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Chapter 32: The monitoring program

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Abstract
The monitoring program of Lake Kinneret and its watershed was established more than 40 years ago with objectives to follow the quantity and quality of the lake water, to observe and predict long-term changes in water quality, and to identify the processes that determine and affect water quality. This chapter describes the various components of the Kinneret monitoring program, alongside its development and evolution during the last decades. Recent application of early warning monitoring systems and advanced techniques for near real time, synoptic, and high resolution data collection of many water quality parameters are briefly outlined.

Key words: Monitoring, database, water quality parameters, early warning monitoring system, real time data collection

Definitions and goals

Routine quality assessment of aquatic ecosystems and water resources is essential for water bodies that constitute major sources of drinking water, as is the case for Lake Kinneret. High-quality assessment of aquatic ecosystems and water resources requires extensive operations of monitoring, including sample collection, laboratory analyses, data storage and organization, and data analyses. The design of these operations must take consider short- and long-term objectives and consider many parameters that affect the physical, chemical and biological nature of the water (Meybeck et al. 1996). The general objectives of the assessment of the quality of the aquatic environment are: 1) assure that the water is suitable for its intended use, and 2) identify temporal changes in the quality of the aquatic environment and point out natural and anthropogenic factors that affect these trends. To be able to meet those objectives, a monitoring program for an aquatic environment must be based on long-term, standardized routine measurement and observation of a suite of parameters characterizing the environment.

A monitoring program should be differentiated from other types of aquatic environmental observation programs that are more limited in time, in scope, or in targets, such as surveys or surveillances. A survey is an intensive program of a finite duration, designed to measure and

observe the quality of the environment for a specific purpose. Surveillance is a system or activity that monitors environmental quality parameters to detect and follow pollution concentration in time for remedial measures. Certain standard elements are common to all water quality assessment programs: defined objectives, preliminary surveys, monitoring design, field sampling, laboratory activities, data quality control, data storage treatment and reporting, data interpretation, and water management recommendations (Meybeck et al. 1996).

An integrated monitoring program for Lake Kinneret and its watershed

Monitoring of Lake Kinneret has been carried out since 1969 with objectives to follow the quality of the lake water, to observe and predict long-term changes in water quality, and to identify the processes that determine and affect water quality. A year later, in 1970, the monitoring of the Kinneret watershed began, with the objectives to quantify the amounts of water and nutrient loads reaching the lake. The on-going monitoring of the lake and its watershed is conducted by teams from several organizations, including: the Kinneret Limnological Laboratory (KLL) of Israel Oceanographic and Limnological Research, the Watershed Unit of Mekorot - the National Water Company, the Israel Hydrological Services of the Israel Water Authority, The Fisheries Department of the Ministry of Agriculture and Rural Development, with most funding from the Israel Water Authority (see Chap. 31). Over time, the need to integrate the various monitoring programs into a single comprehensive program was realized and a specialized 'Kinneret and watershed unit' was set up within the Israel Water Authority, to oversee, coordinate and steer the monitoring activities.

The overall lake and watershed monitoring program has evolved over the last five decades, in order to fulfill the general aim of aiding and supporting management of the watershed and the lake towards meeting the lake's role as a system that is used for water supply and provides ecological services. The multidisciplinary and multi-institutional monitoring program is based primarily on sampling water from several fixed locations (sampling stations) within the lake and along the Jordan River and other inflowing streams (KLL and Mekorot). The water samples collected are analyzed for a wide range of parameters (KLL and Mekorot) which reflect the current status of the water in the lake and its watershed, can be used to examine long-term trends in water quantity and quality, and assist in identifying sources of pollution. In addition, water discharge is measured on the inflowing rivers and saline springs (Hydrological Services). Saline springs around the lake are further sampled for their salt content (Mekorot). Fish catch and fingerling stocking are also monitored (Fisheries Department).

The different organizations participating in the Kinneret monitoring produce monthly and/or annual reports (mostly in Hebrew) in which the data are presented and analyzed, with implications being highlighted (i.e. Berger et al. 2012, Weinberger et al. 2012). Some of those data are also presented on the organizations' websites.

This established monitoring program will continue to be essential in the coming years even though a new source of water, from desalination, has entered the Israeli water budget. Long-term plans of the Israel Water Authority (IWA 2012) confirm that Lake Kinneret will continue to be an important strategic source of freshwater.

The monitoring program for Lake Kinneret

Historical perspective

Scientific data collection from Lake Kinneret was initiated in 1757, by Hasselquist, a student of Linnaeus, who collected faunal specimens and helped describe *Tilapia galilaea* as an endemic fish of the lake. Subsequently other scholars, such as Triastram (1862), Barrois (1894) and Annandale (1916) studied the lake and its environment, unveiling its flora, fauna, chemical composition and hydrography, as described by Serruya (1978). Later, intense and targeted surveys were performed in response to specific practical aspects of water productivity and fisheries (Ricardo-Bertram 1944). It was only after the establishment of the State of Israel in 1948, and the planning of the National Water Carrier, making Lake Kinneret Israel's primary water source, first for agriculture and later for drinking water, that intense studies of the Lake Kinneret ecosystem were initiated.

Problems of water quality in Lake Kinneret were first identified with the initial operation of the National Water Carrier in 1964 and were associated with the spring algal bloom that contributed to bad taste of the water (Serruya 1978). Consequently, a multiannual monitoring program, designed to reflect ecosystem variability in time and space, was initiated in 1969. Since then it provides a long-term limnological and hydrological database. The Kinneret Limnological Laboratory jointly with the Watershed Unit of Mekorot carry out this entire program.

Sampling stations, depths and frequency

The objectives of the monitoring program for Lake Kinneret, balanced by practical considerations of available resources, dictate the frequency of sampling, the number of sampling sites, and their location in the lake. Furthermore, the physical dimensions of the lake, its bathymetry and current regime are used to determine the number of samples collected along the water column at each station and the type of analyses performed on these samples.

The Kinneret sampling stations used for the monitoring of most chemical and biological parameters are presented in Fig. 1A. Station A, located near the deepest site in the lake, is the main station. Samples from Station A are collected weekly and analyzed for many physical, chemical and biological parameters (Table 1). Stations G, D and K, located along a line stretching from north to south, as well as Station H, at the inlet of the National Water Carrier, are sampled for fewer parameters and for some parameters, at lower frequency (Table 1). At these five stations, discrete-depth water samples are collected from depths covering the entire water column, with high depth resolution (1-3 m) near the surface and at 5 m intervals from

10 m to the bottom sediments. During stratification, (April through November) three additional samples are collected at Station A, one from the middle of the thermocline, and two located 1 m above and below it. Other sampling stations marked in Fig. 1A, and/or sampling depths are employed for parameters that for technical or other reasons are not sampled with the weekly/fortnightly sampling for chemical and biological parameters, as discussed below and in the relevant book chapters (Chaps. 6, 8, 16, 27, 28, 33.2 and 33.3).

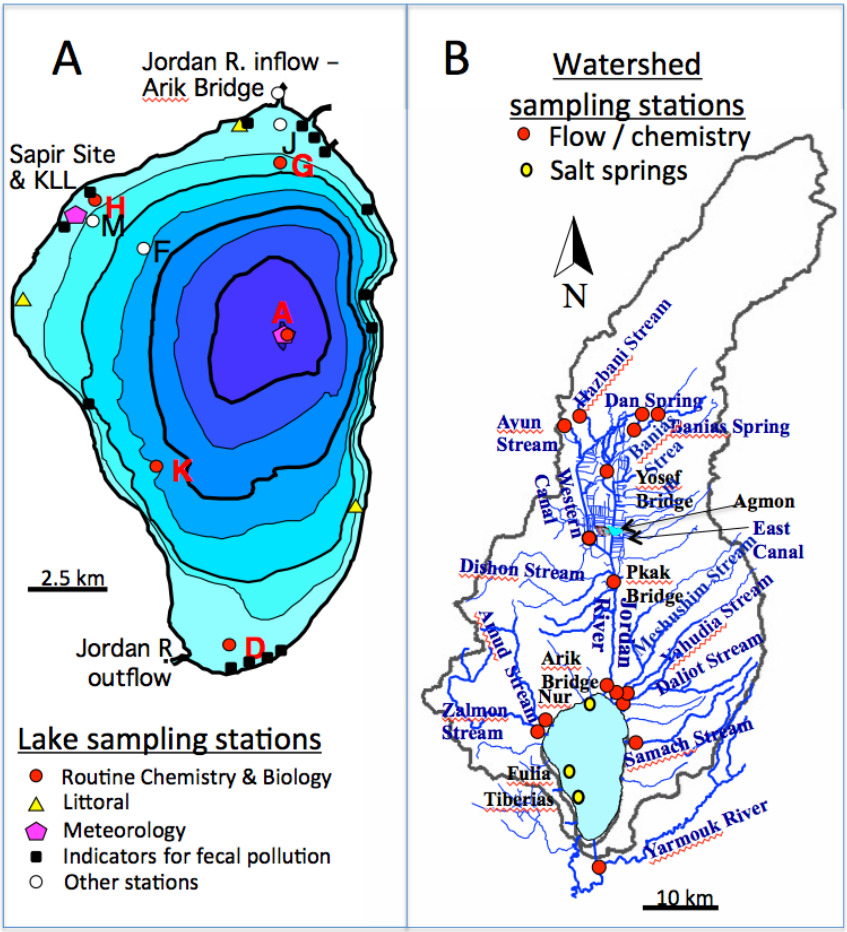


Fig. 1 Location maps of monitoring stations in Lake Kinneret and its watershed. A. Lake Kinneret (symbol legend below map), B. Watershed (symbol legend above map). Additional explanations: "KLL" – Kinneret Limnological Laboratory. "Other stations": stations F, M are used for sedimentation flux measurements, J for occasional biological measurements, Arik for pesticides. Littoral stations – shallow water stations for occasional biology and chemistry measurements.

Table 1 The monitoring program of Lake Kinneret: parameters, sampling stations and sampling frequency. Samples for the chemical and biological parameters are collected from fixed depths along the water column (up to 13 depth samples).

Parameter	Station(s)	Frequency
Meteorology		
Air temperature	A, Ginnosar	10 min
Surface water temperature	A, Ginnosar	10 min
Relative humidity	A, Ginnosar	10 min
Wind (speed and direction)	A, Ginnosar	10 min
Long wave radiation	A, Ginnosar	10 min
Short wave radiation	A, Ginnosar	10 min
Barometric pressure	A, Ginnosar	10 min
Light radiation (PAR)	Roof of KLL	Continuous
Physics		
Water level	Tiberias	Daily
Temperature profile in water column	A, D, G, H, K 5-15 additional stations	Weekly fortnightly
	A, H	10 min
Secchi depth	A, D, G, H, K	Weekly
Currents	Variable sites	Continuous
Profile of light penetration	A	Every other week
Sedimentation fluxes	A, F, K, M	Every other week
Chemistry (in water column)		
Alkalinity	A, D, G, H, K	Every other week
Chloride	A, D, G, H, K Salt springs	Weekly Weekly
Conductivity	A, D, G, H, K	Weekly
Calcium	A, D, G, H, K	Every other week
Organic carbon (dissolved; particulate)	A	Every other week
Soluble Nitrogen (Kjeldahl)	A,	Weekly
	D, G, H, K	Every other week
Total nitrogen (Kjeldahl)	A, D, G, H, K	Weekly
Ammonia	A, D, G, H, K	Weekly
Nitrite	A, D, G, H, K	Weekly
Nitrate	A, D, G, H, K	Weekly
Oxygen	A	Weekly
	D, G, H, K	Every other week
pH	A, D, G, H, K	Weekly
Total dissolved phosphorous	A	Weekly
Orthophosphate	A, D, H, K	Weekly

Parameter	Stations(s)	Frequency
Chemistry (in water column)		
Total phosphorous	A, D, G, H, K	Weekly
Silica	A	Every other week
Sulfate	A, D, G, H, K	Every other week
Sulfide	A, D, H, K	Weekly
Total suspended solids	A, D, G, H	Every other week
Turbidity	A, D, G, H, K	Weekly
Biology		
Phytoplankton species & abundance	A	Every other week
Chlorophyll	A	Every other week
Primary productivity	A	Every other week
Zooplankton species & abundance	A, D, G, H, K	Every other week
Microzooplankton abundance	A	Monthly
Fish abundance	All over the lake	8 surveys per year
Heterotrophic bacterial abundance	A	Monthly
Bacterial production	A	Monthly
Community respiration rates	A	Every other week
Nitrogen fixation rates	A	Monthly
Harvested biomass of commercial fish species	Fish market, fishing harbor	Monthly
Stocked fingerlings	Ginnosar	Annually
Health-related		
Pesticides	A, D, G, H, Arik Bridge	Every other week
cyanotoxins	A surface scums	Monthly during blooms
Fecal bacteria	14 littoral sites	Monthly
Synoptic & remotely operated monitoring		
Temperature, conductivity, turbidity, chlorophyll (U-TUMS)	Transects over entire lake	Every 2 months
Surface distribution of surface water temperature and chlorophyll (satellite images)	Entire lake	Every 3 days
Water column temperature (T-chain)	A	Every 10 min.
Profiler (O_2, pH, turbidity, ORP, chlorophyll, temperature, conductivity)	A	4 profiles/day

Additional routine monitoring of salinity and temperature at 5 to 15 additional sampling stations, depending on season, is conducted fortnightly by Mekorot, to supplement the database for their monthly estimates of salt, heat and water balances (Assouline 1993; Berger et al. 2012).

Parameters monitored

The Kinneret monitoring program includes parameters that are meteorological, physical, chemical, biological and public health related, as detailed in Table 1.

Meteorological data are collected continuously from two "meteorological stations" (Fig. 1A), at Sta. A, and on the western shore at Ginnosar (which in 2006 replaced a station 1 km offshore the Kinneret Limnological Laboratory). Each meteorological station is equipped with instruments to measure wind speed and direction, long- and short-wave radiation, barometric pressure, air temperature and relative humidity (details in Table 2 and Chap. 6). Photosynthetically active radiation is also recorded continuously (Table 2) on the roof of the Kinneret Limnological Laboratory.

Physical data: Lake water level is recorded daily at an offshore station near Tiberias. Full depth profiles of water temperature (instrument details in Table 2) and Secchi depth are taken at each of the five pelagic sampling stations and times. Light penetration is measured every second week with a LiCor light meter (Table 2). Sedimentation fluxes are followed using sediment traps (Chap. 27) at ~2-week intervals, the procedure requires making the sampling on designated boat trips. With technological developments, automatic instruments recording water temperatures by thermistor chains (Table 2) were introduced and are now installed at two stations, collecting water column temperature data continuously in addition to the routine weekly profiles.

Table 2 Instrument and manufacturer details for meteorological and physical parameters measured on Lake Kinneret

Parameter	Instrument	Manufacturer
Wind speed and direction	Wind monitor Model 05103 R M	Young Company, Michigan, USA
Long- and short-wave radiation	CNR 4 net radiometer	Kipp & Zonen, Delft, The Netherlands
Barometric pressure	CS106 Barometric Pressure Sensor	Campbell Scientific, Logan, UT, USA
Air temperature and relative humidity	MP101a - humidity-temperature meteorological probe	ROTRONIC Instrument Corp. NY, USA
Photosynthetically active radiation	LI-190 quantum sensor with a LI-1400 Data logger	LiCor, Lincoln, Nebraska USA
Light intensity	LI-190 quantum sensor with a LI-250A Light Meter	LiCor, Lincoln, Nebraska USA
Vertical profiling of water temperature	Oceanographic's MinosX	AML Oceanographic, Sidney, B.C. CANADA
Automatic recording of water temperatures	Thermistor chains	PME, Carlsbad, CA, USA

Chemical data: A long suite of chemical parameters (Table 1) are determined routinely on water samples brought to the lab from Stations A, D, G, H, K (Fig. 1). Water samples are collected by a Vertical Point Water Sampler (Aquatic Research Instruments, Hope, ID, USA). The chemical parameters include nutrient concentrations (all species of N and P), pH,

alkalinity, total and dissolved organic C, dissolved oxygen, sulfide and sulfate, silica, chloride, conductivity, total suspended solids, and turbidity (Table 1). All analytical procedures follow Standard Methods (APHA 2005). In recent years, some of these parameters are also monitored automatically at Sta. A (see below – Ecoraft). In addition, the salinity of the major salt springs within and around the lake perimeter is monitored at weekly intervals.

Biological parameters: Most of these parameters are determined routinely on samples from a single station (Sta. A), due to the greater time investment required for their analyses as compared to chemical parameters. Both standing-stock and rate parameters are being determined regularly. The standing-stock parameters include phytoplankton (chlorophyll, species composition, species abundance and biomass), zooplankton (species and abundance), and heterotrophic bacteria (abundance) (See methods in Chap. 10, 13 and 15 respectively). Rate parameters include primary production, bacterial production, community respiration, and nitrogen fixation (See brief description of relevant methodologies in Chap. 24.1, 25.1, 25.2 and 22 respectively). Fish abundance is determined separately, in dedicated night surveys, by means of scientific echo-sounding equipment (Chap. 16). Harvest estimates of all commercially important species are made monthly, based on catch statistics. The annual amounts of fingerlings stocked in the lake are also documented (Chap. 36).

Public health parameters: The need for monitoring public health related parameters developed over time. As the Kinneret watershed is mostly agricultural, the need to monitor pesticide residues in the lake and its watershed arose and was initiated in 1980 (Chap. 33.2). Similarly, since the lake provides drinking water and is a major recreational site, health standards required that bacterial indicators for fecal contamination be monitored (Chap. 33.3). Since 1987 indicators for fecal pollution are monitored at 14 near-shore stations (Fig. 1) representing major water pumping sites, recreational beaches and inflows of the Jordan River and other streams. With the first appearance and blooming of toxin-producing Nostocalean cyanobacteria in Lake Kinneret in 1994 (Chap. 12) the need to monitor cyanotoxins was identified and initiated (Chap. 33.1).

Data storage: the Lake Kinneret Database (LKDB) and the Kinneret Data Center

The Lake Kinneret Data Base, housed at the Kinneret Limnological Laboratory, contains all the monitoring information collected by the Kinneret Limnological Laboratory since 1969, with metadata to describe how the data were collected, organized and archived. It is a unique source of information due to the quality of the data and its long-term continuity. Much of the data is viewable on-line at the Kinneret Data Center
http://www.ocean.org.il/Eng/KineretDataCenter/ProfileDC.asp
Mekorot, the Hydrological Services, and the Dept. of Fisheries maintain additional complementary databases. In addition, the Israel Water Authority houses and maintains a comprehensive database, containing all data from all organizations taking part in the Kinneret monitoring.

Advanced near real time monitoring approach – rationale, technology and examples

The design of the routine monitoring program with several fixed stations and weekly/fortnightly sampling makes it nearly impossible to detect phenomena and processes at higher spatial and temporal resolution, such as patchy distribution of a particular parameter. Intensification of the traditional monitoring scheme by adding stations and increasing sampling frequency could resolve this problem but would require substantial investment in manpower, equipment, and operational costs. On the other hand, ignoring patchy structures and short-lived processes limits our understanding of the organization and functioning of the ecosystem. Several innovative approaches have been implemented in Lake Kinneret to resolve issues of limnological and water quality aspects at high spatial and temporal resolutions. These include: 1) automated sampling, including an unmanned automated monitoring station that profiles and samples the water column several times a day; 2) application of underwater-towed undulating monitoring system (U-TUMS) that is carried behind a boat and can sample within a short time large portions of the lake volume; 3) Remote sensing.

Automated sampling equipment – the meteorological parameters (at the two meteorological stations) as well as water temperature (using thermistor chains at two stations) are being monitored by automated equipment that sends real-time or near-real time data to the laboratory.

An unmanned monitoring platform for real time monitoring of water quality parameters – The Ecoraft (Fig. 2A), an acronym for "ECOlogical monitoring RAFT", was installed in Lake Kinneret in February 2002. The Ecoraft is a 10 x 7 m, 10-ton catamaran-type steel raft, anchored at the deepest part of Lake Kinneret (Sta A), providing a platform for continuous monitoring using automated instrumentation, telecommunication with the shore-based lab, and space for additional on-lake monitoring and research activities (Wagner et al. 2005). Solar panels roofing part of the raft attached to a storage battery, supply the energy required for uninterrupted operation of the scientific instruments. A cabin provides shelter for sensitive equipment and a bench for sample processing. A fence, protecting from vandalism, was also found essential. The Ecoraft is equipped with the following scientific functions:

- A winch-operated sampler designed and manufactured for the Ecoraft by ISI (Instrumental solutions Inc. Vicksburg, MS USA). The profiler hosts an upgraded multi-sensor Eureka Manta2 (Eureka Environmental Engineering, Austin, Texas USA), presented in Fig 2B and C, which records depth, temperature, conductivity, pH, dissolved oxygen, chlorophyll and turbidity. The profiler is programmed to conduct a depth-profile of those parameters at 0.5 m intervals every 6 h and transfer the data to the lab.
- A full meteorological station, installed and maintained by the Israel Meteorological Services.
- Dust collectors for monitoring aeolian nutrient loading.

- A thermistor chain with 40 thermistors spread over the 42 m water column, recording water temperature at 10 min intervals.

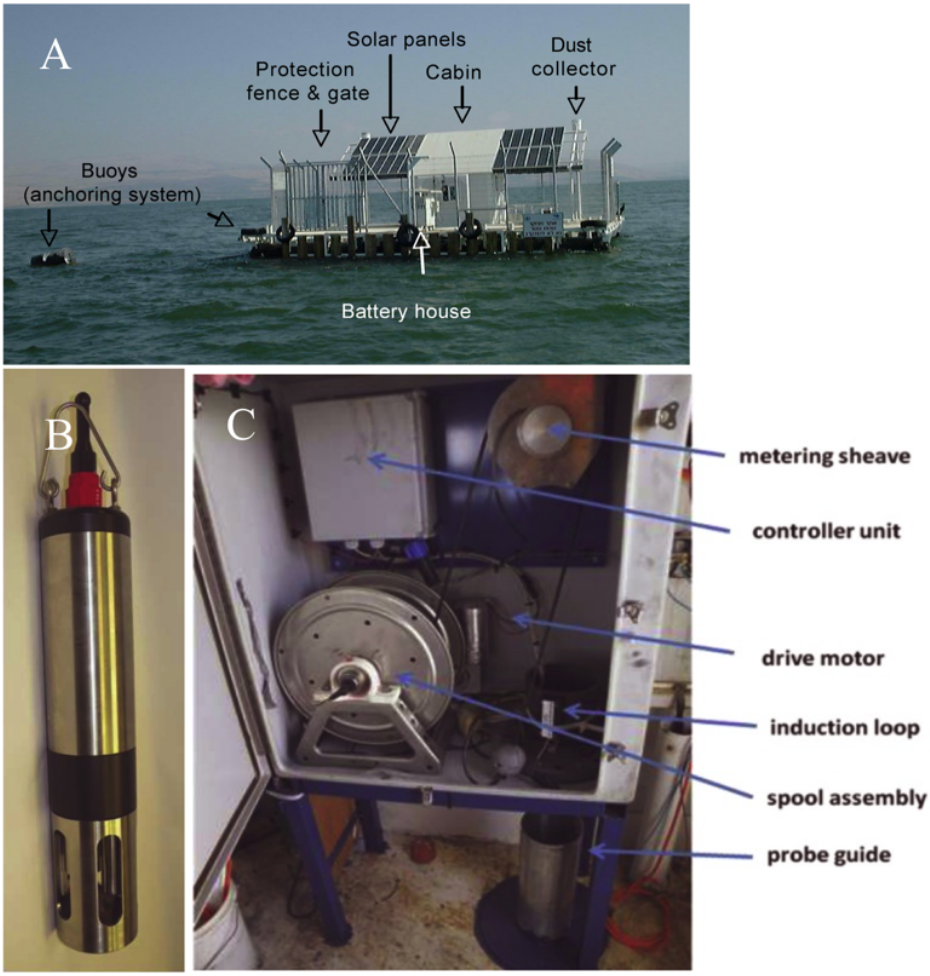


Fig. 2 An unmanned monitoring platform for real time monitoring of Lake Kinneret water quality parameters. (A) The Ecoraft, anchored at Sta. A, equipped with solar panels and batteries to supply local energy requirements, a cabin for housing scientific equipment and for conducting fields work, and dust collectors. (B) An upgraded multi-sensor Eureka Manta2 used in conjunction with (C), a winch-operated sampler housed inside the cabin.

With the Ecoraft and the automatic profiler, continuous records of water quality data spanning the entire water column are being collected at full diel cycles, 365 days a year, including weekends and holidays. Sampling is easily performed during storm conditions that do not allow conventional sampling by boat. Much of the data collected automatically is posted in near real time at the Kinneret Data Center [http://kinneret.ocean.org.il/Default.aspx]. Additional sampling and measuring equipment can be installed on the raft, currently an instrument that measures phytoplankton abundance

by taxonomic groups and its photosynthetic activity, a PhytoPAM (Walz, Germany), operates on it.

Examples for new insights or features revealed by the automatic profiler on the ecoraft include fluorometric data demonstrating diel vertical migration in *Peridinium* (Usvyatsov and Zohary 2006), the temporal dynamics of a metalimnetic layer of photosynthetic bacteria (Rimmer et al. 2008) and the temporal dynamics of a layer with residual oxygen in the upper hypolimnion in late spring (Nishri et al. 2011)

Underwater-towed undulating monitoring system - to increase the spatial resolution of several *in situ* measured limnological parameters (temperature, turbidity, salinity, and chlorophyll) an underwater-towed undulating monitoring system (U-TUMS) has been applied over the last decade. The U-TUMS is suitable for studying processes that occur over a large portion of the water body. It is composed of a vehicle (carrier), a set of sensors, and navigation devices (geographic positioning system-GPS, SONAR, and speedometer), which are interconnected and operated via an on-board computer. The U-TUMS vehicle - MiniBAT (GuildLine Canada) is loaded with fast response sensors that collect measurements while the vehicle is towed behind a boat along chosen transects at a speed of 4 knots and undulates (diving or climbing) at rates of up to 90 cm s^{-1}.

Data collected by the U-TUMS demonstrated strong spatial heterogeneity of water quality parameters during different seasons and at specific locations (Sukenik et al. 2002). Distinctive features, such as thermocline location and tilting, were identified during the stratification period. The river inflow plume and sites of underwater saltwater intrusion were easily detected. A high fluorescence signal of the *Peridinium* bloom was recorded concomitant with high turbidity values during the spring bloom (Ostrovsky and Sukenik 2008; Zohary et al. 2012).

Remote sensing – The aim of remote sensing of Lake Kinneret is to provide truly synoptic monitoring of water quality parameters. Satellite image-based lake water quality mapping is done using SISCAL (www.siscal.net), a facility developed within a European research program and currently operated by Informus and Israel Oceanographic and Limnological Research. This monitoring is based on two satellites (MODIS Aqua, Terra) with a spatial resolution of 1x1 km, and a third (MERIS) satellite with spatial resolution of 300x300 m, that passes over the lake every three days. The obtained satellite images are processed using calibrated algorithms and the spatial distribution of surface water temperature, Secchi depth, total suspended solids (TSS) and chlorophyll are produced and posted at http://isramar.ocean.org.il/isramar2009/siscal/default.aspx?id=Kinneret. The calculated maps are frequently verified with ground data collected at the monitoring stations.

The monitoring program for the Kinneret watershed

A monitoring program for the watershed of Lake Kinneret originated in the 1940's with the beginning of discharge measurements on the Jordan River. However, the current coupled quantity-quality approach for this program was initiated only in 1970, a year after the establishment of the monitoring program for the lake. 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 jointly 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. The parameters being determined are chloride, all nitrogen and phosphorus species, alkalinity, sulfate, calcium, total suspended matter. The locations of the sampling stations (Fig. 1B) were chosen to enable quantification of the loads from the main Jordan River tributaries (Dan, Hazbani and Banias), as well as from the Jordan River proper and from other main streams flowing into Lake Kinneret (Meshushim, Yahudia, Daliot, Samach, Amud and Zalmon). The southernmost monitoring station is located near the intersection of the Yarmouk River with the Lower Jordan River. This station monitors the water pumped from the Yarmouk River and discharged into Lake Kinneret according to the 1994 peace agreement between Israel and Jordan.

Discharge at each sampling station is calculated from continuous measurement of the water level with a hydrometric gauge at a calibrated control section of the river. The continuous discharge data are then translated to daily, monthly and annual volumes of water. Water quality measurements are made on water samples taken next to each hydrometric gauge. Some of the sampling stations contain automatic samplers, which sample the river or stream every 30 min, storing the water samples in a refrigerated bottle that is replaced automatically every 6 h (See Fig. 2 in Chap. 18). Thus, four successive bottles, mixed into one bottle in the laboratory, comprise a time-integrated water sample representing a single day. A series of chemical analyses is then conducted on those daily-integrated samples. Finally, the daily discharge is multiplied by the daily-integrated concentration of each chemical component, to get the daily load of this component (Chap. 18) The daily loads are summed up to monthly loads, which are the units reported in the Israel Water Authority Data Base and used in many related studies. So far, automated sampling was applied at four of the 16 watershed stations: Hazbani, Banias, Pkak Bridge and Meshushim Stream (Fig. 1B).

The 12 other watershed stations are being sampled manually once or twice a week. Consequently, due to insufficient sampling frequency, monthly loading estimates from those other stations are inaccurate. In particular, flood events with peak nutrient concentrations may be missed or alternatively over-emphasized. Nevertheless, other sources of inaccuracy are associated with the automatic samplers, as explained in Chap. 18. Therefore, while

considering the monthly loads from the Kinneret watershed, one should not ignore these sources of inaccuracy. Moreover, since the automatic sampling stations were installed in the beginning of the 1990s, the long-term record from the water quality measurement stations also requires attention when comparing data from pre- and post- automatic sampling (Chap. 18). Lastly, nutrient loads to Lake Kinneret from the Jordan River are being calculated based on data from the Pkak Bridge Station, ~20 km upstream of the Jordan River entrance into Lake Kinneret. This site was chosen rather than Arik Bridge, right at the inflow (Fig. 1), because for technical reasons discharge estimates at Arik Bridge are inaccurate.

Advanced monitoring and alarm stations in the watershed

Since September 11, 2001, the world's attitude regarding water security has changed. This trend led the development of water security precautions in the water sector of Israel, including the Kinneret watershed monitoring system. As part of that new attitude, some of the water-quality measurement stations in the watershed were upgraded to be water quality alarm stations. The purpose of this upgrade was to provide managers with alarms that will make it possible to prevent events of exceptional/severe water contamination. These systems include a set of on-line electrodes (pH, temperature, conductivity, oxidation reduction potential-ORP, ammonium and turbidity) that are dipped in a PVC bath. The bath is part of a flow-cell system through which fresh stream water flow continuously (See Fig. 2 in Chap. 18). The electrodes in the bath generate on-line measurements, the data are sent through cellular communication to a data center at Sapir Site (Fig. 1A), run by the Watershed Unit of Mekorot.

A real-time control system developed by the Watershed Unit of Mekorot introduced a new dynamic water quality index, designed to explore and alarm of any systematic change in water quality in the watershed. This index weighs and integrates the measurements recorded from all available sensors into a single overall easily tractable index value. The resulting integrated index value is highly sensitive to any simultaneous change recorded in measurements such as deviation from acceptable ranges, a sudden 'jump' in recordings or a continuously (may be even low) increase or decrease in values over time. An alarm message is sent when the overall index deviates from its acceptable range.

In addition to this alarm system, an on-line bioassay tool was added by Mekorot to provide yet another sensitive alarm for a drastic change in the water quality of the Jordan River or its tributaries. The combination of the hydro-chemical on-line measurements, a decision support system for announcing an alarm, and a bioassay tool created a comprehensive warning system that allows mangers to decide on drastic steps due to an alarm of acute contamination of the river water. Operational steps that follow include an immediate halting of all pumping of water from Lake Kinneret, fast and intensive monitoring to identify the exact pollutant, and a series of operational steps that may reduce its impact on water quality.

Concluding remarks

The monitoring program for Lake Kinneret and its watershed has produced a database spanning more than four decades that is one of the most detailed long-term records for a natural subtropical lake subjected to a Mediterranean climate. Most of the chapters in this book have relied heavily on data generated as part of this monitoring program. As Lake Kinneret continues to be a strategic source of drinking water for the State of Israel, even in the current situation with desalinated water providing a greater portion of Israel's freshwaters, the monitoring program will continue to generate important data and understanding on the functioning of a stratified subtropical lake.

It is expected that the current effort to establish on-line real time monitoring methods will be further implemented in additional monitoring sites and will cover other environmental parameters that represent biological processes (i.e. primary production and respiration) and biological stocks (i.e. phytoplankton, zooplankton and fish) in addition to various geochemical parameters. Video assisted classification and enumeration of planktonic organisms is recently discussed as a viable option using advanced video recording devices of rapid flow of aquatic samples via micrometric flow through capillary (Flow-cytometry, FlowCAM, Fluid Imaging Technologies Ltd.). *In situ* estimation of photosynthetic activity in aquatic ecosystems is currently possible with various fluorescence approaches (FRRF, PAM, Delayed Fluorescence).

On-line monitoring procedures generate huge data sets. These need to be acquired, treated, and processed in ways that are user-friendly and easily accessible for interpretation and presentation. Thus, there is room for greater involvement of information technology experts, who will contribute to the development and application of software to deal, analyze and present those large data sets. They will also contribute to communicate those observations and conclusions based on them, to water managers and to the public, using advanced web technologies.

The Lake Kinneret monitoring program has been evolved into its current status over four decades. The conceptual aspects of the monitoring program and its various operational components can be easily implemented in monitoring plans designed for other freshwater and marine ecosystems. Different aspects of the monitoring program should be considered while implemented in other systems. This includes the design of the program, technical details of how to conduct the sampling and the analytical determinations and how to report them, the multi-disciplinary character of the scientists and the organizations involved, the combination of collecting data in conventional ways at low spatial and temporal resolution with automated ways at high resolution, the creation of a database, the presentation of data on-line.

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