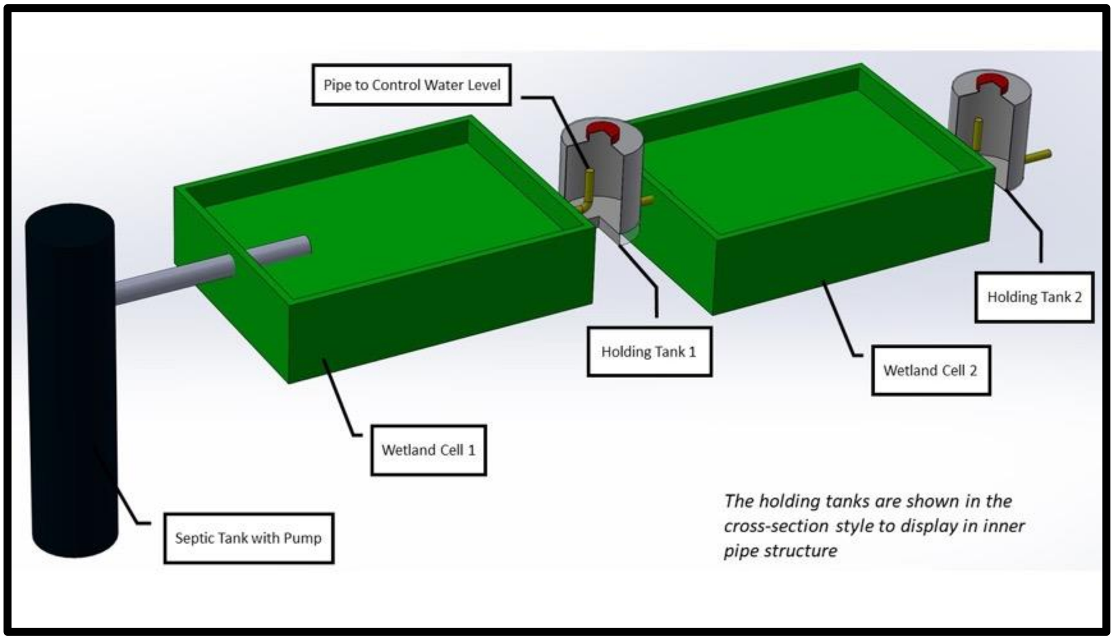
Decentralized Wastewater Treatment in Southern Israel

An Interactive Qualifying Project Submitted to the Faculty of WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the Degree of Bachelor of Science



Anna Correia, Quang Huynh, Karistan Swan

March 1, 2020

Submitted to:

Professor Isa Bar-on and Professor Seth Tuler, Worcester Polytechnic Institute

Alex Cicelsky and Mike Kaplin, Kibbutz Lotan

Abstract

Constructed wetlands were introduced as a promising solution for the water scarcity problem in the Southern Arava. However, there have been questions about the success and popularity of the systems in the region. We evaluated whether using a small scale constructed wetland can be a reliable option for decentralized household wastewater treatment in Southern Israel. Our study was focused on household-scale systems and our results reflect that scale. We assessed a small-scale constructed wetland model at Kibbutz Lotan through theoretical water intake calculations, field observations, and qualitative testing. We discovered that constructed wetlands can offer wastewater treatment and water reuse and have a high level of maintenance and monitoring.

Authorship Page

Section	Primary Author	Primary Editor	Secondary Editor
Abstract	All	All	All
Chapter 1	All	All	All
2.1	Quang	Karistan	Quang
2.1.1	Quang	Anna	Karistan
2.1.2	Quang	Karistan	Anna
2.2	Anna	Quang	Karistan
2.2.1	Anna	Karistan	Quang
2.2.2	Karistan	Quang	Anna
2.2.3	Quang	Anna	Karistan
2.3	Karistan	Anna	Quang
3.1	Anna	Quang	Stan
3.2	Quang	Anna	Stan
3.3	Anna	Quang	Stan
3.3.1	Anna	Stan	Quang
3.3.2	Karistan	Anna	Quang
3.4	Karistan	Anna	Quang
3.4.1	Anna	Stan	Quang
3.4.2	Karistan	Anna	Quang
4.1	Quang	Karistan	Anna
4.1.1	Quang	Anna	Karistan
4.1.2	Quang	Anna	Karistan
4.2	Karistan	Quang	Anna
4.2.1	Karistan	Quang	Anna
4.2.2	Karistan	Quang	Anna
4.3	Anna	Karistan	Quang
5.1	Quang/Anna	Anna	Karistan
5.2	Karistan	Quang	Anna
5.3	Anna	Karistan	Quang
Chapter 6	Karistan	Anna	Quang
Appendix A	Anna	Karistan	Quang
Appendix B	Karistan	Quang	Anna
Appendix C	Karistan	Anna	Quang
Appendix D	Anna/Karistan	Quang	Karistan
Appendix E	Quang	Anna	Quang

Acknowledgements

There were many people that helped us complete our project and achieve our goal. We would like to thank our advisors, Professor Isa Bar-On and Professor Seth Tuler, for their consistent support, feedback and guidance. We are so appreciative of the time and effort you gave to our team. We would also like to thank our friends at Kibbutz Lotan, Shira Kronich, and Mike Nitzan for their time and assistance in our projects development. To our Sponsors Alex Cicelsky and Mike Kaplin we are so grateful for your time and dedication to our project and allowing us to work on your constructed wetland.

To the entirety of Kibbutz Lotan, we cannot thank you enough for opening your community to us. We have felt so welcomed and included throughout our time here and undergone so much growth in your midst. Thank you to Eran Meiri for advising us on construction for the wetland. Thank you to Mark Naveh for sharing the story of Lotan with us and Debby Dell'ariccia for leading our bonding activities. Thank you to Maya Galimidi for planning so many wonderful experiences for us and guiding us through life in the desert. We cannot express enough gratitude to this community and our friends for allowing us in and making our IQP experience so meaningful.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Water is a vital resource for humankind, from daily activities and entertainment to economic development. However, not every region in the world has access to abundant water supply from rivers or natural reservoirs. The Water Stress[1] report by World Resources Institute highlights the Middle East and North Africa regions as the most water-stressed regions in the world, suffering from hot, dry weather and increasing population (WRI, 2015). Positioned on the edge of the Middle East, Israel bears the same problem. Israel was ranked 8th on the list of the most water-stressed countries by WRI (WRI, 2015). As the population grows and the economy becomes more demanding, there is increasing stress upon Israel's limited water sources. Limited water supply is more problematic in Southern Israel, where the desert climate adds additional challenges to the water scarcity problem. Hence, there is an urgency to successfully implement programs to conserve water and extend its lifetime.

In order to combat the water scarcity problem, with the help of the European Union (EU), Israel has introduced the Southern Arava Waste Management Plan. This treatment plan included a pilot program for constructed wetlands (CW) in the region to create decentralized agricultural wastewater treatment helping them gain popularity in the region (Nusinow, 2007). Those CW dealt with water treatment at a large scale but opened up the question of their plausibility at the household level. For families interested in getting another use out of their water, CW can also be integrated with other water-saving methods such as drip irrigation. In the Arava region where water is scarce and the land is dry, CW can provide reused water for drip irrigation and an oasis for plants to prosper within the desert landscape.

Our project goal was to evaluate if using a small scale constructed wetland is a reliable option for decentralized household wastewater treatment in Southern Israel. The goal was achieved through the following objectives:

1. Running an experiment on the CW at Kibbutz Lotan to evaluate quality of water treatment
2. Considering building and maintenance aspects of small-scale systems
3. Evaluating the chances for success based on the experience with some of the systems in the Arava.

This project will help to evaluate the feasibility of wide-spread constructed wetland use and could help bring water reuse to the household level.

Some key findings discovered while completing the project are that Kibbutz Lotan's constructed wetland has limitations. These include the lack of plants for biotic treatment, the lack of a defined maintenance schedule of the system, and the lack of regular testing of the filtered water. One success that we found was how to fix the water flow and control the water level of Lotan's CW. For wider successful use of CWs on the household scale, building, maintenance, and testing requirements need to be considered. Based on our findings, we recommend that Lotan put in place a monthly maintenance plan and a biannual testing plan for water quality tests. We also recommend that long term research on CW sustainability should be done to advance this area of wastewater treatment.

1 Water stress: the intensity level of impacts due to high water consumption relative to water availability

Chapter 2: Background

2.1 Water Demand in Israel

Water scarcity is a growing concern globally because of both the fundamental concepts of water shortage (due to low availability per capita) and water stress. While the world water consumption increased fourfold from the 1900s to the 2000s, the population under water scarcity increased from 0.24 billion (14% of global population) to 3.8 billion (58%) (Kummu et al, 2016). Israel also faces the water scarcity problem; its consumption of fresh water has exceeded sustainable yields since the mid-1970s (Lipchin, 2001). The country's severely limited water sources have been challenged significantly, as there is not enough for both personal usage and economic development.

In recent years, the situation has developed into a crisis caused by both natural and man-made circumstances. As Israel has suffered from four consecutive years of drought (Times of Israel, 2018), the country's current water sources are just enough to provide quality life for its residents. Growing population (figure 2.1) and changes in the country's consumption habits have led to an increase in urban water use and further burdened fresh water resources (Avgar, 2018). The increase in domestic demand for water, coupled with the need of water for agriculture development, has led to Israel's water crisis.

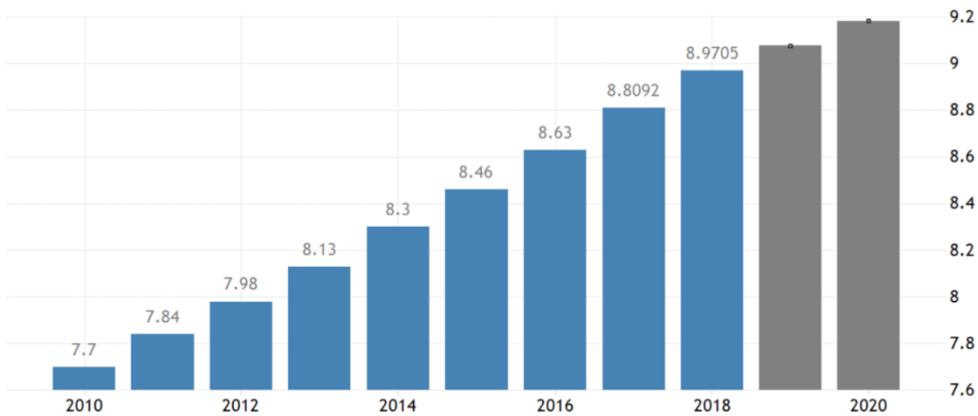


Figure 2.1 Israel population growth (in millions) (Central Bureau of Statistics, Israel)

2.1.1 Key Programs in the Israeli National Water Sector

Facing the water shortage crisis and having used almost all of its readily available water supply, Israel has made it a national mission to stretch the existing sources through the development of non-conventional water sources and promoting water conservation. Tremendous effort has been put into these following fields and achieved significant successes:

1. *Increase water supply through desalination facilities:* Since the late 1990s, the government has focused on building multiple facilities for desalinating seawater and brackish water, which in 2016 provided up to 25% of water consumption. By October 2015, the five main seawater desalination facilities had begun operation—Ashkelon, Palmachim, Hadera, Sorek and Ashdod—each capable of producing 90–150 million cubic meters of water a year (Avgar, 2018).
2. *Reuse of treated wastewater for agriculture:* As one of the leading countries in the world in the percentage of treated wastewater, Israel reuses 87% of its treated wastewater for agriculture. In order to further protect the public health (Avgar, 2018). In January 2010, the Public Health Regulations (Effluent Quality Standards and Rules for Sewage Treatment) were approved. These set forth criteria for permissible levels of salt, pollutants, metals, and more in reclaimed wastewater. In 2014, half of reclaimed wastewater met the state's quality standards required for multi-purposed irrigation (Marin et al, 2017).

3. *Efficient water irrigation method:* Maintaining a competitive agricultural sector given the situation of extreme water scarcity becomes a national priority for Israel. In the early 1950s, every normal irrigation system nationwide was replaced with drip irrigation using micro-sprinklers. The efficiency of irrigation systems has reduced average water supply to agricultural land from 7,000 m3/ha in 1990 to 5,000 m3/ha in 2000 (Marin et al, 2017).
4. *Promote water management and public awareness:* Since 1959, through national law, every water resource has been made public property. The State of Israel now acts as the legal guardian and helps to ensure sufficient water supply. Water conservation maps and regularly-recorded water data are well-managed to effectively protect the underlying water sources (Israeli Ministry of Foreign Affairs, nd). In the domestic and urban sectors, there have been tremendous changes in repairing, controlling and monitoring all water systems. Citizens are urged to 'save the water' in all aspects of their usage (Avgar, 2018).

Despite a crisis of water scarcity, implementation of these programs has allowed Israel to achieve water security while drastically reducing overexploitation of aquifers (Marin et al, 2017). This has been achieved through a massive increase in the production of non-conventional water sources (figure 2.2) and a legal framework that asserts strong governmental control over water resources and boosts public awareness about water conservation.

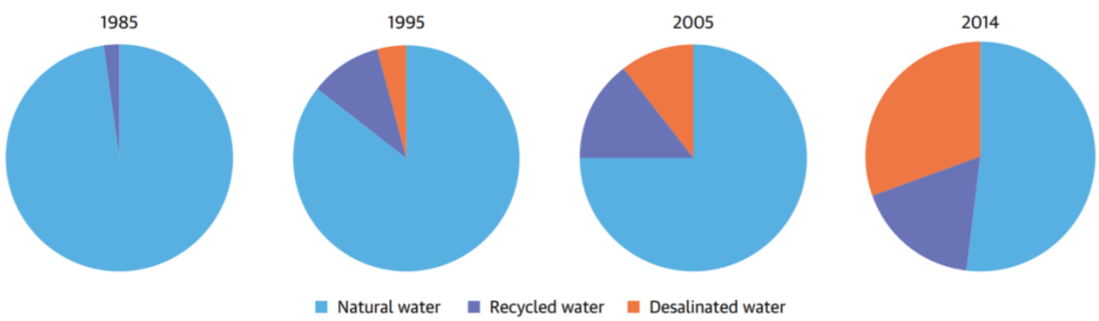


Figure 2.2 Breakdown of Water Sources in Israel, 1986, 1995, 2005, and 2014 (Marin et al, 2017)

2.1.2 Water Sustainability Movement in the South

For years, the Arava Valley has faced a water crisis, which has manifested itself in low precipitation and dwindling natural resources (groundwater reservoirs). The Arava, including the desert valley that extends from the Dead Sea to Eilat along Israel's border with Jordan, has a hyper-arid climate. This type of climate is comprised of strong solar radiation, prominent dryness, high temperatures, and low annual rain. Annual precipitation in the Arava Valley averages 25 millimeters, and only 4 millimeters in Eilat (Israel Meteorological Service, 2019). This low precipitation rate is also accompanied by high annual rates (3.500 mm) of evaporation (Israel Meteorological Service, 2019). Furthermore, the small number of water aquifers in the middle Arava Valley have been overly-exploited.

The Israeli government is planning for massive future development in the Negev, in both population and infrastructure. The Negev and Arava Valley regions are home to 8% of the Israeli population, despite comprising 70% of the land. The goal is to raise those numbers within the next three decades so that the region will account for 15% of the country's population (Times of Israel, 2014). In order to achieve such ambition, the Arava's infrastructure needs to meet the requirements for sustainable water conditions. There were considerations about a new desalination project in the South: however, it had major disadvantages. Each of the desalination plant projects had encountered delays in construction and operation, spikes in cost, and environmental and marine life's damage. Therefore, under the EU's funding support, the authority has taken a different approach with piloting constructed wetland wastewater treatment systems in Kibbutz Ketura and Kibbutz Lotan (Dalcher, D, 2016).

2.2 Defining a Constructed Wetland System

A constructed wetland is a wastewater treatment system that has basins filled with filtering materials, usually soil and gravel, and planted with vegetation that can endure saturated conditions (Greywater Actions, nd). As the wastewater comes into the system, there are 2 main processes involved: biotic and abiotic remediations. For the abiotic process, the gravel helps to settle the solid matters and filter the water. As the plants' roots mature, they become more effective biological filters (Bhatia & Goyal, 2014). For the biotic process, the solid matter starts to pile up and form a bacterial environment. The bacteria combine with fallen plant matter, so-called litter, to create a chemical transformation (Dupoldt et al, 2015). The mixture will absorb, breakdown, and transform the pollutants in the water (Dupoldt et al, 2015). Plants are a crucial part of a constructed wetland. Plant growth provides a vegetative mass that provides attachment sites for microbial development; its death creates litter and releases organic carbon to fuel microbial metabolism.

CWs are a good example of a system that filters wastewater to be reused in another way such as irrigation for agriculture. There are benefits and disadvantages to constructed wetlands as well as different types for different purposes. The following information focuses on the applications of household size constructed wetland systems.

2.2.1 Benefits of Constructed Wetlands

CWs can provide animal protection, wastewater treatment, and heat storage and release at the industrial scale (Stefanakis, 2015). While these benefits are very important, there are specific benefits that apply to household systems. Some of these benefits are listed below (Dupoldt et al, 2015).

- Environment: Wetlands create small oases in the middle of deserts bringing in flora and fauna to the area. They also allow for the irrigation of garden spaces and trees. Most importantly, they allow for the protection of groundwater from contamination and reduce demand from other water sources.
- Education: Wetlands allow families to be more aware of their water usage.
- Economy: This system type can offer a low-cost solution to families. Wetlands also reduce sewage costs for outside contracting. Construction costs of CWs are 50-90% lower than construction costs of conventional systems (National Small Flows Clearinghouse, n.d.). Operational costs of CWs can be up to 90% lower than operational costs of traditional wastewater treatment systems (Stefanakis, 2015).
- Health: Constructed wetlands eliminate pathogens and pollutants that would normally affect human health and hygiene (Stefanakis, 2015).

2.2.2 Requirements of Constructed Wetlands

While constructed wetlands provide many benefits to a household and how it deals with waste, they also come with a set of limitations regarding the initial build, maintenance plan, and monitoring procedure. As CWs are a relatively new technology for domestic wastewater treatment, there is a lack of procedures and standards that are present for larger industrial wetlands.

Building Requirements

During the initial build phase, the primary requirement for building a constructed wetland is the land required. According to Purdue University's publication on Individual Residence Wastewater Treatment, a household requires one square foot per gallon of water used (Taylor, Jones, Yahner, Ogden,

& Dunn, 1998). The absorption field[2] is typically the same size as the initial wetland cell, translating to around 300-600 square feet for the two cells, not including their pumps (Taylor et al, 1998).

Maintenance Requirements

Maintaining a constructed wetland at the household scale has a set of requirements. This includes an inspection approximately every six months to remove weeds, replant essential plants, and clean out pipes for blockages to ensure the wetland is working efficiently. Besides the six month inspection, users should drain the system two to three times a year to prevent clogging and encourage deep root growth (Gikas & Tsihrintzis, 2010). Water input also must be consistently maintained as constructed wetlands need a minimum amount of water at all times.

Monitoring Requirements

In order for the wetland to be successful functions, it must reliably remove key biochemical aspects including COD[3], BOD5[4] and NPK[5] which is typically tested for in a lab environment without a current "at home" solution (Lin, Jing, Lee, & Wang, 2002). Despite constructed wetlands being an efficient and effective option for household sewage treatment the options for testing its reliability are limited.

Constructed wetlands are an innovative alternative to typical wastewater treatment methods but are still in the process of development. There are many factors to design into the system to mimic the success of a natural wetland therefore, their effectiveness and sustainability are still under evaluation (Torczon, 2018).

2.2.3 Types of Constructed Wetlands

Depending on the application, one of several wetland designs can be selected. There are multiple different models of constructed wetlands but the most popular and low-cost model is the Flow Water Surface Wetland (FWS), presented below (figure 2.3). In this system, the plant grows above the gravel bed. The wetland looks more like a natural habitat, providing high aesthetic value. However, it takes more land than other systems do.

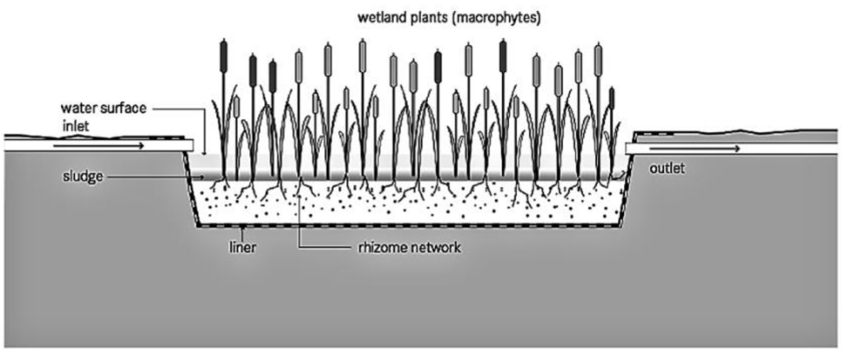


Figure 2.3 Flow Water Surface Wetland diagram (Hydrik Wetlands Consultants, 1998)

The other type of constructed wetlands, Subsurface Flow systems (SSF), can be divided into Horizontal type and Vertical type. A SSF is a constructed wetland consisting of a trench or bed underlain

2 Absorption Field: a polishing cell made of mostly gravel for final filtration.

3 COD: Chemical Oxygen Demand measures that amount of oxygen consumed by reactions

4 BOD5: Biochemical Oxygen Demand measured after 5 days which shows the dissolved oxygen needed by aerobic biological organisms.

5 NPK: Nitrogen, Phosphorus and Potassium measures the amount of nitrogen in the water after it has gone through the system. While plants benefit from some nitrogen, it is harmful to put nitrogen in groundwater.

with layers of clay, sand, gravel, and other liners. The bed contains media which will support the growth of emergent vegetation such as cattails and bulrushes (figure 5.4). Within this system, the wastewater is treated by filtration, absorption and precipitation processes in the soil and by microbiological degradation. The advantage SSF wetlands have over FWS wetlands is that they do not create a flooded tank: in the SSF, plants grow in gravel or soil (figure 2.4).

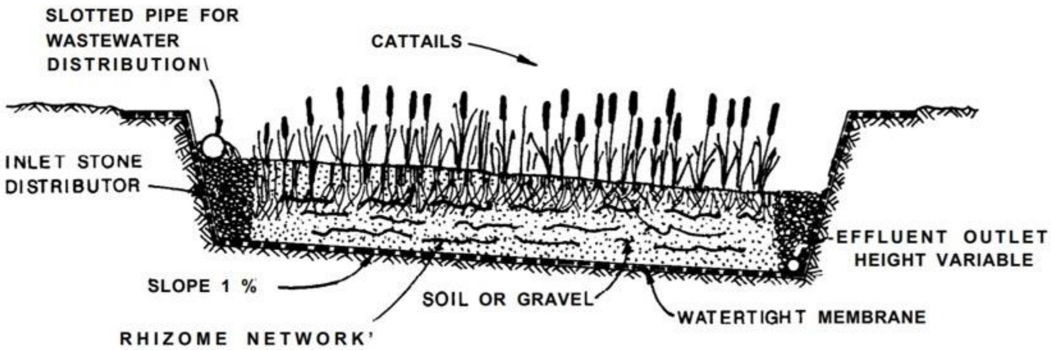


Figure 2.4 Cross section diagram of SSF (Hydrik Wetlands Consultants, 1998)

The basin of a SSF wetland is dryer and does not contain standing wastewater (surface systems, which have standing water, are never allowed under Israeli state codes for family usage). Therefore, the recommended type of wetland for Israeli household applications is Subsurface Flow constructed wetland (Torczon, 2018). This type can also endure colder temperatures, create less odor, and prevent public access to wastewater (Dupoldt et al, 2015).

The EcoKef's Wetland Model in Kibbutz Lotan

Kibbutz Lotan, 55 kilometers north of Eilat, was founded in 1983 by settlement groups of Israelis and North Americans. In the kibbutz, the main economic sources are the field crops, dates farms, and milk production from a large dairy farm. The kibbutz has become increasingly involved in ecological issues such as exploring sustainable agricultural practices and waste composting since its foundation. Therefore, in 1997, the residents of Lotan established the Center for Creative Ecology, EcoKef. In 2006, Kibbutz Lotan started the building and implementation of a pilot constructed wetland. The intention was to bring an end to the flow of untreated wastewater to the valley (Dalcher, 2016). The pilot system consisted of 14 wetland basins processing the wastewater from the dairy farm. However, it did not succeed due to technical issues. The project was canceled and re-evaluated. After that, the EcoKef Center recreated a small-scale CW model that is used for wastewater processing and tourism demonstrations.

The model in place is a Horizontal Subsurface Wetland system. The SSF uses the wastewater from the nearby Solar Tea House's kitchen (a cafeteria) and the 4 sinks from the composting toilet public restroom. The greywater goes into the sewage tank where the main pump delivers the water into the treatment tanks. There is also leachate dumped from the composting toilets periodically. There are 2 treatment cells in this wetland system: the first one is filled with gravelly sand and covered with wild weeds while the second one is packed with more gravel to remove the impurities (figure 5.5 and 5.6).

Figure 2.5 Cell 1 and Cell 2 of the system.

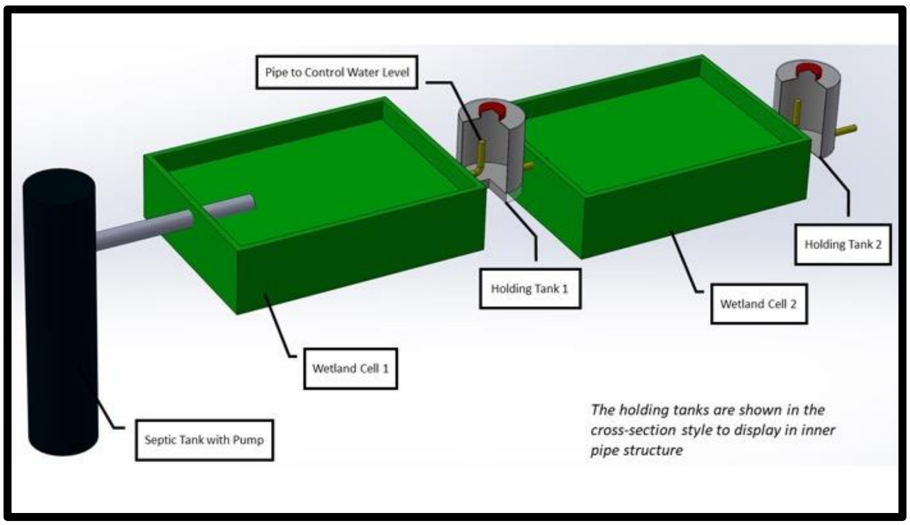


Figure 2.6 Diagram of Wetland System in EcoKef

From the first cell, the water goes into a holding tank which helps to control the water flow into the second cell. Inside the holding tank, the workers applied standing pipes to simply the flow control mechanism (figure 5.6). After the second cell's filtration, the water will be stored in the final holding tank to gradually irrigate a tree nearby.

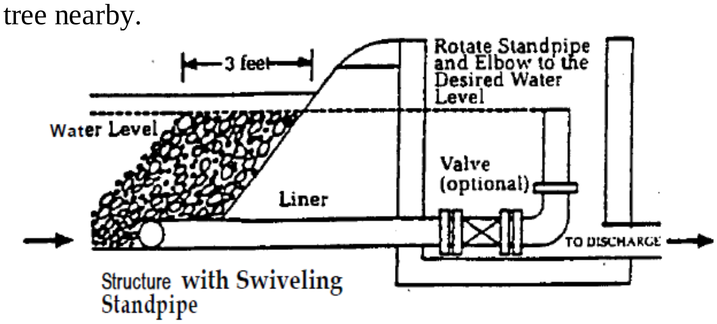


Figure 2.7 Structure with swiveling standpipe (Dupoldt et al, 2015)

2.3 Constructed Wetlands as a Treatment Solution

The Southern Arava Waste Management plan created pilot CWs that sparked the concept of decentralized treatment at the household scale (Dalcher, D, 2016). CWs offer an enticing alternative to municipal wastewater treatment. For those located in the Arava Valley who face a desert climate and minimal rainfall, CWs offer another life cycle to the water they use for daily tasks prior to its return to the ground. Lotan's Eco Kef constructed wetland seems to be a reasonable solution for a family's wastewater in Southern Israel, however, there is much to question and develop regarding the reliability and functionality that a constructed wetland brings to domestic wastewater treatment.

Chapter 3: Methods

3.1 Factors of Success for a Constructed Wetland

In order to assess the use and functionality of a household size CW system, we used Lotan's CW system as a model. In the following sections, we discuss the relevant steps taken to adapt the EcoKef's system to household purposes. We looked for three signs of success while performing this project:

1. Simple testing accessible for home users
2. Adaptability to household scale
3. Successful filtration for greywater.

These objectives are the center of our design plans throughout the methods chapter.

3.2 Overall Design Assessment

The wetland system of the EcoKef has been in place for 14 years. There has not been testing or diagnoses on the system during that time. With the objective of ensuring successful filtration of greywater, we investigated the current wetland system in the EcoKef for basic flaws. We ran an initial assessment of the EcoKef CW system through both theoretical calculations and field observation. Therefore, we established the following procedure for our investigation:

1. Gather information about the wetland system through interviews with the employees, system schematic files, and site observation.
2. Analyze the data we obtained such as wetland dimensions, average water flow, past and current water depth inside the system, etc. We used the formulas and equations from Dupoldt's Constructed Wetlands Handbook and the Hydrik Wetland Consultants' Manual Design to check if the system meets the expected criteria of CW systems.
3. After identifying the challenges through the calculations, we developed a working plan in order to restore the wetland system and a testing plan to figure out if the system has worked correctly after the fixing.

3.3 Testing the Functionality and Performance of the System

In order to assess the functionality of Kibbutz Lotan's constructed wetland at the household scale, our team designed an experiment to test the wetland's efficacy for a two person household. We took into account the retention time of the system to determine how long it would take wastewater to pass through the system. Therefore, we could test the output water as well as the quantity of water needed in a standard two-person household. Explanation and calculations for The EcoKef's system retention time are provided in Appendix B. From that, we determined a nine day test was needed using 401 liters to represent a two person household. After those nine days, we were able to see the full cycle of wastewater flowing through the system and exiting the outlet to water the nearby tree.

3.3.1 Determining Wastewater from an Average Israeli Household

An important part of this experiment was determining how much wastewater an average Israeli household uses in a day. A table of approximate amounts of wastewater one person might use is provided in Appendix A (Water Use in Your Home, 2010). These amounts were used to determine the amount of wastewater we would load into the system. It is important to note that these amounts only include greywater and not blackwater. As blackwater may have been harmful to the system, our team decided to not include it in our testing to decrease disruptions to bacteria in the wetland.

3.3.2 Adapting the Bacterial Population of Lotan's Constructed Wetland

For our experiment, we tested the current system to the new type of wastewater that we made and put in. As described in Appendix A, household wastewater has detergents, soaps, and other hygiene products that the system is not currently filtering. Typically, a constructed wetland requires up to 700 days for its bacterial population to reach stability when introducing change (Samsó & García, 2013). For our short term project, we were not able to wait that amount of time. However, as the wetland has been in operation for multiple years, we made an assumption that the bacteria will be able to adapt to the change for the short period of time it will be altered. Short and long term effects on the system due to this change are not completely known which reduces accuracy in our experiment (Iasur-Kruh, Hadar, & Minz, 2012).

3.4 Testing Method for Household Constructed Wetland

In order to assess the success of filtration, we tested for the reduction of nitrogen and biochemical oxygen demand (BOD) in the water as it passed through the system. For this system to be considered for household use, testing should be done simply and with minimal supplies. In the following sections, we discuss why this type of testing is relevant to wetland success and how to perform small scale testing throughout our nine-day experiment. For both nitrogen and BOD testing, we will be sampling at the flush tank - where the water is initially added, the holding tank between cells one and two, and the water coming out of cell two after it has finished filtration.

3.4.1 Nitrogen Testing on Small Scale

Although some nitrogen is good for fertilizing plants, nitrogen can be drained into groundwater to be introduced into streams and other bodies of water (Brenner, 2006). If there is excess nitrogen in a body of water, oxygen is limited which can kill plant and animal species. Testing for nitrogen can be done at home by using nitrite/nitrate and ammonia test strips. These test strips can be ordered online and found in stores, but are not readily available in the Arava Region due to slow shipping times.

3.4.2 Biochemical Oxygen Demand Testing At Home

As described by United States Geological Survey's water science school, biochemical oxygen demand (BOD) "represents the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic (oxygen is present) conditions (USGS & Water Science School). In a wastewater treatment system, such as a constructed wetland, the BOD is lowered throughout treatment. This illustrates the effectiveness of the bacterial population in decomposing the organic material introduced to the system. Typical BOD testing is a detailed lab experiment with many chemicals and specific equipment required. While at home BOD testing has not been developed for Constructed Wetlands, we adjusted the standard procedure to be done with limited resources and lab exposure. Our procedure explanation and details are included in Appendix C.

Chapter 4: Findings & Discussion

Through our theoretical evaluation and site assessment, we developed the following findings concerning the constructed wetland system of the EcoKef Center, and the various factors and principles which affect its success.

4.1 Design and Mechanisms of the EcoKef Wetland

Following our methods, we measured and obtained all the data we needed. We used all the information to calculate and create a framework for an ideal CW system. Then, we compared the estimated numbers with the real-life measurements to identify any existing issue. We found critical issues related to the current wetland, our next step is to develop a restoring plan and maintenance program for the system.

4.1.1 Constructed Wetlands Theoretical Intake

We found that the size of the EcoKef's wetland system does not match up with the wastewater source.

The wetland is a lot bigger and requires much more water than the EcoKef can provide. The wetland system needs a minimal amount of water to prevent complete drying and keep the bacteria and plants alive (Dupoldt et al, 2015). Through our qualitative observation, the cells are very dry. With such prolonged drying period, it is difficult for the wetland to perform properly. To assess the performance of the EcoKef's SSF, we introduce this equation of water balance:

$$Q(inlet) - Q(outlet) + P - ET = dV/dt \qquad (eq\ 4.1)$$

With Q(inlet) and Q(outlet) is the water flows of the system (liters/day)
P is precipitation rate of the region
ET is the evaporation rate of the system

The EcoKef's wetland is a simple model which operates at a relatively constant water depth ($dV/dt = 0$). Taking into account the low precipitation rate and high evaporation rate in the Arava Valley region, the inlet water flow is very important for the system to maintain the water balance. Therefore, in the following sections, we will analyze the sufficiency of the system's wastewater source.

The water source is the key for the system's expected performance and survival. Based on the following equation, we will calculate the required water flow that a wetland of this size needs.

$$A(s) = [\ Q(\ln C_{in} - \ln C_{out})\ ] / (Kt * Depth * Porosity) \qquad (eq\ 4.2)$$

With A(s) is the surface area of the wetland cell
Q is the inlet water flow
C_{in} is the expected BOD level of the inlet
C_{out} is the expected BOD level of the outlet

Kt is the temperature-dependent reaction rate constant.
Depth of water submergence
Porosity of the gravel bed

The temperature-dependent rate constant is calculated from the rate constant for 20°C and the correction factor of 1.1:

$$Kt = K20 * (1.1)^{T-20} = 0.86 * (1.1)^{T-20} \quad \text{(eq 4.3)}$$

With K20 is the rate constant for 20°C. It equals 0.86 for gravelly sand material.
T is the temperature of the water inside the system, measured in Celsius.

With the equation 4.2 and 4.3, we can calculate the required water flow for Cell 1 and Cell 2

Season	**Summer**		**Winter**	
Cell No.	**Cell 1**	**Cell 2**	**Cell 1**	**Cell 2**
Surface Area of Wetland Cell (m^2)	12	12	12	12
Expected BOD level of the inlet	200	200	200	200
Expected BOD level of the outlet	10	10	10	10
Water Temperature (Celsius)	26	32	24	27
Depth (m)	0.18	0.35	0.18	0.35
Porosity	0.42	0.41	0.42	0.41
Required Water Flow (liter/day)	**461.3**	**1551.4**	**381.3**	**963.3**

Table 4.1 Calculations of Required Water for each cell

The retention rate of Cell 1 for 400-450 liters/day flow is approximately 3-3.5 days. Therefore, the required water flow going into Cell 2 is much higher than Cell 1 (table 7.5). It needs to wait for the water to be stored and treated in Cell 1.

With the intention of determining the amount of water put into the system when the Tea House is at full function, we spoke with Debby, the manager of the Tea House. We then estimated the system input in reality. During the summer, the Tea House runs normally with 3 cooking periods per day, roughly providing 45 liters of wastewater, based on Appendix A. In addition, with an average of 3 liters of wastewater per hand washing time (Appendix A), we roughly estimated the sink water from the Compost Toilet. There are 5 employees working at EcoKef and at least a group of 20 tourists per day. Therefore, there will be at least 75 liters per day coming from the sinks. Combining all sources, we have 120 liters per day as the wastewater input into the SSF. When the Tea House is not opened, it means that there are only 75 liters of wastewater fed to the system per day. *This is insufficient to match up with the required water flow of the CW.* We face a big challenge of how to find an adequate water source for the EcoKef's SSF.

4.1.2 Findings from Field Observation

Evaluating Vegetation

There is no current vegetation to provide filtration properties for the wetland.

Based on what we heard from the employees in the EcoKef, there were plants previously inside the wetland. But without a sufficient water level during the winter, they did not survive after a while. The existence of vegetation is crucial for the wetland system. Reeds, cattails, bulrushes, etc. are the types of plants that can deeply root into the wetland bed and survive with a minimal amount of water. For SSF, the main oxygen source for subsurface components in the wetland bed is the oxygen transmitted by the vegetation to the root zone; this oxygen supply will help support the growth of bacterial metabolism. However, the current system in EcoKef only contains layers of gravel and sand that do the filtration process.

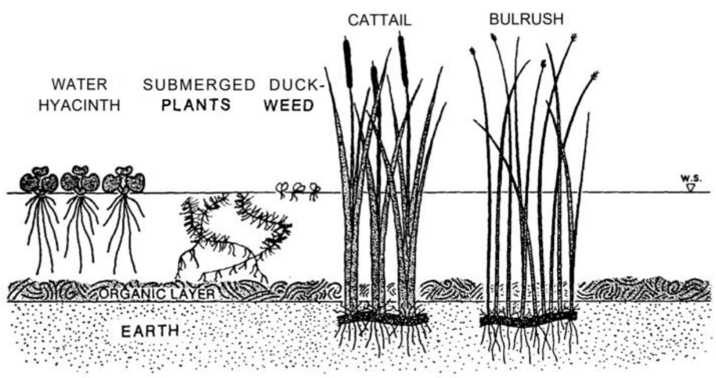


Figure 4.2 Types of plants suitable for wetlands

According to the case study of Emmitsburg's communal subsurface wetland system, the water level under the gravel bed requires constant monitoring for proper vegetation growth (Hydrik Wetlands Consultants, 1998). Their system was started up in the summer of 1984 and continued to operate until March 1986, at which time the system did not receive any wastewater for several days. The resulting stress on the system eventually caused the death of all the seeded cattails. Then, the system was reseeded and re-operated again in October 1986. Emmitsburg's system is a single basin with a surface area of 686.7 squared meters and water depth of 0.9m. They keep their underlain water level at 5 cm below the bed surface. If we run the approximate estimation using the EcoKef's wetland size, we need to have the underlain water levels for 2 cells as shown below.

Cell 1
Surface Area 12 m^2
Water Depth 0.18 m
Suggested Water Level (from the surface) 1.7 cm

Cell 2
Surface Area 12 m^2
Water Depth 0.35 m
Suggested Water Level (from the surface) 3.3 cm

However, when we measured the water level through each holding tank, the water level was 15 cm from the surface in Cell 1 and 20 cm in Cell 2. We need to improve this problem if we plan to adopt the suitable vegetations for the wetland.

There is a positive sign related to this water level matter after we finished our nine-day experiment. As we consistently dumped 401 liters of wastewater into the system, the water level rose and reached the desired height inside the cells (figure 4.3). This proved that our theoretical input is correct and sufficient to restore the required water volume.

Figure 4.3 Expected water level

Evaluating Maintenance

We found out that the system's water flow is not working properly due to three following reasons.

First, the pipes are blocked.

The holding tanks contain lots of sedimentary blockage that can heavily affect the water flow of the system. Furthermore, the position of the end of the pipe (where it pours into a small standing cylinder for irrigation) is on the same level as the beginning of the pipe (which is the exit from the 2nd cell's holding tank). This does not create a slant for the processed water to flow down to the garden. Hence, we cleaned out 2 holding tanks and dug a deeper trench for the water flow (figure 4.4).

Figure 4.4 The new trench

Second, the base of the 1st cell's output tank is sinking.

This leads to the bending of the input and the output pipelines. The trouble lies at the output pipe: since the pipe is bent downward, it is impossible to maintain sufficient water flow into the second cell; and stress over time can lead to pipe damage. As we need to raise the pipe shape back to normal (figure 4.5), we built a new platform to get the system running again and reinforce for future stability (figure 4.6).

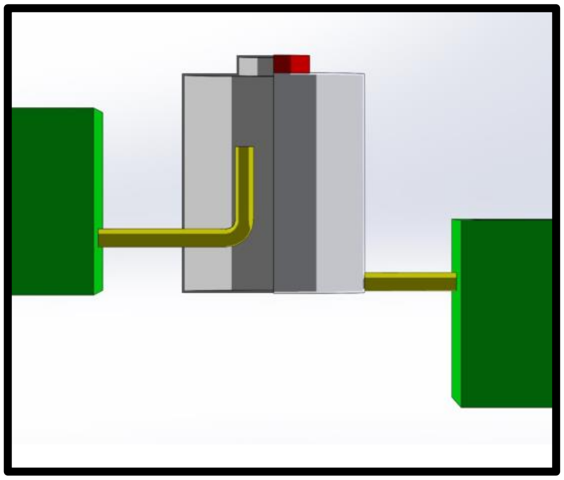


Figure 4.5 Ideal shape of the pipes *Figure 4.6 The newly built platform*

Third, there is standing water stored inside the 1st cell's holding tank.

The standing water collects all the sediments that are not filtered after Cell 1 and does not transfer them into Cell 2. This creates a dirty pond inside the holding tank and affects the water quality. The solution was to fill up the tank with concrete mixed with rocks and gravel to eliminate the gap from the bottom of the tank (figure 4.7).

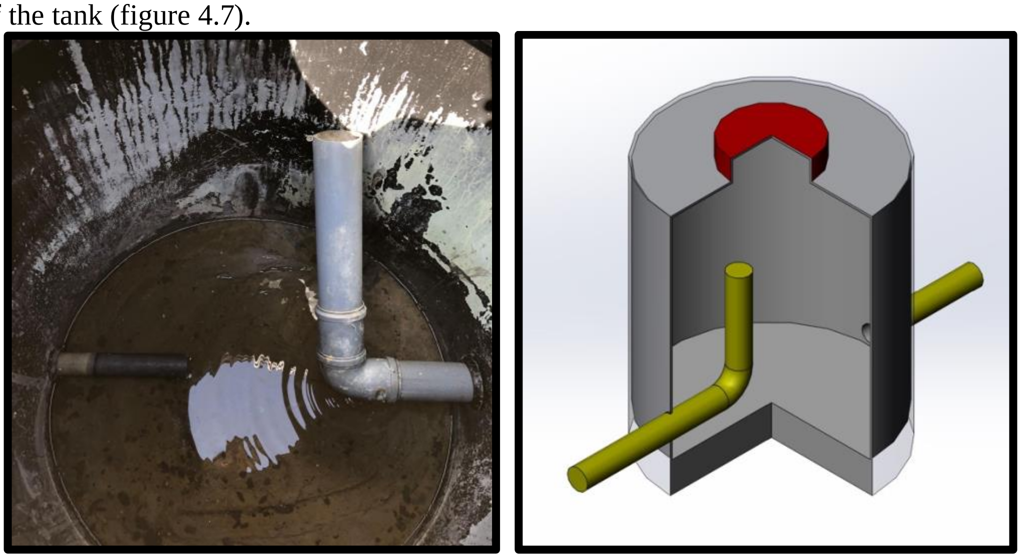


Figure 4.7 The concrete floor inside the tank

4.2 Experimental Findings

In order to assess the plausibility of constructed wetlands at the household scale, our team performed a nine day experiment with theoretical greywater use explained in the methodology chapter. During our experiment, we found various limitations to single family use through qualitative evaluations of water samples and analytical testing.

4.2.1 Findings from Qualitative Assessment of Water Quality

Upon making our qualitative assessment, we subject our data to a set of limitations.We recognize that these results may be skewed because of our own bias working with the wetland for this period of time. Despite the limitations of this research, it is useful when discussing user experience and will have an effect on the potential popularity of a constructed wetland at the household scale. In the following sections, we will discuss three major factors found during our assessment and we will discuss the impact they have on the probability an average family will want to use a constructed wetland for their water treatment.

Throughout our nine-day experiment, we performed daily assessments of the wetlands qualitative factors. The three points of assessment were at the flush tank, holding tank 1 between the cells, and our output holding tank. We did not assess at the sewer tank prior to the flush tank as we were overriding it by dumping our theoretical wastewater directly into the flush tank, nor did we assess at the final outlet point where the wetland watered a nearby tree as the water was being soaked up by the soil.

Evaluating Smell

The smell of the wastewater improved through filtration by the constructed wetland.

During our assessments, we took time to smell the system. We looked for the signature "rotten egg" smell that occurs in sewage gas. This can be caused by hydrogen sulfide gas that is naturally occuring when organic matters break down and produced by human waste (Pubchem, nd). Another factor to the smell is the presence of sulfur bacteria, creating the brown colored slime around the flush tank seen in figure 4.8. As we were introducing new organic material into the system, the leechant and food scraps, the smell will become stronger in the flush tank as the material breaks down. Theoretically, as the wastewater enters the system, it should filter out the organic materials and therefore reduce the smell as it passes through the system.

Throughout the experiment, we found that our observations match the theory. Smell improved consistently from the flush tank to the outlet in our daily sampling. This is an indicator that the wetland is performing as it should.

Figure 4.8: (Left) Flush Tank

Evaluating Water Clarity

The water became more transparent through filtration but experienced a change in color.

Similar to the evaluations completed daily for the smell, we assessed the clarity of the water. Transparency indicates a reduction in organic material as it flows throughout the wetland. The following images show the quality of water at each of the three testing points; the flush tank, holding tank 1 and the outlet tank.

Figure 4.9: Clarity Day One

Taken at the first 24 hour cycle of the experiment the included photo, figure 4.9, shows the progression of clarity. The far-left jar is more opaque and grey in color. The second sampling is much clearer and pale yellow in color. The third jar, which is the final output sample, is dark yellow in color but maintains clarity.

Figure 4.10: Clarity Day Four

Figure 4.11: Clarity Day Nine

Over the nine day experiment, you can see in Figure 4.7 - 4.9 that clarity consistently improved from the flush tank to the final output. This is a solid indicator that the water is improving while filtering through CW. The yellow color seen in the final jars is "associated with the organic material" decomposition which supports the functionality of CW (State Water Resources Control Board, 2012).

Evaluating Suspended Solids

Suspended solids were not a reliable qualitative indicator of the constructed wetland.

Alongside our other qualitative assessment, SS was a visual factor to take into account. Unlike the other factors we have addressed in our findings, there was not an improvement in suspended solids throughout the constructed wetlands filtration process. This is likely due to the wetland going from a dry state to filling with water rapidly. The system has many loose materials that were in our samples during the first couple of days but were minimized at the end of testing. Therefore, due to this disruption in our samples, we are unable to conclude if suspended solids were reduced as a function of the CW. Another factor in the disruption is that it rained on our final day, flushing the system of much of its contaminants.

Figure 4.12: Day Two (Higher SS)

Figure 4.13: Day Eight (Lower SS)

4.2.2 Findings from Water Quality Testing

At Lotan, there are limited testing capabilities and resources for use. In order to achieve a better performance and testing design, we would need access to more materials and require more time for testing interactions.

Nitrogen Testing

User friendly at home testing is possible for nitrogen testing of Constructed Wetlands.

Nitrogen testing can be completed with any level of user knowledge with the use of nitrate strips. They are easily accessible at online and retail stores for water testing in agricultural runoff. For an average Israeli household to do testing, they need only maintain a set of supplies and have access to their constructed wetlands water for sampling. Simplified testing allows the system of a constructed wetland to be reasonably maintainable by a small family.

Findings for Nitrogen Testing were not completed during our project period.

Due to outstanding circumstances, we were unable to receive lab results prior to the completion of our project. Data from nitrogen testing was sent to Kibbutz Lotan when it was completed but will not be included in this paper.

Biochemical Oxygen Demand Testing

At home testing for Biochemical Oxygen Demand is possible with Limitations.

Throughout our project experience, we have found that there is a lack of literature on accessible testing of BOD to be performed at home. This means users are unable to test their system's performance without calling out a contractor to sample for them. In order to bring our CW to the public, it was important that we create our own testing plan that was user friendly and accessible. The methodology that we designed from adaptations of known BOD testing procedures is detailed in Appendix C. While this methodology is much simpler than at lab testing, it is still limited in its ability for widespread use. It requires users to have access to the compound Sodium Thiosulfate which is an irritant for skin and eyes, limiting their use at the household scale. Users will also need to create a solution from soluble potato starch by mixing with a few milliliters of distilled water. This discourages potential users from taking on the testing plan. Our methodology also requires that users have knowledge of general titration and can keep their samples at the ideal temperature for five days.

Due to these limitations, the design of our testing plan is flawed and would need considerable improvements before it can be offered as a procedure for any level of user that would have a constructed wetland at the household scale.

Findings for the BOD levels in the Eco Kef System were not completed during our project period.

Despite the development of our adapted BOD testing procedure, we were not able to find Sodium Thiosulfate, a key chemical needed for testing. In order for one to feasibility test BOD in the region without access to the necessary chemicals or knowledge of titration, a contractor would need to be called out.

4.3 Findings for Implementation

Our last assessment of constructed wetlands for at-home use is the social adaptability of the systems. To help us understand the different types and uses for constructed wetlands, we studied a few different systems in the area and reviewed their stories.

There is a need for decentralized wastewater treatment systems in areas such as the Southern Arava.

In the Southern Arava, the improper treatment of wastewater has resulted in degradation of the desert environment, increase in the number of mosquitos, and destruction of natural habitats (Nusinow, 2007). A project of creating two pilot constructed wetlands was performed to help combat this issue. In Ketura Valley, there is a CW that contains a pre-treatment plant and six ponds. At Kibbutz Lotan, there was a CW that filtered waste from the dairy farm as well as wastewater from the kibbutz (Dalcher, 2016). The large CW at Kibbutz Lotan is no longer functioning as the wetland could not filter the dairy waste properly. This project seemed to be a start to the solution to groundwater pollution from untreated wastewater. However, only one of the two pilot CWs is still currently functioning. To continue improvements in wastewater treatment in Southern Israel, there needs to be development of decentralized wastewater treatment systems due to previous failures at the industrial level.

The user must be fully committed to the time and maintenance that a constructed wetland requires.

As discussed above, there is much time and maintenance required to own a constructed wetland. For a person to own a single home CW, they must be very dedicated to the system and be willing to test and do work on the wetland frequently. Even in a community setting, the committee in charge of operating the CW must be aware of the resources needed to keep the wetland functioning properly. If the owner of a CW is not fully committed to the upkeep, large costs could incur and the water may not filter properly. This would defeat the original purpose of the CW being a low cost wastewater management solution.

Chapter 5: Recommendations

Upon completion of our qualitative and quantitative assessment we would like to make the following recommendations to Kibbutz Lotan, potential household users and for next steps concerning constructed wetlands.

5.1 Recommendations for Lotan

We recommend the EcoKef ensure a sufficient wastewater supply because it is critical for keeping the system functional and the bacteria alive.

Based on our calculations of the required minimum water flow for the system, there is not enough water for a wetland of this size. It needs water to filter properly. The EcoKef should establish an additional source of wastewater in order to meet the minimum required water amount during specific periods of water shortage or high levels of evaporation. This can be done by directing a pipeline from another dining hall or facility. If this is not possible, Lotan should consider draining the system and discontinuing use until the Tea House is reopened because there cannot be a successful filtration without proper water source.

We recommend the EcoKef plant suitable vegetation to improve the performance of the wetland system.

Plants such as cattails and bulrushes play an integral role in supporting the wetland's performance. The most effective constructed wetlands are those that foster all the necessary elements of a natural wetland: soil, gravel, vegetation, etc.

We recommend the EcoKef maintain the wetland system once every 6 months and implement a consistent monitor program.

Wetlands for wastewater treatment can be expected to change more quickly than most natural wetlands because of the rapid accumulation of sediment, litter, and pollutants (Dupoldt et al, 2015). Therefore, they require consistent maintenance. For an effective maintenance plan, there should be scheduled cleaning of the system, mowing, and inspection. Dupoldt's Constructed Wetlands Handbook (2015) recommends an inspection approximately every six months to remove weeds, take care of essential plants, and clean out pipes for blockages. We present our recommended maintenance plan in Appendix E.

A monitoring plan is also needed to keep track of the wetland's biological effectiveness (Dupoldt et al, 2015). This plan is to provide informative data on water flow consistency, chemical concentration, and biological diversity inside the wetland. Ideally, the monitoring should be enforced at least once per month. Natural systems can change drastically in a short-time; therefore, good-record keeping is essential.

We recommend that Kibbutz Lotan implements a long term project plan to continue work on the constructed wetland.

This project should include carrying out our experiment for a much longer period of time to allow for the 700 day adjustment period and development of filtration plants. This project is very suitable for Kibbutz Lotan's Green Apprenticeship program which focuses on permaculture and ecological design. In order for this project to be carried out continuously, there would need to be a few kibbutz staff members to perform the experiment in the gaps between different Green Apprenticeship programs.

5.2 Household Use Recommendations

Throughout our research and project completion we have found success and limitations in using a constructed wetland for a single family home. In order for constructed wetlands to be a reliable wastewater treatment system in Southern Israel we make the following recommendations.

We recommend users keep in mind the size, maintenance and testing requirements for safe implementation.

For anyone considering if a constructed wetland is a wastewater filtration solution suitable for their lifestyle there are important things to keep in mind. We recommend that users closely reference CW manuals in their design and build. Designing a system too large or small for their use or using plants that will die in the local climate deteriorates the functionality of the CW. Another factor to reference is how much land space the user is willing and able to commit to their CW. Rural areas are the most suited to this type of filtration system as it takes up much space an urban resident would not be able to give up. Finally the user must consider how much time and effort they are willing to put into a CW. There will need to be maintenance plans put in place to keep the system healthy and testing procedures to assure that the system is working at full efficacy. Similar to a garden or pond the user must be willing to care for it and do upkeep as needed.

We recommend the creation of an at home testing kit for Biochemical Oxygen Demand.

For an average user to be able to test their system as things are in Israel they will need to hire a contractor to come take samples and perform the testing of the CW. We suggest creating a BOD testing kit similar to the nitrogen testing strips. It would need to have individual packets of the chemicals and step by step instructions for use that would indicate if the CW is in the proper range for safe use.

We recommend using a hybrid system filtering greywater and blackwater separately to reduce risk of potential groundwater pollution.

Due to limited long term research on CW performance and the high potential for user error we recommend developing a hybrid method for wastewater filtration. By using typical sewage treatment for a household blackwater and limiting the constructed wetland to only address grey water there is a reduction in the risk associated with typical use. While this is less desirable than using the Constructed Wetland for the entire homes water filtration, this strategy allows for greater variance in use and limits disruption to user lifestyle.

We recommend taking into consideration a communal, larger constructed wetland to filter the water from an entire community in order to reduce individual burden of maintenance and testing and increase reliability.

Supported in our findings, we believe that a more effective way of using a constructed wetland as a decentralized wastewater treatment system is not at the household scale and instead for servicing a community. (insert information from Neot Semedar interview and their success - this finding could change but we anticipate it remaining true as a communal wetland offers the opportunity for more filtration ponds and less maintenance for each party)

5.3 Next Steps

Beyond the above recommendations, we recommend some long term goals both for future Interactive Qualifying Projects and the general research of constructed wetlands. There is far more to be done with the EcoKef's wetland that will be valuable to the surrounding region.

We recommend that future Interactive Qualifying Projects continue research on constructed wetlands in the Southern Arava.

One Interactive Qualifying Project (IQP) that could take place at Kibbutz Lotan next year is continuing our experiment to further evaluate the EcoKef's wetland. This IQP should include planting the proper vegetation and fixing the cell sidings of the wetland. We also recommend a second IQP that Shira recommended for ourselves that involves intensive research on the success and failure of constructed wetlands in the region with the goal of providing literature that fills gaps for someone looking to build a system and for policymakers to reference.

We recommend that there be more long term studies about how wetlands age over time and how age affects the efficiency of the system for general constructed wetland research.

We also recommend that people research the lifespans of different types of wetlands so future owners know what to expect. This research is necessary for constructed wetlands to be considered more seriously as a sustainable solution to wastewater treatment.

Chapter 6: Conclusions

Working with Lotan's EcoKef Constructed Wetland, we evaluated qualitatively if this type of system can successfully filter out organic material and be implemented at the household level. From this, we were able to recommend improvements to the Lotan system, future long term studies and considerations for potential at home users. Ultimately, we found that constructed wetlands at the household level require further research and development to be reliable for Southern Israel. Following in the steps of the Southern Arava Waste Management Plan, we support the theory that a communal wetland is the ideal solution for decentralized wastewater treatment. A community size wetland is able to service multiple homes, use more filtration pools to better assure safe groundwater, and spread the tasks of maintenance between many. With our findings in mind we hope for future researchers to be able to develop a reliable system at the household scale.

Appendix A: Household Wastewater Quantities

Type of Wastewater	Number of Times per Day	Total Amount per Day (L)
Showering	1	50
Dish Washing	3	31.5
Clothes Washing	1/week	4
Hand Washing	10	30
Face Washing/Teeth Brushing	2	40
Making Food	3	45

Appendix B: EcoKef Retention Rate and Explanation

The EcoKef System has two cells, each 3 meters by 4 meters. The first cell has a maximum water depth of .18 meters and the second has a maximum water depth of .35 meters. We then can calculate the water volume inside each cell by multiplying area and water depth. Each cell is also filled with gravel with determined levels of porosity at 41.9% which reduces the retention time to 51.8% of the calculated amount. As shown in section 3.1, a single person has an estimated average of 200.5 liters of wastewater used per day. Upon testing the wetland for a two-person household with 401 liters of water used per day, retention time can be calculated as follows.

Calculations for the first cell: $([3m * 4m] * .18 * 1000l/m^3) \div 401\ l\ =\ 5.39 * .581 = 3.13\ days$
Calculations for the second cell: $([3m * 4m] * .35 * 1000l/m^3) \div 401\ l\ =\ 10.47 * .581 = 6.08\ days$

Appendix C: Biochemical Oxygen Demand Testing Procedure

Average Israeli household wastewater has an approximate BOD of 250 mg/l when exiting the house, however, following treatment in a Constructed Wetland, the BOD must be brought down to the 8standard of 20 mg/l (Iasur-Kruh, Hadar, & Minz, 2012). Using this we can base our experiment.

Our procedure is loosely based on the Winkler Method for measuring dissolved oxygen in the water. While this procedure usually uses specific BOD bottles that are airtight and light-resistant, we used airtight food jars wrapped in electrical tape in order to mimic those important qualities. The Winkler Method also uses titration as a method for measurement using a burette, this is replaced with the use of small syringes to add in the titrant. While the procedure has been almost entirely adapted for at-home testing there are still two chemicals that are required, sodium thiosulfate acting as our titrant and a starch solution used as an indicator. The complete effects of our testing design on accuracy are unknown as there has not been an at-home testing procedure completed before. In order to test if our procedure has any relevance, we tested Lotan's dairy effluent for BOD and compared our data points to that of which was recorded two years ago. Our testing was then compared to other local Constructed Wetland levels for estimation

1. Sampling Procedure
    a. Completely submerge sampling bottle so that no air bubbles are trapped (invert bottle and slowly turn over, capping bottle underwater)
    b. Store in a dark, cool place for up to 8 hours prior to testing, covering cap with aluminum foil
2. DO Testing Procedure
    a. In a glass bottle, titrate 201 mL of the sample with sodium thiosulfate to a pale straw color. Titrate by slowly dropping titrant solution from a syringe into the bottle, continually stirring
    b. Add 2 mL of the starch solution so a blue color forms.
    c. Continue slowly titrating until the sample turns clear.
    d. The concentration of dissolved oxygen in the sample is equivalent to the number of milliliters of titrant used. Each mL of sodium thiosulfate added equals 1 mg/L dissolved oxygen
3. BOD Testing
    a. Upon the original sampling date, take two samples.
    b. Store the duplicate samples at 20-degree Celsius for a 5 day incubation period, stirring often.
    c. After the 5 days come back to repeat the DO test and use the following equation to calculate BOD. $DO_1 - DO_2 = BOD_5$ with mg/l as all of their units.

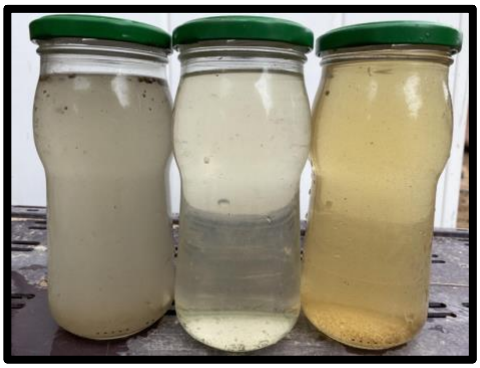
Appendix D: Images from Nine Day Experiment

Below are the images of the samples taken every day. The leftmost jar is from the flush tank, the middle from the center holding tank, and the right is the outer tank.

Day One Above

Day Two Above

Day Three Above



Day Four Above

Day Five Above

Day Six Above

Day Seven Above

Day Eight Above

Day Nine Left

Appendix E: Maintenance and Monitoring Plan

According to the needs of EcoKef's wetland, its maintenance plan should address the following:

- Cleaning and maintaining the inlet and outlet pipes, valves, and holding tanks.
- Inspecting for structural damage of 2 cells.
- Adjusting pipes for water depth and depth of sediments before cleaning and removal.
- Inspecting the slope of the existing pipe is steep enough for water flow.
- Checking system performance: for domestic wastewater of the EcoKef, the parameters that matter are BOD (biochemical oxygen demand), nitrogen, phosphorus, total suspended solids, heavy metals, and bacteria (total or fecal coliform). Due to the difficulty of the testing methods, we recommend hiring professional contractors. After establishing that the system is functioning, testing can move to yearly increments

The recommended monitoring plan:

- Monitoring Water Flow: constantly measure water depth and ensure that the flow is appropriate using sensors; collect small water samples for testing purposes.
- Monitoring Wetlands Health: for the EcoKef's wetland which does not have much vegetation planted, vegetation monitoring can be done through qualitative observations of the site. Sediment, litter, and water depths should be checked, to avoid affecting the depth of the water in the wetland and potentially altering flow paths (Dupoldt et al, 2015).

References

Adera, S., Drizo, A., Twohig, E., Jagannathan, K., & Benoit, G. (2018). Improving performance of treatment wetlands: Evaluation of supplemental aeration, varying flow direction, and phosphorus removing filters. Water, Air, & Soil Pollution; an International Journal of Environmental Pollution, 229(3), 1-15. doi:10.1007/s11270-018-3723-3

Avgar, I. (2018). Israel's water sector - key issues. Kiryat Ben-Gurion: Retrieved from https://m.knesset.gov.il/EN/activity/mmm/mmmeng250218.pdf

Bhatia, M., & Goyal, D. (2014). Analyzing remediation potential of wastewater through wetland plants: A review. Environmental Progress & Sustainable Energy, 33(1), 9-27. doi:10.1002/ep.11822

Brenner, A. (2006). Removal of Nitrogen and Phosphorus Compounds in Biological Treatment of Municipal Wastewater in Israel. Israel Journal of Chemistry, 46(1), 45–51. https://doi.org/10.1560/1KRL-CYGN-3LY7-7R6X

Dalcher, Darren. (2016). Further advances in project management. London: Routledge Ltd. doi:10.4324/9781315464374 Retrieved from https://www.taylorfrancis.com/books/9781315464367

DuPoldt, C., Edwards, R., Garber, L., Isaacs, B., Lapp, J., Murphy, T., . . . Harold. (2015). A handbook of Constructed Wetlands.

Gikas, G., & Tsihrintzis, V. (2010). On-site treatment of domestic wastewater using a small-scale horizontal subsurface flow constructed wetland. Water Science and Technology, 62(3), 603-614. doi:10.2166/wst.2010.172

Greywater Actions. (nd). Backyard Greywater Wetlands. Retrieved February 11, 2020, from https://greywateraction.org/greywater-constructed-wetland/

Hydrik Wetlands Consultants. (1998). Design manual - constructed wetlands and aquatic plant systems for municipal water treatment United States Environmental Protection Agency.

Israel Meteorological Service (2019) Weather Data of Southern Negev Region. Retrieved from: https://www.gov.il/en/departments/israel_meteorological_service

Israel Ministry of Foreign Affairs (n.d.). Israel's Chronic Water Problem. Retrieved February 11, 2020, from https://mfa.gov.il/MFA/IsraelExperience/AboutIsrael/Spotlight/Pages/Israel-s%20Chronic%20Water%20Problem.aspx

Iasur-Kruh, L., Hadar, Y., & Minz, D. (2012). Bacterial composition of constructed wetland's biofilm: the influence of biotic and abiotic parameters on the composition of the biofilm. Hebrew University of Jerusalem.

Kummu, M., Guillaume, J. H. A., de Moel, H., Eisner, S., Flörke, M., Porkka, M., . . . Water and, C. R. (2016). The world's road to water scarcity: Shortage and stress in the 20th century and pathways towards sustainability. Scientific Reports, 6, urn:issn:2045-2322.

Lin, Y., Jing, S., Lee, D., & Wang, T. (2002). Nutrient removal from aquaculture wastewater using a constructed wetlands system. Aquaculture, 209(1-4), 169-184.

Lipchin, C. (2001). Report from the field: Perceptions of water use in the arava valley of israel and jordan.8(2) Retrieved from: https://quod.lib.umich.edu/j/jii/4750978.0008.207/--report-from-the-field-perceptions-of-water-use-in-the-arava?rgn=main;view=fulltext;q1=clive+lipchin

Marin, P., Tal, S., Yeres, J., & Klas, R. (2017). Water management in israel - key innovations and lessons learned for water-scarce countries. Retrieved from: http://documents.worldbank.org/curated/en/657531504204943236/pdf/Water-management-in-Israel-key-innovations-and-lessons-learned-for-water-scarce-countries.pdf

National Center for Biotechnology Information. PubChem Database. Hydrogen sulfide, CID=402, https://pubchem.ncbi.nlm.nih.gov/compound/Hydrogen-sulfide (accessed on Feb. 18, 2020)

National Small Flows Clearinghouse. (n.d.). Constructed Wetland Factsheet. Retrieved from https://engineering.purdue.edu/~frankenb/NU-prowd/cwetfact.htm

Nusinow, U. (2007). SASWMP - southern arava sustainable waste management plan. ().Layman report. Retrieved from: http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=2802&docType=pdf

Samsó, R., & García, J. (2013). Bacteria distribution and dynamics in constructed wetlands based on modelling results. Science of the Total Environment, 461-462, 430-440. doi:10.1016/j.scitotenv.2013.04.073

State Water Resources Control Board. (2012). Color of water fact sheet. HIV Medicine, 13, 7-10. doi:10.1111/j.1468-1293.2012.01029_2.x

Stefanakis, A. (2015). Constructed Wetlands: description and benefits of an eco-tech water treatment system.

Taylor, C., Jones, D., Yahner, J., Ogden, M., & Dunn, A (1998) .Individual residence wastewater wetland construction in Indiana.

Times of Israel (2018). 5-year drought raises questions over Israel's water strategy. Retrieved from: https://www.timesofisrael.com/5-year-drought-raises-questions-over-israels-water-strategy/

Time of Israel (2014). Israeli planning 11 new towns in the Negev Desert. Retrieved from: https://www.timesofisrael.com/israel-plans-11-new-towns-in-negev-desert/

Torczon, M. (2018). Constructed wetlands for industrial wastewater treatment (1st ed.). Newark: John Wiley & Sons, Incorporated. Retrieved from https://ebookcentral.proquest.com/lib/[SITE_ID]/detail.action?docID=5437560

Water Use in Your Home. (2010). South Staffs Water.

World Resources Institute. (2015, August 26,). Ranking the world's most water-stressed countries. Retrieved from https://www.wri.org/blog/2015/08/ranking-world-s-most-water-stressed-countries-2040