AIES Constructed Wetland Greywater Treatment Systems:
Water Quality Monitoring and System Report

Image Credit: AIES. Nablus as seen from a single-family home. The home hosts one of AIES' greywater systems.

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1 Preface

This document is meant to inform current and future members of the Arava Institute for Environmental Studies (AIES) and the Center for Transboundary Water Management (CTWM) about findings, mistakes, and suggestions regarding the greywater treatment project. Many of the sampling and field-testing protocols outlined in this document have not been previously documented.

This document is written for both a technical and non-technical audience. Data for main water quality parameters (eg. BOD_5, COD, pH, DO) have been included in the body of the report. Data deemed less meaningful for the average reader (eg. full chemical analysis) has been included as an appendix.

2 Executive Summary

As part of the broader Mitigating Transboundary Wastewater Conflicts project (USAID No. 294-A-12-00005), the Arava Institute for Environmental Studies designed and built 7 greywater treatment systems throughout Israel and the West Bank. Intended to demonstrate the feasibility of temporary, small-scale off-grid water treatment systems in lieu of politically unfeasible large-scale water treatment plants, the systems were installed in homes and municipalities as fully operational demonstration tools. The pilot systems, incorporating a range of technologies from constructed wetlands and suspended fabrics to membrane bioreactors, provided usable, treated greywater for irrigation and helped families cut down on water bills by reusing their wastewater in place of expensive freshwater.

3 Theory

3.1 Greywater

According to the United States Environmental Protection Agency (EPA), greywater (also called graywater, grey water, or gray water) is "reusable wastewater from residential, commercial and industrial bathroom sinks, bath tub shower drains, and clothes washing equipment drains" (Water Recycling and Reuse: The Environmental Benefits, 2013). Sometimes, it includes wastewater from kitchen sinks. However, it does not include wastewater from toilets, which is referred to as blackwater. The pollutant and pathogen levels of greywater are lower than those of blackwater, which makes it a good candidate for reclamation and reuse. Before it is reused, greywater must be treated, as it can contain pollutants that are harmful to the surrounding environment.

Greywater contains differing levels of pollutants, depending on the source, but generally contains the same set of pollutants. Organic matter is the main pollutant treated. Among the chemicals that greywater can contain are ammonia, phosphate, chloride, boron, sodium, and sulfate (Friedler, 2004). These can originate from various cleaning products that are used to clean appliances attached to a greywater system. A wide variety of both harmless and pathogenic microorganisms can also exist in greywater. A list of pathogens that can be found in wastewater is taken from a recent survey of constructed wetland technologies (Hoffman, Platzer, Winker, & von Muench, 2011):

- Bacteria: *Escherichia coli, Salmonella typhi, Vibrio cholera, Shingella, Legionella, Leptospira, Yersinia*
- Protozoa: *Entamoeba, Giardia, Cryptosporidium*
- Helminths (intestinal worms): *Ascaris, Enterbios, Taenia, Schistosoma, Trichuris, Fasciola*
- Viruses: *Adeno-, Entero-, Hepatitis A-, Polio-, Rota-Norwalk Virus*

Using greywater instead of freshwater can save money and conserve freshwater for other purposes. Treated greywater can be used for flushing toilets and irrigating crops. Since greywater contains nutrients such as phosphate and nitrate, using it for irrigation can reduce the use of fertilizer (Water Recycling and Reuse: The Environmental Benefits, 2013). It is important that treated greywater is used to irrigate only non-edible crops, or edible crops where the water does not contact the edible portion of the plant, as treated greywater can still contain pathogens (Barker, et al., 2013). However, even if this recommendation is not followed, it is still better than irrigating with raw sewage, a practice used by around 200 million farmers worldwide (Eichenseher, 2008).

3.2 Constructed wetlands (CWs)

There are many techniques for treating greywater. They range from high-tech membrane bioreactors (MBRs) to low-tech systems that utilize or imitate natural water-treatment systems. Constructed wetlands fall under the latter category.

Wetlands are natural water treatment systems. Left to their own devices, they effectively remove pollutants and require little to no maintenance, as long as their capacity to remove nutrients and pollutants is not exceeded, which causes environmental degradation. Constructed wetlands take advantage of these processes and provide a low-cost, low-tech, low-maintenance approach to greywater treatment, well-suited to the climate and conditions in the West Bank.

In a constructed wetland, wastewater is treated by a variety of biological and physical processes. Bacterial colonies in the wetland are responsible for the biological treatment of organic matter. This occurs via either aerobic or anaerobic respiration, either with or without diatomic oxygen (O_2). It is important to note that in both forms of respiration, a source of oxygen is needed. The difference is that in anaerobic respiration, the oxygen comes from substances like sulfate (SO_4^{2-}) and nitrate (NO_3^-) (Wikipedia: Anaerobic Respiration, 2014). Physical processes include filtration, absorption, precipitation, nitrification, and decomposition (Hoffman, Platzer, Winker, & von Muench, 2011).

There exists a wide variety of constructed wetland technologies. “Constructed wetlands are classified according to the water flow regime into either free water surface flow (FWS) or subsurface flow (SSF) CWs, and according to the type of macrophyte plant as well as the flow direction” (Hoffman, Platzer, Winker, & von Muench, 2011). With SSF CWs, the water level remains below the surface of the filter bed, unlike in FWS CWs where the water level is above that of the filter bed. This gives SSF CWs the advantage of resilience against mosquito problems. To avoid confusion, SSF CWs are also referred to as reed beds.

SSF CWs can be further classified into either a horizontal flow bed (HFB) (Figure 1) or vertical flow bed (VFB) (Figure 2). This refers to the primary direction that the water flows through the treatment media. VFBs have higher treatment and space efficiencies, requiring about half as much space as HFBs, but should receive wastewater only intermittently, not continuously (Hoffman, Platzer, Winker, & von Muench, 2011). This is especially important when using densely-packed treatment media, such as sand, because drying allows for oxygen replenishment in the media, which allows for aerobic respiration. HFBs, on the other hand, remove more pathogens, can receive wastewater continuously, and are easier to design. While HFBs are more prevalent in developing countries, the large space requirements may prove troublesome, especially in urban environments.

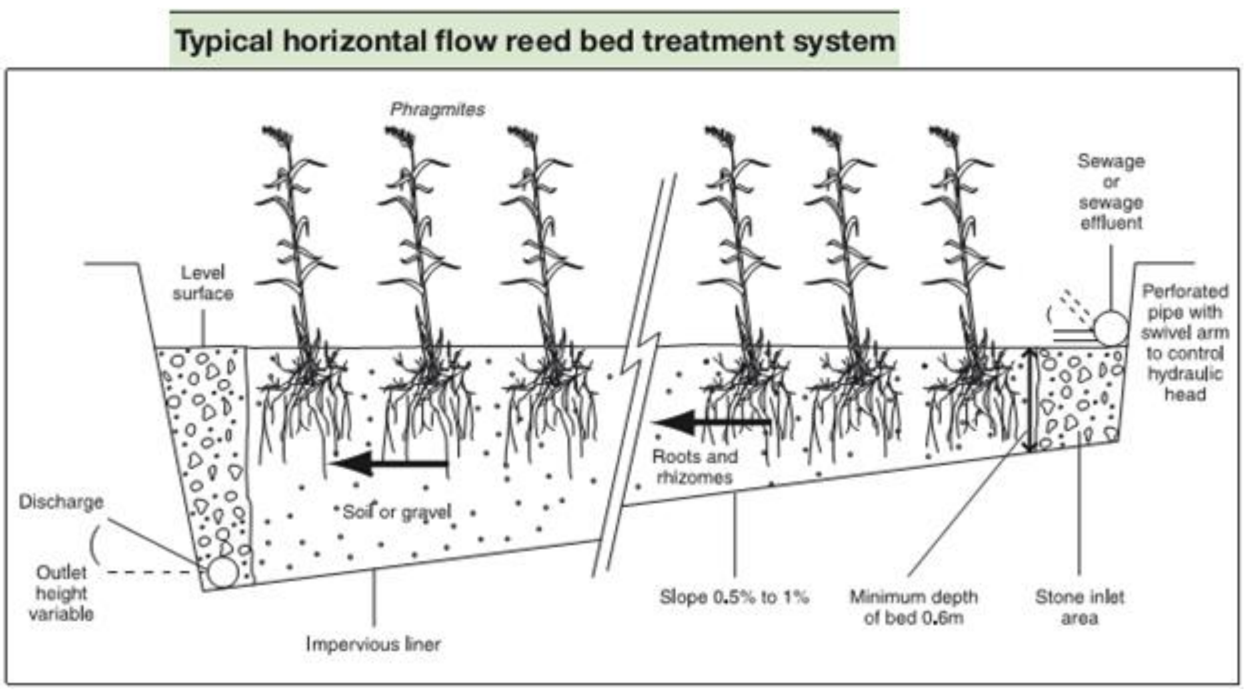

Figure 1: Cross section of an example of an HFB. Notice how the water flows from left to right through the treatment media (SpecifiedBy: HFB).

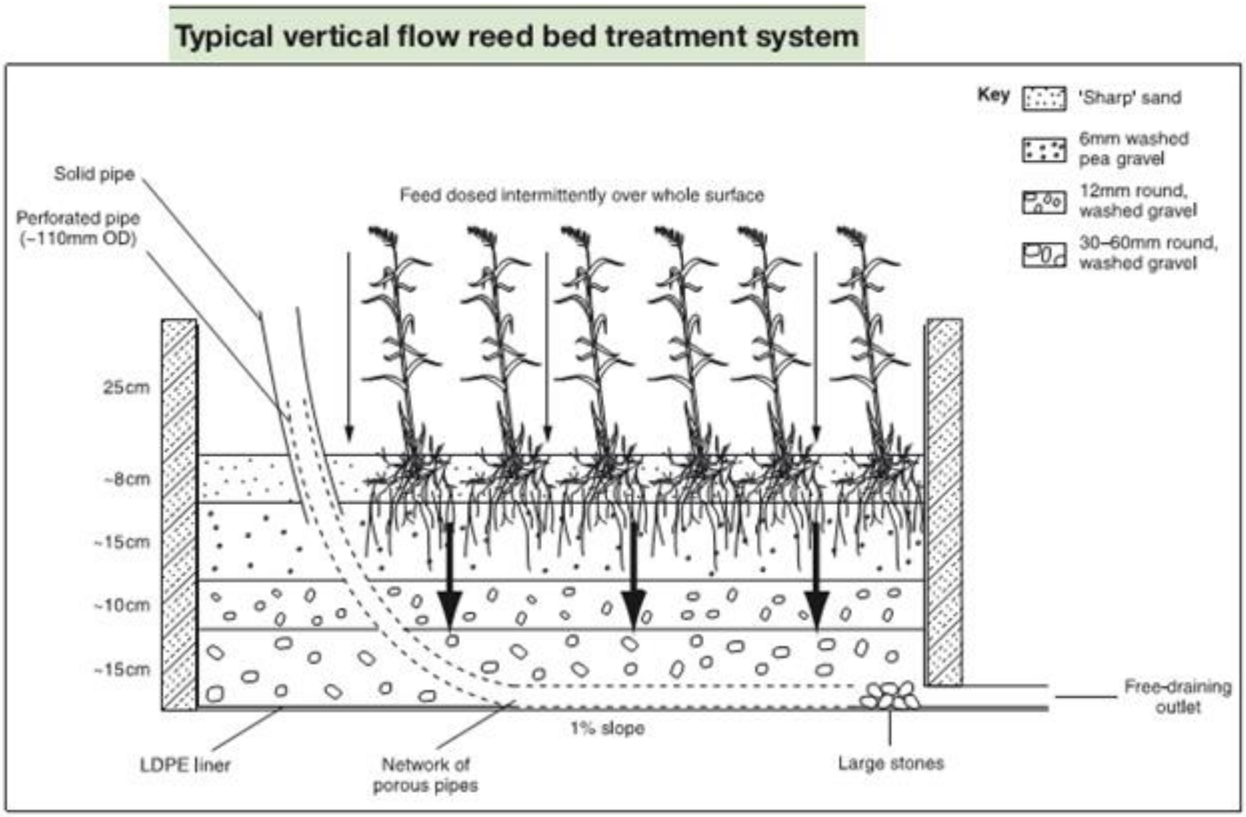

Figure 2: Cross section of an example of a VFB. Notice how here, the water is evenly distributed over the surface so that all of the treatment media is used as the water trickles down (SpecifiedBy: VFB).

Plants also play an important role constructed wetlands. They reduce nutrient levels via uptake through the roots and maintain the hydraulic conductivity of the treatment media, as well as creating root structures that serve as growth media for bacteria (Hoffman, Platzer, Winker, & von Muench, 2011). According to Hoffman, plants also increase oxygen transport to the bacteria, allowing for more aerobic respiration to occur.

Pre-treatment steps used upstream of the CW itself is important to prevent clogging in SSF CWs. These steps can include the following: "sand and grit removal, grease trap, compost filter (for small-scale systems), septic tank, baffled tank (or anaerobic baffled reactor), Imhoff tank, up-flow anaerobic sludge blanket (USAB) reactor (only used for large-scale systems)" (Hoffman, Platzer, Winker, & von Muench, 2011). Failure or lack of pre-treatment steps can lead to overloading of the system. According to Hoffman, while short overloading peaks do not reduce system performance, chronic overloading will cause a CW to degrade and lose its treatment capacity. Hoffman recommends maintaining the pre-treatment steps by checking their efficiency, checking that all pumps are functioning properly, and that influent is being evenly distributed over the treatment media.

Following biological treatment, greywater must be disinfected before it can be safely used. This is because the water still contains microorganisms and pathogens which can cause human disease. Effluent disinfection is usually accomplished using chlorine, ozone, or ultraviolet (UV) light (US EPA Office of Wastewater Management, 2004).

According to the proposed Israeli greywater standards, treated greywater must contain at least 12 mg/L of residual chlorine in order to be used for unrestricted irrigation. This is to prevent the regrowth of pathogens in the treated effluent, while the treated effluent is being stored for future use. One issue with chlorination is that it can create disinfection by-products, such as trichloromethane (commonly known as chloroform). According to the US Center for Disease Control, trichloromethane is a possible human carcinogen (Disinfection By-Products and the Safe Water System, 2014). However, since the effluent from our systems is to be used for agriculture and not drinking, this may not be an issue, as long as human contact with the effluent is minimized. Additionally, it is possible that such pollutants will dissipate quickly, due to their volatility, so that the treated effluent will contain them in very low levels. However, this will require further research to determine.

3.3 AIES System Design

The system begins with water being collected in an inflow collection tank. Here, anaerobic digestion and settling take place. Both of these processes reduce the levels of organic matter of the greywater that flows into the rest of the system. This tank also functions as a protective measure. It helps to level out pollutant concentration peaks in raw greywater before it comes into contact with the plants and bacterial colonies in the gravel treatment tanks, as these peaks could overload and damage the system.

Water flows out of the inflow collection tank and into the chain of gravel treatment tanks via a siphon. The inflow to the siphon is sufficiently lower than the water level in the tank, such that fats, oils, and grease (FOG) remain in the septic tank, lowering the organic load and preventing clogging in the rest of the system.

Figure 3: Surface crust and the siphon in the inflow collection tank. The siphon draws from about 30 cm below the surface. Photo credit: Antonia Bacigalupa Albaum

The systems designed by CTWM vary from traditional constructed wetlands in one main aspect: the treatment media is organized into 1 m x 1 m x 1 m plastic crates instead of being designed to look like a wetland. Each tank should have its own set of reeds with well-established root systems. Creating these gravel treatment pond units allows the system to be easily installed and modified to meet the needs of the location and users. The gravel treatment tanks are made out of recycled materials and the system is entirely gravity-fed, both of which reduce the cost of the system. The only part of the system that requires any electricity is a small pump in the effluent collection tank which allows for irrigation.

Figure 4: (right to left) Inflow collection tank and first 2 gravel treatment tanks of the CW system at Deir al-Hatab. Photo taken on the October 2014 CTWM monitoring trip.

4 Water quality monitoring

4.1 Parameters

Greywater can be analyzed through the measurement of its organic matter levels, physical and chemical parameters, and its appearance. This section describes the parameters that have been tested for in the West Bank greywater systems.

4.1.1 Biological and Chemical Oxygen Demand (BOD & COD)

BOD and COD measure the amounts of organic matter present in a sample, and are key parameters in the evaluation of water quality. They are reported in the concentration of oxygen necessary to fully oxidize the organic matter. BOD refers to the organic matter that can be broken down through aerobic respiration. COD encompasses BOD, and also includes organic compounds that can be oxidized by chemical treatment. They are most often tested in a lab. A review of literature did not reveal a correlation between BOD and COD and parameters that are easily measured in the field (eg. pH, turbidity, DO). BOD and COD have been correlated to absorbance at certain wavelengths, which allows for measurement by of these parameters by ultraviolet-visible absorption spectroscopic methods (Fleischmann & et al, 2014). There are UV/VIS probes that can be installed in a system that provide continuous monitoring.

4.1.2 Total Suspended Solids (TSS)

TSS is a measure of the amount of filterable particulate solids present in a water sample. It is an important metric of water quality, as particulate matter can house bacteria and other pathogens. Its units are reported in mg/L, and is tested in a lab.

4.1.3 Fecal coliforms

Fecal coliforms are a type of bacterium that originate in the intestines of warm-blooded animals and are commonly found in wastewater. While fecal coliforms are not harmful themselves, they can indicate the presence of pathogens (Fresno County Department of Public Health, 2009). Levels are reported in cfu/mL or cfu/100 mL (colony forming units).

4.1.4 Dissolved Oxygen (DO)

DO is an important parameter in wastewater treatment, as dissolved oxygen is necessary for aerobic respiration to occur. Low levels of dissolved oxygen can indicate decomposition of organic matter and nutrients, as it DO is consumed in the process of aerobic respiration. No value for an aerobic-anaerobic threshold could be found in research. Units are reported in mg O_2/L.

4.1.5 Electrical Conductivity (EC)

EC is used to describe a sample's salinity through its ability to conduct electricity. Pure water itself does not conduct electricity. Rather, it is the free-floating ions in the water it that allow current to flow. These ions come from salts that have dissolved in the water. Units are usually reported in mS/cm.

4.1.6 pH

pH s a measurement of a sample's acidity or basicity, with low values meaning acidic and high values meaning basic. It is represented mathematically as:

$$pH = -\log([H_3O^+])$$

where $[H_3O^+]$ is the concentration of hydronium ion, H_3O^+. Hydronium ions are formed when a proton is donated to a water molecule, an event that happens more often the more acid is present. Therefore, the higher the concentration of acid present, the higher the concentration of hydronium ions.

4.1.7 Turbidity

Turbidity is a measurement of a sample's appearance, specifically, how the sample transmits light. Water that is cloudy or murky is highly turbid. That is, it does not transmit light very well. This is caused by light scattering due to colloidal particles in the water. Its units are standardized measurements known as Nephelometric Turbidity Units (NTU).

Turbidity is a measurement that is primarily linked with aesthetics. However, water that is more turbid often has higher levels of BOD, COD, and pathogens. It is important to note that it is quite difficult to relate turbidity to TSS, as light transmittance is based on both the size and number of colloidal particles present. Recall that TSS is measured in units of mass per volume, while turbidity is measured in NTU. Two samples with the same TSS levels could have different turbidity readings if the two samples have different particle size distributions.

4.1.8 Phosphate

Phosphate (PO_4^{3-}) is an ion that can end up in greywater from the use of some dishwashing detergents (Schneider, 2009). Phosphate and other forms of phosphorous are important nutrients related to plant growth. Excess phosphorous or phosphate in water can create algal blooms. Levels of phosphate are reported as concentrations, usually parts per million (ppm) or mg/L.

4.1.9 Sulfate

Sulfate (SO_4^{-}) is an ion that can end up in greywater from the use of soaps and detergents which contain sodium lauryl sulfate. It is used as an oxygen source in order for bacteria to undergo anaerobic respiration, producing foul-smelling hydrogen sulfide (H_2S) (Harshman, P.E. & Barnette, 2000). Levels of sulfate are reported in ppm or mg/L.

4.1.10 Ammonia, Nitrate & Nitrate

Ammonia, nitrate, and nitrite are important compounds in the nitrogen cycle. Ammonia can end up in greywater through cleaning products and is widely used as a fertilizer. Through the biological processes of nitrification, ammonia is converted to nitrate, and then to nitrite, before it undergoes denitrification to form nitrogen gas. Denitrification is carried out by anaerobic bacteria. These levels are reported in ppm or mg/L.

4.1.11 Total Residual Chlorine

Total residual chlorine is an important parameter related to disinfection. It is a measurement of how much chlorine remains in the water after disinfection is considered complete. This prevents regrowth of bacterial colonies in the treated water and keeps it clean during transportation to its site of use. Levels of total residual chlorine are reported as concentrations, usually ppm or mg/L.

4.1.12 Sodium

Sodium (Na^{+}) is an ion that can precipitate out as a salt, such as NaCl (table salt). It can end up in greywater from different soaps and detergents that contain sodium lauryl sulfate. Too much salt in influent can harm the bacterial colonies in the constructed wetland system, and can lead to salinization of the irrigated soil, making it more and more difficult to grow crops as it accumulates. It can be measured through a variety of chemical tests, and is reported in ppm or mg/L.

4.2 EQUIPMENT

This section describes the main equipment involved in collecting and testing the samples in the field. A comprehensive list of the sampling equipment is included in the appendix to serve as a reference for future sampling trips and experiments.

4.2.1 Grab sampling device

This device consists of a wide-mouth 500 mL duct-taped to a broom handle. It is lowered into the tank to collect grab samples. Future modifications could include a lid that can be opened with a trigger, allowing for sample collection at a specific depth.

Figure 5: Grab sampling device being used to collect samples at Dar Salah. Photo credit: Antonia Bacigalupa Albaum

4.2.2 Turbidity meter

Turbidity is measured in the field using a portable turbidity meter. The kit is shown in figure 6 below. No special instructions are recommended, outside what is provided in the instruction manual.

Figure 6: Turbidity meter and accessories: (left to right) Distilled water for cleaning, cleaning cloth, turbidity meter, testing vial, and calibration vials.

4.2.3 Photometer for chemical tests

A dual-frequency photometer is used to test various chemical parameters, including phosphate, sulfate, total residual chlorine, and ammonia. A sample is added to the sample well and then stirred with a test strip, which creates a chemical reaction that allows for measurement to occur. CTWM has a wide variety of test strips, with a comprehensive list included in the materials list in the appendix. No specific instructions are recommended outside of what is in the instruction manual. However, there are many different testing protocols for different chemical tests, and so it is important to familiarize oneself with the specific tests of interest before attempting to do field tests.

Figure 7: Photometer and accessories: (left to right): Ammonia testing reagents, photometer, dilution vessel and syringe, cleaning brush, photometer cover, and sulfate testing reagents.

4.2.4 Electrical conductivity meter

This meter is used to test EC in the field. When testing with this meter, it is important to gently stir the probe in the water sample. If the sample is in a large bucket, EC, pH, and DO can be measured simultaneously by holding all three probes in a bundle and gently stirring the bundle. The temperature compensation was set to 2.0% (default).

Figure 8: Electrical conductivity meter with calibration solution.

4.2.5 Dissolved oxygen meter

DO is measured in the field using this meter. The tape on the probe indicates the level to which the probe should be immersed to when taking DO readings. Do not touch the probe tip, as it is a sensitive membrane that, if damaged, could lead to incorrect readings. Be sure to cover the probe tip with the red cap when not in use to protect the membrane. Additionally, be sure to gently move the probe while taking readings. The salt compensation was set to zero, as it was assumed that the salt concentration was low enough so as not to affect the measurements. Additionally, the height was not compensated for due to human error. Lastly, before using the probe, check that the probe electrolyte chamber has been filled to ensure accurate measurement.

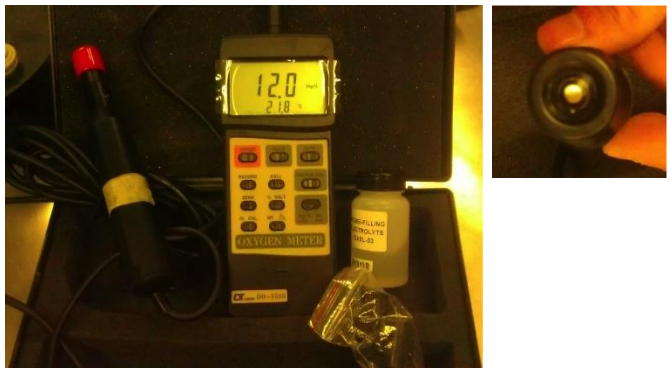

*Figure 9: Dissolved oxygen meter and accessories: **Left: (**left to right): DO probe with protective cover, DO meter, extra electrolyte for refilling probe, and spare tips for DO probe. **Right:** head-on view of DO probe tip without protective cover.*

4.2.6 pH meter

This meter is used in the field to test pH. By connecting the temperature probe, the meter automatically adjusts the pH using the temperature reading. Otherwise, the temperature must be entered manually. The bulb at the end of the pH probe is an electrode. Even though the manual says to blot the electrode dry, do not do this. Rinse the probe with whatever sample is going to be tested next. Many pH probes can be damaged by touching the electrode. To be safe, treat this probe with care. Lastly, do not let the electrode dry out. When all measurements have been completed, store the electrode in the storage solution vial included. While the manual says to use 4 M KCl, 3 M KCl was used because that was all that was present.

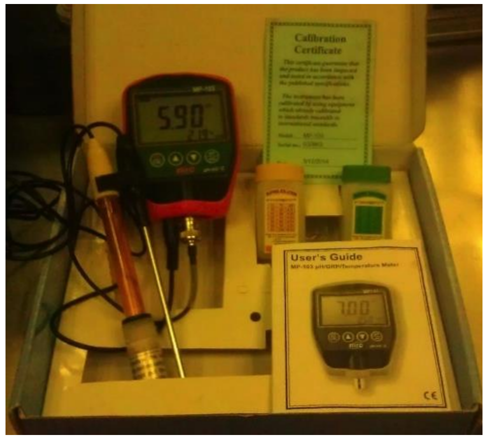

Figure 10: pH meter and accessories: (left to right) pH probe in 3 M KCl storage solution, temperature probe, pH meter, and calibration solutions.

4.3 Calibration practices

The in-field testing equipment must be calibrated regularly in order to ensure accurate results. Every meter is calibrated differently and at different intervals.

4.3.1 Turbidity Meter

The turbidity meter is calibrated at the beginning of each day of testing using the 0 NTU and 100 NTU vials provided with the kit. This should take around 3 minutes. Instructions for calibration can be found in the operator's manual, located in the testing kit.

4.3.2 Photometer

The photometer is not calibrated by hand. Be sure to clean the cell with clean water following each test. Consult the instruction manual included in the kit for specific instructions.

4.3.3 EC Meter

The EC meter should be calibrated roughly every 2 weeks. This is accomplished by using the provided 1.413 mS/cm calibration solution and a screwdriver to manually adjust the tuning via screws in the battery compartment. Consult the operation manual included in the testing kit for specific instructions.

4.3.4 DO Meter

The DO meter should be calibrated at the beginning of each day of testing, by using the ambient oxygen level in the air. Be sure that the switch on the meter is set to "O_2 (AIR)" while calibrating, and then it is switched to "mg/L (DO)" while testing. More specific instructions can be found in the operation manual.

4.3.5 pH Meter

The pH meter should be calibrated roughly every week of use. This can be accomplished with a 2-point calibration using pH 4 and pH 7 solutions, included in the AIES Renewable Energy lab, or the buffer solutions included with the meter. Refer to the user's guide included in the pH meter kit for specific instructions.

4.4 SAMPLING PROCEDURES

During the October 2014 sampling trip, samples were collected from Dar Salah, Deir al-Hatab, and Zawata by the members of CTWM, with the exception of the lab samples from Dar Salah. These were taken by HWE, by collecting effluent greywater in a large bucket, and then collecting a 1.5 liter sample from that bucket in a 1.5L water bottle. The sampling method used by CTWM evolved over the course of the site visits, so sampling procedures were not the same for every sample or site. This section reflects the sampling procedures used on the October 2014 set of site visits.

4.4.1 Field-test samples

At Dar-Salah, the first site visited, the field-test samples were collected first from the outflow collection tank, followed by the inflow collection tank. Sample collection in this order reduces the risk of contamination, as a small lingering amount of a heavily polluted sample could significantly change the test results of a clean sample. The sample from the effluent collection tank was taken using the grab sampling device after briefly mixing the tank contents. The sample consisted of one aliquot, and pH, DO, and EC were tested in the grab sampling device. Only one aliquot was taken, due to the fact that the water appeared quite clean, and gradients were unlikely to occur in the tank, meaning that the sample was likely representative. The sample from the inflow collection tank consisted of 6 aliquots poured into a 12L bucket. Before the sample was collected, the surface crust was broken and the contents were stirred in the hope that this would lead to a representative sample of the tank contents. The sample was collected at an unspecified height, about a meter below the surface of the water. In hindsight, this did not make sense to test, as we were more interested in the water that ended up flowing into the constructed wetland tanks, not including the water that stayed stagnant in the bottom of the tank.

At Deir al-Hatab, the effluent sample was pumped through a hose into a 12 L bucket. The sample from the inflow collection tank was taken from the top half of the tank by using the grab sampling device. The crust had to be broken in order to take a sample. It is uncertain whether the tank was mixed before taking the sample, but it likely was. Additionally, although it was not recorded, it is likely that the effluent sample consisted of 6 aliquots poured into a 12 L bucket.

Similarly, at Zawata, the effluent sample was pumped through a hose into a 12 L bucket. The sample from the inflow collection tank was collected by taking 6 grab samples. These samples were collected by slowly lowering the grab sampling device into the inflow collection tank, allowing it to fill as it moves. The idea behind this was to collect a more representative sample of the tank contents. Again, upon further reflection, this does not represent the water that flows into the rest of the system, and may not be a very meaningful measurement. It is also unknown if the tank was mixed, but it is likely that it was.

4.4.2 Lab-test samples

At Dar Salah, the lab samples for influent and effluent were collected the same way that the field test samples were: mixing the tank and collecting samples from deep in the tank (about 1 m down). The only difference is that the samples were poured through a funnel into 1.5 L plastic water bottle until it was full. This consisted of about 3 grab samples.

At Deir al-Hatab, the lab sample for effluent was collected through the hose, while the lab sample for inflow was collected by mixing the tank and taking grab samples from the bottom of the tank, which is different than the way the field-test samples were collected.

At Zawata, the lab samples for influent and effluent were collected in the same ways that the field test samples were collected: pumping through a hose for effluent and grab samples by slowly lowering the sampling device. However, due to pressure and time constraints related to the lab, the sampling methods for the lab samples were not recorded, so the sampling methods are not certain.

4.5 Field testing procedure development

At the first few sites, the field tests were conducted one at a time. It was helpful to have one person measure and read off the different measurements, while another person could record the values. DO was not tested first, as there was concern that the sampling methods could oxygenate the water, providing inaccurate readings for what is going on in the system. Therefore, other parameters were measured first while the DO was allowed time to equilibrate.

At later sites, it became clear that DO, pH, and EC could be tested at the same time. This was accomplished by pouring the samples into a 12 L bucket and gently stirring the bundle of probes (DO, pH, EC, temperature) in the sample. This proved to be more time efficient. At Zawata, there was concern over the observation that the DO probe did not have much electrolyte in it. After refilling the electrolyte, DO was retested, but the values ended up being close to what was measured before, although the values continued to fall very slowly (about 0.1 mg/L every 1-3 minutes).

For the photometer, only measurements deemed important at each site were taken. This varied from site to site as more information became available.

5 Results

In October, samples were collected at all three active sites (Dar Salah, Deir al-Hatab, and Zawata) and tested for a variety of physical and chemical parameters. DO, turbidity, pH, EC, sulfate, phosphates, and total residual chlorine were tested in the field, while BOD_5, COD, TSS, fecal coliforms, EC and pH were tested in the lab. Testing pH and EC in both the field and the lab allowed for validation of field test methods compared to lab tests (which were assumed to be more accurate). Test results for key water quality parameters are shown in this section, while full data tables of other tests are included in the appendix.

If there is a bar missing from the graphs and no number is present, it indicates that the measurement was not taken. It does not reflect a zero value. The blue lines in each graph represent different standards. When available, the proposed Israeli greywater standards are used. When these are not available, the Inbar standard is used. If neither is available, than no standard is included.

5.1.1 Biological and Chemical Oxygen Demand (BOD & COD)

BOD_5, none of the effluent measurements met the proposed Israeli greywater standards. However, the values at Deir al-Hatab and Zawata show 94.1% and 92.7% decreases, respectively, from the system influent to the effluent.

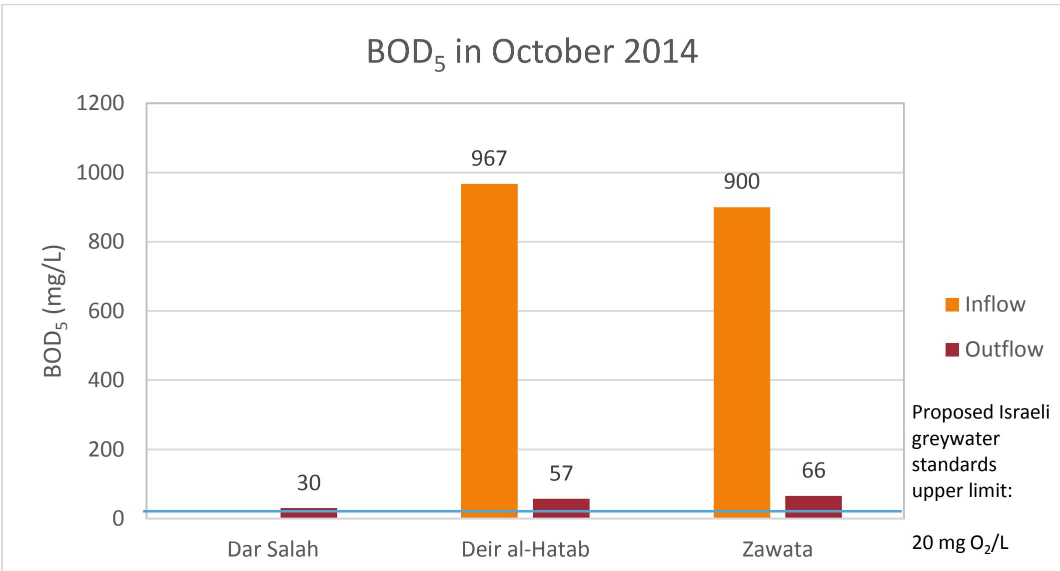

Figure 11: BOD_5 at all 3 sites in October 2014

Deir al-Hatab exceeded Inbar standards for COD, while Dar Salah nearly met them. The COD values at Deir al-Hatab and Zawata show 96.2% and 90.8% decreases, respectively, from the system influent to the effluent.

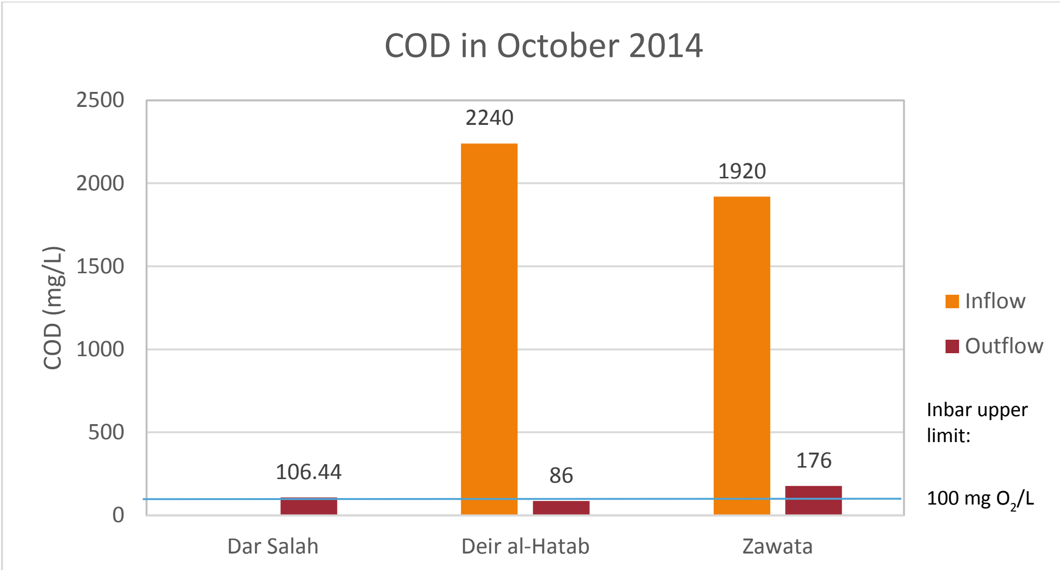

Figure 12: COD at all 3 sites in October 2014

5.1.2 Total Suspended Solids (TSS)

The effluent TSS values meet the proposed Israeli greywater standards at both Deir al-Hatab and Zawata, with 99.8% percentage decreases at both sites, dropping two orders of magnitude.

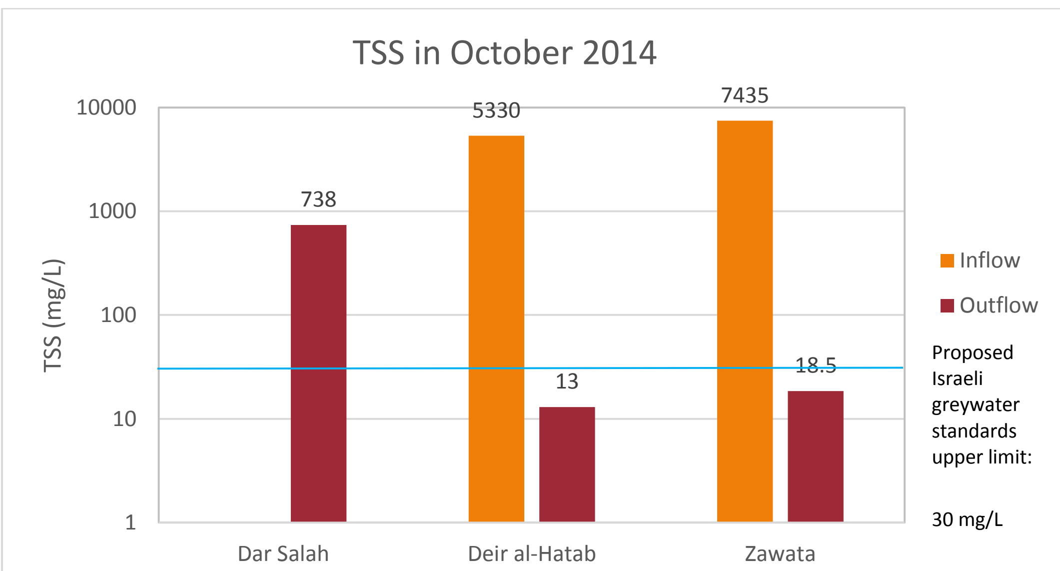

Figure 13: TSS at all 3 sites in October 2014. Note that the vertical axis is logarithmic.

5.1.3 Fecal coliforms

None of the effluent values met the peak or average upper limits of the proposed Israeli greywater standards. However, Deir al-Hatab and Zawata showed 98.5% and

98.6% reductions of fecal coliforms, respectively, from system influent to effluent, dropping two orders of magnitude.

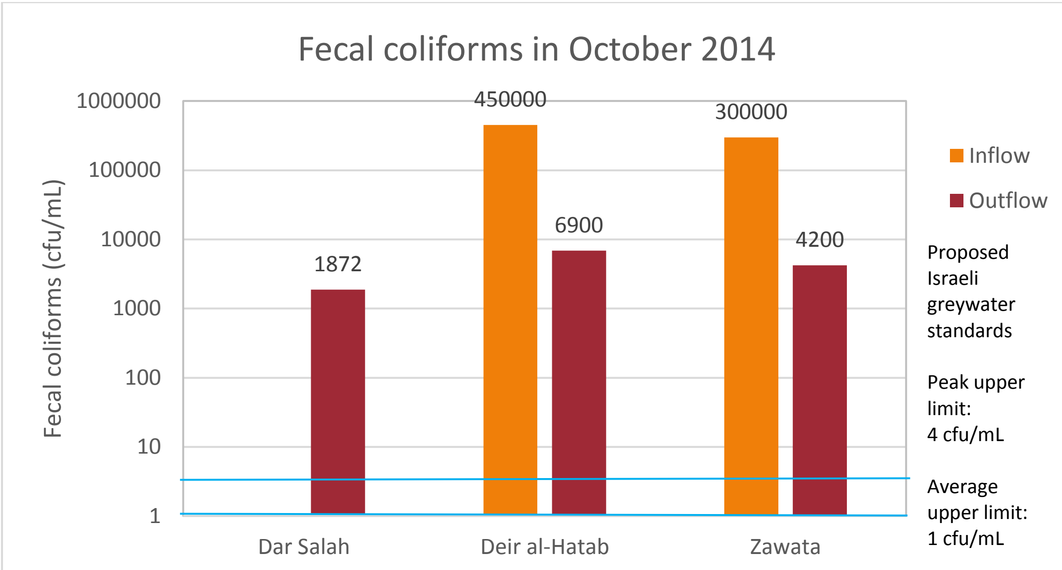

Figure 14: Fecal coliform levels for all 3 systems in October 2014. The top blue line is the peak upper limit, while the bottom blue line corresponds to the average upper limit.

5.1.4 Dissolved Oxygen (DO)

Effluent DO levels at Dar Salah and Deir al-Hatab both met the Inbar lower limit. Zawata fell short by 0.1 mg O_2/L. DO decreased over the systems at Dar Salah and Zawata, while it increased over the system at Deir al-Hatab.

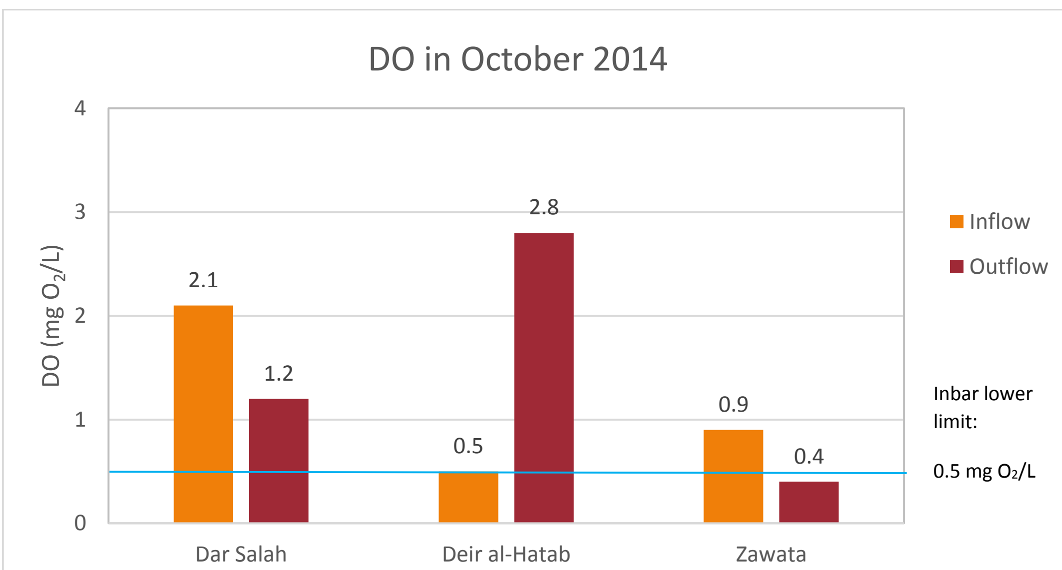

Figure 15: DO levels for the 3 sites in October 2014. Note that here, the blue line represents a lower limit, as opposed to a higher limit.

5.1.5 Electrical Conductivity (EC)

Effluent at both Deir al-Hatab and Zawata met Inbar EC standards for both the field and lab tests, while Dar Salah was too high for both field and lab tests. In the field tests, EC increased from the influent to the effluent, while it decreased over the system in the lab tests.

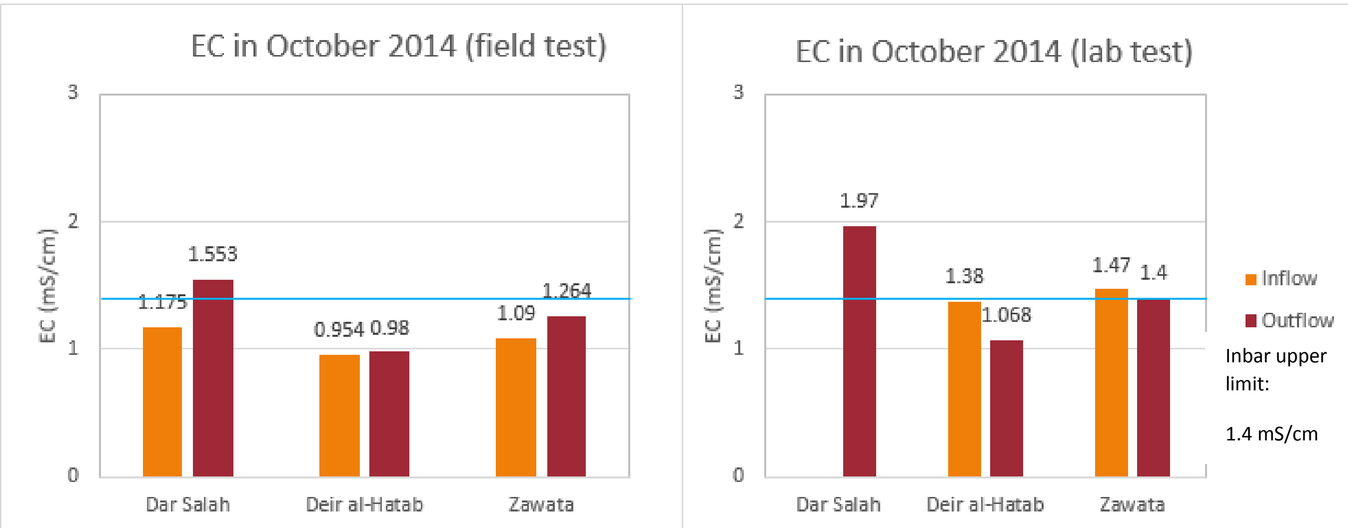

Figure 16: Field and lab test results for EC in October 2014. Notice that the EC increases over the system for the field test, while it decreases over the system for the lab test.

5.1.6 pH

Effluent at all 3 sites fell well within Inbar standards for pH. The field tests and lab tests achieved very similar results, so only the field results are displayed here. The lab test results are displayed in the appendix.

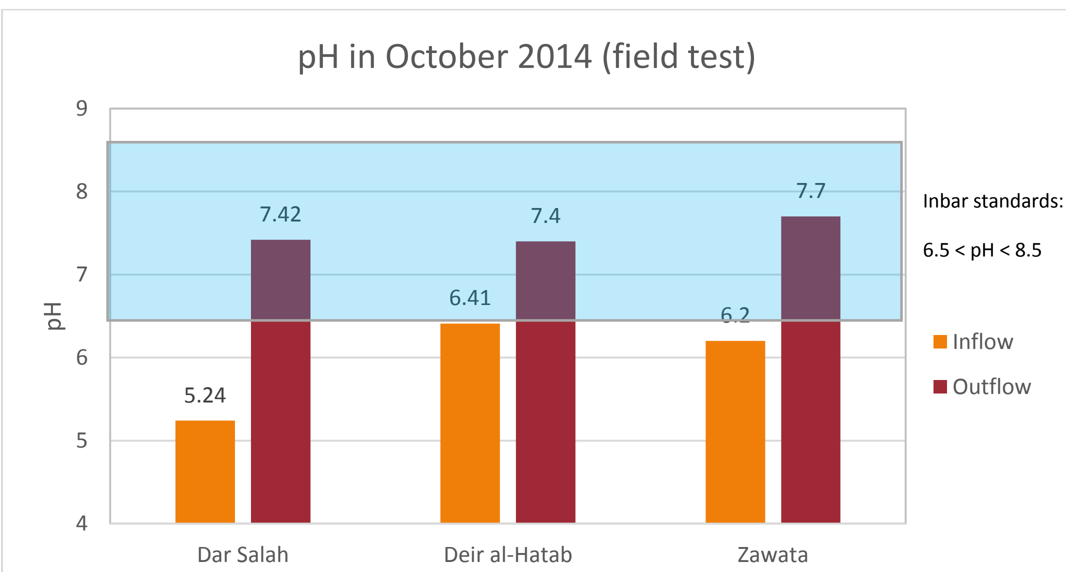

Figure 17: Field test results for pH in October 2014.

5.1.7 Turbidity

None of the effluent samples met the daily average upper limit in the proposed Israeli greywater standards, but Deir al-Hatab produced effluent that just barely met the peak upper limit of 20 NTU. The inflow and outflow samples from Zawata had drastically different colors (black and clear/gray, respectively), so the values represented in the graph may not be accurate.

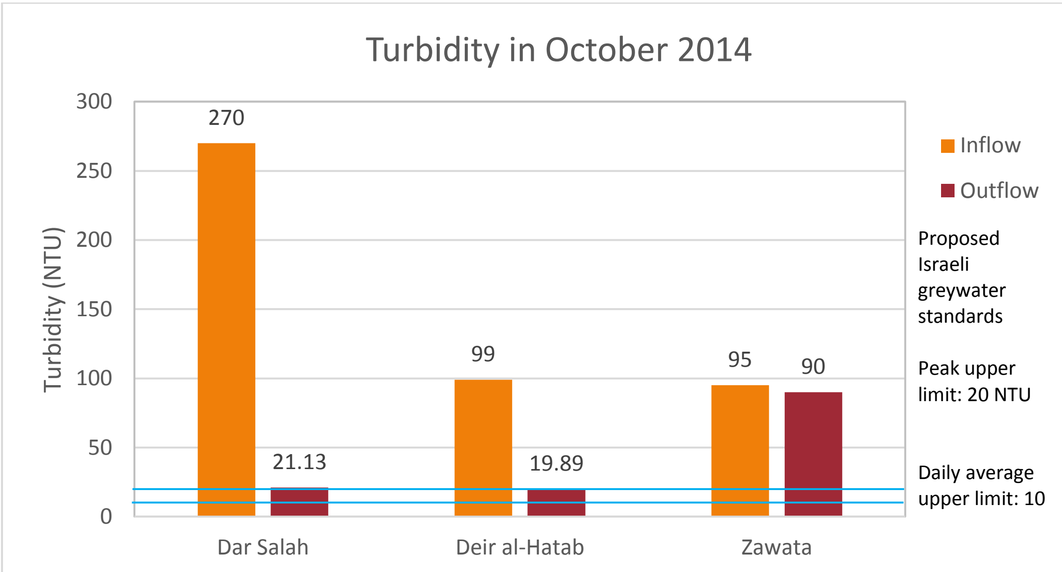

Figure 18: Turbidity results from all 3 sites in October 2014. The top blue line represents the peak upper limit, while the lower blue line represents the daily average upper limit.

5.1.8 Phosphate

No guidelines for phosphate could be found in either the Inbar or proposed Israeli greywater standards. All values for phosphate were quite similar. There is no inflow reading for Zawata because the photometer could not zero. It is important to note that the photometer was not washed with the needed reagents between tests, and so these results should be verified.

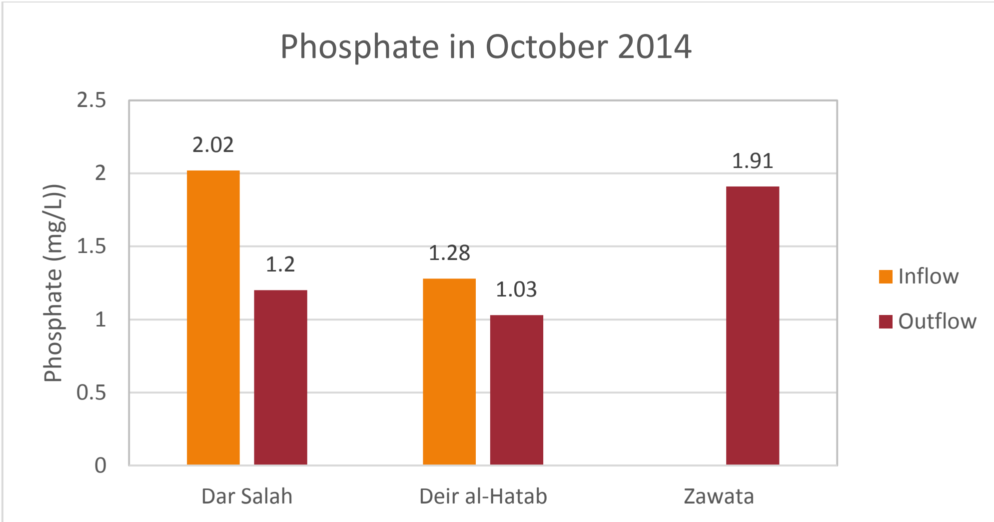

Figure 19: Phosphate results for all 3 sites in October 2014.

5.1.9 Sulfate

No guidelines for sulfate could be found in either the Inbar or proposed Israeli greywater standards. There is no inflow reading for Zawata because the photometer could not zero.

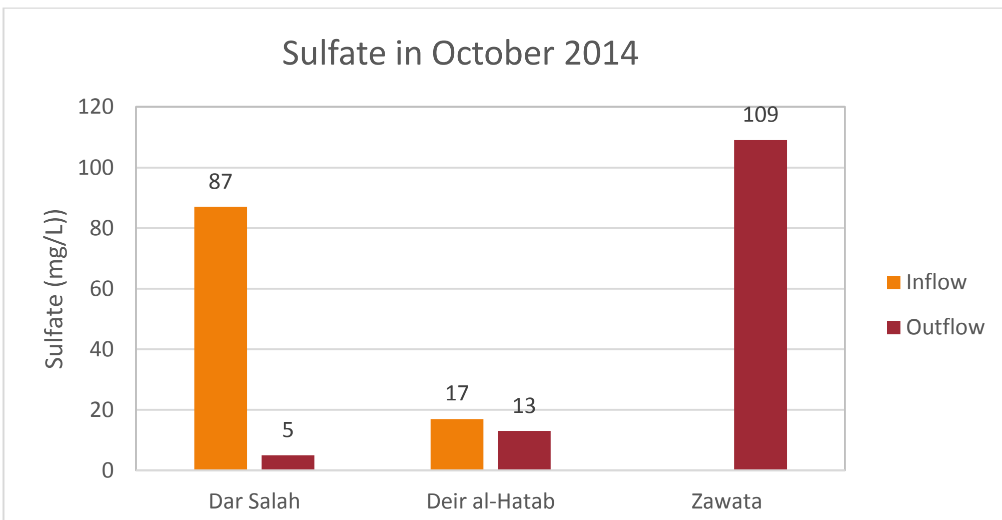

Figure 20: Sulfate readings at all 3 sites in October 2014.

5.1.10 Ammonia, Nitrate & Nitrate

Ammonia tests in the Dar Salah inflow revealed that levels were below the detectable limit of the photometer. Given the time constraint at the site, it did not make sense to test for nitrate or nitrite, as some ammonia must be present in order for nitrification to occur. Thus, the effluent was not tested at any of the three sites. With less of a time constraint at Zawata, ammonia was tested for in the inflow. However, the photometer could not zero, so no measurement was attained.

5.1.11 Total Residual Chlorine

Total residual chlorine was only tested in the effluent at Dar Salah, for which the reading was below the detectable limit. Since none of the sites had chlorinators in the effluent collection tank, it was decided to not test for total residual chlorine at any of the other sites.

5.1.12 Sodium

In an internal AIES report from spring 2014, the sodium in both the influent and effluent were over the Inbar standard of 150 mg/L. The reductions that occur over the system are most likely due to precipitation, which appears to be more influential on the concentration than evaporation which would increase the concentration.

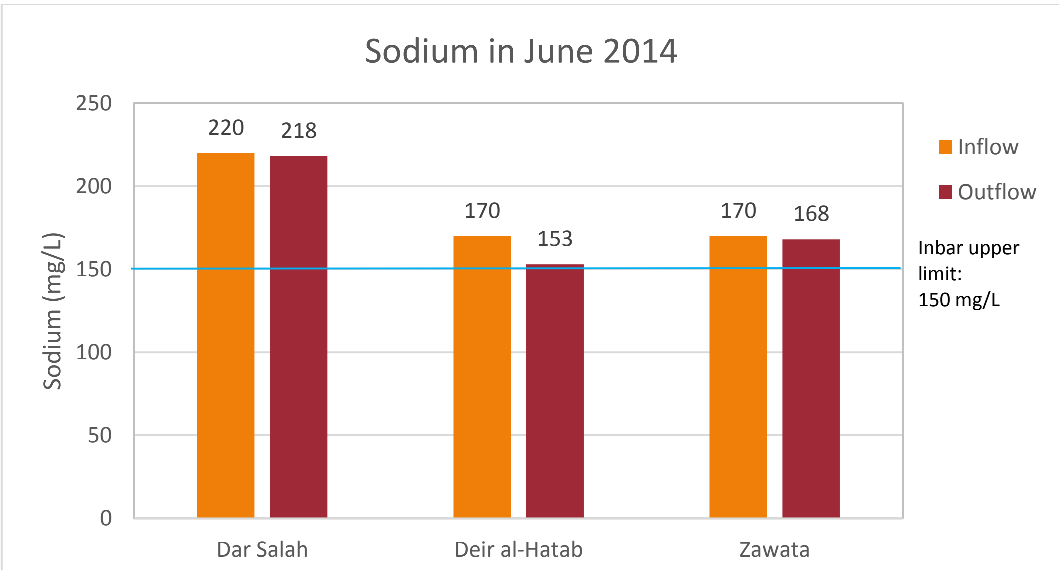

Figure 21: Sodium concentrations at all 3 sites in June 2014 (Bondy, June/July 2014).

5.1.13 Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

ICP-MS allows for the measurement of many metals and several non-metals. Some of these can have harmful effects on plant life, while for others, the toxicity is unknown. In June 2014, an ICP-MS analysis was conducted. Most of the tested parameters fell within Inbar standards and recommendations laid out by the EPA for groundwater and a report from Texas A&M for agriculture (Driscoll, Carter, Williamson, & Putnam, 2005) (Irrigation Water Quality Standards and Salinity Management Strategies). The exceptions to this are bromine, fluorine, potassium, calcium, strontium and magnesium, for which the limits are not specified. The full ICP-MS results are included in the appendix.

5.1.14 Family interviews

Interviews with the homeowners at each site were given. This was done to indicate what is going into each system. The maximum family size refers to the number of people present at family gatherings, which is a common occurrence (roughly every week). This likely corresponds to a high load from the kitchen sink. The results are described in the table below.

Location	Family size	Greywater sources	Source frequency	Kitchen sink waste	Bleach used?	Foul odor?	Comments
Halhul (old site)	Normally 2, max 18	Kitchen	Kitchen at lunch (big meal)	Oil, coffee grounds, cooking waste	Yes	Yes, and neighbors complain.	Disconnected
Dar Salah	Normally 7, max 15	Sinks, kitchen, shower	Kitchen at lunch (big meal), 2 showers/day total	Oil, coffee grounds, cooking waste	Yes	Yes	Water bill reduced from 100 to 75 NIS, larvae present in inflow and outflow tanks
Deir al-Hatab	Normally 9, max 25	Sinks, kitchen, washing machine	Kitchen at lunch (big meal), washing machine 2 times/week	Coffee grounds, cooking waste	Yes	We didn't notice a smell, but they complained	Effluent has an odor.
Zawata	Normally 8, 2 houses	Sinks, kitchen, shower	Kitchen at lunch (big meal), shower every day	Oil, coffee grounds, cooking waste	Yes	No, and no complaint	Complaints about bugs

Figure 22: Results of family interviews.

6 DISCUSSION

6.1 WATER QUALITY RESULTS

In the sites where our systems are located, the greywater contains high pollutant levels, namely BOD, COD, and fecal coliforms. At this point, it is unclear whether this is reflective of highly polluted greywater or the water going septic in its inflow collection tank.

6.1.1 Physical, chemical, and biological parameters

Despite high initial levels, BOD and COD were greatly lowered to near-acceptable levels. When compared with the data from last spring, the effluent COD levels dropped dramatically across all systems (see appendix). At Deir al-Hatab and Zawata, BOD consumption more than doubled from June 2014 to October 2014 (Bondy, June/July 2014). COD consumption stayed about the same at Deir al-Hatab over the same time period, while it nearly doubled at Zawata. Due to the lack of inflow samples at Dar Salah in October 2014 no change in BOD and/or COD removal was observed. The observed increases could reflect the development larger bacterial colonies, which means that the system is maturing. However, this may be more reflective of a change in sampling procedure or even a change in system inputs. More studies will have to be conducted to draw any causal relationships.

The TSS levels in the outflow collection tanks at Deir al-Hatab and Zawata are expected. However, the value for the outflow collection tank at Dar Salah is suspicious. The water was quite clear, but had many larvae or worms living in it. It is possible that these were included in the TSS measurement and skewed it high.

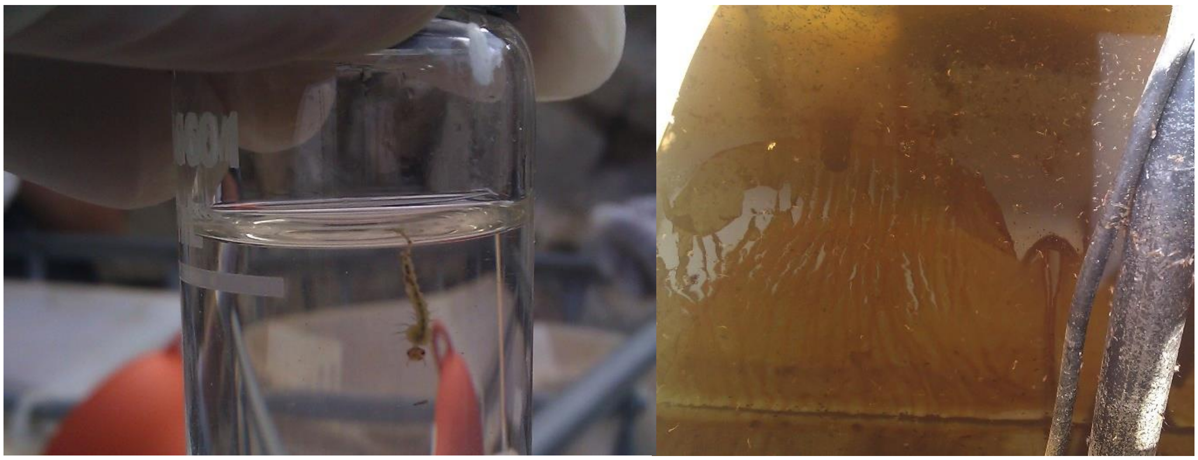

Figure 23: Close-up of larvae found in outflow collection tank at Dar Salah in (left). All of the solids seen in the water in the outflow collection tank are larvae or worms (right). Both pictures taken at Dar Salah in October 2014.

Fecal coliform counts were very high at all sites tested, especially in the inflow collection tanks at Deir al-Hatab and Zawata (Dar Salah inflow was not tested). One potential cause of this could be the long residence time of water and pollutants in the inflow collection tank (discussed below in “Short Circuiting”). While some of the water quickly passes through the inflow collection tank, other water stays in the tank. This could allow for the formation and persistence of large bacterial colonies over time. Literature strongly recommends that raw greywater not be stored for more than 24 hours before treatment (McGovern, 2010). After 24 hours, the water becomes septic, and bacterial levels skyrocket. One study found that after 72 hours of storage, fecal coliform levels increased from 100 cfu/100 mL to 8,400,000 cfu/100 mL (Tal, Sathasivan, & Bal Krishna, 2011). As mentioned before, the presence of fecal coliforms can indicate the presence of harmful pathogens, ad so levels this high are concerning.

The DO levels at all systems had dropped significantly since the visit in the spring. This may be due to the fact that the probe was not stirred during the Spring 2014 visit (Bondy, June/July 2014), and during testing, the DO level continued to drop as the probe was continuously stirred. It is usually expected that DO decrease over the course of a system, as it is consumed by the bacteria. However, aeration at various points throughout the system could re-oxygenate the water, leading to higher DO values. An example of this is the effluent at Deir al-Hatab, where the effluent is discharged through a narrow hose at high velocity. When the sample was collected into a bucket, the water was frothy and even though the water sat for a while (about 5-30 minutes), it is possible that the water still retained a higher level of DO. This could account for why the effluent DO reading at Deir al-Hatab was higher than the inflow. The effluent sample from Zawata was also collected through a discharge hose, but the water was at a lower velocity, so it was not aerated to the same extent, which would explain why it had a lower value than at Deir al-Hatab. The samples from Dar Salah were collected using the grab sampling device, which would most likely not aerate the samples as much as collecting water at high velocity from a hose. Thus, the DO readings are a combination of both the original DO of the water and the DO added by the sampling method.

An alternative explanation is that the decrease in DO could be due to the further development of bacterial colonies. Having larger bacterial colonies could lead to lower steady state values of DO in the inflow and outflow. If this is true, it could explain the increases in BOD and COD removal mentioned above. One issue with this theory is that the DO reductions have actually decreased from June 2014 to October 2014. However, if the water is re-oxygenated periodically throughout the system, this theory could still be correct. Further study is needed to draw any causal relationships.

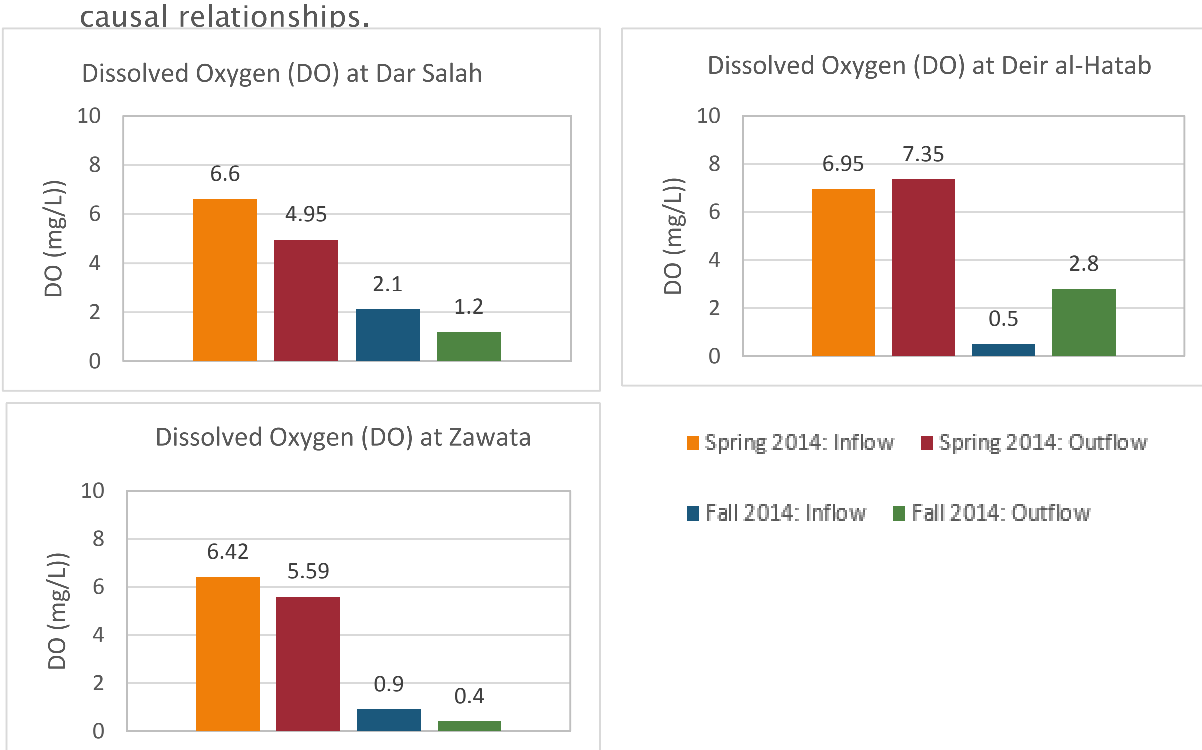

Figure 24: DO results over time at all 3 sites. Notice the different trends between the graphs on the left and the graph on the right. Citation for spring 2014 data: (Bondy, June/July 2014).

The trend discrepancy for EC is somewhat troubling, as this demonstrates that different methods of measurement could not only yield different results, but indicate different trends. It is expected that EC would increase over the course of a system, as water losses through evaporation concentrate the salts present. It is also possible that precipitation of salts throughout the system could counteract this and actually decrease over the course of the system. However, as most of the effluent values meet in Inbar standards, EC is not a major problem at this point.

The results for pH are to be expected and reflect the same trends shown in data from spring 2014 (Bondy, June/July 2014). This parameter is not a concern at this point.

Reductions in turbidity are likely most related to drops in TSS. The high turbidity reading for the Dar Salah inflow may have been caused by the sample being collected from the bottom of the tank, where suspended solids could be disturbed and collected in the sample. The apparent lack of turbidity reduction in Zawata may be more likely attributed to equipment malfunction or some constituent of the water, as the photometer also seemed to malfunction at this site.

The only sulfate value that stands out is for the Zawata effluent. This is shockingly high. However, the photometer may have been malfunctioning at this site (as evidenced by subsequently being unable to zero). Additionally, as no inflow value could be attained, it is difficult to draw conclusions about what is happening in this system.

Sodium was high at all 3 sites in spring 2014, so follow-up testing will have to be conducted, as well as implementing a mechanism for sodium removal.

6.1.2 Grease, oil, and food scraps

During the October site visit, the systems at Dar Salah, Deir al-Hatab, and Zawata all had a thick crust that had formed on top of the water in the inflow collection tank. This had to be broken in order to collect samples. On a subsequent visit to Dar Salah in December, the crust was not as thick, as the homeowners had removed the crust layer beforehand.

6.1.3 Larvae

As mentioned above, both the inflow and outflow collection tanks at the Dar Salah system were infested with different larvae during the October 2014 visit. Upon visiting the sites in December 2014, the problem had been completely remedied in the inflow collection tank, and drastically reduced in the effluent collection tank. Additionally, the larvae in the effluent collection tank appeared to be of a different species from the first visit.

*Figure 25: **(Left)** Larvae floating in the effluent collection tank. **(Right)** A single larvae on the threads of the effluent collection tank, where the lid is screwed on. Photo credit: Antonia Bacigalupa Albaum.*

6.2 Short-circuiting

In fluid flow, a short circuit is when some of the fluid flows faster than the rest of the fluid, leading to uneven retention times. In the inflow collection tank, it is possible that this causes eddies and/or stagnation in the bottom of the tank. This could keep raw greywater in the tank for extended periods of time, allowing BOD, COD, TSS, and fecal coliforms to accumulate in the inflow collection tank. While it was originally thought that the inflow collection tanks were mostly stagnant, discussions and inspection of the Dar Salah and Deir al-Hatab systems revealed that they operate using siphons. Based on this, it is likely that the Zawata system also uses a siphon.

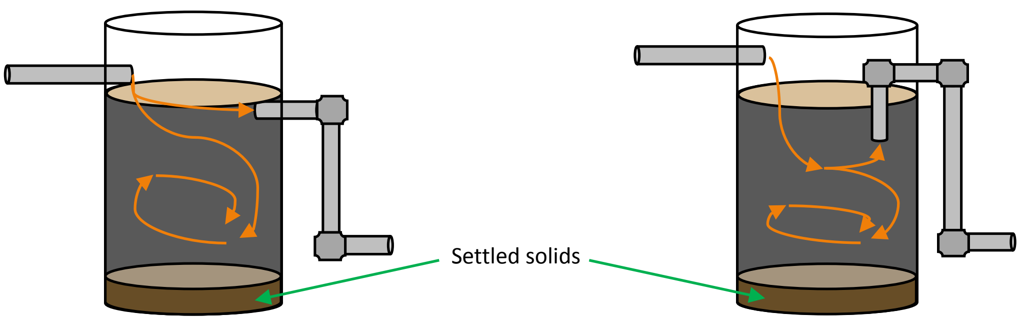

Figure 26: What we thought was happening in inflow collection tank without a siphon (left) and what is really happening in the inflow collection tank with the siphon (right). Orange arrows indicate fluid flow. Notice the smaller eddy due to the siphon.

6.3 Reeds

While it is recommended that all the systems have reeds planted in the systems, site visits revealed that Dar Salah and Deir al-Hatab did not have much vegetation growing out of the tanks. This may contribute to the low DO levels observed in the systems. However, the system in Zawata had many different plants growing in the tanks, and still gave low DO readings, while achieving around the same reductions in BOD and COD as the system in Deir al-Hatab. Therefore, it is difficult to conclude if the plants are helping the systems.

6.4 Sampling methods

Recall that in October 2014, the samples at Deir al-Hatab and Zawata from both the inflow and outflow collection tanks were taken by mixing up the tank contents and slowly lowering the sampling device to collect water from the entire water column. As a result, the following values most likely represent the upper limits of the inflow collection tank: BOD, COD, TSS, fecal coliforms, and turbidity. The value for DO is likely a lower limit because as organic matter settles to the bottom of the tank, bacteria in the bottom of the tank consume DO to break down that organic matter, resulting in lower values than water higher up in the water column. The outflow collection tank results would not have been as affected by mixing as those for the inflow collection tank, due to the water already having most of the settled solids and organic matter removed.

The sampling technique described above is not the recommended sampling method for sampling the inflow collection tank, as the water collected this way is not representative of what enters the gravel treatment tanks. Solids settle to the bottom of the inflow collection tank and build up over time, meaning that they have to be removed periodically (i.e. the inflow collection tank is not at steady state). To get samples representative of what is going into the gravel treatment tanks, the sample should be collected at the same height as the siphon inlet. This was done at Dar Salah on the December 2014 trip (results not included).

7 Conclusions, recommendations, and future work

7.1 Analysis of each system

The purpose of this section is to provide a summary of each system in its current state. Data and information are from October 2014 unless otherwise stated.

7.1.1 Dar Salah

The system at Dar Salah consists of an inflow collection tank, 3 gravel treatment tanks, and an effluent collection tank, which discharges water for drip irrigation via a pump. The schematics below reflect the system in October 2014, before the rectangular effluent collection tank was replaced with a circular one, similar to the inflow collection tank.

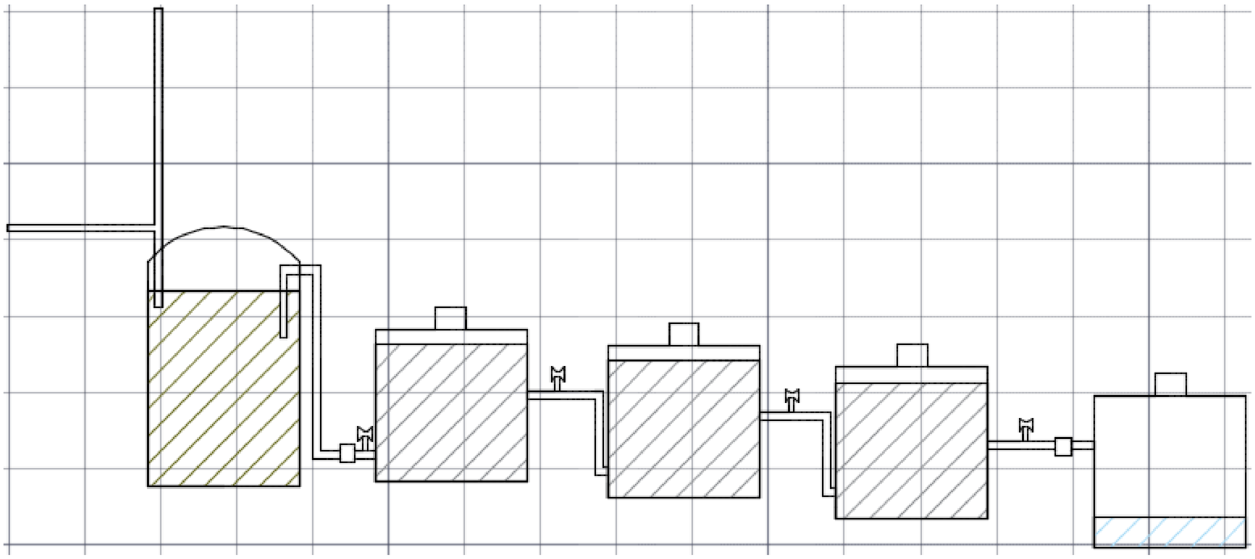

*Figure 27: **Side view:** Dar Salah constructed wetland system, to scale. Flow meters are represented as rectangles on connecting pipes. The small devices on the pipes are valves.*

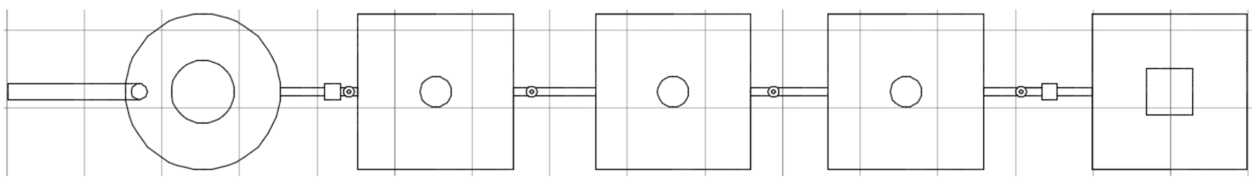

*Figure 28: **Top view:** Dar Salah constructed wetland system.*

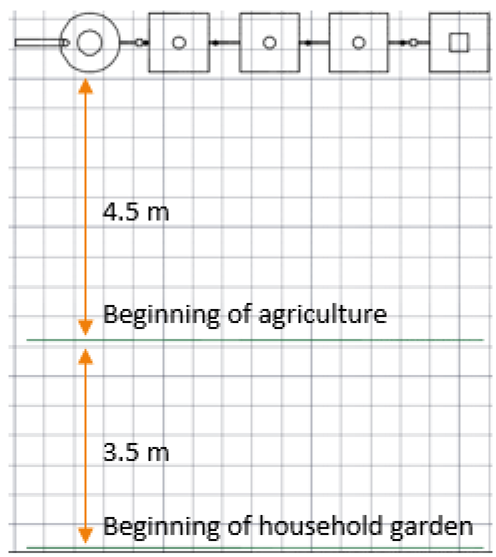

*Figure 29: **Extended top view:** Dar Salah constructed wetland system, with reference to agriculture and crops.*

Each gravel treatment tank has several developing reeds. The system used to have black larvae in the inflow collection tank before the crust was removed. Since then, the effluent collection tank has also been replaced, and now has fewer larvae in it, although they appear to be of a different species. Additionally, the system was disconnected from the kitchen and attached to a new shower and sink in October 2014. We will follow up to see if the washing machine was connected as well.

BOD and COD levels in the effluent are very close to achieving the standards for reuse. Effluent TSS was reported very high, but this may be due to larvae affecting the result. Fecal coliforms, while lower than the other two systems, are still 3 orders of magnitude too high. DO appears to be declining over time, but further studies are needed. Effluent pH falls within reasonable levels. Effluent EC is too high. Turbidity shows drastic reductions over the system, but still does not meet proposed Israeli greywater standards, and has likely gotten worse, due to the cloudy effluent. No data was collected for phosphate. Sulfate shows a drastic reduction over the system. Lastly, sodium was too high in the effluent.

7.1.2 Deir al-Hatab

The system at Deir al-Hatab is larger than the system at Dar Salah, consisting of an inflow collection tank, 5 gravel treatment tanks, and an effluent collection tank, which discharges water through a hose used for manual irrigation via a pump. Each gravel treatment tank has several very small reeds. There are plans to install a septic system in front of the inflow collection tank. We will follow up to see if it was installed before the inflow collection tank or if it replaced it.

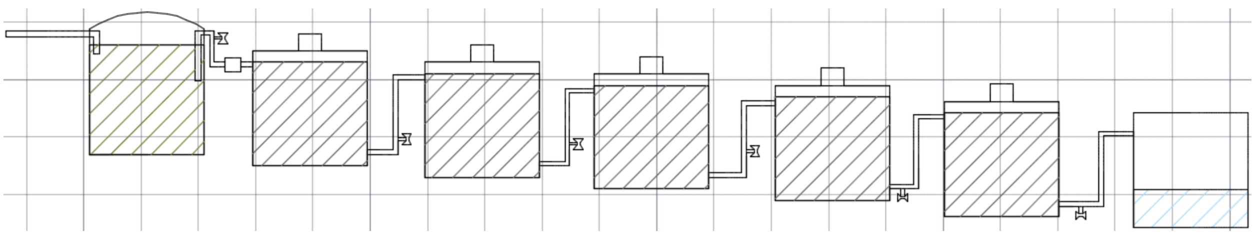

Figure 30: ***Side view:*** *Deir al-Hatab constructed wetland system.*

BOD level in the effluent is very close to achieving the standards for reuse, while the COD level meets Inbar standards. Effluent meets the proposed Israeli greywater standards. Fecal coliforms in both the inflow and outflow are higher than the inflows and outflows of the other systems, and the effluent is nearly four orders of magnitude too high. DO appears to be declining over time, and also appears to increase over the system, which is unexpected. Effluent pH falls within reasonable levels. Effluent EC also meets Inbar standards. Turbidity is reduced to around the peak upper limit of the proposed Israeli greywater standards, but still does not meet the daily average upper limit. No data was collected for phosphate. Sulfate was not very present in the influent, and shows a slight reduction over the system. Lastly, sodium was too high in the effluent.

7.1.3 Zawata

The system at Zawata is the largest of the three systems, consisting of an inflow collection tank, 8 gravel treatment tanks, and an effluent collection tank, which discharges water through a hose used for manual irrigation via a pump. Several of the gravel treatment tanks have various plants growing out of them.

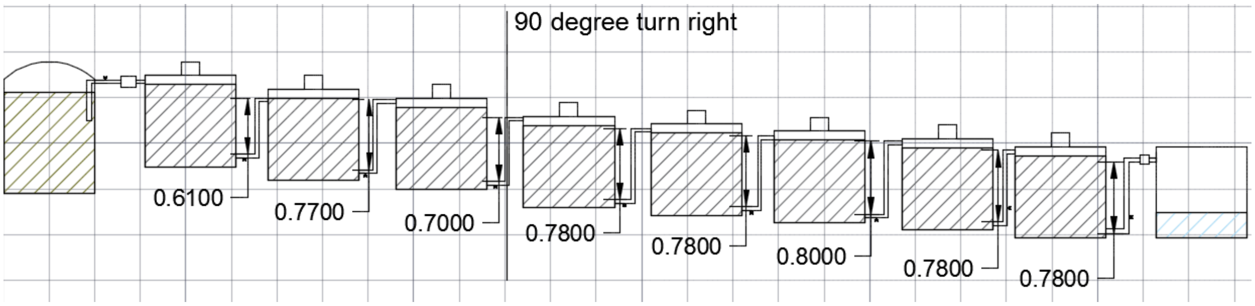

*Figure 31: **Side view:** Zawata constructed wetland system. Notice the 90 degree turn between the third and fourth gravel treatment tanks.*

BOD and COD levels in the effluent are within one order of magnitude to achieving the standards for reuse, and are the highest of all three systems. Effluent TSS meets the proposed Israeli greywater standards. Fecal coliforms in were very high in the influent, and above the proposed Israeli greywater standards by over three orders of magnitude. DO appears to be declining over time here as well, with the lowest effluent value of all three systems, but further studies are needed. Effluent pH falls within reasonable levels. Effluent is slightly too high, as it is the same value as the upper limit proposed by Inbar. Turbidity in the effluent was reported about the same as the inflow, but this did not mesh with first-hand observation of the water appearance. No data was collected for phosphate. Sulfate in the effluent was reported to be extremely high (higher than the inflow at Dar Salah), but this could be due to malfunctioning equipment. Lastly, sodium was too high in the effluent.

7.2 Challenges and problem-solving

This project has had several challenges that have been, or are being, addressed through homeowner practices, design modifications, and research. The first challenge has been the smell of the systems. This is likely due to degradation of organic matter in the inflow collection tank, which is not well-sealed. To fix this, homeowners were recommended to remove the crust on a weekly basis. Additionally, a septic tank is being experimented with at Deir al-Hatab, and the kitchen was disconnected at Dar Salah to change the organic loading and input of FOG and food waste.

Another issue being faced is the high levels of fecal coliforms. To address this, experiments will be conducted using chlorine as a disinfectant. Chlorine is the most practical disinfection method for our purposes, due to its low cost and ease of implementation with a floating chlorinator, such as those used in swimming pools and hot tubs (right). To check for efficacy and safety, experiments will be conducted on the CW system in Ketura regarding proper chlorine dosing and the concentrations of disinfection byproducts and remaining bacteria following chlorination.

Figure 32: (right) Floating pool chlorinator that may be used to disinfect water in the effluent collection tank (Automatic Chlorinators & Brominators, 2014).

7.3 Lessons Learned

The main lesson learned throughout the course of this project has to do with monitoring protocol. Future sampling protocol is as follows:

1. Be sure that all equipment is clean and calibrated before a site visit, and that the DO probe is filled with electrolyte.
2. Make sure that the distilled water wash bottle is full.
3. Pick up a 6 pack of 1.5 L water bottles and ice for the lab samples on the way to visit the sites.
4. Properly mark each 1.5 L water bottle with the site, date, and sample location (influent or effluent) of sample.
5. Be sure to wear proper protective equipment (close toed shoes; long pants and long sleeves; safety glasses; plastic, rubber, or latex gloves).
6. Have one person conduct the field testing and another record the measurements in a notebook.
7. Sample and test from least polluted source to most polluted source (i.e. effluent before influent).
8. For field test samples, collect the sample in a 12 L bucket so that pH, DO, temperature, and EC can be measured simultaneously.
9. When collecting lab samples, try to avoid macro-organisms (larvae, etc.) as this may throw off the measurement of TSS.
10. After collecting a lab sample in a 1.5 L water bottle, store it in the ice chest.
11. For each sample taken from the effluent collection tank, use the hose attached to the pump to simplify the sampling process.
12. For each sample taken from the inflow collection tank, submerse the grab sampling device to the same depth as the entrance to the siphon so that the sample represents water that enters the constructed wetland tanks.
13. When testing with the photometer, be sure to clean the sample cell with a brush after each test, as residual chemicals can affect future test accuracy. Additionally, to prevent contamination, wash the cell 3 times with water to be tested before test is conducted.
14. When testing for phosphate with the photometer, be sure to have acetic acid or 0.1 M hydrochloric acid for cleaning the cell, as per the operation manual.
15. Before leaving each site, wash the grab sampling device, buckets, probes, and hands with soap and water. Rinse and dry all probes and buckets.
16. Properly dispose of dirty paper towels and used gloves.

Additionally, make sure that the homeowners are removing the crust in the inflow collection tank periodically. This is may reduce organic loading and macro-organism growth.

7.4 Other Questions and Objectives

In addition to continuing to monitor key water quality parameters at the sites and experimenting with chlorination, there are several other questions and objectives that may be worth investigating.

7.4.1 What is the aerobic-anaerobic profile throughout the system?

The oxygen profile is likely to vary throughout each tank and the system as a whole, which will affect pollutant removal and efficiency. Understanding how this varies may help to improve the efficiency of the systems and guide future design and operating practices. It may be possible to observe this profile by testing the DO level at different heights in a tank. By doing this over the course of the whole chain of tanks, a pattern may emerge. Anaerobic respiration can be confirmed by testing nitrate and sulfate levels at different points throughout the system and observing how much conversion occurs.

We hypothesize that for a downflow constructed wetland system, DO levels will decrease down the water column, as oxygen is consumed as the water moves downward at a rate faster than it is replenished by convection and diffusion from inflowing water and ambient air.

7.4.2 Can we find metrics for overall system health and performance that homeowners can observe?

It is possible that the system quality can be monitored by observing simple aspects of the system. One of these aspects may be smell. The aerobic or anaerobic conditions of the system may affect the odors given off by the system. It may be possible to establish a “smell baseline” of what a healthy system should smell like and diagnose issues with the system based on deviation from this.

7.4.3 Come up with a way to monitor the settled solids level in the inflow collection tank/septic tank.

Settled solids need to be removed periodically to keep the system working properly. It is uncertain how often settled solids need to be removed. There is an apparatus that may allow for the manual measurement of the settled solids height, but it needs to be tested.

7.4.4 Look into low-tech methods for reducing sodium

Since sodium is problematic for bacterial colonies, soil, and plants, it is important to find a way to reduce its concentration in the greywater. Its initial concentration can be reduced if homeowners use alternative detergents that do not contain sodium lauryl sulfate. This would require education and possibly subsidization to aid homeowners to purchase these products. It may be possible to convince homeowners to switch cleaning products by telling them how long-term use of their detergents will reduce the soil quality and make it more difficult to grow crops as time goes on. Unfortunately, convincing others to change their behavior is difficult, so we must explore low-tech methods of removing sodium chemically or physically, preferably in a pretreatment step.

7.4.5 Look into UV-VIS probe for BOD/COD for continuous monitoring

As small-scale domestic wastewater treatment becomes more widespread, automatic monitoring of BOD and COD becomes a necessity to ensure safety. This can be accomplished using UV-VIS probes that can correlate absorbance to COD and BOD, rather than relying on traditional lab-based methods of testing. While these probes are expensive, it may be possible to design the monitoring systems to include multiple homes (like in the MERC proposal) to split the cost of purchase, implementation, and upkeep. A cost-benefit analysis would need to be conducted to explore this option.

8 References

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Note: all data before October 2014 comes from AIES CTWM records and Jan Bondy's report.

9 APPENDICES

9.1 MATERIALS LIST

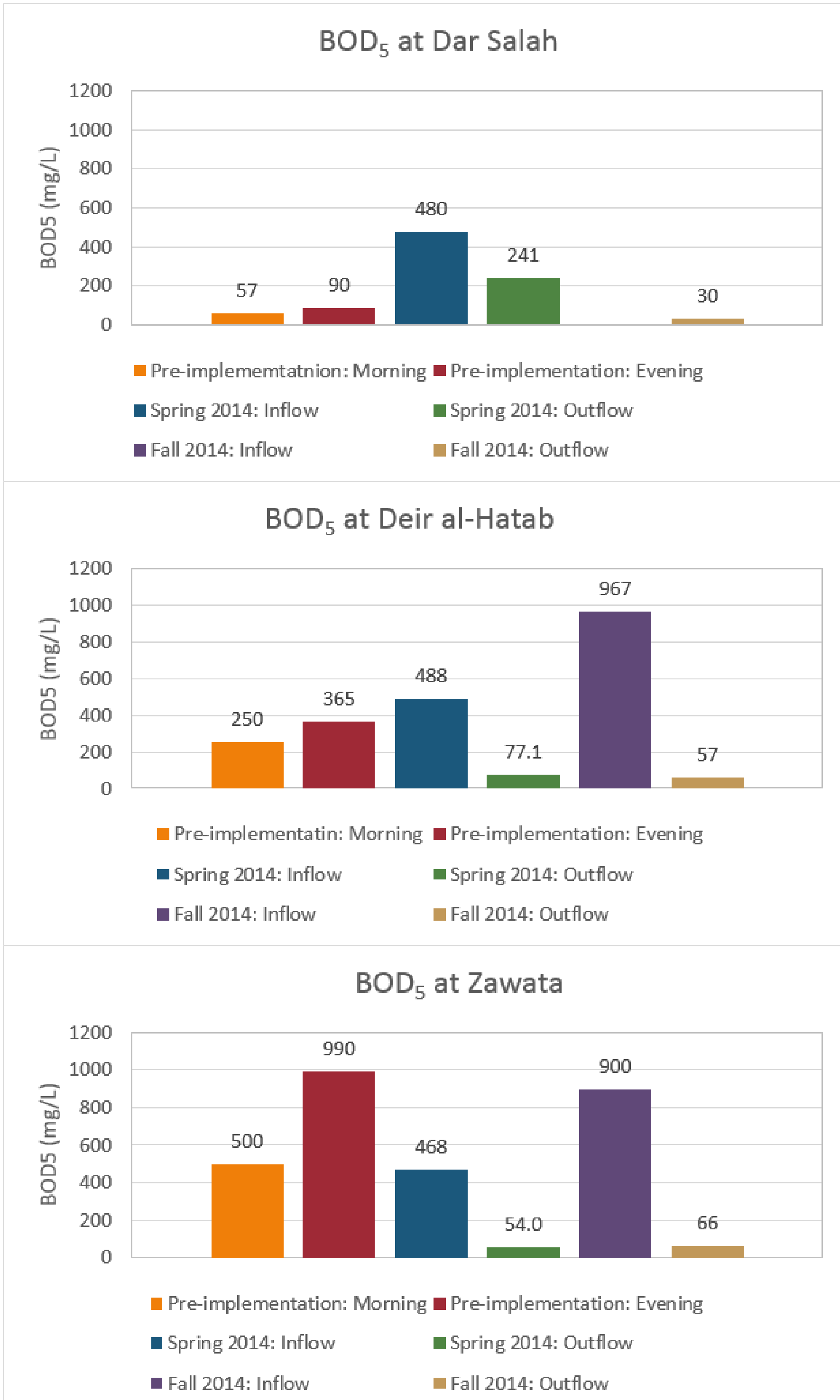
- 12 liter buckets (2)
- Plastic funnels (2)
- Dish soap (1 bottle)
- Tape measure (1)
- Safety glasses (1)
- Paper towels (1 package)
- Cleaning brushes (2)
- Disposable gloves (1 box)
- Reusable paper face masks (3)
- Duct tape (1 roll)
- 1.5 L plastic bottles for lab samples (We pick up packs of 1.5 L water bottles on site visit days, giving us water to clean equipment with and containers to send samples to the lab) (2)
- Plastic cooler for sample transportation (1)
- Wash bottle with distilled water (1)
- Grab sampling device (1)
- Coffee mugs for sample testing (3)
- Squeeze bottle of distilled water for cleaning equipment (1)
- **Water quality testing kit**
    - **Turbidity testing kit (Lutron)**
        - Turbidity meter (TU-2016) (1)
        - Bottle cleaning solution (Distilled Water) (1)
        - Bottle cleaning cloth (1)
        - 10 mL Sample testing bottles (Model 0601) (2)
        - 10 mL bottle of 0 NTU solution for calibration (1)
        - 10 mL bottle of 100 NTU solution for calibration (1)
    - **Photometer testing kit (Industrial Test Systems)**
        - eXact Micro 20 Dual Wavelength Advanced Photometer (1)
        - Photometer cell cover (1)
        - Dilution vial (1)
        - Dilution syringe (1)
        - Photometer cell brush (1)
        - Blue plastic paddle (1)
    - **Photometer test reagents (Industrial Test Systems)**
        - Strips (eXact Strip Micro)
            - Phosphate (PO_4) (2)
            - Sulfate (SO_4) (2)
            - Nitrite (NO_2) (2)
            - Nitrate (NO_3) (2)
            - Ammonia (NH) (3)
            - Chloride (CH) (3)

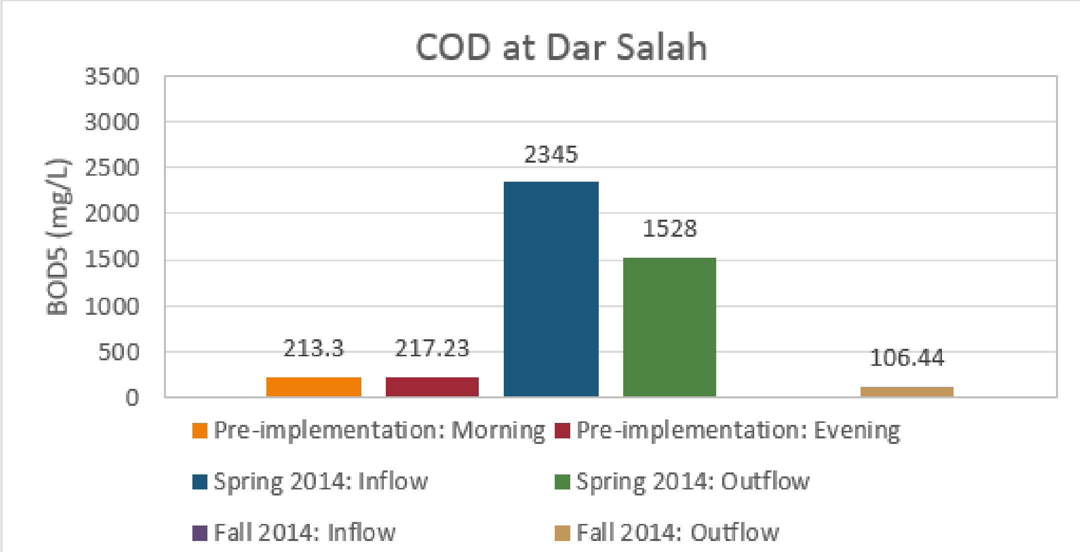
        - Total chlorine (CL DPD-3) (1)
        - Free chlorine (CL DPD-1) (1)
        - Total hardness (TH) (2)
      - Drops (eXact Reagent)
        - Ammonia (NH) (3)
    - **Electrical conductivity testing kit (Lutron)**
      - Conductivity meter (CD-4303) (1)
      - Conductivity probe (1)
    - Conductivity meter 1.413 mS/cm calibration solution (CD-14) (1 bottle)
    - **Electrical conductivity testing kit (Milwaukee)**
      - Sharp EC conductivity meter (1)
      - Screwdriver for calibration (1)
      - 1.413 mS/cm conductivity solution for calibration (1 packet)
    - **Dissolved oxygen testing kit (Lutron)**
      - Oxygen meter (DO-5510) (1)
      - Oxygen probe w/ red tip cover (1)
      - Probe-filling electrolyte (OXEL-03) (1 bottle)
      - Extra probe tips (2)
    - **pH testing kit (MRC)**
      - pH/ORP/Temperature meter (MP-103) (1)
      - pH probe (ALpHA, unsure of model number) (1)
      - temperature probe (1)
      - pH 4.01 $\pm$ 0.02 @ 25 °C buffer solution (1 bottle)
      - pH 7.00 $\pm$ 0.02 @ 25 °C buffer solution (1 bottle)
- Experimental settled solids measurement tube (not tested yet, may not work) (1)

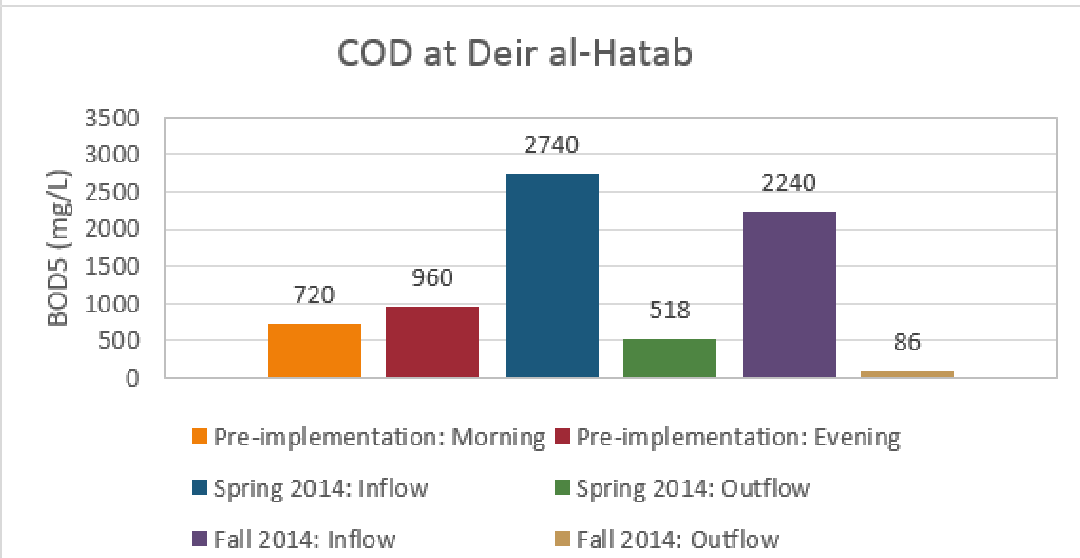
9.2 Time series of Data

In most cases, the vertical axis scales have been kept constant across three sites so that data can be easily be compared. This creates some graphs that look strange (eg. fecal coliforms), but it is meant to help analyze trends more easily.

Figure 33: BOD_5 for all 3 systems over time.




COD at Dar Salah
BOD5 (mg/L)
3500
3000
2500
2000
1500
1000
500
0
213.3
217.23
2345
1528
106.44
Pre-implementation: Morning
Pre-implementation: Evening
Spring 2014: Inflow
Spring 2014: Outflow
Fall 2014: Inflow
Fall 2014: Outflow


COD at Deir al-Hatab
BOD5 (mg/L)
3500
3000
2500
2000
1500
1000
500
0
720
960
2740
518
2240
86
Pre-implementation: Morning
Pre-implementation: Evening
Spring 2014: Inflow
Spring 2014: Outflow
Fall 2014: Inflow
Fall 2014: Outflow

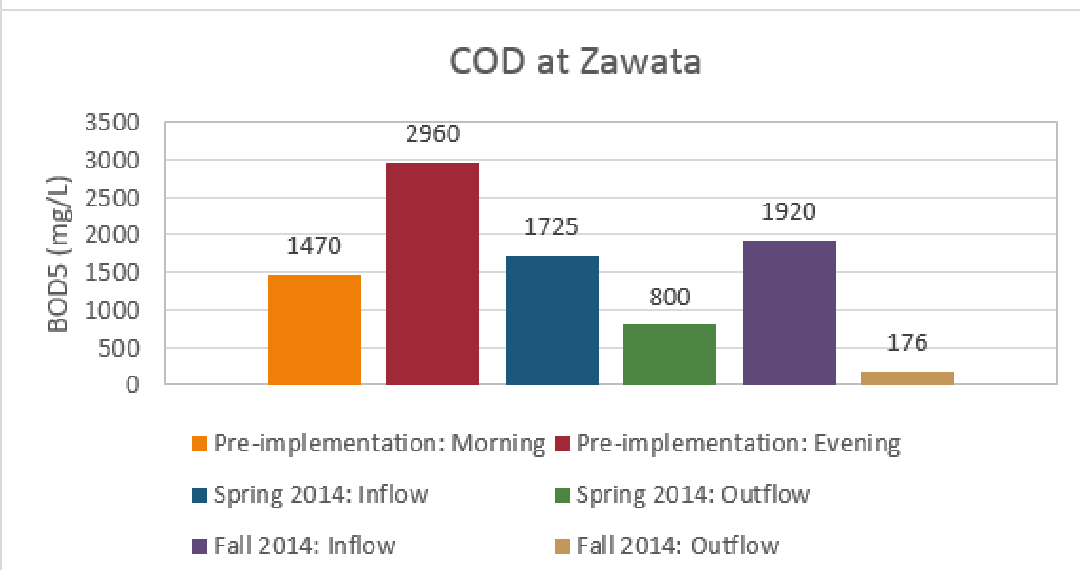

COD at Zawata
BOD5 (mg/L)
3500
3000
2500
2000
1500
1000
500
0
1470
2960
1725
800
1920
176
Pre-implementation: Morning
Pre-implementation: Evening
Spring 2014: Inflow
Spring 2014: Outflow
Fall 2014: Inflow
Fall 2014: Outflow

Figure 35: TSS at all 3 sites over time

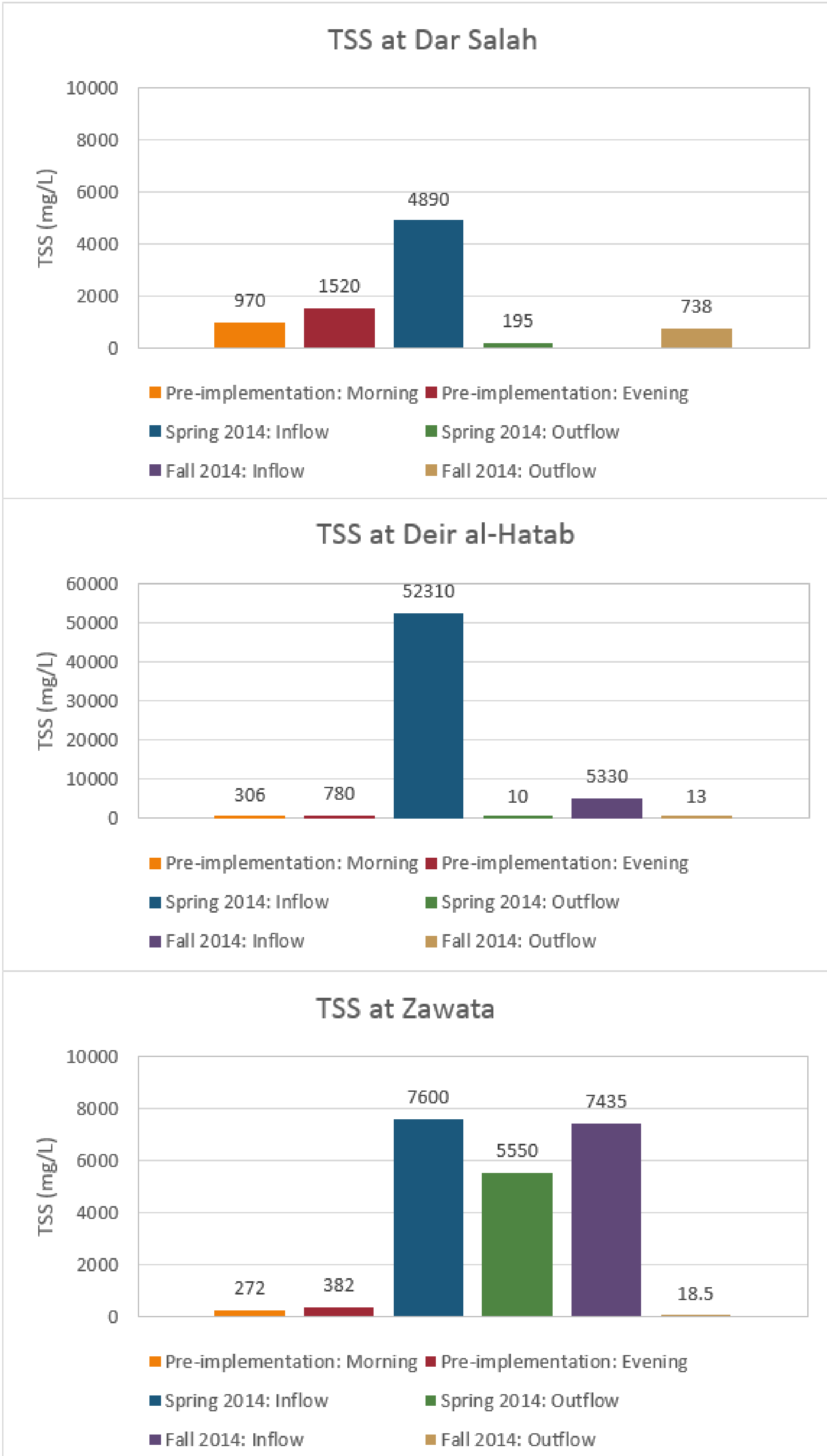


Figure 36: Fecal coliforms at all 3 sites over time.

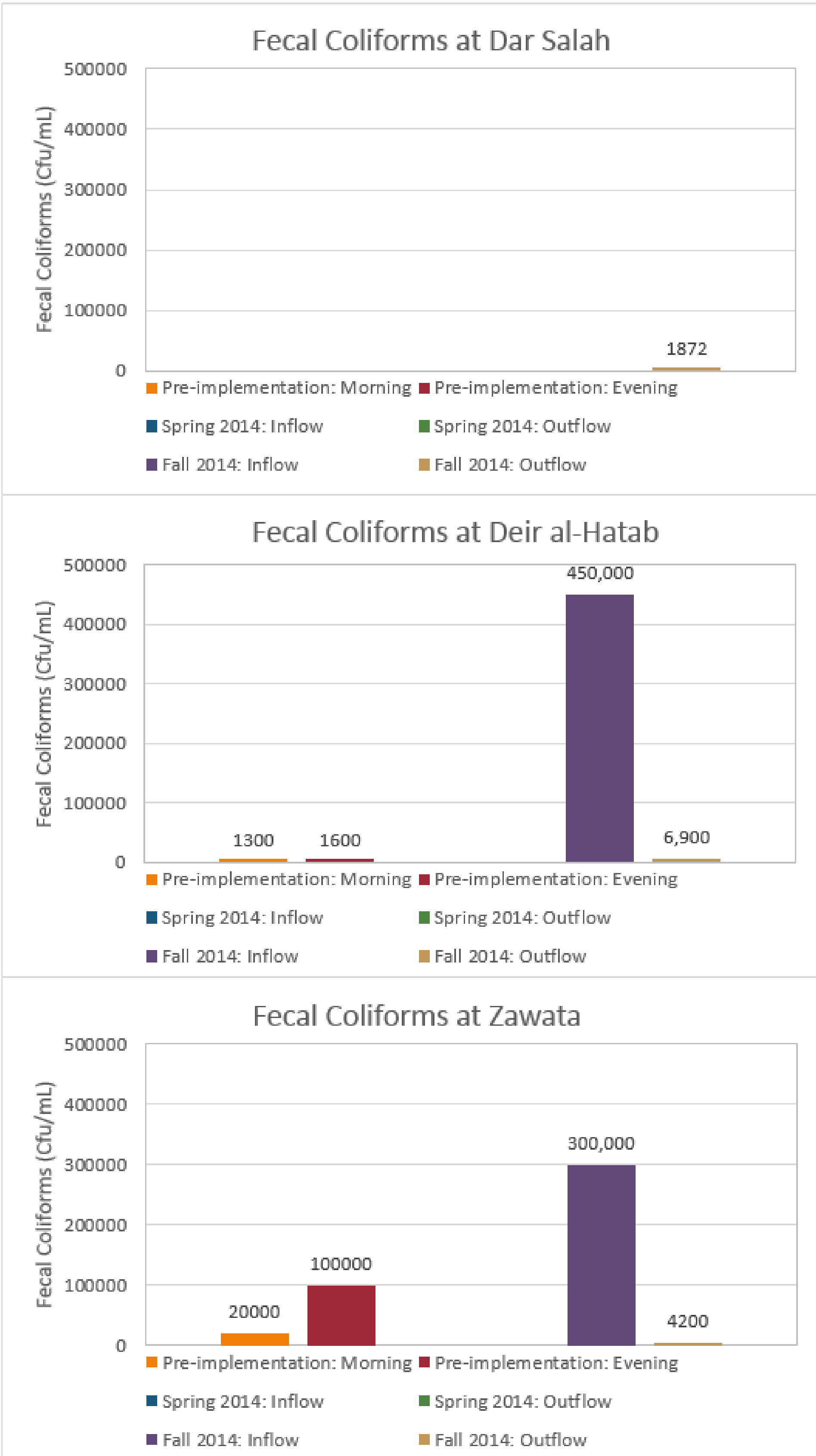


Figure 37: DO at all 3 sites over time

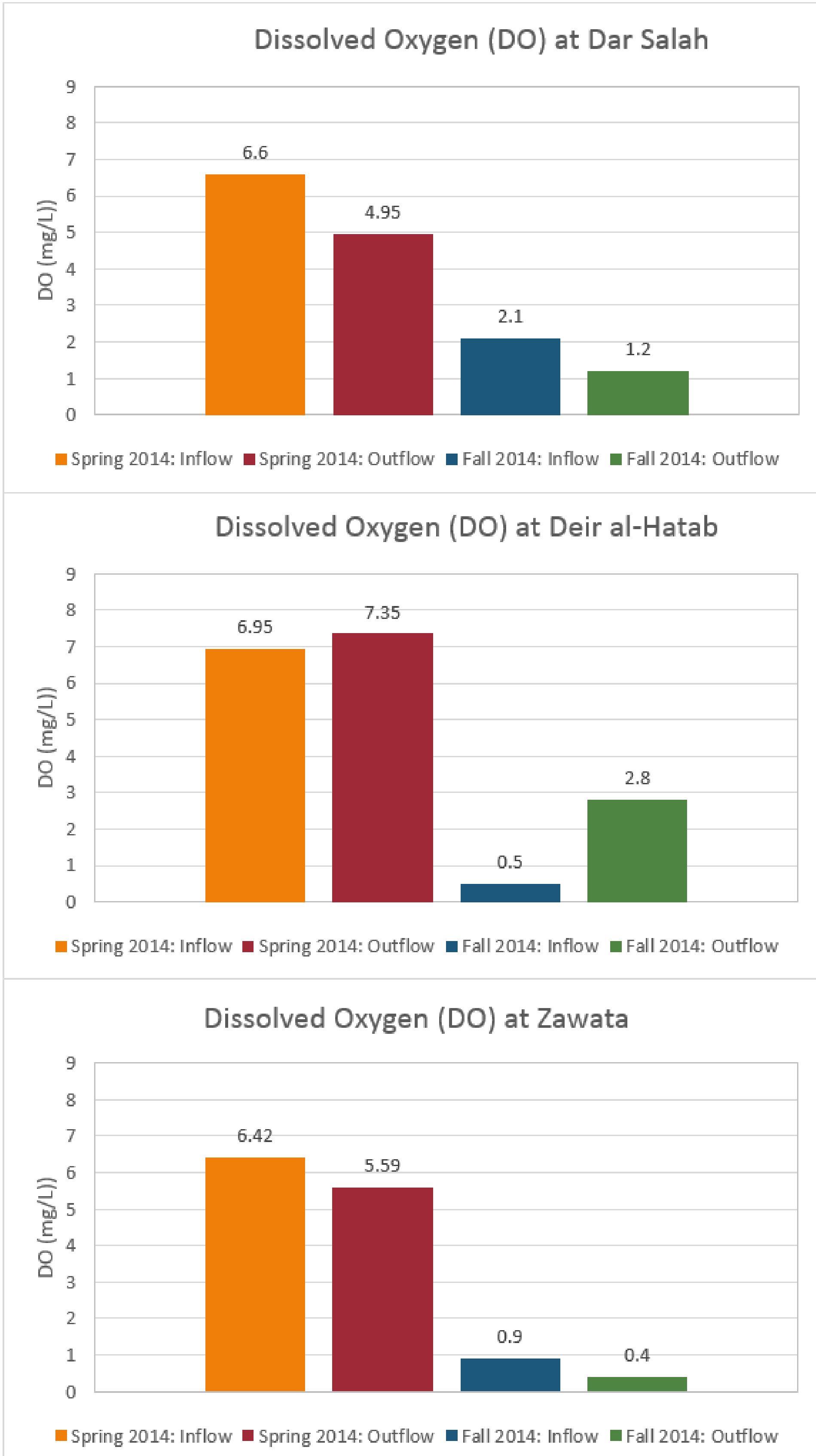
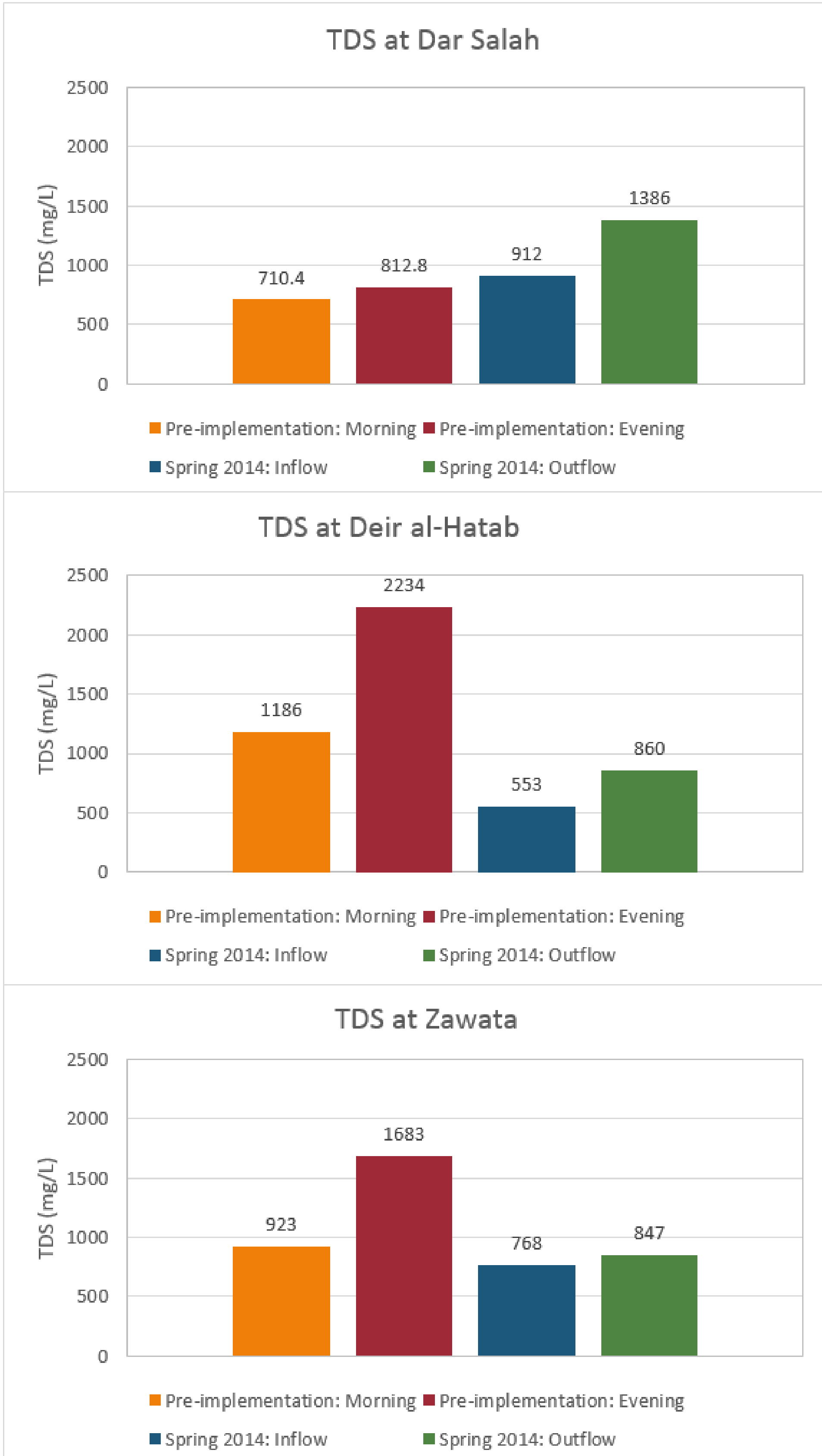


Figure 38: TDS at all 3 sites over time



9.3 Other Data

Figure 39: pH lab data from October 2014. Even with the variation, all effluent values still fall within Inbar standards.

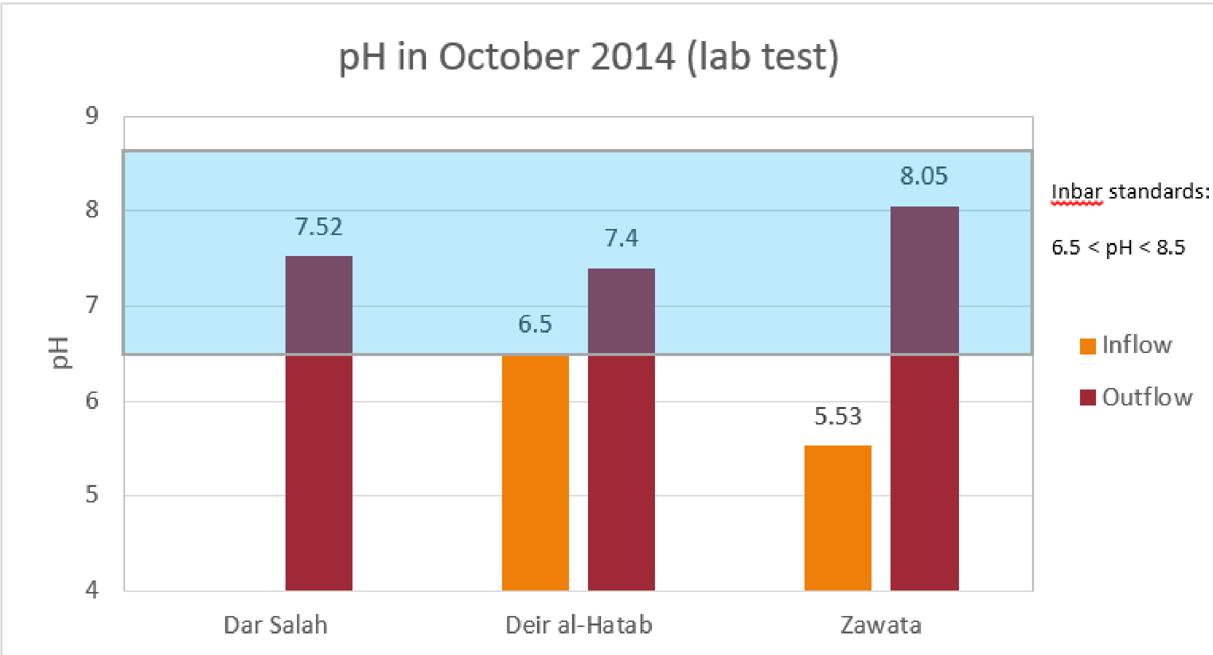


Figure 40: Chemical, physical, and ICP-MS test results from June 2014.

West Bank 11.06.14	pH	EC	Cl	SO4	Br	NO3	CO3	HCO3	Na	K	Ca	Mg	alk.	TDS	NO2	NH4	DO	F
Location		mS	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg CaCO3/L	mg/L	mg/L	mg/L	mg/L	mg/L
Dar Salah inflow	5.17	1.411	210	84.4	0.0	0	0	250	220	31.4	92.5	24.0	205	912	0	4.32	6.66	103
Dar Salah outflow	7.64	1.785	230	4.95	0	0	0	720	218	29.5	170	13.4	590	1386	0	1.12	4.95	24.6
Zawata inflow	6.68	1.296	160	40.7	0	2.55	0	310	170	22.8	48.2	14.0	254	768	0	10.3	6.42	28.1
Zawata outflow	7.28	1.146	175	3.50	0	1.38	0	415	168	21.7	47.6	14.5	340	847	0	7.50	5.59	4.38
Deir al-Hatab inflow	5.64	0.995	121	56.0	0	1.04	0	160	170	12.9	25.5	6.86	131	553	0	11.4	6.95	46.6
Deir al-Hatab outflow	7.58	1.102	110	23.0	0	0.38	0	470	153	17.2	67.6	18.8	385	860	0	6.00	7.35	5.25

West Bank 11.06.14	Al	B	Co	Cr	Cu	Fe	Mn	Ni	Li	Sr	Zn	Si	Ba	P	Ag	TSS	COD filtered	BOD filtered	BOD total
Location	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	mg/L	mgO2/L	mgO2/L	mgO2/L
Lower detectable limit	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.001	**0.005**	0.001				
Dar Salah inflow	0.180	0.16	0.002		0.009	0.205	0.040	0.020	0.009	0.455	0.210	7.88	0.140	**1.371**	0.002	4890	2345	480	
Dar Salah outflow	0.024	0.20	0.002		0.005	0.080	0.027	0.002	0.006	0.440	0.192	9.68	0.915	**0.250**		195	1528	240	241
Zawata inflow	0.035	0.05			0.006	0.125	0.018	0.005	0.002	0.140	2.000	4.53	0.420	**0.325**		7600	1725	468	
Zawata outflow	0.005	0.02	0.002		0.002	0.085	0.033	0.006	0.017	0.185	0.022	10.9	0.066	**0.258**	0.002	5550	800	32.1	54.0
Deir al-Hatab inflow	0.076	0.08		0.002	0.006	0.089	0.015	0.004	0.003	0.098	0.274	10.2	0.840	**0.245**	0.003	52310	2740	488	
Deir al-Hatab outflow	0.006	0.05	0.003		0.003	0.042	0.008	0.002	0.003	0.148	0.240	9.37	0.870	**0.015**		<10	518	76.2	77.1