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ESTIMATING RELATIVE BENEFITS OF DIFFERING STRATEGIES FOR MANAGEMENT OF WASTEWATER IN LOWER EGYPT USING QUANTITATIVE MICROBIAL RISK ANALYSIS (QMRA)

World Bank Water Partnership Program

Final Report
February 2012

Holding Company
for Water and Wastewater

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A report on research carried out by the School of Civil Engineering, University of Leeds, the World Bank and the Holding Company for Water and Wastewater, Government of Egypt with support from the National Research Centre, Cairo, Egypt

World Bank Water Partnership Program

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This study was carried out with financial support from the World Bank Water Partnership Program. The principal investigator was Barbara Evans, University of Leeds, and the Task Manager was Param Iyer, World Bank.

It presents a practical example of how to operationalize the 2006 WHO *Guidelines on the Safe Use of Wastewater, Excreta and Greywater* and the recent World Bank Policy Research Paper 5412 *Improving Wastewater Use in Agriculture; An Emerging Priority*.

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Barbara Evans and Param Iyer

February 2012

The World Bank Water Partnership Program

The Water Partnership Program (WPP) is a multi-donor trust fund established in 2009 and administered by the World Bank's Water Unit in the Sustainable Development Network. The WPP consolidates two previous programs, the Bank-Netherlands Water Program in Supply and Sanitation (BNWP) and the Bank-Netherlands Water Partnership Program in Water Resource (BNWPP) into an improved realignment and restructuring of these programs. The Program is funded by the governments of the Netherlands, the United Kingdom, and Denmark, for a total contribution of $23.7 million.

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Foreword

The Holding Company for Water and Wastewater through its ACs is responsible for the operation and maintenance of the existing facilities to deliver safe water supplies and the management of domestic and industrial wastewater in Egypt. The management of wastewater in particular presents a growing challenge. The country is highly dependent on the water of the Nile for agricultural production. The managed re-use of agricultural runoff from the agricultural drainage network is becoming increasingly important as an input to crop production particularly in the delta region. In this context, the commitment to deliver modern networked sanitation to all householders in the region presents particular challenges. Domestic wastewater contains valuable nutrients which could be useful in crop production but also contains potentially harmful disease-causing pathogens.

It is the task of HCWW to identify, develop and manage appropriate sanitation facilities, including wastewater collection networks and treatment plants, so as to ensure that domestic wastewater is treated and disposed of in ways which ensure protection of health. Recognising the potential for reuse of diluted effluents in agricultural drains HCWW are continually looking for ways to optimise the planning and design of wastewater management systems. Modern statistical tools enable the assessment of relative health risks when effluent from treatment plants is discharged into the agricultural drainage network in locations where reuse could have value in the agricultural system.

Engineer Mamdouh Raslan, Deputy Chairman

Holding Company for Water and Wastewater

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List of Abbreviations

AS	Activated Sludge
BCM	Billion cubic meter (m^3)
CER	Cost-effectiveness Ratio
DALY	Disability-adjusted Life Years
HCWW	Holding Company for Water and Wastewater
JMP	WHO/UNICEF Joint Monitoring Program for Water and Sanitation
MPN	Most Probably Number (laboratory method for counting pathogens)
NAWQAM	National Water Quality and Area Management Project
NPV	Net Present Value
OD	Oxidation Ditch
OFT	On-farm Treatment
pppy	Per person per year
QMRA	Quantifiable Microbial Risk Assessment
ST	Septic Tank
UNDP	United Nations Development Program
UNICEF	United Nations Childrens Fund
WHO	World Health Organization
WSP	Waste Stabilization Pond
WWTP	Wastewater Treatment Plant

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1. INTRODUCTION

This report, prepared in collaboration with the World Bank, supported by the Water Partnership Program, and the University of Leeds, lays out an approach, using modern modeling techniques and a statistical tool known as Quantifiable Microbial Risk Assessment, by which the relative effectiveness of different wastewater management strategies can be assessed in terms of optimising health benefits to downstream populations. The report uses a theoretical model of a typical drainage basin, but the approach could be applied to many of the drainage basins managed by the Holding Company for Water and Wastewater in Egypt. The conclusions of the study provide an indication of how such methods could increasingly be used to enable the selection of cost-effective and appropriate wastewater management strategies.

The analysis presented here, which make a realistic assessment of relative health risks using robust statistical techniques and empirical information, has the potential to increasingly inform the debate about effluent discharge standards and the management of wastewater and agricultural runoff for reuse in agriculture.

2. THE STUDY

Wastewater Reuse and Health

Wastewater treatment serves two main purposes; the removal of harmful pathogens from waste with a view to protecting health and the removal of nutrients (significant amongst which are Nitrogen and Phosphorous) from waste to protect the environment. Different wastewater management systems perform these two functions with different degrees of effectiveness and at different costs. Process selection is often a matter of tradeoff between these two objectives since few processes are very effective at both. Many modern high-energy processes focus on nutrient removal and rely on chlorination for pathogen removal. A focus on nutrient removal however removes or makes significantly more costly the capture of these valuable inputs for downstream agriculture. Reuse of treated wastewater which is pathogen-free has significant potential to increase agricultural productivity and reduce reliance on chemical fertilisers.

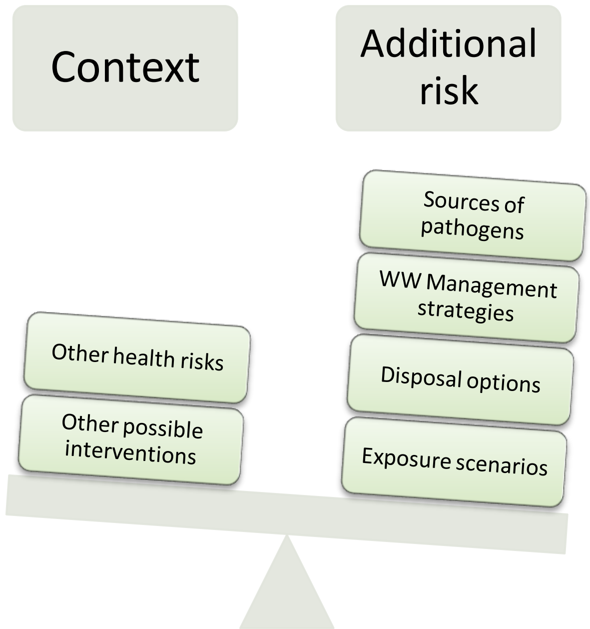
Decisions about wastewater management strategies are a process of balancing costs and effectiveness across these two objectives.   The removal of pathogens is a priority where wastewater reuse is common.   The transport of pathogens from human excreta back to a human host is one of the primary routes of transmission of significant disease groups, in particular diarrheal disease.   The core assumption of this research is that the movement of pathogens from wastewater, via irrigation both directly to farm workers and to consumers of crops, is one of the primary transmission routes for diarrheal disease.   In 2005 the UNDP Human Development Report for Egypt stated that “[p]oor water quality affects both health and land productivity with damage costs estimated …. to have reached LE 5.35 billion …. or 1.8% of GPD in 2003” (UNDP, 2005).

The study makes use of the framework laid down in the WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater – Volume 2; Wastewater Use in Agriculture published in 2006, along with the 2010 update also published by WHO. The value of the 2006 WHO guidelines lies in the fact that this increased health impact can be calculated in the context of downstream conditions

including current disease burden and the likely pathways by which people will be exposed to contaminated wastewater (see for example Figure 1).

A major advantage of the 'relative risk' approach taken in the 2006 WHO guidelines is that they encourage progressive measures to reduce risk of exposure to microbial hazards in contrast to earlier approaches which were more binomial in nature (either meeting or failing to meet rigid standards). This approach allows for different strategies to reduce risk exposure to be assessed. The use of normative tools such as Disability-adjusted Life-Years (DALYs) or disease incidence rates as a measure of disease burden associated with known levels of risk further allows for a direct comparison between different risk-reduction strategies.

Figure 1: Balancing context and additional risk



Source: Authors illustration

For example, in Ghana, non-treatment options such as improved irrigation practices at the farm and post-harvest handling and treatment of crops have been explored alongside more conventional approaches to improve wastewater treatment to assess the most cost-effective strategies to reduce diarrheal disease incidence in urban areas (Seidu & Drechsel, 2010). That study compared the "health gains in terms of diarrheal disease reduction [with the] cost of treatment and non-treatment interventions associated with wastewater irrigation in Ghana" (Seidu & Drechsel, 2010)p. 263.

Aims and Objectives

This study set out to assess the relative health impacts of different wastewater management strategies on health in the Nile delta region using an approach similar to that used in the Ghana case study mentioned above.

The ultimate objective was to develop a framework for long-term investment planning based on monitoring of health and productivity impacts of proposed Bank operations which could be included in Project M&E systems. This would equip Task Teams to assess the risks and opportunities which

arise due to the proposed shift from on-site to networked sanitation in four governorates where the Bank has wastewater operations.

A secondary objective was to assess the extent to which existing legislation supports health risk-based planning.

3. THE CONTEXT

Wastewater Reuse in Egypt

Egypt is highly dependent on reuse of agricultural drainage water for irrigation. In 2002/3 it was estimated that 4.3 billion m^3 (BCM) of drainage water were being used in the delta region and Fayoum through official reuse projects, and this was set to rise to around 7.6BCM on completion of further planned drainage projects (Mostafa, El-Gohary, & Shalby, Date Unknown). Unofficial reuse is generally estimated to be considerably higher.

There are several water quality issues relating to agricultural reuse of drainage water.

- Firstly, salinity and concentrations of naturally-occurring pollutants in irrigation water can rise to unacceptable levels due to the effects of evaporation and consequent concentration in residual flows.
- Secondly, the biochemical characteristics of the drainage water can be adversely affected by the inflow of unregulated domestic and industrial wastewaters and the effluent from wastewater treatment plants.

However, from a health perspective, high concentrations of harmful pathogens are of greatest concern. According to some observers "…the major problem regarding drainage water quality is not salinity, but chemical and bacteriological pollution…" (Mostafa, El-Gohary, & Shalby, Date Unknown) p.98. This report focuses on the health implications of pathogenic contamination of agricultural drainage water which is reused in agriculture.

Sanitation and Wastewater Treatment

The main sources of pathogenic contamination in the agricultural channels are livestock wastes from cattle sheds and fields, industrial discharges (tanneries and dairies presenting particular challenges) and informal discharges of human excreta from onsite sanitation systems.

By presidential decree (Presidential Decree 135/2004), all households in Egypt are guaranteed individual connections to networked sewerage for their sanitation services. Disposal of wastewater into irrigation channels is not officially permitted and the discharge of treated domestic wastewater into such agricultural channels is strictly regulated (Government of Egypt, 1982). In theory therefore, all sewerage connections should be made to wastewater treatment facilities. A major objective of The Holding Company for Water and Wastewater (HCWW) is to increase the rate of connection to sewerage and to develop new wastewater treatment capacity.

Progress towards this objective has been relatively slow. Between 1990 and 2008 rates of access to improved sanitation (essentially a hygienic toilet) in the rural areas of Egypt rose from 57% to 92% but rates of sewerage connection were around 18% in 2008 and between 2005 and 2008 progress

appears to have virtually stagnated (WHO/UNICEF Joint Monitoring Program for Water and Sanitation, 2010) and (WHO/UNICEF Joint Monitoring Program on Water and Sanitation, 2011).

Many rural households have onsite vaults which are emptied between two to four times per month due to high water tables (World Bank, 2008). Most of this effluent is either used directly on the fields or discharged into agricultural drains and canals without treatment. In Gharbeya, Kafr El Sheikh and Beheira Governorates for example there are some 15 wastewater treatment plants serving the larger agglomerations, but most are running well below capacity and do not serve the majority of the population. A survey carried out in Gharbeya, Kafr El Sheikh and Beheira in 2007 reported that while 88% of households had latrines, 48% were connected to septic tanks. Thirty-nine percent were deemed to be 'unsanitary' (implying that the pits or tanks were not providing adequate storage or protection) and 12% of households had no toilet at all. Of those families with septic tanks or cess pits, 25% of households in Beheira reported that these were emptied directly into agricultural drains or canals, while 44% in Kafr El Sheikh reported that they were emptied into the canal (EcoConServ, 2007).

Informal private operators provide emptying services and dispose of wastes in both irrigation channels and drainage channels.

Thus the Nile delta has a high prevalence of poorly-managed onsite sanitation facilities, low rates of connectivity to wastewater treatment facilities and is cris-crossed by a network of agricultural canals and drains. None of the water companies in Lower Egypt are able to guarantee 100% collection and treatment of domestic wastewater. Significant volumes of untreated domestic wastewater and discharges from wastewater treatment facilities that are operating under-capacity are therefore discharged into the agricultural drainage system and significant volumes of the resultant mixed drain water are certainly used for irrigation in downstream areas.

This undoubtedly exposes agricultural workers downstream to health risks (Abd El Lateef, Hall, Lawrence, & Negm, 2006).

4. THE APPROACH

Focus on Health Risks

The research examined the relative health risks associated with different wastewater management strategies in a 'typical' drainage basin in the delta region. The study focused on the health risks associated with the use of untreated and treated wastewater lifted from agricultural drains and canals downstream of a notional drainage basin. Inflow to the drainage basin was considered to be wastewater flows from houses, plus the flow in a notional drain.

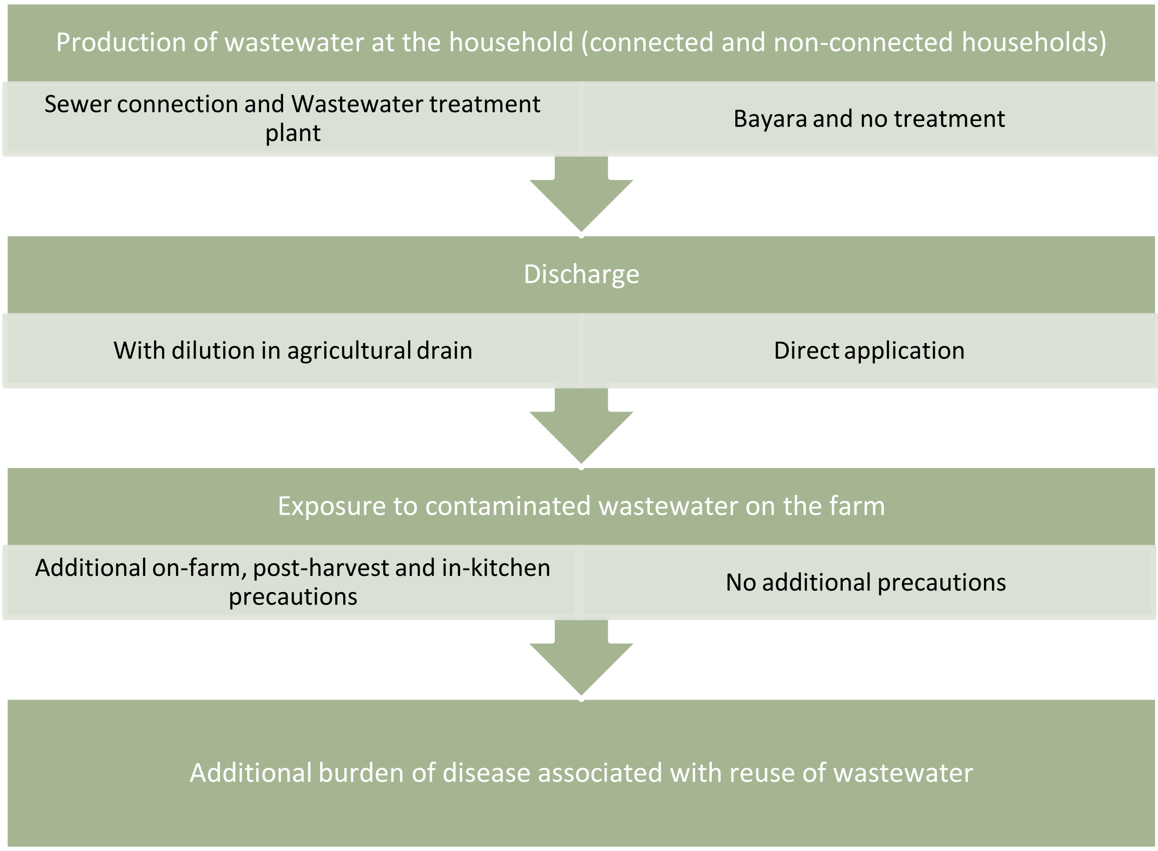
Health risks in downstream areas are a function of water quality and farming practices. In Egypt, particularly in the Nile delta region, most wastewater is discharged into agricultural drains either directly or via the sewerage/ wastewater treatment network. The resultant water quality in downstream channels therefore depends primarily on the;

- Baseline water quality and flow upstream of the sanitation system under consideration
- Rate and quality of water discharging via sewerage and wastewater treatment system

- Rate and quality of water discharging outside the sewerage/ wastewater treatment system (from domestic onsite systems and unregulated commercial discharges).

Figure 2 shows how pathogens flow from households to farm workers and consumers.

Figure 2: Pathogen flow in the notional drainage basin



Source: Authors illustration

On the left is what could be called the "low-risk transmission route" which involves collection of household waste in a sewer, its treatment at an appropriate treatment plant, dilution in an agricultural drain or canal prior to re-use, and the deployment of appropriate on-farm, post harvest and in-kitchen interventions, all of which minimize the risk of transmission of disease. On the right is a notional "high-risk transmission route" where untreated waste is applied directly to the field and there are no on-farm, post-harvest, or in-kitchen interventions.

The actual situation is a blend of these two extremes along with a number of "medium-risk" transmission routes utilizing some but not all of the precautionary measures shown on the left hand side of Figure 2.

Risk Management Strategies

Reductions in risks associated with reuse of wastewater can broadly be achieved in three ways:

(a) diversion of wastewater flows from low-treatment to high-treatment facilities prior to discharge;
(b) improved levels of treatment in existing facilities; and

(c) improved on-farm and post-harvest practices.

The focus of current investment strategies in the Nile Delta region is primarily on:

- rehabilitating existing treatment plants;
- commissioning new treatment plants; and
- construction of new sewer networks.

As long as connectivity rates to the sewer network remain low none of these strategies is likely to reduce health risks to downstream agricultural workers or consumers. Furthermore little work has been done to assess the performance of existing treatment processes on removal of the key pathogens responsible for adverse health impacts.

In reality, there are additional wastewater management options which could be considered and which might have additional merit in terms of health benefits. These include:

- providing alternative (or additional) treatment steps at the household or wastewater treatment plant level;
- creating incentives for higher rates of connectivity to the existing sewer networks;
- increasing formal septage collection rates from onsite sanitation systems and delivery to wastewater treatment facilities thereby reducing discharge of untreated wastes;
- modification of downstream agricultural practices; or
- a combination of these strategies.

The study set out to explore the impacts of these strategies by modeling the overall flow of pathogens through a single drainage basin, using a combination of theoretical and field-based data. The study explored likely current and future scenarios and examined a range of interventions and their impact on downstream health outcomes.

5. THE MODEL

Typical Drainage Basin

The study made use of a simple mass-balance model of a 'typical' drainage basin or sanitation area. It explored how the various streams of waste, treated to difference levels, impact on water quality downstream. To give maximum flexibility the model allowed for a range of scenarios to be explored.

Five categories of households were defined and each household in the notional basin was assigned to one of these categories:

- Category I: Connected via sewer to Wastewater Treatment Plant (WWTP) - Oxidation Ditch or Activated Sludge process
- Category II: Connected via simplified sewer to WWTP - Waste Stabilization Pond
- Category III: Not connected to sewer – using improved anaerobic treatment and secondary polishing),e ach system shared between three households
- Category IV: Not connected to sewer – using effective septic tank, one per household

- Category V: Not connected (no facilities or utilizing a bayara or trench to collect household waste)

At the start the model was set up using a 'typical scenario' for the delta region; 88% of households using poorly-functioning household facilities (known as bayaras or trenches) and the remaining 12% connected to either a centralized oxidation ditch system or a centralized activated sludge system which was assumed to be working at 50% capacity.

Interventions

For simplicity, the model considered that wastewater from already-connected households (category I) would remain with the same treatment option. Only households currently NOT connected to the network and having no treatment (category VI) were considered as having potential to move. Various interventions were modeled (Table 1). In each case it was assumed that new sewer connections would be made to the existing treatment plant to bring it up to full capacity. For the remaining households one of six possible interventions was considered. The model then calculated the worst-case scenario for downstream water quality assuming typical upstream values in the receiving drainage water.

Table 1: Intervention Options used in this research

Intervention	Category shift	Comment
1. **Convert Bayaras to septic tank**	V to IV	This option assumes the provision of onsite facilities. It would be enhanced by the addition of well regulated and properly financed collection services. Proprietary all-in-one systems would provide better protection from groundwater infiltration
2. **Improved Bayaras to provide anaerobic treatment and secondary polishing**	V to IV	This option assumes provision of shared facilities (one per three households). It would be enhanced by the addition of well regulated and properly financed collection services.
3. **Connect Bayara households to WSP WWTP**	V to III	Requires construction and operation of sewerage or incentives for septage to be delivered to WWTP. Sewerage may require pumping so costs will be modeled with and without pumping. WSPs may be decentralized or centralized.
4. **Connect Bayara households to oxidation ditch or activated sludge WWTP**	VI to II	
5. **On-farm and post-harvest interventions**	-	Non-infrastructure intervention with behavior change
6. **Convert Bayaras to septic tank or shared anaerobic process with polishing PLUS on-farm and post-harvest interventions**	VI to V plus behavior change	Infrastructure plus behavior change intervention

Source: Authors summary of model scenarios

Field Test Sites

To help link the model to conditions on the ground, two locations were selected for detailed field study. These were Sidi Salem, an oxidation ditch treatment plant with extended aeration in Kafr-El

Sheikh Governorate, and El-Moufty El-Kobra Waste-stabilization Pond plant in the same area. Water quality testing was carried out in these two sites over the period between December 2010 and February 2011. Data from the field-testing was used to calibrate the model.

Calculating Health Risks from Water Quality

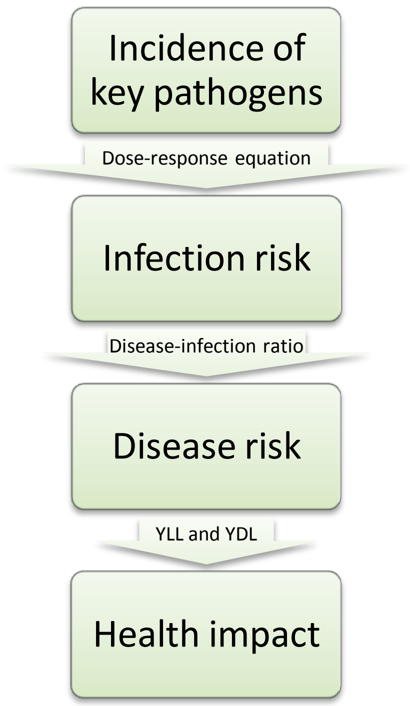
Quantifiable microbial risk assessment (QMRA) is a tool which can be used to help operationalize the 2006 WHO guidelines on reuse of wastewater agriculture (World Health Organisation, 2006). It does this by determining a numerical value of the risk (or probability) of a disease or infection occurring as a result of an individual being exposed to a specified number of a particular pathogen.

Provided dose-response data are available QMRA can be used to estimate disease and infection risks which accrue to downstream populations who come into contact with contaminated wastewater in a range of ways for any pathogen.

Figure 3 shows the logical relationship between incidence of pathogens and health impacts.

In order to calculate health impacts the dose-response equation, disease-infection ratio and the impact in terms of ill-health and death must be known or estimated. QMRA then allows the probable health impacts from exposure to certain pathogens to be calculated. Further information on QMRA techniques is summarized in Appendix 1. Mara (2010) and Mara, Hamilton and Sleigh (2010) provide full details of QMRA techniques for assessing health risks associated with wastewater reuse.

Figure 3: Relating incidence of pathogens to health impact in downstream populations



Source: Authors illustration

6. PARAMETERS FOR USE IN THE MODEL

Acceptable Additional Risk to Health

A key step in the process was to establish an acceptable level of additional risk to health over baseline conditions associated with the use in agriculture of wastewater, either directly used or after mixing in downstream drains and canals. Using Quantifiable Microbial Risk Analysis (QMRA), this acceptable additional risk of certain disease types, could then be converted into reference standards for incidence of key pathogens in irrigation water applied at the field level.

Health risk is expressed in terms of DALYs, a measure which combines both mortality and morbidity to calculate the overall impact of a disease or disease group (see Box 1).

In this study a maximum tolerable additional DALY loss of 10^{-4} per person per year was used following the publication of the WHO Update to the 2006 Guidelines (World Health Organisation, 2006). This corresponds to an additional disease risk of 10^{-2}. For an individual this is "equivalent to an additional episode of diarrheal disease every 100 years" (ibid.) over and above generalized diarrheal disease incidence which globally is equivalent to two episodes every three years.

Box 1: Disability-adjusted Life Years (DALYs)

DALYs are a measure of the health of a population or burden of disease due to a specific disease or risk factor. DALYs attempt to measure the time lost because of disability or death from the disease compared with a long life free of disability in the absence of the disease. DALYs are calculated by adding the years of life lost due to premature death (YLL) to the years lived with a disability (YLD). Years of life lost are calculated from age-specific mortality rates and the standard life expectancies of a given population. YLD are calculated from the number of cases of the disease multiplied by its average duration and a severity factor ranging from 1 (death) to 0 (perfect health) based on the disease − for example, watery diarrhea has a severity factor from 0.09 to 0.12, depending on the age group. DALYs are an important tool for comparing health outcomes because they account for not only acute health effects but also for delayed and chronic effects − i.e., they include both morbidity and mortality. When risk is described in DALYs, different health outcomes (e.g., fatal cancers and non-fatal diarrheal diseases) can be compared and risk management decisions can be prioritized.
Source: (World Health Organisation, 2006)

Key Indicator Pathogens

Diarrheal disease is caused by a wide range of pathogens. The 2006 guidelines propose the following indicator organisms when considering risks from wastewater reuse in agriculture: Rotavirus, Campylobacter, e-Coli, Cryptosporidium and Ascaris

In 2010, WHO noted that norovirus is the major viral pathogen causing diarrhea in adults while rotavirus mainly affects children under 5. Since adults are more likely to face exposure due to wastewater use than children, norovirus is a better indicator pathogen than rotavirus. However, due to the lack of appropriate sampling and testing facilities near to the field test sites rotavirus, e-coli and ascaris were taken as the key indicator organisms in this study.

On-farm, Post-harvest and In-kitchen Measures to Reduce Health Risks

Since irrigation in Egypt is usually practiced by means of flooding the fields, most of the usual on-farm precautions are not available (use of drip irrigation, watering cans etc). The only option considered in the model is the use of pathogen die-off through ensuring a time delay between irrigation and harvesting. Post-harvest (overnight storage of harvested crops and special preparation of crops for market) was considered but in-kitchen preparation options were not. A summary of the relevant post-harvest interventions are shown in Table 2.

Table 2: Health protection control measures and associated pathogen reductions

Control Measure	Pathogen reduction (log units)	Comments
On-farm Options		
Crop restrictions (no food crops eaten uncooked)	6-7	Excluded - hard to enforce, depends on crop prices
On-farm treatment		
- Three tank system	1-2	
- Simple sedimentation	0.5-1	Excluded due to lack of space
- Simple filtration	1-3	
Application methods		
- Furrow irrigation	1-2	Excluded due to prevalence of flood irrigation
- Low-cost drip irrigation	2-4	
- Reduction of splashing	1-2	
Pathogen die-off	0.5-2 per day	Included
Post-harvest options at local markets		
Overnight storage in baskets	0.5-1	Included
Produce preparation		
- Rinsing salad crops with clean water	1-2	
- Washing with running tap water	2-3	Excluded – hard to enforce
- Removing outer leaves of lettuces etc	1-3	
In-kitchen preparation methods		
- Disinfection	2-3	
- Peeling	2	Excluded – behavior change hard to enforce
- Cooking	5-6	

Based on (Mara, Hamilton, Sleigh, & Karavarsamis, 2010)

Wastewater Treatment Products

A review of the literature found limited information relating to the health implications of application of wastewater sludge from wastewater treatment processes in Egypt. For this reason, the sludge stream was not included in the analysis and only wastewater effluent from treatment plants was included. This would tend to have the effect of underestimating health risks associated with all the wastewater treatment plant options considered. For the onsite options, the quality of the mixed slurry including liquid and solid fractions was considered.

Dilution Options

The conditions of the channel downstream of the treatment plant or where untreated waste is discharged are a key determinant of the likely quality of water reused in agriculture. Effluent is discharged into drains of varying size – from major drainage channels to minor ditches. The quality of water in the downstream receiving water body is also important in determining how significant

any contamination caused by the effluent will be. The model therefore allowed for varying flow and varying water quality in the receiving drain. Resultant concentrations of pathogens in water for reuse were calculated using a simple mass-balance calculation. No assumptions for pathogen die-off were included.

Cropping Patterns

The model has the potential to examine health impacts on a range of cropping outcomes. The typical Egyptian diet contains a significant element of grains and meat, none of which represent significant transmission risks for pathogens from wastewater due to the processing involved in their preparation. The diet does however contain a significant volume of tomatoes (estimated consumption 99kg/capita/ year) and grapes (17 kg/capita/year) (Arab Republic of Egypt, 2009) . Since detailed data on tomato preparation are not available, the assumption is made that 50% of the total consumption of tomatoes and all of the grapes are consumed uncooked. Contamination from this consumption pattern is assumed to be via consumption of water from the crop surface. Ingestion of contaminated soil attached to the crop is considered to be marginal.

7. RESULTS

Downstream Water Quality

Data from the field observations and a review of previous studies confirmed that the quality of water in receiving drains is extremely poor in the Delta region (see Appendix 2). Incidence of Ascaris and Rotavirus is highly variable (probably reflecting infection rates in the command areas of the plants under study) and the performance of the plants in removing pathogens was also mixed.

There have been numerous studies that have analyzed and modeled water quality in various drains and canals in the delta region. Few of these provide detailed information on pathogenic contamination. Work carried out in preparation for the World Bank'-supported Integrated Sanitation and Sewerage Infrastructure Project (ISSIP) however noted very "high pollution loads as a result mainly of sewage and industrial wastewater discharges" (EcoConServ, 2007). This finding confirmed earlier extensive monitoring of the Nile system (DAI and IRG, June 2003) which noted that "total coliform bacteria reach 10^6 MPN/11ml …in many drains in the delta which is considerably higher than the Egyptian standard of 5000 MPN/100ml." A selection of data from Gharbeya and Kafr El Sheikh are shown below.

Table 3: Incidence of Fecal Coliforms in Drains and Canals

Location	Observed Value
Mit Yazid Canal	>10,000 MPN/100ml
Mit Yazid Command Area Drains	>60,000 MPN/100ml
Mahmoudia Canal System Drains	>100,000 MPN/100ml

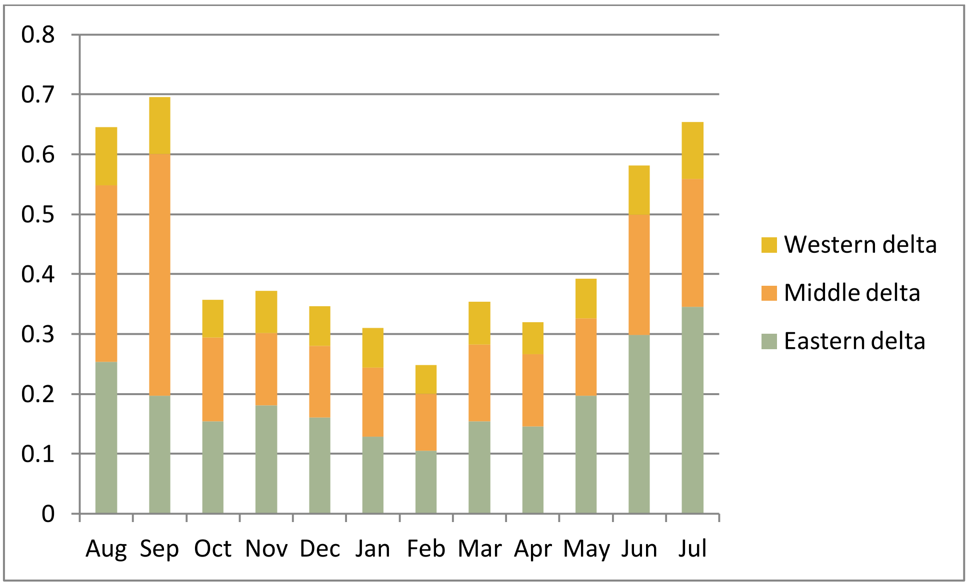
Source: (EcoConServ, 2007)

Most observers comment that the highest concentrations of most water quality parameters occur during the winter time (El Sayad & Abdel Gawad, September 2001). This finding was confirmed by a study of the incidence of parasite eggs in drain water where incidence appeared to be higher in the

autumn and winter months (August-January) than in spring and summer (Stott, Jenkins, Shabana, & May, 1997).

This higher concentration of pathogens in the winter coincides with the period of minimum flow. Seasonal variation in reuse for example is high with peak reuse flows in the period from June to September coinciding with the peak summer season (Figure 4) and the lowest rates in January and February.

Figure 4: Monthly reuse of drainage water in the Nile delta during 2002/2003 (BCM)



Source: (Mostafa, El-Gohary, & Shalby, Date Unknown)

Overall the literature confirmed that there are high levels of pathogenic contamination in the canal and drain network. Likely sources include both domestic waste discharged directly from household septic tanks and cess pits, discharge of partially treated wastes from treatment plants and industrial effluent discharges.

Information on the quality of wastewater and the incidence of our key indicator pathogens is drawn from the field testing carried out as part of this project and cross checked with data from earlier field studies ((Stott, Jenkins, Shabana, & May, 1997), (El Gohary, El-Hawarry, Badr, & Rashed, 1996) (Sherief, El-S Easa, El-Samra, & Mancy, 1996). A summary of the data used for the model is shown in Table 4.

Effectiveness of Treatment

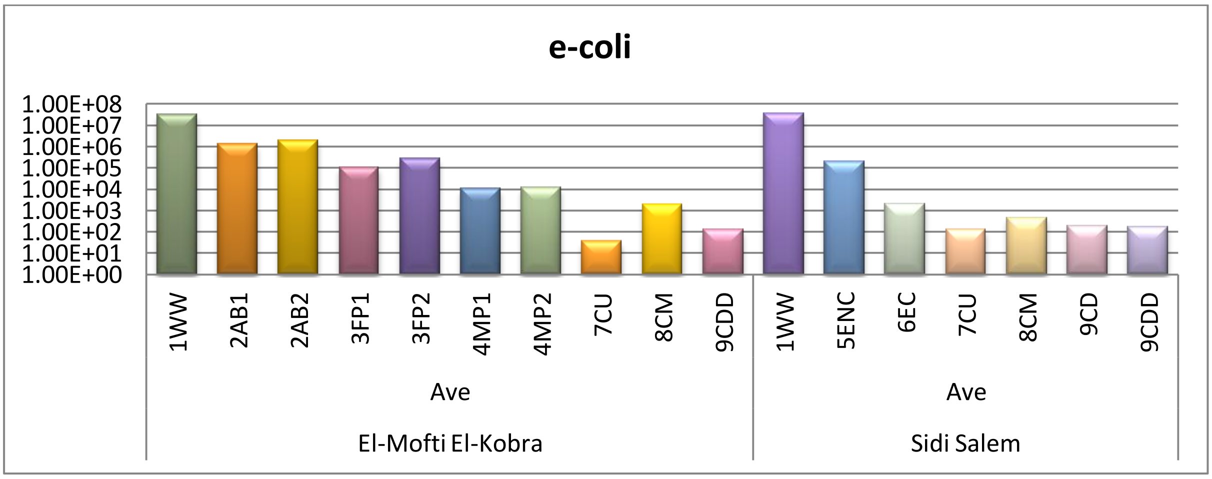
The waste stabilization pond at El Moufty El Kobra appeared to be functioning well below its design capability during the period of this study. This was confirmed by field observations to be caused by contamination of the sewer network from a dairy operation within the community. Visual observations confirmed heavy algal growth in all the ponds and possibly overloading which may have been exacerbated due to high levels of animal excreta in the influent. At Sidi Salem, as would be expected, the removal of pathogens upstream of the chlorination system was relatively poor, and even below the chlorinator some pathogens remained suggesting some inefficiencies in the process.

Table 4: Model Parameters for Water and Wastewater Quality

	Model Parameter
Raw Wastewater (Bayara)	
e-Coli	2.00E+07 (/100ml)
Rotavirus	1.00E+05 (/100ml)
Ascaris	3 nr/liter
Raw Sewage	
e-Coli	1.00E+07(/100ml)
Rotavirus	1.00E+04(/100ml)
Ascaris	3 nr/liter
Receiving Drain Water	
e-Coli	4.00E+02(/100ml)
Rotavirus	1.00E+01(/100ml)
Ascaris	0 nr/liter

Source: Authors summary estimates

Figure 5: Average observed rates of e-coli in study wastewater treatment plants*



Source: Field study data

*See Appendix 2 for a detailed breakdown. WW= wastewater influent, AB=Anaerobic Basin, FP=Facultative Pond, MP= Maturation Pond, CU=Drain upstream of WWTP discharge point, CM = drain at mixing point, CDD = drain downstream of mixing point, ENC= effluent upstream of chlorination, EC = effluent downstream of chlorination

The baseline scenario is thus very poor. A high percentage of wastewater is reaching drains untreated, drains are in poor condition generally to begin with, and pathogen removal at the existing treatment plants is not particularly effective.

Using both the field observations and literature, typical treatment efficiencies for the options under consideration were used in the model assuming that treatment processes were working to their full potential for Egyptian conditions (see Table 5).

Table 5: Parameters for treatment options

Effectiveness of Treatment Log reduction rates				
	Activated Sludge/ oxidation ditch	Waste stabilization pond	Anaerobic treatment and polishing	Septic tank
Upstream of chlorination				
e-Coli	0.44	3	3	2
Rotavirus	0	2	2	2
Ascaris	0	2	2	2
At Chlorination				
e-Coli	3	n/a	n/a	n/a
Rotavirus	3	n/a	n/a	n/a
Ascaris	2	n/a	n/a	n/a

Source: Authors summary estimates

Impact of Sanitation Options on Water Quality

The project model reconfirmed the observed results for the Baseline scenario in the context of the model drainage basin. Downstream water quality was then calculated under the study scenarios and the results are shown in Table 6 which indicates the worst quality water that would result under each intervention.

Table 6: Downstream water quality in receiving drain assuming chlorination

Intervention		Baseline	1	2	3	4	5	6
Mixed drain water								
total fecal coliforms	unit/100ml	1.E+08	1.E+06	1.E+05	3.E+04	3.E+04	4.E+04	1.E+06
e-coli	unit/100ml	2.E+07	1.E+05	1.E+04	3.E+03	3.E+03	4.E+03	2.E+05
Rotavirus	unit/100ml	1.E+05	1.E+02	1.E+02	8.E+01	9.E+01	1.E+02	1.E+03
Ascaris	unit/100ml	3.E+00	8.E-01	8.E-01	8.E-01	9.E-01	1.E+00	3.E-02
Sludge								
total volume	kg/day	9.E+02	9.E+02	1.E+03	5.E+03	6.E+03	1.E+04	9.E+02
total fecal coliforms	MPN/day	9.E+11	9.E+11	1.E+12	9.E+11	2.E+12	1.E+13	9.E+09

Source: Study results

Incidence of Ascaris is low (and this is reinforced by findings in the literature) (Stott, Jenkins, Shabana, & May, 1997) but it has been included in the analysis because of its relative importance with respect to onsite sanitation systems. The main health impacts however are associated with Rotavirus infection which remains a significant health risk in Egypt (Khoury, Ogilvie, El Khoury, Duan, & Goetghebeur, 2001).

Table 7 shows the results for QMRA simulations of health risks associated with exposure to rotavirus as a function of exposure to all fecal coliforms (for a longer discussion on this method see (Mara, Sleigh, Blumenthal, & Carr, 2007)).

Table 7: Median Infection risks from consumption of wastewater-irrigated tomatoes estimated by 10,000-trial Monte Carlo Simulation*

Wastewater Quality (e-coli per 100ml)	Median Infection risks associated with rotavirus pppy
10^7 - 10^8	1
10^6 - 10^7	1
10^5- 10^6	0.96
10^4 - 10^5	0.28
10^3 - 10^4	3.2E-02
10^2 - 10^3	3.1E-03
10 – 10^2	3.2E-04
1 – 10	3.34E-05

Source: Results of simulations using (Mara & Sleigh, QMRA: A Beginners Guide - Monte carlo simulation programmes, 2008)

*375g of raw tomato eaten per person per 2 days; 3.5–4ml wastewater remaining on 375g tomato after irrigation; 0.1–1 rotavirus per 10^5 e. coli; 10^{22}–10^{23} rotavirus die-off between harvest and consumption; ID50 ¼ 6.7 ^ 25% and a ¼ 0.253 ^ 25% for rotavirus.

The acceptable marginal health risk is 10^{-2} (See above and also (Mara, Sleigh, Blumenthal, & Carr, 2007) gives a target wastewater quality at the farm gate (for irrigation workers) or at market (for consumers of crops) of the order of 10^3 total FC per 100ml. Based on the median wastewater quality experienced in the downstream drains under baseline conditions a total reduction in pathogens of the order of 10^6 is required to achieve this acceptable level of risk.

Using the QMRA to assess the impact on downstream health of exposure to irrigated crops Table 8 indicates the annual incidence of disease in the affected population. It is worth noting here the very conservative assumption which is that only the population in the command sanitation basin under consideration consumes crops irrigated there. In reality crops are likely to be exported to urban areas and the affected population is likely to be greater than that shown here.

Table 8 shows that some of the proposed interventions could have a significant positive impact on health. Improved on-farm and post-harvest management of food crops could reduce diarrheal incidence by more than 90%, preventing more than 2.5 million diarrhea cases in the area over 20 years (for a population of around 225,000 people) when combined with improvements to the design and operation of onsite sanitation systems. Networked sewerage with treatment also has a significant impact on health but in the case of activated sludge and oxidation ditches this is highly dependent on effective and continuous chlorination. The overall health impact, expressed in diarrheal disease incidence in the total population is summarized in Table 9.

Table 8: Incidence of diarrhea and DALY burden under various scenarios

Scenario	Baseline	1	2&3	4	5	6
Disease Risk pppy						
Rotavirus	1.00E+00	9.90E-01	2.40E-01	2.75E-01	9.90E-01	9.00E-02
Cryptosporidium	1.80E-01	1.70E-02	1.45E-03	1.65E-03	1.70E-02	2.00E-04
Ascaris	3.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disease incidence (cases per year)						
Rotavirus	225,000	222,750	54,000	61,875	222,750	20,250
cryptosporidium	40,500	3,825	326	371	3,825	45
Ascaris	68	0	0	0	0	0
Total	265,568	226,575	54,326	62,246	226,575	20,295
REDUCTION	**0%**	**15%**	**80%**	77%	15%	92%
DALYs (cases per year)						
rotavirus*	5,850	5,792	1,404	1,609	5,792	527
cryptosporidium	61	6	0	1	6	0
Ascaris	1	0	0	0	0	0
Total	5,911	5,797	1,404	1,609	5,797	527
REDUCTION	**0%**	**2%**	**76%**	73%	2%	91%

*/1 DALY loss per case of disease Rotavirus: 2.6E-2; Cryptosporidium 1.5E-3; **(Mara & Bos, Risk Analysis and Epidemiology; The WHO 2006 Guidelines for Safe Use of Wastewtater in Agriculture, 2010)** Ascaris 8.25E-3 (**(Mara D. D., Hamilton, Sleigh, Karavarsamis, & Seidu, 2010)**
*/2assume children under 2 not consuming irrigated crops

Source: Model results

Table 9: Overall reduction in icidence of diarrhoeal disease and DALYs by intervention (20 years)

Scenario	ddi		DALY	
	Annual reduction	*Total reduction*	*Annual reduction*	*Total reduction*
1	38,993	779,850	114	2,281
2&3	211,241	4,224,825	4,507	90,136
4	203,321	4,066,425	4,302	86,040
5	38,993	779,850	114	2,281
6	245,273	4,905,450	5,385	107,695

Source: Model results

Cost Effectiveness

Cost data for the various options was assembled from project reports and cross checked with data included in the Egyptian Guidelines on Rural Sanitation (Chemonics Egypt, Ahmed Gaber and Associates, 2006). Unit costs were assessed for typical systems of a reference size since the unit costs of sewerage networks and wastewater treatment systems do vary with the size and distribution of the population served. Typical values were selected for this analysis, but more

detailed comparisons could be made for particular cases on the ground. The cost data are summarized in Table 10.

These unit costs were converted to 20-year lifecycle costs assuming discount rate of 8%. Net present values were then calculated for each option (Figure 6).

Using these data, costs of the notional interventions could be compared to the 20-year health impacts computed from the data in Table 8.

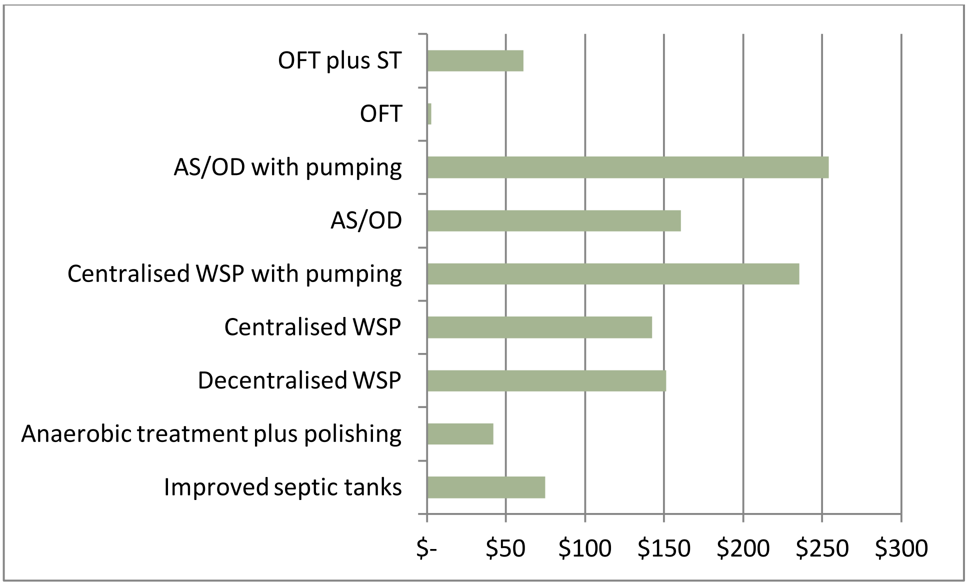
Cost-effectiveness ratios for each option are shown in Figure 7 against a logarithmic scale. Figure 7 shows that replacing septic tanks with no additional treatment improvements is significantly less cost-effective than other 'engineered' solutions. Figure 8 therefore shows only the engineered solutions against a linear scale.

Table 10: Unit costs for sanitation interventions

			Unit Capital costs		Annual Operational costs (per unit)	
	Connections	Design population	EGP	US$	EGP	US$
Household/ cluster options						
Network		0	0	0	0	0
Septic tank	1	5	600	101	150	25
Anaerobic Treatment plus Polish	3	15	750	126	200	34
Decentralized options						
Network	1,000	5,000	4,000,000	670,017	60,000	10,050
Waste stabilization pond (WSP)	1,000	5,000	500,000	83,752	25,000	4,188
Centralized options						
Network	10,000	50,000	40,000,000	6,700,168	600,000	100,503
Network with pumping	10,000	50,000	40,000,000	6,700,168	4,000,000	670,017
Waste stabilization pond (WSP)	10,000	50,000	2,500,000	418,760	250,000	41,876
Activated sludge/ oxidation ditch	10,000	50,000	12,500,000	2,093,802	2,500,000	418,760
On farm practices (36 months)						
			3,000,000	502,513	120,000	20,101

Source: Authors estimates based on ISSIP project documents and cross checked with (Chemonics Egypt, Ahmed Gaber and Associates, 2006)

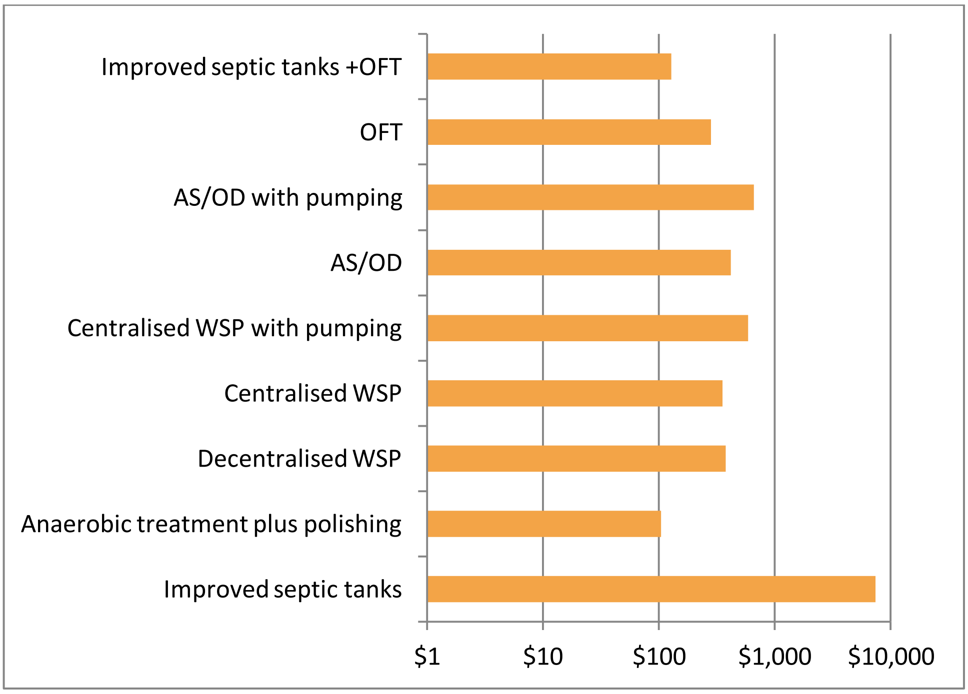
Figure 6: 20-year discounted NPV for sanitation options



Source: Model results

OFT – On-farm treatment; AS/OD = Activated Sludge or Oxidation Ditch; WSP = Waste Stabilization Pond

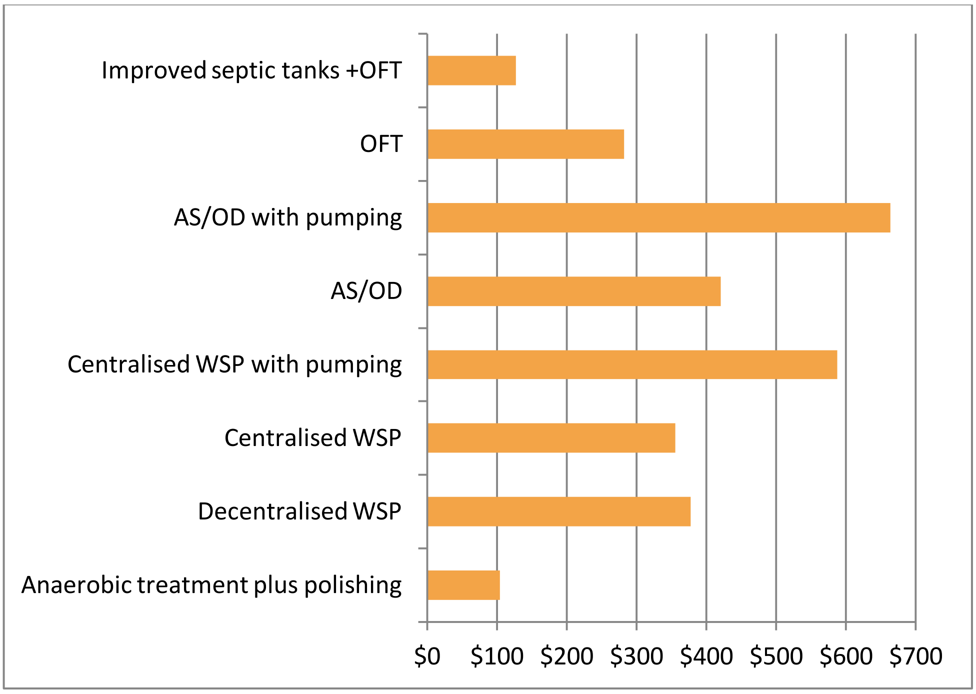
Figure 7: Cost effectiveness of interventions US$ per DALY avoided (log scale)



Source: Model results

OFT – On-farm treatment; AS/OD = Activated Sludge or Oxidation Ditch; WSP = Waste Stabilization Pond

Figure 8: Cost effectiveness of interventions (excluding household septic tanks) US$ per DALY avoided



OFT – On-farm treatment; AS/OD = Activated Sludge or Oxidation Ditch; WSP = Waste Stabilization Pond

8. DISCUSSION AND CONCLUSIONS

Current situation

The data and model all confirm that **the most significant health risk is posed by the un-regulated dumping of waste from poorly-performing household cess pits and septic tanks**. It is worth noting here that discharges from industrial units have not been included in this analysis, but this could be incorporated relatively easily. In the drainage basins observed during this study however visual observation suggests that dumping of the contents of domestic systems is a significant contributory factor in polluting the drains. Furthermore, some domestic waste may be being dumped into secondary and tertiary drainage/ irrigation channels and recycled for irrigation without dilution.

Effective sanitation options

Currently the focus of much HCWW investment is on the construction of additional treatment capacity. However the mass –balance modeling carried out here along with an analysis of potential water treatment options suggests that other, lower cost, alternatives may have equal importance and more potential in the short term to reduce health risks to downstream irrigators.

The most effective treatment intervention was the replacement of faulty household septic tanks/ cess pits, with effective primary and secondary treatment. This could be provided through neighborhood anaerobic systems with polishing or proprietary household septic tanks which are properly constructed and managed.

Even where centralized systems are preferred in the long run improvements **to onsite sanitation represent an important and cost-effective short-term intervention that could have significant health implications**. Furthermore household facilities could take advantage of more flexible approaches to finance, with households bearing a greater share of the upfront costs; willingness to pay to reduce the inconvenience of the current system of bayaras which need to be emptied frequently. Improved management of onsite systems could be a very useful focus of wastewater management strategies in the delta.

Waste stabilization ponds also provide good health protection and are not reliant on the operation of chlorinators for pathogen removal**.**

Surprisingly, the available field data and data from the literature along with the modeling **did not suggest that the Extended Aeration Oxidation ditches and Activated Sludge plants have a significant impact in terms of achieving required health targets unless effective chlorination could be guaranteed**; field observations suggest this is not the case at present. Furthermore the analysis presented here excludes the health implications of managing sludge products from these plants – the cost and risks associated with sludge handling make these options even less attractive than is suggested by our analysis.

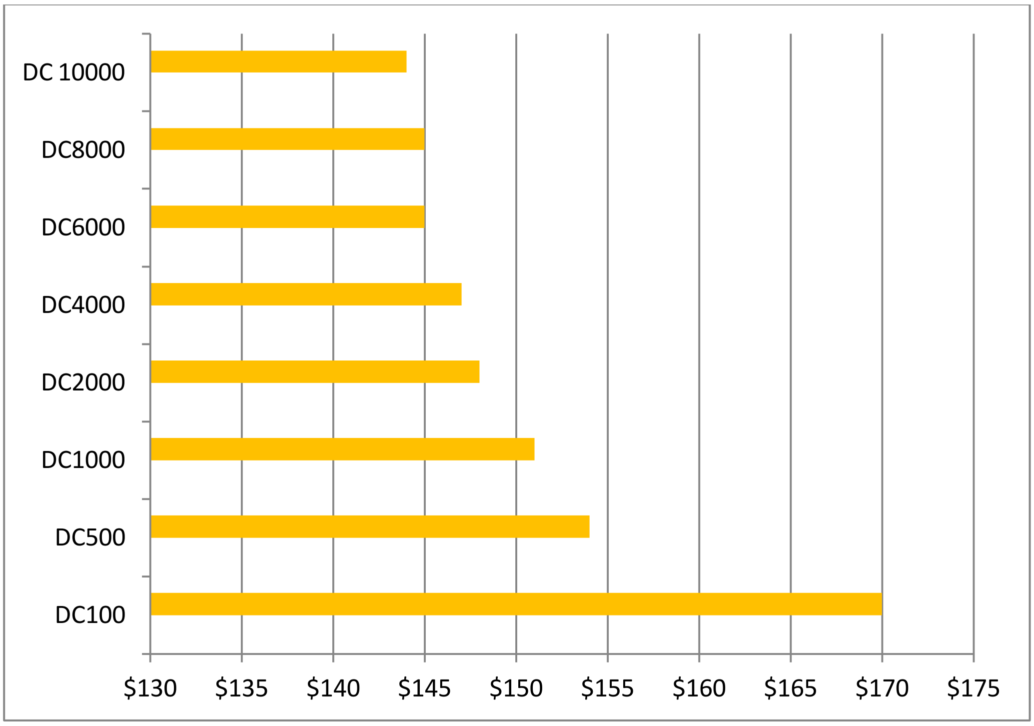
More significantly, **almost all infrastructure interventions were bettered by changes in on-farm and post-harvest behaviors** in terms of cost-effective health protection. This is an intervention which should not be ignored.

The costs of aerated systems are extremely high when compared to ponds because of the high operational costs of the former when energy prices are properly calculated. Ponds are considered to be expensive due to their higher land take, but at flow rates up to around 20,000m3 per day, the Rural Sanitation Guidelines suggest that they are better value for money over their operational lifetime (Chemonics Egypt, Ahmed Gaber and Associates, 2006).

The relative cost-effectiveness of all the treatment processes is highly dependent on their scale. Like most networks with treatment processes, centralization has a positive effect on unit costs up to a point. Decentralized waste stabilization ponds for example are more costly than centralized systems using the same treatment (Figure 9) if we assume that per capita operational costs for the sewer network remain equal.

If however community management of at least some part of the operation of the system is viable and advantageous for other reasons, then decentralized options become more financially attractive. Furthermore the use of smaller systems could obviate the need for pumping which is the single most effective way of bringing down unit costs and reducing the long term financial burden on the water companies.

Figure 9: Cost effectiveness of waste stabilization ponds systems of varying sizes (US$ per DALY avoided)



Source: Model results

Note: Y axis values indicate the number of connections per system under consideration.

Water and Wastewater Quality Standards

Until recently, legislation relating to reuse of agricultural drainage water was extremely restrictive. It is based on Egyptian Water Protection Law 48/1982 Articles 65 and 68 respectively.

Table 11: Selected Water quality parameters in Law 48/1982

Parameter	Standard
TDS	2000 mg/l
DO	>4mg/l
Temperature	<35°C
Ph	6-9
TDS	2000mg/l
TSS	50mg/l
BOD	60mg/l
NO_2	1mg/l
NO_3	45mg/l
Phosphate	1mg/l

The National Water Quality and Availability Management Program (NAWQAM) developed two composite indicators for water quality based on the standards. Table 12 shows the parameters considered in the development of these indices.

Table 12: Water quality parameters considered in the development of water quality indices (WQI)

Parameter	WQI-65	WQI-68
TDS	Yes	Yes
DO	Yes	Yes
Fecal Coliform	Yes	Yes
Temperature	Yes	Yes
pH	Yes	Yes
Turbidity	Yes	Yes
BOD	Yes	No
NO_3	Yes	No
Phosphate	Yes	No

Source: (NAQWAM, 2001)

NAWQAM went on to carry out extremely valuable monitoring and analysis of water quality in selected drains and to assess the impact of WWTPs on water quality. However, Table 12 shows the very high number of parameters that must be considered when assessing drain water quality irrespective of the downstream context in which drainage water will be reused. The conclusion of the study on the Hados drain was that 'most WWTPs operating within the study area violate the Egyptian law 48/1982'. The study further went on to conclude that 'the most appropriate treatment technique in the Delta of Egypt is the activated sludge process. Trickling filters and oxidation ponds may also be used' (NAQWAM, 2001). This final conclusion suggests that the use of composite parameters may place a much stronger emphasis on nutrient removal than on the removal of pathogens that are harmful to human health since the activated sludge process tends to be more effective at the former than the latter (Jimenez, Mara, Carr, & Brissaud, 2010).

Some observers have noted that the new National Code for wastewater reuse issued in 2000 is "less restricted" than previous legislation (notably Decree 44). The National Code allows for a consideration of standards and levels of treatment alongside monitoring and analysis of cropping patterns, irrigation methods and health protection measures. This approach is more in line with the latest guidelines for WHO on safe use of wastewater, excreta and greywater (World Health Organisation, 2006) which take a risk-minimization approach rather than the earlier approach of setting absolute targets for a range of water quality parameters. Use of this more flexible approach opens up the opportunity for a more nuanced analysis of investment strategies – with more emphasis on achieving optimum outcomes in terms of both health protection and nutrient re-use when considering agricultural applications of treated, partially treated and untreated wastewater. Such an approach might result in rather different conclusions than those reached by the NAQWAM team.

Conclusions and Further Work

The study explored the likely health impacts of wastewater management and sanitation investments in the Delta region of Egypt. Overall the study found that conventional approaches to sanitation management, and in particular the preference for centralized wastewater treatment processes with extended aeration many not always offer the most cost-effective solution in terms of health protection. While these options will remain an important part of the solution, health considerations as well as the need to keep operational costs as low as possible suggest that other more modern approaches may offer a better solution. These might include a blend of onsite sanitation

improvements, including the use of proprietary prefabricated septic tanks, better management and financial arrangements for emptying of septic tanks and pits and some decentralized and centralized wastewater treatment.

The study developed a modeling approach which combines simple assessments of impacts on downstream water quality with QMRA to assess broad health impacts. The approach, while relatively simple and easy to carry out, would be improved with more detailed location-specific data and in particular more information on downstream irrigation and harvesting practices for key crops.

Further work would enhance the value and accuracy of the model used as real cost data from operational systems could progressively be included to provide a more accurate assessment particularly of operational costs. Field testing of key indicator pathogens could usefully be scaled up as there is limited data currently available with which the efficacy of existing treatment processes in terms of health protection can be assessed.

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APPENDIX 1: QMRA

Introduction

Quantifiable microbial risk assessment (QMRA) is a tool which can be used to help operationalize the 2006 WHO guidelines on reuse of wastewater agriculture (World Health Organisation, 2006). It does this by determining a numerical value of the risk (or probability) of a disease or infection occurring as a result of an individual being exposed to a specified number of a particular pathogen.

Provided dose-response data are available QMRA can be used to estimate disease and infection risks which accrue to downstream populations who come into contact with contaminated wastewater in a range of ways for any pathogen. Figure 3: Relating incidence of pathogens to health impact in downstream populations in the main text shows the logical relationship between incidence of pathogens and health impacts.

In order to calculate health impacts the dose-response equation, disease-infection ratio and the impact in terms of ill-health and death must be known or estimated.

Dose-response relationships

Infection risk from a single exposure to a particular pathogen is computed using a dose-response equation. Mara gives the following approach to estimating disease and infection risk using one of the following two QMRA dose-response equations (Mara, 2010):

Exponential dose-response equation (commonly used for protozoan pathogens):

$$P_I(d) = 1 - e^{-rd} \quad (1)$$

(b) Beta-Poisson dose-response equation (commonly used for viral and bacterial pathogens):

$$P_I(d) = 1 - \left(1 + \frac{d}{N_{50}}\left(2^{1/\alpha} - 1\right)\right)^{-\alpha} \quad (2)$$

where $P_I(d)$ is the risk of infection in an individual from a single exposure to (here, the ingestion of) a single pathogen dose d; N_{50} is the median infective dose (i.e., the value of d that causes infection in 50% of the exposed population); and α and r are pathogen 'infectivity constants'.

The annual risk of infection is given by:

$$P_{I(A)}(d) = 1 - [1 - P_I(d)]^n \quad (3)$$

where $P_{I(A)}(d)$ is the annual risk of infection in an individual from n exposures per year to the single pathogen dose d.

Disease-infection ratios

Not all infections however result in disease. The risk of disease, as opposed to the risk of infection, is given by:

$$P_D(d) = aP_I(d) \quad (4)$$

where $P_D(d)$ is the risk of disease in an individual from a single exposure to the single pathogen dose *d*; and *a* is the disease/infection ratio (i.e., the proportion of the infected population that becomes clinically ill (thus the value of *a* is in the range 0−1).

Mara goes on to discuss how these values of risk (probability) expressed per person per exposure event can be translated into an annual infection risk – i.e. the percentage chance an individual has of becoming infected as a result of *n* exposures per year. Since the values of N_{50} and α are subject to some uncertainty Monte Carlo (MC) risk simulation is used to provide a more robust solution to QMRA calculations (for further information on MC simulation see for example Mara, 2010).

QMRA can thus be used to compute risk of disease.

APPENDIX 2: DATA TABLES

Table 13: Water Quality Data – El Moufty El Kobra

Site	Date	Location	Total Coliforms (NRC)	e-Coli (NRC)	Rotavirus	Helminths
El-Moufty El-Kobra	26/12/2010	1WW	2.00E+08	7.00E+07	0	0.00E+00
El-Moufty El-Kobra	09/01/2011	1WW	4.80E+08	2.60E+07	0	2.00E+00
El-Moufty El-Kobra	27/01/2011	1WW	4.80E+08	1.80E+07	1.00E+05	1.00E+00
El-Moufty El-Kobra	21/02/2011	1WW	1.10E+08	1.10E+07	1.00E+04	3.00E+00
El-Moufty El-Kobra	Ave	1WW	3.18E+08	3.13E+07	0	0
El-Moufty El-Kobra	26/12/2010	2AB1	2.40E+07	3.10E+06	0	0.00E+00
El-Moufty El-Kobra	09/01/2011	2AB1	1.50E+07	1.60E+06	0	0.00E+00
El-Moufty El-Kobra	27/01/2011	2AB1	1.10E+07	2.10E+05	1.00E+04	1.00E+00
El-Moufty El-Kobra	21/02/2011	2AB1	1.60E+07	1.30E+05	1.00E+04	1.00E+00
El-Moufty El-Kobra	Ave	2AB1	1.65E+07	1.26E+06	0	0
El-Moufty El-Kobra	26/12/2010	2AB2	2.80E+07	2.30E+06	0	0.00E+00
El-Moufty El-Kobra	09/01/2011	2AB2	1.10E+07	1.10E+06	0	0.00E+00
El-Moufty El-Kobra	27/01/2011	2AB2	3.10E+06	4.60E+06	1.00E+05	0.00E+00
El-Moufty El-Kobra	21/02/2011	2AB2	2.80E+06	2.60E+05	1.00E+04	0.00E+00
El-Moufty El-Kobra	Ave	2AB2	1.12E+07	2.07E+06	0	0
El-Moufty El-Kobra	26/12/2010	3FP1	2.10E+06	1.50E+05	0	0.00E+00
El-Moufty El-Kobra	09/01/2011	3FP1	6.80E+05	1.40E+05	0	0.00E+00
El-Moufty El-Kobra	27/01/2011	3FP1	4.10E+05	1.00E+05	1.00E+04	0.00E+00
El-Moufty El-Kobra	21/02/2011	3FP1	3.10E+05	4.80E+04	1.00E+03	0.00E+00
El-Moufty El-Kobra	Ave	3FP1	8.75E+05	1.10E+05	0	0
El-Moufty El-Kobra	26/12/2010	3FP2	9.30E+06	7.00E+05	0	0.00E+00
El-Moufty El-Kobra	09/01/2011	3FP2	4.10E+06	2.80E+05	0	0.00E+00
El-Moufty El-Kobra	27/01/2011	3FP2	4.80E+05	4.60E+04	1.00E+04	0.00E+00

Site	Date	Location	Total Coliforms (NRC)	e-Coli (NRC)	Rotavirus	Helminths
El-Moufty El-Kobra	21/02/2011	3FP2	1.60E+05	6.80E+04	1.00E+03	0.00E+00
El-Moufty El-Kobra	Ave	3FP2	3.51E+06	2.74E+05	0	0
El-Moufty El-Kobra	26/12/2010	4MP1	7.00E+05	1.20E+04	0	0.00E+00
El-Moufty El-Kobra	09/01/2011	4MP1	1.50E+05	1.30E+04	0	0.00E+00
El-Moufty El-Kobra	27/01/2011	4MP1	7.40E+04	1.30E+04	1.00E+04	0.00E+00
El-Moufty El-Kobra	21/02/2011	4MP1	4.20E+04	4.10E+03	1.00E+02	0.00E+00
El-Moufty El-Kobra	Ave	4MP1	2.42E+05	1.05E+04	0	0
El-Moufty El-Kobra	26/12/2010	4MP2	2.80E+05	1.60E+04	0	0.00E+00
El-Moufty El-Kobra	09/01/2011	4MP2	2.60E+05	1.80E+04	0	0.00E+00
El-Moufty El-Kobra	27/01/2011	4MP2	4.60E+04	6.90E+03	1.00E+03	0.00E+00
El-Moufty El-Kobra	21/02/2011	4MP2	3.80E+04	6.10E+03	1.00E+03	0.00E+00
El-Moufty El-Kobra	Ave	4MP2	1.56E+05	1.18E+04	0	0
El-Moufty El-Kobra	26/12/2010	7CU	1.20E+02	1.30E+01	0	0.00E+00
El-Moufty El-Kobra	09/01/2011	7CU	1.10E+02	4.20E+01	0	1.00E+00
El-Moufty El-Kobra	27/01/2011	7CU	1.00E+02	5.10E+01	1.00E+01	0.00E+00
El-Moufty El-Kobra	21/02/2011	7CU	1.30E+02	3.40E+01	0.00E+00	0.00E+00
El-Moufty El-Kobra	Ave	7CU	1.15E+02	3.50E+01	0	0
El-Moufty El-Kobra	26/12/2010	8CM	7.00E+04	4.60E+03	0	0.00E+00
El-Moufty El-Kobra	09/01/2011	8CM	1.30E+04	1.10E+03	0	0.00E+00
El-Moufty El-Kobra	27/01/2011	8CM	6.80E+03	1.80E+03	1.00E+03	0.00E+00
El-Moufty El-Kobra	21/02/2011	8CM	4.60E+03	4.60E+02	1.00E+02	0.00E+00
El-Moufty El-Kobra	Ave	8CM	2.36E+04	1.99E+03	0	0
El-Moufty El-Kobra	26/12/2010	9CDD	2.30E+02	1.80E+02	0	0.00E+00
El-Moufty El-Kobra	09/01/2011	9CDD	2.10E+02	1.00E+02	0	0.00E+00

Site	Date	Location	Total Coliforms (NRC)	e-Coli (NRC)	Rotavirus	Helminths
El-Moufty El-Kobra	27/01/2011	9CDD	2.40E+02	1.20E+02	1.00E+02	0.00E+00
El-Moufty El-Kobra	21/02/2011	9CDD	1.80E+02	1.00E+02	0.00E+00	0.00E+00
El-Moufty El-Kobra	Ave	9CDD	2.15E+02	1.25E+02	0	0

Table 14: Water Quality Data – Sidi Salem

Site	Date	Location	Total Coliforms (NRC)	e-Coli (NRC)	Rotavirus	Helminths
Sidi Salem	26/12/2010	1WW	1.20E+08	7.00E+07	0	1.00E+00
Sidi Salem	09/01/2011	1WW	3.10E+08	4.60E+07	0	0.00E+00
Sidi Salem	27/01/2011	1WW	1.50E+08	2.70E+07	0.00E+00	0.00E+00
Sidi Salem	21/02/2011	1WW	1.10E+07	1.80E+06	0.00E+00	4.00E+00
Sidi Salem	Ave	1WW	1.48E+08	3.62E+07	0	0
Sidi Salem	26/12/2010	5ENC	2.30E+06	6.40E+05	0	1.00E+00
Sidi Salem	09/01/2011	5ENC	4.10E+05	6.40E+04	0	0.00E+00
Sidi Salem	27/01/2011	5ENC	6.10E+05	4.60E+04	0.00E+00	1.00E+00
Sidi Salem	21/02/2011	5ENC	3.80E+05	2.80E+04	0.00E+00	2.00E+00
Sidi Salem	Ave	5ENC	9.25E+05	1.95E+05	0	0
Sidi Salem	26/12/2010	6EC	7.00E+04	7.20E+03	0	1.00E+00
Sidi Salem	09/01/2011	6EC	6.20E+03	7.10E+02	0	0.00E+00
Sidi Salem	27/01/2011	6EC	4.30E+03	3.80E+02	0.00E+00	0.00E+00
Sidi Salem	21/02/2011	6EC	2.30E+03	1.30E+02	0.00E+00	0.00E+00
Sidi Salem	Ave	6EC	2.07E+04	2.11E+03	0	0
Sidi Salem	26/12/2010	7CU	3.00E+02	1.20E+02	0	0.00E+00
Sidi Salem	09/01/2011	7CU	1.60E+03	1.60E+02	0	0.00E+00

Site	Date	Location	Total Coliforms (NRC)	e-Coli (NRC)	Rotavirus	Helminths
Sidi Salem	27/01/2011	7CU	4.80E+02	1.40E+02	0.00E+00	0.00E+00
Sidi Salem	21/02/2011	7CU	2.60E+02	9.00E+01	0.00E+00	0.00E+00
Sidi Salem	Ave	7CU	6.60E+02	1.28E+02	0	0
Sidi Salem	26/12/2010	8CM	4.60E+03	1.10E+03	0	0.00E+00
Sidi Salem	09/01/2011	8CM	1.10E+03	3.10E+02	0	0.00E+00
Sidi Salem	27/01/2011	8CM	1.10E+03	2.10E+02	0.00E+00	0.00E+00
Sidi Salem	21/02/2011	8CM	4.80E+02	2.00E+02	0.00E+00	0.00E+00
Sidi Salem	Ave	8CM	1.82E+03	4.55E+02	0	0
Sidi Salem	26/12/2010	9CD	1.80E+03	4.10E+02	0	0.00E+00
Sidi Salem	09/01/2011	9CD	4.10E+02	1.60E+02	0	0.00E+00
Sidi Salem	27/01/2011	9CD	3.20E+03	1.10E+02	0.00E+00	0.00E+00
Sidi Salem	21/02/2011	9CD	2.10E+02	1.10E+02	0.00E+00	0.00E+00
Sidi Salem	Ave	9CD	1.41E+03	1.98E+02	0	0
Sidi Salem	26/12/2010	9CDD	3.70E+02	1.60E+02	0	0.00E+00
Sidi Salem	09/01/2011	9CDD	2.10E+02	1.20E+02	0	0.00E+00
Sidi Salem	27/01/2011	9CDD	1.00E+02	3.10E+02	0.00E+00	0.00E+00
Sidi Salem	21/02/2011	9CDD	1.10E+02	1.00E+02	0.00E+00	0.00E+00
Sidi Salem	Ave	9CDD	1.98E+02	1.73E+02	0	0

Table 15: Hourly Water Quality Data – El Moufty El Kobra

Site	Location	Time	Total Coliforms (NRC)	e-Coli (NRC)
El-Moufty El-Kobra	1WW	1415	3.10E+08	4.10E+07
El-Moufty El-Kobra	1AP2	1415	4.60E+05	6.30E+04
El-Moufty El-Kobra	1WW	1515	2.60E+08	1.60E+07
El-Moufty El-Kobra	1AP2	1515	2.30E+05	4.10E+04
El-Moufty El-Kobra	1WW	1615	2.10E+08	1.80E+07
El-Moufty El-Kobra	1AP2	1615	4.10E+04	1.20E+04
El-Moufty El-Kobra	1WW	1715	6.70E+07	7.20E+06
El-Moufty El-Kobra	1AP2	1715	1.10E+04	3.20E+03
El-Moufty El-Kobra	1WW	1815	3.50E+07	2.40E+06
El-Moufty El-Kobra	1AP2	1815	2.10E+04	2.60E+03

Table 16: Hourly Water Quality Data – Sidi Salem

Site	Location	Time	Total Coliforms (NRC)	e-Coli (NRC)
Sidi Salem	1WW	700	2.60E+08	2.10E+07
Sidi Salem	5ENC	700	1.20E+06	3.10E+04
Sidi Salem	6EC	700	1.10E+03	4.10E+02
Sidi Salem	1WW	800	4.10E+08	6.80E+07
Sidi Salem	5ENC	800	3.10E+05	1.10E+04
Sidi Salem	6EC	800	1.20E+03	1.00E+02
Sidi Salem	1WW	900	3.40E+08	4.10E+07
Sidi Salem	5ENC	900	9.80E+05	6.70E+04
Sidi Salem	6EC	900	4.40E+03	4.70E+02
Sidi Salem	1WW	1000	2.80E+07	1.10E+07

Site	Location	Time	Total Coliforms (NRC)	e-Coli (NRC)
Sidi Salem	5ENC	1000	1.10E+05	2.10E+04
Sidi Salem	6EC	1000	1.00E+03	1.10E+02
Sidi Salem	1WW	1100	4.10E+08	1.30E+06
Sidi Salem	5ENC	1100	2.10E+06	2.60E+04
Sidi Salem	6EC	1100	3.10E+03	4.10E+02
Sidi Salem	1WW	1200	2.10E+07	4.30E+06
Sidi Salem	5ENC	1200	1.20E+04	6.40E+03
Sidi Salem	6EC	1200	2.60E+02	1.00E+02
Sidi Salem	1WW	1300	1.10E+08	4.10E+07
Sidi Salem	5ENC	1300	7.50E+06	2.10E+05
Sidi Salem	6EC	1300	6.90E+03	3.20E+02
Sidi Salem	1WW	1400	2.60E+07	1.70E+06
Sidi Salem	5ENC	1400	1.80E+05	1.14E+02
Sidi Salem	6EC	1400	6.40E+03	1.70E+02
Sidi Salem	1WW	1500	1.80E+08	2.80E+06
Sidi Salem	5ENC	1500	2.60E+04	2.30E+03
Sidi Salem	6EC	1500	1.00E+02	9.00E+01
Sidi Salem	1WW	1600	2.30E+07	4.60E+06
Sidi Salem	5ENC	1600	4.50E+04	1.20E+04
Sidi Salem	6EC	1600	2.30E+02	1.00E+02
Sidi Salem	1WW	1700	1.60E+08	2.30E+06
Sidi Salem	5ENC	1700	3.40E+04	1.80E+03
Sidi Salem	6EC	1700	1.40E+02	9.00E+01
Sidi Salem	1WW	1800	4.20E+07	2.60E+05
Sidi Salem	5ENC	1800	3.70E+04	1.70E+03

Site	Location	Time	Total Coliforms (NRC)	e-Coli (NRC)
Sidi Salem	6EC	1800	1.30E+02	8.00E+01

Table 17: Water Quality Data – Trench/Bayaras

Command Area	Total Coliforms (NRC)	e-Coli (NRC)
Sidi Salem	4.10E+09	1.20E+08
Sidi Salem	2.60E+08	3.10E+06
Sidi Salem	3.20E+08	4.10E+07
Sidi Salem	1.70E+08	2.10E+07
Sidi Salem	6.10E+08	1.60E+07
Sidi Salem	4.20E+07	2.10E+06
Sidi Salem	3.90E+07	2.30E+06
El-Moufty El-Kobra	4.30E+08	1.20E+00
El-Moufty El-Kobra	6.10E+08	3.10E+07
El-Moufty El-Kobra	2.80E+07	1.10E+06
El-Moufty El-Kobra	2.10E+08	4.30E+06
El-Moufty El-Kobra	6.30E+07	2.80E+06