

## Lake Management Perspectives in Arid, Semi-Arid, Sub-Tropical and Tropical Dry climate

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### ABSTRACT

Water scarcity is natural- typical feature of arid and semi-arid regions.. In arid zones precipitation is <250 mm/y, whilst in semi-arid areas 250-500 mm/y. Due to atmospheric circulation (convection cells) arid and semi-arid zones are common within 23.5<sup>0</sup> north and south latitudes, ("Horse": Capricorn-Cancer), where, warm and dry conditions are dominant. Total area of arid and semi-arid deserts >0.05x10<sup>6</sup> km<sup>2</sup> (38) is 19.5x10<sup>6</sup> km<sup>2</sup> : in Africa- 3, Asia-6, Australia-9, Europe-5, Middle East-6, North America and Mexico-4 and 5 in South America. Eco-hydrological changes in arid and semi arid aquatic ecosystems are due to climate fluctuations and human intervention. Sufficient water availability (quantitative and qualitative) in arid and semi arid zones is the key factor for economical and cultural prosperities and might be a reason for geo-political conflicts. Water demands per capita is depends upon resource availability, and cultural and political heritage. Lakes in arid zones are mostly shallow and fed by underground sources and seasonal floods whilst those in semi-arid and sub-tropical regions are mostly fed by continuous surface flows, direct rain and sub-lacustrine influxes. Due to the high evaporation, salinity in desert lakes is high, sometime suitable for fish production and frequently-not. Fish production in semiarid and subtropical lakes, water supply and recreational tourism are common usage. Climatological changes (global warming) and ecological sensitivity of these ecosystems, deserve utilization precautious. Several lakes were partly (or higher) destructed, some became very polluted and some are well protected by thorough study and consequent implementation. Four case studies of arid, semi arid and subtropical lakes are presented: Lake Chad in the Sahara desert, two Egyptian lakes in the Sahara desert, Wadi El-Rayan and lake Quarun, Lake Kinneret in Israel and Lake Tai-Hu in China. Some of them represent deterioration of water quality and perturbation of further utilization, limnological changes, pollution and an urgent need of protection policy.

*Keywords: Lakes; Arid; Semi-Arid; Sub-tropical; dry tropical*

### INTRODUCTION :

Our Globe is moving counterclockwise in an elliptical orbit at an average distance of 150x10<sup>6</sup> km around the sun. The globe axis makes an angle of 66<sup>0</sup> 31' related to the orbit plane (i.e. 23<sup>0</sup> 30' with the equator plane) resulted in one of the hemisphere receives more radiation than the other when solstices and vice versa. When earth is not titled towards or away from the sun as during equinoxes, the two hemispheres receives an equal amount of radiation.. Nevertheless the dominant factor affecting the formation of arid and semi-arid regions on the globe is atmospheric circulation in the form of convection cells. Formation of arid and semi-arid zones occur mostly along the Cancer and Capricorn tropics (the "Horse" latitude). The distribution of the sun's radiation depends upon globe's axis inclination: when sun rays strike earth at a right angle, insolation is maximal (Table 1):

The lowest variation of sun rays strike angle with earth surface occur at the equatorial region and therefore maximal annual insolation whilst maximal amplitude of this angle changes is due to the tropics. Ascending air masses from the equator followed by cooling and spread to north and south up to the "Horse" latitudes where their descending cause

them to increase heating and loosing moisture and forming of large arid core zone (Sahara, Arabian Peninsula, Middle East and part of Iranian deserts) and a narrow transition belt of semi-arid zones beside wide zone in the north and marginal in the south of subtropical regions. Global consideration of heat balance (radiation received and emitted by earth and atmosphere) represent positive and negative net balance of the earth and atmosphere respectively. Nevertheless, various altitudes on earth indicates different all-wave radiation balance: annual deficit of radiation northern to 40<sup>0</sup> and southern to 30<sup>0</sup> and excess of radiation within the central zone (the Warm Belt) of which the margin regions are arid and semi-arid zones.

Table 1: Sun insolation during the year at the Horse tropics at two axis tilting (solstice and equinox) positions (Serruya & Pollinger 1983).

Season/Tilting	Cancer Tropic 23 <sup>0</sup> 30' N	Equator 0 <sup>0</sup>	Capricorn Tropic 23 <sup>0</sup> 30' S
Summer/Solstice	90 <sup>0</sup>	66 <sup>0</sup> 30'	43 <sup>0</sup>
Spring/Equinox	66 <sup>0</sup> 30'	90 <sup>0</sup>	60 <sup>0</sup> 30'
Winter/Solstice	43 <sup>0</sup>	66 <sup>0</sup> 30'	90 <sup>0</sup>
Fall/Equinox	66 <sup>0</sup> 30'	90 <sup>0</sup>	66 <sup>0</sup> 30'

## Hydrology

Amounts of precipitation in the two hemispheres are similar but there is net excess of evaporation over precipitation in the Southern Hemisphere (SH). Therefore water balance of the Northern Hemisphere (NH) is positive and that of the SH is negative. This unequal balance generate continuous oceanic flows from NH to SH and an opposite transport direction in the atmosphere. Continental precipitation and evaporation is greater in the NH than in the SH and consequently runoffs.

Continental precipitation (P), Evaporation (E), Runoff ( $R=P-E$ ), total area (S) and water depth(mm)( $S=P-E$ ) in the SH and NH of the Warm Belt are given in Table No.2.

Table No.2: Continental precipitation (P) ( $\text{km}^3$ ), Evaporation (E) ( $\text{km}^3$ ), Runoff ( $R=P-E$ ) ( $\text{km}^3$ ), total area (S) ( $10^3 \text{ km}^2$ ) and water depth(mm) ( $D=P/S$ ) in the SH and NH of the Warm Belt (Serruya & Pollinger 1983).

Zone	S	P	E	R
NH	44348	39929	26290	11639
SH	32147	38331	26341	11990
Total	<u>76495</u>	<u>78260</u>	<u>52631</u>	<u>25629</u>
<u>D = P/S</u>		<u>mm</u>	<u>mm</u>	<u>mm</u>
NH		900	593	308
SH		1192	819	373
Total		<u>1023</u>	<u>701</u>	<u>335</u>

The % of warm belt (inc. arid, semi arid and tropical climates) continental values from the Global capacity are: Area – 51%, Precipitation – 70%, Evaporation – 75% and Runoff – 65%. Thirty three % of the global Warm Belt evaporation is due to Africa ( $35^0$  South –  $35^0$  North), 35% to Asia ( $35^0$  North –  $15^0$  South) and 39% to South America ( $15^0$  North –  $35^0$  South), and 26%, 26% and 34% of global Warm Belt precipitation respectively.

Only 14% of the total world volume of lakes are bodies of water (lakes and reservoirs) within the warm belt which receive 70% of the global continental precipitation. Moreover, about 95.3% of the warm belt lake volume ( $36.2 \text{ km}^3$ ) is located in the driest continent of the warm belt, Africa, and only 4.2% ( $1.6 \text{ km}^3$ ) in the wettest region of the warm belt, South America, and <1% in South-East Asia and Australia. The reason for this water distribution paradox in the warm belt is geomorphological: The formation of the African Rift Valley and desert depressions in the Sahara, are the only large scale generation of topographic structures suitable for large scale water storage.

The global distribution of arid and semi arid climate in Africa is spreading out between  $15^0$  –  $35^0$  south,  $10^0$ - $35^0$  north, and  $0^0$ - $10^0$  in north-eastern part of the continent; between  $10^0$ - $35^0$  in the middle east, major part of eastern Europe; between  $25^0$ - $35^0$  in Kashmir, and a strip in the continental middle part of

southern India ( $10^0$ - $20^0$  N and  $75^0$ - $78^0$  E); a tropical dry climate is spreading out over most of China; in Australia, arid and semiarid climate cover most of the continent between  $30^0$ - $20^0$  south altitudes; The southern part of south America between  $20^0$ - $50^0$  is covered by arid-semiarid –tropical dry climate and in Northern America the same climate types exist in the western of the continent. Ice deserts are not discussed in this paper.

## Water consumption in the Middle East (Hotzl 2004)

Arid and semi-arid zones cover most of the land surface of the middle-East region. Most of the surface area of Syria, Lebanon, Israel, Egypt, Jordan, Iraq, Iran, Saudi-Arabia and the Sultanate of Oman is covered by arid and semi arid deserts. In northern parts of Israel, parts of Lebanon, Syria, Iran, and Iraq, on high altitude mountains the climate (precipitations  $500$ - $800$ mm per annum) is subtropical, Sudano-Decan and Irano-Touranian. Israel and Jordan are countries under water stress. Water scarcity in the middle east is a case with a very long history. The middle east population represent throughout thousands of years the desire for sufficient water supply. Settlements, migrations and permanent settling of human and livestock in the middle east was strongly related to water availabilities, either as underground or surface resources. Therefore, rivers, lakes, temporal pond, canals and wells are well known sites with historical, cultural and sociological significances. The arid and semi arid zones in the middle east generated in the past, present and future a stressed situation of population increase and mode of life limited by water availability and reasons for political conflicts. Modern human life include three major issues which are limited by water: food production, industrial development and personal requirements. In Israel, for example only 5% of personal water demands are due to drinking and the rest are channeled to household cleaning, hygiene, gardening, luxury demands like swimming pools, car washing etc. The World Health Organization recommended  $24 \text{ m}^3/\text{y}$  for sanitation as minimal for a healthy habitat. The personal consumption of water in humid industrial countries is commonly varied between  $45$ - $70 \text{ m}^3/\text{capita}/\text{y}$ , whilst in arid zones– $90$ - $95 \text{ m}^3/\text{capita}/\text{y}$ , in Israel– $120 \text{ m}^3/\text{capita}/\text{y}$ , in the Jordanian Kingdom–about  $50 \text{ m}^3/\text{capita}/\text{y}$  and for the Palestinians in the West Bank it is– $20$ - $30 \text{ m}^3/\text{capita}/\text{y}$ . Consequently, the protection of water quality and quantity, and the development of additional water resources is a major concern of all countries in the middle east where natural resources as lakes, temporal ponds, canals and underground aquifers are scarce.

More than 60% of water consumption in the middle east is due to food production and about 30% as personal demands and about 5% for industrial

usage. It has to be considered that almost all water resources in the middle east are already utilized and to increase supply three optional achievements are relevant: enhancement of runoff storage capacity, intensification of geo-hydrological search for new underground sources, intensification of reuse of waste waters and above all desalination of oceanic waters.

### **Lakes in Arid and Semi Arid Zones (exc. The Americas) (Serruya & Pollinger 1983)**

Arid and Semi Arid region is part of the Warm Belt. The Warm belt is the 0<sup>0</sup>-40<sup>0</sup> latitudes North and South strip. The tropical part is located between 0<sup>0</sup>-10<sup>0</sup> N&S latitudes and the arid and semi arid zones are situated between 10<sup>0</sup>-40<sup>0</sup> N&S latitudes.

The African lakes within the arid and semi arid zones include the followings: Lake Ambadi, Lake Tana, Lake Nasser, Lake Mariut, Lake Edku, Lake Burullus, Lake Manzalah, Lake Quarun, Lake Wadi el Rayan, Lake Chilwa, Lake Chivta, and Lake Chad. These bodies of water are characterized as freshwater and brackish water lakes.

The Middle East Lakes within the arid and semi arid zones are: Bardawil Lagoon, The Bitter lakes in the Suez Canal system, Lake Kinneret, The Dead Sea; Reservoirs that were constructed aimed at flood control on the Tigris and Euphrates rivers: Samarra, Kut Barrages, Ramadi, Hindiya, Yao, Meshkab, Hafar and Akaika Dam regulators; Several temporary or permanent shallow waters wetlands (Hors) resulted from the inundation regime of the lowland flows: Habbaniya, Thartar, Dibbis and Hammar .

*Iran:* The Iranian arid and semi arid zone of the warm belt include the high altitude (1525 m asl) large Lake Niriz and several other lakes and reservoirs at lower altitudes: Hamun-e-Jaz-Murian, Kuh-e-Bazman, Daryachen-ye-Tashk, and Daryachen-ye-Bakhtegan.

*India:* There are many lakes and reservoirs in the arid and semi arid zones of India. Large reservoirs along the Cauvery river (Stanely, Krishnaraja Sagar, Tungabhadra, Nizam Sagar, Amaravathy and many others in the northern part of the sub-continent and Kashmir region.

*Pakistan and Afghanistan:* Most of the land in Pakistan and Afghanistan is arid and semi arid zone with several lakes and large reservoirs: among others are, Tarbela Dam, Hamun-e-Saberi, Ab-e-Istaden-ye-Moqor.

*Australia:* There are several lakes and reservoirs in the arid and semiarid zone of Australia: among others, L. Mueller, L. Galilee, L. Buchanan, L. Tennant Creek, L. Woods, L. Eyre, L. Gregory, L. Blanche, and L. Frome

## CASE STUDIES

### **Lake Chad ( Serruya et al, 1983)**

Lake Chad is located in a semi arid zone close to the wet tropical region of the northern part of Africa. Until the 1980's the lake was located at 12<sup>0</sup>30' N and 13<sup>0</sup>-15<sup>0</sup>30' W, 282 m altitude sharing territories of Cameroon, Chad, Niger and Nigeria The drainage basin of Lake Chad is (2.5x10<sup>6</sup> km<sup>2</sup>) cover territories of Cameroon, Chad, Niger, Nigeria, Central African Republic, Sudan, Libya, and Algeria. The drainage basin area of the lake is swept alternatively by dry north-east wind (Harmattan) during October through April) (air temp.29-32<sup>0</sup>C) and humid wind rain bringing south-east during May-September (air temp. 22-24<sup>0</sup>C).One of the most affecting climatological parameter is the high evaporation, 2.05-2.25 m/y. Rainfall vary between 125-565 mm/y during July-September. Cardinal impact on the limnology of Lake Chad is due to its flat bathymetry, resulted in significant change of surface area and depth in consequence to climate variation: During 1960- 26000 km<sup>2</sup> and in 1972- 18000 km<sup>2</sup> (2.5 m mean depth); in 1977- 12000 km<sup>2</sup>, 1.5m mean depth.

Lake Chad provide water to more than 20 million people living in the four countries around it.. The Chari River is its largest source of water, providing over 90% of the Lake budget. The Lake has no surface outlet and water loss is channeled through underground infiltration and geo-chemically (8%) and evaporation 92%). The size of Lake Chad has increased and shrunk at regular intervals. Increasing aridity in the Sahel area and more demand for freshwater for irrigation may however entail that Lake Chad will continue shrinking. Lake Chad varies in extent between the rainy and dry seasons, from 50,000 to 20,000 km<sup>2</sup>. Precise boundaries have been established between Chad, Nigeria, Cameroon, and Niger. Sectors of the boundaries that are located in the rivers that drain into Lake Chad have never been determined, and several complications are caused by flooding and the appearance or submergence of islands. A similar process on the Kovango River between Botswana and Namibia led to a military confrontation between the two countries. Climate change severely enhanced the drying up of already arid zones in Africa. For the Zambezi basin, simulated runoff under climate change is projected to decrease by about 40% or more. Growing water scarcity, increasing population, degradation of shared freshwater ecosystems, and competing demands for shrinking natural resources distributed over such a huge area involving so many countries have the potential or creating political conflicts. Since lake Chad was first surveyed by Europeans in 1823, it has shrunk considerably. An increased demand for the lake's water by the local population has likely accelerated its shrinkage over the past 40 years which is also due to overgrazing, decline of

vegetation and desertification. The lake and adjacent area is a well known site for its millions of migrating and residential birds, as well as mammals, reptiles, and amphibians. The sensitivity of Lake Chad ecosystem and high level of climatic perturbation resulted in ecological instability is probably the reason for lack of endemic species.

In the 1960's the lake surface area was more than 26,000 km<sup>2</sup> and by 2000 less than 1,500 km<sup>2</sup>. The lake was nearly dried out in 1984. This is due to reduced rainfall combined with intensification of water consumption for irrigation as withdrawn from the lake and inflow rivers. It is likely that the lake will shrink further and it is not impossible that complete disappearance will occur during the 21<sup>st</sup> century. Several parameters of the Lake Chad limnology are given in Table 3.

Residence time of water in the northern basin is app. 2 years and in the southern basin it is only 6 months. Under such conditions, 8.2 % of chemical elements input remain in the southern basin and 91.8 flow into the northern part. Consequently, increase of salinity in the northern basin is 3.2 times higher than in the southern basin and therefore deficit of rivers input generate a greater increase of salinity in the northern basin emphasizing the high level of instability in this part of the lake.

But surface area, lake volume and water availability and fishery crops are not the only modifications observed in Lake Chad during the last 50 years. Surface shrinking and volume decline enhanced oxygen depletion. The water level decline enhanced algal biomass from 77x10<sup>3</sup> tons in 1972, to 183x10<sup>3</sup> tons in April 1974, and 244x10<sup>3</sup> tons in February 1975 with species composition transition to dominant species of *Euglenophyta*, diatoms and *Cyanophyta* accompanied by enhancement of primary productivity (from 1.8-3.7 to 3.4-13.3 gC/m<sup>2</sup>/d). There are 140 fish species in Lake Chad and annual landing was about 230,000 tons before the 1970's and half of it during early 1970's but only 50,000 tons presently. The alternate of eco-hydrological conditions between low and high levels enhanced fish kill phenomena. The 1970'S droughts transformed the lake into the shallow bodies of water causing intensive re-suspension followed by oxygen depletion and high turbidity. Furthermore, high level occurred and the dense high plant vegetation was covered by water, decomposed and enhanced oxygen

deficit. Lake Chad is a significant example for a large lake in arid zone which is heavily utilized by man and represent eco-system sensitivity with extreme response to climate and anthropogenic modification which strongly related to socio-economic significances. The Lake Chad in broad view (including drainage basin as a whole) is an arid (dry desert) ecosystem under significant stressed ecology initiated mostly by human intervention and partly by climate changes. Nevertheless, the appropriate management aimed at water supply, food production and eco-tourism is a matter of international awareness, cooperation and action.

### Lake Quarun (Egypt; Kamel 2007a; Serruya & Pollingher 1983)

The lake is located (ca 80 km south-east from Cairo) in the Fayoum depression in the Sahara desert (Libyan part) in Egypt at -43m altitude. The lake is 42 km long and 9 km width and separated from River Nile by a ridge. Lake surface area is 230 km<sup>2</sup> and mean depth is 4.2m (maximum depth-8m) and total volume-800x10<sup>6</sup>m<sup>3</sup>. Water input into the lake is mostly (370x10<sup>6</sup> m<sup>3</sup>/y) drainage flows which influx into the lake annually 430x10<sup>6</sup> tons of salts. Rainfall in the area is negligible and since water level is presently constant it is suggested that the evaporation rate is 370x10<sup>6</sup>m<sup>3</sup>/y and therefore underground inputs are negligible as well.. Due to salts accumulation, salinity increased from 13.4 ppt in 1901, 18 in 1923, 23.4-in 1934, 30.6 in 1955, to 34.5 ppt in 1976. The present salinity (34.5 ppt) is very close to sea water concentration. The Nile high dam construction also enhanced drainage waters salinization and consequently lake water salinity. The biological features of lake Quarun indicated replacement of freshwater species by marine organisms of plankton. The lake fauna and flora is sensitive to sewage effluents inputs into the lake which in some cases were accompanied by massive kill cases.

The lake was also a subject to aquaculture development and exotic fishes were stocked: *Tilapia zillii*, *Mugil cephalus*, *Mugil capito* and *Solea vulgaris*; and the crustacean *Macrobrachium rosenbergii*. Several of these exotic species established stable populations in the lake and the trophic relations is a matter of intensive studies.

Table No.3: Limnological parameters of Lake Chad when water level was 281.5 m altiude (Serruya and Pollingher 1983).

Basin	Water Surface (km <sup>2</sup> )	Depth (m)	Secchi Depth(m)	Conductivity (mS)	Volume (Km <sup>3</sup> )	Annual Renewal (%)
Northen	8299	4-8	0.4-0.8	0.2-1.5	47	40
Southern	8476	2-4	0.1-0.35	0.05-0.65	25	85

Table 4: Annual removal of nutrients (Tons/Year) by NWC and "No Dam Control"(NDC, open dam all year around) policies are:

	<u>NWC</u>	<u>NDC</u>
TN	219	408
TP	7	13
C-Organic	1319	2067

The lake area and the whole Fayoum depression is world wide known for its archaeological and historical values which increase significances of restoration and protection management. Because drainage waters are the only input resource and evaporation the only outflow, as typically due to arid zone lakes, it is highly important to eliminate point and non-point pollutant sources as human sewage and agricultural drainage. Agricultural development in the Fayoum depression enhanced excess water diversion. These drainage effluents could not be stored in Lake Quarun because of inundation in the vicinities and drainage canals were ultimately needed to remove excess of water and this was the case which initiated the formation of Wadi-El-Rayan lakes. Lake Quarun is a good example for a body of water located in arid zone (dry desert) where food production within the lake and in the vicinity together with protection and development of archeological-historical values and eco-tourism are integrated in management design.

#### **Lakes Wadi El Rayan (Egypt) (Kamel 2007b)**

This is a site including two small lakes and connected flow with falls is located about 65 km from the El-Fayoum town and 80 km west of the Nile River in the Egyptian part of the Sahara western desert. To enhance agricultural production in the Fayoum depression area more waters were diverted into the site and drainage flux was enhanced as well. In 1974 a 9 km canal and 8 km of a tunnel were constructed to connect the western side of the Fayoum depression and the Wadi-El-Rayan depression aimed at drainage waters transport and the two lakes were formed: the upper lake (51 km<sup>2</sup> area) and lower lake (62 km<sup>2</sup> area) nearby two sulphur rich springs. In 1989 the site was declared by the Egyptian Environmental Affair Agency (EEAA) as a protected Area. The site is surrounded by sand dunes were rare species of *Gazella*, *Vulpes*, Fox, reptiles, birds (resident and migrators) can be watched. Moreover, it was practically indicated that these two lakes can be utilized for food production by stocking *Tilapia* (*S.galilaeus*, *T.zillii*, *O. aureus*). Recent studies of the food web structure documented typical freshwater assemblages and densities of phytoplankton, zooplankton, bottom fauna and fish communities (stocks and reproduction). Wadi-El-Rayan lakes exemplify a potential application of desert (extreme dry condition) lakes for food

production, eco-tourism and hydrological management.

Wadi El Rayan was originally an arid desert depression located to the south-west of Fayoum, with an average elevation of 43 m below sea-level and a maximum depth of 64 m below sea-level. As of 1973, excess drainage water from Fayoum was diverted into the depression, flooding large parts of it. Two large lakes were formed as a result. The first lake reached its current level of 5 m below sea-level in 1978. The second lake, which lies at a lower elevation, has a current estimated water-level of 20 m below sea-level and is still in the process of filling. It is expected that the water-level in the lake will be allowed to reach 13 m below sea-level. About 0.25 km<sup>3</sup> of drainage-water reaches the lakes of Wadi El Rayan annually (salinity 1 g/l). This is carried through a canal and a tunnel, which link the first lake and El Wadi Drain and flows from the first lake to the second via a shallow, swampy canal and a small waterfall. Because water-levels in the first lake have been stable for a considerable length of time, a very dense growth of *Phragmites* and *Tamarix* has developed along the shores of this lake. In contrast, the second lake has scant cover along its shores because of the constantly, though slowly, rising level of water in it. Salinity is also rising slowly in the second lake (which has no outflow) as a result of evaporation. The salt-level in the lake is currently about 2.5 g/l, but it is only a matter of time before it becomes as saline as Lake Qarun. Salinity is expected to remain stable in the first lake, since it is constantly flushed. The lakes of Wadi El Rayan produced an average of 477 tonnes of fish annually between 1980 and 1990, composed mostly of *Tilapia* sp. and *Mugil* sp.

To the west of the lakes of Wadi El Rayan is a further, shallower, sandy depression that supports three natural springs and extensive desert scrub. A limestone escarpment surrounds the depression on all sides except the east, where it is closed off by a series of high longitudinal dunes. The vegetation is dominated by shrubs of *Alhagi*, *Nitraria*, *Calligonum* and *Tamarix*. This is an excellent and rare example of an undeveloped Saharan oasis.

#### **Lake Kinneret (Israel)**

Lake Kinneret (Sea of Galilee) is the only natural freshwater lake in Israel located in the Syrian-African rift valley in northern Israel. This region has a sub-tropical climate feature with arid-desert zone on its eastern side. The lake is fed mostly (65%) by Jordan river inflow from north and additional smaller rivers from western, and eastern sides. The Kinneret-River Jordan system is utilized mainly for water supply and partly for agriculture (food production), recreation, tourism, and fishery. Therefore the water quality of the Kinneret and the rivers in the watershed is of a national concern (Gophen 2002;

2003a,b,c). The lake and rivers are highly dependent on Israel nation and the nation is highly dependent on the lake and rivers. River Jordan is crossing the Hula Valley before meeting the Kinneret water. Human intervention in the ecosystem structure, and climate changes has a significant impact on the water quality. As a result of a long history of human activities and climate changes, ecological and limnological conditions of the Hula Valley (northern to the lake) and Lake Kinneret were modified.

Lake Kinneret supplies 16% during drought and commonly 30% of the Israeli water demands and >55% of drinking water requirements. Fifty mcm/y are supplied to the Jordanian Kingdom. The drainage basin area of Lake Kinneret is 2730 km<sup>2</sup>, located mostly northern to the lake of which "Hula Valley" is about 200 km<sup>2</sup>. The Hula valley's altitude in its northern part is between 150-170 m and in the southern part of the valley 61-65 above sea level. River Jordan flows 15 km from the Hula Valley southward, from +60 m altitude into Lake Kinneret with water level of 212.50 m (24.10.07) below sea level.

The warm monomictic Lake Kinneret is stratified from May through mid December (anoxic hypolimnion) and totally mixed during Mid December through April. During the last 60 years the Kinneret ecosystem has undergone several man-made modifications: construction of the south Dam (1932/3); salty springs diversion (1964); construction of the National Water Carrier (NWC) (operation - 1964); implementation of the Hula Project (1994-1998), exotic and native fish stocking since 1930's and onwards, subsidized Bleak fishing (1994-present), construction and operation of 1700 ha fish ponds (1960-70's) and restriction (450 ha) presently, and sewage removal within the drainage basin mostly by reservoir construction (total volume about 25 mcm). High ranged fluctuations of natural parameters such as water level amplitude between 208.57 and 214.87 m bsl; high inflow discharges (>10<sup>9</sup> m<sup>3</sup> per annum) and droughts (<260 x10<sup>6</sup> m<sup>3</sup> per annum); low (333 mm/y) and high (1060 mm/y) precipitations; low (10-50 g/m<sup>2</sup>) and high (170 – 412 g/m<sup>2</sup>) monthly averages of the biomass of *Peridinium spp* during its blooming season; decline of zooplankton biomass during 1969 – 1993 and increase afterwards; low (1983, 1992) and high (1970, 1979, 1999) epilimnetic temperature.

The pattern of seasonal distribution of hydrological, chemical and biological parameters consistently represent subtropical climate conditions of the Kinneret region: high levels in winter and low in summer months but high hypolimnetic inventories of dissolved phosphorus, ammonium, sulfides and CO<sub>2</sub> in summer – fall period as a result of the thermal and chemical stratification (Gophen 2003a,c; 2004).

The lake is exploited for its fishing by ca 200 licensed fishermen which remove commercially an

average of 1832 ton of fish (108 kg/ha) per annum. The zooplanktivorous *Lavnun* (Bleak, *Acanthobrama spp.*) comprised 40-60% by weight of total catches and >50% of the stock biomass (Gophen 2004). Only 8 species out of 24 recorded in the lake are commercially fished (Gophen 2003c; 2004).

Long term (1969-2004) data record of the Epilimnion (0-15m) indicates the following trend of changes: Increase of organic carbon concentration; increase of TP concentration; decline of TN concentration; phytoplankton biomass enhancement from mid – 1970's; biomass enhancement of nano-phytoplankton (*Cyanophyta*, *Chlorophyta*, Diatoms); on the other hand, chlorophyll concentration, and primary production, declined. Secchi depths became shallower. The mass ratio (Wt/Wt) of TN/TP declined. The community structure of phytoplankton represent a shift from large cell algae-*Peridinium* to a smaller cell size of nano – phytoplankton. It is likely that these changes caused an increase of water turbidity as reflected by the shallower depth of Secchi measurements. These changes are probably, also, reflected by the decline of chlorophyll concentration and reduction of primary production due to the decline of light penetration. Particle density was enhanced and size fraction became smaller resulted in higher cell surface area in relation to cell volume and therefore light reflection was enhanced. Decline of nitrogen accompanied by phosphorus increase (lower TN/TP mass ratio) caused N deficiency and P sufficiency resulted in by nitrogen fixing cyanophyte blooms, as previously predicted (Gophen et al. 1999; Gophen 1999). The alteration of the phytoplankton communities from winter-spring dominant *Peridinium* to non-pyrrhophytes dominance is highly related to changes of nutrient dynamics. The Kinneret is a P and N limited ecosystem in summer months and heavily loaded by external flux of TN and TP in winter. Nevertheless, most of the TP is not bio-available and the most effective N form on *Peridinium* bloom forming is TDN. *Peridinium* is able to form heavy blooms in February-June as a result of the winter TDN supply from external sources and the high intra-cell P content of the free swimming cells that were emerged from the resting cysts. The *Peridinium* cysts are formed during the bloom collapse (May-June) and are sinking to the bottom sediments where they incorporate P. This incorporated P is sufficient for bloom forming next year when TDN is a sole limiting nutrient. In recent years, when external supply of organic-N was declined-*Peridinium* was suppressed. During summer months very low densities of *Peridinium* assemblages do exist in the lake. These summer cells are very P and N starved and therefore consume intensively external P and TDN supply at the beginning of the bloom season (<20 g/m<sup>2</sup>). When *Peridinium* densities are low (<20 g/m<sup>2</sup>) the demand for P and TDN is high and their concentration in the epilimnion is abruptly decline.

Later, densities increase ( $>20 \text{ g/m}^2$ ) occur if TDN availability is higher but demand for TDP are lower because of the high cell P content. *Peridinium* density increase ( $> 40 \text{ g/m}^2$ ) is not significantly depend on TIN and TDP supply.

Decrease of zooplankton biomass (*Copepoda*, *Cladocera*) between 1969 and 1990 and increased later was documented by Gophen (2003a). The increase of *Lavnun* biomass was the outcome of reproduction success by supportive climatological conditions, high density, small body size and therefore reduction of fishery pressure (Gophen 2004). Implemented recommendation to reduce *Lavnun* biomass by subsidized fishery resulted in rehabilitation of zooplankton biomass from early 1990's. The expected decline of nano-phytoplankton as a result of enhanced grazing pressure by zooplankton was not achieved.

The Kinneret Nitrogen loads are mostly affected by external supply. Therefore, reduction of nitrogen concentrations together with discharge decline in River Jordan (climate change) resulted in lowering of lake loads. Because *Peridinium* is sensitive to nitrogen availability its biomass is normally enhanced during flood season and particularly under heavy floods. The long term decline of nitrogen supply suppressed *Peridinium* biomass in the lake. Phosphorus availability in Kinneret was enhanced and consequently induced proliferation of the P limited nano-phytoplankton from mid 1980's when grazing zooplankton biomass was suppressed by *Lavnun* fishes. It was suggested that reduction of *Lavnun* (started early 1990's) might indirectly, as top-down effect, suppress nano-phytoplankton. But this was not the case: the grazers biomass increased and diatoms and chlorophytes biomass was enhanced. It is suggested that due to optimal P availability, the higher grazing pressure was insufficient for reduction of nano-phytoplankton. Benndorf et al. (2002) concluded that fishery management, Biomanipulation, is insufficient for nano-phytoplankton suppression if P is not reduced in mesotrophic- non-shallow and non-deep lakes. The reasons for the reduction of nitrogen supply from the watershed of Lake Kinneret are probably anthropogenic. The increase of P availability in Lake Kinneret is probably the result of enhanced SRP supply via Jordan flows and unknown or unmeasured sources such as, underground preferential flows (Litaor et al. 2003; 2004; 2006), or dust deposition. The agricultural management in the Hula Valley partly supported reduction of P flux. This management include increase of soil moisture by elevation of ground water level and green crops cover throughout year around.

The bloom forming  $\text{N}_2$  fixing cyanophytes were enhanced by nutrient conditions of nitrogen deficiency and phosphorus sufficiency. To improve water quality in Lake Kinneret by means of cyanophyte suppression it is suggested to achieve a

better control of P supply. Such a management might also affect reduction of chlorophytes and diatoms and biomanipulation (biomass reduction of *Lavnun*) is very supportive.

### Climate changes

Temperatures data indicates cooling trend of Kinneret water during 1970 – mid 1980's and warming (by  $1.8 \text{ C}^0$ ) afterwards. The temperature increase started earliest in upper layers (mid – 1980's) and latest (end of 1980's) in deep layer. Air temperatures that were measured simultaneously 3 m above water surface in a station located on the western side represent similar pattern of changes. The temperature of the thermocline increased and its depth was reduced (shallower). Consequently, the epilimnion volume became smaller. Warmer epilimnion, shallower and warmer thermocline indicates elevation of epilimnetic specific heat ( $\text{cal/g}^0\text{C}$ ). It is in agreement with intensification of light absorbance (shallower Secchi depth), enhancement of small particles (nano-phytoplankton) density accompanied by increase of heat storage capacity (heat budget). It is suggested that the shift of phytoplankton composition from large cells *Peridinium* to small sized algae with higher particle density enhanced heat capacity (budget) of the Epilimnion. The implication of the warming process might have an impact on the lake metabolism: enhancement of biological, microbiological, chemical and obviously physical rates of processes.

### The National Water Carrier (NWC) Effect

The National Water Carrier (NWC) operation (1964) together with the previously (1932-33) operated south dam modified the hydrological budget of the lake. Before the operation of the south dam (<1933) and until the operation of the NWC (1933-1964) most or all water inputs in winter were out fluxed through an open dam or naturally without dam regulation. Most of the nutrient rich winter influxes crossed the lake via the upper layer and major part of the nutrient inputs were withdrawn from the lake. After 1964 the southern dam was opened only for the releasing of excess water as part of the water level (WL) control and most of the external nutrient loads accumulated within the lake. Long term perspective indicate it as an eutrophication factor. Moreover, since its operation, the NCW conveyed about 13 billion cubic meters (about 3 times the Lake volume) of water which were supplied in Israel (from Haifa in the north to Ramon in the southern desert) for drinking (practically for house hold utilization of which only 5% for drinking), agricultural irrigation, industry, and aquifers recharging. These NWC's waters transported also about 8 million tons of salts (3.1 – Chloride, 1.6 – Carbonate, 1.4 – Sodium, 0.4 – Magnesium, 0.1 – Potassium, 0.7 Calcium, 0.7 –

Sulfate) which enhanced soil and underground aquifers salinization

For the study of eutrophication by NWC effect two seasons were considered: winter (December and January through April) and summer months (May through November). TP, TN and organic Carbon removal from the lake under the two (NWC, NDC) management regimes were calculated and results are given in Table 4.

Consequently, the lake is a sink for 11 – 16 % of the epilimnetic nutrients above natural regime as a result of the man-made changes.

The long term trend of changes in the Kinneret are given in Gophen (2007).

Due to overlapped type of impact it is not clear which one of the two kind of changes, natural and man-made is dominant. The seasonal pattern of nutrient fluxes from the peat soil in the Hula Valley was measured and the low contribution of pollutants in surface runoffs in the drainage canals was documented. Nevertheless, the underground peat and marl soils in the Hula Valley create a complicated system where preferential pathways are very common and the information about water and nutrient migrations is poor.

Conclusively, the utilization of a lake like Kinneret, located in a semi arid sub-tropical zone is highly depends, beside natural fluctuations, on man made intervention and the thorough understanding of the eco-system structure is crucial for optimal management.

#### Lake Tai-Hu (China) (Chen et al 2007; Gao et al 2007; Townsend-Small et al 2007)

Lake Tai Hu is the third largest freshwater lake in China located about 100 km from the east coast in central China in the Yangtze plain delta. There are about 90 islands of various size in the lake. The adjacent area is densely populated and the soil is very fertile. There are many small lakes, canals and streams in the vicinity to the lake. The lake outflow enter the Yangtze river. The big old (7<sup>th</sup> century) canal which connect Beijing and Hangzhou is crossing this territory as well. Water inputs comes mostly through rivers from west and southwest and outputs mostly through the east part of the lake. The water budget is controlled by dams which are also functioning as flood control. The lake surface area is 2338 km<sup>2</sup> and the volume is 4.3 km<sup>3</sup>. Maximum depth is 2.6 m and mean depth-1.9 m. The water residence time in Lake Tai Hu is lower than 9 months. Limnological parameters of Lake Kinneret and Lake Tai Hu are given in Table 5:

Data presented in Table 5 emphasise the limnological differences and its impact on optimization of management design.

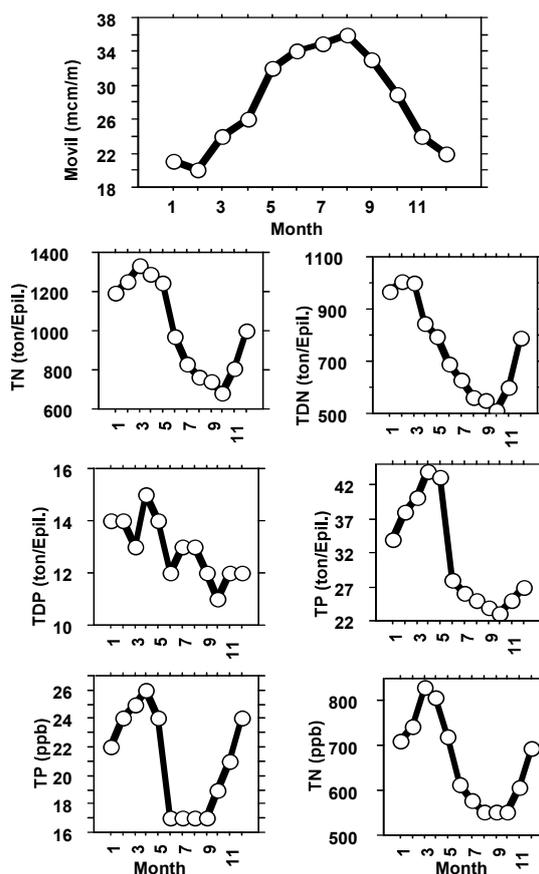


Fig.1: Monthly means (1969-2001) of pumping regime in the National Water Carrier (Movil) (mcm/month)(Data source: Mekorot-Water Supply Co.); and Epilimnetic concentration and loads of nutrients: TDP and TP (tons/Epilimnion); TP and TN (ppb).

Table 5. Limnological parameters of Lake Tai-Hu (China) and Lake Kinneret (Israel):

Parameter	Tai Hu	Kinneret
Surface Area (km <sup>2</sup> )	2338	170
Depth(m): Max.	2.6	44.0
Mean	1.9	26.0
Volume (km <sup>3</sup> )	4.3	4.0
Residence Time (month)	5	60
Secchi Depth (m)	0.15-1.0	0.2-7.1
Stratification	Daily slight	9months stable
Temperature (°C)	2.9-29.9	14-28
Fishery and Aquaculture (kg/ha)	56(fish, crustaceans)	108(Fish)
Watershed area (km <sup>2</sup> )	34207	2730
Population density (Ind./km <sup>2</sup> )	1052	~75
Agricultural area (% of Watershed)	40	<10
Industry (factories)	~2800	~50(no metallurgy)
Blue-Green alga	Severe	Moderate
Trophic status	Hypertrophic	Meso-eutrophic
River inflows(km <sup>3</sup> /y)	8.0	0.8
Direct Rain(km <sup>3</sup> /y)	2.922	0.012
TP (ppm)	0.2-0.8	0.08-0.01

Climate conditions at the two lake regions are quite similar, both are heavily utilized for food production, tourism and water supply and above all, crucial for their nations. Nevertheless, Lake Kinneret, is deeper, stably stratified in summer, and the impact of re-suspension of bottom sediments on water quality is much lower. Lake Tai Hu is severely contaminated by blue greens and L. Kinneret only at a moderate level. The protection of water quality in lake Kinneret system is more advanced than in Lake Tai Hu. It is prominent that lake Chad conditions are worst than the Chinese lake probably due to the fact that the African lake share territory between several countries and cooperation is more difficult. Moreover, desert conditions amplify sensitivity of the ecosystem in response to climate and anthropogenic changes. The relative fairly good conditions of Quarun and Wadi El Rayan lakes is due to the lower anthropogenic pressure and water balance.

The utilization of Lake Tai Hu is aimed at food production (fishery and aquaculture of fishes and crustaceans), water supply, transportation, recreation and tourism. The big cities of Shanghai, Wuxi and Suzhou strongly rely on water supply from the lake. The climatological zone definition of the lake area is "tropical dry climate" which is close to the semi arid sub tropical region of Lake Kinneret. Annual precipitations -1250 mm, (75% during monsoon season-May-October) and air temperature (monthly means) amplitude in winter (October-March) vary between 16.7 °C (October) and 2.9 °C (January). Summer (April-September) amplitude of air temperature is 15.1-29.9°C. The lake has no freezing period. The lake is slightly stratified in mid summer several hours a day. The lake is shallow and productive.

The lake is a subject to very many studies by local and international scientists. There is a huge bulk of scientific information about the lake in local and international journals, books, and popular magazines in China and abroad.

Water quality deterioration in Lake Tai Hu thoroughly predicted. Rice paddies were replaced by chemical plants (2800 in the lake northern basin). Due to economical benefits for example, most of revenues of the city of Yixing originated from industrial taxes. Cases of fish kill enhanced and rice yields declined. A one person awareness to the deteriorated environment of Lake Tai Hu became now days a national issue. The first worst signal came on May 2007 when the lake was overtaken by heavy bloom of cyanobacteria. The low water level was blamed but input pollutant dynamics were not thoroughly considered. Water deterioration in lake Tai Hu was declared as a national disaster by the Chinese government accompanied by unjustified ignorance of the anthropogenic impacts. But it was changed in October 2007 when the government gave a shut down notice to more than 1300 factories

around the lake. Townsend-Small et. al. (2007) documented high rate of atmospheric N<sub>2</sub> fixation (probably by cyanobacteria) in summer and other N sources were: sewage effluents (industry + agriculture + aquaculture < human), fertilizers, and rain (air pollution) as dominant in the rainy season. Present running projects of water quality improvement predict significant progress by 2015 but present studies results indicate existing serious problems of pollution. Beside heavy blooms of cyanobacteria oxygen depletion accompanied. During early 2000's 5.3x10<sup>9</sup> tons of household sewage were dumped into the lake annually. Another significance of the hyper-eutrophic highly polluted lake status is indication of bacterial production higher than primary production emphasizing the microbial component of the food web as very important. It is suggested that the dominant processes within the entire food web are external inputs. It was also documented (Chunhua et al. 2006) that wind induced re-suspension is very effective in this shallow lake, enhancing quality deterioration. Chen et al (2001) documented algal response to pollution process: oligo-mesotrophic stage before 1981, eutrophic level with *Microcystis* blooms during 1988-1995 and hyper-eutrophic status dominated by *Planctonema* during 1996-97. The N and P concentration increased by 62% and 24% respectively since 1999.

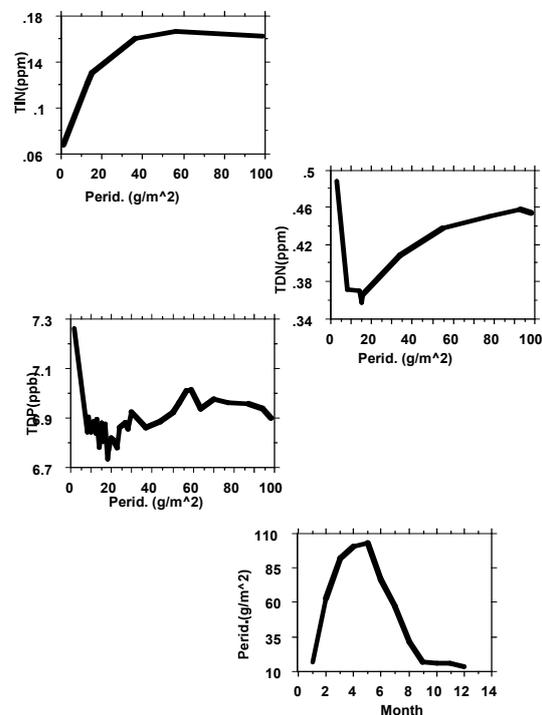


Figure 2: Trend of changes of *Peridinium* biomass (monthly means, g/m<sup>2</sup>) when varied between 0-100 g/m<sup>2</sup>) in relation to nutrient concentrations(monthly means: TDN & TIN-ppm; TDP-ppb) in the Kinneret Epilimnion (0-15m) and (bottom) seasonal changes of *Peridinium* biomass during 1969-2001

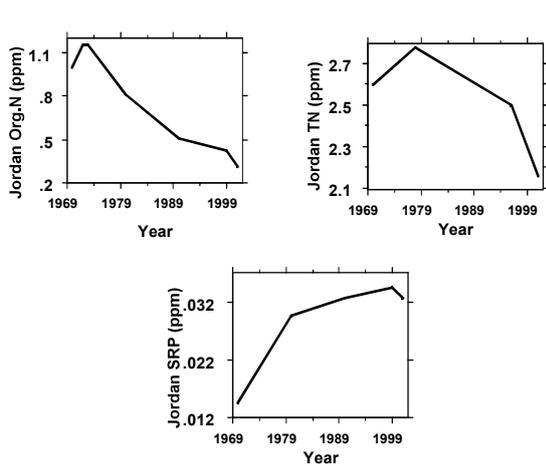


Figure 3: Temporal changes of nutrient concentrations (ppm) in River Jordan during 1970-2001: SRP, TN, and Organic- N. (Data source: Mekorot Water Supply Co.).

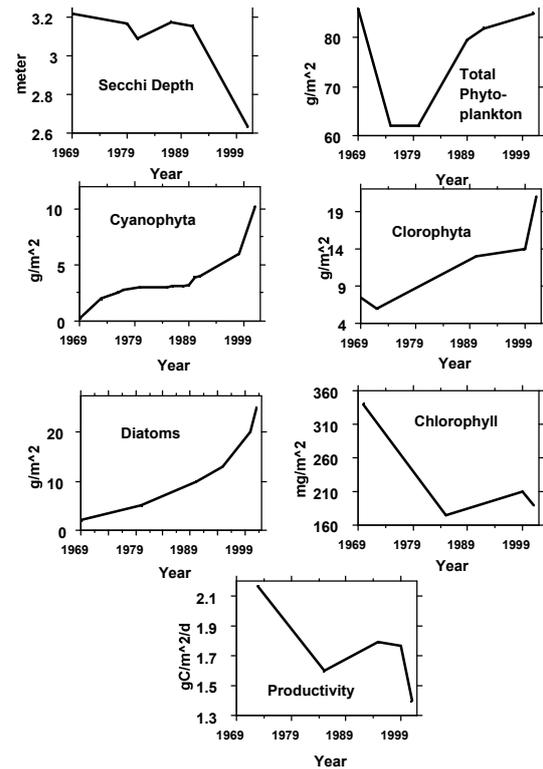


Figure 5: Temporal changes in the Kinneret epilimnion (1969-2001): Total Phytoplankton Biomass ( $\text{g/m}^2$ ), Chlorophyll ( $\text{mg/m}^2$ ), Secchi depth (m), Productivity ( $\text{gC/m}^2/\text{day}$ ), Cyanophyta ( $\text{g/m}^2$ ), Chlorophyta ( $\text{g/m}^2$ ), Diatoms ( $\text{g/m}^2$ ). (Data source: LKDB).

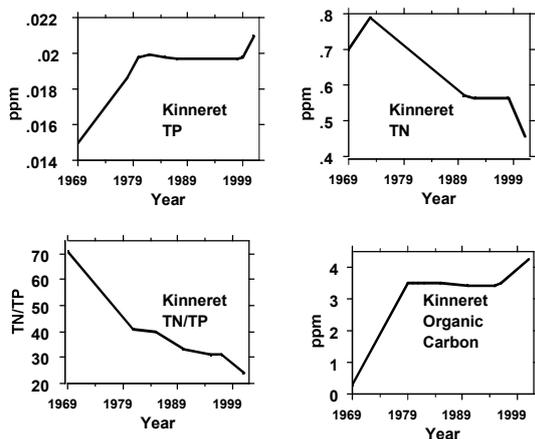


Figure 4: Temporal changes in the Kinneret epilimnion (1969-2001): concentrations (ppm) of Organic-Carbon, TP, TN; TN/TP mass ratio. (Data source: LKDB).

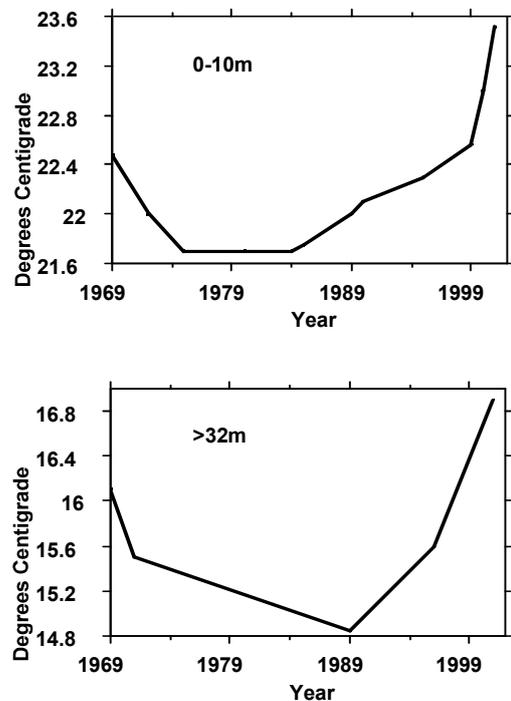


Figure 6: Temporal changes of Kinneret water temperature ( $\text{C}^0$ ) in 2 layers: 0-10m, and >32m during 1969-2001

## CONCLUSION

Case studies of lakes presented here exemplify two gradient lines: climate and utilization. The climate route starts in dry desert, goes to semi arid and terminated in dry tropical. The utilization course start at the point of low human pressure and terminated at the intensive anthropogenic impact. Several other factors with resemble impacts as in the two tracks include: climate changes, physical parameters as depth, bathymetry, water and heat budgets, wind and current action, and others. Analysis presented here was focused on the two major lines. It should be taken into account that the final status of the lake is a combination of all parameters. It is clear that the more the climate is dry the more the aquatic ecosystem is sensitive. Lake Chad is located in a region dryer than Lake Tai Hu and anthropogenic intervention is high in both systems and therefore the final product (the present Lake status) is severe pollution in Tai Hu and lake size shrinkage in Chad. Pollution is severer in Tai Hu than in Lake Chad but system deterioration and damage to human welfare are similar or higher in Chad.. The two systems in Egypt are located in dry arid desert but not yet damaged whilst lake Quarun is more exposed to anthropogenic impacts and therefore susceptible to potential deterioration more than Wadi El Rayan lakes. Lake Kinneret represent a system under intensive human intervention and crucial status for its country but fortunately physical features and thorough study and results implementation enabled managers to slow down deterioration processes. The need for international action aimed at protection of aquatic eco-systems is a significant outcome.

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