University of Texas at Austin

GIS in Water Resources

Fall 2010

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Hydrology of the Jordan River Basin

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Introduction

The Jordan River Basin

The Jordan River is a transboundary river with a catchment area of 18,300 square kilometers.[1] The Jordan River and its tributaries, the Yarmouk, Banias, Hasbani, and Dan River are shared between more than two riparian nations, which makes the task of managing and distributing the water between the riparian countries complicated. The Jordan River today is a damaged river, with sub-standard water quality, and very little inflow into the Dead Sea. The region is under a great hydric stress, there is a need to promote cooperation between all riparian countries and achieve an equitable distribution of water, increase inflows into the Dead Sea and further support the peace process in the region.

The countries located in the Jordan River Basin are: Jordan, Lebanon, Syria, Palestine (West Bank) and Israel (see Figure-1)

Calculating the drainage area of each catchment within the Jordan River Basin and then the volume of water available for run off is an important task. This will show how much each country is contributing to the watershed. Yearly average precipitation data will be obtained in order to calculate the potential runoff in each country's subwatershed.

The Dead Sea

The Dead Sea is a closed sea with no outlet except by evaporation. In the past, the evaporation losses were replenished by an inflow of fresh water from the Jordan River and its tributaries. Today, the Jordan River only discharge about 200 Mm^3/year. Consequently, the water level has

[1] Amery, H., and Wolf, A. *Water in the Middle East*, University of Texas Press, 2000.

declined in recent years to 403 m below sea level, almost 10 m lower than its historical equilibrium level of 1930.[2]

Figure-1 Riparian countries of the Jordan River Basin

The decline in the Dead Sea level is due to a negative water balance of the lake, evaporation greatly exceeds the inflow. An attempt to calculate the water balance of the

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[2] Gavrieli, I. and Oren, A. 2004. The Dead Sea as a dying lake. In: Dying and Dead Seas; Climatic versus Anthropogenic causes. (eds. Nihoul J.C.J., Zavialo P. and Micklin P.P.) NATO ARW/ASI Series, Kluwer Publ., Dordrecht pp. 287-306.

Dead Sea will be performed using GIS and see if the result is the same as the literature which estimates the decrease in the level of the Sea to 1m/year.[3]

Watershed delineation

The first step was to download world basins shape files from Hydrosheds (http://hydrosheds.cr.usgs.gov/)

Figure-2 World's watersheds

Hydrosheds stands for Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales. It was developed by the Conservation Science Program of World Wildlife Fund (WWF). The data sources used to generate Hydrosheds are high resolution elevation data obtained from NASA's Shuttle Radar Topography Mission (SRTM). We can zoom in to the area

[3] Gavrieli, I., Lanski, N., Yaari-Gazit, N. and Oren, A. 2002. The Impact of the Proposed "Peace Conduit" on the Dead Sea: Evaluation of Current Knowledge on Dead Sea – Seawater Mixing. Geological Survey of Israel, Report GSI/23/2002, 42 pp.

of interest and download 3sec Void-filled DEM, 3sec drainage directions and 15 sec shape files of drainage basins.

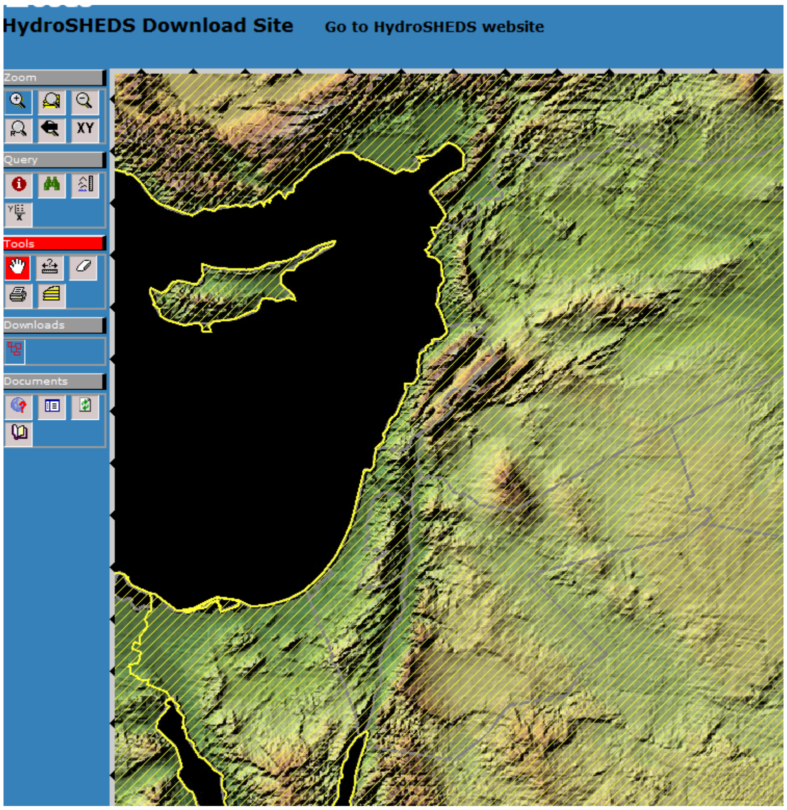

Figure-3 Hydrosheds DEM area

The 15 sec shape files will be useful only to extract the Dead Sea Basin, the resolution being 15 sec, the Jordan River Basin was not represented in the shape files. The next step was to dissolve the Dead Sea Basin using the technique used in exercise 2.[4] Because the drainage directions were already provided from Hydrosheds, we can start to delineate the watershed using the drainage directions instead of starting from the raw DEM. I kept encountering errors when I stated with the DEM because of the particular fact that the Jordan River is below sea level. Starting South of Lake Tiberias and extending to the Red Sea, the Jordan Valley altitude varies from 200 meters to 400 meters below sea level![5] (See Figure-4)

[4] http://www.ce.utexas.edu/prof/maidment/giswr2010/Ex2/Ex2_2010.htm

[5] Courcier, R.; Venot, J. P.; Molle, F. 2005. *Historical transformations of the lower Jordan river basin (in Jordan): Changes in water use and projections (1950-2025).*

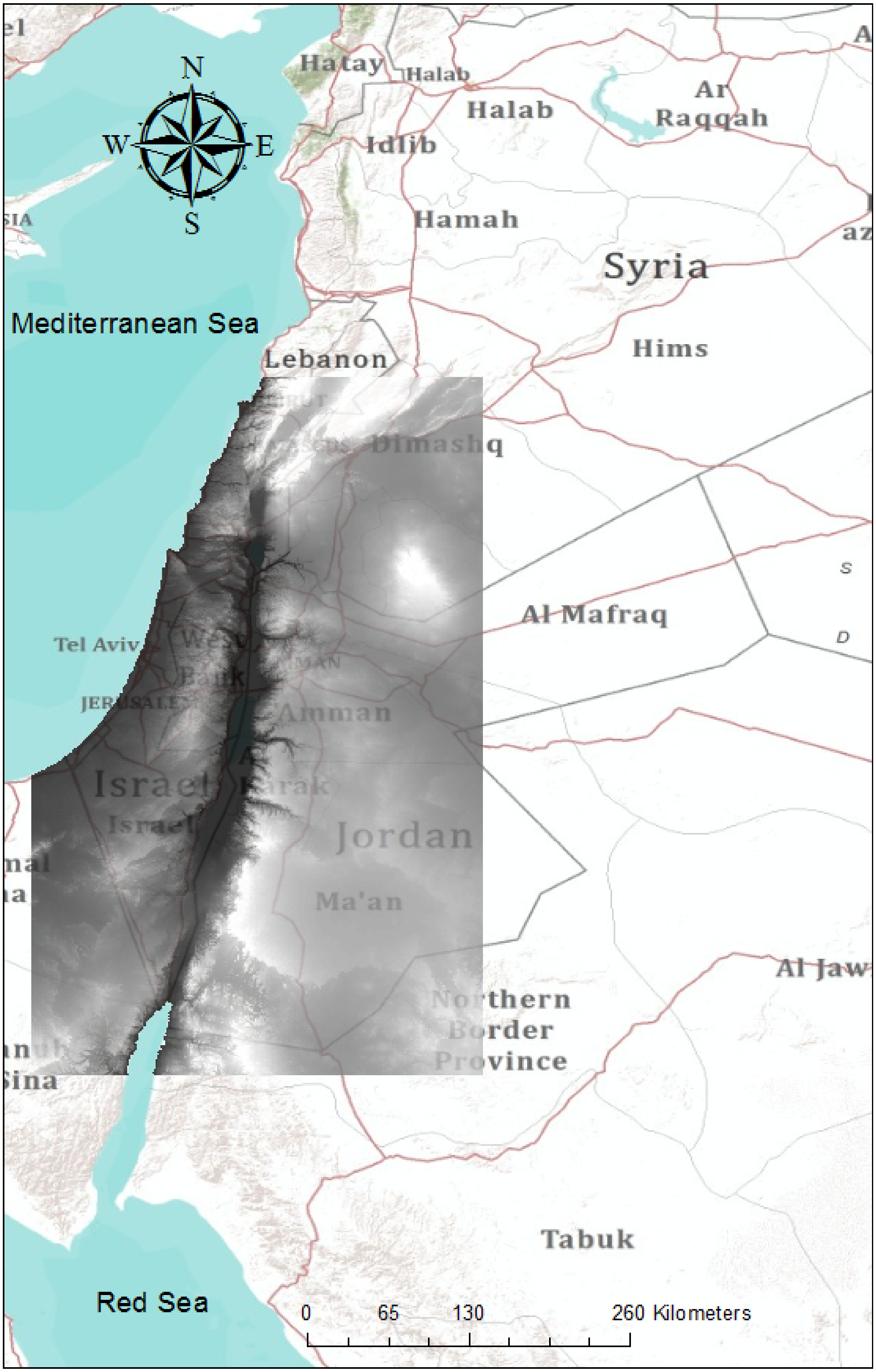
N
W
E
S
Hatay
Halab
Idlib
Hamah
Syria
Mediterranean Sea
Lebanon
Hims
Dimashq
Al Mafraq
Tel Aviv
Amman
Israel
Jordan
Ma'an
Northern
Border
Province
Al Jaw
Tabuk
Red Sea
0
65
130
260 Kilometers

Figure-4

The drainage directions (15sec DEM).

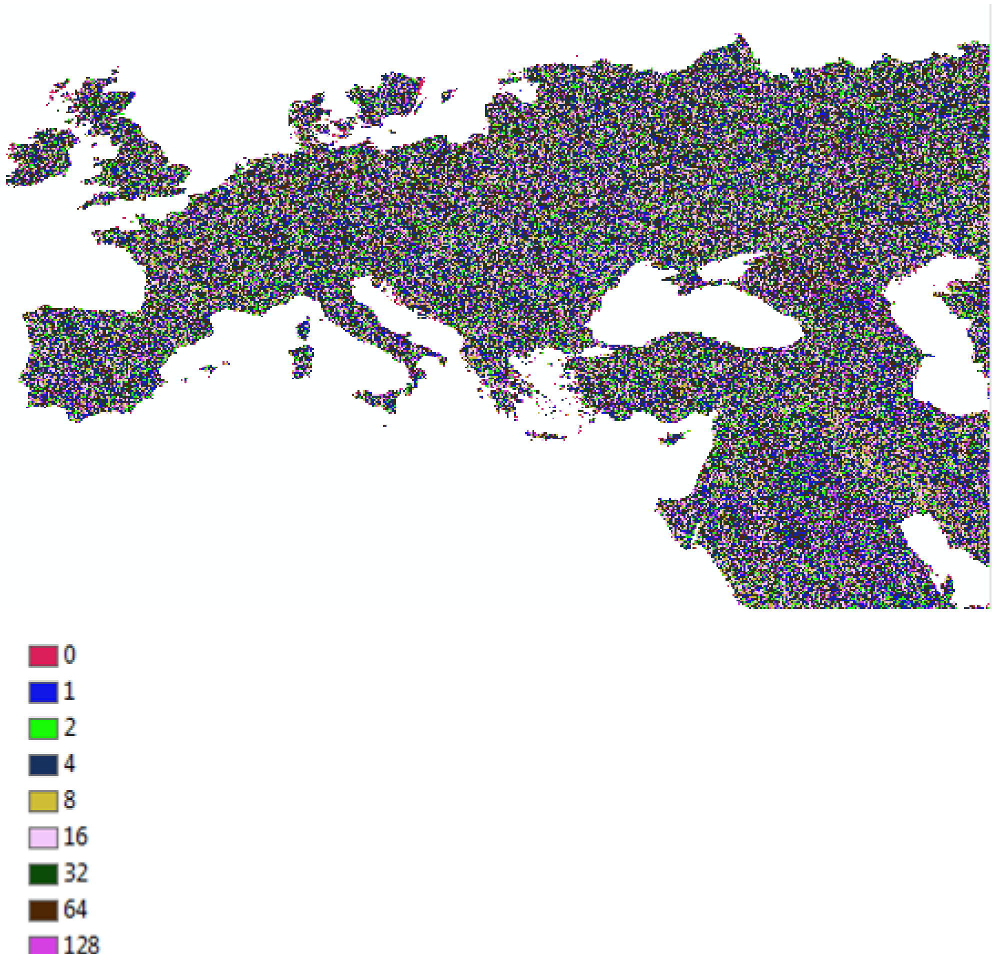

Figure-5 Drainage directions from Hydrosheds

This is why the shape file of the Dead Sea was useful:

1- Data management tools, under raster click raster processing then clip

2- Select the flow direction DEM as input raster, the output extent is the dead sea basin

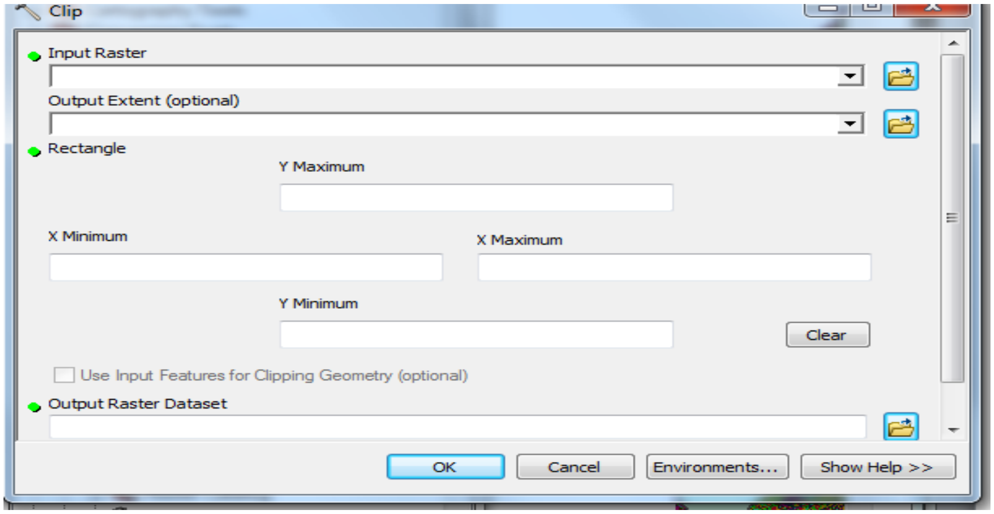

Figure-6

3- The result is a clipped flow direction DEM that extent a little bit beyond the dead Sea watershed

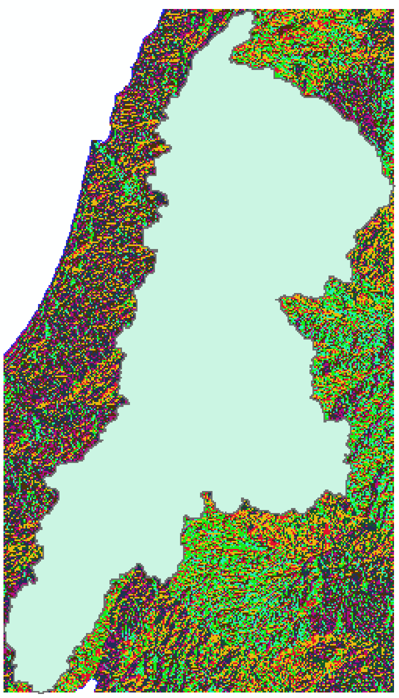

Figure-7 The Dead Sea basin overlaying the flow direction DEM.

The DEM was clipped in order to speed up the calculation time and projected to Jordan JTM. After following the steps of Exercise 4[6], we isolate the Watershed; the outlet of the Jordan River is the Dead Sea.

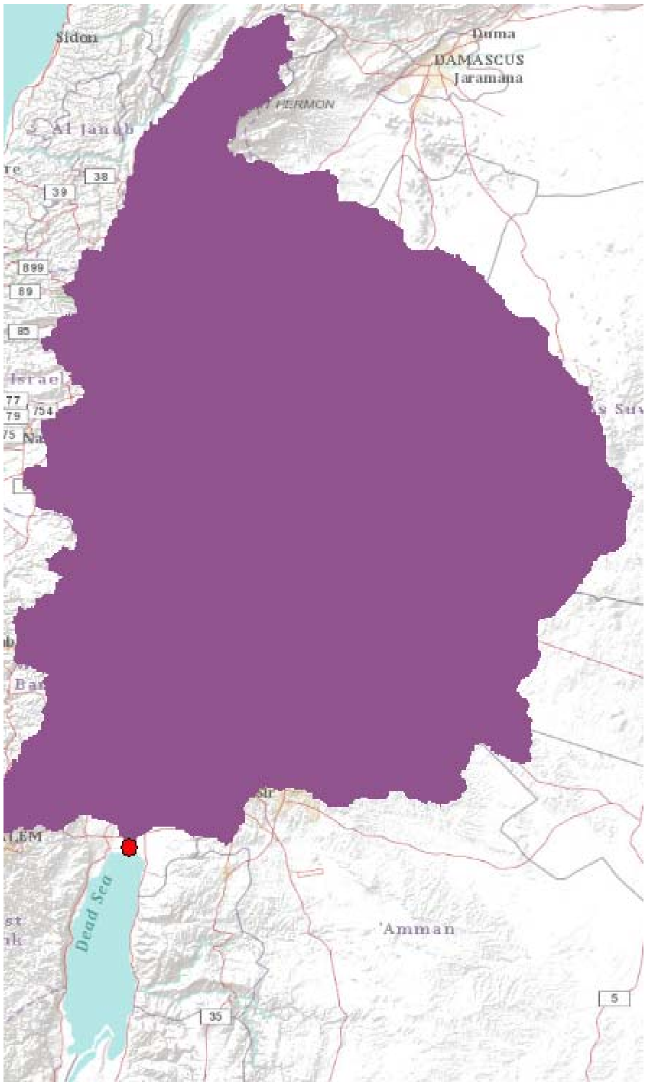

Figure-8 The Dead Sea as the outlet

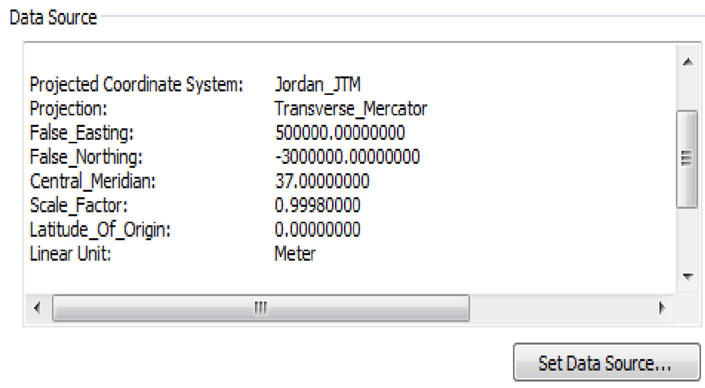

Figure-9 Projection used

6 http://www.ce.utexas.edu/prof/maidment/giswr2010/Ex4/Ex42010.htm

If we define the streams based on the same flow accumulation threshold as the exercise we get the following:

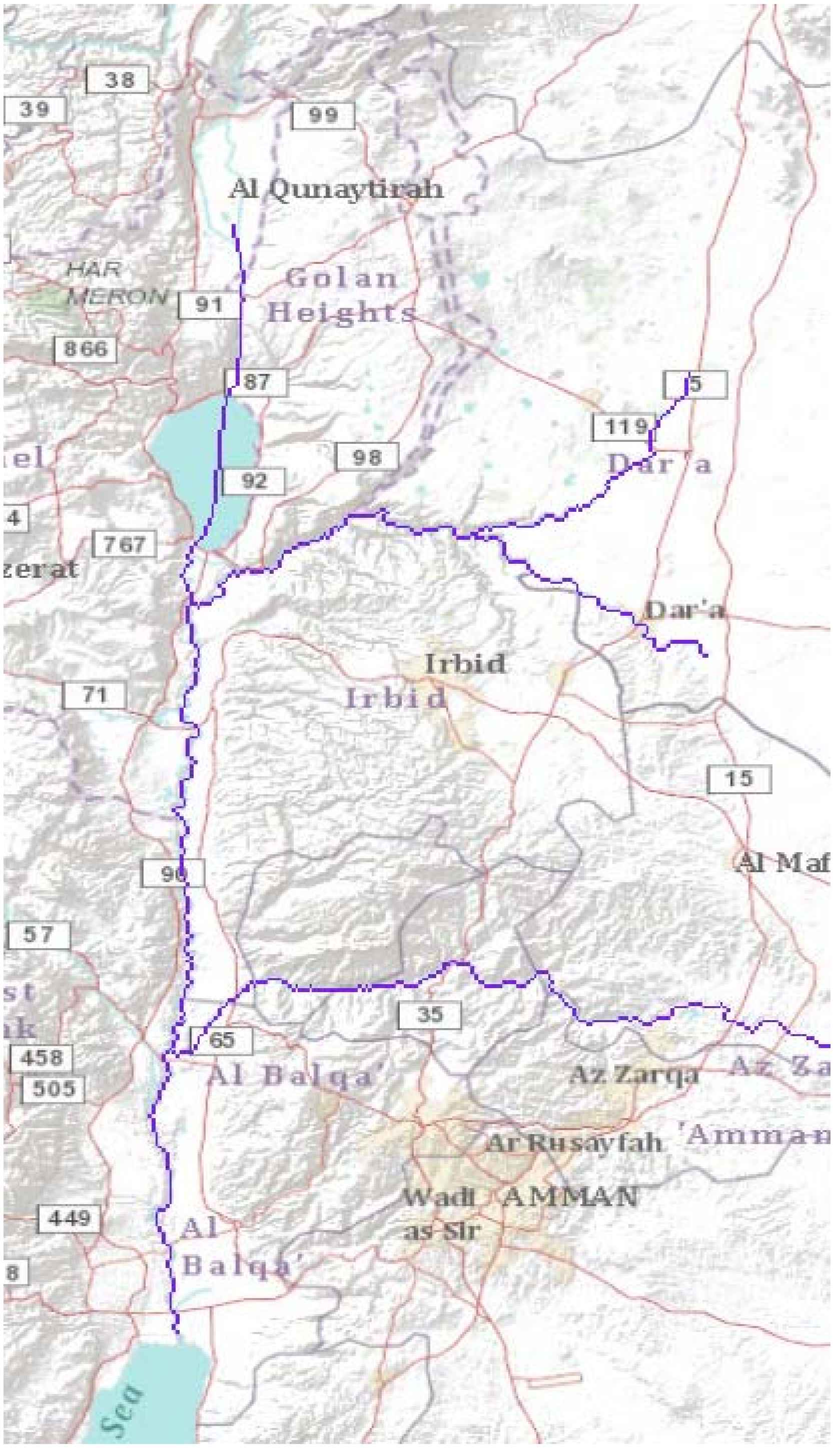

Figure-10 Streams using the raster calculation of Exercise 4

This is not good enough, some of the Jordan River tributaries are missing, including the Hasbani River that flow from Lebanon. The raster calculation should be modified:

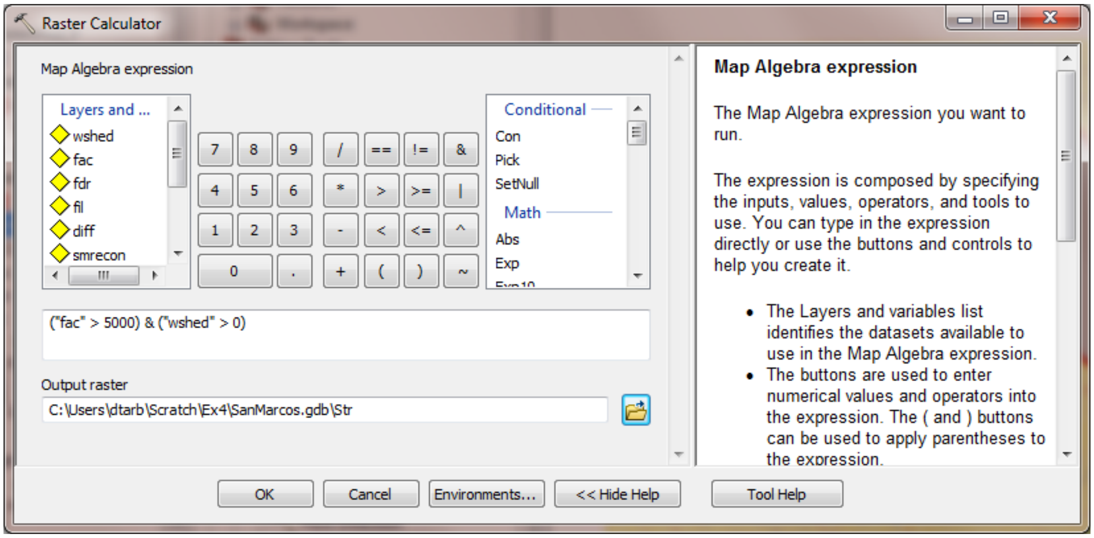

Figure-11 Raster formula

(fac>900)&(wshed>0) The result will be a raster representing the streams delineated in the Jordan River Basin. The Hasbani River is well defined.

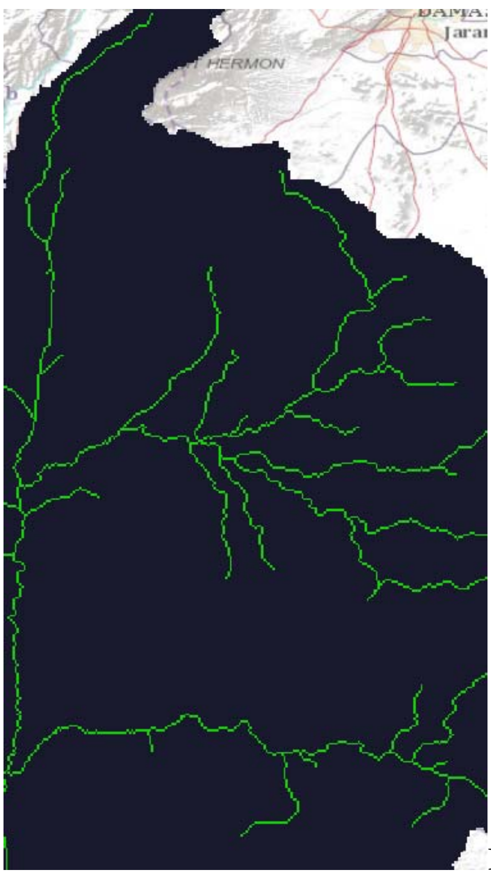

Figure-12 Result after modifying the equation

Now we have the Jordan River Basin!

Figure-13 The Jordan River Basin delineated on Arc Map 10

The online topographic basemap provided by Bing was very useful to verify that we got all the Streams in the watershed.

Using calculate areas, under spatial statistics we input the feature class to be the basin created (catchpoly) and the output are Areas.

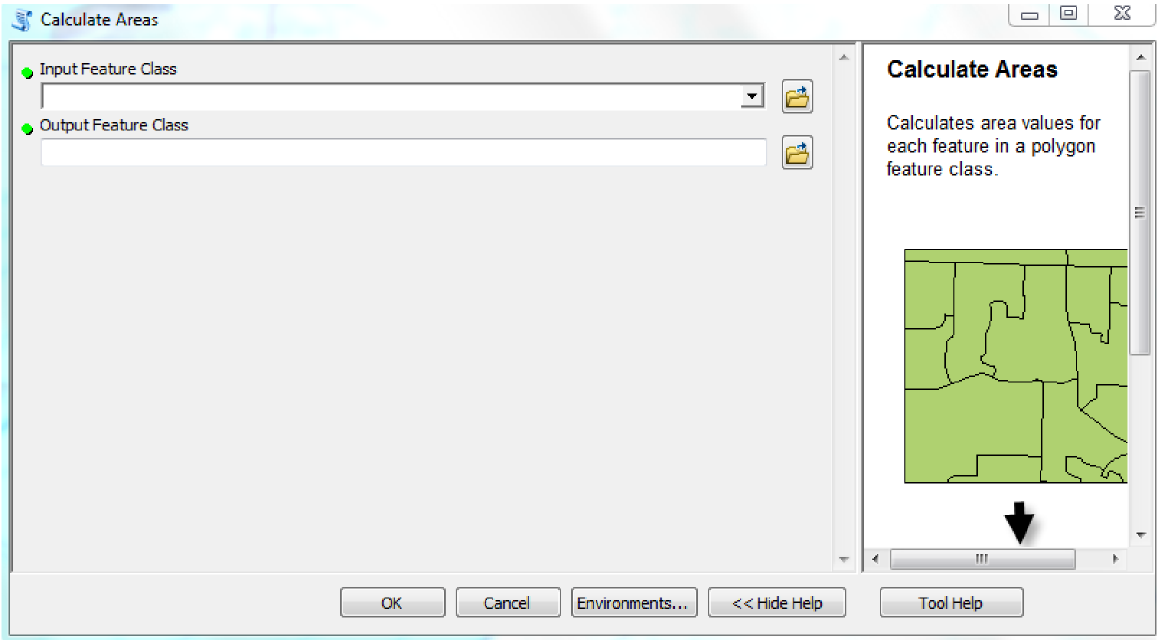

Figure-14

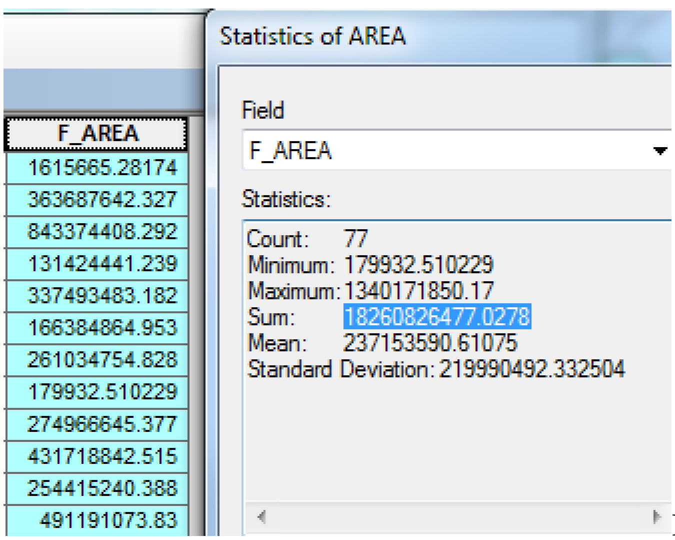

Figure-15 Total area of the Basin

The total are of the Jordan River Basin is about 18,260,826,477 m^2 which is about **18,261 km^2**

This is consistent with the literature that estimates the basin area to be about **18,300 km^2**[7]. The Basin was accurately delineated.

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[7] Courcier, R.; Venot, J. P.; Molle, F. 2005. *Historical transformations of the lower Jordan river basin (in Jordan): Changes in water use and projections (1950-2025).* Comprehensive Assessment Research Report 9.

Subwatersheds for each country

In order to isolate the catchments of each country, each 77 catchment was selected one by one. Then we export and save it as a new polygon feature, in order to separate each catchment and know exactly the ones that are part of two countries.

For example, the Hasbani River basin shown below.

The river source is in Lebanon. However, part of the catchment is in Lebanon and part of it in Israel. The Hasbani River from Lebanon is one of the main inflow to the Jordan River. The other is the Dan River of Israel.

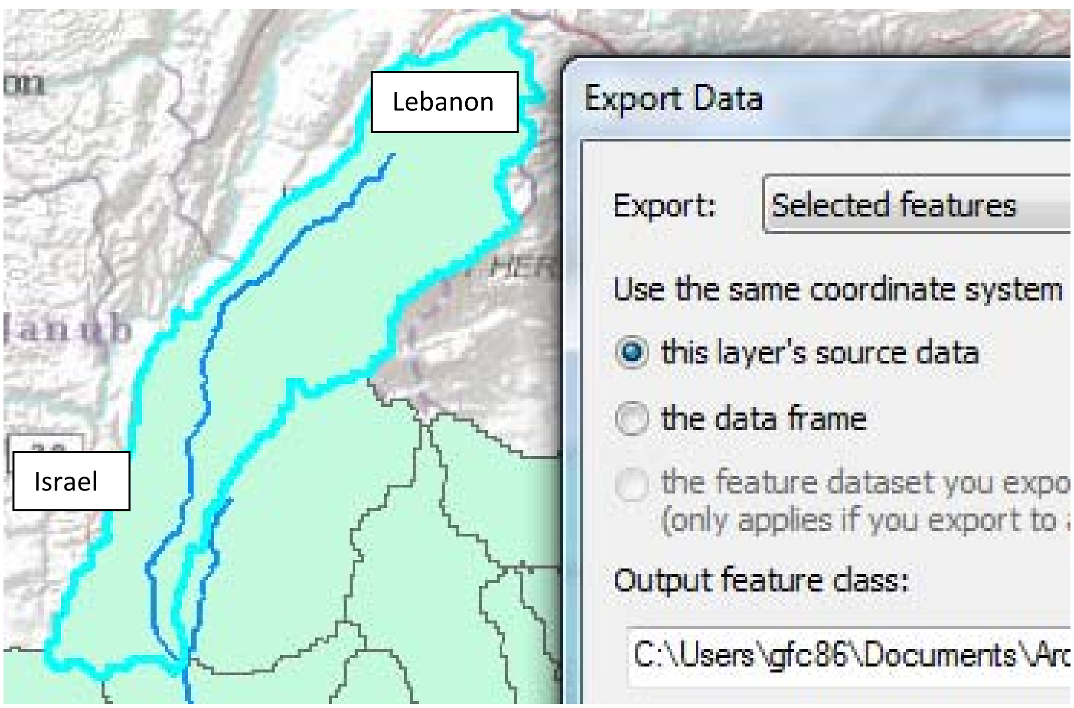
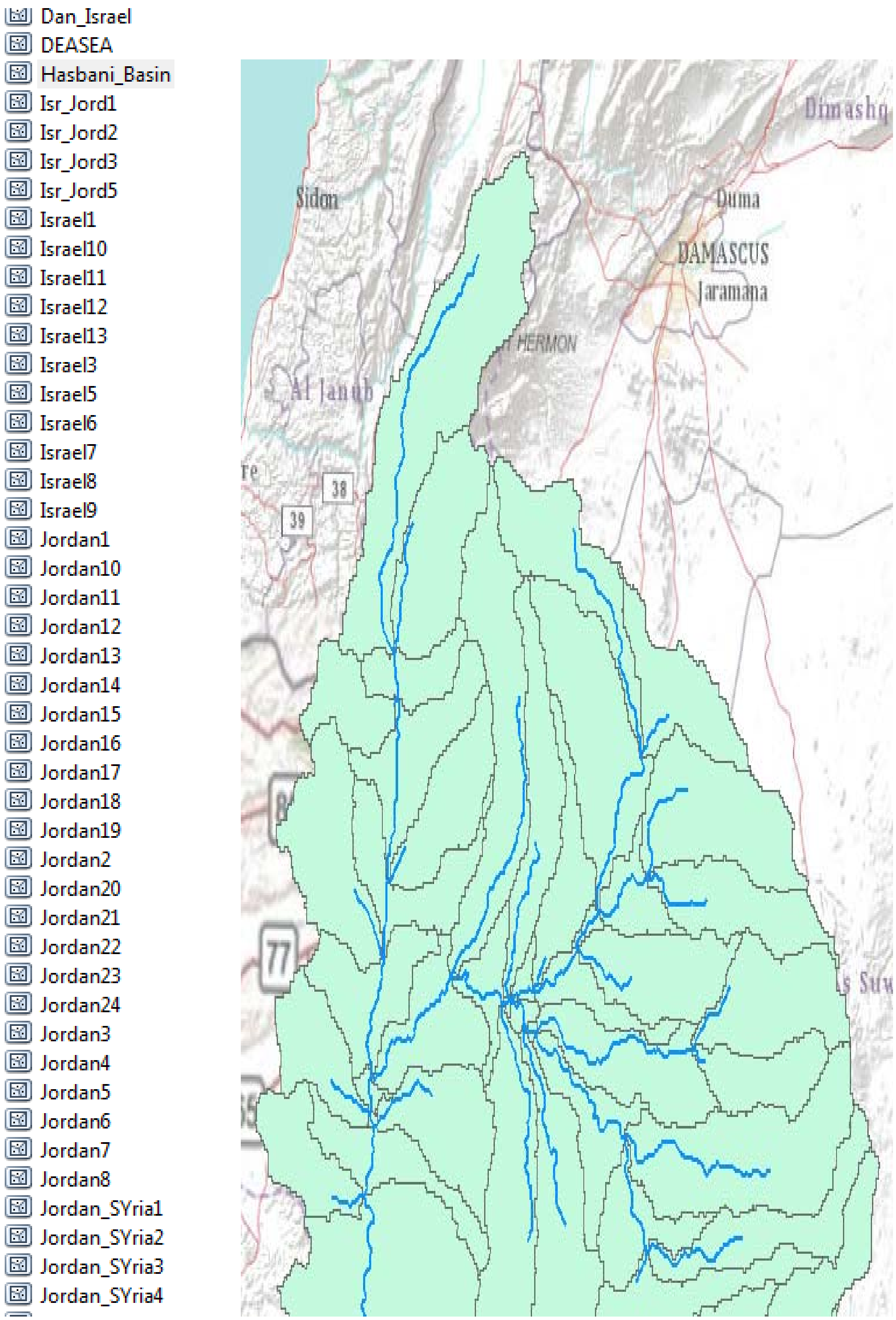


Figure-16 Hasbani River Basin


Dan_Israel
DEASEA
Hasbani_Basin
Isr_Jord1
Isr_Jord2
Isr_Jord3
Isr_Jord5
Israel1
Israel10
Israel11
Israel12
Israel13
Israel3
Israel5
Israel6
Israel7
Israel8
Israel9
Jordan1
Jordan10
Jordan11
Jordan12
Jordan13
Jordan14
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Jordan16
Jordan17
Jordan18
Jordan19
Jordan2
Jordan20
Jordan21
Jordan22
Jordan23
Jordan24
Jordan3
Jordan4
Jordan5
Jordan6
Jordan7
Jordan8
Jordan_SYria1
Jordan_SYria2
Jordan_SYria3
Jordan_SYria4
Dimashq
Sidon
Duma
DAMASCUS
Jaramana
HERMON
Al Janub
38
39
77

Figure-17

Identify the location of each catchment

Using the editor toolbar, each subbasin was identified and given the name of each country it belongs too. The Bing online basemap was used to determine in which country each subbasin was located.

We create a new field name countries.

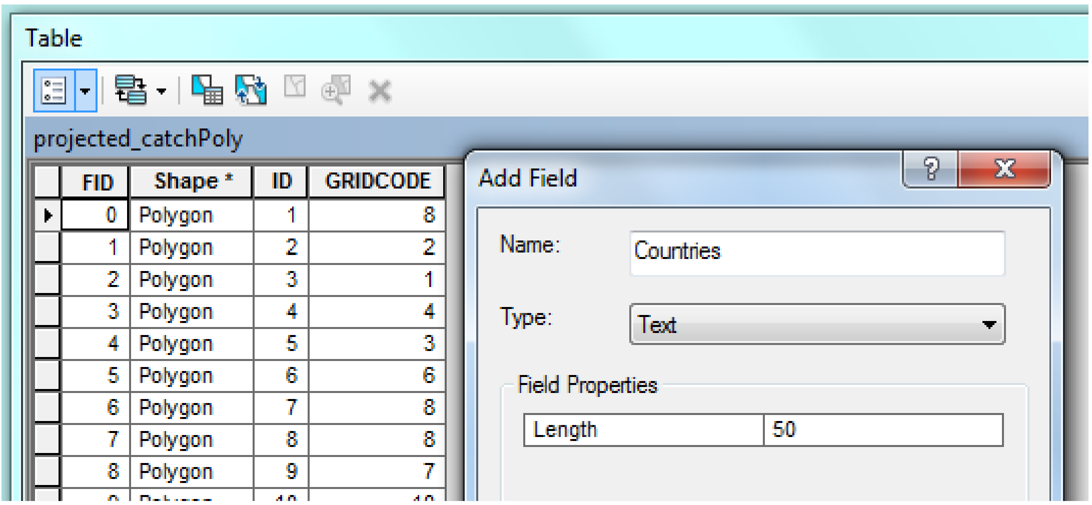

Figure-18

We start naming each 77 subbasin by the name of each country; if a catchment is located within 2 countries we give it the name of both countries. (We used the same name as the features previously shown on figure 17).

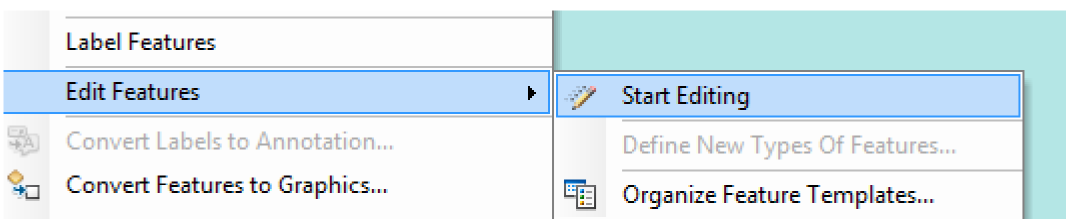

Figure-19

0	Syria3	20	20	323435
0	Jodan/Syriasmalll	21	21	208
0	Syria5	22	22	26446
0	Jordan/Syria7	23	23	4011
0	Syria8	24	24	331857
0	Jordan/Syria2(same as 6)	25	25	21666
0	Syria14	26	26	5418
0	Syria6	27	27	128928
0	Syria16	28	28	376644
0	Israel6	29	29	286372
0	Jordan/Syria1	30	30	113076
0	Israel/Jordan5	31	31	273635
0	Syria15small	32	32	195
0	Israel/Jordan1	33	33	23879
0	Jordansmall1	34	34	195
0	Syria17	35	35	212638
0	Syria7	36	36	348536
0	Israel1	37	37	235210
0	Israel/Jordan2	38	38	3406
0	Syria15	39	39	655960

(0 out of 77 Selected)

Figure-20

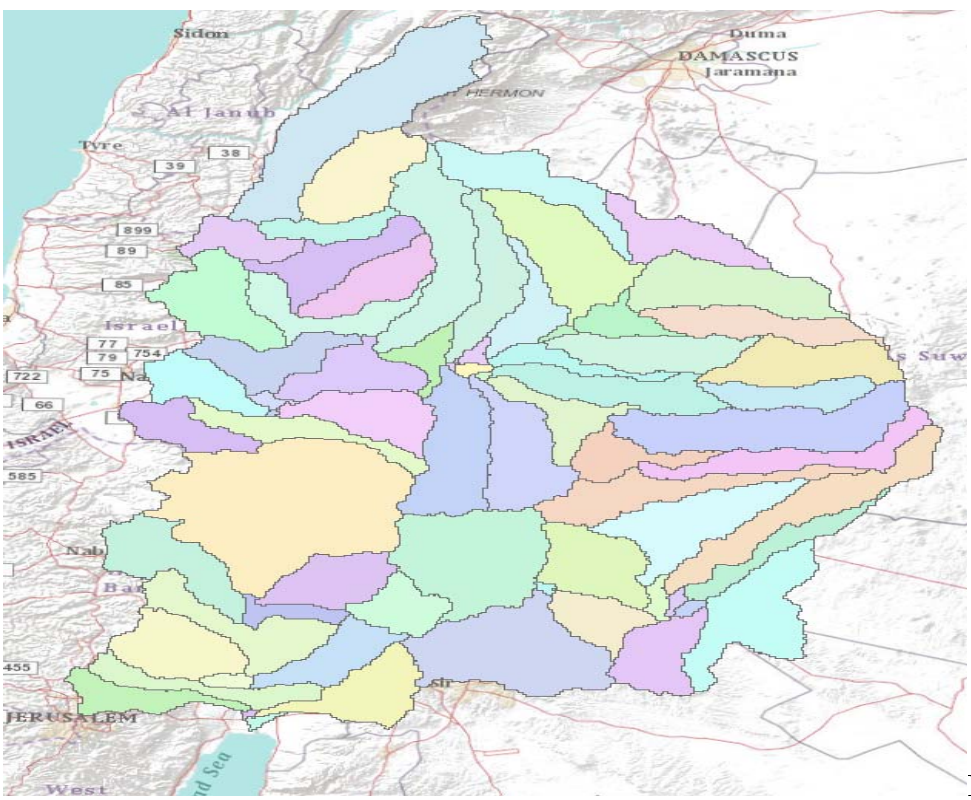

Figure-21Catchments

Precipitation Data

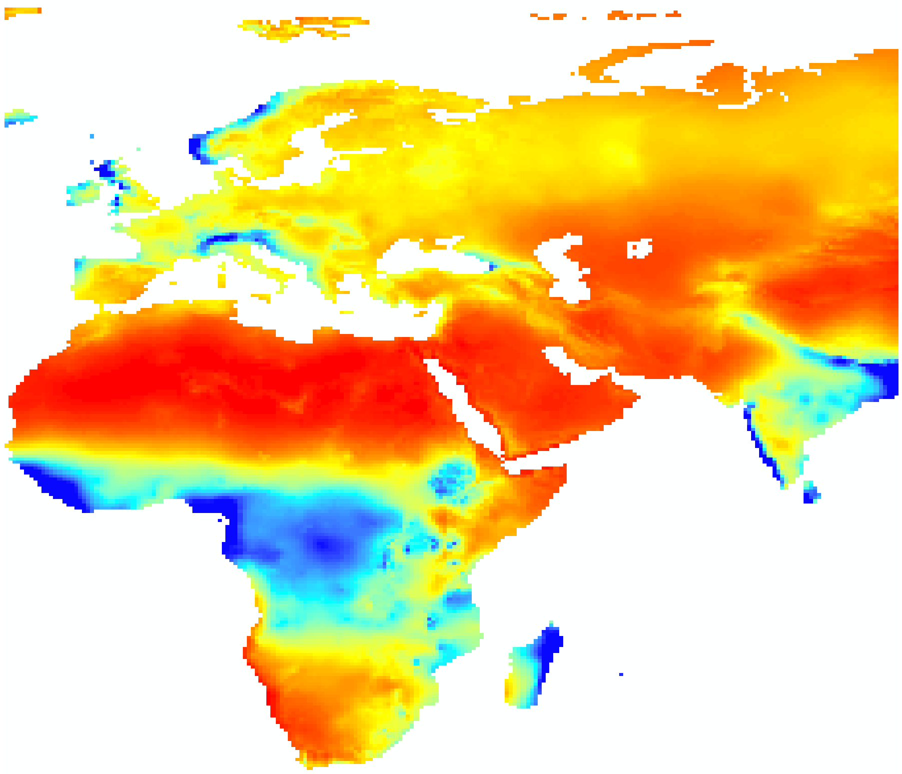

Figure-22 Precipitation in the World

Precipitation data was obtained from the Water Systems Analysis Group, University of New Hampshire.[8] The data was downloaded from GIS online as a raster.[9] The raster represents long term (1950-2000) average annual precipitation for the globe (mm/yr) on a 0.5 X 0.5 global grid.

[8] Fekete, B. M., C. J. Vorosmarty, W. Grabs. 2002. High-resolution fields of global runoff combining observed river discharge and simulated water balances, Global Biogeochemical Cycles, 16 (3): 15-1 to 15-10.

[9] http://app.databasin.org/app/pages/datasetPage.jsp?id=a5915100b8ac47db8dcee9839e838a2c

The raster is projected and clipped

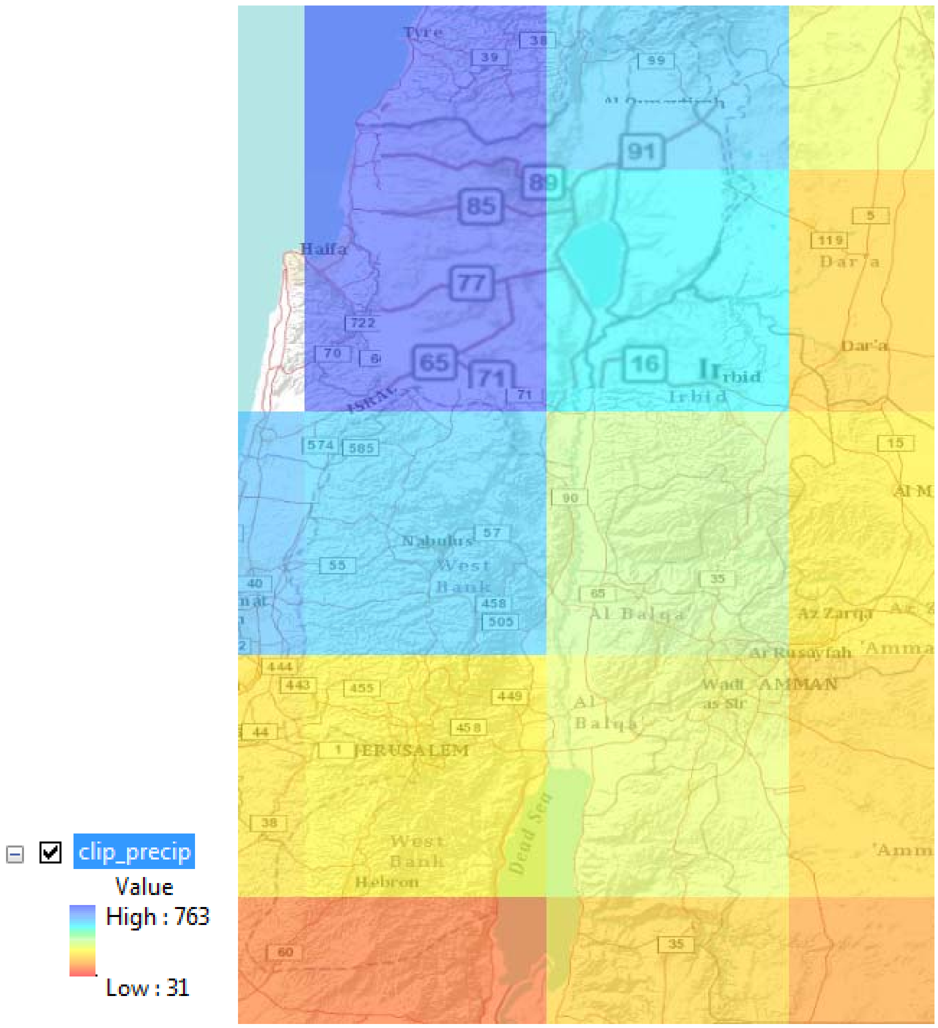

Figure-23 Zoom in of the precipitation raster

Resample under raster processing

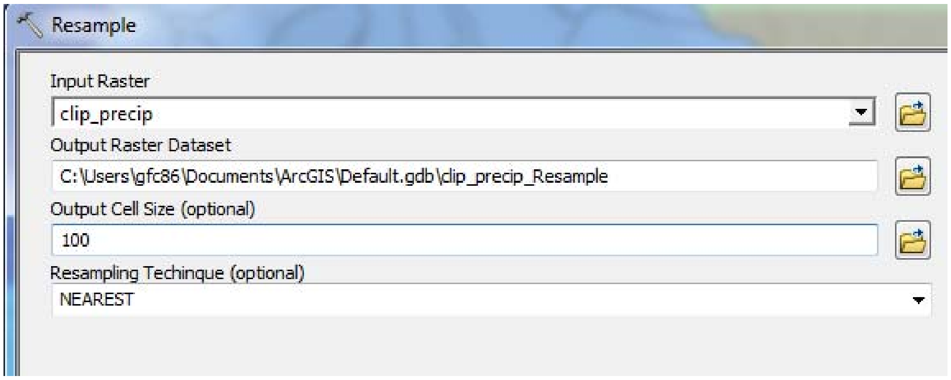

Figure-24

Zonal statistics as table to find the mean precipitation for each catchment

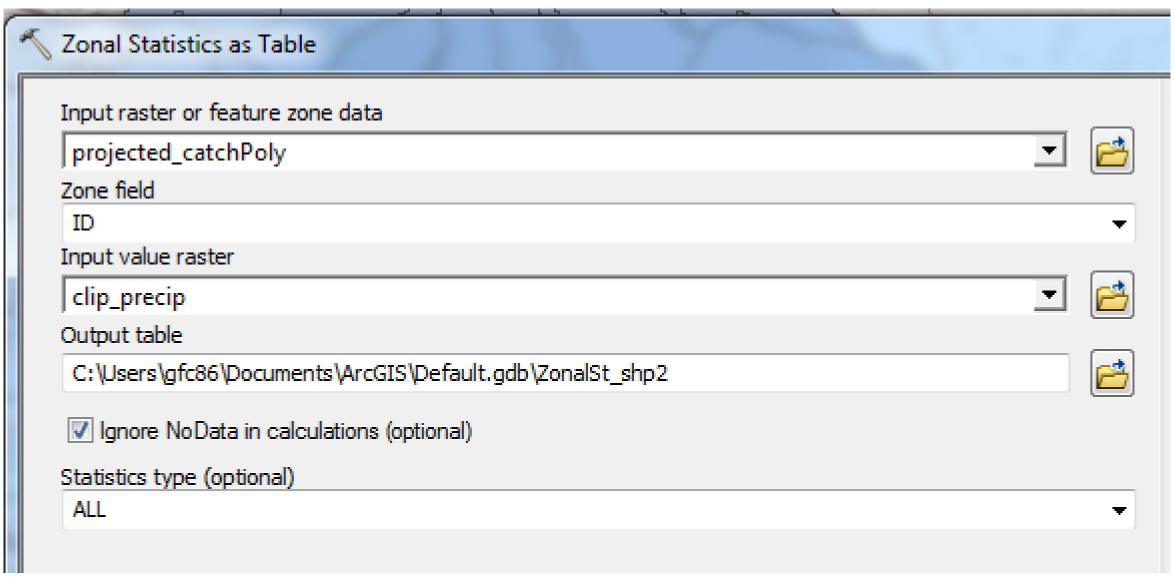

Figure-25

countrie_1	OBJECTID	ID_1	COUNT	AREA	MIN	MAX	RANGE	MEAN
Syriasmalll	1	1	1799	1619100	259	259	0	259
Israel/Dan	2	2	404161	363744990	470	470	0	470
Israel/Lebanon-Hasbani	3	3	937099	843388990	470	617	147	501.85599
Israel11(same as IS2)	4	4	145988	131389000	470	470	0	470
Syria1	5	5	374937	337443010	179	470	291	342.776
Israel13	6	6	184872	166384990	432	580	148	521.27802
Syria2	7	7	289978	260980000	179	259	80	252.739
Syriasmallll	8	8	202	181800	179	179	0	179
Israel10	9	9	305507	274956000	432	470	38	448.586
Syria12	10	10	479721	431748990	141	259	118	172.47501
Israel9	11	11	282658	254392000	432	470	38	436.47101
Syria13	12	12	545791	491212000	179	470	291	244.457
Syria9	13	13	130711	117640000	179	179	0	179
Syria10	14	14	16420	14778000	179	179	0	179
Israel8	15	15	261367	235230000	432	432	0	432
Syria11	16	16	312257	281031010	141	179	38	164.811
Israel7	17	17	396601	356940990	432	580	148	537.15002
Israel12	18	18	566021	509419010	432	470	38	452.461
Syria4	19	19	206006	185404990	179	470	291	226.851
Syria3	20	20	323435	291091010	179	470	291	403.173
Jodan/Syriasmalll	21	21	208	187200	432	432	0	432
Syria5	22	22	26446	23801400	432	432	0	432
Jordan/Syria7	23	23	4011	3609900	432	432	0	432
Syria8	24	24	331857	298671010	179	179	0	179
Jordan/Syria2(same as 6)	25	25	21666	19499400	432	432	0	432
Syria14	26	26	5418	4876200	432	432	0	432
Syria6	27	27	128928	116035000	179	432	253	201.759

Figure-26 Mean precipitation in each catchment

We have the mean precipitation for each subwatershed, we can see how much it contributes to the total Jordan River Basin.

Results

32 subwaterched were located in two different countries. The editor toolbar was used to draw polygons for each subwateshed in order to estimate the area of the two parts in each country. As seen in this figure below, this catchment has a part in Israel and a part in Jordan.

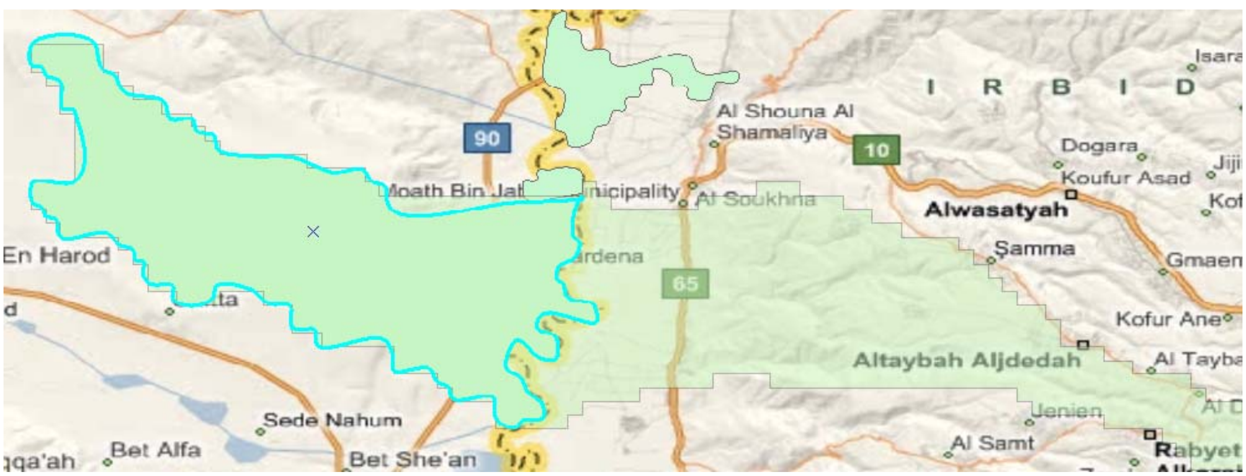

Figure-27 A subbasin located in two countries

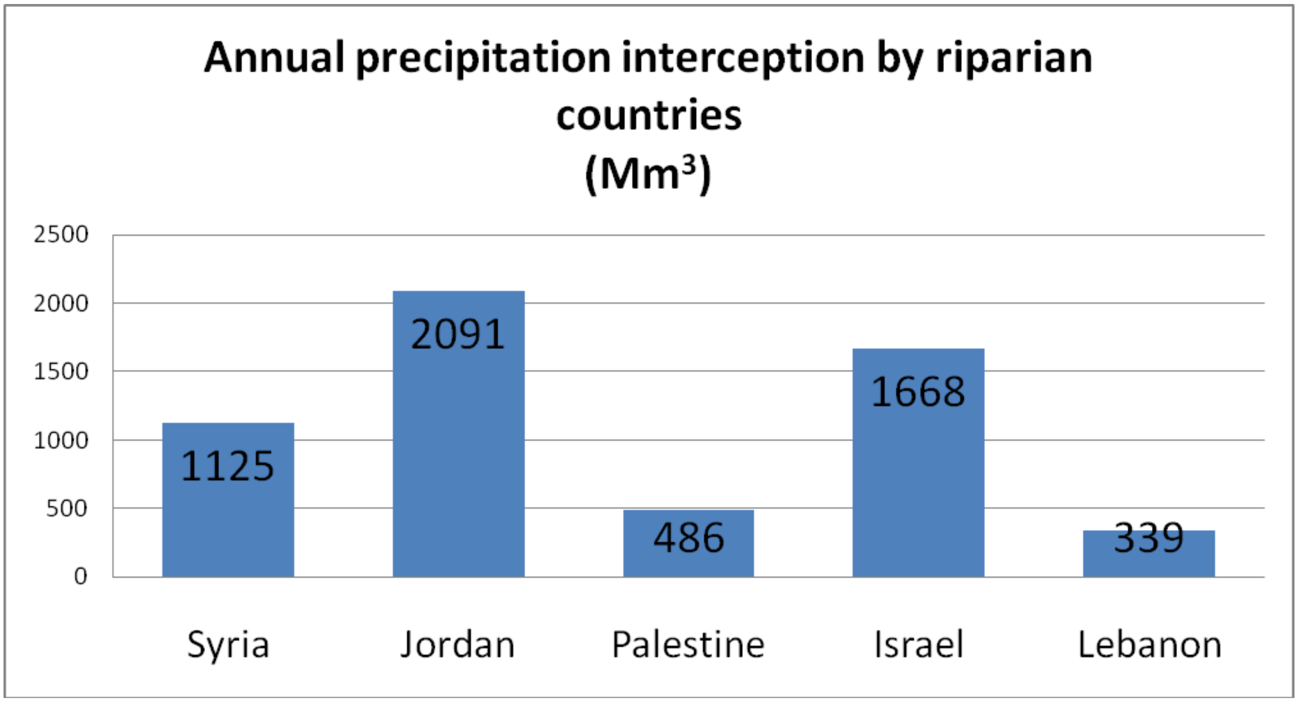

Figure-28 Histogram of the volume (million cubic meters) available for run off

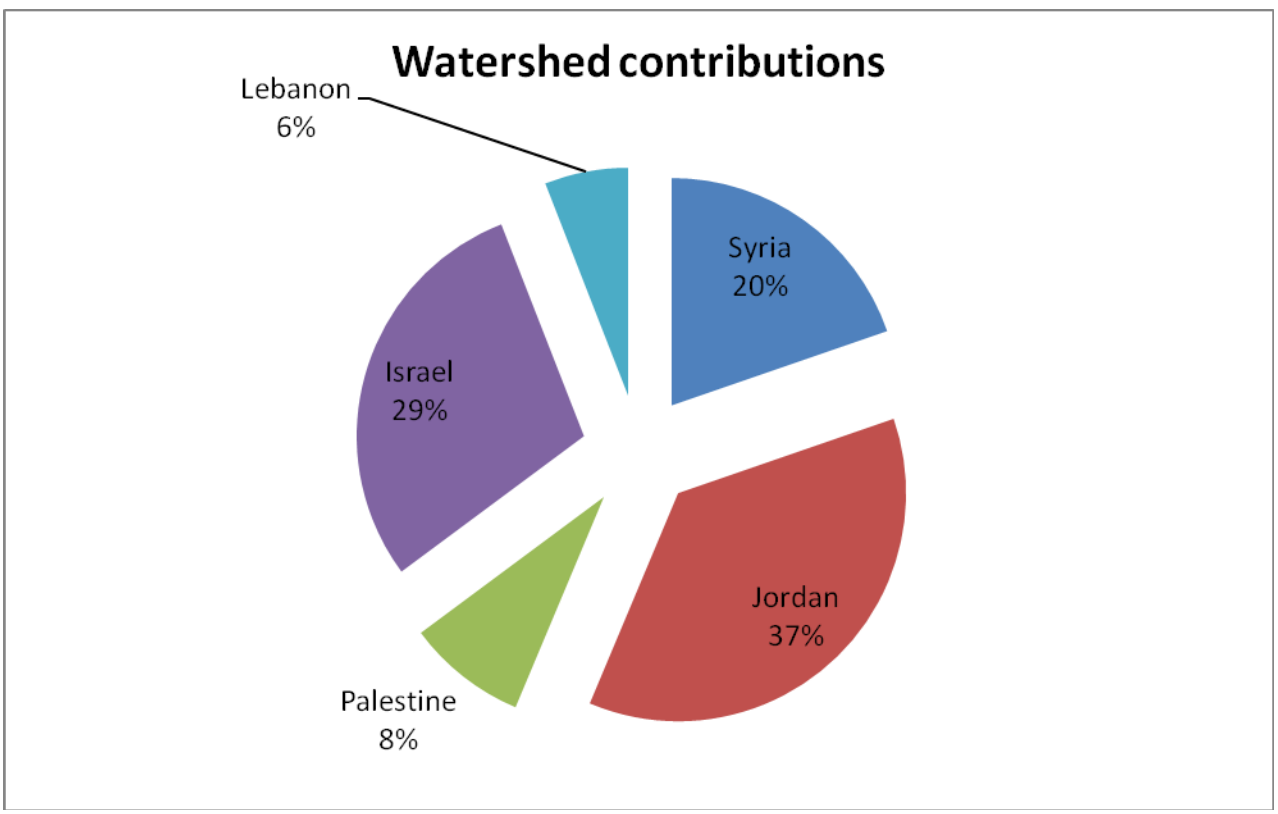

Figure-29 Pi chart showing the contribution of each catchment in percent

The total precipitation in the Jordan portion of the Jordan River Basin was about **2091** Mm^3/year. When compared with a study done by the French Regional Mission for Water and Agriculture, the values were close; the literature estimates the total precipitation to be **2200** Mm^3/year on the Jordan part of the Basin.[10] This shows that the analysis done on GIS was acceptable, but lack of precision because of the low resolution of the data and the lack of precipitation stations.

The analysis done on GIS is useful for a rough estimate of subbasin contribution to see each country's contribution to the total Jordan River Basin. We can see that the largest contribution of all riparian countries is from Jordan. That is why previous water allocation plans in the Basin allocated 56% of the available freshwater to Jordan (see figure 30). One of the plans was the famous Johnston Plan of 1953, which after tough negotiations was rejected by all the stakeholders.[11]

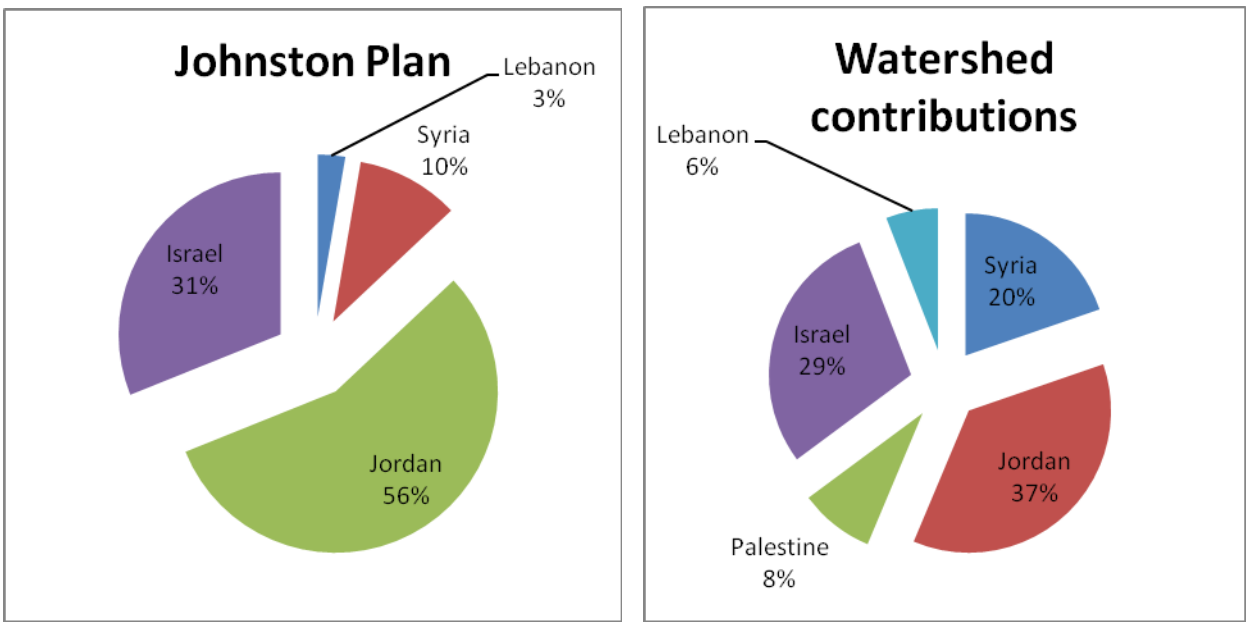

Figure-30 Johnston Plan compared with each countries watershed contribution

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[10] Courcier, R.; Venot, J. P.; Molle, F. 2005. *Historical transformations of the lower Jordan river basin (in Jordan): Changes in water use and projections (1950-2025).* Comprehensive Assessment Research Report 9

[11] Soffer, A. 1994a. The relevance of Johnston plan to the reality of 1993 and beyond. In *Water and Peace in the Middle East,* ed. J. Isaac; H. Shuval. Amsterdam: Elsevier.

For future work, evapotranspiration data and streamflow data could be used with the precipitation volume calculated in order to develop a hydrologic information system that can be used for hydrologic modeling of the basin, including a surface water balance.

Dead Sea water balance

The Dead Sea being a closed sea, it has no outlet, evaporation is the only output. The input besides precipitation is the Jordan River inflow, about 200 Mm^3 of water per year reaches the Sea.

A shape file for the Dead Sea was created using the editor toolbar, as seen below. This is an approximation of the Dead Sea shape.

Figure-31

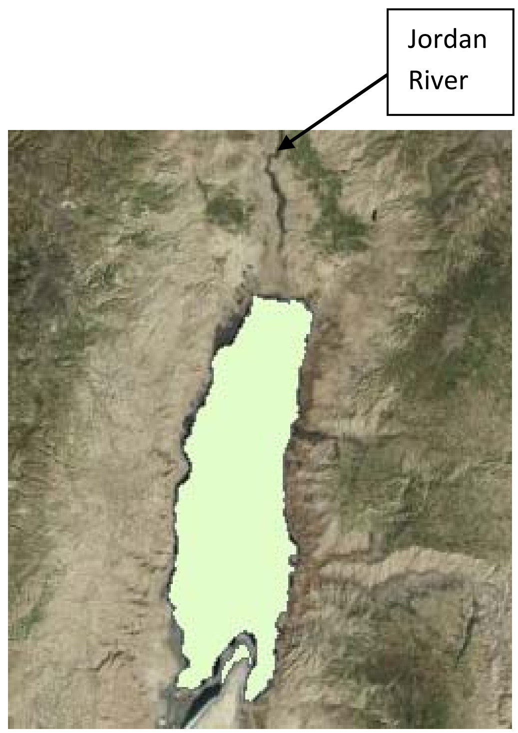

Figure-32

The area was estimated using GIS, and it was about 621.4 Km^2, the literature estimates this number to be 625 Km^2.[12]

[12] Philip P. Micklin. *Dying and Dead Seas: Climatic versus Anthropic Causes : [Proceedings of the NATO Advanced Research Workshop, Liège, Belgium,7-10 May 2003]*. Dordrecht: Kluwer Academic Publ., 2004. Print.

Besides inflow from the Jordan River, the most important factor in the calculation of the water balance is the rate of evaporation, which is estimated to range between 1.05 and 2 m/yr.[13] The same precipitation data was used for a rough estimate of the water balance. The total precipitation on the Dead Sea was determined to be approximately 115 Mm^3/year.

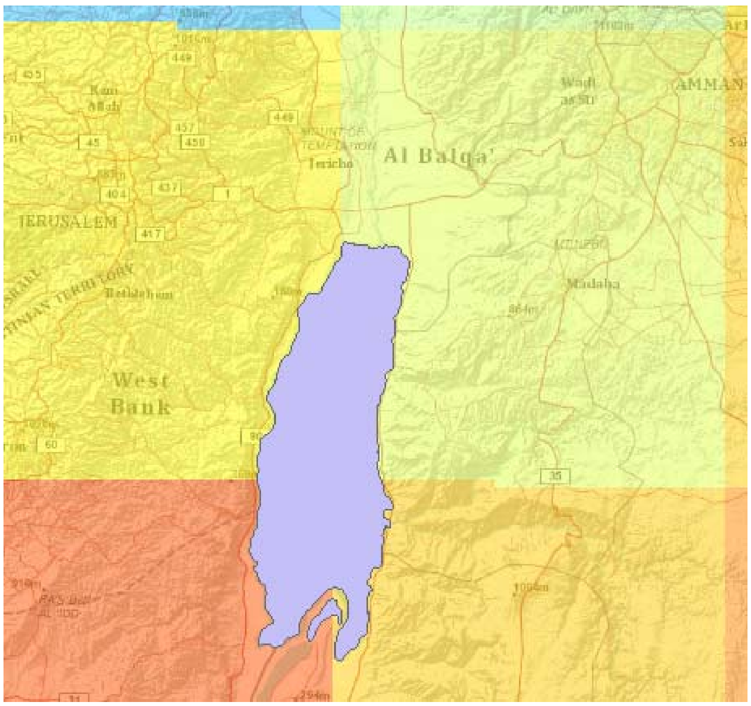

Figure-33

Currently the water level of the Sea declines by 1m/year. Evaporation greatly exceeds inflow. In the past the Jordan River was the single most important water source to the Dead Sea, discharging 1,200 Mm^3 of water per year. The discharge today is 150 to 200 Mm^3/year.[14]

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[13] *Stanhill, G. 1994. Changes in the rate of evaporation from the Dead Sea. International Journal of Climatology 14, 465-471.*

[14] *Gavrieli, I., Lanski, N., Yaari-Gazit, N. and Oren, A. 2002. The Impact of the Proposed "Peace Conduit" on the Dead Sea: Evaluation of Current Knowledge on Dead Sea – Seawater Mixing. Geological Survey of Israel, Report GSI/23/2002, 42 pp.*

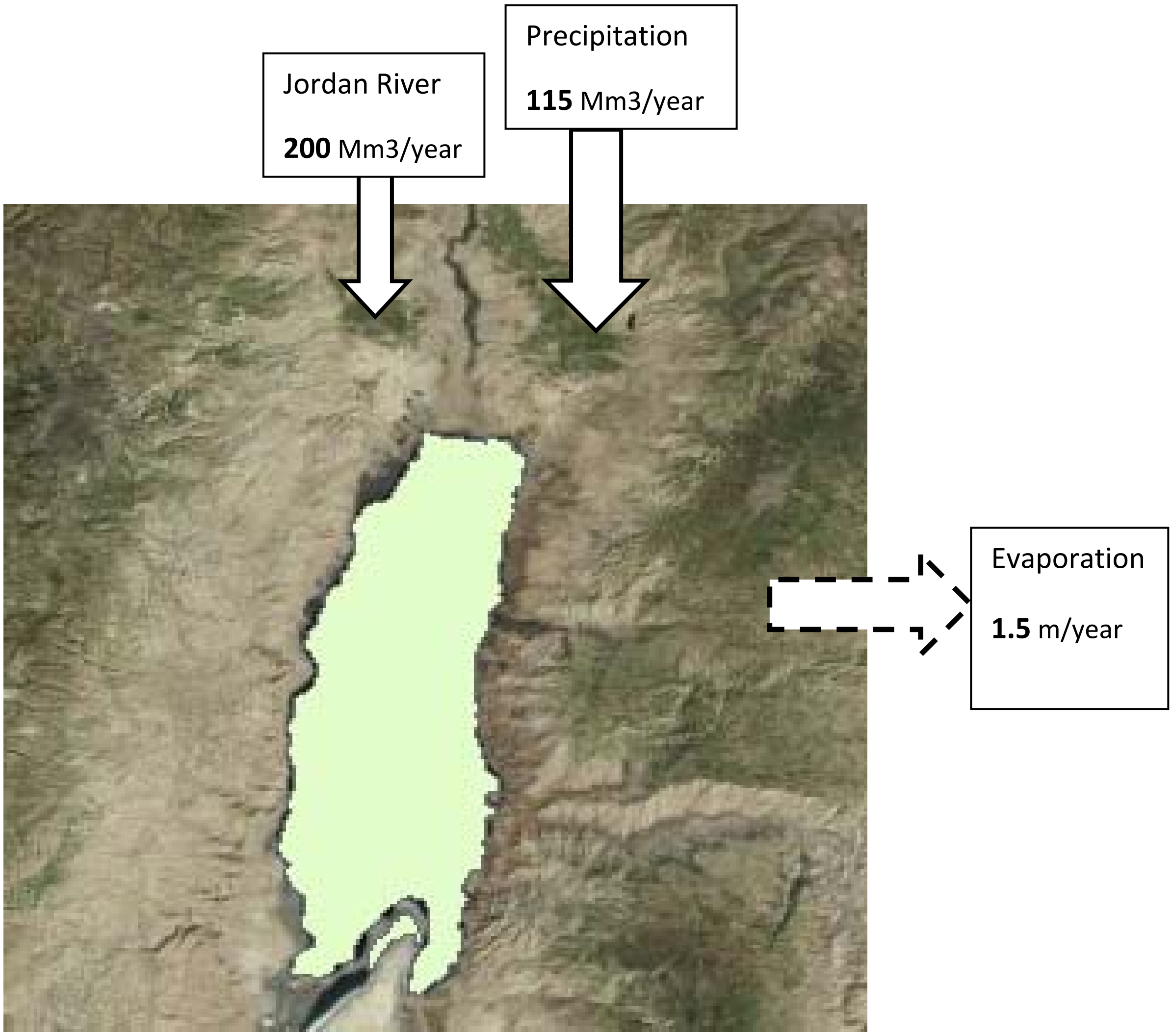

Figure-34 Dead Sea water balance

<u>Water balance:</u>

Average Precipitation + Jordan River Inflow – evaporation = Water deficit

$$200 \times 10^6 \frac{m^3}{yr} + 115 \times 10^6 \frac{m^3}{yr} - 1.5 m yr^{-1} \times 621.4 \times 10^6 m^2 = -617.1 \times 10^6 \frac{m^3}{yr}$$

The average decline in water level in one year of the Dead Sea is:

$$\frac{Volume}{Area} = \frac{-617 \times 10^6 m^3}{621.4 \times 10^6 m^2} = -0.993 \frac{m}{year}$$

Thus we estimate the decline in the Dead Sea level to be about 1m/year, this is consistent with Ittai Gavrieli and Amos Bein estimations from the Geological Survey of Israel they state: “The rate of water level drop over the last 10 years is about 0.9 m/yr, representing an annual water deficit of about **600** million cubic meters."[15] The deficit calculated in this report was **617.1** million cubic meters per year!

Conclusion and future work

It is important to recognize the potential of GIS in water resources as a tool for improving water demand management in the implementation of the integrated water resources planning (IWRP) and management (IWRM). The use of GIS in studying the hydrology of the Jordan River Basin enabled calculation of the drainage area of each catchment within the Basin, the volume of water available for runoff and the decline of the water level in the Dead Sea estimated to be about 1m/year. This result is consistent with Ittai Gavrieli and Amos Bein estimations from the Geological Survey of Israel.

The Jordan River today is a damaged river with depletion of its aquifers, sub-standard water quality, severe damage to its ecosystem, and very little inflow into the Dead Sea. The main objective of my work with Dr. McKinney would be to contribute to the promotion of cooperation between all riparian countries of the Jordan River to achieve an equitable distribution of water, rehabilitation of the Jordan River Ecosystem, increased inflows into the Dead Sea and further support for the peace process in the region.

[15] Gavrieli, I., Bein, A. and Oren, A. 2005. The expected impact of the "Peace Conduit" project (the Red Sea - Dead Sea pipeline) on the Dead Sea. Mitigation and Adaptation Strategies for Global Change.http://www.ipcri.org/watconf/papers/ittai.pdf