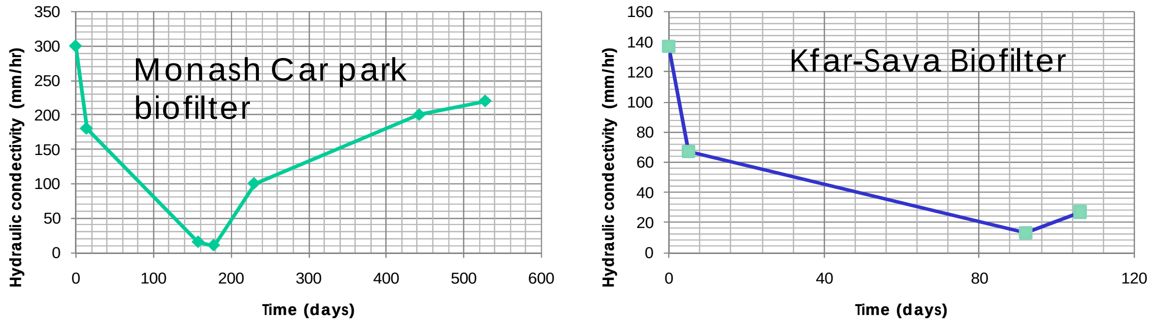

Figure 7: Hydraulic conductivity of Monash Car Park biofilter (left) and Kfar-Sava biofilter (right).
Note: Monash biofilter was measured using constant head test applied over the whole biofilter (after achieving saturation), whilst the Kfar-Sava measurements are taken during real storm events and thus may not represent fully saturated conditions.

Groundwater Treatment

The preliminary results on nitrate removal from all the experiments with groundwater inflows (during dry weather season of 2010) are reported in Table 1, indicating a very high levels of removal during low inflows (of 2-3 m^3/day). The outflow water quality meets requirements for irrigation and streams and marine health (Inbar committee, 2010, Israeli Ministry of Health, 2000, Australian Guidelines, 2009) and regularly meets drinking water guideline for nitrate of 70 mg/l. The treatment efficiency dropped considerately when aquifer water was introduced at higher flow rates, with mean outflow concentrations not meeting the targets. This provides some insight to guide the sizing of the system for aquifer remediation and may also suggest that the current system is limited in its nitrate reduction capacity by the storage volume of the saturated zone (which limits of the denitrification rate within that zone).

Exp. No	Date	NO_3 [mg/l]		NO_3 removal [%]	Inflow flow rate
		IN	OUT		
1	5/08/2010	122	66.0	46%	
2	18/08/2010	143.5	74.0	48%	
3	25/08/2010	144	77.0	47%	2-3 m3/day
4	15/09/2010	131	46.0	65%	
5	19/09/2010	129	35.0	73%	
6	6/10/2010	144.4	115.8	20%	40 m3/hr
7	20/10/2010	137.1	89.4	35%	17 m3/hr
8	3/11/2010	134.2	103.1	23%	8m3/hr

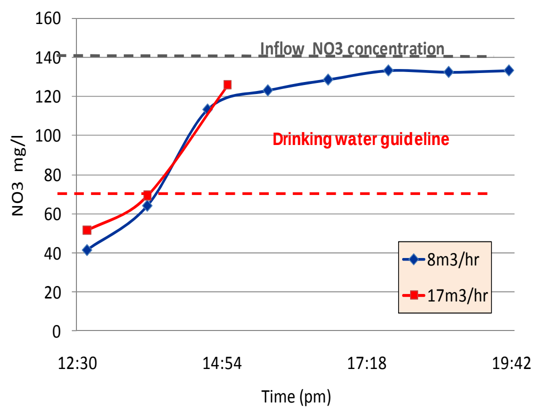

Figure 8: *Left*-The preliminary results of groundwater treatment experiments. *Right*- breakthrough of nitrate during groundwater experiments at 8 and 17 m^3/hr inflow rates.

CONCLUSIONS

The first stormwater biofilter in Israel built in Kfar-Sava was tested for a dual purpose operation: (1) capture and treatment of stormwater during the wet season and (2) groundwater treatment (aquifer remediation) during dry season. The monitoring of nine events during winter 2010-2011 revealed that Kfar-Sava stormwater is rather polluted with median Even Mean Concentrations (EMCs) of TSS, TN and TP of 600, 3.27, 0.89 mg/l respectively, well above the typical values found in stormwater. The *E.coli* levels were within expected levels while some higher than typical metals concentrations were observed. Untreated stormwater is considered not suitable for direct injection into groundwater or non-potable uses (such as outdoor irrigation). Stormwater biofilter was found to treat this stormwater to required standards for irrigation and infiltration (Inbar committee, 2010), meeting even the stringent TSS and *E.coli* targets of irrigation Australian Guidelines (2009). Treated stormwater monitored to date met all drinking water guidelines except for pathogens. This does not mean that the outflows are directly drinkable (without additional filtration and disinfection), but the data has demonstrated the potential of stormwater harvesting and treatment as a potable water source. Preliminary data are showing high potential for nitrate removal in remediation of contaminated groundwater, albeit at low flow rate. Further research will be directed at optimisation of treatment of highly polluted groundwater at high flow rates and development of operational regime of intermittent biofilter inundation, allowing enough time for digestion of nitrate. The effectiveness of introducing more reactive electron donor into the incoming inflow to support a more rapid denitrification will also be studied.

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