Monitoring Lake Kinneret and Its Watershed: Forming the Basis for Management of a water Supply Lake

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Abstract

Lake Kinneret is the only large water surface source in Israel, with an area of 167 km^2 in a watershed of 2730 km^2, and supplies some 30% of the country's freshwater. Monitoring water quantities and qualities in the lake and its watershed provides the basis for current operation and for decision making in planning management of the watershed, the lake, and proposed engineering projects. This chapter describes the physical setting, the management issues, the structure of the monitoring system and the way in which it has been operated and developed, mainly in the last 3 years. The Monitoring Task Force, se up by the Water Commissioner in 1998, coordinates the monitoring work of all organizations and guides improvements of the monitoring system, by introducing new sampling and analysis techniques.

1 Introduction

Lake Kinneret is the only freshwater lake in Israel, from which about 30% of the country's potable water is supplied. The lake also sustains a large private and commercial fishery with an annual yield of 2000 tons (http://marine.ocean.org.il/about.html). In addition, the lake is a prime tourist attraction, as well as a religious site. Since 1964, when the National Carrier began transferring water from Lake Kinneret to the center and south of the country, water supply for urban and agricultural consumers has become the main role of the lake. The lake and its basin supplies on average ca. 550 mcm annually, of which about 400 mcm are pumped through the National Carrier to the center of the country and 100 mcm are supplied directly to consumers around the lake. In addition, 55 mcm are supplied annually to the Hashemite Kingdom of Jordan. Maintaining and improving water quality in Lake Kinneret are therefore a major national and regional concern.

Two major aquifers - the Mountain Aquifer and the Coastal Aquifer - provide most of the remaining water to the national consumption of Israel. Extraction from the aquifers has for many years exceeded the average replenishment, which has resulted in declining water levels in the aquifers and deterioration of water quality, and mandates a decrease in the quantities supplied from groundwater (Kessler 1999). At the same time, the level in the Kinneret has reached its lowest level in recent history (Fig. 2), well below the “red line” (the operational minimum) – which itself has been lowered first from –212 m (ASL) to –213 m in 1986, and then to –214 m in 2000. Hence, there is serious concern that the water quality of the lake will deteriorate as a consequence of the water-level drop.

The area of the Lake Kinneret is approximately 167 km^2, changing somewhat with water level. The area of the watershed is 2730 km^2, of which 2070 km^2 are in Israel and the rest in Lebanon (Fig. 1). The watershed is bordered in the north by the basin of the Litany River and the Hermon Mountain, the Golan Heights in the east, and Galilee in the west. The major water inflow to the lake is the Jordan River, which drains the relatively high-rainfall region of the Upper Galilee and the Golan Heights. In addition, there are several smaller streams such as Meshushim Stream, which drains the Golan Heights, and Amud Stream, which drains the carbonate UpperGalilee.

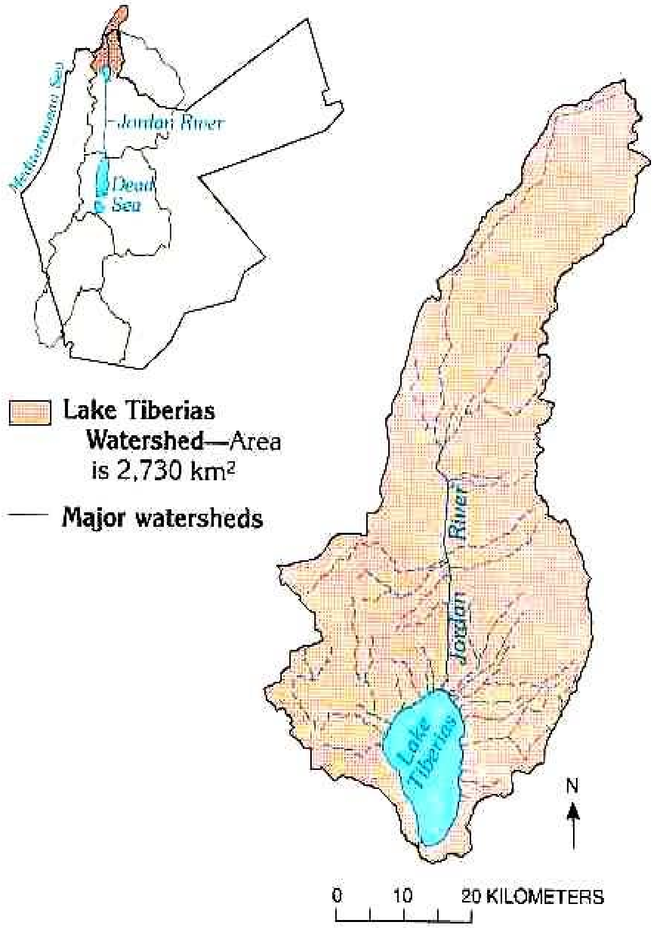


Figure 1

Some 200 000 people live in the Israeli part of the basin, under 6 regional authorities, and 25 local and municipal authorities. About 2-3 million tourists visit Lake Kinneret and its basin annually, which adds significantly to the anthropogenic pollution. The area of the basin is used primarily for agriculture: orchards, field crops, fishponds, cowsheds, and cattle-grazing areas. This determines the main pollutants in the watershed: nutrients, herbicides, pesticides, and pathogenic bacteria (Berman 1998). Industrial areas in the basin are few and small, hence they produce only a small fraction of the pollution that enters the lake from its basin.

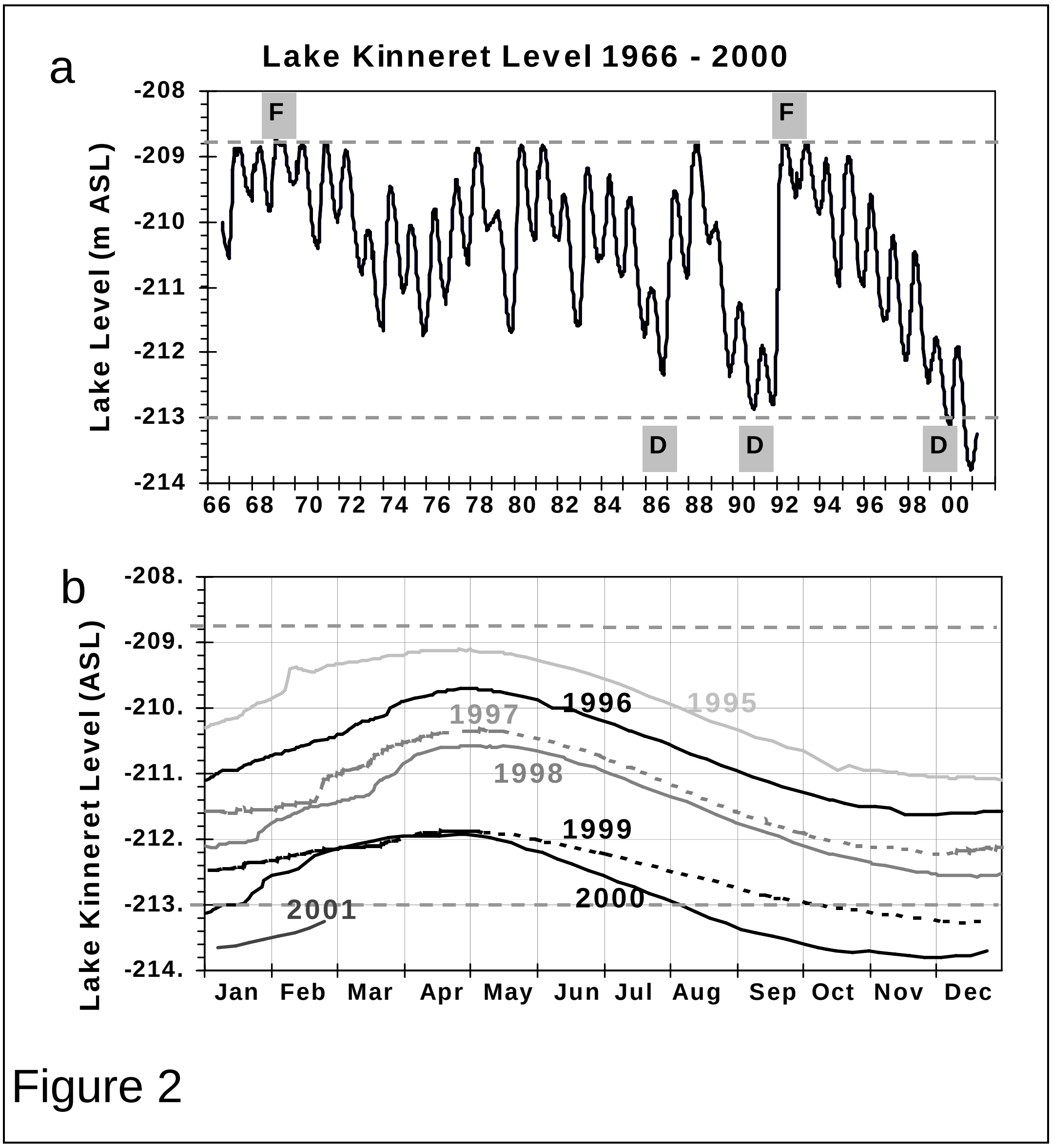


Fig. 2. a Water levels of Lake Kinneret 1966-2001. F marks flood years and D drought years. b Seasonal changes in Lake Kinneret level 1995-2001. (Source: Israel Hydrological Service). In both figures the maximum and minimum operational levels are marked by horizontal dashed lines

The large increase in human activities in the drainage basin over the past 50 years has led to the appearance of various diffuse sources of pollutants, including agricultural, industrial, and anthropogenic sewage sources. Superimposed on these were the drainage of swamps in the Hula Valley and the diversion of the Jordan River from its historical route through the 1950s. Since 1994 there has been a noticeable change in water quality in Lake Kinneret, mainly regarding the population of algae (Berman 1996b). It is reasonable that these changes are related to the increased input of pollutants from the watershed and the changes in water level. Accordingly, concern for water quality in the lake has led to the creation of an extensive water quantity and quality monitoring system.

2 The Organizational Setup

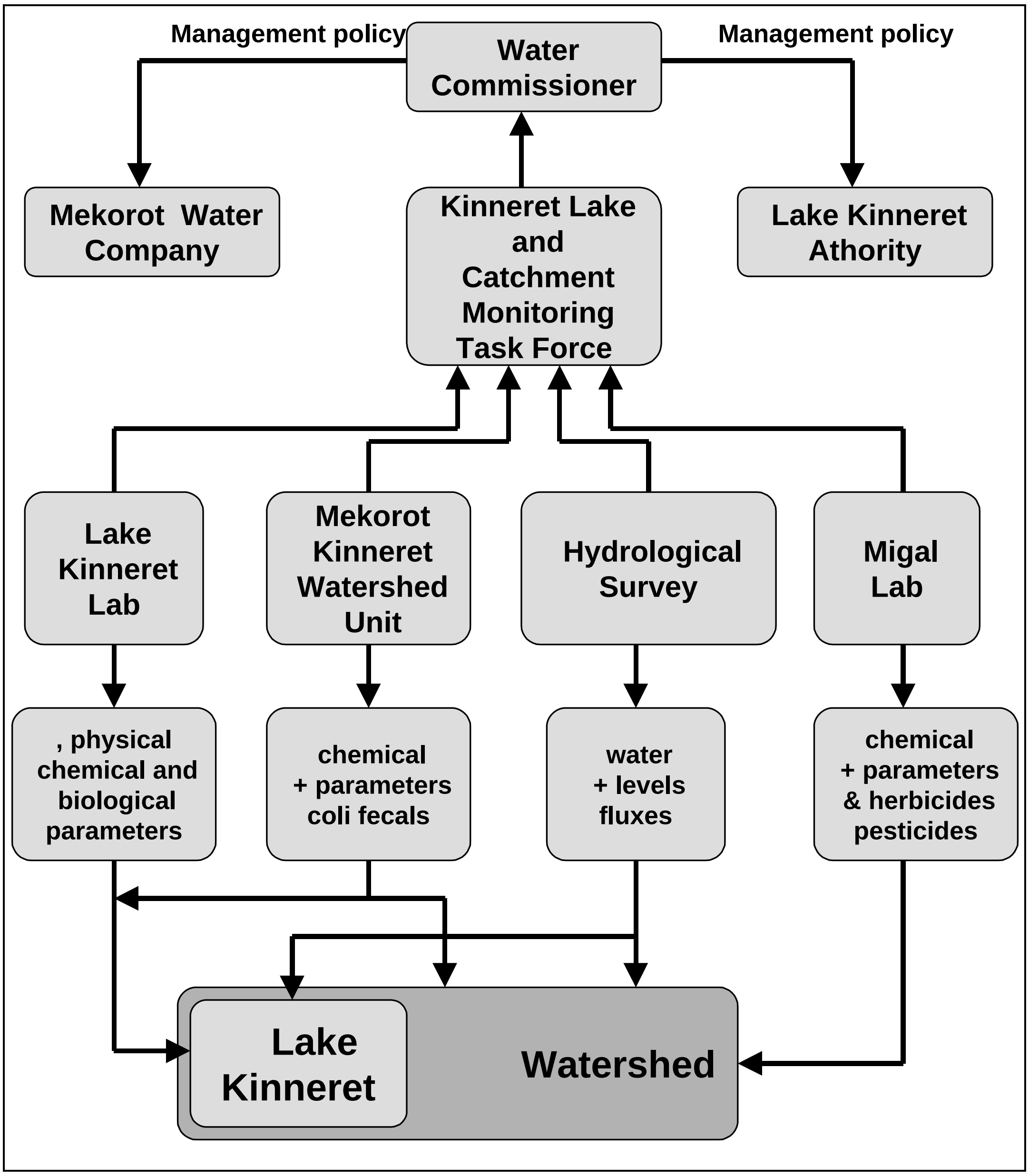
The responsibility for managing Lake Kinneret resides with the Water Commissioner, the senior government official in charge of water in the country. The Water Commission belongs to the Ministry of National Infrastructure, but it is also guided by instructions from a number of other Ministries. Mekorot Water Company is responsible for the supply from the lake, through the National Water Carrier to the south of the country, and by several local water systems to consumers in and around the watershed. The organizations involved in monitoring and managing Lake Kinneret and its watershed and their roles and responsibilities are (Fig. 3):

- Hydrologic Service – flows in the watershed and lake water levels.
- Alon Laboratory of the National Oceanographic and Limnologic Organization (KLL) – chemical and biological water quality in the lake.
- Mekorot Kinneret Watershed Unit - water quality in the watershed's waterways, and volume, salinity and energy balance in the lake.
- MIGAL - a private regional research institute and laboratory – herbicides, pesticides and organic contamination in the watershed.
- The Kinneret Authority – supervision over activities in the watershed, around, on and in the lake.
- The Kinneret Lake and Watershed Monitoring Task Force – appointed by the Water Commissioner to coordinate and supervise the monitoring and analysis activities of the other bodies, and assist in converting the findings into operational decisions by the Water Commissioner.

The Water Commissioner set up the Monitoring Task Force in 1998, following several reports critical of the monitoring situation, to coordinate and guide the work of all organizations. The task force responsibilities are:

- To create a mechanism for planning, operating, analyzing, and reporting of the monitoring results.
- To secure integration and coordination among all organizations and components of the monitoring system.
- To guide improvement of the monitoring system, by introducing new sampling and analysis techniques, and to optimize the number, location and frequency of the sampling stations, and the parameters monitored.

- To improve the process of interpretation, reporting and advice to the decision-makers.
- To evaluate the utility of proposed new models for simulating lake processes, designed to aid decision-making with respect to planning and management alternatives in the watershed and the lake.



3 The Monitoring System

The monitoring stations in the lake and watershed are shown in Fig. 4. There are five stations in the lake (denoted by letters). Station A is at the deepest point (about 44 meters), while the others span a range of depths (10 – 20 m) and conditions. Station A is the most intensively monitored and analyzed, and it has been found that its data are indeed the most representative of conditions throughout the lake, except in the littoral (Gafny and Gasith 1993).

An important question was raised regarding the optimal number and location of the monitoring stations in Lake Kinneret. It was argued that measurements at five stations do not adequately represent the whole lake volume. However, significantly increasing the number of stations would lead to a decrease in the sampling frequency, due to budget constraints. A recent analysis (Rom et al. 2000) showed that decreasing the number of sampling locations from 33 to 17 (Mekorot Company sampled, monthly 33 stations in the lake since 1990), while increasing the sampling frequency from once a month to twice a month, would lead to an increase in information of 30%. Another option for solving the spatial distribution problem was the introduction of a Mini Bat, which is a towed vehicle carrying instruments for spatial monitoring (Sukenik et al. 2001). The Mini Bat carries a set of electrodes and other measurement tools to measure conductivity, temperature, and turbidity, and will be able to measure chlorophyll and particle concentration in the future (A. Sukenik, this Vol.).

The chemical parameters and frequency of measurements in the watershed and the lake are shown in Table 1. Most of the parameters are measured weekly at five stations at several depths. Thus, the measurement system in Lake Kinneret is one of the most detailed in the world. For example, Lake Tahoe, California, an important ultra-oligotrophic and large lake (with an area of 500 km^2 and average depth of 313 m), is monitored by sampling 13 depths at a single station once every 10 days (Goldman 1988).

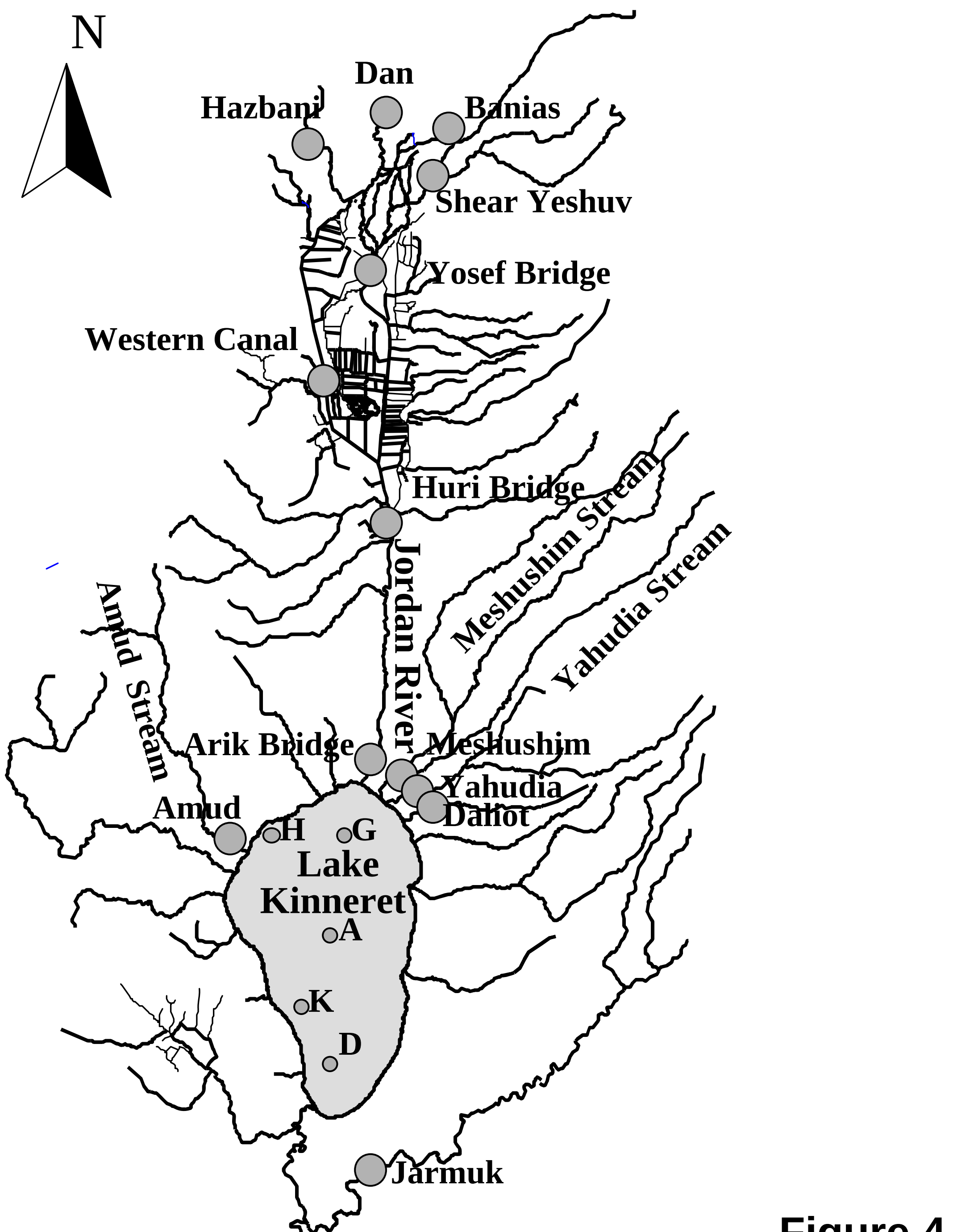


Figure 4

3.1 Improving the Monitoring

The Kinneret Lake and Watershed Monitoring Task Force initiated a set of projects in order to improve the monitoring, notably:

- Publishing an integrated report for the state of the lake and its watershed (Kolodny et al. 2000). The fragmented approach to the lake and its watershed has been a main criticism regarding the monitoring system.
- An intercalibration project among 30 labs in Israel, as a quality assurance test of the labs involved in the monitoring effort. The project was led by the Geological Survey of Israel and Mekorot Company's central laboratory.
- A program for monitoring Cyanobacteria and their products, led by KLL and financed by the Water Commission prior to the appointment of the Task Force.
- Increasing the number of sampling stations for algae and their dynamic activity - from one single station to eight, with three of them on the shores of the lake.
- Introducing a spatial monitoring system (towed vehicle) that carries electrodes for spatial measurement of pH, temperature, conductivity, turbidity, and chlorophyll (A. Sukenik, this Vol.).
- Monitoring of heavy metals - Fe, Mn, Al, Cu, Cd, Pb, Cr, Mo, Zn, U, and a few others.
- Introduction of a new method for measuring the primary production by $\delta^{18}O$ of the dissolved oxygen in the waterbody (Luz and Barkan 2000).
- Measuring the concentration of the protozoa *Giardia* and *Cryptosporidium* in the lake and some of the streams.
- Quantifying the amount of phosphorus and nitrogen that is emitted from the trout ranches in the north part of the watershed.

4 Water Quantities and Lake Levels

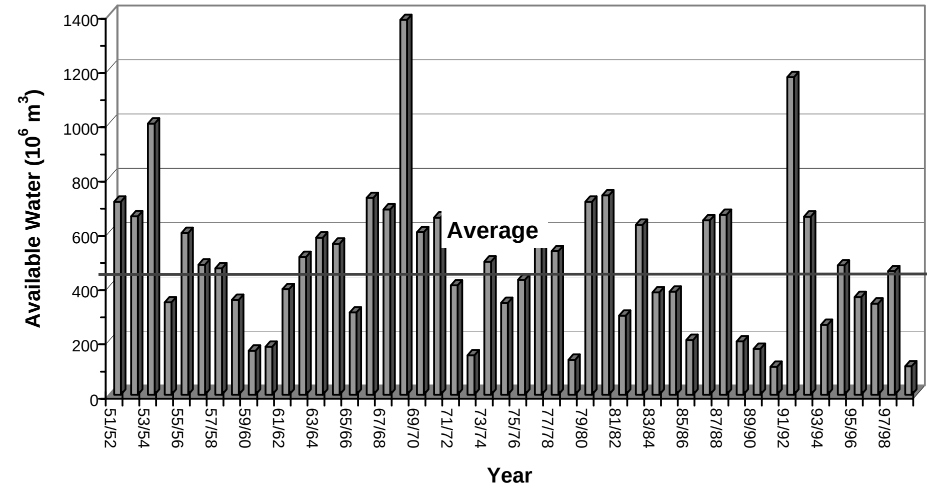


Figure 5

The history of lake levels since 1966 is shown in Fig. 2a. The normal range has been between -208.9, which is the height of the outflow weir at Degania, and –213, the “lower red line” until last year, creating a range of 4.1 m and an operational volume of 680 mcm for an average annual inflow of 500+ mcm. The “lower red line” used to be at –212 until a few years ago, and was lowered to increase the operational volume and thus the average yield from the lake. Lake levels are affected by both the inflows, which decreased in recent years, due to increased withdrawals in the upper watershed and also to a drop in natural flows. The trace of water levels in the lake throughout the last 6 years is shown in Fig. 2b. Lake levels have been dropping since the late 1980s, and in 1999 dropped below –213. 2000 was a second dry year, and the level dropped further; 2001 began lower than any recent year of record.

5 Water Quality

Physical, chemical, and biological qualities of the water in the lake are the result of a complex set of physical, chemical, and biological processes and interactions. Space here does not allow elaboration, and the interested reader is referred to the extensive literature of reports and scientific papers published regularly (Assouline 1993; Berman 1996a,b, 1998; Gophen et al. 1990; Walline et al. 1990). Other references (some in Hebrew) can be found in the data-base of the Grand Water Research Institute (http://wri.technion.ac.il/cgi-bin/abstract.html).

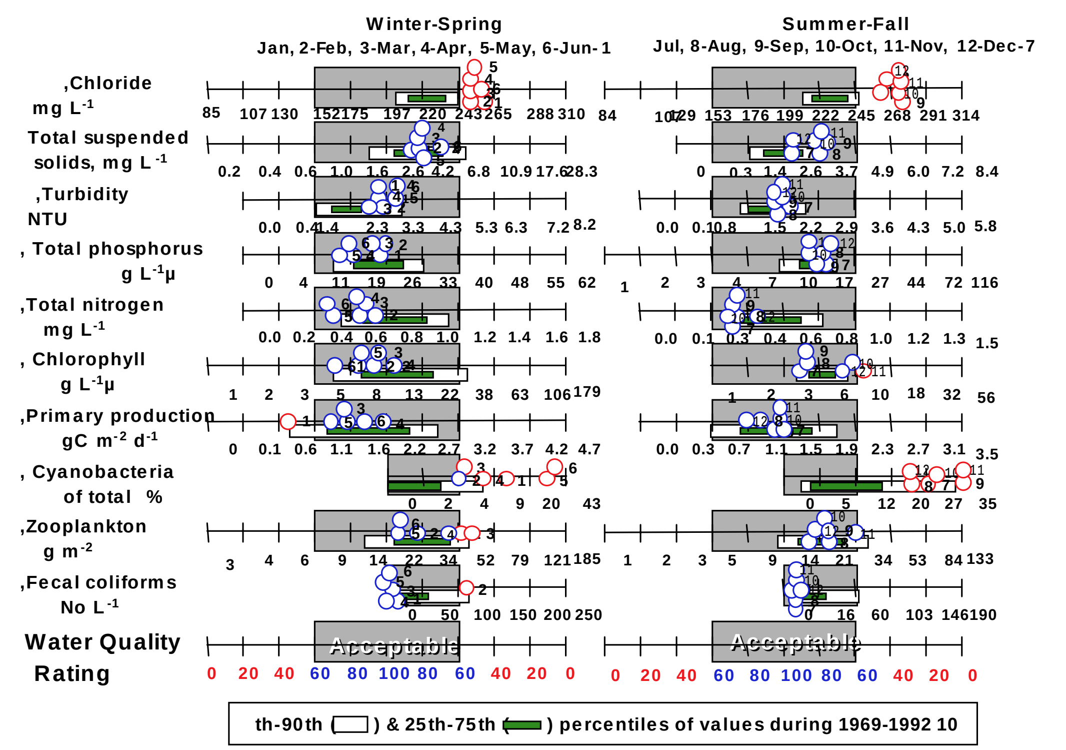


Figure 6

A main question regarding the water quality of Lake Kinneret is how to characterize and present it, since there is a large number of parameters. There are several ways to present water quality of a lake, most of them based on the concentrations of important parameters (such as: PO_4^{-3}, NO_3^-, Cl^-, turbidity, BOD, chlorophyll, chlorophyll, E. Coli, and Cyanobacteria), their change over time, and their relation to a defined range of values. A similar method has been developed for Lake Kinneret and is shown in Fig. 6.

6 Salinity

In the early 1960s the salinity of the lake was in the range of 380 mg Cl$^-$l^{-1}. This relatively high Cl^- concentration reflects mixing of low salinity (15-30 mg l^{-1}) water from the Jordan River and other streams with highly saline (1000-18,000 mg l^{-1}) littoral springs (Kolodny et al. 1999). The Salinity Diversion Channel (SDC) along the west shore of the lake was constructed in 1967 to divert saline water from springs and wells located in the northwest and west side of the lake (Nishri et al. 1999). A very large inflow in the winter of 1968/1969 (see Figs. 2

and 7) combined with the diversion to bring the salinity down to the order of 220 mg $Cl^{-}l^{-1}$. Until 1999 the salinity was kept at around 230 mg Cl^{-} l^{-1}, and has climbed since to over 270 mg Cl^{-} l^{-1} (Fig. 7).

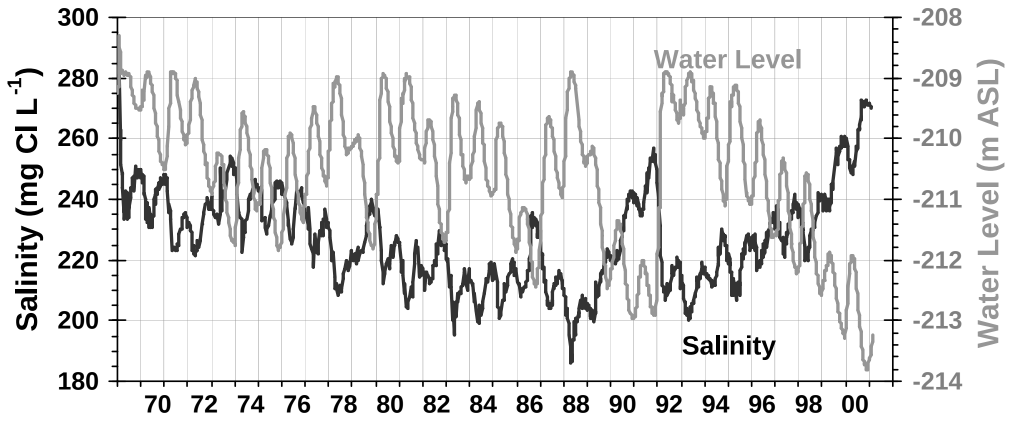


Figure 7

Salinity of the lake is a major concern. The water from the lake is transported to the center and south of Israel, and much of it is used for irrigation. The salts are deposited in the ground, reduce the productivity of soils and raise the salinity of the native groundwater in the aquifers. It is therefore imperative to keep the salinity of the lake as low as possible. One reason for the increased salinity in 1999 is that the diversion of saline water was reduced, with the aim of increasing the amount of water entering the lake. It is considered that the added amount of water was not worth the damage due to the increased salinity.

There have been many studies of the mechanism of salinization of the lake, and still there are open questions on this matter. The most plausible mechanism is entry of saline waters from below, driven by hydraulic pressure of recharge in the uplands on saline waterbodies in the layers below the lake (Goldshmidt et al. 1967; Gvirtzman et al. 1997).

Monitoring the salinization process in Lake Kinneret is carried out by calculation of a salt mass balance. The contribution of the unmonitored saline springs is an unknown component in this mass balance, hence it is calculated by closing the balance equation of the other measured components (Assouline 1993). A major advance in the methodology is simultaneous solution of the water volume, heat content, and salt mass equations in the lake (Assouline 1993). Another problematic component in the salt mass balance is the salt content in the lake. Calculation of this component requires mapping of the spatial distribution of salinity throughout the lake, which is one the tasks of the monitoring system.

7 Modeling and Databases

Many models have been developed and used over the years, to aid in understanding the processes in the lake and its watershed, to guide the monitoring system design and operation, and to form the basis for water management decision-making. The models range from simple statistical analysis of individual water-quality parameters, through correlations in time and space among different parameters, to compartment and numerical models of processes in the lake. The interested reader is referred to the database http://wri.technion.ac.il/cgi-bin/abstract.html.

A major modeling effort for the lake has been under way in recent years to produce a scientifically based, operational decision-support system for management of Lake Kinneret. This project is financed by the Water Commission and is carrying out by a collaboration between the Alon Laboratory of the IOLR (KLL) and the Center for Water Research at the University of Western Australia (CWR). The system is based on a combination of long-term (years) and short-term (days) hydrodynamic simulation models, DYRESM (one-dimensional) and ELCOM (three-dimensional). An ecological model, CAEDYM, will be used to simulate the biogeochemical processes in the lake. This project is expected to simulate the entire physical-ecological structure of the lake and to provide a basis for evaluation of changing conditions and proposed decisions. The main scenarios to be examined are lowering the water level below –214 m, diverting Jordan River water north of the lake directly to the National Water Carrier (thus bypassing the lake), introducing large amounts of Yarmouk River water to the lake and changes in nutrients load from the watershed. The model project is expected to help in improving the monitoring system, determine which are the parameters that need to be monitored, where and how frequently, as well as to focus further research on the physical, chemical, and biological processes in the watershed and the lake.

The first phase of the project was completed successfully in summer 2000, when calibration runs passed the acceptance tests

(http://www.cwr.uwa.edu.au/~contract/Current_projects/kinneret.html, A. Sukenik, this Vol.). The second phase involves further development of the models and their application to address a set of event analysis and management scenarios as mentioned above.

A new database is being planned, which will incorporate the data from all sources and for all purposes, and be available to everyone who has a need for the information and a legitimate role to play in analyzing and managing the lake.

8 Conclusions

The monitoring system in Lake Kinneret and its watershed has evolved over several decades. Since 1998, a new organizational structure is in place, to direct and coordinate the work of the several entities that collect and analyze flow and water-quality data, and develop models of processes in the lake and its watershed. This structure has resulted in improved effectiveness and efficiency of the monitoring and analysis system, and hence improved the ability of decision-making regarding the management of Lake Kinneret.

Acknowledgments: The authors wish to thank the many colleagues who participate in monitoring and analyzing Lake Kinneret and its watershed, for productive collaboration, in particular Yoel Geifman, Director of the Kinneret Watershed Unit of Mekorot Water Co., Assaf Sukenik, Director of the Alon Laboratory of the Israel Oceanographic and Limnological Research Organization, Shmuel Kessler, Director of the Hydrological Service and Yehoshua Kolodny, the former chair of the Kinneret Lake & Watershed Monitoring Task Force, Zvi Dubinsky and Boaz Lazar, members of the Lake & Watershed Monitoring Task Force.

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Table 1: Chemical, biological and physical parameters measured by the monitoring system of Lake Kinneret and its watershed.

Symbol	Parameter	Frequency in the Lake	Frequency in the Basin	Accuracy (%)
	Chemical parameters			
Cl^-	Chloride	weekly	daily/weekly (1)	2
Alk	Alkalinity	bi-weekly	daily/weekly	1
SO_4^{2-}	Sulfate	bi-weekly	daily/weekly	1

Na^+	Sodium	n.m. [2]	daily/weekly	
K^+	Potassium	n.m.	daily/weekly	
Mg^{2+}	Magnesium	n.m.	daily/weekly	
Ca^{2+}	Calcium	bi-weekly	daily/weekly	
DIC	Dissolved Inorganic Carbon	bi-weekly	n.m.	
TOC	Total Organic Carbon	bi-weekly	n.m.	
H_2S	Sulfide	bi-weekly	n.m.	
SiO_2	Silicate	bi-weekly	daily/weekly	
NO_3^-	Nitrate	weekly	daily/weekly	
NO_2^-	Nitrite	weekly	n.m.	
NH_4^+	Ammonium	weekly	daily/weekly	
DKN	Dissolved Kjeldahl Nitrogen	weekly	daily/weekly	
TKN	Total Kjeldahl Nitrogen	weekly	daily/weekly	
TON	Total Organic Nitrogen	weekly	daily/weekly	
TN	Total Nitrogen	weekly	daily/weekly	
DP, SRP	Dissolved phosphorus (orthophosphate)	weekly	daily/weekly	
TDP	Total Dissolved Phosphorus	weekly	daily/weekly	
TP	Total Phosphorus	weekly	daily/weekly	
TSS	Total Suspended Solids	weekly	daily/weekly	
Turb	Turbidity	weekly	daily/weekly	
PH	PH	weekly	daily/weekly	
DO	Dissolved Oxygen	weekly	n.m.	
Cond	Electrical Conductivity	n.m.	daily/weekly	
	Biological parameters			
Coli F.	Coli Fecal	monthly	daily/weekly	
Chlrph.	Chlorophyll A	biweekly	n.m	
P.P.	Primary Production	biweekly	n.m	
Phyto	Phytoplankton (Biomass and species)	biweekly	n.m	
Zoo	Zooplankton	biweekly	n.m	
Fish	Total Fish Biomass	bimonthly	n.m.	
	Physical parameters			
Temp	Water Temperature	weekly	daily/weekly	
Seki	Seki Depth	weekly	n.m.	
LP	Light Penetration	biweekly	n.m.	
AT	Air Temperature	10 minutes	n.m.	
SWT	Surface Water Temperature	10 minutes	n.m.	
RH	Relative Humidity	10 minutes	n.m.	
LI	Light Intensity	Hourly	n.m.	

[(1)] Daily/weekly means that in some of the basin stations the parameter is measured daily and in some weekly.

[(2)] n.m. - the parameter is not measured in the Lake or the watershed.

Figure Legends

Fig. 1: Location map of Lake Kinneret and its watershed.

Fig. 2: a. Water levels of Lake Kinneret 1966-2001. F marks flood years and D droughts years. b. Seasonal changes in Lake Kinneret level 1995-2001. Source: Israel Hydrological Service. In both figures the maximum and minimum operational levels are marked by horizontal dashed lines.

Fig. 3: Organizational structure of Lake Kinneret and watershed monitoring system.

Fig. 4: Location map of monitoring stations in Lake Kinneret and its watershed

Fig. 5. Available water in Lake Kinneret since 1951 and the multi annual average value. Data from the Hydrological Service.

Fig. 6. Monthly water quality index for Lake Kinneret in 2000. Adapted from Berman et al (1997). Each monthly average is marked by its number on different scale for each parameter. The gray rectangles represent acceptable values for each parameter, the white recangles represent 10^{th} to 90^{th} percentiles and the green rectangles represent 25^{th} to 75^{th} percentiles. Blue circles mark acceptable values while red circles mark exception values. The data was collected by Alon Laboratory of the National Oceanographic and Limnologic Organization (KLL).

Fig. 7: Salinity (in mg Cl $^{L-}$1) and water levels of Lake Kinneret 1969-2000. Data was collected by KLL and Hydrological Service.