Informal Irrigation in the Peri-Urban Zone of Nairobi, Kenya

An assessment of surface water quality used for irrigation

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Report OD/TN 105
March 2001

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Contract

This Technical Note is an output from the Knowledge and Research Contract R7132, Improved Irrigation in Peri-Urban Areas, carried out by the Water Management Department of HR Wallingford for the British Government's Department For International Development (DFID). The research aims to improve understanding and knowledge of the productivity and hazards of peri-urban irrigated agriculture, with the objective of identifying measures to improve output whilst minimising risks to health and the environment. Fieldwork has been conducted in and around Kumasi, Ghana, and Nairobi, Kenya.

The HR job number was MDS 0529

The DFID KAR details are:

Theme:	W5 Improved availability of water for sustainable food production and rural development.
Project title:	Improved irrigation in peri-urban areas
Project	No. R7132

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Technical Director
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Date 17/09/2001

This document is an output from a project funded by the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

Executive Summary

Informal Irrigation in the Peri-Urban Zone of Nairobi, Kenya

An assessment of water quality used for irrigation

J M Hide, C F Hide and J Kimani

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This report is an output from KAR project R7132, "Improved Irrigation in Peri-Urban Areas", which aims to identify and quantify the productivity, constraints and potential health hazards associated with informal peri-urban irrigation, with the objective of identifying practical measures to sustain and enhance the productivity of these systems. The research is based on field studies carried out in and around Kumasi, Ghana, and Nairobi, Kenya.

Peri-urban farmers who take irrigation water from streams in and downstream of urban centres are practising indirect reuse of urban wastewater. This water is often highly polluted with untreated municipal and industrial effluents. Municipal authorities and government ministries, along with the local population and media, have raised concern regarding the potential health threats posed by use of polluted waters to crop irrigators and consumers alike. However, there is frequently a lack of quantitative information available on which sound judgements can be based. An earlier component of this study has drawn together existing knowledge of wastewater reuse for agriculture and collected additional water quality data from the peri-urban zone of Kumasi, Ghana (Cornish et al., 1999). This report presents the results of a complementary programme of water quality sampling carried out in the peri-urban zone of Nairobi, Kenya.

The monitoring programme was carried out over a seven week period during August and September 2000. This coincided with the end of the dry season when irrigation is widely practised. At this time, river flows are low and consequently, pollutant concentrations are high. Following several years with lower than average rainfall, river levels were particularly low during the monitoring period.

The samples were tested for microbiological (total and faecal coliforms), physical (temperature and pH) and chemical (nitrate, phosphate, BOD and manganese) quality parameters.

Results show that microbiological contamination of water used for irrigation from the Nairobi River exceeds, by many magnitudes in downstream areas, the recommended levels set by WHO for unrestricted irrigation. As such, the health of farmers and consumers of produce is potentially put at risk.

As expected, contamination of the river increases in the downstream direction and reaches the point where there is no observable difference in quality between samples taken from the river and those taken from raw sewage used for irrigation at Maili Saba. The current practice in certain areas, whereby farmers deliberately

Executive Summary *continued*

interfere with the sewage infrastructure in order to obtain raw sewage for irrigation purposes, should be strongly discouraged.

A number of options to address these problems are discussed. These include:

Crop restriction
A licensing system could be introduced whereby regular water quality monitoring takes place and farmers are restricted in the crops they are permitted to grow, according to observed water quality. Production of vegetables would be limited to upstream of the city, whilst fodder or industrial crops could be grown downstream. It would probably be necessary to ban all irrigation in certain locations where water quality is particularly poor. However, agricultural activities provide the main source of income in many areas of Nairobi. A balance would need to be found between protecting the health of farmers and consumers and maintaining the livelihoods of some of the poorest sectors of the community.

It should be noted that contamination of crops can occur at all stages: at farm level, from the use of poor quality water, at market level, from the use of dirty water for washing of produce, and at the consumer level, through cross-contamination and poor personal and home hygiene. It will be necessary to consider all potential sources of contamination before attempting to regulate the production of irrigated crops.

Additional pre-treatment
Water quality could be improved through pre-treating wastewater prior to use, perhaps with small-scale wetland systems or shallow wells. The contamination found in the well at Thiboro highlights the fact that measures are required to protect wells from possible contamination sources.

Alternative irrigation methods
Risks to farm workers can be reduced through the use of improved irrigation methods such as spray, drip and trickle irrigation. The revised recommended WHO guidelines take this into account when considering restricted irrigation. They set varying levels of faecal coliform contamination according to the irrigation method used and also whether children come into contact with the water.

Controlled reuse of effluent from Ruai sewage works
The controlled reuse of effluent from sewage works is a common practice in many countries. The effluent from Ruai is of a high microbiological quality and falls well within the WHO guidelines. It can be used for the irrigation of any crop type without risk to workers or the public. Any move in this direction is clearly a policy decision that must be made by the Nairobi City Council and other concerned bodies.

Clearly, further research is required to assess the practicalities of the various technical and policy options outlined above. It must also be borne in mind that it is unlikely that any one solution will provide a panacea for all situations. A sustainable strategy is likely to require a combination of technical, social and policy solutions.

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1. INTRODUCTION

This report is an output from Phase Two of the Improved Irrigation in Peri-Urban Areas Project. The Project studied informal irrigation within the peri-urban area of Kumasi, Ghana, and Nairobi, Kenya. It was carried out by the Water Management Department of HR Wallingford, and was funded by the British Government's Department for International Development (DFID) through their Knowledge and Research Programme.

The overall aims of the research were to:

- investigate the productivity of peri-urban irrigated agriculture
- identify and analyse the hazards posed by using water polluted by urban effluents, for irrigation
- identify measures which could improve agricultural output, whilst minimising risks to both human health and the environment

Fieldwork was conducted in and around Kumasi and Nairobi.

Peri-urban farmers who take irrigation water from streams in and downstream of urban centres are practising indirect reuse of urban wastewater (Westcot, 1997). This water is often highly polluted with untreated municipal and industrial effluents. Municipal authorities and government ministries, along with the local population and media, have raised concern regarding the potential health threats posed by use of polluted waters to crop irrigators and consumers alike. However, there is frequently a lack of quantitative information available on which sound judgements can be based. An earlier component of this study drew together existing knowledge of wastewater reuse for agriculture and collected additional water quality data from the peri-urban zone of Kumasi, Ghana (Cornish et al., 1999). This report presents the results of a complementary programme of water quality sampling carried out in the peri-urban zone of Nairobi, Kenya.

Chapter 2 summarises key references relating to microbiological contamination of water and its use for irrigation. Chapter 3 describes the study area and Chapter 4 the methodology adopted for the water quality sampling programme. The results are presented in Chapter 5 along with comparison with results from earlier studies. Conclusions and recommendations from the work are given in Chapter 6.

2. SYNOPSIS OF KEY REFERENCES ON WATER QUALITY FOR IRRIGATION

This chapter provides a summary of key references relating to water quality and associated impacts when used for irrigation. A fuller summary is provided in Appendix A. Much of this information was reported previously in report OD/TN 95 (Cornish et al., 1999), but is included in this report for completeness. Of particular relevance is the recent work carried out by both Dr Ursula Blumenthal et al., at the London School of Hygiene and Tropical Medicine, and by WEDC, Loughborough University. They are both investigating the appropriateness of the recommended levels in the WHO guidelines (Mara and Cairncross, 1989). This work is described in Section 2.1.2.

2.1.1 Microbiological contamination

Guidelines for the use of treated wastewater and excreta "based on epidemiological evidence of actual risks to public health, rather than on potential hazards indicated by the survival of pathogens on crops and in the soil" were published by WHO in 1989 (Mara and Cairncross, 1989). They provide guidelines for permissible levels of microbiological contamination to be used as design values in the design of water treatment plants. Mara and Cairncross (1989) state explicitly that the values are not intended for use as quality surveillance norms, though they offer no suggestion as to what norms might be used in this respect. The guidelines, providing design values for water quality, are based on the number of viable nematode eggs per litre and faecal coliform bacteria per 100 ml. Table 1 presents the guidelines in detail.

Table 1 Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture [a]

Category	Reuse condition	Exposed group	Intestinal nematodes [b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100 ml[c])	Wastewater treatment expected to achieve the required microbiological quality
A Unrestricted	Irrigation of crops likely to be eaten uncooked, sports fields, public parks [d]	Workers, consumers, public	≤ 1	≤ 10^3 [d]	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B Restricted	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees [e]	Workers	≤ 1	No standard recommended	Retention in stabilisation ponds 8-10 days or equivalent, helminth and faecal coliform removal
C Localised	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

[a] In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly.
[b] *Ascaris* and *Trichuris* species and hookworms. See Figure 1.
[c] During the irrigation period.
[d] A stringent guideline (≤ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[e] In the case of fruit trees, irrigation should cease two weeks before fruit is picked and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

Source: WHO (1989), cited by Pescod (1992)

2.1.2 Recommended revisions to WHO guidelines based on new reasearch evidence

The WHO's 1989 guidelines have influenced the standards for wastewater reuse adopted in many countries. With the aim of assessing the validity of the guidelines, the London School of Health and Tropical Medicine have carried out epidemiological studies in Mexico and Indonesia, and Leeds University have undertaken microbiological studies of crops irrigated with treated wastewater in Brazil and Portugal. The review was carried out under the premise that there should be no measurable excess illness in the exposed population.

Blumenthal et al. (2000) found that "the results of the studies of consumer risks do not provide any evidence to suggest a need to change the WHO *faecal coliform* guideline of $\leq 10^3$ FC/100ml for *unrestricted irrigation*. Epidemiological studies in a situation where enteric infections are endemic suggest that risks of enteric infections are significant, but low, when the guideline is exceeded by a factor of 10."

The WHO guidelines also "appear to offer similar levels of protection" as US microbial standards for drinking water, which are based on the criteria that human populations should not be subjected to the risk of infection by enteric disease greater that 10^{-4} (or 1 in 10,000 persons/year). However, "in situations where there are insufficient resources to reach 10^3 FC/100ml, then a more relaxed guideline of 10^4 FC/100ml could be adopted, but should be supplemented by other health protection measures".

With regard to helminths, "the *nematode egg* guideline of ≤1 nematode egg/litre for *unrestricted irrigation* appears to protect consumers of cultivated vegetables spray-irrigated with effluent of consistent quality and at high temperatures, but not necessarily consumers of vegetables surface-irrigated with such effluent at lower temperatures".

Also, for *unrestricted irrigation*, "the nematode egg guideline of ≤1 egg per litre is adequate if no children are exposed, but a revised guideline of ≤0.1 egg/litre is recommended if children are in contact with the wastewater through irrigation or play".

There is an observed increased risk of *Ascaris* infection amongst children eating vegetables irrigated with water containing 1 nematode egg per litre. Therefore, "it is recommended that a stricter guideline of ≤0.1 egg/litre is adopted to prevent transmission of *Ascaris* infection and to allow for the risks to farm workers involved in cultivating the vegetable crops".

The studies concluded that a faecal coliform guideline for *unrestricted irrigation* should be added. "A reduced guideline of $\leq 10^3$ FC/100ml would be safer where adults are involved in flood/furrow irrigation and children are regularly exposed (through farm work or play)". However, "where there are insufficient resources to provide treatment to reach this stricter guideline, a guideline of 10^5 FC/100ml should be supplemented by other health protection measures for children".

Finally, "a range of health protection measures including crop restriction, irrigation technique, human exposure control and chemotherapeutic intervention should all be considered in conjunction with partial wastewater treatment".

A summary of the recommended revised guidelines is shown in Table 2.

Table 2 Recommended revised guidelines for treated wastewater use in agriculture [a]

Category	Reuse conditions	Exposed group	Irrigation technique	Intestinal nematodes[b] (eggs/litre[c])	Faecal coliforms (FC per 100ml[d])
A	*Unrestricted irrigation*				
	A1 Vegetable and salad crops eaten uncooked, sports fields, public parks [e]	Workers, consumers, public	Any	≤ 0.1 [f]	≤ 10^3
B	*Restricted irrigation*				
	Cereal crops, industrial crops, fodder crops, pasture and trees [g]	B1 Workers (but no children <15 years), nearby communities	Spray/ sprinkler	≤ 1	≤ 10^5
		B2 as B1	Flood/ furrow	≤ 1	≤ 10^3
		B3 Workers including children <15 years, nearby communities	Any	≤ 0.1	≤ 10^3
C	Localised irrigation of crops in category B if exposure to workers and the public does not occur	None	Trickle, drip or bubbler	Not applicable	Not applicable

a In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly
b Ascaris and Trichuris species and hookworms: the guideline is also intended to protect against risks from parasitic protozoa
c During the irrigation season (if the wastewater is treated in WSP or WSTR, which have been designed to achieve these numbers, then routine effluent quality monitoring is not required)
d During the irrigation season (faecal coliform counts should preferably be done weekly, but at least monthly)
e A more stringent guideline (≤ 200 FC/100ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact
f This guideline can be increased to ≤ 1 egg/litre if (i) conditions are hot and dry and surface irrigation is not used, or (ii) if wastewater treatment is supplemented with anthelmintic chemotherapy campaigns in areas of wastewater re-use
g in the case of fruit trees, irrigation should cease two weeks before fruit is picked and no fruit should be picked off the ground. Spray/sprinkler irrigation should not be used

Source: Blumenthal et al. (2000)

The report also describes the wastewater treatment that would be needed to achieve a required microbiological quality.

2.1.3 Trace elements and heavy metals

It is widely accepted that levels of trace elements and heavy metals in irrigation water are likely to be toxic to plants at concentrations below that at which they pose a significant risk to human health. This provides a degree of natural protection to irrigators and consumers as plants fail to thrive and farmers abandon the source well before levels present a risk to human health. There are currently no guidelines for permissible levels of trace elements and heavy metals in wastewater used for irrigation which relate to the potential risk to human health as a consequence of crop uptake and bio-accumulation. Most authors cite either a table of phytotoxic thresholds prepared by the National Academy of Sciences and National Academy of Engineering (1972) and Pratt (1972), or refer to the WHO drinking water guidelines (WHO, 1993). These data are reproduced in Table 3.

Table 3 WHO and EU Drinking Water Quality Guidelines for Heavy Metals and Threshold Values Leading to Crop Damage (mg/l).

Element	WHO drinking water guielinea	EU drinking watr guidelineb	Recommended maximum concentration for crop[c]
Arsenic	0.01	0.05	0.1
Cadmium	0.003	0.005	0.01
Chromium	0.05	0.05	0.1
Copper	2	0.1 – 3.0	0.2
Iron	0.3	0.2	5.0
Mercury	0.001	0.001	-
Manganese	0.5	0.05	0.2
Nickel	0.02	0.05	0.2
Lead	0.01	0.05	5.0
Zinc	3	0.1 – 5.0	2.0

Sources:

a WHO (1993)

b Cited by Chapman (1996)

c Cited by Pescod (1992)

3. STUDY AREA

Nairobi is located in southern Kenya, 500 kilometres from the coast and at an elevation of 1670 m. It has a population of two million people, and covers an area of 700 square kilometres. It extends from the foothills of the Aberdares in the north, to the Ngong Hills in the south, and from the Embakasi plains in the east, up to the slopes of the Great Rift Valley wall in the west. Rainfall follows seasonal patterns, with the "long" rains falling between March and May, and "short" rains between October and December. Irrigation is needed during the driest months between June and September. The total average annual rainfall is 680 mm.

Four main rivers flow from west to east through the centre of Nairobi. The Mathare River lies furthest to the north, and enters the Nairobi River just downstream of the city centre. The Montoine River lies to the south of Nairobi River, and becomes the Ngong River downstream of Nairobi dam. The Ngong River flows into the Nairobi River east of the city. Several smaller tributaries drain into the four rivers along their course.

Urbanisation is occurring in Nairobi at a rapid rate. Large quantities of raw sewage and household waste drain directly into the city's rivers from housing estates and slums located along their banks, and untreated industrial effluents are pumped into the rivers. Riverbanks are a common dumping ground for solid waste. Nairobi's rivers are heavily polluted, and there is great concern that their waters are unsuitable for use in crop irrigation, particularly downstream of the city's industries. Naturally, the use of raw sewage for irrigation, in places such as Maili Saba, is also a concern.

Three of the five sites selected for water quality sampling were located at sites where the farm budget and wealth ranking components of the parallel study, reported in OD/TN 104 (Hide et al., 2001), were carried out.

At Thiboro, 20 km to the west (upstream) of the city centre, the farm plots are situated on land sloping down to the Nairobi River near its source. Small hand-dug wells have been constructed, and water is drawn from here and spread over the crops using buckets and watering cans. A typical plot size is 60 m by 20 m, and typical crops being grown include kale, cauliflower, broccoli, lettuce, cucumber, tomato, celery, pepper, sweetcorn, potato, sweet potato, carrot, onion, garlic, eggplant, and courgette.

Although Mau Mau Bridge is situated upstream of the main city and its industries, slums are located on the slopes above the Nairobi River at this location, and wastewater drains directly into the river. The farmers along the river have constructed small dams and weirs to raise the water level. This allows water to flow into hand constructed canals which irrigate the lower areas of the farm plots. Water is drawn from ponds, dug at the end of the canals, to irrigate crops at higher elevations, using buckets and watering cans. Typical plot size and typical crops being grown are as at Thiboro.

At Maili Saba, 15 km east of the city, farmers have removed manhole covers and blocked the city's main sewer, causing raw sewage to rise out of the manholes and flow out over the land. Hand-dug canal systems have been constructed to irrigate approximately 50 farm plots at Maili Saba. Farmers operate the canal system on a weekly basis, allowing flow to each farmer's plot on two specified days of the week. Farmers who do not wish to be included in this scheme must work at night. A typical plot size is 40 m by 20 m, and typical crops being grown include kale, sweetcorn, potato, sweet potato, and arrowroot. No additional fertilisers are required as the crops thrive on the nutrients present in the raw sewage.

Details of the farming practices carried out at these three locations are described in detail in report OD/TN 104 (Hide et al., 2001).

4. WATER QUALITY MONITORING PROGRAMME

The water quality monitoring programme was carried out over a seven-week period during August and September 2000. This coincides with the end of the dry season when irrigation is widely practised. At this time, river flows are low and consequently pollutant concentrations are high. Following several years with lower than average rainfall, river levels were particularly low during the monitoring period.

Five sampling sites were selected to provide an indication of the variation in water quality used for irrigation within the peri-urban zone. The focus of the study was on the Nairobi River, where three of the sampling stations were located: at Mau Mau Bridge, Kimathy and Njiru. Kimathy is located a few kilometres east of the city centre and just downstream of the main industrial area where crop irrigation occurs. Njiru is situated 20 km east of the city centre on the downstream edge of the zone defined by this project (figure 1). Weekly samples were also taken from a shallow well at Thiboro and at Maili Saba.

Water quality sampling and analysis procedures were based on the methods recommended by WHO (WHO, 1996). Samples were collected by placing a clean bottle in the flow of water, approximately 10 cm below the water level, replicating a farmer collecting water in a bucket for irrigation. The temperature of the water was measured using a mercury thermometer. 250 ml of the sample was transferred to a sterile glass sample bottle, which was placed in a refrigerated box for transportation to the laboratory. The water samples had to reach the lab and be analysed within 6 hours of collection. Weather conditions at the time of collection were also recorded.

The samples were tested for microbiological, physical, and chemical quality parameters at the Nairobi City Council Kabete Central Laboratory. These parameters were:

- microbiological - total and faecal coliforms
- physical - temperature and pH
- chemical - nitrate, phosphate, Biochemical Oxygen Demand (BOD) and manganese levels

There are two basic methods by which coliform bacteria in wastewater are usually counted: (i) most probable number (MPN) methods, or (ii) membrane filtration methods. This study utilised the first of these techniques, since it can be used for both clean and highly turbid water. The results are reported as a most probable number (MPN) index. This is a statistical best estimate of the number of coliform bacteria obtained by culturing a number of samples at various dilutions (WHO, 1996).

The work in Kumasi concluded that accurate analysis of helminths, an indicator of microbiological contamination, is expensive and difficult to achieve. Therefore, helminths were not analysed in this study.

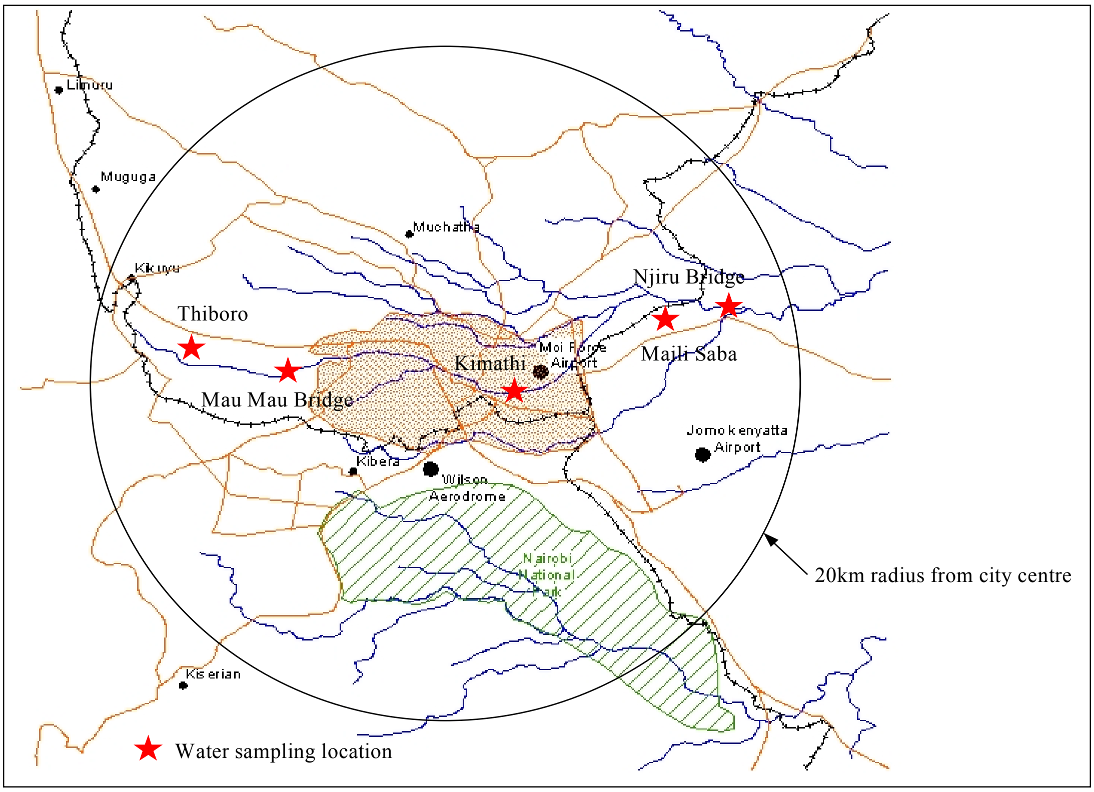

Figure 1 Water sampling locations

Manganese was selected as the most relevant heavy metal to be monitored following analysis of UNEP's (1999) "Save the Nairobi Rivers" water quality test results. Of the heavy metals that UNEP considered, manganese levels fluctuated the most with distance downstream. At some locations, levels of manganese recorded by UNEP also exceeded recommended WHO levels for crop irrigation.

An initial intensive study was undertaken over two days at the three Nairobi river sites (Mau Mau Bridge, Kimathy, and Njiru) to ascertain how the total and faecal coliform counts changed during the day. These indicated some variation, with the average concentrations occurring around mid-morning. Over the next few days, a daily sample was taken at each of these three locations to gauge how the total and faecal coliform counts varied through the week. Apart from the results at Mau Mau Bridge, these results showed no clear trend. Results at Mau Mau Bridge showed a reducing trend. During this period, two weekly samples were also taken from the shallow well at Thiboro, and the irrigation canals of raw sewage at Maili Saba. In the remaining weeks, fortnightly samples were taken at all five sites to study the seasonal variations that existed in the overall water quality, with nitrate, phosphate, BOD, and manganese levels also being monitored. All samples were also tested for all the physical parameters.

5. RESULTS

This chapter sets out the results obtained by this project along with water quality results obtained from a UNEP (1999) study and routine monitoring carried out by Nairobi City Council at the Ruai sewage treatment works.

There is little routine monitoring of river water quality by government agencies in Nairobi. However, weekly water quality tests are made at the sewage treatment works located approximately 25 km east of Nairobi at Ruai. Analysis for BOD, Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), faecal coliform, and pH are carried out on the incoming raw sewage, water in each of the four settling ponds and the outflowing effluent.

Indicative figures obtained for the inflow and effluent are given in table 4 below. (Detailed data could not be provided to this project by the Nairobi City Council. However, typical values are known and are tabulated below). This information provides a means of verifying the results obtained in this study for the raw sewage used for irrigation at Maili Saba.

Table 4 Indicative water quality results for inflow and effluent at Ruai Sewage Works

Parameter	Inflow	Effluent
BOD	470 mg/l	40 mg/l
Total suspended solids	450 mg/l	100 mg/l
Faecal coliform	3×10^7 FC/100ml	0 FC/100ml
PH	7.2	

Water quality tests were also undertaken by UNEP (1999) under their "Save the Nairobi Rivers" project. Geographical, socio-economic, and pollution data were collected along the lengths of the three main rivers. UNEP collected samples from a wider range of locations and tested for a wider range of parameters than this study. However, only single samples were obtained at 24 locations along three rivers. Samples were analysed for microbiological, physical, and chemical water quality parameters. The UNEP results are used below for comparison with the data collected in this study.

5.1 Total and faecal coliform

Table 5 and figure 2 show the number of total coliform detected in the various samples taken along the Nairobi River and at Maili Saba. (More detailed information, including sampling dates and times, is given in Appendix B, where all results are reported). As would be expected, the number of coliform detected increases with distance downstream. Similar numbers of coliform are found at Kimathi and Njiru Bridge on the Nairobi River as are found in the raw sewage used by farmers at Maili Saba.

Table 5 Total coliform per 100ml (MPN)

Sample no.	Location				
	Thiboro	Mau Mau Bridge	Kimathi	Njiru Bridge	Maili Saba
1	7×10^4	3×10^6	8×10^6	5×10^7	2×10^7
2	2×10^4	3×10^6	9×10^7	3×10^7	9×10^7
3	1×10^3	3×10^6	9×10^7	3×10^6	8×10^6
4	6×10^2	3×10^4	1×10^7	1×10^7	3×10^7
5	1×10^3	1×10^6	7×10^6	4×10^7	4×10^6
6	-	7×10^4	4×10^7	5×10^7	-
7	-	8×10^3	9×10^7	5×10^7	-
8	-	5×10^3	1×10^7	2×10^7	-
9	-	4×10^3	1×10^7	3×10^6	-
10	-	2×10^3	7×10^6	-	-
Mean (geometric)	**4×10^3**	**8×10^4**	**2×10^7**	**2×10^7**	**2×10^7**

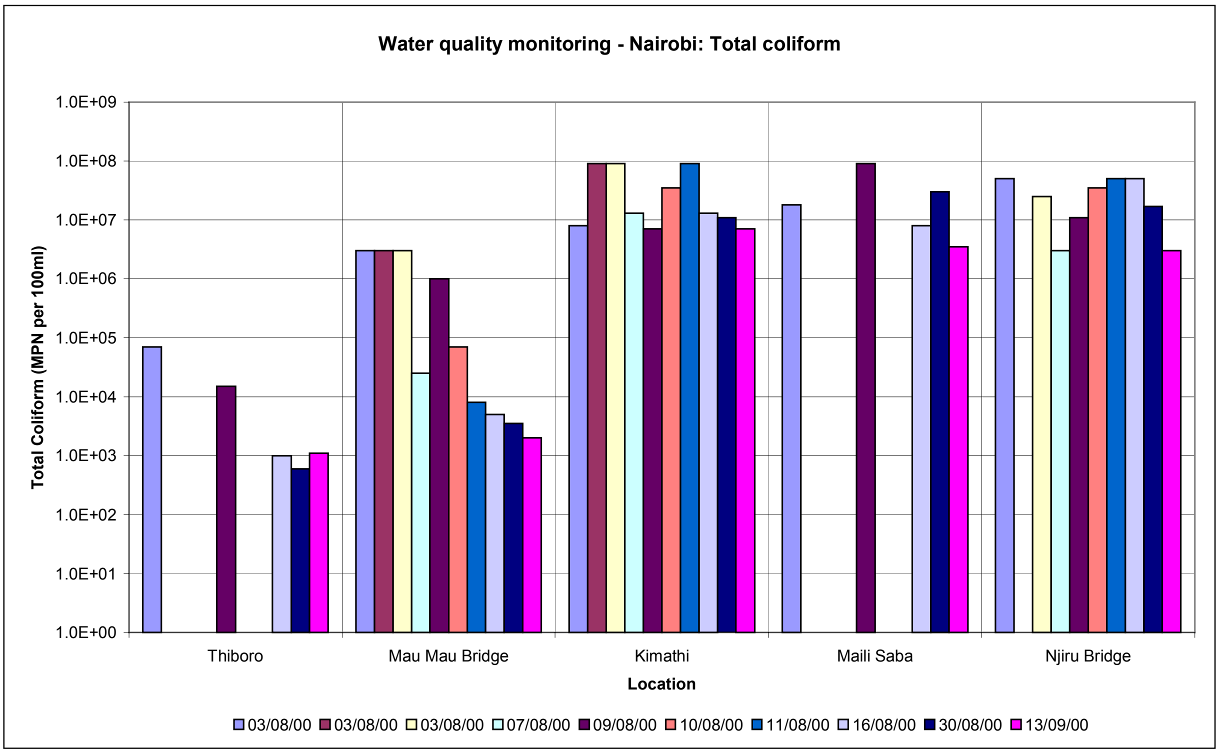

Figure 2 Total coliform count per 100ml

Table 6 and figure 3 give similar results for faecal coliform levels. As with the number of total coliform, faecal coliform counts increase moving downstream and rise to a maximum of 10^7 FC/100ml. The average number of faecal coliform from the water samples taken from the dug-out at Thiboro was 6 x 10^2 FC/100ml, which is just within the WHO guideline of 10^3 FC/100ml.

Table 6 Faecal coliform per 100ml (MPN)

Sample no.	Location				
	Thiboro	Mau Mau Bridge	Kimathi	Njiru Bridge	Maili Saba
1	3 x 10^4	1 x 10^6	6 x 10^6	2 x 10^7	2 x 10^7
2	5 x 10^3	1 x 10^6	4 x 10^7	1 x 10^7	4 x 10^7
3	-	1 x 10^6	5 x 10^7	1 x 10^6	8 x 10^6
4	4 x 10^2	5 x 10^3	1 x 10^7	7 x 10^6	1 x 10^7
5	1 x 10^3	1 x 10^6	7 x 10^6	4 x 10^7	4 x 10^6
6	-	7 x 10^4	3 x 10^7	5 x 10^7	-
7	-	8 x 10^3	4 x 10^7	2 x 10^7	-
8	-	-	8 x 10^6	5 x 10^6	-
9	-	1 x 10^3	6 x 10^6	3 x 10^6	-
10	-	2 x 10^3	6 x 10^6	-	-
Mean (geometric)	**6 x 10^2**	**2 x 10^4**	**1 x 10^7**	**1 x 10^7**	**1 x 10^7**

There is little variation within results at each location, suggesting that the results are consistent.

The mean faecal coliform count for the raw sewage at Maili Saba (1 x 10^7 FC/100ml) and the indicative value for the sewage inflow at the Ruai sewage treatment works (3 x 10^7 FC/100ml) are similar. These values are typical for raw sewage and thus provide some verification of the reliability of the coliform counts measured in this study.

The number of faecal coliform in water samples taken from Mau Mau Bridge, Kimathi, Maili Saba and Njiru Bridge are all greater than the WHO guideline of 10^3 FC/100ml (Figure 3).

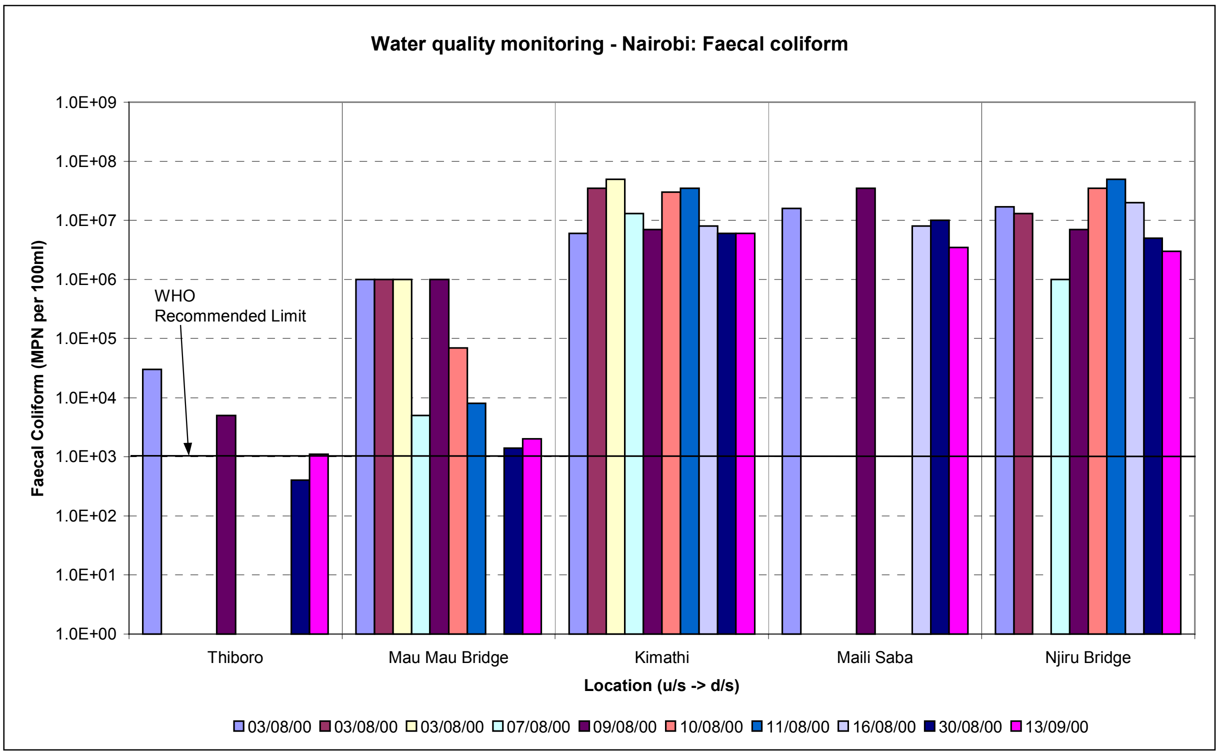

Figure 3 Faecal coliform counts

Total coliform counts from the UNEP study ranged from 30 to 1800 per 100 ml. These values are many magnitudes smaller than those obtained in this study. The UNEP data was collected in November 1999, when river flows would probably have been higher than when the samples for this study were taken. However, the variation in flows, and hence in dilution of the pollutants, is not large enough to explain the great differences between the two data sets. As comparison between other parameters shows that the results from the two studies are broadly similar, it seems likely that the coliform data reported by UNEP are erroneous. Further measurements would be needed to resolve this issue.

5.2 pH

Mean values of pH ranged from 7.1 at Njiru Bridge to 7.6 at Maili Saba (raw sewage). Individual samples ranged from 6.2 at Njiru Bridge to 8.2 at Maili Saba. These figures are within the normal limits of most natural waters, which range from 6.0 to 8.5.

UNEP found that values of pH ranged between 6.4 and 7.8, with the slightly acidic values tending to occur immediately downstream of industrial areas. There are no noticeable differences in the pH of the three rivers.

5.3 Biochemical oxygen demand

Table 7 and figure 4 show 5-day BOD results for the five main sampling locations. Average values of BOD increase downstream, from 96 mg/l at Thiboro to 453 mg/l at Njiru Bridge. The samples at Maili Saba (raw sewage) had an average BOD value of 567 mg/l. Typical values of BOD for unpolluted waters are 2 mg/l or less and for raw sewage about 600 mg/l. Industrial wastes may have BOD values of up to 25,000 mg/l. The results also show an increase in BOD levels over the four-week period of the samples, perhaps due to reducing river flow.

Table 7 BOD (5-day) results (mg/l)

Sample no.	Location				
	Thiboro	Mau Mau Bridge	Kimathi	Njiru Bridge	Maili Saba
1	10	80	120	120	140
2	72	5	320	420	440
3	205	300	880	820	1120
Mean (arithmetic)	**96**	**129**	**440**	**453**	**567**

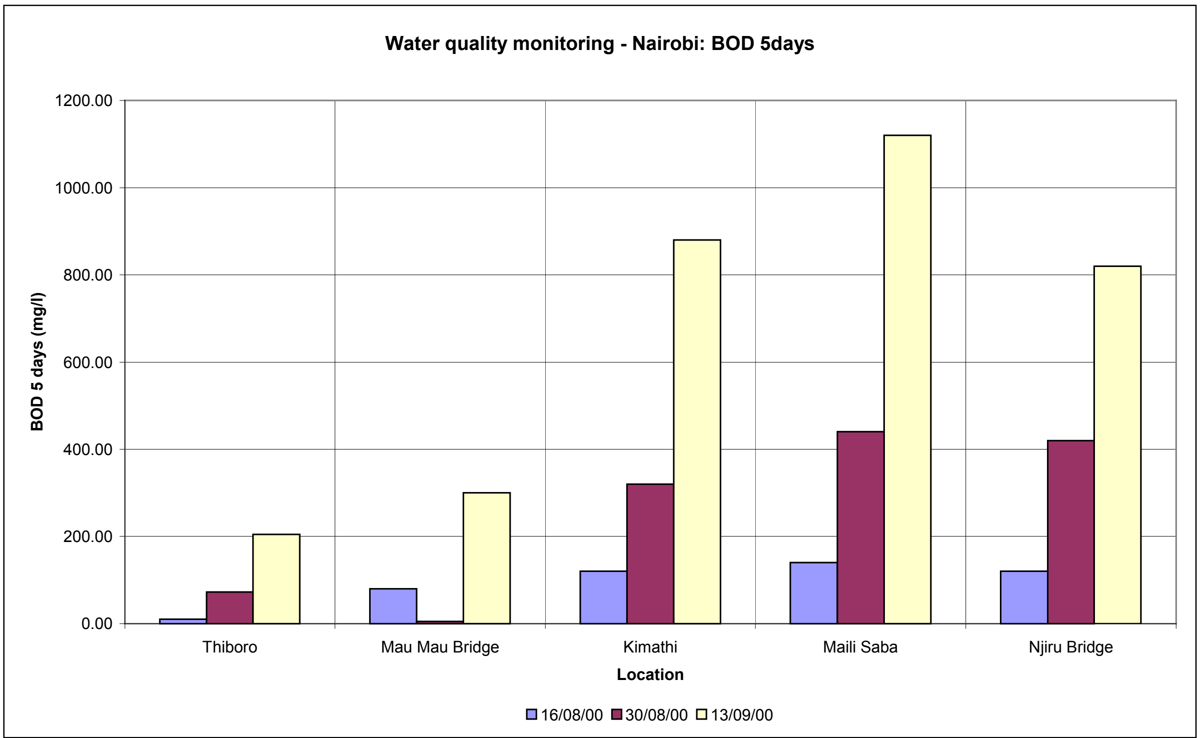

Figure 4 BOD (5-day) results

The UNEP results show that BOD varied from 40 to 4400 mg/l O_2 with values of 40 to 78.5 mg/l O_2 occurring in the western areas of the river basin, and values of 1075 to 4400 mg/l O_2 in the east. This demonstrates that high levels of pollution exist throughout the Nairobi River system, but the extreme pollution occurs downstream of the city's slum and industrial areas, where raw sewage and industrial waste drain directly into the river.

5.4 Nitrate and phosphate

Nitrate (NO_3) and phosphate (PO_4) results are shown in tables 8 and 9. Average nitrate figures varied from 2.0 mg/l at Njiru Bridge to 13.8 mg/l at Thiboro. However, greater variations were observed between individual samples. Average phosphate levels ranged from 3.9 mg/l at Mau Mau Bridge to 18.6 mg/l in the raw sewage at Maili Saba.

Table 8 NO_3 (mg/l)

Sample no.	Location				
	Thiboro	Mau Mau Bridge	Kimathi	Njiru Bridge	Maili Saba
1	9.0	1.4	0.5	0.5	0.5
2	6.0	0.5	0.5	0.5	24.1
3	40.0	19.0	9.0	7.0	7.0
4	0.0	1.5	0.0	0.0	0.5
Mean (arithmetic)	**13.8**	**5.6**	**2.5**	**2.0**	**8.0**

Table 9 PO_4 (mg/l)

Sample no.	Location				
	Thiboro	Mau Mau Bridge	Kimathi	Njiru Bridge	Maili Saba
1	7.0	5.0	2.0	5.9	34.2
2	2.6	3.6	14.8	10.6	0.4
3	3.4	2.7	23.5	6.8	13.0
4	3.7	4.4	26.2	16.9	26.8
Mean (arithmetic)	**4.2**	**3.9**	**16.6**	**10.0**	**18.6**

The major cations tested for in the UNEP programme were sodium, potassium, calcium, and magnesium. Sodium concentrations varied between 5.00 and 126.25 mg/l. In the Ngong and Nairobi Rivers, there was a general upward trend in the concentrations with distance moved downstream, whereas sodium levels in the Mathare fluctuated. In the Ngong River in particular, an appreciable increase in sodium concentrations occurred downstream of the industrial area, which is probably due to industrial effluents.

Potassium levels ranged from 13.75 to 90 mg/l. There is no marked trend in any of the rivers, though higher potassium concentrations are seen downstream of the industrial area in the Ngong River. This may suggest that potassium salts are present in the industrial effluents. The highest potassium concentration, of 90 mg/l, was found at the Naivasha road bridge over the Nairobi River. Much farmland is adjacent to the river at this location, and potassium enters the river from fertilisers.

Calcium concentrations varied between 7.50 and 43.75 mg/l. Lower values were found in the industrial areas. This could be due to chemicals in the industrial effluents causing the calcium cations to precipitate out of solution.

Magnesium levels ranged from 0.44 to 10.00 mg/l. Localised high concentrations could be due to magnesium based detergents, which drain into the river from slum areas, and are dispersed quickly by the river water.

Chloride and fluoride anions, with respective concentrations varying from 20.0 to 107.0 mg/l, and 0.1 to 1.4 mg/l, were detected in the waters of the three rivers. These probably enter the rivers in municipal and industrial waste, but do not give cause for concern at these low levels.

Phosphate concentrations ranged from 0.01 to 0.69 mg/l, and nitrate levels from 0.25 to 6.00 mg/l. Sampling was undertaken during a dry period, when there was no significant input into the rivers from surface runoff. Therefore, locations exhibiting higher nitrate concentrations than the expected natural baseline of 0.10 mg/l, must be near a point source of nitrate. Sources of both nitrate and phosphate are likely to be: agricultural fertiliser, municipal sewage and animal wastes.

Values of phosphate in water samples were generally much higher in the present study than in the UNEP programme. In the present study, average values of nitrate in water samples at Mau Mau Bridge, Kimathi and Njiru Bridge were within the range of values found in the UNEP programme. However, average values of nitrate in water samples at Thiboro and Maili Saba were greater than in the UNEP programme.

5.5 Manganese

Results of manganese levels are shown in Table 10. Average values ranged from 0.15 mg/l at Thiboro to 2.05 mg/l at Njiru Bridge, with a general increasing trend moving downstream. The higher levels recorded greatly exceed the FAO threshold value of 0.2 mg/l leading to crop damage (cited by Pescod, 1992).

Table 10 Manganese (mg/l)

Sample no.	Location				
	Thiboro	**Mau Mau Bridge**	**Kimathi**	**Njiru Bridge**	**Maili Saba**
1	0.0	1.0	0.0	0.0	0.0
2	0.6	0.2	0.0	1.6	2.0
3	0.0	0.2	0.0	3.8	0.0
4	0.0	0.7	1.4	2.8	2.8
Mean (arithmetic)	**0.15**	**0.53**	**0.35**	**2.05**	**1.20**

UNEP showed that concentrations of heavy metals present in the rivers could be toxic to plants that are irrigated using river water. Bioaccumulation of the heavy metals occurs in plants, but it is unlikely that this will pose a threat to human health, as the plants fail to thrive and farmers thus abandon the water source before concentrations exceed human health limits. Heavy metal concentrations increase downstream of the city's industrial areas, with the main pollutants being chromium, copper, zinc, and lead. Chromium is used extensively in industry, particularly for electroplating, tanning, and welding; copper is used for electroplating, and dyeing of textiles; zinc for producing galvanised steel, batteries, pigment, paints, and cosmetics, and lead is often required in the manufacturing of cars, acid batteries, paint, and plastics. Of the heavy metals tested, manganese levels fluctuate most with distance moved downstream. At some locations, levels of manganese recorded by UNEP also exceeded recommended FAO levels for crop irrigation.

5.6 Conductivity

The water conductivity varied between 0.25 mS/cm to 1.07 mS/cm in the UNEP samples. Generally, conductivity values of river water may exceed 1.00 mS/cm if the waters are polluted, which may include contamination from run-off. Since the samples were taken during a dry period when runoff inputs were at a minimum, these conductivity values are primarily due to non-runoff related pollutants. The water demonstrates least conductivity furthest upstream, to the west of Nairobi. Values get progressively larger with distance moved downstream, which reflects the rising pollution levels as the water passes through the city.

5.7 Total suspended solids

Total Suspended Solids (TSS) concentrations range between 4 and 124 mg/l, as measured by UNEP, and are made up of silt, clay, fine particles of organic matter, soluble organic compounds, and microscopic organisms. On the upstream river reaches, there is limited erosion of the land and river channels, and so TSS concentrations are low. Low TSS concentrations are also seen at some locations downstream. This correlates with river sections of low discharge. Conversely, where high levels of human activity cause greater levels of land and river channel erosion, or where the river discharge is high, TSS concentrations are seen to be larger.

6. CONCLUSIONS AND RECOMMENDATIONS

Microbiological contamination of samples taken from the Nairobi River exceeds, by many magnitudes in downstream areas, the recommended limits set out by WHO for unrestricted irrigation. As such, the health of the farmers, farm workers and consumers is potentially put at risk. Recent work by Blumenthal et al. (2000), to verify and refine the WHO guidelines, would suggest that the levels of contamination at Kimathi, Njiru Bridge and Maili Saba are such that restricted irrigation also poses a danger. The results by Blumenthal et al. also provide strong evidence that previously perceived risks of using contaminated water are valid.

The water sampled from the well at Thiboro was just within the recommended limit for unrestricted irrigation. It is thought that the well was contaminated either from run-off from the adjacent housing or from the use of the shallow well as a latrine. If the wells were protected, it would be expected that the quality of water would be significantly better and would pose no danger when used for irrigation. Farmers should be encouraged to adopt suitable practices to protect their water source.

The current practice at areas such as Maili Saba, where farmers interfere with the sewerage infrastructure to obtain raw sewage for irrigation purposes, should be strongly discouraged and prevented. The sewerage system has been constructed with a clear aim of protecting human health and improving the environment.

As would be expected, contamination of the Nairobi River becomes worse downstream and reaches the point where there is no observable difference in quality between samples taken from the river and those taken from the raw sewage used at Maili Saba.

There are a number of options that could be considered to improve the situation:

<u>Crop restriction</u>
A licensing system could be introduced, whereby regular water quality monitoring takes place and farmers are restricted in the crops they are permitted to grow, according to observed water quality. In this way, production of vegetables would have to be limited to upstream of the city, whilst fodder or industrial crops could be grown downstream. This option could include banning all irrigation in certain locations where water quality is particularly poor.

Agricultural activities represent the main source of income in many areas of Nairobi. A ban on crop production would thus have major social and economic repercussions. A balance has to be found between protecting the health of farmer and consumers, and maintaining the livelihoods of some of the poorest sectors of the community.

A slightly less draconian system could be established, whereby farmers who irrigate with good quality water have their produce certified and sold at a premium price. Thus farmers might be encouraged to seek alternative, safer sources of water and consumers would become more aware of the potential danger of eating crops contaminated with poor quality water.

It should also be noted that contamination of crops can occur at all stages: at farm level, from the use of poor quality water, at market level, from the use of dirty water for washing of produce and at the consumer level, through cross-contamination and poor personal and home hygiene.

<u>Additional pre-treatment</u>
Water quality could possibly be improved through pre-treating wastewater prior to use, perhaps with small-scale wetland systems or shallow wells. The contamination found in the well at Thiboro highlights the fact that measures are required to protect wells from possible contamination sources.

<u>Alternative irrigation methods</u>
Risks to farm workers can be reduced through the use of improved irrigation methods such as spray, drip and trickle irrigation. The revised recommended guidelines take this into account, when considering restricted

irrigation. They set varying levels of faecal coliform contamination according to the irrigation method used and also whether children come into contact with the water.

Controlled reuse of effluent from Ruai sewage works

The controlled reuse of effluent from sewage works is a common practice in many countries. It has been seen that the effluent at Ruai is of a high microbiological quality and falls well within the WHO guidelines. As such, it could be used for the irrigation of any crop type without risk to workers or the public. Any move in this direction is clearly a policy decision that must be made by the Nairobi City Council and other concerned bodies.

Clearly, further research is required to assess the practicalities of the various technical and policy options outlined above. It must also be borne in mind that it is unlikely that any one solution will provide a panacea for all situations. A sustainable strategy is likely to require a combination of technical, social and policy solutions.

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Appendices

Appendix A

Synopsis of key references on water quality for irrigation

Appendix A Synopsis of key references on water quality for irrigation

A1 Definitions and terms

The literature relating to wastewater quality, treatment and reuse uses a range of terms that require definition. The following paragraphs give working definitions of different terms used, the aspects of wastewater treatment and re-use to which they refer and the significance of those different aspects to peri-urban irrigation. An explanation of terms referring to smallholder peri-urban irrigation is also provided.

A1.1 Wastewater

Wastewater is a broad term and it is helpful to sub-divide it into the following categories:

- Raw or untreated wastewater — Liquid discharged from homes or commercial premises to individual systems or municipal sewers. It is a mixture of domestic sewage - dirty water and human excreta - and municipal wastewater. It may or may not contain substantial quantities of industrial effluent.
- Treated/partially treated wastewater — Wastewater that has been treated by a natural or artificial purification process to improve its physical, chemical or bacteriological quality before it is discharged into a surface water body. The degree of treatment can vary greatly. Partially treated wastewater may still pose a threat to some receiving environments.
- Industrial Effluent — Water polluted by industrial processes and containing high levels of heavy metals or other chemical or organic constituents. Industrial effluent does not normally contain high levels of microbiological pollution.

A1.2 Marginal quality water

A term normally referring specifically to water which is “marginal” for use in agriculture. Abbott and Hasnip (1997) define it as, “water which might pose a threat to sustainable agriculture and/or human health by virtue of its quality but which can be used safely for irrigation provided certain precautions are taken.” It describes water which has been polluted as a consequence of mixing with wastewater or agricultural drainage.

A1.3 Forms of wastewater reuse

Westcot (1997) makes the important distinction between:

- Direct Reuse — The planned use of raw or treated wastewater where control exists over the conveyance of the wastewater from the point of collection or discharge from a treatment works to a controlled area where it is used for irrigation. This is the situation pertaining in most developed nations where physical and institutional infrastructure is well established to monitor and control the quality of the water and the area where it is used for irrigation.
- Indirect Reuse — The situation found in many developing countries where much municipal and industrial wastewater is discharged without treatment, monitoring or control into the watercourses draining an urban area. The resulting water quality varies according to the flow regime of the watercourse and the volume and composition of effluent that drains into it. There is no control over the use of the water for irrigation (or domestic consumption) downstream of the urban centre. As a

consequence, many downstream farmers indirectly reuse wastewater or marginal quality water of unknown composition. However, without knowledge of the water quality and the autopurifier effect of the river, the risks associated with this indirect reuse are unknown.

Much of the available literature, including the development of water quality guidelines for wastewater reuse, has focused on direct reuse systems where regulation and control can be applied at the point of treatment and discharge, and over the area where the water is used. This has little direct application for many countries in the developing world. The recent work by Westcot (1997) is one of the few texts to have recognised and addressed this issue.

A2 Key references on irrigation water quality and health implications

The synopsis presented here provides a summary of a wider literature review carried out by Ghesquière (1999).

A2.1 Microbiological contamination

Although the volume of published information on wastewater reuse for irrigation and its implications for human health is substantial, a smaller number of major studies and publications can be identified, which are listed here in date order:

Cross & Strauss, 1985	Health Aspects of Nightsoil and Sludge use in Agriculture and Aquaculture. Part I, Existing Practices and Beliefs in the utilization of Human Exceta. Part II, Pathogen Survivial. IRCWD Report no. 04/85
Blum & Feacham, 1985	Health Aspects of Nightsoil and Sludge use in Agriculture and Aquaculture, Part III. An Epidemiological Perspective. IRCWD Report no. 05/85
IRCWD, 1985	Health Aspects of Wastewater and Excreta Use in Agriculture and Aquaculture: The Engelberg Report. IRCWD News No. 23, December 1985.
Shuval et al., 1986	Wastewater Irrigation in Developing Countries. World Bank Technical Paper No. 51. World Bank, Washington, USA.
Mara & Cairncross 1989	Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture: Measures for Public health Protection. WHO, Geneva.
Westcot, 1997	Quality Control of Wastewater for Irrigated Crop Production. FAO Water Report No. 10. FAO, Rome.
Blumenthal et al., 2000	Guidelines for Wastewater Reuse in Agriculture and Aquaculture: Recommended Revisions Based on New Research Evidence. WELL Study Report Task No 68, Part 1. http://www.lboro.ac.uk/well/studies/t68i.pdf

1981 and 1982 saw the initiation of two major, parallel studies into the use of excreta (nightsoil and sludge) and wastewater in agriculture. The division of the topic between two different implementing agencies was done for "practical reasons". The International Reference Centre for Waste Disposal (IRCWD) at Dubendorf, Switzerland sought to determine the actual health risks associated with the use of human excreta. The work was sponsored by the WHO and UNEP. The World Bank, under the UNDP Integrated Resource Recovery Project, commissioned a team of consultants to study the health effects of wastewater irrigation. These two studies resulted in what were state-of-the-art reports in 1985 and 1986.

The findings of the two studies were reviewed at a meeting in Engelberg, Switzerland, in July 1985 (IRCWD, 1985). Here, a new set of guidelines, for the use of treated wastewater and excreta, were drafted, "based on epidemiological evidence of actual risks to public health, rather than on potential hazards indicated by the survival of pathogens on crops and in the soil." (Mara and Cairncross, 1989).

The draft guidelines were reviewed at a second meeting of experts in Adelboden, Switzerland in June 1987, where the use of wastewater and excreta for aquaculture was considered. The guidelines were finally published in 1989 (Mara and Cairncross, 1989).

The resulting guidelines provide values for permissible levels of microbiological contamination to be used as design values in the design of water treatment plants. Mara and Cairncross (1989) state explicitly that the values are not intended for use as quality surveillance norms, though they offer no suggestion as to what norms might be used in this respect. The guidelines provide design values for water quality, based on the number of viable nematode eggs per litre and faecal coliform bacteria per 100 ml. Table 1 presents the guidelines in detail.

Table A1 Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture [a]

Category	Reuse condition	Exposed group	Intestinal nematodes [b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100 ml[c])	Wastewater treatment expected to achieve the required microbiological quality
A Unrestricted	Irrigation of crops likely to be eaten uncooked, sports fields, public parks [d]	Workers, consumers, public	≤ 1	≤ 10^3 [d]	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B Restricted	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees [e]	Workers	≤ 1	No standard recommended	Retention in stabilisation ponds 8-10 days or equivalent, helminth and faecal coliform removal
C Localised	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

a In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly.
b *Ascaris* and *Trichuris* species and hookworms. See Figure 1.
c During the irrigation period.
d A stringent guideline (≤ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
e In the case of fruit trees, irrigation should cease two weeks before fruit is picked and no fruit should be picked off the ground. Sprinkler irrigation should not be used.
Source: WHO (1989), cited by Pescod (1992)

These standards represent a relaxing of previous bacteriological standards that can be traced back to standards of the California State Health Department. Those early standards were based on a "zero risk" concept and took no account of epidemiological evidence of the practices and effluent qualities that actually lead to measurably greater incidence of disease in a population. Whilst the new standards are less stringent with regard to bacteriological quality, they did for the first time set a standard for the presence of helminths, recognising that the major health risks in many developing countries are associated with helminthic diseases.

These major studies and the guidelines arising from them represented a major advance in the state of knowledge concerning wastewater reuse. However, the guidelines were intended for use in the design of wastewater treatment plants in the possibly optimistic belief that the relatively simple and low cost technology of waste stabilisation ponds could be used to treat the wastewater of the developing world's urban areas. This goal may be realised in the medium to long term, but in the short term the uncontrolled discharge of municipal and industrial effluent into natural watercourses will remain the norm for many cities.

Westcot (1997) addressed the question of how the WHO guidelines (Mara and Cairncross, 1989) can be applied where there is no treatment of wastewater and farmers downstream of large urban centres are irrigating with wastewater of variable composition and dilution – a practice he describes as indirect reuse. He predicts this form of reuse will, "expand rapidly in the future as urban population growth outstrips the financial resources to build adequate treatment works." Having acknowledged that the WHO guidelines are intended as design guidelines, he suggests that, in the absence of better information, it is "prudent" to use the WHO standards for faecal coliforms as the quality standard to aim for in waters that are known to currently fall short of that quality. Shuval et al. (1986) concluded that the presence of helminth eggs in irrigation water (specifically roundworms of the species Ascaris and Trichuris, see Figure A1) posed the greatest risk to health. They have long persistence in the environment, require only a small number to cause infection and there is little possibility of immunity occurring in the human population. However, there are no routine and simple techniques available to monitor helminth egg numbers in water samples and therefore Westcot considers it impractical to use the helminth guideline in routine monitoring of water quality for irrigation.

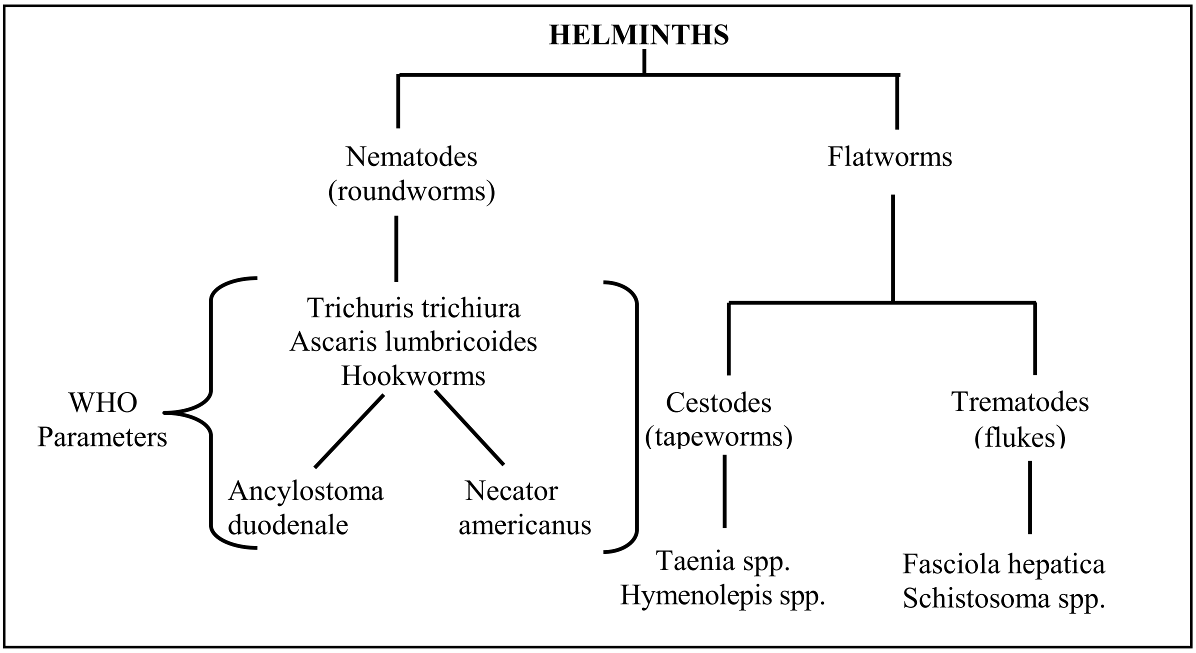

Figure A1 Characterisation of Helminths showing those Considered under WHO (Mara and Cairncross, 1989) Guidelines

Westcot (1997) argues in favour of establishing a routine water quality monitoring programme, based on faecal coliform numbers, to support a certification programme certifying that high risk or restricted crops – mainly vegetables and particularly those eaten raw – are produced in a safe environment. This in turn requires education of consumers and encouragement of market forces, whereby consumers choose to buy only certified produce. It is argued that this approach is more realistic under conditions of uncontrolled wastewater reuse than attempts to impose crop restrictions which are almost impossible to enforce.

A programme of this type might be difficult to establish and sustain in the poorer countries of Africa. However, the approach merits serious consideration by any authority concerned about the health implications of peri-urban irrigation carried out with wastewater. In particular, the ranges of contamination and consequent recommendations put forward by Westcot provide a useful point of entry in any attempt to monitor and interpret water quality data for irrigation. These are summarised in Table A2.

Table A2 Ranges of Contamination and Recommendations (after Westcot, 1997)

Mean number of faecal coliform per 100 ml [a]	Recommendation
< 1,000	Appropriate for irrigation of vegetables
1,000 – 10,000	Potentially safe if the source of contamination (presumed to be localised) can be eliminated
10,000 – 100,000	Heavy contamination requiring treatment before the water can be used for unrestricted cropping
> 100,000	Extensive heavy contamination – highly unsuited for irrigation.

[a] Based on a minimum of 5 samples taken over the irrigation season

A2.2 Recommended revisions to WHO guidelines based on new reasearch evidence

The WHO guidelines (Mara and Cairncross, 1989) have influenced the standards for wastewater reuse adopted in many countries. With the aim of assessing the validity of the guidelines, the London School of Health and Tropical Medicine have carried out epidemiological studies in Mexico and Indonesia, and Leeds University have undertaken microbiological studies of crops irrigated with treated wastewater in Brazil and Portugal. The review was carried out under the premise that there should be no measurable excess illness in the exposed population and also that model generated estimated risk should be below a defined acceptable risk.

Blumenthal et al. (2000) found that "the results of the studies of consumer risks do not provide any evidence to suggest a need to change the WHO *faecal coliform* guideline of $\leq 10^3$ FC/100ml for *unrestricted irrigation*. Epidemiological studies in a situation where enteric infections are endemic suggest that risks of enteric infections are significant, but low, when the guideline is exceeded by a factor of 10."

The WHO guidelines also "appear to offer similar levels of protection" as US microbial standards for drinking water, which are based on the criteria that human populations should not be subjected to the risk of infection by enteric disease greater than 10^{-4} (or 1 in 10,000 persons/year). However, "in situations where there are insufficient resources to reach 10^3 FC/100ml, then a more relaxed guideline of 10^4 FC/100ml could be adopted, but should be supplemented by other health protection measures".

With regard to helminths, "the *nematode egg* guideline of ≤1 nematode egg/litre for *unrestricted irrigation* appears to protect consumers of cultivated vegetables spray-irrigated with effluent of consistent quality and at high temperatures, but not necessarily consumers of vegetables surface-irrigated with such effluent at lower temperatures".

Also for *unrestricted irrigation*, "the nematode egg guideline of ≤1 egg per litre is adequate if no children are exposed, but a revised guideline of ≤0.1 egg/litre is recommended if children are in contact with the wastewater through irrigation or play".

There is an observed increased risk of *Ascaris* infection amongst children eating vegetables irrigated with water containing 1 nematode egg per litre. Therefore, "it is recommended that a stricter guideline of ≤0.1 egg/litre is adopted to prevent transmission of *Ascaris* infection and to allow for the risks to farm workers involved in cultivating the vegetable crops".

The studies concluded that a faecal coliform guideline for *unrestricted irrigation* should be added. "A reduced guideline of $\leq 10^3$ FC/100ml would be safer where adults are involved in flood/furrow irrigation and children are regularly exposed (through farm work or play)". However, "where there are insufficient resources to provide treatment to reach this stricter guideline, a guideline of 10^5 FC/100ml should be supplemented by other health protection measures for children".

Finally, "a range of health protection measures including crop restriction, irrigation technique, human exposure control and chemotherapeutic intervention should all be considered in conjunction with partial wastewater treatment".

A summary of the revised recommended guidelines is shown in Table A3.

Table A3 Recommended revised guidelines for treated wastewater use in agriculture [a]

Category	Reuse conditions	Exposed group	Irrigation technique	Intestinal nematodes[b] (eggs/litre[c])	Faecal coliforms (FC per 100ml[d])
A	*Unrestricted irrigation*				
	A1 Vegetable and salad crops eaten uncooked, sports fields, public parks [e]	Workers, consumers, public	Any	≤ 0.1 [f]	$\leq 10^3$
B	*Restricted irrigation*				
	Cereal crops, industrial crops, fodder crops, pasture and trees [g]	B1 Workers (but no children <15 years), nearby communities	Spray/ sprinkler	≤ 1	$\leq 10^5$
		B2 as B1	Flood/ furrow	≤ 1	$\leq 10^3$
		B3 Workers including children <15 years, nearby communities	Any	≤ 0.1	$\leq 10^3$
C	Localised irrigation of crops in category B if exposure to workers and the public does not occur	None	Trickle, drip or bubbler	Not applicable	Not applicable

a In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly
b Ascaris and Trichuris species and hookworms: the guideline is also intended to protect against risks from parasitic protozoa
c During the irrigation season (if the wastewater is treated in WSP or WSTR, which have been designed to achieve these numbers, then routine effluent quality monitoring is not required)
d During the irrigation season (faecal coliform counts should preferably be done weekly, but at least monthly)
e A more stringent guideline (≤ 200 FC/100ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact
f This guideline can be increased to ≤ 1 egg/litre if (i) conditions are hot and dry and surface irrigation is not used, or (ii) if wastewater treatment is supplemented with anthelmintic chemotherapy campaigns in areas of wastewater re-use
g in the case of fruit trees, irrigation should cease two weeks before fruit is picked and no fruit should be picked off the ground. Spray/sprinkler irrigation should not be used

Source: Blumenthal et al. (2000)

The report also describes the wastewater treatment needed to achieve a required microbiological quality.

A2.3 Trace elements and heavy metals

Both the major programmes of research that culminated in the Engelberg guidelines focused on the microbiological aspects of wastewater quality. They make only passing reference to the potential or actual risk from trace elements and heavy metals. Mara and Cairncross (1989) assert that the health hazards due to chemical pollution are of only minor importance when considering the reuse of domestic wastes. Pescod

(1992), in a review of wastewater treatment and use in agriculture, acknowledges that municipal wastewater may contain toxic levels of trace elements (heavy metals and other chemical elements).

It is widely accepted that levels of trace elements and heavy metals in irrigation water are likely to be toxic to plants at concentrations below that at which they pose a significant risk to human health. This provides a degree of natural protection to irrigators and consumers alike, i.e. plants fail to thrive and farmers abandon the source well before levels present a risk to human health. There is concern over the possible long-term accumulation of some heavy metals in soil as a result of wastewater irrigation (Kaddous and Stubbs, 1983; Siebe and Cifuentes, 1995), but this lies outside the scope of this review and field study. There are currently no guidelines for permissible levels of trace elements and heavy metals in wastewater used for irrigation which relate to the potential risk to human health as a consequence of crop uptake and bio-accumulation. Most authors cite either a table of phytotoxic thresholds prepared by the National Academy of Sciences and National Academy of Engineering (1972) and Pratt (1972), or refer to the WHO drinking water guidelines (WHO, 1993). These data are reproduced in Table A4.

Table A4 WHO and EU Drinking Water Quality Guidelines for Heavy Metals and Threshold Values Leading to Crop Damage (mg/l).

Element	WHO drinking water guideline[a]	EU drinking water guideline[b]	Recommended maximum concentration for crop[c]
Arsenic	0.01	0.05	0.1
Cadmium	0.003	0.005	0.01
Chromium	0.05	0.05	0.1
Copper	2	0.1 – 3.0	0.2
Iron	0.3	0.2	5.0
Mercury	0.001	0.001	-
Manganese	0.5	0.05	0.2
Nickel	0.02	0.05	0.2
Lead	0.01	0.05	5.0
Zinc	3	0.1 – 5.0	2.0

Sources:
a WHO (1993)
b Cited by Chapman (1996)
c Cited by Pescod (1992)

Ghesquière (1999) prepared a summary of the effects of heavy metals on plants and human health and this is reproduced in Table A5.

Reliable detection of heavy metals at the concentrations likely to be encountered in municipal wastewater requires use of sophisticated laboratory equipment and appropriately trained staff. Pearce et al. (1999) evaluated the use of recently developed field equipment to measure heavy metal concentrations in water samples. However, they were unable to endorse the use of such equipment as results were inconsistent and doubts existed over the method's efficacy in water carrying a high sediment load.

Table A5 Heavy Metals and Their Effects on Plants and Human Health

Element	Sources	Agronomic effects	Effect on health
As	Industrial effluents, an impurity in some detergents	Toxicity to plants varies widely	Very harmful, cumulative poison, carcinogenic, skin diseases.
Cd	Washing powders as an impurity in phosphates, impurity in zinc steel industry, paint, plastic	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Risk of accumulation in plants and soils.	Very harmful, cumulative poison. Food main source of intake.
Cr	Leather tanneries (about 40 mg/l in surface discharges)	Not generally recognised as an essential growth element. Lack of knowledge on its toxicity to plants	Carcinogenic, dermatitis, painful chrome ulcers. Food main source of intake.
Cu	Plumbing, animal wastes, pesticides, earth's crust	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions	Liver cirrhosis food main source of intake, uncertain toxicity in humans.
Fe	Plumbing, earth's crust	Essential element of nutrition, not toxic to plants	Not a major hazard to health.
Hg	Pesticides, industrial effluents		Very harmful, for pregnant women, cumulative poison, neurological diseases.
Mn	Industrial effluents	Toxic to a number of crops at a few-tenths to a few mg/l	No convincing data of human toxicity.
Ni	Industrial effluents	Toxic to a number of plants at 0.5 mg/l to 1 mg/l.	Carcinogenic, lack of data on carcinogenic by the oral route
Pb	Lead-acid batteries, solder, alloys	Decrease respiration of soil organisms and inhibit plant cell growth at very high concentrations	Accumulate in skeleton, harmful for children and pregnant women
Zn	Plumbing, animal wastes, pesticides	Toxic to many plants at widely varying concentrations	Not a major hazard to health

Source: Ghesquière (1999). Data drawn from: Pratt (1972); FWR (1993); WHO (1993); Tiller et al. (1994); Leita et al. (1995); Birley and Lock (1998)

The difficulties and cost associated with the accurate measurement of heavy metals and the understanding that heavy metals are unlikely to pose a threat to human health through consumption of irrigated vegetables, mean that the monitoring of heavy metals in wastewater reused for agriculture is not a priority.

Appendix B

Full results from HR Wallingford Study

Appendix B Full results from HR Wallingford study

	Sample	Date	Time	Coliform (MPN/100ml) Total	Faecal	Temp (deg C)	pH	BOD5 mg/l	NO3 mg/l	PO4 mg/l	Mn mg/l
Thiboro	TB 01	04/08/00	10:25	7.0E+04	3.0E+04	18.0	6.91	-	-	-	-
	TB 02	09/08/00	11:20	1.5E+04	5.0E+03	19.0	7.60	-	9.00	6.99	0.00
	TB 03	16/08/00	12:45	1.0E+03	1.0E+00		7.25	10.00	6.00	2.62	0.60
	TB 04	30/08/00	08:55	6.0E+02	4.0E+02		6.79	72.00	40.00	3.36	0.00
	TB 05	13/09/00	08:30	1.1E+03	1.1E+03		7.90	205.00	0.00	3.65	0.00
	Mean	**-**	**-**	**3.7E+03**	**5.8E+02**	**18.5**	**7.29**	**95.67**	**13.75**	**4.16**	**0.15**
Mau Mau Bridge	MMB 01	03/08/00	09:35	3.0E+06	1.0E+06	17.5	7.12	-	-	-	-
	MMB 02	03/08/00	12:15	3.0E+06	1.0E+06	18.5	7.27	-	-	-	-
	MMB 03	03/08/00	14:00	3.0E+06	1.0E+06	20.8	7.48	-	-	-	-
	MMB 04	07/08/00	08:50	2.5E+04	5.0E+03	18.0	7.25	-	-	-	-
	MMB 05	09/08/00	11:45	1.0E+06	1.0E+06	18.0	7.28	-	1.40	4.96	1.00
	MMB 06	10/08/00	11:10	7.0E+04	7.0E+04	19.0	7.43	-	-	-	-
	MMB 07	11/08/00	10:55	8.0E+03	8.0E+03		7.48	-	-	-	-
	MMB 08	16/08/00	12:20	5.0E+03	1.0E+00		7.35	80.00	0.50	3.62	0.20
	MMB 09	30/08/00	09:15	3.5E+03	1.4E+03		6.79	5.00	19.00	2.65	0.20
	MMB 10	13/09/00	08:50	2.0E+03	2.0E+03		7.10	300.00	1.50	4.38	0.70
	Mean	**-**	**-**	**8.2E+04**	**1.9E+04**	**18.6**	**7.26**	**128.33**	**5.60**	**3.90**	**0.53**
Kimathi	KM 01	03/08/00	08:45	8.0E+06	6.0E+06	19.0	7.12	-	-	-	-
	KM 02	03/08/00	11:30	9.0E+07	3.5E+07	21.0	7.18	-	-	-	-
	KM 03	03/08/00	13:20	9.0E+07	5.0E+07	22.0	7.21	-	-	-	-
	KM 04	07/08/00	11:25	1.3E+07	1.3E+07	21.0	7.26	-	-	-	-
	KM 05	09/08/00	10:15	7.0E+06	7.0E+06	20.0	7.29	-	0.50	2.01	0.00
	KM 06	10/08/00	10:30	3.5E+07	3.0E+07	20.5	7.35	-	-	-	-
	KM 07	11/08/00	09:05	9.0E+07	3.5E+07		7.35	-	-	-	-
	KM 08	16/08/00	11:20	1.3E+07	8.0E+06		7.19	120.00	0.50	14.78	0.00
	KM 09	30/08/00	11:00	1.1E+07	6.0E+06		7.04	320.00	9.00	23.54	0.00
	KM 10	13/09/00	10:50	7.0E+06	6.0E+06		8.00	880.00	0.00	26.22	1.40
	Mean	**-**	**-**	**2.1E+07**	**1.4E+07**	**20.6**	**7.30**	**440.00**	**2.50**	**16.64**	**0.35**
Njiru Bridge	NJ 01	04/08/00	09:15	5.0E+07	1.7E+07	19.0	7.41	-	-	-	-
	NJ 02	04/08/22	12:10	2.5E+07	1.3E+07	22.0	7.11	-	-	-	-
	NJ 03	07/08/00	10:50	3.0E+06	1.0E+06	20.5	7.39	-	-	-	-
	NJ 04	09/08/00	09:30	1.1E+07	7.0E+06	19.5	6.24	-	0.50	5.85	0.00
	NJ 05	10/08/00	09:55	3.5E+07	3.5E+07	20.0	7.27	-	-	-	-
	NJ 06	11/08/00	10:00	5.0E+07	5.0E+07		7.25	-	-	-	-
	NJ 07	16/08/00	10:25	5.0E+07	2.0E+07		7.32	120.00	0.50	10.56	1.60
	NJ 08	30/08/00	10:20	1.7E+07	5.0E+06		6.25	420.00	7.00	6.78	3.80
	NJ 09	13/09/00	10:05	3.0E+06	3.0E+06		7.29	820.00	0.00	16.87	2.80
	Mean	**-**	**-**	**1.8E+07**	**9.8E+06**	**20.2**	**7.06**	**453.33**	**2.00**	**10.02**	**2.05**
Maili Saba	MS 01	04/08/00	12:25	1.8E+07	1.6E+07	22.0	7.40	-	-	-	-
	MS 02	09/08/00	09:45	9.0E+07	3.5E+07	21.5	8.15	-	0.50	34.17	0.00
	MS 03	16/08/00	10:40	8.0E+06	8.0E+06		7.22	140.00	24.11	0.40	2.00
	MS 04	30/08/00	11:00	3.0E+07	1.0E+07		6.97	440.00	7.00	12.96	0.00
	MS 05	13/09/00	10:20	3.5E+06	3.5E+06		8.10	1120.00	0.50	26.76	2.80
	Mean	**-**	**-**	**1.7E+07**	**1.1E+07**	**21.8**	**7.57**	**566.67**	**8.03**	**18.57**	**1.20**
Others	ND 01	10/08/00	08:45	2.0E+06	2.0E+06	17.5	7.25	-	0.00	8.91	4.00
	DB 01	10/08/00	09:25	9.0E+07	5.0E+07	21.0	7.44	-	0.60	14.28	0.00
	BSB 01	11/08/00	10:35	8.5E+04	3.5E+04		7.32	-	0.80	1.72	0.10
	MAB 01	11/08/00	10:50	1.6E+08	2.0E+07		7.45	-	0.60	22.02	0.00
	BB01	11/08/00	11:25	8.5E+04	3.5E+04		7.32	-	0.80	1.72	0.10