Roadmap for the Rehabilitation of the Lower Jordan River

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EcoPeace/ Friends of the Earth Middle East
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Executive Summary

The Lower Jordan River is dying. An estimated 97% of its historical flow of some 1,250 million cubic meters (MCM) per year has been diverted by Israel, Syria and Jordan. In large patches of the LJR, there is almost no flowing water. In other parts, the remaining flow is primarily saline and wastewater. The river has already lost 50% of its biodiversity and has essentially been converted into a sewage canal.

This report was initiated by EcoPeace/Friends of the Earth Middle East (FoEME), with the aim of providing decision-makers with a specific, implementable vision for the first phase of a rehabilitation plan for the Lower Jordan River (LJR). This initial phase focuses on the Israeli side of the river between the Sea of Galilee (SoG) and Bezeq Stream (i.e. Upper LJR). All but a small portion of this stretch of the river is shared by Israel and Jordan and the resulting plan will require the approval of the Israeli-Jordanian Joint Water Committee before being implemented in practice.

The required quantities and quality of water for the LJR were identified in FoEME's Environmental Flows report published in 2010. This report concluded that the LJR requires 400 MCM/Yr (less than a third of the historical flow), to be expanded to 600 MCM over time. The river's salinity should be reduced to no more than 750 milligram per liter (mg/L). At least one flood event should be allowed per year with a discharge of approximately 20-50 m^3/s lasting at least 24 hours, totaling to some 4 MCM. Summer flow should reach at least 30% of historical flows. Implementation of this strategy would allow the recovery of stable communities of flora and fauna while achieving a fair to high ecosystem integrity and health.

This goal cannot be met by one country alone and all riparian sides should be involved in the rehabilitation of this important shared natural resource. Out of the historical 1,250 MCM/Yr, some 580 MCM/Yr (46%) has been historically diverted by Israel. Adjustments for socio-economic considerations conclude that Israel should be responsible for returning 54% or 220 MCM of the minimum 400 MCM, Syria 24% or 100 MCM and Jordan 90 MCM at 22%. Palestine would not be asked to contribute water rather it needs to receive a fairer share of Jordan River waters as a riparian to the river.

On this basis, the aim of the paper is to devise viable options for Israel to reintroduce water to the LJR to meet the goal of returning 220 MCM annually, with a minimal flow of 9 MCM/month (3.5 m^3/s) south of Alumot dam and maximum chloride salinity of 750 mg/L.

At present day, no active hydrometric stations exist on the LJR. Therefore, the first stage in this work was to build a computerized model of the basin, using the software WEAP (Water Evaluation And Planning), which is based on the principle of closing the water balance in a basin by drawing a scheme and inserting flow data of all the water sources, reaches, demand sites, etc. The WEAP then calculates flow and salinity in a monthly resolution at different reaches of the LJR and its tributaries. Three scenarios are built in the model:

1. Current Accounts representing the present situation (1996-2010);
2. Zero Scenario (AKA Business As Usual) for the years 2011-2041;
3. Rehabilitation Scenario based on the Zero Scenario with added measures to rehabilitate the LJR.

Each scenario is presented in two chapters. The first deals with the methodology, scope and assumptions that were used to build the scenario. The second presents and discusses the results.

THE LJR – AN INTRODUCTION

Chapter 2 offers a brief description of the LJR followed by a description of the model.

The LJR starts at the southern most point of the Sea of Galilee (SoG) and flows along some 100 km down to the Dead Sea. The meandering length is about 200 km and the total basin area is roughly 15,000 km^2. The Upper LJR stretches from the SoG to Bezeq Stream, with an aerial length of 35 km and a meandering length of 60 km. Hydrologically, the LJR can be divided as follows:

1. Deganiya to Alumot (2 km) – The northern most section lies between two closed dams, but the water level of the SoG since 2006 has been so low that no water could flow out of the lake even if the Deganiya dam was open. A few MCM/Yr are pumped into the reach as it serves as a conduit for local irrigation. This water is stopped at Alumot - a boulder dam that was built to segregate between the fresh water in the north and the saline and polluted water to its south.

2. Alumot to the confluence with the Yarmouk River (6 km) - In this section the main water sources are the Saline Water Carrier (SWC) that discharges some 15 MCM of brackish water, nearly 2 MCM of poorly treated effluents, and a seasonal contribution from Nahal Yavniel.

3. Yarmouk to Harod Stream (15 km) – The Yarmouk, which was once the main tributary of the LJR, is now almost completely dry. Other major streams in this stretch include the Tavor and Issachar Streams. Tavor has some base flow while Issachar is a wadi with only runoff. In this section, substantial volumes of saline groundwater enter the LJR.

4. Harod Stream to Bezeq Stream (14 km) – Harod Stream is today a tributary that still has significant sources of its own contributing some 10 MCM/Yr to the LJR. Along this section lies a valley with dozens of springs that total 80 MCM/Yr. Most of this water is today used, and the greater part of the water that does reach the LJR is agricultural return flows and Fishponds effluents.

The SoG is the largest surface reservoir of fresh water in Israel, responsible for some 20% of the country's water supply. On average, 320 MCM of water are available to the lake annually.

Most of the water comes from the Upper Jordan River (UJR). Since the construction of the Israeli National Water Carrier (NWC) that draws some 290 MCM/Yr on average; the SoG was regarded as an operative reservoir of the Israeli water market with an operational volume of 677 MCM that lies between -208.80 and -213 MSL respectively (between the Bottom and Top Red Lines respectively). The outlet to the LJR at Deganiya lies today at a level of -211 MSL.

The SWC is an artificial conduit, built for the purpose of lowering the salinity of the SoG. It heavily influences the LJR, as below Alumot dam 60-90% of the water comes from the SWC. Its waters originate at two saline springs to the west of the lake. Below Alumot dam, the SWC discharges to the LJR at about 14 MCM/Yr of saline water including:

- Tabgha Spring – 12-14 MCM/Yr with a chloride concentration of 2,000 mg/L;
- Tiberius Hot Springs (THS) – 1-2 MCM/Yr with a chloride concentration of 15,000-18,000 mg/L.

Another saline spring that today still flows to the SoG from the north west is the Foliya, which will be diverted to the SWC in the coming years. Another approved plan is to desalinate some of the water in the SWC, dilute it with the effluents of Bitaniya wastewater treatment plant (the WWTP is currently being upgraded) and use the water for irrigation. The brine will be discharged south of Harod Stream.

The Yarmouk drains about 46% of the basin of the LJR. It flows from the east and forms the border between Syria and Jordan and later between Jordan and Israel, until connecting with the LJR south of Kibbutz Ashdot-Ya'akov. Historically, some 470 MCM/Yr flowed in the Yarmouk, but today, as far as the LJR is concerned, the Yarmouk starts at Adassiya dam, where Jordan diverts most of the remaining water to the King Abdullah Canal (KAC). Consequently, the annual flow downstream to Adassiya has dwindled to less than 40 MCM. Israel uses most of the water before it reaches the LJR.

The LJR receives a significant amount of groundwater, although quantification of the flow is extremely difficult and inaccurate. A research by Farber concluded that downstream of Alumot, groundwater Cl concentration is 1150 mg/L and quantity is between 6 and 24 MCM. Meaning, 12 km downstream of Alumot, about 20-50% (120-450 l/s) of the flow stems from groundwater.

Most of the springs in the basin are concentrated in the south of the Upper LJR, between Harod Stream and Tavor Stream. Historically, this area called "Emeq Hamaayanot" (Valley of Springs in Hebrew) witnessed a gushing forth of some 120 MCM/Yr from about 40 springs, of which 70% came from 5 large springs (Homa, Amal, Shokek, Muda, and Migdal). Today, due to overexploitation, the springs total 60-80 MCM/Yr, most of which is diverted and does not reach the LJR directly.

The bulk of the consumed water in the area (nearly 100 MCM/Yr) is consumed by fishponds that concentrate around Harod Stream and in Emeq Hamaayanot. Fish cultivation is periodical, with most of the effluent being discharged in October-December at which time the ponds serve as a major pollution source to the LJR.

CURRENT ACCOUNTS

The current accounts (CA) model is based on a modification of Assaf Chen, to a model originally made by GLOWA. All the data on the Kingdom of Jordan and the Palestinian Authority was taken from the GLOWA model without alternations. From GLOWA's results, it seems only negligible amounts of water flows from the east to the upper LJR until Wadi Jumrum (opposite and 3 KM North to Bezeq Stream), and that no significant Jordanian consumption directly from the LJR was found. One can say that the Kingdom of Jordan disconnected itself from the Upper Jordan River with the construction of the KAC and dams on all of the main LJR tributaries. Data on the Israeli elements of the model was compiled from various sources including the Israeli Water Authority, Mekorot, local water associations, National Parks Authority, local farmers, literature, etc. The scenario represents the present situation and is largely based on averages of data from 1996-2010.

The methodology of the Current Accounts (CA) construction is detailed in chapter 3. The results, which were calibrated against salinity measurements of the National Parks Authority, are given in chapter 4.

The annual flow upstream of Wadi Jumrum is 71 MCM. The highest flow is in February at 11 MCM, while in June, the flow goes down to 3.3 MCM. The saltiest spot in the Upper LJR is the mouth of the SWC, with an average of more than 2,000 mg/L and typically, salinity falls as we go southwards down to a level of 1,500 mg/L at the confluence with Bezeq Stream. In October-February however, owing to discharges from fishponds, salinity increases below Harod Stream and via Emeq Hamaayanot.

The annual flow at the confluence with Bezeq is 76 MCM. The overall amount of water that enters the LJR south of Alumot is roughly 106 MCM/Yr but by the time the water reaches Bezeq, about 17 MCM are directly pumped out from the river, and 13 more are lost through evaporation. The top five contributors to this flow are:

a. Drainage from Emeq Hamaayanot – 27 MCM;

b. The SWC - 19 MCM;

c.Groundwater (not represented as a tributary in the maps) – 18 MCM;

d. Harod Stream – 13 MCM;

e. Tavor Stream – 8 MCM.

ZERO SCENARIO

The Zero Scenario (ZS) (Figure 2) simulates the forecasted state until 2041, if no action is taken to reinstate water into the LJR, on top of already approved plans (AKA Business As Usual). The scenario is based on several assumptions that are described in chapter 5. The two most important assumptions are the reduced consumption of the NWC and climate change. The later is taken from a work by Rimmer & Givati et.al, and assumes increased evaporation and a long term decrease in the available water to the SoG, with a defined annual variability.

Other assumptions are the addition of artesian wells upstream of the SoG, partial desalination of the SWC with usage of Bitaniya effluents, diversion of the Foliya spring into the SWC, transfer of brine to fishponds in Emeq Hamaayanot, allocation of 14 MCM/Yr from SoG to the LJR, depletion and salination of springs and wells in the basin, reinstating quotas in the Upper Jordan River basin, population growth, and future trends in agriculture including the pending fishery reform.

Results of the ZS show that the next 30 years can be split into three periods:

A. The next decade will be a transition period to the era of desalination in Israel. In that time, the SoG water level will rise on account of the pumping reduction to the NWC, but downstream flow will be minimal. The average annual flow upstream of Bezeq will be 79 MCM.

B. A short period is then expected, when the SoG will already be high, but overspills will still be minimal and sporadic. In the ZS, this period will last five years between 2020 and 2025, when the average annual flow upstream of Bezeq will be 112 MCM.

C. From the mid 2020's on, the SoG will be close to the top red line, and overflows into the LJR will be more common. Drought years could end up with no overflows at all, but in average and above average years overflows will occur. The average annual flow in this period upstream of Bezeq will be close to 177 MCM, with a great annual variability. The maximum annual flow is 399 MCM while the minimal is only 69 MCM.

Comparison to the CA shows flow is expected to more than double in period C, and salinity will somewhat improve, especially upstream of Harod Stream. The two main reasons for the improvement are the return of the overflows from the SoG and the partial desalination of the SWC. Nevertheless, salinity will still be higher than the goal of 750 mg/L, throughout the entire length downstream Alumot, and the average flow at Bezeq will still be 35 MCM short of the goal of 220 MCM/Yr.

In years of extreme droughts in period C, the LJR will resemble the present day situation, with two important differences. First, the annual flow in the upper reaches of the LJR will be higher by 8 MCM, owing to the 14 MCM allocated from the SoG. Downstream at Emeq Hamaayanot, the picture changes and the flow will be lower by 3 MCM than in the CA as a result of the growing water shortage in the area. Second, salinity through the most part will be lower than in the CA, thanks to the partial desalination of the SWC and transfer of the brine to the fishponds of Emeq Hamaayanot. At the inflow points of Yarmouk and Tavor salinity will average 1,148 and 1,101 mg/L respectively (a drop of 700 and 400 mg/L from CA values, even in the driest year). Downstream of Harod however, the picture is more complicated. There, seasonal salinity fluctuations are larger. Throughout the summer, salinity will range from 1250-1300 mg/L, about 300 mg/L lower than the CA on average. In November, when the discharges from the ponds peak, salinity will rise to 2050 mg/L, about 300 mg/L higher than today. The reason is that the bulk of the salt mass from the SWC that today is spread evenly along the year will in the future be put into the ponds and discharged only during a 3 month period (baring leakage).

As far as salinity is concerned, the Upper LJR will be divided at the confluence with Harod Stream. Upstream, overall salinity will drop sharply all year round. Downstream, salinity will remain at the same magnitude from February-September, and increase noticeably in October-January as a result of the emptying of the fishponds in the area, enhanced by the SWC brine that will now serve as a water source to the ponds. Thus, the reach with the sweetest flow in the LJR will be located below the confluence with Tavor Stream.

In rainy years of period C, more than 80% of the flow in the Upper LJR will originate in the SoG. The bulk of the flow will concentrate in February-April, which will also witness a sharp drop in salinity. In other months (May-January) however, even in the rainiest year, there will be no overflow at Deganiya dam. Consequently, the flow at Shifa could drop from 140 MCM in February to 4.9 MCM in June. Should this seasonal variability be mitigated, a change in the operation of Deganiya dam will be needed.

Water demand in the area is expected, at large, to remain the same over the next 30 years. The largest change in consumption will be a drop of 10 MCM/Yr in the demand of fishponds, as a result of the fishery reform. Local water sources however, are expected to dwindle. The available water in Emeq Hamaayanot is expected to drop by 12-18 MCM. The decrease of the natural sources will be higher, but will be somewhat mitigated by the addition of effluents, which by 2040 should amount to 5-6 MCM/Yr, and perhaps the brine from the SWC. Coupled with the decreasing flow, is an increase in the salinity of local springs. The combined effect will bring about an increasing problem to maintain present consumption levels. In dry years the shortage could top 6 MCM/Yr. Supply of fresh water for irrigation will be on the edge as well. The drainage from Emeq Hamaayanot that reaches the LJR will drop by 10 MCM/Yr, as a result of the water shortage.

REINTRODUCTION SCENARIO

The Reintroduction Scenario (RS) is built on the basis of the ZS, with added measures to reintroduce water to the LJR. The measures are defined in chapter 7. One of the measures is changing the operation of Deganiya dam to **release 125 MCM/Yr from the SoG** with a minimum flow of 9 MCM in the summer and a maximum flow of 14 MCM in March. During periods when the lake drops below the bed level at Deganiya dam, the released flow should be halved. If the level of the lake will subside even further to half a meter above the bottom red line, the released flows should be quartered. The model shows that this release **is sustainable in period C**, and that the lake will remain above the bottom red line even in extreme situations.

Besides the operation of Deganiya dam, 10 distinct measures were identified in the RS that aim at increasing flows and reducing salinity in the LJR. Among the most important measures are transferring the SWC brine to the Dead Sea instead of Emeq Hamaayanot, a further reduction in the pumping to the NWC, reducing agricultural consumption in the basin and the fishponds particularly by nearly 50 MCM/Yr by 2020, limiting quotas in the Upper Jordan River, and desalinating 1.5 MCM/Yr more of the SWC water.

The results of the additional measures described above are detailed in chapter 8. For period C, average annual flow at Shifa in the RS is 238 MCM, 18 MCM higher than the FoEME environmental goal. Unlike in the ZS, more than half of the flow originates in the SoG, so the river witnesses significant flows along its entire length, all year round. Average salinity in the RS is fairly even throughout the year and is constantly lower than the environmental goal (although downstream of Emeq Hamaayanot it is tangent). However, average salinity is not enough of an indicator as it has little meaning for the biota vitality in aquatic systems. Instead, one should check the Frequent Maximal Salinity (FMS), which is the average of the maximal values in each year. Until Emeq Hamaayanot, the river's FMS is below 750mg/L. Downstream, the FMS is 753 mg/L but that is well within the error range of the model. Regardless, it is clear that meeting the 750 mg/L line will be very difficult downstream of Emeq Hamaayanot.

On average, flow and salinity meet the environmental criteria in the RS, but what about dry years? In the driest year of period C, flow at Shifa is nearly 100 MCM/Yr less than the average and is well below the desired environmental flow. Nevertheless, it is double the flow in the ZS for the parallel year, so the improvement is significant. As for salinity, throughout most of the year the improvement at Shifa compared to the ZS is in the range of 400-600 mg/L owing to the increased flow and the decreased salinity load from the SWC. In October-January the improvement is most pronounced (up to 1300 mg/L in November) thanks to the attenuation of the fishponds and the transfer of the SWC brine to the Dead Sea. Despite that improvement, the salinity goal set by FoEME is not met for the most part. Downstream of Emeq Hamaayanot, salinity is very high during most of the year (although it stays below 1,000 mg/L). Upstream of Emeq Hamaayanot salinity levels exceed the goal from March to May because of the higher flow of the saline springs nourishing the SWC in these months.

In short, even in the driest of years the LJR shows substantial improvement in RS, **but the environmental goals that can be met on average, will not be achieved in cases of subsequent droughts**. The situation of the river today is grim. If nothing is done in addition to the approved plans (ZS), then the situation will improve but will still be inadequate. If the measures suggested in this paper are taken, then within a period of 10-15 years the LJR can reach a satisfying, albeit not perfect, condition.

The undiscounted direct costs were calculated for each of the measures, including capital investments in new infrastructure, maintenance; and variable costs, which comprise of energy and lost revenues to farmers according to the water usage (fresh irrigation, saline irrigation and fishponds). The real costs were calculated for 30 years (2011-2041) in NIS, according to the values specified in Table 10, assuming an annual discount rate of 4%, with capital costs that are financed through loans for 20 years with an interest rate of 5%. Energy cost was assumed to be 0.45 NIS/kWh. Lost revenues were calculated according to the variable benefits per m^3, multiplied by the difference in the supply to agriculture between the ZS and RS. Only direct costs were taken into account and externalities were excluded (for both benefits and costs).

The net costs and losses in revenues of all the alternatives total to 3.4 billion NIS over 30 years, on top of future costs of ZS, which are split as follows: 730 million in lost revenues for the farmers in the LJR basin, 970 million in lost revenues for the farmers in the UJR basin, 370 million for dealing with the SWC and its brine, 1,300 million to decrease flow in the NWC, and 100 million to transfer effluents from the Kishon Water Works to AMWA. Note that lost revenues will probably be replaced in the long run with other economic possibilities (such as tourism), so putting them together with costs is somewhat skewed.

Once the LJR has been restored to an acceptable degree, its water should allow all forms of saline cultivation. Present day agricultural consumption in Emeq Hamaayanot amounts to 100 MCM/Yr and in the later years of the RS, a 40 MCM/Yr reduction from farmers is needed. Allowing the local water association to pump those 40 MCM from below the confluence with Bezeq for the purpose of saline agriculture (not fishponds) could compensate local farmers with a net worth of 600 million NIS, reducing the 'total cost' of rehabilitation to 2.8 billion NIS over the next 30 years. The sensitivity of soils in the "new" fields to saline water should be examined prior to implementation. The return flows would increase salinity in the river so both the pumping and the drainage of the fields should be located as southwards as possible to minimize the effect upstream of Bezeq. Water can also be used for saline irrigation south of Bezeq Stream, in the Jordan Valley region. Best results would be achieved if the water is pumped upstream of Adam (Damya) Bridge, and even upstream of Wadi Kharuba, because of the gradual salination of the river as a result of salty groundwater in the area.

CONCLUSIONS

Today, the condition of the LJR is grim with flows that equal 2% of the historical flow and high levels of pollution and salinity in the river. In the next 30 years, the situation is expected to improve with the rise in the water level of the SoG and the partial desalination of the SWC. In the 2020's overspills of the SoG will even return instances of high flows to the LJR, albeit not in the same magnitude as historical flows.

Salinity wise, the river will be split at Harod Stream as a result of the SWC brine being transferred to Emeq Hamaayanot and the fishery reform. Upstream of Harod, the LJR will be sweetened to about 1,300 mg/L. Between Harod and Bezeq, the LJR's salinity will increase sharply, especially at autumn and early winter when it can top 2,000 mg/L, unless the brines will be transferred to the Dead Sea.

The object of this paper is to provide a roadmap for the initial phase of the rehabilitation of the LJR, by suggesting implementable measures to reintroduce water and reduce pollution in the river from the Israeli side. The first recommendation is to change the operation of the Deganiya dam after the rise in the SoG. The anticipated improvement is not enough to sustain a healthy biological system in the LJR and further actions will be needed. **The combination of measures that is suggested in this paper could, within 10-15 years, bring the LJR to an adequate environmental condition.**

Although on average the environmental goals are achievable, in drought years, especially if consecutive, that will not be possible. Meeting the salinity goal of 750 mg/L will be most difficult downstream of Emeq Hamaayanot and perhaps downstream of Harod Stream. Having said that, the proposed plan will greatly improve the condition of the LJR even in the driest of years to a level that could probably sustain the ecological system to a degree that it could quickly recover in average years.

Part of the proposed plan includes cutting back existing water rights in the area. Much of the water reintroduced into the LJR could be reused downstream of Bezeq Stream and even in Emeq Hamaayanot, as the expected quality should allow all forms of saline irrigation. Utilization of 40 MCM/Yr from the LJR should offset most of the reduction in water quotas in the LJR basin.

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Abbreviations and Units

AMWA	Afikey Maim Water Association
CA	Current Accounts
ET	Evapotranspiration
FMS	Frequent Maximal Salinity
FoEME	EcoPeace/Friends of the Earth Middle East
IWA	Israeli Water Authority
JVWA	Jordan Valley Water Association
KAC	King Abdullah Canal
kWh	Kilowatt Hour
L/s	liter per second
LJR	Lower Jordan River
m3/s	cubic meter per second
MCM	Million Cubic Meters
mg/L	milligram per liter
MSL	Mean Sea Level
NIS	New Israeli Shekel
NPA	National Park Authority
NWC	National Water Carrier
RS	Reintroduction Scenario
SoG	Sea of Galilee
SWC	Saline Water Carrier
THS	Tiberius Hot Springs
UJR	Upper Jordan River
WW	Wastewater
WWTP	Waste Water Treatment Plant
ZS	Zero Scenario

1 Introduction

This report was initiated by EcoPeace/Friends of the Earth Middle East (FoEME), with the aim of providing decision-makers with a specific, implementable vision for the first phase of a rehabilitation plan for the Lower Jordan River (LJR). Full rehabilitation of a river is an endeavor engulfing various fields. This report presents a roadmap for the first phase of reintroducing water to the LJR. This initial phase focuses on the Israeli side of the river between the Sea of Galilee (SoG) and Bezeq Stream (i.e. Upper LJR). All but a small portion of this stretch of the river is shared by Israel and Jordan and the resulting plan will require the approval of the Israeli-Jordanian Joint Water Committee before being implemented in practice.

1.1 Background

The Lower Jordan River is dying. 97% of its historical flow of some 1,250 million cubic meters (MCM) per year (see Figure 1 below), has been diverted by the countries of Syria, Jordan and Israel. In large patches of the LJR, there is almost no flowing water. In other parts, the remaining flow is primarily saline and wastewater. The river has already lost 50% of its biodiversity and has essentially been converted into a sewage pipeline.

The countries of the region have expressed interest in the rehabilitation of the LJR. Within Israel, this willingness has come to expression in a variety of different fashions. First and foremost, within the context of the 1994 Peace Treaty, the countries of Israel and Jordan signed a commitment to cooperate towards the ecological rehabilitation of the LJR. Second, representatives from several government ministries in Israel, Jordan and the Palestinian Authority have met on both a national and regional level to discuss their joint interest in revitalizing the river. Third, the Knesset issued a committee resolution calling on the Prime Minister to make rehabilitation of the Lower Jordan River a national priority. Finally, the Water Authority has included an expression of its willingness to rehabilitate the river as part of its Long Term Master Plan for Managing the Israeli Water Economy.

Three primary obstacles stand in the way of adopting a plan to rehabilitate the LJR. (1) water scarcity, (2) the political context, and owing in large part to the previous two, (3) the absence of a comprehensive plan which addresses the needs of the different riparian nations on the one hand and the ecological needs of the river on the other. The aim of this work is to begin the process of overcoming these obstacles by providing a vision for the river's rehabilitation which factors in (a) the ecological needs of the river, (b) the realities and constraints of the Israeli water economy and its hydrological context, and (c) the water needs of Israel as one of the riparian countries.

1.2 Recommended Environmental Flows

The required quantities and quality of water for the LJR were identified in FoEME's Environmental Flows report published in 2010 [1]. This report concluded the LJR requires 400 MCM/Yr (less than a third of the historical flow), to be expanded to 600 MCM over time. The river's salinity should be reduced to no more than 750 milligram per liter (mg/L). The amount of effluent should not exceed 25% of the total flow, not counting cycling of water. At least one flood event should be allowed per year with a discharge of approximately 20-50 m^3/s lasting at least 24 hours, totaling to some 4 MCM. Summer flow should reach at least 30% of historical flows. Implementation of this strategy would remove most of the disturbances, restore the river's structure and function, allow natural riparian plant communities to recover and restore stable communities of flora and fauna while achieving a fair to high ecosystem integrity and health.

This goal cannot be met by one country alone and all riparian sides should be involved in the rehabilitation of this important shared natural resource. To determine the share each riparian should be responsible for returning to meet this rehabilitation goal FoEME determined two criteria:

1. How much each country was diverting and;
2. Socio-economic considerations.

Out of the historical 1,250 MCM/Yr, some 580 MCM/Yr (46 %) has been historically diverted by Israel. Adjustments for socio-economic considerations conclude that Israel should be responsible for returning 54% or 220 MCM of the minimum 400 MCM, Syria 24% or 100 MCM and Jordan 90 MCM at 22%. Palestine would not be asked to contribute water rather it needs to receive a fairer share of Jordan River waters as a riparian to the river.

On this basis, the aim of the paper is to devise viable options for Israel to reintroduce water to the LJR to the meet the goal of returning 220 MCM with a minimal flow of 9 MCM/month (3.5 m^3/s) below Alumot.

1.3 The WEAP model

At present day, no active hydrometric stations exit on the LJR. Therefore, the first stage in this work is to build a model of the basin. The model itself will be built using the software WEAP (Water Evaluation And Planning), which is based on the principle of closing water balance in a basin by drawing a scheme and inserting flow data of all the water sources, reaches, demand sites, etc. Three scenarios are built in the model:

4. Current Accounts representing present situation (2010);
5. Zero Scenario (AKA Business As Usual) for the years 2011-2041;
6. Rehabilitation Scenario based on the Zero Scenario with added measures to rehabilitate the LJR.

Each scenario is presented in two chapters. The first deals with the methodology, scope and assumptions that were used to build the scenario. The second presents and discusses the results.

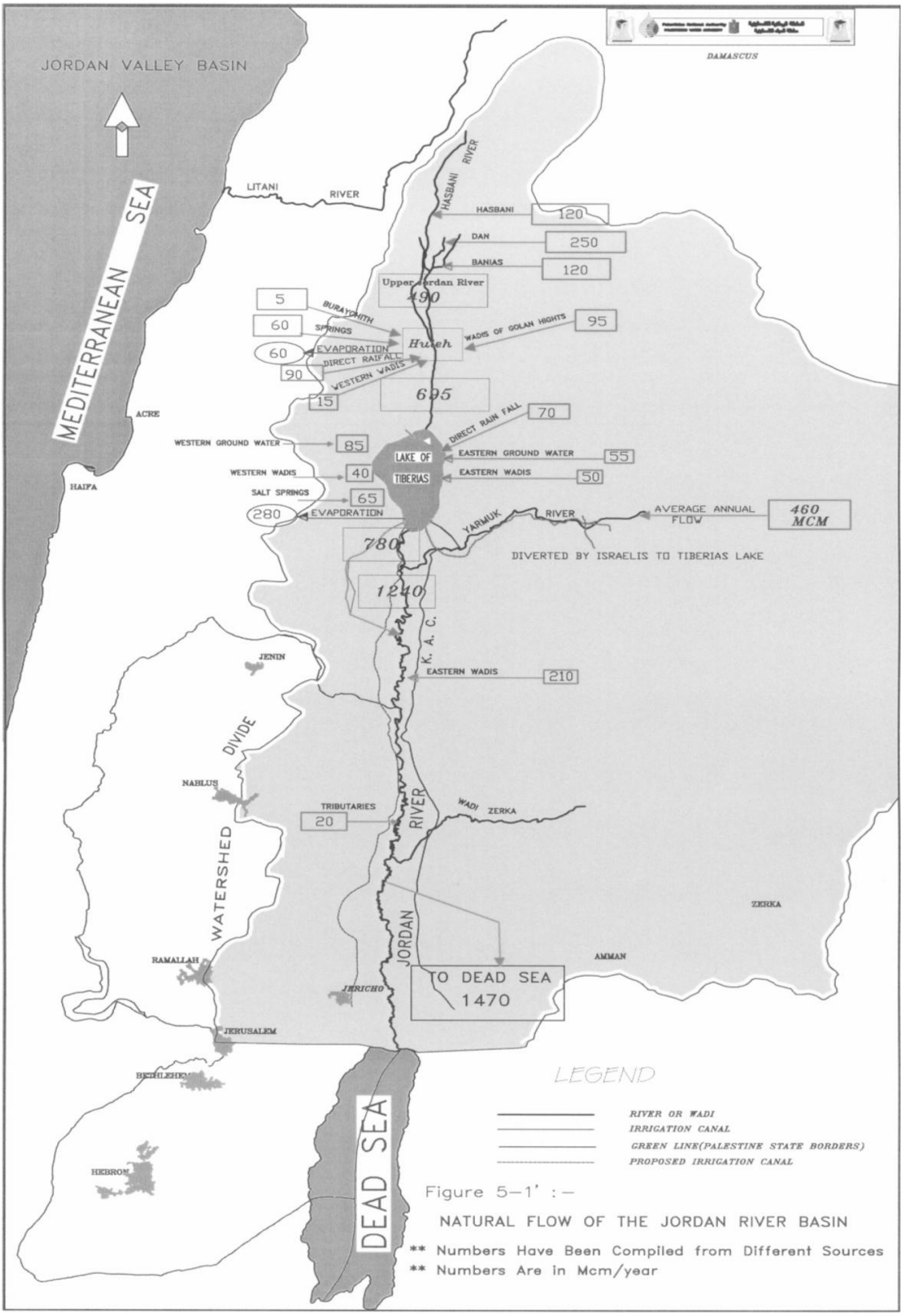


Figure 1: Natural historical flows in the Jordan River [2]

2 Lower Jordan River – Present State

This chapter refers to the current situation of the water flow in the LJR, as a preparation for the model description in chapter 3. Therefore, the chapter briefly introduces the different sections of the LJR, the surface water sources, groundwater, salinity and consumption. The project, including this chapter, focuses on the flows from the Israeli side. Historical accounts and elaborate descriptions of the basin as a whole may be found in numerous reports among them are: [1], [3] and [4] in the bibliography at the end of the report.

2.1 Flow Scheme

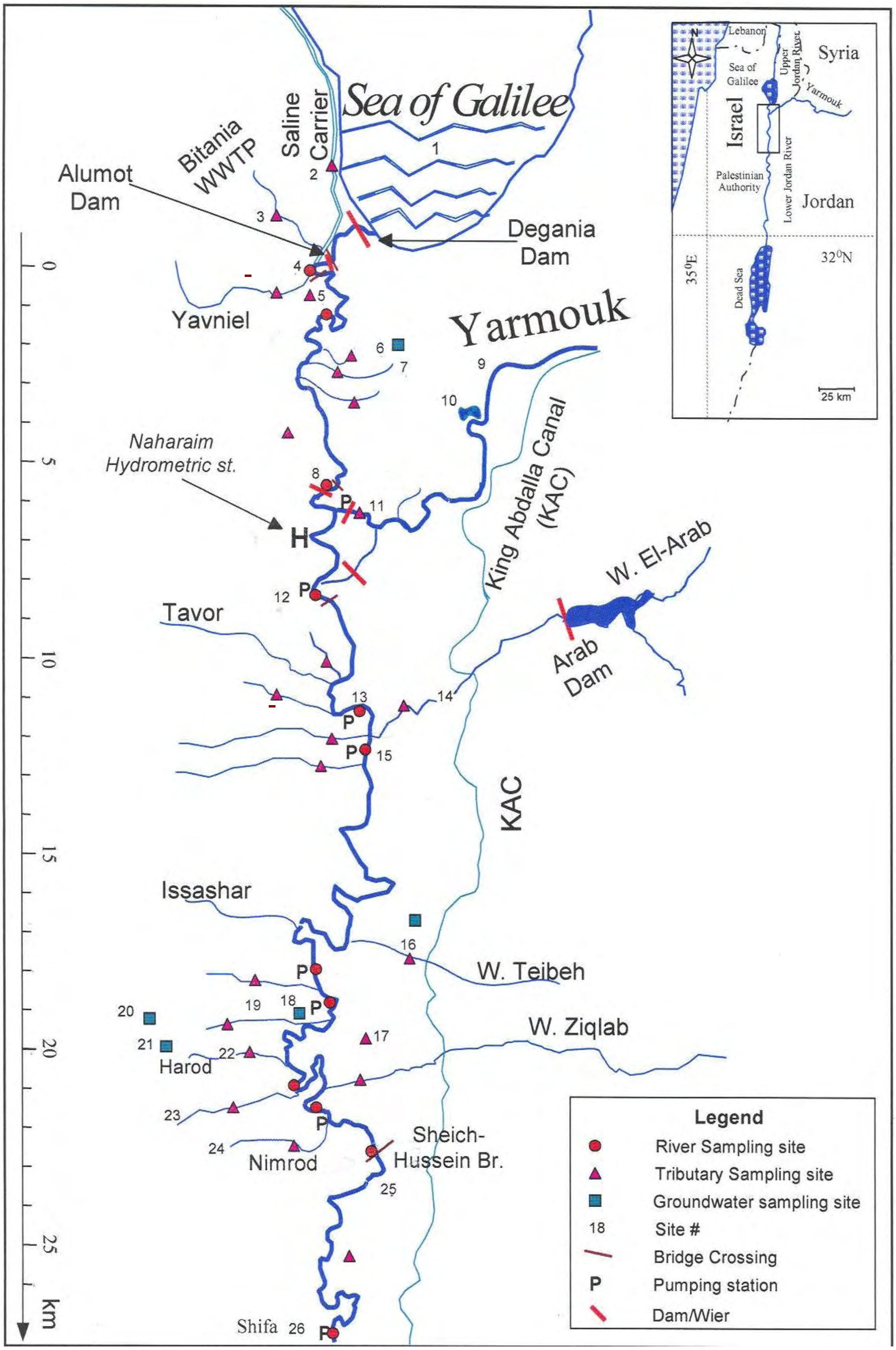
Figure 2 in the next page presents a flow scheme of the LJR. The LJR starts at the south most point of the SoG (Lake Kinneret) and flows along some 100 km down to the Dead Sea. The meandering length is about 200 km and the total basin area is roughly 15,000 km^2 [5]. The Upper LJR stretches from the SoG to Bezeq Stream, with an aerial length of 35 km and a meandering length of 60 km. Hydrologically, the LJR can be divided as follows:

5. Deganiya to Alumot (2 km) – The north most section lies between two dams: Deganiya and Alumot. Deganiya dam is closed, but as the level of the SoG since 2006 has dropped below -211 [6], which is the artificial level of the river bed, no water could flow out of the lake even if it was open. A few MCM/Yr are pumped from the SoG pass Deganiya dam, as the section serves as a conduit for local irrigation. This water is stopped at Alumot [1] - a boulder dam that was built to segregate between the fresh water in the north and the saline and polluted water to its south [4]. This part is disconnected from the rest of the LJR and in fact, serves as an extension of the SoG.

6. Alumot to the confluence with the Yarmouk (6 km) - River starts from zero here. The main sources are the Saline Water Carrier that discharges some 15 MCM of brackish water, Bitaniya Wastewater Treatment Plant (WWTP) that discharges nearly 2 MCM of poorly treated effluents, and a seasonal contribution from Nahal Yavniel.

7. Yarmouk to Harod Stream (15 km) – The Yarmouk, which used to be the main tributary of the LJR, has gone almost completely dry. Other major streams are Tavor Stream and Issachar Stream. Tavor has some baseflow while Issachar is a wadi with only runoff.

8. Harod Stream to Bezeq Stream (14 km) – The first tributary that today still has significant sources of its own is Harod Stream that contributes some 10 MCM/Yr. Along this section lies a valley with dozens of springs that total to 80 MCM/Yr. most of the water is used today and doesn't reach the LJR.


Sea of Galilee
Saline Carrier
Bitania WWTP
Alumot Dam
Degania Dam
Yarmouk
Yavniel
Naharaim Hydrometric st.
H
King Abdalla Canal (KAC)
W. El-Arab
Arab Dam
Tavor
KAC
Issashar
W. Teibeh
W. Ziqlab
Harod
Nimrod
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km
N
Lebanon
Syria
Sea of Galilee
Upper Jordan River
Yarmouk
Israel
Palestinian Authority
Lower Jordan River
Jordan
35°E
32°N
Dead Sea
25 km
Legend
River Sampling site
Tributary Sampling site
Groundwater sampling site
18 Site #
Bridge Crossing
P Pumping station
Dam/Wier

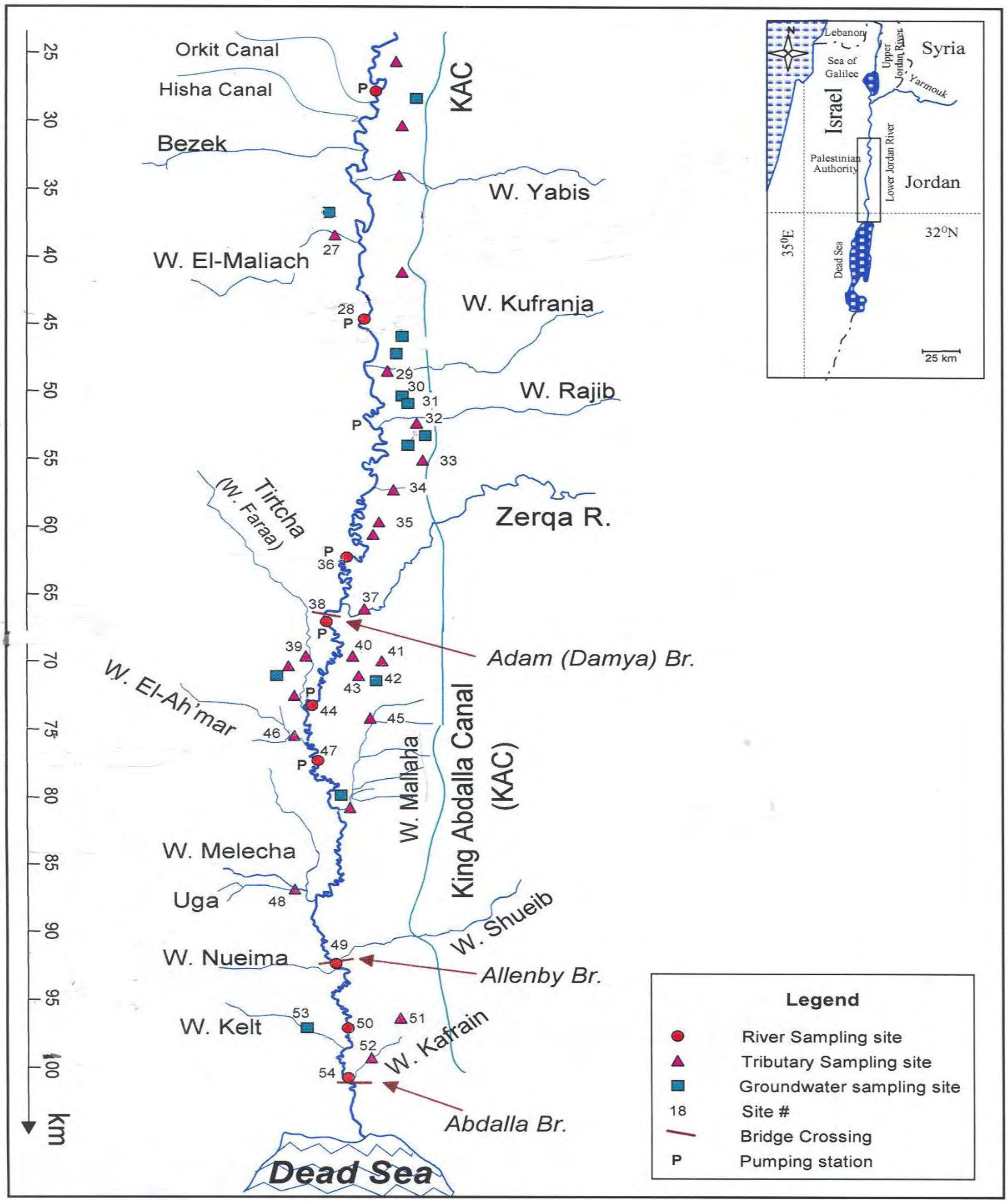

Figure 2: Flow Scheme of the upper (A) lower (B) LJR [3]

2.2 Surface Water

The surface water in the basin can be classified according to their origin:

- Sea of Galilee
- Saline Water Carrier
- Western Streams

- Yarmouk River

Other eastern streams are not mentioned here, as essentially no water flows to the LJR from the Kingdom of Jordan today, following the construction of the King Abdullah Canal (KAC).

2.2.1 Sea of Galilee

The SoG is the largest surface reservoir of fresh water in Israel, responsible to some 20% of the country's water supply. On average, 320 MCM of water are available to the lake annually (Inflows minus evaporation, see water balance of the SoG in section 3.2). Most of the water comes from the Upper Jordan River (UJR), which is in itself, a fairly complicated system. This paper however, deals with the LJR and so, will treat the SoG as a reservoir.

As such, the lake can be viewed as a reservoir with a volume of 4,340 MCM (depending on the operation), of that the operational volume of 677 MCM. The very bottom of the lake is at -255 below Mean Sea Level (MSL), while the operational volume lies between the upper and lower red lines (-208.80 and -213 MSL respectively) [7 ;6].

Since the construction of the Israeli National Water Carrier (NWC) that draws some 290 MCM/Yr on average, the SoG was regarded as an operative reservoir of the Israeli water market. The outlet to the LJR lies today at a level of -211 MSL. Since 1994, the SoG has been is constantly below that level and so, no water flows naturally from the lake southwards [6].

The tendency in the new master plan of the IWA (which has not yet been approved), is to abandon this old concept and regard the SoG as integral part of the nature of the land and as a valuable ecological system in its own right. In that view, the lake should first meet its ecological and economic needs that serve the general public and only after fulfilling this part, it will be used as an operative reservoir as well [8].

2.2.2 Saline Water Carrier

The Saline Water Carrier (SWC) that is shown in Figure 3 below is an artificial conduit, built for the purpose of lowering the salinity of the SoG. It carries water from two saline springs (and some wastewater from the town of Tiberius) to the west of the lake. Below the Alumot dam, the SWC discharges to the LJR, about 14 MCM/Yr of saline water as follows [9]:

- Tabgha – 12-14 MCM/Yr with a chloride concentration of 2,000 mg/L;
- Tiberius Hot Springs (THS) – 1-2 MCM/Yr with a chloride concentration of 15,000-18,000 mg/L.

The SWC influences heavily the LJR as below Alumot dam, 60-90% of the water comes from the (SWC) [3]. Additional effluent of nearly 2 MCM/Yr of poorly treated wastewater is discharged near the outlet of the SWC, Bitaniya WWTP. The SWC also discharges at a rate of 500-1,000 m^3/day to the LJR above the Alumot dam [4].

Another saline spring that today still flows to the SoG at its north west is the Foliya. In the future, this spring will be diverted to the SWC, and contribute 10 MCM/Yr with a Cl concentration of 2,200 mg/L [9]. Another approved plan is to desalinate some of the water in the SWC, dilute it with the effluents of Bitaniya (The WWTP is being upgraded these days) and use the water for irrigation. The brine will be discharged south of Harod Stream [10].

Figure 3: The SWC near Alumot dam

2.2.3 Western Streams

5 major streams flow to the Upper LJR from the west (From north to south) [11]:

- Yavniel:
    - Basin Area – 106 km2
    - Length: 17 km
    - Beginning at: west to the town of Tiberias
    - Ending at: south to Alumot Dam
    - No permanent springs [4], although there are some seasonal springs that are not surveyed [10]
- Tavor [11]:

  - Basin Area – 208 km2
  - Length: 25 km
  - Beginning at: east to the town of Nazareth
  - Ending at: east to Belvoir Fortress
  - 5 large springs with a total volume of 2.8 MCM and Cl concentration of 200 mg/L. some is taken today for local use as drinking water although a plan exists to release all the water to the river again [12].
- Issashar [11]:
  - Basin Area – 66 km2
  - Length: 22 km
  - Beginning at: east to the village of Tamara
  - Ending at: south to the Kibbutz of Beit Yosef
- Harod[13] - The largest of the western tributaries. Its basic flow of 65 MCM/Yr stems from a series of springs. The production of some of those springs shows a declining trend in recent years due to production from the aquifer being constantly higher than the natural replenishment:
  - Basin Area – 195 km2
  - Length: 32 km
  - Beginning at: east to the town of Afula
  - Ending at: east to the town of Beit-She'an
  - Several Springs that total to 60 MCM, most are taken for irrigation [11].
- Bezeq:
  - Basin Area – 220 km2
  - Length: 25 km
  - Beginning at: the Palestinian village of Raba
  - Ending at: east to the Kibbutz of Tirat-Zvi

On top of that numerous small wadis and canals drain to the LJR and are not measured, although at times they could show significant flow [14].

2.2.4 Yarmouk

The Yarmouk drains about 46% of the basin of the LJR [5]. It flows from the east and forms the border between Syria and Jordan and later between Jordan and Israel, until it connects with the LJR south of the Kibbutz of Ashdot-Ya'akov. Historically, some 470 MCM/Yr flowed in the Yarmouk, but today practically all the water in the upper basin is used by Jordan and Syria who built a series of dams on the Yarmouk. The last and largest, the Unity dam, was completed in 2007 [1].

As far as the LJR is concerned, the Yarmouk starts at Adassiya dam, where Jordan diverts most of the remaining water to the KAC. According to the peace agreement with Jordan, Israel is permitted to withdraw 25 MCM/Yr from the Yarmouk with an additional amount of water to be diverted to the SoG. Consequently, the annual flow downstream to Adassiya has dwindled down to less than 40 MCM, where Israel uses most of the water before it reaches the LJR. Salinity at the confluence with the LJR, inversely to the quantity of water, has risen up to an average of more than a thousand mg/L of chlorides [15].

2.3 Groundwater

The Jordan rift valley forms a complicated geological system. As a result, groundwater flow in the region is complicated as well, as can be seen by the sub-aquifers map in Figure 4 below. Note that each of the 5 sub-aquifers is also divided into cells. While the Aquifers, sub aquifers and even the aquifer cells in the region are well defined, the quantification of relationships between them remains a mystery.

The LJR receives a significant amount of groundwater through direct contact, although quantification of the flow is extremely difficult and inaccurate. A research by Farber that is based on solute mass balances concluded that downstream of Alumot, groundwater Cl concentration is 1150 mg/L and quantity is between 6 and 24 MCM. Meaning, 12 km downstream of Alumot, about 20-50% (120-450 l/s) of the flow stems from groundwater [3].

2.3.1 Springs in Harod Stream and Emeq Hamaayanot

Evidence to the complexity of the system, is a group of springs south to Harod Stream. Although the springs in the group span over only 2.5 km, and gush at about the same elevation; the Cl concentration of the different springs range between 100 and 1500 mg/L. Those four and other springs combine to a natural yield of some 58 MCM/Yr on average in the Harod basin. Some of the known springs of the Harod are not monitored and their flow is unknown, so it is likely that the natural yield is higher. The hydrometric station on Harod records however, only 9.8 MCM/Yr, with a strong decreasing trend. That suggests growing consumption from the springs nourishing the Harod and/or constant consumption that is larger than the natural replenishment. As a result, many of the springs show a continuing trend of salination, that should it be allowed to continue, could affect future consumption.

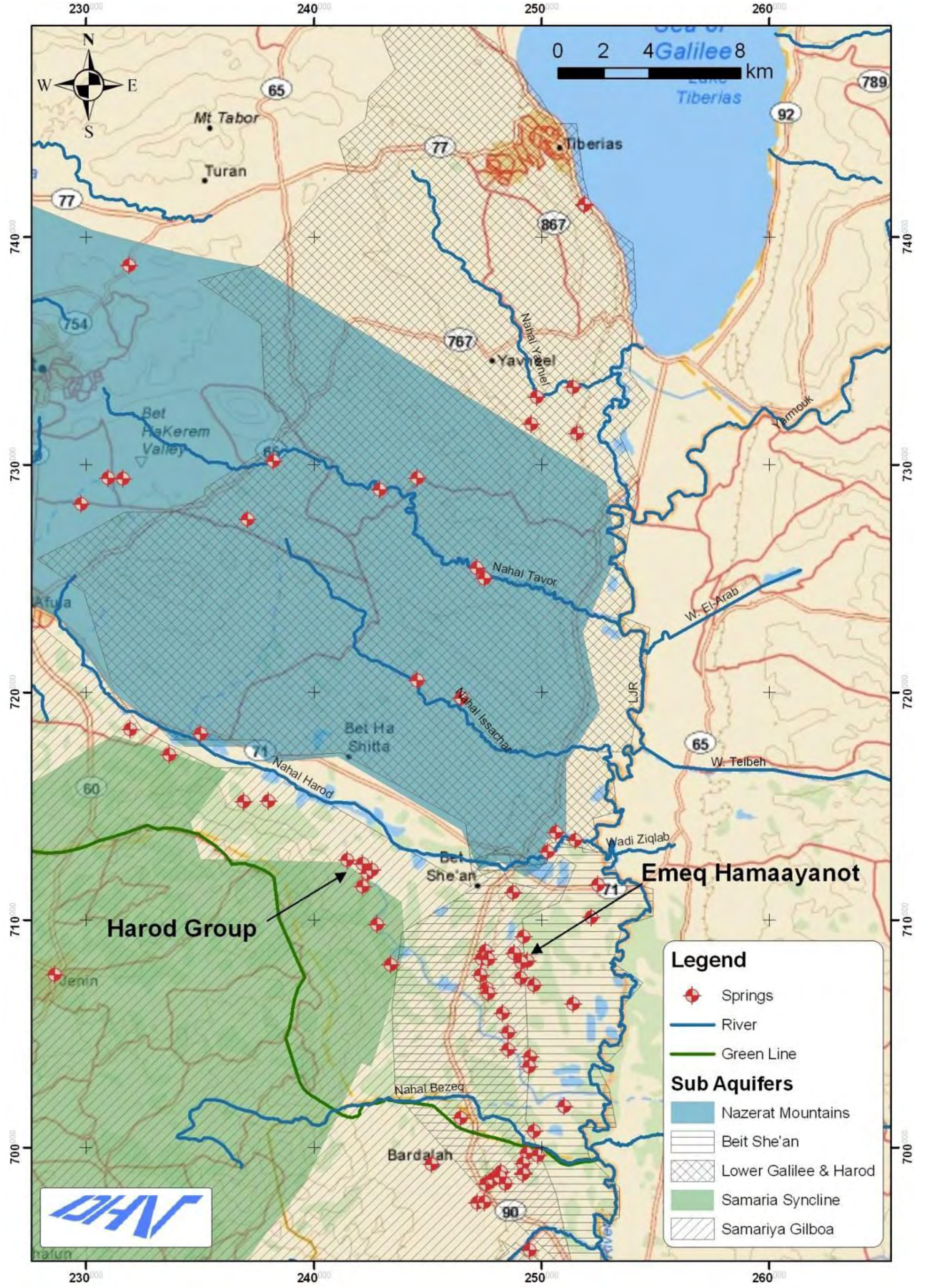

Figure 4: Sub aquifers and springs

Most of the springs are concentrated in the south of the Upper LJR, between Harod Stream and Tavor Stream. Historically, this area is called "Emeq Hamaayanot" (Valley of Springs in Hebrew), witnessed a gushing forth of some 120 MCM/Yr from about 40 springs. Of which 70% came from 5 large springs (Homa, Amal, Shokek, Muda, and Migdal) [16]. Today, due to overexploitation, the springing amounts to 60-80 MCM/Yr out of 30 springs. Most of it is being diverted and does not reach the LJR directly (see section 2.5 below) [17]. In that area, there is some contradiction between the data of the IWA and data of the local water association.

2.4 Salinity

The main parameter that characterizes the water quality in this work is salinity, which is characterized by concentration of chlorides (Cl) as milligrams per liter (mg/L) or millimoles. In this report, chlorides concentration and salinity are interchangeable. Salinity is used for two reasons:

- It is a parameter that does not undergo processes of decay or is taken by the biota, and can be modeled by using mass balance.
- Other "classic" pollutants (like organic pollutants and nutrients) can be relatively easily removed from water and/or diminish in aquatic environments. Salinity on the other hand, requires desalination to be removed and is often the limiting factor in the development of a habitat.

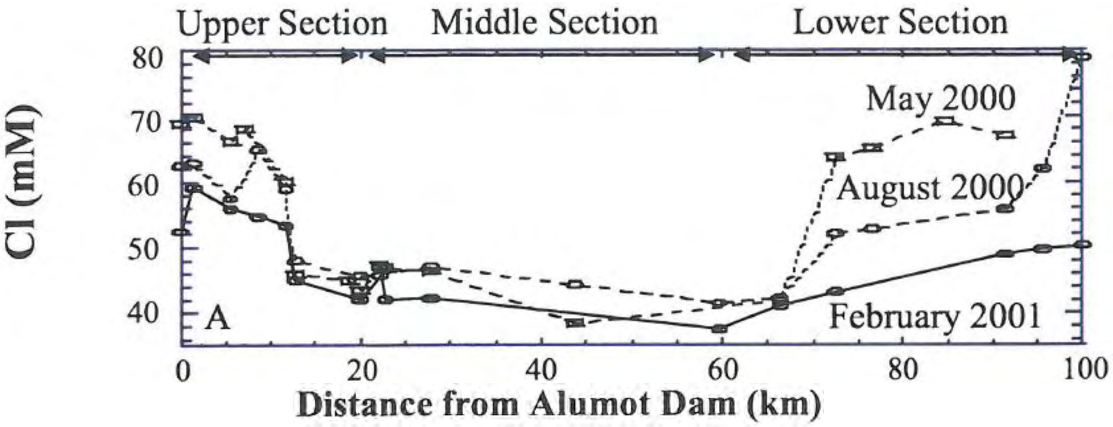

Figure 5: Chloride molar concentration along the LJR, distance refers to km from Alumot dam [3]

Figure 5 shows the salinity along the LJR. The X axis denotes kilometers whereas Alumot dam is the starting point and the Dead Sea, after a 100 km, is the ending point. Around Alumot, the salinity goes up to 2300 mg/l. Actual Salinity would have been higher if Mekorot (the Israeli national water company) wouldn't have added water from local fresh wells, to dilute the SWC for operational purposes.

20 km downstream, the salinity decreases to 2000 mg/L, thanks to contribution of groundwater. At the southernmost point in the LJR – the Abdullah Bridge, the historical Cl concentration at the beginning of the 20th century was 400 mg/l. Today it ranges between 1500-2500 mg/l during most of the year and can reach up to 5400 mg/l [3].

2.5 Israeli Water Consumption

This paper deals with water re-introduction to the LJR from Israeli sources and therefore, the discussion here focuses on Israeli consumption. The Israeli consumption that affects the LJR can be largely divided into 4 groups:

- Consumption at the UJR basin – roughly estimated at 70-150 MCM/Yr
- Consumption from other parts of the SoG drainage basin (parts of the Golan Heights and the Eastern Galilee) – not considered in the framework of this study.
- The National Water Carrier (NWC) pumping water from the SoG and transferring it southwards to other regions in Israel – about 290 MCM/Yr
- Direct local consumption from the SoG – about 89 MCM/Yr including 50 MCM/Yr that are transferred to the Kingdom of Jordan according to the peace agreement.
- Local consumption at the basin of the LJR from Alumot dam to Bezeq Stream – about 196 MCM/Yr

The average annual Israeli consumption in the basin, other parts of the SoG basin and pumped wells, is 595 MCM/Yr (645 minus the 50 MCM that are transferred to Jordan).

2.5.1 The National Water Carrier

The NWC transfers water from SoG southward to the population centers of Israel. On an average year, it draws 290 MCM, with a great annual variability, depending on the rain. In 2004, which came after the wet winter of 2003, 525 MCM were pumped from the SoG to the NWC. Just 2 years before that, in 2002 when the water level at the lake approached the black lines, the NWC transferred only 152 MCM [6]. As desalination of sea water progresses, the expectation is that water transfer from north to south will decrease and possibly cease altogether.

2.5.2 Direct local consumption from the Sea of Galilee

The settlements around the SoG pump water directly from the lake, mainly for irrigation. Mekorot, the Israeli national water company, pumps some 60 MCM/Yr from the lake, just before Deganiya dam. 50 MCM of that water are allocated to Jordan according to the peace agreement and are diverted to the KAC. Hence, the net Israeli consumption directly from the SoG (excluding the NWC and including the JVWA) amounts to 39 MCM/Yr.

2.5.3 Local consumption at the LJR basin

Most of the water that is consumed in the basin of the LJR is taken by two large water associations:

- Jordan Valley Water Association (JVWA) – extracts about 40 MCM/Yr mainly from the extension of the SoG north to Alumot dam and the Yarmouk. The association supplies water to 12 villages situated south of the SoG. About half of the taken water is diverted to the SoG [10].

- Afikey Maim Water Association (AMWA) – extracts 90-100 MCM/Yr from local springs, drills and some direct pumping from the LJR. It lies in the broad area of "Emeq Hamaayanot" regional council, stretching from Neve-Ur in the North and down to the Green Line in the South [17].

The area is heavily cultivated and so, the bulk of the consumption is used for irrigation and fishponds. The main water consuming crops in the area are bananas, avocadoes and field crops (JVWA) and wheat, dates and Lucerne (AMWA). The consumption given here includes effluents, although in this particular region of Israel, its share is less important (currently, less than 5 MCM/Yr).

Fishponds are pivotal to understanding the local consumption and water balance in the LJR. On average, a fishpond requires 3-6 MCM per km2. Since most of the ponds in the area were constructed without lining, water losses by percolation are estimated at 20-50% of the water put in the ponds, most, if not all finds its way to the LJR. Another 40-50% is lost to evaporation and the rest is discharged back to the river as saline polluted effluent. The surface area of fishponds in the region totals to 18.4 km2, which means a combined consumption nearly 100 MCM/Yr. Most of the fishponds – 16.8 km^2, are concentrated around Harod Stream and in Emeq Hamaayanot (Figure 19 at page 59). Fish cultivation is periodical with most of the effluent being discharged in October-December [17]. In Emeq Hamaayanot there is also some discharge in January-February [18].

That consumption is facilitated by a series of reservoirs. Typically, the reservoirs serve a dual purpose of operational storage and fish cultivation. Each reservoir is designated for a specific water quality. For example, the AMWA maintains a total storage capacity of 32 MCM as follows [17]:

- 5 MCM for fresh water (under 500 mg/L Cl).
- 2 MCM for treated wastewater (WW) – namely from the newly built WWTP of Beit-She'an, which produces 0.7 MCM/Yr.
- 25 MCM for saline water that come from local springs.

3 Current Accounts model

A preliminary step to devising future alternatives is creating a model of the present state. This chapter describes the methodology of modeling. The model itself was built with the software WEAP (Water Evaluation And Planning), which is based on the principle of closing the water balance in a basin. The modeling effort consists of the following steps:

1. Definition of scope and working area
2. Data collection on flows, consumption, sources and quality of water
3. Processing the data
4. Drawing a flow scheme
5. Calibration
6. Analysis of results

The model is based on a modification by Assaf Chen a model originally made by GLOWA. All the data on the Kingdom of Jordan and the PA was taken from the GLOWA model as is, with linear extrapolation (using either Forecast or Linest functions in Excel, depending on the case) or averaging monthly variations for the future, when the data was available only to some of the required years. Having said that, from the results of GLOWA it seems only negligible amounts of water flow from the east to the upper LJR until Wadi Jumrum, and that no significant Jordanian consumption directly from the LJR was found. One can say that Jordan (the country) has disconnected itself from the upper Jordan (the river) with the construction of the KAC. The available data from the PA in the GLOWA model is from the year 2004.

The primary source of data for the Israeli elements of the model was the IWA, although lack of concrete data necessitated integration of data from various sources including the Mekorot, local water associations, National Parks Authority (NPA), local farmers, literature, etc. The lack of data affected calibration, which is discussed in section 4.1 below.

3.1 Timeframe

Hydrological year in Israel starts at October 1st so the model's timeframe is a hydrological year from October to September with a monthly temporal resolution. The model strives to describe the current situation. In light of the vast changes the LJR has gone through the past decades, historical data is of little use. Keeping that in mind, two contradicting factors affect the choice of time series that nourish the model: a) The need for updated data that properly corresponds with the present and B) The need for a long time series that is statistically sound. February 1995 was the last time more than 5 MCM were released from the SoG through the Deganiya dam[1] [6]. Therefore, only data from the hydrological years of 1996-2010 (October 1995 – September 2010) are used, unless stated otherwise.

Similar models, including the GLOWA model that is the basis for this one, are typically constructed with long series of data representing many years. In this case however, all the data from those 15 years were compiled to represent an average year for two reasons:

- Big gaps were found in the existing data. Besides the SoG, no other water source or consumer was monitored continuously in the years 1994-2010.
- The object of phase 2 in the project is to build a long term scenario until the year 2040 and for that purpose, an average year of the present state will serve better.

The flow scheme of the model built thus far is presented in Figure 6 below. The methodology leading to this model, as wells as the challenges it still faces, are detailed underneath in this chapter.

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[1] Following the exceptional winter of 1991, some 260 MCM/Yr were released from the SoG in 2 subsequent winters. In February 1995, 66 MCM were released. In the 15 years since then, less than 5 MCM/month were pumped out for the SoG and all was used for irrigation north of Alumot dam.

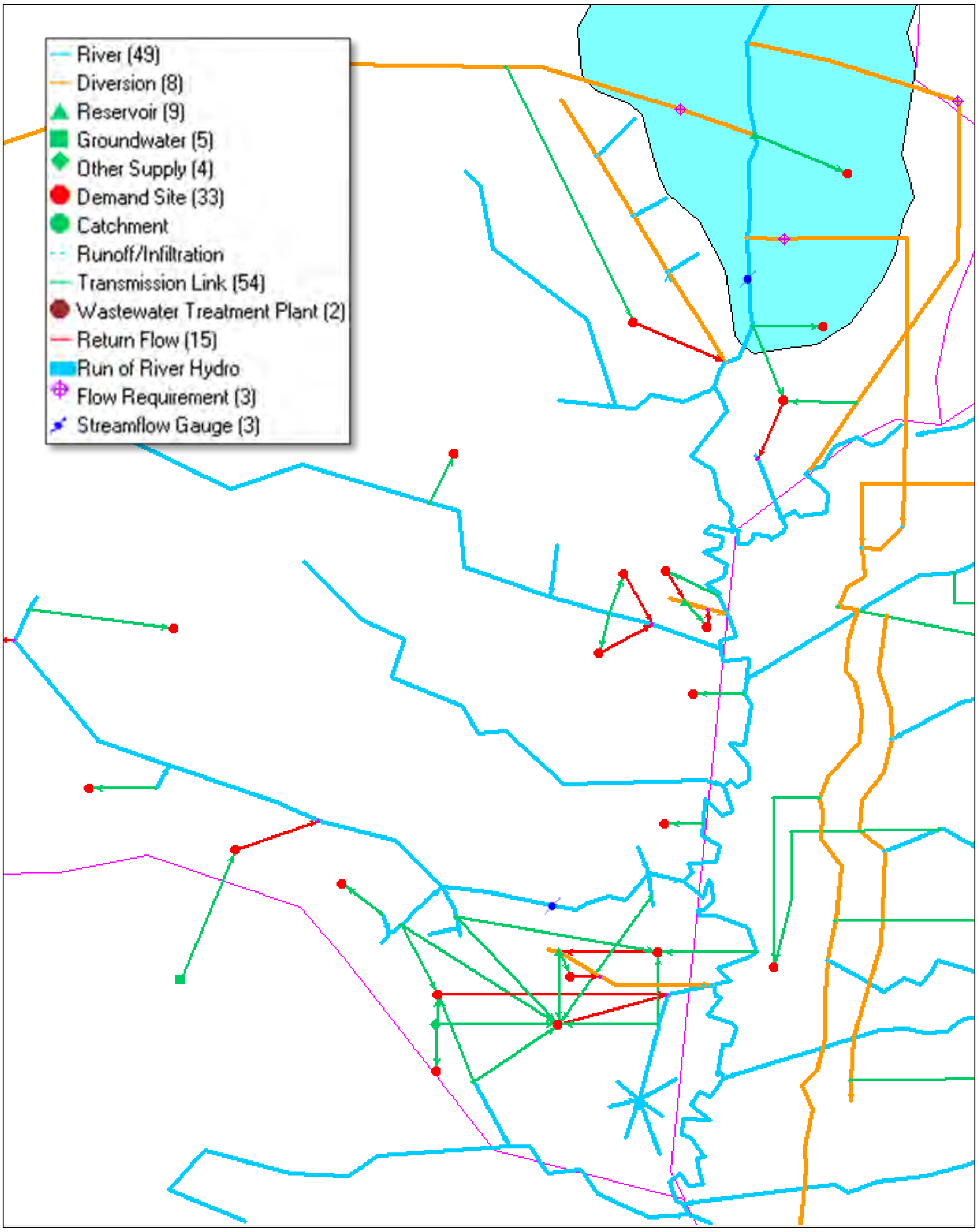

Figure 6:Flow scheme of the Israeli side of the Upper LJR WEAP model

3.2 Sea of Galilee

Figure 7 below presents a scheme of the annual water balance of the SoG in 2007/08 comparing with the average values (the numbers in brackets).

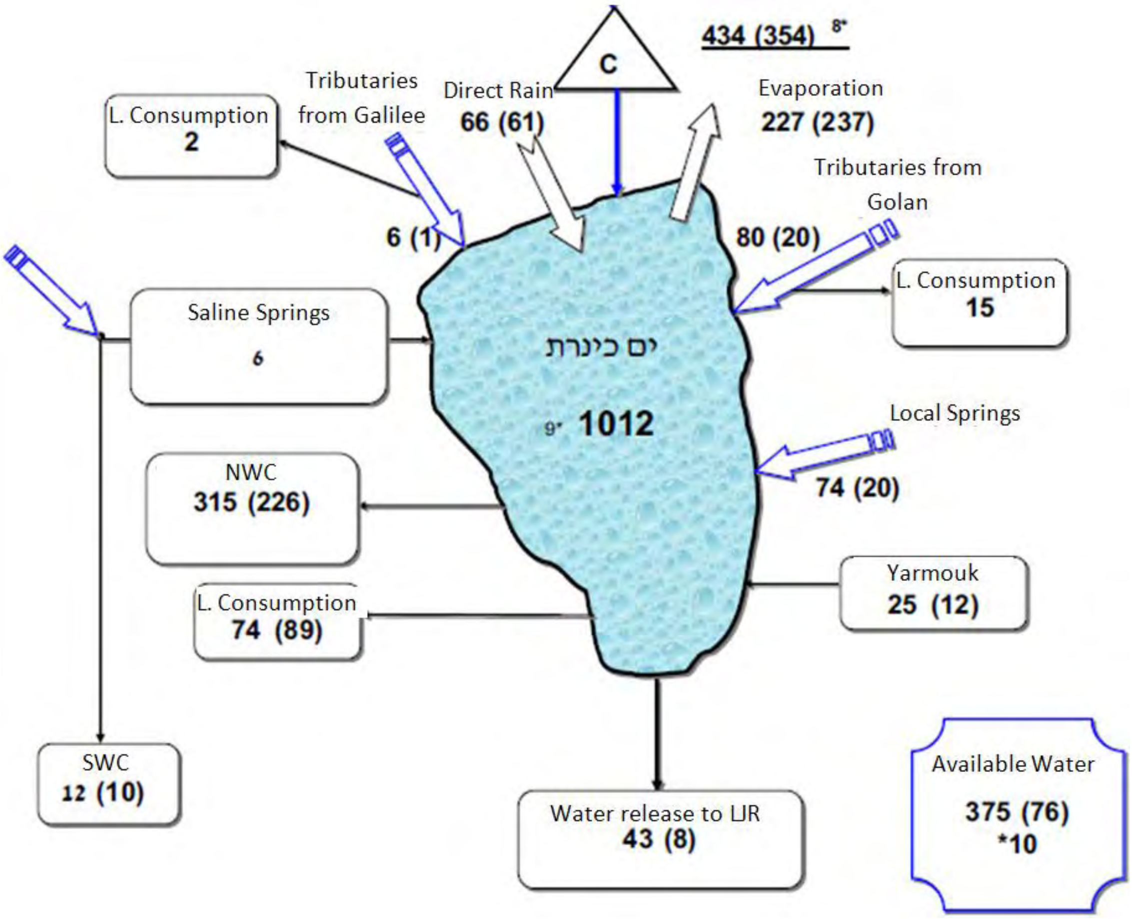

Figure 7: Annual water balance of the Sea of Galilee in MCM [6]

To facilitate better creation of future scenarios, this scheme was simplified for the model (Figure 8 below) and is comprised of the following:

- Available Water – Total entry of water form all streams and springs plus direct rainfall
- Diversion from the Yarmouk to the lake
- Diversion from the lake to the KAC
- Consumption by NWC
- Direct local consumption from the lake including private consumers and Mekorot, excluding diversion to NWC and KAC
- Exit in Deganiya – The pumping through the dam is monitored and was used for calibration. The data put in the calculation however, was the total demand of 5 stations between Deganiya and Alumot.

- Evaporation – was calculated with the help of Dr. Alon Rimmer. For future scenarios, the water level and with it, the surface area of the lake and evaporation might change. This effect will be neglected and evaporation will not change with water level.

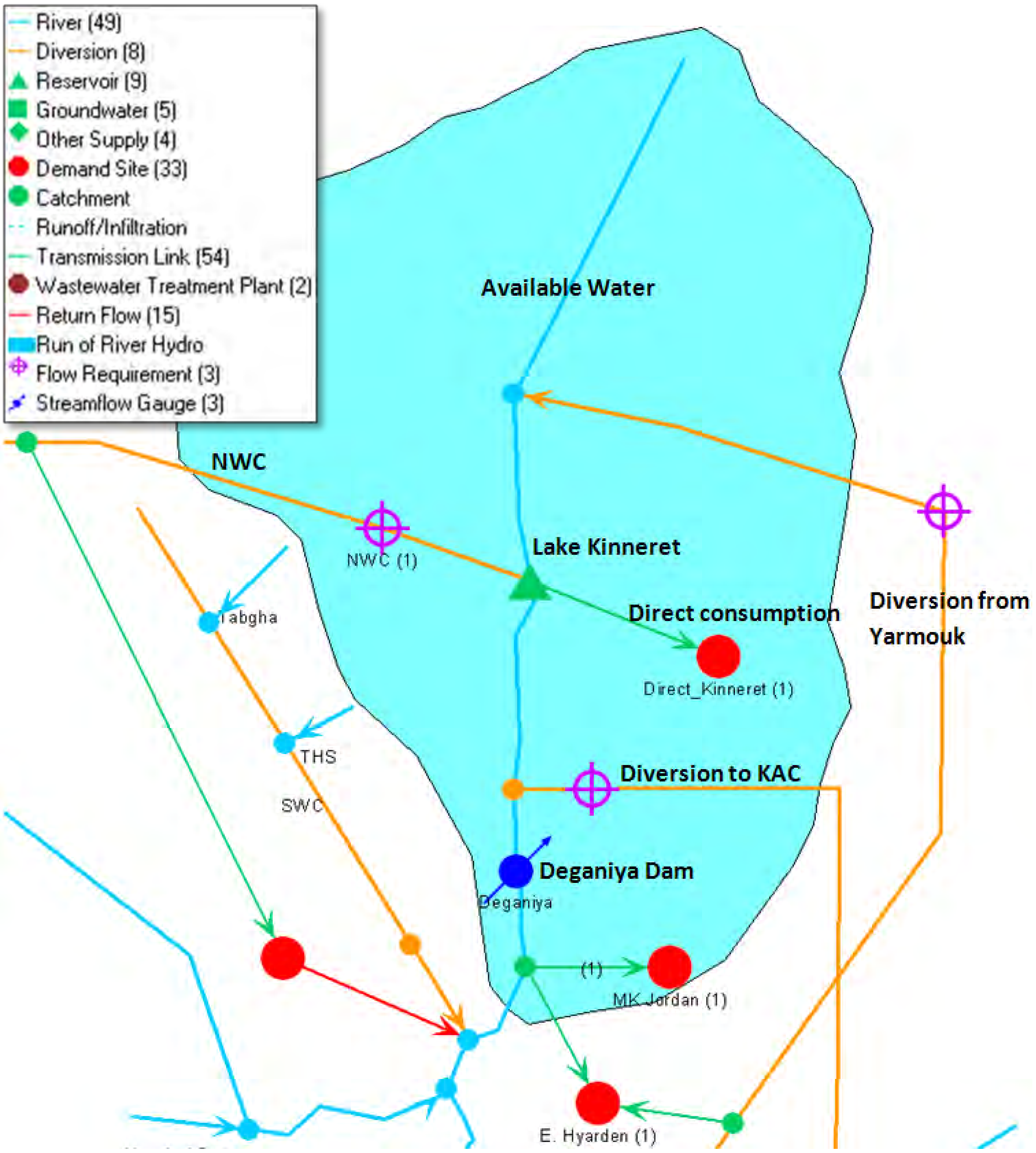

Figure 8: The model scheme around the Sea of Galilee

The water elevation of the lake in the beginning of October 2009 was -214.24 MSL [20 ;19], which corresponds to a storage volume of 4,413 MCM according to the volume elevation curve received from Dr. Alon Rimmer. As explained in section 2.2.1, that initial level of the lake is well below the bottom red line. To avoid the risk of reaching the black line, Mekorot and the IWA often reduce the pumping to the NWC (on the expense of other strategic reservoirs such as the coast and mountain aquifers). That trend was modeled through a buffer coefficient that, when the lake is under the red line, allows consumption of only 30% of the water that is available above the black line per month. The meaning is that if in a given month the storage volume has fallen down to 100 MCM above the black line, then only 30 MCM will be available for consumption in that month.

Another factor in the model is the priorities of demand. Since the transfer to the KAC and the local consumption is rigid, they were given the highest demand priority. The NWC's priority is lower than the other consumptions, but is still higher than the SoG refill, under the constraint of the above-described buffer coefficient. In the model, the SoG is indirectly linked to some demand sites in Jordan. These sites suffer from water shortage and to avoid Jordanian consumption that is higher than the volumes specified in peace agreement, they were given the lowest priority.

According to the calculated balance that is shown in Table 1, the SoG suffers from an average annual deficit of 49.9 MCM. Because of the buffer coefficient, the modeled cycle should be more balanced as long as the SoG is under the bottom red line.

Table 1: Water balance of the Sea of Galilee in the model in MCM

Month	Available Water	From Yarmouk	To KAC	To NWC	Direct Consumption	Exit in Deganiya	Evaporation
October	31.1	0.9	-5.7	-27.5	-4.1	-0.8	-26.5
November	28.8	2.2	-5.1	-20.8	-1.8	-0.7	-20.2
December	44.2	2.9	-2.8	-18.2	-1.3	-0.6	-15.2
January	74.5	3.6	-0.1	-13.1	-1.3	-0.4	-10.9
February	99.9	5.0	-0.9	-9.7	-0.7	-0.3	-8.3
March	91.3	4.4	-5.1	-17.6	0.6	-0.3	-10.5
April	61.8	2.5	-5.2	-20.9	-1.8	-0.4	-14.0
May	38.9	0.3	-6.1	-31.2	-3.7	-1.0	-20.0
June	25.3	0.0	-6.1	-33.4	-5.1	-1.3	-24.9
July	21.0	0.0	-6.3	-33.3	-5.3	-1.6	-30.0
August	20.1	0.0	-6.0	-33.9	-5.9	-1.6	-31.8
September	22.8	0.0	-5.8	-29.8	-3.7	-1.0	-29.5
Total	**559**	**21**	**-55**	**-289**	**-34**	**-9.9**	**-242**

3.3 Baseflow

For the purpose of the model, only single water sources with a flow of more than 1 MCM/Yr, or sources that serve a significant consumer directly, were used. One exception was "Emeq Hamaayanot" with its abundance of large and small springs alike. There, all the small springs were grouped into one source of water. Figure 10 in page 40 shows the water sources that were put in the model. The particulars of the different types of sources are detailed below:

3.3.1 Saline Water Carrier

Yearly data on the saline springs that are diverted to the SWC (see description in section 2.2.2) was used from the years 2004-2010. Both springs show a decreasing trend in flow, which could be linked to the decreasing water level at SoG. The Tiberias Hot Springs (THS) produces 0.8

MCM/Yr with an average salinity of 17,100 mg/L. Both the flow and salinity are fairly constant throughout the year.

Tabgha springs produce an average of 13.6 MCM/Yr with a salinity of about 2,000 mg/L. Both the flow and the salinity however, fluctuate (Table 2). Since monthly data was available only for one year (2009/10), the deviation of flow and salinity throughout the year was taken from one year but the overall magnitude was corrected to fit the multiannual average [9]. Tabgha is the only water source in the model whose salinity ebbs and flows throughout the year.

Table 2: Flow and salinity of Tabgha springs in the model

Month	MCM	Cl (mg/L)
OCT	0.8	2240
NOV	0.8	2175
DEC	1.0	1939
JAN	1.2	1768
FEB	1.1	1636
MAR	1.5	1918
APR	1.3	2020
MAY	1.3	2032
JUN	1.0	2096
JUL	1.2	2036
AUG	1.2	2087
SEP	1.1	2110

In addition, some wastewater and runoff spills from the city Tiberius to the SWC. The volume of the flow is unknown, but judging by salinity measurements of the NPA downstream (see calibration in section 4.1 below), it was estimated at 1.4 MCM/Yr with a salinity of 350 mg/L.

3.3.2 Yarmouk

The Yarmouk below Adassiya dam is disconnected from upstream, as Jordan draws all the water to the KAC, except for 25 MCM/Yr that belong to Israel according to the peace agreement and some additional water for storage at the SoG. The water is then pumped by the JVWA from the Yarmouk at station No. 229662. The transfer from Jordan, which comprises the entire flow in the Lower Yarmouk, is measured by a hydrometric station of the IWA, situated below gate 121 (Station No. 34160). This station however, is not accurate and should not be relied on [10]. The scheme described above is illustrated in Figure 9.

Looking at the data, indeed until 2006, the recorded flow at the station was lower than the recorded pumping. Additionally, the recorded flows at both locations have dropped significantly after 2006. That drop corresponds with the completion of the Unity Dam by Syria and Jordan that have effectively ceased runoff from upstream, and also with the personal account by Arik Reuveni from the JVWA.

Seeing that, using only data from the years 2006-2009 would make sense. The problem is that this is a very short time series and one unusual month distorts the whole picture. Indeed, in March 2009 the Lower Yarmouk witnessed an unusual flow of nearly 14 MCM. That one month causes data from only 3 years to show that the average flow in March equals January and February together. Hence, the headflow of the Lower Yarmouk was taken as the pumping at station 229662 (see description of demand sites in section 3.6 below).

Figure 9: The Lower Yarmouk

3.3.3 Harod

Most of the natural baseflow of Harod Stream originates in a group of four large springs (Amal, Shokek, Homa & Migdal) around the tributary of Nahal Hakibutzim that differ significantly in salinity (see section 2.32.3.1). Because of that difference, those springs were not grouped together, but were divided into two tributaries, one for fresh water and one for saline water. Each has one spring as the headflow and the other spring flowing into the tributary (that scheme can be seen in Figure 18 in page 56). In reality, that area has a different flow scheme but that would neither change the overall flow nor the salinity calculations.

Figure 10: The different water sources that were put in the model

Another important spring at the lower Harod is Huga spring (38270), located just east of Beit She'an. As can be seen in Figure 11 below, this spring has been showing a steady decrease in its yield over the past 15 years, and nearly halved its flow. As a result, for the years 1995-2010 the average flow is 3.7 MCM/Yr even though it hasn't reached 3 MCM/Yr since 2006. To represent current situation better, the calculated average Huga was factored to 80% in the model.

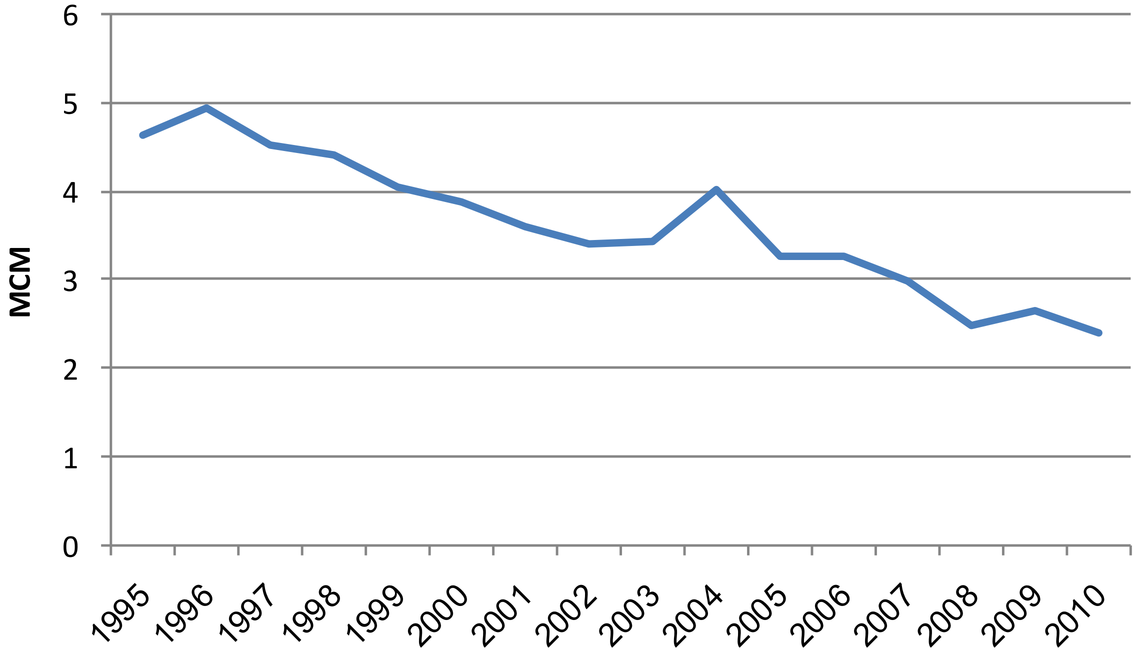

Figure 11: Annual flow of Huga Spring (38270) in MCM

3.3.4 Emeq Hamaayanot

Emeq Hamaayanot between Harod Stream and Bezeq Stream is characterized by some 30 springs that drain locally to the LJR in several canals. Some of the springs are unquantified, but the larger springs are.

Figure 12 shows the springs that are listed in the IWA in red compared with the water sources that were put in the model in blue. The different local canals are also apparent in Figure 12, as well as the rural nature of the area and the abundant fishponds. Most of the larger springs could not have been grouped due to differences in salinity and/or different trends that will later affect future scenarios. Those who were grouped are Merhav & Hisha, and 7 small springs whose salinity is unknown. Similarly to the case of Harod Stream, the different canals were joined in the model into one local tributary that drains all the springs.

Figure 12: Springs at Emeq Hamaayanot

3.3.5 Tavor

5 main springs nourish Tavor Stream. Measurements of the IWA in 4 of those springs show an annual flow of nearly 5 MCM [21]. Because none of the springs is used directly, all were grouped together in the model. The calculated average salinity of all four springs 170 mg/L. Samples by the NPA however, found salinity in the Tavor to range between 380 and 670 mg/L. No source of water that can attribute to such salinity was found so in the model, the salinity of the springs was multiplied by 4. It is highly recommended to further investigate this point.

In addition, there some known springs whose flow is unquantified (for example, "Ein Tahavit") and reports of some sewage flowing in the river [22]. Hence, a demand site taking 0.5 MCM/Yr from the NWC and discharging it to Tavor Stream was put in the model.

3.3.6 Direct Groundwater

Direct contribution of groundwater to the LJR was calculated according to Holtzman (sections 2.3 and 3.6), who quantified groundwater in 2 segments of the LJR, between the Yarmouk and Harod Stream. The model added the simulated groundwater contribution, by adding groundwater inflow in two reaches: below the Yarmouk and below Issachar. The annual contribution of groundwater was estimated at 18 MCM, with an average salinity of 1150 mg/L.

Holtzman's calculations are based on measurements taken between February and August, 2001, which came after subsequent drought years [3; 15; 14]. The measurements showed at times unexplained fluctuations. At station 19 for example, which is situated in a canal that drains the irrigated fields of Gesher, the Cl concentration in June was 1700 mg/L while in August it jumped to 2883 mg/L. The values of the 5 months calculated by Holtzman were extended to the rest of the year using the average of the 5 months, taking into account seasonal changes.

3.4 Runoff

Runoff is the flow above ground, which is the direct result of a rain event. Floods are continuously measured by the IWA only at the existing hydrometric stations (i.e. Harod & Yarmouk, which essentially has no basin). The recorded events are compiled in a flood report, prepared by the Hydrological Service. Since the model works in a monthly resolution, the recorded floods were summarized to months according to the date of the flood peak. Thus, the runoff of Harod Stream was obtained, but there was still the need to estimate it in the other ungauged tributaries.

For that, the assumption was taken of an equal rainfall-runoff coefficient in the entire area. That assumption is not 100% accurate of course; as such coefficient would depend on topography, soil type, coverage, rainfall distribution etc. Nevertheless, known flood events in the western tributaries are small in volume and their relative share of the total balance in the LJR basin is less than 10%. Combining it with the monthly temporal resolution, chances are that this approach would lead to insignificant errors. That assumption allows runoff calculation according to the recorded data in Harod Stream.

Figure 13: Basins of the western tributaries and their calculated runoff

The average runoff in Harod Stream is 1.9 MCM/Yr according to the floods report of the IWA. To that, 1.5 MCM that are caught upstream [23] were added, totaling to 3.4 MCM/Yr. Rainfall typically starts in October, peaks in February, and ends in April. Runoff salinity is estimated to be 200 mg/L. The calculation was done as follows (note Figure 13 and Table 3 below for a better understanding of the results and process:

a) Each basin's area was calculated with a polygonal layer of the drainage areas in GIS.

b) The annual rain depth was calculated for each basin by dissolving the basins layer with an existing polygonal layer of average annual rainfall.

c) The rain volumes were normalized, using Harod depth as 1, thus producing a relative coefficient that can be compared between the basins.

d) The recorded runoff at Harod in each month was multiplied by the coefficient to obtain the estimated runoff in each basin.

The described process yielded a runoff coefficient of 3.6% in the LJR basin, producing an annual runoff of 14.2 MCM/Yr.

Table 3: Calculated runoff in the different basins

Basin	Area (Km^2)	Rain Volume (MCM)	Relative Coefficient	Runoff (MCM/Yr)
Yarmouk	9	4	0.04	0.1
Tavor	252	127	1.37	4.6
Issachar	87	36	0.39	1.3
Harod	214	93	1.00	3.4
Emeq Hamaayanot	58	19	0.20	0.7
Yavniel	106	51	0.55	1.8
Bezeq	161	57	0.61	2.1
Local Jordan Valley	12	5	0.05	0.2

One exception for the relative co. was made in the Lower Yarmouk. The relative coefficient of the Yarmouk is 4% of Harod Stream but in this case, it was set at 20% for 3 reasons:

- Runoff arrives from the Jordanian side as well;
- The vast majority of the area is heavily cultivated and drained, so the rainfall-runoff factor should be higher than that of Harod;

The entire basin practically lies on the bank of the river, thus minimizing runoff losses.

3.5 Salinity

As noted in section 2.4, salinity is the indicator of water quality in the model. Designated salinity values of water sources are mentioned above and are documented in the model itself. The calculations of Cl concentrations in the different reaches are based on simple mass balance with no decay mechanisms. Other assumptions that were made are:

- Salinity of all water sources is fixed throughout the year. Particularly, the salinity of the SoG does not change with water level and is fixed at 280 mg/L [9];
- Runoff salinity is 50 mg/L;
- Salinity of return flow from irrigation is 800 and 1500 mg/L for fresh and saline water respectively;
- Salinity of Israeli Sewage is 350 mg/L;
- Effect of evaporation on salinity in the river itself is neglected.

3.6 Evapotranspiration from the LJR

In the WEAP model, evapotranspiration (ET) is characterized by percentage of lost water. The ET percentage was calculated according to Holtzman's work [14], which valued ET according to calculations of chemical mass balance for 5 months in 2001. Holtzman divided the area into 2 zones. For the northern zone (called N1), which lies between Dalhamiya Bridge and Neve-Ur, ET% was calculated according to Table 3 of the article using the values north of Gesher, which is the longest reach of the section. For the southern part (called N2) that is situated between Neve-Ur and Hamadia, ET percentage was calculated from the values in Table 2 of the article after the southern pump of Neve Ur.

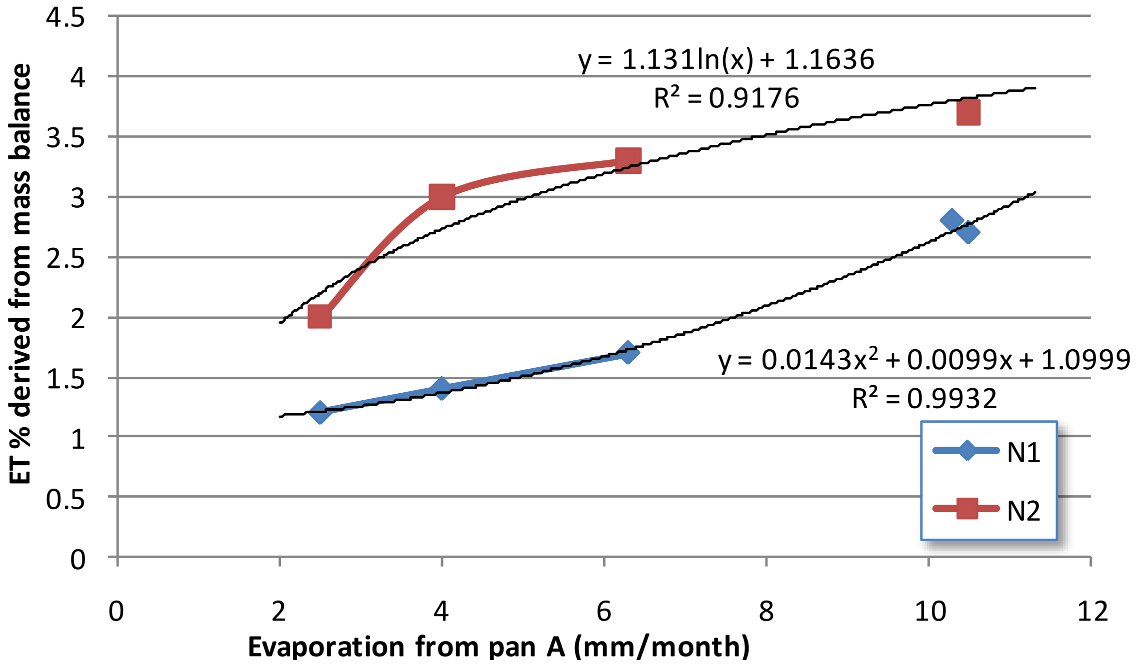

Figure 14: Scatter graph of ET [14] versus average evaporation from pan A [24]

For the rest of the year, values were completed according to the evaporation from pan type A at Beit She'an [24], which is given in mm/month. The translation from depth to percentage was done according to the formulas of the trend lines of the scatter graphs in Figure 14. For N1, a polynomial trendline was found to be the best, while for N2, a logarithmic trendline fitted better. The line of N2 has only 4 points because Holtzman calculated an ET of 7.1% in August for N2. This value was omitted as it seems to stem from particularly low flow in that month and probably does not represent well an average August.

After calculating the monthly ET in both sections, the next step was calculating the percentage of ET per km of river. According to a GIS analysis, the meandering length of N1 and N2 is 11.6 and 14.4 km respectively[2]. Therefore, the calculated ET% in both sections was divided by their respective length to obtain the ET%/km.

Table 4 below shows the result of the aforesaid process. Columns 2 and 3 are the ET % per month for N1 and N2. The black values in the middle columns are the calculated ET by Holtzman and the red values are the completed ones from the trendlines in Figure 14. Thus, as far as ET is concerned, the LJR was split in two around Neve-Ur. Columns 4 and 5 in Table 4 show the ET %/km, which in the model were multiplied by the length of the given reach. The ET loss was calculated in 5 points (reaches) along the LJR, representing the full length between Deganiya dam and Alumot.

The meaning of this calculated percentage is that the LJR, along its entire length from the SoG to the Dead Sea, suffers a water loss of 50% in the summer and 30% in the winter, due to ET. ET from the tributaries has been neglected.

Table 4: Monthly ET from the LJR

Month	% of ET from LJR		% of ET per km		Pan A Average Evaporation[3]
	N1	N2	North to Neve-Ur	South to Neve-Ur	
October	1.7	3.2	0.15	0.23	6.3
November	1.3	2.6	0.11	0.18	3.5
December	1.2	1.9	0.10	0.14	2
January	1.2	1.9	0.10	0.14	2
February	1.2	2.0	0.10	0.14	2.5
March	1.4	3.0	0.12	0.21	4
April	1.7	3.3	0.15	0.23	6.3
May	2.4	3.7	0.20	0.25	9.1
June	2.7	3.7	0.23	0.26	10.5

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[2] Holtzman's paper states a length of 9.5 and 17 km for N1 and N2, but our own GIS data yielded different results.

[3] Monthly mean daily evaporation (mm) - Class A pan at Beit She'an [24]

July	3.0	3.9	0.26	0.27	11.3
August	2.8	3.8[4]	0.24	0.26	10.3
September	2.2	3.6	0.19	0.25	8.6

3.7 Demand Sites according to the IWA

A total of 88 demand sites are licensed with IWA in the region (see appendix 10.1 for the full list). Some of the demand in the model was taken directly from the IWA data, most of it was used to authenticate the demand (see next section for otherwise calculated demand). Not all are active and for the purpose of modeling the present state, sites meeting the following criteria were ignored:

- Monthly consumption has never surpassed 0.1 MCM.
- Inactive in the past 5 years (since 2004)
- Sporadic small consumption from permanent water sources such as effluents (sporadic consumption of floods was not ignored as those are sporadic by nature)

Thus, 44 production installations were taken into account. This chosen half of the installations represents 192.5 MCM/Yr out of a total consumption of 196 MCM/Yr in 2009. The next step was grouping installations of the same water type (i.e. salinity), owner and geographic proximity. The different consumers that were grouped together are documented in the WEAP model. Figure 15 below shows the 25 demand sites that are the result of the aforesaid process, plus the NWC and the direct demand from the SoG (total of 27 demand sites). The sites are colored according to the salinity of the consumed water, as defined by the IWA.

The data acquired from the IWA spans from 1995 to 2009. Analysis of the data reviled vast changes in consumption over the years. These changes stem from various reasons (rise in the usage of effluents, changes of crops, closure of polluted sources, development of new sources, enlargement of storage and transfer infrastructure, etc.). As such, no governing trend was found that applies to all the sources or even to a group of sources (with the possible exception of effluents, but even that trend is rough). Generally, consumption from over 10 years ago does not represent the current situation well.

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[4] Calculated value of Holtzman is 7.1% and was disregarded here

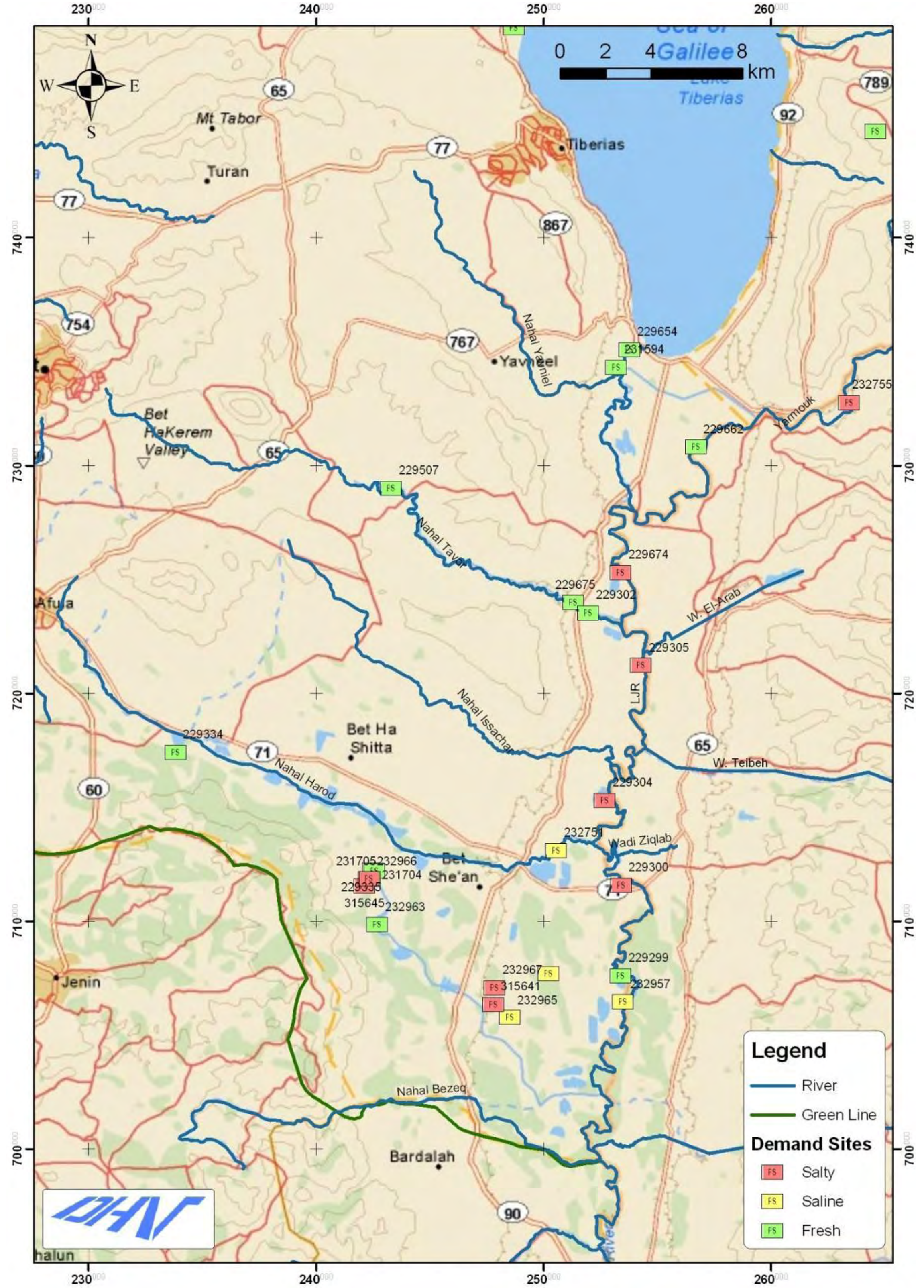

Figure 15: Demand sites according to water quality

Hence, data on consumption was used only from the years 2005-2009 (October 2004 – September 2009). Furthermore, some new installations began operating after 2005. The raw data indicates their consumption before operation as zero. For that reason, except for flood reservoirs, straight zeroes in the beginning of the period were ignored as well, while calculating the average monthly consumption.

This short period (2005-2009) should be regarded with care as, on top of the statistical glitches that might rise from the relatively short time series, all the respective years experienced a precipitation that is well below average. On the other hand, the climate change scenario that will be used later for long term prediction, assumes further diminishment in precipitation, so those 5 years might represent Current Accounts (CA) better than historical data.

Four other specific issues were reveled in the consumption data:

- 9 negative values were found in the data. These values were omitted from the average calculations.

- Some of consumers show a steady consumption of round numbers. In all likelihood, that it is not the actual consumption but rather the quota allocated in the production license. Since no better data was found, these values will be used.

- Consumer No. 229675 (Kibbutz Gesher) has empty values in the months June-November 2007, except for October when consumption rises to 0.7 MCM, comparing with a monthly average of 0.1 MCM. It was assumed that the 0.7 MCM are distributed among the empty months.

Consumer No. 229507 (Flood reservoir of Kibbutz Gazit), pumps floods at a rate of nearly 0.1 MCM in all the winter months, except January when pumping nearly halts. It was assumed that pumping in January is the average of December, February and March.

3.8 Modeling irrigation

As mentioned above, the listed demand in the IWA was used for only part of the demand in the model. The irrigation and fishponds were modeled in other methods. This section describes the modeled irrigation, divided according to the responsible water association. Fishpond modeling is described in section 3.9 below

In principle, agricultural demand was modeled through the area of the different crops multiplied by the water consumption of each crop per dunam. That method was used instead of the IWA data in order to account for future trends later in the project (section 5.8.4).

As for returning flows from irrigation, Tahal estimated that 15% of all watering of crops return to the LJR, with an average salinity of 800 mg/L [5]. The salinity of return flows from irrigation with saline water was estimated at 1500 mg/L.

That method though suffers from certain uncertainties:

- Irrigation is sometimes driven by soil salinity and not by the "normal" needs of the plant. That has 3 possible effects:

  - ○ Higher irrigation
  - ○ Irrigation during the winter although otherwise, it is not necessary
  - ○ Changing water sources to offset trends in soil salinity

- A given area can be listed as a plantation although in fact in has young trees that don't bear fruits yet and need less water. Bananas for example are replanted every now and then and at any given time, 5-15% of the listed area comprises of young plantations that take about half the water per area.

- Uprooting of plantations for various reasons. For example, in 2008 thousands of dunams were uprooted as a result of cutbacks in water quotas.

- Spreading the planting of seasonal crops (namely spices, onion, garlic, corn, carrot) according to market prices.

- Nearly half of the cultivated area is used for field crops. Field crops can be either dryland farming or irrigated. The exact ratio between them changes according to the delta between the watering of other crops and the given annual quotas.

- Winter irrigation depends on rainfall. An extreme month either way, can shift the irrigation pattern.

- Differences between regions and sub species of crops. Dates for example, are divided into dry and wet types. Their irrigation is of the same magnitude except for August-October when the dry dates receive about half the water of wet dates. Additionally, there are differences between date plantations west of road 90 and east of road 90 and differences between the area south of the SoG and the area of Beit-She'an.

- Differences in the estimations between farmers.

All those uncertainties were handled by crossing the agricultural data with the water supply data received from the IWA and the water associations.

3.8.1 Jordan Valley Water Association

The entire consumption of the JVWA that totals to 21 MCM/Yr was modeled as a single demand site, taking water from the Yarmouk and the LJR above Alumot. The return flow discharges into a local drainage canal that flows to the Yarmouk (Figure 16 below).

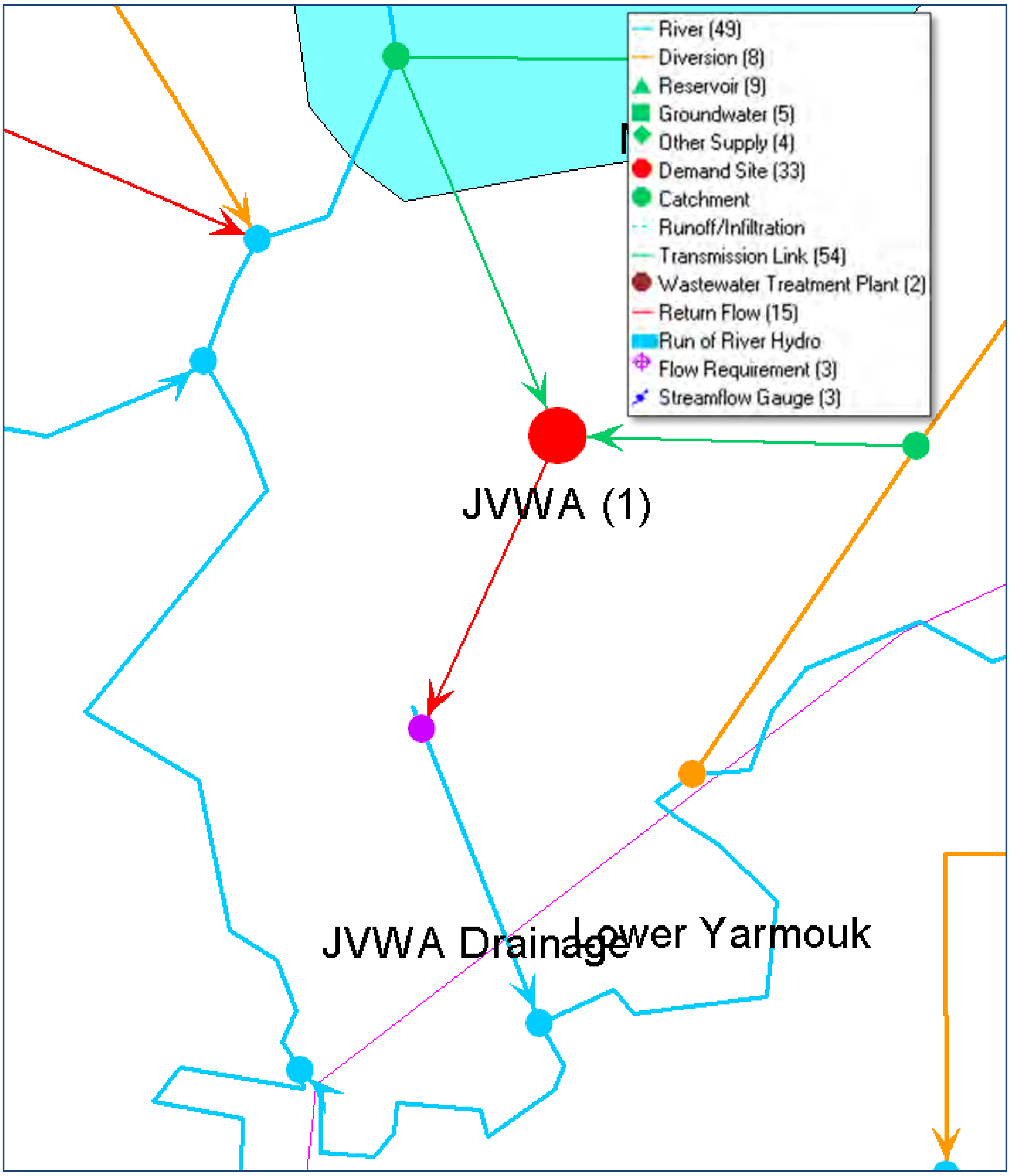

Figure 16: Flow scheme of the JVWA in the WEAP model

The agricultural information for the JVWA was received from Ron Yitzhaki [25], local farmers and agricultural instructors. The received data was calibrated according to the listed demand in the IWA (Figure 17 below). The irrigated area divided into the major crops is given in Table 5 below.

Table 5: Agricultural activity in the area served by the JVWA

Crop	Area (dunams)	Annual water use rate (m^3/dunam)
Bananas	6500	1800
Subtropical Trees	4080 (5100*0.8)	735 (1050*0.7)
Dates	2200	945(1050*0.9)
Olives	2800	424 (530*0.8)
Field crops	4500 (30,000*0.15)	150
Vegetables	4900 (7000*0.7)	530

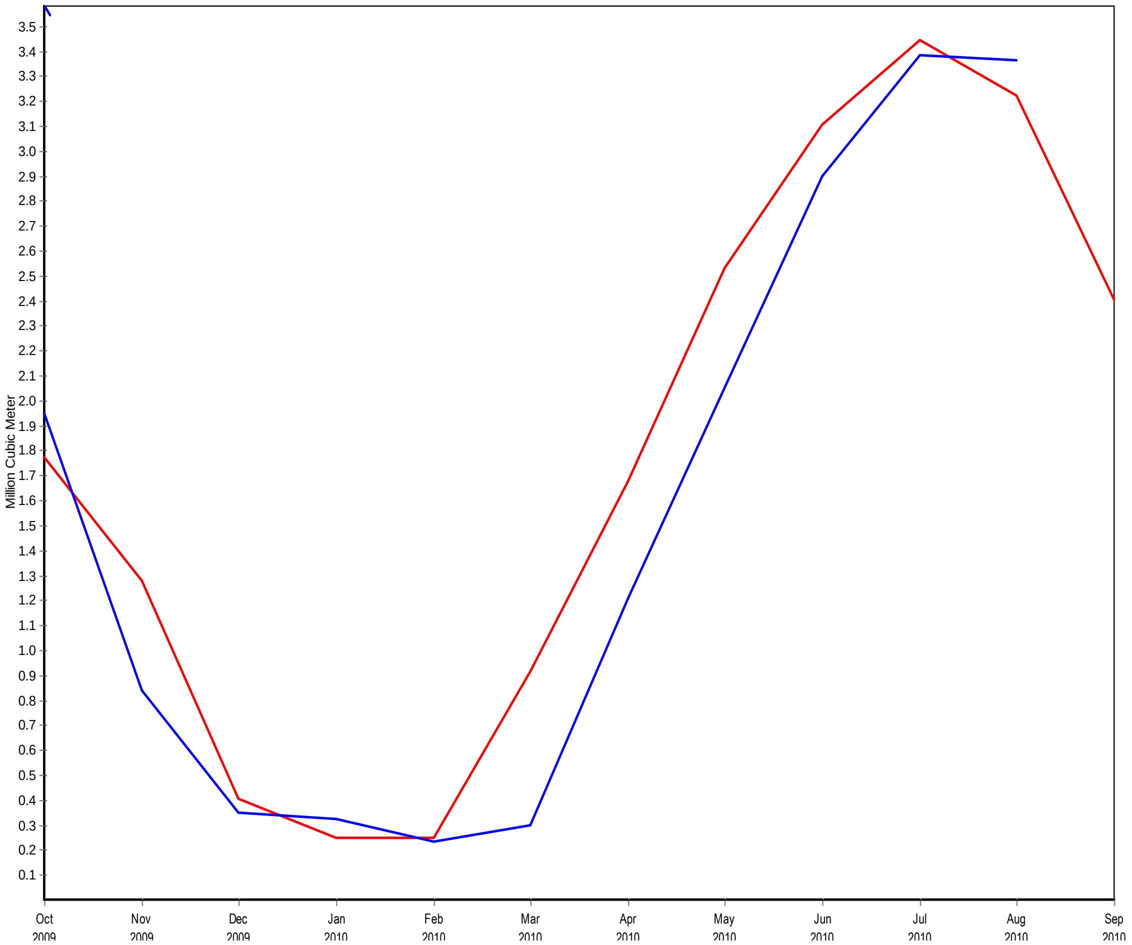

Figure 17: Monthly consumption by the JVWA in MCM, simulated by crops (red) and as listed in the IWA (blue)

The assumptions for each of the crops are given below:

Bananas

Banana plantations can be either open or covered with net. The open plantations require more water (m3/dunam*year) comparing with the netted ones (1600 m3/dunam*year).

Today there are about 4000 dunam of netted plantations and 2500 dunam of open plantations, with a gradual transfer to netted ones. In the CA, the average consumptions is estimated at 1800 m^3 per dunam, with a decreasing trend down to 1600 m^3 per dunam in 2020.

Subtropical Trees

The group of subtropical trees includes 3 crops with a similar irrigation pattern throughout the year, but different annual consumption:

- Mango - 1000 m^3/dunam*Yr
- Avocado - 1200 m^3/dunam*Yr
- Citrus - 1050 m^3/dunam*Yr

Many of the plantations were uprooted in 2008 when the IWA temporarily cut back water quotas. The uprooted areas were largely replanted but consist of young trees that do not bear fruits and take up less water. The annual water use rate was therefore, factored to 70% in the CA, and gradually grows in future scenario. Additionally, many citrus plantations were grafted in 2008 and take almost no water today, so the area was factored to 80% and increases gradually in the future scenario.

Dates

Assumptions regarding dates are noted above as an example for the complications of modeling agricultural consumption.

Olives

Olives are new to the region with many young trees. Therefore, water use rate was factored to 80%.

Field Crops

Field crops are grown in about 30,000 dunams, of which only a fraction is irrigated. The exact portion that is irrigated changes significantly each year, according to rainfall, leftover water quotas, market prices etc. The assumption in the model is that only 15% of the area is irrigated.

Vegetables

The net irrigated area is about 70% the area that was reported by the farmers as gross area.

3.8.2 Afikey Maim Water Association

Information for the AMWA was received from Gil Korati [17] and Abraham Gilboa [26]. The supply of the water association was divided into four (see detailed subdivision in Table 6):

- Municipal and Industrial – about 6 MCM/Yr supplied from local wells;
- Fresh irrigation – about 12.7 MCM/Yr supplied from fresh springs and local wells;
- Saline irrigation – about 39 MCM/Yr supplied from the reminder of the fresh water, saline wells, and fishponds with dual usage;
- Fishponds – about 50 MCM/Yr (see section 3.9.3 below).

Table 6: Subdivision of the water supply by the AMWA in the WEAP model

Crop/Demand Branch	Area/Inhabitants	Annual use rates (m^3)
Municipal and Industrial consumption		
Beit She'an	17,000 inhabitants	90 per capita
Emeq Hamaayanot Regional Council	11,000 inhabitants	240 per capita
Industry	n.a	1,200,000
Tourism	n.a	600,000
Fresh Irrigation up to 400 mg/L		
Subtropical Trees (Mango Avocado & Citrus)	5,100 dunam	1,200 per dunam
Autumn Vegetables (Spices, onion, garlic, corn, carrot)	11,000 dunam	600 per dunam
Saline irrigation		
Dates	6,700 dunam	1,400 per dunam
Olives	5,000 dunam	940 per dunam
Field Crops (mainly wheat)	33,000 dunam	200 per dunam
Spring vegetables	18,000 dunam	530 per dunam
Sunflower & Malali Watermelon	3,500 dunam	450 per dunam
Lucerne	5,000 dunam	1,500 per dunam

As explained is section 2.3.1, the area enjoys some 40 springs that differ in water quality. Each of the crops that appear in Table 6 (which shows only the major crops that cover more than a thousand dunam) has a different requirement for water quality. All that merits a very complicated water system, which is shown in Figure 18 below as it is in the model.

The scheme lies to the west of the LJR, between Harod Stream in the north, and Bezeq Stream to the south. The four consumers noted above are represented by the red dots called: AMWA Muni, AMWA Agri Fresh, AMWA Agri Saline, and AMWA Fishponds. The demand site of the fishponds discharges its water to a large reservoir of 40 MCM, representing the ponds (see discussion on the ponds in section 3.9.3 below).

The measured springs are represented by the small rivers (blue lines) and are grouped according to their location and salinity. All the springs that drain directly to the LJR are saline and discharge to an imaginary reach called "Emeq Hamaayanot Local". The local wells are represented by the green rhombus.

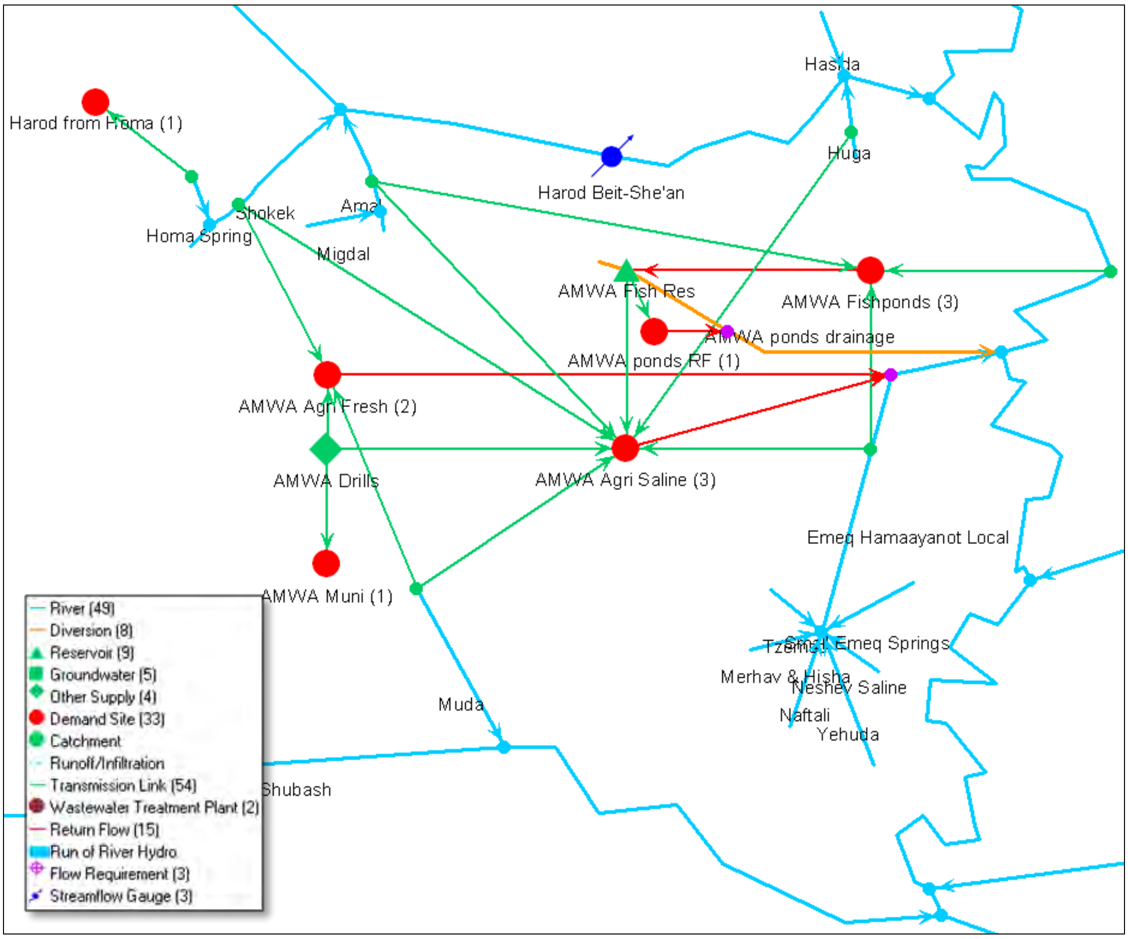

Figure 18: Water scheme of the AMWA in the WEAP model (Current Accounts)

Each demand site is connected to its water sources via a transmission link (green lines) and the irrigated areas drain their return flow via the red lines. The correct ratio between the different sources and consumers is kept by defining priorities as follows:

1. Municipal consumption takes water from the wells;
2. Fresh crops take water from wells and fresh springs;
3. Saline agriculture takes water from fresh springs;
4. Saline agriculture and fishponds take water from saline springs;
5. Saline agriculture take water from the fishponds;
6. Fishponds take water from the LJR.

This set of rules, based on the water quality, assumes the LJR water is the last choice and is directly used only by the fishponds (and indirectly by saline irrigation). Hence, inconsistencies in the modeled system would be revealed first and foremost by a wrong demand from the LJR. Data from the AMWA revealed that the demand from the LJR ranges at 3-15 MCM/Yr. The modeled result showed a demand of 13.3 MCM/Yr from the LJR, well within the range of the known data. Known consumption of the crops and municipal consumers as well as estimated flows within Emeq Hamaayanot suggests that the described scheme provides a good representation of reality in an annual timeframe.

Some inaccuracies might be found at the monthly level, such as February in which the combined demand of all consumers and the relatively high flow in the rivers leave enough water so that no pumping is required from the LJR. These uncertainties could not be verified in the timeframe of the project.

3.8.3 Harod Water Association

The third large water association in the basin of the LJR is Harod, which supplies some 32 MCM/Yr. Most of its water however (28 MCM/Yr), comes from wells that originate in the north-east mountain aquifer and their connection with the LJR is unclear [23]. Therefore, the only consumption that is directly taken from the river is the pumping from Harod and Homa springs (the demand site at the left of the Figure 18, called "Harod from Homa"), which are listed in the IWA and were modeled as two demand sites; and flood catchment.

According to the IWA, floods are caught in 3 reservoirs with an average annual of 0.7 MCM/Yr. For a river the size of Harod this is a surprisingly low number. Indeed, according to Efraim Bar, the annual flood catchment is 1.5 MCM/Yr. Hence, a demand site that catches floods with a magnitude of 1.5 MCM/Yr, with a monthly variation of the listed floods of the Harod (section 3.4) was put in the model.

Irrigation in the region amounts to some 22 MCM/Yr [23], but the important component for the water balance in this case is the return flow. Elsewhere in the model, return flow from irrigation is assumed to be 15%. In the Harod it should be lower, as most of the fields lie further from the river (behind the fishponds). Seeing that, 11.5% of return flow was assumed (together with a specific monthly variation), to successfully calibrate the flow in the Harod according to the hydrometric station of the IWA. The return flow was modeled in the same demand site as the Harod Fishponds (see section 3.9.4 below).

3.9 Fishponds

Extensive fish cultivation is a major economic branch in the LJR. Analysis of ortophoto revealed that fish ponds in the area span over 20 km^2, with large concentration of ponds in Emeq Hamaayanot and around Harod Stream (marked in Figure 19 below). These large ponds affect the water balance significantly. A fishpond requires on average 5-6 MCM/Yr per km^2 (section 2.5.3). 20 km^2 means a combined annual consumption of 120 MCM[5].

Evaporation in the ponds increases the salinity and the estimation is that the returning discharge has an average Cl concentration of 2500 mg/L to the north of Harod Stream [5], 2,000 mg/L in Emeq Hamaayanot, and 4,000 mg/L in Harod. The range of salinity stems from differences in operation as well as differences in the background salinity [18]. About 75% of the emptying of the ponds takes place between October and December, and the rest lasts until February.

Unlike typical reservoirs, fishponds are comprised of numerous small ponds that often differ in age, depth, lining etc. Water is circulated several times between the ponds (up to 3 years of circulation) until it is discharged. As such, fishponds could not be modeled as a simple reservoir in a similar manner to the SoG (section 3.2). Rather, the fishponds were grouped into 4 cases, according to their operational differences, responsible water association, and geographic location. Each was modeled in a different way that is described below.

The fishpond of the JVWA that belongs to Afikim was disregarded as it has decreased its production in recent years and is about to be turned into a reservoir (see section 5.3.3 below). Additionally, its water consumption is already considered as part of the total consumption of the water association.

3.9.1 Gesher

Gesher fishponds (the red ponds in Figure 19) pump 2 MCM/Yr from the LJR. The listed demand in the IWA varies slightly between the months, but looking at the data, no apparent trend was found, as operation differs significantly between the years. Hence, the consumption was modeled as a consumer with an annual consumption of 2 MCM/Yr (560 dunam * 3700 m^3/dunam) spread evenly along the year.

The estimation is that half of the water is evaporated, a quarter is being discharged and another quarter leaks and eventually reaches the LJR. The ponds themselves were modeled as a reservoir (see flow scheme in Figure 20 below) but since a volume-elevation curve is not available for the ponds, evaporation could not be modeled directly. Instead, evaporation was

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[5] Some of the ponds serve as operational reservoirs as well, so the net consumption could be somewhat different.

put in the model as a "loss to groundwater". Annual evaporation was set at half of the annual consumption (1 MCM), with a monthly variation of evaporation from pan in Beit She'an [24].

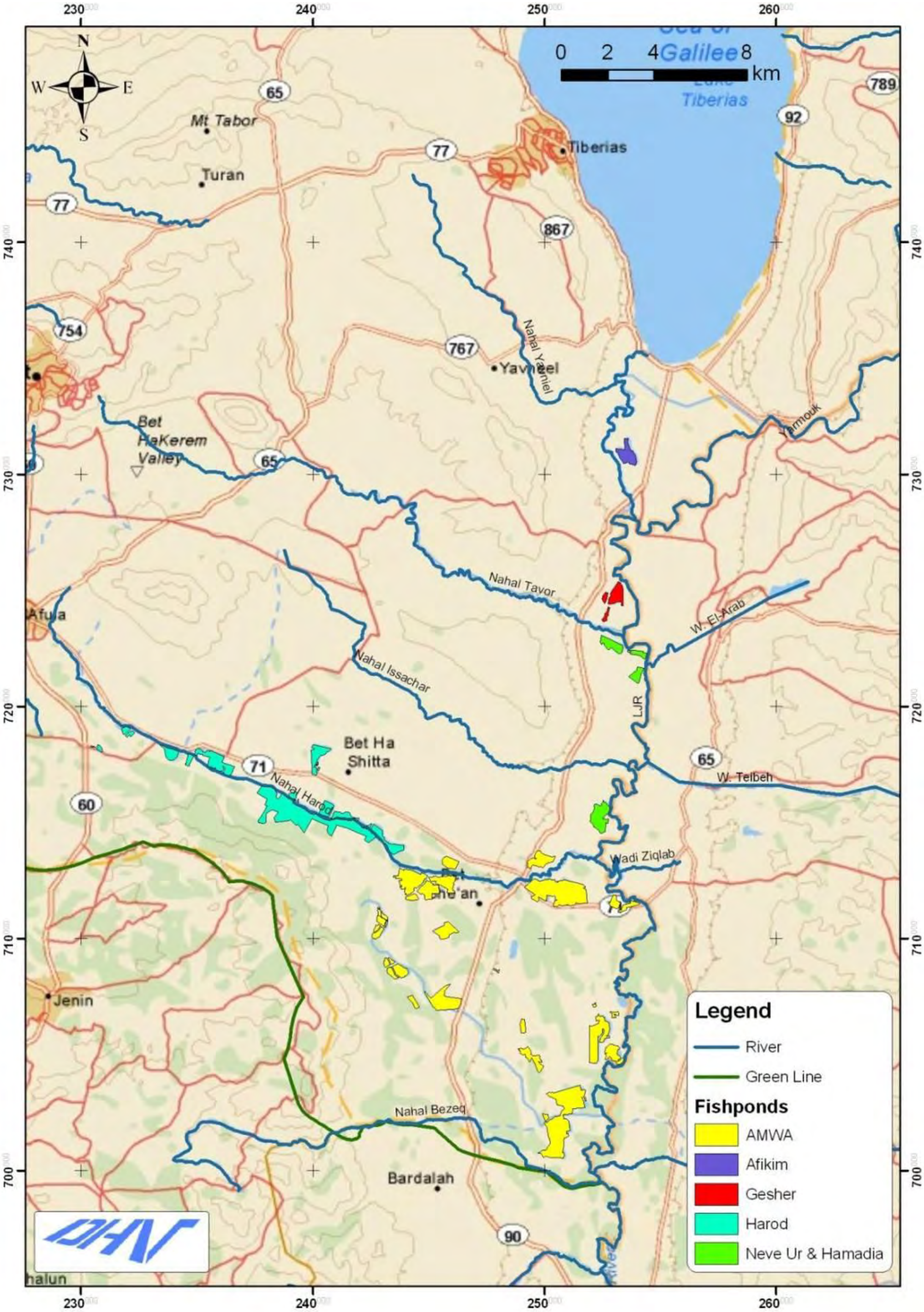

Figure 19: Fishponds according to the responsible water association

The discharge was modeled as a demand site taking water from the reservoir. The leakage, which is assumed to reach the LJR, is the excess water that flows downstream through the diversion (the orange line in Figure 20). That setting also allows to properly represent the expected decrease in the area of the fishponds of Gesher in the ZS (section 5.8.5).

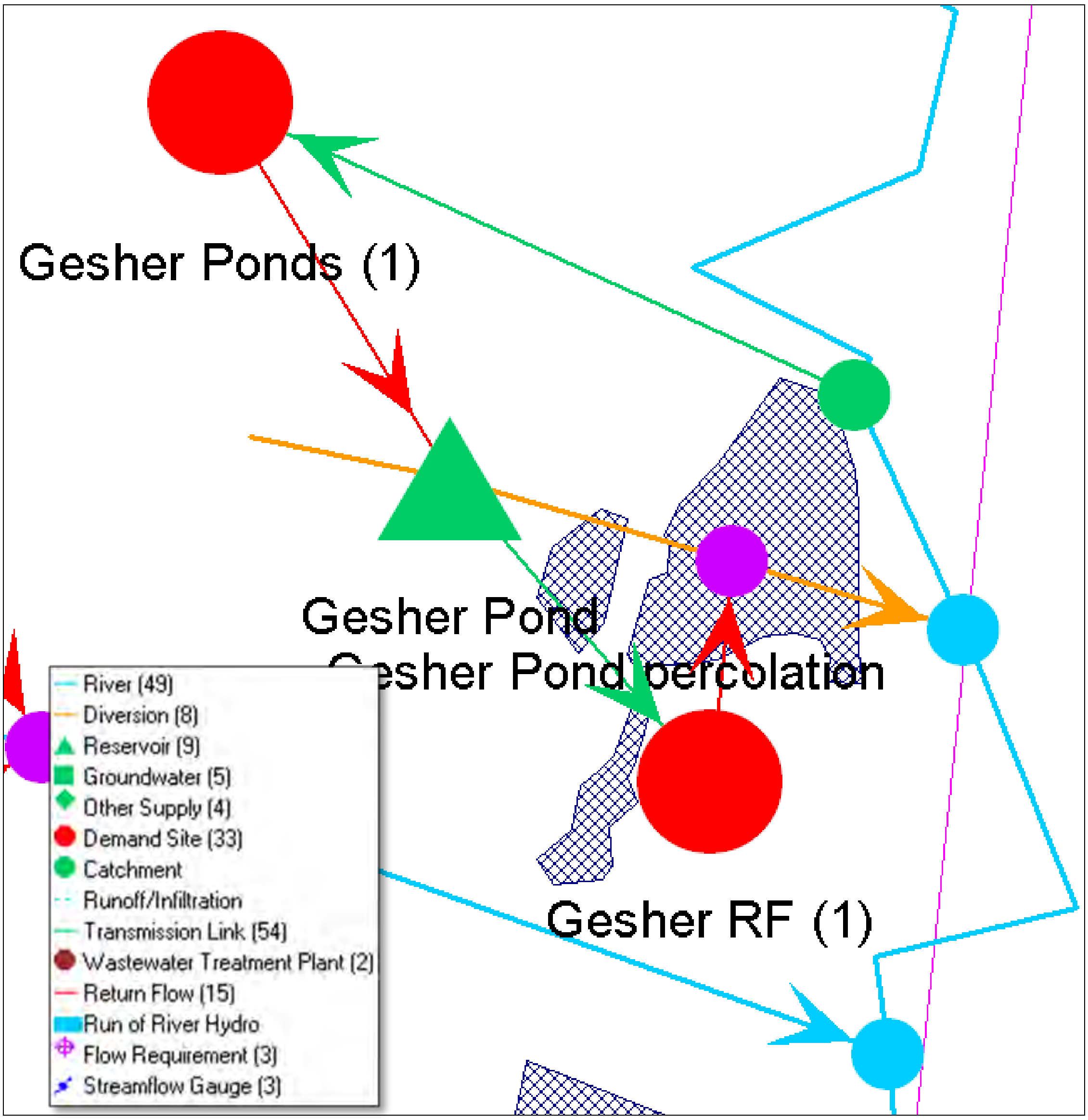

Figure 20: Flow scheme of the fishpond of Gesher in the WEAP model

3.9.2 Neve Ur & Hamadia

The listed consumption of the ponds of Never Ur & Hamadia (the green ponds in Figure 19) is 10 and 6.9 MCM/Yr respectively. This consumption is much higher than what would be expected from ponds with a surface area of 500-600 dunam each. The reason for the high consumption is that most of the water leaks back to the LJR, as the ponds are very old and are highly permeable. The even monthly variation (as noted in the IWA) as well as in the salinity of their discharge, which corresponds with the river's salinity [18] serve as further evidence to the high leakage.

Since most of the water is circulated with the river, the only significant effect of the ponds on the water budget is increased evaporation. The evaporation from the ponds was thus modeled as a demand site (one for each pond), with the monthly measured evaporation from a pan, multiplied by their surface area. This yielded an annual water loss of 2.6 MCM/Yr from both ponds.

3.9.3 Afikey Maim

The ponds of Emeq Hamaayanot span across 10,000 dunam and consume 50 MCM/Yr (5,000 m^3/dunam). The total storage volume is estimated at 40 MCM. Some of the ponds serve dual purpose for growing fish and as a reservoir for saline irrigation [18 ;17]. In the model, that is represented by a transmission link through which the AMWA saline demand site takes water from the reservoir. Since many operators run different ponds that supply water to different crops, it is unclear how much water is transferred from the ponds to irrigation each year. In the model, the scheme described in section 3.8.2, yielded such a transfer of 7.6 MCM/Yr.

The principle of modulation is the same as with the fishpond of Gesher. That is, the ponds are represented by a single reservoir receiving its water from a single demand site; the evaporation is modeled through loss to groundwater, the emptying through a demand site (the red dot called "AMWA Ponds RF" in Figure 18). The main difference is that the leakage is modeled through the same demand site of the emptying, in a different branch, instead of simply flowing downstream. The reason for that difference is that due to the water transfer from the ponds to agricultural consumption, an overflow modeling of leakage would be skewed.

It is possible that some of the leaked water flow to Harod, or in the ponds that are further from the river flow belowground along fault lines southwards. This unquantified possibility was neglected as at the end of the day, the water will find its way to the LJR at one point or another. The rate of leakage was adjusted to even out the annual water balance of the reservoir and was thus set at 850 m^3/dunam.

3.9.4 Harod

Since most of the water of Harod Water Association comes from wells and not from the river itself, the important elements for the purposes of this work, are the emptying of the ponds into the river and the leakage. As such, the ponds were modeled as a demand site, taking water from the north-east mountain aquifer and discharging it to Harod river.

The ponds themselves span across 3,600 dunam and discharge about 800 m^3/dunam (a total of nearly 3 MCM/Yr) with a salinity of 4,000 mg/L. The monthly variation of the emptying differs than that of the other ponds that drain to the LJR [18] but depends on operational circumstances and can vary between the years. The variation in the model was based on the LJR one, but was changed in order to calibrate flow with the hydrometric station.

The annual leakage from the ponds amounts to 500 m3/dunam, but some percolates and doesn't reach Harod Stream (and also does not reach the LJR directly, at least not upstream

Bezeq Stream) [18]. The exact ratio is unknown, and just as an assumption to calibrate the flow with the hydrometric station, half of the leakage reaches Harod Stream in the model (about 1 MCM/Yr).

3.10 Wastewater Treatment Plants

Two WWTPs (Bitaniya and Harod) were modeled as demand sites, taking water from the NWC, distributed evenly throughout the year. In reality much of the consumed water in the region does not come from the NWC, but this model deals with the LJR and not the entire country, so this scheme was used for the sake of simplicity. The effluent is discharged into the LJR with a salinity of 350 mg/L. There was no need to model it as a WWTP, because treatable pollutants are not modeled.

The sewage effluent discharges at 2010 were 1.5-2 MCM. The WWTP serves Jordan Valley Regional Council, which amounts to roughly 11,000 people. The average domestic sewage production in Israel is 160 liter per person per day (72 m3/year), meaning sewage production of nearly 0.8 MCM/Yr. Additional 1 MCM/Yr arrives from Poriah hospital and some resorts. In the future, two thirds of the city of Tiberius will be connected to the WWTP, adding about 20,000 people more.

Later in the project, the annual sewage production per capita will be used for modeling instead of the known discharge, to better define future scenarios.

Harod WWTP is not an actual one treatment plant but rather several discharges from villages that still spill their sewage to the river (some, after primary treatment). About 1 MCM/Yr of sewage flow to the Harod [23] and that amount was modeled as one demand site, taking water from the NWC, with a return flow to Harod Stream.

4 Current Accounts results

This chapter presents the results of the CA model, following the construction process that is described in chapter 3. It begins by discussing the accuracy of the results. Then it presents the calculated flow and salinity in the different reaches of the LJR and the tributaries, and finishes with the demand.

4.1 Accuracy of the results

As mentioned before, the only reliable active hydrometric station in the entire basin is the station at Harod Stream (38175). The measured annual flow in the Harod is 9.86 MCM comparing with the modeled flow of 9.82 MCM. Figure 21 below shows that the monthly variation of the flow is well modeled.

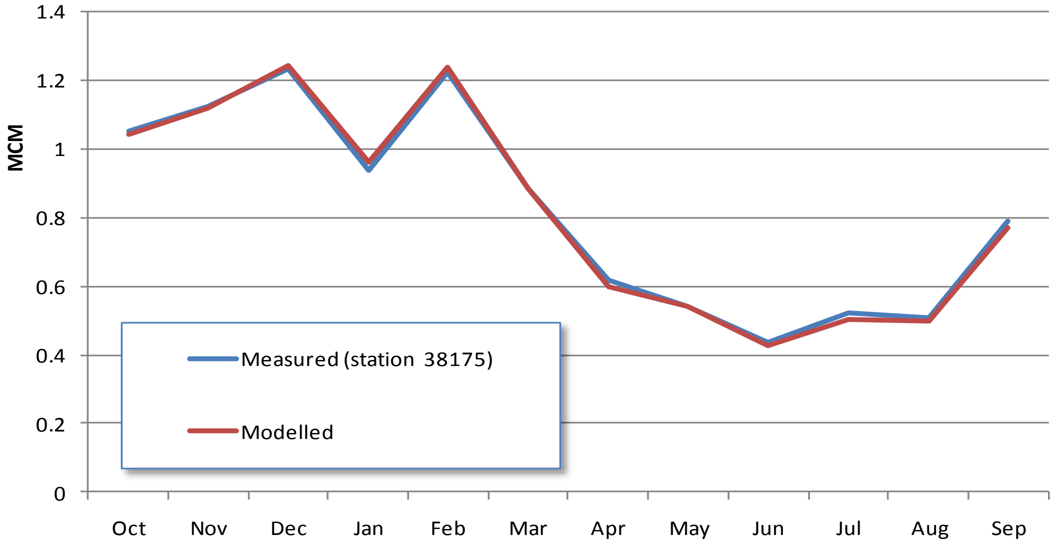

Figure 21: Measured versus modelled flow in Harod Stream

The presence of the hydrometric station made calibration fairly easy in one particular stream. The results in the rest of the basin however, had to be calibrated against salinity samples. The NPA takes samples at several spots of the LJR twice a year, in autumn and spring. Figure 22 below compares the average of 10 years (1999-2009) of NPA measurements[6] with the results of the WEAP model, at 5 locations between the SoG and Bezeq Stream. Considering the assumptions regarding salinity in the model (detailed in section 3.5), the modeled values correspond well with the measurements. The largest margin between the measurements and calculation is 11%.

Just below Alumot dam, the modeled values are higher than the measurements, especially in autumn. The reason is that because of the drought of 2006-2008, some saline water that

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[6] One measurement below Alumot dam, which registered 270 mg/L was omitted from the calculation

would normally be diverted to the SWC was allowed to flow to the SoG to keep it from reaching the black line. Consequently, less saline water reached the LJR. The average salinity below Alumot in autumn was 1,784 mg/L in those three years, lowering the decadal average.

In the stations that are downstream of the Yarmouk, the model calculates a salinity that is 3-11% lower than the measured values. That difference is expected as the model neglects the effect of evaporation in the river on the salinity which in the summer in that region, can reach to 10% of the flow.

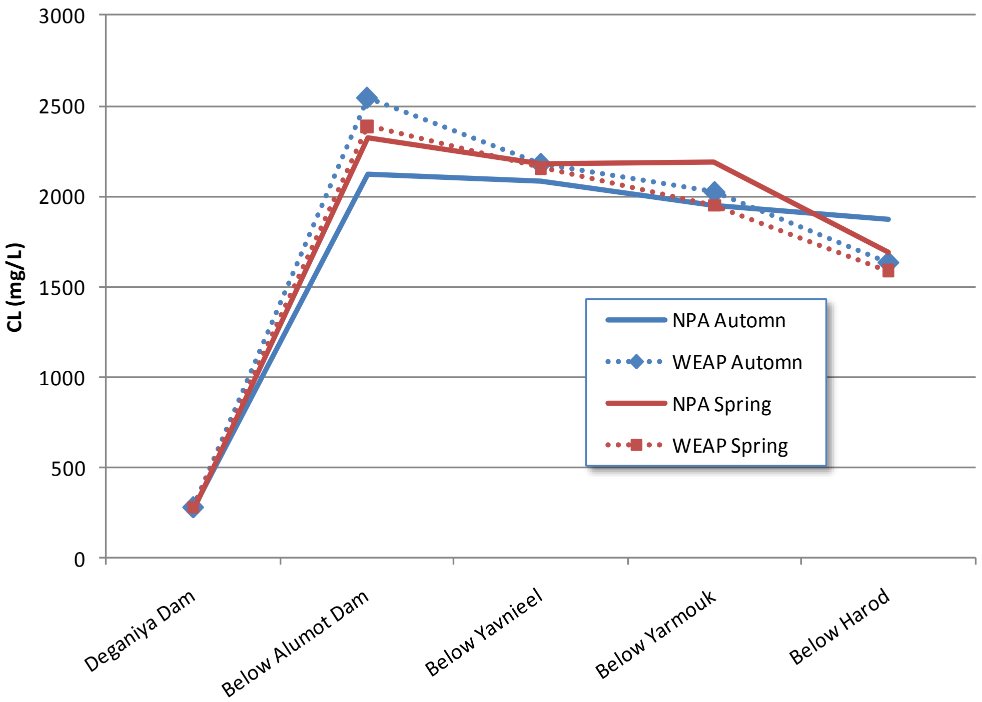

Figure 22: NPA salinity measurements compared with model's results (dashed)

Salinity below Harod in the model ranges at 1,351-1,696 mg/L[7]. According to data from the AMWA, salinity of water pumped from the LJR is at 1,200-1,700 mg/L [17]. That serves as additional evidence to the overall validity of the model.

Figure 23 below shows a flow scheme of an average year in the LJR, according to a model by TAHAL that was completed in 1999. The labels show the flow in MCM at the top and the salinity in mg/L at the bottom. The flow below Bezeq Stream according to the TAHAL model (marked in a red circle), was 126 MCM/Yr in 1999 (average year). The annual flow of the WEAP model (see section 4.2 below) is 77 MCM/Yr. that difference of nearly 50 MCM/Yr is mainly the result of the following changes in the catchment:

- The completion of Unity dam on the Yarmouk in 2007 (minus 15 MCM/Yr)
- Reduced flow from eastern wadis (minus 15 MCM/Yr)

---

[7] With the exception of February, when salinity drops below 1,000 mg/L.

- Reduced flow of Israeli effluents (3-5 MCM/Yr)
- An under estimation of evaporation in the TAHAL model (minus 9 MCM/Yr)

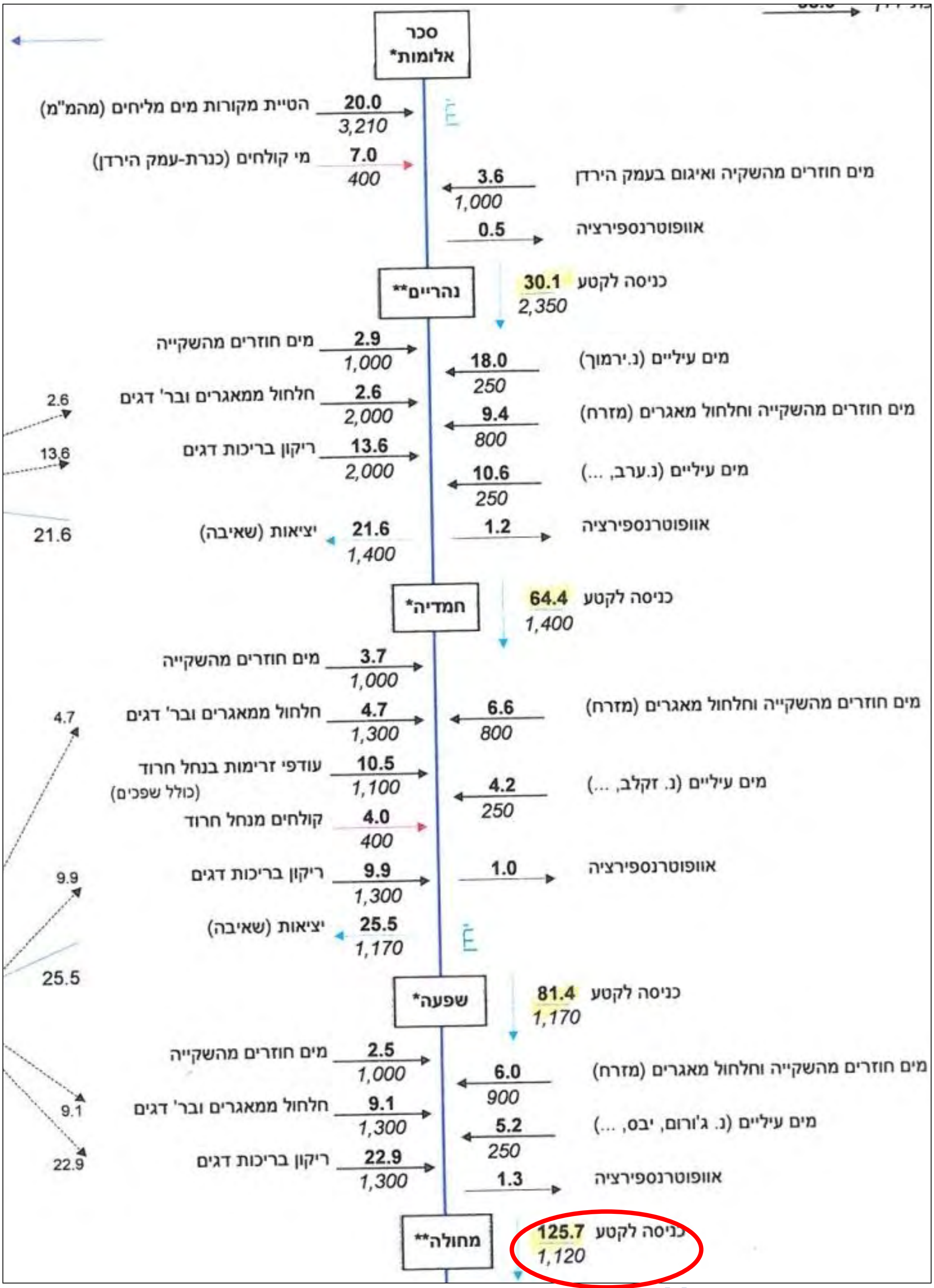

Figure 23:Flow Scheme of an average year in the LJR in 1999 according to TAHAL [5]

4.2 Flow and salinity in the LJR

Figure 24 below presents the monthly flow at different reaches of the LJR (bottom) and the salinity in gram/liter (top)[8]. The color gradient goes from red in Deganiya dam to purple at Kfar Rupin[9], which corresponds to the legend that is ordered from north to south. The relative annual flow in each reach is given in the colored bars that are left to the legend.

The annual flow upstream W. Jumrum is 71 MCM. The highest flow is in February - 11 MCM, while in June, the flow goes down to 3.3 MCM. February is also the month with the lowest salinity – less than 1,000 mg/L downstream the mouth of Tavor Stream. This is the result of reduced agricultural consumption coupled with fresh runoff. While this trend of low salinity in February is likely to be true, it might be somewhat exaggerated in the model. The saltiest spot in the Upper LJR is the mouth of the SWC with an average of more than 2,000 mg/L and typically, salinity falls as we go southwards down to a level of 1,500 mg/L at the confluence with Bezeq Stream. In October-February however, owing to discharges from fishponds, salinity increases below Harod Stream and via Emeq Hamaayanot.

The 3 maps in pages 68-70 present the flow and salinity throughout the year[10], in February, and in June respectively. The size of the streams represents the flow in MCM while the color represents the salinity in mg/L. The scales of flow are different in each map and so, sizes cannot be compared between maps. Rather, they indicate the relative share of the reaches within each map. The colors of salinity on the other hand are comparable, with yellow representing 750 mg/L (the target salinity). The labels on the reaches show the flow at the top and the salinity at the bottom. The tributaries in the maps are not divided into reaches so the entire lengths of the tributaries show the values at their mouths.

The annual flow at the confluence with Bezeq is 76 MCM. The overall amount of water that enters the LJR south to Alumot is roughly 106 MCM/Yr but by the time the water reaches Bezeq, about 17 MCM are directly pumped out from the river, and 13 more are lost through evaporation. The top five contributors to this flow are:

f. Drainage from Emeq Hamaayanot – 27 MCM;

g. The SWC - 19 MCM;

h. Groundwater (not represented as a tributary in the maps) – 18 MCM;

i. Harod Stream – 13 MCM;

j. Tavor Stream – 8 MCM.

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[8] The output data tables are given in appendix 10.2.

[9] Kfar Rupin is located in Emeq hamaayanot, just above the confluence with the eastern Wadi Jumrum. In the WEAP model, this location assumes all the flows of Emeq Hamaayanot, but largely excludes the eastern tributaries from Jordan, which are taken from the GLOWA model.

[10] Average of the salinity of all months, without weighing flow.

The ratio of the different sources changes throughout the year. The winter runoff is a major component in the flow of Tavor Stream for example. As such, it serves as the largest contributor in February, but in June its share is minuscule. The flow of the SWC is fairly constant on the other hand, but its relative share in February is smaller, as the overall flow is larger.

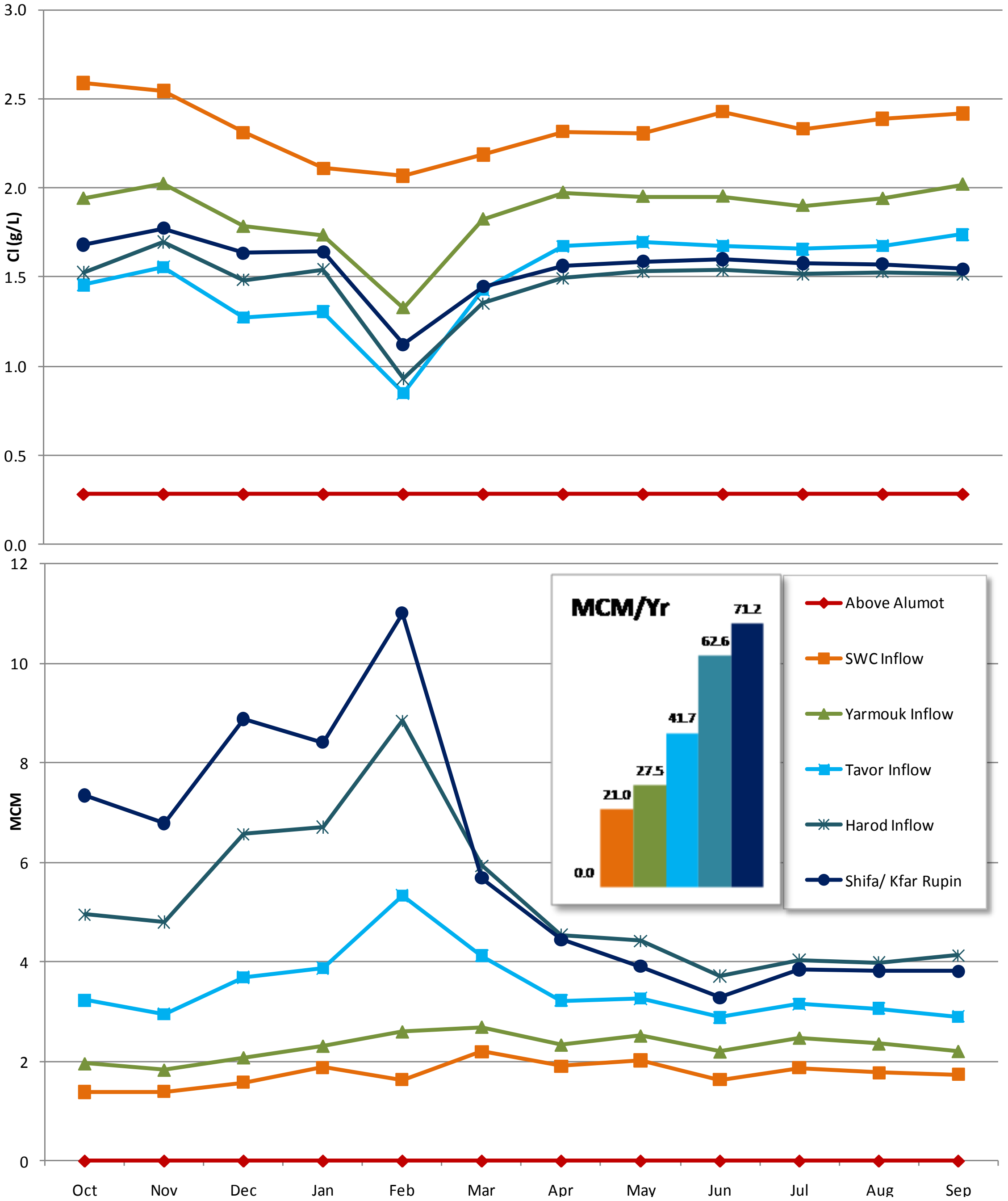

Figure 24:Monthly salinity in gram/L (top) and flow in MCM (bottom) at different spots of the LJR for the Current Accounts scenario in the WEAP model

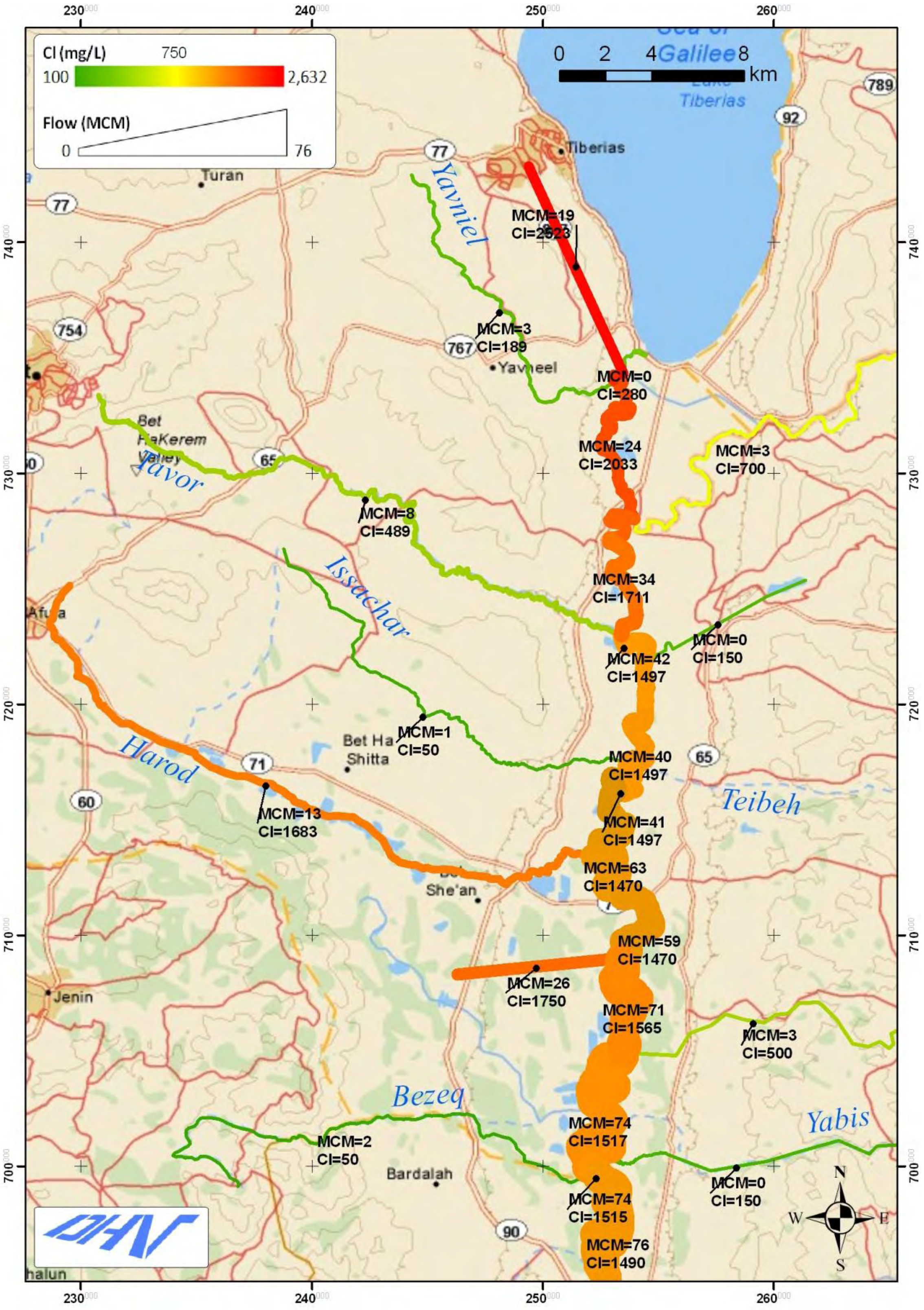

Figure 25: Annual surface flow and Salinity in the LJR basin

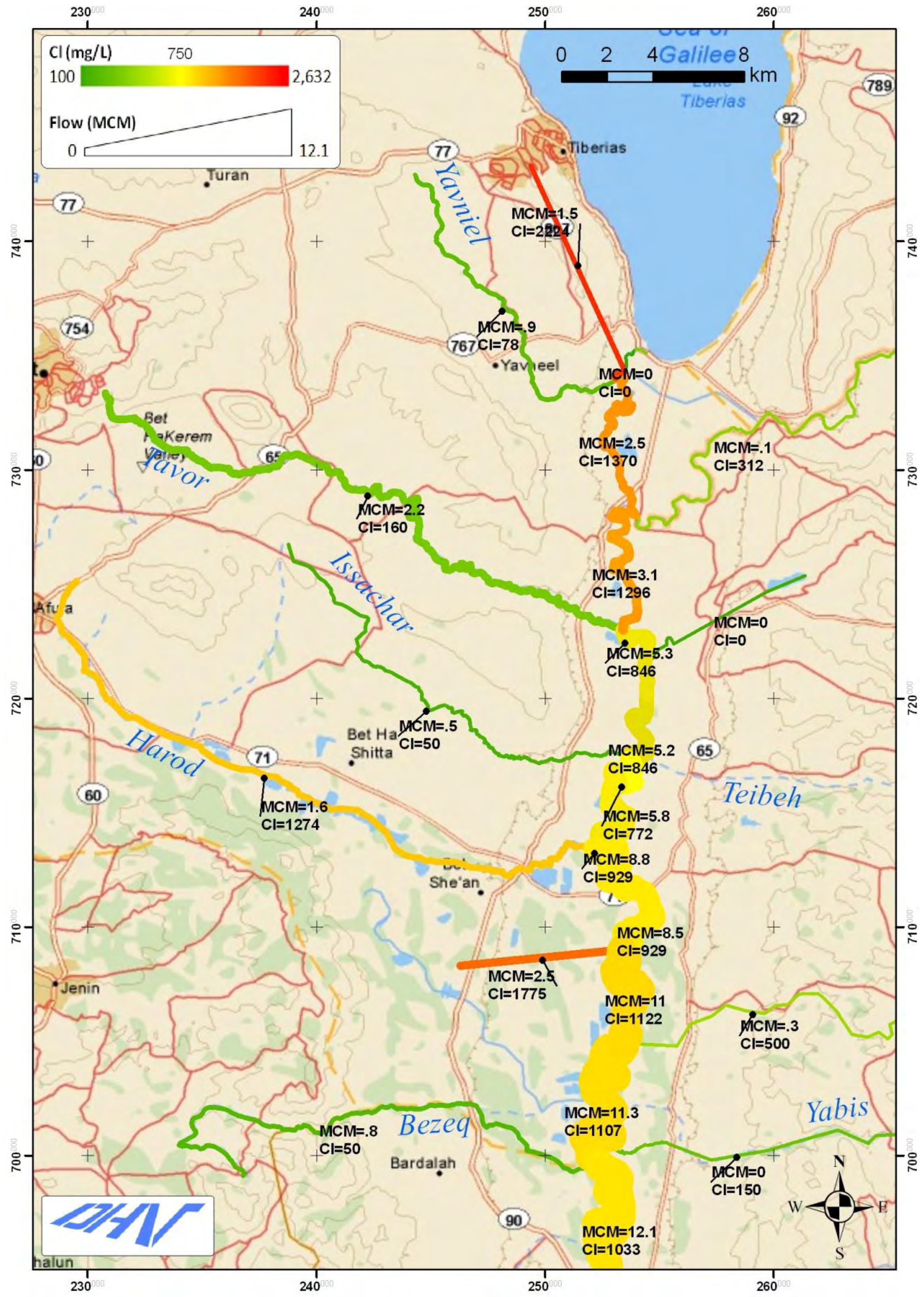

Figure 26: surface Flow and Salinity in the LJR basin at February

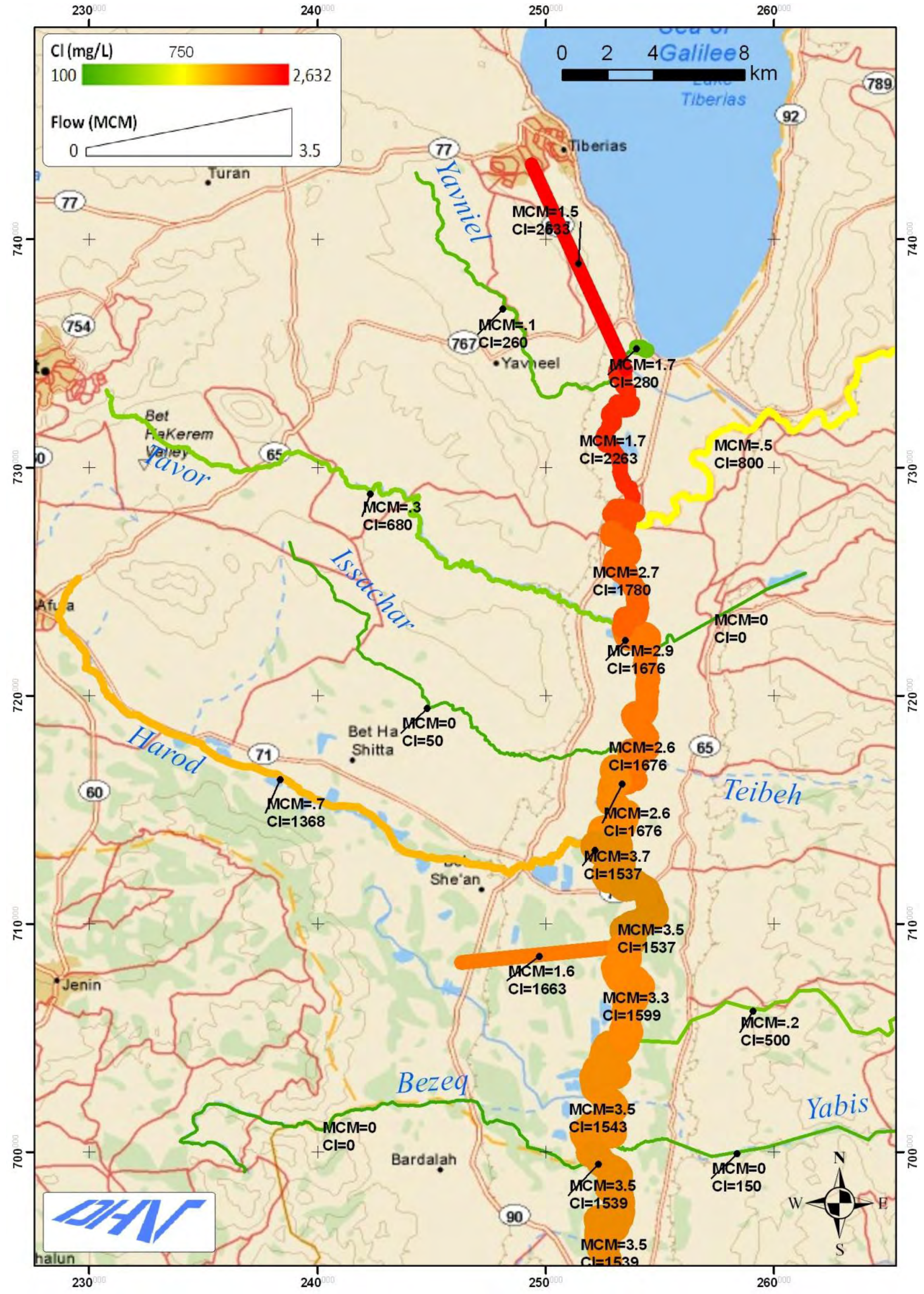

Figure 27: Surface Flow and Salinity in the LJR at June

4.3 Water demand

The reason that flow in June is slightly lower than that of the other summer months (July – September) is that water demand in the Upper LJR basin (Figure 28 below) is higher in June. The increase in demand stems from the saline irrigation at Emeq Hamaayanot, which peaks in May and June. The annual water demand in the LJR catchment, excluding demand from the SoG, totals to 138.7 MCM, and the monthly demand ranges between 7.6 MCM in February to 14.9 MCM in May. About half of the consumption goes to the local fishponds, and the bulk is consumed in Emeq Hamaayanot. The four branches of the AMWA that supplies water in Emeq Hamaayanot (see description in section 3.8.2), are colored separately from the rest in Figure 28.

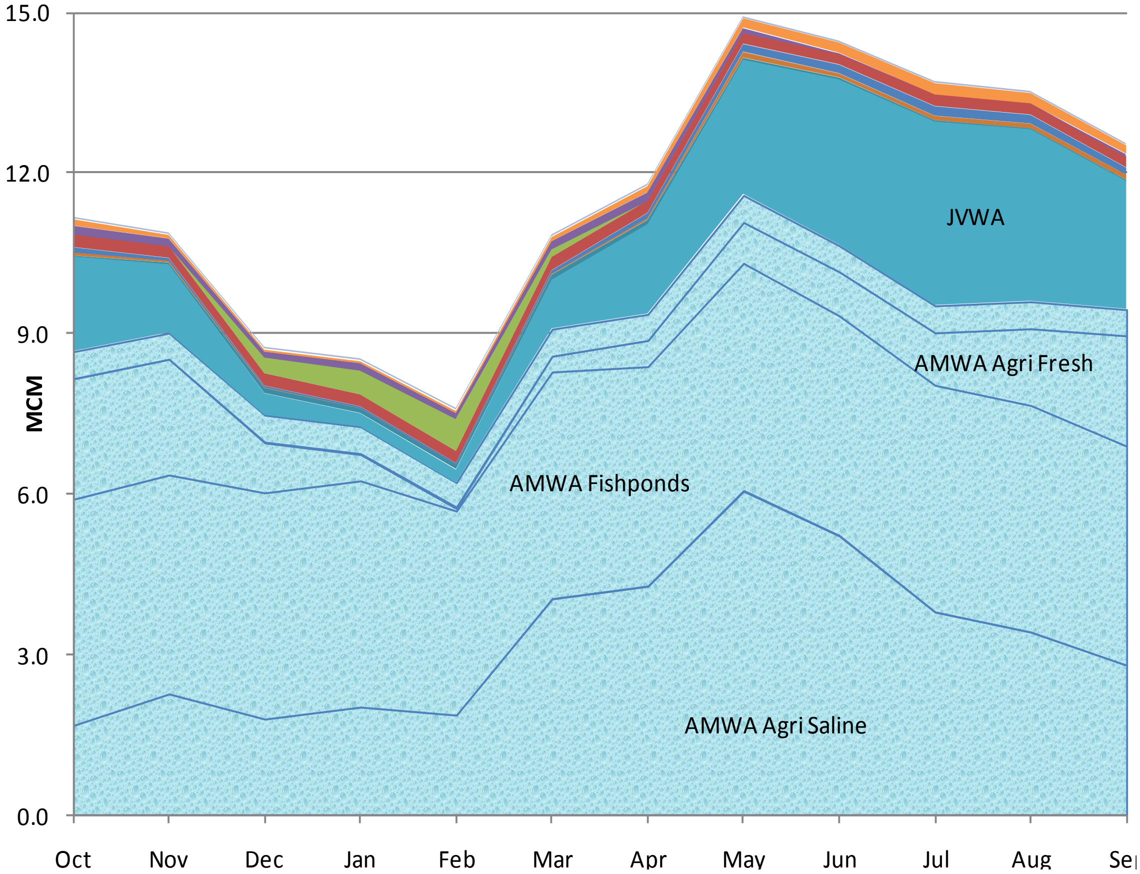

Figure 28: Water Consumption in the basin of the Upper LJR

5 Zero Scenario model

The zero Scenario (ZS) is a future scenario, demonstrating the state of affairs until 2041, if no action is taken to reinstate water into the LJR, on top of already approved plans. This chapter describes the methodology and assumptions of the ZS. Out of all the assumptions covered here, the three most important ones are inflows to the SoG, changes in the consumption of the NWC and transfers to the KAC.

5.1 Sea of Galilee & Climate Change

Figure 29 below shows long term climatic trends that were used in the model. The data on inflows and evaporation was taken as is from a report of Rimmer et al. who used an ensemble of climatic and hydrologic models to derive a future time series [27].

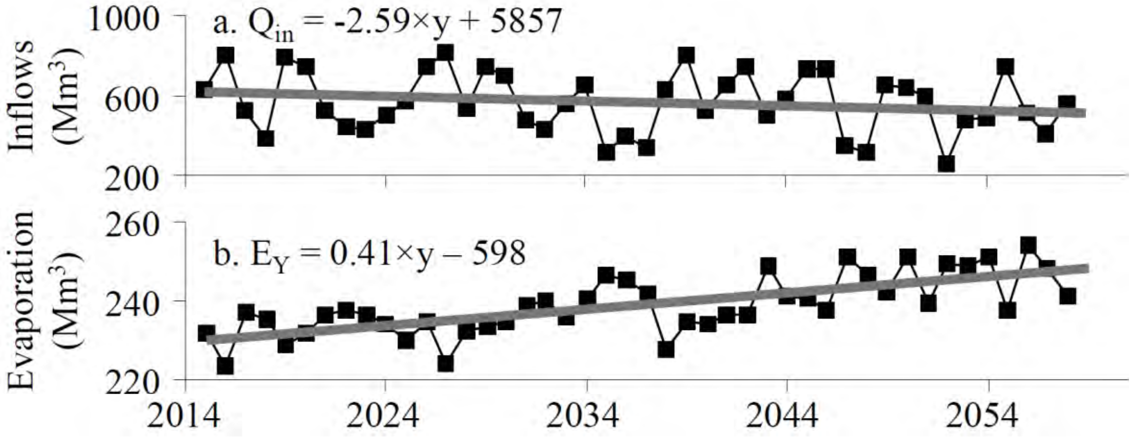

Figure 29: Long term climatic trends in the Kinneret [27]

The given time series start at 2016 and it was necessary to complete the missing years of 2011-2015. For that, the annual inflows to the SoG for the first five years in the predicted data (2016-2020) were compared with the known time series from 1932 to 2009. The 5 years of 1963-1967 were found as the best fit. Therefore, for the years 2011-2016, the annual inflows of the 5 years before (1958-1962) were used. The linear trendline of the complete series for the years 2011-2041 has an X factor of -2.6097, which is very similar to the X factor of -2.59 in Figure 29.

The monthly variation of the 5 years was taken from the monthly variation of the CA. The monthly variation however, as can be seen in Figure 30 below, is expected to remain the same as it is today. Only the annual volumes will decrease.

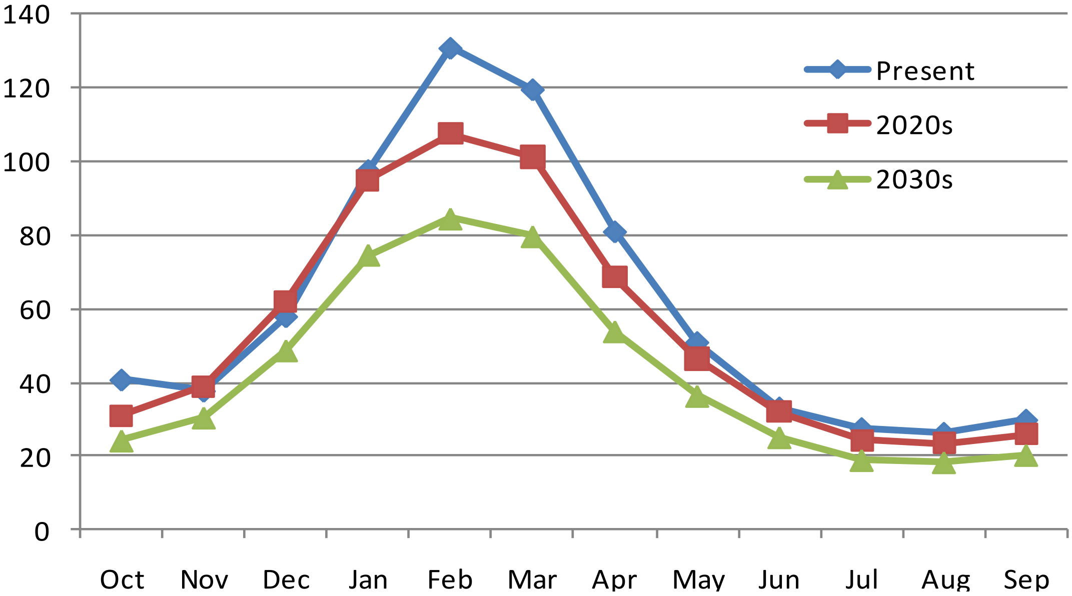

Figure 30: Decadal comparision of inflows to the Sea of Galilee (MCM)

As Figure 31 shows below, an inverse relation exists between evaporation and inflows. Since evaporation in the WEAP model is specified in values of depth and not volume, the evaporation was modeled via the following formula that represents both the increasing evaporation trend of 0.17%/Yr and the inverse relation with inflows:

$$E_n = E_c \times \left(1 - \frac{\frac{JR_n}{JR_c} - 1}{7}\right) + (Y_n - Y_c) \times 0.0017 \times E_c$$

Where:

E_n=Evaporation of n' timestep
E_c=Evaporation of current accounts
JR_n= UJR headflow at n' timestep
JR_c=UJR headflow at current accounts
Y_n=Year of n' timestep
Y_c=Year of current accounts

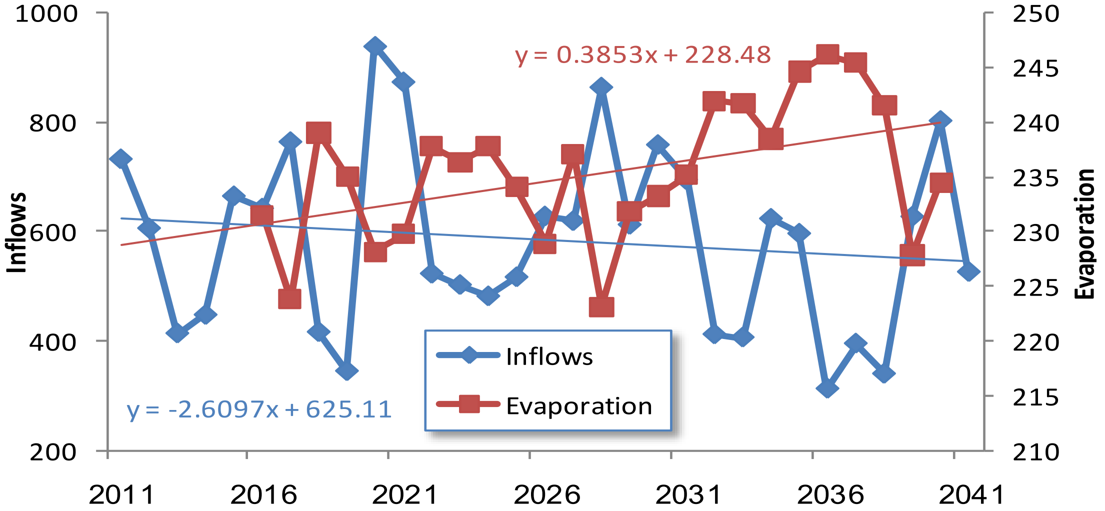

Figure 31: Prediction of annual inflows and evaporation from Sea of Galilee (MCM) [27]

Data on salinity however, was not taken from Rimmer's report as it only takes into account climatic and hydrological parameters, while the salinity of the SoG in recent decades was affected more by operational actions: Namely the SWC and upper basin demand. Further operations (like the expected diversion of the saline Foliya springs into the SWC) are likely to offset climatic effects. Hence, salinity of the SoG is assumed to remain at the current level.

As for Deganiya dam, the assumption in the ZS is that it is kept closed as long as the SoG stays below the top red line. As a result, overflows in the model will happen only when the reservoir reaches its maximum capacity.

5.1.1 Addition of Artesian wells

Table 7: Monthly variability of the artesian wells in the WEAP model

month	M^3/hour	M^3/sec	MCM
Oct	1000	0.3	0.72
Nov	1500	0.4	1.08
Dec	2250	0.6	1.62
Jan	3000	0.8	2.16
Feb	3500	1.0	2.52
Mar	4500	1.3	3.24
Apr	4200	1.2	2.88
May	3000	0.8	2.16
Jun	2250	0.6	1.62
Jul	500	0.1	0.36
Aug	500	0.1	0.36
Sep	500	0.1	0.36
		Total:	**19.08**

New wells are being drilled these days in the basin of the UJR, from an artesian aquifer, which until recently has not been exploited. Currently (2011), 4 wells have been dug with a combined flow of nearly 3,000 m^3/hour. This yield is not final as not all the wells are in full production, and new drills are planned for the future. Some of the water is intended for municipal and agricultural use, but much of this "new" water will flow southwards to the SoG.

The estimation for the ZS is that the artesian wells will contribute 19 MCM/Yr to the SoG, with a variability as specified in Table 7 below, Reaching full production by the year 2020.

5.2 Evaporation from the Lower Jordan River

The method of calculating evaporation from the LJR for the CA (section 3.6) is purely empirical. Evaporation from reaches is specified in WEAP as the percentage of evaporation from the flow volume. The problem here is that the physical shape of the channel is unknown. If the flow in a given reach changes significantly, then the effect of the change on evaporation cannot be quantified because the future surface area cannot be calculated. For example, if the flow multiplies by 10 folds then obviously, evaporation should increase in absolute terms, but not by 10 folds as it will decrease relatively to the flow. To calculate evaporation from the river with physical formulas, further research is required on the morphology of the river (and indeed, on evaporation from rivers in general and from the LJR in particular).

Since that data is unavailable, other assumptions had to be taken. The most significant increase in flows in the LJR is when the SoG is overflowing. Therefore, whenever the SoG is over the top, it was assumed that the evaporation percentage drops to 30% of the CA values. The other factor that was considered is the expected effect of climate change on evaporation, which was assumed to be identical to the effect on the SoG. Hence, the formula of the evaporation from the LJR is:

$$E_n = (E_c + (Y_n - Y_c) \times 0.0017 \times E_c) \times \mathrm{K_f}$$

Where:

E_n=Evaporation of n' timestep
E_c=Evaporation of current accounts
Y_n=Year of n' timestep
Y_c=Year of current accounts
K_f= Flood coefficient – if the SoG is overflowing then K_f =0.3, else K_f =1

5.3 Saline Water Carrier

The SWC is about to change significantly from its present situation thanks to the desalination project and the diversion of Foliya A spring to the SWC and the water level of the SoG, as detailed below:

5.3.1 Tabgha & Tiberius Hot Springs

The yield of both springs is related to the water level of the SoG. As the water level in the lake drops, the flow in the springs drops along. As the head of the lake decreases compared to the saline groundwater, the flow in lower level springs grows on the expense of the higher springs [9]. That phenomenon was modeled through the following formula:

$$Q_n = Q_c \times \left(1 + (1 - \frac{\mathrm{H}_i}{H_{n-1}}) \times \mathrm{K_s}\right)$$

Where:

Q_n=Spring flow in n' timestep
Q_c=Spring flow in current accounts
H_i=Initial water level in the SoG from the bottom (not MSL)
H_{n-1}=SoG water level in n'-1 timestep from the bottom (not MSL)
K_s=Spring coefficient: For Tabgha =3, for THS=7

5.3.2 Foliya Spring

The group of Foliya saline springs was revealed in 2001, when the SoG subsided. In 2009, Mekorot put a large iron dome on Foliya A spring, with the purpose of quantifying it and establishing the feasibility of its diversion to the SWC. Temporary results show a flow of 10 MCM/Yr with an average salinity of 2,200 mg/L. The flow of Foliya A is inversely related to the level of the SoG, the higher is the lake the lower is the flow of the saline water due to the hydrostatic pressure, but this phenomenon is not well quantified yet. The flow peaks in the spring and almost stops in late summer [9]. Foliya A is expected to be diverted to the SWC within the next 2 years [28].

Table 8: Monthly diversion of Foliya A into the SWC (MCM) in the WEAP model, starting from 2013

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	0.2	0.5	1	1.5	2	2	1.5	0.7	0.3	0.2	0.1

In the model, the diversion of Foliya A to the SWC starts at 2013 and is governed by the following formula:

$$Q_n = Q_t \times \left(2 - \frac{\mathrm{H}_{n-1}}{H_\mathrm{i}}\right)$$

Where:

Q_n=diversion in n' timestep

Q_c=diversion according to Table 8

H_i=Initial water level in the SoG from the bottom (not MSL)

H_{n-1}=SoG water level in n'-1 timestep from the bottom (not MSL)

5.3.3 The desalination project

The completion of the desalination project is expected by 2015. The plan consists of four major components [10]:

- Desalination plant with a capacity to produce 7 MCM/Yr of water for agriculture. The plant, represented in Figure 32 by the red dot named SWC desalination, will take 9 MCM/Yr from the SWC.
- The brine of the plant (estimated at 2 MCM/Yr), all the water of the THS, and 4.5 MCM of Tabgha, will be pumped through a different pipe and transferred southwards to the fishponds of Emeq Hamaayanot ("SWC Brine" on the left of Figure 32).
- Bitaniya WWTP will be upgraded to tertiary level and will receive the wastewater of about 60% of the city of Tiberius, thus increasing the effluent to 3-4 MCM/Yr.
- The fishpond of Afikim (the green triangle at the bottom right of Figure 32 below) will be converted to a reservoir with a storage volume of 4 MCM. The reservoir will receive water from the desalination plant and Bitaniya WWTP. The water will be used for irrigation by the JVWA.

The project is expected to produce some 10 MCM/Yr for the JVWA.

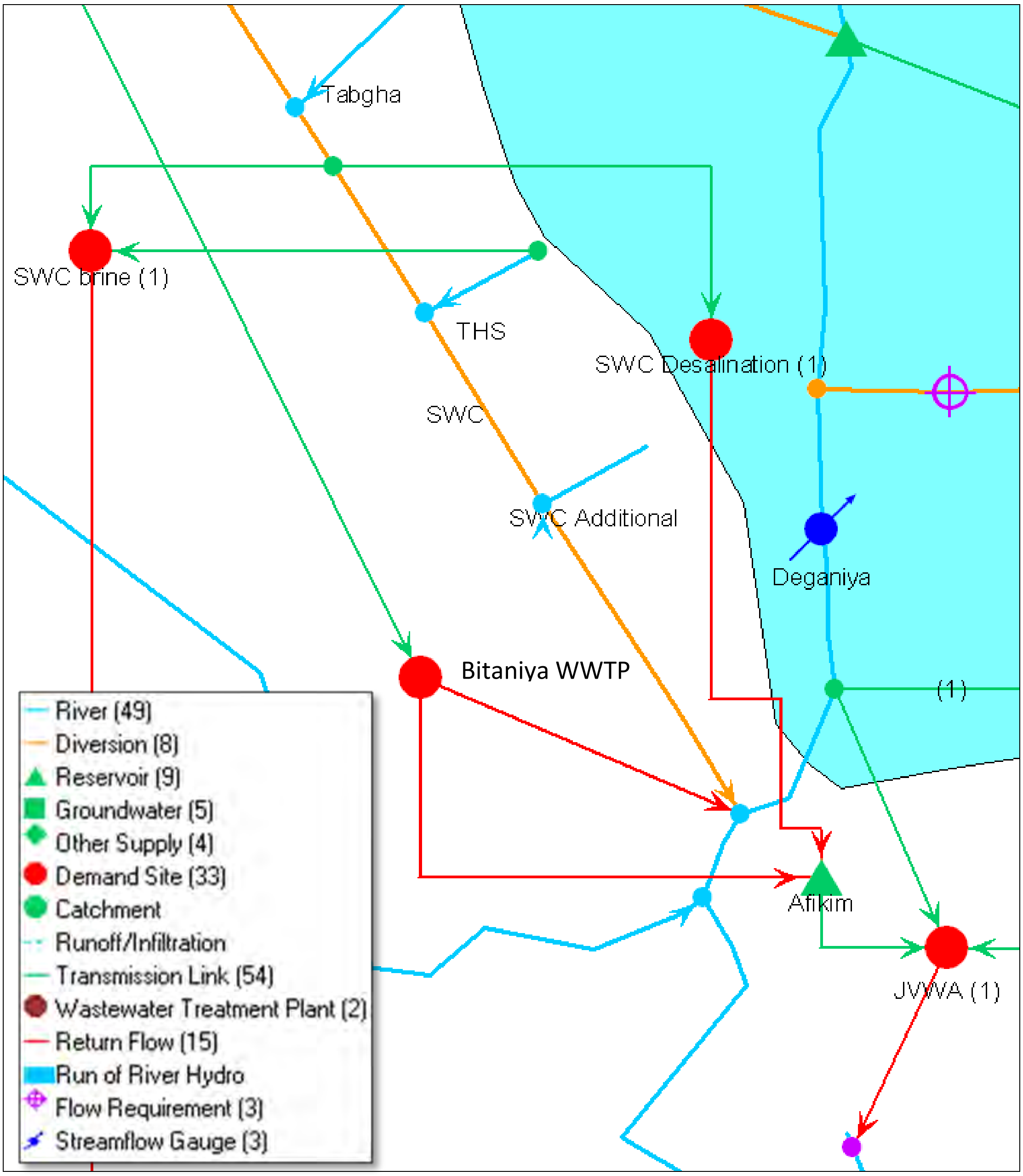

Figure 32: Flow scheme of the SWC, after the desalination project in the WEAP model

5.4 Water exchange between the SWC and the Sea of Galilee

Another aspect of the mentioned reclamation plan is an allocation of 14 MCM/Yr from the SoG to the LJR. The overall purpose is to ensure a flow in the Upper LJR of at least 30 MCM/Yr (together with 16 MCM/Yr from the SWC, including Foliya A) with a salinity of less than 1,000 mg/L. the plan is supposed to be realized within the next two years [28].

In the WEAP model, this aspect was modeled through a Flow Requirement upstream Alumot dam, starting from 2016. The required flow was assumed to equal the Foliya A headflow multiplied by 1.4, to get 14 MCM/Yr. The Flow Requirement was given a priority lower than that of the NWC but higher than the filling of the SoG, so in times the lake is below the bottom red line; some of the requirement will not be met (see section 3.2).

5.5 Runoff from the western tributaries

Unlike for the UJR and the SoG, no reliable sources were found regarding long-term climatic trends in the Western tributaries of the LJR. The current model of GLOWA assumes a gradual reduction of 30% by 2040, but that coefficient refers to the entire flow and not just surface runoff. In addition, the GLOWA project currently engages in a new modeling effort to create catchment-based long-term trends, but that work has not yet been finalized. Therefore, runoff from the western tributaries was assumed to follow the same trend as the inflows to the SoG. In the model, the runoff was calculated via the following equation:

$$R_n = R_c \times \frac{JR_n}{JR_c}$$

Where:

R_n=runoff of the calculated tributary for n' timestep
R_c= runoff of the calculated tributary for current accounts
JR_n= UJR headflow at n' timestep
JR_c=UJR headflow at current accounts

5.6 Springs

Establishing a 30 year future trend for springs, that include both flow and salinity, is an almost impossible task in the region of the LJR. First, the aquifers in the region are compartmented in several sub-aquifers and numerous cells. The relations between the cells are not always clear and are sometimes dominated by various faults (see section 2.3). Second, many of the springs are nourished by aquifers that start in the west bank and are heavily influenced by Palestinian demand. A policy for that demand however, has not been set yet.

The springs in the model were divided into two groups:

- Springs that so far have shown little to no sensitivity to aquifer exploitation;
- Springs whose flow in the past 15 years has decreased as a result of upstream exploitation.

5.6.1 Springs oblivious to current aquifer exploitation

Disregarding changes in aquifer exploitation, the spring's ebbs should follow climate change, as more water will evaporate and less of the rainfall will percolate to groundwater. The ratio between springs decrease and rainfall reduction should be higher than 1. In the model 50% more reduction of flows in springs was assumed. If total precipitation decreases by 10% for example, then springs flow should decrease by 15% in the long run. The short-term fluctuations however, are more subtle than with surface runoff. To model those two trends, springs flow was calculated via the following formula:

$$Q_n = Q_c \times \mathrm{K_p} \times \frac{\left(1-\left(\frac{\mathrm{JR}_c}{\mathrm{JR}_n}-1\right)\right)}{\mathrm{K_s}}$$

Where:

Q_n=Spring flow in n' timestep
Q_c=Spring flow in current accounts
K_P=Precipitation decrease coefficient: linearly decreases from 1 to 0.85 in 2041
JR_n= UJR headflow at n' timestep
JR_c=UJR headflow at current accounts
K_s=Spring coefficient: 7

5.6.2 Springs that are sensitive to upstream exploitation

Some springs however, have already shown sensitivity to pumping from aquifers. Those springs are characterized by distinct trends of flow and salinity. The springs flow data from 1995 onwards was thus analyzed. For springs with evident trends, the K_P coefficient in the formula above was adjusted accordingly. In some cases salinity was corrected as well. The corrected springs are (in brackets, the spring ID in the IWA):

Emeq Hamaayanot

- Tzemed Spring (39218) shows in the recent 4 years a steady and sharp increase in salinity from 800 to 1055 mg/L. Salinity increase of 200 mg/L per decade was assumed.

- Yehuda spring (39220) shows a decline a steady decline in flow from 1.1 MCM in 1995 to 0.8 MCM in 2010. Flow decline of 0.2 MCM per decade was assumed.

- Karnaim spring (39260) showed a slow and steady declining salinity trend from 1800 to 1600 mg/L. in the year 2005, it suddenly dropped to around 1000 mg/L, and has been keeping a steady salinity since. Salinity decrease of 100 mg/L per decade was assumed. This spring is grouped in the "Small Emeq Springs" reach in the model. So the salinity of the entire group is lowered from 869 to 826 mg/L in 2040.

Tavor

- Dor Spring (35215) shows a steady trend of an increase in salinity from around 300 mg/L in 1995 to 500 mg/L in 2010. Salinity increase of 100 mg/L per decade was assumed.

Harod

- Harod Spring (38220) shows a steady decrease in its yield from 4.5 MCM in 1995 to 2.5 MCM in 2010. Flow decline of 0.5 MCM per decade was assumed. salinity was steady at 300, in recent 2 years, salinity has jumped to 500. Salinity was assumed to remain at 500 mg/L, as the jump was sudden and could be a onetime occurrence due to aquifer level reaching a saline layer.

- Homa Spring (38260) shows a steady decrease in its yield from 4.5 MCM in 1995 to 3 MCM in 2010. Flow decline of 0.5 MCM per decade was assumed. It also presents a slight increase in salinity from 330 mg/L to 480 mg/L in 2010.most of the increase occurred in recent years. Salinity increase of 50 mg/L per decade was assumed

- Huga Spring (38270) shows a steady decrease in its yield from 4.5 MCM in 1995 to 3 MCM in 2010. Flow decline of 0.5 MCM per decade was assumed. The spring's salinity has been steady at around 1500 mg/L, but in 2005 it dropped to 1136 mg/L and stayed at that level. Salinity is assumed to remain at 1136 mg/L.

- Migdal Spring (38263) shows a steady trend of an increase in salinity from around 600 mg/L in 1995 to 700 mg/L in 2010. Salinity in CA was set at 680 mg/L and it was assumed to increase at a rate of 50 mg/L per decade.

- The salinity of Shokek Spring (38266) was steady at 300 mg/l until the year 2002. Since then it has been increasing up to 430 mg/l. Salinity in CA was set at 400 mg/L and it was assumed to increase at a rate of 50 mg/L per decade. The spring also shows a declining trend in flows from 11 MCM in 1995 down to 7 MCM in 2010, despite a large increase in the year 2003. Flow decline of 1 MCM per decade was assumed.

Bezeq

- Muda Spring (39290) has been showing a steady decrease in its yield from 9 MCM in 1995 to 7.5 MCM in 2010. Flow decline of 0.5 MCM per decade was assumed. Salinity has shown a steady increase from around 250 mg/L in 1995 to 350 mg/L in 2010. Salinity increase of 75 mg/L per decade was assumed.

5.7 Drills of the AMWA

The AMWA operates 8 drills that currently supply 16 MCM/Yr of fresh water. The groundwater levels in the region are going down and it is likely that current level of supply is unsustainable [17]. The assumption in the model is that by 2040, the drills will allow production of 14 MCM/Yr. the drop will be gradual.

The monthly variation of the pumping, as it is today, draws relatively small amounts in the winter – only 0.6 MCM/month for December and January. Keeping the current variation will result in a shortage of municipal water by 2022 as the municipal demand of the AMWA is expected to grow (section 0 below). Therefore, the monthly variation was adjusted to meet the minimum municipal requirement. To maintain the annual quota, pumping in the model is reduced in other months with higher demand.

Figure 33 below shows the result of the gradual changes described above in 2040, the water yield of the AMWA drills will be lower than it is today in all the months, except for November-January. The total annual yield in the future will be lower.

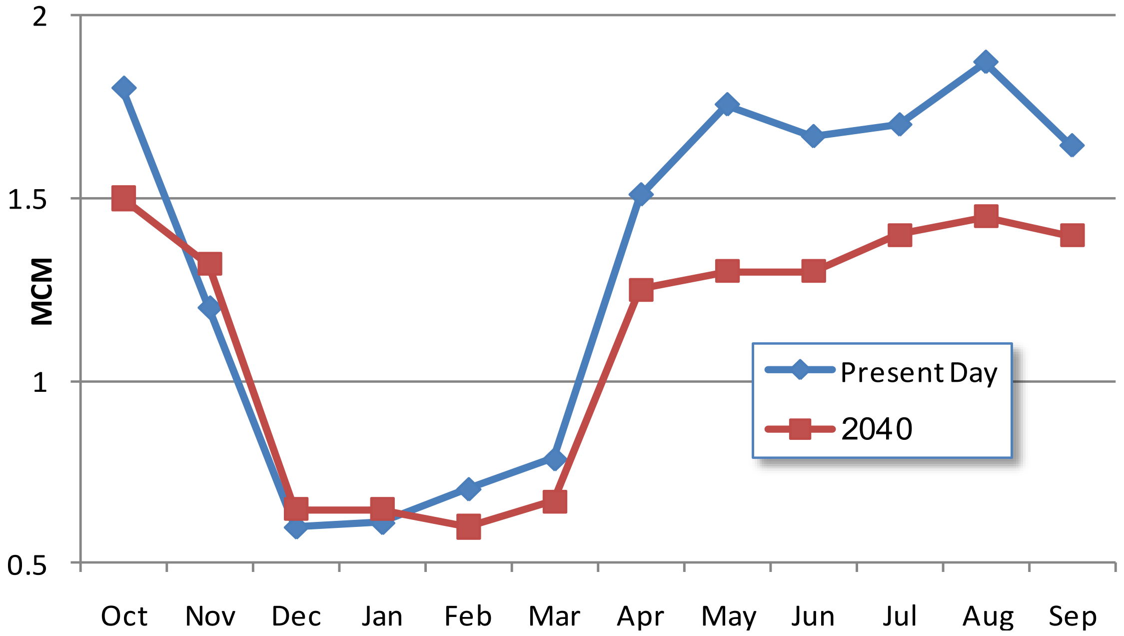

Figure 33: Pumping from the drills of the AMWA today and expected in 2040

5.8 Expected Demand

Several changes are expected in the water demand. The largest changes though, should outside the basin of the LJR but affect it significantly. The larger changes are:

- Drop in pumping to the NWC;
- Increase in the transfers to the KAC;
- Water quota changes in the basin of the UJR;
- The Fishery Reform.

This section describes all the relevant demand changes, both outside and inside the basin. For Jordan and the PA, data and assumptions were taken from the "Climate Change Trend, SAS - Poverty and Peace" scenario of GLOWA.

5.8.1 National Water Carrier

The NWC has been the backbone of the Israeli water system since 1965. These days, the Israeli water market is undergoing a revolution as desalination is gradually becoming the largest source of fresh water in the country. As a result, less water will be transferred from north to south and the pumping to the NWC from the SoG is expected to decrease in the long run.

As for the annual variability, thus far it has been weighty with some years showing a consumption of more than 500 MCM/Yr while in others, less than 200 MCM/Yr were consumed; depending on the condition of the lake and the given inflows in that year. This annual variability is expected to become more moderate, as the SoG water level will rise and the dependency on its water will decrease.

The Demand from the NWC was calculated with the following formula:

$$D_n = D_c \times \mathrm{C_y} \times \left(1 - \frac{\frac{I_c}{I_n} - 1}{2}\right)$$

Where:

D_n=Demand from the NWC of n' timestep
D_c= Demand from the NWC of current accounts
I_n=Inflows to the SoG of n' timestep
I_c= Inflows to the SoG of current accounts
C_y=Year coefficient that interpolates linearly through the following points:
if year<2013 then 1
Year=2016 then 0.8
Year=2021 then 0.6
Year=2041 then 0.2

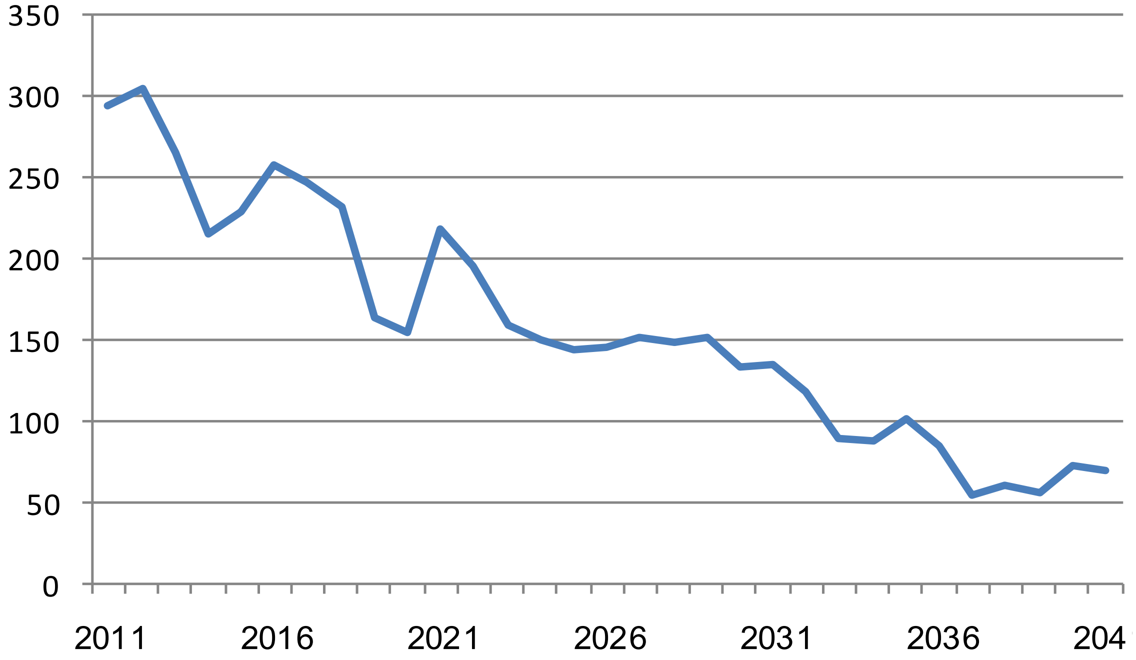

Figure 34: Modelled annual demand of the NWC (MCM)

Figure 34 shows the modeled annual consumption which is the result of the above formula. One has to remember that the computed pumping to the NWC might be lower if the SoG is below the bottom red line (see section 3.2). Theoretically, it can be higher if the demand is not high enough to meet the requirements of Jerusalem/Ramallah and the wastewater generating demand sites that are connected in the model to the NWC. This possibility of higher demand is unlikely though.

5.8.2 Water quotas changes in the Upper Jordan River

In the UJR basin, water quotas for farmers have been regularly cut back due to the low level of the SoG. Those quotas are expected to be returned to the farmers with the increase of the water level in the lake. A precise estimation of the returned quotas, including a possible increase in demand, would require a full model of the UJR. Such a model is outside the scope of this project though.

Hence, the assumption was that when the SoG rises above the Bottom Red Line (see section 2.2.1) then 15 MCM/Yr will be returned to the farmers upstream. When the SoG rises above the bottom level of Deganiya dam, then 30 MCM/Yr of quotas will be returned. That scheme was modeled through a demand site located upstream of the reservoir of Lake Tiberius. The monthly variation of this demand site is shown in Figure 35 below.

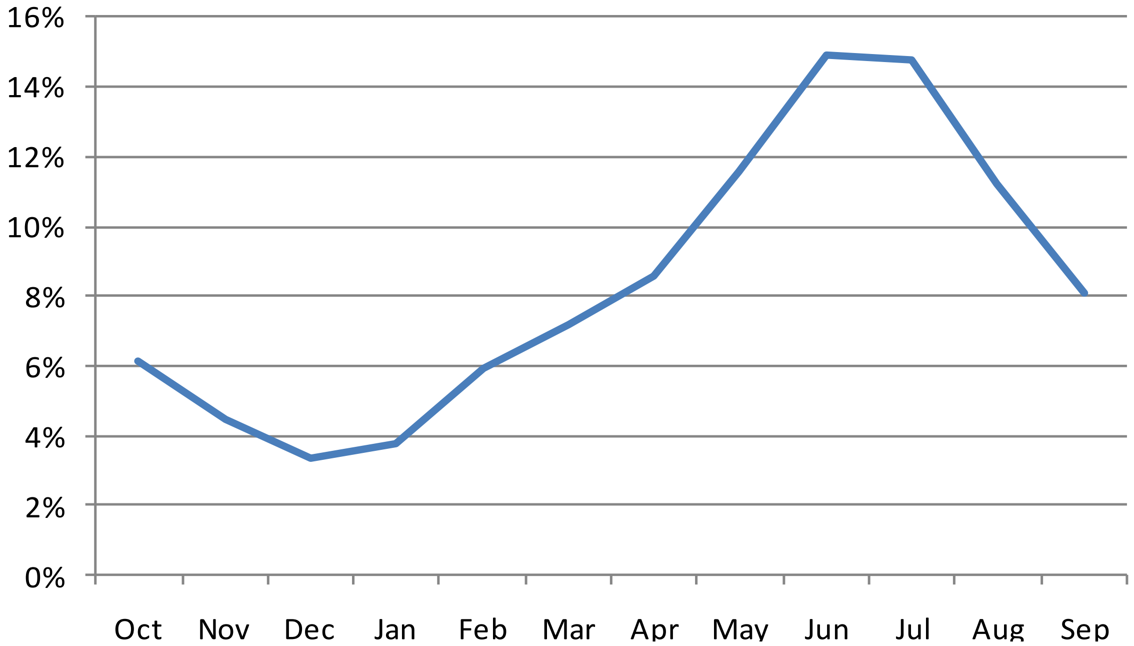

Figure 35: Monthly variation of the demand site representing the UJR quotas

5.8.3 Local Municipal Demand

The municipal demand is affected by two variables: the number of people and the demand per capita. Municipal Demand exists in the model in the demand sites of Bitaniya WWTP and AMWA Muni. Table 9 below shows the population growth in the 4 relevant local authorities. Other types of municipal consumption are hospitals, tourism, other peripheral (to the model) authorities etc. For those, the medium growth alternative of the Central Bureau of Statistics in Israel was used. This alternative assumes an annual population growth of 1.5% in 2011-2015, 1.4% in 2016-2020, and 1.3% from 2021 on [29]. Industrial water demand is estimated to grow by 0.5% annually [30].

The demand per capita is divided into urban consumption (90 m^3/Yr) and rural consumption (240 m^3/Yr). The master plan of the Water Authority does not distinguish between them and simply states that per capita consumption will decrease from 100 to 95 m^3/Yr by 2050 [30]. For the model, the taken assumption is that most of the consumption decrease by 2040 will happen in the rural sector that will reduce its demand to 200 m^3/Yr; while the urban sector will reduce it to 88 m^3/Yr. Production of wastewater per capita will remain constant at 72 m^3/Yr.

Table 9: Population growth in relevant local authorities in 2008 [29]

Local Authority	Growth (%)
Emeq Hayarden	1.8
Tiberius	0.1
Beit She'an	1.4
Emeq Hamaayanot	1.1

5.8.4 Irrigation

Though no research was undertaken on the effect of climate change on irrigation in the region [26], the need to water crops is likely to intensify as a result of higher evaporation. This likelihood might be offset by improved utilization of the water. Hence, long term climatic effects on agricultural demand are not included in the model, unless stated otherwise.

New artificial sources will be available to irrigation within the coming few years. Those sources are:

- Bitaniya WWTP to JVWA at 2013;
- Desalination project of SWC to JVWA at 2016;
- Beit-She'an WWTP to AMWA at 2011;
- Some of the WW of Harod (1 MCM/Yr) to AMWA at 2016.

JVWA

Today the irrigated area of the JVWA is 70 km2. The potential area is 85 km2, and it is likely that with the effluents of Bitaniya, more areas will be irrigated [10]. In light of that, the following assumptions were made for the different branches in the model [25]:

- Subtropical trees: many of the plantations were uprooted in 2008, and were replanted as young trees that take less water. So annual water use rate was factored to 70% in the CA. In the ZS, it gradually grows back to 90% by 2025. Additionally, many plantations were grafted and take almost no water today, so in the CA, the area was multiplied by 0.8. in the ZS it gradually goes back to 100% by 2020. On top of that, 50 dunams are assumed to be planted every year.
- Bananas: The consumption of bananas per dunam should drop from 1800 to 1600 m^3/dunam due to the shift towards netted plantations.

- Olives - many of the trees are young and are expected to require 20% more water as they grow up by the year 2030. New areas are being planted, so the expectation is for an increase of 10% in the area of olives by 2020.
- Field crops – The irrigated area should increase to about 50% of the cultivated area by 2040, owing to the desalination project and climate change that should affect dryland farming most.

AMWA

Not too many changes are expected in the agricultural branches of the AMWA. The main result is the lack of fresh water that prohibits further growth. One probable change is additional planting of olives - about 10% growth by 2020.

Harod

Harod spring is about to be released within 5 years. The replacements for its water, which is mainly used for irrigation, will come from effluents of the Kishon Water Works (namely the WWTP of Haifa) [23].

5.8.5 Fishponds

Several major changes are expected in the local fishponds. The first is a new reform in the fishponds market that is underway. For the water balance of the LJR, this reform will have to consequences [18]:

- The total area and water consumption of the fishponds is expected to decrease by 20% in the coming decade.
- The release of water to empty the ponds will take place from the mid of October until the mid of January, only. The change is assumed to happen from 2014 on.

The second change is the usage of brine from the SWC, described in section 5.3.3. This brine will add some water to the ponds of the AMWA, but will also increase their salinity, and the effluent is assumed to reach 2,700 mg/L by 2016.

Finally, Evaporation will increase according to climate change trend, but will decrease due to closure of ponds. Hence, the formula of the evaporation from Fishponds is:

$$E_n = (E_c + (Y_n - Y_c) \times 0.0017 \times E_c) \times \mathrm{A_n}$$

Where:

E_n=Evaporation of n' timestep
E_c=Evaporation of current accounts
Y_n=Year of n' timestep
Y_c=Year of current accounts
A_n=% of the pond area in current timestep, of the pond area in the current accounts

6 Zero Scenario results

This chapter presents the results of the ZS, whose methodology is detailed in chapter 5 above. The results focus on 3 main topics:

- The Sea of Galilee
- Flow and salinity in the LJR
- Local demand

The ZS represents one plausible future scenario. Naturally, if one alters the assumptions described in chapter 5, then results will change as well. For example, the climate change time series assumes particularly wet years in 2020-2021 and three consecutive drought years in 2036-2038. Sequences of wet and dry years are bound to happen, but not necessarily in the exact order of the modeled time series. Another example is the decreasing pumping to the NWC. The overall trend of decline is an almost certainty in light of the sea water desalination, but will it occur exactly at the rate put in the WEAP model?

Therefore, the results presented here should be regarded with due care. They can illustrate long term trends and extreme situations, but are not to be taken literally. When looking at the results, one should refer to periods rather than to chronological years. Extreme years should be looked at as study cases for a given period. For instance, one of the years analyzed below is 2028, which in the model is the rainiest year. It should not be looked upon as a prediction for 2028 per se, but rather as a representative of an extreme wet year.

6.1 Sea of Galilee

Figure 36 below shows the calculated water level of the SoG. Today, the level of the lake is between the bottom red line and the black line. It is expected to remain between the two lines in the coming decade. In the years 2020/21 the water level jumps sharply in reaches the top red line (i.e. the SoG fills up completely). That sharp rise is the combined result of two consecutive exceptionally wet winters and the decrease in the consumption of the NWC (Figure 37 below), which should in 30 years, reach the magnitude of the transfers to the KAC (assuming the later remains the same).

Afterwards the SoG remains high most of the time, thanks to the decreasing pumping to the NWC, which outweighs climate change (see section 5.1). Nonetheless, the temporary decline of 2036-2038, shows that the SoG might still be somewhat vulnerable to extreme drought situations in the long run.

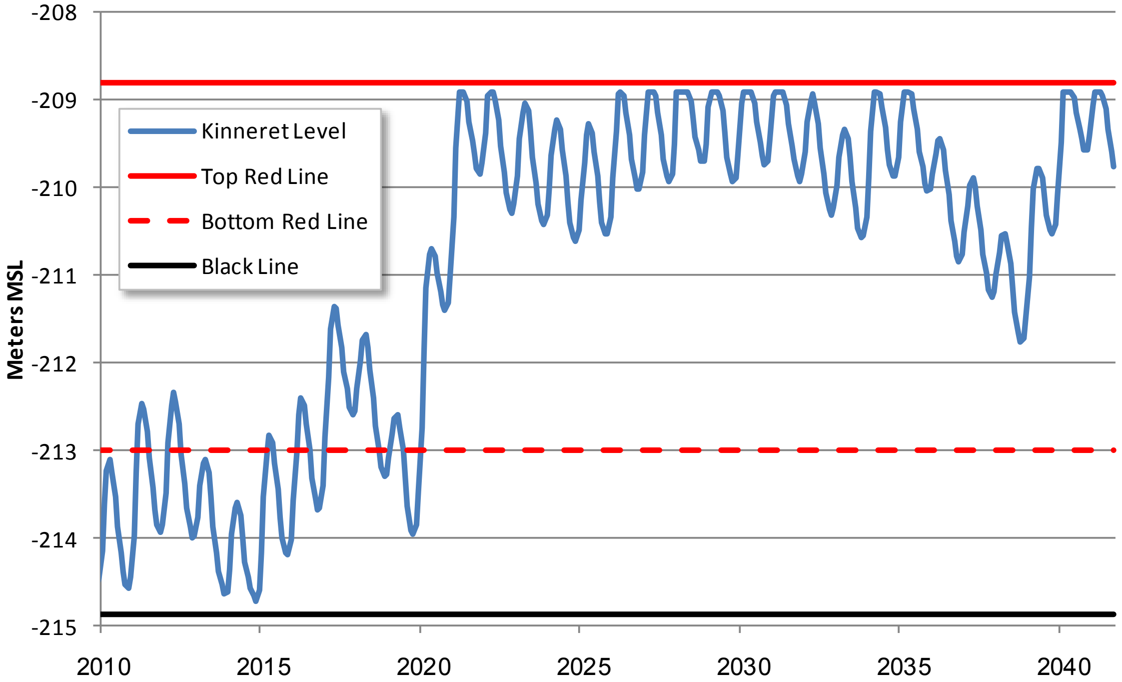

Figure 36: Projected water level in the Sea of Galilee

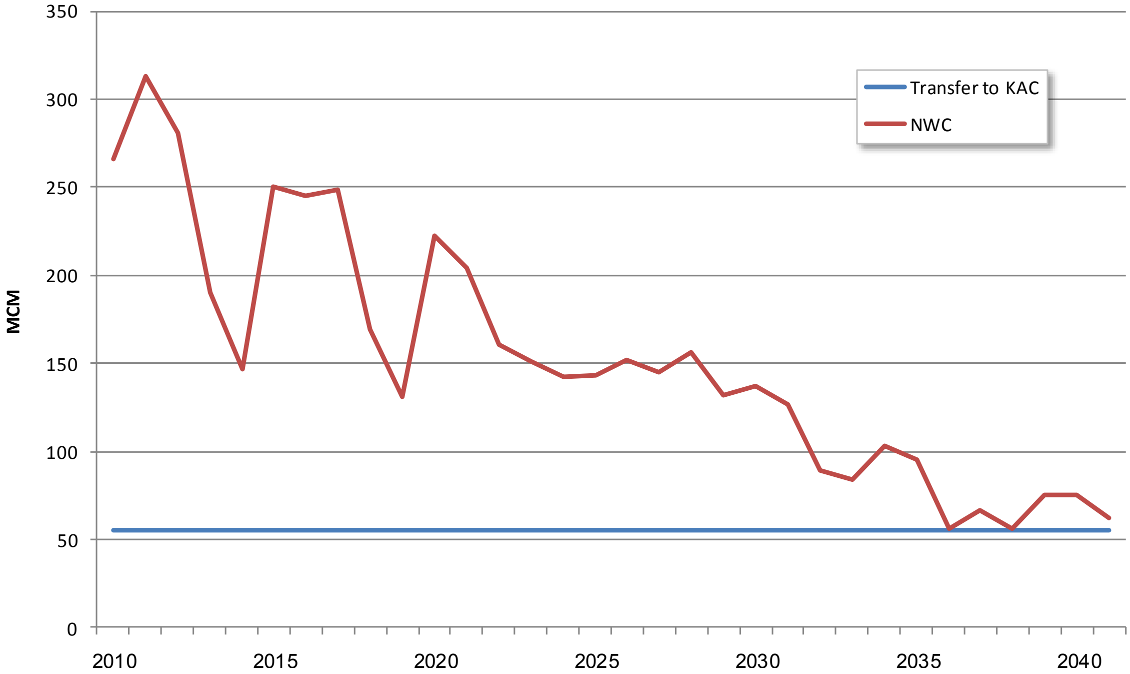

Figure 37: Annual delivered supply in the NWC and the transfer to the KAC from the Sea of Galilee (MCM)

6.2 Annual flow and salinity in the LJR

Figure 38 below shows the predicted flow in the LJR at two reaches: Deganiya and Shifa. This illustration demonstrates the importance of flows from the SoG to the water balance of the LJR. Note that in the ZS, the Deganiya dam is closed unless the SoG threatens to overspill. The next 30 years can be thus split into three periods (as marked by the thin vertical red lines in Figure 38):

D. The next decade will be a transition period to the era of desalination in Israel. In that time, the SoG water level will rise, but downstream flow will be minimal. The average annual flow at Shifa will be 79 MCM. In the middle of the decade the water exchange plan from the SoG will kick in (14 MCM/Yr, see section 5.4), offsetting the dwindling of the SWC and climate change.

E. A short period is then expected, when the SoG will already be high, but overspills should still be minimal and sporadic. In the ZS, this period will last five years between 2020 and 2025, when the average annual flow at Shifa will be 112 MCM.

F. From the mid 2020's on, the SoG will be close to the top red line, and overflows flowing downstream to the LJR will be more common. Drought years could end up with no overflows at all, but in average and above years some floods will occur. The average annual flow in that period at Shifa is close to 177 MCM, with a great annual variability. The maximum annual flow is 399 MCM while the minimal is only 69 MCM.

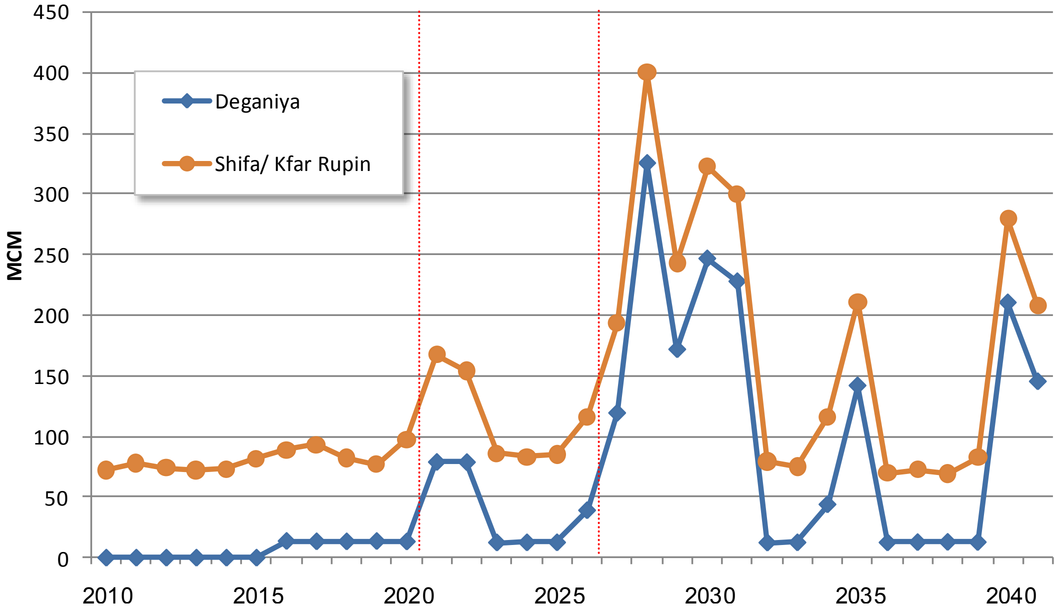

Figure 38: Annual flow in the LJR (MCM) in 2010-2041

Figure 39 below shows the average annual flow and the Frequent Maximal Salinity (FMS) in the third period. The display in the map follows the principles of the maps in section 4.2 (pages 68-70). Salinity values were calculated according to the Frequent Maximal Salinity, which is the average of the maximal values in each year. This measure was developed to properly represent maximal values on one hand, but to prevent exaggerated reference to extreme rare values. Average salinity was not used as it has little meaning for the biota vitality in aquatic systems.

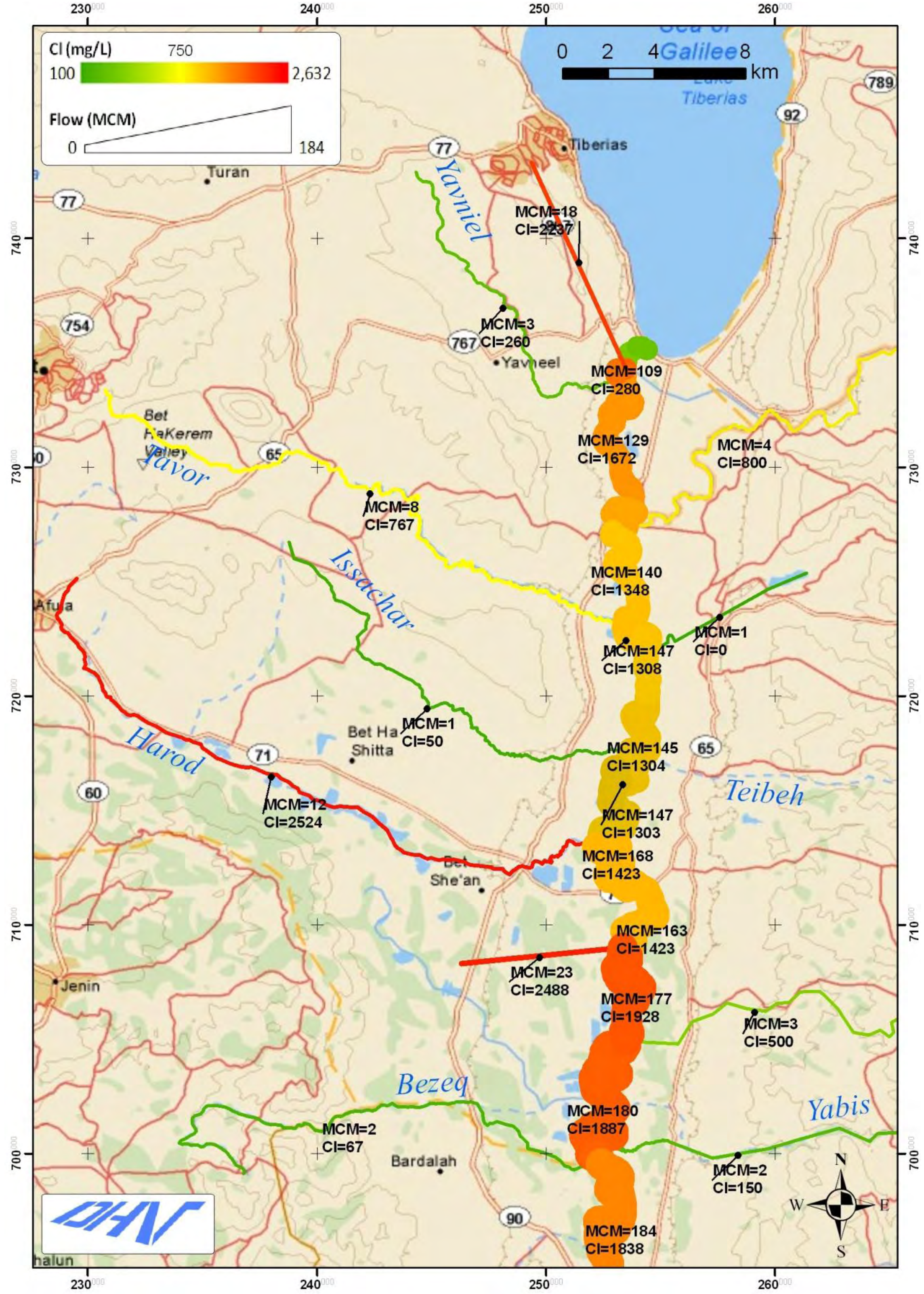

Figure 39: Annual average Surface flow and frequent maximal salinity in the LJR in 2026-2041 (zero scenario)

Comparison to the CA shows flow is expected to more than double in period C, and salinity will somewhat improve[11], especially upstream Tavor. The two main reasons for the improvement are the rise of the SoG and the partial desalination of the SWC. Nevertheless, Salinity will still be higher than the goal of 750 mg/L, throughout the entire length downstream Alumot, and the average flow at Bezeq will still be 35 MCM short of the goal of 220 MCM/Yr.

6.3 Monthly Flow and Salinity in the LJR

Annual flow does not tell the whole story. This section highlights important issues in the monthly flow of the third period (2026-2041) and focuses on extreme years. Figure 40 below shows high flood peaks in contrast to low summer flow, even in wet years. The flood events do not translate past May if Deganiya dam is opened only when the SoG reaches the top red line.

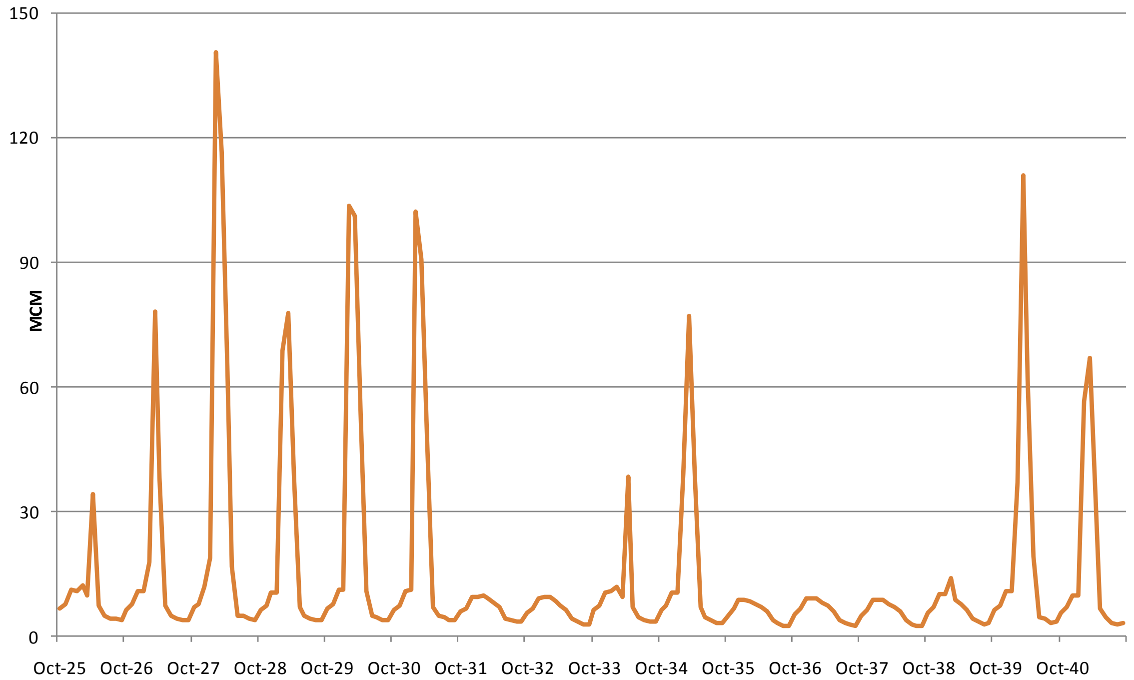

Figure 40: Monthly flow above W. Jumrum (Shifa) in the years 2026-2041 (zero scenario)

6.3.1.1 Drought years

2038 in the model is an extreme dry year, with only 333 MCM that flow to the SoG. It is also the third consecutive year of drought. The WEAP model does not simulate hydrogeological processes so cumulative multiannual trends are minimal. The meaning is that consecutive drought years could in reality result in even lower flows than those presented in Figure 41 below.

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[11] Note that the salinity in Figure 25 refers to the average (as it deals with only one year) while in Figure 38 it refers to FMS

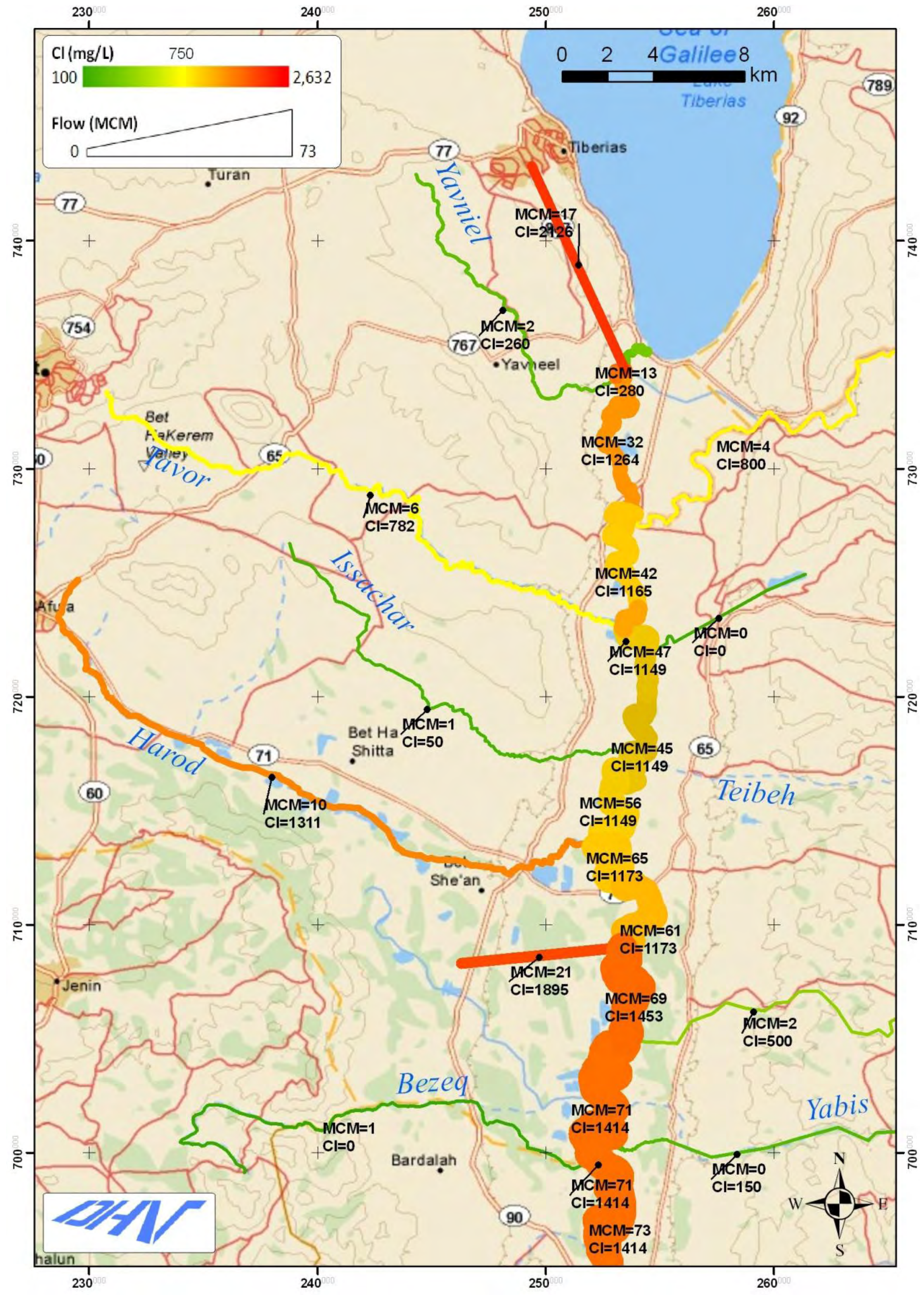

Figure 41: Annual Surface flow and Salinity in the LJR in 2038 (Zero Scenario)

The annual flow in 2038 is 73 MCM at the confluence with Bezeq Stream. The top five contributors to this flow are:

a. Drainage from Emeq Hamaayanot – 21 MCM (27 in Current Accounts);

b. The SWC - 17 MCM (19 MCM in Current Accounts);

c.Groundwater (not represented as a tributary in Figure 41) – 18 MCM;

d. Harod Stream – 10 MCM (13 MCM in Current Accounts);

e. Tavor Stream – 6 MCM (8 MCM in Current Accounts);

The volume of water in the SWC in extreme droughts will be similar to CA, but its composition will change significantly as the desalination removes the saltier water on one hand, and Foliya A spring adds additional saline water on the other hand. Additionally, the rise of the SoG also increases the flow of the saline springs. The decrease in return flows from Emeq Hamaayanot is expected in light of the growing shortage in that region (see section 6.4.1 below).

Figure 42 below shows three distinctive differences with Figure 24 in page 67. First, the annual flow in the upper reaches of the LJR is higher in 2038 by 8 MCM, owing to the 30 MCM of the water exchange plan. Downstream at Emeq Hamaayanot, the picture changes and the flow in 2038 is lower by 3 MCM than in the CA as a result of the growing water shortage in the area.

Second, the highest flow at Shifa is spread almost evenly across 3 months (December-February) with 8.7 MCM monthly, comparing with one month of significantly higher flow in the CA – February with a flow of 11 MCM. The reason is the fishery reform, which will shift the emptying of the ponds (see section 5.8.5). February is still the rainiest month, but since this year in the model is exceptionally dry, the low volume of runoff does not make up for the higher release of water from the fishponds, which amounts to 3.8 MCM in December. Naturally, the effect of the ponds is noticeable downstream Harod.

Third, salinity through the most part is lower than in the CA, thanks to the partial desalination of the SWC and transfer of the brine to the fishponds of Emeq Hamaayanot (see section 5.3). Downstream Harod Stream however, the picture is more complicated. There, seasonal salinity fluctuations are larger. Throughout the summer, salinity is 1250-1300 mg/L- about 300 mg/L lower than the CA on average. In November, when the discharges from the ponds peak, salinity goes up to 2050 mg/L – about 300 mg/L higher than today. The reason is that the bulk of the salt mass that today is spread evenly along the year will in the future be put into the ponds and discharged during only 3months (baring leakage).

Upstream of Harod Stream however, salinity is expected to drop dramatically, due to the decrease of salt input from the SWC. At the inflow points of Yarmouk and Tavor salinity will average 1,148 and 1,101 mg/L respectively (a drop of 700 and 400 mg/L from CA values, even in the driest year).

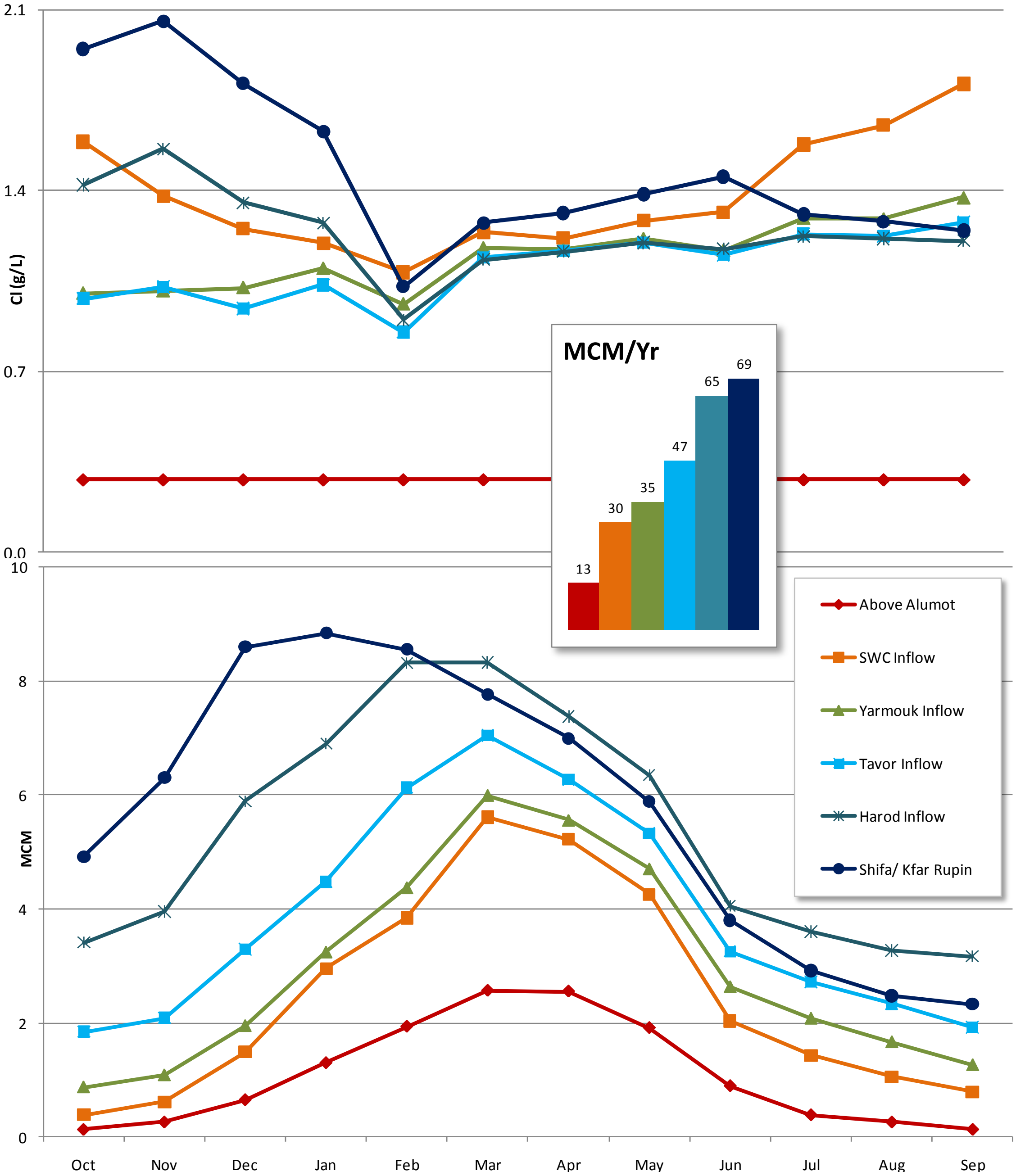

Figure 42: Monthly salinity in gram/L (top) and flow in MCM bottom at different spots of the LJR in 2038 (ZS)

As far as salinity is concerned, the Upper LJR will be divided at the confluence with Harod Stream. Upstream, overall salinity will drop sharply all year round. Downstream, salinity will remain the same in February-September (and increase slightly at Emeq Hamaayanot, though still somewhat less than present values), and increase noticeably in October-January. That phenomenon of alternating salinity between summer and autumn is also evident in wet years, as can be seen in Figure 46. In any year, the sweetest reach in the LJR is below the confluence with Tavor Stream.

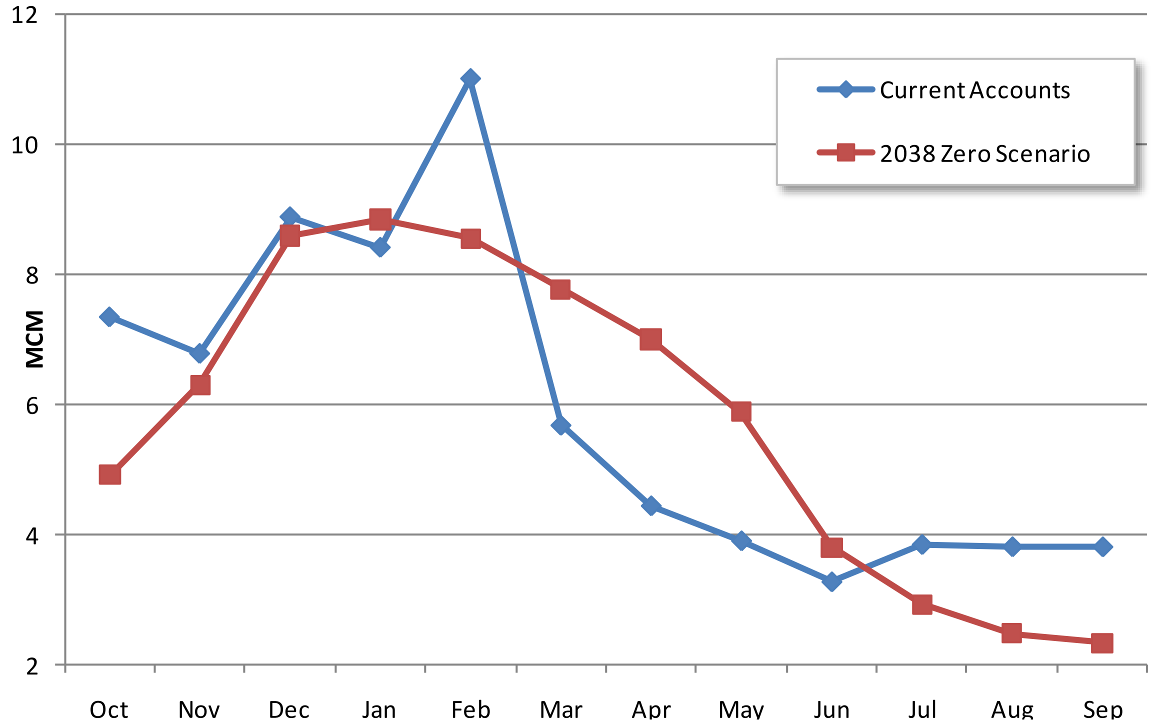

Figure 43: Comparision of monthly flows between Current Accounts and 2038 zero scenario at Shifa

Comparing flows between CA and 2038 in the ZS (Figure 43), shows that the flows in an extreme drought year in 30 years are lower in the summer and autumn but are higher in the spring. The annual flow at Shifa is similar (71 MCM in the CA comparing with 69 in MCM in 2038).

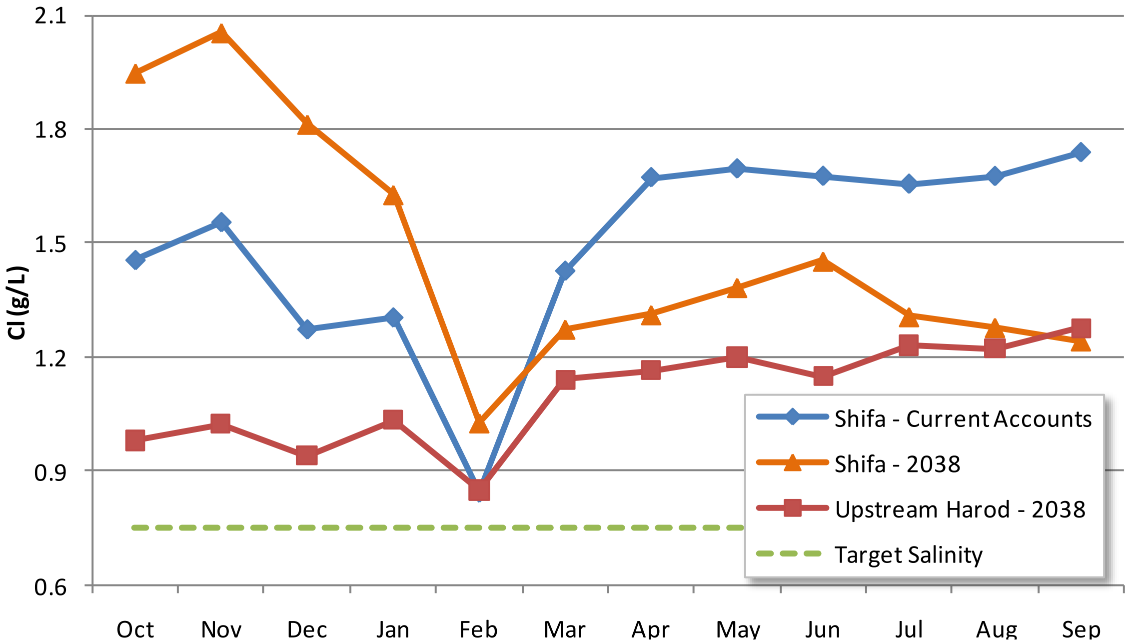

Figure 44: Comparision of salinity between Current Accounts and 2038 zero scenario at the confluence with Tavor Stream

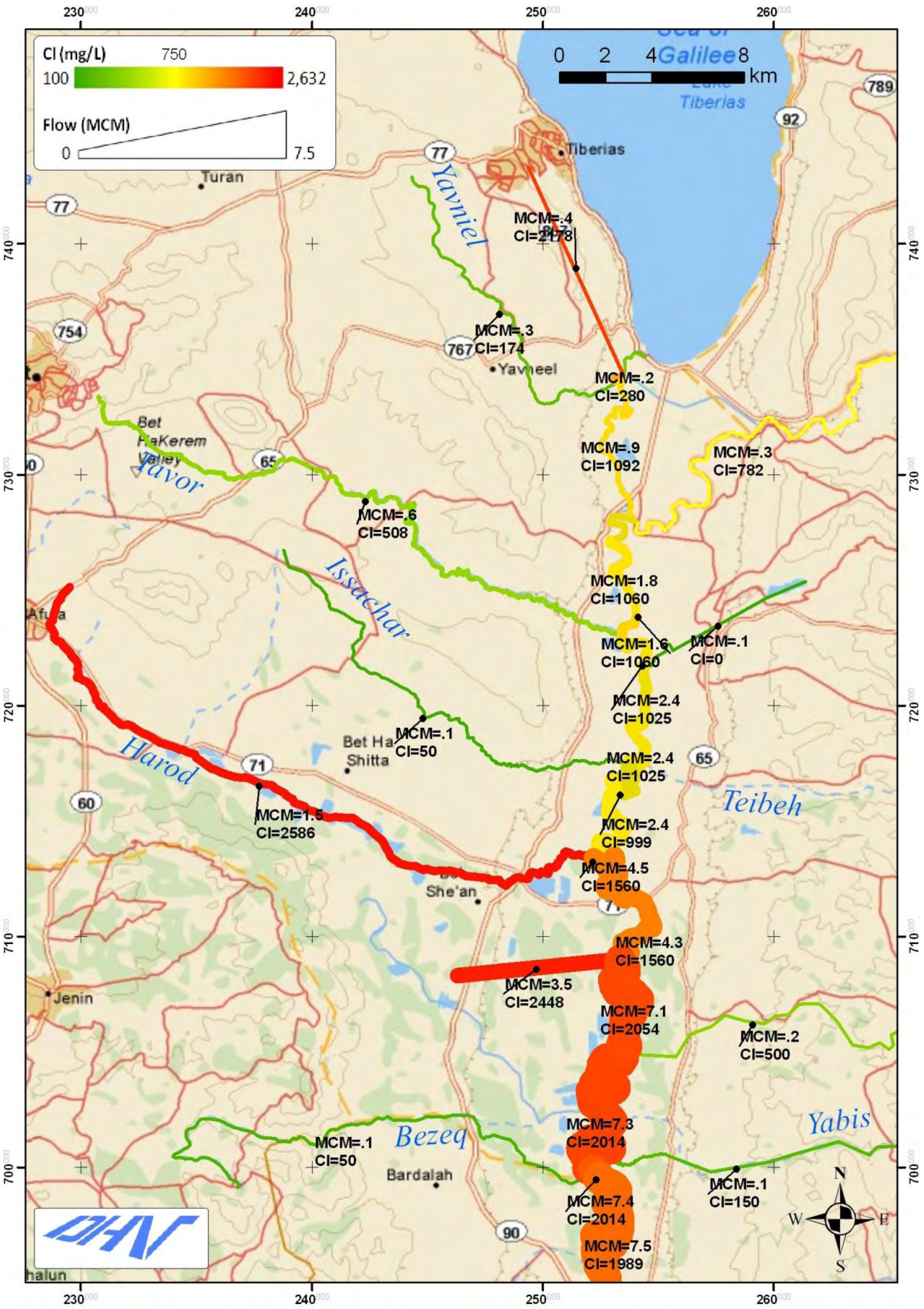

Figure 45: Surface flow and Salinity in the LJR in November 2038 (zero scenario)

Comparing the salinity upstream of Harod Stream on the other hand, shows an improvement between the CA and 2038. Nevertheless, salinity is still higher than the goal of 750 mg/L

(Figure 44). Downstream Harod Stream, salinity throughout five months is higher than it is in the CA, as a result of the fishponds effluents.

The pivotal importance of the discharge from the fishponds in November is evident in Figure 45. The drainage of Emeq Hamaayanot contributes nearly than half of the flow in November (Harod Stream is responsible to nearly 20% as well). Combined with the high salinity of the two (Even saltier than the SWC), it's no wonder that the salinity in the LJR, jumps up so sharply Between Harod Stream and Bezeq Stream. In November SWC is nearly empty because flow of the springs is at its minimum but pumping to desalination is constant in the model.

6.3.1.2 A particularly rainy year

In 2028, inflows to the SoG total to 868 MCM. As can be seen in Figure 46 below, more than 80% of the flow in the Upper LJR originates in the SoG. The bulk of the flow concentrates in February-April. The high winter and spring flows cause a sharp drop in salinity.

In 7 months of that year however, there is no sign whatsoever to the wet winter at Deganiya dam. Consequently, the flow at Shifa drops from 140 MCM in February to 4.9 MCM in June. Overspills from the SoG in the 3rd period will affect the LJR only for a few months, even in the wettest years. Should the seasonal variability be mitigated, a change in the operation of Deganiya dam will be needed.

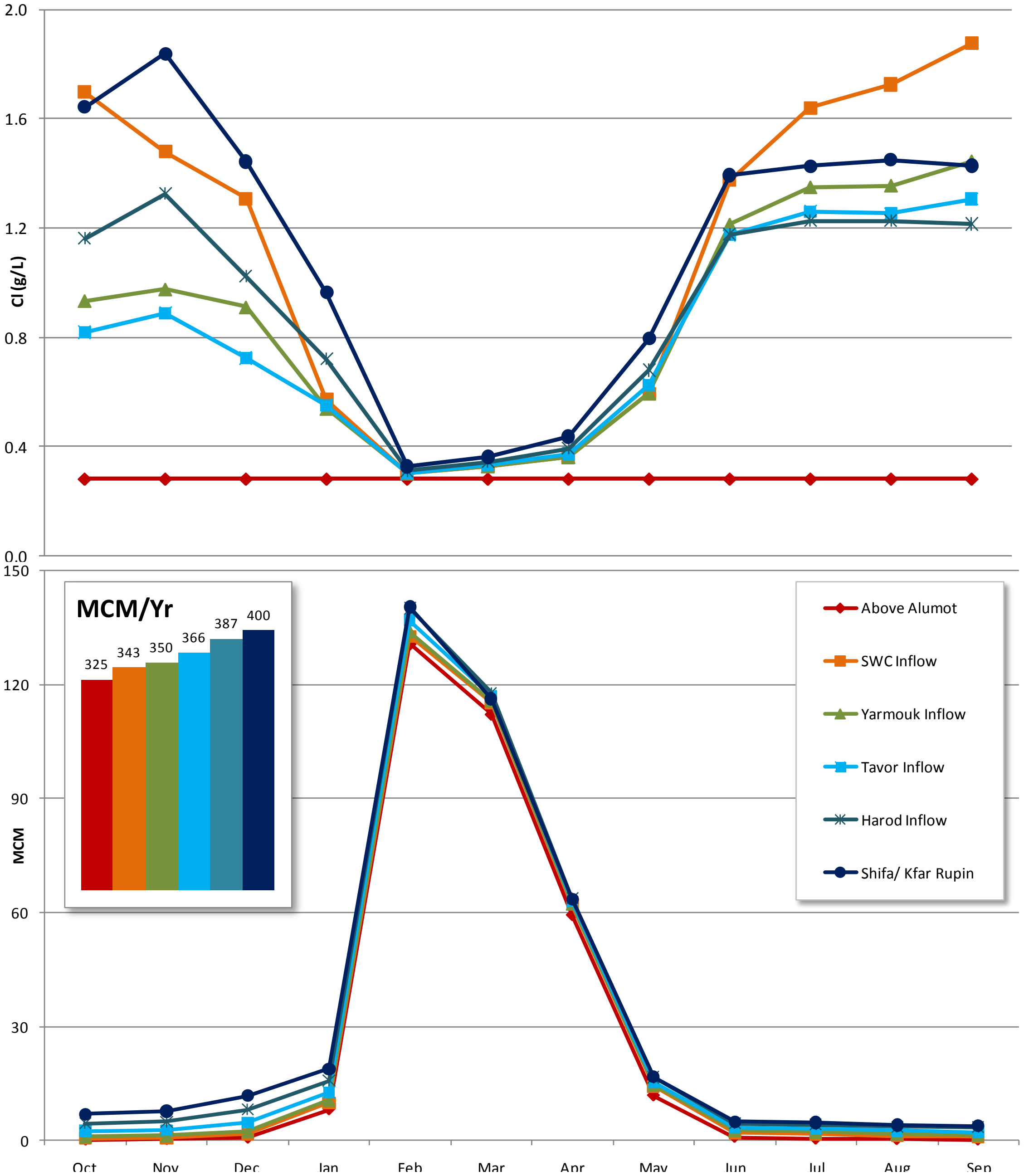

Figure 46: Monthly salinity in gram/L (top) and flow in MCM bottom at different spots of the LJR in 2028

6.4 Local Demand

Figure 47 shows the annual supply in the Upper LJR basin, meaning the water that if allowed to flow, will surely reach the LJR. Demand will go down from 139 MCM/Yr today, to 128 MCM/Yr in 2020, mainly due to the reform in fishponds and the release of Harod Spring. From 2020 to 2040, demand will gradually increase to 132 MCM/Yr. The largest supplier in the region is the AMWA, which in Figure 47 is divided into four branches. All in all, the vast changes in the upper LJR will not stem from changes in demand.

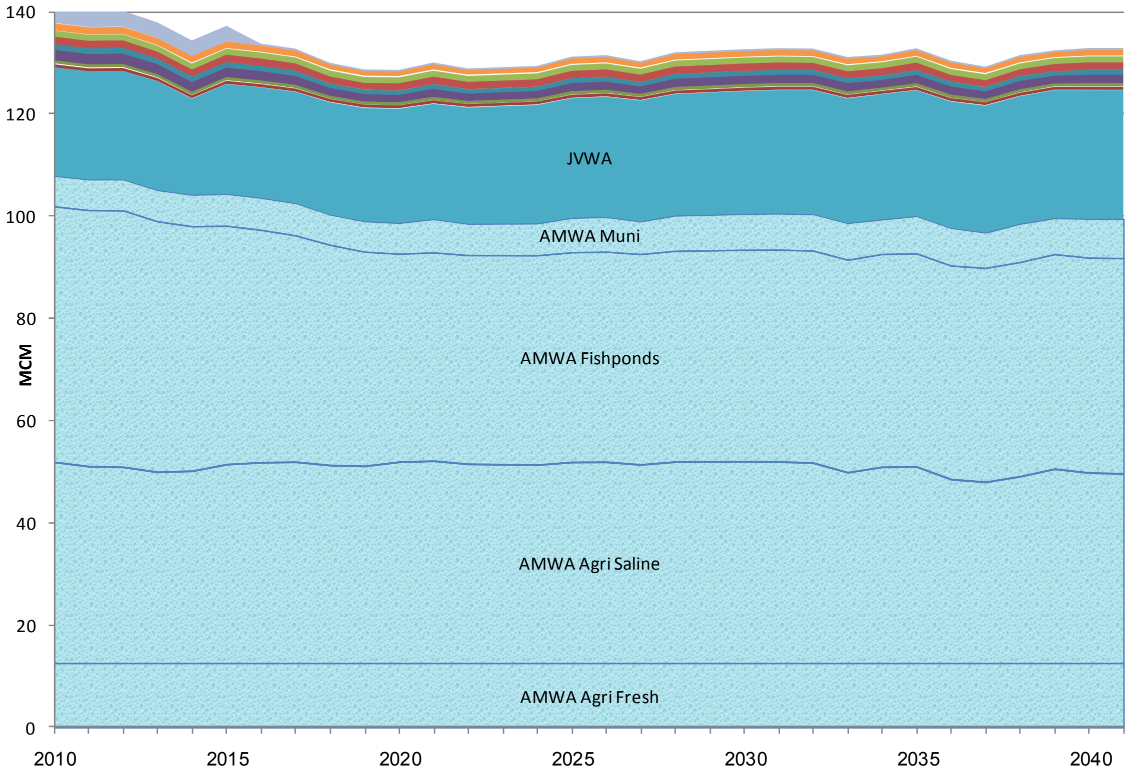

Figure 47: Annual water supplied (MCM) in the Upper LJR basin

6.4.1 Water Availability in Emeq Hamaayanot

Increase in demand will be limited by artificial quotas but especially by dwindling local sources. Figure 48 below shows the predicted available water in Emeq Hamaayanot of all sources except direct demand from the LJR[12] and the brine from the SWC[13]. Over the next 30 years, the flow is expected to drop by 12-18 MCM. The decrease of the natural sources will be higher, but will somewhat mitigated by the addition of effluents which by 2040, should amount to 5-6 MCM/Yr. That drop, coupled by the expected increase in salinity, will bring about an increasing problem to maintain present consumption levels. In dry years the shortage could top 6 MCM/Yr. Supply of fresh water for irrigation will be on the edge as well, as a result of the gradual salination of springs. Management of mixing between the different water sources will be necessary to maintain acceptable salinity levels for irrigation.

The drainage from Emeq Hamaayanot that reaches the LJR will drop by 10 MCM/Yr, as a result of the water shortage.

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[12] Unlike other sources of the AMWA, the pumping from the LJR is limited only by quotas.

[13] It is unclear whether the brine will indeed serve as a water source

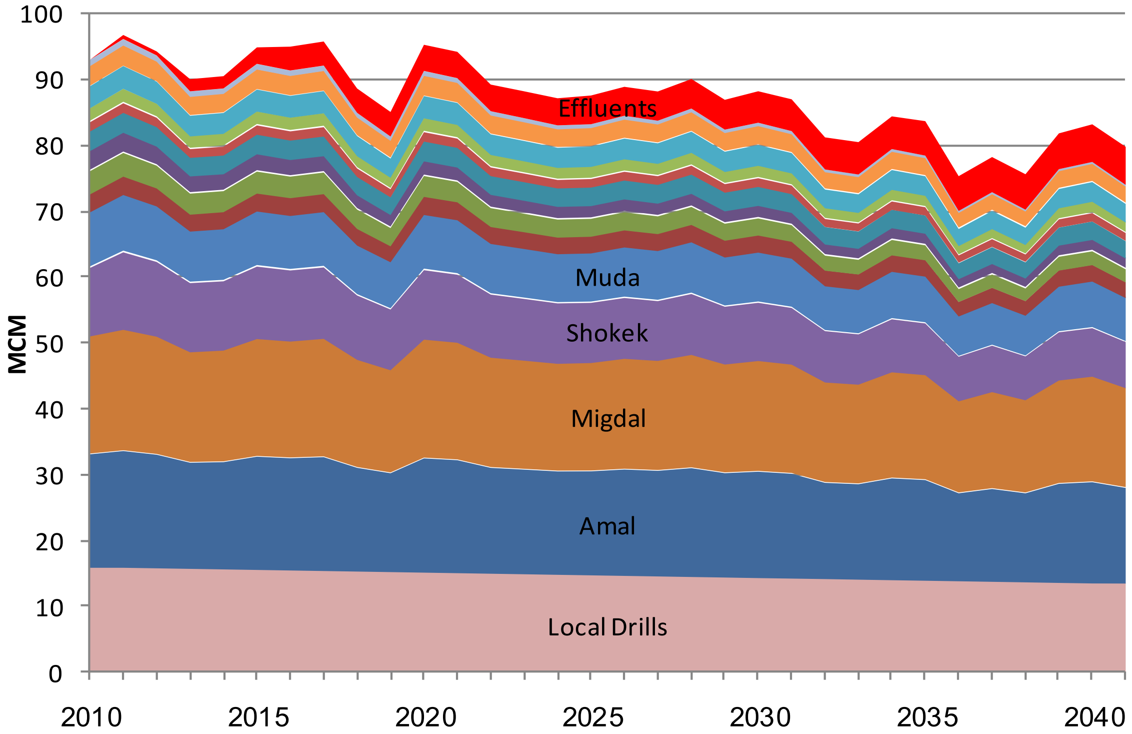

Figure 48:Available water (MCM/Yr) in Emeq Hamaayanot

6.5 Conclusions

The following conclusions summarize the analysis above and are given as bullet points:

- The next 30 years can be divided into three periods: A) transition to desalination when the SoG is low; b) rise of the SoG and c) after the refilling of the SoG.

- The third period will be characterized by the return of floods to the LJR, even if not in the same magnitude as before.

- Changing of the operation of Deganiya dam might be useful to maintain better environmental flows in the third period.

- Salinity wise, the river will be split at Harod Stream as a result of the desalination of the SWC and the fishery reform. Upstream of Harod the LJR, although still saltier than the goal of 750 mg/L, will be sweetened. Between Harod and Bezeq, the LJR's salinity will increase sharply, especially at autumn and early winter.

- Water supply in the region will become more complicated and current level of agriculture will be hard to meet in dry years. Water availability, will limit further growth in agricultural production.

7 Reintroduction Scenario model

This chapter presents the Reintroduction Scenario (RS), which is built on the basis of the ZS, with added measures to reintroduce water to the LJR. The chapter describes the definition of environmental flows in the WEAP model and the suggested measures to meet these demands.

7.1 Representation of environmental flows in WEAP

The flow requirements that were defined in the model for this scenario are based on the definitions of FoEME that are detailed in section 1.2. The monthly environmental flows desired below Alumot Dam are given in Figure 49 below. Note that typically environmental flows are given in momentary discharges, but the WEAP model runs in a monthly resolution so the flows here are given accordingly.

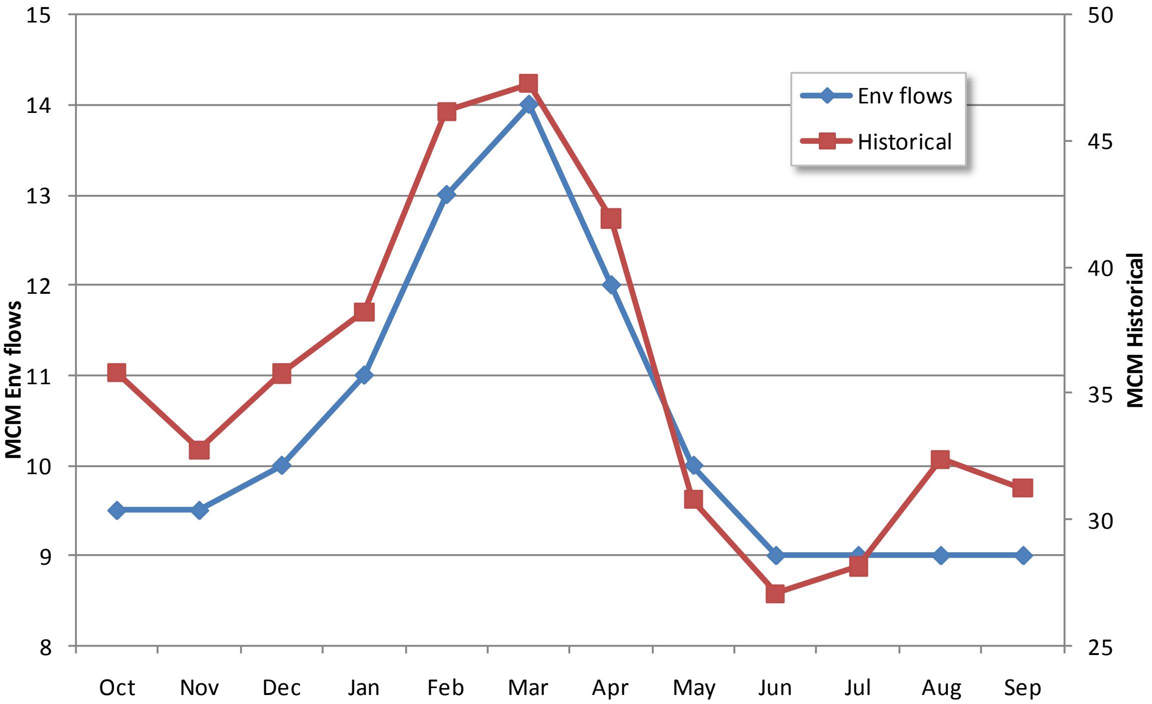

Figure 49: Required monthly flow in the LJR below Alumot dam and average historical flows in Deganiya (MCM)

Figure 49 also presents the average historical flow at Deganiya dam from before the inauguration of the NWC (referring to the vertical axis on the right). Since historically the springs of the SWC flew to the SoG, the requirement at Alumot and historical flow at Deganiya are comparable.

The minimum environmental flow was set at 9 MCM/month, which is 30% of the average historical flow in the summer. Flow in the rest of the year was set to better represent historical hydrograph. The high flow in February-March should include at least one minor flood event, with flows of some 50 m^3/s for at least 24 hours. That requirement amounts to 4 MCM. The model however, is run in a monthly resolution so this feature is given only in the overall monthly flow. The annual flow at Alumot should be 125 MCM.

The above-mentioned flow is influenced by the water level of the SoG. If the lake at the end of the previous month is below the bottom red line, then the prime goal should be keep water in the lake and so, no flow downstream should be allowed. Up to half a meter above the bottom red line, the delivered environmental flow should be quartered (multiplied by 0.25). When the lake is between the bottom red line and the bed level at Deganiya dam, the flow should be halved. That scheme could serve as a **rudiment proposal for the management of Deganiya dam** (a real-time application would be more complicated obviously).

Another environmental definition is prioritization of the water sources exploitation at Emeq Hamaayanot. In the RS, preference for water usage by the AMWA was set to release first the fresh springs that drain to the Harod (i.e. Shokek & Homa), while maintaining a mixture of sources that will meet the salinity needs of the fresh agriculture in the region. The reason is to lower salinity downstream Harod. Muda Spring that drains into Bezeq Stream is not released, since this paper addresses the Upper LJR.

7.2 Water reintroduction measures

On top of changing the operation of Deganiya dam (which could be regarded as a measure in its own right), 10 distinctive measures were identified and put into the WEAP model. Table 10 below presents the different measures, with the following columns:

- Measure: a short description of the measure.
- MCM: Annual volume of water the measure is expected to contribute, if implemented alone. A combination of measures however, will result in a different total contribution.
- Salinity: the effect of the measure on salinity. Concentration is meaningless in that regard as it depends on the flow, so the effect is given in tones of Cl per year. Note that the exact effect could be heavily influenced by the combination of measures (e.g. measures No. 10 and No. 2). Some alternatives, like No. 4, contribute indirectly by adding large amounts of fresh water, but do not remove masses of salts from the river. Their influence on the salinity was estimated qualitatively.
- NIS (undiscounted): three columns providing the costs in New Israeli Shekels (NIS). Externalities were omitted from the analysis.
    - Capital: the initial costs of the measures in million NIS (e.g. laying of new pipes)
    - Fixed: Annual costs that are not related to the amount of water in million NIS (e.g. maintenance of infrastructure). For infrastructure were assumed to be 3% of the capital costs.
    - Per m^3: Costs that are directly related to the amount of water in NIS (i.e. pumping energy or lost profits for agriculture).
- Remarks

Table 10: Measures for water reintroduction to the LJR

	Measure	MCM	Salinity ton/Yr	NIS (Undiscounted)			Remarks
				Capital	Fixed	Per m^3	
1	Cease pumping from lower Yarmouk to the SoG, if the later is higher than the bottom red line		2,300			-0.09	-saving in pumping energy -Does not contribute water when the SoG is full
2	The brine of the SWC will be transferred to the Dead Sea	-8	47,000	130m	3.9m		-necessitates a 83 km long, 24", gravitational pipe -less water to the AMWA fishponds
3	Transferring effluents from Kishon to AMWA and Harod	10-15	-	40m	1.2m	0.07	- Homa spring will be partially released by 2018 - necessitates a 15 km long, 32", pipe
4	Further and faster decreasing pumping to the NWC[14]	30	++			1.55	-price per m^3 calculated by average price of desalinated water **[31]** minus pumping costs to the NWC **[32]** (2.4-0.85)
5	Exchanging 50% of the fishponds with field crops and alfalfa[15]	10	36,000			0.2	- price per m^3 represents the direct average profit to the farmer from a cubic meter used in the ponds **[17]**
6	Diminish saline agriculture by 30% by 2020	10	+			0.7	- price per m^3 represents the direct average profit to the farmer from a cubic meter of saline water **[17]**
7	Diminish fresh agriculture by 30% by 2020	9-12	+			1.6	- price per m^3 represents the direct average profit to the farmer from a cubic meter of fresh water **[17]**
8	Maintain present consumption level in the UJR	27	++	-	-	1.6	-Keeping the quotas of 2010, which are already cut from the original quotas
9	Discharge some of the effluents of the Kishon to Harod River to reduce salinity	2-3	+	-	-	-	-Less water available for AMWA farmers, which indirectly might result in reduced profits in case of shortage
10	Desalination of 1.5 MCM/Yr of the SWC water, on top of the current plan	-	3,000	7 m	-	1.5	- 1.5 MCM/Yr is the maximum that can be desalinated all year round, as the flow of the SWC springs fluctuates - variable costs include pumping and transferring brine southwards

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[14] C_y Co. in the formula of the NWC, as explained in section 5.8.1, changes to: 2013>0.7; 2021>0.5; 2026> 0.4; 2031>0.3; 2036> 0.2, 2041>0.15

[15] Planting abandoned ponds with trees is probably not feasible due to soil salination and drainage

8 Reintroduction Scenario results

This chapter details the results of the model for the RS, with a comparison to the ZS and CA. In graphs that compare scenarios, results from the ZS appear in dotted lines, while environmental goals are shown in dashed lines.

ZS and Rs are both scenarios that span across 30 years. Putting extreme years aside, analyzing periods is better than addressing specific years when comparing scenarios. So most of the analysis here refers to periods B` (transitional period when the SoG is already above the bottom red line) and C` (SoG overspills regularly) as they are defined in section 6.2. Note that for the ZS, periods B' and C' refer to the years 2020-2025 and 2026-2041 respectively. In the RS, as a result of the measures described below, the SoG rises faster so those periods refer to the years 2013-2019 and 2021-2041.

The chapter ends with discussions on the effectiveness of the proposed measures, their costs and possibilities for utilization of some of the water downstream.

8.1 Sea of Galilee

Figure 50 below presents the water level of the SoG in the RS and ZS. Overall, the trend in both scenarios is similar. The lake will rise at about the same time and with the same magnitude. That should be expected as the main constraints on the system (the red and black lines) have not changed.

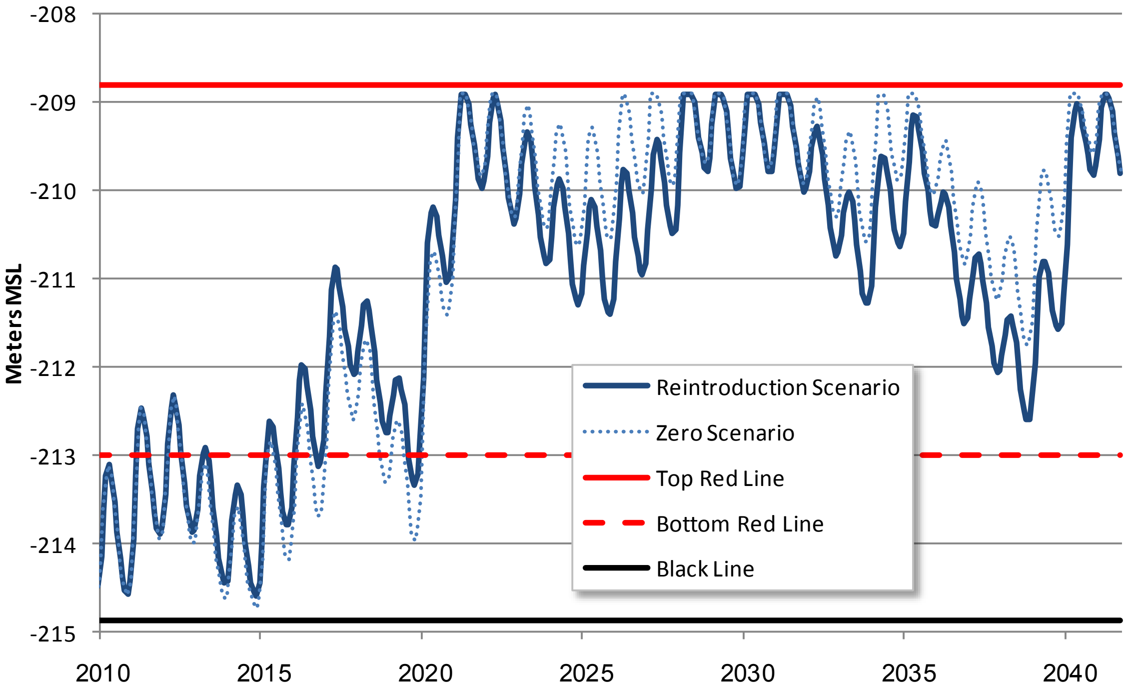

Figure 50: Water Level of the Sea of Galilee in the Reintroduction Scenario, compared with the Zero Scenario

Nevertheless, two differences can be found:

- In the coming decade when the lake is still low, the enhanced reduction of pumping to the NWC will cause the lake to rise faster in the RS, thus bringing forward periods B' and C'.
- After the lake has risen it will be somewhat more vulnerable to consecutive droughts in the RS, as water will be constantly released from Deganiya dam. In the years of 2036-38, the difference between the two scenarios reaches to 1.3 meters. Having said that, the remains above the bottom red line, as the environmental flow requirement halves when the water drops below the Deganiya Dam bed level. In average years, the lake recovers very quickly, so the added "risk" under these conditions is low.

8.2 Water demand in the Upper LJR basin

The implementation of measures 5-7 from Table 10, should decrease the agricultural water consumption in the basin by nearly 50 MCM by 2020. Figure 51 below shows the supplied water in the Upper LJR basin, compared with the ZS (the dashed red line). Note that the increase in flow in the LJR will not be identical to the supply reduction, since some of the water used for agriculture does reach the river in the end.

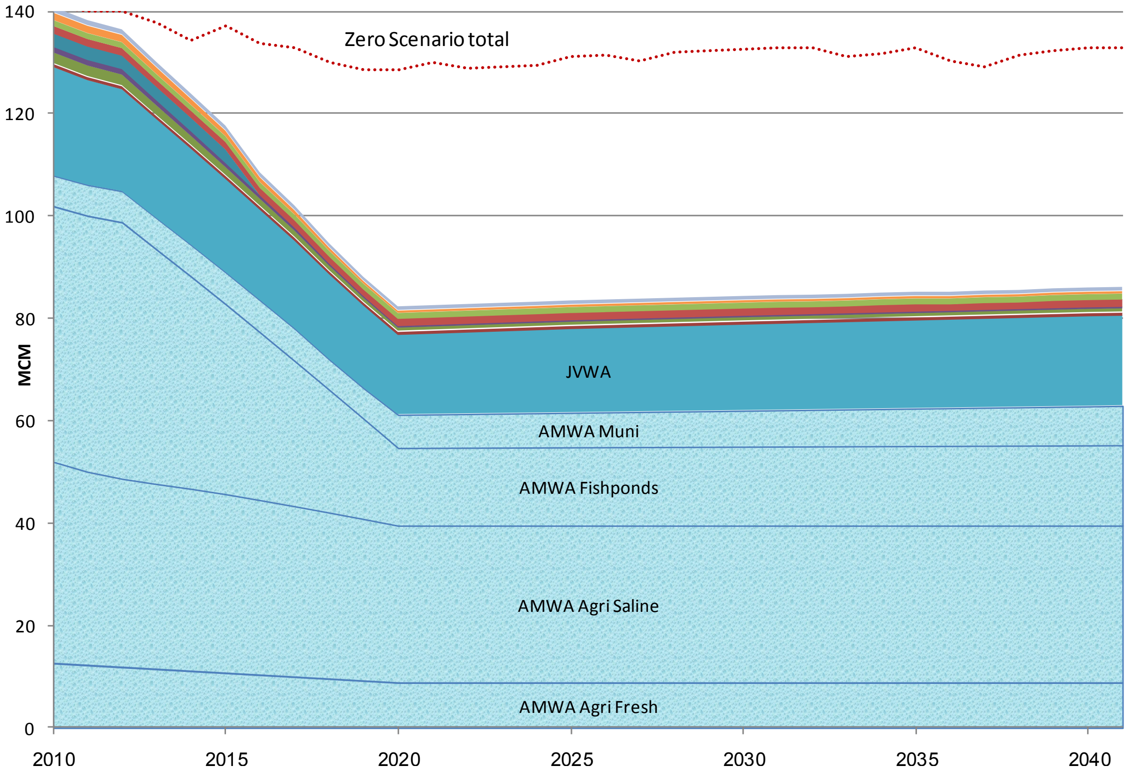

Figure 51: Annual water supplied (MCM) in the Upper LJR basin in the Reintroduction scenario

8.3 Flow and salinity in the LJR

Significant differences in flow between the RS and ZS begin at 2015, as can be seen in Figure 52 below. Differences are most pronounced in dry years of period C (after 2020), as the environmental flows defined in section 7.1, constantly release water from the SoG to the LJR.

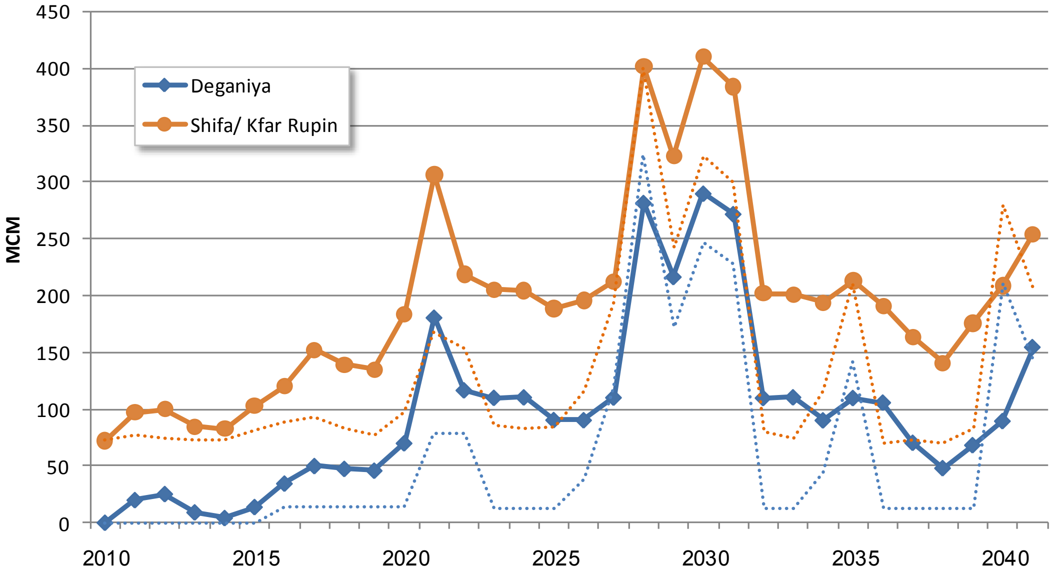

Figure 52: Annual flow in the LJR (MCM) in 2010-2041 for the Reintroduction scenario (Zero Scenario is dashed)

Inversely, at some peak months in late winter, the flow in the ZS is actually higher large. The reason is that overflows in the SoG are mitigated because of the constant water release at Deganiya. This phenomenon is illustrated in Figure 53 below, which shows the flow at the confluence with of the LJR with Bezeq in the RS, relatively to the ZS. Most of the time, the flow is higher by 10-15 MCM/month in the RS. In distinct months at late winter (Some of which are labeled in Figure 53), flow in ZS can be significantly higher. In short, the measures taken in the RS, take water from extreme overspills that last a few days and distribute it along the year.

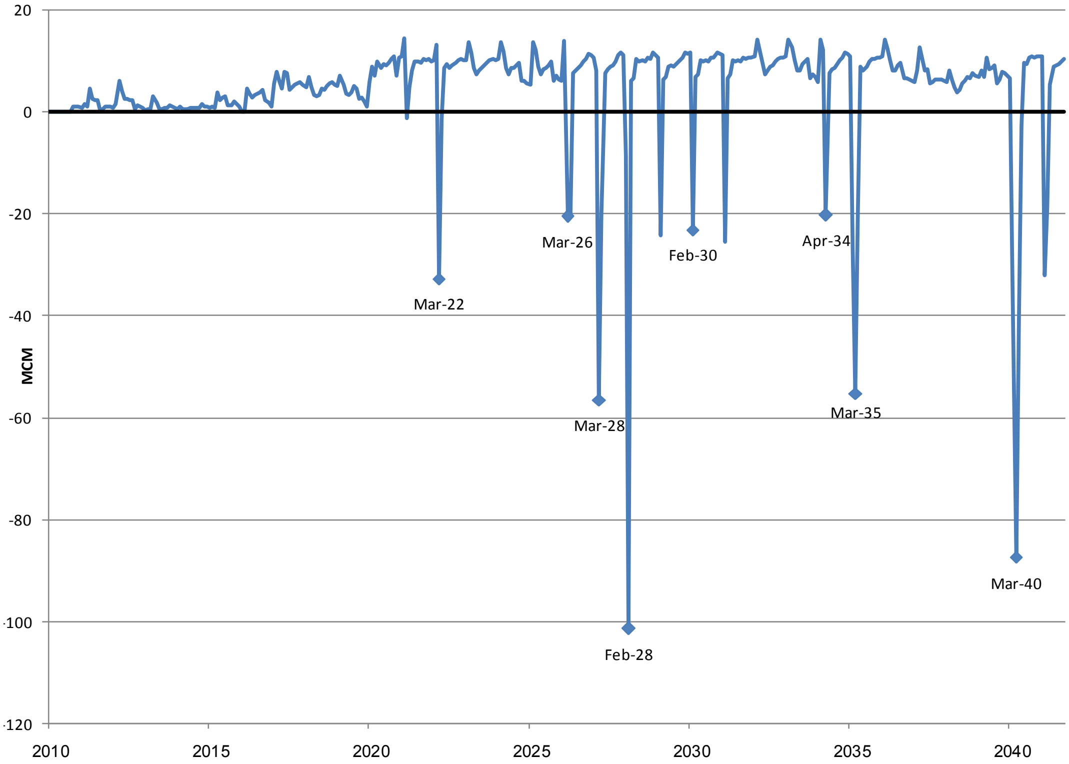

Figure 53: Monthly flow in the LJR at the confluence with Bezeq (MCM) in RS Relative to ZS

As a result, the maximal monthly flow for period C at the inflow point of the SWC in the RS is 115.5 MCM compared with 132.7 MCM in the ZS. On the other hand, the minimal monthly flow in the RS is one order of magnitude higher (4.6 MCM compared with 0.4 MCM).

8.3.1 Monthly averages for period C

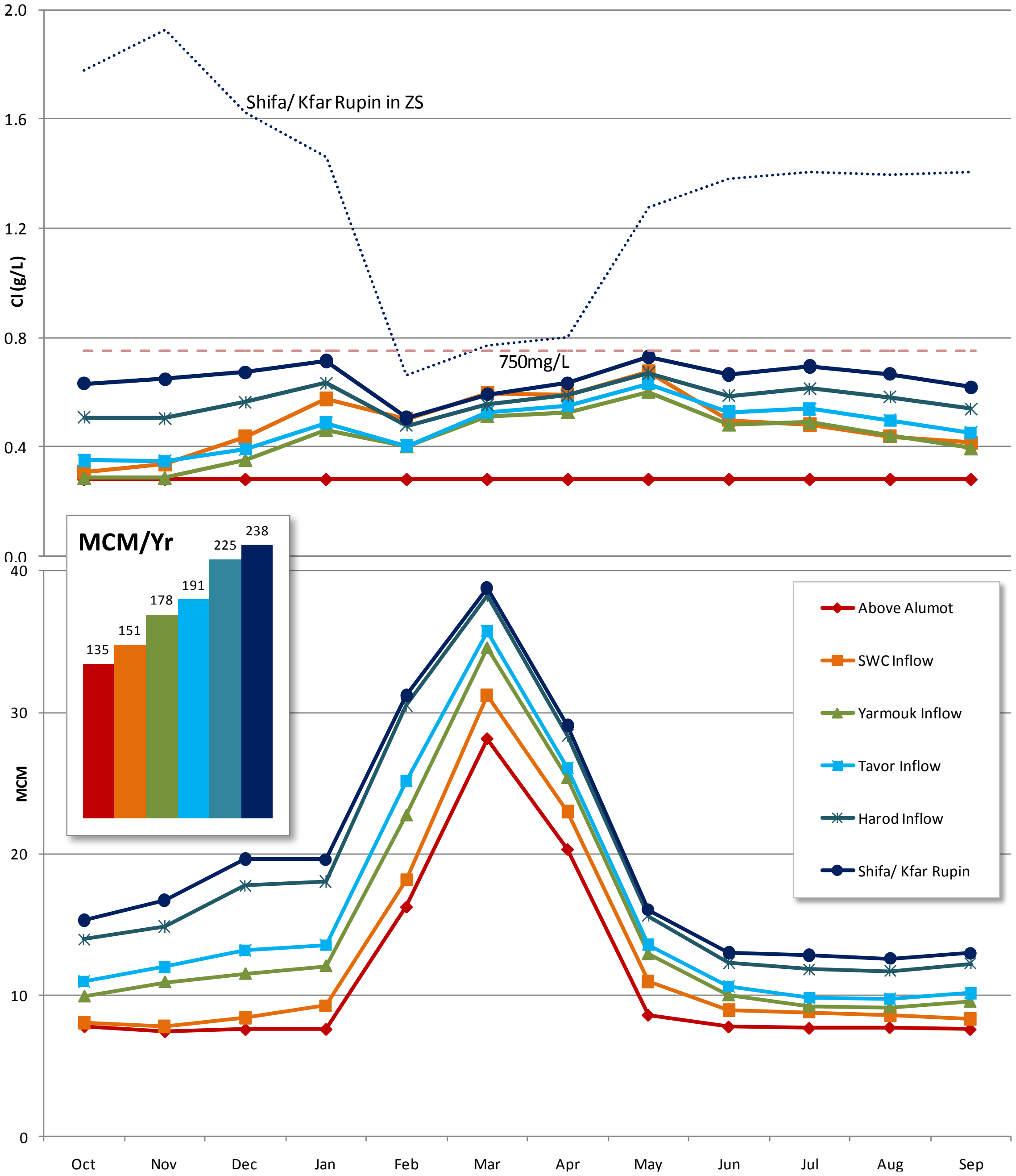

Figure 54: Monthly averages for period C of salinity in gram/L (top) and flow in MCM (bottom) at different spots of the LJR

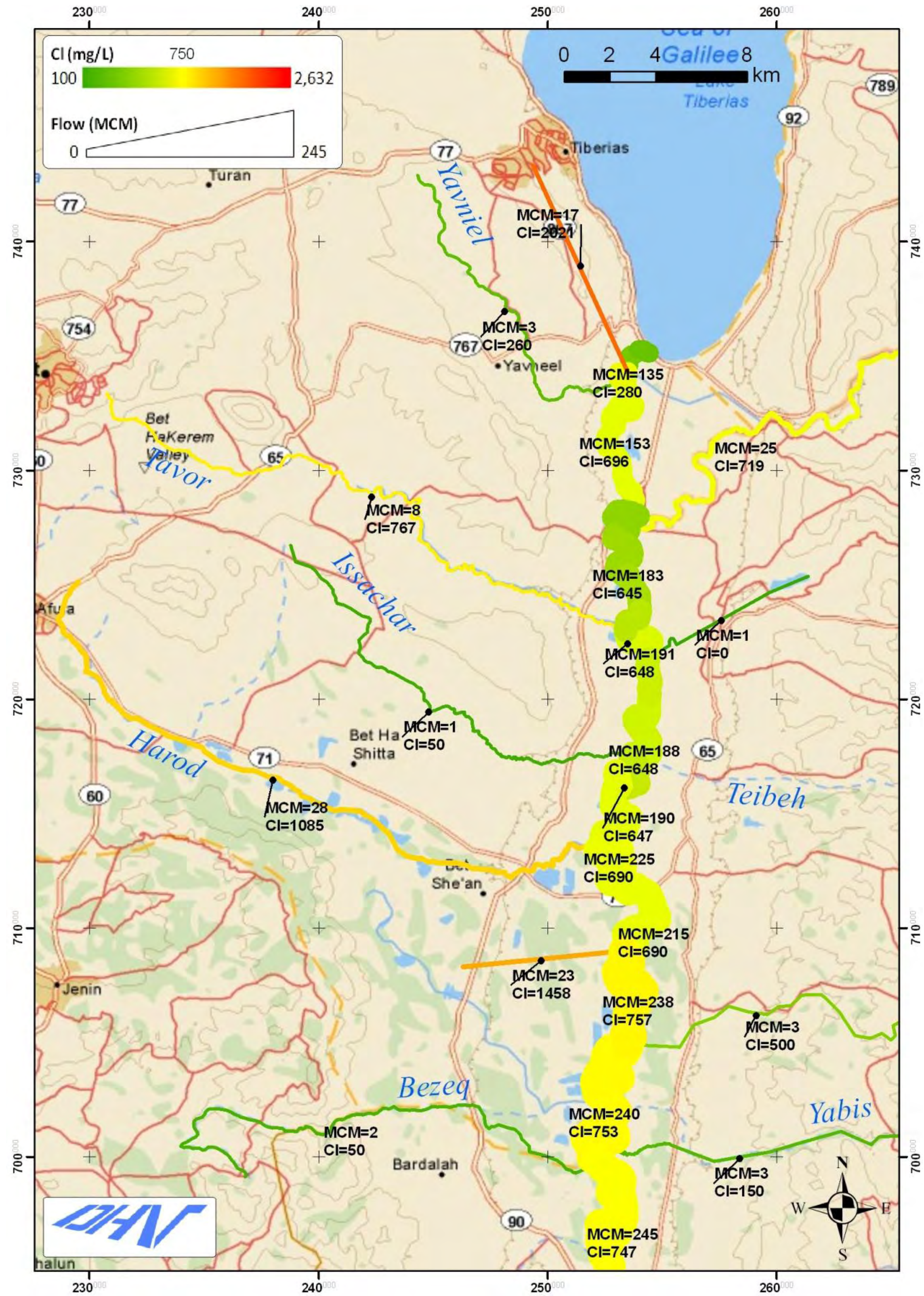

Figure 55: Annual average Surface flow and frequent maximal salinity in the LJR in period C (Reintroduction Scenario)

Figure 54 follows the principles of Figure 42 in page 93 and displays the monthly averages of salinity and flow in the LJR for period C of RS. In the salinity section of the graph (top), there are two additional lines representing the average salinity in ZS at Shifa and the FoEME environmental goal of 750 mg/L. Average annual flow at Shifa is 238 MCM – 18 MCM higher than the FoEME environmental goal. Unlike in the ZS, more than half of the flow originates in the SoG, so the river witnesses significant flows along its entire length, all year round. Average monthly flow meets the environmental criteria as well set in Figure 49.

Average salinity in the RS is fairly even throughout the year and is constantly lower than the environmental goal (although downstream Emeq Hamaayanot it is tangent). As explained in section 6.2 though, average salinity is not enough and one should check FMS, which is shown in Figure 55, which demonstrates considerable improvement comparing to Figure 40 in page 90. Up until Emeq Hamaayanot, the river's FMS is below 750mg/l. downstream, FMS is 753 mg/L but that is well in the error range of the model. Regardless, it is clear that **meeting the 750 mg/L line will be very difficult downstream Emeq Hamaayanot**.

8.3.2 Drought years

On average, flow and salinity meet the environmental criteria in the RS, but what about dry years? Figure 56 below shows the monthly flow and salinity for the RS in 2038, which represents a particularly dry year (see section 6.3.1.1). Flow at Shifa in 2038 is nearly 100 MCM/Yr less than the average for period C and is well below the desired environmental flow. Nevertheless, it is double the flow in the ZS for the parallel year, so the improvement is significant.

Since the SoG in 2038 goes below the bed level of Deganiya, it releases only half of the water required downstream, but still 30 MCM more than in the ZS. Local tributaries and springs contribute more water along the way due to the diminished irrigation in the RS.

As for salinity and in comparison with the dotted line in Figure 56, throughout most of the year the improvement at Shifa is in the range of 400-600 mg/L owing to the increased flow and the decreased salinity load from the SWC. In October-January the improvement is most pronounced (up to 1300 mg/L in November) thanks to the attenuation of the fishponds and the transfer of the SWC brine to the Dead Sea.

Despite the improvement and the fact that salinity in the RS varies less, the salinity goal set by FoEME is not met for the most part. Downstream Emeq Hamaayanot, salinity is too high during most of the year (although it stays below 1,000 mg/L). Upstream Emeq Hamaayanot the failure concentrates in March-May, because of the higher flow of the saline springs nourishing the SWC in these months. That could be the result of the location of flow requirement in the WEAP model though. Since it was put downstream the SWC inflow, when flow in the SWC rises, flow from SoG decreases. On average and wet years, there is enough water to offset this feature, but in dry years it is probably somewhat embellished. In reality, during the spring probably more water could be spared from SoG to mitigate salinity even in dry years.

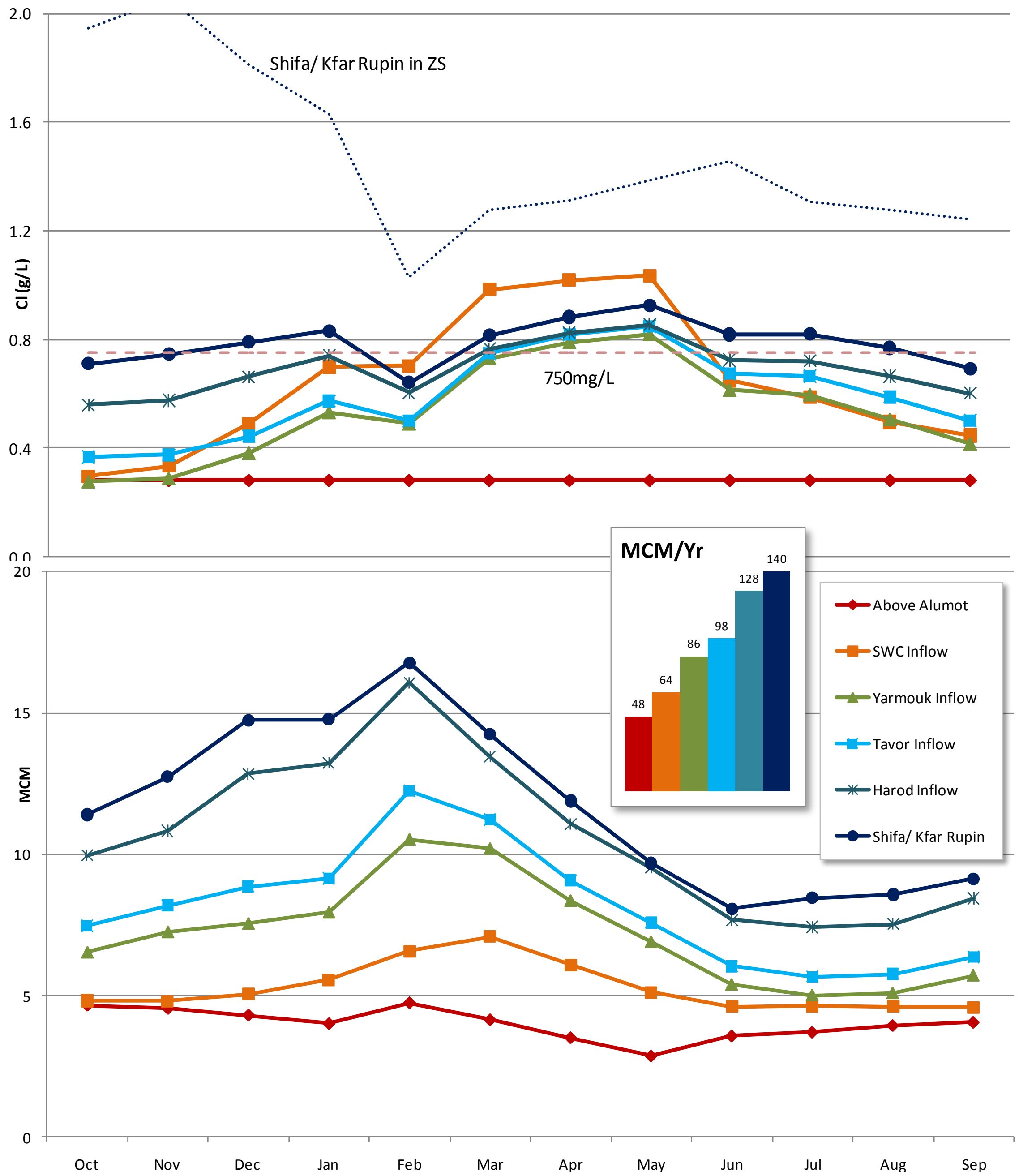

Figure 56: Monthly salinity in gram/L (top) and flow in MCM bottom at different spots of the LJR in 2038 (RS)

Figure 57 below presents the annual flow and unweighed average salinity in 2038 (RS). On annual average, the salinity goal is met during most of the river and even downstream, it is fairly close to 750 mg/L. Besides the SoG that contributes 48 MCM/Yr, the largest contributors are:

a. Drainage from Emeq Hamaayanot – 20 MCM (21 in ZS) with a significant decrease in agricultural return flows and an increase in released springs;

b. Groundwater (not represented as a tributary in Figure 57) – 18 MCM (equal in ZS);

c. The SWC - 15 MCM (17 MCM in ZS) with major decrease in salinity;

d. Harod Stream – 23 MCM (10 MCM in ZS) with major decrease in salinity;

e. Tavor Stream – 6 MCM (equal in ZS);

In short, even in the driest of years the LJR shows **substantial improvement in RS, but the environmental goals that can be met on average, will not be achieved in cases of subsequent droughts**.

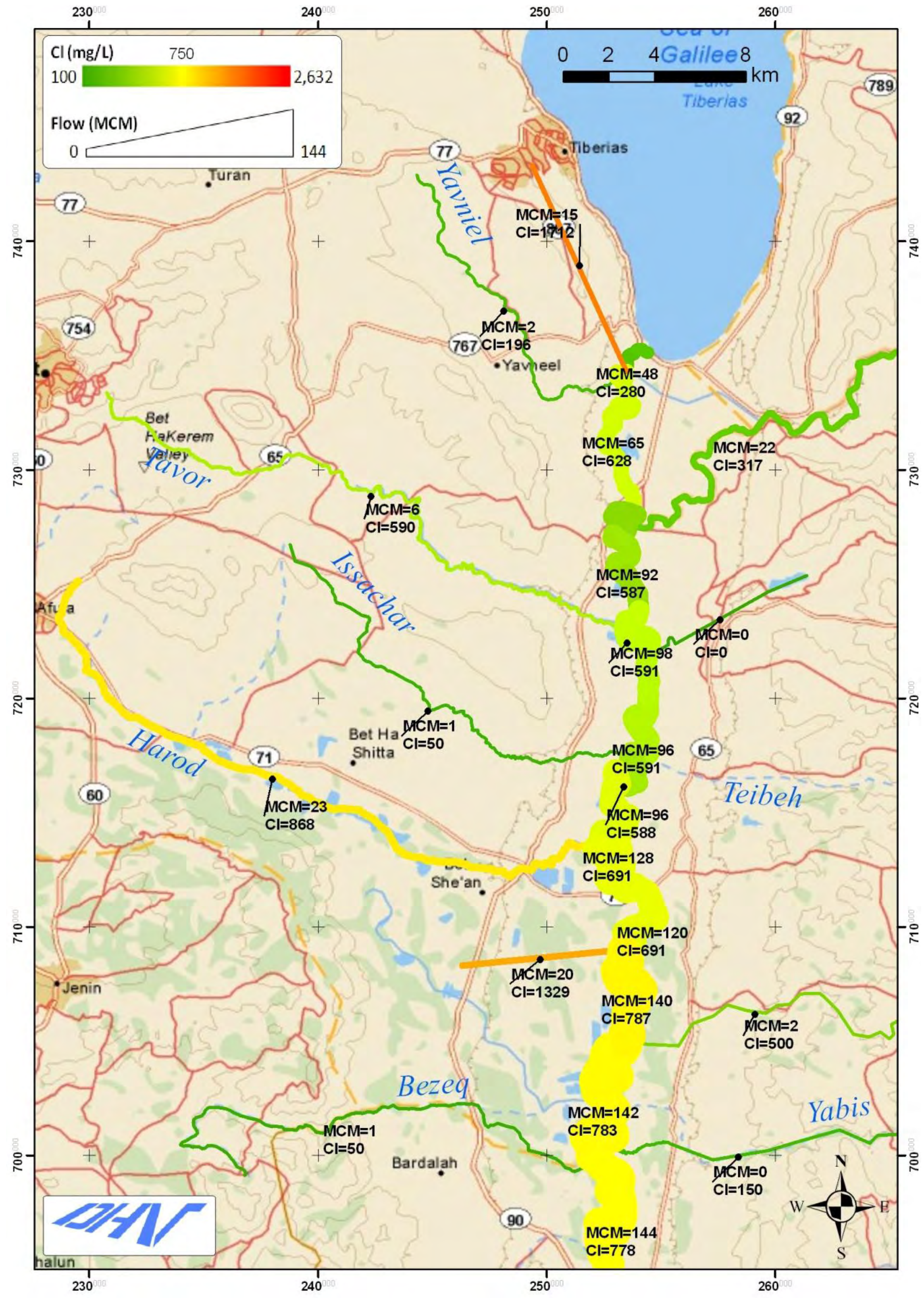

Figure 57: Annual Surface flow and Salinity in the LJR in 2038 (Rehabilitation Scenario)

8.4 Effectiveness of the measures

Table 11: Parameters for evaluating measures effectiveness

Parameters	Env. Req.	CA	Zero Scenario		Rehab. Scenario	
			Period B	Period C	Period B	Period C
Average annual flow downstream SWC (MCM)	125	21	52	127	50	151
Average annual flow downstream Emeq Hamaayanot (MCM)	220	72	112	177	117	238
Average annual flow coverage below Emeq Hamaayanot (%)	100	33	54	69	53	92
Average flow in March downstream Yarmouk (MCM)	19	2.6	14.2	47.5	7.9	34.5
Average annual minimum flow downstream SWC (MCM)	9	1.4	0.7	0.4	2.5	7.2
Average discharge coverage downstream SWC (%)	100	17	26	32	40	91
FMS downstream Tavor (mg/L)	750	1,738	1,484	1,308	1,289	641
FMS downstream Emeq Hamaayanot (mg/L)	750	1,783	1,884	1,928	1,362	753
Months above 750 mg/L downstream Tavor (%)	0	100	86	82	56	1
Months above 750 mg/L downstream Emeq Hamaayanot (%)	0	100	93	85	95	8
Total score	**100**	**13**	**28**	**45**	**35**	**95**

Sporadic comparison of data between scenarios is not sufficient to assess the effectiveness of the reintroduction measures. For that, one would need to define and use objective parameters. The left column of Table 11 offers ten such parameters that are used in this analysis. The second column shows the environmental criteria set by FoEME (and their derivatives). The rest of the columns show the results in three scenarios: CA (i.e. 2010), ZS and RS[16]. ZS and RS are each split into periods B' and C'. The meaning of each parameter is explained below:

- Average Annual flow downstream SWC – Since the environmental flow was set according to the historical flow at Deganiya, which at the time included the saline springs nourishing the SWC today, this parameter is comparable with the requirement of 125 MCM/Yr.
- Average Annual flow downstream Emeq Hamaayanot – One of the main environmental requirements of FoEME is an annual flow at Bezeq of 220 MCM/Yr. Since only 2 minor

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[16] Partial combinations of the measures were examined as well, but are not presented since only a full implementation came close to meeting the environmental flow requirements, particularly with respect to salinity.

tributaries from the east enter the LJR between Emeq Hamaayanot and Bezeq, this parameter represents this requirement.

- Average annual flow coverage below Emeq Hamaayanot – for every year the percentage of modeled flow relative to the requirement (220 MCM) was calculated, with 100% being the maximum. For example, if the modeled annual flow was 110 MCM, then the coverage for that given year would be 50%. If the flow exceeds the requirement (say 300 MCM), then the coverage is 100%. This parameter is the average of all years.

- Average flow in March downstream Yarmouk – February/March should witness the highest flows in the LJR, including one minor flood. An average flow above 19 MCM should meet the criterion of minor flood.

- Average annual minimum flow downstream SWC – The monthly minimum flow criteria was set at 9 MCM, which is 30% of the historical summer flow at Deganiya.

- Average discharge coverage downstream SWC – for every month the percentage of modeled flow relative to the requirement (Figure 49) was calculated, with 100% being the maximum. For example, if the monthly requirement is 10 MCM but the modeled flow was 5, then the coverage for that given month is 50%. If the flow exceeds the requirement (say 13 MCM), then the coverage is 100%. This parameter is the average of all months.

- FMS downstream Tavor – The concept of Frequent Maximal Salinity is explained in section 6.2. The reason for evaluating FMS downstream Tavor is that in many instances, the LJR is split at the confluence with Harod stream because of the fishponds effluents, as illustrated in section 6.3.1.1 (see Figure 45).

- FMS downstream Emeq Hamaayanot – FMS after the return flow from all the fishponds and irrigation.

- Months above 750 mg/L downstream Tavor – Counts the percentage of months that salinity topped 750 mg/L. This parameter does not refer to the magnitude of exception as theoretically, it is nearly infinite. Opposite to the coverage parameters, here the lower is the number, the better.

- Months above 750 mg/L downstream Emeq Hamaayanot – Same as the parameter above, after the drainage of all fishponds and irrigation.

- Total score – all the scores of the parameters above for each scenario and period were percentiled relatively to the environmental requirement. The average of all percentiles is the total score.

As can be seen by the total score, the situation of the river today is grim. If nothing is done in addition to the approved plans (ZS), then the situation will improve but will still be inadequate.

If the measures suggested here are taken, then within a period of 10-15 years the LJR can reach a satisfying, albeit not perfect, condition.

8.5 Costs of measures

The real costs were calculated for 30 years (2011-2041) in NIS, according to the values specified in Table 10, assuming an annual discount rate of 4%, with capital costs that are financed through loans for 20 years with an interest rate of 5%. Energy cost was assumed to be 0.45 NIS/kWh. Lost revenues were calculated according to the variable benefits per m^3, multiplied by the difference in the supply to agriculture between the ZS and RS. Only direct costs were taken into account and externalities were excluded (for both benefits and costs).

The net costs and lost revenues of all the measures total to 3.4 billion NIS over 30 years, on top of future costs of ZS. Note that lost revenues will probably be replaced in the long run with other economic possibilities (such as tourism), so putting them together with costs is somewhat skewed. In the years 2015-2035 expenditure will range between 50-90 million NIS per year until the loans for the capital investments are paid. After 2035, only energy costs and maintenance for the existing infrastructure will remain, and total to 20-30 million NIS per year. The costs and lost revenues are split as follows:

- 730million in lost revenues for the farmers in the LJR basin;
- 970 million in lost revenues for the farmers in the UJR basin
- 370 million for dealing with the SWC and its brine, including further desalination and transferring brine to the Dead sea;
- 1,300 million to decrease flow in the NWC;
- 100 million to transfer effluents from the Kishon Water Works to AMWA.

8.6 Utilization of water downstream

The main concern of this paper is the rehabilitation of the Upper LJR, until Bezeq Stream. Once the LJR has been restored to an acceptable degree, its water should allow all forms of saline cultivation. Present day agricultural consumption in Emeq Hamaayanot amounts to 100 MCM/Yr and in the later years of the RS, 40 MCM/Yr are being taken from the farmers (4 MCM of fresh water, 7-9 MCM of saline water and 26 MCM of fishponds water, some of which are the result of the fishery reform). Returning those 40 MCM from below Bezeq to the AMWA for the purpose of saline agriculture (not fishponds!) could compensate local farmers, at least partially.

Assuming this compensation will start at the beginning of period C, the total net benefit for farmers will be 600 million NIS, reducing the total cost of rehabilitation to 2.8 billion NIS over the next 30 years. Capital investments in the scheme cannot be estimated at this point, although they should range in the millions as pumps on the LJR and nearby reservoirs already exist.

Implementation is pending the existence of 40,000 dunam of suitable land for saline irrigation, on top of present day cultivated areas. Prima facie, there are enough lands (there are 55,000 dunam of field crops with only minimal irrigation) but their sensitivity to saline water should be examined prior to implementation.

Water salinity will probably entail over-irrigation to preserve soils, so 15% of return flows from the "new" fields can be assumed. If return flow's salinity is double the salinity of irrigated water then the effect on the LJR will be a salination in the range of 20-30 mg/L on average. Therefore, both the pumping and the drainage of the fields should be located as southwards as possible to minimize the effect upstream Bezeq.

8.6.1 Utilization downstream Bezeq Stream

Water can also be used for saline irrigation south of Bezeq, in the Jordan Valley. Best results would be achieved if the water is pumped upstream Adam (Damya) Bridge, and even upstream W. Kharuba. The reason is the gradual salination of the water as a result of salty groundwater in the area that range between 1,500-3,000 mg/L. Today, the water in the LJR is at similar salinity magnitude so up until Adam Bridge, groundwater has little effect on salinity in the river (see Figure 5 in page 29). After the implementation of the measures in the RS however, salination is expected to begin sooner.

9 Conclusions

Today, the condition of the LJR is grim with flows that equal 3% of the historical flow and high levels of pollution and salinity in the river. In the next 30 years, the situation is expected to improve with the rise in the water level of the SoG and the partial desalination of the SWC. In the 2020's overspills of the SoG will even return instances of high flows to the LJR, though not in the same magnitude as before.

Salinity wise, the river will be split at Harod Stream as a result of the SWC brine being transferred to Emeq Hamaayanot and the fishery reform. Upstream Harod the LJR will be sweetened to about 1,300 mg/L. Between Harod and Bezeq, the LJR's salinity will increase sharply, especially at autumn and early winter when it can top 2,000 mg/L.

Water supply in the region will become more complicated and current level of agriculture will be hard to meet in dry years. Water availability, will limit further growth in agricultural production.

The object of this paper is to provide a roadmap for initial phase in the rehabilitation of the LJR, by suggesting implementable measures to reintroduce water and reduce pollution in the river from the Israeli side.

The first recommendation is to change the operation of the Deganiya dam after the SoG will have risen. Analysis shows that releasing 125 MCM/Yr will be sustainable when the lake is above the bed level of Deganiya dam; assuming the transfers to the KAC remain at their current level and the seawater desalination in Israel progresses as planned.

The anticipated improvement will not suffice though to sustain a healthy biological system in the LJR, and further actions will be needed. The combination of measures that is suggested in this paper could, within 10-15 years, bring the LJR to an adequate environmental condition.

Although on average the environmental goals are achievable, in drought years, especially if consecutive, that will not be possible. Meeting the salinity goal of 750 mg/L will be most difficult downstream Emeq Hamaayanot and perhaps Harod Stream. Upstream Harod it is achievable. Having said that, the proposed plan will greatly improve the condition of the LJR even in the driest of years to a level that could probably sustain the ecological system to a degree it can quickly recover in average years.

Parts of the proposed plan include cutting back existing water rights in the area. Much of the water in the LJR could be used downstream Bezeq Stream and even in Emeq Hamaayanot, as the expected quality should allow all forms of saline irrigation. Utilization of 40 MCM/Yr from the LJR should offset most of the cut back quotas.

10 Appendices

10.1 List of consumers

ID	Name	X	Y	Producer	Type	Quality	BASIN
229298	כפר רופין קבוץ א	253534	707456	אפיקי מים אג' שת' חק'	שטפון	שפיר	בזק
229299	מי ירדן	253400	707600	אפיקי מים אג' שת' חק'	שטפון	שפיר	בזק
229300	אפיקי מים-מאגר	253407	711572	אפיקי מים אג' שת' חק'	עילי	מלוח	בזק
229301	נווה אור	253599	722454	אפיקי מים אג' שת' חק'	עילי	מלוח	תבור
229302	נווה אור קבוץ	251970	723530	אפיקי מים אג' שת' חק'	עילי	שפיר	תבור
229303	חמדיה א (עדן - דושן)	252842	716052	אפיקי מים אג' שת' חק'	שטפון	שפיר	יששכר
229304	חמדיה ב	252701	715305	אפיקי מים אג' שת' חק'	עילי	מלוח	חרוד
229305	נוה אור קב	254301	721224	אפיקי מים אג' שת' חק'	עילי	מלוח	יששכר
229306	מעוז חיים קיבוץ	253500	716600	אפיקי מים אג' שת' חק'	עילי	מלוח	יששכר
229307	טירת צבי	251200	702700	טירת צבי קבוץ	שטפון	שפיר	בזק
229308	נוה איתן קבוץ	249700	712000	נוה איתן קבוץ	שטפון	שפיר	חרוד
229309	רשפים קבוץ	243325	708890	רשפים קבוץ	קולחין	קולחין	בזק
229334	אג מ עמק חרוד	233830	717410	אגודת המים השת' בעמק חרוד	עילי	שפיר	חרוד
229335	מעין חומה	242500	712250	אגודת המים השת' בעמק חרוד	עילי	שפיר	חרוד
229371	מאגר שטפונות	242500	714300	בית אלפא קבוץ	שטפון	שפיר	חרוד
229372	קולחין	241600	714700	בית אלפא קבוץ	קולחין	קולחין	חרוד
229373	קולחין-שטפנונות	241200	715450	חפציבה קבוץ	קולחין	קולחין	חרוד
229374	יזרעאל-קולחין	231880	718760	יזרעאל קבוץ (מחוץ למערכת הארצית)	קולחין	קולחין	חרוד
229375	כפר יחזקאל-קולח	234650	717890	כפר יחזקאל מושב	קולחין	קולחין	חרוד
229377	ע.חרוד אחוד-מאג	239900	715200	עין חרוד איחוד קבוץ	מאגר	שפיר	חרוד
229378	ע.חרוד אחוד-קלח	236400	718000	עין חרוד איחוד קבוץ	קולחין	קולחין	חרוד
229379	מי שטפונות	238150	720500	עין חרוד מאוחד קבוץ	שטפון	שפיר	חרוד
229380	קולחי מח תל יוס	237700	715000	עין חרוד מאוחד קבוץ	קולחין	קולחין	חרוד
229464	בית קשת קבוץ	238290	736120	בית-קשת קבוץ	קולחין	קולחין	תבור
229470	שדמות דבורה	241990	734420	שדמות דבורה מושב	שטפון	שפיר	תבור
229477	מאגר	249500	736000	עלי-באר אג' שת' חק' להשקאה בע"מ	שטפון	שפיר	יבניאל

ID	Name	X	Y	Producer	Type	Quality	BASIN
229478	עין מזרב	247700	732920	עלי-באר אג' שת' חק' להשקאה בע"מ	עילי	שפיר	יבניאל
229479	עין ימה	247800	733700	עלי-באר אג' שת' חק' להשקאה בע"מ	עילי	שפיר	יבניאל
229480	עין חורי וטינה	246000	732280	עלי-באר אג' שת' חק' להשקאה בע"מ	עילי	שפיר	תבור
229484	עין שרונה	245150	735550	שני יצחק	עילי	שפיר	יבניאל
229506	גזית קבוץ	245500	723750	גזית קבוץ (מחוץ למערכת הארצית)	מאגר	שפיר	תבור
229507	גזית קבוץ	243300	729000	גזית קבוץ (מחוץ למערכת הארצית)	שטפון	שפיר	תבור
229511	דברת-קולחין	233370	729930	דברת קבוץ	קולחין	קולחין	תבור
229519	מרחביה קבוץ	232600	722130	מרחביה קבוץ	קולחין	קולחין	חרוד
229522	עין דור קבוץ	238550	729550	עין-דור קבוץ	קולחין	קולחין	תבור
229523	עין דור קב	237300	729550	עין-דור קבוץ	עילי	שפיר	תבור
229524	עין דור מאגר	238500	729550	עין-דור קבוץ	מאגר	שפיר	תבור
229525	דברת - בית קשת	235950	729900	שותפות דברת-בית קשת	קולחין	קולחין	תבור
229581	מנחמיה מ מ	251580	731370	מנחמיה המועצה המקומית	עילי	שפיר	תבור
229654	עמק הירדן-ירדן	253780	735080	אגודת המים - רישיון אזורי עמק הירדן	עילי	שפיר	ירדן דרומי
229655	עמק הירדן-ירדן	253500	734400	אגודת המים - רישיון אזורי עמק הירדן	עילי	שפיר	ירדן דרומי
229656	עמק הירדן-ירדן	253500	734400	אגודת המים - רישיון אזורי עמק הירדן	עילי	שפיר	ירדן דרומי
229657	עמר הירדן-ירדן	253000	734100	אגודת המים - רישיון אזורי עמק הירדן	עילי	שפיר	ירדן דרומי
229658	עמק הירדן-ירמוך	257760	731720	אגודת המים בעמק הירדן בע"מ	עילי	שפיר	ירמוך
229659	עמק הירדן-ירמוך	257050	731200	אגודת המים בעמק הירדן בע"מ	עילי	שפיר	ירמוך
229660	עמק הירדן-ירמוך	255600	728700	אגודת המים בעמק הירדן בע"מ	עילי	שפיר	ירמוך
229662	עמק הירדן-ירמוך	256700	730800	אגודת המים - רישיון אזורי עמק הירדן	עילי	שפיר	ירמוך
229671	ירמוך	253990	727900	גשר קבוץ (מחוץ למערכת הארצית)	עילי	שפיר	ירמוך
229672	גשר קבוץ	252900	726000	גשר קבוץ (מחוץ למערכת הארצית)	עילי	מליח	תבור
229673	גשר קבוץ	252900	726000	גשר קבוץ (מחוץ למערכת הארצית)	עילי	מלוח	תבור
229674	גשר קב	253400	725300	גשר קבוץ (מחוץ למערכת הארצית)	עילי	מלוח	תבור
229675	גשר קב	251320	723980	גשר קבוץ (מחוץ למערכת הארצית)	עילי	שפיר	תבור
231594	ירג"ת תח."	253200	734300	חברת מקורות	עילי	שפיר	ירדן דרומי
231604	קולחין-שטפונות (מאגר מיצר)	246400	740900	ישובי מי גולן כמפורט בנספח	קולחין	קולחין	יבניאל
231608	עין סחינה	263000	732800	ישובי מי גולן כמפורט בנספח	עילי	שפיר	ירמוך
231609	עין סחינה	263000	732800	ישובי מי גולן כמפורט בנספח	עילי	שפיר	ירמוך
231704	מגדל שוקק	242560	712200	חברת מקורות	עילי	שפיר	חרוד

ID	Name	X	Y	Producer	Type	Quality	BASIN
231705	מגדל שוקק-תח.	242380	711850	חברת מקורות	עילי	מליח	חרוד
232745	מק תל אור	253700	728500	חברת מקורות	עילי	שפיר	תבור
232751	סודה תח	250560	713100	חברת מקורות	עילי	מליח	חרוד
232755	מק חמת גדר תח.	263450	732750	חברת מקורות	עילי	מלוח	ירמוך
232772	מק תח עין שוקק	242140	711610	חברת מקורות	עילי	מלוח	חרוד
232952	מק כנר ב שאן	254080	735260	חברת מקורות	עילי	שפיר	ירדן דרומי
232957	מק שפעה	253480	706450	חברת מקורות	עילי	מליח	בזק
232961	מעינות בית שאן	248220	706035	חברת מקורות	עילי	מלוח	בזק
232962	מעינות בית שאן	249300	709200	חברת מקורות	עילי	מלוח	בזק
232963	מודע מעין	242705	709840	חברת מקורות	עילי	שפיר	חרוד
232964	שוקק פתוח מעין	242140	711540	חברת מקורות	עילי	שפיר	חרוד
232965	חשק-מעין	248520	705790	חברת מקורות	עילי	מליח	בזק
232966	עמל-מגדל	242340	711845	חברת מקורות	עילי	מלוח	חרוד
232967	נשב מעיין	247850	707065	חברת מקורות	עילי	מלוח	בזק
232968	רוויה-מעין	243530	708000	חברת מקורות	עילי	מליח	בזק
232969	נפתלי-נסיר מעיין	247750	708600	חברת מקורות	עילי	מלוח	בזק
232970	מעיו עפרוני	251145	713780	חברת מקורות	עילי	מליח	חרוד
232971	שוקק פתוח מעין	242290	711340	חברת מקורות	עילי	שפיר	חרוד
232972	מחצצים מעיין	251100	701900	חברת מקורות	עילי	מליח	בזק
232985	נוה אור קב	252100	726200	אפיקי מים אג' שת' חק'	עילי	שפיר	תבור
232991	עמק הירדן-מעין	244565	729315	אגודת המים בעמק הירדן בע"מ	עילי	שפיר	תבור
313920	מאגר שדה אילן	242500	739500	מי גל' תחת' (2001) אגש"ח למי קולחין בע"מ	קולחין מומרים	קולחין	יבניאל
313958	מאגר מעין צבי ב	244000	723000	מי חוף הכרמל אג' שת' חק' בע"מ	קולחין מומרים	קולחין	תבור
315641	מרחב מעיין	247850	707065	חברת מקורות	עילי	מלוח	בזק
315642	רחוב מעיין	247850	707065	חברת מקורות	עילי	מלוח	בזק
315643	צבי-סבחה מעיין	247750	708600	חברת מקורות	עילי	מלוח	בזק
315644	יהודה מעיין	247750	708600	חברת מקורות	עילי	מלוח	בזק
315645	שוקק סגור - מעיין	242140	711540	חברת מקורות	עילי	מלוח	חרוד
315647	חומה מעיין	242340	711845	חברת מקורות	עילי	מלוח	חרוד
315648	נמרוד בלה מעיין	242705	709840	חברת מקורות	עילי	מלוח	חרוד
317494	מאגר ח.ח.י. - דברת ב'	233250	729550	פלגי מים בע"מ	קולחין	קולחין	תבור

10.2 Current Accounts Results

Table 12: Flow in different reaches of the LJR (MCM)

Reach	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Above Alumot	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SWC Inflow	1.4	1.4	1.6	1.9	1.6	2.2	1.9	2.0	1.6	1.9	1.8	1.7	21.0
Yarmouk Inflow	2.0	1.8	2.1	2.3	2.6	2.7	2.3	2.5	2.2	2.5	2.4	2.2	27.5
Tavor Inflow	3.2	3.0	3.7	3.9	5.3	4.1	3.2	3.3	2.9	3.2	3.1	2.9	41.7
Harod Inflow	4.9	4.8	6.6	6.7	8.8	5.9	4.5	4.4	3.7	4.0	4.0	4.1	62.6
Shifa/ Kfar Rupin	7.3	6.8	8.9	8.4	11.0	5.7	4.4	3.9	3.3	3.9	3.8	3.8	71.2

Table 13: Chlorides concentration in different reaches of the LJR (mg/L)

Reach	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Above Alumot	280	280	280	280	280	280	280	280	280	280	280	280
SWC Inflow	2588	2544	2310	2109	2067	2187	2316	2306	2427	2331	2388	2418
Yarmouk Inflow	1939	2022	1782	1734	1327	1824	1973	1951	1952	1900	1938	2018
Tavor Inflow	1455	1554	1273	1304	846	1427	1672	1695	1676	1655	1675	1738
Harod Inflow	1524	1696	1483	1542	929	1351	1492	1529	1537	1516	1528	1515
Shifa/ Kfar Rupin	1680	1772	1633	1641	1122	1445	1561	1587	1599	1577	1573	1544

Table 14: Water Consumption in the basin of the Upper LJR (MCM)

Demand Site	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
AMWA Agri Fresh	2.2	2.2	0.9	0.5	0.0	0.3	0.5	0.8	0.8	1.0	1.4	2.1	12.7
AMWA Agri Saline	1.7	2.3	1.8	2.0	1.9	4.0	4.3	6.1	5.2	3.8	3.4	2.8	39.3
AMWA Fishponds	4.2	4.1	4.2	4.2	3.8	4.2	4.1	4.2	4.1	4.2	4.2	4.1	50.0
AMWA Muni	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6.0
Gazit Floods 229507	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.6
Gesher Fresh 229675	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.6
Hamadiya ponds 229304	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.1	1.2
Harod 229334	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.7
Harod Floods	0.0	0.0	0.3	0.5	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.5
Harod from Homa	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.1	1.2
JVWA	1.8	1.3	0.4	0.2	0.2	0.9	1.7	2.5	3.1	3.4	3.2	2.4	21.2
Neve Ur Ponds 229305	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	1.4
All Others	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Total	**11.2**	**10.9**	**8.7**	**8.5**	**7.6**	**10.8**	**11.8**	**14.9**	**14.5**	**13.7**	**13.5**	**12.6**	**138.7**

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