

Groundwater Model of the Nahr Ibrahim Valley, Lebanon

by

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Submitted to the Department of Civil and Environmental Engineering
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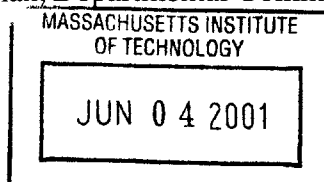
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BARKER

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ABSTRACT

The Nahr Ibrahim is one of Lebanon's most pristine rivers. The Lebanese Ministry of Environment wishes to maintain the natural grandeur of the region, even during the massive renewal that is occurring as a result of the end of their civil war. In order to understand the interconnectivity between the river and the groundwater a groundwater-surface water interaction study was completed. This study utilized a groundwater flow model and a mass balance analysis to determine where the river is losing and gaining. The analysis found that the river is both losing and gaining. Further study is recommended to determine which portions lose and gain.

Thesis Supervisor: Charles F. Harvey

Title: Assistant Professor of Civil and Environmental Engineering

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MIT Lebanese Club

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1 Introduction

1.1 Significance of Nahr Ibrahim Basin

The Ibrahim River, known in Arabic as the Nahr Ibrahim, is one of the main rivers running through Lebanon. Located in the Mount Lebanon Province, the Nahr Ibrahim is well known for its natural grandeur and provides an important water resource to the country. It is a popular site for camping and picnicking, as well as extreme adventure sports such as caving, among the locals. With many scenic views, the Lebanese Ministry of Environment has classified the valley as a Natural Site. This region has great potential of being tapped for the development of ecotourism (travel to a location to enjoy its natural splendor).



Figure 1 – The Nahr Ibrahim

Local residents primarily use the water from the Nahr Ibrahim for irrigation, washing, and drinking. Since a hydroelectric plant was built in the valley 50 years ago, the river has been used to generate hydroelectric power for the residents and factories in the area. In addition, there once were a small number of industrial facilities and quarries in the lower course of the river that utilized the water from the Nahr Ibrahim for its daily operations.

1.2 The Need for an Environmental Study

The Lebanese economy has been growing since the end of the recent civil war. As a result, industry in the Nahr Ibrahim Basin increased. At the onset of this urban renewal, environmental issues were not considered and polluting industries were allowed to operate. The Lebanese Ministry of Environment is now attempting to correct for these environmentally careless actions. Thus, in the past few years, the government has shut down most industry in the region. However, with the increased population and the absence of any wastewater treatment system, the integrity of the river is in danger of being polluted. In order to maintain the Nahr Ibrahim as a useful resource for both

individual use (as a source of drinking water, recreation, and aesthetics) and for industrial uses, present and future environmental assessments must be performed.

1.3 Objective of the Study

Groundwater currently accounts for 30 to 40 percent of the water used for domestic, industrial, and agricultural use in Lebanon (Macksoud, 1998). In order to develop an understanding of the interconnectivity of the Nahr Ibrahim Basin, and the effects of current and future development, the groundwater-surface water interaction was examined. If the river was found to be a losing river (river water flows through the riverbed and into aquifers), contaminants discharged into the river could enter the groundwater, polluting the groundwater aquifers in the watershed. If the Nahr Ibrahim was found to be a gaining river (meaning water flows from the ground into the river), any contaminants that infiltrate through the ground and into the watertable could seep into the river. Such problems could affect the water quality and the aesthetic appeal of the river, jeopardizing the ecotourism business.

1.4 Challenges in Performing an Environmental Study in Lebanon

The major difficulty in performing an environmental study in Lebanon was the availability of reliable data. During the fifteen years of civil war in Lebanon (1975-1990), much of the historical data and statistics of the river were lost. The government in Lebanon does not know the fate of the precipitation and flow gauging stations built before the war and there are few records left from the pre-war period. In addition, little information regarding the river region can be found outside the country.

Another challenge for performing this study is the general lack of environmental awareness in the country. After the civil war, the country prioritized economic development and little attention was given to environmental sustainability until recently. For example, there are no sewage treatment plants in Lebanon to handle municipal waste. The waste has been traditionally discharged directly into the Mediterranean Sea and other surface waters.

The author also faced challenges, as she did not speak the predominant local languages. Although the large majority of persons in urban areas, such as Beirut, speak English, Arabic and French are the two most widely spoken languages of Lebanon. Most people in rural villages, such as those found in the Nahr Ibrahim Basin, speak only Arabic. Because many different dialects of Arabic exist and translation into English and French is not always consistent, the authors found that the name of a single village could have multiple different spellings. As a result, this report may make reference to Lebanese regions using a variety of translations.

2 Historical Background

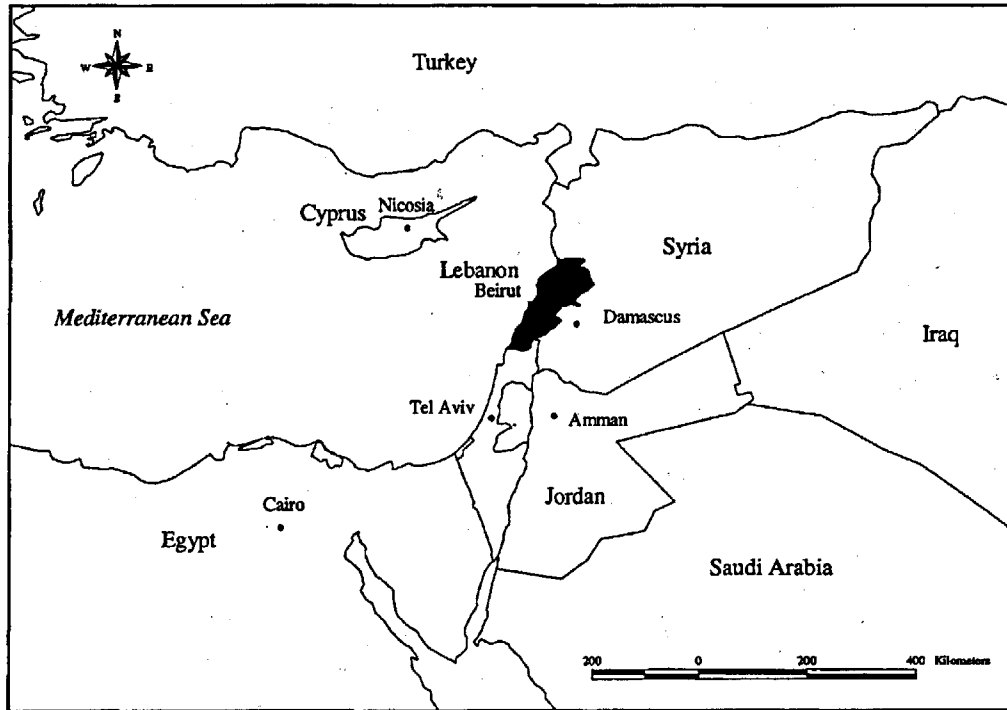
In order to understand the environmental attitude in Lebanon, it is important to be aware of the country's recent history. The civil war had far reaching environmental consequences. During the civil war, the country could not prioritize environmental issues. In the years since the war, the country has focused on renewal, again ignoring environmental consequences.

It is duly important to appreciate the outlook of the Lebanese people. Lebanon has a long and rich past, touched by many different civilizations, making it unique from other countries in the Middle East. Furthermore, in order to recognize the value of that the Lebanese place on the Nahr Ibrahim Basin, it is important to understand the history and culture associated with this specific region, such as the Legend of Adonis and Astarte.

2.1 History of Lebanon¹

The region that is now defined as Lebanon (see Figure 2) has been occupied by over 17 different cultures. The first traces of costal settlement in Lebanon date back to 9000 BC. The first recorded history is from 3000 BC, when the Canaanite, a Semitic people (called Phoenicians by the Greek) inhabited mainly costal cities, living and trading on the sea. Assyrians conquered the Phoenicians (875-608 BC) taking away their freedom, spurring many fruitless revolts. In 612 BC, Lebanon broke away from Assyrian control, now ruled by Babylonian and the Persian Empire (which was controlled for some time by Alexander the Great). In 64 BC, the region became part of the Roman Empire, and Beirut grew to become a major city (<http://www.geocities.com/CapitolHill/Parliament/2587/hist.html>, visited 5/4/2001).

¹ This section was authored in coordination with Jessica Fox.



**Figure 2 – Political Map of the Middle East
(El-Fadel, 2000)**

In 35 AD disciples came to Lebanon to preach the word of Christ and conversion to Christianity began. The Arabs first entered the region in 634, as followers of the Prophet Muhammed, the founder of Islam, embarked on a movement to establish their religious control. The Arab Conquest (634-36), a holy war against non-Muslims, was followed by attack by the Umayyads (660-750), and by the Abbasids (750-1258). The Crusades, a Christian holy war, lasted from 1095 to 1291. The Mamluks then ruled the region from 1282 to 1516. Their rule was followed by the Ottoman Empire, which lasted until 1916. Shortly thereafter (September 1, 1920), Lebanon's present boundaries were defined as General Gouraud proclaimed the establishment of Greater Lebanon with Beirut as its capital. (<http://www.geocities.com/CapitolHill/Parliament/2587/hist.html>, visited 5/4/2001).

Since its creation in 1920, Lebanon has been repeatedly afflicted with political instability, war, and economic devastation. The most recent war, between 1975 and 1990, ravaged the social, economic, and political fabric of this once prosperous nation. In the 10 years since the end of the war, Lebanon has begun to rebuild and restore order.

However, as the industries return, little is known about what effect the rapid growth of the country will have on the environment. This project will attempt to characterize the risks of this environmental danger through the study of the Ibrahim River (Nauphal, 1997).

2.1.1 Causes of War

During the Ottoman Empire (13th – 20th centuries), portions of what is now Lebanon (Sildon, Tripoli, and Beirut) were under direct Ottoman rule. These areas were inhabited by the dominant orthodox religions of the Byzantine and Islamic empires. The rest of Lebanon, however, maintained only indirect Ottoman rule and became a haven for the persecuted Christian and Muslim heterodox religions, including the Maronites, Druzes, and Shi'a (Nauphal, 1997).

When the Ottoman Empire was dismantled during World War I, the League of Nations gave France control of Syria and Lebanon. The Republic of Lebanon was formally created in 1926, bringing together the small sects and the large orthodox religions. Because the two groups had enjoyed separate histories and socio-economic systems, this combination became the root cause of the subsequent civil wars (Nauphal, 1997).

There soon was a power struggle between the Lebanese nationalists (Christians), the French supported groups (Maronites), and the Arab nationalists (Muslims). The French helped the Maronites implement their national political program. The Lebanese nationalists claimed an independent Lebanon. The Arab nationalists wanted Lebanon to become part of a larger Arab-Islamic empire. This divide jeopardized the legitimacy of the republic (Nauphal, 1997).

There are many probable causes of the 1975-1990 civil war in Lebanon. The inequities in cultural group representation in the government, army, and eventually in monetary wealth contributed to a general struggle within the country. Another contributor is that Lebanon was used as a "surrogate battleground" for the foreign conflicts between the Palestinians, Israelis, and Syrians. Palestinians displaced by the creation of Israel became increasingly militarized and launched guerrilla operations from Lebanon (Nauphal, 1997).

The intentions of the neighboring nations for the state of Lebanon also led to war. Syria has never accepted the sovereignty given to Lebanon by France, believing it to be a province of its country. Additionally, Israel desired to end the Palestinian terrorist groups within Lebanon as well as expand its territory (Nauphal, 1997).

Internal and external tensions within the country reached a breaking point in 1975, inciting the civil war (Nauphal, 1997).

2.1.2 The 1975-1990 Civil War

The war began in 1975 when the main Christian party accused the Palestinians of violating the sovereignty of the State. The violence soon spread to the entire country, generally between the militias of the pro-Palestinian groups and the Israeli supported Christian group. In 1976, the Palestine Liberation Organization (PLO) joined the war on the Palestinian side while Syria joined to oppose the Palestinians. Two years later, following a bomb attack near Tel Aviv, Israel invaded Lebanon to eliminate the Palestinian bases in the southern region of the country. The United Nations stepped in to replace the Israeli army (Nauphal, 1997).

In July 1981, the United States stepped in to mediate a cease-fire agreement between Israel and the PLO. However, in 1982 Israel invaded again, surrounding the capital of Beirut and pushing the PLO into Syria (Nauphal, 1997).

The war continued until 1990, when Syria and Lebanon signed a Treaty of Brotherhood, Cooperation, and Coordination and a Pact of Defense and Security, which outlined peace between the two nations. However, despite these peace accords, Israel occupied southern Lebanon until the year 2000 and approximately 40,000 Syrian soldiers remain in the country (Nauphal, 1997).

In the years since the war, Lebanon has worked to rebuild its infrastructure and economy. Although relations with Syria and Israel are still tense, there has been relative peace since 1990 (Nauphal, 1997).

2.2 Legend of Adonis and Astarte

In addition to the current merits of the river, such as its natural beauty, the Nahr Ibrahim has another a very special importance. Afqa is the setting for the famed legend of Adonis and Astarte.

The prince Adonis was to be the most gorgeous baby ever born. As he approached manhood, Adonis became known as the most handsome and most skilled hunter in the land of Canaan (Lebanese Ministry of Tourism, 2001).

The beautiful Astarte heard of the attractive prince. She pined to make his acquaintance, although she had many admirers. The young prince, however, was content to hunt and dance with the nymphs and play the lyre (Lebanese Ministry of Tourism, 2001).

One day Astarte secretly followed Adonis. When she finally emerged from the forest and came into his view, he immediately fell deeply in love. The two lovebirds talked for hours about the beauty of Afqa, and swore they would never leave each other. Days passed as they strolled together along the Nahr Ibrahim, followed by nymphs, birds and butterflies (Lebanese Ministry of Tourism, 2001).

Now in love with Astarte, Adonis no longer felt a desire for hunting, much to her delight. Astarte feared he would be lost or hurt, and made him promise not to go hunting (Lebanese Ministry of Tourism, 2001).

Adonis promised, but soon his old passion returned. One day he decided to kill a wild boar. They were the most difficult animals to kill because they are fast and have big, sharp tusks. Adonis was not afraid, but enjoyed the challenge. He saw a boar and skillfully stabbed it in the head. The animal did not die, but became furious. The angry boar charged Adonis more than five times. Adonis and the beast battled extensively. Adonis thought he had the upper hand and just as the boar started to collapse, the swine quickly turned about face and thrust his sharp tusk into Adonis' thigh. The monstrous boar charged Adonis again and jabbed the young hunter's stomach, and then his chest (Lebanese Ministry of Tourism, 2001).

By the time Adonis' friends, the nymphs of the forest, came to rescue him, he was lying in a pool of blood. This blood later turned into beautiful red anemones. The nymphs gently lifted Adonis, and carefully carried him to Afqa Cave. Once safe inside the cave, they tried to revive him, but alas they were too late. Astarte arrived soon thereafter. When she found her beloved dead, she wept for hours. Roses grew on the land where her tears fell (Lebanese Ministry of Tourism, 2001).

Alone on Earth, Astarte led the body of Adonis to the underworld. She was now filled with great emptiness. To improve her spirits, the great God El declared that each spring Adonis would return to visit Astarte in Afqa for a few weeks. During this time the anemones would blossom and the Nahr Ibrahim again would turn red (Lebanese Ministry of Tourism, 2001).

For many years after, the people of Canaan memorialize the death and resurrection of Adonis with three-day-long festivities. As they watched the river turn red, they believed it was the blood of Adonis being spilled again. The red color is actually caused by a mineral carried in the water as the snow melts (Lebanese Ministry of Tourism, 2001).

3 Nahr Ibrahim Basin

The major difficulty in performing this study was the difficulty in obtaining reliable data. This chapter describes data sources, followed by a compilation of the data currently available, relevant to this study.

3.1 Data Sources

The data used in this study came from three major sources: existing literature and reports, geographic information system databases, and field measurements. Most of this data was compiled when the author visited Lebanon in January 2001.

3.1.1 Data From Literature

During the 15 year civil war, most scientific data in Lebanon was been lost or destroyed. Minimal amounts research or data gathering was conducted during this time. During the author's trip to the country, several reports were brought together. The most beneficial reports included "A Hydrogeological Study of the Nahr Ibrahim Basin in the Vicinity of the Paper Mill Project of Indevco in Lebanon" (Papazian, 1981), "Relance des Projects Hydro-Agricoles: Barrage de Iaal dans le Liban Nord, Barrage de Yahchouch sur le Nahr Ibrahim" (Electrowatt, 1981), and "Etude des Apports de Nahr Ibrahim" (Bureau d'Etudes Hydrauliques, 1994).

Though far from being informatively exhaustive, these reports give rather detailed data about the Nahr Ibrahim watershed. However, these reports often gave conflicting information. For example the location of the Djinni gauging station varies from report to report.

3.1.2 Geographic Information System Data

The Lebanese Ministry of Environment made a substantial amount of Geogrphic Information System (GIS) data available. GIS databases available included satellite maps, population data, river location, watershed delineations, and more. It is unknown to the Ministry of Environment officials how current most of this data is. Furthermore, it was unclear who has gathered this information.

3.1.3 Field Measurements

The author traveled to the project site in January 2001 and performed field measurements for the Nahr Ibrahim. At nine of locations, cross-sectional and flow measurements were conducted to assess the hydrogeometric characteristics of the channel. A Rickly Hydrological Company pygmy flow meter was used to measure the flow in the river. These measurements the cross-section approximations can be found in the Appendix.

3.2 Data Compilation

The following section summarizes information pertaining to the Nahr Ibrahim Basin, as collected from the sources described above.

3.2.1 River Statistics

The Nahr Ibrahim, highlighted in Figure 3, is one of fifteen major rivers of Lebanon. The river, which is 28 km long, is located 20 km north of Beirut. Beginning at the crest of Mount Lebanon, the river flows westward, emptying into the Mediterranean Sea (Papazian, 1981).



Figure 3 – Map of Lebanon

(http://www.ibiscus.fr/dsipays/lb_admi.html, visited 11/16/2000)

Nahr Rouieiss is the major tributary feeding Nahr Ibrahim, joining the main river in Kartaba. The Nahr Dibb and the Ouadi Ghabour are other major tributaries. Several other small perennial tributaries also feed the main river, as seen in Figure 4 (Papazian, 1981).

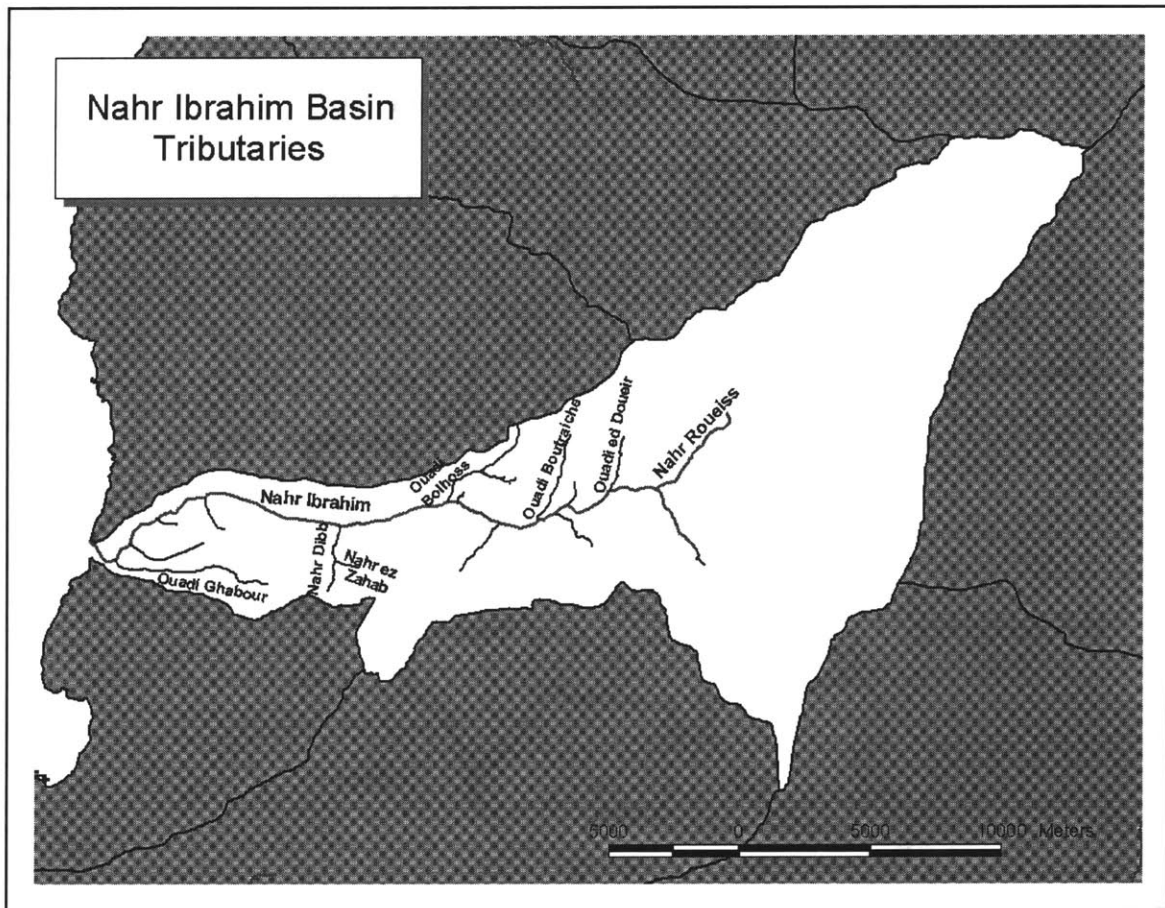


Figure 4 – Tributaries

3.2.2 Watershed Description

The Nahr Ibrahim Basin is located in central Lebanon. The watershed is 330 km², stretching from the Western slope of Mount Lebanon to the Mediterranean Sea. At the northern border of the watershed is the drainage basin of Nahr el-Djoz, and at the southern border is the basin of Nahr el-Kelb. Towards the east are the Yammouneh basin and the Nahr Litani Basin. (See Figure 5.) The crest of Mount Lebanon forms the eastern

border, which is 27 km long. The elevation of this rim decreases from the North to South, from 2625 m to 1875 m (Papazian, 1981).

The majority of the drainage basin is comprised of steep-sided mountain ridges. A large portion of the drainage basin lies on a high plateau, extending between the two sources and the eastern rim of the basin. This high plateau, which forms Jebel Mneitri, is rectangular, having a surface area of 200 km² (Papazian, 1981). The elevation of the plateau varies between 1200 and 2500 m and is covered by snow from December first until the beginning of April (Bureau d'Etudes Hydrauliques, 1994).

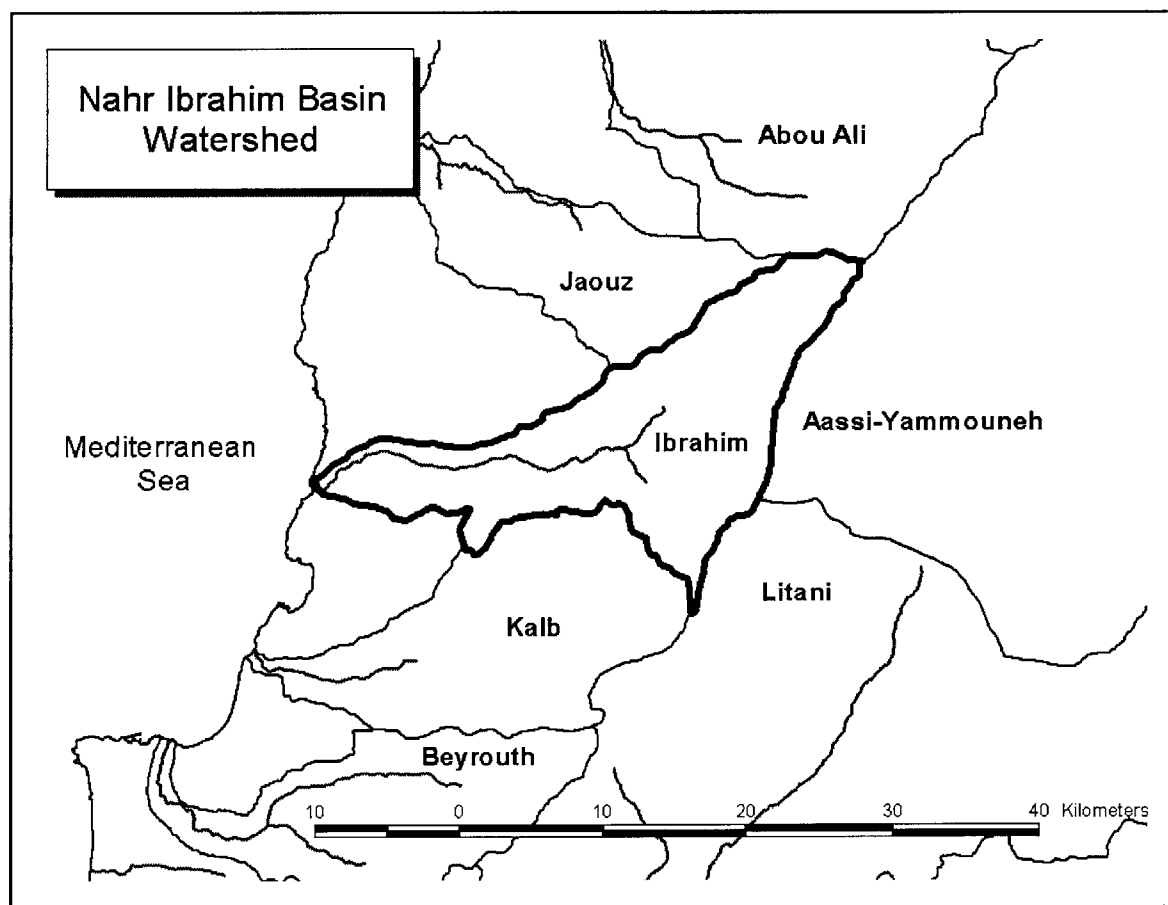


Figure 5 - Watershed

3.2.3 Springs

The major sources of the Nahr Ibrahim are the Afqa spring and the Nahr Roueiss, a tributary. Afqa spring is located inside a cave, at an elevation of 1250 m. The Nahr

Roueiss, which is fed by the Roueiss Spring (elevation of 1170 m) and other tributaries, meets Nahr Ibrahim below Kartaba (Papazian, 1981).

Afqa and Roueiss are both perennial springs, experiencing high flow in the winter and spring season, and extremely low flow at the end of the summer and early fall seasons. Afqa's summer flow is 0.75 m³/s and Roueiss has a summer flow of 0.4 m³/s. In addition to the two source springs, the Nahr Ibrahim is fed by a group of approximately 30 springs of variable flow, scattered over the surface of the basin (Papazian, 1981).

Other major springs include:

Nabaa el Moudik	0.6 m ³ /s in the dry season 0.925 m ³ /s during the rainy season (Bureau d'Etude Hydrauliques, 1994)
Nabaa Ser'aita	0.06 m ³ /s
Nabaa Boutraiche	0.025 m ³ /s
Nabaa el-Koudeira	0.012 m ³ /s

Minor springs include:

Ain el-Mneitra	0.006 m ³ /s
Ain el-Akoura	0.004 m ³ /s
Ain el-Mejdel	0.002 m ³ /s
Ain el-Bardi	0.00125 m ³ /s
Ain el-Ghabate	0.001 m ³ /s
Ain Khalaff	0.0005 m ³ /s (Papazian, 1981)

These springs are shown in Figure 6. They most often occur where less permeable soils impede the groundwater flow and force it to the surface. Rainfall continuously infiltrates the ground during the winter season, increasing the volume of water stored in aquifers, which maintains the flow of perennial springs all year (Papazian, 1981).

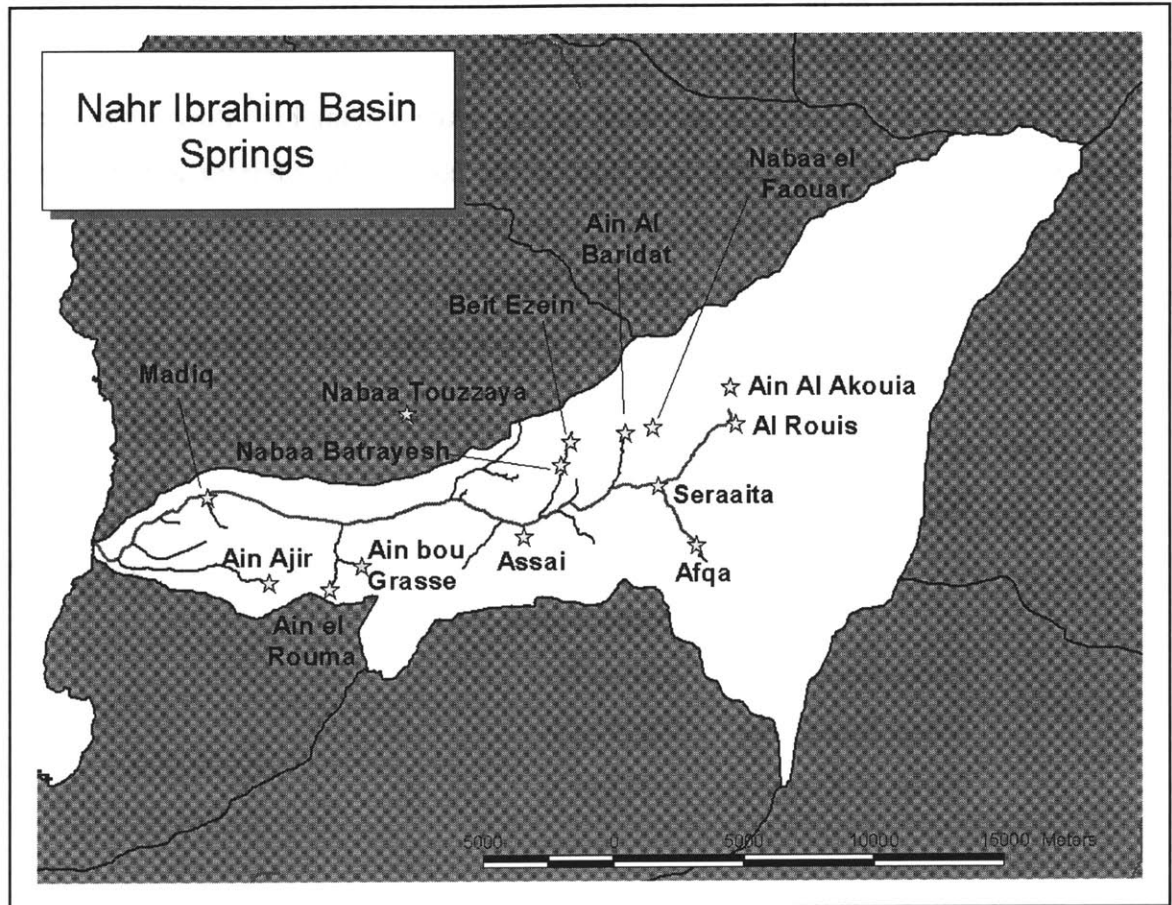


Figure 6 - Springs

3.2.4 Flow Data

The Ministry of Public Works installed three gauging stations along the Nahr Ibrahim in July of 1939. One was installed near the Koudeira bridge (at an elevation of 135 m), the second between the present hydroelectric power plants at Yahchouche (elevation of 150 m), and the third at Koudeira or Bezhel (elevation 86 m). During the fall of 1951, the Ministry of Public Works put in a fourth gauging station, located just downstream the village of Mougheire at Majdel (elevation of 1200 m), and a fifth station located between the confluence of Nahr Roueiss and Nahr Afqa in Djinni (elevation of 775 m) (Papazian, 1981). Another station was built at the mouth of the river. These gauging stations were not monitored during the civil war, and are no longer in operation. Flow data at Majdel (Bureau d'Etudes Hydrauliques, 1994), Djinni, Koudeira, and the

Mouth (Papazian, 1981) are summarized in Table 1. The location of these stations can be seen in Figure 8.

Table 1 – Flow Recording at Gauging Station

Flow Recorded at Gauging Station (m³/s)				
	Majdel	Djinni	Khouaira	Mouth
September	0.20	1.38	1.95	2.06
October	0.30	1.29	2.00	2.12
November	0.30	2.26	3.04	3.22
December	0.35	3.19	7.36	7.79
January	0.30	6.00	13.21	13.98
February	0.30	15.33	16.19	17.04
March	8.00	13.99	27.49	29.09
April	13.50	30.76	38.45	40.69
May	10.00	26.42	28.58	30.24
June	3.00	11.21	10.29	10.89
July	0.50	3.57	4.29	4.54
August	0.20	1.76	2.39	2.53
Yearly Average	3.08	10.05	13.24	13.68

The hydroelectric plant, which maintains three dams along the river, keeps daily records of the flow through their dams. The flow data at Chouwen and Yahchouche from January 18, 2000 to November 18, 2000 can be found in Figure 7. Note that the measured flow values reach a maximum during high flow periods. As the dam reaches flow capacity, excess water is spilled, and is not measured. Dam locations can be seen in Figure 8.

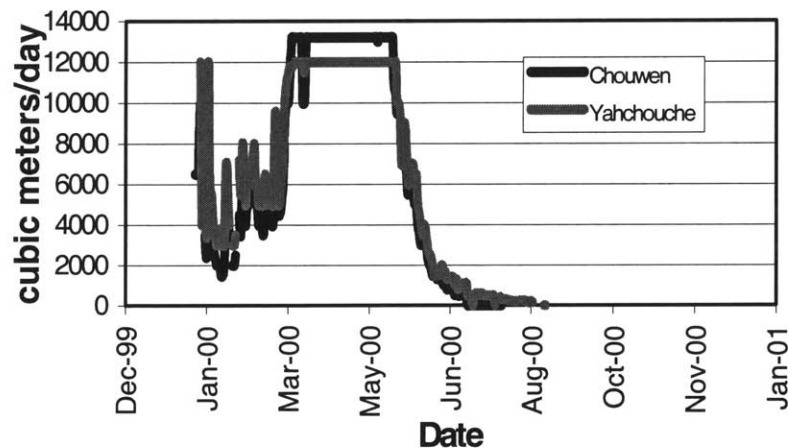


Figure 7 – Flow at Hydroelectric Plants

The authors collected flow data during a site visit in January 2001. Table 2 lists the measured flow at the sample locations, shown in Figure 8. A Rickly Hydrological Company Pygmy Flow Meter was used to measure the current at nine locations across the river. The current, used in coordination with approximations of the cross section, is used to estimate flow in the river. Although these measurements were collected at many locations along the river, it must be noted that flows were measured on a single day at various points throughout the day. Also, no flow was measured in the middle portion of the river, as access is not possible by road.

Table 2 – Flow Measured During Site Visit

LOCATION	River Flow
	m³/s
Site 1	0.08
Site 2	0.82
Site 4	0.61
Site 6	0.22
Site 7	0.12
Site 8	2.05
Site 9	4.05
Site 10	1.98
Site 11	3.54

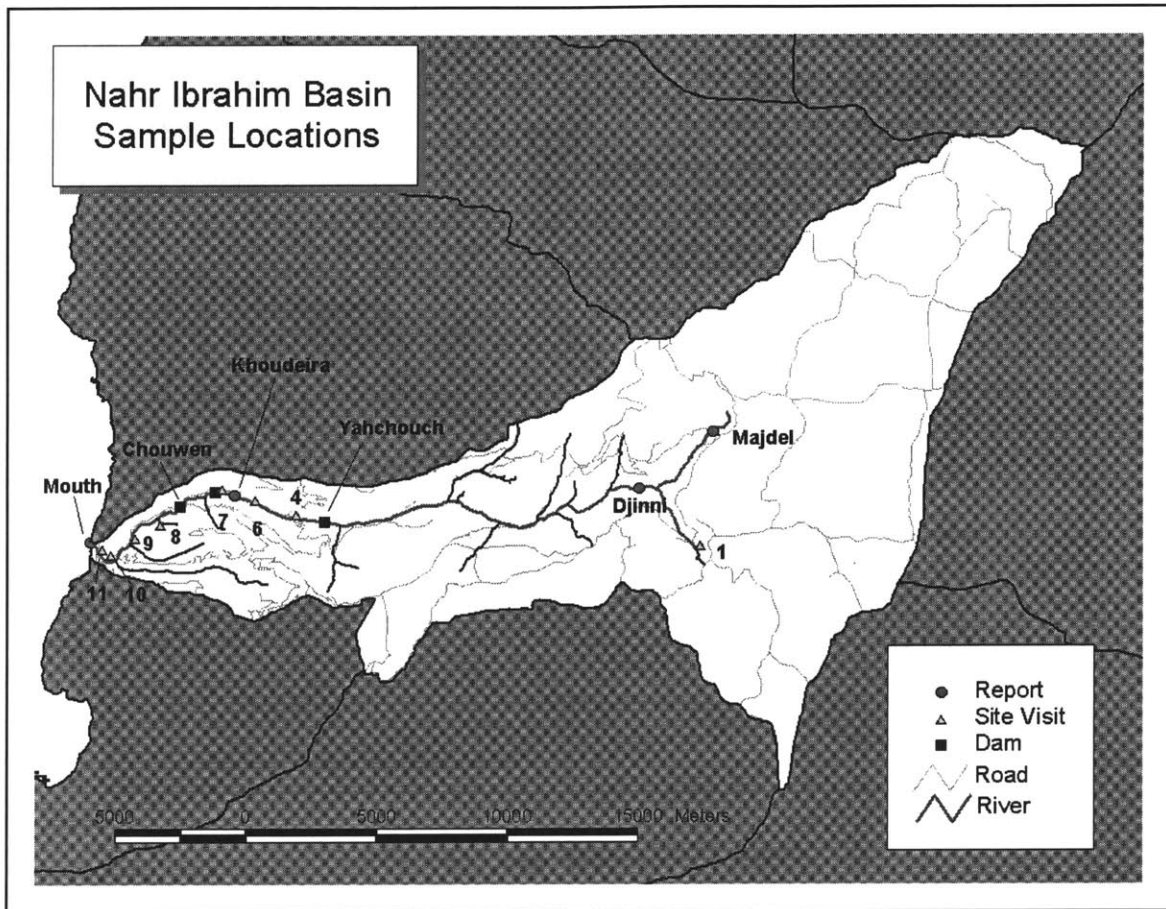


Figure 8 – Sample Locations

3.2.5 Aquifer Description

Geological formations outcropping in the Nahr Ibrahim range from the Jurassic to Cretaceous. The majority of the basin is permeable, but near impermeable terrain exists (Electrowatt, 1981). (See Figure 9 and Figure 10.)

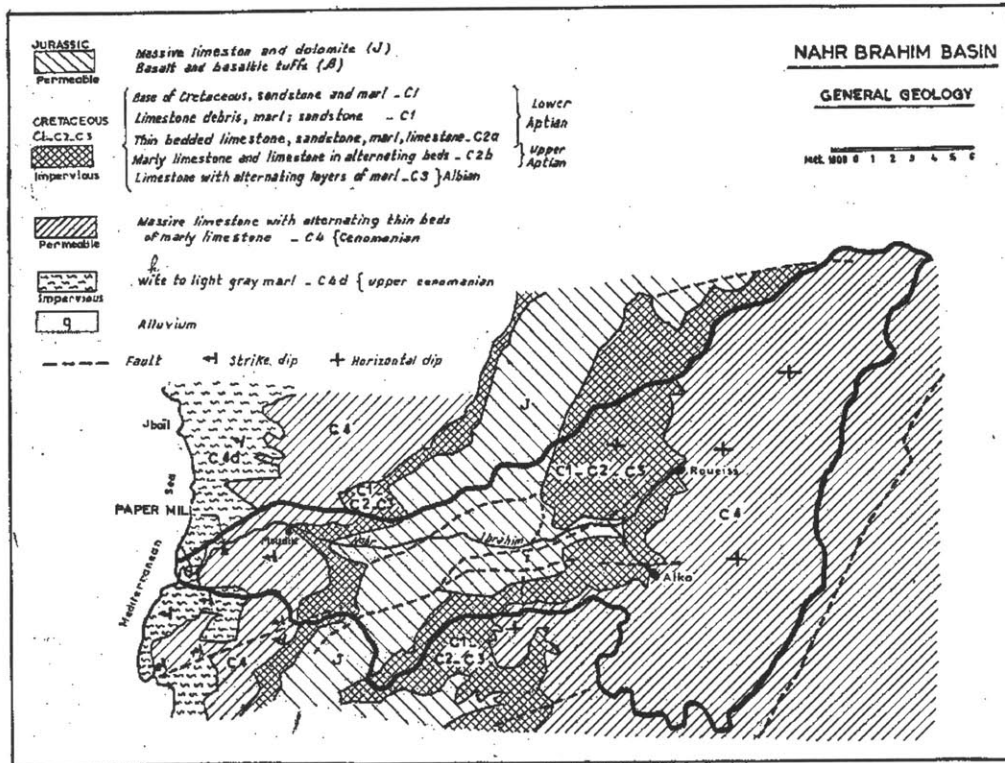


Figure 9 – General Geology: Plan View
(Papazian, 1981)

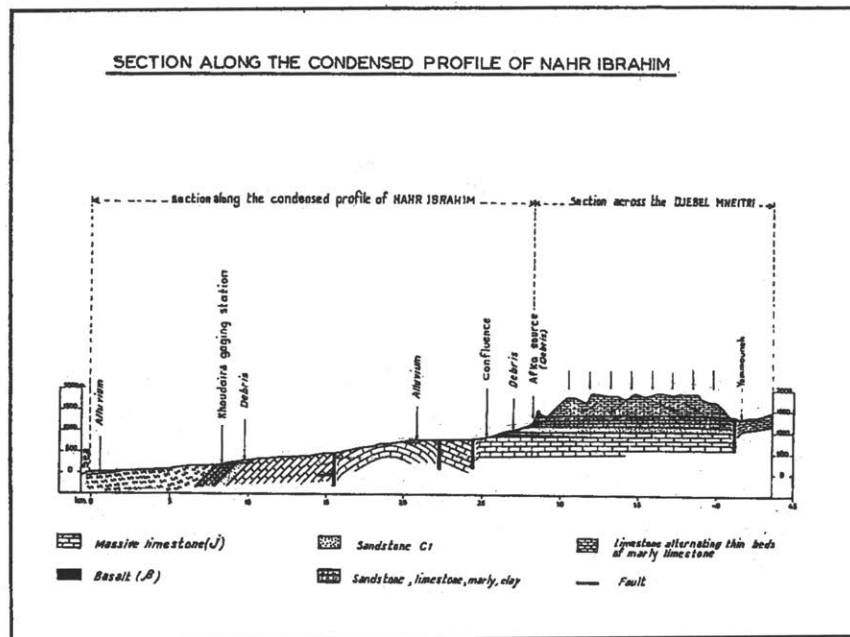


Figure 10 – General Geology: Cross Section
(Papazian, 1981)

In the basin, as in the rest of Lebanon, the major subterranean water reservoirs are located in the compact limestones having a karstic surface. The karst terrain involves a group of pure limestones, the surface of which have been eroded by rainfall into a highly characteristic type of landscape known as Lapiez. The Lapiez is formed by the attack of carbonic acid dissolved in rainwater. When the rain trickles over the rock faces and into cracks and bedding planes it carves channels, caverns and caves. The water in these channels joins together forming torrents and rivers until it reaches the deep surface of unaltered compact limestones. The continuous infiltration of rainfall during the winter season increases the volume of stored water, and maintains the flow of perennial springs all along the year. The majority of the rainfall in the Nahr Ibrahim Basin penetrates into the rock, leaving little to land surface flow. All of the water that seeps into the limestone ultimately reappears as springs flowing from the rock, creating large caves, such as Afqa and Jeita (Papazian, 1981).

There are three major water-bearing aquifers in the Nahr Ibrahim watershed. One Cenomanian aquifer is located at the easternmost portion of the basin. A second is located in the west of the basin. These two aquifers are massive limestone formations with alternating thin beds of marly limestone. Between them lies the Jurassic aquifer, which is comprised of massive limestone and dolomite. Impermeable layers of cretaceous, sandstone, marl, and limestone debris separate these aquifers. Along the border of the basin shared with the Mediterranean Sea is another impervious layer consisting of white to light gray marl. (See Figure 11.)

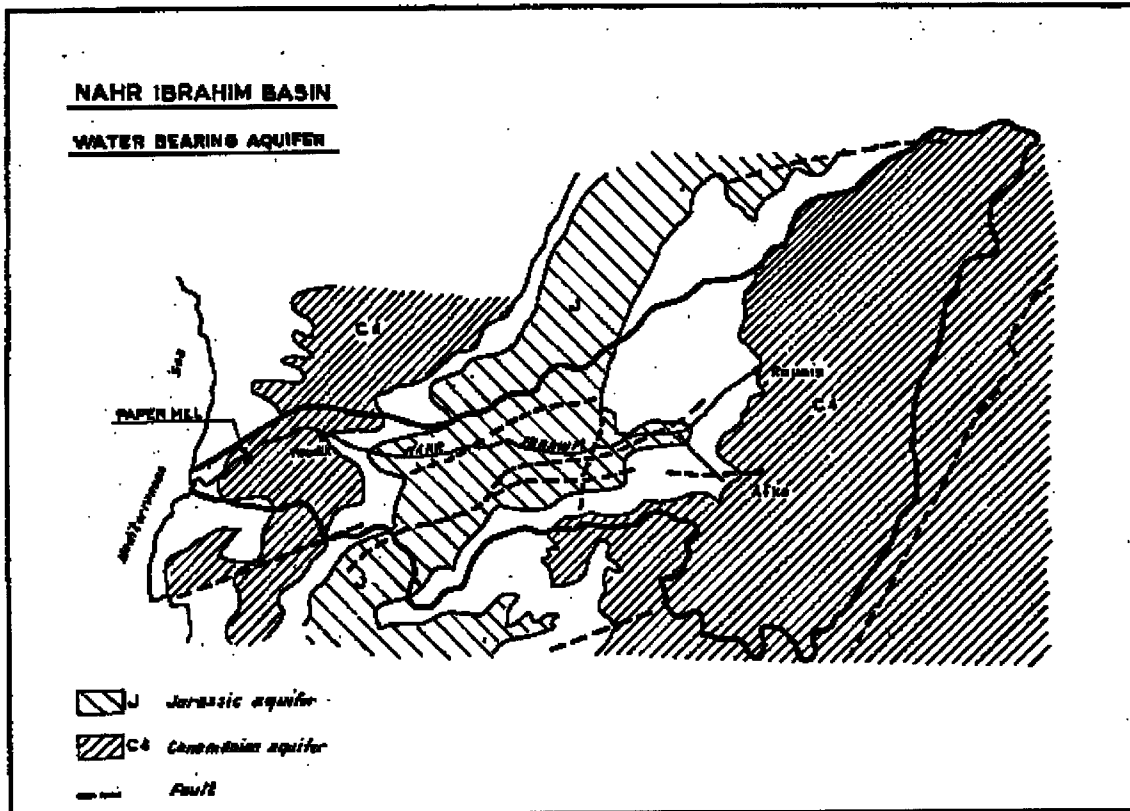


Figure 11 – Water Bearing Aquifers
(Papazian, 1981)

3.2.6 Climate within the Basin²

The Nahr Ibrahim Basin experiences a typical Mediterranean climate, with moderately cold and wet winters and warm, dry summers. The mouth of the river is located in a semi-tropical zone, while the area around the source is considerably cooler. The temperature within the basin spans from approximately 10°C (January) to 24°C (July and August) at low elevations, and from approximately 6.7°C (January) to 23.3°C (August) at high elevations (Papazian, 1981).

The prevailing wind in the basin is estimated to be from the Southwest, with a maximum of 50 m/s based on data from nearby observatories at the Beirut International Airport and the American University of Beirut (Papazian, 1981).

²This section was authored in coordination with Jessica Fox.

The humidity along the coast of Lebanon is relatively high throughout the year, with a continuous influx of moist air from the Mediterranean. In the winter, the Mediterranean cyclonic disturbances produce precipitation. In the summer, the hot, humid air remains along the coast, maintaining high humidity. The precipitation in the basin ranges from an average of 1000 mm at low elevations to 1400 mm at high elevations. The average precipitation over the whole surface of the basin is estimated to be 1300 mm (Papazian, 1981).

3.2.7 Industry in the Basin

Historically, there have been several industries along the river including a tannery, a paper mill, two quarries, and three hydroelectric plants. However, efforts by the Ministry of the Environment have closed down all the industries except for the hydroelectric plants.

3.2.8 Population

There are many small villages inside the Nahr Ibrahim basin. The largest villages are Kartaba (4500 persons in 1980) and Akoura (2000 persons in 1980). In the early 1980s the total population of the basin was roughly 15000 persons. The majority of these people work in agriculture (Papazian, 1981).

Population data was also available from the Ministry of Environment in a GIS database. (See Figure 11.) However, due to the racial tension and political implications, the Lebanese government has failed to conduct any official census for the last few decades. It is unknown to the Ministry of Environment officials how current are the data or the manner with which this unofficial census was conducted. Furthermore, it was unclear who has gathered this information.

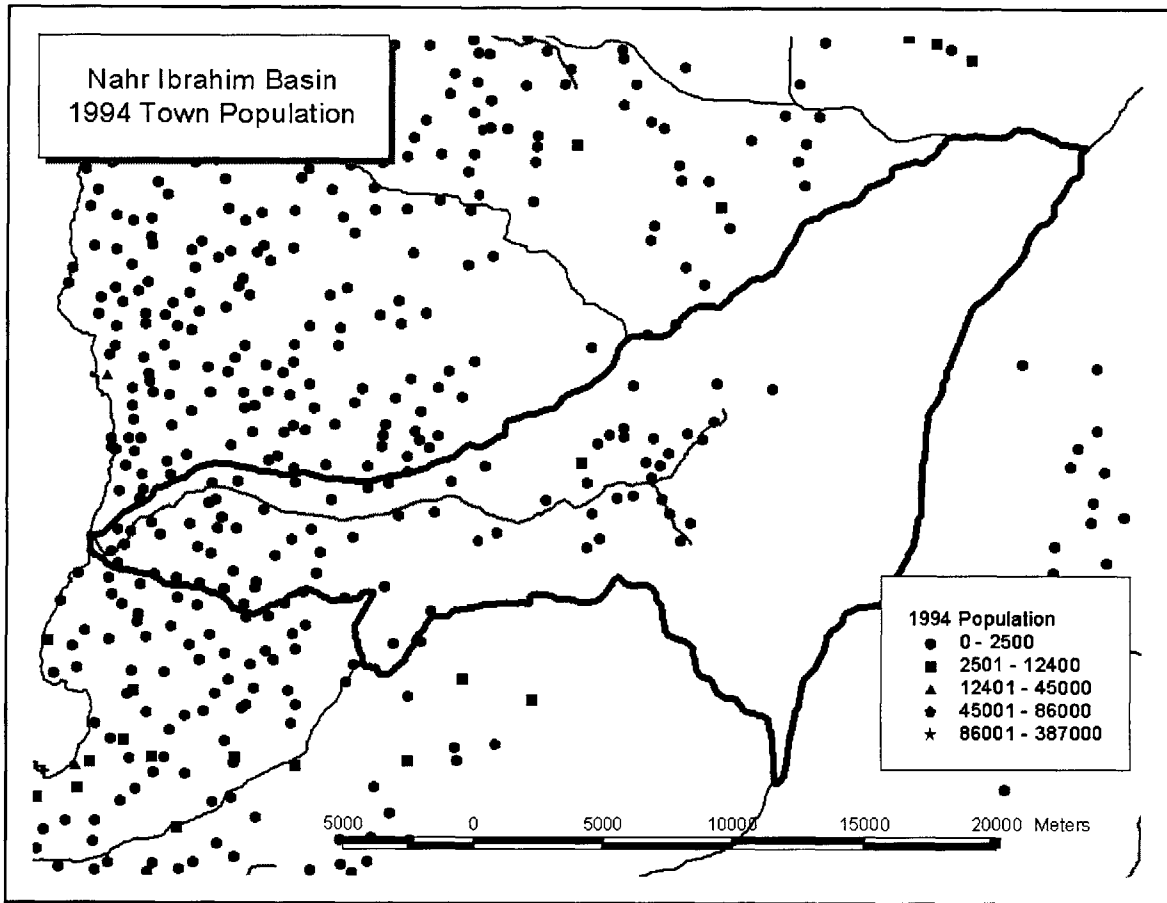


Figure 12 – 1994 Population Data

4 Groundwater-Surface Water Interaction

4.1 Objective

To study the groundwater-surface water interaction, two forms of analysis were used. Firstly, groundwater flow in the watershed was modeled using Groundwater Vistas. Secondly, a mass balance model was created. The mass balance analysis uses flow measurements and precipitation data to estimate the amount of groundwater flowing into or out of the river. The combined results of these two analyses show where the river is gaining and losing.

4.2 Groundwater Flow Model

The groundwater flow in the Nahr Ibrahim Basin was modeled using Groundwater Vistas, which is the graphical user interface for the program MODFLOW. MODFLOW is the USGS modular three-dimensional finite-difference groundwater flow model created by Michael G. McDonald and Arlen W. Harbaugh. The most widely used groundwater model in the world, MODFLOW is accepted by courts, regulatory agencies, universities, consultants, and industry (<http://www.modflow.com/modflow/modflow.html>, visited 3/14/2001).

4.2.1 Inputs

Groundwater Vistas requires the entry of units and grid settings, boundary conditions, and aquifer properties. The settings utilized in the model of the Nahr Ibrahim Basin are described below.

4.2.1.1 Units and Grid

Groundwater Vistas used consistent units in all computations. The Nahr Ibrahim model uses the following:

Length Unit: Meter
Time Unit: Day
Mass Unit: Kilogram

The plan view of this watershed area is divided into a series of columns and rows using a finite difference grid. Only 50 columns are allowed in the student version, which was employed for this project. Thus, in this model the squares are either 500 m high and 1000 m wide or 500 m high and 500 m wide. The more narrow columns were used around the river, where a higher resolution was desired. The finite difference grid used can be seen in Figure 14 and Figure 15.

The model uses two layers. The lower layer ranges from 500 m below sea level to 1300 m above sea level. The upper layer ranges from 1300 m to 1900 m above sea level.

4.2.1.2 Boundary Conditions

A no flow boundary was set around the exterior of the watershed. This boundary condition was based on the assumption that the groundwater flows in coordination with the surface elevation, as seen in Figure 13. A watershed boundary is set based on peak surface elevations, and groundwater table elevations can be assumed to mimic these peaks. The no flow boundary conditions can be seen in surrounding the watershed in Figure 14 and Figure 15.

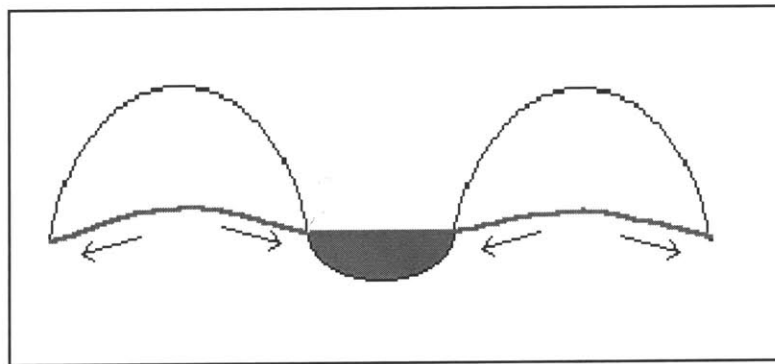


Figure 13 – Watertable-Surface Elevation Relationship

A constant head boundary was used where the Nahr Ibrahim meets the Mediterranean Sea. The sea was given a constant head value of zero meters. The constant head boundary can be seen in leftmost side of Figure 15.

The river was modeled using MODFLOW's river package. River characteristics were entered for the source and mouth of the river. The intermediate points were interpolated from the end data. A summary of the input data is given in Table 3. Realistic

values for the thickness and hydraulic conductivity of the riverbed were difficult to determine, due to lack of data. No core samples of the riverbed were available to determine the thickness. The hydraulic conductivity can be affected by any sediment on the bottom of the river, including silt or organic material such as dead leaves and dead fish. In the absence of available data, these parameters were assumed to be constant throughout the length of the river. The river can be seen in running through Figure 15.

Table 3 – Nahr Ibrahim Characteristics

	At Source	At Mouth
Stage (m)	1300	0
River Bottom Elevation (m)	1299.5	-0.5
Width (m)	2	10
Length (m)	28,000	28,000
Thickness of Riverbed (m)	0.5	0.5
Hydraulic Conductivity (m/s)	10^{-5}	10^{-5}

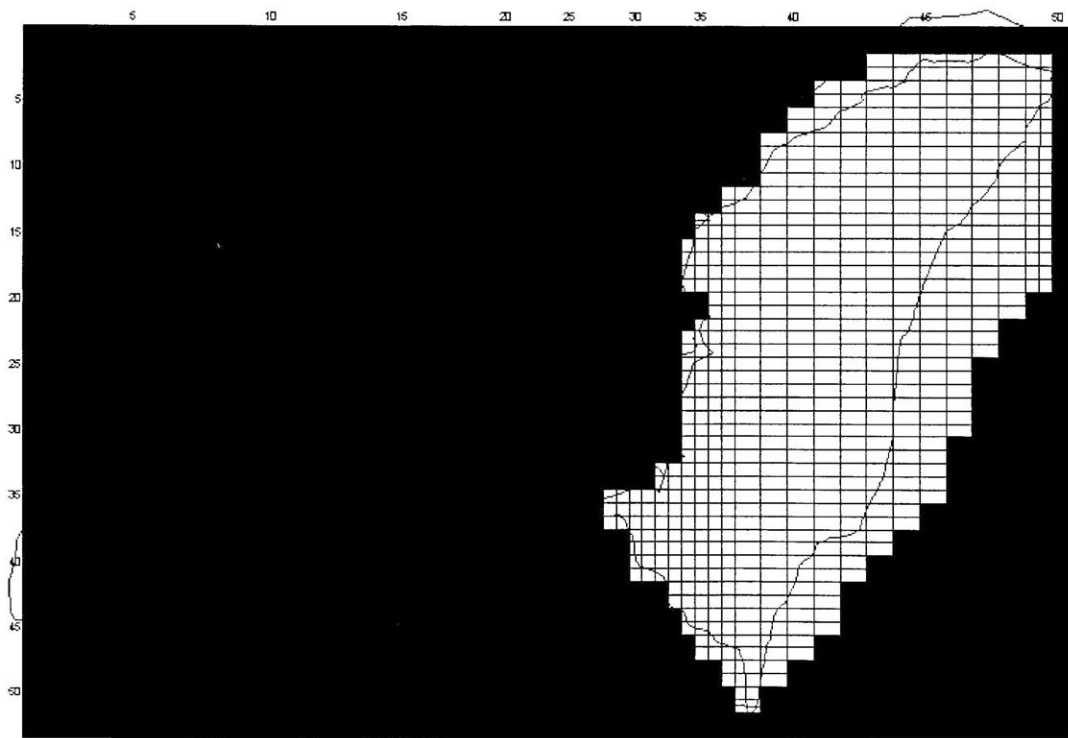


Figure 14 – Groundwater Model: Boundary Conditions, Layer 1

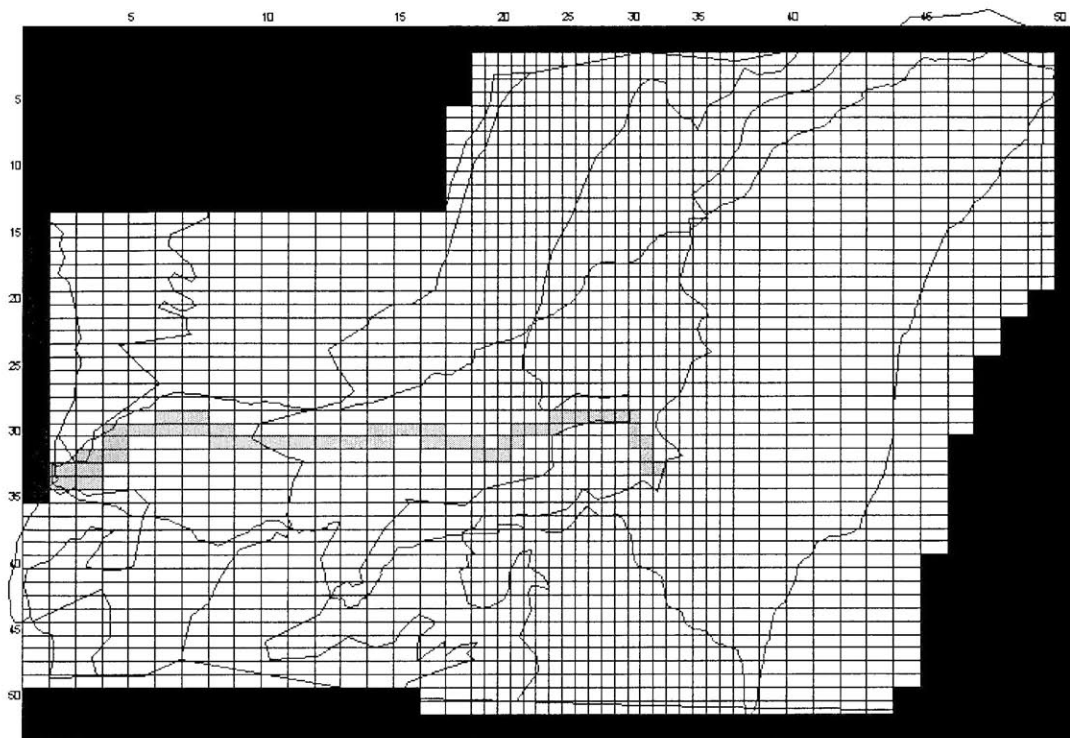


Figure 15 – Groundwater Model: Boundary Conditions, Layer 2

4.2.1.3 Aquifer Properties

The Nahr Ibrahim Basin contains a series of alternating permeable and nearly impermeable strata. A simplification can be seen on the left in Figure 16, where the light colored stratum are permeable, and darker are near-impermeable. This system was modeled in Groundwater Vistas using two layers, as shown on the right in Figure 16. The upper layer of the model represents the first permeable stratum (1) and the first near-impermeable stratum (2). Both strata were modeled in a single layer by using high hydraulic conductivity, K , values for the x and y directions to represent stratum (1), but a low K value for the z direction, to represent stratum (2). The lower layer in the model contains strata (3), (4), and (5). Strata (3) and (5) were assigned high K values, while stratum (4) was assigned a low K value.

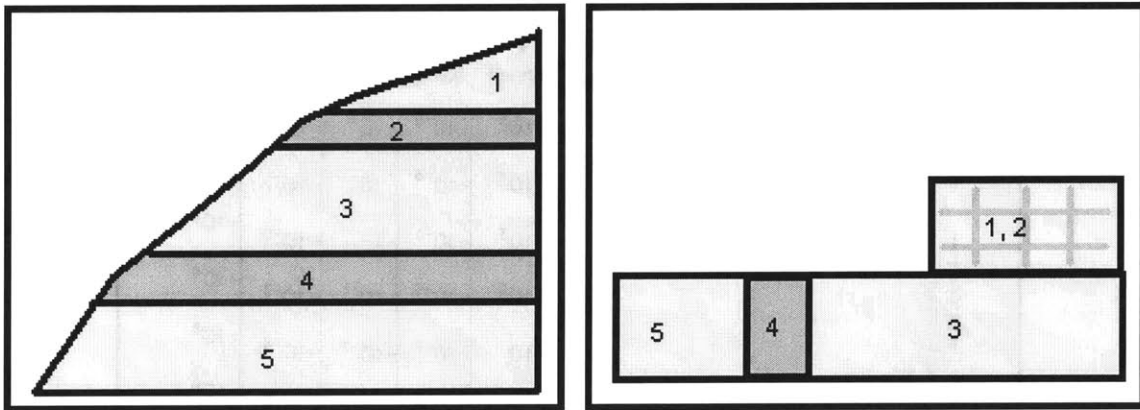


Figure 16 – Groundwater Flow Model Layers

Hydraulic conductivity, K , was specified based on the general geology of the watershed, as shown in Figure 9. Each region was assumed to be homogeneous (i.e. $K_x=K_y=K_z$). The permeable regions are comprised of (a) massive limestone and dolomite, (b) basalt and basaltic tuffs, or (c) massive limestone with alternating thin beds of marly limestone. These were assumed to have a K of 10^{-5} m/s. The near-impermeable regions are comprised of (a) sandstone, marl, limestone debris, (b) thin bedded limestone, sandstone, marl, limestone, (c) marly limestone and limestone in alternating beds, (d) limestone with alternating layers of marl, or (e) white to light gray marl (Papazian, 1981). These near-impermeable regions were assumed to have K of 10^{-8} m/s. The K values were assumed based on the aquifer compositions and values given in “Groundwater,” by Freeze and Cherry, as seen in Figure 17.

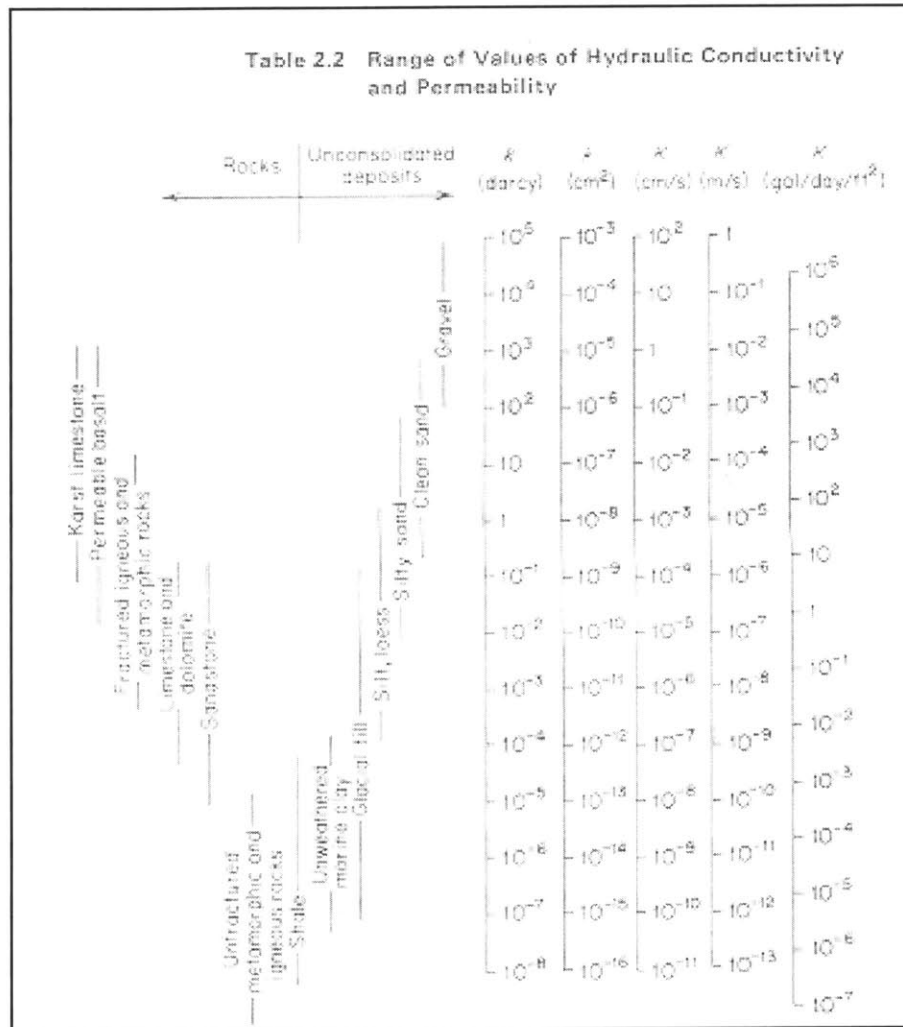


Figure 17 – Hydraulic Conductivities from “Groundwater” by Freeze and Cherry

Hydraulic conductivities, as entered into the model can be seen in Figure 18. The bottom layer, shown in plan view in the figure contains light and dark regions. The lighter regions indicate near-impermeable areas with K equal to 10^{-8} m/s. Darker regions indicate permeable regions with K equal to 10^{-5} m/s. The top layer, (a cross-section is shown at the top of the figure) has $K_x=K_y=10^{-5}$ m/s and $K_z=10^{-8}$ m/s.

These hydraulic conductivities may not accurately represent the region, due to the difficulty associated with modeling karst terrain. As described in Section 3.2.5, karst terrain often contains many underground caverns and flow channels, which would greatly influence the hydraulic conductivity.

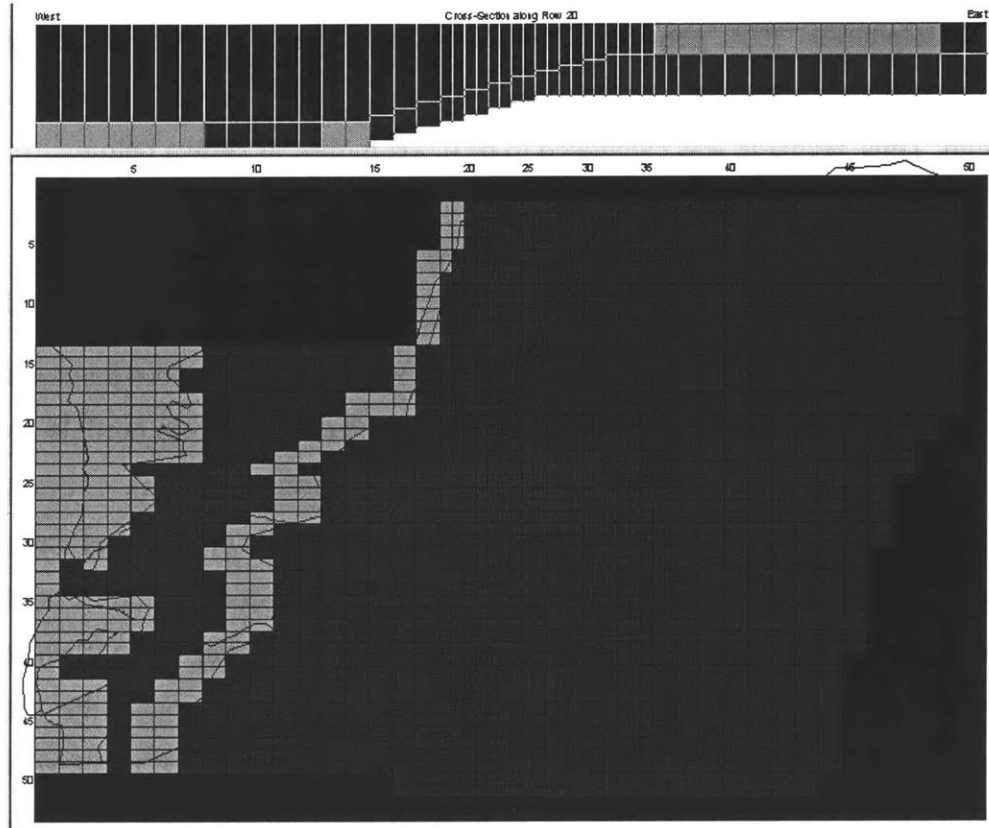


Figure 18 – Groundwater Model: Hydraulic Conductivity

Recharge was assumed to be 0.002 m/day. Hydrogeological studies made on various Lebanese watersheds showed that on an annual basis, 30 percent of precipitation infiltrates into the ground, 13 percent goes to overland flow, and 57 percent is lost to evapotranspiration, as seen in Table 4. The Nahr Ibrahim Basin is different from average Lebanese watersheds, as the large majority of precipitation infiltrates into the ground, most likely due to the karst terrain (Papazian, 1981). Based on these parameters, the Nahr Ibrahim Basin was assumed to have 60 percent of precipitation infiltrate, 10 percent run overland, and 30 percent evapotranspire, as shown in the table below.

Table 4 – Precipitation Allocation

	Average Lebanese Watershed	Nahr Ibrahim Basin
Infiltration	30 %	60 %
Overland Flow	13 %	10 %
Evapotranspiration	57 %	30 %

Precipitation that goes to infiltration recharges the groundwater aquifers. Recharge was calculated based on the percentage of rainfall. Average yearly rainfall is 1300 mm. Thus, recharge was calculated to be 0.002 m/day, as shown below.

$$(1300 \text{ mm/year}) * (0.6) = 0.002 \text{ m/day}$$

Top and bottom elevation for each layer were entered in coordinance with the elevation of the river. Elevations were considered to be constant from north to south (i.e. each column in the finite difference grid has a uniform elevation). Elevation does decrease from east to west, with the profile of the river (i.e. the elevation of each column decreases from right to left). The high mountain elevations (which would be on the north and south of the river) were not entered directly into the model using elevation data. However, they were accounted for with no flow boundaries around the watershed, assuming that the water table follows the contour of the topography, as show in Figure 13. Elevation can be seen in Figure 19. The lower layer ranges from 500 m below sea level to 1300 m above sea level. The upper layer ranges from 1300 m to 1900 m above sea level.

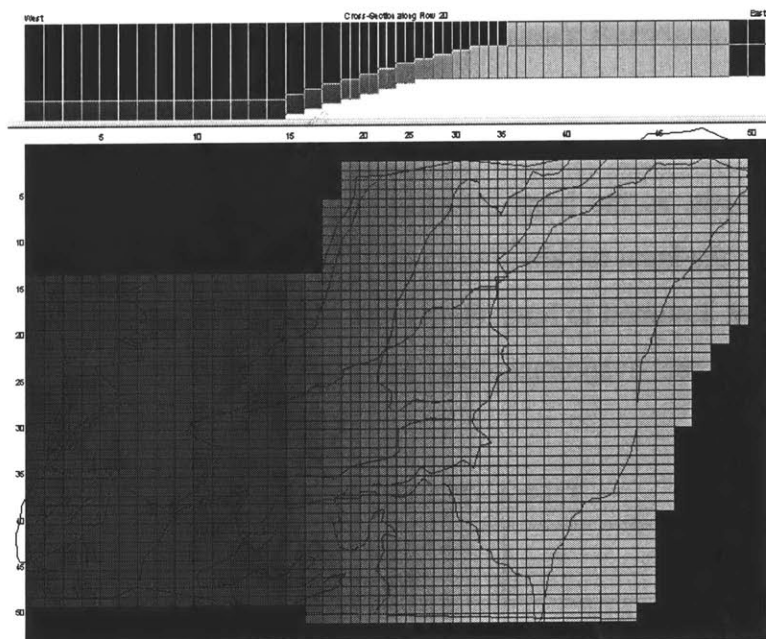


Figure 19 – Groundwater Model: Elevation

4.2.1.4 Unused Parameters

Groundwater Vistas has several parameters that could be entered, but were not used for this simulation, as they do not affect the groundwater flow. These parameters include soil density, evapotranspiration, storage, leakance, porosity, dispersivity, and sorption. These parameters would be useful to input if solute transport analysis was being performed, and may be useful in the future.

4.2.2 Output

The resulting model output shows approximations of the head values within the Nahr Ibrahim watershed. The upper layer reaches heads of 1650 m and decreases to 1450 m, from east to west as water infiltrates into the bottom layer. In the lower layer, heads decrease from east to west, from 1550 m to 0 m, as water flows into the Mediterranean Sea. The head contours for layer 1 and layer 2 and be seen in Figure 20 and Figure 21.

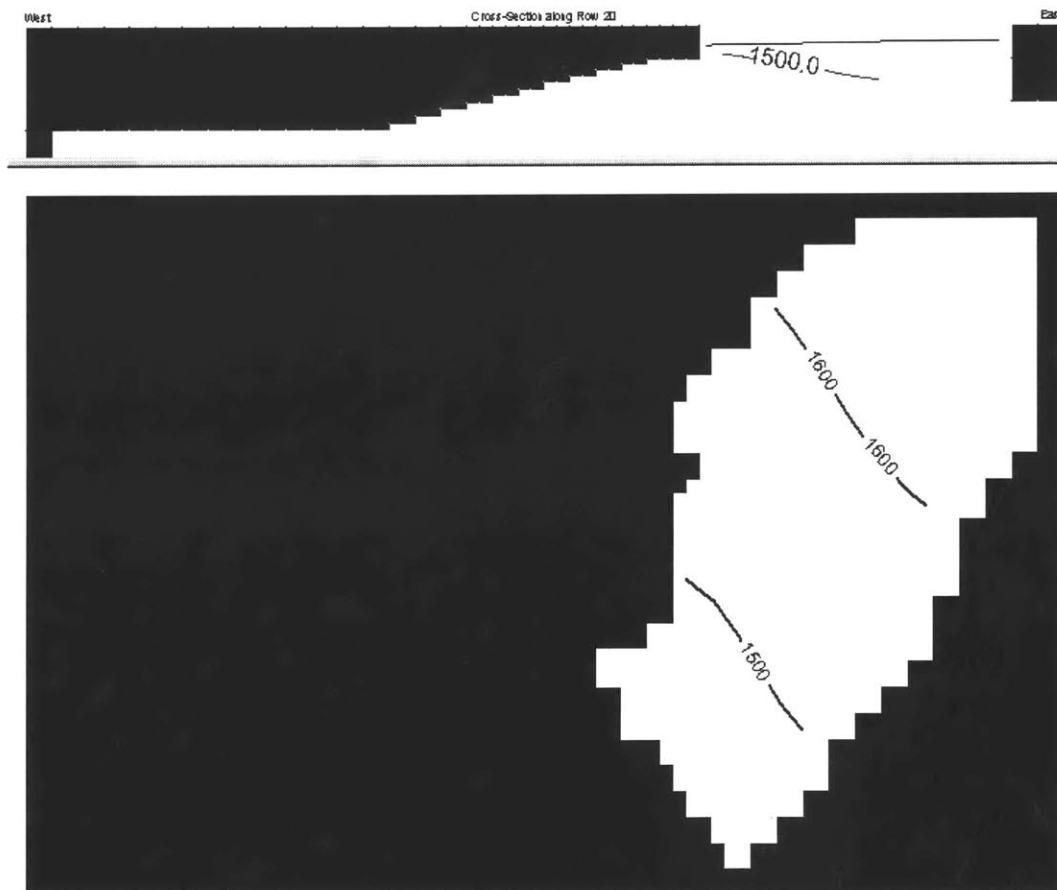


Figure 20 – Groundwater Model: Head Contours, Layer 1

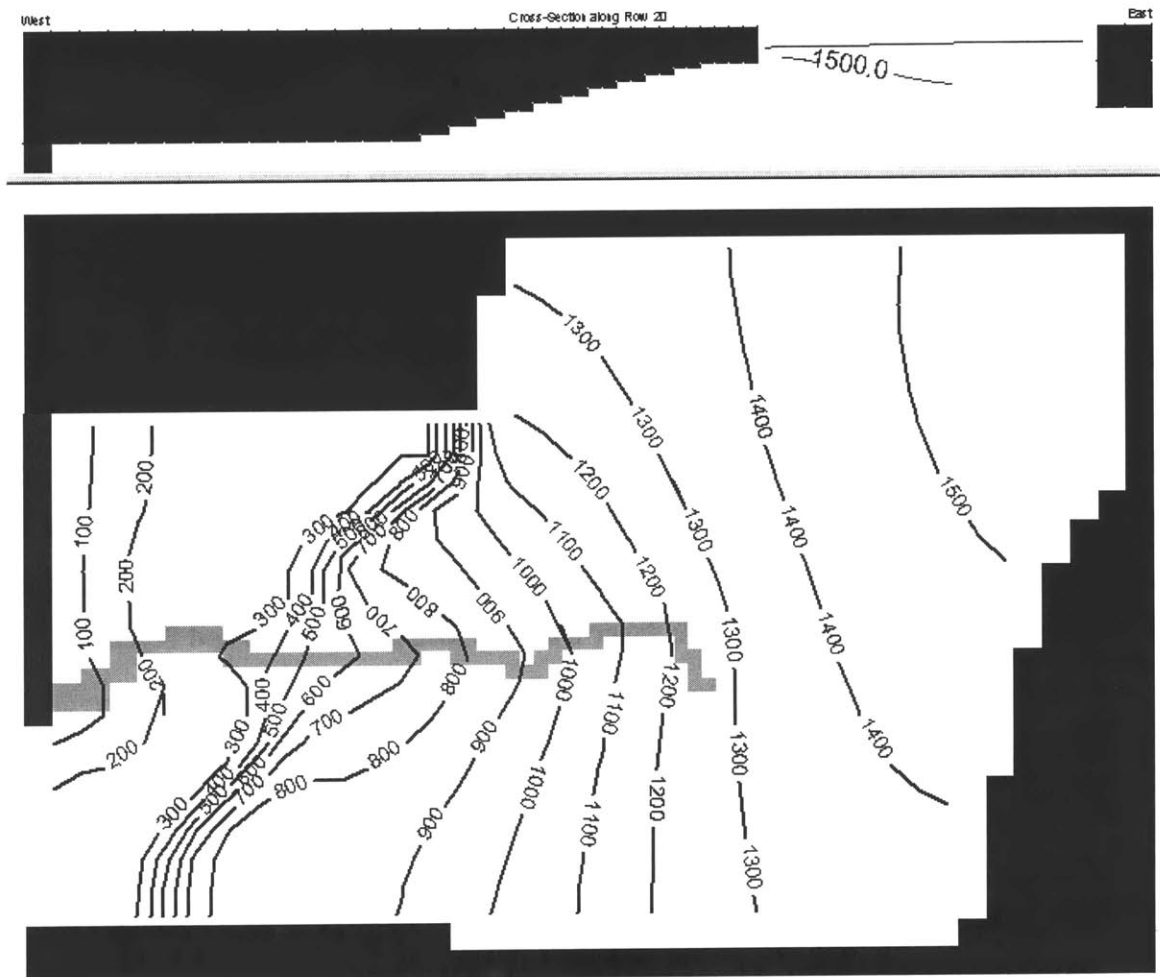


Figure 21 - Groundwater Model: Head Contours, Layer 2

Groundwater flows from high head to low head. The head contour lines around the river can be used to determine if the river is gaining or losing. Head contours shown on the left in Figure 22 are gaining, while contours shaped like those on the right are losing, when the contours on the right have higher values than those on the left. Based on this pattern, the Nahr Ibrahim is both losing and gaining.

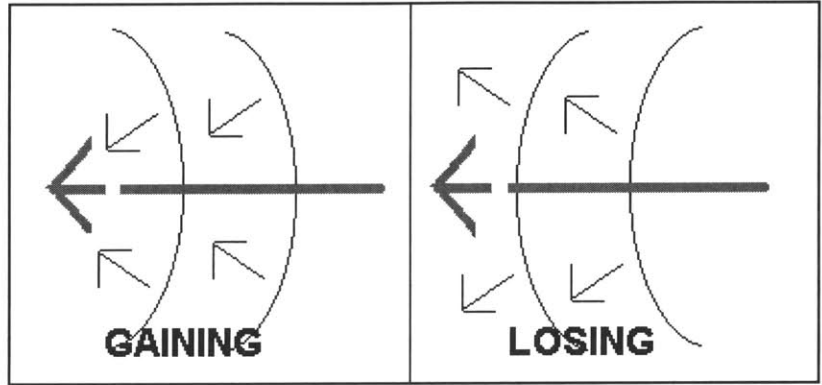


Figure 22 – Gaining and Losing Head Contours

Mass balance was examined in each cell along the river in the computer model to see if they were losing or gaining. Figure 23 shows gaining portions in blue, losing portions in pink, and portions that alternate between gaining and losing in green.

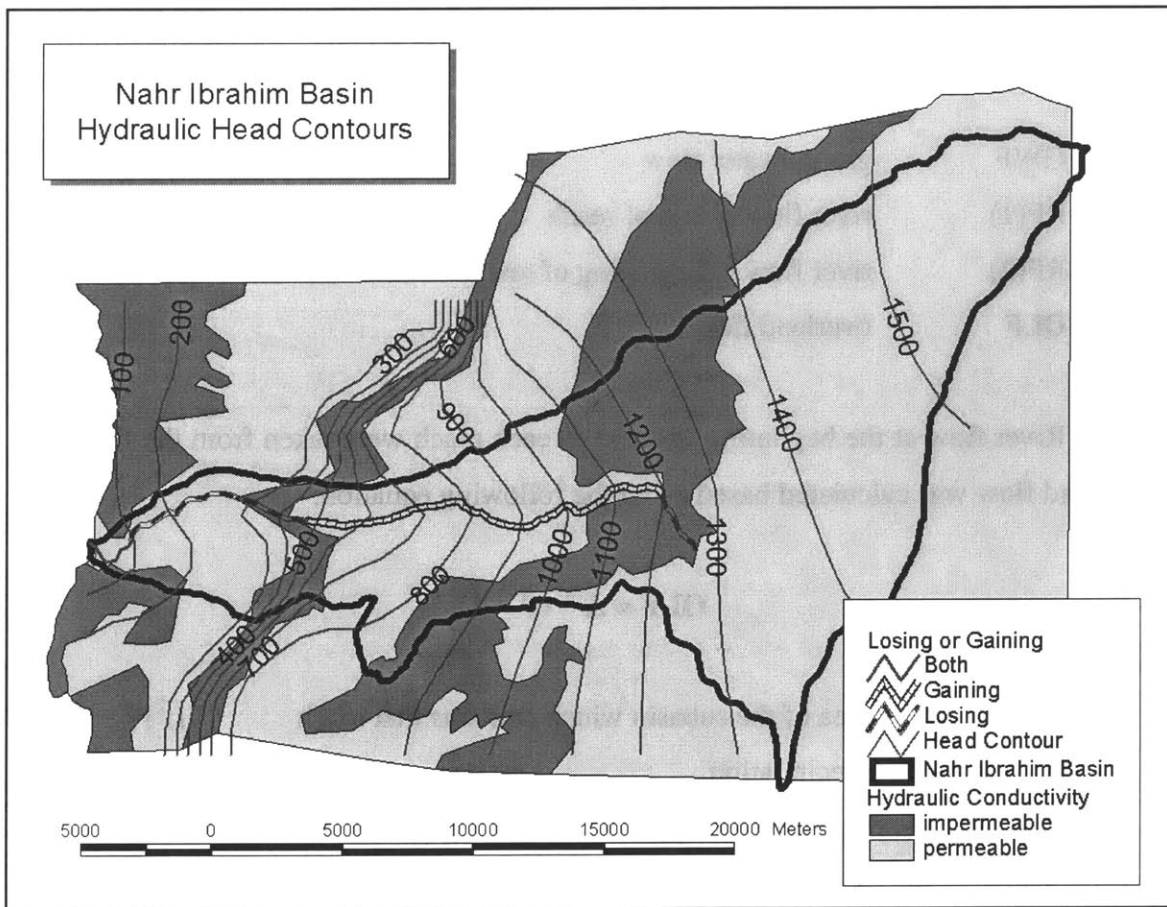


Figure 23 – Groundwater Model: Losing and Gaining

4.3 Mass Balance

In addition to the computer model, two mass balances were constructed using flow data. The first used data from the January 2001 site visit performed by the authors and the second used October data compiled from past reports. These two balances were performed separately to account for three discrepancies in the data. (1) Different flow measurement techniques were utilized, as the authors collected data the using a Rickly Hydrolocigal Company pygmy flow meter, and by the past reports utilized data compiled at gauging stations. (2) Pygmy flow meters report flow at a single time during a single day, while the gauging station data is averaged over many days. (3) The authors collected data for 2001, while the gauging station data is averaged from the 1930s to the 1970s.

Mass balances estimated groundwater flow reaches of the river between two sampling points using the following equation:

$$\mathbf{GWF = RF(1) - RF(2) - OLF}$$

where

GWF	groundwater flow	[L ³ /T]
RF(1)	river flow at end of reach	[L ³ /T]
RF(2)	river flow at beginning of reach	[L ³ /T]
OLF	overland flow	[L ³ /T]

River flow at the beginning and end of each reach were taken from the flow data. Overland flow was calculated based using the following equation:

$$\mathbf{OLF = A * (P - E)}$$

where

A	area of the subbasin which contains that reach	[L ²]
P	precipitation	[L/T]
E	evapotranspiration	[L/T]

Precipitation was based on average monthly precipitation values for January for the site visit data, and October for the gauging station data. October was chosen, as it is a

month with relatively low precipitation and low river flow, so groundwater flow would be more prominent. The results are shown in Table 5 and in Table 6. Sample location (column 1), and flow (column 2) were estimated from report data or measured in the field. Subbasin area (column 3) was calculated in ArcView based on flow sample location and elevation contours. Rainfall (column 4) was taken from Papazian (1981). The percentage of evaporation (column 5) and the runoff coefficient (column 6) were based on the values estimated in Table 4. Runoff (column 7) was calculated using the previously described equation. Surface inflow (column 8) was taken from the river flow in the previous reach. Groundwater flow (column 9) was calculated using the previously described equation. Note that negative values indicate that the river is losing, while positive values indicate the river is gaining. As seen in these tables, the Nahr Ibrahim is both a losing and gaining river.

Table 5 – Gauging Station Groundwater Flow Mass Balance

1	2	3	4	5	6	7	8	9
Location	River Flow	Subbasin Area	Rainfall	Evaporation	Runoff Coefficient	Runoff	Surface Inflow	Groundwater Flow
	m ³ /s	m ²	mm/month	mm/month		m ³ /s	m ³ /s	m ³ /s
Djinni	1.29	203,903,653	63.36	19.01	0.10	0.48	0	0.81
Khouaira	2.00	88,259,766	63.36	19.01	0.10	0.21	1.29	0.50
Mouth	1.70	24,725,762	63.36	19.01	0.10	0.06	2.00	-0.36

Table 6 – Site Visit Groundwater Flow Mass Balance

1	2	3	4	5	6	7	8	9
Location	River Flow	Subbasin Area	Rainfall	Evaporation	Runoff Coefficient	Runoff	Surface Inflow	Groundwater Flow
	m ³ /s	m ²	mm/month	mm/month		m ³ /s	m ³ /s	m ³ /s
Site 1	0.08	51,174,437	320.00	96.00	0.10	0.43	0.00	-0.34
Site 2	0.82	108,954,895	320.00	96.00	0.10	0.91	0.00	-0.09
Site 4	0.61	125,858,894	320.00	96.00	0.10	1.05	0.91	-1.35
Site 6	0.22	4,533,950	320.00	96.00	0.10	0.04	0.61	-0.43
Site 7	0.12	2,235,473	320.00	96.00	0.10	0.02	0.22	-0.11
Site 8	2.05	7,701,086	320.00	96.00	0.10	0.06	0.12	1.86
Site 9	4.05	2,457,824	320.00	96.00	0.10	0.02	2.05	1.98
Site 10	1.98	13,028,516	320.00	96.00	0.10	0.11	4.05	-2.18
Site 11	3.54	584,860	320.00	96.00	0.10	0.00	1.98	1.55

The results can be seen graphically in Figure 24. Note that the results are shown as points, but the value at these points is really the average for the entire reach. A reach begins at the previous sample location and ends at sample location which is labeled

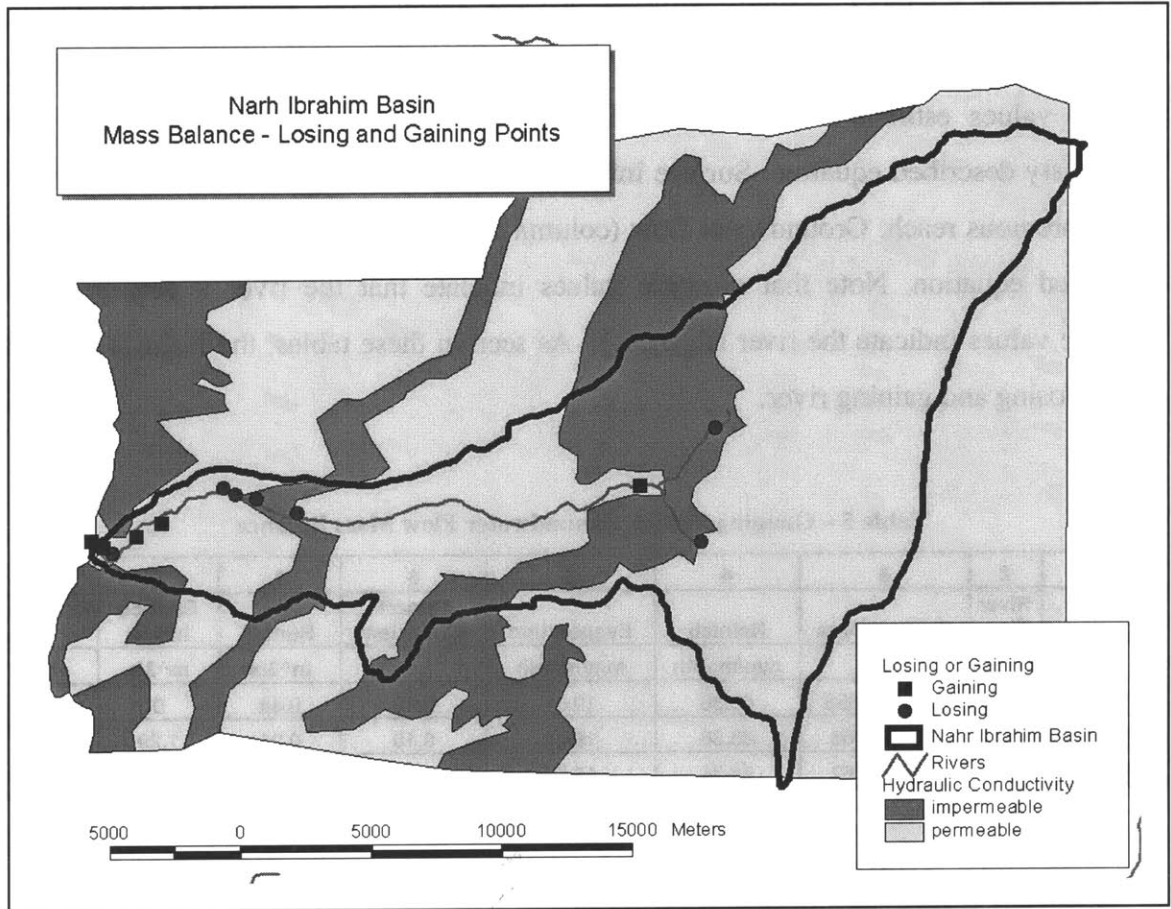


Figure 24 – Mass Balance: Losing and Gaining Points

The flow values measured during the site visit are estimations and have a certain amount of error associated with them. In order to assess the sensitivity of this data the error will be assumed to be 30 percent, as several measurement factors could contain error. There could be error with the flow meter (such as the wheel is not spinning freely). There could be error associated with user inexperience (this was the author's first time using such a device). The river cross-section was extremely approximate. Volume of flow using the measured speed and cross section was calculated using approximations. Also

note that while these flow values are specific values measured on a certain day, the rainfall and evapotranspiration are estimated using average values.

Groundwater flow, GWF, was calculated based on the river flow (RF) at the beginning and the end of a reach, as defined by the data collection points. These terms could be 30 percent higher or lower than the actual value. A high groundwater flow value was calculated assuming that the flow RF(1) was high, and RF(2) was low. A low GWF value was calculated using the low estimate for RF(1) and a high estimate for RF(2), as shown in the equations given below.

$$\text{HIGH GWF} = 1.3*\text{RF}(1) - 0.7*\text{RF}(2) - \text{OLF}$$

$$\text{LOW GWF} = 0.7*\text{RF}(1) - 1.3*\text{RF}(2) - \text{OLF}$$

The results of this sensitivity analysis are shown in Figure 25. Table 7 shows at each location, for high, average, and low, whether the river is gaining or losing for that reach. With the exception of Site 2 and Site 11, the high and low estimates are consistent with the average value calculated. Based on this analysis, Site 2, which is located near the Spring Roueiss, could be losing or gaining. The groundwater flow at this reach is relatively small (near zero), and could easily be above or below, losing or gaining. At Site 11, the High GWF estimate, and the Average GWF estimate are well above zero, while the Low GWF Estimate is just below zero. Most likely this reach is gaining. However, note that the flow in this portion of the river alternates from gaining to losing, so if Site 11 is losing, it is consistent with the analysis.

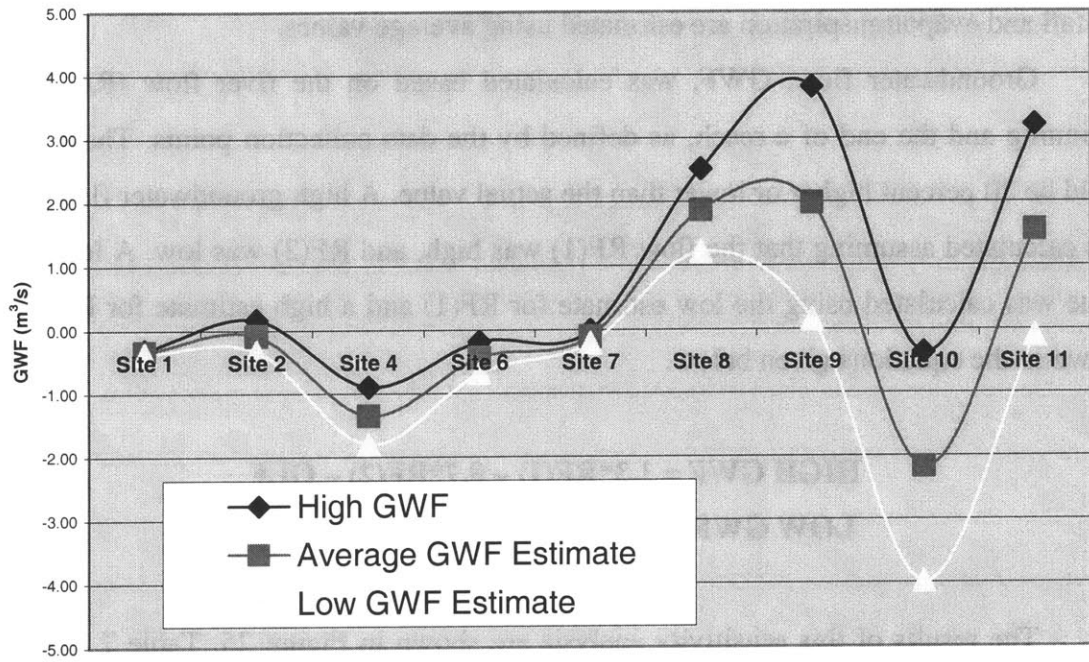


Figure 25 – Sensitivity Analysis

Table 7 – Sensitivity Analysis: Losing or Gaining

	HIGH	AVERAGE	LOW
Site 1	L	L	L
Site 2	L	G	L
Site 4	L	L	L
Site 6	L	L	L
Site 7	L	L	L
Site 8	G	G	G
Site 9	G	G	G
Site 10	L	L	L
Site 11	G	G	L

5 Conclusion

5.1 Results

The results from the groundwater flow model and the mass balance show that the Nahr Ibrahim is both a losing and gaining river. Figure 26 shows the combined results from the two types of analysis. Although both forms of analysis show that the river is both losing and gaining, they are not completely consistent in identifying same portions of the river as losing and gaining.

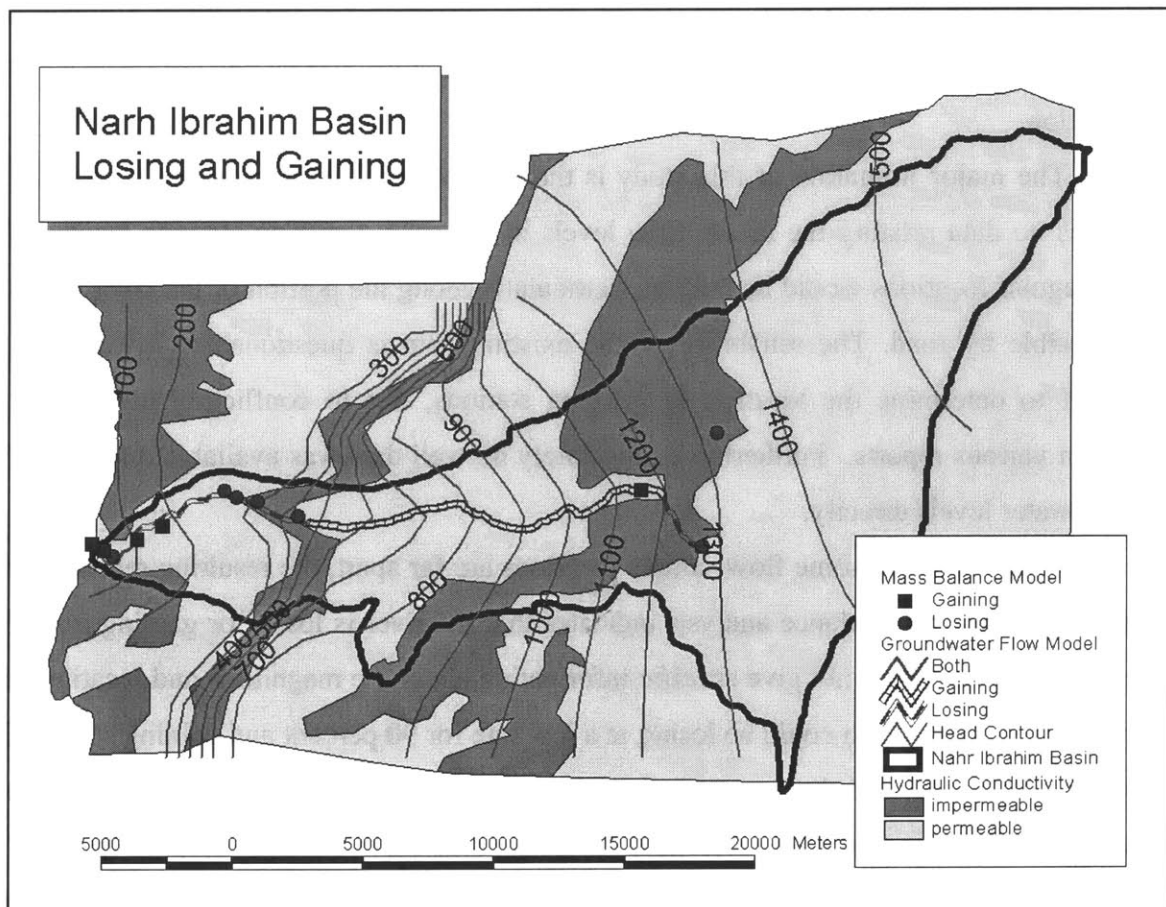


Figure 26 – Gaining and Losing River

Note that in Figure 26 each point from the mass balance model really indicates that the reach up to that point is gaining or losing, not only at that certain point. Look at the reach stretching from the source to where Nahr Ibrahim meets Nahr Roueiss. The

groundwater flow model indicates that this portion is losing, while the mass balance model indicates that it is gaining. For the next reach (through the permeable region in the middle of the basin) the groundwater model indicates that the river is gaining, while the mass balance indicates that it is losing. Through the following near-impermeable strata, both models are consistent in indicating that the river is losing. From that point to the sea, according to both models, the river alternates between losing and gaining.

5.2 Limitations

There are several limitations associated with this study. Due to these limitations, the two types of analysis gave conflicting results. Improvement upon these limitations would yield in more accurate analysis of the Nahr Ibrahim groundwater-surface water interaction.

The major limitation of this study is the lack of reliable data, or any data at all. There is no data relating the recent flow levels in the river. Gauging stations located at more regular locations would be helpful, particularly along the portion of the river that is inaccessible by road. The reliability of the existing data is questionable. It was often difficult to determine the location of gauging stations, due to conflicting information given in various reports. Furthermore, absolutely no well data was available, to measure groundwater levels directly.

Note that since some flow sample locations are far apart, the resulting reaches are quite long. The mass balance analysis indicates that the river is losing or gaining for the entire reach, but it does not give specific information about the magnitude and location of this loss or gain. A reach could be losing at a low rate for 90 percent and gaining at a high rate for 10 percent, and the entire reach could be labeled as either losing or gaining. It may be wise for this analysis to disregard the longer reaches in the mass balance analysis.

Other difficulties in modeling this basin are the same associated with any similar basin. Karst terrain is extremely difficult to accurately model, due to the unknown nature of the fracture system. Also, the hydraulic conductivity of the riverbed is difficult to estimate, due to the debris that could be settled there.

A final issue is with the way that MODFLOW handles river information. River elevation is entered for the source and mouth of the river. The intermediate points are

interpolated to be a straight line. This straight line is not consistent with the Nahr Ibrahim. The groundwater flow model actually models the river as though it were in deep into the ground for some portions and levitating in the air for other portions.

5.3 Further Studies

Although this study has determined that the Nahr Ibrahim is both losing and gaining, further study is required to determine which portions are losing and which portions are gaining. Such a study could build upon the groundwater flow model or the mass balance analysis that were created for this study.

If the groundwater flow model is used, further enhancements of the model should be made. The river elevation data should be entered in such a way that the river is at the surface elevation, not above or below it. Spring location and flow data is available, and could be incorporated into the model using MODFLOW's drain package.

Building upon the mass balance model requires more data than is currently available. Flow measurements, taken at more regular locations using uniform sampling methods, are essential. A greater number of sampling points will alleviate the uncertainty associated with long reaches.

Furthermore, groundwater-surface water interaction studies, using any model, could be performed at various times throughout the year to see if there is a seasonal fluctuation.

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Appendix A: Nahr Ibrahim Cross-Sections

CROSS SECTIONS OF NAHR IBRAHIM

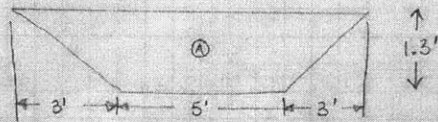
- * All cross sections drawn so that flow is coming out of the page.
- * All widths are approximate.
- * Cross sections are not drawn to scale.
- * All flow readings were taken at approximately $\frac{1}{2}$ of the depth. (This exclude the leaf time trials which were at the surface.)
- * "fps" = feet per second

50 SHEETS
100 SHEETS
200 SHEETS



If you have any questions, ask!

Location #1 (016)



(Width of River)
Estimated

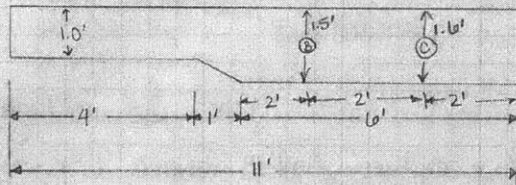
Ⓐ $110 \text{ rev} / 60 \text{ sec} = 0.288 \text{ fps}$

3.0 F³/s

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS



Location #2 (017)



Ⓑ $53 \text{ rev} / 40 \text{ sec} = 1.324 \text{ fps}$

Ⓒ $108 \text{ rev} / 40 \text{ sec} = 2.665 \text{ fps}$

29.1 F³/s

leaf time trials

8 feet

2.21 sec = 3.620 fps

2.86 sec = 2.797 fps

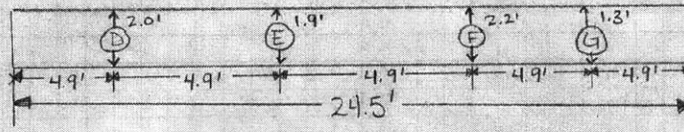
2.47 sec = 3.239 fps

avg. 3.219 fps at surface

Location #3 (018)

A tributary.
No cross section measurements taken.

Location #4 (020)



Ⓓ 9 rev / 40 sec = 0.248 fps

Ⓔ 9 rev / 40 sec = 0.248 fps

Ⓕ 20 rev / 40 sec = 0.516 fps

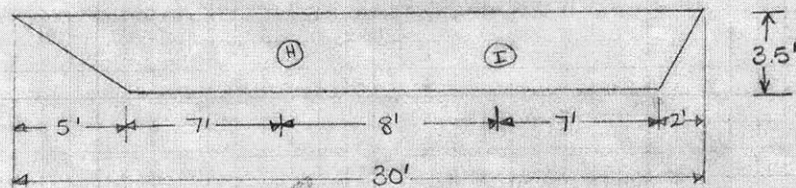
Ⓖ 10 rev / 40 sec = 1.000 fps

21.6 F³/s

Location #5 (021)

No cross section taken, due to close proximity to dam.

Location #6 (023)



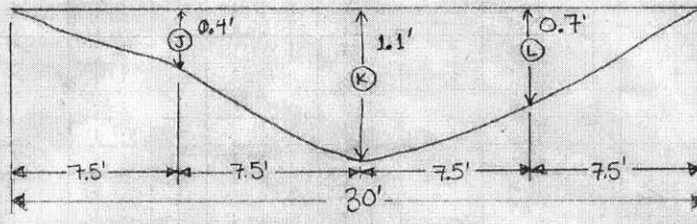
Ⓗ 1 rev / 60 sec = 0.028 fps

Ⓘ 7 rev / 60 sec = 0.142 fps

7.6 F³/s

50 SHEETS
100 SHEETS
200 SHEETS
22-141
22-142
22-144
AMPRO

Location #7 (024)



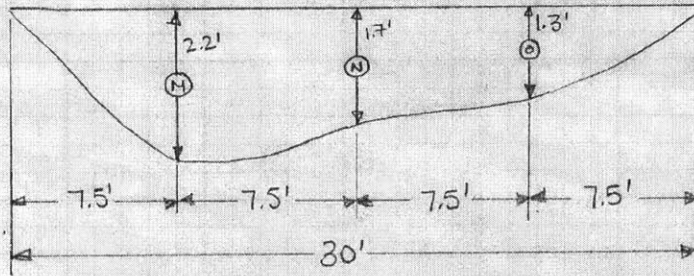
Ⓜ 17 rev / 40 sec = 0.443 fps

Ⓝ 12 rev / 40 sec = 0.321 fps

Ⓞ 0 rev / 40 sec = 0 fps

4.3 F³/S

Location #8 (025) After Quarry



Ⓜ 140 rev / 40 sec = 3.446 fps

Ⓝ 85 rev / 40 sec = 1.373 fps

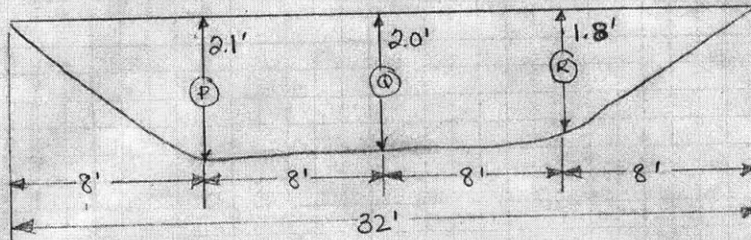
Ⓞ 71 rev / 40 sec = 1.760 fps

72.4 F³/S

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS



Location #9 (0216)



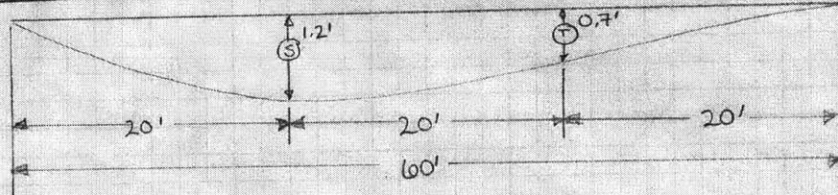
Ⓟ $106 \text{ rev} / 40 \text{ sec} = 2.65 \text{ fps}$

Ⓠ $220 \text{ rev} / 40 \text{ sec} = 5.5 \text{ fps}$

Ⓡ $147 \text{ rev} / 40 \text{ sec} = 3.675 \text{ fps}$

143 F³/S

Location #10 (027)

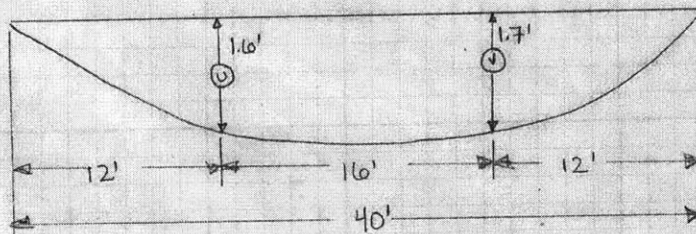


Ⓢ $86 \text{ rev} / 40 \text{ sec} = 2.15 \text{ fps}$

Ⓣ $54 \text{ rev} / 40 \text{ sec} = 1.35 \text{ fps}$

70 F³/S

Location #11 (028)



Ⓤ $76 \text{ rev} / 40 \text{ sec} = 1.9 \text{ fps}$

Ⓟ $64 \text{ rev} / 40 \text{ sec} = 1.6 \text{ fps}$

125 F³/S

6421-34