Chapter 19

Western Aquifer Basin

INVENTORY OF
SHARED WATER RESOURCES IN WESTERN ASIA (ONLINE VERSION)

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DEUTSCHE ZUSAMMENARBEIT

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Western Aquifer Basin

EXECUTIVE SUMMARY

The Western Aquifer Basin is the most productive water basin in Israel and Palestine, yielding the highest-quality water in the area. The aquifer formation extends from the western slopes of the West Bank, through large parts of Israel to the north of the Sinai Peninsula. The aquifer's water resources and groundwater flow are concentrated to the north of the mostly impermeable Afiq Channel and its extention running along a line from the city of Gaza via Be'er Sheva in Israel to the southern limits of the West Bank.

Average annual abstraction over recent decades exceeds the estimated long-term average annual recharge, which means the aquifer is gradually being depleted. Israel currently controls 100% of the aquifer and abstracts 94% of its water, while Palestinians abstract only 6%. Egyptian use of the aquifer is negligible.

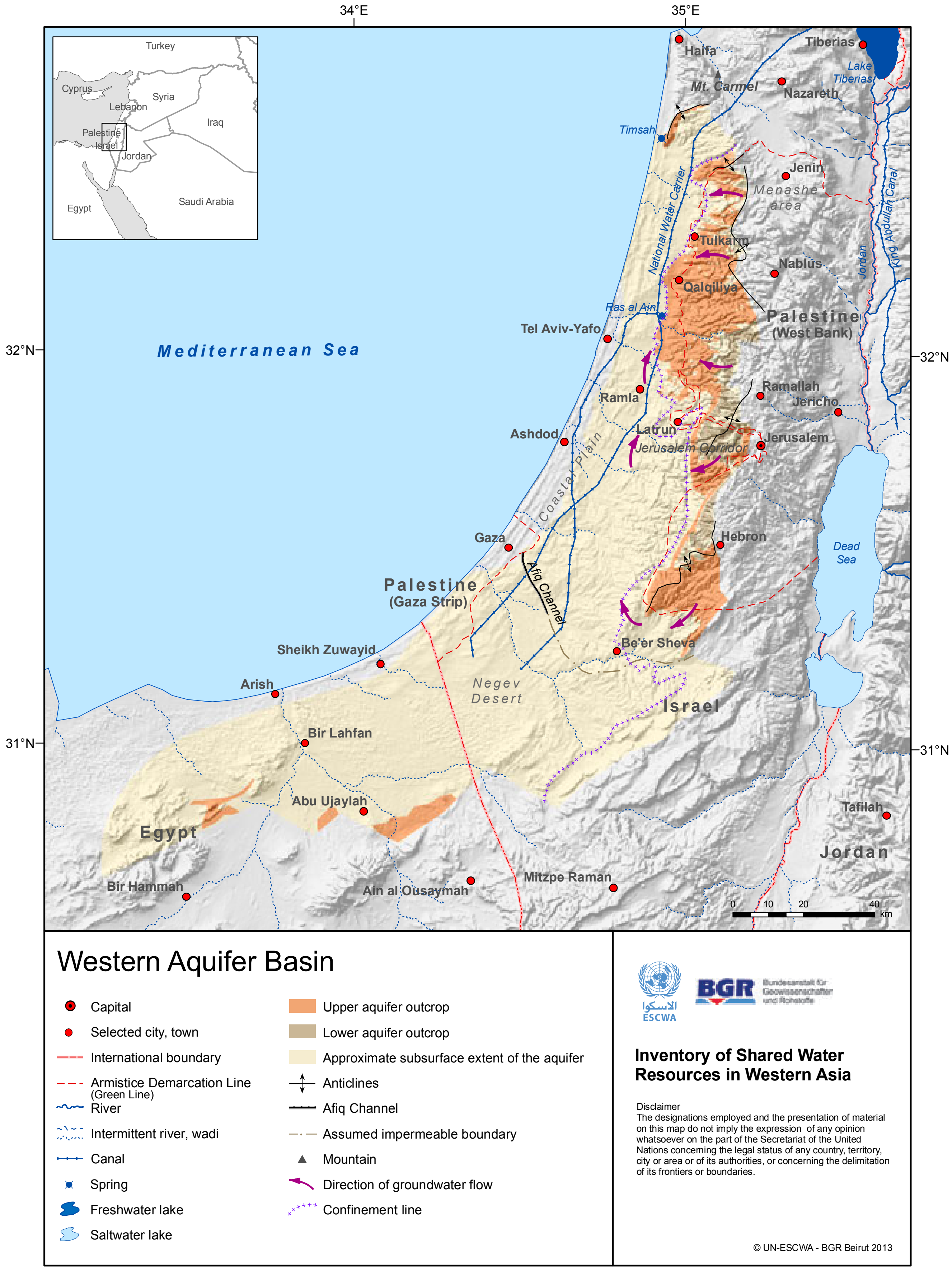
Riparian cooperation on water resources management in the Western Aquifer Basin is largely related to the Israeli-Palestinian conflict. While there is no basin-wide agreement between the three riparians, Israel and PLO have signed two temporary bilateral agreements (Oslo I and II) that both include articles on water resources in the aquifer basin. In particular, the 1995 Oslo II agreement established a Joint Water Committee (JWC), which is responsible for regulating water resources use in the West Bank, including licensing of wells and changes in water allocations. However, in practice the committee has had limited impact and the complicated licensing procedures form a major obstacle to the development of Palestinian infrastructure in the basin. Since the Oslo II agreement, no high-level technical or political negotiations on water-related issues have taken place.

As a productive aquifer with high-quality water, the Western Aquifer Basin is considered a key resource by Israelis and Palestinians. It will therefore form an important point of discussion during final peace negotiations between the two parties.

BASIN FACTS

RIPARIAN COUNTRIES	Egypt, Israel, Palestine
ALTERNATIVE NAMES	Palestine: Western Mountain Aquifer, Ras al Ain-Timsah Aquifer Israel: Yarkon-Taninim Aquifer
RENEWABILITY	Low to medium (2-100 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Groundwater from the basin used to discharge through two major springs in Israel and Palestine
ROCK TYPE	Fractured, karstic carbonates
AQUIFER TYPE	East (recharge area): unconfined Centre and west: confined
EXTENT	Total: 9,000-14,167 km^2 Hydrologically most active: 6,035-6,250 km^2
AGE	Middle to Late Cretaceous (Albian to Turonian)
LITHOLOGY	Limestone and dolomite, some marl and chalk
THICKNESS	600-1,000 m
AVERAGE ANNUAL ABSTRACTION	Total: ~390 MCM Israel: 368.7 MCM (1970-2008) Palestine: 23.7 MCM (1995-2011)
STORAGE	..
WATER QUALITY	Very good
WATER USE	Agricultural, domestic and industrial
AGREEMENTS	Israel-Palestine (PLO) 1993 - Oslo I 1995 - Oslo II
SUSTAINABILITY	Over-abstraction; infiltration of untreated sewage

OVERVIEW MAP



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LOCATION

The Western Aquifer Basin is the most productive aquifer basin in Israel and Palestine, yielding the highest-quality water in the area. The aquifer basin stretches from the West Bank mountain tops in the east, down the western slopes to the Coastal Plain and the Mediterranean Sea in the west. From north to south it extends from the Mount Carmel foothills to the northern Sinai Peninsula. The Western Aquifer Basin is also referred to as the Western Mountain Aquifer or named after its principal historic outlets, the Ras al Ain Spring[1] north-east of Tel Aviv-Yafo and the Timsah Spring[2] south of Mount Carmel.

AREA

The Western Aquifer Basin covers a total area of 9,000 to 14,167 km^2, depending on the definition of the aquifer's southern boundary in the Sinai Peninsula.[3] This chapter focuses on the area north of the Afiq Channel (see section on Hydrogeology below), which is the more productive part of the aquifer. Different studies estimate the surface area of this part of the basin between 6,035 and 6,250 km^2,[4] of which approximately 70% lies in Israel and 30% in the West Bank.

CLIMATE

The Western Aquifer Basin is characterized by a semi-arid climate. The West Bank mountains cause orographic lifting, which results in precipitation from moisture-laden clouds drifting in from the Mediterranean Sea. Average annual precipitation lies between 550 and 700 mm, with rain- and snowfall occurring mainly between October and March. On the Coastal Plain, average annual precipitation ranges from around 600 mm in the north to 250 mm in the south, while the arid Sinai Peninsula receives no more than 50 mm.

POPULATION

The total population within the most hydrologically active part of the basin north of the Afiq Channel is estimated at around 4.6 million. Around 1 million people live in the Palestinian part of the basin, including populations in the governorates of Bethlehem, Qalqiliya, Salfit and Tulkarm, and part of the governorates of Hebron and Ramallah/Al Bireh.[5] The number of Israeli settlers in the Western Hills was estimated at 148,000.[6] Around 3.4 million people live in the Israeli part of the basin, including populations in the Central District, and parts of the districts of Tel Aviv, Haifa (Hadera Sub-district), Jerusalem (Bet Shemesh), as well as the Southern District (Ashkelon and Be'er Sheva Sub-districts).[7]

OTHER AQUIFERS IN THE AREA

The Western Aquifer Basin is surrounded by seven aquifers, with which it stands in partial flow contact.[8] In the north, it is bounded by the Carmel Coastal, the Western Galilee and the North-Eastern Aquifer Basins. To the west, it is overlain by the Coastal Aquifer Basin (see Chap. 20), while to the east it is bounded by the Eastern Aquifer Basin. To the south, the Western Aquifer Basin is in contact with the Negev Aquifers, the shallow Coastal Aquifer and the deep Kurnub Aquifers in the Sinai Peninsula.

INFORMATION SOURCES

This chapter focuses on the parts of the Western Aquifer Basin that are located in Israel and the West Bank and draws on data published in scientific studies, official government documents and organization reports as listed in the bibliography. Certain data (e.g. spring discharge, well abstractions) was obtained directly through the Inventory's Country Consultation process. Very little information was available for the part of the aquifer located in the Sinai Peninsula. The Overview Map was delineated based on local and regional references.[9]

Al Khadr, South Hebron Hills, West Bank, 2010. Source: EWASH.

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

On a local and sub-regional scale, the Western Aquifer Basin contains two aquifer horizons (a lower and an upper), which act as a single combined aquifer unit on a regional and basin-wide scale.[10]

The lower aquifer crops out along the crest of the West Bank Anticlinorium,[11] predominantly within the West Bank, but occasionally also in Israel (e.g. the Jerusalem Corridor) and dips with increasing steepness towards the coast in the west. Similarly, the upper aquifer crops out in the middle and lower slopes of the West Bank, with small outcrop areas to the west of the Green Line.[12] Both series plunge deep beneath thick impermeable Neogene series in the Coastal Plain and in most of the Sinai Peninsula.[13]

The aquifer outcrops, which cover a total area of about 1,976 km^2, mainly occur in the mountains and foothills of the West Bank. Based on the total aquifer extent, the West Bank contains 65% of the total combined outcrop area (1,276 km^2), while 25% of the outcrops occur in Israel and 10% in the Sinai Peninsula.[14]

In the mountainous regions, the aquifer strata dip more steeply than the slopes and expose the deepest formations – the core of the anticline – at the mountain tops. That means that the aquifer is receptive to direct rainfall recharge in the mountains and foothills, especially in the eastern part of the aquifer basin. Here, active epikarst systems develop with wide fractures, cracks, channels and even caves that allow for rapid, deep infiltration of the percolating waters and remarkably high recharge rates (up to 57% of rainfall).[15]

The lateral boundaries of the aquifer (see Overview Map) have been discussed at length in the literature.[16] Of particular importance for the aquifer configuration is the Afiq Channel, which stretches from Be'er Sheva in the east to northern Gaza in the west.[17] This buried erosion channel is filled with impermeable series (evaporites, fine clastics etc.) that deeply bisect the aquifer basin into a northern, hydrologically active aquifer and a southern part, which barely contributes to the active flow system. The section to the east of the Afiq Channel (east and south-east of Be'er Sheva) does not contribute significantly to the hydraulic system of the Western Aquifer Basin, due to lower flow, saturated thickness, recharge and conductivities.[18]

STRATIGRAPHY

The Western Aquifer Basin is composed of Upper Cretaceous (Upper Albian, Cenomanian and Turonian) carbonatic sediments, layers of limestone and dolomite,[19] alternating with confining layers of marl and some chalk. On a local and supra-local scale two aquifer horizons (lower and upper) can be identified, which act as one combined aquifer system on a regional and basin-wide level.[20] Parts of the aquifer are strongly karstified, which explains high local productivity rates.

Table 1. Lithostratigraphy of the Western Aquifer Basin

<table>
<tr><th>AGE</th><th colspan="2">FORMATION</th><th colspan="2">LITHOLOGY</th><th colspan="2">HYDROSTRATIGRAPHY</th></tr>
<tr><td>Senonian</td><td colspan="2">Abu Dees</td><td colspan="2">Chalk, chert, marl</td><td colspan="2">Aquitard</td></tr>
<tr><td>Turonian</td><td>Daliya</td><td>Jerusalem</td><td rowspan="6">Chalky marl</td><td>Limestone</td><td rowspan="6">Aquitard</td><td rowspan="3">Upper aquifer</td></tr>
<tr><td rowspan="3">Cenomanian</td><td rowspan="5">Undifferentiated Talme Yafe</td><td>Bethlehem</td><td rowspan="2">Dolomite, limestone, marl, chalk.</td></tr>
<tr><td>Hebron</td></tr>
<tr><td>Yatta</td><td>Chalk, marl, limestone.</td><td>Aquitard</td></tr>
<tr><td rowspan="2">Albian</td><td>Beit Kahel</td><td>Dolomite, limestone, marl.</td><td>Lower aquifer</td></tr>
<tr><td>Qattana</td><td>Marl, clay.</td><td>Aquitard</td></tr>
</table>

Source: Compiled by ESCWA-BGR based on Abusaada, 2011, p. 46, fig 2.3 (modified after PWA and UNuT, 2004 and Weinberger and Rosenthal, 1994).

The aquifer basin is underlain by the Qattana Formation,[21] an aquitard of the Aptian and Lower Albian Kobar Group sediments, which consists of a 300-500 m-thick succession of mostly impermeable marl, clay and shale with thinner intercalations of carbonates.[22]

In the Coastal Plain in Israel and most of the Sinai Peninsula, the aquifer basin is overlain by thick sequences of impervious younger sediments, such as the Senonian Mount Scopus and Neogene Saqiye Groups.[23]

AQUIFER THICKNESS

The upper and lower aquifers have a combined thickness of 600-900 m.[24] On average, the upper and lower aquifers each have a thickness of around 350 m. The layers are incompletely separated by less permeable and impermeable marly and chalky series with a thickness of 100-150 m. This results in an overall thickness of 700-1,000 m for the entire aquifer system.[25]

AQUIFER TYPE

The aquifer system is generally unconfined in the mountain and slope areas in the eastern part of the basin.[26] Saturation increases gradually towards the west, first in the lower and then the upper aquifer. West of the confinement line – which runs roughly along the Green Line – the aquifer system experiences strongly confined hydraulic (in the past even artesian) pressure, which brings water levels in bore-holes in the Coastal Plain up to a few dozen metres below ground level and feeds the (now partially dried up) Ras al Ain and Timsah Springs.

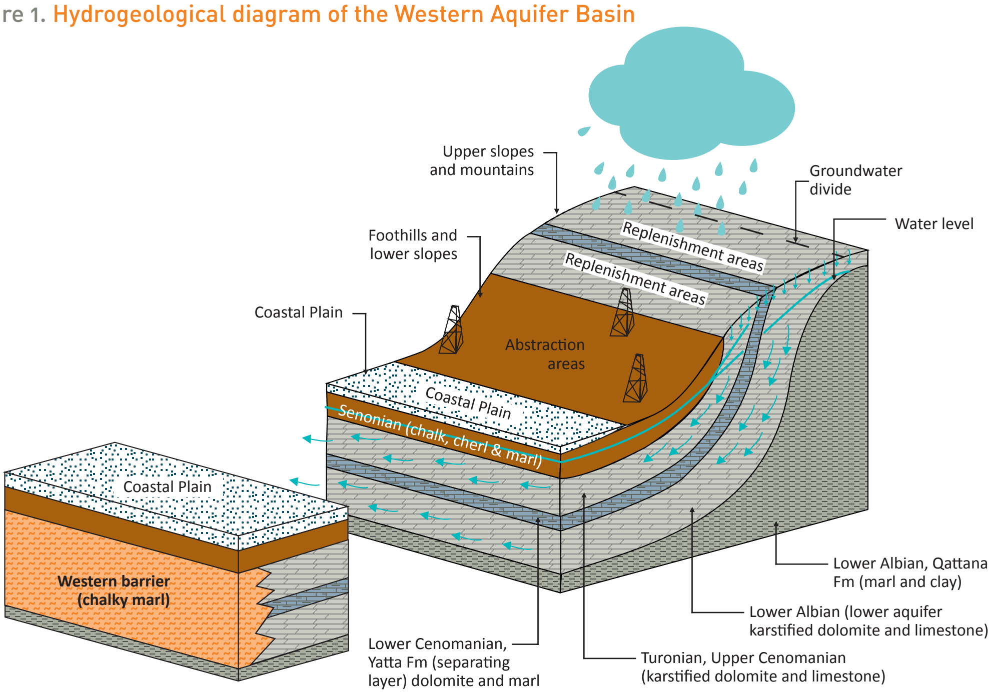
AQUIFER PARAMETERS

Aquifer parameters in karst aquifers are generally highly variable. Annual well discharges range from less than $1x10^{-1}$ MCM to more than 7.5 MCM. Specific yield was found to vary between 1% and 8%,[27] while storativity in the confined areas ranges between 10^{-6} and 10^{-4}.[28]

In the confined areas in the Coastal Plain, transmissivities of between $1.7x10^{-1}$ and $4.63x10^{-1}$ m^2/s have been reported, while they only reach several hundred square metres per day in the unconfined area near the margins of the aquifer basin.[29] In the most productive wells transmissivity can reach up to 1.16 m^2/s. Transmissivity values derived from groundwater model calibrations were sometimes double or triple the values measured in specific wells,[30] which may confirm the double continuum system in the aquifer basin, with diffuse and conduit flow systems.

Horizontal conductivities for the upper and lower aquifer are considered mostly similar, except in the mountain areas where the values increase along the flow path from less than 1-10 m/d (Hebron, Jerusalem, Ramallah) to 5-15 m/d (Tulkarm), 85-160 m/d (Timsah) and 85-600 m/d in the most productive, central parts of the Coastal Plain.[31] The vertical conductivities in the aquifer are estimated to be much lower,[32] ranging between $1.3x10^{-6}$ and $2.2x10^{-4}$ m/d.[33] Conductivities in the aquitard between the upper and lower aquifers can be as low as $7.9x10^{-3}$ m/d.[34]

Figure 1. Hydrogeological diagram of the Western Aquifer Basin



Source: Redrawn by ESCWA-BGR based on Abusaada, 2011, p. 44, fig 2.1.

Hydrogeology - Groundwater

RECHARGE

Recharge in the Western Aquifer Basin is mainly natural from direct infiltration along the karstified outcrops in the mountainous and sloped areas in the eastern part of the aquifer system. Around 73% of recharge to the aquifer takes place in the West Bank.[35] In Israel, recharge mainly takes place in the northern part of the basin (Menashe area) and in the Jerusalem Corridor. Sparse aquifer outcrops and low average annual rainfall in the Negev (Al Naqab) Desert in Israel and the Sinai Peninsula allow for only negligible recharge amounting to less than 1 MCM/yr.

A wide range of values for annual recharge is reported in the literature, from 318 to 430 MCM (Table 2). This Inventory uses the results of a recent study, which estimated a long-term average annual recharge value of 385 MCM for the period 1970-2006.[36] However, pronounced inter-annual variations in recharge are the norm and annual recharge values can range from 212 to 864 MCM, depending on precipitation and other meteorological factors.[37]

Other, smaller sources of recharge to the aquifer system include network losses, agricultural and wastewater return flows, infiltration from wadis, seawater intrusion[38] and artificial recharge through deep-injection wells. Limited agricultural development and water use in the West Bank means that the sources of recharge are less important than direct infiltration from precipitation. In Israel, where the Western Aquifer Basin is mainly confined hundreds of metres below ground, both precipitation and return flows infiltrate the overlying Coastal Aquifer.

Table 2. Recharge estimates for the Western Aquifer Basin

SOURCE	RECHARGE (MCM/yr)	COMMENT
Goldschmidt and Jacobs, 1955, p. 8.	318	Mass balance, based on low outflows from the main springs: Ras al Ain and Timsah.
Bachmat, 1995.	330, 332	Coastal Plain flow model (Goldschmidt/ Jacobs).
Assaf et al., 1993, in Hughes et al., 2008, p. 848.	350	-
Sabbah and Miller, 2012.	350	Based on the 10-year (2001-2010) average.
HSI, 2008, p. 221.	358	Estimate for the period 1970-2007.
Israel and the PLO, 1995.	362	So-called "aquifer potential"; method not specified.
HSI, 1999, in Hughes et al., 2008, p. 4.	366	Rainfall recharge over outcrops.
EXACT, 1998, p. 22.	366	Sum of outflows.
Abusaada, 2011.	385	Estimate for the period 1970-2006 based on water-level fluctuation/storage change.
Messerschmid, 2008, p. 20.	389	Water-level fluctuation, mass balance calculation.
PWA and UNuT, 2004, p. 16.	408	Maximum perennial yield (calibrated steady state and transient models).
PWA and UNuT, 2003b, p. 86.	410	Water budget calculation for Steady State Model.
Hughes et al., 2008, p. 853.	430	Modelled with wetting threshold and soil moisture deficit.

Source: Compiled by ESCWA-BGR.

FLOW REGIME

The flow in the Western Aquifer Basin is generally from east to west in the mountains and turns gradually from south to north in the Coastal Plain. South of the Afiq Channel, the flow is very limited under natural flow conditions.[39] Steep gradients in the elevated recharge and accumulation zone are followed by gentle gradients in the foothills and the lower-lying productive zone. In the recharge zone, water levels generally lie at 300-600 m asl. A gradual increase in saturation occurs in the accumulation zone, and water levels in the lower aquifer drop from 300 to 60 m asl in an east-west direction. In the foothills, water levels lie below 50 m asl, while in the Coastal Plain, a very gentle gradient slopes from more than 30 m asl in the south (Be'er Sheva), to less than 20 m asl in the centre (Ras al Ain Spring) and 5 m asl in the north (Timsah Spring).

Most of the flow is transboundary from the West Bank into Israel. Average annual inflow from the West Bank to Israel amounts to 212 MCM, of which 87% comes from the northern West Bank.[40] Locally, large-scale abstraction from Israeli wells has altered flow lines considerably, for example near Latrun. Flow from and to Egypt is negligible. The aquifer's most productive and exploitable zone lies in the Coastal Plain along the border with the West Bank (Figure 2).

The shallow Carmel Coastal Aquifer and the Coastal Aquifer Basin receive inflow from the Timsah Springs in the northern part of the Western Aquifer Basin. The Coastal Aquifer directly overlies the Western Aquifer near Qalqiliya, with modest recharge.[41]

The North-Eastern Aquifer Basin and the Western Aquifer Basin share a flow boundary in the northern sections of the West Bank mountains. The Eastern Aquifer Basin only has minor flow boundaries with the Western Aquifer Basin; most of the boundary is no-flow or even a structurally divided erosion zone between the basins along the axis of the West Bank Anticlinorium. The Negev Aquifers in the south receive some groundwater from both the Eastern and the Western Aquifer Basins.[42] Occasionally, deep-seated upward leakage along faults occurs from the Jurassic Aquifers below.[43]

STORAGE

Information on groundwater storage was not available.

DISCHARGE

Before the large-scale development of the aquifer in the 1950s, natural discharge occurred almost exclusively from the two principal spring groups, the Ras al Ain and Timsah Springs, which had an average historic discharge of 220 MCM/yr and 100 MCM/yr respectively.[44]

Since the 1950s, spring discharge has decreased sharply due to groundwater abstractions from Israeli and Palestinian wells, resulting in the drying up of the Ras al Ain Spring in the 1960s. The average discharge of the Timsah Spring also dropped to 40 MCM/yr after 1970 (Figure 3).[45] The time series shows that the springs respond quickly to wet years, underlining the highly karstic nature and interconnectivity of the aquifer.[46] After the very wet year in 1991/92, the Ras al Ain Spring started flowing again and discharge from the Timsah Spring increased significantly. However, the increase only lasted a few years and the overall discharge trend continues to be negative, due to sustained over-abstraction from the aquifer.

Figure 2. Aquifer productivity in the Lower and Upper Western Aquifer

Source: Compiled by ESCWA-BGR based on Messerschmid and Abu-Sadah, 2009.

Groundwater levels exhibit similar behaviour (Figure 3) for selected groundwater cells located in the lower, coastal part of the basin.

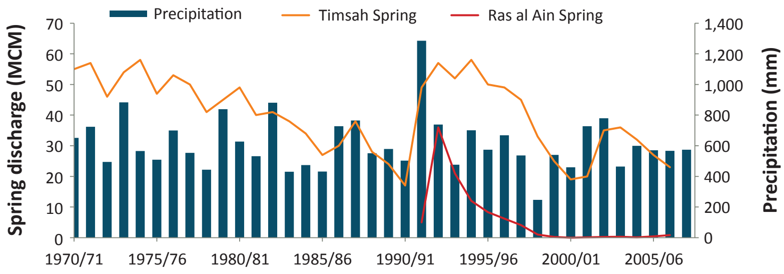
WATER QUALITY

Groundwater in the West Bank is generally fresh with chloride (Cl^-) levels mostly below 100 mg/L.[47] In Israel water is fresh in the vicinity of the Green Line, but becomes slightly brackish (250-600 mg/L) to the west (Figure 4). In the western part of the central Coastal Plain, salty and sulphate-rich leakage from overlying aquifers (e.g. the Eocene Avedat Group) is a local source of additional salt. Farther to the west, groundwater is brackish to highly brackish (600-1,000 mg/L).

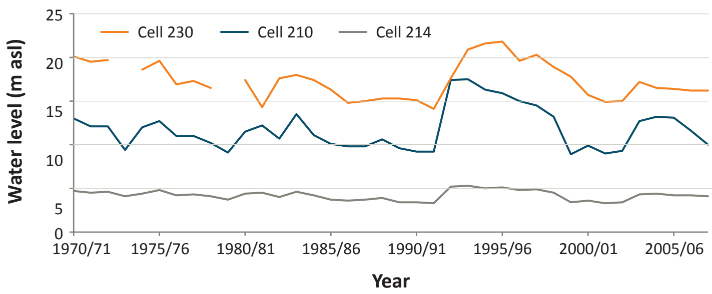
In the north-western part of the basin near the Timsah Springs, seawater intrusions of 3.5-3.9 MCM/yr[48] occur alongside deep saline water bodies at the bottom of the aquifer (>1,000 mg/L). In the area south of the Afiq Channel, most groundwater can be assumed to be strongly brackish to saline (up to approx. 2,000 mg/L), making it unfit for human consumption.

Figure 3. (a) Annual discharge of the Timsah and Ras al Ain Springs and average annual precipitation in the Western Aquifer Basin area (1970-2007); (b) annual water level fluctuations of different groundwater cells in the Israeli part of the basin (1970-2007)

a)



b)



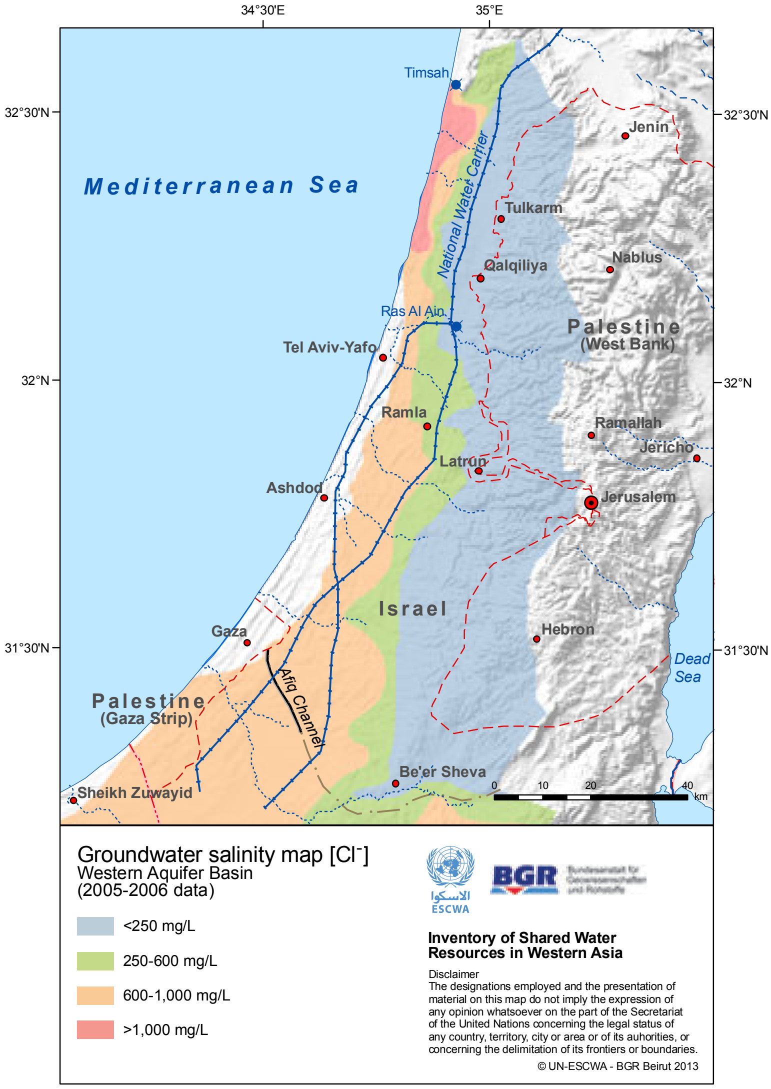
Source: Compiled by ESCWA-BGR based on PWA, 2012a.

South Hebron Hills, West Bank, 2010. Source: Adam Groffman.

EXPLOITABILITY

According to the standardized exclusion criteria used to assess exploitability in this Inventory,[49] the aquifer basin can be classified as theoretically exploitable across most of its extent, with the possible exception of the recharge zone near the eastern margin due to limited saturation and the depth of the groundwater table. More detailed studies of the renewable and intensively developed aquifer basin were found in the literature. Figure 2 shows the productivity for the upper and lower aquifer in the basin. The main productive zone of the aquifer lies near the Green Line and in the Coastal Plain in Israel, and hence constitutes only a relatively small part of the overall basin.

Figure 4. Groundwater salinity map - Western Aquifer Basin



Source: Compiled by ESCWA-BGR based on Messerschmid, 2011 with data from HSI 2008, p. 211, 231.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Palestine (West Bank)

Local farmers, villagers and city dwellers used the Ras al Ain and Timsah Springs together with the water of small local springs. Abstractions from the Western Aquifer through bore-holes started only during the British Mandate period.[50] During the period from the early 1960s to 1967 when Jordan controlled the West Bank, abstraction from private wells with depths up to 150 m amounted to around 20 MCM/yr.[51] The water was mainly used for agricultural purposes.

Since the Israeli occupation of the West Bank in 1967, Palestinian water use in the Western Aquifer Basin has not substantially increased due to Israeli restrictions (Box 1). There are around 140 operational Palestinian wells[52] in the Western Aquifer Basin. Average annual abstraction for the period 1980-1999 was around 21.3 MCM, of which 15.5 MCM was for agricultural use and 4.7 MCM for municipal use.[53]

The Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip (also known as the Oslo II Accords), which was signed in 1995 to cover a five-year period until 1999, allocated Palestinians in the Western Aquifer Basin an annual 22 MCM.[54]

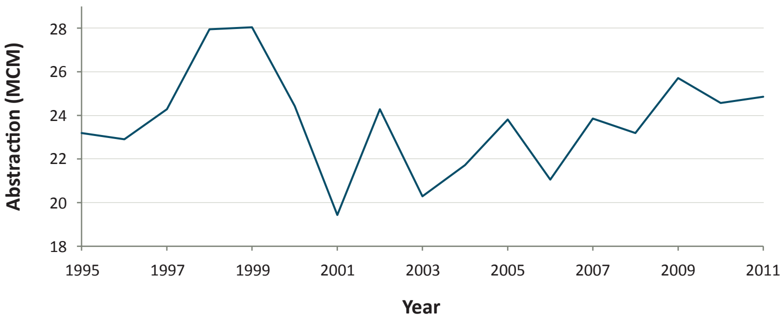
During the period between 1995 and 2011, the annual average Palestinian abstraction from wells was 23.7 MCM, exceeding the value outlined in the Oslo II agreement by 1.7 MCM/yr, or 8% (Figure 5).[55] On average, Palestinian abstractions account for approximately 6% of total abstractions from the Western Aquifer Basin.

Additional abstractions from the Western Aquifer Basin in the West Bank include around 2 MCM/yr from five Israeli operated wells.[56]

Most of the shallow private wells and the few small springs (from intermediate perched aquifer horizons) with discharges of less than 1×10^{-1} MCM/yr (1 L/s) are used for small-scale irrigation or to provide supplementary domestic supply during the dry summer months. In 2009, the combined discharge from those small springs was about 2.4 MCM.[57]

In the entire West Bank, local water production in 2010 amounted to 98.3 MCM, of which

Figure 5. Palestinian abstractions from wells from the Western Aquifer Basin (1995-2011)



Source: Compiled by ESCWA-BGR based on PWA, 2012a.

South Hebron Hills, West Bank, 2010. Source: Adam Groffman.

71.5 MCM were pumped from around 250 wells and 26.8 MCM were produced in springs.[58] Agriculture accounted for approximately 70% of local water use in the West Bank. An additional 55.5 MCM were purchased from Israel's national water company Mekorot in 2010, mostly for domestic use.[59]

Israel

Groundwater development in Israel experienced rapid and sustained growth in the early 1950s.[60] Exploitation of the Western Aquifer Basin in the Coastal Plain accelerated after 1958, mainly from Mekorot wells. Today around 500 wells abstract water from the Israeli part of the Western Aquifer Basin.[61] Most Israeli wells are situated in the productive zone of the aquifer and individual well yields are far higher than Palestinian well yields in the West Bank, which are generally older and shallower.

From 1970 to 2008, average annual pumping from the Western Aquifer Basin in Israel was 368.7 MCM (Figure 6)[62] or 94% of total abstractions from the aquifer basin.[63] Israel also has exclusive access to a number of large springs which discharge an annual average of 43.9 MCM, bringing the total average yield from the aquifer basin in Israel to 412.6 MCM.[64]

Israeli abstractions have remained high since 1970, without a clear trend. Annual abstractions vary with rainfall, and the maximum and minimum annual abstractions of 245 MCM (1991/92) and 576 MCM (1998/99) are inversely correlated to the years of highest (1991/92) and lowest (1998/99) rainfall (Figures 3 and 6).

The Oslo II Accords allocated Israel a temporary share of 340 MCM from the Western Aquifer Basin.[65] Figure 6 shows that Israel's average annual abstraction from wells in the basin reached 393.3 MCM for the period 1995-2008, 53.3 MCM or around 15% more than the volume outlined in the agreement. In addition, if full use of spring discharge is taken into account, Israel's total annual average use after 1995 amounts to 429.3 MCM, which represents 89.3 MCM or 26% more than the amount stipulated in the Oslo II agreement.[66]

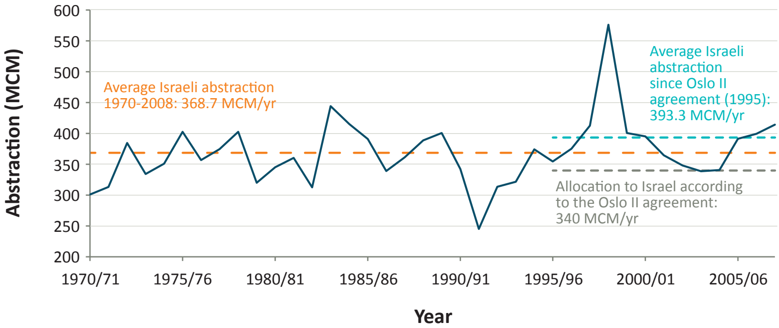
Israeli over-abstraction has led to continuously dropping water levels, which in turn increases salinity problems, particularly in the north of the aquifer basin.[67] Spring flow has also sharply diminished (see section on Discharge above). Israel has used the deep aquifer to compensate for reduced surface water availability from the Jordan River and Lake Tiberias, especially after successive dry winters.[68] Artificial recharge of the Western Aquifer in Israel was introduced early on, reaching 55 MCM/yr in the mid-1970s. After 1995, this figure dropped to 3 MCM/yr.[69]

No information is available on the sectoral allocation of Israeli abstractions in the basin. Most Israeli wells in the Western Aquifer Basin are connected to and feed centrally into Israel's National Water Carrier system,[70] which distributes water from different sources across the country for municipal and agricultural use. It is therefore difficult to trace where the water that is abstracted from the Western Aquifer Basin in Israel is used and for which purposes. Figures from 2010 show the following sectoral allocation of total available water sources in Israel: 57% was used in agriculture, 36% for domestic purposes and 7% in the industrial sector.[71]

Egypt

A few bore-holes have been drilled into the Cenomanian series of the Western Aquifer Basin in the Sinai Peninsula. However, no data is available on abstractions and use in Egypt.

Figure 6. Israeli abstractions from wells in the Western Aquifer Basin (1970-2008)



Source: Compiled by ESCWA-BGR based on PWA, 2012a, similar to Zeitoun et al., 2009.

Table 3. Groundwater use from wells and springs with differing salinity values in the Western Aquifer Basin (1994-2007)

SOURCE	SALINITY		GROUNDWATER USE (MCM)		
	Type	Cl (mg/L)	Israel	Palestine	Total
Well abstraction	Very fresh	0-99	132	19	151
	Fresh-brackish	100-399	225	7	232
	Brackish-saline	>400	7	—	7
	TOTAL		364	26	390
Spring flow	Very fresh	<50	0.07	1.95	2.02
	Fresh-brackish	50-399	1.42	..	1.42
	Brackish-saline	>400	37.16	..	37.16
	TOTAL		38.6	2	40.6

Source: Compiled by ESCWA-BGR based on HSI, 2008; PWA, 2010.

GROUNDWATER QUALITY ISSUES

As shown above, only 7 MCM/yr (<2%) of all abstractions from the Western Aquifer Basin are brackish-saline (Table 3). The sustained over-abstraction of the aquifer has increased the risk of salinization in the aquifer.[72] Spring outflow has declined drastically and groundwater levels have dropped substantially, which increases the risk of saline water being drawn into the northern and western part of the aquifer.

Pollution by untreated sewage is another threat in the outcrop and recharge areas, both in Israel[73] and the West Bank, where domestic wastewater from Palestinian towns and villages and Israeli settlements is released into the environment without treatment.[74] This raw sewage flows through wadi beds and seeps into the aquifer below. Over 2 million people live in outcrop and recharge areas in the eastern part of the aquifer basin in Israel and the West Bank. The lack of adequate wastewater treatment facilities and the absence of sound agricultural practices mean that nitrate levels locally exceed the World Health Organization guidelines. While few wells have been affected to date, nitrate levels reach 100-145 mg/L in the area of Tulkarm and Qalqiliya and 60-80 mg/L in the Hebron area.[75]

SUSTAINABILITY ISSUES

The water resources in the Western Aquifer Basin have come under increasing pressure since the 1950s, with abstraction rates rising close to and beyond sustainable levels. It is beyond the scope of this Inventory to provide a reliable and detailed water balance estimate, but a simple comparison of long-term annual averages may be indicative of the over-abstraction of groundwater that has taken place in the Western Aquifer Basin.[76]

In the period 1970-2006, average annual outflows reached 434 MCM, while average annual recharge from rain amounted to 385 MCM. The injection of 15 MCM/yr of water into the aquifer has made up for part of the overdraft, but leaves a 34 MCM deficit, which is equal to nearly 9% of natural recharge.[77]

There are pronounced variations in annual recharge and abstractions however, and while available data points to over-abstraction, the aquifer partially and/or locally recovers in particularly wet years, as reflected in spring and groundwater levels (Figure 3).[78] It is important to note that the data series mostly refer to locations in the western part of the basin, which is the confined and productive zone. The effects of over-abstraction may be felt quite differently in the eastern part of the West Bank, where groundwater is located at greater depth, is partly unconfined and undergoes more pronounced fluctuations. A more detailed study on sustainability in the Western Aquifer Basin, covering a longer time period and taking into account spatial and temporal variations as well as cyclical climate patterns, was not available during the preparation of this Inventory.

Finally, it is important to point out that the current use pattern in the aquifer basin and the respective abstractions by the two main riparians take place within the context of the ongoing Israeli-Palestinian conflict. Since the Israeli occupation of the West Bank in 1967, Palestinians have been unable to freely access, use or develop water resources in the West Bank, including the Western Aquifer Basin (Box 1). Thus in addition to unsustainable use of the aquifer, the issue of inequitable use of the Western Aquifer Basin also needs to be addressed.

BOX 1

Palestinian Access to Water in the West Bank

Since the start of the Israeli occupation of the West Bank in 1967, the Palestinian population living in the Western Aquifer Basin area has been unable to further develop or at times maintain its water infrastructure. A series of military orders issued by the Israeli authorities in the late 1960s requires Palestinians to obtain different permits and authorizations for all water-related projects including the drilling of new wells, increasing abstraction from existing wells or carrying out maintenance work on supply and distribution networks. The military orders remain in force today.[a]

As a result, Palestinians have not been authorized to drill a single well in the Western Aquifer Basin since 1967.[b] Networks, reservoirs and pumping stations no longer meet current needs and are often severely run down, while the Israeli army regularly destroys private household rainwater harvesting cisterns if they lack proper permits.[c]

The multiple restrictions mean that Palestinians in the West Bank suffer from chronic water scarcity. Overall, average actual domestic availability and consumption for Palestinians in the West Bank is estimated at about 50 L/cap./d, with many households consuming as little as 20 L/cap./d.[d] The extremely low levels of consumption place most West Bank communities well below accepted international standards.[e]

In addition, many areas in the relatively water-rich West Bank experience annual supply shortages and interruptions during the dry summer months, with inhabitants in parts of Hebron Governorate consuming 10-15 L/cap./d, and receiving water only every 40 days.[f] Many communities have to transport water by tanker from filling points to their village. However, the supply is unreliable, partly because of checkpoints and the Israeli regulation of the operation of filling points. It is also much more expensive than water from the municipal network. Water availability is further restricted by the fact that permit applications for well repair are regularly rejected (Figure 7).

Overall, Israeli restrictions on Palestinian water development projects mean that water supply from Palestinian-controlled wells and springs in the West Bank no longer meets the demands of the growing population. While average abstraction from wells has remained nearly constant at around 61-62 MCM/yr over the past 30 years, average discharge of Palestinian-controlled springs has dropped from an average of 64 MCM/yr in the period 1980-1999 to 40 MCM/yr in the period 1999-2010, a 40% decrease.[g] Overall, average groundwater availability for Palestinians in the West Bank dropped from 126 MCM/yr in 1980-1999 to 101 MCM/yr in 1999-2010, a 20% decrease. In combination with high population growth rates, the gradual reduction in access to water sources strains per capita water availability.[h] As a result, Palestinians in the West Bank are increasingly dependent on water from the Israeli water company Mekorot and purchased an estimated 55.5 MCM for domestic use in 2010.[i]

(a) Officially only in Area C, de facto in Areas A and B.
(b) ECHO, 2009.
(c) Amnesty International, 2009, p. 12.
(d) World Bank, 2009, p. 107.
(e) The World Health Organization (WHO) recommends a standard of 100 L/cap./d for optimal water supply.
(f) World Bank, 2009, p. 16.
(g) For the period 1980-1999, average annual values are available in PWA and UNuT, 2001b: abstraction from Palestinian wells in the West Bank was 62 MCM and discharge of Palestinian springs amounted to 64 MCM, giving a total annual water yield of 126 MCM. For the years 1999-2010, annual averages were calculated based on water statistics in the Palestinian Territory Annual Reports 2000-2012: abstraction from wells was 60.9 MCM and spring discharge amounted to 39.6 MCM, giving a total water yield of 100.5 MCM.
(h) According to official censuses, the Palestinian population in the West Bank grew from 1.87 million in 1997 to 2.35 million in 2007, a 26% increase.
(i) PWA, 2012b, p. 17.

Agreements, Cooperation & Outlook

AGREEMENTS

Riparian cooperation on water resources management in the Western Aquifer Basin is inextricably linked to the Israeli-Palestinian conflict. There is no agreement in place for the aquifer basin as a whole, which is shared between Egypt, Israel and Palestine.

However, Israel and the Palestine Liberation Organization (PLO) have signed two bilateral agreements regarding the use, protection and allocation of water resources in the Western Aquifer Basin. Officially referred to as the Declaration of Principles on Interim Self-Government Arrangements (DOP), the 1993 Oslo Accords between Israel and PLO were the result of extensive negotiations in the aftermath of the Madrid Conference.[79] The agreement dedicates a short paragraph to water, outlining principles of cooperation, joint management, water rights and equitable use.[80]

The Oslo Accords were followed in 1995 by the Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip or Oslo II, which addressed the topic of water and sewage in Article 40 of the Protocol on Civil Affairs

BOX 2

The Western Aquifer Basin in the Oslo II Agreement

A section of the Oslo II agreement emphasized the importance of safeguarding the existing use of the Western Aquifer Basin in Israel and the West Bank. Schedule 10, entitled "Data Concerning Aquifers", stipulated "existing extraction, utilization and estimated potential" and, where applicable, the "remaining quantities" for each of the Eastern, North-Eastern and Western Aquifers. The exact nature, origin and relationship of the numbers provided were not specified. Schedule 8 of the agreement stated that the
"...average annual quantities (...) shall constitute the basis and guidelines for the operations and decisions of the JWC".[a] The decisions included the licensing and drilling of wells, increases in extraction, etc.

For the Western Aquifer Basin, an annual average of 362 MCM/yr was given, based on estimates of Israeli and Palestinian "existing utilization" (or shares) of 340 MCM/yr and 22 MCM/yr, respectively, and there were no remaining quantities. The Joint Water Committee (see section on Cooperation) has not approved further development of the Western Aquifer Basin in the West Bank.

Using the data from this Inventory, existing use in the Western Aquifer Basin prior to 1995 was 426 MCM, 64.5 MCM or nearly 18% more than the figure stated in the Oslo II agreement.[b] Other sources published similar findings[c] and recent average annual recharge estimates for the basin are also higher (Table 2).

(a) Joint Water Committee.
(b) For the period from 1970-1995, Israeli average annual abstractions were 355.8 MCM and spring discharge amounted to 47.7 MCM (PWA, 2012a). Assuming a Palestinian abstraction of 23 MCM, the total pre-Oslo yield was 426.5 MCM.
(c) HSI, 2008, p. 221 calculated total outflows from the Western Aquifer Basin before 1995 at 404 MCM/yr, representing 42 MCM/yr or 12% more than the existing use according to Oslo II.

Timsah Spring, Israel, 2012. Source: Adi Faran.

(Annex III) and which was intended to cover the five-year period 1995-1999. The agreement recognized Palestinian water rights in the West Bank, which are to be negotiated in permanent status negotiations.[81] It also acknowledged the need to develop additional water resources[82] for various uses and the importance of safeguarding existing use (Box 2).

Other topics covered in Oslo II include the mutual avoidance of harm and protection of the aquifer from over-abstraction and pollution. Water purchases at full cost and mutual cooperation in studies and future projects, training, research and knowledge transfer, emergency situations and data exchange were also addressed in the agreement.[83] Furthermore, the Interim Agreement made provisions for the parties to establish a permanent Joint Water Committee (JWC) for the interim period. The body was charged with regulating water resources use in the West Bank.[84]

In Israel, the Oslo II agreement is widely seen as a turning point that shifted responsibility for the Palestinian water sector to the Palestinian Authority. Yet in practice it did not change the scope of Israeli control,[85] and all Palestinian abstractions and water resources development projects in the Western Aquifer Basin remain subject to Israeli approval.

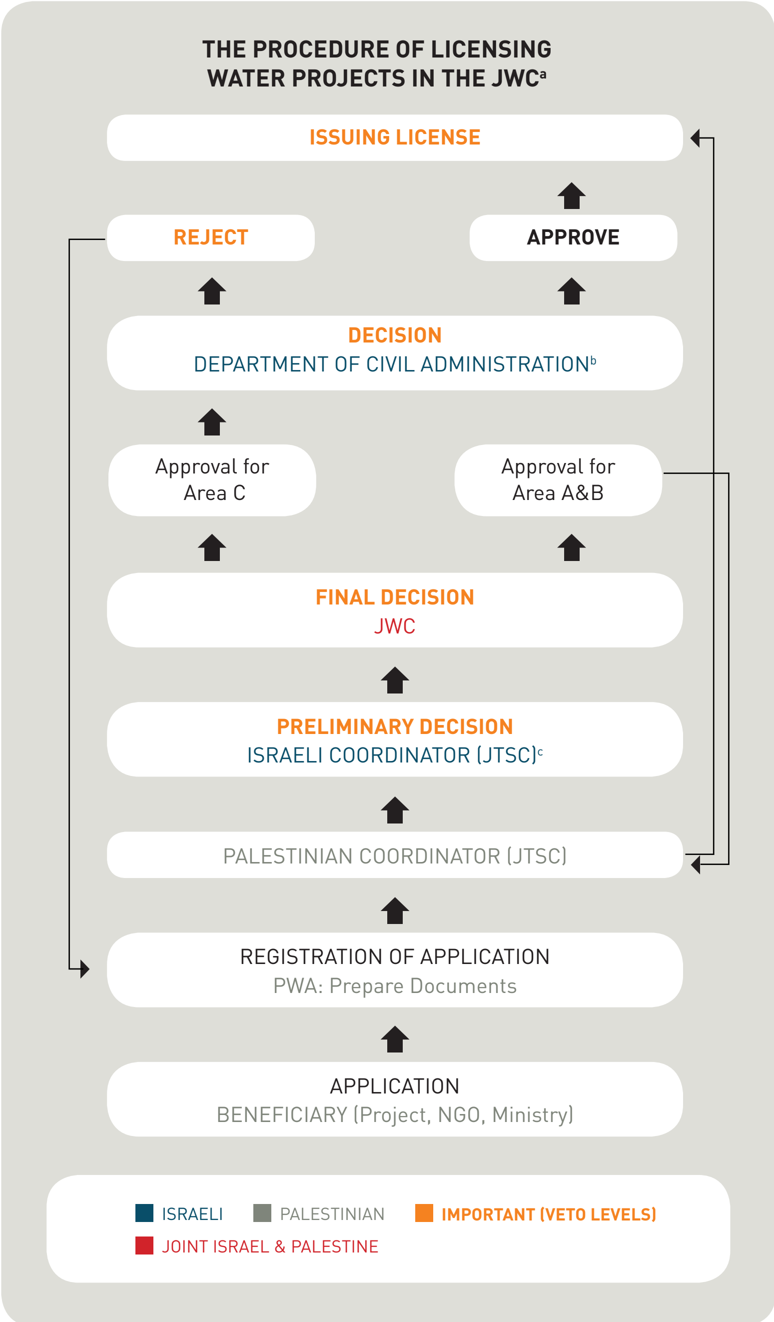
COOPERATION

In 1994, in accordance with the Interim Agreement, the parties established the Joint Water Committee (JWC), which comprises an equal number of Israeli and Palestinian representatives.[86] According to the agreement, JWC was established to discuss and decide upon the licensing and drilling of new wells, increasing extractions, development of water resources and systems, allocation of additional water, and changes in allocations. In addition, JWC was given the responsibility to establish and annually update a schedule of extraction quotas based on existing licences and permits.[87]

Although it was hailed as success story for Israeli-Palestinian cooperation, the committee's work has had limited impact.[88] Critics have described JWC as ineffective and as a means of "dressing up domination as cooperation".[89]

While both parties have full veto power over development activities in the section of the Western Aquifer Basin that is located in the West Bank, Israel's water resources development projects are concentrated in the aquifer's main production zone in the Coastal Plain in Israel, over which JWC has no mandate. As a result, Palestinians have no say over Israeli water development projects in the Western Aquifer Basin, while Israel regularly exercises

Figure 7. Licensing water projects through the Joint Water Committee



Source: Redrawn by ESCWA-BGR based on Attili, 2007.
(a) JWC: Joint Water Committee.
(b) The Department of Civil Administration (DCA) is part of the Israeli Army, established to manage local governance issues and security operations in the West Bank and Gaza. Following the Oslo process, the DCA retains this role in Area C (World Bank, 2009).
(c) JTSC: Joint Technical Sub-Committee.

its veto right to obstruct Palestinian plans to build new water infrastructure or carry out maintenance work on existing structures.[90]

The Israeli minister of the environment and the Palestinian minister of water conceded in December 2011[91] that JWC was ineffective. While they disagreed on how it could be remedied, they both called for the re-examination of the committee's structure and operational mechanism.[92]

The licensing of Palestinian water projects, including gaining approval for the drilling of a well, remains a long process that is often obstructed by complicated procedures as shown in Figure 7. After registration of the application needed for the licence, it is submitted to the Palestinian coordinator of the Joint Technical Sub-Committee (JTSC), and then to the Israeli coordinator who takes a preliminary decision before submitting it to JWC. The final decision is taken by JWC and at this stage both the Palestinian and Israeli side have a veto right. For projects approved in Area A and B[93], the project approval is re-submitted the Palestinian coordinator of JTSC, which is responsible for issuing the licence. Projects approved in Area C require a second approval by the civil administration which has the right to reject the application. More than half of the West Bank remains under the control of the Israeli military (Area C), further restricting Palestinian water infrastructure development.

OUTLOOK

Final status negotiations and agreements have stalled since 1996 and the five-year interim period outlined in the Oslo II agreement elapsed more than a decade ago. In addition, no high-level technical negotiations on water-related issues have taken place in the intervening period.[94]

From a Palestinian perspective, the inequitable distribution of water resources from the Western Aquifer Basin and the issue of water rights form the crux of the conflict. In addition, the JWC licensing procedure continues to form a key obstacle to the development of Palestinian infrastructure in the basin. Israel, on the other hand, maintains pressure on Palestinians to improve wastewater treatment in recharge areas in the West Bank, and also claims that in contradiction of the agreement, Palestinians have drilled several hundred unauthorized wells in the West Bank, and are not developing new water sources such as reuse of treated wastewater or desalination.[95]

Palestinian negotiators have developed a position based on the principles of international water law with the aim of ensuring long-term sustainable and equitable use of the basin's water resources.[96] However, given that the wider Israeli-Palestinian conflict remains unresolved, the inequitable distribution of water resources from the Western Aquifer Basin is unlikely to be addressed in the foreseeable future.

Potential future land swaps[97] and their relevance to recharge zones and/or productive abstraction zones in the aquifer basin are also likely to play an important role in future negotiations.[98]

Yarkon Spring (Ras al Ain Spring), Israel, 2009. Source: Ian W. Scott.

Notes

1. Referred to as the Yarkon Spring in Hebrew.
2. Referred to as the Taninim Spring in Hebrew.
3. PWA, 2012a estimates the Western Aquifer Basin area at 11,862 km^2 with Egyptian, Israeli and Palestinian basin shares of 19%, 62% and 19%, respectively. Abusaada, 2011 estimates the total area at 9,000 km^2, while Messerschmid, 2008, p. 25 indicates an area of 14,167 km^2. Generally, the depth of extension of the aquifer basin into the Sinai Peninsula is a matter of contention: Sheffer et al., 2010 quote an area of 13,000 km^2. Dafny et al., 2010, p. 2 just provide a lower limit of >10,500 km^2; Guttman and Zukeman, 1995 discuss different Israeli models such as Shakhnai, 1980 who extends the basin in the Sinai Peninsula "towards Jabal Hilal and further to El-Arish" while Guttman, 1988 is quoted to have "shifted the boundary from the Boqer Anticline to the structure of the Shalid El-Arish fields" (Guttman and Zukerman, 1995, p. 2) and the basin area is quoted as 10,481 km^2 (Guttman and Zukerman, 1995, p. 14). SUSMAQ reports mostly assume the maximum area size quoted here, but also a slightly smaller area of 14,148 km^2 (PWA and UNuT, 2003b, p. 6). Weinberger et al., 1994, p. 233 extend the area into the Sinai Peninsula as well, but without giving a value for area size.
4. Messerschmid, 2008, and Abusaada, 2011 respectively.
5. The population estimate for the area of the basin situated in Palestine is based on a 2007 population census by PCBS, 2009.
6. PCBS, 2011.
7. The population estimate for the area of the basin situated in Israel is based on a 2008 census by Central Bureau of Statistics in Israel, 2009.
8. Messerschmid, 2010, p. 6.
9. Abusaada, 2011; Messerschmid, 2010, PWA and UNuT, 2001a.
10. PWA and UNuT, 2005, p. 37. See also Avisar et al., 1997. On a local scale, however, many more subdivisions are noticeable (Dafny et al., 2010, p. 6; PWA and UNuT, 2003b; PWA and UNuT, 2003a).
11. The West Bank Anticlinorium is composed of the Anabta Anticline (in the north), the Ramallah Anticline (in the centre) and the Hebron Anticline (in the south). See Overview Map.
12. The Green Line was delineated in the 1949 Armistice Agreements after the 1948 Arab-Israeli war and refers to the demarcation line between Israel and neighbouring countries. The line was maintained as a boundary until 1967, when Israel occupied the Jordanian-controlled West Bank and East Jerusalem, as well as the Egyptian-held Gaza Strip and the Syrian Golan Heights. Today, the part of the Green Line that runs between Israel and the West Bank is used to differentiate between areas administered by the Israeli government and those under the authority of the Israeli military or the Palestinian National Authority.
13. PWA and UNuT, 2002, p. 178.
14. Outcrop calculations by Messerschmid, 2011. Other authors reach similar figures (PWA and UNuT, 2003a; Weinberger et al., 1994).
15. Abusaada, 2011, p. 82.
16. Such as Weinberger et al., 1994; PWA and UNuT, 2001a; Messerschmid, 2010; Abusaada, 2011.
17. PWA and UNuT, 2001a, p. 37.
18. PWA and UNuT, 2001a.
19. PWA and UNuT, 2001a, p. 113.
20. PWA and UNuT, 2005, p. 37. Also see Avisar et al., 1997.
21. Abusaada, 2011.
22. Messerschmid, 2003, p. 6. In the Israeli petroleum industry and the domain of geophysical stratigraphy, the aquitard is also referred to as Yakhini.
23. PWA and UNuT, 2002, p. 178.
24. Ibid., p. 166.
25. PWA and UNuT, 2002.
26. Confined conditions may also be observed locally in the eastern part of the basin, according to PWA, 2012a.
27. Zukerman, 1999 estimates a specific yield range of 1.8% to 8%, while recent model calibrations (Abusaada, 2011) suggest a range of 1% to 7.5%.
28. Guttman and Zukerman, 1995 found storativity to be within a range of 10^{-5} to 10^{-4}. Based on model calibrations, Abusaada, 2011 reports a different range of 10^{-6} to 10^{-5}.
29. Guttman and Zukerman, 1995, p. 19.
30. Dafny et al., 2010; Abusaada, 2011.
31. Ibid. The estimates are based on model calibrations and largely confirm earlier assessments. See Guttman and Zukerman, 1995; Zukerman, 1999 and PWA and UNuT, 2002.
32. Abusaada, 2011.
33. Weiss and Gvirtzman, 2007.
34. Dafny et al., 2010, p. 12, fig.10.
35. PWA, 2011.
36. Abusaada, 2011 reviewed a number of recharge methods and concluded that the method using water level, fluctuation and storage change provides the best estimate for yearly groundwater recharge. The method was used to calculate the long-term annual recharge of 385.2 MCM for the period 1970-2006.
37. Guttman and Zukerman, 1995, in PWA and UNuT, 2003a, p. 49.
38. Water discharging from the Timsah Springs is a mixture of freshwater and seawater. More than 3 MCM/yr of seawater is estimated to discharge from the springs (Paster et al., 2006).
39. Near Be'er Sheva intensive abstraction has altered natural flow lines (PWA and UNuT, 2001a, p. 39).
40. Messerschmid and Abu-Sadah, 2009. The areas of Baqa, Qalqiliya, Rantis and Tulkarm.
41. Messerschmid, 2010.
42. Ibid.
43. Weinberger and Rosenthal, 1994.
44. HSI, 2004 in Paster et al., 2006, p. 157. The values refer to pre-1950s spring discharge.
45. HSI, 2008, p. 221.
46. See also Abusaada, 2011, p. 136.
47. HSI, 2008, p. 211.
48. Paster et al., 2006, p. 164,166.
49. The following criteria are used to assess exploitability in this Inventory: drilling depth/depth to top of aquifer; groundwater level; and water quality/salinity. For more information on the approach, see 'Overview & Methodology: Groundwater' chapter. See Figure 4 for information on water quality. Depth to top of aquifer was determined using the Middle East Geological Map (MEG-Maps), sheet "Cretaceous": the deepest part of the basin reaches 800 m, while the area north of the Afiq Channel is less than 600 m deep. Groundwater level data was not available (see section on Flow regime).

50. Harpaz and Schwarz, 1967, p. 83.
51. According to PWA and UNuT, 2001c.
52. Most sources only provide well numbers for the entire West Bank. Many of the shallow, older production wells have low productivities or are no longer operational and due to Israeli restrictions, only a few have been rehabilitated. PWA and UNuT, 2001b states an average of 144 Palestinian production wells in the Western Aquifer Basin for the period 1980-1999. PWA, 2011 states 137 in 2009.
53. All figures from PWA and UNuT, 2001b. The total figure of 21.3 MCM includes an additional abstraction of around 1.1 MCM by the West Bank Water Department. Palestinian Statistics count domestic and industrial use under municipal supply.
54. According to Schedule 10 of the agreement, the Palestinian allocation of 22 MCM/yr in the Western Aquifer Basin includes 20 MCM/yr of unspecified origin and 2 MCM/yr from springs near Nablus.
55. This assumes that the Palestinian abstraction figures presented in Figure 5 include the spring abstractions near Nablus mentioned in the Oslo II agreement. Otherwise average Palestinian abstractions of 23.7 MCM/yr represent an excess of 3.7 MCM/yr or 18% of the Oslo II value of 20 MCM/yr.
56. According to PWA and UNuT, 2001b there were four Israeli wells with an average annual abstraction of 2.1 MCM in the period 1980-1999. PWA, 2011 stated that Israel absracted 2 MCM annually from five wells in the West Bank.
57. PWA, 2011.
58. PWA, 2012b, p. 22, 81.
59. Ibid., p. 17, 23. According to IWA, 2012 a slightly lower quantity of 52.6 MCM was provided to the Palestinian Authority in the West Bank in 2010; Palestinian water purchases from Mekorot have risen steadily from 27.9 MCM in 1995.
60. Zeitoun et al., 2009.
61. PWA, 2011. More than 500 Israeli wells according to PWA and UNuT, 2001c.
62. Data on Israeli abstractions was provided by PWA, 2012a and is based on records of the Hydrological Service of Israel for the various groundwater cells in the Western Aquifer Basin. Some doubt remains as to whether the data sets represent Israeli abstractions only as Palestinian sources affirm. The data sets may also include Palestinian abstractions in the West Bank, though it is not clear which level of abstraction is assumed. In the latter case, all Israeli values in the text need to be corrected (reduced) accordingly.
63. Assuming Palestinian abstractions of 23 MCM/yr; PWA, 2011 states the same percentage.
64. Data on spring discharge in Israel provided by PWA, 2012a.
65. The Israeli allocation of 340 MCM in Schedule 10 of the agreement does not specify the origin of utilized water (i.e. from wells or springs). It is, however, specified for the Eastern and North-Eastern Aquifer Basins which are also covered in Schedule 10.
66. All water use figures in this paragraph are from the data set provided by PWA, 2012a. See note 62 as well. If the data sets include Palestinian abstractions in the West Bank, Israel's average annual abstraction since 1995 would have to be corrected (reduced) accordingly.
67. HSI, 2008.
68. Zeitoun et al., 2009.
69. HSI, 2008, p. 221.
70. Israel's National Water Carrier is a 200 km conduit that conveys water from Lake Tiberias in the Jordan River Basin to urban centres along the Israeli coast and further south to the Negev (Al Naqab). See Chap. 6 for more information.
71. Central Bureau of Statistics in Israel, 2012. See Chap. 6 for more information on sectoral water use in Israel.
72. Zeitoun et al., 2009.
73. Particularly the sewage from Jerusalem. For 40 years, untreated sewage has flowed into the streambed of Nahal Soreq, located west of Jerusalem in the Western Aquifer Basin recharge area (Haaretz, 2008).
74. FoEME, 2004.
75. Ibid.
76. In the following approximation, average annual outflows are composed of Israeli and Palestinian abstractions and discharge of major springs. Israeli abstractions (366.5 MCM) and spring discharge (44.4 MCM) for the period from 1970-2006 were calculated from the data set provided by PWA, 2012a as presented in figures 3a and 6. Due to the lack of data prior to 1995, Palestinian abstractions were assumed to be 23 MCM/yr throughout, giving a total average outflow of 433.9 MCM/yr. Inflows considered in the approximation include recharge from rain, which amounted to 385.2 MCM/yr on average for the period 1970-2006 according to Abusaada, 2011. An additional average inflow of 14.5 MCM/yr for the same period stems from artificial groundwater injection to groundwater cells 210 and 211 as listed in the data set provided by PWA, 2012a. The remaining deficit amounts to 34.2 MCM.
77. The deficit is only a rough approximation and may even represent a serious over-estimation as Israeli abstractions in the PWA, 2012a data set may already include unspecified Palestinian abstractions in the West Bank (see note 62 above), in which case Palestinian abstractions would have been counted twice as outflows. If a correction of 23 MCM is made, the remaining overall deficit amounts to only 11 MCM/yr or 3% of recharge. Given the uncertainties and errors inherent in all of those estimates, a 3% gap may not be sufficient to conclude that there is over-abstraction from the aquifer.
78. PWA, 2012a provided water level data for groundwater cells 210, 211, 212, 214, 220 and 230 for the period 1964-2007. While a falling trend due to over-abstraction can be observed throughout much of the observation period, water levels rose after the wet winters of 1991/92 and 2002/03.
79. The Madrid Conference, which was held in Spain in October 1991, was led by the United States of America and jointly sponsored by the Soviet Union. Its aim was to initiate a negotiated peace process involving Israel and Palestinians, as well as other Arab countries, including Jordan, Lebanon and Syria. The conference comprised negotiations on various issues, including shared water resources and is considered the catalyst for the later Oslo Accords (Hiro, 2003; MERIP, 2012).
80. Israel and the PLO, 1993, Annex III, partly focuses on cooperation in the field of water and mentions the joint establishment of a water development programme as a basis for cooperation on water management, water rights and the equitable use of joint water resources.
81. Israel and the PLO, 1995, Annex III, Article 40.
82. The additional quantities of water described in the agreement are: 28.6 MCM/yr, to be made available immediately and 70-80 MCM/yr to be made available over the interim period until 1999/2000 (Israel and the PLO, 1995, Annex III, Article 40, Paragraph 7).

83. Israel and the PLO, 1995, Annex III, Article 40, Schedule 11.
84. Israel and the PLO, 1995, Annex III, Article 40, Schedule 8.
85. Zeitoun, 2008.
86. Israel and the PLO, 1995, Annex III, Article 40, Schedule 8.
87. Ibid.
88. Rouyer, 2000.
89. Selby, 2003. Similarly, Amnesty International, 2009 refered to JWC as a pretence of cooperation.
90. World Bank, 2009.
91. The discussion took place as part of the panel "Cross-Border Waters and Regional Sustainability" moderated by Gidon Bromberg, Israeli Director of Friends of the Earth Middle East. The Palestinians have suspended their participation in JWC since September 2011, arguing that the committee is unable to effectively address any water-related issue. A number of sub-committees are still active but the main decision- making body is not working.
92. According to Bromberg's conclusion of the meeting. See EMWIS, 2012.
93. Following the Oslo II agreement, the West Bank was split into three Areas A, B, and C, with different security and administrative arrangements and authorities (Israel and the PLO, 1995, Article 11) Area C is under full control of the Israeli military for both security and civilian affairs related to territory, including land administration and planning. See Chap. 6, Box 11 for more information.
94. In Camp David (July 2000), water negotiations did not reach the level of specific technical discussions on allocations. At Annapolis (2008/09), only exploratory negotiations in the domain of water were initiated.
95. IWA, 2012. However, most of the wells are located outside the Western Aquifer Basin.
96. Phillips et al., 2007, p. 250.
97. Rothem, 2008. In the context of future negotiations towards a final status agreement, Israel has proposed land swap deals to compensate Palestinian loss of land in the West Bank as a result of settlement activity.
98. Israel's separation barrier, constructed mainly in the West Bank, east of the 1967 Green Line, further diminishes Palestinian access to the productive zone of the aquifer. See Messerschmid and Abu-Sadah, 2009, p. 16.

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