Maintaining Rainwater Harvesting Practices in Southern Lebanon: the *kaza* of Tyre

by

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Abstract

Despite relatively extensive surface water and groundwater networks, along with abundant rainfall, Lebanon is facing water scarcity due to factors such as pollution of freshwater resources, climate change, population growth, and increased demand. Limited surface water resources in southern Lebanon have fostered a cultural tradition of rainwater harvesting in the area. Rain is collected on both the household and the community level through rooftop and runoff collection systems (i.e. *birki*s), respectively. Rainwater harvesting has the potential to play a major role in achieving water security in Lebanon by acting as an emergency water supply. However, several of the towns in the area have decreased their dependence on privately collected rainwater and have further been considering whether to maintain *birki*s.

A comparative analysis of two specific towns in the *kaza* of Tyre is used to better understand what drives the local decision to maintain rainwater-harvesting practices. Calculations show that the estimated water supply from rainwater harvesting could be used to meet the basic water needs of the respective populations in an extended dry season. In addition, five factors are identified as possible driving forces in the *birki* maintenance decision: land scarcity, cultural shift (i.e. a divergence from traditional practices), public health and safety, water needs, and organizational capacity. This research can be helpful in amending the design of *birki*s to address these drivers while preserving the water-storing capacity of the *birki*. Opportunities for further study are also identified.

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In Loving Memory…

Amou Nakhleh, may the world know
how many lives you have deeply touched,
as I am sure the Lord already does.

TABLE OF CONTENTS

FIGURES

TABLES

~ CHAPTER 1 ~

Introduction and Problem Statement

While the Middle East region has limited water resources (World Bank, 2008), Lebanon is particularly well endowed in this aspect, such that water is often listed as one of its natural resources (CIA, 2007). These resources arise from a combination of extensive surface-water networks, significant groundwater reserves, and relatively abundant precipitation in the winter. Yet even with full exploitation of the country's available freshwater resources, serious water shortages are projected for Lebanon in the next ten to fifteen years (Metni, 2004; Halwani, 2009). Lebanon's water resources are discussed in more detail in Chapter 2.

This thesis posits that traditional rainwater harvesting practices may potentially play a role in achieving water security for towns in southern Lebanon. Research shows that during a drought in India, villages that continued to harvest rainwater, even after the introduction of piped networks, were not significantly affected by water scarcity (CSE, 1997). Meanwhile, villages that no longer harvested rainwater experienced acute water crisis. It is hoped that a similar outcome would result from maintenance of rainwater harvesting practices in southern Lebanon.

Rainwater harvesting in southern Lebanon takes place on two different scales: private water collection and community water collection. Both of these collection methods were studied during the summer of 2008 in two towns in the southern *kaza* of Tyre. Detailed information about these practices can be found in Chapter 3. Private collection may occur via either rooftop or runoff rainwater-harvesting systems. In this case, water is stored in privately owned cisterns. Community collection, on the other hand, is done by capturing runoff from a large area in which the slope of the land surface directs water to a common point (i.e. catchment area). This common point is typically a large, open, earthen cistern with stone walls, locally referred to as a *birki*.

Based on discussions with aid-providing organizations and town officials, many towns in southern Lebanon are currently deciding whether their *birki*s should be maintained. Some towns are working to keep and maintain their existing *birki*, while others are allowing the *birki* to fall into disrepair or removing it altogether. At this point, it is unclear what is driving these decisions. If we can understand what drives the decision to maintain a *birki*, then we can propose alternatives that address those drivers while still preserving the water-harvesting capacity of the *birki*s.

This study attempts to identify what drives the decision to maintain a *birki* in Southern Lebanon through a comparative analysis of two local towns, each of which is making a different decision. Site visits and interviews were conducted in July and August of 2008 for two towns in the *kaza* of Tyre. The case examples of these two towns—Town A and Town B—are included in Chapter 3. Estimations of the rainwater harvesting potential in both towns are discussed at the beginning of Chapter 4 to ascertain if there is any significant hydrologic reason for variance in rainwater harvesting practice between the two locations. Alternative explanations for different decisions in *birki* maintenance are developed based on a comparison of town characteristics. The two towns were different in a variety of aspects, making it difficult to determine a simple explanation for their respective decisions. However, enough information was gathered during site visits to hypothesize a series of plausible decision drivers, which are also discussed in Chapter 4.

Chapter 5 concludes this thesis with a discussion of how the various drivers identified in Chapter 4 can be addressed while maintaining the *birki*s' water-harvesting capacity. Also discussed are ways in which the results can be practically applied to projects in Lebanon by adapting the design of newly installed *birki*s.

~ CHAPTER 2 ~

Water Management in Lebanon

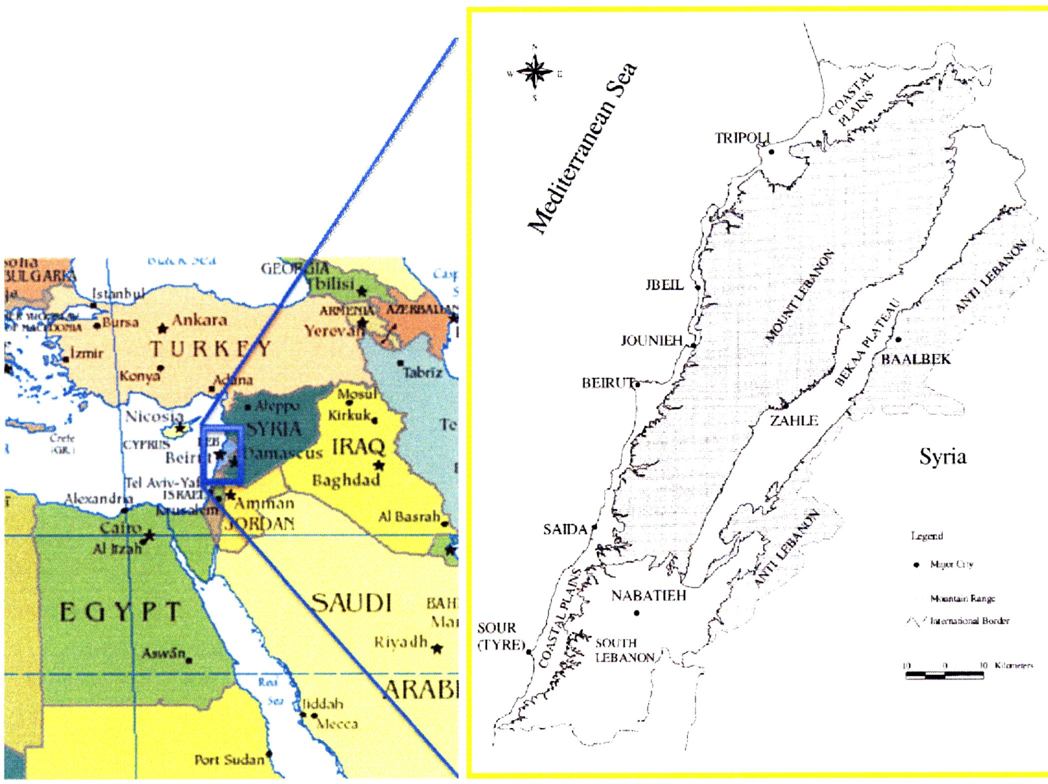

Figure 1. Lebanon's geographic location and physiography (adapted from El-Fadel, 2000)

Lebanon is a small country in the Middle East, about four-fifths the size of the state of Connecticut. It is bordered to the south by Israel, to the north and east by Syria, and to the west by the Mediterranean Sea (Figure 1). The capital, Beirut, is located along a narrow coastal plain, the eastern portion of which is bordered by the first of the country's two mountain ranges—the Lebanon Mountains and the Anti-Lebanon Mountains. These mountain ranges run parallel for almost the entire length of the country from north to south. The area in between the two ranges is known as the Bekaa Valley.

Lebanon, with its rich history and culture, has ample water resources in its rain, surface water, and groundwater sources. This chapter looks at these resources and the way that they are managed in the context of water security. It further examines the importance of rainwater harvesting and the role it can play in achieving water security.

Cultural Context of Water

The importance of water as an element to life has earned it increasing international recognition as a basic human right (Klawitter, 2005). In 2002, the United Nations Committee on Economic, Social and Cultural Rights adopted a General Comment on the Human Right to Water. Consequently, governments are required to supply "sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic use" (UN, 2002), regardless of religion, political alliance, or economic status. Lebanon's acceptance of the principle that water is a basic human right is evidenced by the country's ratification of several major human rights conventions (Makdisi, 2007). However, it can be argued that Lebanon has yet to incorporate these ideas meaningfully into its legal and administrative structures to reflect the principles in practice (Makdisi, 2007).

Lebanon's diverse history has resulted in significant foreign influence on water law and a myriad of religious, sectarian, and economic divisions. To a certain degree, economic disparity can be linked to differences in religion and political power (Cobban, 1985). Areas with the most religiously, politically, and economically disadvantaged populations tend to be the ones that also have the least access to water resources (El-Fadel, 2000).

Foreign Influence

Lebanon has experienced a rich and diverse history, with influences from a number of foreign entities, including the Romans, the Ottomans, the British, and most recently, the French. The time spent as a French Mandate from its creation in 1918 to its independence in 1943 has had a long-lasting effect on the culture, with Beirut often being referred to as the Paris of the Middle East. It is still common to hear French expressions woven into the Arabic dialect used by Christians in Lebanon. Barring the dangers of occasional conflict, Lebanon is considered tourist-friendly. French and English are widely spoken along with Arabic.

Foreign influences have also affected the development of Lebanese water law. Lebanon's water laws are largely based on a combination of both Ottoman *Mejelle* code and French Mandate laws (Makdisi, 2007; Caponera, 2007). In general, Lebanese water law places water in the public domain and prohibits its sale for profit. The only exceptions to this limit on private ownership are: (1) rainwater collected by individuals, (2) resources under a certain volume that are extracted from private land and do not come directly from a river, and (3) water for which the rights were acquired and claimed prior to 1925.

The Ottoman *Mejelle* code is a codification of Islamic water laws, or *Shari`a* (Caponera, 2007). For this reason, *Shari`a* overlaps significantly with Lebanon's water law, with one important distinction: protection of land surrounding bodies of water. Islamic teachings encourage followers to embrace the role of environmental stewards and maintain cherished resources, especially water, to which all people have equal rights of access (Faruqui, 2001). The protection provided under *Shari`a* also maintains the quality and enables the sustainability of local water resources.

Religious Diversity and Sectarian Divisions

As a result of the way that its boundaries were drawn in 1943, Lebanon has three major religious populations: Maronite Christians, Sunni Muslims, and Shi`a Muslims. According to a 1932 census, the Maronites were the largest group with 29 percent of the total population, followed by the Sunni with 21 percent of the total population, and then the Shi`a, who comprise almost 18.5 percent of the total population (Anderson et al. 2007).

Positions in the Lebanese Government are organized according to the National Pact of 1943, which used the 1932 census to divide power among the religious groups. The major government officials in the original order of decreasing power are: the President, the Prime Minister, and the Speaker of Parliament. The President's post is held by a Maronite Christian, the Prime Minister's post is held by a Sunni Muslim, and the Speakership of Parliament's post is held by a Shi`a Muslim. Furthermore, seats in the Parliament were originally appropriated in a six-to-five ratio, favoring Christians over Muslims. As a result, Christians have historically enjoyed significant privileges in Lebanon, both economically and politically.

No official census has been done in the country since 1932—a topic of great domestic contention since it is highly suspected that the makeup of the current population has shifted significantly. More specifically, the Shi`a population is expected to have surpassed both the Sunni and the Maronite populations (Cobban, 1985). These growth patterns have been attributed to a combination of different birth rates and emigration rates. Christian families tend to have fewer children than Muslim families. Furthermore, the Maronite population in Lebanon has emigrated at a higher rate than the Shi`a population (Collelo, 1987). The government was reformed under the Taif agreement in 1989 to address this problem by redefining the distribution of power among the major government posts and creating an equal balance of Christians and Muslims in the Parliament.

Many hoped that the National Pact of 1943 would encourage Christians and Muslims to live together more acceptingly. However, this distribution of political power reinforced divisions between the two groups. The shift in populations as described above and a resulting perception of inequity are often cited as major driving forces for the civil war that began thirty-two years later. Consequently, it is still common to observe religious segregation both within and across towns throughout the country (Saab, 2008). These geographical divisions enhance the potential for disparate water services based on location.

Economic Disparity

According to a survey conducted by Bayt.com in January 2009, only four percent of surveyed Lebanese employees are highly satisfied with their salaries. About 13 percent currently earn a monthly salary under 500 US dollars and only about six percent earn a salary of 5000 US dollars or greater. While these employees received an average raise of 12 percent in their salaries over 2008, the cost of living went up by 31 percent. Consequently, the cost of living has become a larger percentage of their total salary, which can make it difficult to save money. About 29 percent of survey respondents said they save none of their household income and another 27 percent said they manage to save less than five percent of their household income (Bayt.com, 2009).

Since Lebanese water tariffs are too high for many households to afford, even when subsidized (Makdisi, 2007), a disproportionate number of households without connections to the public water supply system are poor households. For example, the poor suburbs of Beirut comprise about forty-five percent of the city's population (El-Fadel, 2000). While only approximately eighty-five percent of all Lebanese citizens are not connected to public water supply networks (MoSA &UNDP, 1998), almost half of the households in the poor suburbs of Beirut are not connected to the public water network (El-Fadel, 2000). Furthermore, those who are able to purchase water from the public supply in those suburbs receive inadequate supplies of potable water, with only ten hours of service every other day.

Finally, neighboring countries have often taken advantage of poorer areas during occupation and fighting. During Syrian occupation of Lebanon, poor regions along the El-Kabir River, which borders Lebanon and Syria, claim that water access was strictly controlled (Bleier, 1994). In addition, southern Lebanon has historically experienced reduced accessibility to water in that area due to Israeli control of resources (Bleier, 1994). Israeli occupational forces attempted to create a connection with residents in southern Lebanon by supplying them with water (R. Shibli, personal communication, July 2008). When Israeli forces were pulled out of Southern Lebanon upon the request of the United Nations in 2000, city wells in the area became part of the national water supply system under the South Lebanon Water Establishment (more information in subsequent sections).

Water Scarcity in Lebanon

As mentioned earlier, it is projected that Lebanon will be facing serious water shortages in the next ten to fifteen years (Metni, 2004; Halwani, 2009). Shortages of fresh water resources have already been experienced during the summer in Beirut (El-Fadel, 2000). Water scarcity can be caused by changes in water supply or changes in water demand, both of which are currently taking place in Lebanon.

Available Water Resources

Understanding availability and access to water resources is an important component for effectively managing those resources. Water in Lebanon is typically obtained from three major sources: surface water, groundwater, and rainwater.

Surface Water

A substantial network of surface water extends across Lebanon (Figure 2). Of the country's forty streams—none of which are navigable—only fourteen to seventeen can be classified as perennial rivers (El-Fadel, 2000; Halwani, 2009). While most of these perennial rivers originate and terminate within Lebanese borders, there are a few exceptions. The Orontes, located in the northern portion of the Bekaa Valley, flows north into Syria. The El-Kabir River traces Lebanon's northern border with Syria. Allocation of resources from each of these rivers has been negotiated between the two countries.

Finally, the Hasbani River, which is one of the Jordan River tributaries, flows south into Israel.

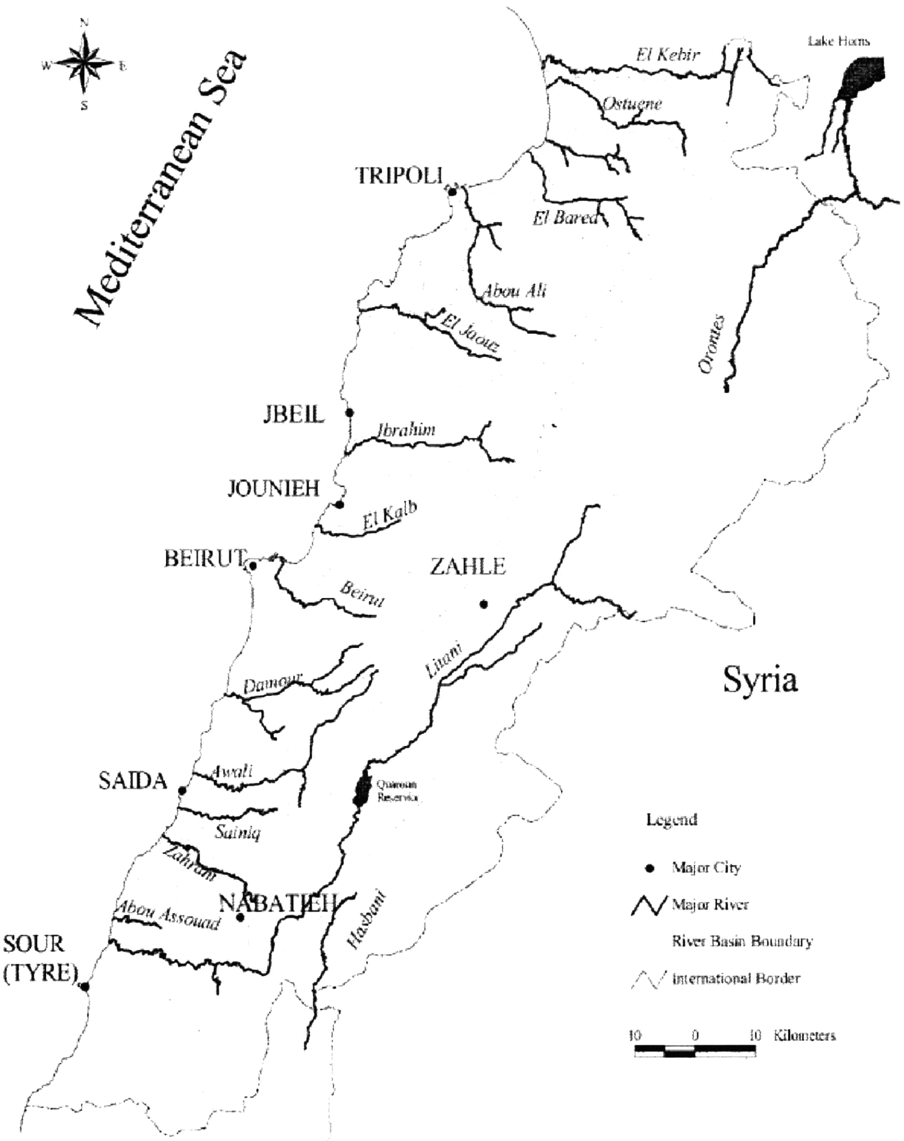

Figure 2. Lebanon's Surface Water (El-Fadel, 2000)

The Litani River is the only large river that is completely contained within Lebanon's borders. The Litani begins in the Bekaa Valley, at approximately the north-south midpoint of the country, and continues southward toward the Israeli border before veering to the west and eventually emptying into the Mediterranean Sea. The remaining unnamed rivers are also internal, but relatively small. They tend to originate in large springs high in the Lebanon Mountains and flow westward towards the Mediterranean Sea. No one river in Lebanon is the sole source of water for irrigation and drainage patterns are determined in large part by the topography and climate.

Groundwater

In addition to its bountiful surface-water resources, Lebanon has an extensive network of groundwater aquifers. Limestone formations delineate two major groundwater aquifer systems separated by an impervious zone (Figure 3). Fresh water can be found in the aquifers all year round, unlike some surface waters that can dry up during the summer season. Groundwater is primarily recharged by melting snow and rainwater. From there, the groundwater can either remain in aquifers, resurface from springs in the mountains that then feed into rivers, or discharge directly into the sea.

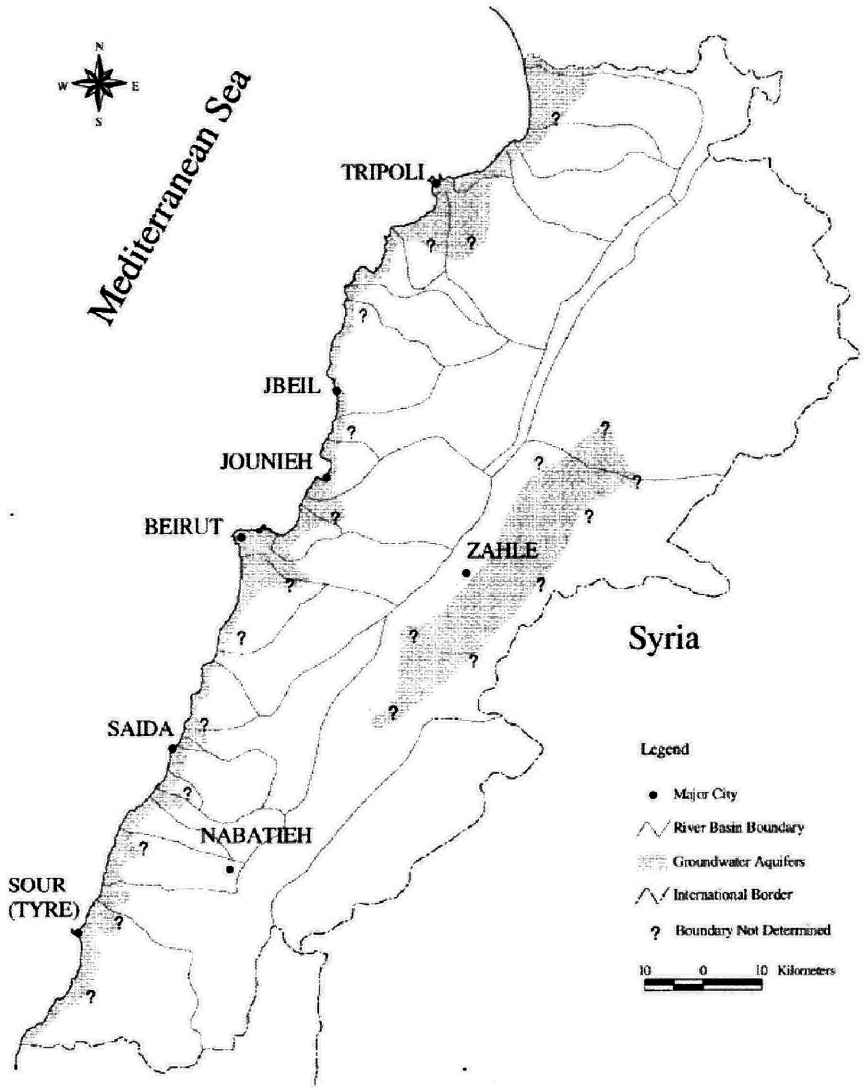

Figure 3. Lebanon's Groundwater (El-Fadel, 2000)

Groundwater resources in Lebanon are accessed through private and city wells, but the number of homes with private wells is small and not every home is connected to the piped-water system in any given town. Even the homes that have connections to a piped water system are not being reliably supplied, since pumping from the well is dependent on intermittent electricity.

Rainwater

Lebanon's climate is generally characterized as Mediterranean, with long, hot, dry summers and cool, rainy winters (Collelo, 1987). Temperatures do not vary greatly along the coast with season; however, the mountainous terrain shields the Bekaa Valley and blocks the temperature-regulating effects of the Mediterranean Sea, thereby causing a larger seasonal disparity in temperature for that particular part of the country. Precipitation, which is typically concentrated in the winter months, varies across the country from around 200 millimeters a year in parts of the Bekaa Valley to over 2000 millimeters a year in the mountains (Figure 4). Rainfall along the coast is in between the two extremes, though slightly lower in the southernmost part of the country. The mountaintops are generally covered in snow year-round, with the Anti-Lebanon Mountains receiving greater precipitation than the Lebanon Mountains due to higher altitudes.

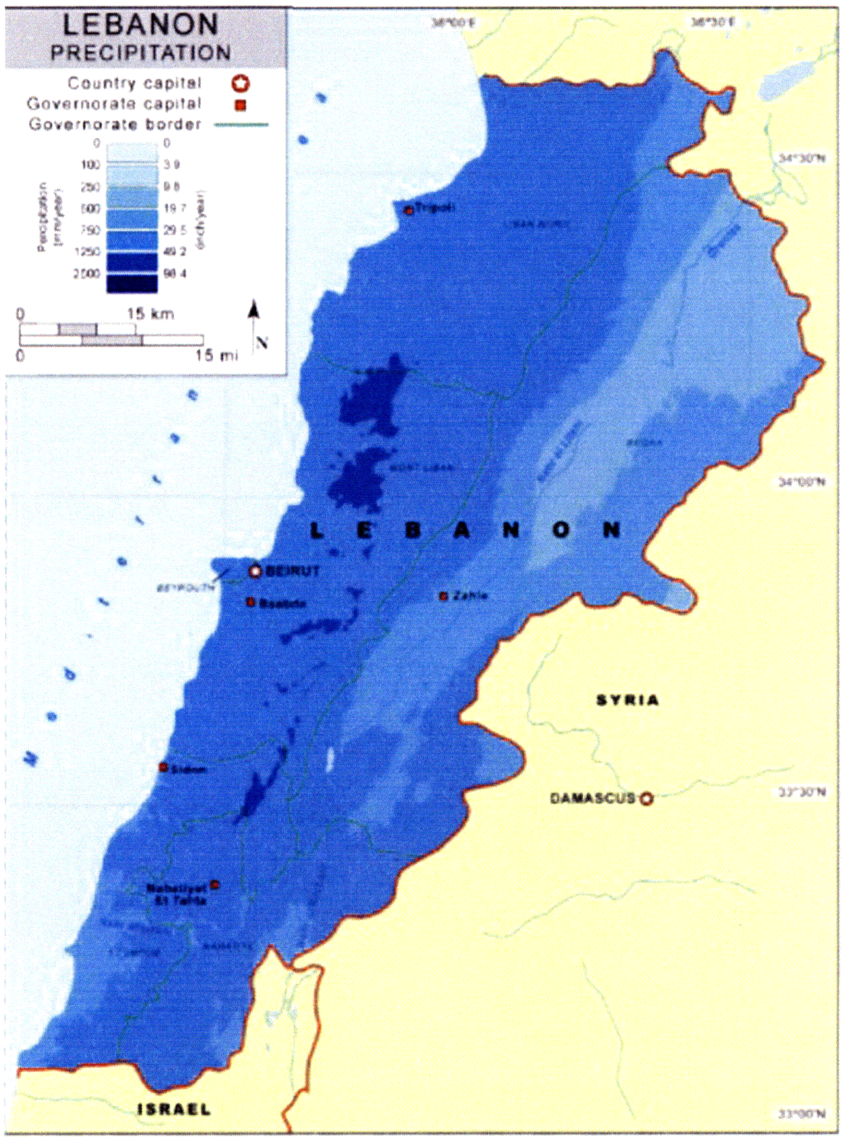

Figure 4. Precipitation patterns in Lebanon (World Trade Press, 2007).

As an ancient practice common to the area since as early as 3000 BC (CSE, 1997), rainwater harvesting is an important part of local culture. Prior to the introduction of piped water, rainwater harvesting at the household level in Lebanon ensured a clean drinking water supply during the dry summer months. While many towns no longer harvest rainwater collectively, large, stone-walled, earthen cisterns (i.e. *birkis)* are still observed in the dryer parts of Lebanon (J. Makhzoumi, July 2008). In addition, some communities are even reviving traditional practices and installing new rainwater collection systems (P. Sabatino, July 2008).

Factors Increasing Scarcity

Pollution of water resources can limit supply by reducing potable freshwater resources. Once contaminated, remediation of these sources can be very difficult. Common sources of water pollution in Lebanon are: dumping of municipal and industrial waste, domestic and industrial discharges of untreated wastewater, and runoff from pesticide-treated agricultural land (El-Fadel, 2000; Jurdi 2002a). In addition, overdrawing water supplies from aquifers can significantly lower water tables and has already resulted in saltwater intrusion along coastal areas.

Sources may further be limited by changes in climate, which are trending towards more arid conditions (Halwani, 2009; IPCC, 2001). In general, Lebanon has been experiencing a higher frequency of droughts and torrential rain (Halwani, 2009), thereby increasing the disparity between wet and dry seasons. Furthermore, temperatures in this region are projected to rise by 1-2 °C (IPCC, 2001). Higher temperatures can reduce the reliability of surface water and groundwater resources.

Water scarcity may also be encouraged by increases in demand across sectors. Identifying population trends in Lebanon has always been difficult due to the undefined patterns of immigration and emigration that resulted from years of war and civil unrest, as well as the lack of census data more recent than 1932. However, a growth rate of about two percent (CIA, 1994; CIA, 1996; El-Fadel, 2000) is generally accepted for the country, absent extenuating factors of war. This rate has caused the population to grow beyond the capacity of the water system (El-Fadel, 2000), making it difficult to meet domestic demand without substantial renovations or additions to the infrastructure.

In addition to increased domestic demand for water due to population growth, projections have also shown increases in industrial and agricultural demand (El-Fadel, 2000). Lebanon's existing industry primarily relies on private connections to groundwater resources, as opposed to the public supply system (El-Fadel, 2000). As a result, industrial water use is largely unregulated. It is likely that the industrial sector will grow as the country attempts to continue revitalizing its economy after the Civil War.

Agricultural demands vary with climatic conditions (Comair 2005). The current distribution of resources among the agricultural, domestic, and industrial sectors is approximately 58 percent, 32 percent, and 10 percent, respectively. During the dry season, the distribution becomes more heavily weighted toward agricultural use, with 69 percent going to agriculture, and only 25 and 6 percent going to domestic and industrial use, respectively. As summers become hotter and drier, agricultural demand for water will consequently rise even more.

Achieving Water Security

The achievement of water security has several components as defined by the Ministerial Declaration of The Hague on Water Security in the 21st Century (2000). For the purposes of this paper, "water security" is defined as the ability to meet a population's basic water needs. The generally accepted per capita basic water need is 50 liters per day (Gleick, 1994). This minimum requirement is comprised of 5 liters for drinking water, 20 liters for sanitation services, 15 liters for bathing, and 10 liters for cooking and kitchen use. It should be noted that water needed to grow food is not included in this value.

Given the threat of water scarcity in Lebanon, effective management of existing water resources is important for achieving water security. This section explores political water-management frameworks and performance, the local challenges to effective water resources management, and the potential role of rainwater harvesting.

Political Water-Management Frameworks

A variety of legal authorities are responsible for managing Lebanon's water resources. The national government's Ministry of Energy and Water[1] oversees the activities of five regional water establishments, one of which is the South Lebanon Water Establishment. The Council for Development and Reconstruction[2], which was created after the Civil War, is responsible for prioritizing and providing financial support for all major infrastructure repairs. Finally, there is a small overlap on the subject of water with other ministries, such as the Ministry of Public Health[3] and the Ministry of the Environment[4].

Ministry of Energy and Water

The Ministry of Energy and Water (MEW), which was established by the Lebanese government in 1966, is responsible for all issues relating to water in Lebanon. The MEW identifies, monitors, assesses and analyzes the country's water resources to create a national water policy. They are further authorized to enforce the laws necessary for the protection and use of public waters. Lebanese Law also requires the MEW to manage all water and energy concessions.

The MEW operates and maintains the country's large water facilities, including dams and sewage and wastewater treatment plants. Prior to 2000, the MEW was also responsible for planning and implementing most domestic water and energy projects. Furthermore, the MEW oversees and evaluates the activities of the autonomous regional water authorities (discussed below) in an effort to maximize efficiency and productivity.

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[1] http://www.energyandwater.gov.lb/
[2] http://www.cdr.gov.lb/
[3] http://cms1.omsar.gov.lb/
[4] http://www.moe.gov.lb/

Regional Water Establishments
Prior to 2000, Lebanon's Autonomous Water Authorities (AWAs) consisted of 22 water boards and 200 local committees. The AWAs were responsible for providing potable water and irrigation water to consumers under their jurisdiction, as well as implementing small-scale projects that had been pre-approved by the MEW. In addition to these tasks, the AWAs operated and maintained infrastructure facilities that had been provided by the MEW in their territories.

As mentioned earlier, the activities of the AWAs are supervised by the MEW and evaluated in an effort to enhance performance. As of 2000, cooperation across the autonomous water authorities was extremely poor (Kunigk, 1999). The boards were initially created in accordance with geopolitical boundaries as opposed to hydrologic boundaries, which led to a lack of accountability and unclear authoritative hierarchies. A series of laws passed between 2000 and 2002 restructured the framework for authority in the water sector. All of the local committees and 21 of the water boards were reorganized to form the following four Regional Water Establishments (RWEs): Greater Beirut and Mount Lebanon; North Lebanon; Bekaa (both North and South); and South Lebanon (Makdisi, 2007). The twenty-second water board was conserved as the fifth water establishment: the Litani River Authority.

During the restructuring process, responsibilities were redefined for both the MEW and the RWEs. The RWEs are now responsible for almost all water projects within their jurisdiction, with the MEW now only implementing large-scale projects that fall outside the territorial scope of any one RWE. The MEW's additional responsibilities have been reduced to creating the national water policy and master plan. In effect, there has been a significant transfer of power, from the MEW to the RWEs. The RWEs are now, in principle, viable commercial institutes, with their own budgets overseen by the Ministry of Finance.

Council for Development and Reconstruction
The Council for Development and Reconstruction (CDR) was established to manage the country's lengthy reconstruction and development in 1977, after the first part of the civil war. By creating a separate entity with unprecedented authority, Lebanon was able to avoid many administrative routines that would have slowed down the reconstruction process. The CDR has an important influence in the water sector because it designates and provides the fiscal support for a variety of infrastructure projects to remedy the physical damages that the distribution network sustained during war periods, as well as to extend the capacity of the system to accommodate current populations.

Overlap With Other Ministries
In addition to the MEW, there are a few other ministries with jurisdiction over specific water issues. The Ministry of Public Health has the authority to set water quality standards to ensure the health and safety of individuals that rely on the public supply system. Due to a history of little emphasis on environmental safety (Kunigk, 1999), pollution of the country's surface water and groundwater is a significant issue. The

Ministry of the Environment is, therefore, responsible for alleviating environmental pollution, including wastewater discharges to coastal and surface waters.

Dissatisfaction with the Public Water Supply

Only sixteen percent of users connected to the public water-supply network in 1998 expressed a high satisfaction with their service and seventy percent expressed an intermediate satisfaction (Makdisi, 2007). These high levels of dissatisfaction have resulted in reduced reliance on the public water-supply network and a lack of monitoring. In turn, decreased monitoring, as well as increased pollution from untreated sewage, has led to inadequate water quality in many areas (Makdisi, 2007).

In addition, the perception of water as an economic good is a foreign concept for the entire Middle East Region (Kunigk, 1999). Due to the relative abundance of water in Lebanon, the public tends to feel that it is a plentiful resource and, therefore, that it need not be purchased and should be made available to all (Kunigk, 1999). This belief and inadequate service from water providers has led to consumers' refusal to pay for service and a resistance to tariff increases (Yamout and Jamali, 2006). As an alternative, some consumers have dug their own wells or otherwise tapped into the groundwater to avoid using the public water supply system (Makdisi, 2007). Furthermore, the little payment that is received by the water board is difficult to collect because of faulty or nonexistent meters, especially in high-density areas such as urban centers (El-Fadel, 2000). These factors limit the funds available for system improvements and salaries to support employees with specialized skills, further exacerbating the reliability of the system.

Challenges to Effective Management

Those responsible for water resources in Lebanon have faced several management challenges. Water infrastructure in Lebanon sustained a significant amount of physical damage as a result of the Civil War (Mardelli, 1992). Furthermore, a 1991 assessment of the water sector indicated that in addition to the physical destruction of infrastructure during the war, there had been further deterioration due to a lack of maintenance by the responsible ministries and agencies (Mardelli, 1992; Kunigk, 1999). While improvements have been made since then, more recent damage to infrastructure from the July 2006 War with Israel has created similar problems in Southern Lebanon and near Beirut.

With the exception of the Beirut office, the water boards generally lack any significant technical expertise (Kunigk, 1999; Makdisi, 2007). Staffing of positions was often based on political influence rather than having the proper qualifications. Many employees, the average age of which was fifty-five, had not been trained and it had become increasingly difficult to draw new talent to the sector. The average salary for a water board director in 1999 was approximately four hundred and fifty US dollars per month, providing little incentive to skilled and trained professionals (Kunigk, 1999). In addition to a lack of sufficient funds to pay highly skilled professionals, the domestic supply of qualified individuals has dwindled significantly as a result of war (Kunigk, 1999). Faced with the constant uncertainties that generally accompany civil unrest, those with the fiscal and legal ability to do so left the country. Many of those who left were highly educated and could therefore find skilled jobs elsewhere.

The Potential Role of Rainwater Harvesting

Rainwater harvesting can play an important role in achieving local water security in Lebanon. For instance, it was found that during 1987 droughts in the Churu district of India, towns that had maintained rainwater-harvesting practices, even after the introduction of piped water, were virtually unaffected by water scarcity (CSE, 1997). Meanwhile, towns that had not maintained these traditional practices experienced severe water shortages. Since Lebanon is facing similar threats of water scarcity and has a similar history of rainwater harvesting traditions, it is reasonable to believe that similar security can be achieved through the local maintenance of these traditions.

The following chapters delve deeper into specific rainwater harvesting practices in southern Lebanon, their potential contribution to water resources, and the factors that may be affecting town decisions about maintaining these practices.

~ CHAPTER 3 ~

Rainwater Harvesting Practices in Southern Lebanon

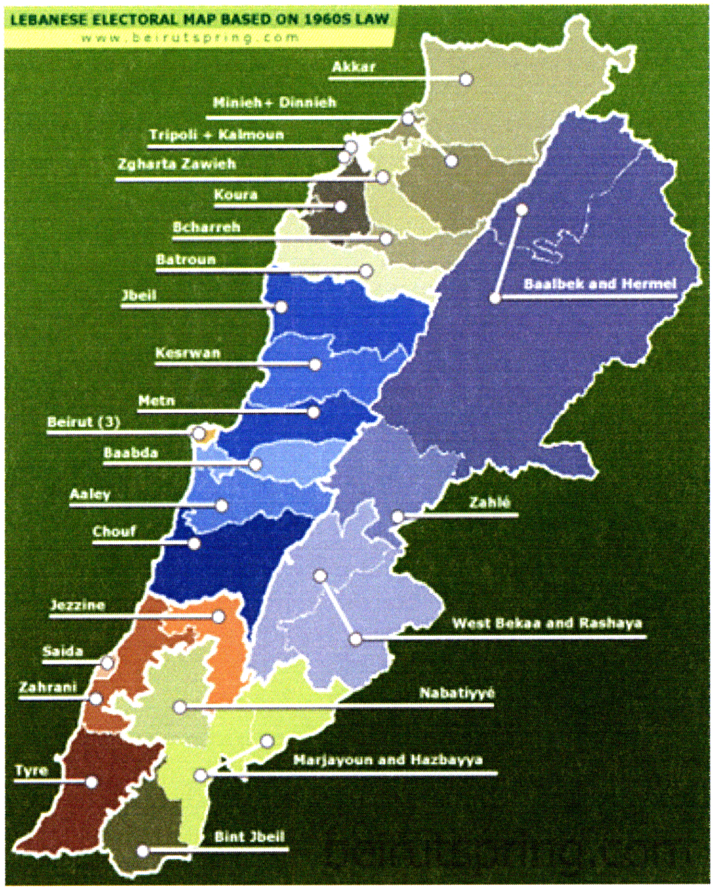

Figure 5. *Kaza*s of Lebanon. The kaza of Tyre is located in the southwestern corner.

The *kaza*, or electoral county, of Tyre (local pronunciation: Sur) is located in the southwestern corner of Lebanon, extending from the Israeli border to just north of the city of Tyre (Figure 5). Since fresh surface-water resources are scarce in this part of the country, water is often obtained from both groundwater resources and rainwater (J. Makhzoumi, personal communication, July 2008). This chapter outlines rainwater collection practices typical to Southern Lebanon and presents detailed case studies of water resources in two towns in the *kaza* of Tyre. This information was collected through field visits to the two towns and interviews with town officials, residents, and representatives from locally active aid organizations.

Data Collection

Unless otherwise noted, the information presented in this chapter was collected through a combination of field observations and interviews conducted in Lebanon in July and August of 2008. Field observations took place in two towns in the *kaza* of Tyre, which are henceforth referred to as Town A and Town B for purposes of anonymity. These locations were selected by Rabih Shibli from the organization 'House in the South: Enhanced Post-War Reconstruction in South Lebanon' and Dr. Jala Makhzoumi from the American University of Beirut. My aunt—Georgette Hayek—and a representative from House in the South—Issam A. Shibili—accompanied me on all field visits (Figure 6). All of the field team members spoke both Arabic and English. The team was joined by a local representative when in either of the two towns.

Figure 6. Field guides, Georgette Hayek and Issam Shibili.

Those interviewed in Town A and Town B included political town representatives, community leaders, and residents. Interviews were semi-structured and conducted on site in the Lebanese dialect of Arabic. Guidelines for interview questions can be found in Appendix A. Information pertaining to Town B is more detailed than that pertaining to Town A due to a longer length of time spent in the town and a more cordial reception of the team.

Additional interviews were conducted with representatives from a variety of locally involved aid organizations and faculty members at the American University in Beirut. These interviews were unstructured and generally conducted in either English or Arabic, based on the comfort level of the interviewee.

Constraints on Social Research in Lebanon

The political, social, and cultural conditions in Lebanon, as well as the methods of data collection, have imposed several constraints on the research conducted. First, there is a general lack of official census data due to the previously discussed political sensitivity of conducting a new census. This makes it difficult to attain information about a town's official population, which can be further divided into additional categories. The permanent population is defined as those who inhabit the town throughout the week at all times of the year. Additional residents come to the town on weekends, the majority of whom are males employed in surrounding areas. Seasonal residents tend to come to the area only in the summer, either for the weekends or for longer periods of time. Finally, local officials will also tend to boost their population numbers by including families that are permanently residing abroad, even though they return infrequently.

In Lebanese culture, it is considered rude not to answer a question when directly asked (Keen, 1995). Consequently, a Lebanese person would prefer to make up an answer than to say that they do not know something. This preference is most often conveyed to tourists in travel guides as a warning when asking for directions; however, it is also an issue when doing field research because the accounts of interviewed individuals may conflict. In these cases, it is often clear that one individual is better equipped to respond because they are better informed on the subject. For example, someone in charge of maintaining the town well would likely be considered more knowledgeable about well characteristics than, say, a local public official. Conflicting testimonies are noted.

Differing qualitative accounts during interviews were also an issue when the interviewees had different perceptions of the study goals. I was often asked if I were a reporter or if I were representing an agency that provided aid. While I attempted to make my purpose for being in each town clear to the local populations, there seemed to be some distrust of my answers. As an area that had recently been subject to war damages, interviewees may have thought that an exaggeration of negative situations might encourage more aid.

Finally, it should be noted that interviews were conducted in Arabic and are, therefore, subject to the common problems associated with interview translation (Oliver 2005). Since the interviewer was familiar with the local dialect of Arabic, there was little difficulty with direct translation. However, minor difficulties were experienced when local expressions were used or when a statement was overlain with a culturally understood exaggeration. In the event that something was unclear, bilingual field guides were able to help with interpretation. These instances are noted when possible.

Rainwater Harvesting Practices in the Kaza of Tyre

Rainwater harvesting in southern Lebanon takes place on both the individual and the community levels. Individually, houses gather rainwater through rooftop collection systems, which direct the water to cisterns. Less frequently, households may gather rainwater using a runoff collection system. In this case, the water is typically diverted into a carved stone cistern. Rainwater collection on the community level involves large runoff catchments, locally known as *birki*s. The ultimate use of the water collected varies by town and type of catchment.

Private Rooftop and Runoff Collection Systems

Buildings equipped with rooftop rainwater collection systems are typically only a few stories high and have cement rooftops with areas ranging from 80 and 500 square meters (Figure 7). A berm around one foot high contains the water during a rain event and a slight slope of the roof's surface directs the water towards a pipe inlet (Figure 8). The pipe leads down the side of the building before connecting to that household's cistern on or below ground level. While roofs that are used for rainwater collection are not regularly cleaned during the dry season, they are usually swept just before the wet season begins to remove any dust, debris, or other possible water contaminants. Typically, a first-flush device diverts less clean water that washes off the roof at the beginning of a rainstorm.

Figure 7. Typical cement rainwater-collecting rooftop.

Figure 8. Pipe inlet for rainwater collection.

In general, new homes built in southern Lebanon begin with the construction of a cistern for rooftop rainwater collection. The cost of constructing a cistern can amount to almost half the cost of the entire house. The most common cisterns are cement and may be located either partially above ground adjacent to the house (Figure 9), or under the house itself (Figure 10). Cement cisterns observed in the field ranged in storage volume from approximately 50 cubic meters (50,000 liters) to approximately 250 cubic meters (250,000 liters). In general, an opening near the top of a cistern allows water to spill out when a cistern is full. Residents in both towns claim that the cisterns remain full during the rainy season.

Figure 9. Above ground cement cistern.

Figure 10. Underground cement cistern.

On rare occasions, older homes in this region sometimes use a runoff rainwater collection system instead of a rooftop collection system. The storage area or cistern in this case is known as a *bier* (Figure 11). A *bier* is created by hand-carving a cavern into existing stone formations. While there is a small hole or an opening for runoff to enter the *bier*, the larger opening of the storage area is typically covered with a removable lid (Figure 12), similar to the cement cisterns. Much like the rooftops, the rainwater catchment area is typically cleaned just before the wet season begins.

Figure 11. Runoff capturing cistern carved into stone.

Figure 12. Collection opening and cover for *bier*.

Water may be retrieved from cisterns using either a pump connected to a spigot (Figure 13) or a simple bucket-and-rope system (Figure 14). Filtration is generally done with a cloth when necessary. In the first case, a cloth is fixed over the spigot opening. Water retrieved with a bucket and rope, on the other hand, is filtered through a cloth as it is poured into a glass vessel for drinking (Figure 15).

Figure 13. Pump and spigot retrieval system with cloth filter for household rainwater cistern.

Figure 14. Retrieval of water from a cistern using a bucket-and-rope system.

Figure 15. Filtering of rainwater retrieved with a bucket-and-rope system

Community Runoff Collection: *Birkis*

Also known as Roman ponds in North Africa, *birki*s are usually installed in naturally low-lying areas surrounded by a gentle slope, thereby enabling the collection of water that would naturally flower to that area (Oweis et al. 2004). *Birki*s are typically earthen reservoirs with walls constructed from stone or cement blocks (Figure 16). The size and capacity of a *birki* can vary based on the location. For example, the town of Maghdoucheh in southern Lebanon historically had two relatively small *birki*s, each of which had a capacity on about 1,000 cubic meters (1 million liters). The *birki*s upon which the following analyses are based are larger, with capacities around 10,000 cubic meters (10 million liters).

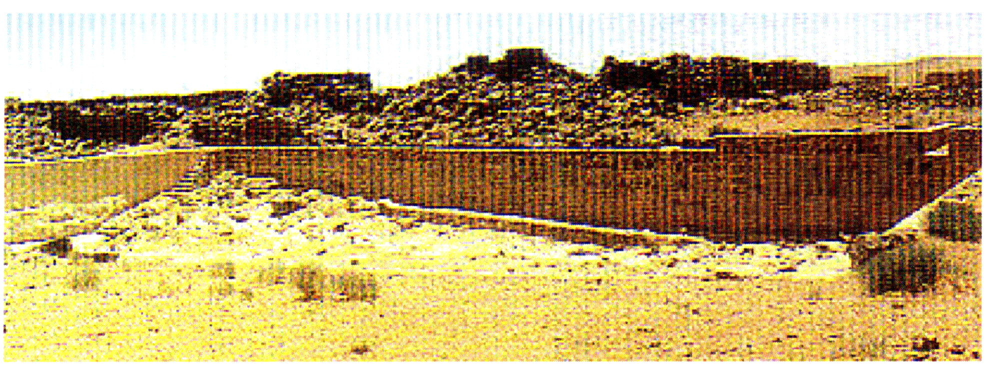

Figure 16. A *birki* for community rainwater collection (Oweis et al., 2004).

*Birki*s can be used for either private irrigation, or community water collection (M. Hayek, personal communication, March 2009). While there are no local laws governing water rights in community *birki*s, it is generally understood that harvested water is available to the entire town. Up until recently, *birki* maintenance was a collective effort; community members worked together to keep the *birki* clean or make repairs as needed. However, maintenance of contemporary *birki*s tends to be a function of the municipality. In some towns, this shift in responsibility has resulted in the loss of knowledge regarding traditional maintenance practices.

When taken at face value, there are both benefits and deterrents to maintaining *birki*s in southern Lebanon. Continued maintenance of the *birki*s has at least three ancillary benefits. First, the water is accessible during regular outages of the country's intermittent electricity. Second, more energy would be needed to pump the same amount of water from a groundwater well at greater depth. Third, rainwater would be captured before it came into contact with potentially contaminated water in the aquifers. However, *birki*s may also pose several problems to the local population. First, catchments that are located close to residential areas in the town are taking up land that could otherwise be developed. Second, municipal resources required for *birki* maintenance cannot be used for other things. Finally, the *birki*s can raise public health issues by attracting insects or presenting a danger of drowning.

Presentation of Case Example 1: Town A

Town A is located in the *kaza* of Tyre at an elevation of 370 meters above sea level. It is primarily an agricultural town, with approximately 210 homes, two small corner stores, a mini-market, and three mosques. There used to be a single school, but it was closed because there were not enough young children in the town to justify keeping it open with the town's limited resources. Building density is relatively low. Town A sustained heavy damage during the July 2006 war with Israel. Practically every building had somehow been affected, with several being completely destroyed (Figure 17). According to discussions with the town representative, the funding to rebuild those structures was exhausted halfway through the reconstruction process. With the exception of one home, the inhabitants did not have enough of their own resources to complete reconstruction.

Figure 17. House destroyed during the July 2006 war. The underground cement reservoir for rainwater is still visible on the right

The population is estimated to be almost entirely Shi`a Muslim. There are approximately 300 permanent residents, many of whom are over 60 and the majority of whom are female. There are approximately 200 weekend-only residents, 500 seasonal residents, and 1,900-2500[5] residents living abroad. The most common mode of occupation of those living in Town A is agriculture. The main crop is *hasheesh*, which is dried and ground for use in hookas.

The town has one fifteen-year-old groundwater well that feeds the public water supply. The well is approximately 279 to 300 meters deep.[6] Water is pumped into a reservoir at high elevation for about three to four hours a day while there is electricity. Water is then gravity-fed into the system during the remainder of the day, until the reservoir is empty. Most of the homes are connected to this supply, but a small portion of the town is located on a second hill at an elevation that cannot be reached by the gravity-fed system. Instead, the inhabitants of these homes buy water in tankers from neighboring towns. The town is researching the possibility of drilling a second well in order to provide these homes with adequate water resources.

The well has been under the control of the South Lebanon Water Establishment since the end of Israeli occupation in that town in 2000. According to political representatives, the Ministry of Health had investigated the well a few years ago because two children in the town had somehow contracted typhoid. Investigators determined that the disease was not contracted from the well water, but may have instead been the result of a contaminated private supply. However, inspectors did identify other issues with the community well. First, the location of the well is dangerously close to electricity lines. Second, it was determined that calcium levels in the water were very high. Finally, inspectors noted that the well was leaking.

A German-funded company installed a chlorination system for the well after the July 2006 war. Due to problems with the pipes and installation, the system has never been functional. Other locations got the same kinds of pipes put in and they did not work there either. A private company that takes its orders from the government is responsible for maintaining the well. They have not sent anyone to fix the chlorination system despite several calls made by the town officials. While the Lebanese water company has been responsible for the water in Town A's well since 2002, sampling did not occur until after the 2006 war. Town officials were told that water sampling in the well would take place every six months, but samples stopped after only two tests and nobody had checked the water in about a year at the time of my visit. The residents have been told that this water is clean and suitable for drinking, but they do not fully believe it.

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[5] The official being interviewed said there were 1900 people living abroad, but he also said that the total population was 3500 people. The upper end of this range was therefore determined by subtracting the other populations from the total population.

[6] The individual in charge of maintaining the well supplied the reported well depth. Alternatively, a political figure in the town estimated the well to be approximately 400 meters deep. The former's account is believed to be more accurate based on his area of expertise.

Almost all the homes in Town A are equipped with some sort of rainwater capture system: rooftop, runoff, or both. This water is perceived to be cleaner than the piped water and is therefore the preferred choice of drinking water when available. With typical water usage patterns, the water collected is sufficient to provide drinking water for the households for about one half to three-fourths of the dry season on average according to local residents. The individual rainwater collection reservoirs are supplemented by water from the piped supply or bottled water (when income allows) as needed.

In addition to the two water sources mentioned above, the town also has a community runoff rainwater catchment (Figure 18). The water collected in the *birki* is typically used for irrigation purposes, helping to sustain the livelihood of most residents. The *birki* is located a short walk away from the town along a dirt path. When we arrived at the *birki*, we found that it was mostly empty, with some residual water enabling the growth of flora at the deepest corner.

Figure 18. Town A's *birki*.

According to community members, the *birki* is dry for a longer period of time now than it was in the past. The residents of Town A would like to maintain the *birki*, but they believe that the water is leaking out and they are unsure how to fix it. None of the local residents were aware of traditional maintenance practices. Political officials had been considering more modern maintenance alternatives, including a plastic lining for the *birki*.

Presentation of Case Example 2: Town B

Town B is located in the *kaza* of Tyre at an elevation of 440 meters above sea level. It is considered one of the larger towns in the *kaza* of Tyre, with 331 homes, at least one church, three schools, and several local stores. The primary religion is Christian, with a mix of Maronite and Melkite Christians. Building density is high in the older part of town, which is near the center of town, and medium around the outer edges of the town. Little damage from the July 2006 war was observed during the site visits. However, there was evidence of post-war aid, particularly in the context of ensuring adequate drinking water resources. Examples of observed post-war aid include pillow-tanks and a filter station, both of which are discussed in more detail below.

There are approximately 800 permanent residents occupying 220 of the town's 331 houses. Political officials in the town estimated that the majority of permanent residents are female. Furthermore, half of the entire population is estimated to be under the age of sixteen. According to town officials, the weekend-only population is estimated at 200 residents, the summer-only population is estimated at 700, and there are approximately 1500-2800[7] residents living abroad. It appeared that local offices of international organizations, such as the United Nations, employed the majority of residents in this town. Agricultural activities are still observed in Town B, but usually on a recreational basis, as opposed to an occupation. Examples of foods grown in this town are avocados, watermelons, pears, and bananas.

The groundwater well that feeds this town's piped water supply is 490 meters deep, three inches in diameter, and pumped at 100 horsepower. The well was first installed in 1993 and was taken over by the South Lebanon Water Establishment shortly after the withdrawal of Israeli occupational forces in 2000. It was at this time that the water-distribution pipes for connections to homes were first laid and the residents of Town B first began to pay for their water. The South Lebanon Water Establishment is currently in charge of well maintenance, which takes place on a regular basis. Maintenance of the water-distribution network is also ongoing.[8]

Approximately 200 of the buildings in this town are connected to a piped water supply. These homes represent the majority of permanently occupied residences. According to residents, the piped water supply is more reliable now than it was in the past. However, intermittent electricity means that the well can only be pumped at certain times, such that the reservoir supplying the town may be empty at times. This limitation means that, "the ones who take the water the fastest when the reservoir is full are the ones who get water." To mitigate the possibility that water will not be available when it is needed, many homes

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[7] The official being interviewed said there were 1500 people living abroad, but he also said that the total population was 4500 people. The upper end of this range was therefore determined by subtracting the other populations from the total population.

[8] Political officials claimed that pipes were being replaced around the city as part of routine maintenance. While those underlying unpaved areas have already been replaced in recent years, future replacements will take place in paved areas and require significant construction.

have built cement cisterns similar to those used in rainwater harvesting. These cisterns are then filled when the water is running. In addition, some homes still collect rainwater and use it for washing clothes or flushing toilets.

The remaining 131 houses in the town depend primarily on alternative water sources. Only five houses have private wells for irrigation. The remaining homes either have rooftop rainwater harvesting systems or are supplied from the town well via a tanker truck (Figure 19). Some homes also had pillow tanks that had been supplied to the town after the war (Figure 20). The town received fifteen 10,000-liter and thirty 20,000-liter pillow tanks, which were then distributed based on need.

Figure 19. Tanker truck for water delivery.

Figure 20. 10,000-Liter pillow tank.

Finally, all of the town's inhabitants have access to a centrally located filter station supplied by a Caritas Lebanon, a local branch of a French aid organization (Figure 21). The filter station is on the outside of the town well and removes calcium from the water. Town officials felt that having residents fill their own bottles at a filter station, as opposed to distributing the filtered water to individual reservoirs, would reduce the likelihood of contamination. Most households in the town use filter water for drinking, though some homes still buy bottled water.

Figure 21. Filter station (left) and close-up of filling area (right) in Town B.

Town B's *birki* (Figure 22) was primarily used for irrigation in the recent past, but political representatives said it is no longer widely used.[9] Several difficulties with *birki* maintenance were identified during interviews. The *birki* is located in a populated portion of the town, with homes along one half and agricultural land along the other half. Four people have drowned in the *birki* in the past. A fence (Figure 22) has been erected on the residentially adjacent half since that time. In addition, residents living adjacent to the *birki* complained that it was attracting mosquitoes and bringing other insects into their homes. Finally, the municipality has complained about the resources needed to clean trash and accumulated sediment from the bottom of the *birki* (Figure 23). Even though they sweep the bottom every year, it always ends up looking the same towards the end of the summer.

Figure 22. Town B's *birki*.

In light of low utility and the additional difficulties discussed above, the *birki*'s bottom was broken to facilitate its emptying in the summer. A town representative commented that they had never seen the *birki* this dry before. Town officials talked about plans to fill the *birki* and use the land for something else. Proposed alternate uses for the land include a parking lot and building or a park with seating.

[9] One person interviewed said that the *birki* is only used by a handful of people who have adjacent agricultural land, while another person said "no one" uses it. It is believed that the second account was an exaggeration.

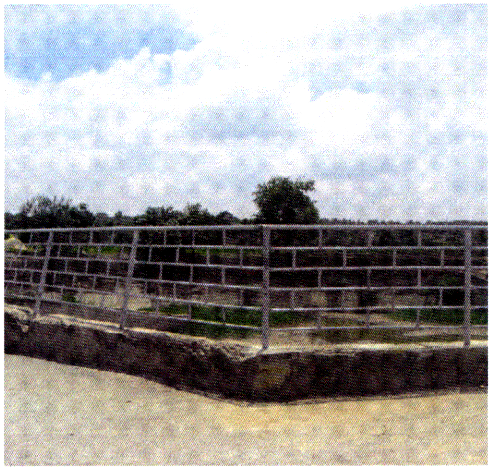

Figure 23. Fence surrounding the side of Town B's *birki* that borders residential areas.

Figure 24. Rubbish at the bottom of Town B's *birki*.

~ CHAPTER 4 ~

Maintaining Rainwater Harvesting Practices

Figure 25. Typical water level in Town B's *birki* (Firassaya, 2007)

The value of maintaining rainwater-harvesting practices in these towns is evaluated through a hydrologic analysis of harvesting potential and storage capacity. Harvesting potential is analyzed for rooftop systems using precipitation data and estimations of the number of homes collecting rainwater and the average roof size. Harvesting potential for community runoff is analyzed using a climatic water balance for the area, along with field observations of catchment characteristics and typical water levels.

The second portion of this chapter looks at the decision and the ability to maintain community *birki*s. A comparative analysis of Town A and Town B is used to identify differing town characteristics that could explain the decisions being made with respect to *birki* maintenance. These differences are then classified into five overarching factors that may be responsible for driving the decision. The possible decision drivers proposed in this thesis include: land scarcity, cultural shift, public health and safety, water needs, and organizational capacity.

Potential for Rainwater Harvesting

Evaluating the benefit of maintaining rainwater-harvesting practices requires an understanding of whether the magnitude of water that can potentially be harvested in this area can sustain the population for an extended period of time. This process can begin with an analysis of the local climatic water balance, in which water retained in soil (i.e. soil storage) can be calculated for a given location using average monthly precipitation amounts, average monthly temperatures, and soil type (Thornthwaite and Mather, 1955; Thornthwaite and Mather, 1957) (Figure 26). The details of these calculations can be found in Appendix B.

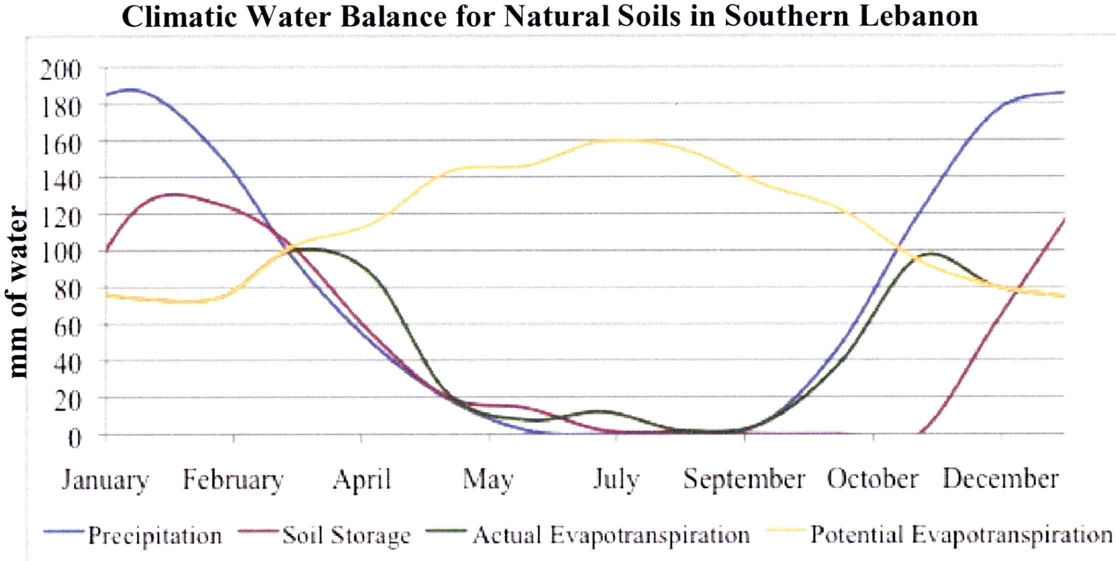

Figure 26. Climatic water balance for natural soils in southern Lebanon.

Soil storage can be thought of as a bank account, with deposits—precipitation—and withdrawals—water that runs off the surface (i.e. runoff), water that evaporates or is taken up by plants (i.e. evapotranspiration), and water that trickles down into groundwater aquifers (i.e. percolation). Precipitation and temperature data is collected at limited locations in Lebanon, one of which is the nation's capital, Beirut. Based on the patterns shown in Figure 4 and the location of Town A and B, both of the towns are assumed to have precipitation magnitudes and temperatures similar to those of Beirut. How much of this precipitation infiltrates into the soil and how much potentially runs off the surface is dependent on the type of surface upon which rain falls. Natural soils in this part of Lebanon are lithic xerorthents (Tavernier *et al.*, 1980), which typically have about 20 percent of rainfall run off its surface (i.e. a runoff coefficient of 0.2) (Pardini, *et al.* 2003) and a soil retention capacity of approximately 125 mm (Pardini, *et al.* 2003) Meanwhile, evapotranspiration and percolation are determined based on temperatures and vegetation type (Thornthwaite and Mather, 1957).

The total precipitation received in this area is 856 millimeters. However, monthly precipitation values show a clear demarcation of the wet season (November-June) and a dry season (July-October). As would be expected, potential evapotranspiration is higher in summer months and lower in winter months. Soil storage varies with the time of year, dropping down to almost nothing during the dry season in the absence of irrigation. Since the soil is, therefore, incredibly dry during summer months, the actual evapotranspiration that would take place is also very small. The total annual evapotranspiration is 627 millimeters.

The total annual gross surplus computed by the water balance is 70 millimeters of water (accumulated during the wet winter month); the total annual gross deficit is 316 millimeters of water (accumulated during the dry summer months). These figures yield a net annual deficit of 244 mm/yr. Thus, a small amount of runoff may be generated in winter months especially during wet years and flood events, and depending upon soil moisture recharge.

While there is not much potential for runoff under natural conditions, the potential for rainwater harvesting is increased with the introduction of paved surfaces and collection containers. The total water availability for both towns is shown in Table 1. The period of May through November was chosen to encompass the entire dry season as indicated by the climatic water balance, with a slight buffer into the wet season in the event of future climatic changes. Details of how these figures were estimated for both the rooftop collection systems and the *birki*s can be found in the following sections.

Table 1. Total rainwater harvesting supply in Town A and Town B. Per capita water availability is determined for the period from May through November (214 days).

	Privately Collected Water (L)	Communally Collected Water (L)	Total Water Availability (L)	Per Capita Water Availability (L/day)
Town A	23,000	12,000	35,000	550
Town B	30,000	8,000	38,000	220

Private Rooftop Rainwater Collection

The amount of water, $S_{rooftop}$, that can potentially be captured by a rooftop surface is given by:

$$S_{rooftop} = P * A * C_r \quad , \qquad \text{(Eq.1)}$$

where P is precipitation, A is the area of the rooftop from which water is being collected, and C_r is the runoff coefficient (Gould, 1999). The runoff coefficient is a property of the surface from which you are harvesting and denotes what fraction of the water will be captured. Water that is not captured may either be absorbed by the surface, evaporate, or may splash off the surface, away from the collection point. The design of rooftops in southern Lebanon is most similar to what the literature refers to as a concrete-lined ground catchment, which has a runoff coefficient between 0.73 and 0.76 (Gould, 1999). Since water is generally contained by a raised berm, thereby reducing the amount that splashes off the surface, the runoff coefficient for these calculations is taken as 0.8.

As previously mentioned, the annual precipitation for both towns is approximately 856 millimeters. The average rooftop area for each of the two towns was determined through a random sampling of rooftop areas calculated from aerial imagery (Appendix C). The estimated average rooftop areas in Town A and Town B are 250 square meters and 190 square meters, respectively. Finally, it is estimated from field observations that 95 percent of homes in each town collect rainwater. Calculations of rooftop rainwater harvesting supply are summarized in Table 2. These calculations also yield an annual collection of 0.7 cubic meters per square meter of rooftop surface.

Table 2. Rooftop rainwater harvesting supply in Town A and Town B.

	Average Rooftop Area (m^2)	Homes Collecting Rainwater	Rain Collected per Rooftop (m^3)	Total Supply (m^3)
Town A	250	189	170	32,000
Town B	190	298	130	39,000

While it is useful to know the total supply, these values are not necessarily the ones that we would use to assess the ability of rainwater to supply residents during the dry season. The storage capacity of collection cisterns is invariably less than the annual total supply, and thus the stored rainwater supply cannot exceed the storage capacity at the beginning of the dry season. The storage capacity of rainwater harvested from the rooftop is calculated by multiplying this average storage volume by the number of homes collecting rainwater. Again, it is estimated from field observations that 95 percent of homes in each town collect rainwater. Calculations are summarized in Table 3. Average cistern storage volumes of 120 and 100 cubic meters for Town A and Town B, respectively, were estimated from measurements and observations in the field.

Table 3. Rooftop rainwater harvesting supply in Town A and Town B.

	Average Cistern Volume (m^3)	Homes Collecting Rainwater	Storage Capacity (m^3)
Town A	120	189	23,000
Town B	100	298	30,000

Since the estimated supply exceeds the estimated storage capacity for rooftop rainwater harvesting in both towns, it can be assumed that the stored rainwater supply cannot exceed the storage capacity. Based on discussions with residents in both towns, the cisterns fill completely.[10] Using the estimated storage capacity and the populations of each town, it can be estimated that for the duration of the May through November dry season, Town A has a per capita water supply of 360 liters per day and Town B has a per capita water supply of 175 liters per day (Table 4).

[10] Residents said that water use is not monitored at all during winter months because the cisterns are always full.

Table 4. Per capita water availability from rooftop rainwater harvesting supply in Town A and Town B from May to November (214 days).

	Population	Initial Water Availability (L)	Per Capita Water Availability (L/day)
Town A	300	23 million	360
Town B	800	30 million	170

Community Rainwater Collection in *Birki*s

Catchment areas for the *birki*s in each town were estimated using Geographic Information System (GIS) software with a combination of aerial imagery and elevation data. The catchment area for Town A (Figure 27) is located along a natural channel, such that any overflow of water to the *birki* would simply continue down the hillside in the southwest direction. Meanwhile, the catchment area for Town B (Figure 28) is a closed basin, such that overflow to the *birki* would cause local flooding.

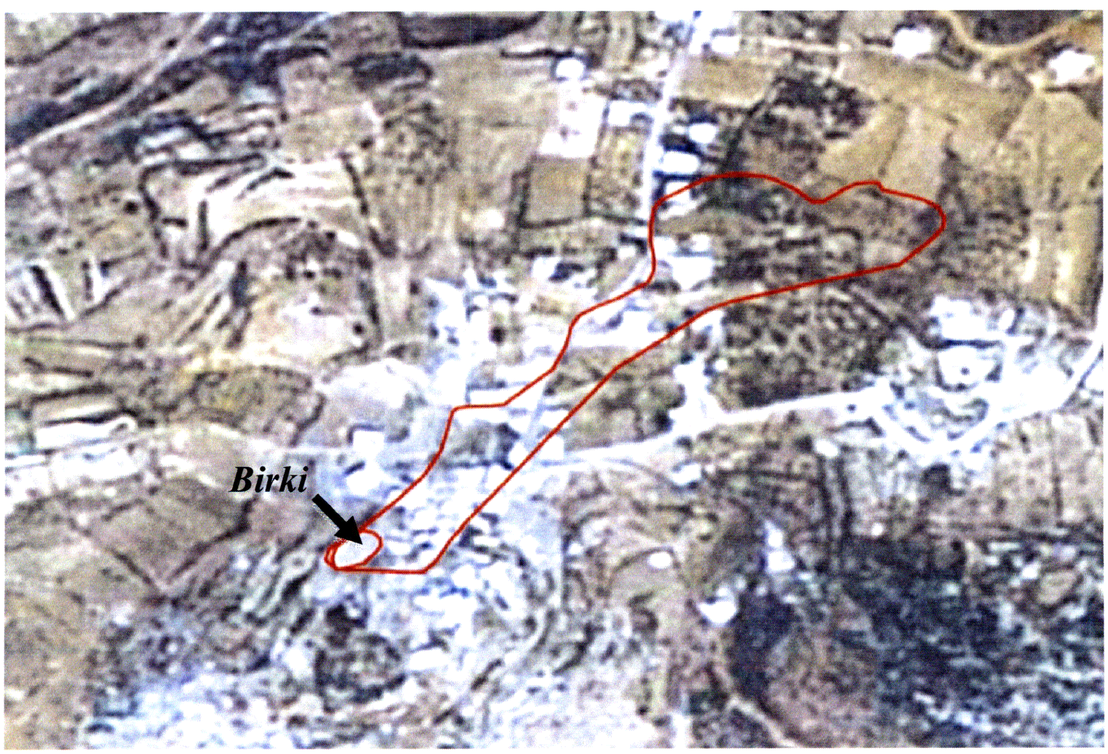

Figure 27. Catchment area for *birki* in Town A.

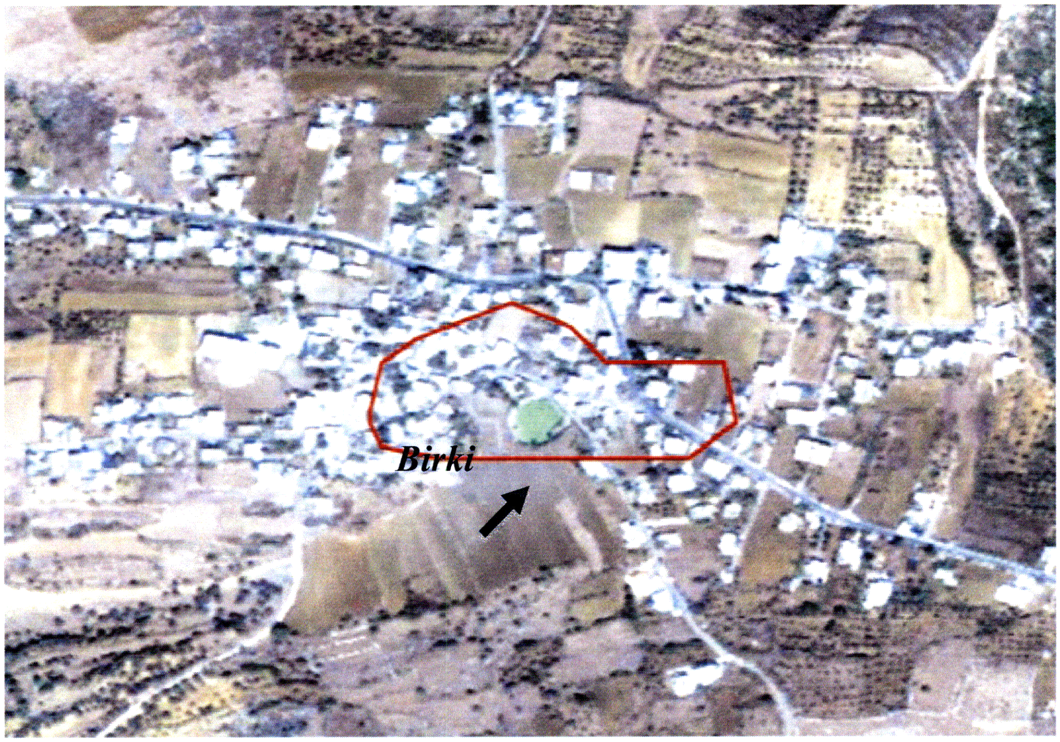

Figure 28. Catchment area for *birki* in Town B.

Water that can be captured by the *birki* in each town must be calculated using a different equation parameters, since the rain falls on a catchment area with mixed surface types—natural soils and paved surfaces. Also, unlike the cisterns, *birki*s are not covered and therefore will lose water through evapotranspiration processes occurring across the surface. Therefore, the rainwater supply to a *birki*, S_{birki}, can be approximated by the following equation:

$$S_{birki} = A_{collection} * P * [(X_{paved} * C_{r,paved}) + (X_{natural} * C_{r,natural})] - A_{surface} * PET \qquad \text{(Eq. 2)}$$

where $A_{collection}$ is the total collection area, which is equal to the part of the catchment area that is not occupied by homes with rooftop harvesting, P is precipitation, $C_{r,paved}$ is the runoff coefficient for paved surfaces, X_{paved} is the fraction that is paved, $X_{natural}$ is the fraction that is not paved, $A_{surface}$ is the surface area of the *birki*, and PET is the potential evapotranspiration. Note that there is no term in this equation to account for seepage through the *birki* bottom. While this process is most likely taking place, it is very difficult to estimate and due to the general nature of these estimations, is not included for the following calculations.

Again, the annual precipitation for both towns is 856 mm. The annual potential evapotranspiration is 1,400 mm. The runoff coefficient for a paved surface is taken as 0.7 (Gould, 1999). The runoff coefficient for natural soil in southern Lebanon is 0.2 (Pardini, *et al.* 2003). The catchment area, the surface area of the *birki*, and the percentages of paved and unpaved areas in each town were estimated from aerial imagery of the catchment area (Figure 26, Figure 27). These parameters and the calculated harvesting potential each *birki* can be found in Table 4.

Table 5. Parameters for *birki* harvesting potential calculations.

	$A_{catchment}$ (m^2)	$A_{surface}$ (m^2)	X_{paved}	$X_{unpaved}$	*Birki* Harvesting Potential (m^3)
Town A	30,000	800	0.2	0.8	13,000
Town B	25,000	1000	0.5	0.5	8,000

Much like the discussion of private rainwater collection, the storage capacity of each *birki* is also important to calculate (Table 5). Town A's *birki* is estimated from aerial imagery to be approximately 33 meters in width and 44 meters in length. Based on site visits, it is approximately 7 meters deep and therefore has a capacity of almost 12,000 cubic meters (12 million liters). Town B's *birki* is circular with an approximate diameter of 35 meters and a depth of 9 meters. Therefore, its capacity is nearly 9,000 cubic meters (9 million liters).

Table 6. Rooftop rainwater harvesting supply in Town A and Town B.

	Shape	Length (m)	Width (m)	Storage Capacity (m^3)
Town A	rectangular	44	33	12,000
Town B	circular	35	35	9,000

The storage capacity of Town A's *birki* exceeds supply, while the storage capacity of Town B's *birki* is less than its rainwater supply. This makes sense because, as mentioned earlier, an overflow in Town B's *birki* would cause flooding due to the shape and relative location of the catchment area. Therefore, the per capita values calculated for Town A and Town B from *birkis* is 187 and 50 liters per day for the period from May through November (Table 6).

Table 7. Per capita water availability from community rainwater harvesting supply in Town A and Town B from May to November (214 days).

	Population	Initial Water Availability (L)	Per Capita Water Availability (L/day)
Town A	300	12 million	190
Town B	800	8 million	50

As previously mentioned, the minimum basic water requirement excludes agricultural water use. While the water collected via household systems exceeds this basic water need, allowing part of it to be devoted to sustaining agriculture, agricultural water use can also be supplemented by community rainwater collection. In addition, this water can also be used as an emergency water supply if properly treated after collection.

Comparative Analysis for Factors Affecting Birki *Maintenance*

The methods in this section represent a combination of grounded theory and case study methods of qualitative analysis. The case study fieldwork identified different characteristics in the two towns. Some of these different characteristics were deemed to potentially affect birki maintenance. These potential influences were then grouped to identify categories of driving forces. This inductive method yields a theoretical model that is thus "grounded" in the empirical case study fieldwork. Differences in town characteristics and their respective influences on *birki* maintenance are identified using information from Case Example 1 and Case Example 2 (see Chapter 3). These relationships are then analyzed to infer possible decision drivers for municipal maintenance of community rainwater catchments.

Identification of Differing Town Characteristics

Since both Town A and Town B have the hydrologic ability to harvest rainwater, differences between town characteristics could potentially provide insight what drives a municipality's decision to maintain a town's *birki*. The two towns presented in this study differed in many ways. Certain important town characteristics were identified as possible influences in the maintenance decision after reviewing field observations (Table 8). Each of these differing town characteristics is discussed in more detail below.

Table 8. Town characteristics that may affect the decision to maintain rainwater harvesting practices.

Important Differing Town Characteristics
• *Birki*'s relative location
• Local land availability
• Age distribution
• Religious affiliation
• Relation to foreign influence
• Residents' primary mode of occupation
• Access to alternative water resources
• Available economic resources
• Knowledge of *birki* maintenance practices

Birki's Relative Location

Town A's *birki* was located a short walk away from the town, while Town B's *birki* was closer to the town center. Consequently, Town B's *birki* was partially bordered by residences, while Town A's *birki* was completely surrounded by

Local Land Availability

Residential areas in Town B were particularly dense, with some homes in the older part of town sharing an exterior wall. Meanwhile, the residential areas of Town A were much more spread out. These trends were also reflected in the total permanent population and the number of buildings, both of which were larger in Town B.

Age Distribution
The age distribution of town A was more heavily weighted to an elderly population than that of Town B. Political representatives in each of the two towns estimated that Town A had almost no young population and nearly half of the permenant population in Town B is under the age of sixteen, respectively. This phenomenon was further reflected in the number of schools each town had; Town A had closed its only school because there weren't enough students to keep it open, while Town B had three schools within its borders.

Religious Affiliation
The primary religious affiliation in Town A was Shi`a Muslim, while the primary religious affiliation in Town B was Melkite Christian.

Relation to Foreign Influence
My United States citizenship was an issue in Town A, as some individuals questioned whether my loyalties were aligned with Israel. It is noted here that my reception was not solely affected by my national affiliations, but also undoubtedly influenced by my gender and religion. Meanwhile, residents in Town B outwardly expressed gratitude for my interest in their town, asking me to tell them how to do things right because they felt the *birki* was primitive and therefore should be removed.

Residents' Primary Mode of Occupation
Residents in Town A tended to be farmers, while residents in Town B are generally employed in offices.

Access to Alternative Water Resources
Town B had better access to alternative water resources than Town A. While both towns has a piped water network, a higher proportion of the permanent residents in town B were on the piped water system than those in Town A. The town supply well and distribution pipes also appeared to be better maintained in Town B than in Town A. In addition, Town B has a filter station at which residents could fill empty bottles for household use.

Available Economic Resources
The fiscal resources available in Town A were significantly less than those observed in Town B. This was a combination of the average household income and the effects of the July 2006 War. Those living in Town B were wealthier than those living in Town A, with more stable and likely higher-paying occupations. In addition, the dollar value of damages sustained during the July 2006 war was significantly smaller in Town B than in Town A. Furthermore, Town B seemed to have received significantly more outside aid than Town A after the July 2006 War.

Knowledge of Birki Maintenance Practices
Town A had the desire to maintain their *birki*, but did not know how to do so. None of the residents or political officials in this town possessed knowledge regarding traditional maintenance methods used by their ancestors in the past. Town B, on the other hand, was conducting routine annual maintenance on the *birki*.

Effects of Town Characteristics on *Birki* Maintenance

The individual town characteristics identified in the preceding section can be aggregated based on the associated probability of *birki* maintenance (Table 9). This probability is affected by both the desire and the ability to maintain a *birki*. As previously mentioned, Town A desired to maintain its *birki*, unlike Town B. On the other hand, Town B had the ability to maintain its *birki*, unlike Town A.

Table 9. Expected effects of town characteristics on the probability of *birki* maintenance.

Town Characteristics Indicating a High Probability of *Birki* Maintenance	Town Characteristics Indicating a Low Probability of *Birki* Maintenance
Other land available for development	Little local land available for development
Birki is located away from residences	*Birki* is directly adjacent to residences
The elderly population is larger than the young population	The young population is larger than the elderly population
Significant local dependence on agriculture	Little local dependence on agriculture
Aversion to foreign influence	Openness to foreign influences
Major religious affiliation is Islamic	Major religious affiliation is Christian
Limited reliable alternative water resources	Access to reliable water alternatives, such as a filter station
	Lack of knowledge regarding *birki* maintenance practices
	Inadequate fiscal resources

Posited Decision Drivers

The town characteristics that affect the probability of *birki* maintenance can be classified under five main factors that may be driving the decision to maintain *birki*s in the *kaza* of Tyre: land scarcity, cultural shift, public health and safety, the perception of water security, and organizational capacity (Table 10). Each of the posited decision drivers and their connection to the previously identified town characteristics is discussed in more detail in the following sections.

Land Scarcity

As Lebanon's population continues to grow, there is an increased demand for limited resources and land consequently becomes more scarce. This inherent increase in the value of land could make municipalities more likely to explore development options for municipal properties. The location of a town's *birki* with respect to residential areas could largely influence whether a town would like to redevelop that land. Town B's *birki* was closer to the center of town and, therefore, in a much more desirable location for redevelopment than Town A's *birki*. Furthermore, greater town density and larger populations, such as those observed in Town B, can limit the existence of alternative land for development.

Table 10. Relation of town characteristics to decision drivers for *birki* maintenance.

Town Characteristic	Decision Drivers				
	Land Scarcity	Cultural Shift	Public Health and Safety	Perception of Water Security	Organizational Capacity
Birki's relative location	X		X		
Local land availability	X				
Religious affiliation		X			
Age distribution		X			
Relation to foreign influence		X			
Residents' primary mode of occupation		X		X	
Access to alternative water resources				X	
Available economic resources					X
Knowledge of *birki* maintenance practices					X

Cultural Shift

Lebanon has often been recognized as a westward-looking country, with Beirut begin referred to as the "Paris of the Middle East" (Keen, 1995). This preference or tendency has been reflected in political decisions since the country gained independence. The adoption of western cultural aspects represents a general divergence from typical practices of the area in favor of more western practices, and will henceforth be referred to as cultural shift. The attraction to western practices comes from the perception that they are more modern, especially compared to the "primitive" ways of one's parents.

Since rainwater harvesting is considered to be a traditional practice, it is reasonable to expect that a town with closer ties to traditional practices would want to maintain their *birki*. Residents in Town A, who wanted to maintain their *birki*, evidenced stronger ties to traditional practices than those in Town B based on their average age, their occupations, and the way in which they received foreign visitors. Elderly populations, such as those in Town A, are more likely to value traditional practices than younger populations. Towns that are agriculturally based are more likely to be more rooted in traditional practices, based on the country's historical dependence on agriculture. Finally, openness to foreign influence may indicate a desire to diverge from traditional practices.

Cultural shift may also be connected to a town's religious affiliation, such that Islamic towns are more likely to maintain traditional rainwater harvesting systems. While there are no civil governance frameworks for water rights of *birki*s, Muslim towns will be more likely to manage a *birki* in accordance with Islamic water law. This is supported by the fact that Town A is primarily Islamic and Town B is primarily Christian. While neither Town had knowledge of traditional maintenance practices, Town A expressed more of a desire for that information than Town B.

Public Health and Safety

Municipalities are expected to uphold public health and safety within a town among their traditional duties. With the relatively recent shift of responsibility for *birki* maintenance to the municipality, it is feasible to expect an increased concern with the public health and safety implications of maintaining a *birki*. While the same public dangers may be present at any *birki*, they do not pose the same threat in the two towns observed. This could be a product of the difference in *birki* location relative to residences, such that towns in which the *birki* is directly adjacent to residences are less likely to want to maintain it.

Two different threats to public health and safety were observed in Town B that were not an issue for residents in Town A: the presence of insects and the danger of drowning. Mosquitoes attracted to the open, standing water present a health risk to residents due to their vector-carrying capacity. These and other insects, including water bugs, were also considered a nuisance to those living directly adjacent to the *birki*. The other issue that arose in Town B was the drowning of four residents in the past. In response to this danger, the municipality erected a fence around the half of the *birki* that borders residential homes. This was not cited as an issue in Town A and there were no structures that indicated it had been a problem in the past. Since Town A's *birki* was located well outside of the inhabited portion of town, populations who are at high risk for drowning have no reason to be near it and it is far enough away that insects are not entering the homes.

Perception of Water Security

Perceived water security can be encouraged by access to alternative water supplies. Reliable water resources alternatives, such as a local filter station, can supplement water supply and may result in decreased dependence on rainwater harvesting as a water source. Therefore, access to these alternatives may decrease the desire to maintain a *birki*.

Higher per capita water demand requires a higher per capita water supply, thereby encouraging a town to maintain additional water sources. Per capita water use is higher with the inclusion of agricultural water use. Town A was largely dependent on agriculture, and therefore had a higher per capita water usage than Town B. Therefore, it is reasonable to expect that a town with higher per capita water needs would want to maintain their *birki*.

Organizational Capacity

Organizational capacity can be defined as the possession of all required maintenance resources. Inadequate maintenance resources can manifest in two ways: a lack of knowledge pertaining to traditional maintenance practices, and a lack of fiscal resources to apply maintenance measures. A town that experiences difficulties with organizational capacity cannot maintain the *birki*, even if they would like to do so. Therefore, organizational capacity is more often a limitation as opposed to a driving force. Lack of organizational capacity would force a town into a specific decision. In the absence of other identifiable drivers within a town, increasing the organizational capacity could affect a change in the decision being made.

~ CHAPTER 5 ~

Conclusion

Figure 29. Town A's *birki*. The town itself can be seen in the distance.

A thorough understanding of what drives a town's decision on whether to maintain a birki is critical to the proposal of effective maintenance solutions. While the comparative analysis carried out in Chapter 4 helped to identify some possible decision drivers, there may be additional factors that were not considered. In addition, it is unclear which of the posited drivers, if any, are most responsible for the sustainability of a town's birki. Further research can help determine the relative importance of each driver in a town's decision regarding *birki* maintenance, while also identifying additional drivers. The collection of information for a larger sample of the 56 municipalities in the *kaza* of Tyre would enable the use of both statistical analysis and further qualitative analysis. In this manner, additional patterns may be identified between town characteristics and the decision being made. Correlation of specific town characteristics with the decision being made could implicate specific drivers in the maintenance decision.

There are also various opportunities for additional hydrologic and climatic research in Lebanon. These opportunities include the measurement of drought and potential climate change effects, as well basic hydrological, hydraulic, and water quality conditions. One example of measures that could be taken to procure this data is the increased installation of monitoring stations.

Finally, the results of this study (and subsequent research) can be used to inform the construction of new *birki*s in Lebanon. Design adaptations can be proposed to avoid the problems that are being observed in current catchments, and address the key positive and negative characteristics that affect maintenance decisions, thereby maintaining the water-harvesting capacity of the *birki*s as emergency and supplemental water supplies.

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Appendix A: Guidelines for Interview Questions

NOTE: Questions 1 through 10 pertain to general information about the town's water use.

1) What is the estimated	total population	age range	percent (%) female	percent (%) male
for permanent or year-round residents?				
for weekend-only residents?				
For summer-only residents?				
for residents that currently live abroad?				

2) Which of the following sources of water does this town have? Identify which are considered drinkable.

	Description	Drinkable?
Piped water supply (and source)		□ yes □ no
Surface water (river, lake, reservoir)		□ yes □ no
Private rainwater capture		□ yes □ no
Community runoff rainwater capture		□ yes □ no
Ground water wells		□ yes □ no
Bottled Water		□ yes □ no
Other		□ yes □ no

3) Approximately how many households are there in the town?

____

4) Approximately how many households are connected to the piped water supply? Do you know how they use this water?

5) Approximately how many households use surface water sources? Do you know how they use this water?

6) Approximately how many households are equipped with private rain water capture systems? Do you know how they use this water?

7) Approximately how many households use the community rain water capture system? Do you know how they use this water?

8) Approximately how many households use ground water wells? When was a ground water well first introduced? Before that what did they do? Do you know how they use this water?

9) Approximately how many households use bottled water? Do you know how they use this water?

10) Approximately how many households use another source of water? Do you know how they use this water?

NOTE: Questions 11 through 16 pertain to the town's community rain water capture system.

11) How and by whom is the collection area currently maintained? How and by whom was it maintained in the past?

12) How many community catchment areas are there? ________

13) What are the shape, material, dimensions and capacity of each catchment area or container?

14) How often do you usually capture rain in the wet season? In the dry season?

15) How full is each catchment in the wet season? In the dry season?

16) How long does the water last? Does this source ever dry out?

17) The following questions are answered through observation:

a) Is there a screened inlet filter to avoid debris entering the storage area or container?	□ yes □ no
b) Is the storage area or container securely covered?	□ yes □ no
c) Does the storage area or container have an extraction system that doesn't contaminate the water, such as a tap or a pump?	□ yes □ no
d) Does the storage area or container have any additional features, such as a device to indicate the amount of water? If yes, specify here: ________	□ yes □ no
e) Is there easy access to the storage area or container for cleaning, such as a manhole and ladder?	□ yes □ no

NOTE: Questions 17 through 19 pertain to irrigation of communal lands.

18) What can you tell me about communal or town lands and their irrigation techniques?

19) Who benefits from these communal or town lands and how?

20) What type of maintenance is performed on the irrigation system(s) and who does it?

Appendix B: Thornthwaite Water Balance for Lithic Xerorthents Soil Type

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
T, air temperature (°C)	13.3	13.7	15.2	18	20.7	23.5	25.7	26.6	25.5	22.7	18.7	15.1	
i, Heat Index	4.40	4.60	5.38	6.95	8.59	10.41	11.92	12.63	11.78	9.88	7.37	5.33	99.24
UPET, Unadjusted PE(mm)	2.8	2.9	3.3	3.5	4.0	4.1	4.4	4.5	4.4	4.2	3.6	3.1	
r, PE Adjusted factor	26.4	25.8	30.9	32.7	35.7	35.7	36.3	34.5	30.9	29.1	26.1	25.8	
PE, Potential Evapo-transpiration (mm)	73.9	74.8	102.0	114.5	142.8	146.4	159.7	155.3	136.0	122.2	94.0	80.0	1401.4
P, Precipitation (mm)	187	151	96	50	19	2	0	1	6	48	120	176	856
RO, monthly runoff (mm)*	37.4	30.2	19.2	10	3.8	0.4	0	0.2	1.2	9.6	24	35.2	171.2
I, infiltration (mm)	149.6	120.8	76.8	40	15.2	1.6	0	0.8	4.8	38.4	96	140.8	684.8
I-PE (mm)	75.7	46.0	-25.2	-74.5	-127.6	-144.8	-159.7	-154.5	-131.2	-83.8	2.0	60.8	-716.6
Accumulated Water Loss (mm)			-25.2	-99.6	-227.2	-372.0	-531.7	-686.2	-817.3	-901.1	-899.1		
SS, Soil Storage (mm)**	125	125	102	55	20	14	2	1	0	0	0	60.8	
ΔSS, Change in Soil Storage (mm)	64.2	0	-23	-47	-35	-6	-12	-1	-1	0	0	60.8	
AET, Actual Evapo-transpiration (mm)	73.9	74.8	99.8	87.0	50.2	7.6	12.0	1.8	5.8	38.4	96.0	79.98	627.3
PERC, Percolation (mm)	11.5	46.0	0	0	0	0	0	0	0	0	0	0	57.5

*The runoff coefficient for this type of surface is 0.2.

**Soil in this region has a water content of approximately 125 mm.