Final Report
Rain Harvesting and Water Recycling in a Neighborhood in Ras Beirut

Prepared by

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in partial fulfillment to the requirements of the course CIVE 501
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ABET LEARNING OUTCOMES: SELF-ASSESSMENT

Learning Outcomes	Page
Students will have demonstrated a basic knowledge of at least three disciplines of civil & environmental engineering.	11, 15, 18-24, 28-30
Students will have designed a system or a component to meet desired needs taking into account realistic constraints such as social, economic, environmental, political, ethical, health, safety, and sustainability.	18-24, 26-31
Students will have used modern techniques and tools necessary for engineering practice.	23, 25, 26
Students will have demonstrated the ability to interact with peers on a project.	9, 10, 12-14
Students will have demonstrated organizational and presentation skills with a professional attitude.	9, 10, 12-14, 20-22
Students will have the ability to appreciate the impact of engineering solutions in a local and global context.	1-8
Students will be aware of contemporary issues and the necessity to engage in life-long learning.	18-24, 25-31

ACKNOWLEDGEMENTS

We would like to acknowledge several professors and professionals for assisting us in gathering the information needed for our report. We thank Dr. George Ayoub for his guidance and advice throughout this process, Dr. Salah Sadek for helping us in obtaining the rainfall data from the "NikulaShahin Weather Station", Mr. Moatasem A. A. Zahra from MAPS s.a.r.l for helping us obtain the maps of the study area, Dr. Cynthia Myntti, Dr. Mounir Mabsout, and Ms. Tonnie Choueiri for their guidance with the surveys and interaction with the community and their continued support, and Dr. Matthew Thomas for his help concerning the greening component of the project. Moreover, we would like to thank Father Germanos, Ms. Maya Abi Chahine, Mr. Maher Bou Ghanem, and the other members from St. Mary's Church and Orthodox College for their cooperation. Last but not least, we would like to thank all the residents who helped us with their ideas, data and time during the interviewing process.

DISCLAIMER

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SUMMARY

The following report entails an in-depth description of the Final Year Project titled "Rain Harvesting and Water Recycling in a Neighborhood in Ras Beirut." The topic and reason behind choosing it are both described. This project was carried out with other departments and professors in AUB (mentioned below) who helped define the scope of work and the area of focus of the research. It is important to note that the strongest drive behind this project is the ability to adapt and implement it to a real situation of a neighborhood in Ras Beirut.

The introduction gives a general idea of the topic and the different components it includes. The literature review provides information from books, journals, academic papers, and online research that were used to help with the project. These include a collection of rainfall, rainwater harvesting techniques, environmental threats in Lebanon, water types and uses for households in Lebanon, and applications in other countries, which are used for comparison. Graphs and tables are provided where necessary to show relations between variables as well as statistics.

The following section presents the scope of work and specifies the area of study. All the tasks required for the project to be completed are also listed. These include a study of the feasibility of the rainwater harvesting system from a social point of view through surveys and interviews that analyze socio-economic characteristics of the residents and their interest in the implementation of the project, the collection of the rainfall data and the consequent designs of different types of systems to different specification levels, and the interdisciplinary studies undertaken to arrive at conclusions that are based on agriculture and related to the possible uses of the collected water. The methodology then describes the steps undertaken to achieve all the different points listed.

The last part illustrates the results and discussion. It includes the conclusions drawn from the interview process, the design results completed, and the conclusions drawn from the interdisciplinary studies. It then covers the impacts and feasibility assessments from an environmental, economic, and social point of view. Last but not least, it addresses the environmental, economic, and social constraints in correlation to Lebanon and to the exact location of this project.

The conclusions and recommendations section then summarizes the final results obtained through the project studies and works.

Finally, the appendices include the survey that was used to accomplish the social aspect

of the project. The original copy of the survey was prepared in English, however it was found necessary to translate it into Arabic for ease of communication with the residents of Ras Beirut. Furthermore, the rainfall data obtained are also attached at the end, with details on average rainfall amounts for a consecutive series of recent months during a specific year (which were used to estimate the amount of rainfall that could be captured). Moreover, the design calculations and drawings are also attached at the end of the appendices.

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LIST OF ABBREVIATIONS

A	Roof Area
C	Discharge coefficient
IRIN	Integrated Regional Information Networks
R	Annual rainfall
RHS	Rainwater Harvesting System
SMOC	Saint Mary’s Orthodox College
VR	Volume of rainfall harvested
WHO	World Health Organization

LIST OF UNITS

$	US Dollars
%	Percent
m^2	Square Meters
m^3	Cubic Meters

1. INTRODUCTION AND PROJECT DESCRIPTION

The main focus of this project is to develop solutions to harvest rainwater in a community near AUB. This project falls under the scope of work of the AUB Neighborhood Initiative and the Center for Civic Engagement and Community Service (CCECS). They have a "proposed three year demonstration project to develop technical and policy solutions to problems limiting the development of urban agriculture in Beirut" (Dr. Mabsout and Dr. Myntti Proposal).

1) "*Water* - the understudied but potentially valuable capture of rainwater and its storage, reuse and/or groundwater recharge.
2) *Plants* – developing a plant database and recommendations that rely predominantly on drought resistant and salt tolerant species native to the coastal Mediterranean, both ornamental and edible.
3) *Soil* – creating an inexpensive alternative through composting.
4) *Structure* – developing simple structural systems and supports for plants on building roofs, facades and balconies" (Dr. Mabsout and Dr. Myntti Proposal).

The scope focuses on the first aspect of the project mentioned above (water) and extends to include parts of the initial steps of the fourth aspect (structure) when designing the prototype. A large area in Hamra bounded by Bliss Street and Hamra Street laterally and Jeanne D'Arc Street and Abdel Aziz Street vertically are considered in the research. However, the focus is on the area of Makhoul Street (one street parallel to Bliss Street). This street was specifically chosen due to its diversity in the types of buildings, institutions, and residents. An excessive search was not needed to find the needed area. The gentrification and densification of the Hamra area was a good representation - with increasing demolition, new construction, and a growing interest to provide a 'green environment.' Finding environmentally friendly solutions includes "[developing] technical [procedures] for rainwater capture, storage, recycling and recharge solutions that will be developed as prototypes for manufacturing." (Dr. Mabsout and Dr. Myntti Proposal)
This topic was of great interest to the team because of the following:

- The recent lack of water in the Greater Beirut area and thus a need for a more efficient use of the available water.
- The lack of techniques available in Lebanon to capture water resources; mainly rainwater.
- The need to provide “Greener areas” to reduce CO_2 emissions especially with booming construction in Beirut.
- The contribution of this study to the community and its role as a prototype for projects in other areas.

The study covers socio-economic considerations and studying rainfall data to decide which rainwater harvesting system (RHS) would be best to use. The feasibility of harvesting rainwater is investigated through a community survey that targets residents of the chosen area. In parallel with this, a prototype system was designed for a chosen institution on Makhoul Street. The results will hopefully offer a clear way of identifying whether rainwater harvesting is possible in this area. A successful installment of a RHS would provide residents of this area with an additional, cheap, and renewable water source. Once this problem is solved at an individual household level, it would help serve the community as a whole.

2. LITERATURE SURVEY

2.1 Rainwater Harvesting: The collection of rainfall and runoff in rural areas

Given that rivers could account for small percentages (~4%) of collecting water produced by precipitation, it is worthwhile to study methods for obtaining rainfall immediately as it falls. “The principle of collecting and using precipitation from a small catchment area is often referred to as ‘rainwater harvesting.’”

Technical and social assessments need to be done to determine the type of water harvesting technology that is to be used for a certain environment. Developing an appropriate water harvesting scheme cannot be achieved by simply collecting information and using it for design. “Innovative Dialogue” should be used where opinion and innovation come from users as well as designers. The suggested social assessment is concerned with the following:

- Views of people as to how much they would be willing to spend.
- Opinions on whether shared or individually-owned tanks would be better.
- Existing harvesting practices, if any.
- Opinions on the usefulness of collecting rainwater.

A questionnaire (refer to Appendices A and B) was prepared to reflect the needs of the community in Hamra on the basis of the social assessment the reference suggests.

Rainwater collected is relatively clean and requires little treatment since water collected from roofs is contaminated from birds and wind-blown dirt. A tank that is completely covered with a filter that prevents organic debris from entering requires almost no treatment other than storage, assuming the tank is not polluted. (Pacey & Cullis, 1986)

2.2 The Global Development Research Center

Natural resources, such as water, are being used beyond their limits; therefore, considerable resources will be required to cater to the needs of an additional three billion people in the next 50 years. Shortages in fresh water sources due to falling water tables, contamination of drinking water, and pollution in water sources are common problems. These issues along with urbanization and the increase in agricultural products are leading to a global water crisis.

In pursuit of sustainable development and optimizing water management systems in face of a global water crisis, rainwater harvesting has been identified as an innovative solution. Advantages of using a rainwater harvesting system include:

- Rainwater harvesting provides a good addition to other water resources and can reduce pressure on them.
- Construction and maintenance of a harvesting system are simple and do not require many resources.
- There are few negative environmental impacts compared to other technologies for water development.
- Water obtained is better for greening because it has a balanced pH and is free of chemicals, such as chlorine.
- Chemical and physical properties of rainwater are superior to that of groundwater, which is more susceptible to contamination (The Global Development Research Center).

2.3 LEBANON: Top five environmental threats

'IRIN humanitarian news and analysis' discusses the top five environmental threats to Lebanon. Water happens to be one of these threats. "Due to water shortages, especially during the dry season, the average household in some areas receives under 50 liters per day, which WHO says is the minimum to ensure a healthy environment. It is particularly urban centers, say scientists that will experience water shortages. Over 80 percent of Lebanon's population lives in urban areas." The reference supports the need for obtaining water from different sources due to the looming crisis the country suffers from (LEBANON: Top five environmental threats, 2010).

2.4 Sources of potable and service water in Lebanon

A statistical fact sheet issued by the Ministry of Social Affairs measures the living conditions of households in Lebanon. One condition was the percentage of household using water from different sources. Although the publication was printed for 2004, an idea about water consumption can still be deduced. The summary is as follows:

Table 1: Percentage of Households Using Different Water Sources for Potable and Service Uses

Water Source	Percentage of Households
Public network as a source of potable water	61.7 %
Mineral water as a source of potable water	64.3 %
Artesian wells as a source of potable water	0.2 %
Public network as a source of service water	20.9 %
Artesian wells as a source of service water	25.9 %

Although it can be inferred that the main source for households is potable water, the information is somewhat misleading as the potable water and service water do not individually add up to 100%. However, as shown in the table above, the percentages relating to potable water add up to more than 100% which could imply that most households use multiple potable water sources. As for the fact that the percentages of households' service water sources do not add up to 100%, this could be because not all of the households that were interviewed provided answers relating to their service supply of water (Ministry of Social Affairs, Central Administration, and the United Nations Development Programme, 2004).

To expand on this finding, the Central Administration for Statistics in Lebanon also provide information on water for both potable and service uses for the same year (2004). These percentages are more complete, as seen below, and therefore more transparently show that most residences rely on the public network for both types of water. Since the statistics provided by this source are more coherent, they should be more reliable (Lebanese Ministiry Republic of Social Affairs, Central Administration for Statistics, UNDP, 2004).

Table 2: Percentage of Households Using Different Water Sources for Potable Uses

Source of potable water	Yes	No	Total
Public network	56.7	43.3	100.0
Mineral water	31.8	68.2	100.0
Artesian well	8.2	91.8	100.0
Purchased water tanks	7.0	93.0	100.0
Spring or running water	6.2	93.8	100.0
Private network	2.1	97.9	100.0

Table 3: Percentage of Households Using Different Water Sources for Service Uses

Source of service water	Yes	No	Total
Public network	75.8	24.2	100.0
Artesian well	21.4	78.6	100.0
Purchased water tanks	15.1	84.9	100.0
Private network	4.0	96.0	100.0
Spring or running water	1.5	98.5	100.0

2.5 Indicators and Aspects of Hydrological Drought in Lebanon

An indication of the hydrological drought in Lebanon is evident from the following:

Table 4: Precipitation Rates in Lebanon between 1967 and 2006

Year	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Precipitation (mm)	967	1,120	1,023	987	1,021	1,103	1,054	1,034	956	1,093	987	1,032	1,002	895
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Precipitation (mm)	1,065	944	1,065	955	942	953	1,021	942	910	897	933	974	876	822
Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005			
Precipitation (mm)	987	873	864	876	888	856	971	834	803	875	894			

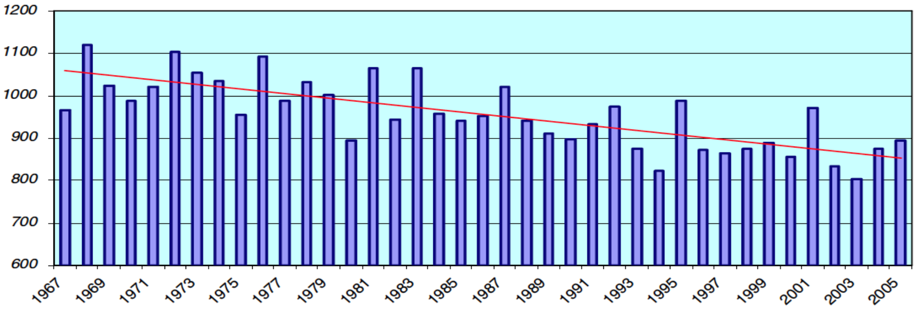

Figure 1: Trend in Lebanese Precipitation Rates between 1967 and 2005

No reliable record of water amounts pumped out of wells exists in Lebanon. However, Lebanese well owners have noticed the decrease in flow from wells, a reduction in water table levels, and that water pumped from wells is unsteady. Another reduction of available freshwater is happening due to the strong saltwater intrusion into coastal aquifers. The decreasing quality of existing water sources encourages finding new solutions that could involve recharging groundwater with rainwater or using rainwater as a supplementary source to reduce strain on underground water (Shaban, 2009).

2.6 Roof rainwater harvesting systems for household water supply in Jordan

Abdulla and Al Shareef have reported in a study entitled *Roof rainwater harvesting systems for household water supply in Jordan* the potential for potable water savings in the 12 governorates in Jordan. The potential for potable water savings ranged from about 1% to 20%. The volume of rainwater that could be collected was calculated using annual rainfall data, total roof area (for each governorate and assuming all rooftops are used), and a run-off coefficient of 0.8. This coefficient indicates a 20% loss during the collection process.

An analysis of a sample of harvested rainwater from rooftops indicated that the measured inorganic compounds generally matched the WHO standards for drinking water.

The formula stated below (refer to List of Abbreviations) was used to calculate the volume of rainfall that could possibly be collected in the study area. Furthermore, the results confirm that the quality of rainwater is superior to other sources and minimal treatment is required for its use (Abdulla & Al-Shareef, 2009).

$$VR = (R \times A \times C/1000)$$

2.7 Artificial Groundwater Recharge: A Preliminary Study

In a study entitled *Artificial Groundwater Recharge: A Preliminary Study*, Ricardo Khoury presented a study revealing the possibility of increasing water availability via artificial recharge of groundwater wells from rainwater collected on building roofs. For the purpose of this study, an area that includes 290 buildings in Ras Beirut was taken into consideration.

A questionnaire was distributed in the area of study to provide information on well availability, well usage, drainage system, water usage, and the location of water discharge. Results showed that approximately 43,000 m^2 (roof area) are available for recharge purposes (buildings with wells). Using a runoff coefficient and an annual precipitation value of 0.9 and 880 mm respectively, the potential recharge volume was estimated to be around 34,060 m^3. This roughly represents about 5.5 percent of annual water consumption in the study area.

This study gives an indication of the amount of water that could be saved in Ras Beirut and the quantities that could be used for greening or as service water (Khoury, 1999).

2.8 Nikula Shahin Weather Station – Ras Beirut

The tables in Appendix D show the monthly weather charts from September 2009 to June 2010. Each chart shows the daily rainfall levels, atmospheric pressure, humidity and temperature. The general average is revised for 21 years from 1981 to 2002. Knowing the average rainfall over a period of time has helped with designing the rainwater catchment system. Given that the data is quite recent, the solutions can be considered to be both reliable and realistic if they are to be compared to the current weather situation in Ras Beirut (Nikula Shahin Weather Station, 2010).

2.9 Ontario Guidelines for Residential Rainwater Harvesting Systems 2010 Handbook

Ontario Guidelines for Residential Rainwater Harvesting System is a handbook that introduces applicable codes, standards, and guidelines for the design of residential rainwater harvesting systems. It handles issues such as catchment area, catchment material, rainwater conveyance network, size of storage tanks, and rainwater quality. These codes were used heavily in the project's design process.

2.10 Market Housing Nutritional Facts

The "Market Housing Nutritional Facts" is a document that was prepared by Architect, J. Matthew Thomas. It lists nutritional facts regarding various kinds of foods that are planted around Lebanon. For the purpose of this project, foods pertaining to the area of Beirut were used for the study related to greening. Supplementary information on the amount of water needed for planting as well as the watering frequency are also stated.

3. SCOPE OF WORK AND METHODOLOGY

3.1 Scope of Work

The project covers socio-economic considerations, water resources, structural assessment, agricultural disciplines in order to study rainfall data and decide accordingly which rainwater harvesting system would be best to use, the feasibility of harvesting the rainwater, and to design the system. A prototype of the rainwater harvesting system will be implemented in a private institution. The following represents the general scope of work.

3.1.1 Interviews

- The Hamra/Ras Beirut area (bounded in the south by Bliss Street and the north by Hamra Street, on the west and east it is bounded by Jeanne D'Arc Street and Abdel Aziz Street respectively) was studied focusing mainly on the feasibility of rainwater harvesting from a water resources and socio-economic point of view. An interview scheme was created to reflect the needs of the area's residents, their greening concerns, and the possibility of incorporating rainwater harvesting systems in their homes (See Appendices A and B).
- The results of the conducted interviews were gathered and analyzed in order to understand the social aspect and possible constraints facing the project (See Appendix C).

3.1.2 Design of System

The design of rainwater harvesting prototypes is divided into different design stages (level of detail) and for different types of buildings, and includes:

- A literature review covering rainwater harvesting techniques, water resources, and Lebanese socio-economic aspects that are related to the topic.
- A general design guideline that includes the amounts of water that can be captured.
- Conceptual designs for three main different types of buildings that were encountered in the area of study.
- Detailed design and cost estimation for the fourth main type of building encountered in the area of study, namely, Private Institutions.

3.1.3 Greening

Interdisciplinary studies were undertaken with students and professors from other departments in order to achieve the following:

- A study of the types of plants that could be planted in the area at the given temperature and rainfall levels.
- The locations where plants can be grown in the different types of buildings, such as balconies, roofs, facades, or common ground areas.

3.2 Methodology

3.2.1 Interviews

After preparing questionnaires in both English and Arabic (see Appendices A and B), a sampling method was needed in order to select the residents that will be interviewed. The interviewing process was planned to target a minimum of 50 different households from different building types in order to obtain good results. However, due to the lack of time, the interviewing process was brought to an end before reaching the target, and it included 19 completed interviews. Given that 50 interviews would not have been representative of the block under study due to the fact that the sampling process was not random, 19 questionnaires were thought to be sufficient. Moreover, since the interviews have no clear statistical relevance due to the small and deliberate sample, choosing quality over quantity was essential.

With the help and contacts of Dr. George Ayoub, Dr. Mounir Mabsout, and Dr. Cynthia Myntti, 19 residents (two of which are also developers of the buildings they reside in) were contacted and interviewed. The interviews were mainly focused on the residents within the block, but few of them reside around the area of concern. The interviews were typed and the answers of each question were grouped from the different questionnaires for analysis purposes (see Appendix C). Afterwards, the answers were analyzed to deduce useful information and some statistical numbers. As mentioned previously, these statistical numbers might not be of relevance due to the nature of the selected sample and the number of interviews conducted, but they give a general perspective of the residents' reactions and ideas. One idea to obtain a better sample would be targeting residents without having direct contact with them, as well as interviewing owners of furnished apartment buildings, who might be highly interested to implement such a system to reduce costs. Therefore, targeting these residents could be an extension to the work in order to increase the statistical relevance of the obtained data.

3.2.2 *Design of System*

The following explains the methodology undertaken to accomplish the different components of the design stage of the project:

- Research has been conducted and general design guidelines were written. To do the latter, rainfall data in Lebanon were obtained and used together with the Ontario guidelines to estimate the amount of water that could be captured. A general design guideline covering rainwater conveyance and storage was included in the results and discussion part of the report.
- Four main types of buildings were encountered in the area of study through our extensive surveys. A conceptual design was prepared for these types of buildings.
- The detailed design was conducted for an institution and might serve as a prototype later on. The selected institution was Saint Mary's Orthodox College (SMOC) on Makhoul Street. The institution was chosen for the prototype because it involves dealing with one entity, would serve as a good example in the neighborhood, and because implementing the project at a school would be a great contribution towards SMOC Students' environmental education. In order to facilitate the work with the school, several meetings were conducted and the school's grounds were thoroughly surveyed and studied. Furthermore, the design has been completed up to detailed levels that can be implemented.

3.2.3 *Greening*

In order to conduct the interdisciplinary studies and obtain the needed information, professors and professionals in both the Architecture and Landscape fields were consulted. These include:

- Mr. J. Matthew Thomas, a Visiting Assistant Professor at AUB during Spring 2011 for an Architectural Design Studio titled "Market Housing: Housing and

Food Security." His work highlights the importance of adapting agricultural investments into residential design.

- Mr. Jamil Corbani, Co-founder and CEO of "Green Studios", was contacted. His company provides services for landscape projects, including vertical gardening.

4. RESULTS AND DISCUSSION

4.1 Results

As a result of the work undertaken (as described in the methodology), the following outcomes and conclusions were obtained.

4.1.1 Interview

The 19 conducted interviews generally revealed that the residents have a high level of interest in implementing rainwater harvesting systems for water conservation and greening purposes. However, the interviews also revealed some constraints that could face this project, such as storage areas, limited or no current planting, and the likelihood that most residents within the building will not be interested in investing in the project. The latter constraint is of high importance because if the system has a high cost, not having many participants may prevent the system from being implemented. This is due to the expensive costs per household when only very few residents decide to participate. Moreover, some buildings have a committee that votes on decisions related to the building, which implies that if a majority amongst the residents was willing to invest in the system, then it could be implemented. Since the interviews conducted showed that about 74% of rooftops are collectively owned by the residents of the buildings, convincing the majority becomes crucial for the system to be implemented. Additionally, buildings must also have enough space to cater for the system's storage tanks. In an attempt to resolve these obstacles or to reduce their influence, the level of awareness related to the importance of water conservation should be raised among residents and different systems with different price ranges should be designed to cater for the different spatial and economic conditions of the buildings' residents. In addition to that, further interventions could be performed on a higher level, where the municipality may introduce some incentives to developers to implement rainwater catchment systems in buildings during the construction phase.

Although the selected sample was limited both in number and variety of people, but the information collected had some variety and could have a statistical significance. It was noticed that 79% of the respondents have heard of different water catchment systems implemented in the mountains, such as dams, wells and water harvesting systems using reservoirs, but none have heard of such systems being used in cities. Moreover, about 58% of the respondents stated that they are careful about water consumption, 21% stated that they are slightly careful and the remaining 21% stated that they are not careful. Respondents that were not careful stated that the main reason behind this is due to the fact that no metering systems are used, and hence, the amount of money paid would be the same regardless of the amount of water they consume. Conversely, some respondents take measures to conserve water, such as not leaving the water running recklessly, closing the tap while brushing their teeth, not taking lengthy showers, and filling the washing machine or buckets with cold water while waiting for water to get warm. Therefore, it was generally obvious that most of the residents interviewed had a high level of awareness related to the importance of water conservation. This is highly crucial to the project because it will be easier to have it implemented when people know the importance and benefits that such a project can offer.

On another aspect, only about 21% of respondents have a water filtering system that is used to provide water for cooking and washing vegetables, and even less respondents use this water for drinking purposes. Moreover, none of the respondents has a water recycling system in their building/household. These two findings imply that no water is being reused and hence, strengthens the importance of a system that can provide an additional source of water for the residents, especially that the municipal water gets reduced in summer to a point that reaches shortage, which forces residents to buy water from private distributors. The prices that residents pay for the different sources of water have different ranges, but these prices seem to be low when compared to the amounts consumed or that could be consumed with the lack of a water metering system. However, calculating the amounts of water consumed is a tedious task with the absence of meters and the automatic refilling of the tanks. Yet, approximations of water consumption levels can be indicated from the volume of the tanks used in the buildings. Taking prices into consideration, about 42% of respondents pay less than $20 per month for municipal water used for services, and about 21% pay between $20-50. This clearly shows the low costs of the water supplied by the municipality given the annual shortage during the dry season. As for drinking water, 63% of respondents stated that they pay less than $50 a month to buy it. Although water prices seem to be low, about 27% of respondents stated that they do not consume water for planting purposes at all, and about 63% of them mentioned that they consume much less than 10% of their total water consumption for planting purposes. Given all of these findings, it is crucial to implement a system that can provide an additional source of water, which can later be used for different purposes depending on the requests of the participants. Since 79% of the respondents stated that they have either gutters and/or drainage pipes that take rainwater from the rooftop and down to sewers or to the streets, it seems that implementing a system that collects rainwater is very plausible since it will use this already-existing system from the rooftop. This water can be diverted into storage tanks to be used for different purposes.

On a more positive note, 95% of respondents believe that collecting rainwater is a good idea and that they would use the collected water for household utilities and cleaning, but only two respondents stated that they would use the water for planting purposes. When asked about the way through which collected water should be divided, answers varied to include: dividing water equally, dividing it among participants, dividing it according to apartment size or number of household members, or using it as a common resource for the building's cleaning and planting activities. However, the biggest constraint remains to be storage as most respondents stated that they have minimal space on the roofs and within the building to place tanks. About 47% of respondents said that tanks must be placed on roofs and 26% stated that tanks can be placed in the basement. As for the willingness to invest in the implementation of a water harvesting system, the answers varied and most respondents stated that they could not give an accurate estimate because they were not sure about the amount of water they can collect for the money they pay. This is due to the lack of a clear cost-benefit scheme. Therefore, the numbers provided seem to have no statistical relevance, but most respondents stated that the system must not cost more than $5,000 for the initial investment per building, and that maintenance costs should not exceed $100 per household.

4.1.2 General Design Guidelines

Theoretically, for every 1 mm of rainfall over an area of 1 m^2, a liter of water can be collected. However, this amount cannot be stored at 100% efficiency in practice due to losses, such as the absorbency of the catchment material, evaporation, leakage, and wind.

Regardless of the type of roof material (aluminum, asphalt shingle, fiberglass, asphalt built-up, or hypalon), the continuous rainfall loss ratio has been found to be about 20% (Despins, 2010). The initial loss however is irrelevant since the first rainfall captured within each season will be flushed to ensure that the water captured is clean. As part of the research, it was found that during the winter of 2009-2010, there was a total of 820 mm of rainfall in Beirut (see Appendix D). However, since this winter was considered to be a rich year for rainfall, a more reasonable precipitation value of 783 mm (averaged over the last 30 years) was used (Harb, 2011). Thus, considering a 30% loss (to add losses through the pipes in addition to the losses mentioned above) and an average of 0.78 m of rainfall per year in Lebanon, a total of $0.7 \times 0.78m \times 1\, m^2 \approx 0.55m^3$ can be harvested a year per m^2 of capturing area. One of the challenges facing the collection of rainwater in Lebanon is the fact that most water shortages occur during summer (dry season), while most of the water will be captured during winter (wet season). Thus, the system will need to store the water collected for a long period of time. Additionally, the issue of storage is a large constraint that will restrict the level of usage of water due to the lack of sufficient empty areas that can be used for storage in the area being studied. In some cases, the water will have to be used only for greening purposes or will need to be recharged into already-existing wells. Therefore, the feasibility of this last point and the different options should be investigated.

This section evaluates the current state of the buildings in the area of study and how they could be modified/altered to capture rainwater and store it. It gives a general perspective on the installation of rainwater harvesting systems.

Rainwater Conveyance

The several interviews and visits that were conducted showed that there are different types of buildings in the area of study. The following attributes differed per building: age, number of floors, and complexity of the existing water system (well, filter, private vs. common tanks, different piping systems, etc). However, through the interviews, it was found that nearly all buildings incorporate a system that drains the water off the roof into either the streets or rainwater sewers. Thus, an intervention can be made on these systems to divert the water into storage tanks, which will reduce implementation costs due to the alteration of an already-existing system.

Furthermore, it was found that most roofs are leveled in such a way that points the water towards gutters that lead into downspouts, then water goes down to the ground level due to gravity. Currently, these downspouts are kept open at the ground level for the water to flow out or are connected to rainwater sewers. This is the point at which the intervention should be made to divert the water into storage facilities. Thus, a pipe system will be connected to the downspouts to take rainwater. Here, according to the location of the storage tank, two different systems may be introduced. First of all, if there is available space at the ground or underground level to incorporate the storage tank(s), the water will flow into the tank(s) through the pipes by gravity without the need of a pump. On the other hand, if spatial constraints are faced in such a way that leads to the use of storage tanks on the rooftop, a small storage tank will have to be placed at the ground level into which the rainwater is first diverted from the rooftop. Then, once the water in the ground level storage tank reaches a specific level, it will be automatically pumped through a different piping system to the storage tank(s) on the roof. However, if the water is going to be injected back into the groundwater aquifer, it will also be first diverted into the ground level storage tank, and once it reaches a specific level, it will be pumped back into the well. The pumping system that will be used in this case will have to be extremely powerful in order to provide the water with the high level of pressure needed to inject the water back into the aquifer.

Rainwater Storage

As mentioned above, the availability of storage areas is the main constraint facing the rainwater harvesting system. The available space and the structural capabilities of the different buildings will limit the size of the used water tank(s). Thus, possible uses of the rainwater should be studied together with storage constraints before an optimal solution can be chosen.

In most countries, water-metering systems are typically used to measure the amount of water consumed per household. Taking this into consideration, any water that can be saved at any time of the year would be financially beneficial to any institution/household on the long-run. This is especially the case when the amount of money saved on the water bill exceeds the initial investment that is made to implement the rainwater harvesting system. Usually, in countries where the water-metering system is applied, the return on investment seems likely to occur in a very short period of time, making the RHS a very attractive investment (Zero M & MEDA Water, 2008). The case is different in Lebanon, because water-metering systems are not used and there is a shortage in the municipal water supply (mainly during the dry season). The current system in Lebanon works in such a way that one pays the municipality water bill as a lump sum on a yearly basis regardless of the amount of water consumed. The lump sum paid is very minimal and municipality water shortages are high during the dry season. Additionally, when water is short in Lebanon, people usually buy water from tankers that are quite expensive or use their own wells. Naturally, if water is to be used for greening purposes, it will mainly be needed during the dry season, making the main purpose of the RHS system to be storing the water during the wet season and using it during the dry season.

Taking the latter into account, it is always better to use larger sizes of water tanks, but two major constraints govern size selection:

1) Lack of available space to place tanks:

   Most of the buildings in the study area do not possess empty spaces around them where the tanks could be placed. This is due to the urban planning of this neighborhood that allows a 100% build up area (i.e., each piece of land can be built up to its saturation level, leaving no empty land). This problem can be overcome by designing in-building integrated water storage systems. This would be a tedious task due to the possible lack of space within the building to install the tank(s). Also, the capacity of various building components should be taken into account since many of these existing components were not designed to withstand this type of additional loads. Given that the storage of water is extremely heavy, investigating the capacity of these components becomes highly important.

2) The potential use of stored water:

   The designed tanks should meet the residents' needs with the highest efficiency that can be attained. If the tanks are undersized, the system would not reach its set target because of excessive shortages, and hence residents will not be satisfied. On the other hand, if they are oversized, extra costs would be incurred with no added benefit. Thus, the amount of water that can be collected and consumed per year should be calculated based on the use of the system, and then appropriate storage tanks should be designed. For example, if the rainwater harvesting system is to be used solely for irrigation purposes, water amounts that the vegetation would require during the dry season could be calculated and the size of the tank designed accordingly.

4.1.3 Preliminary Conceptual Designs for Four Different Types of Buildings

The four most abundant different types of buildings encountered in the area of study are:

1) Private Institution buildings.
2) Buildings with available external spaces for storage.
3) Buildings with no available external space but have existing wells.
4) Buildings with no external spaces and no wells.

The first type of building will be designed to greater detail in another section. The second to fourth types, however, have been designed to a conceptual level. Below is a summary of what these designs entail.

1) Buildings with available external spaces for storage

The main difficulty with implementing a RHS is the lack of available spaces. Buildings with external spaces have the simplest design. Two options could be considered, a tank could be placed either at the ground level or below ground level through excavation.

According to the community survey conducted, it was found that roofs were slanted to allow water to be collected by gutters that lead to downspouts. At ground level, downspouts could be diverted into storage tanks. The water would flow directly into the tanks by gravity without using any pumps.

Assuming a 400 m^2 roof size, a storage volume of 246 m^3 would be needed. An $8 \times 8 \times 4$ m^3 concrete tank could be constructed.

2) Buildings with no available external space but with existing wells

The availability of external spaces might reduce the costs of the implementation of a rainwater harvesting system. However, if external spaces are not available, internal spaces and wells must be considered. If there are available maps for the building, they can be used to determine the capacities of the structural elements and the availability of empty spaces within the building for storage tanks. If spaces are found in the basement, the loads of vertical elements (i.e. columns) should be determined in order to ensure that the elements can take the additional loads of the storage tanks and water. If the loads can be taken by the structural elements, then the required tanks can be placed in the basement. A pump will be needed in order to drive water up to tanks on the roof before it is distributed to different apartments.

On the other hand, if the elements cannot withstand these additional loads or the building does not have available internal spaces, wells must be considered. Additionally, internal spaces cannot be used for storage tanks if there are no as-built maps of the building, due to risks of failure of some elements when the loads are added. Therefore, wells must be taken into account and used to store water. Several additional costs will be encountered in this case. First of all, there will be a need to implement a filtering system to clean the water before it is pumped to the well. This is needed in order to ensure that groundwater will not be polluted. Moreover, the water cannot be recharged into the aquifer as quick as it was extracted and thus has to be recharged slowly. Thus a small tank will have to be introduced out of which the water will be pumped gradually into the aquifer. This would require very strong pressure and thus would be expensive.

3) Buildings with no external spaces and no wells

Buildings with no external spaces represent significant challenges. Tanks could be placed in internal spaces like the roof or in the basement. Structural analysis should be completed to check if the building could handle the additional loads using as-built maps in case they are present. Vertical elements should be investigated to study their capacity to handle the additional load.

As previously mentioned, roofs already have drainage systems that direct water to ground level. Intervention at ground level should be made to redirect the water to storage tanks in the basement. Flow is redirected to the basement by gravity and without the need for pumps. In this case, a pump would be used to direct the water into a small separate storage tanks installed at the roof for intended use.

If the structure would be able to handle the additional load due to storage on rooftops, then a temporary storage site should be incorporated at the basement level to pump the water back to the tanks on the roof. A small storage facility should be installed in the basement for the sole purpose of temporarily keeping the water to be pumped back up to the roof.

4.1.4 Detailed Design of a Rainwater Harvesting System at a Private Institution

An initiative has been taken to make Saint Mary's Orthodox College on Makhoul Street the institution where a RHS prototype will be constructed. Meetings were conducted with both the Priest of the Orthodox Church, Priest Germanos, and with the administration of the School. A proposal was prepared for submittal to the School administration; it was then passed through the School's board and accepted. An official meeting was then held to formally "launch" the project. Furthermore, a detailed RHS design has been conducted for SMOC. In order to understand the following description of the design, the layout of the school premises (outlined in red) could be seen in the figure below:

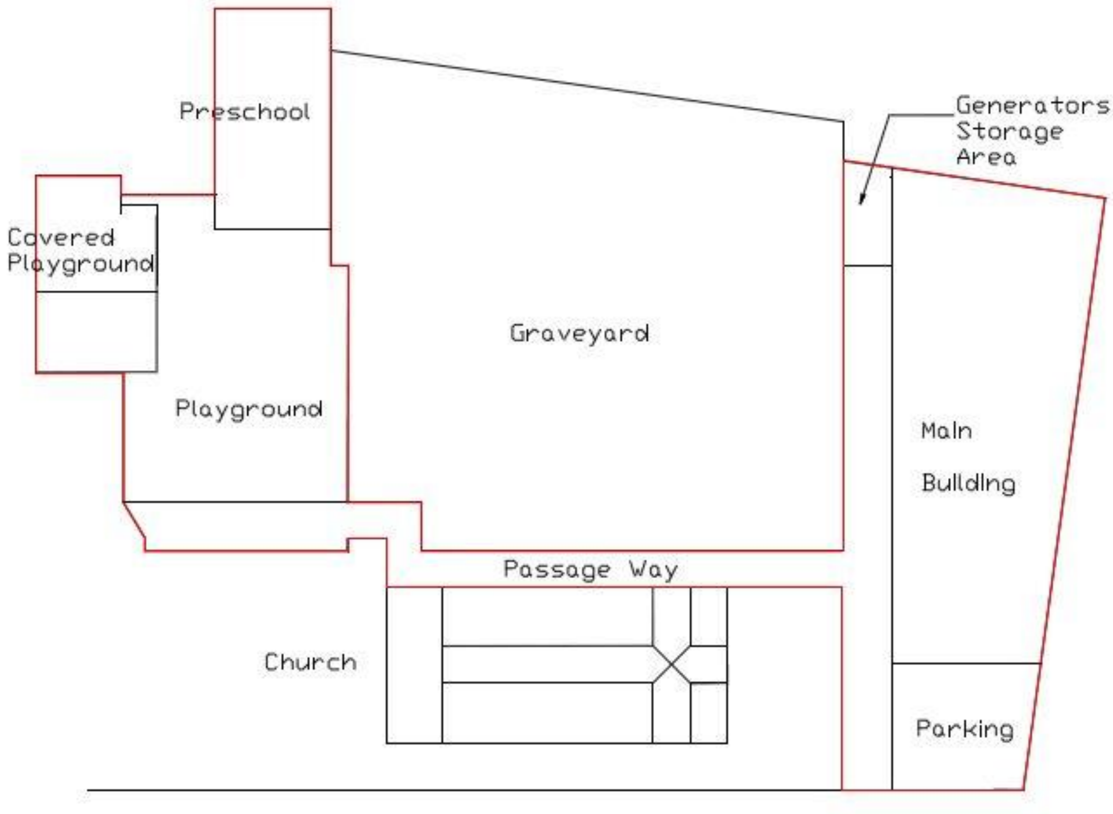

Figure 2: Layout of School Premises

The school premises basically consist of three buildings with roofs that could be used to collect rainwater. After thorough investigation of the buildings, it was found that two of them (the main school building and the covered playground) would be ideal to harvest rainwater. Both the latter buildings have a clear external roof drainage system that could be easily intervened with. The pre-school building was omitted due to two constraints. First of all, water does not drain effectively of its rooftop and secondly, the drainage systems off the rooftop and off the individual floor levels are combined into one piping system. Moreover, as-built water drawings do not exist to facilitate the interference. The rooftop areas of the main building and the covered playground were found to be 600 m^2 and 350 m^2 respectively. If both the buildings' rooftops were to be used for harvesting, the total rooftop area would sum up to 950 m^2 and thus the amount of water that could be harvested would be equal to about 523 m^3 (using a 0.55 m^3 of water that can be collected per 1 m^2 of collection area).

After different discussions were conducted with the school's administration, it was found that they do not face any water shortages. This is mainly because the school does not operate during the summer time (when most of the municipality water shortages occur), and because they possess a well that can be used as an additional source of service and irrigation water. An important perspective to keep in mind is that any drop of water that can be saved is beneficial on the long-run and the concept as a whole can help spread awareness in the community. Additionally, a current issue faced in the Ras Beirut area with most wells is the salinity of the water. Although no sufficient data is available about SMOC's well water, it is perhaps safe to assume that the water is either already saline or will be in the near future. It was also found that the schools greening areas were minimal. Moreover, the only location where a large storage tank could be implemented was found to be under the playground which is far from the Main School building. It was thus deduced that it would be inefficient to collect water from the Main Building's rooftop, pump it to the playground for storage, and then pump it back to the Main Building for usage. During the 'launch' meeting with the school, the administration of SMOC addressed an interest in using water captured off the main building's rooftop for daily cleaning purposes to avoid using their well water. An interest was also addressed in storing just enough water for irrigation purposes during the dry season. Since the only large storage space was found to be under the playground and since the covered playground's rooftop yields enough water for irrigation purposes, it was decided that the latter system will be implemented at the Pre-School side of campus. Therefore, it was decided that the two following different systems would be executed:

1) Main School Building System: This system would basically serve to clean the main building's grounds. It will be capturing rainwater on a per shower basis that would be used shortly after. This requires minimal storage.
2) Pre-School Building System: This system would cater to the irrigation needs of the school. The water collected will be used during the dry season to supply the pre-school's vertical gardening facades and the current vegetation.

An outline of the whole SMOC system can be seen in Appendix E.

System 1: Main School Building System

Currently, the water that is drained off the rooftop of the main school building is led through pipes directly to the generator storage area (refer to Figure 2) from where it is then led into the rainwater sewers. It has thus been decided that the existing rainwater pipes will be intercepted at this point. Moreover, the Generators' Storage Area is the only location where a small water tank could be placed. According to Appendix D, the heaviest showers can reach 75mm of rainfall. Multiplying this amount by the surface area of the main building and the collection coefficient mentioned earlier, an amount of $0.075m \times 600m^2 \times 0.7 = 31.5m^3$ of rainwater can be collected per day. Since the water is to be used for utilities purposes in the main building for the next few days after each rainfall, thus the amount of water that is to be used would be the limiting factor to determine tank sizing. A standard $4m^3$ PVC tank would satisfy this need, because of lack of free space in that area; this tank should be placed on a steel stand. Once this tank is full, the rest of the rainwater will be directed into the rain sewers. This tank will be connected to a pressurized tank that would lead the water to each floor of the main school using a piping system. A tap will be introduced on each floor of the main school building that could be used for cleaning purposes.

System 2: Pre-School Building System

Following the greening component of the project, it was decided that two vertical gardening façades will be added to the Pre-School Building to add to the School's current minimal Greening areas. Since the Rainwater Harvesting System at the Pre-School side of campus is being introduced for irrigation purposes, it will basically cater for the vertical gardening facades' and the other existing plants' needs during three months of intense dry season. It was assumed that about ¾ of two of the Pre-School Building facades (the one facing Bliss Street (10mx15m) and the other façade to its right (25mx15m)) will be planted. This resulted in a total vertical gardening area of 393.75 m^2. Moreover, it was found that a 2.4 m by 0.64 m area of vertical greening (Atlantis Gro-Wall) would require about 3 drip heads running for 10 minutes a day and that drip heads have an average flow rate of about 2 US gal/hr (Wikipedia). The latter yielded a total volume of 84 m^3 for three months of watering. It was thus decided that a tank size of 100 m^3 would be constructed to cater for the additional need of the already existing vegetation on the school's grounds in addition to those of the vertical greening facades. After thorough investigation of the grounds, it was concluded that the only way to cater for such a large storage volume would be through the construction of an underground water tank below the uncovered playground. The area will thus be excavated, the tank constructed, and then a slab will be built above the tank returning the children's playground to its original state. However, after meeting the school, it was revealed that a layer of limestone exists at a shallow depth of one meter. If limestone were to be excavated, this would swiftly increase the price of the excavation and would also cause a high level of disturbance to the neighborhood. It was therefore decided to construct a tank with the surface area of 10 by 10 m^2 and a depth of 1 m. The water that goes into the concrete underground tank would be solely obtained from the covered playground which yields $350\, m^2 \times 0.55 \frac{m^3}{m^2} = 192.5\, m^3$. Since the covered playground has two gutters, it was considered that only one would be used. However this would amount to a theoretical value of about 96 m^3. Thus, to be on the safe side, it has been decided that water will be led into the tank from both gutters and that once the tank is full, the remaining water will be diverted to the rainwater sewers. Detailed design calculations and drawings of the concrete tank system can be found in Appendix F. Using the same vertical gardening data above, it was found that 1 m^3 is just enough to cater to one day of watering. Therefore, a pressurized tank will then be included externally taking water out of the main concrete tank and directing it to the vertical façade's drip heads.

4.1.5 *Greening*

During the meeting with Mr. J. Matthew Thomas, the issue of urban greening was thoroughly discussed to reach some conclusions that are relevant to this study. Since Mr. Thomas' work focuses on food plants in the form of trees and shrubs, the following planting options were provided:

Table 5: Examples of Foods for Greening

Food	**Water Needs**
Olive	60 L in summer, weekly
Cucumber	2-3 times per day, water for 20 minutes at each time
Tomato	Once every 2-3 days, water at an average rate of 2.4L/sqm

(Thomas, 2011)

These watering needs of these selected foods are applicable for a dry sesons's irrigation needs. Therefore, the rainwater harvesting system's main purpose would be to provide water during summer or other months throughout the year with no rain.

It was also noticed through the field studies that one of the existing buildings on Makhoul Street (Makhoul 303) has an olive tree planted at its entrance:

Figure 3: Olive Tree on Makhoul Street

As for the possible locations for planting, Mr. Thomas stated that it depends on specific case studies of buildings where the system will be implemented. For example, in apartments with common gardening areas on the ground level, this area would be ideal to plant an olive tree. Other foods may be planted on the roof, however this depends on the availability of space (the roofs might be already saturated with obstacles such as tanks). Additionally, the bearing capacity of the roof could be a constraint due to the heavy loads of the soil. The appropriate planting method and watering system needs to be chosen. Balconies are also an option, but this becomes the decision of the resident as to whether to use them for this purpose and how. Moreover, some plants that need direct sunlight may not be able to grow on balconies.

A modern form of greening could be used through the implementation of "vertical gardens", which falls under the category of "organic architecture". This is a special kind of planting since the "plants don't need soil [to grow] because the soil is merely nothing more than a mechanic support. Only water and the many minerals dissolved in it are essential to plants, together with light and carbon dioxide to conduct photosynthesis" (Vertical Garden: The art of organic architecture, 2006). "You can grow herbs, flowers, and plants all within this limited space. Plants like ivy or clematis [easily grow] up the wall" (DK, 2011). *Figure 4* below illustrates a vertical garden.

Figure 4: Vertical Garden (DK, 2011)

A local company that constructs and plants vertical gardens is "Green Studios". The company provided an offer, found in Appendix H, which includes "[installing] green wall panels on fair faced wall or metallic structure including [an] embedded irrigation network, masonry works or steel works to erect the fair faced wall or metallic structure on which our green panels are fixed are outside our scope [and] all piping works from technical room to pumps and green wall are outside our scope" (Corbani, 2011). This offer was based on a general concept of greening two facades of the pre-school building and further site assessment will be needed to obtain more detailed information on the system and final plant list.

4.1.6 Financial and Economic Feasibility of the Designed System for SMOC

Following the developed designs for the SMOC institution, it is crucial to assess the financial and economic feasibility of the designed system. The system mainly involves the design of a rainwater harvesting system and discusses the possibility of implementing vertical gardening on two of the pre-school building's facades.

As previously mentioned, the rainwater harvesting design consists of two different systems: (1) The Main School Building system that will capture rainwater on a per shower basis serving to clean the main building's grounds daily and (2) The Pre-School Building system that will collect water during the wet season and save it for irrigation purposes during the dry season. After consultation with Green Top International (a contracting company), prices for the RHS were obtained. It was found that system 1 will cost $1750 (see Appendix I). Even though the school does not resolve to buy privately distributed service water, it does use saline well water at times of municipality shortages and thus the availability of a cheap source of fresh water would reduce the strain on the aquifer. Therefore, taking into consideration the benefit obtained from an environmental point of view (saving water), the example that the system would give to the students of the school and residents of the area, and the replacement of saline water by fresh water, as well as investing $1750 in the RHS at the main school building seems to be appropriate. As for system 2, a quotation of $10,439.27 was provided (see Appendix I). This system is meant to provide the school with 100 m^3 of water storage to irrigate the potential vertical gardening facades of the pre-school building during the dry season. However, after consulting Mr. Jamil Corbani from Green Studios, an estimate of $320,000 to $400,000 (see Appendix H) was given to green the two facades. While this might seem as a significant price to pay with no financial return, but greening these façades will set a fine example of greening in a very congested neighborhood. Paying this price might be justified by the aesthetic and educational appeal. Even if it is decided not to implement the vertical greening façades, the 100m^3 water tank could still be used for other purposes such as utility use at times of municipality water shortages (avoiding the use of saline water), irrigating the already present green spaces in the church, graveyard, and school grounds. Thus, investing $10,439.27 in 100m^3 of rainwater storage is still an attractive concept.

4.2 Economic Impact Assessment

Economic feasibility is a crucial component of any project. However, in projects with a green perspective, the economic benefits could be based on the environmental benefits, such as water conservation. Whilst the project might not always prove to be financially beneficial, its economic benefit is undeniable when one considers the shortages of water that the world, and more importantly Lebanon, is starting to face and that will become even more critical with time. Thus, in order to assess the economic and financial feasibility of the project, the amount of rainwater that can be captured will be estimated, and the amount of investment that this would require together with the money that can be saved should be assessed.

In order to approximate the amount of water that can be captured, an aerial photograph of the study area was first imported into the GIS program in order to calculate the total rooftop areas of the buildings in this neighborhood. The total surface area summed up to 45,207m^2. Multiplying this area by 0.55 (the volume that could be captured per m^2 of surface area per year due to the average rainfall and different losses), the total volume of water that could be captured in this study area if a rainwater harvesting system was fully utilized in every building would be around 24,864m^3. This volume of water could have a great economic and environmental benefit in a neighborhood where the residents experience shortages during the dry season. The value of collected water becomes even higher when considering the fact that some residents have to resort to buying water from private water distributors during the dry season, which has a high cost.

The amount of money spent on buying water from private water distributors can be saved by installing rainwater harvesting systems. This amount can be calculated as follows. A typical residential building that has one apartment per floor has a rooftop area of around 250m^2. Thus, this would result to a total volume of 138m^3 of water that can be captured per year. A regular private water distributor would charge in the range of $10-15 per m^3 of water. Therefore, implementing a rainwater harvesting system in such a building would save between $1380-2070 per year. The initial installation cost of such a system is predicted to be higher than these amounts, but since the annual maintenance cost would be relatively low (cleaning the storage tanks, changing the pump, cleaning and maintaining the pipes), an investment in such a system has the potential of being financially feasible on the long-run. Many residents currently do not buy water from private distributors during municipality water shortages and resolve to the use of privately owned wells as a source of water instead. Whilst at a first glance this might seem more financially beneficial than buying privately distributed water or installing an RHS, it must be taken into account that the Ras Beirut's well water is saline and with time would corrode one's piping system.

As for economic feasibility, there is no doubt that the system would be economically beneficial. It has the potential of saving an extensive amount of water, a resource that is becoming less and less abundant nowadays.

4.3 Environmental Impact Assessment

When assessing the environmental impact of a rainwater harvesting system, one may be able to divide it into two broad concepts: water use and greening. A "systematic process [is needed to examine] the environmental, socioeconomic, and health effects during all life cycle stages of the project" (Cotruvo, Voutchkov, Fawell, Payment, Cunliffe, & Lattemann, 2010). Capturing rainwater and storing it for future use is heavily based on the concept of conservation of water. Greening automatically follows through using this water to make a building "environmentally friendly" by planting the roofs, balconies or facades.

One has to conduct a cost-benefit scheme in order to identify whether the implementation of a rainwater harvesting system in urban areas is beneficial to the environment and humans or not. The *socioeconomic and sociocultural environment* deals with the population, which in this case is the people living or working in the institution where the system will be implemented in. It also covers land use and planned development activities, which tell us what the exact design of the system will be and how it will be put into place. The *abiotic environment* is the climate and meteorology data that will help us in deciding the size of tanks depending on catchment amount as well as which plants can live in Beirut's climate(Cotruvo, Voutchkov, Fawell, Payment, Cunliffe, & Lattemann, 2010).

The most prevalent problem in Lebanon is not the lack of water, but the absence of systems to capture rainwater and relying on municipal water supplies for both residences and institutions. As individuals in a society, believing that every drop counts can significantly change water consumption habits.

The study area happens to be an urbanized region almost directly on the coast. After conducting interviews with the residents, three apparent categories were found: buildings with wells that are functioning properly and still provide a good amount of usable water, buildings with wells that have been contaminated by intrusion of sea water, and buildings without wells. It is apparent that whatever the case, reliance on wells is not the solution, especially with the fact that in the very near future, almost all existing wells will become saline. This is why conservation of water is done best through a system that uses a renewable source of water, such as collecting rainwater and storing it in tanks in order to use it during the dry season.

Given that tanks require space to be installed, if this space happens to be on the ground level garden, they may pose environmental threats. This might be the case because an economic analysis may show that the amount of rainwater collected may only prove useful for utility purposes and not gardening. This means that residents may choose to excavate and place a storage tank under a garden space. The consequences that damage the environment due to construction should be weighed against the benefits of using the water for utilities (Cotruvo, Voutchkov, Fawell, Payment, Cunliffe, & Lattemann, 2010).

The number of rainy days throughout the year may not be that numerous, (Thomas, 2011) with an average of 80cm of precipitation per year, generally condensed over a four month period - roughly December to March (Nikula Shahin Weather Station, 2010). However, if one looks at conservation on an individual scale, certain costs may be reduced. Looking at average numbers that have been calculated specific to the area being studied in this project, the average roof area over our whole study area was found to be about 45,207m^2 with an average of 0.55m^3 of water for every 1m^2. This does not yield a volume of catchment worthy of distributing to each resident. What would seem more logical would be to store this water and use it for either common areas such as cleaning the stairs, hallways and entrances or to use it for greening at both the communal and building level.

In general, “rainwater harvesting follows ecologically sound principles for water use as it…promotes sustainable practices…reduces reliance on ground and surface water…and promotes water conservation” (The Cabell Brand Center, 2007). Little or no destruction is done to the environment or its surrounding population (residents) by such a system. Following this idea, few mitigation measures will be needed to reduce the potential of the few negative environmental impacts.

4.4 Social Impact Assessment

The conducted interviews revealed that residents interviewed are generally interested in implementing this project, because they suffer from water shortages and would want to benefit from any extra source of water. However, since the selected sample was relatively small compared to the size of the chosen block, there might be residents who will not be interested in the project. This might be due to the unawareness in issues related to water conservation and the importance of utilizing an available source of water in the best way possible. Therefore, awareness programs might help to educate people concerning the benefits that this project can provide for them and the community as a whole. Furthermore, if the municipality's coordination is obtained, the incentives they might offer will help in implementing the system in new buildings, which will occur at a stage before residents move into the building. If this is performed, the importance of the social aspect might be reduced at the implementation level, but it will still be important during the operational phase.

4.5 Project Constraints and Limitations

The impacts mentioned above may be of a direct or indirect nature and sometimes positive or negative. It is important to evaluate the probability and frequency of these impacts occurring and duration of time during which the impact will last. Impact mitigation helps discover the project's constraints and limitations, as well as "[identifies] the most feasible and cost-effective measures to avoid, minimize, or remedy significant negative impacts to levels acceptable [by] the affected community" (Cotruvo, Voutchkov, Fawell, Payment, Cunliffe, &Lattemann, 2010).

A main issue that needs to be tackled is proving that implementing such a system will yield enough positive effects to overcome the cost. In order to do this, residents must be informed and awareness needs to be raised about the positive consequences of rainwater harvesting such as the potential to use it for utilities, greening, etc.

Choosing a building where all residents agree to participate in this project may be problematic and the project cannot be implemented in a building where only a number of people support the rainwater harvesting system. Also, even if all residents agree, finding an empty space to place the storage tanks on the rooftop might be uneasy, if not impossible, which can lead to using the area of the ground floor that is already being used as a garden. It should be decided whether replacing this garden with a tank is worth the costs. Implementing the system at a public location, such as St. Mary's School, is preferable because it would be easier to find spaces to accommodate both tanks and gardens on the ground level (without sacrificing one for the other).

The planting aspect may have negative impacts due to the weather conditions; therefore, further investigations should be performed on gardening techniques in order to identify plants that can grow in Beirut's weather conditions. Conflicts might also arise when getting the public involved in the decision-making process, such as deciding what plants to grow and where.

5. CONCLUSION AND RECOMMENDATIONS

"Rainwater harvesting systems serve as an alternative decentralized water source, especially in the age when groundwater supplies are depleting and municipal water infrastructures are facing high replacement costs. Decentralized water sources, like rainwater, are needed to guarantee long-term ecologically sound water supplies" (The Cabell Brand Center, 2007).

The area in consideration is a good representation for such a project because of its diversity. With the increasing densification and reconstruction of the area, existing water sources are being strained. In addition, according to the findings of the conducted survey, residents of this area are generally interested in the concept for both environmental and economical reasons; especially because of the severe shortages that they face during the dry season.

Generally, the design of such a system is simple since most roofs already have installed drainage systems. What needs to be done is diverting the water drained from the roofs into a storage area. In an attempt to overcome the differences between the types of buildings in the area (depending on the age, availability of space, and public or private use of the buildings), the design will be divided into four categories. However, lack of storage spaces represents the biggest constraint in such a saturated neighborhood.

Also, such a system was proven to be economically feasible on the long-run because of the frequent shortages that force residents to pay extra money for external water supply from private water distributors. Shortages are most likely to occur and become worse in the near future because of the increasing demand and decreasing supply.

Several meetings were conducted with St. Mary's Orthodox college in order to 'launch' a project that entails constructing a prototype at their facility. After obtaining the approval of the school's board and receiving detailed information about the water systems in the school's buildings, two different systems were designed. One system collects water from the roof of the main school building, which is then used for daily utilities needs. The other system is constructed underground below the basketball court, and water is diverted from the rooftop of the covered playground to the underground storage tank. This water is stored until summer for irrigation purposes, including vertical gardening and existing green areas within the school's premises.

Recommendations to alleviate the pressure on existing water sources include: 1) promoting an awareness program which educates people about the scarcity of water and the importance of conserving it; 2) coordination of the municipality to promote the project through offering benefits for developers as an incentive to invest in rainwater harvesting systems; 3) implementing a new water pricing scheme that relies on a water metering system in order to control the reckless consumption of this valuable resource; and 4) implementing rainwater harvesting systems in both urban and rural environments.

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APPENDICES

APPENDIX A: Survey (English)

As Civil and Environmental Engineering students at the *American University of Beirut*, we are required to conduct a Final Year Project as a graduation requirement. The topics we have chosen are water consumption, water sources, and urban gardening. Our target area is between Hamra and Makhoul streets, and hence, we are targeting residents of this area for study purposes.

The information collected from this survey will remain anonymous and will only be used for the purposes of this project.

Building Name:
Floor:
Apartment #:
Institution/Business:

I agree to participate in this survey

- Yes
- No

- How many people live in your household?
- What is the relationship to the head of the household: self, spouse, parent, child, other
- What is your current occupation?
- Are you a renter or owner of the apartment?
- What is your age range?
  - 18-30
  - 31-40
  - 41-50
  - 50+
- For how long have you been in your apartment?
- What kind of relationships do you have with your neighbors? (no contact whatsoever, polite but no visiting, friendly with regular visits, family relations)

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1) What traditional rainwater catchment systems do you know of or have heard of in Lebanon? If you have heard of any, which of these methods have been applied in cities?

2) Is there collective or individual ownership of roof? Who has the right to use the rainwater from the roof?

3) What kind of drainage system do you have from your rooftops such as gutters, drainage pipes…?

4) Where is the drained water discharged?

- Sewers
- To the streets
- Recycled

5) Water Filtering System
   a) Do you have a water filtering system?
   b) What type of water filtering system do you have in your home or building?
   c) How does it work?
   d) Where is it located?
   e) If water is shared, how is the water divided?
   f) What is the water used for?
   g) What led you to install this system?

6) Water Recycling System
   a) Do you have a water recycling system?
   b) What type of water recycling system do you have in your home or building?
   c) What is the source of water that is being recycled?
   d) How does it work?
   e) Where is it located?
   f) If water is shared, how is the water divided?
   g) What is the water used for?
   h) What led you to install this system

7) If you buy your water:
   a) Is your water bought individually or for the whole building?
   b) How often do you refill the tank (x/month or x/year)?
   c) What is the volume of your tank?

8) Out of these quantities how much goes for planting?
   - 0 %
   - <10 %
   - >10%

9) How careful are you about water consumption? And why or why not?

10) What measures do you take to conserve water?

11) Where do you get your water from and how much do you pay monthly for each? (can circle more than one answer)

- Service Water (e.g. sanitation,cooking, and gardening):

MUNICIPAL WATER	**<20$**	**20$ - 50$**	**51-100**	**>100$**
WELLS				
PRIVATE WATER DISTRIBUTORS	**<20$**	**20$ - 50$**	**51-100**	**>100$**
OTHER	**<20$**	**20$ - 50$**	**51-100**	**>100$**

- Drinking Water:

MUNICIPAL WATER	**<20$**	**20$ - 50$**	**51-100**	**>100$**
WELLS				
PRIVATE WATER DISTRIBUTORS **(E.G. TANNOURINE, SANNINE…)**	**<20$**	**20$ - 50$**	**51-100**	**>100$**
SUPERMARKET **(E.G. 1-5 L BOTTLES)**	**<20$**	**20$ - 50$**	**51-100**	**>100$**
OTHER	**<20$**	**20$ - 50$**	**51-100**	**>100$**

Now, we would like to ask you some questions about the possibility of collecting rainwater in your building:

12) Do you think it is a good idea to collect rainwater?

13) If you were to collect rainwater, what would you use it for?

14) How do you feel it should be divided?

15) Where would you store it?

16) If you are willing to invest in such a project, how much would you be willing to contribute as a **total (entire building/institution)** initial investment?

- < $500
- $500-1000
- $1000-5000
- $5000-10000

17) How much would you willing to spend for **annual maintenance costs per apartment**?

- <$50
- $100
- >100 $

18) Would you like to add any comments or other useful information?

APPENDIX B: Survey (Arabic)

نحن طلاب هندسة مدنية في الجامعة الأمريكية في بيروت، وكجزء من متطلبات التخرج، علينا العمل على مشروع تخرج. الموضوع الذي اخترناه متعلّق بتجميع معلومات عن استهلاك المياه، ومصادر المياه، واستعمال وسائل للحفاظ على البيئة. المنطقة المستهدفة في هذا المشروع تقع بين شارعي الحمراء والمكحول من جهة، وبين شارعي جان دارك وعبد العزيز من جهة أخرى، ولذلك سنستهدف سكان هذه المنطقة لجمع المعلومات.

المعلومات التي سنجمعها من هذه الدراسة ستبقى مجهولة الاسم، وستسعمل ضمن هذه الدراسة فقط.

اسم المبنى:

الطابق:

رقم الشقة:

المؤسسة/مكتب العمل:

أوافق على الاشتراك في هذا المسح

- نعم
- لا

- ما هو عدد الأشخاص الذين يسكنون في المنزل؟
- ما هي علاقتك برب المنزل؟ بشخصه، زوج/زوجة، والد/والدة، ابن/ابنة، غير ذلك.
- ما هي وظيفتك الحالية؟
- هل أنت مالك أو مستأجر لهذا المنزل؟
- كم تبلغ من العمر؟
  - 30-18
  - 40-31
  - 50-41
  - 50+
- منذ متى وأنت تعيش في هذا المنزل؟
- ما هو نوع علاقتك مع جيرانك؟
  - لا يوجد أي نوع من التوصل
  - احترام متبادل من دون زيارات
  - علاقة ودية مع زيارات
  - علاقات عائلية

1) ما هي طرق تجميع المياه التقليدية التي سمعت بها في لبنان؟ إذا سمعت بطريقة من هذه الطرق، أياً منها يتم تطبيقها في المدن؟
2) هل ملكية سقف البناية فردية أم جماعية؟
3) ما نوع شبكة تصريف المياه المستعملة على سقف المبنى؟ مثل المزاريب أو أنابيب الصرف الصحي.
4) إلى أين يتم تفريغ المياه المصرفة؟
   - قناة المجاري
   - إلى الطرقات

- يتم معالجتها

5) نظام تنقية المياه

- هل لديكم نظام لتنقية المياه؟
- ما هو نوع النظام المستخدم لتنقية المياه في منزلكم أو المبنى؟
- كيف يعمل هذا النظام؟
- أين يوجد هذا النظام في المبنى؟
- إذا كانت المياه مشتركة، كيف يتم تقسيمها؟
- ما هي استخدامات هذه المياه؟
- ما الذي بكم لاستعمال هذا النظام؟

6) نظام إعادة تدوير المياه

- هل لديكم نظام لإعادة تدوير المياه؟
- ما نوع النظام المستخدم لإعادة تدوير المياه في منزلكم أو المبنى؟
- كيف يعمل هذا النظام؟
- أين يوجد هذا النظام في المبنى؟
- إذا كانت المياه مشتركة، كيف يتم تقسيمها؟
- ما هي استخدامات هذه المياه؟
- ما الذي بكم لاستعمال هذا النظام؟

7) إذا كنتم تشترون المياه الخاصة بكم:

- هل يتم شراء هذه المياه بشكل فردي أم لكافة سكان المبنى؟
- ما هو عدد المرات التي يتم فيها إعادة تعبئة الخزان شهرياً أو سنوياً؟
- ما هو مقدار خزان المياه الذي تستعملونه؟

8) من كمية المياه المستهلكة، ما هي الكمية المستهلكة من أجل الزراعة؟

- %0
- أقل من 10%
- أكثر من 10%

9) هل أنتم حريصون على توفير المياه؟ اماذا أو لم لا؟

10) ما هي الوسائل التي تستعملونها في توفير المياه؟

11) من أين تحصلون على المياه وكم تدفعون من أجل الحصول على هذه المياه شهرياً لكل من المصادر التالية؟ (بإمكانك اختيار أكثر من إجابة واحدة)

المياه الستعملة للخدمات (مثل الصرف الصحي، الطبخ، التشجير)

مياه البلدية	أقل من 20$	من 20-50	من 51-100	أكثر من 100$
الآبار				
شركات توزيع المياه	أقل من 20$	من 20-50	من 51-100	أكثر من 100$
غير ذلك	أقل من 20$	من 20-50	من 51-100	أكثر من 100$

مياه الشرب

مياه البلدية	أقل من $20	من $50-$20	من $100-$51	أكثر من $100
الآبار				
شركات توزيع المياه (تنورين، صنين)	أقل من $20	من $50-$20	من $100-$51	أكثر من $100
السوق المركزي (عبوات من 1 إلى 5 ليتر)	أقل من $20	من $50-$20	من $100-$51	أكثر من $100
غير ذلك	أقل من $20	من $50-$20	من $100-$51	أكثر من $100

سنسألك الآن أسئلة عن إمكانية تجميع مياه الأمطار في المبنى.

12) هل تعتقد/تعتقدين أن تجميع مياه الأمطار فكرة جيدة؟

13) إذا قمنا بتجميع مياه الأمطار، ما هي الاستعمالات الممكنة لها برأيك؟

14) برأيك، كيف يجب أن يتم تقسيم هذه المياه بين سكان المبنى؟

15) أين ستخزنون هذه المياه؟

16) كيف بإمكان جميع سكان المبنى استخدام المياه المجمعة على سقف المبنى؟

17) إذا كنت على استعداد للاستثمار بمثل هذا المشروع، ما هو باعتقادك المبلغ الأولي الكلي الذي على سكان المبنى دفعه؟

- أقل من $500
- $1000-$500
- $5000-$1000
- $10000-$5000

18) ما هو المبلغ الذي لديك الاستعداد لدفعه من أجل الصيانة السنوية؟

- أقل من $50
- $100-$50
- أكثر من $100

19) هل لديكم أي تعليقات أو اقتراحات أخرى أو معلومات هامة متعلقة بهذا المشروع؟

APPENDIX C: Summary of Interviews

1) What traditional rainwater catchment systems do you know of or have heard of in Lebanon? If you have heard of any, which of these methods have been applied in cities?

15 respondents (~79%) have heard of different traditional rainwater catchment systems, such as wells, dams, rainwater harvesting systems using reservoirs in the mountains, and even buckets.

4 respondents (~21%) haven't heard of any traditional rainwater catchment systems.

Note: none of the respondents have heard of any rainwater catchment systems that have been implemented in cities.

2) Is there collective or individual ownership of roof? Who has the right to use rainwater collected from the roof?

14 respondents (~74%) have collective ownership of the roof in their building.

2 respondents (~11%) have the roof of the building individually owned by one of the residents.

1 respondent (~5%) has the roof of the building owned by an institution.

1 respondent (~5%) has half of the roof of the building owned individually by one of the residents and the other half owned collectively.

1 respondent (~5%) has the roof of the building divided among few residents (a family that owns the building).

3) What kind of drainage system do you have from your rooftops such as gutters, drainage pipes…?

12 respondents (~63%) have drainage pipes from the rooftops.

3 respondents (~16%) have gutters from the rooftops.

4 respondents (~21%) do not know or did not answer.

Note: some respondents expressed concern regarding the inefficient drainage system on their rooftops.

4) Where is the drained water discharged?

12 respondents (~63%) have the drained water discharged to sewers.

5 respondents (~27%) have the drained water discharged to the streets.

1 respondent (~5%) has the drained water discharged to both sewers and to the streets.

1 respondent (~5%) does not know.

Note: none of the residents has a system that recycles the drained water discharged.

5) Water Filtering System

h) Do you have a water filtering system?

4 respondents (~21%) have a water filtering system.

13 respondents (~68%) do not have a water filtering system.

2 respondents (~11%) do not know or did not answer.

i) What type of water filtering system do you have in your home or building?

Different systems are used: 1) a filter to clean the water used for drinking, cooking, and cleaning; 2) a system which relies on a reverse osmosis treatment.

j) How does it work?

The system that uses reverse osmosis treats the poor-quality water underground, then pumps water back to the tank that is used for household activities.

k) Where is it located?

Different locations: 1) under the sink; 2) the system that uses reverse osmosis is located underground.

l) If water is shared, how is the water divided?

The system that uses reverse osmosis is used by the residents that participate in the system.

m) What is the water used for?

Drinking, cleaning vegetables, and cooking.

n) What led you to install this system?

Care for the family and the unclean water that is supplied by the municipality.

6) Water Recycling System

None of the respondents has a water recycling system.

7) <u>If you buy your water:</u>

d) Is your water bought individually or for the whole building?

11 respondents (~58%) buy their water with the whole building.

7 respondents (~37%) buy their water individually.

1 respondent (~5%) does not know or did not answer.

e) How often do you refill the tank (x/month or x/year)?

10 respondents (~53%) said that the tanks are refilled automatically.

9 respondents (~47%) do not know or did not answer.

Note: one of the respondents specified that the tanks are refilled about twice a week, while another respondent said that they are refilled about twice a week during the summer and more often during winter.

Note: some respondents mentioned that water is scarce during summer as the supply is reduced compared to winter.

f) What is the volume of your tank?

6 respondents (~32%) have individual tanks with different volumes: 1) 3.4 m^3; 2) 4 tanks, 3 of which have a volume of 1 m^3 and the fourth tank has a volume of 0.125 m^3 (total of 3.125 m^3); 3) 1 m^3; 4) 2 tanks, with a volume of 2 m^3 each (total of 4 m^3); 5) 2 tanks, one of which has a volume of 2 m^3 and is located on the ground floor, and the other has a volume of 4 m^3 and is located on the roof (total of 6 m^3); 6)2 tanks, both have a volume of 1 m^3 and one is located at the roof, while the other is at the basement level.

6 respondents (~32%) have common tanks with different volumes: 1) two tanks with a volume of 11.25 m^3 each (total of 22.5 m^3); 2) 3 tanks with a total volume of 12 m^3; 3) 4 tanks with a volume ranging from 8-16 m^3; 4) 3 tanks with a capacity of 2 m^3 each (total of 6 m^3); 5) 1 tank with a volume ranging from 18-20 m^3; 6) 1 tank with a volume of 20 m^3.

7 respondents (~36%) do not know or did not answer.

8) Out of these quantities how much goes for planting?

5 respondents (~27%) allocate about 0% of their water consumption for planting.

12 respondents (~63%) allocate less than 10% of their water consumption for planting.

1 respondent (~5%) allocates more than 10% of his/her water consumption for planting during summer.

1 respondent (~5%) does not know or did not answer.

Note: some respondents pointed out the fact that their plants die during the dry season due to the weather conditions and not having enough time to take care of the plants.

9) How careful are you about water consumption? And why or why not?

11 respondents (~58%) stated that they are careful.

4 respondents (~21%) stated that they are slightly careful.

4 respondents (~21%) stated that they are not careful.

Note: some respondents mentioned that there is a lot of water being wasted in the area. On the other hand, some mention that there is no incentive to conserve water because water metering systems are not used. Therefore, households would pay the same amount of money for the water being supplied regardless of the amount of water they consume. Yet, some respondents still choose to conserve water because of the scarcity of water supply, especially during summer.

10) What measures do you take to consume water?

Some measures mentioned by respondents include: not leaving the water running recklessly, closing the tap while brushing their teeth, not taking lengthy showers, and fillings the washing machine or buckets with cold water while waiting for water to get warm. Another measure brought up is that the water used from cleaning vegetables is later used to clean the floors.

Note: the general consensus is that most respondents seem to be aware that conserving water is pivotal. However, a few do not try to save water at all, and most respondents do not save water while showering.

11) Where do you get your water from and how much do you pay monthly for each? (can circle more than one answer)

a. <u>Service Water (e.g. sanitation, cooking, and gardening):</u>

Municipal water:
8 respondents (~42%) pay less than $20.
4 respondents (~21%) pay between $20-50.
1 respondent (~5%) pays more than $50.
6 respondents (~32%) do not know or did not answer.

Wells:
6 respondents (~32%) have wells in their building.
13 respondents (~68%) do not know or did not answer.

Private water distributors:
1 respondent (~5%) pays between $51-100 during summer only.
18 respondents (~95%) do not buy service water from private water distributors.

b. Drinking Water:

None of the respondents uses municipal water or wells for drinking water.

Private water distributors:

5 respondents (~26%) pay less than $20.

7 respondents (~37%) pay between $20-50.

1 respondent (~5%) pays $51-100.

6 respondents (~32%) do not know or did not answer.

Supermarket (1-5 L):

5 respondents (~26%) pay less than $20.

14 respondents (~74%) do not buy small water bottles from the supermarket.

Now, we would like to ask you some questions about the possibility of collecting rainwater in your building:

12) Do you think it is a good idea to collect rainwater?

18 respondents (~95%) think it is a good idea.

1 respondent (~5%) did not answer.

13) If you were to collect rainwater, what would you use it for?

Most respondents would use rainwater collected for household utilities and cleaning, while 2 respondents mentioned using the water for planting.

14) How do you feel it should be divided?

Common ideas include dividing water equally, dividing it among participants, dividing it according to apartment size or number of household members, or using it as a common resource for the building's cleaning and planting activities.

15) Where would you store it?

9 respondents (~47%) said that it will be stored in roof tanks that should be designed for that purpose.

5 respondents (~26%) said that it will be stored in basement tanks that should be designed for that purpose.

1 respondent (~5%) said that it will be stored in the yard in tanks that should be designed for that purpose.

2 respondents (~11%) said that it will be stored next to the building's entrance in tanks that should be designed for that purpose.

2 respondents (~11%) do not know or did not answer.

Note: some respondents voiced concerns regarding the possibility of placing extra tanks on the rooftop due to added loads, and stressed that further structural assessment would be needed, especially in old buildings.

Note: one respondent suggested excavating an existing available area and embedding some tanks underground.

16) If you are willing to invest in such a project, how much would you be willing to contribute as a **total (entire building/institution)** initial investment?

3 respondents (~16%) are willing to participate if the system costs less than $500.

2 respondents (~10%) are willing to participate if the system costs between $500-1,000.

4 respondents (~21%) are willing to participate if the system costs between $1,000-5,000.

3 respondents (~16%) are willing to participate if the system costs between $5,000-10,000.

4 respondents (~21%) were unsure about the amount of money they are willing to invest for the system.

3 respondents (~16%) did not answer.

Note: most respondents stated that they could not give an accurate estimate because they were not sure about the amount of water they can collect for the money they pay. This is due to the lack of a clear cost-benefit scheme.

17) How much would you willing to spend for **annual maintenance costs per apartment**?

9 respondents (~47%) are willing to spend less than $50 for maintenance.

5 respondents (~26%) are willing to spend $100 for maintenance.

3 respondents (~16%) are willing to spend more than $100 for maintenance.

2 respondents (~11%) do not know or did not answer.

18) Would you like to add any comments or other useful information?

In general, the comments included the following:

- Promoting awareness of the importance of conserving water.
- Newly constructed buildings exploit every inch of space and it is increasingly difficult to find any extra space to use.
- Water is extremely needed and there will be severe water shortages in the future.
- Greening is wanted and needed in the area of study.
- Working hand-in-hand with the municipality in order to offer financial incentives for developers of buildings that use rainwater harvesting systems, such as reducing the license fee.
- The project should be done in collaboration with the municipality, since it can provide incentives for developers.
- The municipality should take the extra money, which is currently being paid for private water distributors for adequate water supply during the summer, in order to provide residents with continuous water supply.
- The financial feasibility of the project should be investigated.

APPENDIX D: Rainfall Data

September 2009

Day	Rainfall, 24 hours (m/s)	Cumulative to Date	Last Year to Date	General Average	Atm. Pressure	Humidity (%)	Temp. (°C)
1	-	-	-	-	761	80	27
2	-	-	-	-	762	82	28
3	-	-	-	-	762	85	28
4	-	-	-	-	761	86	28
5	-	-	-	-	760	85	28
6	-	-	-	-	758	85	27
7	-	-	-	0.25	758	80	28
8	-	-	-	0.75	762	80	28
9	5.5	5.5	-	0.75	762	85	27
10	-	-	-	1.35	760	80	27
11	-	-	-	1.35	759	78	26
12	-		-	1.50	759	80	29
13	9.5	15	-	1.65	763	74	27
14	-	-	-	1.65	765	77	26
15	-	-	-	1.65	765	77	27
16	-	-	-	1.75	762	82	27
17	-	-	-	1.75	761	82	27
18	-	-	-	1.75	760	82	27
19	8	23	-	1.85	761	82	26
20	10	33	-	1.85	761	82	25
21	24	57	-	1.90	762	82	26
22	-	-	-	2.00	764	80	26
23	-	-	-	2.20	764	72	26
24	-	-	2	2.40	764	72	26
25	-	57	-	2.65	763	83	26
26	-	-	9	2.75	764	84	26
27	-	-	12	2.75	763	85	26
28	-	57	-	3.35	762	85	27
29	-	57	-	5.00	764	62	25
30	-	57	-	5.00	763	69	26
	Month (Total)	57					

October 2009

Day	Rainfall, 24 hours (m/s)	Cumulative to Date	Last Year to Date	General Average	Atm. Pressure	Humidity (%)	Temp. (°C)
1	-	57	12	6.25	765	81	27
2	-	-	-	6.50	764	84	26
3	-	-	-	7.00	764	85	26
4	-	-	-	7.50	763	85	27
5	-	-	-	8.00	762	82	25
6	8	65	-	9.25	763	80	25
7	-	-	-	9.75	763	85	26
8	-	-	-	10.25	763	86	26
9	-	-	-	10.25	762	86	27
10	-	-	-	11.00	763	87	26
11	-	-	-	11.25	764	87	26
12	-	-	-	11.75	765	88	25
13	-	-	-	12.25	764	87	25
14	-	-	-	13.25	765	87	25
15	-	65	26	13.75	765	75	27
16	-	-	31	14.75	764	88	26
17	-	-	-	17.50	763	88	26
18	-	-	-	19.75	761	53	29
19	-	-	-	24.00	762	55	30
20	-	-	-	25.25	763	45	30
21	-	-	-	26.00	766	85	25
22	-	65	52	27.25	766	80	25
23	-	-	56	30.25	764	898	25
24	-	-	-	34.25	761	88	26
25	-	-	-	35.75	761	85	26
26	-	65	88	39.00	764	69	27
27	-	-	106	39.50	762	66	26
28	-	-	149	42.75	761	78	24
29	-	-	152	47.00	762	78	23
30	12	77	-	48.50	762	87	19
31	10	87	155	50.00	762	79	22
	Month (Total)	30					

November 2009

Day	Rainfall, 24 hours (m/s)	Cumulative to Date	Last Year to Date	General Average	Atm. Pressure	Humidity (%)	Temp. (°C)
1	75	162	155	52.00	759	86	20
2	58	220	-	55.00	760	83	18
3	7	227	-	59.75	765	77	20
4	2	229	-	61.25	765	76	22
5	-	-	-	62.50	768	82	22
6	-	-	-	70.00	768	83	22
7	-	-	-	72.75	765	84	23
8	-	-	-	78.75	762	70	25
9	-	-	-	87.75	767	83	22
10	-	-	-	92.75	765	81	22
11	-	-	-	94.50	762	80	22
12	-	-	160	101.50	764	81	22
13	2	231	-	104.50	766	78	21
14	1	232	170	106.50	767	80	20
15	-	-	-	109.50	767	77	19
16	-	-	-	112.50	765	77	19
17	15	247	-	115.50	765	70	19
18	2	249	-	119.50	768	68	18
19	-	-	-	122.50	769	72	19
20	-	-	-	124.50	770	71	19
21	-	-	176	129.00	770	83	19
22	-	-	195	131.00	769	79	19
23	-	-	199	136.00	768	85	21
24	-	-	-	140.50	764	68	22
25	9	258	-	143.50	765	84	19
26	-	-	-	148.00	768	77	19
27	-	-	-	149.00	768	78	18
28	-	-	202	150.50	770	81	18
29	1	259	-	154.00	770	84	18
30	1	260	-	160.00	772	84	18
	Month (Total)	173					

December 2009

Day	Rainfall, 24 hours (m/s)	Cumulative to Date	Last Year to Date	General Average	Atm. Pressure	Humidity (%)	Temp. (°C)
1	-	260	202	163.50	770	75	20
2	-	-	-	169.00	766	65	20
3	-	-	-	172.50	765	75	21
4	12	272	-	179.00	766	84	19
5	13	285	-	184.50	766	84	15
6	8	293	-	187.00	764	85	15
7	3	296	-	189.00	764	82	17
8	4	300	-	197.00	766	82	16
9	6	306	239	207.00	765	85	16
10	1	307	-	210.50	764	85	19
11	-	-	-	213.00	762	75	19
12	41	348	-	222.00	762	85	15
13	14	362	-	230.00	765	85	17
14	6	368	245	235.50	768	80	17
15	-	-	-	239.50	766	76	18
16	57	-	-	243.00	758	52	22
17	35	425	-	246.00	762	70	20
18	2	460	-	249.00	764	86	17
19	-	462	-	255.50	767	84	19
20	16	-	-	260.00	767	75	18
21	-	-	249	264.00	764	73	21
22	-	478	251	268.00	770	78	18
23	-	-	253	272.00	770	85	18
24	-	-	280	275.50	771	85	18
25	-	-	283	282.50	770	85	18
26	-	-	290	288.00	767	86	18
27	-	-	-	293.00	767	85	18
28	-	-	-	296.00	765	85	19
29	4	482	302	300.50	762	83	19
30	4	486	304	303.00	764	83	18
31	-	-	-	308.00	768	82	17
	Month (Total)	226					

January 2010

Day	Rainfall, 24	Cumulative	Last Year	General	Atm.	Humidity	Temp. (°C)

	hours (m/s)	to Date	to Date	Average	Pressure	(%)	
1	-	486	305	313.50	768	84	18
2	-	-	-	318.00	764	78	21
3	0.2	-	-	322.50	766	80	19
4	4	490	-	326.00	767	84	18
5	-	-	-	335.00	769	80	18
6	-	-	-	342.00	771	85	17
7	-	-	-	346.00	771	85	19
8	-	-	310	350.50	770	84	19
9	-	-	314	356.00	770	84	19
10	-	-	-	362.00	767	70	20
11	-	-	327	368.00	767	70	19
12	-	-	-	369.50	765	80	18
13	10	500	-	371.00	764	83	16
14	2	502	-	375.00	675	73	19
15	-	-	-	383.00	768	71	19
16	-	-	-	393.00	765	70	18
17	-	-	-	400.00	766	70	20
18	21	523	329	409.00	759	87	14
19	32	555	-	416.00	764	86	15
20	48	603	330	421.50	765	83	14
21	24	627	-	424.50	771	85	13
22	-	-	-	430.00	768	80	17
23	9	636	-	434.00	768	86	15
24	29	665	-	440.00	764	85	12
25	18	683	333	445.50	768	68	14
26	2	685	-	448.50	768	68	13
27	-	-	337	453.00	771	72	12
28	-	-	-	457.50	760	76	17
29	-	-	349	461.50	763	85	18
30	-	-	385	466.00	765	78	20
31	-	-	380	474.50	766	80	19
	Month (Total)	199					

February 2010

Day	Rainfall, 24 hours (m/s)	Cumulative to Date	Last Year to Date	General Average	Atm. Pressure	Humidity (%)	Temp. (°C)

1	2	687	425	600.00	768	78	17
2	-	687	426	603.00	766	85	17
3	6	693	-	605.00	766	85	18
4	6	699	-	607.00	769	80	18
5	1	700	-	609.00	765	78	20
6	-	-	-	613.00	766	85	18
7	-	-	-	615.00	771	85	18
8	-	-	-	621.00	766	85	22
9	6	706	-	623.50	768	73	21
10	-	706	437	625.50	767	65	24
11	-	706	441	627.00	765	55	25
12	-	706	-	630.50	768	82	19
13	-	706	-	635.00	765	86	19
14	-	706	-	638.00	757	64	25
15	-	706	-	640.50	760	84	21
16	-	707	453	646.00	768	68	18
17	-	707	463	648.00	768	74	17
18	-	707	469	650.50	771	74	15
19	-	707	-	652.00	773	55	17
20	-	707	477	657.00	773	55	17
21	-	707	495	660.00	774	76	17
22	2	708	-	664.50	769	85	18
23	6	714	503	670.50	765	85	18
24	-	714	508	674.50	765	66	21
25	-	714	-	678.50	763	85	17
26	11	725	-	684.00	764	83	18
27	13	738	520	686.00	764	85	18
28	35	773	542	687.00	765	85	17
29	-	-	-	687.50	768	72	18
				691.00	768	62	19
	Month (Total)	88		691.50	770	72	18

March 2010

Day	Rainfall, 24 hours (m/s)	Cumulative to Date	Last Year to Date	General Average	Atm. Pressure	Humidity (%)	Temp. (°C)
1	3	776	557	600.00	768	78	17

2	-	776	557	603.00	766	85	17
3	2	778	564	605.00	766	85	18
4	-	778	567	607.00	769	80	18
5	-	778	567	609.00	765	78	20
6	-	778	567	613.00	766	85	18
7	-	778	567	615.00	771	85	18
8	-	778	567	621.00	766	85	22
9	-	778	573	623.50	768	73	21
10	-	778	576	625.50	767	65	24
11	-	778	576	627.00	765	55	25
12	-	778	576	630.50	768	82	19
13	-	778	576	635.00	765	86	19
14	-	778	588	638.00	757	64	25
15	-	778	596	640.50	760	84	21
16	-	778	596	646.00	768	68	18
17	-	778	596	648.00	768	74	17
18	18	796	596	650.50	771	74	15
19	-	796	-	652.00	773	55	17
20	-	796	602	657.00	773	55	17
21	-	796	602	660.00	774	76	17
22	-	796	602	664.50	769	85	18
23	-	796	602	670.50	765	85	18
24	-	796	630	674.50	765	66	21
25	-	796	630	678.50	763	85	17
26	-	796	630	684.00	764	83	18
27	-	796	641	686.00	764	85	18
28	-	796	647	687.00	765	85	17
29	-	796	647	687.50	768	72	18
30	-	796	647	691.00	768	62	19
31	-	796	647	691.50	770	72	18
	Month (Total)	23					

April 2010

Day	Rainfall, 24 hours (m/s)	Cumulative to Date	Last Year to Date	General Average	Atm. Pressure	Humidity (%)	Temp. (°C)
1	-	796	796	694.00	765	62	20
2	-	796	796	695.00	768	70	21

3	-	796	796	698.50	765	55	24
4	-	796	796	700.00	766	85	20
5	-	796	796	701.00	765	82	20
6	-	796	796	702.00	761	80	20
7	-	796	796	703.00	762	76	20
8	1	797	653	706.00	763	74	19
9	-	797	654	708.00	765	72	18
10	-	797	654	710.50	761	85	18
11	-	797	654	712.00	755	73	23
12	1	798	654	712.50	760	78	19
13	-	798	654	713.50	762	78	19
14	-	798	654	714.00	763	81	19
15	-	798	654	714.00	763	85	19
16	-	798	674	715.50	760	85	20
17	-	798	681	716.00	762	83	20
18	-	798	681	717.00	762	83	20
19	-	798	681	719.00	762	85	21
20	-	798	681	720.50	758	83	23
21	2	800	681	721.50	757	84	22
22	5	805	681	722.00	762	84	19
23	3	808	681	723.50	765	84	20
24	-	808	681	724.50	765	80	20
25	-	808	681	725.00	762	84	20
26	-	808	681	726.00	762	84	20
27	-	808	681	726.50	760	85	22
28	-	808	681	726.50	762	80	21
29	-	808	681	727.00	762	80	21
30	-	808	681				
	Month (Total)	12					

May 2010

Day	Rainfall, 24 hours (m/s)	Cumulative to Date	Last Year to Date	General Average	Atm. Pressure	Humidity (%)	Temp. (°C)
1	-	808	681	730.00	760	80	20
2	-	808	681	731.00	762	80	19
3	-	808	681	731.50	763	80	20

4	-	808	681	734.00	762	85	20
5	-	808	682	735.50	760	85	21
6	-	808	682	736.00	760	85	22
7	-	808	682	736.50	758	85	23
8	-	808	682	737.00	758	85	23
9	-	808	682	740.00	757	82	24
10	-	808	682	740.50	755	85	23
11	-	808	682	741.00	758	81	23
12	-	808	682	741.50	759	81	23
13	-	808	682	743.00	759	80	23
14	-	808	682	744.00	759	66	24
15	-	808	682	744.50	762	69	24
16	-	808	682	745.00	761	83	27
17	-	808	682	745.00	763	82	23
18	-	808	682	745.00	763	83	22
19	-	808	682	745.00	762	75	22
20	1	809	682	745.00	762	75	22
21	-	809	682	745.00	762	75	22
22	-	809	682	745.00	758	68	24
23	-	809	682	745.00	762	68	23
24	2	811	682	745.00	764	69	22
25	-	811	682	745.00	762	80	23
26	-	811	682	745.00	758	80	23
27	-	811	682	745.00	755	80	24
28	-	811	682	745.00	758	80	24
29	-	811	682	745.00	762	83	24
30	-	811	682	745.00	760	81	24
31	-	811	682	745.00	758	85	25
	Month (Total)	3					

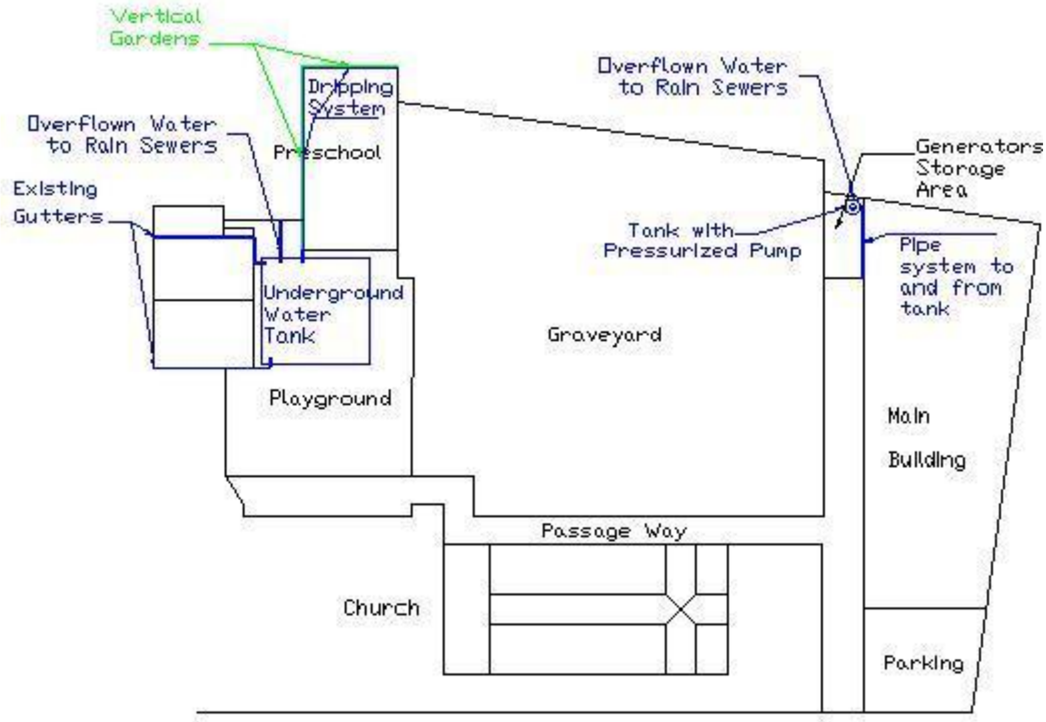
June 2010

Day	Rainfall, 24 hours (m/s)	Cumulative to Date	Last Year to Date	General Average	Atm. Pressure	Humidity (%)	Temp. (°C)
1	-	811	682	745.00	758	84	25
2	-	-	-	745.00	760	82	25
3	-	-	-	745.00	762	82	25
4	-	-	-	745.00	762	85	24

5	-	-	-	745.00	762	84	25
6	-	-	-	745.00	760	83	24
7	-	811	682	745.50	758	84	25
8	-	-	-	745.50	758	83	24
9	-	-	-	745.50	758	83	24
10	-	-	-	745.50	758	83	25
11	-	-	-	745.50	757	83	25
12	-	811	682	747.00	757	83	25
13	-	-	-	748.00	758	82	25
14	-	-	-	748.50	758	82	24
15	-	-	-	748.50	760	83	24
16	-	-	-	748.50	757	84	25
17	-	-	-	748.50	755	84	26
18	-	-	-	748.50	755	84	26
19	-	811	682	749.00	756	84	26
20	-	-	-	749.00	757	80	26
21	-	-	-	749.00	758	79	28
22	-	-	-	749.00	756	75	27
23	-	811	682	750.00	756	75	25
24	-	-	-	750.00	760	75	24
25	4	815	-	750.00	758	75	25
26	5	820	-	750.00	758	75	26
27	-	-	-	750.00	760	73	24
28	-	-	-	750.00	757	72	25
29	-	-	-	750.00	757	75	26
30	-	820	682	750.00	759	76	26
	Month (Total)	9					

(Nikula Shahin Weather Station)

APPENDIX E: Outline of SMOC RHS



APPENDIX F: Design of Underground Water Tank Calculations

Refer to Appendix G for drawings of steel reinforcement for the various structural elements and a plan view of the water tank.

WALLS

Use coefficient of negative and positive moment = 1.

$$M = 1 \times w \times a^3 = 1 \times 1 \times 1^3 = 1\ Tm/m$$

Take thickness of wall = 22 cm, so d = 19 cm.

$$\rho = 0.85\ \times \frac{f_c'}{f_y}\left(1 - \sqrt{1 - \frac{2.35M_u}{0.9bd^2 f_c'}}\right) = 0.85\ \times \frac{280}{4200}\left(1 - \sqrt{1 - \frac{2.35M_u}{0.9bd^2 \times 280}}\right)$$

$$= 9.2175\ \times 10^{-4}$$

Since ρ is very small, it is taken to be $\rho_{minimum}\ = 0.0018$.

$$A_s = 0.0018 \times 100 \times 19 = 4.75 \frac{cm^2}{cm}$$

Use T14 @ 25 cm for outer and inner edges in both vertical and horizontal directions.

FOOTINGS

Since the rectangular tank is square, the tank will require four wall footings (one for each side) with the same characteristics. The calculations to arrive at the characteristics of the footings can be found below.

The $q_{allowable}$ of the soil was assumed to be 25 T/m^2. Assume maximum footing depth of 50 cm and weight of soil of 2 T/m^3. The Live Load on the slab was assumed to be 0.5T/m^2.

Thus $q_e = 25 - 1.5 \times 2 = 22.0\ T/m^2$.

Load of Footing = Weight of Wall + ½ Weight of Slab + ½ Live Load on Slab.

$P = 1m \times 0.22m \times 1m \times \frac{2.5T}{m^3} + \frac{1}{2} \times 10m \times 1m \times 0.20m \times \frac{2.5T}{m^3} + \frac{0.5T}{m^2} \times 1m \times 5m = 0.55 + 2.5 + 2.5 = 5.55\ T/m.$

$P_u = 1.4 \times DL + 1.7 \times LL = 1.4 \times (0.55 + 2.5) + 1.7 \times 2.5 = 8.52\ T/m.$

Width of footing:

Excentric Wall Footing: Moment = 1Tm/m (maximum moment calculated from side wall calculations).

$Area\text{:}\ \frac{P}{(B-2e_y)(1)} \leq q_{all}\ = 22T/m^2.$

$e_{y\ max}\ = \frac{1}{5.55} = 0.180\ m.$

$\overset{\Delta}{\rightarrow} Useful\ area: B' = B - 2e = B - 0.360m\ and\ L' = L.$

$\rightarrow B \geq 0.61$. Therefore take B = 0.70 m.

Check stresses:

$$Q_{min} = \frac{P}{BL}\left(1 - \frac{6e_y}{B}\right) = \frac{5.5}{0.7}\left(1 - \frac{6(0.18)}{0.7}\right) = -ve$$

Since the solution is negative, we increase the section due to uplift.

Take B=1.2 m

$$Q_{min} = \frac{P}{BL}\left(1 - \frac{6e_y}{B}\right) = \frac{5.5}{1.2 \times 1}\left(1 - \frac{6(0.180)}{1.2}\right) = 0.4583\frac{T}{m^2}$$

$$Q_{max} = \frac{P}{BL}\left(1 + \frac{6e_y}{B}\right) = \frac{5.5}{1.2 \times 1}\left(1 + \frac{6(0.180)}{1.2}\right) = 8.7083\frac{T}{m^2} \ll 22\ \frac{T}{m^2}$$

Get k:

$$P_u = 8.52\frac{T}{m}$$

$$M_u = 1.4\ \left(1\frac{Tm}{m}\right) = 1.4\frac{Tm}{m}$$

$$e_{ymax} = 0.1643\ m$$

$$q_{max} = \frac{8.52}{1.2 \times 1}\left(1 + \frac{6(0.1643)}{1.2}\right) = 12.934\frac{T}{m^2}$$

$$q_{min} = \frac{8.52}{1.2 \times 1}\left(1 - \frac{6(0.1643)}{1.2}\right) = 1.267\frac{T}{m^2}$$

Assume h = 0.2 m and d = 0.15 m.

Check shear @ d away:

$$V_u = \left(\frac{9.63 + 12.934}{2}\right)(0.6 - 0.11 - 0.17) = 3.610\ T/m$$

$$V_{u\ max} = \frac{V_u}{0.85}\ 4.247\ T/m$$

Check $V_c = 0.53\sqrt{280} \times d \times 1 \times 10 = 13.303\frac{T}{m} \gg 4.247\frac{T}{m}\quad OK$

So take depth of footing = 20 cm and d =15 cm.

Design for flexure:

Stress @ end of wall = 8.17 T/m^2

$$M_u = \left(\frac{12.934 - 8.17}{2}\right)\left[(0.49)\left(\frac{2(0.49)}{3}\right)\right] + 8.17(0.49)\left(\frac{0.49}{2}\right) = 0.381 + 0.981$$

$$= 1.362\frac{Tm}{m}$$

$$A_s = \frac{1.362 \times 10^5}{0.9 \times 4200 \times 0.95 \times 15} = 2.53\frac{cm^2}{cm}$$

Transverse reinforcement:

$$Minimum\ reinforcement = 0.0018\ bk = 0.0018 \times 100 \times 20 = 3.6\frac{cm^2}{cm} > A_s$$

So use minimum reinforcement.

Bottom reinforcement = T12 @ 30 cm

Check spacing:

$< 3 \ \times thickness = 60\ cm \quad OK$

$< 18'' = \ 45\ cm \quad OK$

Longitudinal reinforcement:

$$Minimum\ reinforcement = 0.0018 \times 120 \times 20 = 4.32\frac{cm^2}{cm} > A_s$$

So use minimum reinforcement T12 @ 30 cm

Check spacing:

$< 3 \ \times thickness = 60\ cm \quad OK$

$< 18'' = \ 45\ cm \quad OK$

Dowels T14 @ 25 cm

BOTTOM SLAB

Use a 20 cm thick bottom slab.

Using minimum reinforcement:

$$A_s = 0.0025 \times b \times d = 0.0025 \times 100 \times 17 = 4.25\ \frac{cm^2}{cm}$$

Use T12 @ 25 cm in both directions.

TOP SLAB

Use 20 cm thick upper slab.

$Dead\ Load = 0.75\ T/m^2$

$Live\ Load = 0.5\ T/m^2$

Bottom Reinforcement:

$$M = 0.044 \times 1.9 \times 10^2 = 8.36\frac{Tm}{m}$$

$$\rho = 0.85 \times \frac{f_c'}{f_y}\left(1 - \sqrt{1 - \frac{2.35M_u}{0.9bd^2 f_c'}}\right)$$

$$= 0.85 \times \frac{280}{4200}\left(1 - \sqrt{1 - \frac{2.35M_u}{0.9b \times 17^2 \times 280}}\right) = 0.00824$$

$$A_s = 14.008 \ \frac{cm^2}{cm}$$

Use T20 @ 20 cm in both directions.

Top reinforcement:

$$A_s = 0.0018 \times 100 \times 17 = 4.25 \frac{cm^2}{cm}$$

Use T12 @ 20 cm in both directions.

SHEAR REINFORCEMENT

$$V_u = 9.5 \frac{T}{m}$$

$$V_n = \frac{9.5}{0.9} = 10.55 \frac{T}{m}$$

$$V_c = 2\sqrt{f_c'} \times b_w \times d = 15.1 \frac{T}{m}$$

$V_n < V_c$ no need for shear reinforcement

Use T10 @ 25 cm ties

APPENDIX G: Underground Water Tank Reinforcement Drawings

APPENDIX H: Green Studios Vertical Gardening Offer

APPENDIX I: Quotation for RHS from Green Top International