Monitoring and management Lake Kinneret (Sea of Galilee) – preserving Israel's major surface water resource

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Abstract: Lake Kinneret is a major water resource for the state of Israel that provides about 20-30% of the state's fresh water supply. It resides within a 2,730 km² watershed, 25% of which is outside Israel's borders. The watershed is populated and contains urban, agricultural and minor industrial activities, which produce a variety of nutrient and pollution loads that endanger water quality in the lake. This paper outlines the organizational structure, the monitoring program, and the management frameworks of Lake Kinneret and its watershed. It is concluded that ongoing and expanded lake and watershed management is promising means for maintaining a healthy ecological system and improved water quality in Lake Kinneret.

Introduction
Lake Kinneret (Sea of Galilee) is the only natural surface fresh water reservoir among the major water resources of Israel (Fig. 1). The other main sources are the Coastal Aquifer and the Mountain Aquifer. Together with its watershed, the lake supplies 400-550 10⁶ m³ yr⁻¹. Water supplied from the lake is transferred through the National Water Carrier (NWC), first operated in 1964, but also through local supply including a pipeline which transfers 50-55 10⁶ m³ yr⁻¹ to the Hashemite Kingdom of Jordan (Markel et al. 2014). Since the 1990s, extraction from Lake Kinneret exceeded the annual replenishment and its water levels declined to the "lower red lines", endangering the ecological stability and the water quality of the lake. Therefore, preserving the water quality by constructing a comprehensive and integrative monitoring and management system was, and still is, a national high importance goal. This paper describes this system which was originally initiated in 1969 and then further enhanced and improved since the mid-1990s.
Fig. 1. A. Map of Lake Kinneret (Sea of Galilee) including lake monitoring stations. B. Lake Kinneret Watershed map showing the locations of the monitoring stations and saline springs around the lake.

**Hydrological and Geographical Background**

The total inflow from the watershed plus the direct rain exceed ca. 600 $10^6$ m$^3$ yr$^{-1}$, while the Jordan River contributes about 70% of the total (Rimmer and Givati 2014). The annual available water (inflows minus evaporation) in Lake Kinneret has decreased significantly during the last 40 years (Fig. 2). The decline in the net replenishment to the lake was ca. 150 $10^6$ m$^3$ yr$^{-1}$ over 36 years. Sixty percent of this reduction is attributed to decreased precipitation and a change in the rain pattern (Givati and Rosenfeld 2007). The remaining 40% is attributed to increased water consumption in the watershed, including in Lebanon. It is also clear from Figure 2 that the inflows to the lake vary from year to year (annual evaporation is approximately constant).

As shown in Fig. 2, there have been extended periods of low inflow years, while the extractions were driven by demands. As a result, water levels have declined during these dry years, as seen in Fig. 3. In 1986 the level dropped for the first time below -212 m, reaching -213 m (the "Lower Red Line") by 1990. During the high rainfall winter of 1991/92 the water level rose back to the Upper Red Line, but over the next 10 years the total amount pumped exceeded the available water year after year. The years 1992-2002 and 2004-2009 experienced cumulative declines of lake level by 6 m and 5.5 m, respectively, dropped below the "Lower Red Line". The wet years of 1991-2 and 2002-4 produced periodic recoveries, but were soon succeeded by normal and low inflow years that resulted in lowering the lake levels.
The area of Lake Kinneret watershed is 2,730 km² (Fig. 1) of which ca. 75% is in Israel and the rest in Lebanon. Some 220,000 people live in the Israeli part of the basin, in 6 regional authorities and 27 local and municipalities (Markel et al 2014). The watershed is primarily used for agriculture, including orchards, field crops, fishponds, cowsheds, and cattle-grazing. This determines the main pollutants in the watershed: nutrients, herbicides, pesticides, and pathogenic bacteria (Berman 1998; Markel et al 2014). The drainage of Lake Hula and its surroundingswamps in the 1950s by diverting the Jordan River from its natural route was the most dramatic change in the watershed geography during the 20s century (Dimentman et al. 1992). 40 years later, the Hula area was reclaimed through the "peat soil reclamation project" and the creation of a new wetland in order to stabilize groundwater levels, reduce pollution flow, and generate new income from eco-tourism (Markel et al. 1998).

Organizational Setup

The responsibility for managing Lake Kinneret as a water resource (among other national water resources and systems) resides with the Director of the Israeli Water Authority (IWA, until 2007 the Water Commission). The IWA was established in 2007 as a sequel to the
Water Commission, and has taken on the dual roles of regulator and manager of the water resources.

In 1998 the Water Commissioner adopted the recommendation of two professional reports, by an Israeli panel and an international expert, and established the Lake Kinneret & Watershed Unit (LKWU) within the Water Commission. A senior scientist was appointed to head this unit. The major objective of the LKWU has been to establish a coordination and management platform for all monitoring activities in the lake and its watershed (Markel 2008).

In 2003, the unit’s responsibility was expanded to all management activities in the lake and its watershed. The LKWU, together with a group of experts that functions as its Steering Committee, constitutes the IWA’s arm for supervising activities in Lake Kinneret and its watershed, where several formal and informal entities with different perspectives and responsibilities operate. The LKWU currently coordinates and supervises the monitoring program, as well as the lake and its watershed management, and serves in an advisory capacity to the Director of IWA (Markel et al. 2014).

The institutional and organizational setup of the monitoring and management systems of Lake Kinneret and its watershed are depicted in Fig. 4. This Figure shows that several different organizations take part in the monitoring program:

- The Kinneret Limnological Laboratory (KLL) of Israel Oceanographic & Limnological Research (IOLR) – monitors biological, chemical, physical parameters in the lake.
- The Kinneret Watershed Unit, of the Mekorot Water Company – monitors water quality in the watershed’s waterways, and in the saline springs.
- The Kinneret Hydrometric Unit of the Israel Hydrological Service, which is part of the IWA – measures water levels in the lake and streams, calculates stream discharges and produces water balances of the lake and its watershed, including forecasts of future water balances.
- MIGAL Laboratory, a regional scientific institute of the Galilee—monitors herbicides, pesticides and organic contamination in the watershed, as well as the water quality of the water bodies in the Hula Project (the reclamation project of the Hula peat soils).
- The Fisheries Department of the Ministry of Agriculture and Rural Development monitors the catch of the commercial fisheries, and jointly with the IWA it decides on the fish-stocking program in the lake.
- The Operating Department of the IWA assists the IWA Director in decision making on water production from the lake and hence on water level control.
- Mekorot Water Company assists the Operating Department of the IWA to achieve this goal, as well as the goal of salt removal from the lake.
- The Lake Kinneret Administration Unit (LKA, in Hebrew: Minhelet Hakinneret), a non-statutory unit established in 1969, serves as an arm of the IWA for pollution control and prevention in the watershed.
- Many organizations are involved with the operation of the lake’s shores, including the Kinneret Municipal Council, the Ministry of Environmental Protection, as well as LKWU.
- Management in the watershed involves also the Planning Department of the IWA, Keren Kayemet Le’Israel (KKL) and the Israel Nature and Parks Authority.

Lake and watershed monitoring

The important role of Lake Kinneret as a national water resource and the concern for water quality in the lake have led to the creation of an extensive water quantity and quality monitoring program in both the lake and watershed (Markel 2008). Therefore, a monitoring program was initiated in 1969, five
Fig. 4. The organizational setup of the Monitoring and Management System of Lake Kinneret and its watershed. Israel Water Authority (IWA) units are in blue, other organizations in green, monitoring activity in orange and management activities in purple. Data reporting and transfer are shown by red arrows while instructions and performance control are in blue arrows.

years after initial operation of the National Water Carrier. The monitoring program operated mainly over 5 lake stations and 15 watershed stations (Fig. 1). Since the initiation of the LKWU in 1998, many changes have been introduced to improve the system, in particular its spatial coverage and online real time monitoring. For example, the introduction of the Mini Bat, which is an undulating towed vehicle carrying instruments for spatial monitoring within the water body, the introduction of the lake Ecoraft Station A (The deepest part of the lake) in 2002 and the on-line alarm systems in several watershed stations (Sukenik et al. 2014). As can be seen in Figure 5, the water quality of Lake Kinneret during 2010 was acceptable, with the exception of Cl concentration and cyanobacteria to total algae ratio. These two parameters have been the main water quality problems of Lake Kinneret for the last two decades (Markel et al. 2014). The watershed-monitoring program combines continuous discharge measurements with sampling of water for chemical analyses that jointly yield loading estimates. This program is carried out by the Israel Hydrological Services of the Water Authority (discharge measurements) and the Watershed Unit of Mekorot Water Company (sampling and chemical determinations). The main objective is to quantify the loads of particulates and solutes entering Lake Kinneret, focusing on phosphorus and nitrogen species, and to identify their sources. Total phosphorus load from the watershed, as measured at Pkak Bridge station on the Jordan River, increased in 1970s from ca. 100 ton year⁻¹ to ca. 125 ton year⁻¹ and then decreased to ca. 70 ton year⁻¹ in the 2000s (Fig. 6).
Fig. 5. Monthly water quality index for Lake Kinneret in 2010, (After Hambright et al. 2000). Each monthly average is marked by its number on different scale for each parameter. The blue rectangles represent acceptable values for each parameter. Acceptable value marked in blue while non-acceptable range is marked in red while acceptable value.

Lake and Watershed Management
Management of Lake Kinneret and its watershed is a set of operational activities intended to preserve the lake as a major water resource and to improve its water quality. Data and knowledge results from the monitoring system are integrated by the LKWU and its steering committee. This integrative process advises the decision makers to implement management activities. The management activities are divided here to lake management and watershed management.

Lake management
Water levels management
Decisions on the volumes of water to be withdrawn each year from Lake Kinneret are determined primarily based on the forecasted minimum water level that would be reached at the end of each hydrological year. The Israel Hydrological Service (IHS) recommends a withdrawal plan from all major water sources including Lake Kinneret, with due consideration of their current and forecasted quantity and quality states. The LKWU synthesizes the IHS recommendation with the knowledge and experts' inputs regarding the chemical-biological-ecological state of the lake, and recommends the minimum level that should be reached in the coming fall season. Once the Director of the IWA decides upon a withdrawal plan, Mekorot Water Company follows these instructions and adjusts its supply plan accordingly.

Salinity control
The salinity of Lake Kinneret ranges between 240-300 mgCl·L⁻¹, which causes salt accumulation when its water is delivered to
irrigated lands and therefore it is deemed too high for irrigation. Therefore, reduction of the lake's salinity is an important management objective. The mechanism of salt entry into the lake is ruled by the "Gravity Driven Mechanism". According to this mechanism, the fresh water that flows to the lake from the Eastern Galilee aquifer (North West of the lake) mixes with the deep brines and discharges into the lake through saline springs (Gvirtzman et al. 1997; Rimmer et al. 1999). With this understanding of the salinization mechanism, lowering the groundwater levels in the Eastern Galilee aquifer will reduce saline flows into the lake. To reduce these groundwater levels, the amount of water that is pumped from the aquifer was increased from 15 $10^6$ m$^3$ yr$^{-1}$ in the 1990s to 25 $10^6$ m$^3$ yr$^{-1}$ in the last two decades (Berger et al. 2012).

Since 1967, the waters of some saline springs along the northwest shore of the lake are being diverted into a 'salinewater carrier' that goes along the western shore of the lake and discharges into the Southern Jordan River. A significant portion of the Nur Springs with an average salinity of 2,200 mg Cl$^-$. L$^{-1}$ (See Fig. 1) is diverted to the salinewater carrier, removes about 33,000 tons of Cl$^-$. yr$^{-1}$. In addition, the very saline spring 'HamayTveria' which has a salinity of 17,000 - 18,000 mg Cl$L^{-1}$ is similarly diverted to the saline water carrier and removes another 13,000 tons of Cl$^-$.yr$^{-1}$ (Berger et al. 2012).

The subsurface spring Fullia-A that is estimated to contribute between 10,000 and 20,000 tons Cl$^-$.yr$^{-1}$ has been captured under a 10 m diameter concrete cap with an outlet pipe. After a few years of monitoring the water and salt discharges from the cap its water will also be diverted to the saline water carrier, thereby a further 10-20% of the salt currently entering the lake will be removed in the near future.

**Regulation of the fishery**

Fishery management including Stocking, removal, and other fishery regulations affects the ecosystem components and thus indirectly to affect water quality (Carpenter and Kitchell 1988). Therefore, fishery management in Lake Kinneret is used by the IWA as a tool for managing and balancing the lake ecological system (Ostrovsky et al. 2014). This is achieved by stocking "good" fish, excluding "bad" fish from the lake and using fishery regulations. The stocking and related programs are controlled jointly by the IWA and by the Fishery Department (FD) of the Ministry of Agriculture and Rural Development through the "Stocking and Fisheries Management Committee" (see Fig. 4). Once a decision on a detailed stocking plan had been made, the FD is in charge of rearing or purchase of fingerlings to be stocked, and of monitoring the sizes of the harvested fish and the total mass landed for each species.

**Management of the shores**

Lake Kinneret water levels have undergone substantial changes between 1990 and 2012 (Fig. 3). When the level drops, dense vegetation develops on the exposed shores - mainly Phragmitesaustralis, Tamarix sp., and Cyperus spp. Although it may disturb touristic development of the shores, this vegetation serves as an important habitat for fish reproduction and fingerling survival (Markel et al. 2014). Moreover, according to Tibor et al. (2012), in 2001 the total phosphorus content of the entire mass of vegetation over the full strip of water level fluctuations was only 23 ton P. This should be compared to the 600 tons of P contained in the uppermost 10 cm sediment layer of the same shore strip (Eckert et al. 2003), which the labile part of it (20%) may be released to the lake. The IWA policy, based on ecological knowledge and the "precautionary principle", allows only limited clearing and removal of the vegetation (Markel et al. 2014).

**Management of the Watershed**

**Preventing sewage flow**

Sewage treatment in the watershed began in the mid-1980s. Since then the IWA and the LKA acted vigorously to eliminate point source pollution in the Israeli part of the watershed.
This of course, does not include the sewage in Lebanon, which accounts for 25% of the total watershed area. Practically, as for now all of the anthropogenic sewage in the Israeli part of the watershed is treated in treatment plants and then stored in reservoirs for summer irrigation. All dairy cowsheds have been refurbished in the past decade so that the winter rain does not flush the manure to the drained streams and their effluent is transferred to a treatment plant in the watershed.

Fish pond management
Many fish ponds were operated in the northern sections of the watershed in the 1960/70s. In the 1980s the number of fishponds decreased due to low market price of carp and to the fact that growing tilapia (locally called “Musht”) is not possible in the cold water of the Jordan River. Since the 1990s regulations were set for eliminating pollution from fishponds, by water recycling and filtering of the pond outflows.

Minimization of diffuse pollution sources
The IWA acts to minimize nutrient outflow from irrigated crop and pasture areas through regulations and enforcement. A new project based on cooperation between the IWA, the Ministry of Agriculture and Rural Development and the Ministry of Environment Protection is planned to remove pasture cows from the vicinity of running streams during the summer. This project will be implemented by introducing watering points far enough from the streams. In addition, the IWA and the Ministry of Environmental Protection enforce and control the amounts, types and application modes of pesticides and herbicides that are used in the watershed.

Prevention of fuel and oil pollution
Fuel and oil repositories are closely controlled and monitored, to prevent the spills that in the past caused substantial pollution. Means have been put in place for dealing with oil spill events on the Lake itself, from boats or fueling stations.

Management the restored Hula Peat and Wetland
A large scale rehabilitation project - the Hula Project - was initiated in 1994, creating some 90 km of regulating canals and the small shallow Agmon Wetland, which is a focal point for ecotourism. It also serves for storage and reuse of peat drainage and prevents it from being drained down to Lake Kinneret due to its high nutrient content (Hambrght and Zohary 1999, Markel et al. 1998). The LKWU leads the Hula operating team, which includes representatives from LKA, KKL, Israel Nature and Parks Authority, Galilee Water Association, the Peat Farmers Association, and Mekorot Water Company (Fig. 4). This team makes operating decisions regarding Agmon water levels, and whether to direct peat drainage water to the Einan Reservoir or to Lake Kinneret.

Conclusions and Summary
The changes in loadings of nutrients and other materials into Lake Kinneret are correlated with long-term changes in Jordan River discharge volumes and are affected by anthropogenic developments and management actions in the watershed (Rom et al. 2014). The increase in total phosphorus load during the 1970s (Fig. 6) as well as the increase in \( N_{\text{org}} \) and \( \text{NH}_4^+ \) loads is attributed to the rapid population increase and following increase in the number of dairy farms and sewage amount (Markel et al. 2014). The decrease in total phosphorus since the 1980s and until present (Fig. 6) as well as the decrease in \( N_{\text{org}} \) and \( \text{NH}_4^+ \) loads is most probably a consequence of different management activities took place in the watershed since the 1980s, including the operation of different sewage treatment plants.
Fig. 6: Annual load of total phosphorus (TP) transferred from the Jordan River to Lake Kinneret between 1970/71 to 2012/13, including the Theil-Sen trend (Rom et al. 2014). However, the decrease of water inflow from the watershed to the lake has influenced the material loads as well. In summary, Lake Kinneret confronted increased pollution in the 1970s, followed by decrease water inflows and dramatic water level changes since the 1980s until present. As a consequence, water quality of the lake decreased slightly since the 1990s, mainly due to salinity increase and cyanobacteria blooms.

The Israel Water Authority (former Water Commission) leads an integrated lake-watershed management which is based on a comprehensive monitoring system and a complex organizational setup. Effective lake and watershed management, including stable water levels, salinity control, fisheries regulations, shoreline management as well as point and diffuse pollution prevention is promising means for maintaining a stable ecological system and improved water quality in Lake Kinneret.

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References


