EVALUATION OF WATER BUDGET FOR THE WESTERN AQUIFER BASIN IN THE WEST BANK, PALESTINE

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Abstract

This paper provides an update for the water budget for the Western Aquifer Basin (WAB) in the West Bank. The WAB is a shared inter-boundary groundwater basin between the West Bank (in Palestine) and Israel. Two thirds of the Palestinians in the West Bank (1.5 million capita) are living within the upstream portion of the WAB, where 75 percent of its geologic aquifer outcrops (recharge area) are located.

We used a spatial modeling approach to create 10-meter cell-size grids showing the spatial distribution of precipitation, crop evapotranspiration (ET_c), and runoff based on the 10-year (2001-2010) average available records of hydro-meteorological data. We used the general water budget equation to estimate rates and volumes of groundwater recharge by subtracting the spatial grids of ET_c, runoff, and an assumed change in storage from precipitation grid. Change in storage, which includes minor losses by initial abstraction, subsurface flow, depression storage, soil's field capacity, and errors of measurement and estimation, was assumed at a lumped sum value of 5 percent of total precipitation. GIS geo-processing tools were used to clip the spatial grids of various water budget components for the WAB's aquifer outcrops and for the West Bank portion of the WAB.

The 10-year average groundwater recharge for the entire WAB (both Israel and West Bank portions) was estimated at 350 MCM/yr (million cubic meters per year). The 10-year average volumes of precipitation, ET_c, runoff, and recharge were estimated for the West Bank portion of the WAB at 889 MCM/yr, 548 MCM/yr, 34 MCM/yr, and 263 MCM/yr, respectively, in addition to 44 MCM/yr of minor losses.

Although the WAB's West Bank portion receives an average recharge of 263 MCM/yr, the 2010 Palestinian water extraction was limited to a total of 29.45 MCM/yr for various water use purposes due to Israeli restrictions on Palestinian water use. The rest of WAB's recharge is being fully utilized by Israel.

Keywords: Water Budget, Watershed, Aquifer, GIS, Agriculture.

Disclaimer: *This work represents the opinion of the authors and does not represent the views of the Utah Geological Survey and/or the Brigham Young University.*

Introduction

This paper presents an updated average water budget for the Western Aquifer Basin (WAB) shared between the West Bank of Palestine and Israel based on the 10-year (2001-2010) average available records of hydro-meteorological data.

Figure 1 shows the location map of the study area which includes the WAB's boundary, the western surface watershed boundary, the geologic aquifer outcrops (recharge areas), and the political boundaries.

The WAB is a shared inter-boundary groundwater basin between the West Bank (in Palestine) and Israel (figure 1). The WAB has a vital importance to the Palestinians due to the fact that two thirds of the Palestinians in the West Bank (~1.5 million capita) are living within the upstream portion of the WAB, where 75 percent of its geologic aquifer outcrops (recharge area) are located.

The WAB emerges from the mountains of the West Bank in the east and extends westward crossing the Palestinian/Israeli border to finally drain its extra water into two historical natural spring outlets, the Auja and Tamaseeh springs, located entirely within the boundary of Israel. The WAB is normally referred to as the "Yarkon-Taninim Aquifer" in the Israeli literature after the Yarkon and Taninim springs. Figure 2 shows the location of wells and springs in the study area (PWA [Palestinian Water Authority], 2011 and HSI [Hydrological Services of Israel], 1999).

Although, the WAB has an area of more than 9000 square kilometers that extends further south to the Negev desert (HSI, 1999), only the northern and central parts of the WAB with an approximate area of 6236 square kilometers were included in this study (report cells 210, 211, 212, and 220 in figure 2). About 98 percent of the total extracted groundwater from the WAB occurs in those report cells, of which 90 percent is extracted from cells 210 and 211 (HSI, 1999; figure 2).

Geologically, the WAB consists of two main aquifers; the Upper Cenomanian-Turonian Aquifer (upper aquifer; 200-250 meters of average thickness) and the Lower Cenomanian Aquifer (lower aquifer; 300-400 meters of average thickness). Both aquifers are outcropped in the West Bank portion (zero thicknesses) of the WAB and are mainly composed of karstic permeable limestone and dolomite inter-bedded with argillaceous formations of low permeability to form an aquitard (intermediate layer; the upper 100-150 meters of the Lower Cenomanian) separating the upper aquifer from the lower aquifer (Sabbah, 2004). However, in some places both aquifers are hydraulically connected to form one combined aquifer known as the Cenomanian-Turonian Aquifer. The Upper Cenomanian-Turonian Aquifer is overlain by a series of aquitards with a total combined thickness of 500-600 meters with geologic ages ranging from the Senonian to the Eocene. Those aquitards confine the Upper Cenomanian-Turonian Aquifer and separates it from the Quaternary Coastal Aquifer on the Mediterranean Sea (HSI, 1999). In some places, the Coastal Aquifer is in direct hydraulic connection to the Upper Cenomanian-Turonian Aquifer (HSI, 1999).

The total groundwater recharge for the WAB's aquifers (as of year 1997) was estimated at 366 MCM/yr which was fully pumped out through 510 wells tapping its aquifers both in Israel and the West Bank (HSI, 1999 and PWA, 2011). A total of 341 MCM/yr was pumped from 372 Israeli wells and 25 MCM/yr (7% of total pumping and recharge) was pumped from 138 Palestinian wells in the West Bank. In addition, 57 MCM/yr were naturally discharged by springs, of which 55 MCM/yr was discharged from the Auja and Tamaseeh springs (Yarkon and Taninim springs) inside Israel and 2 MCM/yr was discharged from another 28 low scale springs in the West Bank (HSI, 1999 and PWA, 2011). Of the total 366 MCM/yr of the pumped water from the WAB's aquifers in 1997, only 30 MCM/yr (8 percent of total extraction) were pumped from the Lower Cenomanian Aquifer (lower aquifer) (HSI, 1999).

The 2010 total water used by the Palestinians from the West Bank portion of the WAB's aquifers is about 29.45 MCM/yr (PWA, 2011) for all purposes which constitute about 8 percent of the overall WAB's recharge and/or pumping. In addition to the Palestinian wells and springs, the Israeli Mekorot water company has 5 operating wells in the West Bank portion of the WAB which roughly pump a total water volume of 3 MCM/yr to be used by Israeli settlements in the West Bank (PWA, 2011). The rest of WAB's recharge is being fully utilized by Israel.

Literature review

Although recharge of WAB's aquifers is generally known in literature to range from 300 MCM/yr to 400 MCM/yr, very limited technical water studies, if any, have been conducted by the Palestinian researchers due to Israeli political restrictions from 1967 to 1993. However, there are some Israeli studies that report the overall water budget for the entire WAB. None of these studies identify the spatial distribution and flow rates of various water budget components nor classify them by governorates or aquifers of the WAB. Also those Israeli studies focus on the downstream portion of the WAB located entirely within Israel boundaries where most groundwater pumping occurs.

The Palestine Consultancy Group (PCG) and the Hebrew University of Jerusalem (HUJ) (1994a, 1994b) organized three joint Israeli-Palestinian workshops entitled "Joint Management of Shared Aquifers" and published their proceedings in three publication volumes (I, II, and III). The aim of the workshops was to propose the best way to maintain the sustainability of various shared Israeli-Palestinian aquifers, and ways to protect them from deterioration and over pumping. Those studies assumed a known water budget from Israeli sources and didn't include any technical study to evaluate spatial distribution of recharge along with other water budget components. In other words, none of these studies have estimated the WAB's water budget volumes for the upstream and downstream portions of the WAB in the West Bank and Israel, respectively.

Gvirtzman (1994) published a paper entitled "Groundwater Allocation in Judea and Samaria" in which he tried to analyze the rights of Palestinians and Israelis in the West Bank Aquifer System based on zones of natural recharge as well as discharge zones within a historical perspective rather than natural and hydrological aspects. His final conclusion was that the actual water needs of the communities that depend on shared waters take precedence over the natural properties of that shared basin. His paper also emphasized that the priority of water use should base on the past and existing water use.

Isaac and Sabbah (1998) submitted their research outcome report on "Water Resources and Irrigated Agriculture in the West Bank" which evaluated the available water resources and their use in various governorates, aquifers, and groundwater basins. ET_c and crop water requirements were also estimated in that study for various governorates of the West Bank.

The Hydrological Services of Israel (HSI, 1999) submitted a state water report (translated from Hebrew), which subdivided the WAB area into 6 report cells of hydrologic meaning based on sources of recharge. That report published the lump sum annual average values of groundwater recharge, well pumping, spring flow discharge, water level, and nitrate and chloride concentrations for each report cell for the period 1968-1997.

The Palestine Consultancy Group and Truman Institute of The Hebrew University (2000) submitted a research report entitled "Environmental Protection of the Shared Israeli-Palestinian Mountain Aquifer". That study reported sources of pollution and simple coarse-grid cells pollution transport model and suggested ways to protect the WAB's aquifers from human related activities.

Sabbah (2004) estimated the 10-year (1991-2000) average recharge for the West Bank portion of the WAB at 336 MCM/yr. That recharge volume was high due to the almost double precipitation/recharge occurred in 1991/1992 hydrologic year. Sabbah (2004) also estimated recharge for the entire WAB's area by using a 1-year (year 2000) steady state groundwater flow model at 366 MCM/yr.

This study provides an update for the WAB's water budget, based on the most recent available hydro-meteorological data for the 10-year (2001-2010) period (HSI, 2000-2010), and integrates the spatial distribution of the various water budget components for both the Israeli and the West Bank portions of the WAB. This study took into consideration the western surface watershed boundary, the WAB's boundary, the entire WAB's aquifer outcrops, the West Bank portion of the WAB's aquifer outcrops, and Israel portion of the WAB's aquifer outcrops.

Methodology of study

In this study, we used the spatial modeling approach and ArcGIS Spatial Analyst (ESRI, 2011) to estimate an updated water budget for the WAB for the 10-year period (2001-2010). The 10-year period is used to make sure that the time span includes at least one drought cycle and one wet cycle. Spatial modeling techniques emerged recently after major development in vector and raster GIS formats which enables the evaluation of the target parameters both spatially and temporally based on a user defined cell-size gridding for the entire study area. The spatial modeling approach used in this study took into consideration various parameters ranging from physical fixed data that does not change with time for the same area to dynamic data which changes with time. Fixed data used in this model includes elevation, geology, geographic boundaries, groundwater boundaries, watershed basin boundaries, and the WAB's aquifer boundaries (recharge areas). Dynamic data used in this model includes values of weather and meteorological parameters such as precipitation, evapotranspiration, and runoff. Figure 3 shows the location map of the western watershed boundaries and their drainage patterns along with 90 locations of the hydrometric stations, rain gages, climate, and weather stations used in this study to integrate the various water budget components (HSI, 1999; PWA, 2011; PCBS, 2012; IMS (Israel Meteorological Service), 2012; and PMD (Palestinian Meteorological Department, 2012). Figure 4 shows the flowchart of the spatial modeling approach used in this study.

We have digitized the boundaries of the WAB and the western surface watersheds from the 1999 hydrologic state report (translated from Hebrew) (HSI, 1999). We have also digitized the geologic outcrops of the principal aquifers, which represent the recharge areas of the WAB's aquifers, from the 200,000 scale geologic map of Israel (Geological Survey of Israel, 1998). Other boundaries and base maps were integrated from a previous study by Sabbah (2004). We have converted all previously mentioned maps into GIS format shape files and all areas of the WAB, surface watersheds, aquifer outcrops (recharge areas), and other base maps were estimated using the ESRI ArcGIS 10 Software and the embedded Spatial Analyst tool (ESRI, 2011). Based on that area estimate, 1582 square kilometers of the WAB's study area (25 percent) are located entirely within boundary of the West Bank. The estimated recharge area of the WAB is about 1703 square kilometers which constitutes about 29 percent of WAB's study area. About 1249 square kilometers of the overall WAB's recharge area is located entirely within West Bank boundary (75 percent of the overall WAB's recharge area).

The 10-year (2001-2010) average hydro-meteorological data were used to derive precipitation, ET_c, and runoff spatial grids, along with an assumed change in storage and minor losses by interpolation from measured and/or estimated values at station points. All these grids were then converted from raster GIS formats into vector GIS format contour maps for the western watershed boundary, the WAB's boundary, and finally for the WAB's recharge area.

We estimated the reference evapotranspiration (ET_0) from the 10-year average annual temperature, solar radiation, relative humidity, and wind speed using the Modified Penman-Montieth equation embedded in CropWat 8.0 for Windows Software released by the FAO (United Nations Food and Agriculture Organization) (FAO, 2010). Modified Penman-Montieth method also uses crop properties and estimated ET_0 to estimate the crop evapotranspiration using the following equation:

$ET_c = K_c * ET_0$ *Equation (1)*

where K_c is the crop coefficient which ranges in this study from 0.4 to 1.33 based on the average K_c values for the 20 most dominant crops (Isaac and Sabbah, 1998). Since this method is used for estimating water budget from natural precipitation, the estimated monthly ET_c was finally adjusted in such a way that it doesn't exceed precipitation in any single month ($ET_c <= P$), which means that the maximum value of ET equals the total monthly value of precipitation.

The surface water runoff was integrated from measurements at 31 Israeli hydrometric stations (HSI, 2010). The spatial distribution of runoff rate was estimated by first estimating the runoff coefficient for all sub-watersheds of the study area by dividing the measured stream flow volume for each sub-watershed by its estimated precipitation volume and those runoff coefficients were then multiplied by precipitation rates in each cell of the spatial model. That would result in spatial runoff grid which is a function of the precipitation grid.

From the authors' own experience, change in storage and minor losses which include, but not limited to, initial abstraction, subsurface flow, depression storage, soil's field capacity, and estimation and rounding errors were assumed at 5 percent of precipitation values at each cell of the entire grid.

Finally, the spatial groundwater recharge grid was estimated using the *Raster Calculator*, which is a single map algebra tool embedded in the ArcGIS 10 Spatial Analyst (ESRI, 2011), by subtracting the spatial grids of ET_C, runoff, and change in storage and minor losses from the precipitation grid (figure 4) based on the following water budget equation:

$P – ET_c – Ru – Re$ = Change in storage and minor losses *Equation (2)*

where,	P	Precipitation/Rainfall grid
	ET_c	Crop evapotranspiration grid
	Ru	Runoff grid (Rainfall Excess)
	Re	Recharge grid

Running the spatial modeling approach (figure 4) produced a spatial grid for each water budget component which shows the cell-by-cell distribution of estimated precipitation, ET_c, runoff, change in storage and minor losses, and groundwater recharge rates for the western surface watershed boundary, the entire WAB's boundary, and the WAB's recharge area boundary. We converted all estimated water budget grids into vector format GIS contours and we calculated areas between contours of the created contour maps using the ArcGIS Spatial Analyst (ESRI, 2011). Then we estimated total volumes and weighted average rates of all water budget components for the entire western surface watershed boundary, WAB's boundary, and the entire WAB's aquifer outcrops (recharge area), the West Bank portion of the WAB's aquifer outcrops, and Israel's portion of the WAB's aquifer outcrops using the following equation:

$$V = \sum_{i=0}^{n} Pi * Ai$$ *Equation (3)*

where,
V is the total volume
Pi is the average value of parameter for each region
Ai is the area between every two contours
i is the contour region number.
n is the total number of contour regions

Results and Discussion

Table 1 shows the various estimated components of water budget both for aquifer and non-aquifer outcrops of the WAB subdivided by the outcrop locations (Israel and the West Bank) of the WAB. Table 2 shows the various estimated components of water budget subdivided by the West Bank governorates and Israel.

The 10-year (2001-2010) average estimated precipitation, ET_C, runoff, and final adjusted recharge were estimated in the West Bank portion of the WAB's outcrops at 889 MCM/yr, 548 MCM/yr, 34 MCM/yr, 263 MCM/yr, respectively, in addition to about 44 MCM/yr in the form of minor losses and change in storage (table 1).

The 10-year (2001-2010) average estimated precipitation, ET_C, runoff, and final adjusted recharge were estimated in the Israeli portion of the WAB's outcrops at 254 MCM/yr, 142 MCM/yr, 13 MCM/yr, 87 MCM/yr, respectively, in addition to about 12 MCM/yr in the form of minor losses and change in storage (table 1).

The overall 10-year (2001-2010) average estimated precipitation, ET_C, runoff, and final adjusted recharge were estimated for the WAB's outcrops at 1143 MCM/yr, 690 MCM/yr, 47 MCM/yr, 350 MCM/yr, respectively, in addition to about 56 MCM/yr in the form of change in storage and minor losses (table 1).

The adjusted recharge is about 68 MCM/yr less than the overall recharge because only aquifer outcrops are considered to have recoverable recharge (table 1). This 68 MCM/yr is stored in aquitards which is mostly non-recoverable unless they leak into upper or lower aquifers.

The WAB's aquifer recharge areas and volumes were estimated for the upper and lower aquifers (table 1) as follows:

- The upper aquifer referred to as the Upper Cenomanian-Turonian Aquifer has a total outcropped recharge area of 1314 square kilometers (975 km^2 in the West Bank and 339 km^2 in Israel) and receives a 10-year (2001-2010) average groundwater recharge of 271 MCM/yr (208 MCM/yr in the West Bank and 63 MCM/yr in Israel).

- The lower aquifer referred to as the Lower Cenomanian Aquifer has a total outcropped recharge area of 389 square kilometers (274 km^2 in the West Bank and 115 km^2 in Israel) and receives a 10-year (2001-2010) average recharge of 79 MCM/yr (55 MCM/yr in the West Bank and 24 MCM/yr in Israel).

In summary, the WAB's Upper Cenomanian-Turonian Aquifer receives about 77 percent of total aquifer's recharge, while the Lower Cenomanian Aquifer receives 23 percent (table 1). As of 1997, a total of 366 MCM/yr was pumped from both the upper and lower WAB's aquifers, of which about 341 MCM/yr was pumped by Israel and 25 MCM/yr was pumped by the Palestinians of the West Bank (HSI, 1999). Only 5 percent (18 MCM/yr) of that total extracted water was pumped from 39 wells tapping the Lower Cenomanian Aquifer (HSI, 1999).

Comparison between recharge and pumping of the WAB's aquifers indicates that the Upper Cenomanian-Turonian Aquifer is fully- or even over-pumped. On the other hand, there is still a potential to develop 61 MCM/yr more water from the Lower Cenomanian Aquifer, of which 55 MCM/yr could be developed in the West Bank because none of the Palestinian wells are currently tapping the lower aquifer.

Although only 25 percent of the WAB's area is located entirely within the West Bank boundary, it receives 75 percent of the WAB's average annual recharge volume, while the rest are received in within the Israeli boundaries (table 1).
Figures 5 through 8 show the spatial distribution, lump sum volumes, and the weighted average rates of the 10-year average precipitation, ET_c, runoff, and recharge for the western surface watershed, the WAB's boundary, the WAB's overall recharge area, the Israeli portion of the WAB's aquifer outcrops, and the West Bank portions of the WAB's aquifer outcrops using the ArcGIS Geo-processing clip and grid calculator tools (ESRI, 2011).

Conclusions and recommendations

The 10-year (2001-2010) average precipitation, ET_c, runoff, and recharge were estimated for the West Bank portion of the WAB at 889 MCM/yr, 548 MCM/yr, 34 MCM/yr, and 263 MCM/yr, respectively, in addition to 44 MCM/yr of change in storage and minor losses (tables 1 and 2). The overall 10-year (2001-2010) average estimated precipitation, ET_C, runoff, and final adjusted recharge were estimated for the WAB's outcrops (in both Israel and the West Bank) at 1143 MCM/yr, 690 MCM/yr, 47 MCM/yr, 350 MCM/yr, respectively, in addition to about 56 MCM/yr in the form of minor losses and change in storage.

Although 75 percent of total annual natural recharge (263 MCM/yr out of 350 MCM/yr) occurs in the West Bank portion of the WAB's aquifer outcrops, Israel is utilizing 92 percent (341 MCM/yr as of 1997; HSI (1999)) of the WAB's aquifers yield while the other 8 percent (30 MCM/yr as of 2010; PWA [2010]) is being pumped and used by the Palestinian communities in the West Bank. In addition to pumping 341 MCM/yr from 367 wells inside Israel, Israel has 5 other wells run by Mekorot in the West Bank portion of the WAB which pump about 3 MCM/yr (PWA, 2011).

The Upper Cenomanian-Turonian Aquifer which has a total outcropped area of 1314 square kilometers receives a 10-year (2001-2010) average recharge of 271 MCM/yr, of which 208 MCM/yr (77 percent) is received within the entire West Bank boundary. The Lower Cenomanian Aquifer which has a total outcropped area of 389 square kilometers receives a 10-year (2001-2010) average recharge of 79 MCM/yr, of which 55 MCM/yr (70 percent) is received within the entire West Bank boundary.

Of the 510 Palestinian and Israeli wells pumping the WAB's aquifers, only 39 wells are pumping from the Lower Cenomanian Aquifer which pumps a total quantity of 18 MCM/yr (HSI, 1999). None of these lower aquifer wells is located in the West Bank portion of the WAB. Comparison between annual recharge and pumping of the WAB's aquifers indicates that the Upper Cenomanian-Turonian Aquifer is fully- or even over-pumped. On the other hand, there is still a potential to develop 61 MCM/yr more water from the Lower Cenomanian Aquifer, of which 55 MCM/yr could be developed in the West Bank as none of the Palestinian wells are tapping the lower aquifer.

There is an urgent need to install at least 20 hydrometric stations at the stream outlets right before they cross the West Bank/Israel border to measure stream flow generated within the West Bank boundary along with other meteorological data on an hourly or daily basis. All hydrometric stations used in this study are located inside Israel and none are located in the West Bank (figure 3).

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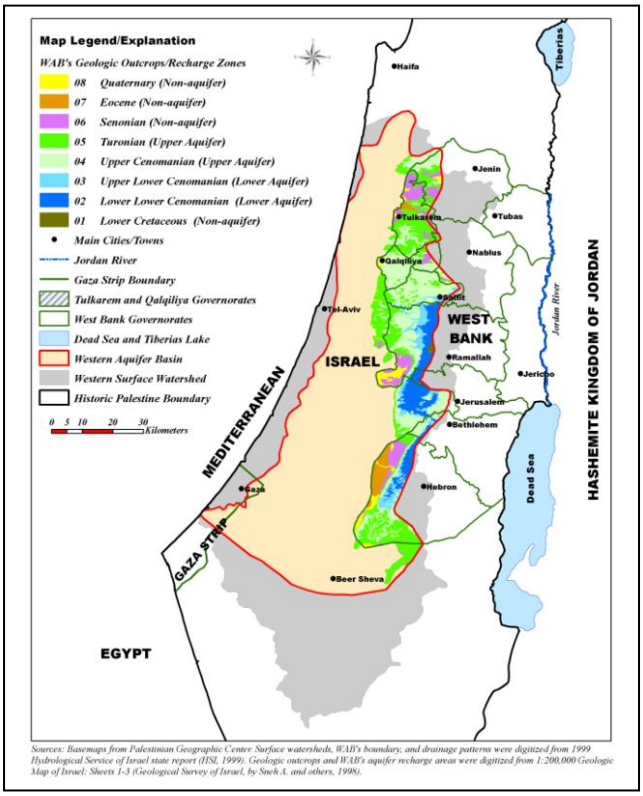

Figure 1. Location map of the study

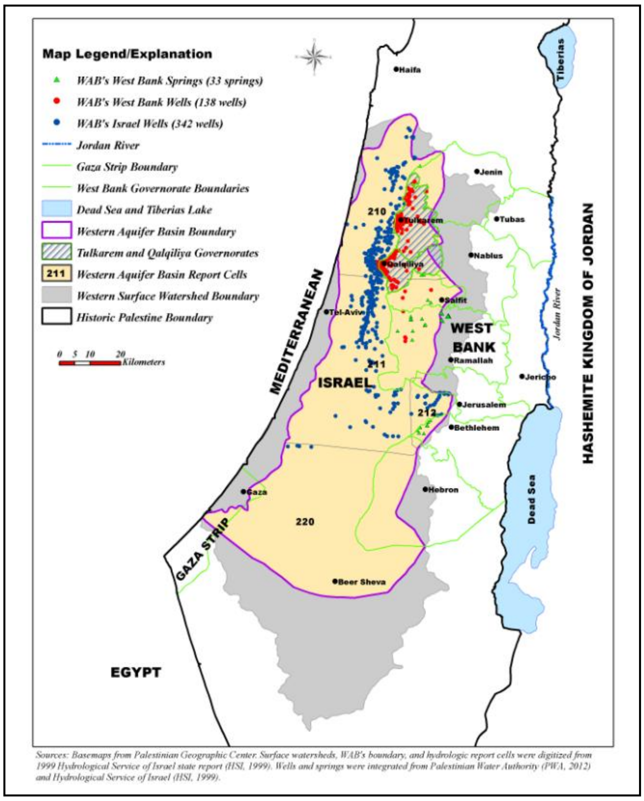

Figure 2. Location of wells and springs in the study

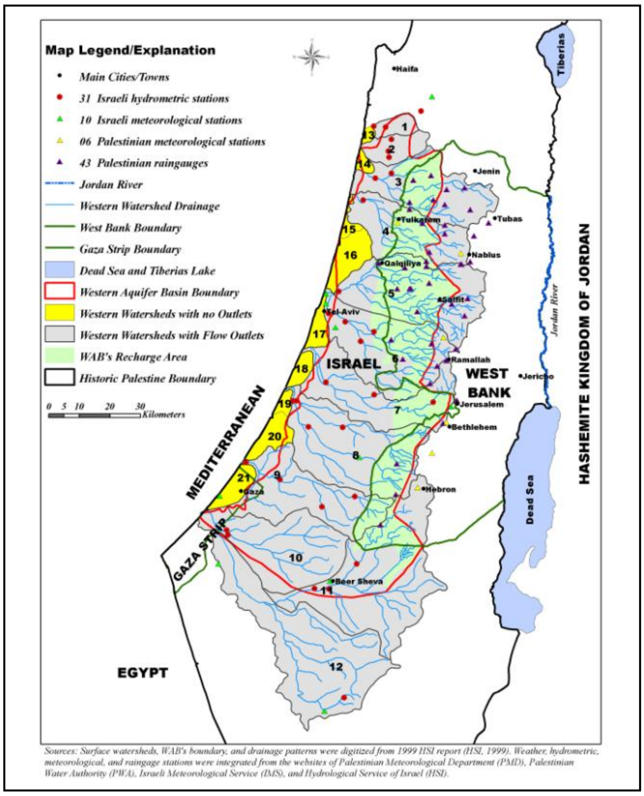

Figure 3. Western watersheds, drainage pattern, and

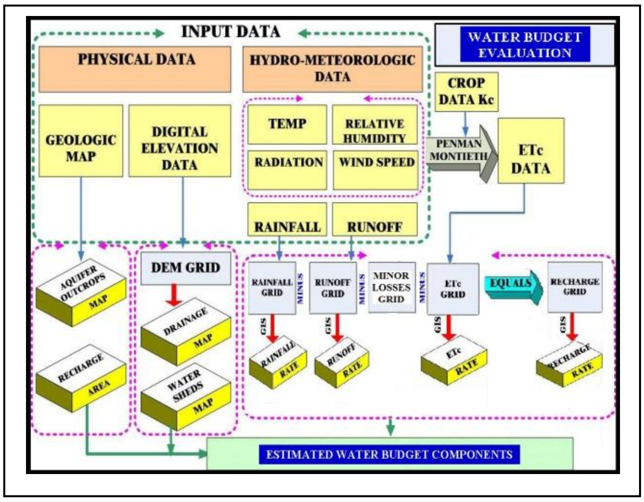

***Figure 4*.** Flowchart for Water Budget

Table 1. Estimated water budget parameters for the WAB's geologic outcrops.

Geologic outcrops in the Israeli portion of the WAB	Rainfall	ET_c	Runoff	Minor Losses	Total Recharge Volume	Aquifer/Non-aquifer outcrop	Total Recharge Area	Adjusted Recharge Area	Adjusted Recharge Volume
	units in million cubic meters per year (MCM/yr)						*km²*	*km²*	*MCM/yr*
Quaternary	2.41	1.35	0.18	0.12	0.81	Non-aquifer	*4.03*	0.00	0.00
Eocene	0.00	0.00	0.00	0.00	0.00	Non-aquifer	*0.00*	0.00	0.00
Senonian	3.54	2.17	0.20	0.18	1.03	Non-aquifer	*7.20*	0.00	0.00
Turonian	107.15	62.99	6.49	5.36	34.19	UC-T Aquifer	207.90	338.87	62.78
Upper Cenomanian	75.98	40.25	3.89	3.80	28.59		130.96		
U. Lower Cenomanian	17.76	9.64	0.64	0.89	6.72	LC Aquifer	31.40	115.14	24.59
L. Lower Cenomanian	47.57	25.63	1.71	2.38	17.87		83.74		
Lower Cretaceous	0.04	0.02	0.00	0.00	0.02	Non-aquifer	0.077	0.00	0.00
Sub-total	**254.45**	**142.05**	**13.11**	**12.72**	**89.23**		**465.31**	**454.00**	**87.37**

Geologic outcrops in the West Bank portion of the WAB	Rainfall	ET_c	Runoff	Minor Losses	Total Recharge Volume	Aquifer/ Non-aquifer outcrop	Total Recharge Area	Adjusted Recharge Area	Adjusted Recharge Volume
	units in million cubic meters per year (MCM/yr)						*km²*	*km²*	*MCM/yr*
Quaternary	37.59	31.65	3.86	1.88	12.71	Non-aquifer	*73.34*	0.00	0.00
Eocene	34.42	31.08	1.63	1.72	11.02	Non-aquifer	*72.20*	0.00	0.00
Senonian	104.30	92.87	6.22	5.21	40.18	Non-aquifer	*180.59*	0.00	0.00
Turonian	235.50	135.97	0.24	11.78	87.51	UC-T Aquifer	428.62	975.21	208.07
Upper Cenomanian	320.52	181.60	1.98	16.03	120.56		546.60		
U. Lower Cenomanian	69.73	27.44	14.56	3.49	24.79	LC Aquifer	126.76	273.79	54.93
L. Lower Cenomanian	82.13	43.74	4.14	4.11	30.14		147.03		
Lower Cretaceous	4.82	3.20	1.38	0.24	1.75	Non-aquifer	7.75	0.00	0.00
Sub-total	**889.00**	**547.54**	**34.00**	**44.45**	**328.65**		**1582.88**	**1249.00**	**263.00**

Geologic outcrops in the WAB's recharge areas	Rainfall	ET_c	Runoff	Minor Losses	Total Recharge Volume	Aquifer/Non-aquifer outcrop	Total Recharge Area	Adjusted Recharge Area	Adjusted Recharge Volume
	units in million cubic meters per year (MCM/yr)						*km²*	*km²*	*MCM/yr*
Quaternary	40.00	33.00	4.04	2.00	13.52	Non-aquifer	77.37	0.00	0.00
Eocene	34.42	31.08	1.63	1.72	11.02	Non-aquifer	72.20	0.00	0.00
Senonian	107.83	95.03	6.42	5.39	41.22	Non-aquifer	187.79	0.00	0.00
Turonian	342.65	198.95	6.73	17.13	121.70	UC-T Aquifer	636.52	1314.08	270.85
Upper Cenomanian	396.50	221.86	5.87	19.82	149.14		677.56		
U. Lower Cenomanian	87.49	37.08	15.20	4.37	31.51	LC Aquifer	158.16	388.92	79.52
L. Lower Cenomanian	129.69	69.36	5.85	6.48	48.01		230.76		
Lower Cretaceous	4.86	3.22	1.38	0.24	1.76	Non-aquifer	7.83	0.00	0.00
Grand total	**1143.44**	**689.54**	**47.11**	**57.18**	**418.23**		**2048.18**	**1703.00**	**350.37**

U.= Upper; L.= Lower; UC-T Aquifer= Upper Cenomanian-Turonial Aquifer; LC Aquifer= Lower Cenomanian Aquifer.

Table 2. Estimated water budget parameters for the WAB's Recharge area, subdivided by the West Bank governorates.

Region	WAB recharge area	Rainfall Volume	ET_c Volume	Runoff Volume	Minor Losses Volume	Adjusted WAB Recharge Volume
	km²	*Volume units are in million cubic meters per year (MCM/yr)*				
Israel	**454.00**	**254.45**	**142.00**	**13.11**	**12.72**	**87.37**
Jenin	78.46	66.45	36.87	3.24	3.32	19.42
Tulkarem	164.2	151.7	84.1	6.4	7.58	46.1
Qalqiliya	141.1	95.4	53.3	4.3	4.77	35.3
Salfit	189.29	119.15	66.29	5.31	5.96	46.41
Nablus	18.47	13.45	7.22	0.58	0.67	4.72
Ramallah	286.46	216.26	138.69	8.31	10.81	61.75
Jerusalem	14.29	8.53	5.17	0.25	0.43	3.14
Bethlehem	39.40	21.50	12.78	0.46	1.08	8.01
Hebron	317.28	196.60	143.13	5.15	9.83	38.22
WB Governorates	**1249.00**	**889.00**	**547.54**	**34.00**	**44.45**	**263.00**
Overall Total	**1703.00**	**1143.44**	**689.54**	**47.11**	**57.18**	**350.37**