EMFULENI COMMUNITY SANITATION INITIATIVE

WASTEWATER IRRIGATION

“A ROTARY SUPPORTED COMMUNITY INITIATIVE”

BUSINESS PLAN STUDY 2

INVESTIGATION REPORT
September 2016

COMMUNITY FORUM

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1. INTRODUCTION

Sanitation problems have been experienced for more than twenty years in the Greater Emfuleni area. The problems include pumpstation failures, pipe failures and blockages, non-compliant effluent, WWTW overloading, etc. All this has resulted in spillages and the severe pollution of the environment and especially the waterways of which the Vaal River is the largest.

In addition to the above the Emfuleni area has a high level of unemployment and poverty. Many of the industries, especially those linked to the steel industry, has scaled down or closed.

The Sedibeng Regional Sanitation Scheme has been approved for the area. The total estimate is R4,5 billion but with an anticipated roll-out at R500 mil per year. The water and sanitation infrastructure generally require input upgrading to ensure sufficient water supply and to prevent damage to the environment through sewage spillages and non-compliant treatment facilities. It can therefore reasonably be expected that the availability of funds will become under increasing strain. In addition to the above it is and will be difficult to convince the communities that the spending of R4,5 billion in their area without any direct targetable benefit to them whilst they battle to survive without jobs and in poverty. Treasury has withdrawn the allocated R4,5 billion and the municipality will have to source different funding. The Rietspruit Works is still scheduled for extension by ± 35 Mℓ/day with a connection pipe between Leeuwkuil and Rietspruit.

The above brought the community and businesses together to explore means to address the sanitation problems, while providing tangible benefits to the communities to create jobs and relieve poverty.

Wastewater comprises water, organic and inorganic materials and nutrients. The wastewater treatment processes remove the inorganic solids by means of screening and degritting, while the organic material and nutrients are removed biologically producing sludge. The challenge is to convert the treatment of sewerage to a resource against the present burden. This can be done by treating the sewerage in such a way that the nutrients are retained and to utilize the water for agriculture to create jobs and relieve poverty. The sludges produced can also be utilized for composting or methane production for power generation.

The utilization of wastewater for agriculture is accepted and practiced widely globally. The World Health Organization (WHO) and DWS have published various guidelines with regard to the safe utilization of wastewater and sludges for agriculture. The guidelines include raw sewerage, faeces, treated wastewater and study utilization.

The effluent utilization of treated wastewater from the three existing plants in the Emfuleni area is considered in this study with WHO Volume II Wastewater Use in Agriculture as main reference.

2. STOCKHOLM FRAMEWORK

Wastewater is increasingly used for agriculture with the main driving forces:

- Increasing water scarcity and stress and the degradation of fresh water supplies.
- Population increase and related demand for jobs, food and fibres.
- A growing recognition of the resource value of wastewater and the nutrients it contains.
- Millennium Development Goals with regard to environmental sustainability and relieving of poverty and hunger.

The Stockholm Framework is an integrated approach that combines risk assessment and management to control water related diseases. The Stockholm Framework was developed for infectious diseases, but can be applied to water related diseases.

The Framework comprises:

- Assessment of health risks based on studies.
- Tolerable health risk / health based targets.
- Health risk management

Tolerable health risk is based on the Disability Adjusted Life Years (DALYs) which is 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 latter because of disability or health from a disease compared with a long life tree of disability in absence of the disease. When risks are described in Dalys different health outcomes can be compared and risk management decisions taken.

3. RISK IDENTIFICATION AND MANAGEMENT

The identified risks are:

- Helminths
- Protozoa
- Viruses

The risks are measured and monitored through the risk management and mitigation processes. The risk groups are:

- Consumers
- Workers
- Nearby communities

The wastewater to be utilized will be treated. In addition the following barriers between the water and the risks group are envisaged:

- Retention storage of 8 – 10 days. The storage will be in an open dam with water depth 4 m. The retention will allow for the setting of any Helminth eggs which has been proven to be effective. Sunlight will assist in stabilization while the anticipated algae growth will increase the pH to further reduce pathogens and Helminth eggs. Retention will also allow for die-off of viruses and pathogens reaching the retention pond. The setting characteristics of biofilter effluent is good which should ensure clean water with limited Helminths.

  Alternatively to the retention ponds tertiary treatment by means of Bamboo on reed beds will be considered. Bamboo has the additional benefit of produce in the form of Bamboo sprouts and bamboo for paper, charcoal, furniture and power generation while providing effective security barrier.

- Irrigation methods

  Flood irrigation will be done to limit exposure of foliage to the water. In addition irrigation will be stopped 6 – 10 days prior to harvesting to allow for die-off viruses and pathogens. Drip and spraying irrigation will also be considered.

- Health education and practices

- PPE – gloves, boots, overalls, safety glasses, moth / nose covers.

- All workers to be inoculated against Hepatitis.

- Regular health examinations
- Risk monitoring and management

The effluent from the plant need not be chlorinated.

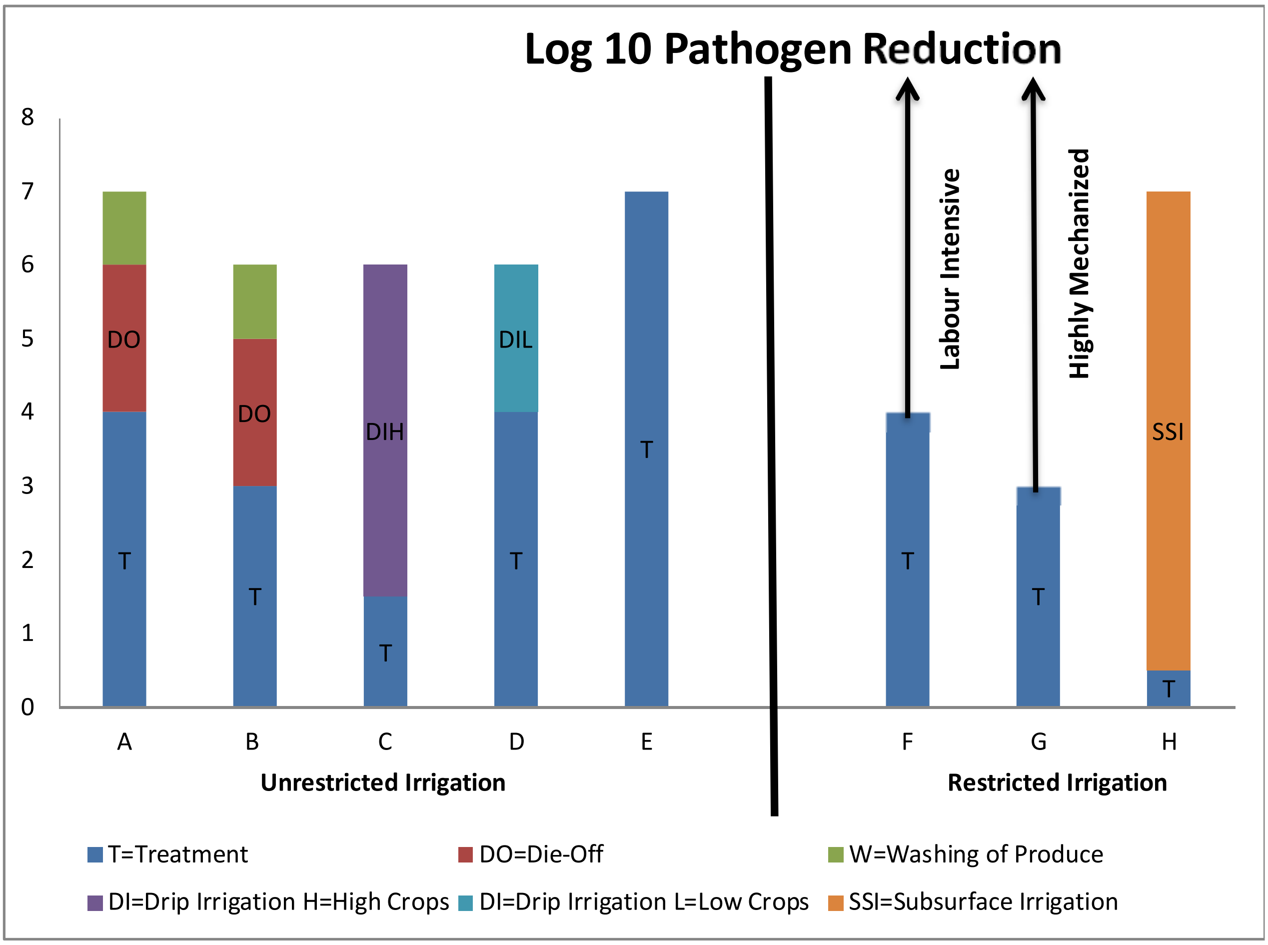
The hazards and corresponding barriers are indicated below.

Pathogen reductions achievable by various health protection measures

Control measures[a]	Pathogen reduction (log units)	Notes
Wastewater treatment	1 – 6	The required pathogen reduction to be achieved by wastewater treatment depends on the combination of health protection measures selected.
Localized (drip) irrigation (low-growing crops)	2	Root crops and crops such as lettuce that grow just above, but partially in contact with the soil.
Localized (drip) irrigation (high-growing crops)	4	Crops, such as tomatoes, the harvested parts of which are not in contact with the soil.
Spray drift control (spray irrigation)	1	Use of micro-sprinklers, anemometer-controlled direction-switching sprinklers, inward-throwing sprinklers, etc.
Spray buffer zone (spray irrigation)	1	Protection of residents near spray or sprinkler irrigation. The buffer zone should be 50 – 100 m.
Pathogen die-off	0.5 – 2 per day	Die-off on crop surfaces that occurs between last irrigation and consumption. The log unit reduction achieved depends on climate (temperature, sunlight intensity, humidity), time, crop type, etc.
Produce washing with water	1	Washing salad crops, vegetables and fruit with clean water
Produce disinfection	2	Washing salad crops, vegetables and fruit with a weak disinfectant solution and rinsing with clean water.
Produce peeling	2	Fruits, not crops
Produce cooking	6 – 7	Immersion in boiling or close-to-boiling water until the food is cooked ensures pathogen destruction.

Sources: Beuchat (1988); Petterson & Ashbolt (2003); NRMMC & EPHCA (2005)

The anticipated DALY reductions for the different barriers are as follows:



The Stockholm Framework and guidelines adopted by the WHO are comprehensive and covers all aspects regarding the health risk associated with wastewater irrigation for agriculture. Monitoring and health mitigation / management measures are well defined. The approach is to develop appropriate barriers between the risk groups and the wastewater in order to reduce the Dalys to acceptable risk levels. The risks and efficiency of the different barriers indicated above will be evaluated with the Pilot Project. This will facilitate the development of local and national barriers and procedures to allow the safe utilization of wastewater for agriculture.

The risk of wastewater related diseases must be considered in context. The general condition of the sanitation infrastructure in the Greater Emfuleni area, as well as, elsewhere within the Vaal catchment areas is poor. This results in not all sewerage reaching the Wastewater Treatment Works. These spillages within the townships which also reach the waterways pose a serious health threat to the residents and water users downstream. Together with the spillages the quality of effluent from the WWTW's contributes to the pollution and degradation of the rivers.

All the above goes unchecked with regard to pollution, as well as, health threats. The proposed irrigation of wastewater effluent and the Pilot Project will assist in quantifying the risks and to develop appropriate barriers and mitigation measures.

The above also supports the initiative to convert the sanitation processes within the area to resources to create jobs and generate funding. This will assist in making funding available for the retrofitting and upgrading of the networks and WWTW's to reduce pollution and associated health risks. The funding earmarked for sanitation in this area can then be diverted to more pressing problems elsewhere. Rolling the initiative out to other areas in the country and generate funding and relieve the pressure on the fiscus.

4. HEALTH BASED TARGETS

The tolerable burden of disease and health-based targets are determined in the following steps:

- **Step 1 : Tolerable risk of infection**

$$\text{Tolerable disease risk}_{pppy} = \frac{\text{Tolerable Dalys}_{pppy}}{\text{Dalys per case of disease}}$$

DALYs, disease risks, disease / infection ratios and tolerable infection risks for rotavirus, Campylobacter and Cryptosporidium

Pathogen	DALYs per case of disease[a]	Disease risk pppy equivalent to 10^{-6} DALY pppy	Disease / infection ratio	Tolerable infection risk pppy[b]
Rotavirus:				
IC	1.4×10^{-2}	7.1×10^{-5}	0.05[c]	1.4×10^{-3}
DC	2.6×10^{-2}[c]	3.8×10^{-5}	0.05[c]	7.7×10^{-3}
Campylobacter	4.6×10^{-3}	2.2×10^{-4}	0.7	3.1×10^{-4}
Cryptosporidium	1.5×10^{-3}	6.7×10^{-4}	0.3	2.2×10^{-3}

IC, industrialized countries; DC, developing countries; pppy = per person per year

[a] *Values from Havelaar & Melse (2003)*

[b] *Tolerable infection risk = disease risk + disease / infection ratio*

[c] *For developing countries, the DALYs per rotavirus death have been reduced by 95 %, as approximately 95 % of these deaths occur in children under the age of two who are not exposed to wastewater-irrigated foods. The disease / infection ratio for rotavirus is low, as immunity is mostly developed by the age of three.*

The tolerable disease risks are in the range of 10^{-3} to 10^{-4} Dalys per person per year. This is conservative taking that the global incidence of diarrhoeal disease is 0.1 – 1 per person per year.

- **Step 2 : QMRA (Quantitive Microbial Risk Assessment)**

Determine by QMRA the corresponding pathogen reduction that needs to be achieved.

- **Step 3 : Required Pathogen Reduction**

Estimating the volume of treated wastewater remaining on the crop following final irrigation (Mℓ/100g of crop) the required pathogen reduction can be determined to achieve the tolerable additional disease reduction of $\leq 10^{-6}$ Daly per person per year.

- **Step 4 : Health based protection measures to achieve required pathogen reduction**

Pathogen reductions achievable by various health protection measures

Control measures	Pathogen reduction (log units)	Notes
Wastewater treatment	1 – 6	The required pathogen reduction to be achieved by wastewater treatment depends on the combination of health protection measures.
Localized (drip) irrigation (low-growing crops)	2	Root crops and crops such as lettuce that grow just above, but partially in contact with the soil.
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Sources: Beuchat (1988); Petterson & Ashbolt (2003); NRMMC & EPHCA (2005)

- **Step 5 : Verification**

For viral and bacterial infections establish verification monitoring levels for selected treatment processes with E. Coli as indicator. For Helminth eggs determine monitoring standard on number of eggs per litre.

Options for the reduction of Helminth eggs by health protection measures for different Helminth egg numbers in untreated wastewater and associated verification requirements

Health protection measure	Number of Helminth eggs per litre of untreated wastewater	Required Helminth egg reduction by treatment (log units)	Verification monitoring level (Helminth eggs per litre of treated wastewater)[a]	Notes
Treatment	10^3 10^2 10	3 2 1	≤1 ≤1 ≤1	Treatment should be shown to achieve this egg quality reliably.
	≤1	0	N/A	The target of ≤1 egg per litre is automatically achieved.
Treatment and produce washing	10^3	2	≤10	The reduction achieved by treatment is followed by a 1 log unit reduction by produce washing in a weak detergent solution and rinsing with clean water[b].
	10^2	1	≤10	As above.
	10	0	N/A	The required 1 log unit reduction is achieved by produce washing in a weak detergent solution and rinsing with clean water[b].
	≤10	0	N/A	The target of ≤1 egg per litre is automatically achieved.

N/A = Not Applicable

[a] *With waste stabilization ponds, the pond retention times can be used as a verification tool. (Currently, there are no generally valid surrogate verification tools for other treatment processes, although it may be possible to develop them locally).*

[b] *Valid only where this practice is common or where it can be successfully promoted and verified.*

Verification monitoring of wastewater treatment (E.Coli numbers per 100 Mℓ of treated wastewater) for the various levels of wastewater treatment in Options A-G

Type of irrigation	Option	Required pathogen reduction by treatment (log units)	Verification monitoring level (E. coli per 100 Mℓ)	Notes
Unrestricted	A	4	$\leq 10^3$	Root crops
	B	3	$\leq 10^4$	Leaf crops.
	C	2	$\leq 10^5$	Drip irrigation of high-growing crops
	D	4	$\leq 10^3$	Drip irrigation of low-growing crops
	E	6 or 7	$\leq 10^1$ or $\leq 10^0$	Verification level depends on the requirements of the local regulatory agency[a]
Restricted	F	4	$\leq 10^4$	Labour-intensive agriculture (protective of adults and children under 15).
	G	3	$\leq 10^5$	Highly mechanized agriculture
	H	0.5	$\leq 10^6$	Pathogen removal in a septic tank

[a] *For example, for secondary treatment, filtration and disinfection: five-day biochemical oxygen demand, <10 mg/ℓ; turbidity, <2 nephelometric turbidity units; chlorine residual; 1 mg/ℓ; pH, 6 – 9; and faecal coliforms, not detectable in 100 Mℓ.*

5. HEALTH PROTECTION MEASURES

5.1 Introduction

Health protection measures include:

- Crop restriction
- Wastewater application techniques
- Pathogen die-off between last irrigation and consumption
- Food preparation techniques
- Human exposure control
- Wastewater treatment

The feasibility and efficacy of any or combination of the health protection measures depend on the following functions:

- Availability of resources
- Existing social and agricultural practices
- Market demand
- Existing proteins of waste related diseases
- Institutional capacity to monitor and enforce protection measures

The wastewater under consideration will be treated by screening, degritting, settling biofiltration and clarification before use. Chlorine disinfection and / or dam retention will be provided.

5.2 Crop restriction

Restricting crop to non-edible or crop that must be cooked before use. Crop selection will be evaluated in the Pilot Project to determine the most feasible crops with regard to health risks, finances, etc.

5.3 Wastewater application techniques

Selection of wastewater application techniques based on health protection

Irrigation technique	Factors affecting choice	Special measures for wastewater
Flood	- Lowest cost. - Exact levelling not required.	- Thorough protection for fieldworkers, crop handlers and consumers.
Furrow	- Low cost. - Levelling may be needed.	- Protection for fieldworkers, possibly for crop handlers and consumers.
Spray and sprinkler	- Medium water use efficiency. - Levelling not required. - Advanced sprinklers that reduce crop contamination and potential contamination of local communities have been developed that can reduce exposure to pathogens by 1 log unit.	- Some crops, especially tree fruits, are prone to more contamination. - Minimum distance of 50 – 100 m from houses and roads. - Anaerobic wastewaters should not be used because of odour nuisance. - New technologies reduce spray drift and may be able to reduce crop contamination by better targeting.
Sub-surface and localized (drip, trickle and bubbler)	- High cost. - High water use efficiency. - Higher yields. - Potential for significant reduction of crop contamination. - Localized irrigation systems and sub-surface irrigation can substantially reduce exposure to pathogens by 2-6 log units.	- Localized irrigation : selection of non-clogging emitters; filtration to prevent clogging of emitters.

5.4 Pathogen die-off before consumption

The interval between final irrigation and consumption reduces the pathogens by 1 – 2 log units per day.

5.5 Food preparation methods

The pathogen reduction for various methods is as follows:

METHODS	REDUCTION (Log units)
Vigorous washing	1 – 2
Peeling	2
Cooking	5 – 6

5.6 Human exposure control

5.6.1 Field workers

a. By means of PPE

- Boots
- Gloves
- Glasses
- Mouth and nose fitters (covers)
- Overalls

b. Hygiene promotion programmes

5.6.2 Consumers

- Food preparation
- Hygiene programmes

5.6.3 Immunization

5.7 Wastewater treatment

Log unit reduction or inactivation of excreted pathogens achieved by selected wastewater treatment processes

Treatment process	Log unit pathogen removals[a]			
	Viruses	Bacteria	Protozoan (oo)cysts	Helminth eggs
Low-rate biological processes:				
Waste stabilization ponds	1 – 4	1 – 6	1 – 4	1 – 3[b]
Wastewater storage and treatment reservoirs	1 – 4	1 – 6	1 – 4	1 – 3[b]
Constructed wetlands	1 – 2	0.5 – 3	0.5 – 2	1 – 3[b]
High-rate processes:				
Primary treatment				
Primary sedimentation	0 – 1	0 – 1	0 – 1	0 – <1[b]
Chemically enhanced primary treatment	1 – 2	1 – 2	1 – 2	1 – 3[b]
Anaerobic upflow sludge blanket reactors	0 – 1	0.5 – 1.5	0 – 1	0.5 – 1[b]
Secondary treatment				
Activated sludge + secondary sedimentation	0 – 2	1 – 2	0 – 1	1 – <2[b]
Trickling filters + secondary sedimentation	0 – 2	1 – 2	0 – 1	1 – 2[c]
Aerated lagoon + settling pond	1 – 2	1 – 2	0 – 1	1 – 3[c]
Tertiary treatment				
Coagulation / flocculation	1 – 3	0 – 1	1 – 3	2[b]
High-rate granular or slow-rate sand filtration	1 – 3	0 – 3	0 – 3	1 – 3[b]
Dual-media filtration	1 – 3	0 – 1	1 – 3	2 – 3[b.d]
Membranes	2.5 - >6	3.5 - >6	>6	>3[b.d]
Disinfection				
Chlorination (free chlorine)	1 – 3	2 – 6	0 – 1.5	0 – <1[b]
Ozonation	3 – 6	2 – 6	1 – 2	0 – 2[e]
Ultraviolet radiation	1 - >3	2 - >4	>3	0[c]

Sources: Feachem et al, (1983); Schwartzbrod et al. (1989); Sobsey (1989); El-Gohary et al. (1993); Rivera et al. (1995); Rose et al. (1996, 1997); Strauss (1996); Landa, Capella & Jiménez (1997); Clancy et al. (1998); National Research Council (1998); Yates & Gerba (1998); Karimi, Vickers & Harasick (1999); Lazarova et al. (2000); Jiménez et al. (2001); Jiménez & Chávez (2002); Jiménez (2003, 2005); von Sperling et al. (2003); Mara (2004); Rojas-Valencia et al. (2004); WHO (2004a); NRMMC & EPHCA (2005).

[a] *The log unit reductions are log_{10} unit reductions defined as log_{10} (initial pathogen concentration / final pathogen concentration). Thus, a 1 log unit reduction = 90 % reduction; a 2 log unit reduction = 99 % reduction; a 3 log unit reduction = 99.9 % reduction; and so on.*

[b] *Data from full-scale plants.*

[c] *Theoretical efficiency based on removal mechanisms.*

[d] *Data from tests with up to 2 log units initial content; removal may be greater than that reported.*

[e] *Data from laboratory tests.*

Advantages and disadvantages of different wastewater treatment processes

Treatment	Advantages	Disadvantages[a]
Low-rate biological systems:		
Waste stabilization ponds, wastewater storage and treatment reservoirs	- Effective at reducing pathogen concentrations (all types of pathogens). - Low costs of construction, operation and maintenance. - Simplicity of operation and maintenance. - Produce little sludge with low helminth ova content. - Work well in warm climates with medium to low evaporation. - No use of electrical energy for operation. - Help to reconcile wastewater production with water irrigation demand because they can store water for use at peak demand times.	- Hydraulic short-circuiting may reduce pathogen removal efficiency. - Algae in effluents may interfere with irrigation application. - Require large amounts of land (especially in temperature environments). - Can facilitate vector breeding if not properly maintained. - High evaporation in arid climates leads to loss of water resources and increased effluent salinity. .
Constructed wetlands	- Effective in reducing pathogen concentrations - medium bacterial and viral removal efficiency. - Low cost, low complexity. - Relatively simple operation and maintenance requirements. - Require no electricity. - May improve environment for other species (e.g. birds).	- Pathogen removal variable, depending upon a variety of factors. - Different designs / plants needed in different settings. - High evapotranspiration in arid climates leads to loss of water resources and increased effluent salinity. - May facilitate vector breeding. - Wildlife excreta may cause deterioration of effluent quality.
High-rate processes:		
Primary sedimentation	- Low cost. - Simple technology.	- Low pathogen removal.
Chemically enhanced primary treatment	- Improves primary sedimentation at low cost. - Low area requirement. - High helminth egg removal efficiency. - Produces effluents suitable for agricultural needs.	- Produces more sludge than normal primary sedimentation. - Need to treat the sludge produced to inactivate pathogens. - Need to use chemicals.
Activated sludge or trickling filters + secondary sedimentation + disinfection	- Technology widely available and understood. - Performance can be optimized for good pathogen removal.	- High cost and complexity. - Need trained staff. - Require electricity. - Produce large volumes of sludge, which need to be handled, treated and disposed of. - Need to treat the sludge produced to inactivate pathogens. - Sludge bulking may increase helminth egg numbers in the effluent.

Advantages and disadvantages of different wastewater treatment processes (Continued)

Treatment	Advantages	Disadvantages[a]
Upflow anaerobic sludge blanket reactor	- Low cost. - Medium helminth egg removal efficiency.	- Effluent can cause odour problems. - Needs trained staff. - Sludge needs digestion and / or treatment to inactive pathogens.
Aerated lagoon + settling pond	- Technology widely available and well understood. - Performance can be optimized for good pathogen removal. - No need for primary sedimentation.	- Require electricity. - Require larger land area than other high-rate processes. - Less expensive and complex than other high-rate processes. - Sludge needs to be treated to inactivate pathogens.
Coagulation, flocculation and sedimentation	- Improve virus and other pathogen removal / inactivation efficiency. - Low additional cost.	- Increase sludge production. - Sludge needs to be treated to inactivate pathogens.
High-rate granular or slow-rate sand filtration	- Improves pathogen removal. - Well understood technology - Low additional cost.	- Needs careful management to optimize performance. - Slow-rate filters require more space. - Sludge needs to be treated to inactivate pathogens.
Dual-media filtration	- When used after primary treatment, efficiently removes protozoan (oo)cysts and helminth eggs. - When used after secondary treatment, improves pathogen removal. - Well understood technology - Low additional cost.	- Low efficiency of bacterial and viral removals. - Needs careful management to optimize performance.
Chlorination (free chlorine)	- Lowest-cost disinfection method. - Well understood technology - Effective inactivation of bacteria and viruses.	- Needs pre-treatment to be efficient. - Low efficiency of protozoan and helminth inactivation. - Creates disinfection by-products. - Hazardous chemical.
Ozone disinfection	- Effective inactivation of bacteria, viruses and some protozoa.	- Effective where organic matter is low. - Higher cost and complexity than chlorination. - Low efficiency of protozoan and helminth inactivation. - Needs to be generated on site. - Production of hazardous by-products.
Ultraviolet disinfection	- Effective in inactivating bacteria, viruses and some protozoa. - Low cost. - No toxic chemicals used or produced.	- Effective only in effluents with low suspended solids content and high transmittance. - Does not inactivate helminth eggs. - Performance can be reduced by particulate matter and biofilm formation. - Needs good maintenance of lamps.
Primary sedimentation + membrane bioreactors	- Remove all pathogens.	- Complex. - Expensive. - Sludge needs to be treated to inactivate pathogens. - Membrane fouling.

Sources: Feachem et al. (1983); Schwartzbrod et al. (1989); Sobsey (1989); Riviera et al. (1995); Rose et al. (1996, 1997); Strauss (1996); Landa, Capella & Jiménez (1997); Asano & Levine (1998); Clancy et al. (1998); National Research Council (1998); Yates & Gerba (1998); Karimi, Vickers & Harasick (1999); Lazarova et al. (2000); Jiménez et al. (2001); Jiménez & Chávez (2002); Jiménez (2003, 2005); Metcalf & Eddy, Inc. (2003); von Sperling et al. (2003); Mara (2004); Rojas-Valencia et al. (2004); WHO (2004a); NRMMC & EPHCA (2005); von Sperling & Chernicharo (2005).

a Many of these disadvantages can be minimized by careful engineering design and good operation and maintenance.

6. MONITORING AND SYSTEM ASSESSMENT

6.1 Control measure monitoring

Validation, operational monitoring and verification monitoring parameters for different control measures

Control measure	Validation requirements	Operational monitoring parameters	Verification monitoring parameters
Wastewater treatment	- Effectiveness of treatment processes at inactivating / removing pathogens and indicator organisms (E. coli, helminth eggs). - System design (e.g. retention time, short-circuiting in waste stabilization pond by conducting dye testing). - Analytical procedures for detecting indicators and / or pathogens (including measuring viability). - Effectiveness of treatment in removing locally important toxic chemicals. - Analytical procedures and capabilities for detecting chemicals in wastewater, excreta or pond water.	*Low-rate biological systems.* - Flow rates. - BOD (loading rates may need to vary during colder periods). - Algal concentrations and species types. - Dissolved oxygen at different pond depths (facultative and maturation ponds). *High-rate processes:* - BOD - Turbidity - pH - Organic carbon - Particle counts - Membrane integrity (pressure testing) - Chlorine residual	*E.coli* - Helminth eggs (including *Schistosome* spp., where appropriate) - Locally important toxic chemicals.
Health and hygiene promotion	- Testing of promotional materials with relevant stakeholder groups.	- Local programmes in operation. - Promotion materials available. - Promotion included in school curriculum.	- Increased awareness of health and hygiene issues in key stakeholder groups. - Improved practices.
Chemotherapy and immunization[a]	- Effectiveness of different vaccines / drugs in preventing or treating locally important infections.	- Numbers of people vaccinated / treated - Villages / schools targeted near waste-water use areas. - Frequency of campaigns.	- Reduced prevalence and intensity of infections. - Fewer disease outbreaks in targeted areas.

Control measure	Validation requirements	Operational monitoring parameters	Verification monitoring parameters
Product restrictions	- Survey of product consumers to identify species always eaten after thorough cooking. - Analysis of marketability of different species / crops. - Economic viability of growing products not for human consumption.	- Types of crops grown in wastewater use areas.	Water quality testing of wastewater to ensure that water used for unrestricted irrigation meets WHO microbial reduction targets.
Waste application / timing	- Test the amount of time needed for pathogen die-off under different climatic conditions and for different pathogens / indicators between waste application and crop harvest to ensure minimal contamination.	- Monitor waste application timing and time to harvest.	- Analyse plant contamination.
Produce washing, disinfection, cooking foods	- Research on which methods are most effective in reducing contamination, pathogen inactivation. - Testing of educational materials among relevant stakeholders.	- Inspection by food safety authorities to ensure that proper procedures are being used at markets or restaurants where products are prepared.	- Periodic microbial testing of hygiene of food preparation spaces in markets and restaurants, product testing to investigate where contamination occurs. - Inspection of markets to assess availability of safe drinking-water for product washing / freshening.
Access control, use of personal protective equipment	- Testing access control measures for effectiveness in preventing public exposures to wastewater. - Identifying which personal protective equipment is available at low cost that workers will wear. - Testing the effectiveness of the personal protective equipment in preventing exposure to hazards.	- Visual inspection of wastewater use areas for warning signs, fences, etc. - Visual inspection of workers to ensure that they are wearing the appropriate personal protective clothing.	- Public health surveillance of workers to document reductions in skin diseases, schistosomiasis (where relevant) and hookworm.

Control measure	Validation requirements	Operational monitoring parameters	Verification monitoring parameters
Intermediate host and vector control	- Test system to evaluate its effect on insect vector breeding and / or survival and growth of relevant snail species. - Test control measures such as the reduction of emergent vegetation and its impact on the breeding of disease vectors or snail intermediate hosts. - Check for obstructed drains, seepage and a rise in ground-water levels that can result in pools of standing water.	- Visual inspection of facilities to observe vegetative growth in irrigation canals or treatment ponds. - Inspection of waters for relevant insect larvae or snail intermediate hosts.	- Public health surveillance to document vector-borne diseases or schistosomiasis in workers and local communities. .

[a] *Chemotherapy and immunization are considered to be supplementary health protection measures and should not be used instead of other health protection measures such as wastewater treatment.*

6.2 Food inspections

Periodically the microbial and chemical contamination of waste irrigated crops should be tested for E. coli and helminth eggs.

6.3 Public health surveillance

Direct measurement of specific health outcomes.

7. SOCIO-CULTURAL ASPECTS

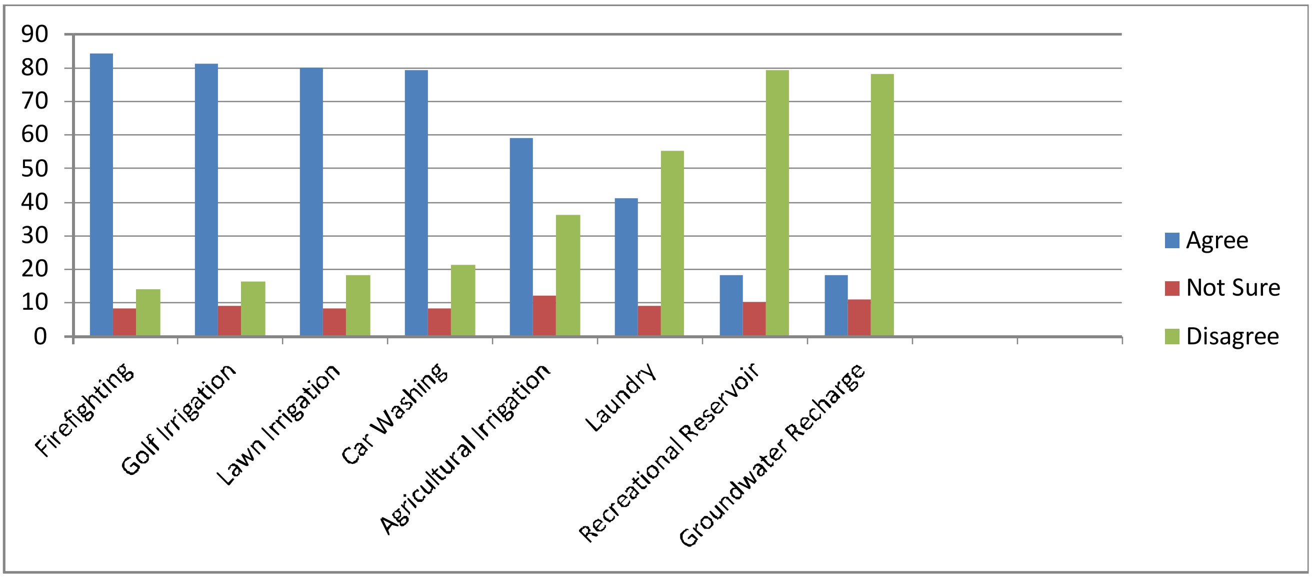
7.1 Cultural religious beliefs

Untreated wastewater is currently used for agriculture in many parts of the world without any significant socio-cultural revolution due to economic necessity. Treated wastewater, under consideration is much less objectionable than untreated sewerage.

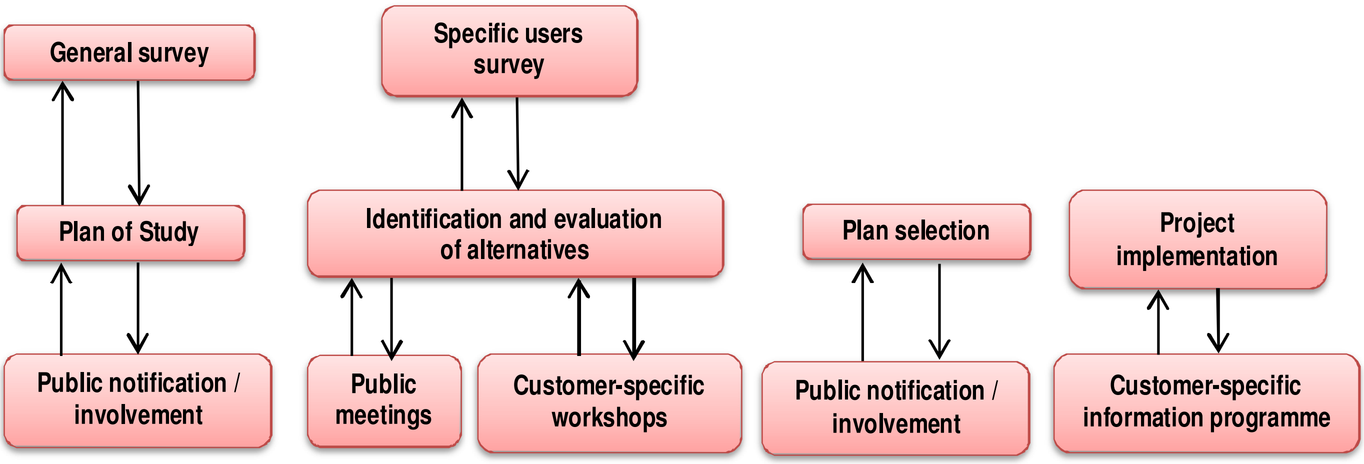
The cultural and religious beliefs of the communities will be ascertained and reported on under a separate study. The above will be taken into consideration in selecting people for the Pilot Project, as well as, the possible future extension of the project.

7.2 Public perceptions

It is important to obtain public support for the initiative. Globally perceptions vary considerably. Where water scarcity prevails acceptance can be expected more readily. The unemployment levels and poverty in the area will also assist in this regard. Assessing and if necessary changing public perceptions are addressed under a separate study. The global perception regarding use of wastewater is indicated below:



The strategy for increasing public participation and the available tools are indicated below:



Tools for increasing public participation in the decision to use wastewater

Purpose	Tools
Education and information	Newspaper articles, radio and television programmes, speeches and presentations, field trips, exhibits, information depositories, school programmes, films, brochures and newsletters, reports, letters, conferences.
Review and reaction	Briefings, public meetings, public hearings, surveys and questionnaires, question and answer columns, advertised "hotlines" for telephone inquiries.
Interaction dialogue	Workshops, special task forces, interviews, advisory boards, informal contacts, study group discussions, seminars

Source: Adapted from Crook et al. (1992).

8. ENVIRONMENTAL ASPECTS

8.1 Introduction

The use of wastewater in agriculture has the potential for both positive and negative environmental impacts.

The main advantage is the preservation of the nutrients. Soil also provides final treatment in polishing of the water.

The main negative impacts are:

- Pathogens. Can be reduced to acceptable levels.
- Increase in soil salinity. Can be reduced and controlled by soil washing, soil drainage and limiting salt inputs.
- Heavy metals

  Limited impact on plants / crops.
- Toxic organic compounds

  Will be reduced significantly through the treatment processes.
- Nutrients

  Will be absorbed / utilized by the crops.
- Organic matter

  Will be composted and used as fertilizer.

8.2 The effects on soils, crops and livestock, by type of compound

Parameter	Concentration in the irrigation water	Soil	Crops	Livestock
Nitrogen	Municipal wastewater with 20 – 8.5 mg TN/ℓ	Acidification problems provoked by synthetic fertilizers are not observed.	Increases productivity in quantity and quality	No problems reported.
			Depending on soil's content and type of crops, problems can arise above 30 mg N – NO_3/ℓ.	
	Wastewater with > 30 mg/ℓ	No reported effects	Can increase succulence beyond desirable levels, causing lodging in grain crops and reducing sugar content in beets and cane.	Forage, being the main food for cattle, can cause grass tetany, a disease related to an imbalance of nitrogen, potassium and magnesium in pasture grasses.
			Beyond seasonal needs, may induce more vegetative than fruit growth and also delay ripening.	
Phosphorus	Municipal wastewater with 6 – 20 mg/ℓ	No reported effects.	Increases productivity.	
	Municipal wastewater with >20 mg/ℓ	No reported effects.	Reduce copper, iron and zinc availability in alkaline soils	
Potassium	Normal content in municipal wastewater [a]	No reported effects.	Increases productivity.	
	Content above normal municipal wastewater values[a]	No reported effects.	Increases productivity.	
Organic matter	Municipal wastewater with 110 – 400 mg BOD/ℓ	Improves microbial activity and soil fertility.	Increases productivity	No problems reported.
		Colloidal and suspended organic matter increase moisture and nutritious content, improving structure.		
		Diminishes salinity effects due to a higher water content.		
		Retains and binds heavy metals.		
		Depending on its composition and soil consumption, can release salts, nitrogen and metals.		

Parameter	Concentration in the irrigation water	Soil	Crops	Livestock
	Content in wastewater greater than content in normal sewage[a]	Continuous irrigation and high organic matter contents may clog soil pores and favour an anaerobic population in the root zone. Organic matter combined with nitrogen and continuous irrigation can cause important nitrogen losses by denitrification.		
Salinity (variable, depending on the water supply content and type of discharges)	Wastewater with: TDS 250 – 850 mg/ℓ Conductivity <3 dS/m SAR 5 – 9 Sodium <100 mg/ℓ	No short-term effects observed. Long-term salinization occurs at a rate that depends upon the frequency of soil washing and land drainage properties.	Problems in sensitive crops with TDS of 450 – 2000 mg/ℓ and conductivities of 0.7 – 3 dS/m. Conductivities between 5 and 8 dS/m and non-sensitive crops do not display problems. If soil is saline, crops absorb more salts, causing the crops' value to diminish in some countries and for some crops, such as vineyards.	
	Wastewater with: TDS >2000 mg/ℓ Conductivity >3 dS/m SAR >8 Sodium >100 mg/ℓ	Loss of soil structure and capacity for water and air transport, and thus to sustain plants. Effects depend on conductivity and SAR values, frequency of soil washing and land drainage conditions.	Impacts in almost all types of crops. Sodium diminishes yields in sensitive crops up to 100 mg/ℓ. SAR >3 affects some crops, depending on the water conductivity Productivity diminishes or even stops if salinization is very high.	
Boron (very variable in wastewaters, depending on the water supply content and discharges)	Municipal wastewater with 0,7 – 3 mg/ℓ Municipal wastewater with >3 mg/ℓ	No reported effects.	Affects very sensitive (0.5 – 0.75 mg/ℓ), sensitive (0,75 – 1 mg/ℓ) and moderately sensitive (2 – 4 mg/ℓ) crops. Affects moderately sensitive (2 – 4 mg/ℓ), tolerant (4 – 6 mg/ℓ) and very tolerant (6 – 15 mg/ℓ) crops.	

Parameter	Concentration in the irrigation water	Soil	Crops	Livestock
Chlorides	Wastewater with 30 – 100 mg/ℓ Wastewater with >140 mg/ℓ	Can cause salinization, depending on other parameters as well as frequency of soil washing and land drainage conditions.	Below 140 mg/ℓ, no effects are observed. >140 mg/ℓ, crops are affected, with every visible effects at concentrations >350 mg/ℓ. Leaves of sensitive plants (crops and woody plants) are burnt when sprinklers are used for irrigation.	
Alkalinity (carbonates and bicarbonates)	Wastewater with 50 – 200 mg $CaCO_3$/ℓ Wastewater with >500 mg $CaCO_3$/ℓ	No reported effects. Concentrations above equilibrium conditions in soils precipitate calcium, affecting soil structure.	In warm climates, bicarbonates burn leaves.	No problems reported.
Metals	Municipal wastewater or industrial effluents without high metal concentrations Municipal wastewater or industrial discharges with high metals content Aluminium and iron Cadmium	Concentration in soil is increased with time in the first soil layers; depending on pH, organic matter content and irrigation time, metals are either bound to the soil particles or mobile. Reduce phosphorus mobility.	No effects are observed with normal metal contents of sewage. Can cause phosphorus deficiencies. Is toxic, and uptake can increase wit time, depending on soil concentrations.	May be harmful to animals in doses much lower than visibly affect plants. Absorbed cadmium is stored in kidney and liver; remaining meat and milk products unaffected.

Parameter	Concentration in the irrigation water	Soil	Crops	Livestock
Metals (Cont)	Copper			May be harmful to animals at concentrations too low to visibly affect plants. Is not a health hazard to monogastric animals, but can be toxic to ruminants (cows and sheep). Tolerance to copper increases as available molybdenum increases.
	Zinc and nickel		Cause visible adverse effects in plants before plant concentrations are high enough to be of concern in animals or humans.	
	Molybdenum			May be harmful to animals at concentrations that are too low to visibly affect plants. Causes adverse effects in animals consuming forage with 10 – 20 mg/kg and low copper content. Consumption of crops with more than 5 mg/kg is toxic to ruminants. Molybdenum toxicity is related to the ingestion of copper and sulfate.
Toxic organic compounds		Long term : some may biodegrade in soils. Some compounds, such as pesticides, might contain metals and contribute to their accumulation in soils.	In general, their large sizes and high molecular mass do not allow them to be absorbed through plants. Can contaminate plant products through water contact during irrigation; sewage normally contains concentrations too low to cause problems.	
Suspended solids	Municipal wastewater with 100 – 350 mg/ℓ	Clog soils, depending on concentration, composition and soil porosity; >100 mg/ℓ of mineral solids can cause problems. If soil is clogged, water infiltration rate diminishes and irrigation becomes less effective.		

Parameter	Concentration in the irrigation water	Soil	Crops	Livestock
pH	Municipal wastewater with pH 7 – 7.4.	No reported effects.		
	Wastewater with pH out of the 6.5 – 8.5 range.	If soil alkalinity is not sufficient to maintain pH above 6.5, metal solubilization can occur; when pH is maintained below 8.5, aluminium can be solubilized and soil deflocculated, and nitrogen can be lost by volatilization.	Effects depend on the solubilized metal.	

dS/m, deciSiemans per metre; SAR, soil adsorption ratio; TDS, total dissolved solids; TN, total nitrogen

Sources: NAS & NAE (1972); Seabrook (1975); Sidle, Hook & Kardos (1976); Benham-Blair & Affiliates, Inc. & Engineering Enterprises, Inc (1979); Marten, Larson & Clapp (1980); Bouwer (1991); Metcalf & Eddy, Inc (1991); Oron et al. (1992); Pescod (1992); National Research Council (1996); Siebe & Fischer (1996); Shahalam, Abuzahra & Jaradat (1998); Siebe (1998); ACTG (1999); Downs et al. (2000); Friedel et al. (2000); Simmons & Pongsakul (2002); AATSE (2004); Jiménez (2004); Jiménez, Siebe & Cifuentes (2004); Lee et al.(2004).

a Municipal wastewater content according to Metcalf & Eddy, Inc. (2003).

8.3 Effect on groundwater by different compounds

Compound	Impact	Relative impact on groundwater or surface water	
		Groundwater	Surface water
Nitrogen	May contaminate underground and surface water bodies by infiltration and irrigation runoff. The amount of nitrogen leached depends on crop demand, hydraulic load due to rain and irrigation water, soil permeability and nitrogen content in soils.	High	Medium
Phosphorous	Agricultural runoff containing phosphorous can cause the growth of aquatic plants as a result of eutrophication in surface water bodies (reservoirs and lakes), which can lead to the obstruction of irrigation infrastructure (filters, weirs, pipes and spillways) and clog filters in water treatment plants.	Not significant	Medium
Biodegradable organic matter	If runoff contains high levels of organic matter, the organic matter can consume dissolved oxygen in lakes and rivers.	Not significant	Medium
Salinity	Saline soil leachates contaminate surface and underground water bodies; up to a certain level, it can limit water use. TDS > 500 mg/ℓ causes flavour but not health problems in water supplies. Very high concentrations have laxative effects on consumers and corrode water distribution equipment.	Medium	Low
Boron	Boron from wastewater is not removed by treatment, almost not retained in soils and not absorbed by plants. Although it is an essential element, it easily becomes toxic above the required levels. By leaching, it enters groundwater and, through runoff or from polluted aquifers, surface water bodies. Accumulation in water bodies limits their use, mainly for irrigation. Some crops are sensitive to boron.	Medium	Low
Heavy metals	By leaching from acid soils, they can reach aquifers and enter surface waters through runoff.	Low	Low
Toxic organic compounds	Mostly removed by soils.	Not significant.	Not significant.

TDS, total dissolved solids

8.4 Control measures by polluting agent

Compound	Control measure
Nitrogen in excess	Dilute wastewater with fresh water when possible.
	Limit the quantity of wastewater applied.
	Remove excess nitrogen from wastewater.
Organic matter	Do not continuously apply wastewater, to allow soil to biodegrade it.
	Enhance removal of organic matter from wastewater.
Salinity	Avoid the use of water with 500 – 2000 mg TDS/l or 0,8 – 2,3 dS/m electrical conductivity, depending on the type of soil and land drainage.
	Reduce upstream salt use and discharge into wastewater.
Chlorides	With sprinklers, only use water with <100 mg/ℓ
	In irrigation by flooding, use water with <350 mg/ℓ.
	Irrigate by night to prevent leaf burn.
Toxic organic compounds in soil and crops	Pretreat or segregate industrial discharges from sewage.
	Promote cleaner production in industries, to avoid using toxic compounds.
	Educate society to use less toxic compounds and, when used, dispose of them safely.
Metals	Pretreat or segregate industrial discharges from sewage.
	Use wastewater only in soils having a pH >6.5.
Suspended solids	Use water without solids > 2 – 5 mm
	Remove suspended solids by pre-treatment of wastewater
	Plough soils when clogged.

TDS, total dissolved solids.
Sources: Seabrook (1975); Bole & Bell (1978); Reed, Thomas & Kowal (1980); USEPA (1981); Ayers & Wescot (1985); Phene & Ruskin (1989); Bouwer (1991); Oron et al. (1991, 1992;: Pescod (1992); Farid et al. (1993); Chang et al. (1995); National Research Council (1996); Jiménez & Chávez (1997); Strauss (2000); Cornish & Lawrence (2001); AATSE (2004); Ensink, Simmons & van der Hoek (2004); Ensink et al. (2004); Foster et al. (2004).

8.5 Control measures according to kind of problem

Problem	Control measure
Evaporation and infiltration of water during storage	Use compact lagoons in series lined with impermeable materials (clay, plastic) to prevent loss of water to evaporation and infiltration.
Clogging of irrigation systems	Use water with low total suspended solids content.
	Use irrigation methods not affected by solids.
Sprinkler clogging / corrosion	Clogging and corrosion can be controlled by using water with <100 mg of chlorine per litre, < 70 mg of sodium per litre and < 1,5 mg of iron and manganese per litre.
Soil salinity and sodicity	Increase soil washing, improve ground drainage and / or apply soil amenders.
	Dilute water with sodium adsorption ration >8 and electrical conductivity >2,3 dS/m.
Formation of a biological soil layer that blocks water infiltration	Reduce the quantity of water applied and / or increase flood and dry periods.
Infiltration to subsoil of low-quality water	Irrigate in places where aquifer level is >3 m below the surface and soil permeability is 60 – 2000 mm/day.
	Reduce the hydraulic load.
Joint leaching of nitrogen and organic matter	Promote biological denitrification in soil by creating an appropriate carbon to nitrogen ratio, promoting anaerobic conditions in soils and avoiding salt accumulations that inhibit denitrification bacteria.

Problem	Control measure
Contamination of water bodies	Adapt irrigation rates according to crop demands and allow sufficient passage of water through soil.
	Irrigate in sites located 500 – 1 000 m from surface water bodies or more than 3 m from aquifers used as water supply.
Water pollution with pesticides	Do not irrigate immediately after pesticide application.
	Do not over-apply pesticides.
	Use integrated pest management approaches to reduce pesticide use.

9. ECONOMIC AND FINANCIAL CONSIDERATIONS

The economic and financial considerations of the different potential crops are addressed in a separate study.

With regard to the benefits of the nutrients it is estimated as follows:

Nutrient	Average concentration mg/ℓ	Fertilizer contribution @ 5 000 kℓ/ha/year (500 mm/year)
Nitrogen	50	250 kg/ha
Phosphorus	10	50 kg/ha
Potassium	30	150 kg/ha

The nutrients provided by the wastewater should be sufficient for the crop cultivated.

The Department of Health published requirements for wastewater irrigation in 1976. The guidelines allow irrigation from treatment plants such as the biofilters under consideration to all crops except those that can be eaten raw.

In the WISA conference in 2000 the strict requirements of the Department of Health were questioned with reference to the WHO investigations into the risks associated with waste irrigation.

In March 2013 DWS released their GA requirements with regard to the irrigation with effluent to 2 000 kℓ/day with the requirement that the effluent must comply with the General Effluent Standard.

The WHO guidelines are considered the leading publication with regard to wastewater irrigation. It is also foreseen that the Emfuleni Wastewater Irrigation of Agriculture Scheme and especially the Pilot Project will be directed towards assisting the WHO and the South African Authorities in developing and refining the guidelines further and specifically for South Africa.

The Australian Department of Environment and Conservation (NSW) published comprehensive guidelines for the use of effluent by irrigation in 2004.

The guidelines are scientifically based and covers all aspects pertaining to the development of agricultural sites, crop selection, soil management, water application and management, etc.

Australia is also a water scarce country that acknowledges the need for the optimum utilization of water which includes wastewater effluent. These guidelines to be referenced with the development of the Emfuleni schemes, together with the WHO guidelines in order to develop and define guidelines appropriate for RSA.

10. CONCLUSION

10.1 The utilization of wastewater effluent is accepted and practiced widely globally.

10.2 Guidelines for the safe and effective use of wastewater effluent have been developed by WHO, DWS, Australian Department of Environment and other countries.

10.3 The socio-economic situation in the greater Emfuleni area necessitates that jobs be created with poverty relief and food security.

10.4 In addition to above, funds must be generated for the upgrading of the water and sanitation infrastructure, to reduce wastage and the pollution of the environment.

10.5 The implementation of the proposed wastewater to irrigation project will assist in developing applicable guidelines for the South African situations.