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Historical Review on Water Level Changes in Lake Kinneret (Israel) and Incomparable Perspectives

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Abstract: A long-term (1933–2022) record of water level (WL) fluctuations in Lake Kinneret was reviewed. The dependence of the Kinneret WL management on climate change (flood–dryness alternate), dam and National Water Carrier (NWC) constructions constrained by water availability and domestic supply demands were indicated. A short-term range of maximal WL decline of 4–6 m and 4.6–6.5% of the total surface area of lake water shrinkage in Lake Kinneret was documented. Nevertheless, incomparably longer periods and higher amplitudes of WL decline accompanied by a dramatic shrinking of the water surface were documented in Lake Tchad, the Aral Sea and Lake Sivan (SAT). Therefore, the comparative results of WL decline in Lake Kinneret and in other lakes as SAT are not justified.

Keywords: Kinneret; water level; dam; supply; climate; Sivan; Aral; Tchad

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1. Introduction

Varieties of ecological services are supplied by the Lake Kinneret ecosystem: fishery, recreation, tourism, drinking and domestic water demands, and also for hydrological energy for electricity production (1933–1948). Across 100 historical years of anthropogenic involvement in the management of Lake Kinneret and its drainage basin, the lake water level altitude (WL) was primarily controlled by the implementation of three anthropogenic projects: the south dam construction (1933), the National Water Carrier construction (inaugurated 10.6.1964) and the Hula drainage (1957). Obviously, rainfall and river discharge vary and consequently water availabilities accompanied by the constraints of consumption demand significantly affected WL fluctuation. The long-term record of maxima and minima of the WL is evaluated in this paper. The results of WL decline in Kinneret and in the SAT (Lake Sevan, Aral Sea, Lake Tchad) are discussed.

2. Study Area

2.1. Regional Hydrology

The Kinneret drainage basin area is 2730 km^2 and is located mostly to the north of the lake, of which the Hula Valley is about 200 km^2 (Figure 1).

The major water source storage feeding the headwater is stored within the mountain-rocky-karst of the Hermon mountain. The mountainous area of the Hermon (788.650 km^2) in the northern part of the drainage basin is an uplifted massif of Jurassic and Lower Cretaceous limestone comprising the highest (summit 2814 masl) peak of the watershed. The Naftali Ridge Mountain demarcates the western side of the Hula Valley and is comprised of Cretaceous and Eocene limestone forming a steep escarpment up to an altitude of 900 m. The central part of the Kinneret watershed side is a karstic depression (500–600 masl) covered by a thin basalt layer and reddish-brown terra-rosa soils southernly limited by the Safed–Meron Mountains reaching an altitude of 1200 m. The central part of the drainage basin, the Hula Valley (70–90 masl), is covered by a 1000–1500 m thickness of deposited sediments.

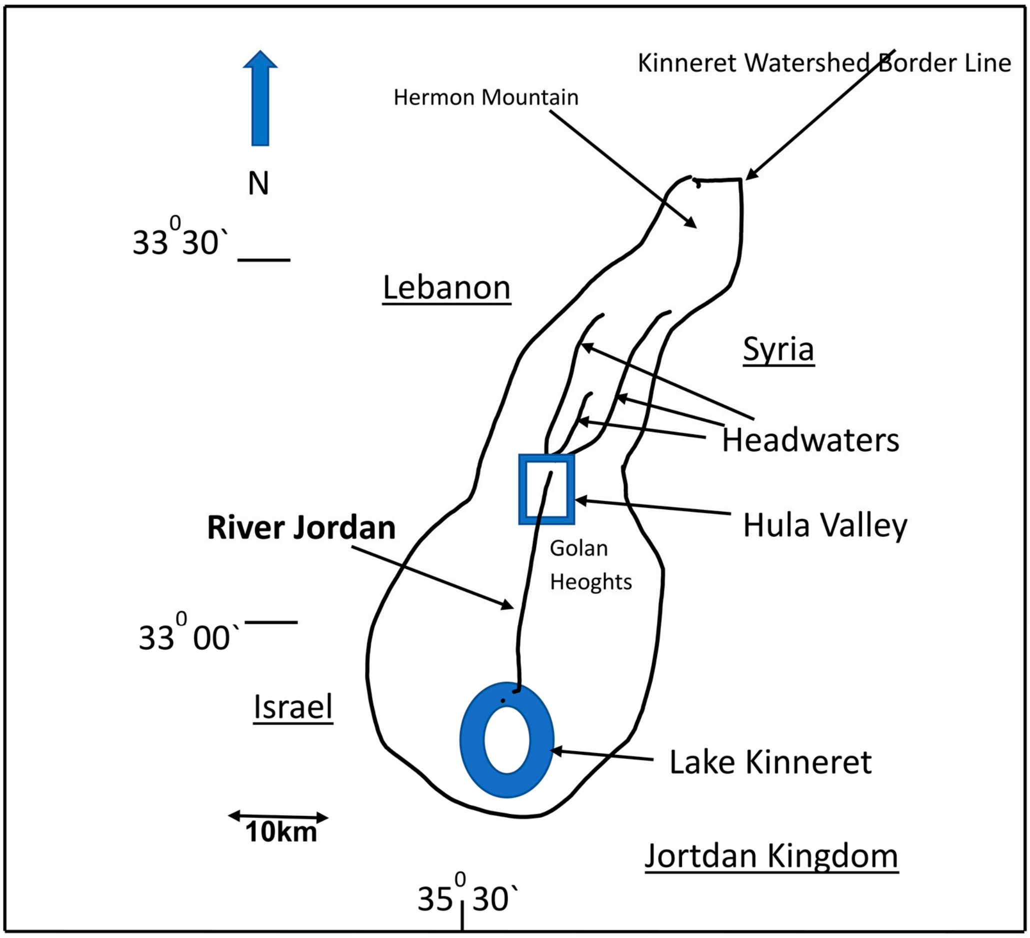

Figure 1. Geographical chart of the Lake Kinneret Watershed. River Jordan, three major headwaters, (Dan, Snir, and Banyas), Longitude and latitude location, Lake Kinneret, the Hula Valley and geopolitical territories are indicated.

Running water input into Lake Kinneret comes through three major headwater rivers, Hatzbani (Snir), Banyas (Hermon), and Dan, and several other smaller rivers merging into the Jordan River crossing the Hula Valley. Jordan River contributes about 63% of the Kinneret water budget. The Hula Valley was covered by the shallow old Lake Hula and swamps. During the 1950s, old Lake Hula and its adjacent swampy wetlands were drained and converted into arable land, and the natural wetlands were converted for agricultural development.

Lake Kinneret, the only natural freshwater lake in Israel, is a multipurpose utilized body of water: water supply, fishery, recreation, and intra- and international tourism. It is a warm-monomictic lake located below sea level. The lake is located in the northern part of the Syrian–African Graben in northern Israel and occupies a rectangle limited by the latitudes 32°53′44″ N and 32°42′15″ N, and by the longitudes 35°30′52″ E and 35°38′55″ E. The lake is stratified from May through mid-December of 7–8 summer months when three water layers are defined: Epilimnion, Metalimnion (Thermocline) and Hypolimnion. During summer, the Hypolimnion is anoxic, and during the three winter months, the lake is fully mixed. The Kinneret drainage basin is part of a sub-tropical region where the winter is short, wet, and cold and the summer is long, dry and hot. The rainfall regime in the catchment varies between 900 mm/y in the northern and 500 mm/y in the southern part. During the late 1960s, a project of salt removal (about 40,000 tons/year) was completed.

2.2. Anthropogenic Involvement

Lake Water Balance (Table 1)

During the last 9000 years, the Kinneret WL fluctuated within an amplitude of 20 m (197–217 mbsl) (Hazan et al., 2005; Vossel et al., 2018). Human-made control of the water balance was achieved in 1933 by the construction of the south dam. Consumption of Kinneret water (300–400 mcm/year; 10^6 m^3/y) started after the inauguration of the National Water Carrier (NWC) (10.6.1964) enabled pumping water withdrawn through a 2.74 m (108 Inches) diameter pipe started from 215.50 mbsl altitude (7 m below lake surface, located 400 m from the shoreline), with a further elevation to 44 mabsl and conveyed 130 km southern to Machtesh Ramon. The system supplies domestic (included drinking), agricultural and underground aquifers that recharge water demands. The implementation (2010) of a sea water desalinization project created an excessive 650 mcm per year of freshwater, of which 100 mcm is diverted into Lake Kinneret (inaugurated 27 December 2022). Consequently, a drastic usage decline of the NWC Kinneret water supply has been achieved.

Table 1. Lake Kinneret annual water balance (year 2000) (mcm; 10^6 m^3).

Input		Output	
Golan Heights rivers	145	Evaporation	280
Jordan and headwater sources	480 (northern consumption abstracted)	Southern Jordan Spiling	80
Direct Rainfall	75	Local Consumption	60
Eastern Galilee rivers	75	National Water Carrier	380
Jarmuch diversion	25	Total Output	800
Total input	800		

Legislation of the upper and lower most Kinneret WLs was instructed as 208.80 (upper) and 213.00 (lowest) mbsl. Over 48 years (576 months; 1970–2018), there were only 97 months (17%) with WLs lower than the legislated bottom line of 213 mbsl and only during winter 1968\1969 was the WL higher than 208.80. The upper legislated WL line is 208.80 mbsl.

Ten years (decade) grouped averages of WL monthly means in Lake Kinneret (1933–2018) (Figure 2). The trend of changes, and anthropogenic events are indicated.

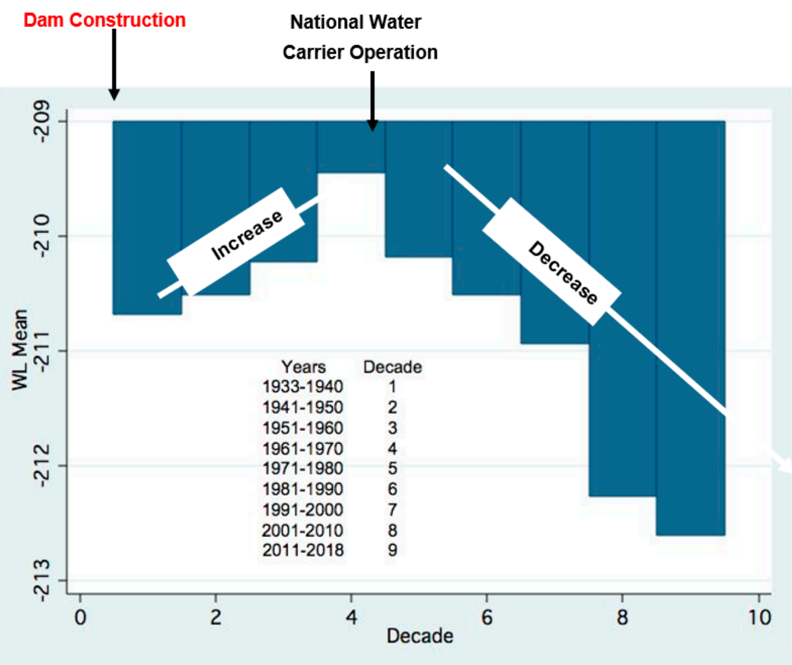

Figure 2. Ten year (decade) grouped averages of monthly means.

During 1970–2018, in spite of climate change, agricultural management and technological modifications, most of the time (83%), the Kinneret WL was not lower than the legislated altitude of 213 mbsl. Moreover, until the 2000s, the WL was higher than the minimal legislated altitude. The decline of the WL below the instructed WL bottom-line (213 mbsl) was recorded during years of exceptional declines of rainfall: 2000–2002, 2008–2011, and 2016–2018, which consequently resulted in the significant restriction of agricultural water allocation by the National Water Authority. The morphometric features of Lake Kinneret at the maximal permitted water level of 208.80 m (mbsl) are given in Table 2:

Table 2. The morphometric features of Lake Kinneret at the maximal permitted water level of 208.80 m (mbsl).

Parameter	Units	Value
Water Surface	km^2	169.5
Maximum Depth (M), latitude	Meter mbsl	48 256
Mean Depth	Meter	26
Mean/Maximal depths Ratio	No dimension	0.54
Volume	km^3	4.471
Maximal Length	km	22
Maximal Width	km	12
Shore line length	km	55
Shore line development Value (D)	No dimension	1.19

During 2000–2022, the management of the Kinneret Hydrological system was significantly modified. Changes of climate conditions (an alternating of periodical droughts and heavy rainfall) accompanied by changing demands for domestic and agricultural water utilization led to a closed dam policy, restrictions of agricultural utilization, and import of desalinized sea water.

3. Statistical Methods

Three methods of regression were performed (STATA 17): (1) fractional polynomial regression (Predicted value and CI 95%, where the grey color space (within the CI) overlap indicates the nonlinearity of the prediction, and (2) trend of changes—lowess smoother (0.8 bandwidth), and fractional polynomial regression.

Data sources.

Institutions.

Hula Reclamation Project-Migal-Scientific-Research-Institute; Kinneret Limnological Laboratory, IOLR; Mekorot—National Water Supply Company; Keren Kayemet Le'Israel (Jewish National Fund); Israel Hydrological Service; National Water Authority; Drainage and Kinneret Authority [1–3].

Literature.

Mekorot, 1986–2018; Hydrological Service 2022; LKDB 1969–2021; Feitelson et al., 2005; Serruya 1978; Gophen 1992, 2018; Gvirtzman 2002; HYBI 1950–1997; TAHAL 1960–1988 [1–10].

4. Results and Discussion

The results given in Figure 3 represent rainfall range fluctuations during 82 years (1940–2022) measured at Dafna station located in the northern part of the Hula valley. The results indicate a long term from 1940 to the late 1980s of enhancement followed by a let decline. The fluctuated amplitude (up and down) ranged annually between 30–50 mm as indicated by the predicted fractional polynomial regression and lowess smoother trend of changes.

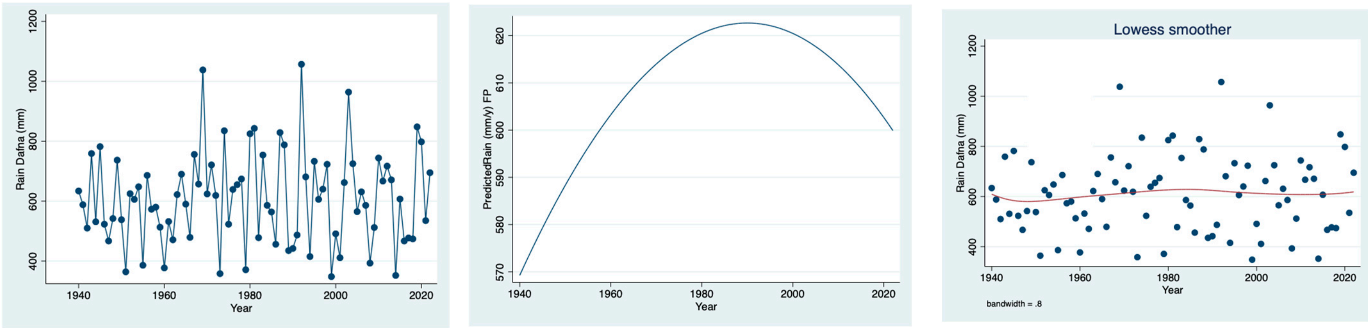

Figure 3. Temporal (1940–2022) fluctuations of annual rainfall (mm) measured in the northern part of the Hula valley (Dafna): scatter plot (**left**), fractional polynomial regression (**middle**) and lowess smoother trend of changes (**right**).

The results given in Figure 4 represent the temporal (1934–2022) maxima of changes in the maximal altitude of the water level. The slight increase prior to the operation of the National Water Carrier (NWC) (1964) and the gradual continuous decline later are prominent. The WL decline reflects the impact of pumping withdrawals for consumption whilst the slight increase between 1934 and the early 1970s was the result of the water storage policy. The storage policy was implemented by dam management.

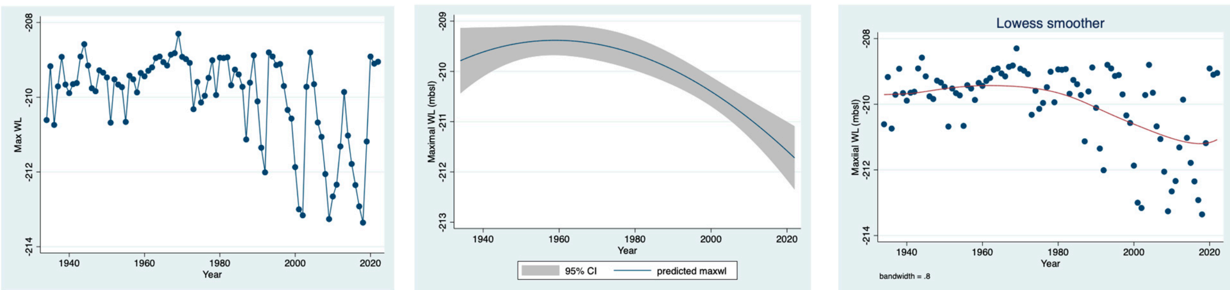

Figure 4. Temporal (1940–2022) fluctuations of annual maximal altitude (mbsl) of water level (WL) in lake Kinneret: scatter plot (**left**), fractional polynomial regression (predicted value) (**middle**) and lowess smoother trend of changes (**right**).

The implementation of the water storage policy by dam control prior to the intensive operation of NWC (1940–early 1970s) and the WL continuously increasing is presented in Figure 5. From the early 1970s and onwards, the NWC was fully operated, the dam was mostly closed and the general temporal trend of the WL was decreased with periodical fluctuations in dependence on climate conditions.

Figures 6 and 7 represent the temporal changes of annual increase and decline in the WL (given in m/y): Figure 6 is the annual increase and Figure 7 is the annual decline. The similar pattern of changes in both the annual increase and decrease imply the management of decline prior to the NWC operation aimed at water storage and the beach floods prevention policy and increase when NWC operation is aimed at maximal withdrawal of the available water in the lake for consumption. In the case of climate change resulting in drought and over-utilization, the bottom "flexible" WL red line moved down. Nevertheless, under heavy rain seasons and an excess of available water, the upper red line was not changed, except in one case in the winter of 1968–1969.

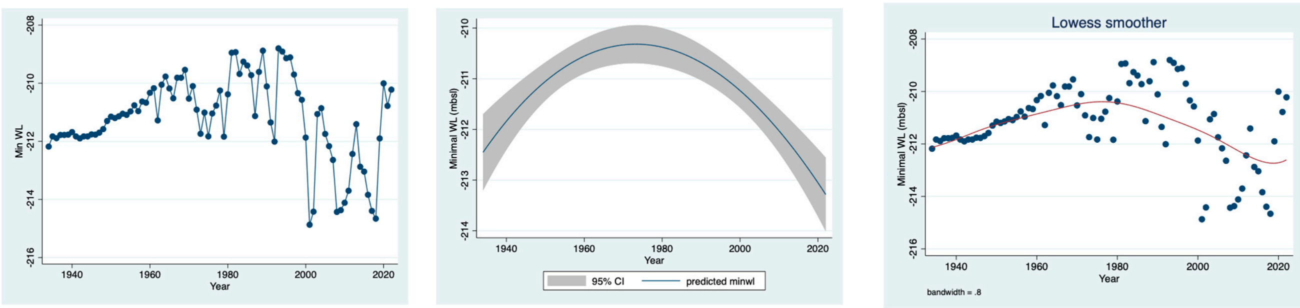

Figure 5. Temporal (1940–2022) fluctuations of annual minimal altitude (mbsl) of water level (WL) in Lake Kinneret: scatter plot (**left**), fractional polynomial regression (predicted value) (**middle**) and lowess smoother trend of changes (**right**).

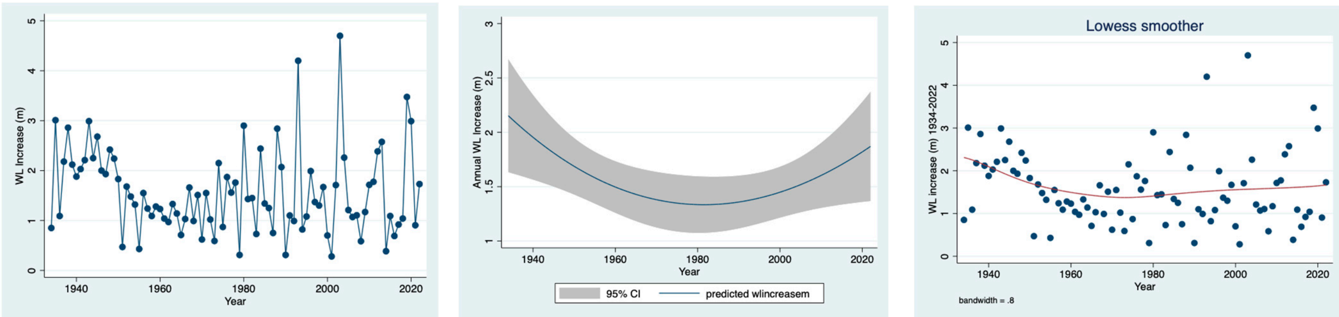

Figure 6. Temporal (1940–2022) fluctuations of annual water level increase (m) in Lake Kinneret: scatter plot (**left**), fractional polynomial regression (predicted value) (**middle**) and lowess smoother trend of changes (**right**).

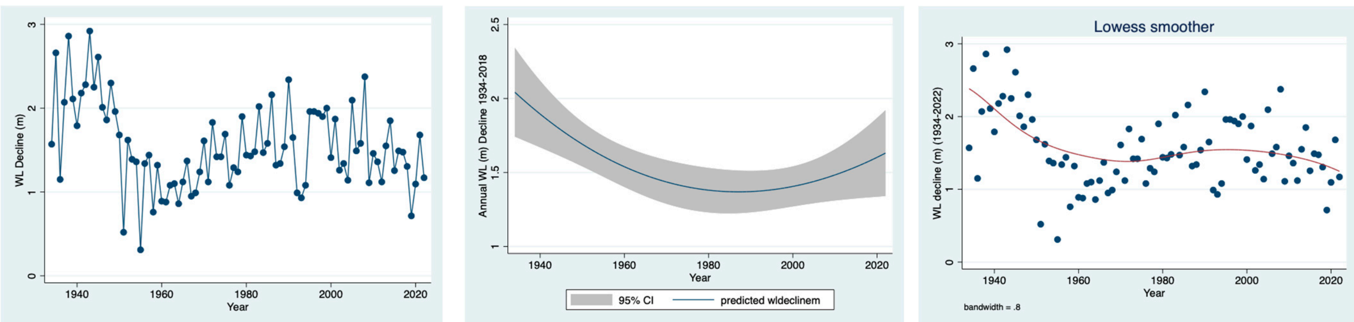

Figure 7. Temporal (1940–2022) fluctuations of annual water level decline (m) in Lake Kinneret: scatter plot (**left**), fractional polynomial regression (predicted value) (**middle**) and lowess smoother trend of changes (**right**).

4.1. Discussion

Since the inauguration of the South Dam (Degania Dam) (1933) located 400 m from the Jordan River outlet, the maximal range of WL fluctuation varied between 214.87 and 208.30 mbsl (6.57 m). Prior to the dam's construction, the fluctuations of the WL were controlled naturally by rainfall and river discharges. Geological stratigraphic research [11] and sediment cores dating through fossil diatom fragment analysis [12] have indicated WL fluctuation between 197 and 217 mbsl during the 9000 years, of which the last 90 years were affected by the dam's operation. The bottom altitude of the Jordan outlet was 212.35 mbsl, as measured in 1932 by the National Electric Company Authority. The objective of the dam when constructed was to ensure a continuous sufficient water flow from Lake Kinneret for the operation of the Hydroelectric Station located approximately 10 km south of the lake.

The electricity supply continued smoothly from 1933 until 1948, when the Naharaiim region was occupied by the Hashemite Kingdom of Jordan and the plant was never operated again. To ensure climate independence through a sufficient water supply, the short section of the Jordan River (app. 400 m) between its outlet and the Dam was deepened by 4 m. In the early 1950s, a national decision was accepted to utilize Lake Kinneret as a national storage of surface freshwater for domestic and agricultural supply, and the National Water Carrier (NWC) was constructed. Later on, a top priority of the Kinneret hydrological management was aimed at the storage capacity controlled by WL operation. The possibility to change the capacities of human water demands is quite limited, but the population size is enhanced. On the other hand, the quantity of available capacity is climate-dependent through rainfall and river discharges. Moreover, the storage capability is a multiannual option through surplus storage to be used later. Prior to the construction of the NWC, while the dam was operated, the WL was elevated gradually, aiming at water storage, whilst after the intensive operation (pumping withdrawal) of the NWC (the early 1970s) and the dam was almost totally closed, the WL was gradual—continuously declining with seasonal upward fluctuations. The focus of this study is limited to the range of annual changes of the WL. Lake evaporation is climatological and seasonal dependent, but not significantly affected by hydrological management. Besides the climate effect on water inflow and consequently on WL, the utilization of Kinneret water resources north of the lake has a partial impact on WL. Nevertheless, the range of northern annual utilization changes is minor (presently 50–70 mcm; 10^6 m^3/y) and consequently has a negligible impact on WL fluctuations.

The validity of the formal legislation of the lower limit of WL in Lake Kinneret since 1934 was significantly modified. Before the operation of the NWC (1934–late 1960s), no uppermost and lowermost WLs were formally instructed. Therefore, the unlimited optional range of management decisions about the WL altitude was dependent during 1933–mid-1960s on two noncorrelated constraints: electricity production and environmental shoreline protection, whilst after the NWC operation, WL management achieved implementations aimed at both water supply (storage) and environmental shoreline protection. The determination of the uppermost WL altitude was fixed during the late 1960s after constructed devices surveyed within a close vicinity to the potential shoreline at various altitudes, whilst the lowermost permitted altitude was considered differently. Two major parameters are involved in the consideration of the lowermost altitude: the altitude of the NWC pumps intake and the potential ecological impact on nutrient dynamics. With regard to the NWC intake depth, the decision is of the engineering trait, which clearly indicates it is not lower than 215 mbsl. Nevertheless, the data recorded about the resulting effect of WL decline on nutrient dynamics were insufficient. Consequently, the experienced available data record was a useful tool for decision-makers. Nevertheless, when Lake Kinneret's status was already dedicated to being a national reservoir of surface water for domestic supply, the water quality became a significant parameter of concern and the quantity and quality of Kinneret's water are dependent on the implications of the WL measurement. The history of WL management (Figures 3–5) indicates: prior to the early 1970s, the WL level altitude increased, but later declined. The legislated uppermost WL altitude was instructed to be 208.8 mbsl and was never changed, but included one exceptional case during January 1969 when the WL was recorded at 208.30 mbsl. Nevertheless, the lowermost limit was changed several times: 212.5, 214.0, and 214.87, and finally the legislated WL altitude level was fixed at 213.0. The essential cases of the lowermost level were due to seasonal dryness and the reduced availability of lake water.

4.1.1. Complex Interactions in WL Management

The consequences of the WL change evaluation since the dam operation, followed by the NWC construction and recent combating climate condition changes indicate partial ignorance of the involvement of water quality parameters among the management discretions. The intensive introduction of limnological features such as water quality into the management design considerations was enhanced during drought prior to the intensive supply of de-salinized sea water in 2010. Higher frequencies of drought seasons and lowering WLs strongly motivated national achievements towards the desalinization program. The rationale for it was an extreme decline of the WL, which initiated suspected enhancing nutrient flux from bottom sediments. Consequently, enhanced investments in desalinization plant constructions were promoted. Furthermore, from 2018, the climate conditions were changed into a wet type, a domestic water supply was almost fully achieved and the input of desalinized water into Lake Kinneret initiated a management complexity: the WL is high, availability of water is sufficient and the national domestic water supply comes almost totally from desalinization, and pumping is therefore diminished and the input of desalinized water already performed.

The achievement of desalinization of 650 mcm (10^6 m^3/y) of sea water was initiated as the result of a long period of dryness. Nevertheless, it was predicted to prevent a WL decline below 214 mbsl, accompanied by water exchange enhancement in Lake Kinneret, and reinforcement of the irrigation supply, but increasing WL above 210 mbsl was not considered. The exceptional increase of the WL (>210.5 mbsl) is the result of a high level of rainfall and river discharge.

The question is, therefore: When and how much of the dam should be open? If the WL is high, whilst desalinized water is available and pumping is therefore diminished, management turns toward procedures aimed at the prevention of damage to beach facilities by the appropriately enabled control of salt accumulation. An efficient tool for optimization of WL control is the dam operation and withdrawal enhancement for agricultural irrigation.

The benefit of gradual dam opening is also the shortening of the hydraulic residence time and water exchange enhancement for water quality improvement.

The schematic formulation of the WL management and hydraulic parameters involved is as follows: Evaporation is a natural parameter dependent on climate conditions and, in comparison with the other parameters, its amplitude of changes is negligible:

A = Total Water Input,

Where: A1 natural River Flow; A2 = Desalinized Sea-Water Insert;

B = Total Water Output,

Where: B1 = Evaporation; B2 = Pumping; B3 = Open Dam Spilling;

C = Lake Volume, WL measure (the consequence of C changes is WL fluctuations);

D = Hydraulic Residence Time;

D = C/A = (A1 + A2) minus (B1 + B2 + B3)/(A1 + A2)

Therefore: Increasing A with a decline of C results in an improvement of the water quality by shortening D and the water exchange enhancement;

The decline of C is enhanced by increasing B2 and B3;

The optimization of WL management relies on natural water availability, which is dependent on the climate conditions and pumping regime.

Conclusively, WL management design is comprised of a comprehensive evaluation where priority grading is included.

Since the dam construction at the Kinneret outlet (1933), four long-term periods of prolonged WL decline were recorded: 1988–1991, 1992–2001, 2004–2008 and 2013–2018: The maximum and minimum of the periodical WL amplitude varied between 208.90 and 214.87, respectively; the decline ranged between 4.1–6.0 m, which is 9–13% of the maximum lake depth; the exposed bottom size resulting from the respective WL decline ranged between 7.7–11 km^2, which comprised 4.6–6.5% of maximal lake bottom surface area; and the time duration of the WL decline period varied between 3.4–7.4 years. Though focusing on the limitation to time duration and bathymetric features whilst eliminating hydrological and ecological parameters, the incomparability of Lake Kinneret to the other three SAT lakes is prominent.

Conclusively, during 1933–1948, Lake Kinneret was proposed to supply water for electricity production. From the early 1970s, the lake designation became a water supply. This designated purpose completely dictated WL management. During 1964–2010, three principal factors controlled WL management in Lake Kinneret: water availability (rainfall, river discharge), and water supply demands. Later on, prior to the implementation of the desalinization program, the control parameters became climate condition changes (drought) and salt loads in the lake. Nevertheless, throughout the entire period, the management tools for objective achievements were the aam and NWC constructions.

4.1.2. The Dramatic WL Decline in SAT Lakes

The objective of the dramatic WL decline in SAT lakes was primarily aimed at the enhancement of food production through an increase in water availability and/or fishery. Nevertheless, abortive attempts created unsuccessful results and ecological disasters. The three SAT cases were commonly negatively exemplified and aimed at the objection to WL decline in Lake Kinneret whilst it is actually inappropriate. The dissimilarity between the morphometric structure of Lake Kinneret and Lake Tchad and the Aral Sea makes them incomparable. Moreover, despite the morphometric structures of the Lakes Sivan and Kinneret being somewhat similar, the hydrological modifications are different.

A brief summary of the anthropogenic involvement and the dramatic WL decline in the SAT lakes followed by the consequence responses are briefly presented:

4.1.3. Lake Sevan

The principal limnological features of Lake Sevan before the anthropogenic involvement are [13]: volume—58.5 km^3; water surface—1416 km^2; maximum depth—100 m; and mean depth—41 m. Due to severe regional distress in agricultural land, and available water for irrigation and electricity, a decision was taken to transport water through a tunnel, lower the outlet river from Lake Sevan into the adjacent Ararat valley (1933–1949) and construct Hydroelectric plants. The lake WL decline was intensively implemented between 1933 and 2002, the WL declined by 19.9 m and its volume constricted by 44%, the surface reduced by 13%, and maximum and mean depths were reduced by 20% and 34%, respectively. Similar parameters for Lake Kinneret, but during much shorter periods of 3–4 years (69 years in Lake Sivan), were significantly smaller: 15–23% and 9–13% for the maximum and mean depths, respectively. The hydrological balance was extremely modified: an inflow reduction of 12% with an outflow enhancement by 94% resulted in an annual deficiency of 1258 m^3, in spite of a reduction of evaporation and bottom infiltration. Fishery management became uncontrollable, resulting in overfishing and the introduction of exotic species. Additional deteriorating factors were inputs of an intensive supply of pollutant and waste substance loads from the watershed. The trophic status of the Lake Sevan ecosystem severely deteriorated: the devastation of biodiversity, severe enhancement of primary production, the devastation of natural habitats, and water quality deterioration were the results. In spite of the morphometrical similarity between Lake Kinneret and Lake Sevan, the major differences that deny comparability between the two lake ecosystems are as follows: the amplitude of the WL decline 19.22 m in Sevan; 4–6 m in Kinneret; and the time duration of the change, short (3–4 years) in Kinneret and much longer (69 years) in Sevan. Moreover, fishery (harvest, stocking) in Kinneret is regulated, anthropogenic improvements in the Kinneret drainage basin are thorough, and sewage and agricultural pollutants are removed. The consequent conclusion of the comparative evaluation between lakes Kinneret and Sivan is that mild WL decline during a short time duration is implementable. The incomparability of the WL decline achievement in Lake Kinneret and Lake Sevan is indicated by their morphometric features resulting from a maximal WL decrease of 6.07 m (during 1–3 years) and a 19.22 m (during 1930–2001; 71 years) decline in LK and LS, respectively, given in Table 3 as a range of change in %:

Table 3. The change of morphometric features in Lake Kinneret and Lake Sevan resulted by maximal WL magnitude of decline during 71 years and 1–3 years in Sevan and Kinneret respectively.

Morphometric Parameter	Kinneret	Sevan
Surface	6.55%	12.7%
Volume	22.7%	43.8%
Maximal Depth	12.8%	19.6%

A significant issue that emphasizes the incomparability of the WL decline in LK and LS is fishery: a historical record of 11 exotic fish species stocking in LK was documented as a failure, whilst in LS a similar introduction accompanied by a WL decline crucially damaged the fishery of endemic species. Moreover, the successful introduction of exotic fish species in LK is due to those which are not reproduced in LK and their feeding habits improve the water quality [14,15].

4.1.4. Lake Tchad

The principal limnological features of Lake Tchad are [14–17]: during the early 1960s, the total water surface of Lake Tchad was 25,000 km^2; the depths were 2–4 m and 4–7 m in the southern and northern basins, respectively; the total volume was 72 km^3 (46.7 km^3—northern, 25.3 km^3—southern) and only 40% and 85% annual water exchange in the northern and southern basin, respectively [16–19]. For 50 years (since the early 1970s), a severe drought existed, which was accompanied by anthropogenic water usage intensification, resulting in a drastic WL decline and shrinking of the water surface by 10 times (<2000 km^2) of the original size. Climate condition changes of global warming during 50 years mostly affected the reduction of water inputs and a minority of the impact was due to anthropogenic utilization [19]. During the 1980s, the hydrological balance deficit was due mostly to the dryness effect and partly to human consumption for irrigation and domestic use, taking into account the human population size, as well as its enhancement. During the 1990s, the renewal of water surface enlargement as a result of rainfall and groundwater inputs increased [19].

4.1.5. The Aral Sea

The extremism case resulting from the WL decline in the Aral Sea is known worldwide due to its consequences of ecological, agricultural, fishery, economical, and public health deteriorations [20] A short and brief list of WL decline events are the following: In the early 1960s, the major inflow rivers, Amu Darya and Syr Darya, were totally diverted in an attempt to irrigate cotton, vegetable and cereal production followed by the annual elimination of 20–60 $\times$ 10^6 km^3 from the Aral Sea water budget; as of 1970, the WL decline in the Aral Sea was enhanced annually from 20 to 50–60 and in the 1980s—80–90 cm [20–24]. Conclusively, from 1960 to 1998, a surface area shrinkage of 60% and water volume diminishment by 80% were recorded. Moreover, the water salinity by 1990 upward increased to 376 g/L. The vast capacity of water diversion created a surface water decline, a huge area of bottom sediment exposure, severe human infection by lung disease, loss of fishery harvests, agricultural crop failure, fertilizer and pesticide contamination and the elimination of sea-transport capabilities. The entire Aral Sea region became heavily polluted with the consequences of severe public health damage and infections.

4.1.6. SAT and Kinneret Incomparability

The conceptual prognosis design of the extreme SAT WL decline was similar: long-term enhancement of the irrigation water supply, whilst in Lake Sevan, hydroelectric production as well. The short-term local temporal exception of a 4–6 m WL decline in the deep and bottom steep Lake Kinneret is therefore not comparable to the SAT lakes. The dissimilarities between Kinneret and Sivan are the time duration: 71 years in Sevan and 1–3 years in Kinneret, as well as the WL decline amplitude range: 19.22 m in Sevan and

4–6 m in Kinneret. The morphometric structures of Tchad and the Aral Sea are significantly dissimilar in comparison with Sevan and Kinneret, which are deep and steep bottom lakes, whilst the Aral Sea and lake Tchad are shallow and flat bottom lakes. Therefore, the evaluated factors indicate a significant dissimilarity of implications. The rationale for the dramatic WL decline was the enhancement of food production through irrigation and domestic water supply improvement in all four lakes, the SAT and Kinneret. The morphometric shape of a lake can influence its biological production, whereas the difference between shallow flat and deeply steep bottom lakes creates incomparable conclusions. The significant difference between the morphometric structure of shallow flat (L. Tchad and Aral Sea) and deep steep bottom Lakes (Kinneret and Sivan) is presented by hypsographic curves (Figures 8 and 9). The depth–volume–surface area relations clarify the results of the WL decline in Lake Kinneret (Figure 8) and theoretically in flat-bottom lakes (Figure 9). One meter of WL decline in L. Tchad and/or in the Aral Sea exposes a very large bottom sediment surface, which is subject to dust storms and deposition, which enhance human health difficulties.

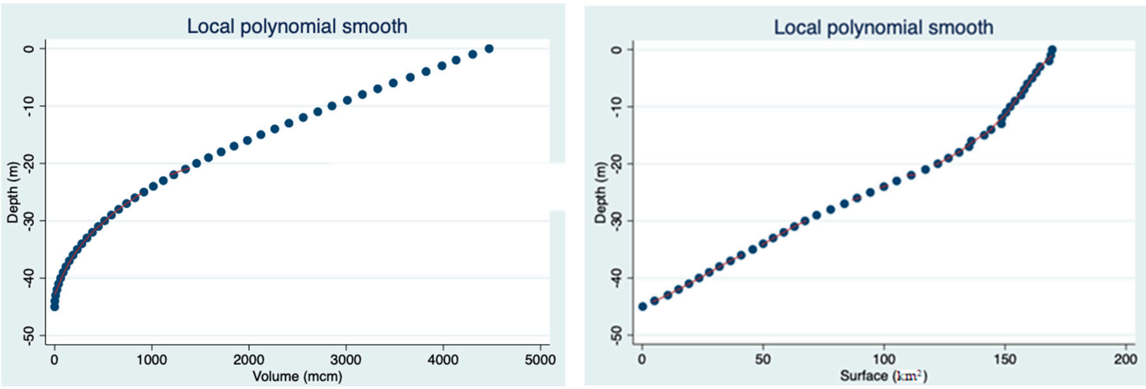

Figure 8. Hypsometric curve of Lake Kinneret: Lake volume (mcm: 10^6 m^3) vs. depth (**left**) and lake water surface (km^2) (**right**) (TAHAL 1961).

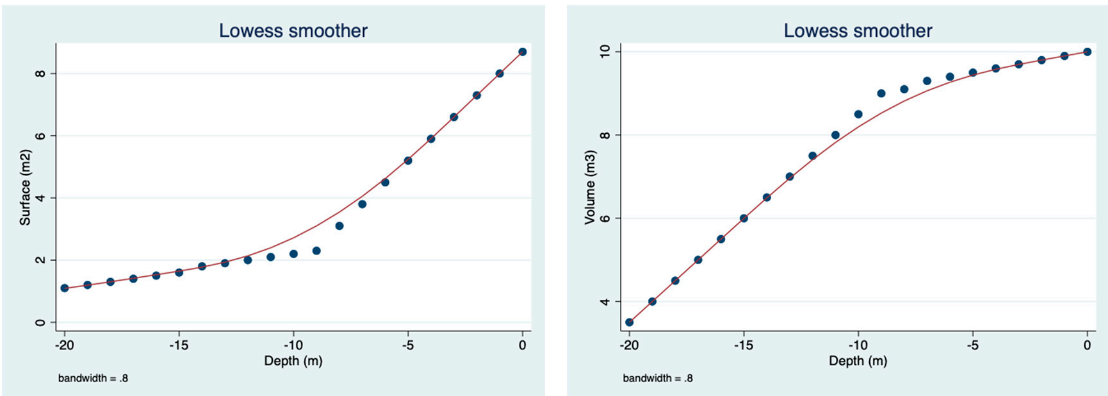

Figure 9. Theoretical (Synthetic values) hypsometric curve in shallow lakes: surface change vs. depth (**left**) gradient is flat in the depth and steeper in the shallows. Vice versa of volume changes (**right**): volume change vs. depth-gradient is flat in the shallows and steeper in the depth.

A speculative and hypothetical indication, partly based on international documents, about the ecological impacts of excessive WL fluctuations (WLF), particularly decline, on the nutrient dynamics and eutrophication in freshwater lakes was published [25]. The consequences of nutrient dynamics in the Kinneret hypolimnion when the WL declines was mentioned earlier in this paper. Nevertheless, further consequent impacts on the water quality in the pelagic epilimnion, or even a trend of temporal eutrophication, are not evidently confirmed [25] as well as in the present paper. Internal loading is tightly associated with thermal structure in lake Kinneret, but epilimnetic consequences are not confirmed [25]. The long-term accumulation of nutrients in the Kinneret ecosystem was not confirmed. LK is not a closed system and intensively interacts with the terrestrial surroundings. Climate changes significantly affected nutrient loading dynamics, and the epilimnetic standing stocks in LK resulted from hydrological features (rainfall, river discharge), but the direct involvement of WLF in it is not confirmed. WLF is undoubtedly affecting the littoral ecosystem [25]; nevertheless, its impact on the pelagic zone is insignificant. The dramatic change of the phytoplankton community structure in LK was widely documented, whilst its relation to WLF was found insignificant. Through the long history (~19,000 years) of the Kinneret ecosystem, WLF events were numerous within a very high range of amplitude, 207–217 [11,12] and 6.57 mbsl (this paper), accompanied by anthropogenic and natural modification, but continuous eutrophication was not confirmed.

5. Conclusive Remarks

A scientifically criticized mutual review in different lakes is justified if comparable parameters are involved. Lake Kinneret, the only natural freshwater lake in Israel, which is dedicated to contributing to ecological services, was in the past and continues presently to be a subject of anthropogenic management. Nevertheless, criticized evaluations of changes in sustainability should be carefully evaluated. Among scientific precautions, the appropriate selectivity of parameters is essential. National constraints forced unpredicted and disputed WL declines in Lake Kinneret, whereas a compromised solution is legitimate if the analyzed parameters are relevant and comparable with other results obtained from other lakes' records. This paper recommends that a case of exceptional WL decline objection, which is confirmed by non-relevant information about extremism, should not be involved. The consequences of an extreme decline in WL in the SAT lakes are therefore not relevant for the consideration of short-term and a smaller range of WL declines in Lake Kinneret. The evaluation of WL decline in Lake Kinneret under climate change conditions with respect to national constraints became essential during four drought seasons in a row, but the SAT cases are not relevant.

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