THE IMPACT OF WATER POLLUTION FROM FORMAL AND INFORMAL URBAN DEVELOPMENTS ALONG THE PLANKENBRUG RIVER ON WATER QUALITY AND HEALTH RISK

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Dissertation presented for
the degree of
Doctor of Philosophy
at the University of Stellenbosch

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December 2003

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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ABSTRACT

The Plankenbrug River runs past the dense settlement of Kayamandi, on the outskirts of Stellenbosch. This site was chosen to study the impact of water pollution from formal and informal urban developments on water quality and associated health factors.

Aims of the study: (1) To determine some basic epidemiological characteristics of the exposed population of Kayamandi, their sanitation problems and reasons for poor hygiene; (2) To determine the microbiological and chemical pollution load patterns in the Plankenbrug River over time; (3) To investigate the spectrum of organisms present in the river (other than the indicator *E. coli*) and their epidemiological implications for health; (4) To establish the possible presence of organisms resistant to chlorine or to antibiotics in the river below Kayamandi as indicators of environmental hazard.

Methods: During the period 5 May 1998 to 10 February 2003 microbiological and chemical analyses have been carried out every 6 weeks on water samples obtained at various points along the Plankenbrug River. Two large surveys (n=2196 persons and n=3568 persons) of the community of Kayamandi have been undertaken and door-to-door education campaigns were carried out with the aid of trained community health workers.

Results: Below Kayamandi the river contains dangerously high levels of faecal contamination and it constitutes a health hazard to all persons coming into contact with the water. Up to 13 million *Escherichia coli* per 100 ml water was recorded (cut-off level as indicator of human safety is 1000 organisms per 100 ml water). Not all the faecal contamination originated from Kayamandi. Substantial amounts of faecal contamination sporadically entered the river at different points below Kayamandi. The pollution load resulting from these intrusions were sometimes larger than that contributed by the whole of Kayamandi.

Water samples below Kayamandi were screened to ascertain what other pathogens were present. Amongst the organisms were β haemolytic *Streptococcus* Group A and B, *Mycobacterium intracellulare*, *Staphylococcus* spp, *Klebsiella spp.*, *Pseudomonas* spp. and many others. The list of pathogens found had such serious implications that a confidential health warning was sent out to health care centres and other affected organisations in the area. β haemolytic *Streptococcus* Group A has never before been reported as isolated in viable form from free-flowing natural waters. Signs of increased resistance to chorine were

found in organisms isolated from the river water. There were also organisms showing signs of resistance to commonly used antibiotics. The *E. coli* organisms that survived various levels of chlorine treatment also showed increased resistance to amoxycillin when compared to untreated *E. coli* organisms sampled from the Plankenbrug River.

During the community phase of the project in Kayamandi a reduction in the pollution levels occurred over the summers of 2000 and 2001 (note that "improved" does not yet mean "safe" by any means). This can be ascribed to the multi-pronged approach of the project. Attention was given to service and repair of sanitation facilities, a strong accent on door-to-door community education about better sanitation behaviour, creation of a central reporting point for blockages and breakages, and training of artisans (plumbers, bricklayers, etc) from the community to help with upkeep. The community showed encouraging signs of wanting better sanitation education. The improvement in pollution levels is however in danger of reverting back to the previous dangerous situation if better support and co-operation cannot be obtained from the relevant authorities. There were 16.9% of households who reported one or more cases of diarrhoea during the survey period (5 weeks) - a very high prevalence seeing that the survey was carried out during a wet and cold winter period.

Conclusions: Active planning and other steps to cope with the sewage intrusions into the river should be instituted without delay. The water quality of the Plankenbrug River downstream from Kayamandi is extremely poor. The water constitutes a serious health hazard and a threat to downstream economic activities. The settlement of Kayamandi demonstrated that education, when coupled with maintenance and repairs of existing toilet facilities, can bring about a reduction in pollution loads, but that this should be an ongoing process and not be reduced to sporadic attempts.

OPSOMMING

Die Plankenbrug Rivier vloei verby die digbewoonde nedersetting van Kayamandi aan die buitewyke van Stellenbosch. Hierdie plek is gekies as studie-area om die impak te bestudeer van waterbesoedeling wat van formele en informele dorpsontwikkeling afkomstig is, asook die geassosieerde gesondheidsfaktore.

Doel van die studie: (1) Om sommige basiese epidemiologiese eienskappe van die blootgestelde populasie, hulle sanitasieprobleme en redes vir die swak higiene te bepaal; (2) Om die mikrobiologiese en chemiese besoedelingspatrone in die Plankenbrug Rivier oor tyd te bepaal; (3) Om die spektrum van organismes teenwoordig in die rivier (anders as *E. coli*) te bepaal asook hulle epidemiologiese implikasies op gesondheid; (4) Om vas te stel, as indikatore van omgewingsgevaar, of daar moontlik organismes teenwoordig is wat weerstandig is teen chloriene en antibiotika in die rivier onder Kayamandi.

Metodes: Gedurende die afgelope vier jaar is mikrobiologiese en chemiese ontledings elke 6 weke uitgevoer van watermonsters wat van verskeie punte op die Palnkenbrug Rivier verkry is. Twee groot opnames is in die gemeenskap van Kayamandi onderneem (n=2196 persone en n=3568 persone) en deur-tot-deur opvoedingsveldtogte is uitgevoer met die hulp van plaaslik opgeleide gemeenskapsgesondheidswerkers.

Resultate: Onder Kayamandi bevat die rivier gevaarlike vlakke van fekale besoedeling en dit hou gesondheidsgevare in vir alle persone war daarmee in aanraking kom. Op tot 13 miljoen *Escherichia coli* per 100 ml water is genoteer (boonste grens van veiligheid vir die mens is 1000 organismes per 100 ml water). Nie al die fekale kontaminasie is afkomstig van Kayamandi nie. Substansiële hoeveelhede kontaminasie dring die rivier binne op verskillende punte ver onder Kayamandi. Hierdie besoedelingslading is soms groter as wat van die hele Kayamandi afkomstig is.

Watermonsters geneem onder Kayamandi is ondersoek om vas te stel watter ander siekteveroorsakende organismes ook teenwoordig was. Onder die organismes gevind was β hemolitiese *Streptococcus* Groep A en B, *Mycobacterium intracellulare, Staphylococcus* spp., *Klebsiella* spp., *Pseudomonas* spp. en baie ander. Die lys van patogene wat gevind is, het sulke ernstige implikasies dat 'n vertroulike gesondheidswaarskuwing uitgestuur is na gesondheidsdienspunte en ander geaffekteerde organisasies in die gebied. β hemolitiese *Streptococcus* Groep B is nog nie vantevore aangemeld as lewensvatbaar geïsoleer uit

vryvloeiende natuurlike waters nie. Tekens is gevind dat daar organismes in die rivier voorkom wat weerstandig is teen chloorbehandeling en ook teen algemeen gebruikte antibiotika. Die *E. coli* organisme wat verskillende konsentrasies van chloorbehandeling oorleeef het, het ook verhoogde weerstand teen amoksisilien getoon wanneer hulle vergelyk was met onbehandelde *E. coli* organisme wat van die Plankenbrug Rivier gemonster was.

Gedurende die gemeenskapsfase van die projek is daar 'n verlaging van besoedelingsvlakke in die rivier gevind gedurende die somers van 2000 en 2001 (let op dat "verbetering" hier nog glad nie "veilig" beteken nie). Dit kan toegeskryf word aan die veelvlakkige benadering wat die projek gevolg het. Aandag is geskenk aan diens en herstel van sanitasiegeriewe met 'n sterk klem op deur-tot-deur opvoedingsveldtogte met die oog op beter sanitasiegedrag, skepping van 'n sentrale aanmeldpunt vir blokkasies en brekasies, en opleiding van ambagslui (loodgieters, messelaars, ens) uit die gemeenskap om te help met onderhoud. Die gemeenskap het bemoedigende tekens getoon dat hulle beter sanitasie opvoeding verlang. Die verbetering in die besoedelingsvlakke in die rivier loop egter gevaar om terug te val na die vorige gevaarlike vlakke as daar nie beter ondersteuning en samewerking van die onderhawige owerhede verkry kan word nie. Daar was 16.9% van huishoudings wat een of meer gevalle van diarree aangemeld het gedurende die 5 weke van die opnameperiode - 'n baie hoë prevalensie siende dat die opname uitgevoer was gedurende 'n nat en koue winterperiode.

Gevolgtrekkings: Aktiewe beplanning en ander stappe om die riool-indringing in die rivier die hoof te bied is gebiedend noodsaaklik en behoort sonder versuim ingestel te word. Die waterkwaliteit van die Plankenbrug Rivier stroomaf van Kayamandi is baie swak. Die water hou ernstige gesondheidsgevare in en is ook 'n bedreiging vir die ekonomiese aktiwiteite stroomaf. Die nedersetting van Kayamandi demonstreer ook dat opvoeding, wanneer gekoppel aan onderhoud en herstel van bestaande toiletgeriewe in verlaging teweeg kan bring van besoedelingsvlakke, maar dat dit 'n voortgesette program moet wees en nie net sporadiese pogings nie.

This work is dedicated to all those who helped to make a difference to the river environment and the living condition of the poor in Kayamandi, especially Marie Slabbert, Annelene Huisamen, Nina du Plessis, Martha Mayembana and Sipho Menziwa. They enabled me to stand on their shoulders and allowed me to reach much further than I ever could have on my own.

ACKNOWLEDGEMENTS

The following contributions, both financial, scientific and personal are acknowledged with gratitude:

1. The Flemish Government, through Prof Em. Paul de Rycke, emeritus professor of the University of Ghent, Belgium for initiation of the project, financial assistance and encouragement.

2. The DANCED programme of the Danish Government for financial and research assistance, not only with the few aspects of the study reported here, but for much more help in the field of community health and sanitation in Kayamandi.

3. The Water Research Commission for making it financially possible to complete this work and for providing assistance in the running of this project, especially Ms Annatjie Moolman and Ms Una Wium.

4. The Department of Water Affairs and Forestry of the Western Cape, especially Ms Wilna Kloppers and Mr Jacques Rossouw, for help, advice and encouragement beyond their professional duties. DWAF is also thanked for providing the analyses of the chemistry parameters of the water samples for the last two years.

5. The Harry and Doris Crossley Foundation for financial assistance.

6. The University of Stellenbosch for financial assistance and study leave to complete the dissertation.

7. Prof B de Villiers, Prof L Liebowitz and the two examiners for their contributions to the study.

8. The Steering Committee of Kayamandi, and especially Mrs Alicia Mgijima (chairperson), Mr Sipho Menziwa (project manager), Mrs Martha Mayembana, Mrs Wilhelmina Mhali and all other members who helped to make such a difference to the sanitation situation in Kayamandi during the project.

9. The Dept of Medical Microbiology for permission to use their laboratory facilities for the analyses. Also to Prof Johan Joubert, emeritus professor of Medical Microbiology, for his encouragement during the early part of the study.

10. Mr Pieter Haasbroek of the Division of Agrometeorology of the Agricultural Research Council for analysis of the pollution data in relation to the weather patterns.

11. Mr Gunnar Sigge of the Dept of Food Science of the University of Stellenbosch for verifying the chlorine concentration with their HACH 2000 spectrophotometer.

12. Prof Gideon Wolfaardt of the Dept of Microbiology, Stellenbosch University and his post-graduate students for their help with the sonication of the biofilms on the stones and general advice and encouragement.

13. Ms Sonja Herbst of the Dept of Community Health for taking all the arrangements for the various meetings of the Water Research Commission Steering Committee for this project on her shoulders as well as the many administrative arrangements.

14. Ms Nina du Plessis of the Dept of Medical Microbiology for keeping the financial statements in good order and providing a valuable administrative service.

15. Ms Hester Otto of the Medical Library at Tygerberg and her sons Gawie and Eddie who created the databases and computerised the vast amount of information collected during the community surveys in Kayamandi.

16. Ms Elsie Geldenhuys of the Medical Library at Tygerberg who efficiently helped to obtain a large number of research articles from many sources, locally and overseas.

17. The guards from the Risk and Security Services of the University of Stellenbosch for keeping me safe during sampling over the last three years of the study.

18. Dr Clarissa Pieper, Prof Shaheen Mehtar, Dr Hanli de Wet and Prof Peter Wranz who offered constructive help, interest in my research and encouragement beyond the call of collegial duty.

19. My husband Brian without whose support I would not have been able to do this work.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
AIDS	Acquired immunodeficiency syndrome
COD	Chemical oxygen demand
CSIR	Council for Scientific and Industrial Research
DALY	Disability-adjusted life-years
DANCED	Danish Co-operation for the Environment and Development
DOC	Dissolved organic carbon
DR	Dependency ratio
DWAF	Department of Water Affairs and Forestry
EHP	Environmental health practitioner
IDP	Integrated Development Planning
IDWSSD	International Drinking Water Supply and Sanitation Decade
IEM	Integrated environment management
ISRDS	Integrated Sustainable Rural Development Strategy
ISH	In-situ hybridization
KTCSC	Kayamandi Test Case Steering Committee
NCCLS	National Committee for Clinical Laboratory Standards
NEMA	National Environmental Management Act of 1998
PCR	Polymerase chain reaction
SABS	South African Bureau of Standards
TB	Tuberculosis
UNICEF	United Nations International Children's Emergency Fund
VIP latrine	Ventilated improved pit latrine
WHO	World health Organisation

CHAPTER 1

Interaction between Community and Environmental Factors and the Impact on Water Quality

1 Background - Sanitation and health

Access to safe water supply and sanitation is a fundamental human need and has been recognised as a human right by the World Health Organisation (WHO)[1] and this right is supported as such by many countries, including South Africa (Preamble to the Water Services Act of 1997).[2]

The inter-related effects of the quality of water supplies, excreta disposal and health status, especially via the faecal-oral route, are well established and can be found in many books on epidemiology,[3] environmental health[4,5], medical microbiology[6,7] or epidemiology of infectious diseases.[8] The intention with this review is not to summarise those basic aspects, which are not under contention. It is rather the intention to review the present information on the epidemiological and community health aspects of the topics as discussed below.

1.1 Public health problems related to poor sanitation

The benefits of improved water and sanitation include both health and non-health effects.[8] The direct health benefits are related to two contrasting roles of water: that of disease vector when it carries pathogens; and that of health mediator through its use in personal and domestic hygiene. Indirect effects related to health include, for example, improved quality of life and decreased expenditure on medical expenses. Non-health effects include time-savings for productive activity or education.

Clean water is not only necessary for drinking, food preparation and washing purposes; it is also necessary for growing food crops. Qualitatively, water can become unfit for human consumption due to contamination from human or animal excreta, toxic industrial effluent or contaminants derived from the surrounding geological formations (less frequent than the first two). Contaminants include waterborne bacteria, viruses, parasites, chemical compounds and heavy metals, all of which may cause disease, with intestinal illnesses being the most frequent.[9]

The collection and sanitary disposal of domestic wastewater is often neglected in many countries.[10] The global provision of improved water supplies to many communities have increased over the previous decade.[10] This reported increase however did not take into account how many of the water supply and sanitaton facilities were functioning at all or functioning only intermittently. It is also ironic that provision of piped water to a previously unserviced area *commonly causes deterioration in existing health conditions until adequate waste disposal facilities have been installed*[9] (my own emphasis). Inadequate disposal of wastewater can cause flooding of roads, housing and communal areas where large numbers of people pass through, thus creating further health hazards. To control this, wastewater drainage systems should be installed as well as toilet facilities of such a nature as to minimise the danger of transmission of disease. Unsanitary toilet facilities encourage the spread of enteric diseases through the faecal-oral route or by flies. Where toilets are shared, the health risks increase.[9]

Apart from direct transmission of disease at the point where the waste is generated, inadequate disposal can also cause pollution of water courses, land and food crops. In general, control measures include installation of piped water systems, and adequate toilet facilities and sewage systems.[9] Different solutions may be needed in urban versus rural areas. In some cases ventilated improved pit (VIP) latrines may be an appropriate option. VIP latrines are improved conventional pit latrines, slightly offset from the pit and having a tall vertical vent pipe with a fly-screen fitted outside the superstructure. It is a non-water dependent latrine.

The hygienic storage, timely collection and safe disposal of household refuse are essential requirements of public health, as well as being aesthetically and environmentally desirable.[9,10] Health effects associated with poorly managed solid waste systems are related to disease transmission by flies, cockroaches, rats and mice, general pollution of the ground around waste disposal containers from the seepage out of such bins, increased fire hazards, injuries from broken glass, tins etc.[9] Open communal waste containers (so-called "skips") for solid household waste placed at convenient intervals in poor areas are open to the elements and rainwater run-off from the skip distribute heavily polluted seepage water over the surrounding ground. Wind also redistributes any waste that can become airborne such as paper, plastic and other contaminated packaging material, feathers and contaminated dust, etc. over the surrounding environment. Poorly managed domestic solid waste in areas lacking sanitation become mixed with excreta, contributing even further to the spread of disease. The urban poor suffer most in this regard as they often live in areas with poorly functioning waste removal or near waste dumps and their children are the waste pickers. Uncollected solid waste is also the most common cause of blocked urban drainage systems, increasing the risk of flooding and waterborne diseases.[9]

The importance of hygiene behaviour in individuals and the proper management of sanitation have only recently returned to the forefront of attention, mainly as a result of the United Nations International Drinking Water Supply and Sanitation Decade (IDWSSD).[11] Concerns about hygiene and the use of toilets, rather than simply their construction, are not new. What is new is the rapid increase of epidemiological evidence pointing to the importance of relatively small behavioural changes in protecting families and communities from faecal-oral disease.[11]

A comprehensive overview, with many case studies, of the unequal human impacts of environmental damage was presented in the Human Development Report 1998 of the United Nations.[12] It also presented case studies as well as data of the important improvements in hygiene and health that can be effected when the creative solutions of the affected communities themselves are harnessed to solve problems. Communication, community participation, and more specifically education are at the heart of all these successes.

The evidence of a causal link between hygiene and infections was reviewed by Alello and Larson.[13] They collected 30 interventional and 24 observational studies published from January 1980 to June 2001. They restricted inclusion of interventional studies to only those with an experimental design (formally randomised) or quasi-experimental design (non-randomised intervention assignment). All studies without implementation of an intervention was considered observational.

Of the interventional studies in this review,[13] hygiene education was the most common intervention (77%) followed by various handwashing practices (20%). Infrastructure interventions in combination with either education or handwashing comprised only 17% of the interventional studies. Less than half of the studies examined diarrhoea or gastrointestinal illness as at least one of the main outcomes. Many other symptoms and signs such as respiratory infections, skin infections, flu-like symptoms, otitis, sinusitis, absence from school due to illness, etc. were also employed in these studies. In general, the reductions in all infectious disease symptoms and infections were appreciable, >20% for most hygiene interventions. Only 2 studies (7%) found no reduction in diarrhoea illness after implementation of hygiene education intervention

The observational studies included in the review[13] were overwhelmingly carried out in developing countries (96%). Most of the studies created 'hygiene indicator variables' that encompassed behaviour (e.g. handwashing, infant feeding practices), knowledge (e.g. transmission routes, methods of prevention) and/or personal and environmental cleanliness (e.g. refuse disposal, food handling, general household hygiene). Diarrhoeal illness was the most common outcome studied (79%), followed by various other illnesses such as trachoma, respiratory illness and helminth infection. All but two of the studies (92%) found a correlation between hygiene variables and a reduction in infection.

Esrey and co-workers[14] carried out an analysis of 144 studies to examine the impact of improved water supply and sanitation facilities on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. These diseases were selected because they are widespread and illustrate the variety of mechanisms through which improved water and sanitation can protect people or promote health. The authors divided the studies under review into two categories: "rigorous" if they were free of one single major design flaw or several known or suspected minor flaws that could have biased the results, and "all studies" meeting their inclusion criteria. The various diseases under scrutiny were treated in turn. The results of the assessment of the results of these studies were as in Table 1.1

Table 1.1 Expected reduction in morbidity and mortality from improved water and sanitation for selected diseases[14]

Diseases	All studies			Rigorous studies		
	n	Median % reduction	Range	n	Median % reduction	Range
Ascariasis	11	28	0-83	4	29	15-83
Diarrhoeal diseases:						
Morbidity	49	22	0-100	19	26	0-68
Mortality	3	65	43-79	-	-	-
Dracunculiasis	7	76	37-98	2	78	75-81
Hookworm infection	9	4	0-100	1	4	-
Schistosomiasis	4	73	59-87	3	77	59-87
Trachoma	13	50	0-91	7	27	0-79
Child mortality	9	60	0-82	6	55	20-82

The results of this review[14] indicated that improvements in one or more components of water supply and sanitation could substantially reduce the rates of morbidity and severity of the diseases used as indicator conditions. Despite the mix of both positive and negative studies, the overwhelming evidence was in favour of positive impacts, with the exception of hookworm infection for which the impact was negligible.

Studies that reported reductions for one disease in isolation most probably underestimated the total effect of water and sanitation on improving health.[14] This was particularly true if several diseases affected by water and sanitation were present in the intervention area. In addition to reducing the incidence or prevalence of disease, improvements in water and sanitation can be expected to affect other aspects of health as well. When infection rates were reduced by chemotherapy, improved water and sanitation facilities in the studies reviewed prevented infection from increasing again to pre-treatment levels. Furthermore, the severity of infection was often reduced more than the incidence or prevalence.

The following recommendations were made after the assessment[14] of these studies. They offer valuable pointers to remedial action for the dire sanitation crisis in the present study site (Kayamandi) as well.

1. To achieve broad health impact, greater attention should be given to safe excreta disposal and proper use of water for hygiene than to drinking water quality.
2. Sanitation facilities should be installed at the same time as water distribution facilities when faecal-oral diseases are present.
3. Access to the water supply should be as close to the home as possible, in order to foster the use of water for hygiene practices.
4. Sanitation facilities should be culturally appropriate to ensure their use.
5. Water and sanitation programmes should complement those in other sectors (e.g. chemotherapy) to reduce disease rates.

Limitations in all comparative studies on sanitation and hygiene education include:[15]

1. The great difficulty in employing blinding in assessing the outcome
2. The difficulty in employing randomisation when selecting participants in the intervention studies
3. The enormous difficulty in controlling for bias and confounding factors as well as effect modifiers

4. The difficulty in selecting two comparable sites so that the baseline disease rates and many other factors are the same before the intervention starts
5. Lack of statistical power in some situations or designs

1.2 Environmental impacts and contamination

Human beings can only be healthy in a healthy environment. We cannot isolate ourselves from the air we breathe, the water we drink, the food we eat and the dwellings and landscapes we inhabit. Most human activities impact on the environment. Therefore sanitation systems for disposal and treatment of wastes are essential for minimising human impact and creating a sustainable environment. A lack of adequate sanitation, or inadequately maintained or inappropriately designed systems can therefore constitute a range of health risks to humans and animals and pollution risks to the environment, especially the contamination of surface and ground water sources:

Most faecal-oral infections are transmitted on hands and during food preparation, rather than through drinking contaminated water directly. Faeces also provide a fertile environment for many organisms that cause diseases in humans apart from those organisms from the normal gut flora already present in the faeces. Any action that prevents faeces from getting onto or into human bodies will help to break the cycle of infection.

Sanitation programmes can have dramatic health benefits because many of the infective organisms are spread from hand-to-mouth or from hand-to-food-to-mouth rather than through drinking contaminated water.[13] Improving hygiene practices and providing sanitation facilities could have a direct influence on a number of important public health problems besetting South Africa. Thus, understanding how infections are transmitted and how to break the cycle of infection are important public health messages.

Significant investments are being made in the provision of safe water supplies for all inhabitants of South Africa. However, the health benefit of this investment is limited where inadequate attention is paid to sanitation and to health and hygiene promotion. Once people's basic needs are met (especially the provision of clean water), sanitation improvements together with health and hygiene promotion result in the most significant impact on their health.[9]

Although natural water systems such as wetlands are able to tolerate and "clean up" a certain small degree of pollution, there is a limit to the amount that can be assimilated without causing the water quality to deteriorate to such an extent that the water cannot be used.

Factors listed in the White Paper on Basic Household Sanitation 2001[16] that affect the impact of sanitation systems on water quality are:

1. Size and density of the settlement being served
2. Sensitivity (or class) of the receiving water resource
3. Type of sanitation system
4. Capacity of the service provider to manage the system
5. Depth to ground water table and the soil type

Absent from this list is the slope of the ground to the nearest water course. Settlements on steep hillsides can cause significant run-off into rivers and water courses without even penetrating the ground to any great extent.

An aim of the national sanitation policy[16] is to promote the environmental sustainability of sanitation systems to ensure that sanitation systems are designed, constructed and operated in such a way that contamination caused by the system is restricted to acceptable levels throughout the life cycle of the system, regardless of the chosen technology option.

Environmental damage almost always hits those living in poverty the hardest.[12] The overwhelming majority of those who die from air and water pollution are poor people living in developing countries.[10-12] All over the world poor people generally live nearest to dirty factories, busy roads and waste dumps. According to the exhaustive review contained in the United Nations Development Programme's Human Development Report[12] there is an irony in these statements. Even though poor people bear the brunt of environmental damage, they seldom are the principal creators of that damage. The affluent generate far more waste and consume far more resources.[12] Yet, there are also environmental challenges that stem from growing poverty, not growing affluence. As a result of increasing impoverishment and the absence of alternatives, a swelling number of poor and landless people migrating to peri-urban areas are putting unprecedented pressure on the natural resource base as they struggle to survive.

Poor people and environmental damage are often caught in a downward spiral.[12] Past resource degradation deepens today's poverty, while the poverty of today makes it very hard to care for or restore the agricultural resource base, to find alternatives for deforestation, to control erosion and to replenish soil nutrients. Poor people are forced to deplete resources to survive and this degradation further impoverishes people. When this downward spiral becomes extreme, poor people are forced onto marginal land and fragile ecosystems in ever increasing numbers. About half of the world poorest people (about 500 million people) live on marginal lands.[12]

The issue of the link between poverty and environmental damage is complex and explaining the observed phenomena only in terms of income is oversimplistic.[12] The following also impact on the relationship:[12]

- Ownership of natural resources – often ill-defined in developing countries under a social system no longer in operation
- Access to common resources – ill-defined in poor communities
- The strength or weakness of communities and local institutions
- The way information about poor people's rights to resources is shared with them
- The way people cope with risk and uncertainty
- The way in which people allocate their scarce time in order to survive – nearest sources are over-exploited first

Some kinds of environmental degradation are truly global concerns, such as global warming and the depletion of the ozone layer. Others cross international borders such as acid rain and the state of the oceans. Yet others are more localized, although they may occur worldwide – water pollution and river and soil degradation are such issues.[10-12] Regardless of categorization, the costs of environmental degradation are enormous. Local or indigenous institutions that could control the wise use of such resources which reflected consensus of ownership and that were once effective, have eroded.[12] There is yet another irony in the fact that the institutions and powerful lobby groups who are able to make changes to the way common property such as rivers and water sources are managed (e.g. politicians, local officials), are not the first to feel the effects of degradation personally. The big time lags built into political systems demand that medium- and long-term action to alleviate environmental damage receive attention now, before it is too late.[12]

1.3 Economic impact of poor sanitation

Whilst the financial cost of providing a basic level of sanitation is easily quantifiable, the economic costs of inadequate sanitation on the health of the community and on the environment are not so easily quantified. The White Paper on Basic Household Sanitation 2001[16] quotes the United Nations Children Fund (UNICEF) and World Health Organisation in linking investing in sanitation to:

1. Reduced morbidity and mortality and increased life expectancy
2. Savings in health care costs
3. Reduced time caring for the sick and sick leave (back to work)
4. Higher worker productivity
5. Better learning capacities of school children
6. Increased school attendance, especially by girls
7. Strengthened tourism and national pride
8. Direct economic value of high quality water such as irrigation water for crops
9. Reduced water treatment costs

The 1993 World Development Report of the World Bank[17] suggested that addressing diseases of high burden with the most cost-effective interventions could do much to reduce disease in the population. The potential economic benefit of improving sanitation can be gauged when it is considered that globally there were an estimated 1,5 million cases of diarrhoea reported in children under the age of 5 every year.[17] This results in huge health expenditures, which could otherwise be avoided through the provision of adequate services. Pruss and colleagues[18] estimated the mostly preventable burden of disease from water, sanitation and hygiene at a global level to be 4% of all deaths and 5,7% of the total disease burden in disability-adjusted life-years (DALYs). The authors conclude, "This significant and avoidable burden suggests that it should be a priority for public health policy".

Varley and co-workers[19] carried out a cost-effectiveness analysis indicating that some water supply and sanitation interventions are highly cost-effective for the control of diarrhoea among under-five-year olds, on par with oral rehydration therapy. These interventions were relatively inexpensive actions such as hygiene education, social promotion ('marketing') of good hygiene practices, regulation of drinking water and monitoring of water quality. Such interventions are needed to ensure that the potentially positive health impacts of water and sanitation infrastructure are fully realised in practice. The authors contended that the perception that water and sanitation programmes were not cost-effective arose from three misconceptions: an assumption that all water and sanitation programmes involve construction of physical infrastructure; a misperception of the role of the health sector in water and sanitation programmes; and a misunderstanding of the scope of cost-effectiveness analysis.

Infrastructure (the so-called "hardware") is generally built and operated by public works agencies and financed by construction grants, operational subsidies, user fees and levies or property taxes. The health sector should provide the "software", such as contributions to project design, hygiene education, and water quality monitoring and regulation, as well as assessment of improvements in the disease profile.[19] Cost-effectiveness analysis should measure the incremental health impacts attributable to health sector investments[17], using actual call on health sector resources as the measure of cost.[19]

The inclusion of water supply and sanitation programmes as a component of primary health care has been questioned on the basis of calculation of the costs of these programmes per infant death averted. Jha and co-workers[20] assessed the cost-effectiveness of 40 health interventions in the Republic of Guinea in order for the state to allocate scarce financial resources optimally. They found that water and sanitation was relatively cost-ineffective in terms of reducing years of life lost. It should be noted here that they concentrated their analyses on mortality. They however state that some interventions such as the provision of water and sanitation are nonetheless important in improving the general quality of life.

The approach used by studies such as that of Jha et al.[20] was criticised by Briscoe.[21] He contended that such calculations are misleading because gross rather than net costs are used and the health impact of interventions such as sanitation and clean water supplies are underestimated since such analyses only concentrate on those dying from diseases directly related to sanitation and unsafe water supplies. These criticisms certainly seemed to be the case in the study by Jha et al.[20] Briscoe[21,22] also contended that the methodology used in such cost-effectiveness analyses is biased against programmes with multiple outputs such as water and sanitation programmes. He mentioned a further set of factors often overlooked by health economists and health systems analysts. The time constraints facing mothers living in poverty-stricken and under-serviced areas in implementing basic hygiene practices to the level where it can make an impact on their family's health and the ability of improved systems to alleviate that burden are seldom taken into account. Simply put: mothers are sometimes not so much *unwilling* as *unable* to make changes in hygiene behaviour. Improvements in the system need to be found that can make changes easier for them in order to improve more than just the health outcome for their families. Such improvement will also free up time for them to spend more productively and lucratively.

Briscoe[21] presented data indicating that, if poor women in developing countries were offered a choice of a mix of activities to be included in primary health care programmes, improved water supply and sanitation would frequently constitute part of the mix.

One last aspect of cost-effectiveness of improved water and sanitation programmes especially the education component, is the sustainability of such programmes in impoverished communities. Often such programmes are not seen as viable because no immediate great changes and no lasting effects are expected from them. Hoque et al.[23] investigated the sustainability of a water, sanitation and hygiene education programme in rural Bangladesh. An integrated water supply, sanitation and hygiene education intervention project was carried out over the period 1983-1987. In the intervention area the project provided hand-pumps, pit latrines and hygiene education to about 800 households. The control population did not receive any intervention, but had access to the usual government and private facilities available in the area. After 1987 no external support was provided to maintain these provisions. A cross-sectional follow-up survey was carried out in 1992 and involved about 500 randomly selected households from the intervention and control areas. By 1987 (end of the active phase), 94% of the pumps were functioning and in 1992 about 82% of the pumps were still in good functional condition. Fewer latrines were still functional in 1992 (64%) than at the end of 1987 (93%). In the former intervention area about 84% of the adults were using sanitary latrines compared with only 7% in the control area. Knowledge related to disease transmission, however, was poor and similar in both areas. People claimed that they used the facilities provided by the project to improve the quality of their lives. The prevalence of diarrhoeal diseases in the 1992 survey in the control population was about twice that among the intervention area. This study conclusively shows that long-lasting effects of water, sanitation and hygiene education programmes can be demonstrated years after the intervention stopped. It is interesting and important to note that the population's reason for using the improved facilities provided by the project was not based on improved level of hygiene knowledge per se, but because it improved the quality of their lives.

1.4 Social and psychological factors associated with poor sanitation

Especially in poor communities, many inhabitants may want sanitation very badly and yet be powerless to express that desire in financial or political terms. Some may want safe excreta management facilities, but not at the prevailing price. Yet others may not want the available "improvements" at any price.

To most people, and especially to the poor, the need for a convenient and safe water supply is self-evident. It is not hard to "generate a demand" for drinking water supply among the poor. They already experience the non-productive time in fetching water from a source distant to their homes every day. There is no lack of demand for water and this is almost always the first priority for communities. This is also the prime reason why squatter settlements almost invariably establish themselves along the banks of watercourses if no other source of water is available.

In contrast, the construction and maintenance of sanitation facilities is often an individual or household affair. In some cases sanitation systems mirror community water supplies, following an extensive piped network, especially in urban settlements. By and large however, such solutions are too expensive for the people currently without service and would require a radically improved water supply to function. On-site sanitation by means of less sophisticated technological options (VIP latrines, septic tanks, etc) is appropriate for the unserved population in rural areas and even some peri-urban areas if the situation lends itself to such solutions (e.g. suitable soil type, space available). Such sanitation arrangements are however a matter for each household to decide and its development consequently requires a different promotional approach.

The Global Water Supply and Sanitation Assessment 2000 Report[11] suggests that a 'marketing approach' be used, i.e. there should be a focus on developing and distributing products that match consumer demands in both quality and price. This in turn requires an understanding of why people want sanitation, *which may differ significantly from the agendas of local and national authorities and service providers*.

There is an increasing consensus that much of the health benefit of water supply and sanitation comes from the changes in hygiene practices that they promote.[11] People wash more often when taps are conveniently located on their property, and people are more likely to practise safe excreta disposal when there is a nearby latrine. Yet other practices such as handwashing with soap and preventing contamination of drinking water are also important, and these behaviour changes do not come about automatically through the provision of hardware. Promoting and motivating people to make these changes require skills that differ from those required to develop and manage facilities.

The Global Water Supply and Sanitation Assessment 2000 Report[11] quotes an unpublished study in the Philippines where the following reasons for satisfaction with a new latrine were recorded (in order of importance):

1. Lack of flies
2. Cleaner surroundings
3. Privacy
4. Less embarrassment when friends visit
5. Reduced gastrointestinal disease

Toilets placed at a distance from the home, inadequate communal facilities, inadequate disposal of waste and other poor sanitation practices result in loss of privacy and dignity, exposure and increased risks to personal safety. It is especially women (notably those with young children), those with impaired mobility and the elderly who are the most inconvenienced. Although the school attendance of girls in South Africa is high compared to other developing countries, it is internationally recognised that poor sanitation facilities at schools can be one of the important contributive factors for girls to drop out of school.[16]

It is important to note how low down on the above list the reduction of disease occurs. The report[11] states that these reasons are echoed in other parts of the world. Candid reflection, even by health professionals, often reveals that health is a less powerful motivator for sanitation than dignity, convenience and social status.

Finding a motivation that will lead people to change their behaviour is a fundamental task of health promoters. Classic approaches, which assume that it is enough for people to be told of the likely health benefits of certain behaviour for them to want to alter lifelong practices, are now understood to be simplistic.[24] In the case of diarrhoeal diseases, studies from all parts of the world show that lay and biomedical conceptions of causation rarely coincide.[24-26] If there is little connection perceived between hygiene and diarrhoea, even among well educated groups in a particular community or population, then teaching about microbes is unlikely to provide sufficient motivation for the modification of practices carrying a health risk.

Stone[27] pointed out that health education should never be undertaken without taking the recipients' beliefs and values into account. She described a programme in rural Nepal organised mainly to provide health education while, in contrast, the local villagers valued modern curative services much higher and felt little need for new health knowledge.

In a study to determine the factors involved in hygiene behaviour in order to design educational programmes in Burkina Faso, Curtis and co-workers[24] documented the following situation that is well known amongst community health workers: "We began by investigating how women understood diarrhoea in their children. ... These illnesses are attributed to events such as teething, contact with damp ground and transgressing the taboo on post-partum sexual relations. This taxonomy was common to all groups ranging from the least to the most educated women. Even after their extensive training, paediatric nurses shared local perceptions of diarrhoea causation in parallel with their biomedical knowledge. We concluded that existing perceptions of diarrhoea are so well grounded in the adult female population that trying to change them is likely to be fruitless. We therefore needed to find motivations other than possible health benefits for mothers to modify their hand washing and stool disposal practices."

Odujinrin et al.[26] also documented the discrepancy between perceptions and observed practices in a rural Nigerian community. During the first phase of the study, mothers in this community provided information on their food handling practices relating to water, handwashing before food preparation and feeding, and food storage. In the second phase, these behaviours were directly observed and found to differ significantly from the mothers' previously reported behaviour.

An ethnographic study of maternal perceptions of the barriers to another primary health care intervention, namely immunisation, was carried out in Haiti.[28] The importance of 'hidden' social and psychological costs such as embarrassment, fear, child care difficulties, and competing demands on maternal time as barriers to complying with health and hygiene promoting behaviour was lifted out in that study. The study identified five categories of maternal factors (competing priorities, low motivation, socio-economic constraints, fear about health and social consequences, knowledge and folk beliefs) and five categories of system factors (accessibility, acceptability, availability, accommodation and affordability) that can deter mothers' compliance with the programme. The discussion focused on how these factors influence mothers' decision-making regarding the use of preventative health services.

McLennan[29] recently identified much the same barriers to good hygiene practices in a poor district of Santo Domingo, Dominican Republic. Biomedical knowledge about some basic hygiene practices appropriate for the disease profile of the area such as handwashing, children wearing shoes outside the home and boiling of drinking water was high, but was not significantly related to reported practice. The barriers to good hygiene practices reported were limited resources, erroneous beliefs, and non-compliance by children. The authors concluded that health education based on a biomedical knowledge deficit model may have little impact on improving the diarrhoea prevention practices of these communities. If sustainable hygiene promotion and education programmes are to be developed, more attention should be paid to the psychosocial costs of health behaviour in developing country settings.

1.5 Community participation: Who is the "community"?

The concept of community participation continues to perplex national and international health policy makers and analysts nearly a quarter of a century after it was formally introduced at the Alma-Ata Conference in 1978.[30] The Alma-Ata Declaration states that "the people have the right and duty to participate individually and collectively in the planning and implementation of their health care". This means that community involvement is fundamental in the battle for health and was listed as a fundamental principle of primary health care.

The notion of community involvement in health has found wide acceptance in all kinds of political regimes and particularly the developing countries.[31] UN agencies, notably WHO, have been particularly active in promoting the concept. Nevertheless, problems remain and these are related at least in part to lack of conceptual clarity. Ideally, community involvement should mean that the initiatives come from the people and that the role of government and other agencies are to provide assistance. In reality this rarely happens. There are many stumbling blocks in the way, especially in impoverished areas.

Community participation projects in health has traditionally been defined according to two distinct perspectives.[32] Firstly, it can be a *utilitarian* effort on the part of donors or governments to use community resources (land, labour and money) to offset the costs of providing services. This can be seen as a *means* to accomplish the aims of a project more efficiently, effectively or cheaply. It can also be seen as a collaboration in which people voluntarily or as a result of some persuasion or incentive agree to collaborate with some externally devised development project, often providing labour and other resources in return for some expected benefit. On the other hand, participation can be defined as an *empowerment* tool through which local communities take responsibility for diagnosing and working to solve their own health and development problems. This is seen as participation as an *end* in itself, where the community sets up a process to control its own development. Viewing community participation as an iterative learning process will enable more realistic expectations and goals to be set.

Although the idea of community participation in health was originally developed by large international institutions such as the World Health Organization[11] and the World Bank[17], the implementation of community participation is the ultimate responsibility of local health programmes. It is therefore at the local level where the day to day realities of incorporating community participation into health service delivery are confronted.

The following is a brief summary of the main problems and lessons learnt in judging a quarter of a century of community participation as collated by Morgan,[32] Madan,[31] Zakus and Lysack,[33] Rifkin,[34] Tatar,[35] Woelk,[36] Stone (1986)[27] and Stone (1992)[37]. These reviews and analyses tend to quote each other as well as many opinions and unpublished sources and internal reports. A combined summary of the above sources is therefore presented.

The lack of conceptual clarity that many authors have pointed out rests on the problem that in many community based projects 'community' status has been conferred on, inter alia families, ethnic groups, and neighbourhoods alike, and at other times upon larger jurisdictions such as health districts and regions. By blurring the two most basic characteristics of community - community as a geographic entity and community as a shared sense of interests, values and identity - the track record of community participation has been complicated and full of contradictions. The term "community participation" conjures up harmonious images of a place where co-operation and shared activities create a favourable climate for upliftment projects of some kind or another. Many times the precise features and dynamics of the particular group calling themselves a community are not investigated before a project is embarked upon. Because so many donor agencies, government structures and health systems call for such participation, the dynamics of working with or in a particular community are poorly identified or even taken for granted. Without investigating the basis on which a particular community is founded, implementation of interventions may run up against less genuine and less 'neighbourly' attitudes constituting severe stumbling blocks.

Community participation requires that a suitable formal organization (e.g. a committee, board, network) be established *and sustained*. There are no hard and fast rules to govern this process, but is it widely taken that this committee must be created by means of some significant community input and that it should have positive links with local political and governmental structures. This committee must also be open, knowledgeable, and able to establish co-operation with other programmes and resource individuals. It should be clear to any reader who has had even a nodding acquaintance with low-income settlement communities that the aforementioned requirements for committee members are rarely met in impoverished areas, even after extensive training of individual members.

It is a hard fact that even the most illustrious committee members cannot *ensure* community participation. The composition of the new committee and the methods used to identify and appoint them (election by whom and how?) are crucial to the legitimacy of the project in the eyes of the community itself, the donor organization or the government structures for health services in the area. In the context of health projects, legitimacy is another of those imprecisely defined concepts. Claims of lack of legitimacy has sometimes proved to be a convenient tool for dissenting groups in the community to stall implementation of the project or derail any progress made.

Participation in health related matters can vary dramatically. This diversity has hampered the development of common approaches and lessons learnt from one situation may not be applicable to the next. Furthermore, community participation relies heavily on the commitment and active involvement of informal local leaders to whom others naturally turn for advice, support and leadership. It is far from clear what attributes such leaders should have or what training they should receive to achieve the greatest effect.

There are many difficulties relating to the matter of community representation. These issues are thrown in particularly sharp focus when individuals in leadership positions get caught between conflicting personal, community and health system agendas. Difficulties also arise when minority segments of the population do not share the values and priorities of the dominant segment.

Competency of newly selected committee members will rarely be optimal and training should be invested in. It is generally agreed that, while the particular skills needed will differ from project to project, broadly speaking, competency is needed in community organising, problem solving, priority setting, collecting of information and rudimentary analysis, health intervention planning and delivery and project evaluation. Even though the levels of competency needed in these fields in order to function as efficient members of the committee may not be high, acquiring these skills can present significant stumbling blocks for some persons. Acquiring these skills does not happen without personal costs in time and sometimes loss of income. It also causes a certain degree of stress to persons not used to adult education activities and can become an embarrassment to those who patently do not manage to acquire those skills, especially those community members who have an important standing in the community. Having trouble mastering skills in front of one's fellow community members when one is an important person in the community causes several 'fall-out' responses, all of them detrimental to the functioning of the project. In local communities there is a high level of denial of all unpleasant realities or unfavourable messages.

If training involves travel and attendance at various information sessions or workshops away from the community, the added sophistication and new knowledge acquired by the selected committee members can begin to set them apart from their community. They may be looked upon especially by the marginalised groups in the community (the 'have-nots"), as new elites (the 'haves'). These committee members who have had experience of the wider world and new insights, begin to see themselves and their neighbours and friends in a different light. Newly acquired abilities to recognise self-destructive behaviour or unhelpful attitudes or resistance to change merely for the sake of resistance can be a hard burden to bear for community representatives on a steering committee. When faced with obvious recalcitrance on the part of some of the local community to even try to improve hygiene behaviour or de-escalate levels of vandalism, community members of a steering committee could fall into one of three coping strategies: those who denied or found ludicrous excuses for the observed happenings; those who actively or passively withdrew; and those who were embarrassed and prepared to say so in private or openly.

It is naive to assume that all persons in high-ranking official positions in the community or persons referred to as community leaders have altruistic motives or are even necessarily honest in their motives. A popular strategy is to identify possible steering committee members from those persons in the community who fill highly visible positions such as school principals, teachers, prominent business persons, property owners and so forth. These persons of power in the community mostly have a particular 'constituency' over whom they wield some form of influence and they are reluctant to harm this position of influence. This results in unpopular messages such as changes of lifestyle not being properly carried over. Such members of the committtee can also withhold information from their constituents that they deem to be unpopular. The pressure to please constituents can result in a partial (passive) withdrawal from the activities of the steering committee should the message from the project not be well received. If, on the other hand, the project looks like it will succeed, such local political figures are suddenly visible on the steering committee again and pushing to be in the limelight when the rewards are visible. Steering committees must find appropriate ways of dealing with the commitment of members from all spheres of influence represented *before the project activities start*. A common set of guidelines underwritten by all parties can prevent a lot of friction, but is seldom negotiated before the activities of the project are launched.

It is mentioned in the reviews on community participation that even the most committed community health activists will eventually find themselves criticised by their own constituency for appearing to be too closely allied with the authorities or the donor organization. This happens especially when they start advocating change from established unhelpful or destructive ways of coping that was adopted by the community in the past. Indeed, the issue of balance of power within communities and within community organizations is a troubling one. As a result there almost invariably will be charges of tokenism and threats to withdraw from the project or the participation process entirely. Managing the ensuing situation is yet another serious challenge in order to achieve the ideal of community participation and to improve the lot of the many marginalised or impoverished people represented on such a committee but without any say in its operation.

On the other hand, the 'outside experts' (e.g. health professionals and governmental officials) represented on the steering committee find themselves in uniquely difficult circumstances too. They often have a vast amount of education and training compared with the community members but no mandate to tell the community what would be 'best' for them - even if they can foresee problems resulting from proposed plans. These professionals can just as quickly find themselves isolated from their own management structures 'back at head office' should the community project not proceed in a constructive direction - even if that was the community's choice. In other words, the officials may only be viewed as doing their job on the committee if the community complies with what was envisaged in the original protocol or plan.

Dealing with minority groups in a community, especially in an impoverished one, is problematic. Minority groups may for reasons of culture, gender, or socio-economic status find it difficult to become involved. The dominant majority then dictates the project agenda with little or no meaningful input from those subgroups who in fact should be the high priority targets of the project - disadvantaged groups like the really poor, the old, the unemployed, those caring for the sick and the dying, or subservient women in traditional relationships with no say in even minor household matters.

Another set of problems arises when the minority groups themselves prefer not to engage actively in the participatory process. This paradoxical finding was discussed by more than one author. It was mirrored in the present study when the car with loudspeaker driving through the streets announcing a community meeting was loudly mocked and sworn at by a group of very poor, older men because the speaker was female (a health educator from the community itself). When it is precisely the poor and disadvantaged who discount the participatory processes, this calls for sensitive handling and regrouping. On the other hand, when minority groups are accustomed to being bypassed, or at most condescendingly asked for their opinion and then ignored, then it is hardly surprising that they will display little interest in being involved.

In some quarters the participatory process also elicits distrust in that some groups fear that the limited services that they do have will be further diminished by 'off-loading' the job onto the community. This is particularly acute in a situation where inhabitants are called upon to help with rubbish removal and cleaning-up campaigns. In the light of the very poor and unreliable sanitation services they receive from local authorities, some inhabitants suspect that the limited services they do get will be replaced with something even less and that the blame will then be shifted even more on the community that they are not able to keep themselves and their environment clean. This is illustrated in the present study by the very unsatisfactory lines of communication for reporting blocked drains and broken toilets to the local authority (the owners of the public facilities). Frequently the local authority officials at meetings denied receiving reports of service problems and placed the blame on the community for failing to report the problems, even when these claims were patently untrue. These fears of a shifting of responsibility onto a community who was already unable to cope, translated into a widespread 'helplessness' - the mythical 'they' or 'the government' should come and clean up the streets and build more houses and give people jobs.

Community participation comes in many forms and if donor organizations and governmental structures recognise only some forms as valuable, there will be a diminishing return on the project. Donors and governments concentrate on measurable outcomes ('deliverables') and tight deadlines which may not bear a great deal of resemblance to the speed with which the community is willing to accept change or even the long time it takes to communicate and engage with a community who is largely illiterate or poorly literate and who has very limited access to phones and other means of communication. Word of mouth is by far the best in such circumstances but it takes *time*. Professional administrators who control the allocation of funds for projects will not necessarily be inclined to support participatory programmes unless the benefits can be demonstrated to them. The tendency is to operationalize and measure participation and a multitude of variables have been proposed as indicators, but with little consensus. Indeed most of these outcome variables do not transplant easily across projects. This in turn lead to a tendency to evaluate community participation projects on an 'all-or-nothing' basis - they either succeeded or they failed. Such cookbook attitudes lead authorities to judge in a very restricted way and to overlook the vast number of spin-off benefits that sometimes only manifest quite some time later.

There is agreement that a community's participation reflects the underlying level of power in its possession. Power struggles are, to many analysts, crucial to the long-term viability of the project. In fact, participatory programmes often fail because they were conceived in a framework which viewed community participation as a magic bullet to solve problems rooted in both health and political power. Struggles over power need not always be destructive though; it can bring a change for the better. Negative sectors of the community who mounted a challenge and lost the power struggle were effectively sidelined in most cases. In order for conflict to be productive, donors and official structures need to anticipate it and devise mechanisms to accommodate it. Participatory projects that cannot cope with disputes over power are likely to fall short of expectations.

There is a great deal of resistance to participatory projects reported among health and other officials, especially at the local and district level. One of the reasons is that community participation is often set as a requirement by the donor organization from outside or from central government and the process bypasses district or local level officials. Lack of understanding on the part of such officials about what the process entails, fears of ceding 'power' to an undetermined and undefined community and uncertainty about clear outcomes and sustainability all contribute to this unfortunate state of affairs. Traditional, ‘safe’ or known ways of handling their jobs tend to change when community demands have to be taken into account and this can lead to unwelcome challenges to municipal officials. Poor co-operation from local municipal officials can be a particularly trying problem for sanitation and hygiene projects to solve because the local authorities control the infrastructure to improve water and sanitation services and, equally importantly, also control the sustained upkeep of such improvements.

Often in impoverished communities the existing level of services is very poor and finger-pointing at local officials are prevalent. Defensiveness and covert 'sabotaging' of the infrastructure needed to help in the upliftment actions are frequently reported. To give a pragmatic example: innovative programmes on improved personal hygiene are of no use if there is no working tap to wash one's hands after a visit to the often filthy or broken toilet. Most pressing primary health problems in an impoverished community cannot be solved without paying attention to other aspects of development such as e.g. sanitation and water supply infrastructure, education, economic development, transport access and communication needs. Trying to improve one aspect, for example hygiene behaviour, in isolation, even with the best community participation in the world is bound to prove unsustainable in the long run.

When participatory projects focus on a local area with water and sanitation problems, the demand for basic services inevitably grow. Demands for repairs, better communication lines to report systems failures, more facilities, etc. are poorly received by officials who do not feel in control of the situation anymore and who in the past balanced competing demands for resource allocation and attention in different ways or who perceived their main 'constituencies' along different lines. They react to the predicament no differently than their community counterparts on the project steering committee - denial, avoidance, passivity, anger and bullying tactics are reported. These officials can undermine the process by refusing to grant power of decision-making or even accountability to those junior officials sent to represent the local authority on the steering committee and even sometimes going so far as to refuse to pay meaningful attention to the report-backs by such junior officials. Thus the local authority is represented on the steering committee without being there in any meaningful way at all. In fact, a large part of the problem is 'political' - true participation is a threat to powerful and vested interests. It makes no difference if the 'powerful' interests are very local in the greater scheme of things. To those officials occupying such a small world, the threat fills their whole world. Donor or government plans that often repeat the need for training of community members of the steering committee, tend to overlook the need to educate and train the local officials as well. They also need to be instructed in productive ways of coping with change.

Harsh words are spoken in a great many articles about the poor level of insight and involvement by the health professions in general. In fact, the medical profession is called an *impediment* by many professionals of many different backgrounds (including clinicians themselves who have participated in community health programmes). Many explanations are given. One is that medical training by its very nature is non-participatory and doctors and even nurses are trained to be authoritarian. They are taught to retain the power to diagnose, prescribe and cure and to target diseases rather than people. Another is the very low and unfashionable status of sanitation-related diseases (still called 'filth' diseases' by many) prevailing among the staff of many large hospitals and medical schools. The vast burden of disease resulting from poor infrastructure and impoverished, uneducated communities is seen as just that - a burden and not a problem the medical profession is primarily involved in solving. They can only suffer the consequences. In other words, it is contended that the health professionals display their own version of unhelpful and unproductive coping strategies. While not being able to judge whether the sometimes harsh opinions expressed by community workers in other parts of the world regarding the lack of interest and commitment by the medical profession are justified for the South African situation, it is certainly true for South African faculties of health sciences that public health and especially sanitation-related issues have a very low status. This problem is compounded by the fact that community health specialists find employment difficult to obtain and even properly supervised temporary positions for rotational study of registrars in community health are difficult to come by, resulting in very few such professionals being trained (personal communications of the candidate's colleagues and own observations).

Sustainability is the latest fuzzy term to emerge in the field of community-based projects. Like community participation it is a term with many meanings. For the donors it may mean that the project costs can be borne by the locals after a certain time. For the government and health agencies it may mean that the problem has abated to such an extent that it can be managed with only local input from a certain point onwards. Warnings abound in the literature about sustainability being one of the latest concepts favoured by governments and donor agencies who often define it in overblown and unrealistic ways. Participation can only be sustainable as long as the relevant actors remain committed and the conditions remain conducive to the process of change. Community participation is not merely an *input*, but the *basis* on which to effect changes for the better. Health services and local governments who do not recognise their continuing role in this dynamic process are bound to allow projects to slowly dwindle and inevitably the former status quo to return.

New challenges will continue to arise in community participation as communities are dynamic and evolving entities. Project implementation is unique at the local level and variations in implementation strategies are opportunities to learn. We should study its complex nature more and be less threatened by what did not work. Increased sharing of experiences, both positive and negative, are needed to make community participation a valued strategy on the way to upliftment of impoverished communities.

1.6 Impact on water quality

Contrary to the unthinking assumptions of many South Africans living in urban and semi-urban areas, water is not readily available at the turn of a tap. Water derives from a supply and the supply is stochastically determined by rainfall. There are practically no freshwater lakes in South Africa - exploitable water supplies are therefore confined to rivers, artificial 'lakes' behind dams and ground water.

The water use in South Africa was already estimated in 1990 to be 50% of the available runoff and ground water and this was estimated to rise to 67% by 2010.[39] This pattern of use is grossly distorted in certain areas. For example, the industrial hub of Gauteng (Pretoria-Witwatersrand-Vereeniging area) is already using >100% of the locally available water and extra water has to be imported (so-called "interbasin transfers") from the Usutu and Tugela rivers.[37] Because of the scarcity of water and what has been termed the "geographical mismatching of demand and supply",[40] large, expensive and sophisticated engineering works have been undertaken to transfer potable water to mainly urban consumers. The costs of these schemes have largely been borne by taxpayers and in part by the urban consumers themselves.

Of the total water available globally, humans already use nearly one-third more than their share, causing damaging and detrimental effects to ecosystems, natural processes and the general environment.[41] Severe stresses are being generated by increasing demand for competing water uses, above all between agricultural and urban needs. The recently defined phenomenon of "virtual water",[41] compounds this problem internationally. Virtual water implies indirect water use: water-poor countries importing food rather than attempting self-sufficiency and thereby keeping their real water resources for economically more profitable uses. There are serious politico-economic and environmental risks involved in such a policy. One proposed solution is water re-use.[41] It is envisaged that the most feasible way to improve water resources management dramatically is to add a water loop in the flow from 'raindrop to crop' by first using the water for human consumption (mainly in urban areas) and thereafter reusing the water for irrigation after treatment. This is especially viable in the many smallholdings producing vegetables and other cash crops usually found surrounding urban areas. The large volumes of wastewater produced in cities need only be relayed after treatment for relatively short distances in most cases. This has been proposed as the only viable long-term solution to the water shortage in countries like South Africa. It can readily be seen that at the present level of attention to sanitation and prevention of water pollution in urban areas practised by the local authorities in many parts of South Africa, this solution in untenable. This provides yet another motivation for taking drastic action to, quite literally, "clean up our act."

The interrelated nature of water and the cyclic nature of the earth's supply of water is often referred to as the water cycle and is represented by the following diagram (Fig 1.1).[38]

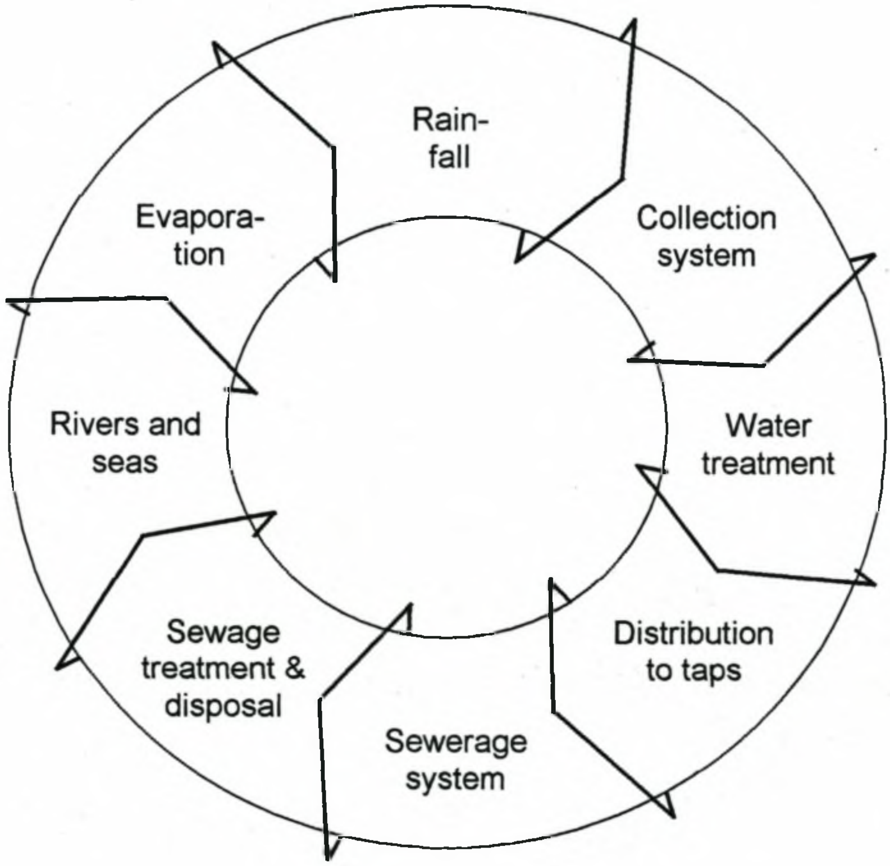

Fig. 1.1 Water cycle (redrawn from Ramsden[38])

The largest users of freshwater in South Africa are farmers, who account for 67% of directly used water and more than half of all water used.[39] Half of the water used by farming operations go for irrigation and a further 1,5% goes for livestock watering.[39] Thus waterborne pollution not only degrades the environment, but enters the food chain as well. This is yet another reason why urban habitation with poor sanitation systems cannot be allowed to contaminate natural watercourses.

Eutrophication of natural water bodies is a process of enrichment of dissolved nutrients and an associated depletion in dissolved oxygen. This in turn affects the structure of the faunal and floral communities in the water by eliminating many species and possibly favouring some.[42] Eutrophication is often a natural process in the ageing of lakes on a geological time scale and is associated with natural accumulation of nutrients.[42] However, the activities of human beings have greatly accelerated this process in many South African rivers. Impoundments in rivers have provided efficient nutrient traps.[39] Even though effluent standards have been improved in order to minimise the euthrophication of natural water courses, the enforcement of these standards seem to be largely absent. Therefore, the entering of untreated effluent should be avoided at the point of its *generation*, not at the point where it causes environmental degradation.

Whether water is, in the technical sense, polluted, depends on whether it is physically suitable for its intended use.[43] Certain water may be unacceptable for drinking but suitable for irrigation. Water pollution can come from human sources or natural causes such as siltation in a river during times of flood. Human sources of water pollution can come from sewage discharge, urban stormwater drainage, refuse disposal, agriculture, mining and industrial activities, etc. Water pollution is generally categorised as coming from point sources or diffuse sources. Water pollution abatement efforts have largely concentrated on point sources because of their ready accessibility, and on pollution symptoms rather than causes.[43] In fact, because of their ready identification and ease of accessibility there has been a tendency in the past to classify water pollution as originating from point sources even when a closer look would have revealed it not to be so. All abatement efforts were then concentrated on the point source, ignoring the diffuse sources, with eventual poor outcome and abandonment of efforts to stop the pollution.

1.7 Transmission and monitoring

1.7.1 Transmission

The mechanisms by which water- and excreta-related diseases are transmitted must be understood in order to evaluate the effect of poor sanitation on health and the likely impact of improved facilities. A framework first proposed by Bradley[44] in 1968 and modified by Feachem[45] in 1975 provided an important advance in classification.

Water-related diseases were categorised as:

1. ***Faecal-oral (waterborne or water-washed),*** for example diarrhoeal diseases, infectious hepatitis
2. ***Water-washed only,*** for example scabies, conjunctivitis
3. ***Water-based,*** for example trachoma, dracunculiasis
4. ***Water-related insect-vector transmitted,*** for example malaria, onchocerciasis

Poor excreta disposal facilities and hygiene practices are mostly associated with the diseases in categories 1 and 2 above.[46] Attention has been focused primarily on those diseases transmitted through the faecal-oral route since they are the most widespread and constitute a large proportion of the morbidity/mortality burden of the population, especially among young children. Transmission is possible through contaminated water, food, hands and eating utensils or via the ground. Hence improvements in water quality and quantity, in excreta disposal facilities and in hygienic practices are all important for the interruption of pathogenic transmission.[46]

The infective dose of a diarrhoea-causing pathogen (the number of ingested organisms required to cause diarrhoea) varies according to the particular pathogen and various host factors. Esrey et al.[47] suggested that water and sanitation improvements would be more likely to have an impact on diarrhoea caused by high-infective dose pathogens than on those caused by low-infective dose pathogens. Their review of aetiology-specific impact studies supported this hypothesis, with reductions of >40% of median and high infective dose pathogenic diarrhoeas and 0%-2% of low infective dose (protozoal) diarrhoeas.

The major orally transmitted infections of high priority and their significance in water supplies are given in the WHO Water Quality Guidelines[48] as summarised in Table 1.2. Most of these pathogens are distributed worldwide and a number of countries contributed to the research quoted in Table 1.2. At any individual site the composition of the prevailing pathogens may differ. The information is given as a guideline only. Ideally, for each problem site, management decisions should be based on local information.

There is an important group of pathogens not listed in Table 1.2 which is of moderate or low pathogenicity in immunocompetent individuals, but holds great risk for the immunocompromised persons in the community.[49] The primary routes of infection of these opportunistic infections, even though they cause serious diseases in vulnerable subgroups,

Table 1.2 Orally transmitted waterborne pathogens and their significance in water supplies (extracted from WHO Guidelines for Drinking Water Quality[48])

Pathogen	Health significance	Persistence in water supplies[a]	Resistance to chlorine[b]	Relative infective dose[c]
Bacteria:				
Campylobacter jejuni *C. coli*	High	Moderate	Low	Moderate
Pathogenic *Escherichia coli*	High	Moderate	Low	High
Salmonella typhi	High	Moderate	Low	High
Other *Salmonellae*	High	Long	Low	High
Shigella spp.	High	Short	Low	Moderate
Vibrio cholerae	High	Short	Low	High
Yersinia enterocolitica	High	Long	Low	High
Pseudomonas aeruginosa	Moderate	May multiply	Moderate	High (?)
Aeromonas spp.	Moderate	May multiply	Low	High (?)
Viruses				
Adenoviruses	High	?	Moderate	Low
Enteroviruses	High	Long	Moderate	Low
Hepatitis A	High	?	Moderate	Low
Enterically transmitted Non-A, non-B hepatitis viruses, hepatitis E	High	?	?	Low
Norwalk virus	High	?	?	Low
Rotavirus	High	?	?	Moderate
Small round viruses	Moderate	?	?	Low (?)
Protozoa				
Entamoeba histolytica	High	Moderate	High	Low
Giardia intestinalis	High	Moderate	High	Low
Cryptosporidium parvum	High	Long	High	Low

[a]Period detected in water at 20°C - Short: up to 7 days, Moderate: 7-30 days, Long: >30 days

[b]Water treated at conventional doses and contact times - Moderate resistance: organisms not completely destroyed

[c]Dose required to cause infection in 50% of healthy adult volunteers. May be as little as one infective unit for some viruses.

are usually by contact or inhalation, rather than ingestion. These opportunistic pathogens are naturally present in the environment. They are able to cause disease in vulnerable groups,[50] such as the elderly, the very young, pregnant women, those with human immunodeficiency virus (HIV) infection or with full-blown acquired immunodeficiency syndrome (AIDS), persons who are chronically malnourished, or those suffering from chronic illnesses such as diabetes. Such persons comprise a substantial segment of South African society, and in the impoverished peri-urban settlements this proportion is even higher.

Examples of opportunistic infections associated with drinking water that are most often reported from many parts of the world are *Pseudomonas aeruginosa*, species of *Flavobacterium, Klebsiella, Serratia, Aeromonas, Acinetobacter, Xanthomonas maltophilia, Legionella*, and certain "slow-growing" mycobacteria.[48,49] The infectious dose for an opportunistic pathogen is lower for immunocompromised persons or for those on antibiotic treatment than for immunocompetent persons.[49]

1.7.2 Persistence of pathogens

After leaving the body of their host, pathogens gradually lose viability and their ability to infect. The rate of decay is usually exponential and a pathogen will become undetectable after a certain period. Pathogens with low persistence must rapidly find a new host and are more likely to spread by person-to-person contact or poor personal or food hygiene than by drinking water.[48] Because faecal contamination is usually dispersed rapidly in surface waters, the most common waterborne pathogens are those that have high infectivity or possess high resistance to decay outside the body.

Persistence is affected by several factors of which temperature is the most important.[48] Decay is usually accelerated by increasing temperature of water and may be mediated by the lethal effects of ultraviolet radiation in sunlight acting near the water surface. Viruses and the resting stages of parasites (cysts, oocysts, ova) are unable to multiply in water. Conversely, relatively high amounts of biodegradable organic carbon, together with warm temperatures and low residual concentrations of chlorine can sustain pathogens, opportunistic organisms and nuisance organisms or allow them to multiply. This is especially important in water distribution systems.

Bacteria released into the environment have a disquieting ability to survive and disperse in groundwater and surface waters.[51-56] Dutka and Kwan[51] reported that *E. coli* organisms in membrane filter chambers placed in Lake Ontario survived for a minimum of 28 days. Sadovski et al.[52] found that drug-resistant *E. coli* persisted in irrigation pipes for at least 8 days and in soil for at least 18 days. Stenstrom and Carlander[53] traced the survival of faecal coliforms through a wastewater wetland in Sweden. In the sediment of the wetland, the number of presumptive *E. coli* was reduced to half (T_{50}) only after 27 days. They pointed out the problem of reintroduction of organisms with such a long survival by resuspension from the sediment. This point was supported by LaLiberte and Grimes[56] who studied the sediment-water interface by placing bags of inoculated sediment on the bottom of a navigation pool in the Mississippi River. Their study only lasted a few days. They found that faecal coliforms in an aquatic environment may not always indicate recent faecal contamination of that water but rather resuspension of sediment-bound, but viable, bacteria.

Flint[54] used *E. coli* introduced into autoclaved, filtered river water at different temperatures. He found no loss of viability up to 260 days in organisms kept at temperatures varying from 4°C to 25°C. Survival times were shorter in water which was only filtered but not autoclaved and even less in untreated water, suggesting that competition with natural microbial flora in the water was the primary factor in the disappearance of the *E. coli*. Lim and Flint[55] showed that *E. coli* survived without decline in viable counts for at least 12 days in filtered-autoclaved lake water. In unfiltered lake water there was a rapid decline in the viable count of *E. coli*. The addition of synthetic sewage to filtered-autoclaved lake water led to an increase in the viable count of *E. coli* at 15°C and 37°C and to an increase in the survival time of the *E. coli* in unfiltered water. The addition of phosphate and carbon sources did not significantly increase the survival time of *E. coli* over controls. The addition of ammonium sulphate and some amino acids (as nitrogen sources) to the unfiltered lake water did lead to an increase in the survival times for *E. coli*. This increase was proportional to the concentration of the added nitrogen source.

Oragui and Mara[57] investigated the survival of various indicators of fecal pollution in fresh water samples held at 5°C, 20°C, and 30°C. *E. coli* and fecal streptococci disappeared after 5 weeks, but for those organisms kept in normal sewage held at 20°C, the survival time was 12 to 26 weeks.

Gagliardi and Karns[58] investigated bacterial movement through three different types of soil, using disturbed (tilled) and intact (no-till) soil cores and different simulated rainfall precipitation levels. Total levels of *E. coli* exceeded the starting inoculum levels for all treatments except intact clay loam. They concluded that tillage practice, soil type and method of pathogen delivery affect but do not prevent vertical *E. coli* O157:H7 and coliform transport in soil and that soluble nitrogen may enhance transport. Data indicated that if soil pores do not become clogged, *E. coli* O157:H7 could travel below the top layers of soil for more than 2 months after initial application. This has obvious implications for agricultural situations where heavily contaminated water is used for irrigation and where workers have extensive contact with such soil.

1.7.3 Infective dose

Most waterborne diseases are caused by pathogens typically transmitted by the faecal-oral route. However, pathogens released into water from skin or hair, wounds, pustules, urine, mucus, saliva and sputum and blood can also be transmitted. Some pathogens can also be excreted by healthy carriers. Infections are generally contracted by drinking contaminated water, recreational exposure to contaminated water, inhaling contaminated aerosols, ingesting shellfish from contaminated estuaries, or the consumption of raw food irrigated by contaminated water.[59]

The minimum infective dose of intestinal bacteria tends to be relatively high,[48,59,60] approximately 10 to >1000 organisms or more, while that of intestinal protozoa can be as low as a single viable unit.[59,60]

Enteric viruses are also primarily transmitted via faecally contaminated water or food. The enteric virus group include the enteroviruses (e.g. polio, coxsackie A and B, and echo); adenoviruses, reoviruses, rotaviruses, hepatitis A and B, caliciviruses (e.g. Norwalk) and astroviruses.[6-8] Viruses are excreted by infected individuals in numbers up to 10^{11}/g faeces.[59,60] Compared with most pathogens, the minimal infective dose is extremely low. In many cases a single virus can cause infection. Quantitative data on the occurrence of enteric viruses are limited due to the complexity and cost of virus recovery and detection methods.[59,60]

Experimental studies provide relative information about infective dose but it is doubtful whether the doses so obtained are relevant to natural infections.[48] Pathogens are likely to be widely dispersed and diluted in drinking water and a large number of people will be exposed to relatively small numbers of pathogens (unless the water is highly contaminated such as rivers below settlements without sanitation). If food is contaminated by water containing pathogens that multiply subsequently, or if a susceptible person becomes infected by water and consequently infects others by person-to-person contact, then the initial involvement of water may be unsuspected.[48] This will lead to underestimation of the health impact of the pollution.

Pathogenic agents have several properties that distinguish them from chemical pollution:[48]

1. Pathogens are discrete and not in solution
2. Pathogens are often clumped together or adhered to suspended solids in water, so that the likelihood of acquiring an infective dose cannot be predicted accurately from their mean concentration in water.
3. The likelihood of a successful challenge by a pathogen resulting in infection depends upon the invasiveness and virulence of the pathogen, as well as upon the immunity of the individual.
4. If infection is established, pathogens multiply in their host. Certain pathogenic bacteria are also able to multiply in food or beverages, thereby perpetuating or even increasing the chances of infection.
5. Unlike many chemical agents, the dose-response of pathogens is not cumulative.

1.7.4 Indicator organisms to determine water quality

Assessment of the safety of water by tests for the many pathogens that may be present would be impractical for technical and financial reasons.[59,60] Indicator organisms are therefore generally used for routine monitoring of the potential presence of pathogens in the water. Indicator organisms should ideally fulfill the following criteria.[59,60]

They must:

1. be suitable for all types of water;
2. be present in sewage and polluted waters whenever pathogens are present;
3. be present in numbers that correlate with the degree of pollution;
4. be present in numbers higher than those of pathogens;
5. not multiply in the aquatic environment;
6. be able to survive in the environment for at least as long as the pathogens;
7. be absent from unpolluted water;
8. be detectable by practical and reliable methods; and
9. not be pathogenic and safe to work with in the laboratory.

There is no single indicator organism that meets all those requirements. The wide variety of indicators used all have their own advantages and disadvantages. There is no universal combination that ensures good predictive ability in all cases. Each situation has to be considered in its own right. Considerations in the choice of indicator organism(s) depend inter alia on the intended water use, risks of infection, potential sources of pollution, as well as financial resources and the availability of laboratory facilities and expertise.[57,58] In the case of drinking water, Edberg et al.[61] reviewed the progress to date on the choice of indicator organism as warning of faecal pollution of drinking water. *E. coli* is found in all mammalian faeces at concentrations of $>10^9$ organisms per gram but it does not multiply appreciably in the environment.[60] They presented compelling evidence for *E. coli* as the best indicator for public health protection and said "Comparison with other practical candidate fecal indicators shows that *E. coli* is far superior overall."

The following is a brief summary of the most generally used indicator organisms:[48,59,60,62]

- **Total coliform bacteria**: Refers to all bacteria that produce colonies with typical metallic sheen within 20-24 hours of incubation at 35ºC on Endo agar. This gives an indication of the general sanitary quality of water since this group includes bacteria of faecal origin. However, many of the bacteria in this group may originate from growth in the aquatic environment. The existence of both non-faecal bacteria that fit the definitions of coliform bacteria and of lactose-negative coliform bacteria limits the applicability of this group as an indicator of faecal pollution. Used to evaluate the general sanitary quality of drinking water and related waters, e.g. swimming pool water.

- **Faecal coliform bacteria:** Refers to all bacteria which produce typical blue colonies on m-FC agar within 20-24 hours of incubation at 44,5ºC and comprises members of the total coliform group which are capable of growth at elevated temperature (thermo-tolerant coliform bacteria). Thermotolerant coliforms other than *E. coli* may also originate from organically enriched water such as industrial effluent or from decaying plant materials and soils. An important secondary indicator of probable faecal pollution of water since this group is much more closely associated with faecal pollution than the broader total coliform group. Some faecal coliforms may not be of faecal origin. Used to evaluate the quality of wastewater effluents, river water, seawater at bathing beaches, raw water for drinking water supply, recreational waters as well as water used for irrigation, livestock watering and aquaculture.

- ***Escherichia coli***: *E. coli* is a member of the family Enterobacteriaceae and is characterised by possession of the enzymes β-galactosidase and β-glucuronidase. It grows at 44° to 45°C on complex media, ferments lactose and mannitol with the production of acid and gas and produces indole from tryptophan. Some strains can grow at 37°C but not at 44° to 45°C and some do not produce gas. Faecal coliforms that test indole-positive generally consist of only *E. coli* that is almost definitely of faecal origin. Used to evaluate the possible faecal origin of total and faecal coliforms, usually when these are isolated from drinking water. The presence of *E. coli* in water can never be ignored because the presumption remains that the water has been faecally contaminated and/or that water treatment has been ineffective.

- **Enterococci (faecal streptococci)**: Refers to bacteria that produce typical reddish colonies on m-Enterococcus agar after 48 hours incubation at 35°C. Taxonomically the faecal streptococci belong to the genera *Enterococcus* and *Streptococcus* and all possess the Lancefield group D antigen. These bacteria often appear in human and animal faeces, but in lower numbers than total or faecal coliforms and are more resistant than coliform bacteria. Not all enterococci are of faecal origin, resulting in taxonomic regrouping of this group in recent years. Enterococci comprise a subgroup of faecal streptococci, being considered to include predominantly faecal streptococci of proven faecal origin. Used as an additional indicator in the evaluation success of treatment processes and safety of recreational waters.

- **Somatic coliphages**: The diverse group of somatic coliphages infects *E. coli* host strains and certain closely related bacteria through cell-wall receptors. These phages occur in large numbers in sewage, and are detectable by relatively simple, economic and rapid techniques. Their numbers may increase in certain water environments suitable for the growth of host bacteria. Somatic coliphages indicate faecal pollution, and their incidence and survival in water environments would seem to more closely resemble that of human viruses than faecal bacteria.

- **F-RNA coliphages**: A restricted group of coliphages (also known as male-specific coliphages) which only infect *E. coli* and related hosts which produce fertility fimbriae during the logarithmic growth phase at temperatures >30°C. These phages can therefore not be replicated in natural water environments, which implies that they are highly specific indicators of faecal pollution. Their numbers in sewage are generally lower than those of somatic coliphages and their behaviour and incidence in water environments would seem to resemble that of human viruses even more closely than somatic coliphages. Detection methods for F-RNA phages are more complicated than those for somatic coliphages.

1.7.5 A few remarks on methods of detection

Microbiological examination provides the most sensitive, although not the most rapid, indication of pollution of drinking water supplies.[59,60] Unlike chemical or physical analysis, it involves a search for small numbers of viable organisms, unless the water is heavily polluted. It does not entail the search for a defined chemical entity or physical property. Because the growth medium and the conditions of incubation can influence the species isolated and the count of such organisms, microbiological examinations may have variable accuracy.[59] This means that the standardization of methods and of laboratory procedures are of great importance if criteria for microbiological quality of water is to be uniform in different laboratories.[59,60,62-64]

In the 1980s *E. coli* was chosen as the biological indicator of water treatment safety.[60] Because of method deficiencies, *E. coli* surrogates such as the 'faecal coliform' and total coliform tests were developed and became part of water quality testing guidelines. With the advent of modern testing techniques the *E. coli* count was re-introduced into drinking water regulations. It is now the indicator organism of choice whenever water quality screening tests indicate a possible problem.[59,60] The multiple tube fermentation method provides the most accurate, but not the cheapest or fastest method to enumerate the number of *E. coli* organisms present in water samples.[63] Membrane filter techniques are widely used, especially since they provide faster, but not necessarily cheaper, results.[63,64] Unfortunately membrane filter techniques progressively underread as the pollution levels in the water increase and they are not suitable for heavily polluted water samples, such as those encountered in the present study. As mere presence-absence tests, they would still be accurate enough, but most water quality guidelines for any other purpose than drinking water have sliding scales of acceptability based on numbers of organisms per 100 ml of water. For this purpose membrane filter techniques become progressively more inaccurate as the pollution levels in the sampled water increase.

There is a great need for rapid, sensitive and specific tests of microbiological water quality. Methods have emerged in recent years that may in time and with more research effort replace the traditional multiple tube fermentation and the membrane filter techniques.[65] The detection of coliforms based on specific enzymatic activity has already improved the sensitivity of the membrane filter techniques.[65] The enzymes β-D galactosidase and β-D glucuronidase are widely used for the detection and enumeration of total coliforms and *E. coli* respectively. Even with the improved membrane filter techniques the incubation time, although reduced, remains too long for same-day results.[65] More sophisticated analytical tools such as solid phase cytometry can be employed to decrease the time needed for the detection of bacterial enzymatic activities, with a low detection threshold. There are also three main molecular methods for the detection of coliforms without the need for a cultivation step.[65] They are immunological, polymerase chain reaction (PCR) and in-situ hybridization (ISH) techniques. In the immunological approach, various antibodies against coliform bacteria have been produced, but to date the application of this technique has shown low antibody specificity. PCR can be used to detect coliform bacteria by means of signal amplification: DNA sequence coding for the lacZ gene (β-D galactosidase gene) and the uidA gene (β-D glucuronidase gene) has been used to detect total coliforms and *E. coli* respectively. However, quantification with PCR is still lacking in precision and necessitates extensive laboratory work. The fluorescent in situ hybridization technique involves the use of oligonucleotide probes to detect complementary sequences inside specific cells. Oligonucleotide probes designed specifically for regions of the 16S RNA molecules of Enterobacteriaceae can be used for tests for microbiological quality control of drinking water as it provides quantitative data in a fairly short period of time (6 to 8 hours), but this technique still requires research effort. Even though many innovative bacterial detection methods have been developed, few have the potential for becoming a standardized method for the detection of coliforms in drinking water.[65]

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CHAPTER 2

Provision of Basic Services and Recorded Burden of Disease

2.1 Background

Safe water supplies and adequate sanitation systems are essential elements of human development and poverty alleviation and constitute an indispensable component of primary health care.[1] There is evidence that provision of adequate sanitation services, safe water supply and hygiene education represents an effective health intervention that reduces the mortality caused by diarrhoeal disease by an average of 65% and related morbidity by 26%.[1] Inadequate sanitation, hygiene and water supply result not only in more sickness and death, but also in higher health costs, lower worker productivity, lower school enrolment and lower retention rates of girl pupils.[1] Most important of all, according to the Joint Report of the WHO and UNICEF on Global Water Supply and Sanitation Assessment 2000[1] and the South African Water Services Act of1997[2], inadequate water supplies and sanitation services also deny people the right to live in dignity.

2.2 Provision of basic services and burden of disease

2.2.1 Situation worldwide

According to the Global Water Supply and Sanitation Assessment 2000 of the WHO[3] the percentage of people with access to some form of improved water supply rose from 79% (4.1 billion people) in 1990 to 82% (4.9 billion) in 2000. Over the same period, the proportion of the world's population with access to excreta disposal facilities increased from 55% (2.9 billion people served) to 60% (3.6 billion). At the beginning of 2000, 16.6% of the world's population (1.1 billion people) was without improved water supply and 40% (2.4 billion) lacked access to improved sanitation. The majority of these people live in Asia and Africa, where fewer than half of all Asians have access to improved sanitation and two out of every five Africans lack an improved water supply.

Globally, rural services lag far behind urban services[3]. Sanitation coverage in rural areas, for example, is less than half of that in urban settings, even though 80% of those lacking adequate sanitation (2 billion people) live in rural areas - some 1.3 billion in China and India alone. This is even more alarming since, during the last two decades of the previous century, concerted efforts were made by the WHO and considerable publicity was spent on improving sanitation coverage. The period 1980 - 1990 was declared the International Drinking Water Supply and Sanitation Decade and intensive campaigns were waged to gather reliable information and improve the situation on the ground.[3]

Access to services improved considerably between 1990 and 2000, with approximately 816 million additional people gaining access to water supplies and 747 million additional people gaining access to sanitation facilities.[3] Unfortunately, the *percentage* increases in access were modest. This is because the global population growth during that time outstripped the gains in coverage by a considerable factor. Unlike the situation in the urban areas where the percentage coverage for improved water supply seem to have increased, the percentage coverage in the rural areas seem to have decreased over the 1990s.

In 2000 the Water Supply and Sanitation Collaborative Council of the WHO[3] started with Vision 21, a strong consensus not only to rely on governments, but to support people's own energy and initiatives to bring about rapid and lasting improvements. Thus, the Council plans to focus on users of services, not providers. Targets vary from country to country, but Vision 21 envisages that the number of people without access to improved water and sanitation services will be halved by 2015 and that universal coverage will be achieved by 2025. To reach those goals, the WHO needs continuous advocacy targeted at all stakeholders and dependable information on improvements.

The water supply and sanitation services will face enormous challenges in the coming decades. The populations of Africa, Asia, Latin America and the Caribbean are expected to increase dramatically.[3] The urban populations of Latin America and the Caribbean are expected to increase by almost 50% in the next 25 years. The population growth in Africa is almost double the global average. The combination of fast population growth with accelerated urbanization, and low levels of water supply and sanitation coverage make Africa especially vulnerable to the risk of water-related diseases.[3]

Projected population growth and migration, especially in Africa and Asia, suggest that urban services will face great challenges over the coming decades to meet fast-growing needs.[3,4] To reach universal coverage by 2025, almost 3 billion people will need to be served with water supply and more than 4 billion with sanitation.

The health hazards of poor water supply and sanitation are manifold, but one of the major indicators used worldwide is the incidence of diarrhoea. According to the WHO Global Health Statistics,[4] an incidence rate of 77 344 cases of diarrhoea per 100 000 occurred worldwide in 1990, which caused 2,9 million deaths or a mortality rate of 56 per 100 000, mostly among children under the age of 5 years. These deaths represent approximately 15% of all child deaths under the age of 5 years in developing countries. Water, sanitation and hygiene interventions reduce diarrhoeal disease on average by between 25% and 33.3%.[5]

Inadequate water supply and poor sanitation therefore carry a considerably increased morbidity and mortality, while improvement of those services will not only bring social and economic improvement, but also specifically help with poverty alleviation due to reduced direct costs of illness as well as improved productivity.

2.2.2 Situation in South Africa - services and disease rates

A District Health Information System has been put into place in South Africa, but there appears to be inadequate resources, both human and financial, to ensure that the system can fulfil its potential to assist with planning and provide information.[6] Obtaining comprehensive health information in South Africa regarding sanitation, water supply and waterborne diseases is therefore not easy. Day and Gray[6] recently collated the available data from the various State and non-governmental sources and publications in South Africa. This information was published in the South African Health Review 2001.[6]

According to the synopsis of this data in the South African Health Review 2001[6], the percentage of households with no toilet was 12.4% in 1996, but was reduced to 9.4% in 1999. In the Western Cape the percentage of households with no toilet was 5.4% in 1996, but was reduced to 3.8% in 1999. These data were obtained[6] from the October Household Survey of Statistics SA. The percentage of households with piped water inside was 44.7% for the country as a whole in 1996, but reduced to 38.7% in 1999. The corresponding percentage of households with piped water inside for the Western Cape was 76.4% in 1996, increasing slightly to 76.7% in 1999.

When the analysts in the South African Health Review 2001[6] collated the data in racial groupings, the percentages of households in 1999 with no toilet were 12.1% for Africans, 4.8% for Coloureds, 0% for Indian/Asians, 0% for Whites (9.4% overall for all South

Africans). The percentages of households with piped water inside were 21.1% for Africans, 73.6% for Coloureds, 95.9% for Indian/Asians, 97.1% for Whites (38.7% overall for all South Africans). It is interesting to note that although the position in 1999 regarding the percentage of households with no toilet improved slightly when compared with the corresponding figures for 1996, the percentage of households with piped water inside declined from 1996 to 1999.

Diarrhoeal disease is one of the leading causes of infant mortality, and is closely related to both socio-economic situation and environmental health issues such as access to clean water. The incidence of diarrhoea is used as an indicator to determine the health status of children and identify possible environmental hazards (e.g. contamination of water sources). The South African Health Review 2001[6] gives data on diarrhoea incidence in children under 5 years of age per 1000 children in the target population. Diarrhoea was formally defined as 3 or more watery stools in 24 hours, but "any episode and/or treated as diarrhoea after an interview with the adult accompanying the child" was also counted[6]. Although no doubt useful for planning purposes, the data were however collected in a format that does not make it easy to compare epidemiologically.

Table 2.1 Extract from Table on p. 314 of the South African Health Review 2001[6] regarding incidence of diarrhoea per 1000 in children under 5 years of age

Year	Eastern Cape	Free State	Gauteng	KwaZulu Natal	Mpuma-langa	Northern Cape	Northern Province	North West	Western Cape	South Africa
1998[1]	275.6	197.5	204.0	236.3	351.5	225.7	316.8	264.7	214.8	286.4
2000[2]	145.7	84.2	67.7	292.2	107.2	135.5	217.6	241.3	99.7	174.3

The following two footnotes were presented with the data:

1. The incidence rates per 1000 given for 1998 were calculated from the percentage of children in the previous two weeks reported in the SADHS 1998[7] to approximate an annual incidence.
2. This [data] refers to the number of children seeking treatment for diarrhoea from primary health care facilities. This is about half the number of cases expected, based on the number of cases reported in the SADHS 1998 survey to have experienced diarrhoea in the 2 weeks prior to the survey. Thus this figure has to be doubled before comparison with the preceding year.

As can be seen from the footnotes above, comparing the two rows of data depends on the acceptance of the stated assumption that the data for 2000 is about half of the actual incidence. Thus the data in the bottom row should be doubled before comparing it with the top row. This is problematic from an epidemiological point of view. It is not possible to determine whether differences thus observed are due to actual changes in the incidence of diarrhoea or to erroneous assumptions about the number of cases in the population represented by the number of cases reporting at primary health care facilities.

2.2.3 Situation at local level

As already mentioned, the District Health Information System that has been put into place in South Africa is not yet functioning at such a level that reliable information regarding disease rates giving complete coverage of the areas concerned can be obtained at a district level.

2.3 Legislative and statutory aspects

Government has a constitutional responsibility to ensure that all South Africans have access to adequate sanitation.[2] Cabinet adopted the White Paper on Basic Household Sanitation in 2001[8] which put in place an improved national sanitation policy. This is an important step in the process of meeting this responsibility and in addressing the problems of inadequate sanitation.

The purpose of the White Paper on Basic Household Sanitation 2001[8] is to:

1. highlight the impact of poor sanitation on health, living conditions and the environment;
2. articulate government policies on sanitation;
3. provide a basis for the formulation of local, provincial and national sanitation improvement strategies aimed at addressing the backlog;
4. provide a framework for municipality driven implementation programmes;
5. promote greater coherence and co-ordination amongst the different spheres of government and amongst other role players in addressing the sanitation problem;
6. ensure that sanitation improvement programmes are adequately funded; and
7. put in place mechanisms to monitor the implementation of this policy and sanitation improvement programmes so that corrective action can be taken when necessary.

The sanitation policy focuses specifically on the provision of a basic level of household sanitation to mainly rural communities and informal settlements. These are the areas with the greatest need. This policy also deals with the need for an environmentally sound approach to providing sanitation services and addresses the need to protect surface and ground water resources from sanitation pollution through integrated environmental management practices.

In the past, sanitation has been seen primarily as a technical issue (toilet building, providing sewer systems, maintenance etc.) whilst other aspects have been given secondary consideration. It is now recognised that toilets are just one element in a range of factors that make up good sanitation.[8] Other aspects such as community participation in decision-making, improved health for large numbers of people, safer living environments, greater knowledge of sanitation-related health practices and improved hygiene are just some of the factors that are central to the development of good sanitation.

For the purpose of this dissertation and in keeping with the definitions in the White Paper,[8] it is necessary to define sanitation and also to describe the minimum acceptable basic level of sanitation as stated in the policy:

> *"Sanitation" refers to the principles and practices relating to the collection, removal or disposal of human excreta, household waste water and refuse as they impact upon people and the environment. Good sanitation includes appropriate health and hygiene awareness and behaviour, and acceptable, affordable and sustainable sanitation services.*
>
> *The minimum acceptable basic level of sanitation is:*
> *(a) appropriate health and hygiene awareness and behaviour;*
> *(b) a system for disposing of human excreta, household waste water and refuse, which is acceptable and affordable to the users, safe, hygienic and easily accessible and which does not have an unacceptable impact on the environment; and*
> *(c) a toilet facility for each household.*

The sanitation policy will focus mainly on the improvement of health and hygiene and the provision of adequate sanitation facilities in households, schools and clinics as well as the collection, removal and disposal of human waste and the related health and hygiene practices.

There are important principles that guide the Government's policy on sanitation[8], especially in the light of the reality of the situation as is manifested in, for example, the present study site (the dense settlement of Kayamandi and its impact on the Plankenbrug River). The policy principles[8] and intervention strategies that will be undertaken to address the sanitation problems in the country are:

1. *Sanitation improvement must be demand responsive, supported by an intensive Health and Hygiene Programme*

Household sanitation is first and foremost a household responsibility and must be demand responsive. Households must first recognise the need for adequate toilet facilities for them to make informed decisions about their sanitation options. For users to benefit maximally, they must also understand the link between their own health, good hygiene and toilet facilities.

2 *Community participation*

Communities must be fully involved in projects that relate to their health and well being and also in decisions relating to community facilities, such as schools and clinics. Communities must participate in decision-making about what should be done and how, contribute to the implementation of the decisions; and share in the benefits of the project or programme.

3. *Integrated planning and development*

The health, social, and environmental benefits of improved sanitation are maximised when sanitation is planned for and provided in an integrated way with water supply and other municipal services. The focal mechanism to achieve integrated planning and development is the municipality driven Integrated Development Planning (IDP) process (of which the Water Services Development Plan is a component).

4. *Sanitation is about environment and health*

Sanitation improvement is more than just the provision of toilets; it is a process of sustained environment and health improvement. Sanitation improvement must be accompanied by environmental, health and hygiene promotional activities.

5. *Basic sanitation is a human right*

Government has an obligation to create an enabling environment through which all South Africans can gain access to basic sanitation services.

6. *The provision of access to sanitation services is a local government responsibility*

Local government has the constitutional responsibility to provide sanitation services. Provincial and national government have a constitutional responsibility to support local government in a spirit of co-operative governance.

7. *"Health for All" rather than "all for some"*

The use of scarce public funds must be prioritised for assisting those who are faced with the greatest risk to health due to inadequate sanitation services.

8. *Equitable regional allocation of development resources*

The limited national resources available to support the incremental improvement of sanitation services should be equitably distributed throughout the country, according to population, level of development, and the risk to health of not supporting sanitation improvement.

9. *Water has an economic value*

The way in which sanitation services are provided must take into account the growing scarcity of good quality water in South Africa.

10. *'Polluter Pays' principle*

Polluters must pay for the cost of cleaning up the impact of their pollution on the environment.

11. *Sanitation services must be financially sustainable*

Sanitation services must be sustainable both in terms of capital costs and recurrent costs.

12. *Environmental integrity*

The environment must be protected from the potentially negative impacts of developing and operating sanitation systems.

2.4 Duties at central and local authority level

The National Water Act No. 36 of 1998[9] and the Water Services Act of 1997[2] are among the most responsible, environmentally friendly water legislation in the world. The acts redefined ownership and custodianship over water in South Africa and cast the net of affected parties to any water use much wider than in the past. It also reiterated the Government's Sanitation Policy[8] that the country's water resources should meet basic human needs and promote equitable access to water, while redressing the results of past discrimination. In doing so water sources should be protected, and pollution and degradation prevented.

2.4.1 Constitutional responsibilities

The institutional arrangements between the different levels of government for the promotion and provision of effective sanitation must be guided by the Constitution[10], which stipulates in Chapter 7 Section 152(1) inter alia that:

> *A municipal council is responsible for promoting a safe and healthy environment and ensuring the provision of services to communities in a sustainable manner.*
>
> *National and provincial governments, by legislative and other measures, must support and strengthen the capacity of municipalities to manage their own affairs, to exercise their powers and to perform their functions.*

2.4.2 The roles and responsibilities of municipal government[8]

The recent reforms of municipal government places local government in a central role in integrating programmes to achieve synergistic development in a participatory and decentralised manner while reflecting actual priorities as they manifest themselves on the ground.[8]

It is the municipality who is in the first instance accountable for the provision of sanitation services and, through its Environmental Health Practitioners, to promote health and hygiene awareness and to monitor the health of its communities.[8] The municipality is similarly responsible for ensuring an environmentally safe approach to sanitation and for monitoring the impact of the sanitation process on the environment.[8]

The municipality must also take responsibility for driving the process set out in this policy at local level, for creating an enabling regulatory environment through its municipal bylaws, and for taking responsible decisions on levels of service to ensure that they are both appropriate and affordable.[8]

The main roles of municipal government[8] in implementing this policy and in addressing the backlog and sustainability of sanitation services are to:

1. Create a demand for sanitation improvement through health and hygiene awareness programmes;
2. Identify local sanitation improvement needs;
3. Prioritise these needs;
4. Plan within the IDP/WSDP process to respond to these needs, including the need for health and hygiene awareness and for sanitation services, together with the needs for other services as an integrated package of services, where appropriate aligned with the development of the Integrated Sustainable Rural Development Strategy (ISRDS) nodes;
5. Align their budgets to achieve the planned objectives;
6. Ensure that sufficient and appropriate human resources are available to execute the plan including the development of building skills within the community;
7. Implement the plan;
8. Monitor and report on the results; and
9. Ensure sustainability.

Because of the pivotal role of local municipalities, it is clear that the success of this policy is inextricably linked to the commitment of local government to the approach and to the target.

A number of key success factors in the management of local authorities responsible for the provision of water supply and sanitation services to developing communities in South Africa have been identified by Schutte[11] as critical to the sustained success of such undertakings. Schutte presented a review of the challenges facing municipal structures in South Africa regarding sanitation and the problems caused by ineffectual ways of dealing with the health and sanitation crises in most poor, urban settlements. According to the review, these factors have to receive urgent, specific and sustained attention from management.

Schutte[11] identified two major groups of factors that are crucial to providing a sustained water and sanitation programme, namely:

1. The credibility of the local authority with the community it serves

2. The creation of an organisational culture of focusing on service to the community, on income generation and on minimising of losses.

Developing crediblity[11]: The successful delivery of water supplies and sanitation to developing communities depends in the first place on the acceptance of the supplier of these services as an organisation by the community. If the community does not accept the service supplier, the organisation can expect resistance, non-payment, vandalism and eventual failure. Acceptance of the organisation is the result of the organisation earning a certain level of credibility with the community. As the level of credibility improves, it can expect that acceptance will at some stage develop into passive support by the community and later on into active support.

The only way any organisation delivering services to a developing community can obtain credibility is by earning it.[11] Credibility cannot be obtained automatically, by an act of parliament, or even by a request from the community for such services. Credibility is earned by delivering a reliable service, at a cost that is perceived to be fair, by assisting the community to solve its water and sanitation related problems and, generally, if the organisation is perceived to act in the best interests of the community.[11]

There are several aspects to the establishment and maintaining of credibility:[11]

- Creating an organisation-wide culture of service to customers
- Ensuring reliability in the supply of services
- Ensuring community involvement

The way in which these aspects manifested in the present study site and the way the situation was handled by the local authority as provider of water and sanitation services to the community of Kayamandi will be discussed in Chapter 4.

Creation of a culture focusing on maximising income and minimising losses[11]**:**

In South Africa potable water is sold as a quasi-public good.[12] The price is not completely market-determined in the same way as consumer goods for example, nor is it a public good or service such as police protection that is funded out of taxation. Water is a quasi-public good because the waterworks that delivers water to a particular area is operated on 'commercial' principles that require the full costs of the services to be ultimately recovered from the users. This is problematical in South Africa where such large proportions of many communities are poor and unemployed. Since water is an essential element in hygiene and combating of disease, a basic amount of water per household has recently been made available to most households free of charge. A good deal of cross-subsidising of water costs is carried out at present and looks set to remain so for the foreseeable future.[12]

Organisations providing water and sanitation services cannot survive if, in the long run, customers do not pay for such services, unless in the case of very poor communities the government provides a subsidy for these services.[11] A subsidy unfortunately has a habit of starting out as temporary, then it becomes indispensable and eventually it becomes unaffordable to the provider of the subsidy.[11] This results in a crisis situation when the subsidy is cut and hardships to the community inevitably follow.

The financial survival of water and sanitation service providers (local authorities for the most part in South Africa) depends on the application of sound financial planning, systems, controls and strict financial discipline. In the case of provision to developing communities, the aforementioned sound financial approaches may not be enough to ensure financial survival. They must be supplemented by *active* approaches and systems aimed at mobilising efforts to maximise collection of income due to the organisation and minimising losses.[11]

The generation and collection of income in a local authority is too often seen as a function only of the financial section.[11] The technical staff see their role only as providing the infrastructure and maintenance. They do not recognise that they constitute the first line of income generation and collection. Generation of income depends in the first place on properly functioning meters, curtailing leaks in the system, etc. The staff in the queries and complaints section also often do not recognise that a bill that is unpaid because of a dispute regarding a failed service actually amounts to income lost.[11]

Bureaucratic systems typically function as cost centres.[11] Expenditure is budgeted for and spent, irrespective of what the income was.[11] To be successful, local authorities should be far more conscious of linking expenditure to income.[11] The culture of cost consciousness does not mean the organisation should minimise expenditure to the extent that the service becomes inoperable. It means that a serious amount of attention should be directed at everyone employed by the municipality to concentrate on eliminating avoidable expenditure, and that is a much wider responsibility than mere cost-cutting.[11] Fixed and operational costs should be scrutinised in order to classify them into controllable and non-controllable costs. *Every official* should assume responsibility for the minimisation of the controllable costs under his or her command.[11] This will obviously only succeed if driven by management to the extent that a culture of loss prevention must be firmly established in the organisation.

It is estimated[11] that water losses in developing communities can account for 30% or more of water supplied. Water losses, or more correctly 'unaccounted-for-water' (water produced but not sold) in developing communities are due to many causes: leaking pipes, malfunctioning or broken taps, illegal connections, vandalism and wastage at communal facilities, overflow of reservoirs, and poorly operating billing systems.[11] Many of these problems are due to poor (and cut-price) infrastructure, poor control of non-payment, and poor supervision. It is evident that a major drive by different sections of the local authority responsible for delivery of services is necessary to address these problems.[11] This will not be successful if the relationship between the community and the local authority is soured by reciprocal blaming, mistrust and subversion. Solving this impasse demands more from management than the classic top-down approach used by most local authorities.[11] The recent upheavals in municipal boundaries and structure and employment arrangements in the local authorities[13,14] and the resultant job insecurity only made matters worse in this respect.

The particular manifestations of this crisis in water and sanitation service provision in the present study site will be discussed briefly in Chapter 4. The poor services and non-co-operation between municipal officials and members of low-income urban communities in South Africa due to the breach of trust on both sides need urgent attention because the magnitude of the crisis in health and environmental pollution stemming from the lack of proper functioning of water and sanitation services cannot be sustained in any country. South Africa simply cannot recover from such large-scale *avoidable* damage and disease, not with all the other, less avoidable, health and environmental emergencies we are facing.

2.4.3 The roles and responsibilities of provincial government[8]

Many municipalities will need assistance and guidance to develop the capacity required to prioritise, plan and implement programmes under the Government's new Sanitation Policy.[8] The province will be a key agent in supporting the municipalities in achieving their objectives and in ensuring that local municipalities perform effectively. The province can provide support to municipalities in a number of areas, including financial, human resource and technical.

The primary roles of the province relating to this policy are to:

1. Monitor legislation through the National Council of Provinces;
2. Ensure compliance with national policy and norms and standards,
3. Develop enabling provincial legislation and norms and standards;
4. Co-ordinate regional planning;
5. Promote integrated development and inter-departmental co-ordination; and
6. Monitor progress.

Furthermore, certain provincial departments, such as the provincial departments of the environment, local government, education, health and housing are the implementation arms of their national counterparts.

Unfortunately, the roles assigned to the provincial authorities (particularly that of ensuring compliance with policy, and monitoring of progress) seem to be at a standstill at present. The Western Cape provincial structures are not fulfilling their duties optimally in this regard and do not seem to work well in synergism with the National Department of Water Affairs and Forestry in enforcing the various pieces of legislation constraining municipalities to carry out proper sanitation to protect the health of people or the environment (W Kloppers, DWAF – personal communication).

2.4.4 The roles and responsibilities of national government in general[8]

The generic roles and responsibilities of national government are:

1. Establish legislation, policies, norms and standards;
2. Co-ordinate and monitor national programmes;
3. Provide support to other spheres of government;
4. Regulate service provision;
5. Intervene where there is a lack of capacity; and
6. Provide advocacy and guidance.

At a national level the roles of all of the national departments must be clarified and co-ordinated to avoid duplication, especially the roles of the Department of Water Affairs and Forestry, the Department of Provincial and Local Government, the Department of Health, the Department of Education, the Department of Housing, the Department of Public Works, the Department of Environmental Affairs and Tourism and the National Treasury.

2.4.5 The roles and responsibilities of the Department of Water Affairs and Forestry[8]

The Department of Water Affairs and Forestry is the custodian of the Nation's water resources and is also the custodian of the National Water Act[9] and the Water Services Act[2].

In accordance with a Cabinet decision, the Department of Water Affairs and Forestry is responsible for co-ordinating the involvement of national government in the sanitation sector. The Department will also, together with the other national role players, be responsible for:

1. Developing norms and standards for the provision of sanitation;
2. Co-ordinating the development by the municipalities of their Water Services Development Plans as a component of their Integrated Development Plans (IDP);
3. Providing support to the provinces and municipalities in the planning and implementation of sanitation improvement programmes;
4. Monitoring the outcome of such programmes and maintain a data base of sanitation requirements and interventions;
5. Providing capacity building support to provinces and municipalities in matters relating to sanitation;
6. Providing financial support to sanitation programmes until such time as these are consolidated into a single Department of Provincial and Local Government programme; and
7. Undertaking pilot projects in programmes of low cost sanitation.

2.4.6 The roles and responsibilities of the Department of Provincial and Local Government[8]

The Department of Provincial and Local Government is the custodian of the Municipal Systems Act[13] and the Local Government Municipal Structures Act[14]. Matters relating to provincial and local government systems and structures fall within this department's ambit.

This department will take primary responsibility for:

1. Promoting the development by the municipalities of their Integrated Development Plans (IDP);
2. Ensuring that provincial and local governments have the capacity required to fulfil their functions;

3. The co-ordination, together with the National Treasury, of the provincial and local governments equitable share and municipal infrastructure grants;
4. Provision of financial support to sanitation programmes; and
5. Monitoring of such programmes and maintaining a database.

2.4.7 The roles and responsibilities of the Department of Health[8]

The vision of the Department of Health is a caring and humane society in which all South Africans have access to affordable, good quality health care.

According to the Sanitation Policy,[8] the Department of Health, in co-operation with the provinces, will take primary responsibility for:

1. Co-ordinating information relating to public health (this includes media liaison and communication);
2. Co-ordinating the planning and interventions aimed at influencing the health and hygiene behaviour of communities and at creating a demand for sanitation services through health and hygiene awareness and education programmes;
3. Standardising existing and prepare new norms and standards relating to health aspects of sanitation and water supply;
4. Preparing educational curricula relating to health and sanitation;
5. Supporting municipalities in employing sufficient and appropriately skilled environmental health practitioners (EHP);
6. Providing development orientated training and other capacity building interventions to EHPs;
7. Monitoring compliance with health legislation, regulations and norms and standards;
8. Co-ordinating interventions when a crisis poses a regional or national health risk (such as a cholera epidemic);
9. Providing a systematic approach to the provision of sanitation facilities in clinics, hospitals and other health installations;

2.4.8 The roles and responsibilities of National Treasury[8]

The responsibility of National Treasury relating to sanitation is associated with the funding of the different departments and spheres of government.

Treasury will take primary responsibility for:

1. Funding arrangements such as the allocation of the equitable share and the various grants to provinces and municipalities;
2. Monitoring of the financial policies and performance of national departments, provinces and municipalities; and
3. Development of financial policies, norms and standards and guidelines.

It is difficult to judge whether the Department of Finance is executing its duties in allocating the necessary financial resources to the various budgets for the task of providing basic services, as required by the Sanitation Policy.[8] Opportunity costs, the competing merits of the various needs for funding in the country, etc. are outside the scope of this dissertation. At a meeting on 31 May 2002 of the Provincial Sanitation Task Team (Western Cape) that this candidate attended, it was mentioned that out of the approximately R3 million to R4 million allocated to the Province for the provision of basic sanitation in poor areas in 2001, only R91 000 was spent. It seems that the magnitude of all the policy changes, changes to the structure and staff of the main service providers (municipalities) and the inexperience of officials in managing changes on so many fronts simultaneously were to blame for this sad state.

2.4.9 The roles and responsibilities of other government departments[8]

According to the Sanitation Policy,[8] the Department of Housing is responsible for, amongst others, developing national policy, including norms and standards, in respect of housing development and for co-ordinating the application of the housing subsidy that is administered by the provincial housing departments.

The Minister of Housing has prescribed a minimum level for each type of service for subsidy purposes. The minimum level of service prescribed for sanitation is a VIP per household ('erf') unless the situation, such as the soil conditions, dictates otherwise.

The National Department of Education is responsible for the development of curricula on hygiene and health matters while the Provincial Departments are responsible for the provision of school facilities, which includes school toilets and other sanitation facilities. The Department of Education, together with the Department of Health, will develop curricula, guidelines and other support mechanisms required by teachers and other educators to take up the important issues relating to health, hygiene and sanitation in their classrooms.

The Department of Education together with the Department of Health, introduced the *Health Promoting Schools Programme* in South Africa. The provincial departments are responsible for implementing this health promoting schools strategy. The Department of Public Works acts as the implementing agent on behalf of national and provincial government departments when facilities, including schools and clinics, are constructed or rented. The Department thus has an important responsibility in ensuring that adequate provision is made for sanitation facilities in government and public buildings, especially in the schools, and for ensuring that norms and standards are observed.

The Department of Environmental Affairs and Tourism is responsible for the protection of the environment. This Department will take primary responsibility for developing policies, guidelines, procedures and norms and standards relating to the impact of sanitation systems on the environment; monitoring environmental impacts of sanitation systems and monitoring compliance with environmental management procedures and guidelines.

2.5 Co-ordination of policies and programmes

The National Water Act No. 36 of 1998[9] and the Water Services Act of 1997[2], read together with the above stipulations of the White Paper on Basic Household Sanitation 2001[8] place the responsibility for establishing, maintaining and extending improved water supply and safe sanitation access to all the dwellings in its area of jurisdiction securely in the hands of the local authorities. Given South Africa's past unequal distribution of access to resources, a considerable backlog of facilities exists. As illustration of this, the problems experienced in the community of Kayamandi chosen for the present study provide valuable lessons for the implementation of the policies in the White Paper on Basic Household Sanitation 2001[8].

Leaving aside the community for the moment, there are also larger issues of environmental safety and the effects of urban dense settlements on water quality in this study. South Africa has dwindling sources of high quality water and the country cannot afford to have natural watercourses polluted with avoidable sources of contaminants related to human habitation.

The state of our rivers is a source of great concern. One of the principles of the White Paper on Basic Household Sanitation 2001[8] is environmental integrity. That means that the environment must be protected from the potentially negative impacts of developing and operating sanitation systems. To minimise the environmental risk inherent in developing new sanitation systems and to ensure the continued protection of the environment throughout the operations phase, an integrated environmental management (IEM) approach must be adopted for the location, selection, design, construction and operations of all sanitation works with special attention to be given to sewage treatment plants and solid waste disposal sites.

As required by the National Environmental Management Act of 1998 (NEMA)[15], environmental plans, policies and programmes of government departments in all spheres must be co-ordinated and harmonised.

The Integrated Development Planning process will form the basis of an integrated approach to environmentally sound planning. The Water Services Act 1997[2] specifically requires that details of existing and proposed water conservation, recycling and environmental protection measures must be included in the Water Services Development Plan which is a component of the Integrated Development Plan (IDP).

The municipal jurisdiction area is however not always the most suitable boundary for managing the negative impact of sanitation systems on the water resource. Water resource protection is best managed on a catchment-wide basis or aquifer-wide basis through the catchment management strategies prepared by catchment management agencies (water management institutions established under the National Water Act 1998).[9]

Alien and invader plants cause a major problem and one that creates an unfavourable environment for the protection of the river and its water sources. These plants use large amounts of water, thereby reducing the volume of water available to flush the river system clean. Some of these plants also invade the instream habitat (the riverbed) and form an impediment to water flow, slowing down the water flow to the extent that sedimentation deposits increase and more visible pollution gets deposited along the riverbed and banks. There are various laws creating a legal duty on landowners to control invading alien plants on their properties. This legal obligation exists as a result of Section 151(1) of the National Water Act 36 of 1998[9]; Section 28 of the National Environmental Management Act, 107 of 1998[15]; Section 31A of the Environment Conservation Act, 73 of 1989[16]; Regulations in terms of the Conservation of Agricultural Resources Act, 43 of 1983[17]; and the National Veld and Forest Act, 101 of 1998.[18]

Unfortunately, the enforcement of all these acts and their laudable aims, whether for the purposes of improving access to clean water and sanitation or for the conservation of river ecosystems, have not been consistent or even very visible. Four or more years after the promulgation of these acts, the situation in many impoverished communities have changed little. Very few consistent and sustainable programmes are undertaken to keep watercourses clean. Only piecemeal efforts are carried out. In fact, as is borne out by the present study, the impacts of poor sanitation servicing, poor river catchment management and inadequate planning in many spheres are steadily worsening.

2.6 Barriers to progress at institutional level

There have been huge investments in time and financial resources into improving water supplies to previously disadvantaged communities in South Africa over the past decade. Although some of these newly established facilities did not prove sustainable in the long run, many more people in South Africa now have access to improved water supplies. Unfortunately, the health benefits that should have accrued from these improvements did not materialise because of serious lack of progress in other areas such as safe disposal of human excreta.[19,20]

The WHO Global Water Supply and Sanitation Assessment 2000 Report[19] summarised some of the most important barriers to progress in the field of sanitation in developing countries. These barriers all exist to a greater or lesser degree in South Africa and particularly so in the study area of Stellenbosch, Kayamandi and the Plankenbrug River.

These barriers are:[19]

1. Lack of political will - for law enforcement at central level and for construction and upkeep at local level
2. Low prestige and recognition for the importance of sanitation
3. Poor policy formulation and application at all levels
4. Weak institutional framework, fragmented responsibilities and lack of accountability
5. Inadequate and poorly used resources
6. Inappropriate technologies or approaches
7. Failure to recognise defects of current excreta management systems
8. Neglect of consumer preferences
9. Ineffective (or absent) hygiene promotion and low public awareness
10. Women and children last.

The knowledge base and levels of experience at local authorities are often insufficient and alternative options for action are not always based on comprehensive cost-benefit analyses.[21] The long-term health costs of particular choices made by the local authorities (even the conscious choice to do nothing) are very seldom taken into account. Very little attention is given, especially at local level, to the long-term consequences of physical changes and interventions brought about in watercourses and riverbanks.

Monitoring of the performance of sanitation systems in economically deprived areas and monitoring of resultant water quality of rivers are especially poor.[21] The monitoring is often not cost-effective and carried out with very little insight. The data generated by these monitoring actions are seldom interpreted properly and even less frequently acted on.

According to the senior officials of the Department of Water Affairs, there is almost a complete absence of education programmes at local level (with the exception of some metropolitan areas) to improve hygiene behaviour and to prevent environmental pollution. There even exists a great reluctance to plan and design such educational interventions on a community based level. This is partly due to lack of knowledge in the local authority structures of many areas, but also an unwillingness to take this duty 'on board' even though it is prescribed by governmental policy.

The low status of public health and sanitation in particular amongst health service professionals[22-28] has seen the decision-making processes regarding these important functions almost completely handed over to the engineering profession whose training tends to predispose them to 'hardware' (structural) approaches and who are on the whole not disposed towards health impacts, hygiene and social participation aspects. There are a number of private enterprises in South Africa now offering a more integrated approach to health and sanitation services, most of them managed by engineering professionals, which is another sign that the health professions are not very visible in this field. This is a regrettable state of affairs.

> "Anyone who has read the history of public health feels trapped in a time machine and transported back to the nineteenth century."
>
> Kickbush (1997)[29]

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CHAPTER 3

Aims of the Present Study, Background, and Objectives of the Substudies

3.1 Brief introduction

The burden of disease caused by waterborne infections is of particular importance since many of these cases could theoretically be prevented with proper water treatment and provision of sanitation. The health services are under considerable pressure in terms of patient numbers, staffing levels and finances and any reduction of the patient load will make an important difference. There is a crucial need for scientifically sound answers to the problems of contamination of water sources with potentially hazardous microbial organisms of human origin and the assessment of the risks posed by such pollution. Identification of particular populations at risk, determination of priorities and impact on economic activities as well as the health services are also urgent needs. Research on the microbiological contamination of our water sources and measures to alleviate the situation have not received sustained attention.

Escalating rates of urbanization, industrialization and population growth have aggravated water pollution as a threat to the economy and well-being of South Africa. One of the major sources of faecal pollution of natural water courses are the many informal dense settlements that have been established near rivers in the last decade or two as the process of urbanization of poverty stricken rural people gather momentum. Kayamandi on the outskirts of Stellenbosch is one such a settlement. It is established on land not very suitable for residential purposes because of a very steep gradient sloping towards a tributary of the ecologically sensitive Eerste River called the Plankenbrug River. Most of the inhabitants of Kayamandi only have communal ablution facilities at their disposal, which are in poor condition. Sanitation services and in particular the solid waste disposal are of a poor standard. This settlement is a good example of an urban township receiving clean water and that had hitherto been regarded as of a lower priority regarding its impact on environmental pollution. The present study aimed to investigate whether this was a true reflection of reality.

3.2 AIMS OF THE PRESENT STUDY

1. *To determine some basic epidemiological characteristics of the exposed population of Kayamandi, their sanitation problems and reasons for poor hygiene*

2. *To determine the microbiological and chemical pollution load patterns in the Plankenbrug River over time*

3. *To investigate the spectrum of organisms present in the river (other than the indicator* E. coli*) and their epidemiological implications for health*

4. *To establish the possible presence of organisms resistant to chlorine or to antibiotics in the river below Kayamandi as indicators of environmental hazard*

The above four aims were addressed in various subprojects. Most of the objectives of the subprojects were formulated at the beginning of the study, but some of the investigations were dependent on the outcome of other prior determinations. One such example is Objective 2.3. When it became clear from the main data set of concentrations of *E. coli* in river water over time that the trend in the indicator organism concentrations did not follow the expected pattern of downstream decay associated with a point source of pollution, an analysis of the 'unexpected' pattern of concentrations was added as an objective.

3.3 Study 1 - Community-based investigations

Aim 1: To determine some basic epidemiological characteristics of the exposed population of Kayamandi, their sanitation problems and reasons for poor hygiene

The following objectives were set:

***Objective 1.1**: To determine basic epidemiological aspects of the exposed population in Kayamandi*

An extensive community-based survey was carried out with the aid of trained volunteer health workers. The survey included a demographic section on all inhabitants of the houses in order to estimate some epidemiological characteristics of the population.

***Objective 1.2**: To identify community-based problems and reasons for pollution and to pilot-test basic hygiene education in the community*

Both qualitative and quantitative investigations were carried out of community-based problems with basic services and sanitation needs, as well as a brief exploration of the attitudes of the community towards environmental cleanliness and health. Three door-to-door education campaigns were carried out at the same time as the information gathering surveys. Information on these will be presented. Community meetings were held with leaders and the general public and inherent problems with sanitation and hygiene were identified by means of the problem tree approach. Problem trees with the identified problems will also be presented.

The results of these investigations are presented in Chapter 4.

3.4 Study 2 - Main data base of river water analyses

Aim 2:	To determine the microbiological and chemical pollution load patterns in the Plankenbrug River over time
Aim 3:	To investigate the spectrum of organisms present in the river (other than the indicator *E. coli*) and their epidemiological implications for health
Aim 4:	To establish the possible presence of organisms resistant to chlorine or to antibiotics in the river below Kayamandi as indicators of environmental hazard

From 5 May 1998 to 10 February 2003 the river water was sampled at roughly six-weekly intervals and analysed for a set of microbiological and chemical parameters.

3.4.1 Substudy 1 - Microbial pollution loads

***Objective 2.1**: To determine the patterns of microbial pollution over time and the 'real' trends in pollution levels after the effect of rainfall has been statistically controlled for*

The seasonal fluctuations in colony counts of microbial pollutants in river water are influenced by rainfall. Seasonal rainfall will be controlled for in the comparisons of the pollution loads over time. The long-term trends can then be reviewed without the "background noise" of rainfall variation. The upward trend in pollution that is at present discernible by eye could then be tested against a possible confounding factor of rainfall. This statistical adjustment has not been carried out on water pollution data in South Africa before and no reference to such techniques could be obtained in health related literature in world databases.

The results of these investigations are presented in Substudy 1 in Chapter 5.

***Objective 2.2**: To determine the difference between 'expected' patterns of pollution and 'unexpected' patterns where the pollution levels rose without discernible causes*

The number of viable *E. coli* organisms obtained during field studies indicated that on about a third of the sampling occasions surprising results were obtained regarding *E. coli* levels downstream from what was previously always assumed to be a point source pollution. During those occasions that 'unexpected' results were obtained, the pollution levels actually rose downstream instead of gradually reducing downstream, as one would expect if Kayamandi were the sole source of pollution. There were also other anomalous patterns observed. The profiles for the "expected" patterns will be compared with the data obtained from sampling occasions when "unexpected" patterns were observed and their implications discussed.

The results of these investigations are also presented in Substudy 1 of Chapter 5.

3.4.2 Substudy 2 - Chemical pollution and its relationship with E. coli *levels*

Objective 2.3: To determine the predictive ability of various combinations of the chemical parameters to indicate faecal contamination

The relationship between the parameters of river chemistry and faecal contamination in the dataset will be explored. Of special interest was the predictive ability of various combinations of the chemical parameters to indicate faecal contamination, since the data set is unique in its availability of chemical and microbiological determinations on the same samples. In the Western Cape routine microbiological analyses are only carried out in rare instances and the authorities rely on the determination of water chemistry to indicate both chemical and microbiological pollution. It was postulated that this approach has poor prognostic ability and this required investigation.

The results of these investigations are presented in Substudy 2 in Chapter 5.

3.4.3 Substudy 3 - Aspects of epidemiological risk assessment

Objective 3 *Survey of spectrum of organisms other than* E. coli *present in the river and in the biofilms on stones in the river*

The coliform group of bacteria and specifically *E. coli* are used as indicator organisms. Once substantial numbers of coliform bacteria are detected, it is prudent to assume that such water has been contaminated with faecal waste and that other, harmful pathogens are also present. However, indicators can never adequately predict the presence of other harmful pathogens. A screen of some of the most important pathogens that could be detected will be presented. The epidemiological implications of the presence of organisms found in the screening will be explored.

The results of Substudy 3 are presented in Chapter 5.

3.4.4 Substudy 4 - Water quality and impact on health: chlorine resistance

The following objectives were set:

Objective 4.1: To establish the presence of chlorine resistant organisms downstream from Kayamandi

The presence of chlorine resistant organisms in treated water is an indication of failure of effective water treatment to inactivate pathogens. Should chlorine resistance be present to any significant degree, this will imply that the ability to make raw water from such polluted rivers safe is severely impaired. The levels of chlorine resistance have not been determined in any of the river systems in the catchment area.

The results of these investigations are presented in Substudy 4 in Chapter 5.

3.4.5 Substudy 5 - Water quality and impact on health: antibiotic resistance

Objective 4.2 *To investigate possible antibiotic resistance of some organisms in river water*

With increasing use of antimicrobial substances, as well as improper disinfection practices, it is possible that the common diarrhoeal pathogens are becoming resistant to various antibiotics and this poses a further health risk. In order for the health services in the area to improve their cost-effective management of endemic diarrhoea, information on pathogens and their susceptibility patterns are needed. This study can serve as a model for many such settlements all over South Africa.

The results of these investigations are presented in Substudy 5 in Chapter 5.

3.5 Ethical aspects

The various studies contributing to the research data presented in this dissertation were properly registered and approved by the Ethics Committee of the Faculty of Health Sciences of the University of Stellenbosch as Project Numbers C073/2000, C083/2000, C084/2000 and Project No. K5/1226B of the Water Research Commission. Financial support for the projects were provided by the Flemish Government, Belgium, the Danish Government via their DANCED programme, the Water Research Commission and the Harry and Doris Crossley Foundation. No conflict of interest was created by the sources of financial aid.

Most of the data obtained in these studies are not directly related to individuals. All surveys of inhabitants were carried out anonymously using specially trained local community health workers and were done only in dwellings where informed consent of the participants was obtained. Participation was refused at only three dwellings. The information is only reported in grouped data form and no individual or dwelling can be identified from these reports.

The study provides essential information for the authorities responsible for ensuring that legal obligations and regulations regarding pollution are complied with. Serious health hazards were uncovered during the course of this study and various authorities and role players had already been informed of the situation. The information will be integrated into a more complete picture than any one substudy can provide on its own. The serious situation will again urgently be brought to the attention of those responsible for addressing the hazards thus uncovered.

The various substudies will also be published in peer-reviewed journals in order to disseminate the information to the various health professions.

CHAPTER 4

Community Health Aspects of the Study

4.1 The study environment

4.1.1 The Plankenbrug River

The Plankenbrug River rises about 9 km northwest of the town of Stellenbosch and is approximately 10 km long. Its upper reaches are not perennial and only have water flowing consistently in the rainy season. Even in its lower reaches the flow slows to a shallow stream during extended dry periods, especially in summer. This frequently occurring low volume of water contributes to the severe problems with water quality experienced on an ongoing basis in the Plankenbrug. The first rains after a prolonged dry spell wash the accumulated pollution on the banks into the river at very high concentrations.

With the slow flow of the water during most of the year, the river does not flush clean and visible pollution in the form of plastic bags; tins, etc accumulate in the riverbed. The periodic fast flows or winter floods simply distribute this visible pollution higher up the banks down-river. The banks and riverbed are choked with alien vegetation that contributes to slow flow, which in turn causes even lower water levels. There are many alien trees growing along the riverbanks, all of them big consumers of water. At various locations there are Category 2 invader pines (*Pinus* spp), Category 2 invader exotic willow (*Salix babylonica* L.), some Category 2 wattle species (*Acacia* spp.) and some oaks (*Quercus* spp.) Shrubs such as the Category 1 weeds sesbania (*Sesbania punicea* (Cav.) Benth.) and bugweed (*Solanum mauritianum* Scop.) also occur, while reeds and other common weeds choke much of the riverbed itself.

There are various laws creating a legal duty on landowners to control invading alien plants on their properties. Refer to Chapter 2, Section 2.5 for an overview of the laws on which this legal obligation is based. The Municipality of Stellenbosch is the legal custodian of large tracts of land along the banks of the Plankenbrug River. Although this local authority has a Parks and Environmental Department, there does not seem to have been a sustained or very effective effort to fulfill their legal obligation in terms of the above-mentioned acts during the study period. Periodic clearing of alien growth is undertaken in some places, but this is not carried out consistently or very often.

For the greater part of the year along extended stretches of the river the actual channel of open, flowing water is no wider than one or two metres. Water trickles sluggishly through the severely polluted vegetation growing in the rest of the watercourse and the stagnant water provides an ideal breeding ground for clouds of mosquitoes and other biting insects, while leeches (Class *Hyrudinea*) also sporadically appear in the water. In summer the mud and silt smell very badly of sewage and anaerobic decomposition of organic matter.

Watershed management along the Plankenbrug River is not at a sophisticated level and control of erosion is not always carried out timeously. Sediment from earthworks on the banks periodically washes into the river in high volumes. This silt can choke the natural flora and fauna in the river, as well as detrimentally affect the downstream farm dams feeding off the river system. When soil on properties adjacent to the river is levelled by grader or disturbed because of building operations, very few, if any, precautions are taken to prevent run-off of mud and silt into the river. Due to the high concentrations of micro-organisms in the water downstream of the dense settlement of Kayamandi, the resultant sediment layers along the watercourse end up in the farm dams feeding off the river. The sediment is not only very thick, but also heavily contaminated with pathogenic organisms.

The upper reaches of the river mainly flow past agricultural land such as vineyards and orchards. It reaches the town of Stellenbosch at its point of worst pollution, namely the informal settlements on the outskirts. The largest of these communities and one of the most important sources of the grossly high level of coliform bacterial pollution of the Plankenbrug River is the township of Kayamandi. The vast majority of the dwellings in Kayamandi are of the informal housing type without on-site services such as water and sanitation.

Kayamandi is perched on a steep hillside overlooking the Plankenbrug River and all run-off water from the slopes, as well as the runoff that drains via a considerable number of stormwater conduits, empty into the river. After Kayamandi, the river flows through an area with light industries such as a cheese factory, clothing manufacturer, spray painting and engine repair workshops, and car washes. Just after the industrial area, the river flows into the Eerste River. There is unquantified but reputedly considerable pollution from these industries into the Plankenbrug, one of the most important being wine cellar effluent. At the point of confluence with the Eerste River, the water is diverted for agricultural use. It is mainly used for irrigation of crops. In the past this water was taken from the Plankenbrug River side of the confluence.

Since the pollution levels in the river made irrigation hazardous to both farm workers and the eventual consumers of the crops, the downstream agricultural water consumers placed gabions in the Eerste River a few metres before the confluence. This was done in order to dam up the cleaner water of the Eerste River before the point of confluence and to divert the remaining more polluted water of the Plankenbrug into the Eerste River below the take-off point. Unfortunately, the downstream users of the "left-over" water from the two combined rivers were not consulted as prescribed by the National Water Act 36 of 1998 and this emergency measure may ultimately prove to be unlawful. Since the placement of the gabions, the riparian owners downstream receive river water with a higher level of pollution than before because a considerable portion of the 'cleaner' Eerste River is now diverted into the irrigation canal during summer.

Apart from agricultural activities, there are extensive tourist developments on some of the properties downstream, especially along the Eerste River. The visitors to these facilities should at all costs be kept from contact with the river water. This is unfortunately not an easy task, nor is it desirable from a publicity point of view to post warning notices at regular intervals along the riverbank. Thus the pollution problem is threatening the livelihood and health of many people downstream.

The possible economic impact of the pollution in the Plankenbrug River should not be underestimated. Overseas consumers are increasingly unwilling to pay high prices for produce from developing countries where the production methods either carry health risks or are associated with unsound ecological practices. The export markets are crucial to the economic survival of the agricultural industry in the Western Cape province.

In a fruit and wine producing region similar to the downstream farming community surrounding the Eerste River namely Elgin-Grabouw, it has recently been estimated that two-thirds of the farms are up for sale and some of them are reportedly going for 25% of their estimated worth. This has the unfortunate consequence that the book values of all the others farms in the vicinity are reduced and the ability of their owners to obtain finance from the banks is thus seriously curtailed. The economic ripple effects of an outbreak of a waterborne disease associated with irrigation water or produce from the region or of a cluster of cases of waterborne disease among inhabitants such as farm workers can therefore be serious.

4.1.2 Brief notes on the town of Stellenbosch

The town of Stellenbosch is situated roughly 50 km northeast of Cape Town. It is the oldest town in South Africa and it is an important historic landmark containing a large number of restored buildings and other historic sites. It is often referred to as a "university town" because the University of Stellenbosch is one of the dominant organisations in the town. The presence of a university makes an important contribution to the number of inhabitants in the town. This also represents a population with a large proportion of its members coming from far and wide and who disseminate back into a wide area over holiday periods. It is also the centre of a widely acclaimed wine-growing region and the investment in agricultural activities represents a vast sum. Because of its historic significance and the natural beauty of the surroundings, the town of Stellenbosch receive a large number of tourists per year. These visitors stay for shorter periods at a time than the university staff and students, but also add to the movement of people. This movement of large numbers of persons in and out of the town is significant in terms of the risk of infectious disease spread.

The surrounding agricultural activities are mainly focused on production of table wines and fruit and vegetables of high quality. The drainage area of the Plankenbrug River is farmed intensively and contains some of the most expensive farmland in the province. The climate is typically Mediterranean, with a hot, dry summer and a cool and wet winter.

4.1.3 The settlement of Kayamandi

The settlement of Kayamandi is perched on a steep hill, next to one of the entrance roads into Stellenbosch. It overlooks the Plankenbrug River, which flows past just on the other side of the road.

The soil on the slope of the hillside is hard, stony and with a high clay fraction in most places. The soil type, the steep gradient and the very high density housing make VIP latrines technically unsuitable as a sanitation solution. The ideal of a latrine for every household will only be achievable if the shack dwellings are considerably reduced in number, which will not be possible for the foreseeable future. There is a waterborne sewage system in Kayamandi, connecting mainly the brick housing, public buildings and communal toilet facilities to the main town sewage system. This sewage system in Kayamandi is in poor condition in some places and some of the branch lines are unable to cope with the volume of sewage produced by the fast growing population, especially at peak times and they are frequently blocked by solid waste.

The formal brick houses in Kayamandi mostly date from the era when the old Department of Bantu Affairs administered the area, although there are smaller new developments where housing projects have already delivered brick-built dwellings. The informal dwellings (shacks) comprise the majority of the houses in Kayamandi and most of them have been erected since about 1990. There is a primary school and a high school in Kayamandi, both accommodating over a thousand pupils in very cramped conditions and a crèche for about a hundred children. All the schools have more learners than can be adequately accommodated and some Kayamandi children attend schools as far afield as Kuilsriver and Somerset West because of the shortage of space.

A housing scheme with blocks of residential flats has also recently been completed, but allocation to new owners had been a slow and politically fraught process. There are also housing schemes on the outer areas of Kayamandi where individual houses (each one on a small plot) have been delivered. Unfortunately not all shack dwellers rehoused in this manner were willing to let go of ownership of their previous shacks so that the land could be redeveloped with properly constructed housing. This is a big bone of contention in Kayamandi. Some people are allocated a new home and then rent out their old shack, obstructing the dismantling process and thereby stopping new development. This is but one of the many 'fault lines' of social and political division in Kayamandi. The entire settlement is full to capacity and the inhabitants are living in a confined, clearly delimited space. There are many backyard dwellers: people living in appalling conditions in makeshift shelters waiting for new homes. Some have been waiting a decade or longer.

At various times representatives of the Municipality provided the following population estimates: 3 100 families living in Kayamandi, 15 500 people living in Kayamandi, and 9496 inhabitants living in Kayamandi (the last-mentioned was provided by an employee of the Municipality who served on the Steering Committee in January 2000). This has proved to be a very big stumbling block in addressing the sanitation situation in the township. The Municipality refuses to accept outside information regarding numbers of people living in Kayamandi. Calculated on the low numbers that they use, the toilets blocks and the sewage systems are quite adequate and therefore need no serious or large-scale improvement.

A note on terminology is needed here. This dissertation refers to informally constructed housing mostly built of flimsy material as "shacks" since this is the term used by the inhabitants of Kayamandi as well as the community members of the Kayamandi Test Case Steering Committee. This term is frowned upon in the international press (the American term shanty is preferred), but shack is the accepted term locally. No condescension or denigration is meant or implied by its use.

In the past, there had been community structures in place with which the Local Authority could liaise (the most recent one was called the Social Compact), but these have all but collapsed over the previous three years. Kayamandi is at present going through a phase of slowly redeveloping its community structures and its sense of community spirit, because the increase in informal housing and new arrivals over a short period of time seriously overstrained the old community bonds. The councillors representing the community of Kayamandi on the Town Council provide valuable leadership, but they are elected officials and can thus only exert a certain amount of influence, depending on the political whims of their support base. Political alliances in Kayamandi are convoluted and at times violent. The crime rate, especially for violent crimes such as armed robbery and murder, is high and taxi violence is endemic. There is a very high rate of unemployment, especially among the shack dwellers. Poverty and low levels of education are the norm. There are many illiterate persons living in Kayamandi, but no formal study has established an exact illiteracy rate yet. Hunger is encountered especially in the households where caregivers are unemployed or where the adults are affected by diseases such as tuberculosis (TB) and AIDS. Kayamandi has started to see its share of young orphans and child-headed households, most of them having lost their parents to AIDS or TB.

The formal brick houses all have individual access to the municipal water reticulation system and the sewage system. The informal dwellings (80% of the dwellings in Kayamandi) do not have running water or toilets inside or even on the premises. The Municipality supplies clean water to all inhabitants of Kayamandi, albeit in the case of the shacks mostly from communal taps attached to the back walls of the communal toilet blocks or in a few cases outside standpipes. The Department of the Municipal Town Engineer is responsible for maintenance of the water reticulation and sewerage networks. Formal tarred roads with kerbstones and stormwater drains are in place in most of Kayamandi. Non-payment for services is very high.

Apart from the poorly functioning toilet facilities, the sanitation habits of many of the inhabitants of Kayamandi are not of a high standard. People relieve themselves on sidewalks, open spaces, against walls and on footpaths. Others use the surroundings of the township, the road into town or the riverbanks for that purpose. The vineyard adjacent to the top boundary of Kayamandi was so severely polluted with faeces that a strip of vineyard half a kilometre wide had to be abandoned and the farm owner compensated, as it became hazardous to work in that vineyard. Very few grapes were left on the vines until harvest time.

The open areas surrounding Kayamandi are contaminated with faeces and the large amount of uncollected solid waste result in a considerable health hazard. The sanitation habits of many of the inhabitants cannot be sustained in a residential area without severe adverse impact on the environment and the people living there.

The waste streams causing problems in Kayamandi include all the traditional elements of sewage, sullage (household 'grey' water), stormwater and solid waste. Because of intermingling of the waste streams, the contributions of the individual sources are not easily separated.

Rainfall can increase the inflow of 'cleaner' water into the river and this can result in lower *concentrations* of pollutants per 100 ml of water downstream from a point source of pollution, but this does not imply less pollution reaching the river. Temperature is however the single most important determining factor of numbers of organisms in free flowing water, given that suitable nutrients are present. So the season of the year also plays a role in the actual concentrations detected in the river. The situation is further complicated by the fact that farm dams along river systems in the Boland are traditionally filled with 'winter' water for irrigation in summer. If significant pollution is actually present in the water during winter, the farm dams may be filled in winter with water carrying more dangerous organisms than previously suspected.

Please refer to the photographs of Kayamandi regarding the sanitation situation at the end of this dissertation.

4.2 The DANCED Test Case Project

South Africa's Constitution places the responsibility for managing the nation's water resources with the Department of Water Affairs and Forestry (DWAF). As such, DWAF must both ensure equitable access to water and the sustainable use of water resources. DWAF must therefore develop policies and strategies to manage the water resources, while at the same time redressing the inequities of the past. These policies not only require a balance between the need to protect the water resources and the need for development and upliftment in the country, but they also require co-operative governance and active community participation.

The Department of Water Affairs and Forestry developed a "National Strategy to manage the water quality effects of densely populated settlements", funded by the Danish Government via their Danish Co-operation for the Environment and Development (DANCED) programme. The project comprised three phases. Phase 1 (June 1997 – May 1998) included the development of a draft strategy in consultation with stakeholders. A bridging phase (June 1998 – December 1998) was used to discuss the strategy with a wide variety of stakeholders. Phase 2 (January 1999 – December 2001) aimed to test the implementation of the strategy in nine test cases (model projects) and then further refine the strategy for implementation on a national scale.

The National Water Act, 1998 (Act 36 of 1998) places particular emphasis on the protection of water resources and makes provision for both resource- and source-directed strategies. The strategy of the DANCED project is a source-directed approach but it is guided by resource-directed strategies.

The strategy aimed to find the appropriate balance between protection of the water resource, the levels of services and the density of the settlement. The strategy is based on a *structured-facilitated* process, whereby DWAF, local authorities and communities jointly identify the main causes of pollution from a settlement and also outline interventions for addressing these problems.

The process is structured around identifying *physical*, *social* and *institutional* problems from four interacting waste streams, namely *sewage*, *sullage*, *stormwater* and *solid waste*. The water quality effects from settlements should be managed by addressing the *physical* problems associated with the four waste streams. However, the sustainability of these physical interventions is based on addressing the *institutional* and *social* aspects that contribute to the problem.

Nine test cases were selected (one per Province) in order to test the implementation of the National Strategy on a local level. The idea was to use the strategy to address as wide a range of settlement problems as possible. It was important to test the applicability of the National Strategy for different climatic and environmental conditions. Climatic conditions that distinguish the Western Cape from the other provinces included winter rainfall (prolonged periods of rainfall impacting on stormwater and catchment wash-off patterns), vulnerable groundwater resources (high water tables, sandy aquifers, etc.) and impacts on the marine environment, which in turn has a major impact on tourism.

Kayamandi was selected as the most suitable site in the Western Cape Province to test the application of the strategy for a number of reasons. The community is well-defined and detailed scientific data about the pollution levels of the Plankenbrug River were available from the projects reported elsewhere in this dissertation, the Local Authority endorsed the Test Case project and varying levels of services were already available in the settlement. Unfortunately, as it turned out, the endorsement of the DANCED Project by the Local Authority was problematic at best.

The composition of the Kayamandi Test Case Steering Committee (KTCSC) was discussed at a National Workshop in July 1999. The KTCSC was established from nominations according to the agreed composition and consists of councillors and officials of the Stellenbosch municipality, members of the Kayamandi community, including the schools, clinic, churches and the Social Compact, an official from DWAF as well as a lecturer from the Department of Community Health of the Faculty of Health Sciences of the University of Stellenbosch at Tygerberg (the author of this dissertation).

The proposed project was discussed with the Municipality and the Social Compact respectively to ensure political support for the project. A public meeting was held to introduce the project and the members of the KTCSC and to establish a platform for information sharing with the community. KTCSC meetings were held on a monthly basis.

4.2.1 Identification of problems with waste streams in Kayamandi

The DANCED Test Case Project required that a problem analysis of the pollution problems in the settlement should be carried out to determine the root causes of the pollution and to formulate an intervention plan to address the problems. At the same time a strategy was supposed to be formulated to monitor the interventions carried out. The monitoring of all the interventions funded or initiated by the project were however not carried out.

The Problem Trees in the next sections (separated into waste streams) were drawn up after extensive consultation and community participation between the Test Case Steering Committee and the community. Meetings were held in Kayamandi, both by public invitation and with special interest groups such as the informal traders and hawkers. Staff members of the Municipality also attended a few of these meetings.

Organising the community meetings was quite difficult. Suitable venues in Kayamandi were few and all owned by and booked through the Municipality. Notices about the meetings were disseminated by means of posters in public places for those who could read, but mostly by driving a car equipped with a loudspeaker announcement system through the streets. The announcer was a member of the Steering Committee, Mrs M Mayembana, a Community Health Practitioner of the Winelands District who worked at the Kayamandi Clinic. She was a well-known member of the Kayamandi community. Even though she was a resident of Kayamandi of many years standing and an ordained preacher of her church, the fact that she was a woman created problems among some of the male newcomers from traditional rural areas, especially the older men.

Although the meetings were scheduled to start at 18h00 at the request of the community members of the Steering Committee, most of the attendees only assembled at about 20h00, causing a lot of repetition, messages only partly carried over to most of those coming late and discussions going round and round without leading anywhere. It was not possible to find a starting time to assemble a majority of the stakeholders, as some inhabitants come home from work late, while others go to bed very early since they start shift work in the early hours.

A Problem Tree analysis method (as prescribed by the DANCED Test Case methodology) was used to analyse the many problems reported by the inhabitants. Apart from the numerous individual complaints, the mutual lack of goodwill between the Municipality as an organisation and members of the community became strikingly clear during the many rounds of public discussion needed to construct the problem trees. Problem Trees 1 - 5 will be presented at the discussion of each waste stream in the following section.

This polarisation meant that neither side was willing to commit itself to constructive action to improve the situation, because that would look like an admission of 'guilt' in the eyes of the other side. The black staff members of the Municipality, who were responsible for the sanitation maintenance tasks in Kayamandi itself, were singled out for particular scorn. Unfortunately, none of these staff members who were present at those meetings could provide adequate explanations for the poor state and upkeep of facilities in Kayamandi, thereby further fuelling the community's resentment.

The Sewage Waste Stream

There are 29 communal toilet blocks in Kayamandi (called 'bus' toilets by the inhabitants because of the similarity in appearance), serving the whole of the informal part of the settlement (amounting to at least 15 000 to 20 000 persons). The ablution blocks consist of a row of toilets. Some of the bigger blocks consist of a double row of toilets, facing each other. Most of the toilets were originally constructed with a showerhead mounted on the wall above the toilet. Almost all of these showers are non-functional by now and were indeed wholly impractical from the outset. Showering would leave the whole toilet drenched and the floor awash. Apart from the water sluicing through the whole toilet, showering would add considerably to slowing of access to the toilets.

At the back walls of most blocks of toilets is a row of taps with washbasins. There are no rubbish bins at the toilet blocks. The consequence of this is that persons coming to wash dishes try to rinse the waste food left on plates and in cooking pots down the basins, clogging them time and again.

Barbed wire fences fitted with lockable gates surround the communal toilet blocks in some areas. In an effort to curb vandalism, the Municipality locks the toilet blocks overnight. Many women also said that it was not safe to visit the toilet block after dark. This situation has contributed to the entrenched habit of the inhabitants of the shack dwellings to collect excreta overnight in any container such as a tin or bucket. The queues in the morning do not allow easy disposal into the toilet, thus most of these containers are emptied into the nearest stormwater drain or, if plastic bags are used, they are disposed of into rubbish bins.

The number of persons allocated to a toilet in the communal toilet blocks is very high. There are usually about 8 families per toilet, but can be as high as 60 persons per toilet in some zones.

PROBLEM TREE 1: SEWAGE - KAYAMANDI

As reported by inhabitants of Kayamandi

Inadequate use of toilets

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- Huge amounts of untreated sewage reach the river
- Toilets too far from houses and too few
- Toilets that are so far from houses are a security risk, especially after dark
- Uncomfortable to use toilets so far away during bad weather
- Toilets are heavily used and not always available
- Keys to toilets not freely available
- Keys not always available to those who do not pay for services
- People use the surroundings/bushes
- Some people use containers for excreta and empty onto street or inside stormwater drains

Blockages/Overflows

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- Out of poverty or ignorance, people use all sorts of paper in toilets
- Newspaper cause blockages, especially in overloaded sewage systems
- Solid waste is frequently disposed of into sewage system
- Manhole covers are stolen, causing more waste to wash into system
- Lack of a reporting system causes overflows to occur for long times
- There is inadequate staff to deal with blockages: 1 team and 1 standby team for big blockages and one vehicle. This causes delays.

PROBLEM TREE 2: SEWAGE - KAYAMANDI

As reported by inhabitants of Kayamandi

Leaking Pipes → **Sewage reaches the river**

- Poor design was sometimes employed in the sewage system
- Poor supervision was sometimes carried out during construction
- Some construction workers are suspected of involvement in stealing/damage
- Vandalism of sewage pipes, etc occur
- Frustration and "anger" are some of the causes of vandalism
- Unemployment/poverty: some people steal to sell
- Lack of ownership and lack of feeling responsible causes a lot of damage
- Lack of awareness of the results of damaged or blocked sewers make problems worse

- Overload of the system due to the large population causes leakages
- There are not enough toilets
- There is not enough space to erect more toilets (overcrowding)
- Not enough money to erect more toilets
- Money budgeted for more toilets do not include all the costs, i.e. maintenance and expansion of the sewage system
- Planning is ad hoc and more geared towards crisis management
- There is not regular, effective maintenance
- Generous planning margins should be used for poor communities because of rapid increase in population. Example: use bigger pipes than usual because use of newspaper in toilets which cause blockages

- The system of reporting problems is not working
- Supervision of sewage system not working: no systematic inspection of sewage lines and no follow-up to check up on inspection
- Whose job is it to (1) report blockages and (2) to do something about it?
- Communication not effective: education needed to use toilets only for the right purpose
- Only 1 team for sewage/stormwater blockages and 1 team for larger blockages and only one vehicle - takes a long time to respond.

The existing toilet blocks, including washbasins and taps, were cleaned up and repaired with the aid of the DANCED project funds. Local unemployed persons were used for the clean-up campaign. This was a huge task because some of the toilet blocks were so filthy and encrusted with faeces that the aid of the fire brigade had to be called in to hose them out with pressurised water hoses.

The Solid Waste Stream

The collection of solid waste is mainly by means of black plastic bags, as well as communal bulk waste containers called skips. The removal of solid waste was the responsibility of the Health Department of the Municipality, although the allocation of departmental responsibilities is in the process of being reorganized at present.

The Municipality provided the following information. There are 30 bulk containers (skips) placed at various points in Kayamandi and these are emptied on Mondays, Wednesdays and Fridays, but individual skips are not necessarily emptied more than once a week. At present one compactor vehicle with five labourers is used to collect refuse in black refuse bags from the households. One truck with five labourers is used to collect loose refuse from open spaces and sidewalks. This team is also supposed to clean up around the skips.

It was maintained at the community meetings (and subsequently substantiated) that the sanitation teams responsible for solid waste removal only work until noon at the latest on any given day. The authority for this concession and the reasons for it could not be established, even by the councillors representing Kayamandi on the Town Council. Whatever the original reason, the staff members in question now use the free (paid) time to generate extra income. The trade union representing these staff members is strongly resisting the abolition of this privilege. This situation meant that solid waste removal in Kayamandi is ineffective and erratic. Because of deposition of human faeces in open places that mix in with other wet and dry waste, there is also considerable danger of exposure to disease amongst sanitation workers.

The solid waste building up around skips and lying in the streets wash into the stormwater drains, clogging these drains as well. The sub-optimal functioning of the sanitation systems dealing with the various waste stream cause ripple effects impacting on the whole system. Thus, ineffective functioning in one domain contributes to poor functioning in another.

PROBLEM TREE 3: SOLID WASTE - KAYAMANDI

Solid waste pollutes river

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- There is a lot of rubbish in the streets: no/little street cleaning
- Dogs and chickens tear the black bags and scatter the contents
- There are no bins in the streets like in the business centre of Stellenbosch
- Lack of co-operation and community ownership
- Not my problem - Municipality should come and clean

Location of skips a problem

- People do not wants skips near their houses: flies, smells, and nuisance
- Increased health risks for residents living near skips
- Children can't reach the top of the skips - too high
- Skips need to be emptied more regularly. Once a week not enough.
- Skips need to be emptied when full, not only on scheduled time

Refuse removal system not working well

- Workforce to cope with Kayamandi waste too small
- There is no space to put black bags for the week (inside shacks)
- Black bags brought and taken away on the same day - not enough time to fill
- One bag per week is not enough for most families
- Bags are used for other purposes by some people
- Refuse in Kayamandi consists of more 'wet' waste than in other areas
- Informal areas too dense for black bag system

Institutional problems with rubbish removal

- Lack of communication between departments of local authority
- Lack of communication between residents and local authority
- Lines of communication too long and too much effort for poor inhabitants
- Response times too long
- There is an urgent need for a contact person inside Kayamandi
- Need for an official of Municipality to be stationed inside Kayamandi. There are empty offices. Needs to be introduced to the inhabitants

The Stormwater Waste Stream

The vast majority of the roads in the settlement are tarred and an underground stormwater system is in place for almost the entire settlement. A considerable number of stormwater conduits from Kayamandi, as well as all the surface run-off water drain into the Plankenbrug River. To keep solid waste from entering the stormwater system, grids were installed in front of the catch-pits. Due to the steep gradient of the roads, stormwater that does not enter a catch-pit runs along the kerb towards the lowest point of the township and then into the river. The Department of the Town Engineer is responsible for the maintenance of the roads and the stormwater system.

The stormwater system works well in the sense that blockages etc. have a minimal impact in terms of flooding on the residential areas. This is because Kayamandi is situated on a steep slope and surface run-off drains rapidly to the Plankenbrug River. Even during heavy downpours, water does not dam up to any large degree because of the topography. Blockages do however spread contaminated water locally, creating health risks for those living nearby.

The poor removal of solid waste causes a lot of rubbish to wash into the stormwater system, resulting in many blockages. Sand and pine needles also wash into the system because the streets are not swept often enough.

There is no suitable place for informal slaughtering with a cement slab, taps and gullies to divert the wastewater into the sewage system. A large amount of informal slaughtering takes place on the sidewalks under very unhygienic conditions and the blood and other slaughtering waste also end up in the river via the stormwater system.

Efforts were made some years ago to relay a couple of the worst affected stormwater conduits directly into the town's sewage system, rather than to the river but it has been confirmed that this was technically a failure. A consultant has very recently been appointed to draw up a plan to relay the water from all the stormwater conduits in Kayamandi to the sewage works, but only during low flow periods. This will at best only be a partial amelioration of the pollution problems. During rainstorms the water volumes will be too large for the traps to hold back the stormwater or for the sewage works to handle the volume and the stormwater overflows will again empty into the river.

PROBLEM TREE 4: STORMWATER - KAYAMANDI

Solid waste in stormwater

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Stormwater system used for disposal of rubbish

Sand/soil and pine needles are washed into the stormwater system (i.e. not deliberate pollution)

Sewage overflow also lands in the stormwater system

Rubbish lying in the streets also gets washed into the stormwater system
Poor provision for rubbish (bins) in the streets

Rubbish bins in the street used for other purposes: disposal of excreta, as urinals, etc

Informal abattoirs cause slaughtering waste to wash into stormwater system

Planning and control problem: no formal control on informal slaughtering

Preparing/selling food on the street: food waste wash or thrown into stormwater system

Planning problem: no suitable site for abattoir, rezoning of land involved

Education needed: do not use stormwater system for disposal of other waste streams

Land steeply sloped towards river: education needed to minimize depositing of faecal waste on open ground

Negotiations needed with the Municipality so that other waste streams are properly catered for

The stormwater system is the only waste stream in Kayamandi that is functioning more or less efficiently. As already mentioned elsewhere, it is being used/abused to stand in for the failure of the sewage and solid waste systems. It has become a way of disposal of excreta collected overnight and household grey water and a dumping system for unwanted material such as car oil and solid waste. Some of this dumping is deliberate but a large proportion of it is unavoidable, due to the lack of functional alternatives.

As with all the other waste systems in Kayamandi, there is vast ignorance as to how such systems operate and what they should be used for. During one of the education campaigns, all the community health workers were equipped with a cut-through model of a pipe with plastic, stones, etc glued to the bottom to explain to the inhabitants how solid waste narrows the lumen of a pipe and causes blockages. The candidate built these models by hand.

Grey Water (Sullage) Waste Stream

The shack dwellings in Kayamandi do not have a water supply on the premises and water is fetched from the nearest communal toilet block or in a few cases from a standpipe next to the road in whatever containers the inhabitants possess. Water containers are mostly open, contributing to contamination at the point of use.

The basins attached to the back walls of the communal toilet blocks are supposed to be used for washing dishes and clothes. Due to ignorance and also to the lack of rubbish bins at the toilet blocks, the basins are often clogged by food waste, etc. Vandalism plays a part in the damage and especially taps are often stolen for their scrap metal value.

Washing of clothes is frequently done on the sidewalks, so is cooking and other activities that result in wastewater. The distance to the supply point and the lack of gullies along the street where grey water can safely be disposed into the sewage system causes almost all of the household wastewater to be deposited into the nearest stormwater drain or just thrown out into the street, thereby draining into the stormwater system eventually.

Dirty water overflows at some point at almost every communal toilet block. The soil underneath the concrete slabs below the washbasins eventually wash away and the concrete caves in. Some of these broken slabs are dangerous to negotiate. One toilet block collapsed in its entirety because the soil underneath was washed away. Even if the concrete slabs are still intact, persons using the basins have to stand in water much of the time.

PROBLEM TREE 5: GREY WATER (sullage) - KAYAMANDI

Household waste water (sullage) reaches the river in great quantities

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Sullage disposed of into stormwater system

No specific, appropriate disposal points for sullage near dwellings

Disposal points only available at public washbasins - too few and too far

Public washing facilities poorly maintained

Not enough washing facilities

Gullies surrounded by a concrete slabs and which are connected to sewage system needed at freestanding taps and at appropriate points near dwellings

No system to report blocked gullies at public washbasins

When the gullies at public washbasins overflow it floods the concrete slab in front of basins - unpleasant to stand in the water

The flooded slabs get undermined and collapsed in places. Not repaired.

The community should be consulted in the placement of new gullies

Community structures that are needed for consultation are not well organized and not always representative of all the inhabitants

4.2.2 The interventions of the DANCED Project

In order to help with the cleaning campaigns and to empower the inhabitants of Kayamandi, teams of artisans were trained under a training scheme of the National Department of Labour as plumbers, painters, carpenters and bricklayers. The project paid for their training. About 10 to 15 persons of both genders were trained for each trade. All members completing their formal courses were issued with proper certificates by the firms subcontracted by the Department of Labour to carry out the training. The idea was that these newly trained artisans will be able to help with repairs during the project and to turn their new-found skills to their own account in their spare time, thereby uplifting the skills base in the community. The teams of trainee artisans repaired the Kayamandi Hall, the toilet blocks (completely rebuilding one block with material supplied by the Municipality), the Strongyard Hall and various other smaller repairs while they were in training. The project supplied the tools and some of the supplies while the Municipality supplied material from their normal budget set aside for maintenance. A few sets of plumbing tools were purchased by the project and kept in safekeeping with the local project manager, Mr Sipho Menziwa. These tools were available to be used after payment of a small deposit and returned to the project manager after use.

After completion of their training, the plumbing team formed a commercial undertaking called Ikamva Lethu Plumbers with the hope that the Municipality will allow them to tender for some of the repair jobs on the toilet blocks in Kayamandi. Unfortunately this proved a vain hope. At first it was contended that the Municipality could only engage contractors who have bank accounts. A savings account was then opened for Ikamva Lethu Plumbers, but this did not bring about any improvement in the stalemate. The community believed that existing repair firms with whom the Municipality has had longstanding business connections were being protected, but there was no way of verifying such suspicions. Unfortunately, the very existence of such suspicions was already harmful to the relations between the community and the Municipality. In the face of the lack of willingness to employ them to help with the upkeep of their own community facilities, the impetus of keeping these teams together is fast being lost. The members are dispersing and it will be difficult to get them together again if they are discouraged from tendering for repairs. This is a good example of the poor relationship between the local community and the Municipality working to the detriment of sanitation and health.

A clean-up campaign to rid the streets of solid waste using school children on the first day of their holidays proved to be a big success. The Municipality undertook to remove the collected bags timeously so that animals could not break the bags open and scatter the contents.

4.3 Community surveys

As was already mentioned there were many attributes of the community of Kayamandi under dispute. This included the number of persons living there and the actual position regarding sanitation facilities. Apart from those disputed aspects, there were many attributes still unknown that would help build a picture of the community for a risk assessment. The exposed population in the case of Kayamandi has never been quantified and described so as to assist in planning both health and sanitation services. Two community surveys were undertaken. The first survey was carried out on its own, but the second survey was designed to coincide with an education campaign visit to each home selected for the survey. The survey was conducted first, followed by an education session.

4.3.1 Aims of the surveys

Survey 1

The community survey undertaken in February 2000 was aimed at serving as a basis for problem analysis in the community and to determine the level of awareness in the community about pollution and the related impacts. Immediately after the survey data were gathered an education session was undertaken for those present in each dwelling.

Survey 2

A second education campaign was launched in July 2001. The survey undertaken immediately afterwards was aimed at assessing the short-term retention of the contents of the education campaign, in order to determine the sanitation situation in the township as well as to verify certain findings of Survey 1.

4.3.2 Methods

Survey 1

A meeting was held between the candidate, Ms Martha Mayembana, Community Health Educator of the Winelands District who often works at Kayamandi Clinic and also lives in the community and Mr Sipho Menziwa, the project leader in Kayamandi, to determine the most urgent information needed for inclusion in the survey questionnaire. There was consensus on the topics (questions) that needed to be probed by means of a survey.

A training manual and questionnaire were drawn up by the candidate that were used during the training of the field workers as well as the field survey (Annexure A and B at the end of this chapter). The questionnaire was designed by the candidate according to the topics agreed on with the community members of the committee and translated into Xhosa by Mr Sipho Menziwa. The training manual was also translated into Xhosa and a copy provided to each field worker. A database was created in Microsoft Access to capture the data. This database had checks specified in all the data fields to reject characters typed into the field that were not specified for that field. This was done to verify data input.

The Steering Committee met to discuss the requirements for the volunteer field workers. It was decided that these volunteers had to be adult, unemployed and able to read and write English well. For some zones in Kayamandi older persons were thought to be more desirable. Since the survey included issues like washing, cleaning, children's health, etc. it was decided to use more women than men, but both genders were represented. After the survey, the field workers were paid a gratuity of R5 per dwelling that was not announced before they started. Spot checks on dwellings were carried out out by the project manager to ensure that field workers did indeed visit their allotted dwellings.

A strictly scientific systematic sampling procedure with a random starting point was employed to select the dwellings included in the survey. The size of the sample was 10% of all the dwellings in Kayamandi, excluding the hostels. The most senior person present in the dwelling at the time of the visit was asked to provide the information for the survey, but the education session was addressed at all present who were willing to participate. The survey workers were instructed to spin a coin and start at every street or back alley without exception, either with the first or the second dwelling (depending on the coin flip) and then to proceed along every street by taking every tenth dwelling thereafter. In this way a 'net' of dwellings covering the township were selected which represented a proportional 10% sample of all the dwellings in the township. For the purpose of this survey the hostels were excluded as their sanitation situation differs considerably from the rest of the township and local political situation at the time made such a move unavoidable. The hostels do not comprise a large proportion of the population of Kayamandi since there are relatively few.

Most survey workers reported very good co-operation from the inhabitants who took part. Very few people declined to participate. An enquiry among the survey workers revealed about three households who declined to participate.

A problem arose during the first day of the fieldwork, when the male head of a household refused permission for a male survey worker to talk to his wife without another woman present. After that, the fieldworkers were paired off in teams of two persons, and all men were allocated a female teammate. Fieldworkers were requested not to visit homes on their own.

In Survey 1 questions were asked about the recent illnesses suffered by the inhabitants of the dwelling. This proved to be a particularly difficult exercise because the mostly illiterate participants reported illnesses not easily classifiable under Western medical diagnoses. The fieldworkers wrote down all information that could not be readily ticked off on the list provided, and Mrs Mayembana afterwards noted down the nearest diagnosis to the information provided. Because this was not deemed to be accurate enough, this information was not analysed quantitatively. A note was made of the most important illnesses only. The same fate befell our attempts to enquire tactfully about any deaths that may have occurred in order to see if mortality rates in the community could be estimated. This is always a sensitive subject to ask about, especially in a black community, and far too few deaths were noted on the forms to be in the realms of possibility. So these data were not analysed in detail either.

Survey 2

The second survey was carried out in July 2001, after the first education campaign, in order to check up on some of the data obtained in Survey 1. For instance, the skew age distribution leaning so heavily towards the younger ages that was produced by the first survey, needed confirmation. The education campaign was a door-to-door one and no dwellings were omitted. This would have produced a number of questionnaires far in excess of what the project could handle. It was therefore decided to target certain zones of Kayamandi in their entirety. The Steering Committee requested that the poorer zones should preferentially be included as there were many questions why only certain houses were included in the Survey 1 sample and those persons expressed a wish not to be excluded in future. Thus Zones A, L, K and the hostels in their entirety were included in the survey.

The questionnaires (one for before the education session and one for a week later) was drawn up by the candidate in the same manner as for Survey 1 and translated into Xhosa (see Annexures B, D and E). The same training procedure was followed with the fieldworkers, except that no new training manual was drawn up since the old one (Annexure A) could still suffice. A new pamphlet was designed to accommodate the extra sanitation messages (Annexure F) and those were handed out to each dwelling.

The survey carried out in two parts ('before' and 'after') at two visits to each dwelling a week apart. The first questionnaire was completed at the start of the first visit, before the education session commenced.

4.3.3 Results of the surveys and the community's perception of pollution

<u>Results of Survey 1</u>

As always with surveys of this size, not all information could be obtained for every person whose data were captured. There were a small number of persons for whom information was not available at each question because the person in the house answering the questions did not know, or because the person him- or herself did not know. Age was one such variable that not all persons could answer, a few even about themselves. For instance the age was noted for 2 148 persons out of the 2 196 reported in the survey (97.8%) and the gender was noted for 2 110 out of 2 196 persons (96.1%).

A total of 528 dwellings were surveyed and the total number of inhabitants recorded as living in those dwellings was 2 196 persons. Multiplying the number obtained by a factor of 10 yielded an estimate of **at least 22 000 persons** living in Kayamandi, excluding the hostel dwellers. If an estimated number of hostel dwellers is added, the total population is nearer the 25 000 mark. That is considerably more than the previous estimations, clearly pointing to the reasons why the waste systems are so overloaded.

<u>Age and gender distribution:</u> The age distribution is depicted in Fig. 4.1. The proportion of males was slightly lower than expected (49%) or 1 034 males to 1 076 females, given that urbanisation due to economic migration seems to favour young males. The mean age of the participants was 23.392 years with a standard deviation of 14.996 years. The median age is

even lower at 22 years. There was a striking absence of older people among the survey participants. As can be seen from Fig. 4.2, there is a large preponderance of children in the survey, to the extent that a third of the participants were under the age of 15 years. These results point to an epidemiologically young population with concomitant serious socioeconomic implications.

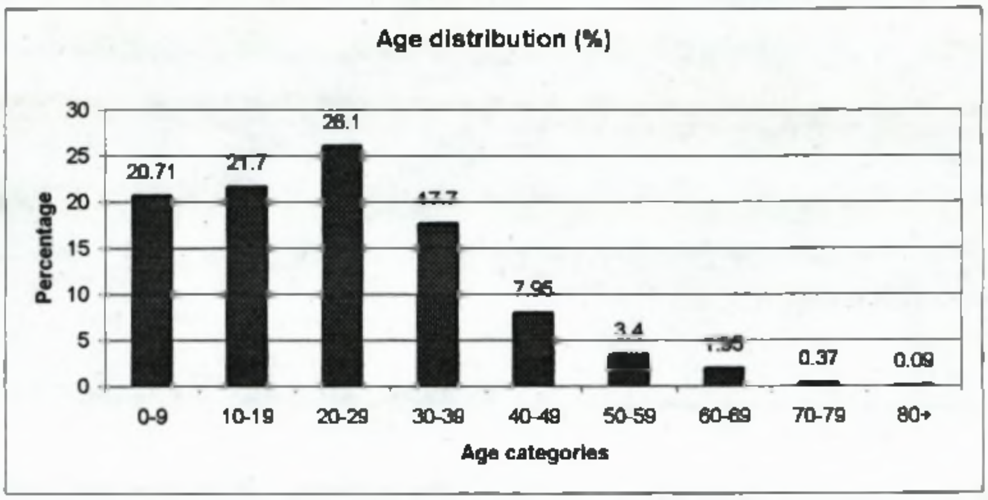


Fig 4.1 Proportional age distribution of the inhabitants of Kayamandi taking part in Survey 1 for whom ages were recorded (N= 2 148)

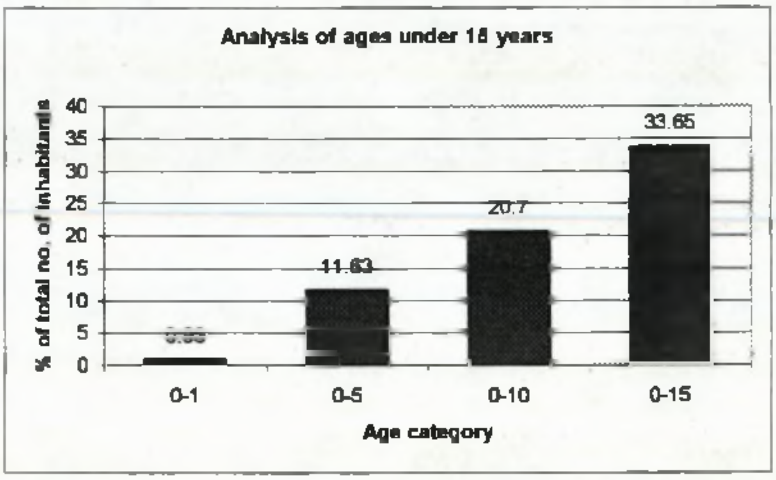


Fig 4.2 Analysis of the proportions of children of various ages taking part in Survey 1, expressed as percentages of the total number of persons with known ages taking part (N = 2 148)

One of the reasons given by community members for the under-representation of older persons was that when the major influx of people into Kayamandi happened about 5 to 10 years ago, the aged from the rural areas (mainly the Eastern Cape) did not accompany the younger family members who relocated to seek better economic opportunities. Also, under conditions of poverty, aged members of the family often go back to the place of their birth when they are no longer able to provide for themselves, especially to the Eastern Cape, where rural members of the extended family then look after them. The lower life expectancy of poverty-stricken communities due to the ravages of disease and malnutrition could also have contributed to the smaller number of aged.

The dependency ratio (DR) is an epidemiological measure describing the relation between the potentially self-supporting portion of the population and the dependent portions of the population at the extremes of age. The period of economic self-sufficiency has been variously defined, but the usual proportions calculated are between the ages of 15 and 65, 18 and 65, or 20 and 60 years of age. The dependent proportions are then those under lower age limit plus those over the upper age limit expressed as a percentage of the theoretically economically self-sufficient in-between. For the Kayamandi population, the DRs for the various definitions are:

For those economically self-sufficient between 15 and 65: 52.6%

For those economically self-sufficient between 18 and 65: 62.1%

For those economically self-sufficient between 20 and 60: 81.6%

Even at the most lenient definition resulting in the smallest of numbers of dependent persons, Kayamandi has a DR above 50%. At the widest age range of dependency (usually used by affluent First World nations) the DR is 81.6%, a hugely elevated figure with serious socio-economic implications for the future. These ratios signify that for any given definition the number of economically dependent persons in that community amount to more than half of those members who are of an age where they are theoretically able to earn a living and look after others. At the highest DR the number of dependent persons almost approach the number of those that are of economically active ages. The dependent proportion of Kayamandi moreover comprises almost entirely of persons below 20 years of age.

Income: No information was supplied in 80 cases. The poverty of the community is reflected in the fact that of those who did reveal the total income of the household, 49% reported earning less than R500 per month, while 37% reported total earnings between R500 and R1000. A further 10% earn between R1000 and R2000 and 3% earn above R2000. As income is not always openly reported and household income can fluctuate considerably, especially in poor communities, these figures probably reflect the basic minimum income.

Kind of dwelling: At the time of Survey 1, there were two main kinds of housing in Kayamandi: 18% of the dwellings in the survey were brick houses and 81% were shacks. Only two dwellings were described as "flats".

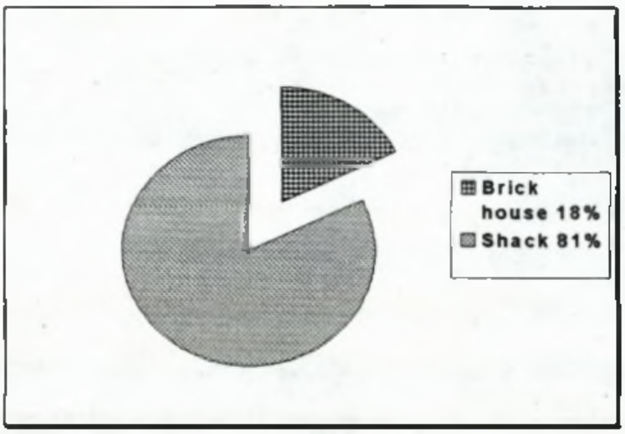


Fig. 4.3 Kind of dwelling

Toilet facilities: 18% of dwellings (the brick houses) had toilets inside the houses, 12% had toilets outside the houses but directly next door (mainly those shacks situated directly next to toilet facilities), inhabitants of 64% of dwellings used communal facilities away from the dwelling and 34 dwellings (6%) reported no toilet available within easy walking distance. Those without toilets reported using the bushes, surrounding fields and in some cases other people's toilets (when available).

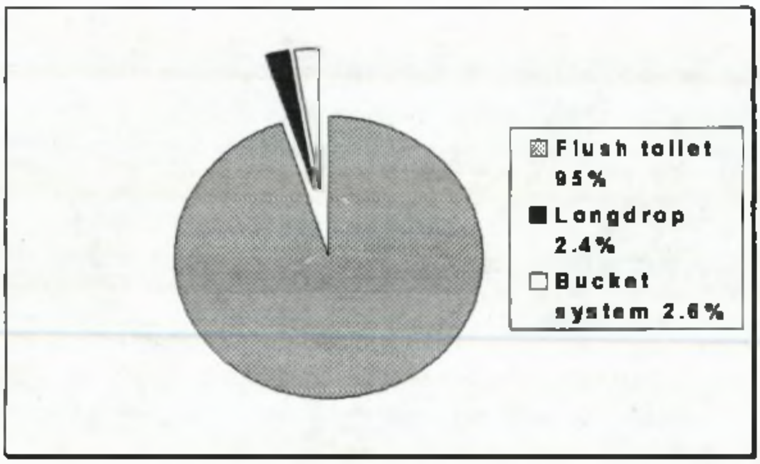


Fig. 4.4 Type of toilet available

Participants from a total of 212 dwellings said that they sometimes found themselves in a situation that no toilet was available. Disposal of excreta when there was no toilet available was as follows: 4% said they disposed of such waste in the street; 83% directly into the stormwater drain and 3% chose "Other" (specified mostly as "bush" or "field").

After excluding a few obviously erroneous estimations of distance, it was calculated that the mean number of paces to the toilet for those who do not have a toilet inside their dwellings was 67 paces.

Of all the toilets available, 95% were reported to be of the flush type. Only 2.4% were reported to be longdrop toilets and 2.6% to be of the bucket system. Neither of these latter two types of toilets exists in Kayamandi according to the Municipality, so the persons who gave these answers may have been thinking of a toilet at work or of the buckets they use overnight. Regarding the cleanliness of the toilets, 44% said that the shared toilets were clean (not always borne out by visual inspection!), 27% said that shared toilets were in an acceptable state and 29% said that they were dirty. The functioning or state of repair was reflected by 46% who said that toilets were often broken/not working. Thirty-six percent of the respondents said that they did not know who to tell if a toilet or drain is blocked or overflowing or were not sure. Ninety percent said that there were facilities nearby to wash their hands after using the toilet. No question was asked about actual hand-washing as experience in similar situations shows the answers almost always to be overestimated.

Washing and other water use: There is a tap with clean water available inside the house for 17.7% of the respondents (those with brick houses), on the property or next to the dwelling for 5.7%, while for 76.6% there was no tap nearby. After excluding a few blatantly erroneous estimations of distance, it was calculated that the mean number of paces to the tap for those who do not have a tap inside their dwellings was 70 paces.

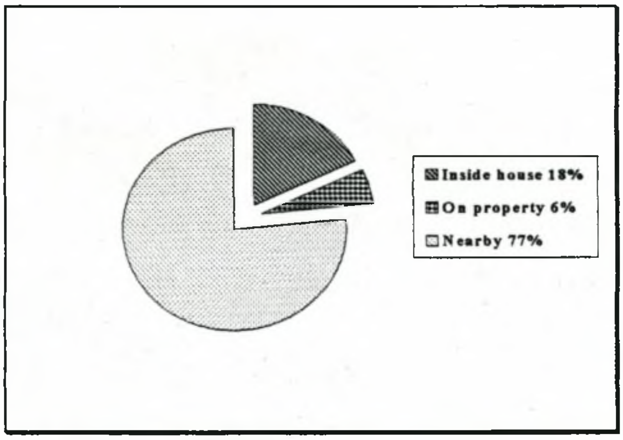


Fig. 4.5 Availability of tap with clean water

The communal facilities are used for washing of clothes by 46%, while 10% reported using a basin and 17.8% a bath (place not specified). The rest said they used own facilities inside the house.

For the shack dwellers only, 86.4% said that they disposed of wash water into the drain - both stormwater and sewerage drains. A few did not specify, but the drains involved were mainly stormwater drain inlets in the streets. A further 12.2% said that they disposed of wash water (grey water) in the street or on the ground.

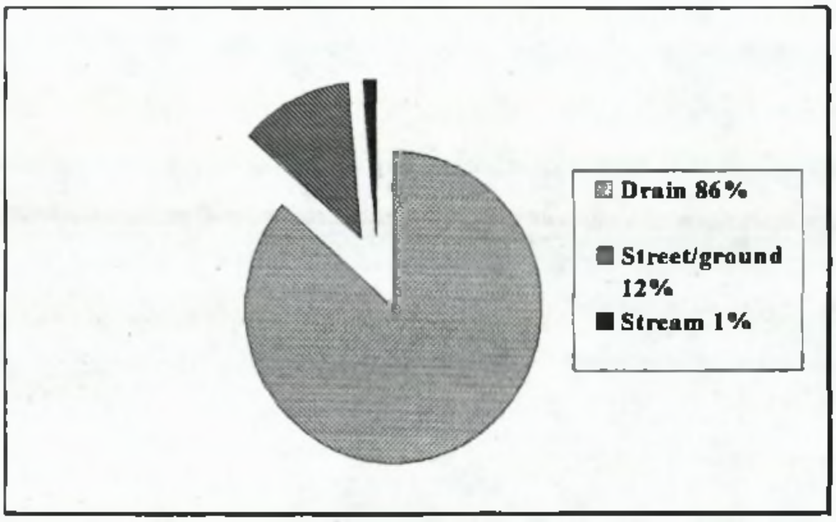


Fig. 4.6 What happens to household wash water? (shack dwellers only)

Solid waste: The following answers were obtained to the question: *"Where does the household put its rubbish?"*

Where does the household put rubbish?	Shack dwellers only	Total survey
In rubbish bin inside house	9.1%	20.4%
In skip outside on street	78.9%	67.3%
On street/open space/ground	5%	5.1%
Other (mostly black plastic bags)	6.9%	7.2%

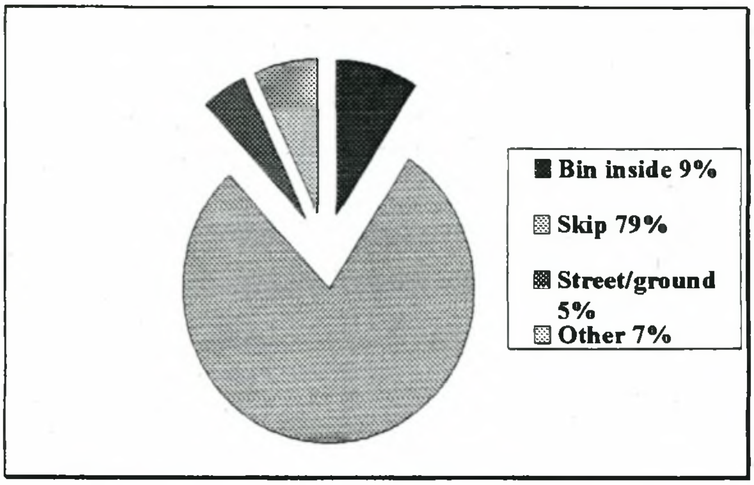


Fig. 4.7 Where does household put its rubbish? (shack dwellers only)

To the question *"Are there enough skips?"* the following answers were obtained:

Enough skips?	**Shack dwellers only**	**Total survey**
Yes	19.3%	19.1%
No	77.1%	76.1%
Unsure	3.6%	4.8%

(No information provided in 13 cases for shacks and 21 cases for total group)

The question *"Why do you think do people throw their rubbish on the ground instead of in the skip?"* yielded the following answers (in order of frequency):

1. Skips are always full / not enough skips / skips not emptied / lack of facilities
2. People are careless (don't care)
3. Don't know what to do / lack of knowledge

For the shack dwellers only the followings answers were obtained when asked *"Do you know where to report it when the skip is full?"* (No information provided in 32 cases)

1. Don't know: 47.2%
2. Municipality: 33.3%
3. Zone Committee / Committee: 3%
4. Yes: 16.4%

How far do the inhabitants have to walk to get to the nearest skip? After excluding a few blatantly erroneous estimations of distance, it was calculated that the mean number of paces to the skip for the shack dwellers was 65.6 paces.

In summary, for the shack dwellers, the distances (in paces) at which important sanitary points were available are as follows:

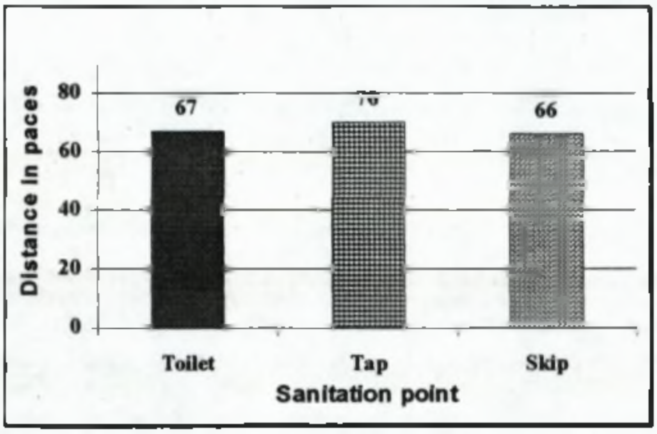


Fig. 4.8 Distance to important sanitation point
A few outlying points excluded. Shack dwellers only

Environmental awareness: Only 13% reported having some sort of garden. It was heartening to see that 95.3% of all participants thought that a clean environment is important while only 3.7% said no and 1% was unsure. Equally encouraging was the 90.2% of participants who said that they were aware that one could get ill from dirt and rubbish in the street and environment.

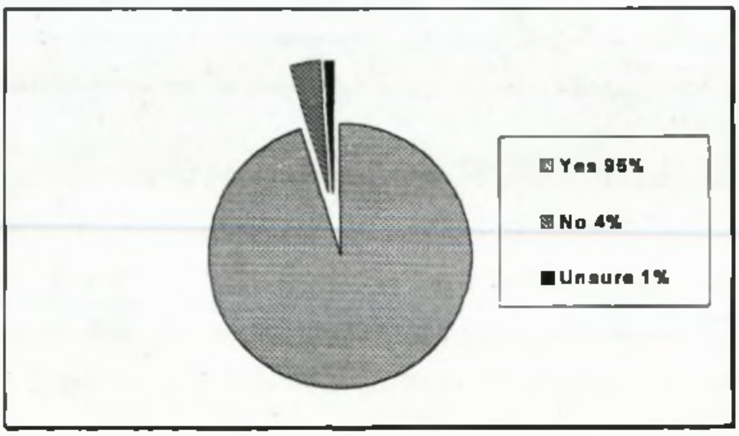


Fig. 4.9 Is a clean environment important?

Medical services, illness, and loss of life: Only 29 deaths over the past year were reported to the fieldworkers, which translates into a mortality rate of 1 320 per 100 000 of the population per year which is a low figure given the circumstances in the settlement. This is a sensitive subject to broach in a black community and most probably an underestimation. This was also the opinion of the fieldworkers. Also, some of the persons present in the dwelling at the time of the survey did not know this information.

By far the most often mentioned illnesses were TB and diarrhoea (especially in children) and skin conditions, followed by childhood infections like chickenpox, etc. From the spoken answers it seemed that many respondents experienced diarrhoea so often, especially amongst the children, that they did not single it out as a disease to be mentioned specially. It has rather become a way of life according to the fieldworkers. Respiratory diseases were also reported very frequently. It should again be mentioned here that some of the illnesses reported by the participants to the fieldworkers were not recognizable in the traditional Western classification of diseases. It may thus be that some diseases were under-reported or not reported at all. The most outstanding feature of the section on reporting of diseases was the fact that children were reported to be "ill often".

Most important sanitary problems: The following were stated most often as the most important sanitary problems by the survey workers.

1. There is an urgent need for more toilets, skips and taps.
2. Poor servicing of sanitation facilities are experienced.The skips are often full, emptying once a week is too little.
4. Drains overflow on a regular basis and are not repaired quickly - not enough inspection.
5. Inspection by municipal officials are mostly carried out in the better parts of Kayamandi.
6. Inhabitants find it very difficult to inform Municipality of blockages and breakages.
7. Children play in the dirt and drain water outside and around the overflowing skips.
8. More rubbish bins are needed in the streets.

General Comments: Under general comments the overwhelming majority of respondents reported that there was an urgent need for better houses, own toilets or at least more toilets, more taps and more skips. Many also mentioned that various authorities (the municipality, the government, the Reconstruction and Development programme or the mythical "they") "should come and clean the place up". The need for other facilities mentioned under general comments, but which did not constitute part of the DANCED study, were a community centre, playgrounds, shopping centre, automated teller machines, swimming pool, and an old age home.

The many instances where inhabitants also said that the people of Kayamandi should keep their own community clean by being more responsible were very encouraging indeed. It was said that people should take care of their lives and be taught how to do this. The wish for more education, including such basic things as sanitation and how to avoid pollution and illness was very clear and should not be wasted by neglecting it. Another theme that emerged was that people should also clean up after themselves and that rubbish is not only the Municipality's problem. From this section is can be seen that there seem to be an awareness of social and community responsibility emerging and that bonding into a community is slowly taking place. It was stated many times that people wanted to be proud of Kayamandi.

Results of Survey 2

The second survey was carried out in July 2001. It formed part of an education campaign for the whole of Kayamandi. There were two questionnaires - before and a week after the education session.

In total 1 027 dwellings were included in Survey 2, with 3 568 persons living in these dwellings. The poverty of these zones can be seen from the distribution of type of dwelling (in contrast to the distribution for the whole Kayamandi found in Survey 1, repeated here for comparative purposes). Note that the hostel accommodation is in most cases of even lower quality than the shacks.

	Survey 2		Survey 1	
Type of dwelling	**No. of responses** (dwellings)	**%**	**No. of responses** (dwellings)	**%**
Brick house	2	0.2%	93	17.7%
Hostel room	415	40.4%	2	0.4%
Flat	1	0.1%	2	0.4%
Shack	609	59.3%	428	81.5%
TOTAL	1027	100%	525	100%

The mean age for the total group in Survey 2 was 26.02 years with a standard deviation of 14.64 years and a median of 26 years. A comparison of the age distributions between Survey 1 and Survey 2 is depicted in Fig. 4.10.

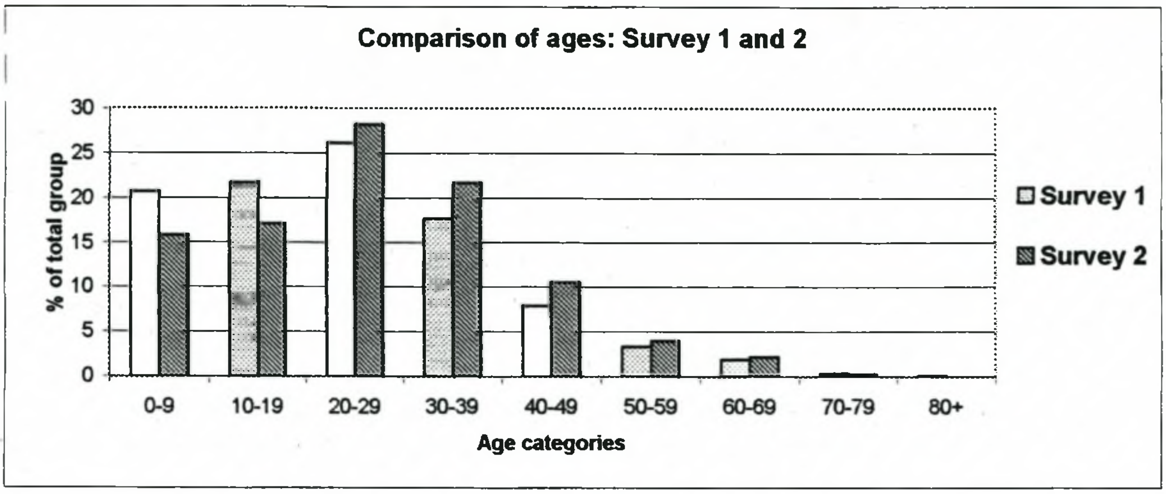


Fig. 4.10 Comparison of ages of total group for Survey 1 (February 2000) and Survey 2 (July 2001)

Of those for whom the gender was reported (99.6%), there were 1 604 females (45.1) and 1 949 males (54.9%). This is more male orientated than the 49%: 51% ratio found in Survey 1 for Kayamandi as a whole.

The most important finding from the age data obtained in Survey 2 was that it confirmed the general distribution obtained in Survey 1. There is definite corroboration for the identification of an epidemiologically "young" population, but with a proportion of aged far below that usually found in even an epidemiologically young population.

The toilet available to persons living in the dwellings were:

Toilet available	**Survey 2**	**Survey 1**
Toilet inside the house	1.37%	17.8%
Toilet outside the house, but on the same property	0.98%	12.5%
Communal toilet away from the dwelling	84.16%	63.3%
No toilet available within easy walking distance	13.5%	6.4%

It can be seen that the zones participating in Survey 2 were worse off than Kayamandi as a whole.

For those dwellings whose inhabitants had to share a communal toilet with other families, they reported on how clean the toilet was:

State of the toilet	Survey 2	Survey 1
Clean	67.5%	43.9%
Acceptable	14.8%	27.3%
Dirty	17.7%	28.8%

Surprisingly, in this instance the inhabitants questioned in Survey 2 found their toilet in a clean state more often than reported for Kayamandi as a whole. This was not borne out by inspection of the actual toilets, so one could conclude that they were willing or forced to accept lower standards of cleanliness.

In contrast, the following numbers reported the toilet as often broken or not working:

Toilet often broken?	Survey 2	Survey 1
Yes	55%	46%
No	40.7%	40.2%
Unsure	4.2%	13.8%

This seemed to contradict the answer obtained for the previous question regarding the cleanliness of the toilets.

The following number of participants reported on whether they knew who to tell if there was a drain blocked or overflowing.

Who to inform of blockages and breakages	Survey 2	Survey 1
Yes	37.3%	63.9%
No	60%	24.7%
Unsure	3.16%	11.4%

The following answers were obtained on the question on who the inhabitants would tell if there was a drain blocked or overflowing.

Will tell Sipho	21.1%
Do not know who to tell	68.7%
Tell the Municipality	7.9%
Have no toilet	2.27%

Mr Sipho Menziwa was the project manager in Kayamandi and he undertook to report all breakages and blockages. He kept a log of the complaints and followed up to see if a response resulted in repairs. He was thus the right person to report to.

The number of participants reporting whether there were facilities nearby to wash their hands after using the toilet.

Place to wash hands?	**Survey 2**	**Survey 1**
Yes	92.1%	90.1%
No	7.56%	8.9%
Unsure	0.3%	1%

The answers on both surveys were very much the same.

The following questions were specifically asked before the education session to ascertain the level of knowledge before the session started.

One of the points in the education session was that solid waste should not be thrown into the toilet. Therefore the participants were asked specifically about what will happen if rubbish was thrown into the toilet.

What will happen?	**%**
Nothing	1.01%
It will block the toilet and the pipes	92.86%
Don't know	6.1%

One can criticize the construction of this question inasmuch as it did not contain any "red herring" answer options. Such a procedure was considered, but it was found that the average attention span of the respondents was not such that a long list of options could be retained (very few of them could read). The red herring option also confused the fieldworkers who found the concept difficult to grasp and therefore the simplest answer option construction was chosen. It did have the effect though of channeling many answers into the most logical middle option, which happened to be the correct answer. It is debatable whether this is a true reflection of knowledge. It would be more constructive to look at the fate of the persons answering No or Don't Know after the education session.

The following three questions were all aimed at establishing baseline knowledge of the relationship between dirt and pollution and illness before education efforts were undertaken.

Can you get ill from not washing your hands after you used the toilet?

Yes	95%
No	1.1%
Unsure	3.4%

Do the people living in the house think that a clean toilet is important?

Yes	97.2%
No	0.9%
Unsure	1.9%

Can you get ill from the dirt and rubbish in the street and environment?

	Survey 2	**Survey 1**
Yes	96.5%	90.2%
No	1.1%	8.5%
Unsure	2.4%	1.4%

Although one must make allowances for obsequiousness bias in these responses, it nevertheless appears that knowledge of some basic aspects of hygiene was already high in this population. It remains an open question how much of this knowledge translates into lifestyle action. Observations by the fieldworkers, experience by Mrs Mayembana, the Community Health Educator, as well as my own observations all point to a poor relationship between professed knowledge and everyday sanitation behaviour in this population.

The matter of illness and especially diarrhoea was highlighted in the comments received on Survey 1. This settlement receives clean water from the main municipal reticulation system and for most of the inhabitants their contact with the river water is limited. The study concentrated on the contribution to the pollution of the river from Kayamandi, and not on any water-washed conditions that may arise from contact with river water. Thus, only a specific enquiry regarding the occurrence of diarrhoea was therefore added to the questionnaire. The results were disquieting.

The fieldworkers were extensively couched during the training sessions about the definition of diarrhoea. In keeping with the way the Health Systems Trust gathers diarrhoea data in impoverished areas, a case of diarrhoea was formally defined as 3 or more watery stools in 24 hours, but any episode and/or treated as diarrhoea after an interview with the adult living with the child was also counted.

Has any person living in the house had diarrhoea ***in the last week?***

	No. of dwellings	%
Yes	107	10.7%
No	882	88.4%
Unsure	9	0.9%

This survey was carried out in the middle of winter. Usually the prevalence of diarrhoea is at a low point during this period. A prevalence of 10.7% of dwellings affected by diarrhoea indicates a fairly widespread occurrence.

Has any person living in the house had diarrhoea ***in the last month?***

	No. of dwellings	%
Yes	132	13.1%
No	864	86.1%
Unsure	8	0.8%

A week later the inhabitants were asked: Has any person living in the house had diarrhoea in the last week since they were last visited (new cases).

Has any person living in the house had diarrhoea ***since I last visited you?***

	No. of dwellings	%
Yes	38	3.97%
No	917	95.9%
Unsure	1	0.1%

This provided 38 more dwellings with one or more case. This gives at least 170 dwellings affected by diarrhoea in the matter of 5 weeks or 16.9% of the dwellings where one or more cases of diarrhoea occurred.

The total number of cases of diarrhoea was 183 cases out of 3 568 people participating in Survey 2, or a prevalence rate of 5 130 cases per 100 000 of the population. This is high, especially when keeping in mind that the survey was done at the height of one of the wettest winters for decades. The surroundings were washed as clean as it would get and food spoilage was down because of the cold. One can almost view this prevalence rate as the "baseline" for diarrhoea in the township.

The gender distribution of the diarrhoea cases was as follows: there were 107 females (59%) and 76 males (41%), in total 183 cases for Survey 2.

The fieldworkers were required to ask as well as check physically whether the educational pamphlet handed out at the first round visit was still available. The following is the result of that check:

	No. of dwellings	%
Yes	918	97%
No	28	3%

This was a remarkable number of dwellings still keeping the leaflet after the first visit, especially since many of the persons cannot read.

Do you know who to tell if there is a drain blocked or overflowing?

Know who to inform of blockages and breakages	Before education	After education
Yes	37.3%	96.6%
No	60%	2.9%
Unsure	3.16%	0.5%

This information indicates a large positive improvement in the knowledge of who to report blockages and breakages to.

The following answers were obtained on the question on who the inhabitants would tell if there was a drain blocked or overflowing.

This was the response on the first round (the correct answer is Sipho = Mr Sipho Menziwa):

Will tell Sipho	21.1%
Do not know who to tell	68.7%
Tell the Municipality	7.9%
Have no toilet	2.27%

After the education session:

Will tell Sipho	96%
All other responses	4%

This was a significant improvement in the knowledge of where to take complaints regarding breakages and blockages.

What will happen if rubbish is thrown into the toilet?

	Before education	After education
Nothing	1%	0.941%
It will block the toilet and the pipes	92.8%	99%
Don't know	6.2%	0.31%

Even though knowledge was already very good, it improved even further.

The following set of questions were directly taken from the contents of the education session and was asked before and one week after the education session in order to ascertain the short-term retention of the messages in the education campaign.

Can you get ill if you do not wash your hands after you used the toilet?

	Before education	After education
Yes	95.5%	99.5%
No	1.1%	0.4%
Unsure	3.4%	0.1%

Do the people living in the house think that a clean toilet is important?

	Before education	After education
Yes	97.2%	99.7%
No	0.9%	0.3%
Unsure	1.9%	0%

Can you get ill from the dirt and rubbish in the street and environment?

	Before education	After education
Yes	96.5%	99.3%
No	1.1%	0.52%
Unsure	2.4%	0.21%

Even though the level of knowledge of proper sanitation behaviour was already high, it improved even further. It was mainly the persons answering No or Unsure (the categories of answers denoting ignorance) whose knowledge improved. This improvement was only measured on a short-term memory basis (one week between education and re-testing) since the requirements of the DANCED project did not allow any longer timeframe. However, no long-term retention is possible without showing short-term retention to start with. So this was deemed a promising first step in educating the inhabitants about safer sanitation habits.

4.3.4 Conclusions from the surveys

There are some important findings arising from the demographic survey of Kayamandi:

The number of people living in the township is considerably higher than the official estimates, greatly exacerbating the conditions of overcrowding and putting even more pressure on sanitation services.

The age distribution is that of a typical "epidemiologically young" population, but there is a dearth of old persons even greater than usually encountered. This causes a lack of the counter-balancing effect of the older generations in any society. Traditionally in poorer communities in South Africa, the older generations, especially the women, are the child minders while the parents work. This ability of the extended family to cope with child care has been eroded and in the post-AIDS era will result in even more unsupervised children in this community than at present. The dependency ratio is very unfavourable which points to further economic hardships and an inability to care for the economically dependent in the community. Social services should be geared to cope with this escalating problem. Very little evidence of active planning on this score is evident in Kayamandi.

The predominance of poor quality housing (80% shack type dwellings) is often mentioned by local officials in discussions on the problems in Kayamandi. According to the surveys and meetings with the community, the inhabitants see the ablution facilities and waste disposal systems as much bigger problems affecting the quality of their every-day lives. There are far too few ablution blocks with far to few individual toilets, taps and basins to serve the number of people. Unfortunately, due to the nature of the soil and the topography, waterborne sewage was the only feasible option. This system is very vulnerable to breakdowns, as is shown in the results as well as the pollution levels in the river. Maintenance of waterborne systems should form a bigger portion of the budget than for VIP type systems, not less. The maintenance of the present sanitation system in Kayamandi is unacceptably poor and under-resourced.

The solid waste removal in Kayamandi is poorly managed, very poorly supervised and under-resourced. The members of the Steering Committee witnessed the fact that the sanitation workers manning the rubbish removal trucks only worked until midday, thereby halving the amount of work done. This partly explains the dirty state of the streets in Kayamandi and the large number of stormwater drains blocked up by solid waste.

There are important structural defects in the planning of services to Kayamandi. There are no points where household sullage could be safely disposed of into the sewage system except at the toilet blocks. There are no gullies to receive dirty water and therefore almost all household waste water produced in the shacks are disposed of in the streets or directly into the stormwater drains. Suitable gullies at convenient distances that are connected to the sewage system could greatly alleviate this problem. This has been suggested to the local authority some years ago already, but to date no discussion regarding this suggestion has even taken place.

Most of the inhabitants experience considerable difficulty in reporting overflowing drains or blocked toilets. There is extensive poverty in Kayamandi and the cost of a phone call from one of the few public phones is as much as half a loaf of bread. The only alternative is to walk to the municipal offices in the central business district of Stellenbosch - at least 2.5 km away. The response of the municipal maintenance crews to the few calls that the inhabitants managed to make, were reported by the project manager to be of very variable quality. They sometimes could not find the site of the problem and departed without repairing the problem. They sometimes did not even arrive in Kayamandi. There seemed to be no supervision on how the jobs were done, therefore this lack of delivery of services was not detected. This is borne out by the maintenance logbook kept by Mr Sipho Menziwa for the duration of the project.

The results of education campaigns were encouraging. Even though a high level of awareness of some basic sanitation behaviour already existed, the increase in knowledge of what to do about systems failures like blocked drains and broken toilets was encouraging.

The vast majority of inhabitants kept the pamphlets and even three years later the posters are still up in the toilet blocks. It was gratifying to see how much the combined programme of maintenance and education reduced the pollution levels in the Plankenbrug River (data presented in Chapter 5). It must however, be pointed out here that the individual contributions of education vs. maintenance cannot be separated. Indeed, they should not be separated because only with such a total approach will it be possible to make an appreciable difference to the cleanliness of the environment and the health of the community.

Contrary to the often expressed opinion (even in the local weekly newspaper and in a letter from the municipality), the inhabitants of Kayamandi do want a clean and healthy environment. They also expressed a wish to learn more about sanitation and keeping themselves and their children safe and healthy. It was clear however, that they did not possess the knowledge of what causes blockages, how flush toilets should be treated so that they last longer, etc. This is a great need and should be addressed both by the local educational institutions as well as the more affluent portions of the community. The provincial and national resources for education and sanitation in dense settlements should be tapped to help alleviate the dire need for improved sanitation in the township.

Diarrhoea can be seen as in indicator condition of poor sanitation, especially if it is present on an ongoing basis over a considerable period of time. The levels of diarrhoea reported during the winter are a serious concern and indicative of sanitation and environmentally related problems. This situation contributes to a heavy case load of patients needing health services, some of which could have been avoided with better sanitation. The impact on the economic activities of the area is considerable. The DANCED project also conducted a study on the economic impacts of pollution in Stellenbosch. The results have not been formally published yet and the following conclusions are quoted with permission (personal communication W. Kloppers, Assistant Director, Dept of Water Affairs and Forestry, Western Cape, 23 October 2002).

Costs of diarrhoea in Stellenbosch (2001):

<u>Direct costs:</u>		
Total costs, hospital	R614 237	19%
Total costs, clinics	R190 687	6%
<u>Indirect costs:</u>		
Lost income	R1 977 987	63%
Self-treatment	R368 641	12%
Total costs	**R3 151 544**	**100%**

These data do not include worm infestations, or any other pollution related diseases.

Of the total costs of R3.1 million, 7% was financed by the local government, which is running the clinics. The provincial government, which is responsible for the running of the hospital, financed 32%. The population affected by diarrhoea, the biggest majority of which resides in Kayamandi, bore 61% of the costs. These were either as lost income due to illness or due to expenses directly related to self-treatment. The report ends (p. 27) with the following: "Stellenbosch also bears significant costs associated with diarrhoea, most of which can be attributed to the pollution in the informal areas in Kayamandi. The bulk of these costs are borne by the community themselves, while the remainder comes from government sources. Once again this makes a compelling argument to address the pollution problems associated with the communal ("bus") toilet system.

The DANCED research programme has identified what they called the capacity gap within local government in South Africa. This is defined as the difference between the capacity required to operate and maintain services in the dense settlements and the capacity available within the local authority. Local authorities with a significant capacity gap are less likely to be able to address problems within their areas and are more likely to show reduced spending on operations and maintenance, which lead to increased pollution. Kayamandi has a waterborne sewage system, which is classified as a high technology level of services. The problems associated with the capacity gap are exacerbated in dense settlements with high technology sanitation services, since these are most vulnerable to service breakdowns.

4.3.5 Recommendations regarding education campaigns and opinions from the community

A mechanism for the implementation of awareness campaigns has been created and should be kept alive at all costs. It should not be the responsibility of researchers with other employment responsibilities to look for funds to continue with this essential action in order to lessen the dangers of pollution in this environment. The local authority should take its responsibilities seriously and start implementing a series of remedial actions in Kayamandi and in and around the Plankenbrug River.

Those actions include:

- Better planning and much more resources for maintenance and servicing of the sanitation system in Kayamandi as well as in the rest of the town, since Kayamandi is by no means the only source of pollution in the river.

- Establishing a reporting system or contact person for service failures within Kayamandi. Such a contact person should greatly improve the lines of communication between the community and the Municipality. There is already an existing office of the Municipality in Kayamandi that is standing empty at this point in time.

- Serious efforts at rehabilitation of the river, removal of alien vegetation in a responsible way (not just spraying a few patches of grass with weed killer as at present), removal of litter from the riverbed and the banks.

- Provision for gullies, informal slaughtering places connected to the sewage system, and other such technical interventions to reduce the pollution load reaching the river.

- Improved access to public ablution facilities that includes more toilets and basins. Some form of supervision by members of the Kayamandi community at the toilet blocks will ensure less vandalism. Such a system has already been designed and presented to the local authority but no reaction had been received.

- Improved solid waste removal and many more skips and other rubbish bins to help reduce the load of litter blocking the sewage and stormwater drains as well as to reduce the health hazards associated with rotting rubbish.

- The artisans trained during the project should be encouraged to be much more persistent in their applications for tenders to the municipality to help repair the toilet blocks and blocked drains and to enlist the help of their councillors should they fail.

- The community of Kayamandi, under the leadership of the councillors, church leaders, etc. should mobilise all willing persons to carry the message further that the people of Kayamandi are the only ones who could make a lasting difference to their town.

ANNEXURE A Training manual for field workers

WORKING TOWARDS A CLEAN AND HEALTHY COMMUNITY

SISEBENZELA UCOCEKO NEMPILO KWINDAWO YETHU

Notes to help the Community Health Workers of Kayamandi in the Education Campaign to promote better health and sanitation.

Isuka Kwikayamandi Test Case Steering Committee
July 2001

FIRST VISIT TO HOUSE

1. Please ask permission first to visit the house. Please tell the persons living in the house that this visit is in order for you to explain the Education Campaign to the inhabitants. Please reassure the inhabitants that their participation is entirely voluntary and that they have a choice whether they want to participate. Nothing will happen to them if they refuse. The campaign and the information given are also anonymous and their names will not be taken for any purpose whatsoever.

2. If permission is given, first complete the questionnaire called First Interview. The instructions are on the questionnaire. It is important that you complete the questionnaire before the first education talk, otherwise the results will not be accurate.

3. Please leave a pamphlet at every house you visit. Please ask the persons in the house to show the pamphlet to other inhabitants and explain the contents to them.

4. Please ask the persons living in the house to keep the pamphlet in a safe place so that they can always have the information on it and telephone number to report blockages.

5. You can now begin with your talk, using your poster and the pamphlet.

PAMPHLET PAGE 1

Your poster contains the same words and pictures as is printed on the pamphlet. The words and pictures on the poster are nice and big so that you can hold it up while you explain the various points to the persons present in the house

On the first page of the folded pamphlet is the following:

GCINA IKAYAMANDI ICOCEKILE!
(Let us keep our Kayamandi clean!)

Show this page to the people in the house and also on your poster.

Please explain to the inhabitants that the Education Campaign is trying to reach everybody by visiting the houses and that we are doing this zone by zone.

Please also explain that the people of Kayamandi need to work together to improve their environment and to help keep themselves and their children healthy. We can only do that if everyone plays his or her part. This campaign is aimed to help the people of Kayamandi to keep their toilets clean and working. This will help them to improve their health as well, because diseases will not spread so easily.

PAMPHLET PAGE 2

On the second page of the folded pamphlet is the following:

NCEDA SUKULAHLA INKUNKUMA KWINDLU YANGASESE, IZAKUXINGA
(Please do not throw rubbish in the toilet. It will block.)

Please show the picture on the pamphlet and on your poster to the inhabitants. Explain what will happen if rubbish is thrown into the toilet by using your model of the pipe with the stones at the bottom. Explain that the rubbish stay inside the pipes and make the pipe smaller so that it blocks after a while. Please show the piece of pipe you have with you with the rubbish glued to it so that the persons can see what you mean.

PAMPHLET PAGE 3

On the third page of the folded pamphlet is the following:

NCEDA UKHAPHE ABANTWANA UKUYA KWINDLU YANGASESE. UKUZE BAFUNDE UKUYISEBENZISA NGENDLELA EYIYO.
(Please accompany children to the toilet so that they can learn to use it properly.)

Children need to be showed how to use a toilet properly and how to wash their hands after they have used the toilet. A grown-up person going with them can also prevent them from throwing rubbish into the toilet and letting it block. They should be taught that the toilet is not a thing to play with and that many people need to use it.

PAMPHLET PAGE 4

Please soften the newspaper so that it does not block up the toilet and pipes.
NCEDA HLIKIHLA IPHEPHA UKUZE LINGAXINGISI ITHOBHI NEMIBHOBHO

Newspaper can block the toilet unless it has been softened. One can soften the newspaper by rubbing the paper between one's hands as if you are doing some washing. This will help prevent the toilet from blocking so quickly. Please show the persons in the house how it is done and ask them to remember to do it every time they go to the toilet.

PAMPHLET PAGE 5

NCEDA HLAMBA IZANDLA ZAKHO WAKU GQIBA UKUSEBENZISA INDLU YANGASESE. OKO KUKHUSELA WENA KWIZIFO

(Please wash your hands after you have used the toilet. This is to protect you from illness.)

It is very important that everybody washes their hands after EVERY visit to the toilet. There are tiny germs that the eye cannot see that stay on our hands after we have used the toilet and they can only be washed off. These germs make people (especially children and old people) very ill and we can carry them into our homes if we do not wash our hands. Please ask the persons in the house to wash their hands EVERY TIME.

PAMPHLET PAGE 5

There is now an office at the Administration Building where anybody can report blockages, overflowing pipes or sewers. The address is on the pamphlet. The Project Cleaning Team has now tried to clean and repair the toilets as best as we can. Please ask all the inhabitants for their own sake and for all in Kayamandi, to look after the toilets carefully and not to break them or leave them dirty.

NCEDA XELA IINGXAKI ZENDLU YANGASESE NOXINGO KU:
MR SIPHO MENZIWA
TEL. 889 7323
KAYAMANDI ADMINISTRATION BUILDING

Please report any blockages to:
Mr Sipho Menziwa
Tel 889 7323
Kayamandi Administration Building

SECOND VISIT TO HOUSE

6. Please ask permission first to visit the house. Please tell the persons living in the house that this visit is in order for you to visit them again in connection with the Education Campaign in Kayamandi. Please reassure the inhabitants that their participation is entirely voluntary and that they have a choice whether they want to participate. Nothing will happen to them if they refuse. The campaign and the information given are also anonymous and their names will not be taken for any purpose whatsoever.

7. If permission is given, first complete the questionnaire called Second Interview. The instructions are on the questionnaire. It is important that you complete the questionnaire before your second education talk; otherwise the results will not be accurate.

8. Please check whether the pamphlet you left at the house last time is still there. Please ask the persons in the house again to show the pamphlet to other inhabitants and explain the contents to them.

9. Please ask the persons living in the house to keep the pamphlet in a safe place so that they can always have the information on it and telephone number to report blockages.

10. You can now begin with your talk (same as the first one), using your poster and the pamphlet.

Training regarding diarrhoea done by Mrs Mayembana.

ANNEXURE B Questionnaire Survey February 2000

WORKING TOWARDS A CLEAN AND HEALTHY COMMUNITY

February 2000

This is a study by the Kayamandi Steering Committee to support community efforts to lessen water pollution from informal settlements. It is jointly carried out by the community of Kayamandi, the Dept of Water Affairs and Forestry, the Municipality of Stellenbosch and the Medical Faculty of the University of Stellenbosch at Tygerberg.

It would be a great help to us in our efforts to work for a clean Kayamandi if you could answer a few questions for us. We are not going to ask your name. No information you give us will be attached to your person or the people living with you. We need the information to help plan a cleaner and better Kayamandi. You have the right to refuse to participate, but your help would make this information more accurate for us and would be appreciated.

Interviewer's name:	
Date of interview:	
Time of interview:	
Site address: (whatever is applicable. Only to avoid duplication. This will be kept strictly confidential)	Stand number .... House number .... Street name .... Zone ....

1. General Information and Background

1.1 Please list the following information for all persons living in the dwelling: All gray blocks must be completed for as many persons as there are living in the house.

Number of person	Role in household e.g. mother, child	Age in years (months for babies)	Sex Please mark the correct block (✓)		Who are currently still learners or students? Please mark only the relevant blocks. (✓)	Highest education Level Please write in the education level, like Grade 7, 8	Is the person employed? N=not employed F= full time P=part time. Please mark the correct block (✓)		
1			Male	Female			N	F	P
2			Male	Female			N	F	P
3			Male	Female			N	F	P
4			Male	Female			N	F	P
5			Male	Female			N	F	P
6			Male	Female			N	F	P
7			Male	Female			N	F	P
8			Male	Female			N	F	P
9			Male	Female			N	F	P
10			Male	Female			N	F	P
11			Male	Female			N	F	P
12			Male	Female			N	F	P
13			Male	Female			N	F	P

1.2 What is the total income for the family group living in the dwelling per month? (Complete only if participants are willing. Do not push for an answer.)

Mark the correct one (✓)

Less than R500 per month	
R500 to R1 000 per month	
R1000 to R2000 per month	
More than R2000 per month	

1.2 What is the kind of house/dwelling?

Mark the correct one (✓)

Brick house	
Hostel room	
Flat	
Shack	

2. Toilet facilities

2.1 Where is the toilet that is available to the persons living in the dwelling?

Mark the correct one (✓)

Toilet inside the house	
Toilet outside the house, but on the same property	
Communal toilet away from the dwelling	
No toilet available within easy walking distance	
If no toilet is available, what do the inhabitants use?	

2.1.1 If they do not have a toilet nearby, where do they dispose of the waste?

Please mark ✓=Yes, **X**=No

In the street	
Into the stormwater drain	
Other.	
If "Other", please specify:	

2.1.2 If the toilet is away from the dwelling, how far do the inhabitants have to walk to get to the toilet?

Distance: [   ] paces

2.2 What sort of toilet is it?
Mark the correct one (✓)

Flush toilet	
Longdrop (pit latrine)	
Bucket system	

2.3 If the people living in the house have to share a toilet with other families, how clean is the toilet?
Mark the correct one (✓)

Very clean	
Acceptable	
Dirty	

2.4 Is the toilet often broken or not working?
Mark the correct one (✓)

Yes	
No	
Unsure	

2.5 Do you know who to tell if there is a drain blocked and overflowing?
Mark the correct one (✓)

Yes	
No	
Unsure	

2.5.1 Who would you tell if there is a drain blocked and overflowing?

....

....

....

3. Washing and other water use

3.1 Are their facilities nearby to wash hands after using the toilet?
Mark the correct one (✓)

Yes	
No	
Unsure	

3.2 Is there a tap with clean water available:
Mark the correct one (✓)

Inside the house	
On the property	
Nearby (not on property)	

3.2.1 If the tap is not on the property, how far do they have to walk to get water?

Distance: [ ] paces

3.3 Where do the people living in the house wash their clothes?

....
....
....

3.4 What happens to the wash water?

....
....
....

3.5 When water is used to wash and prepare food, where is the water thrown away?

....
....
....

3.6 Where do the persons living in the house wash themselves?

....
....
....

3.7 What happens to the wash and bath water?

....
....
....

4. Solid waste

4.1 Where do the household put its rubbish?
Please mark ✓=Yes, X=No

In a rubbish bin inside the house	
At the skip outside on the street	
Throw it on the street	
Other	

If "Other", please specify: ....

....

....

4.2 Are there enough skips?
Mark the correct one (✓)

Yes	
No	
Unsure	

4.3 Why do you think do people throw their rubbish on the ground instead of in the skip?

....

....

....

4.4 Do you know where to report it when the skip is full?

....

....

....

5. Environmental awareness

5.1 Does the household have a garden?
Mark the correct one (✓)

Yes	
No	

5.2 Do the inhabitants think that a clean environment is important?
Mark the correct one (✓)

Yes	
No	
Unsure	

5.3 Can you get ill from the dirt and rubbish in the street and environment?
Mark the correct one (✓)

Yes	
No	
Unsure	

6. Medical services, illness and loss of life

6.1 What important or serious illnesses occurred within the past year in the household (illnesses of longer than a week or which needed treatment at the clinic, hospital or doctor)

....
....
....
....
....
....
....
....
....
....
....
....

6.2 Is the person who answers the questions willing to say whether any member of the household died in the last three years? If so, please complete the following:
(ASK THIS QUESTION VERY SENSITIVELY AS EXPLAINED DURING TRAINING):

Number Of person who died	**Role in household** e.g. mother, child	**Age in years (months for babies)**	**Sex** Please mark the correct block (✓)		**Cause of death** Mark the correct one (✓)		
1			Male	Female	Accident / Injury	Illness	Don't know
2			Male	Female	Accident / Injury	Illness	Don't know
3			Male	Female	Accident / Injury	Illness	Don't know
4			Male	Female	Accident / Injury	Illness	Don't know
5			Male	Female	Accident / Injury	Illness	Don't know
6			Male	Female	Accident / Injury	Illness	Don't know

COMMENTS OR IMPORTANT NOTES:

....

....

....

....

....

....

....

....

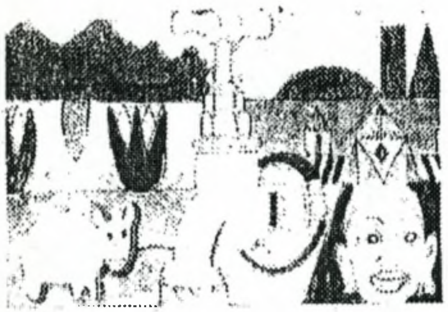
....

ANNEXURE C Pamphlet used during February 2000 education campaign

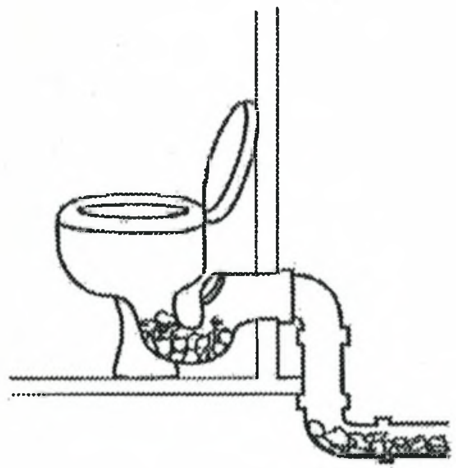
SISEBENZELA UCOCEKO NEMPILO KWINDAWO YETHU

GCINA IKAYAMANDI
ICOCEKILE

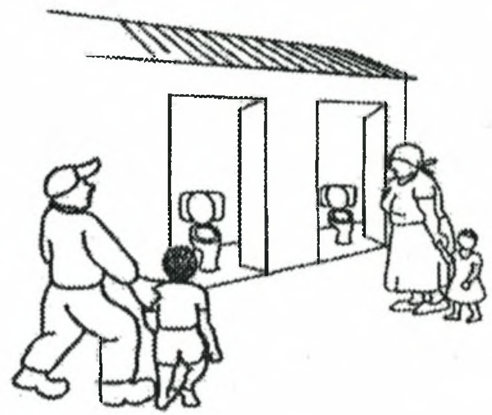
ISUKA KWIKAYAMANDI
TEST CASE STEERING
COMMITTEE



NCEDA SUKULAHLA
INKUNKUMA
KWINDLU
YANGASESE,
IZAKUXINGA

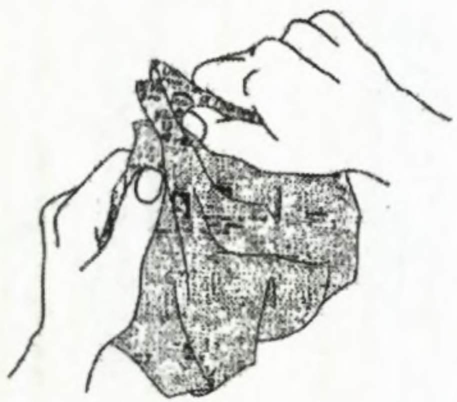


NCEDA UKHAPHE
ABANTWANA UKUYA
KWINDLU
YANGASESE. UKUZE
BAFUNDE
UKUYISEBENZISA
NGENDLELA EYIYO.



SISEBENZELA UCOCEKO NEMPILO KWINDAWO YETHU

NCEDA HLIKIHLA
IPHEPHA UKUZE
LINGAXINGISI
ITHOBHI
NEMIBHOBHO



NCEDA HLAMBA
IZANDLA ZAKHO
WAKU GQIBA
UKUSEBENZISA
INDLU YANGASESE.
OKO KUKHUSELA
WENA KWIZIFO

NCEDA XELA IINGXAKI
ZENDLU YANGASESE
NOXINGO KU:

MR SIPHO MENZIWA
TEL. 889 7323
KAYAMANDI
ADMINISTRATION
BUILDING

Reverse side of pamphlet

ANNEXURE D Questionnaire Survey July 2001 – First interview

WORKING TOWARDS A CLEAN AND HEALTHY KAYAMANDI

First Interview

June/July 2001

This is a study by the Kayamandi Steering Committee to support community efforts to keep Kayamandi clean. It is jointly carried out by the community of Kayamandi, the Dept of Water Affairs and Forestry, the Municipality of Stellenbosch and the Medical Faculty of the University of Stellenbosch at Tygerberg.

It would be a great help to us if you could answer a few questions for us. We are not going to ask your name. No information you give us will be connected to your person or the people living with you. We need the information to help plan a cleaner and better Kayamandi. You have the right to refuse to participate, but your help would make this information more accurate for us and would be appreciated.

Interviewer's name:	
Date of interview:	
Site address: (whatever is applicable. Only to avoid visiting the same house twice. This will be kept strictly confidential)	Stand number .... House number .... Street name .... Zone ....

1. Please list the following information for all persons living in the dwelling: All gray blocks must be completed for as many persons as there are living in the house.

Number of person	Role in household e.g. mother, child, uncle, boarder	Age in years (months for babies)	Sex Please mark the correct block (✓)	
1			Male	Female
2			Male	Female
3			Male	Female
4			Male	Female
5			Male	Female
6			Male	Female
7			Male	Female
8			Male	Female
9			Male	Female
10			Male	Female
11			Male	Female
12			Male	Female
13			Male	Female
14			Male	Female

2. What is the kind of house/dwelling?
Mark the correct one (✓)

Brick house	
Hostel room	
Flat	
Shack	

3. Where is the toilet that is available to the persons living in the dwelling?
Mark the correct one (✓)

Toilet inside the house	
Toilet outside the house, but on the same property	
Communal toilet away from the dwelling	
No toilet available within easy walking distance	

4. If the people living in the house have to share a toilet with other families, how clean is the toilet?
   Mark the correct one (✓)

Clean	
Acceptable	
Dirty	

5. Is the toilet often broken or not working?
   Mark the correct one (✓)

Yes	
No	
Unsure	

6. Do you know who to tell if there is a drain blocked or overflowing?
   Mark the correct one (✓)

Yes	
No	
Unsure	

7. Who would you tell if there is a drain blocked and overflowing?

....
....

8. Are there facilities nearby to wash your hands after using the toilet?
   Mark the correct one (✓)

Yes	
No	
Unsure	

9. What will happen if rubbish is thrown into the toilet?
   Mark the correct one (✓)

Nothing	
It will block the toilet and the pipes	
Don't know	

10. Can you get ill from not washing your hands after you used the toilet?
   Mark the correct one (✓)

Yes	
No	
Unsure	

11. Do the people living in the house think that a clean toilet is important?
Mark the correct one (✓)

Yes	
No	
Unsure	

12. Can you get ill from the dirt and rubbish in the street and environment?
Mark the correct one (✓)

Yes	
No	
Unsure	

13. Has any person living in the house had diarrhoea **in the last week?**
Mark the correct one (✓)

Yes	
No	
Unsure	

14. Has any person living in the house had diarrhoea **in the last month?**
Mark the correct one (✓)

Yes	
No	
Unsure	

15. Who was it?

Number of person	**Role in household** e.g. mother, child, uncle, boarder	**Age in years** (months for babies)	**Sex** Please mark the correct block (✓)	
1			Male	Female
2			Male	Female
3			Male	Female
4			Male	Female
5			Male	Female
6			Male	Female

THANK YOU VERY MUCH FOR HELPING US. WE APPRECIATE IT.
(Remember to hand out the pamphlet and to ask the household to keep it for reference.)

ANNEXURE E Questionnaire Survey July 2001 – Second interview

WORKING TOWARDS A CLEAN AND HEALTHY KAYAMANDI

Second Interview

June/July 2001

This is a study by the Kayamandi Steering Committee to support community efforts to keep Kayamandi clean. We asked you a number of questions a few days ago and we need to ask just a few of them again. It would be a great help to us. We do not want to know your your name. No information you give us will be connected to your person or the people living with you. We need the information to help plan a cleaner and better Kayamandi. You have the right to refuse to participate, but your help would make this information more accurate for us and would be appreciated.

Interviewer's name:	
Date of interview:	
Site address: (whatever is applicable. Only to avoid visiting the same house twice. This will be kept strictly confidential)	Stand number .... House number .... Street name .... Zone ....

1. Do you still have the pamphlet that I handed out to you last time?

Yes	
No	

2. Do you know who to tell if there is a drain blocked or overflowing?
   Mark the correct one (✓)

Yes	
No	
Unsure	

3. Who would you tell if there is a drain blocked and overflowing?

....
....

4. What will happen if rubbish is thrown into the toilet?
   Mark the correct one (✓)

Nothing	
It will block the toilet and the pipes	
Don't know	

5. Can you get ill if you do not wash your hands after you used the toilet?
   Mark the correct one (✓)

Yes	
No	
Unsure	

6. Do the people living in the house think that a clean toilet is important?
   Mark the correct one (✓)

Yes	
No	
Unsure	

7. Can you get ill from the dirt and rubbish in the street and environment?
   Mark the correct one (✓)

Yes	
No	
Unsure	

8. Has any person living in the house had diarrhoea **since I last visited you?**
   Mark the correct one (✓)

Yes	
No	
Unsure	

9. Who was it?

Number of person	**Role in household** e.g. mother, child, uncle, boarder	**Age in years** (months for babies)	**Sex** Please mark the correct block (✓)	
1			Male	Female
2			Male	Female
3			Male	Female
4			Male	Female
5			Male	Female

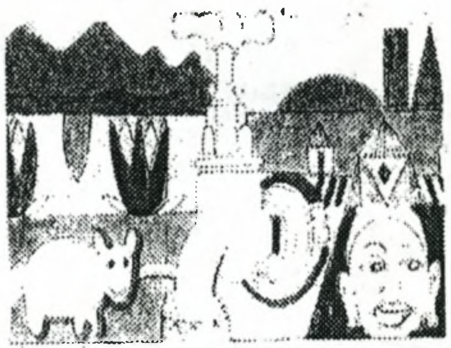
THANK YOU VERY MUCH FOR HELPING US. WE APPRECIATE IT.

ANNEXURE F Pamphlet used during July 2001 education campaign

SISEBENZELA UCOCEKO NEMPILO KWINDAWO YETHU

GCINA
IKAYAMANDI
ICOCEKILE!

Isuka Kwi-
Kayamandi Test
Case Steering
Committee

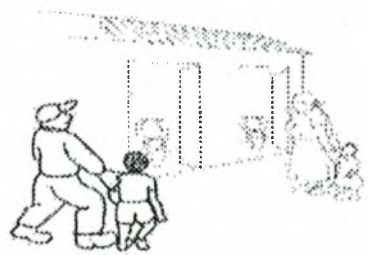


Indalo engcolileyo imbi kwimpilo yethu nabantwana bethu.

Inkunkuma iya emlanjeni yenze amanzi omlambo abe nobungozi kwimpilo yethu. Yenza namanzi ngezantsi komfula angabi nakusetyenziswa.

Nceda sukonakalisa indlu yangasese, iisinki kunye nembhobho.

Izindlu zangasese zethu ezi!



Nceda sukulahla inkunkuma, iingxowa zeplasitiki kwindlu yangasese okanye endleleni.

Nceda sukulahla ukungcola kwama pheyile asebusunku namanzi amdaka e dreyinini nasendleleni. Galela kwindlu yangasese. Okwakungcola kuya emlanjeni kwenze amanzi abe nobungozi empilweni yethu nabantwana bethu.

SISEBENZELA UCOCEKO NEMPILO KWINDAWO YETHU

Nceda sebenzisa iingxowa ezimnyama ekugalaleni inkunkuma. Ezi ngxowa zenzelwe ukusinceda silahle inkunkuma. Nceda khupha iingxowa ezimnyama ngamaxesha afanelekileyo nangentsuku zokuthuthwa kwazo.

Nceda cela abamelwane uthethe nabo babe negalelo ekugcineni uKyamandi icocekile ngokucoca hayi ukusasaza inkunkuma.

Nceda sukulahla ukutya nentshwela nenkunkuma esinkini. Ixingisa imibhobho nesinki.

Amanzi amdaka ne-dreyini ezixingileyo nesinki eziphuphumayo ziyingozi empilweni yakho nasebantwaneni!

NCEDA XELA IINGXAKI ZENDLU YANGASESE NOXINGO KU:

MR SIPHO MENZIWA
TEL. 889 7323
KAYAMANDI
ADMINISTRATION
BUILDING

Reverse side of pamphlet

CHAPTER 5

Water Quality Analyses and River Monitoring

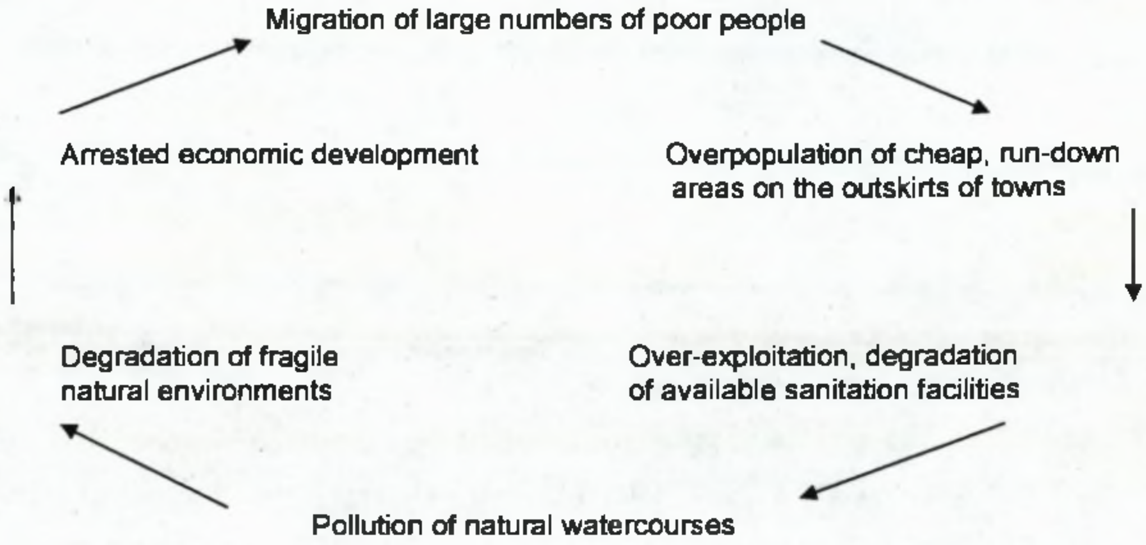
5.1 General introduction

The problems facing environmental epidemiologists today are increasingly complex, multidisciplinary in nature, often ill-defined and solutions to them are uncertain at the best of times.[1,2] There is a great need for integration of the various approaches used to investigate problems of pollution and its health effects.[1,3] Wide-ranging reforms are needed at national and local levels to deal with the assessment and management of environmental health risks. At present these aspects are so under-investigated that information on pollution levels and their associated ripple effects are almost absent in South Africa. No proper health systems planning can take place if the health service sector is expected to 'absorb' the avoidable excess number of cases resulting from poor sanitation, industrial pollution, and food- and waterborne diseases, without being able to predict what the burden of such disease would be.

Many local health risks are the 'downstream products' of large-scale environmental pollution and degradation that are linked to human-induced stresses driven by population growth, economic development and technological forces.[1,4] It is clear that economic development is crucially dependent on cost-effective measures that limit 'upstream' damage to the environment, even though such measures may take time to yield results.

When assessing the outcome of investigations into pollution, one should keep in mind the interrelated nature of all the different aspects of any pollution crisis. Problems escalate when environmentally sustainable development of human habitats are not properly planned and actively managed.

The following circular depiction is an attempt to show the inexorable accumulation of problems when the process of population growth, migration and the degradation of the urban and social structures are not reversed by active and integrated management. This circle should properly be viewed as a downward spiral that can only be arrested by active intervention based on solid scientific, economic and social information.



The complexity of interaction among risk factors hinders risk assessment with conventional research designs usually used with large populations.[4,5] There is therefore a need to study *in depth* smaller models in defined populations living in well demarcated areas and concerned with a relatively small number of high-impact pollution factors before extrapolation to models on a grander scale can be made.[3] The Plankenbrug River and the settlement of Kayamandi provide a very good constrained model in this respect.

The results of the investigations contained in the main database of river water analyses are presented in this chapter. The investigations into the pollution crisis affecting the Plankenbrug River and its downstream catchment area followed the typical course of most exploratory environmental investigations. Some aims of the study could clearly be set before the study began, but some were triggered *post hoc* by the results obtained in earlier investigations.

The primary concern when the study of the water quality of the Plankenbrug River commenced was to establish the magnitude and nature of the microbiological and chemical pollution in the river. The results of this primary investigation are presented in Substudy 1 and Substudy 2.

When the extent and potential health implications of the pollution load became evident, some secondary questions needed to be answered urgently if the health and well-being of the people living in the catchment, especially the inhabitants of Kayamandi, were to be protected. The first of these secondary questions regarding the pollution effects was concerned with the spectrum of pathogenic organisms other than *E. coli* also present in the water of the Plankenbrug River. In other words, this part of the investigation sought to establish which pathogenic organisms *E. coli* is indicative of, in its role as indicator organism. The information on this aspect is represented in Substudy 3.

The second of the secondary questions was concerned with the ability of downstream water users (especially agricultural users and local authorities) to effectively remove the pollution and make the water usable. Thus, an exploratory pilot study of chlorination resistance of the *E. coli* in the water was undertaken. The results of this investigation are presented in Substudy 4.

The third of the secondary investigations concerned another aspect of management of the consequences of the pollution and consequent health effects, namely the ability of the health services to treat infections arising from contact with polluted water effectively. Thus, an explorative survey was undertaken on three separate occasions of the antibiotic susceptibility patterns of *E. coli* and other bacteria present in the water. The results are presented in Substudy 5.

References to General Introduction

1. World Health Organization. Health and Environment in Sustainable Development: Five Years after the Earth Summit: Executive Summary. WHO: Geneva. 1997, pp. 17
2. Aldrich TE. Environmental epidemiology forward. Chemosphere 2000; 41(1-2): 59-67
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SUBSTUDY 1

Quantification of Faecal Pollution in the Plankenbrug River Using *Escherichia coli* as Indicator Organism

5.1.1 Introduction

The Plankenbrug River has been monitored for the presence of faecal coliform bacteria and levels of *Escherichia coli* since 4 May 1998. This was done as a long-term study of the seasonal variation of the level of faecal pollution in the river as well as a way of monitoring the results of various interventions in Kayamandi, a dense settlement along the riverbank from whence a large proportion of the pollution originated. Thus, *E. coli* levels were used in its traditional role as an indicator of faecal pollution, as well as a monitoring index of eventual environmental effects of sanitation education and interventions in the functioning of the sanitation systems in the township.

Enumeration of the coliform group of bacteria, and specifically faecal coliforms and *E. coli*, is the most widely used method in the estimation of health-related water quality.[1] Enumerating the faecal coliform levels and levels of *E. coli* could therefore also serve as bacteriological indicators of the fitness-for-use of the water downstream from the sources of pollution in the same river drainage system. Fitness-for-use also includes irrigation, especially on edible crops and crops consumed by animals. Since the Plankenbrug River runs through some very ecologically, agriculturally and recreationally sensitive areas, this indication of the health of the river is very important in coping with the deleterious effects of the large quantities of pollution.

The main aim of this substudy was to quantify the levels of faecal pollution present in the Plankenbrug River over time.

The question is often raised about the effect on rainfall of the pollution levels, the rationale being that the increased inflow of fresh water ought to reduce the pollution levels. On the other hand, it is known that micro-organisms multiply much more quickly during relatively high temperatures. After the main data base of pollution levels in the Plankenbrug River had been established, a subsequent aim was to carry out a statistical analysis of the effect of rainfall and temperature just prior to sampling of the river. A secondary aim of this substudy was therefore to construct a statistical model to predict the expected *E. coli* levels on the basis of the past *E. coli* levels and the rainfall and temperature data immediately prior to sampling. This model could provide an objective yardstick that would be more accurate than judgement by eye of the crude levels to determine whether the pollution levels were deteriorating.

5.1.2 Materials and methods

Collection of samples

From 4 May 1998 to 25 November 2002, samples were drawn approximately every six weeks in order to do a prospective study of the seasonal variation of the pollution levels in the river. For the first two years, samples were drawn from eight sites along the entire length of the Plankenbrug River (see map Annexure A at the end of this chapter). Three of these samples in the upper reaches (before the urban developments of Stellenbosch Town) were situated in agricultural land, mainly vineyards and fruit orchards. These three sample sites were not used after 27 March 2000 due to consistently low *E. coli* counts. At Elsenburg Road, the *E. coli* levels during this period only exceeded the cut-off level of 2000 *E. coli* organisms per 100 ml water on 16% of the sampling occasions. The corresponding values for the two sites lower down were: Nooitgedacht 33% and Weltevreden 22%. In order to save research funds the first three sites were not sampled after 27 March 2000.

The samples were collected in 2 litre autoclaved plastic sample bottles according to the guidelines set out by the South African Bureau of Standards[2] which incorporates the standard methods set out by the American Public Health Association, American Water Works Association and the Water Environment Federation.[3-5] Samples were taken mid-stream, as far as possible. Whenever the water depth allowed, the samples were taken at 30 cm depth. During low-flow conditions when the water depth was less than 30 cm, the samples were taken at the halfway point between the water surface and the riverbed. All samples were taken between 07h00 and 09h00 and immediately transported on ice to the laboratory. The journey to the laboratory took approximately 30 minutes.

Coliform and *E. coli* counts

The analyses of water samples were undertaken in the laboratories of the Department of Medical Microbiology at Tygerberg Hospital by technologists Ms M Slabbert and Ms A Huisamen.

E. coli counts were determined using the multiple tube fermentation method. Serial dilutions of sampled water, starting at a dilution of 10^{-1} were inoculated into tubes containing laurel tryptose broth (Oxoid) and incubated aerobically for 48 h. Production of gas after 48 h of incubation constituted a positive presumptive reaction. All tubes with gas formation were taken to be positive and the presumptive coliform count were read off from the De Mans tables.[3,4] All tubes with a positive presumptive reaction were subsequently subjected to a confirmation test. A drop of about 0.01 ml from each tube was inoculated with a drop glass pasteur pipette into brilliant green lactose bile broth (Biolab) and indole tryptone water (Oxoid) according to the guidelines set out by South African Bureau of Standards[2] that incorporate the standard methods set out by the American Public Health Association, American Water Works Association and the Water Environment Federation.[3-5]. Those tubes showing gas production on brilliant green broth testing when incubated at 35°C for 24 hours provided the presumptive coliform count and those showing indole production following incubation at 44°C in tryptone water provided an enumeration of *E. coli* count per 100 ml of the sampled water.

Five dilutions were usually used except on a few occasions when up to 7 or 8 dilutions were used for the heavily contaminated sampling sites during summer (peak counts) in order to verify the extraordinarily high values obtained. The analyses were performed in triplicate for the first three years after which the analyses were performed in duplicate.

<u>Statistical analyses of meteorological data</u>

The relevant meteorological data was obtained from the Division of Agrometeorology and the analyses were carried out in co-operation with Mr Pieter Haasbroek, Agrometeorologist from the Agricultural Research Council. The average maximum air temperature for the 3 days preceding sampling and total rainfall over the preceding 7 days for the first four years of the study were included in the model. Two models were constructed: one where temperature and rainfall were taken into account to calculate expected E. coli levels (3D model), and one where only temperature was used (2D model). The model was constructed with the aid of Tablecurve 3D, Version V3.12 from Cystat Software Inc., United States of America.

At the last two sampling sessions of 2002, the logarithmic version of the model was used to predict what the expected load would have been if the *E. coli* status of the river remained the same as for May 1998 to May 2002.

5.1.3 Results

Trends in pollution

Fig. 5.1.1 demonstrates the trends in pollution over time at 2 sampling points namely "Below Kayamandi" and "Before Gilbeys" (the next one lower down). These two sampling sites were specifically chosen because they represent the pollution levels arising from sewage intrusion into the river before too much industrial waste has entered the river, possibly skewing the pollution patterns. The four peak periods on the graphic field coincide with the summer highs in *E. coli* levels. Similar patterns were observed at the other sampling sites.

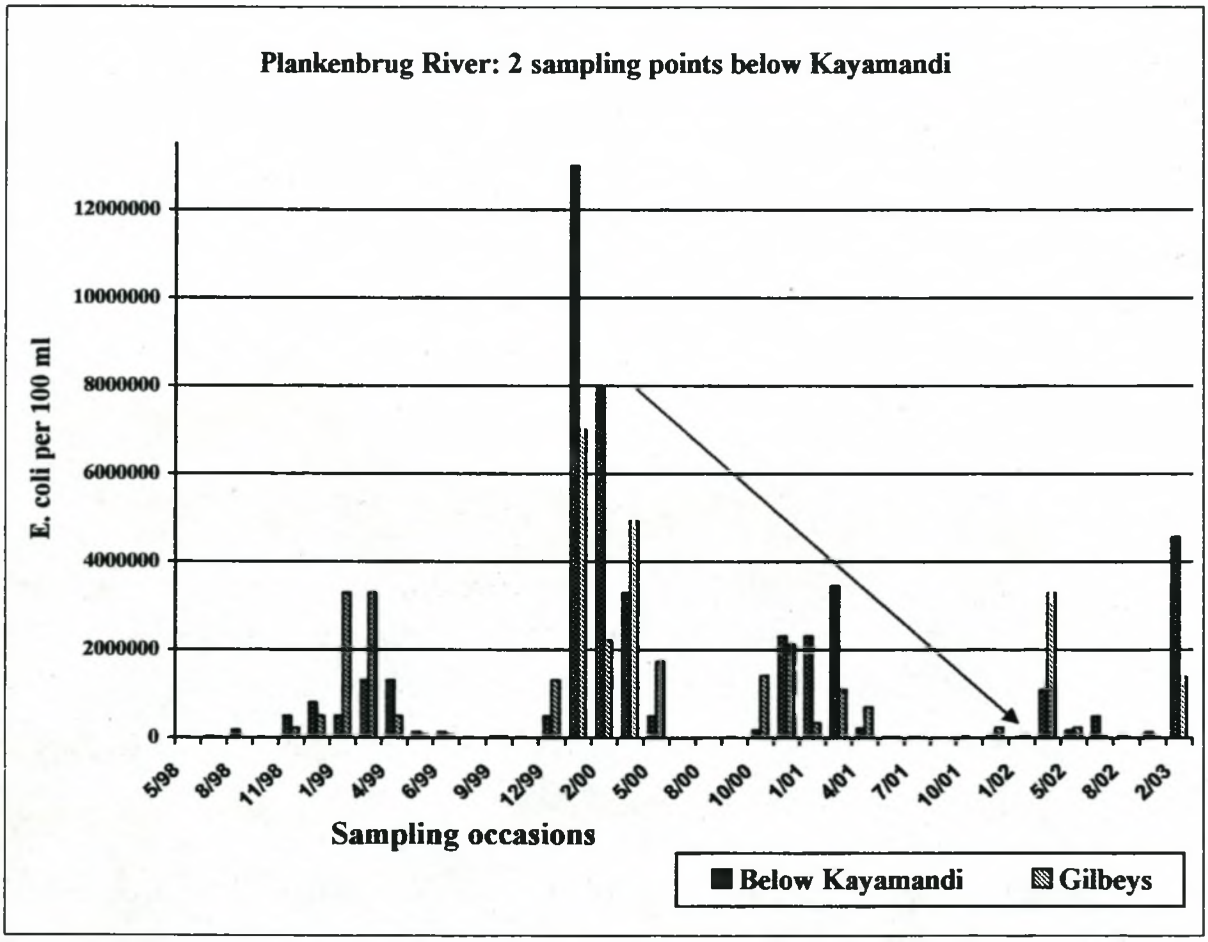

Fig. 5.1.1 *E. coli* counts from May 1998 to September 2002 for the sampling points "Below Kayamandi" and "Before Gilbeys". The x-axis depicts month and year of each sampling occasion. The arrow indicates the change over the period of the DANCED project intervention (maintenance plus education campaigns).

For a Mediterranean climate, during the hot, dry summers, the pollution loads in the river peak in late summer, followed by a trough in mid- to late winter. The expected fluctuations between winter troughs and summer peaks over the first two years (1998 to early 2000) can be seen in Fig 5.1.1. The levels started rising as soon as the DANCED project came to an end (sampling occasion no. 33 in Fig. 5.1.1). This is depicted in more detail in Fig. 5.1.2.

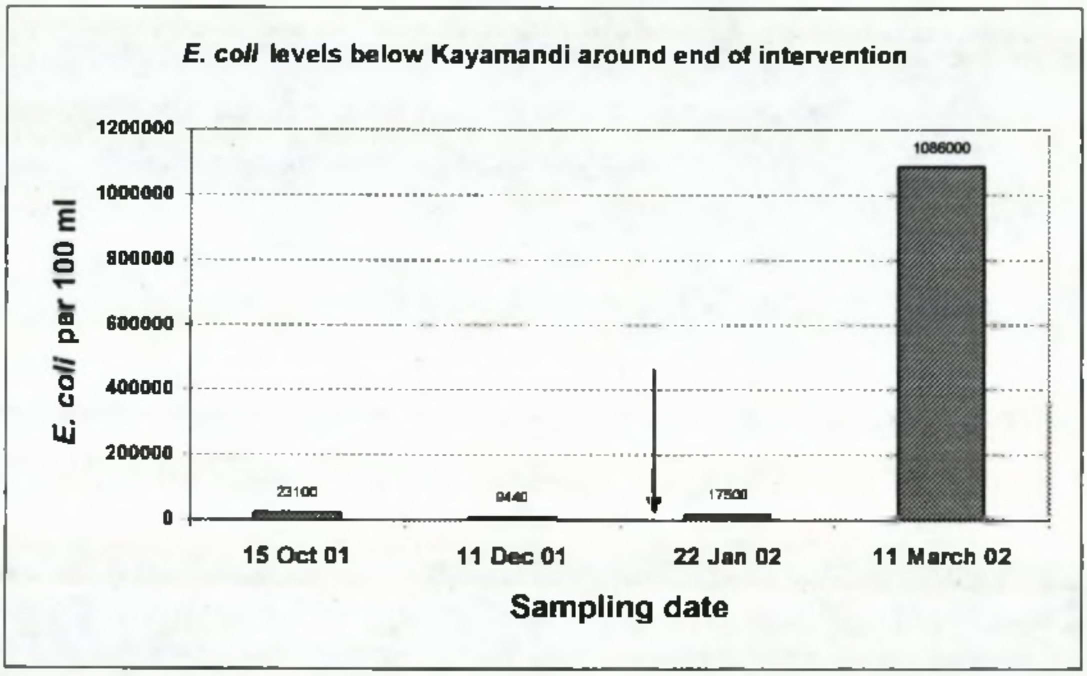

Fig. 5.1.2 E. coli levels below Kayamandi on sampling dates around the end of the DANCED intervention (education and repair and maintenance). The arrow indicates the end of the project on 31 December 2001, although some last repairs were carried out in January 2002. After that no maintenance was carried out and the reporting office for blockages and breakages ceased to function.

Another way of visualising the sustained pollution load experienced in the Plankenbrug River is to quantify the number of times the E. coli levels exceeded the cut-off value of 2000 organisms per 100 ml water during the five years of the study. This is depicted in Fig 5.1.3a. This cut-off value is a generous one, since 1000 organisms per 1000 water is the more usual one used overseas.[2,6]

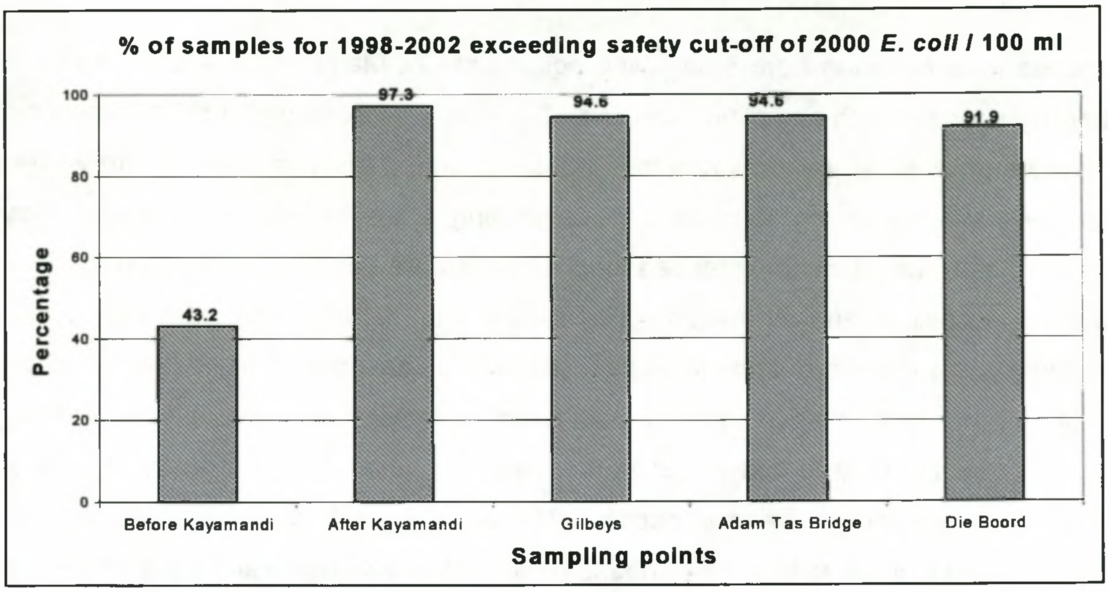

Fig. 5.1.3a Percentage of samples at all five sampling points above the cut-off level of 2000 *E. coli* organisms per 100 ml water

Fig. 5.1.3b is an overview of the changes in *E. coli* levels over time for the full duration of the study at all five sampling points along the Plankenbrug River.

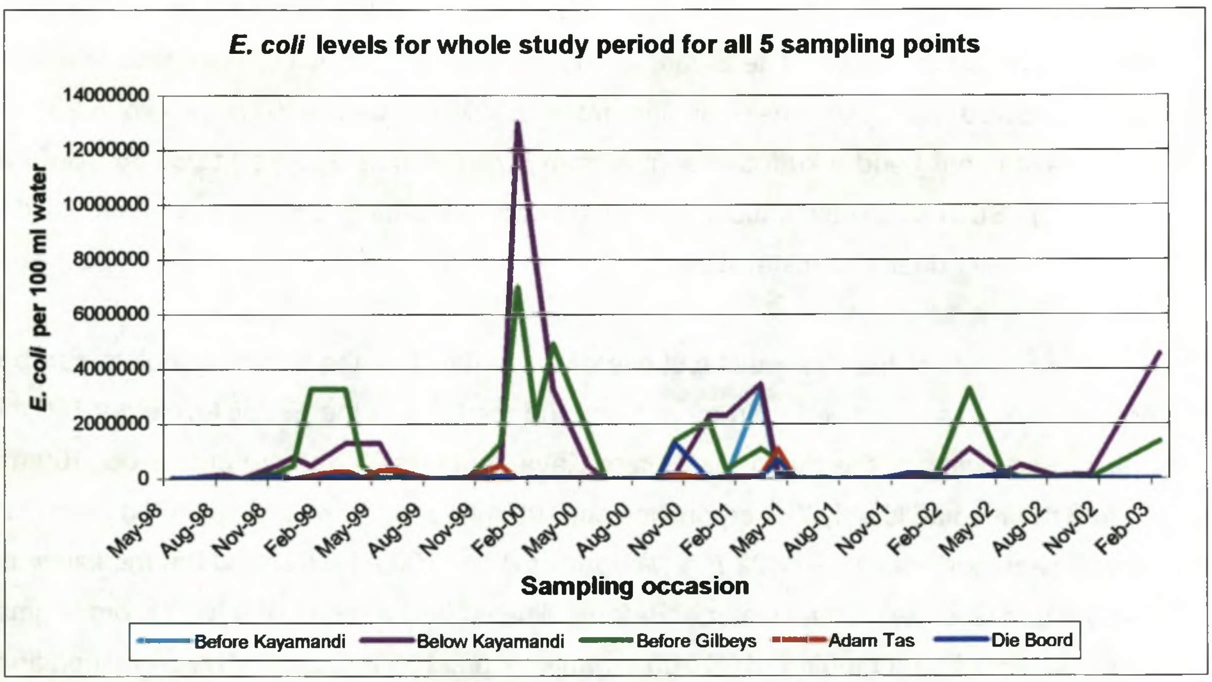

Fig. 5.1.3b. *E. coli* levels for all 5 sampling points over the full duration of the study.

Variation in levels of pollution at different sampling sites

Samples were obtained from 8 sampling points until 27 March 2000 and thereafter from 5 sampling sites on each sampling occasion. The seasonal trend of the *E. coli* levels over the five years showed a peak towards the end of summer, falling to a low in late winter, then increasing steadily during summer and culminating in the highest value around May (this varied a little due to minor inter-seasonal climate differences). This is illustrated for all sampling occasions and all five sampling sites in Fig. 5.1.3b. The following 12 sampling occasions were chosen to show the exact size of the seasonal *E. coli* peaks (summer) and troughs (winter) over the five years: (i) data for the summer high at the beginning of the year; (ii) as near as possible to mid-winter as the sampling schedule allowed; (iii) the end-of-year increase as the next summer approached. These peaks and troughs are tabulated in Table 5.1.1. It should be noted that these peaks were not the only high values experienced during the study period. At other times, sudden high *E. coli* levels were experienced that could rather be ascribed to intrusions of sewage into the river than seasonal fluctuations. Some of these intrusions were wittnessed by the candidate, for others the evidence could still be seen on the ground in the surrounding areas.

The *E. coli* levels observed in this study varied over a wide range. The lowest value obtained over the study period was 130 organisms per 100 ml water and the highest was 12.99 million organisms per 100 ml water. The 5-year distribution at each sampling point was severely positively skewed with skewness ranging from 2.30202 ("Before Gilbeys") to 6.23167 ("Before Kayamandi") and a kurtosis ranging from 5.71 ("Before Gilbeys") to 38.88 ("Before Kayamandi"). Such skew distributions and such a wide variation in absolute values preclude the use of ordinary descriptive statistics.

A further indication of the skew distributions of the data at all the sampling points can be found in a comparison between the means and the medians of the *E. coli* levels per 100 ml of water. For example, the mean for "Before Kayamandi" is 93 333 organisms per 100 ml water and the median is only 792 organisms per 100 ml water. The corresponding mean for "Below Kayamandi" was 1 192 422 *E. coli* organisms per 100 ml water and the median was 172 400 organisms per 100 ml water. "Before Gilbeys" had a mean of 926 266 organisms per 100 ml water and a median of 79 200 organisms per 100 ml water. The corresponding means for "Adam Tas Bridge" and "Die Boord" were 97 599 and 80 601 organisms per 100 ml water, while the medians were 12 990 and 7 920 organisms per 100 ml water.

Means calculated over such a large time span and with such variable and large intrusions of sources of pollution are not scientifically justifiable. Such means are uninterpretable. In order to see if these inherent statistical problems could be overcome, the data were divided into two periods of more homogeneous levels, namely a summer period from January to April, and a winter period from June to September. These arbitrary choices were based on the times of peaks and troughs in the *E. coli* levels. The reason for the choice of 'late' months for the summer period is the fact that the water takes some time to cool down and does not warm as fast as the air temperature when the warmer months of November and December herald the arrival of summer. The summer mean for "Before Kayamandi" was 286 300 *E. coli* organisms per 100 ml of water, but was reduced to 13 236 organisms per 100 ml water if the single huge outlier of 3.29 million organisms per 100 ml of water measured on 5 March 2001 is discarded. In all but one case, the standard deviations were much larger than the means, even for the supposedly more homogeneous summer and winter groups of sampling occasions. The exception was for the summer mean value obtained at "Before Gilbeys" (mean 2 338 100 organisms per 100 ml water; standard deviation 2 106 801 organisms per 100 ml water). These calculations serves to indicate why using summary statistics to represent the data is not very illustrative and can be very misleading. In the case of pollution data, the absolute patterns of pollution, the evidence of entry points, related conditions in the drainage area, etc. are far more important in the interpretation of the data than statistical comparisons. Apart from the actual levels, the shapes of the curve and the slopes of the changes in the curves are the most important characteristics.

Table 5.1.1 Selected results of the microbial monitoring of the Plankenbrug River

1998

Sampling point	Faecal coliforms per 100 ml	*E. coli* organisms per 100 ml
4 May 1998 (start of project):		
Elsenburg Road	920	920
Nooitgedacht	92 000	92 000
Weltevreden	220	220
Before Kayamandi	12 000	6 300
Below Kayamandi	16 000	16 000
Before Gilbeys (±1 km down-stream)	3 500	3 500
Adam Tas Bridge	17 000	11 000
Die Boord (before confluence)	11 000	7 000
17 August 1998 (winter):		
Elsenburg Road	792	792
Nooitgedacht	792	792
Weltevreden	2 110	2 110
Before Kayamandi	329	329
Below Kayamandi	172 300	172 300
Before Gilbeys (±1 km down-stream)	14 060	6 990
Adam Tas Bridge	3 290	3 290
Die Boord (before confluence)	4 930	3 290
7 December 1998 (summer):		
Elsenburg Road	329	329
Nooitgedacht	1 406	1 406
Weltevreden	456	456
Before Kayamandi	6 310	6 310
Below Kayamandi	792 000	792 000
Before Gilbeys (±1 km down-stream)	792 000	493 000
Adam Tas Bridge	17 240	10 860
Die Boord (before confluence)	10 860	7 920

Table 5.1.1. continued

1999

Sampling point	Faecal coliforms per 100 ml	*E. coli* organisms per 100 ml
25 January 1999 (summer):		
Elsenburg Road	329	231
Nooitgedacht	792	792
Weltevreden	493	493
Before Kayamandi	347	347
Below Kayamandi	493 000	493 000
Before Gilbeys (±1 km down-stream)	3 290 000	3 290 000
Adam Tas Bridge	792 000	129 900
Die Boord (before confluence)	4 930	4 930
22 June 1999 (winter):		
Elsenburg Road	4 930	4 930
Nooitgedacht	3 290	3 290
Weltevreden	4 560	4 560
Before Kayamandi	10 860	10 860
Below Kayamandi	49 300	49 300
Before Gilbeys (±1 km down-stream)	12 990	12 990
Adam Tas Bridge	22 120	14 060
Die Boord (before confluence)	10 860	10 860
6 December 1999 (summer):		
Elsenburg Road	130	130
Nooitgedacht	329	329
Weltevreden	2 781	2 781
Before Kayamandi	329	329
Below Kayamandi	4 930 000	4 930 000
Before Gilbeys (±1 km down-stream)	1 724 000	1 299 000
Adam Tas Bridge	490 000	490 000
Die Boord (before confluence)	172 400	108 600

Table 5.1.1. continued

2000

Sampling point	Faecal coliforms per 100 ml	*E. coli* organisms per 100 ml
24 January 2000 (summer):		
Elsenburg Road	10 860	6 990
Nooitgedacht	221	221
Weltevreden	79	79
Before Kayamandi	130	130
Below Kayamandi	17 420 000	12 990 000
Before Gilbeys (±1 km down-stream)	10 860 000	6 990 000
Adam Tas Bridge	944	944
Die Boord (before confluence)	10 860	10 860
26 June 2000 (winter):		
Before Kayamandi	493	221
Below Kayamandi	2 640	1 660
Before Gilbeys (±1 km down-stream)	792	493
Adam Tas Bridge	6 700	6 700
Die Boord (before confluence)	1 406	631
4 December 2000 (summer):		
Before Kayamandi	493	493
Below Kayamandi	3 290 000	2 310 000
Before Gilbeys (±1 km down-stream)	2110000	2110000
Adam Tas Bridge	10 860	7 000
Die Boord (before confluence)	10 860	10 860

Table 5.1.1. continued

2001

Sampling point	Faecal coliforms per 100 ml	*E. coli* organisms per 100 ml
23 January 2001 (summer):		
Before Kayamandi	3 290	3 290
Below Kayamandi	3 290 000	2 310 000
Before Gilbeys (±1 km down-stream)	329 000	329 000
Adam Tas Bridge	79 200	79 200
Die Boord (before confluence)	12 990	12 990
23 July 2001 (winter):		
Before Kayamandi	278	278
Below Kayamandi	32 900	23 100
Before Gilbeys (±1 km down-stream)	12 990	12 990
Adam Tas Bridge	16 600	6 800
Die Boord (before confluence)	9 200	4 930
11 December 2001 (summer):		
Before Kayamandi	221	221
Below Kayamandi	69 900	69 900
Before Gilbeys (±1 km down-stream)	231 000	231 000
Adam Tas Bridge	49300	49 300
Die Boord (before confluence)	264 000	264 000

Table 5.1.1. continued

2002

Sampling point	Faecal coliforms per 100 ml	*E. coli* organisms per 100 ml
22 January 2002 (summer):		
Before Kayamandi	493	493
Below Kayamandi	17 500	9 440
Before Gilbeys (±1 km down-stream)	79 200	79 200
Adam Tas Bridge	9 440	9 440
Die Boord (before confluence)	3 290	3 290
24 June 2002 (winter):		
Before Kayamandi	3 454	3 454
Below Kayamandi	493 000	493 000
Before Gilbeys (±1 km down-stream)	23 100	23 100
Adam Tas Bridge	3 290	3 290
Die Boord (before confluence)	14 060	10 080
14 October 2002 (end of project):		
Before Kayamandi	1 300	1 300
Below Kayamandi	129 000	129 000
Before Gilbeys (±1 km down-stream)	23 100	13 000
Adam Tas Bridge	7 000	4 560
Die Boord (before confluence)	2 310	2 310

Fig. 5.1.4a and b to 5.1.7a and b depict pollution patterns obtained on specific dates as examples of the various pollution patterns obtained downstream from the supposed point source of pollution, namely the township of Kayamandi. The data on these sampling occasions were chosen as good graphic representations of the various patterns observed during the five-year study period. They represent the different major pollution sources involved in the environmental crises encountered in the Plankenbrug River.

Key to numbers of sampling points on X-axes in Fig 5.1.4a and b to Fig 5.1.7a and b

Sampling points on the following graphs are as follows:

Site 1: Before Kayamandi (33° 54' 41.29" S, 18° 50' 58.25" E)

Site 2: Below Kayamandi (33° 55' 36.39" S, 18° 51' 06.67" E)

Site 3: Before the Gilbeys property, just above the cement causeway (33° 55' 58.08" S, 18° 51' 06.67 E)

Site 4: Under Adam Tas Bridge (33° 56' 28.39" S, 18° 50' 41.93" E)

Site 5: Just before the confluence with the Eerste River (33° 56' 35.59" S, 18° 50' 42.25" E)

Descriptions of the background of the dense settlement and the river surroundings were given in Chapter 4. In addition, it needs to be pointed out that virtually the whole town of Stellenbosch is situated on the north-east bank of the Plankenbrug River while the sewage works is situated on the opposite side. Therefore almost all sewage produced in the town has to be conveyed across the river in large mainline sewage pipes. The candidate observed leakages in those main lines from time to time. A further source of sewage intrusions in the section of the river below Kayamandi is the emptying of sewage buckets collected on farms in the district into a sewer right on the river bank. This sewer has frequently been observed to be overflowing. This job was awarded to a private contractor and supervision over the execution of the task seems to have been inadequate. All these problems were reflected in the pollution patterns obtained over the course of the study.

A graphic depiction of the *E. coli* counts on 23 July 2001 is presented in Fig. 5.1.4a. On this date, 278 organisms per 100 ml water were present at Site 1 (before Kayamandi). At the second site (Below Kayamandi), the count increased dramatically to 23100 organisms per 100 ml and then gradually declined downriver. This is the expected pattern associated with pollution from a point source. Such a pattern is characterized by a sharp increase from before the point source of the pollution and this peak then gradually decreasing in a monotone descending fashion. The slope of this decline is not always of a particular mathematical shape such as an exponential one, but it is always monotone (i.e. each successive value is lower than the previous one, however small the decrease may be).

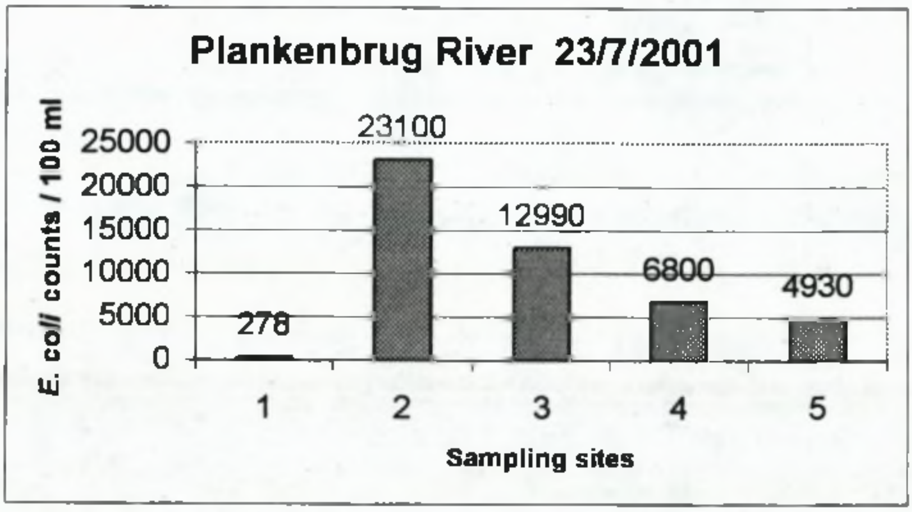

Fig. 5.1.4a *E. coli* levels on 23 July 2001 representing the monotone descending pattern after the point source that is expected if no other intrusions occur.

If the number of E. *coli* organisms per 100 ml of water Below Kayamandi is taken as equalling 100%, the differences between Below Kayamandi and the other sampling points can be depicted as in Fig. 5.1.4.b. In the graph "1 to 2" means the % difference between sampling sites 1 and 2. The sign of the difference indicates whether the change was positive or negative.

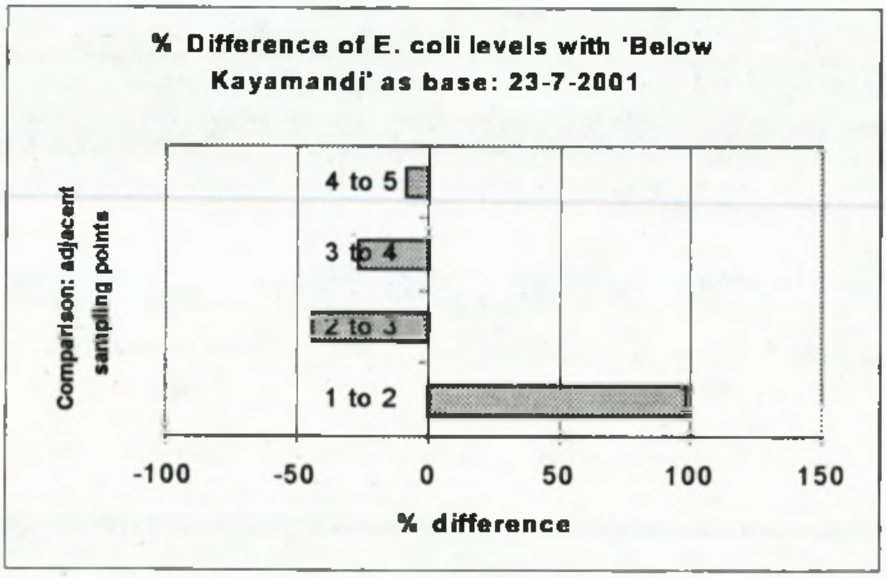

Fig 5.1.4b % Difference of *E. coli* levels on 23 July 2001 with "Below Kayamandi" as base (= 100%) [Note: 1 to 2 indicates the difference between sampling points 1 and 2 and so on.]

Unexpected patterns not reconcilable with pollution originating from a point source occurred on about a third of the sampling occasions. Examples of such unexpected patterns are depicted in Fig. 5.1.5a and 5.1.5b to Fig. 5.1.7a and 5.1.7b.

In Fig 5.1.5a there is a large increase in E. coli count further downstream from Kayamandi, at sampling site no. 3 and then an unusually fast decrease in *E. coli* levels after that.

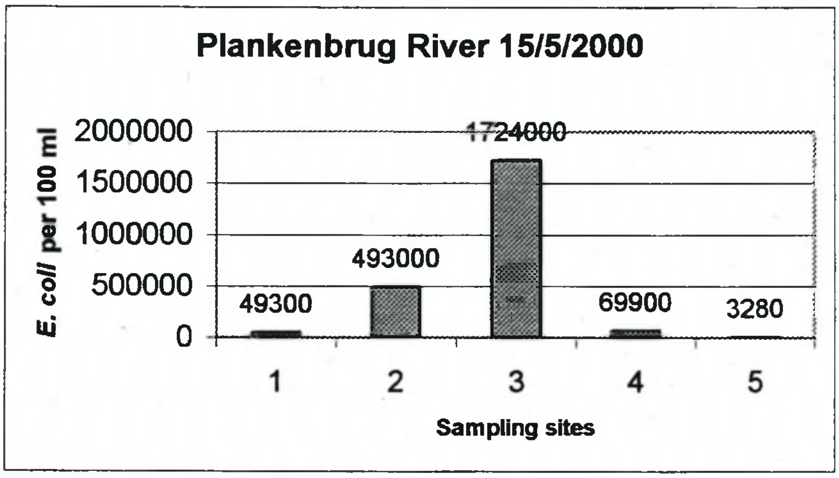

Fig. 5.1.5a *E. coli* counts on 15 May 2000

When depicted as percentage differences, the data are as shown in Fig. 5.1.5b:

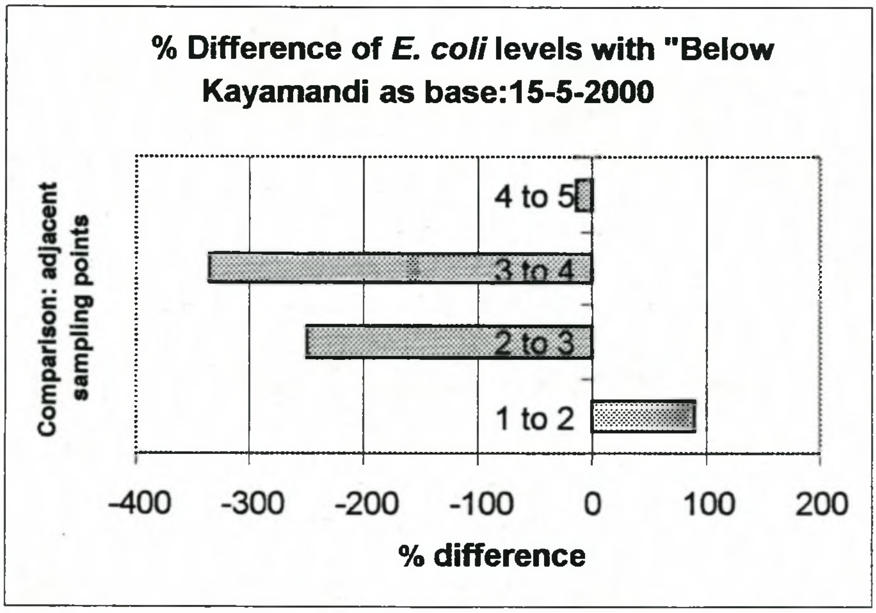

Fig. 5.1.5b % Difference of *E. coli* levels on 15 May 2000 with "Below Kayamandi" as base (= 100%)

On 26 June 2000 the following pattern of pollution was observed (Fig. 5.1.6a):

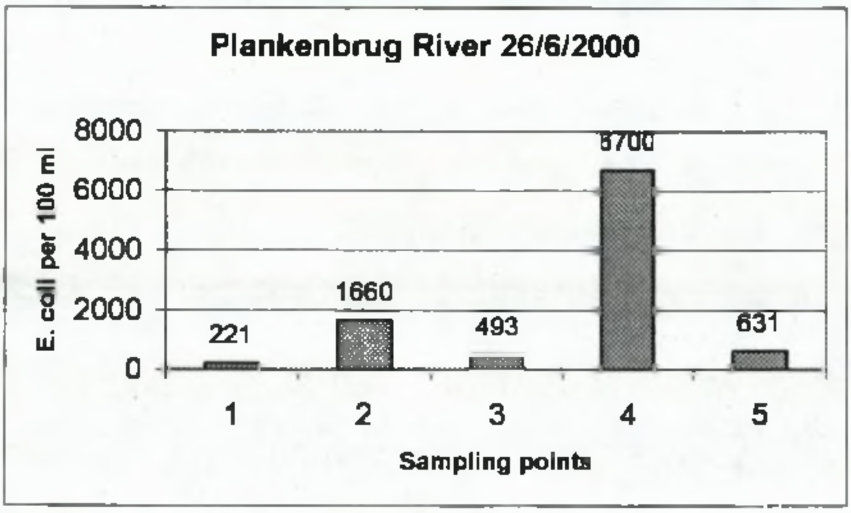

Fig. 5.1.6a *E. coli* counts on 26 June 2000

In Fig. 5.1.6b the percentage differences on 26 June 2000 are shown.

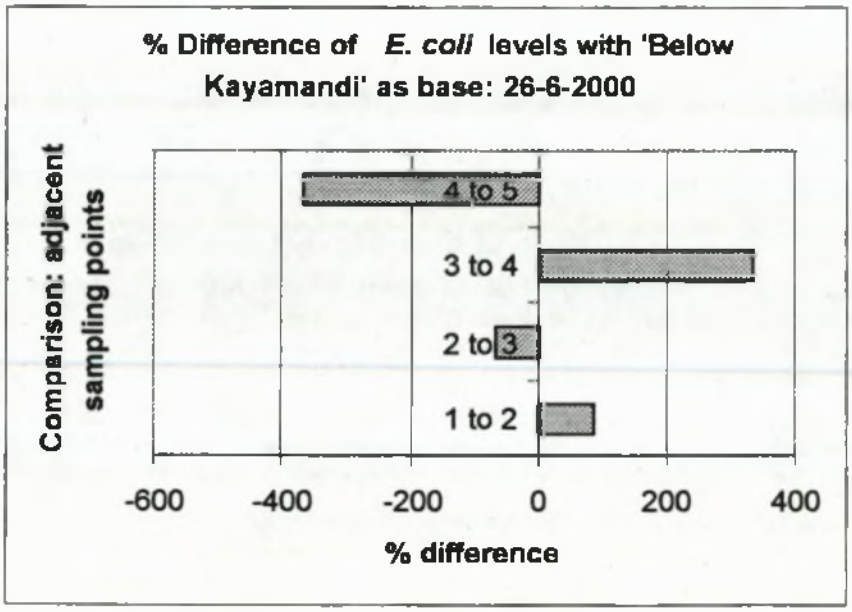

Fig. 5.1.6b % Difference of *E. coli* levels on 26 June 2000 with "Below Kayamandi" as base (= 100%)

On this sampling occasion there was an unusually large increase in *E. coli* levels at sampling point 4 and then a very steep reduction at sampling point 5.

Yet another pattern of pollution was observed on 24 April 2001 (Fig. 5.1.7a):

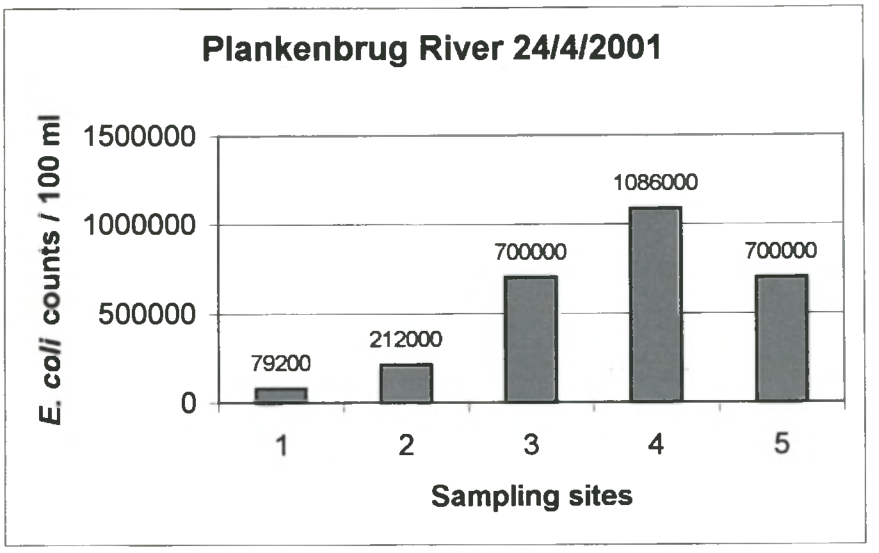

Fig. 5.1.7a *E. coli* counts on 24 April 2001

Fig. 5.1.7b depicts the 5 differences on 23 April 2001.

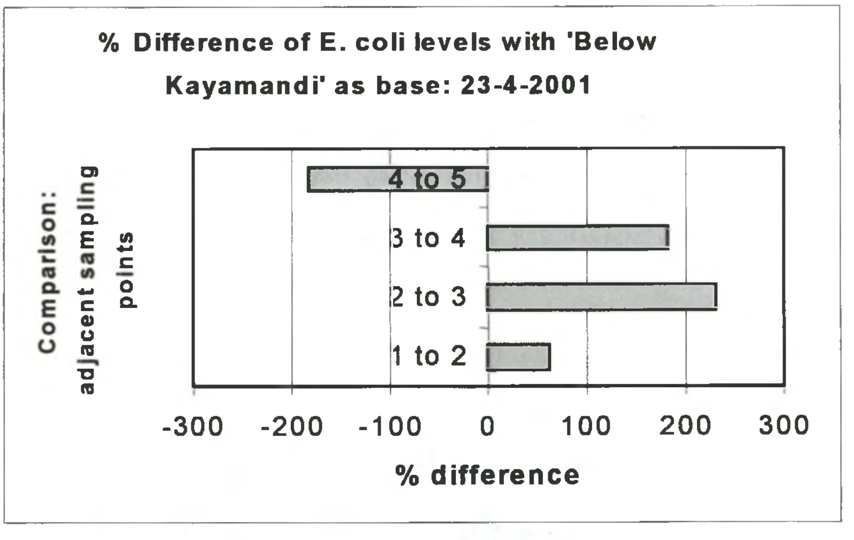

Fig. 5.1.7b % Difference of *E. coli* levels on 23 April 2001 with "Below Kayamandi" as base (= 100%)

Fig. 5.1.7a and 5.1.7b show that an elevated level of *E. coli* organisms occurred along the entire lower stretch of the Plankenbrug River on this sampling occasion. This increased level is significantly higher than the contribution coming from Kayamandi (sampling site 2).

Attempts to relate the "unexpected" patterns in *E. coli* levels observed to any sewage intrusions, overflowing sewers and drains, etc were complicated by the stealthy nature of some of these happenings. Some of the pipes run underground for some distance; some are gravity-fed, while others are pumped (resulting in higher pressure with concomitant increase in leaks). In the industrial area pollution events occur due to unauthorized disposal of forbidden substances during the hours of darkness or unobtrusively into the stormwater drainage system. It was not possible for the candidate to "police" all these happenings all the time. It became clear however, that no inspections of the uses and possible misuses of the stormwater and sewage systems were carried out by the relevant authorities.

If the description of an expected pattern compatible with a point source pollution (monotone descending after the point of pollution entry) is kept in mind, then only 10 out of the 39 sampling occasions fitted this description (25,6%). This indicates that, over the five years of the study, sewage intrusion from whatever sources occurred on 69% of the sampling occasions.

<u>The role of rainfall and temperature in the pollution levels</u>

Fig. 5.1.8 depicts the statistical relationship between rainfall during the previous 7 days, and the air temperature over the previous 3 days at the sampling site "Below Kayamandi" and *E. coli* levels.

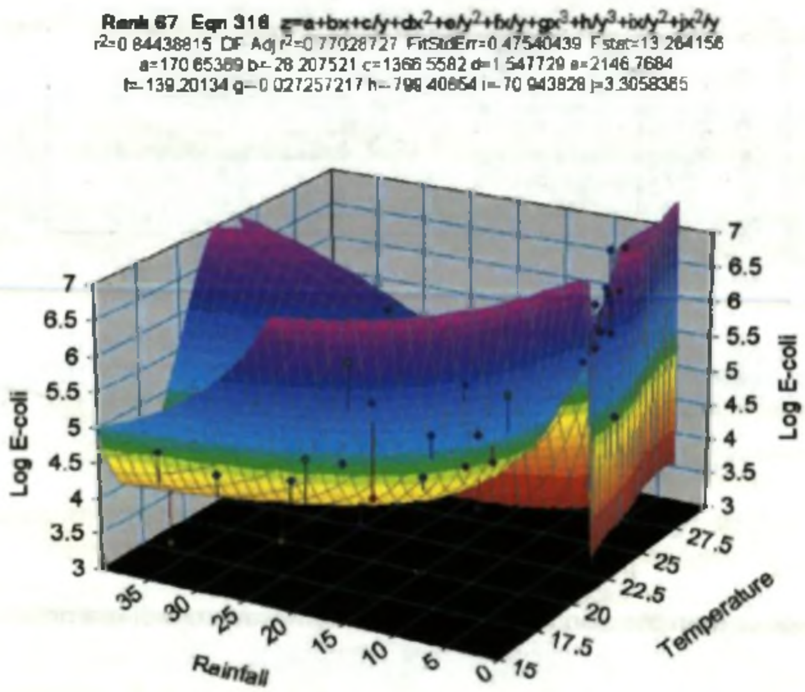

Fig. 5.1.8 Relationship between rainfall in the previous 48 hours, air temperature at the sampling site and *E. coli* levels

The equation on which this graphic depiction is based, is:

$$z = a+bx+c/y+dx^2+e/y^2+fx/y+gx^3+h/y^3+ix/y^2+jx^2/y$$ where

a = 170.65369
b = 28.207521
c = 1366.5582
d = 1.547729
e = 2146.7684
f = 139.20134
g = 0.027257217
h = 799.40654
i = 70.943828
j = 3.3058365

This is one of a series of a Chebychev polynomials[7], chosen to give the best fit of the data coupled with the best stability under conditions of small data changes.
The correlation coefficient was r = 0.9189.

Two models were constructed for prediction of the last two sampling occasions: one where temperature and rainfall were taken into account to calculate expected E. coli levels (3D model) and one where only temperature was used (2D model). On the last two sampling dates, the model was used to predict the *E. coli* levels, based on the observed air temperature and rainfall. This prediction was carried out before the results of the *E. coli* determinations were available from the laboratory. The following results were obtained: On 24/6/2002 the range predicted was 31 623 to 38 904 *E. coli* per 100 ml water and the actual observation was 493 000 organisms. On 19/8/2002 the predicted range was 7 079 to 15 849 *E. coli* organisms, while the observed value was 79 000 *E. coli* organisms. The model was constructed on the actual *E. coli* levels obtained during the first four and a half years of study while taking into account the temperature and rainfall data. It therefore fits the observed situation closely. The fact that the subsequent levels actually obtained were consistently worse than the model predicted that they should be, indictated that the pollution situation in the Plankenbrug River was getting worse when measured against the past performance of the same river.

5.1.4 Discussion

The data presented in this substudy are uniquely valuable for the study of the effects of failing sanitation on the environment. This is the most extensive longitudinal study including microbiological determinations of a single river complex below an informal settlement in South Africa. An extensive search of the databases of the research institutions in South

Africa as well as the unpublished sources available at the University of Stellenbosch where most of the work on the Plankenbrug River had been done in the past, revealed no information on microbiological pollution levels. The availability of information on seasonal fluctuations in *E. coli* levels enables the researcher to judge whether the pollution situation in the Plankenbrug River is actually deteriorating or whether the changes are merely attributable to seasonal variation or changes in the weather.

Drinking water should contain no *E. coli* organisms.[2,3] For irrigation purposes, the international requirement is that the level should not rise above 2000 organisms per 100 ml water.[4,5] Above that level, the hazards increase with increasing organism count and no direct contact with humans, animals or crops should occur. Such water could be dangerous to health. High levels of *E. coli* also indicate that there is an increased likelihood of other pathogenic organisms being present. Over the entire 5 years of the study, the observed *E. coli* counts were dangerously high, especially during summer when peak water extraction from the Eerste River Catchment system occurs. In early summer 2000, the *E. coli* counts reached a peak of almost 13 million organisms per 100 ml water (Fig. 5.1.1).

Comparison of the levels of *E. coli* observed in the Plankenbrug River with those observed in other studies, even from sites elsewhere in Africa,[8-10] is scientifically questionable. The time lapsed between published studies and the present one, specific environmental considerations, varying climatic conditions, sources of pollution, soil types and agricultural and industrial activity at each study site all contribute to a complex pattern of influences that preclude direct comparisons.

In order to illustrate the seriousness of the situation regarding the Plankenbrug River, the following quantification of the risk of developing illness after contact with such water is a better indication of the risk involved. Risks of health effects associated with contact recreational water use increase as *E. coli* levels increase.[11] According to the South African Water Quality Guidelines[11] (adopting a formula developed by the Environmental Protection Agency of the United States of America[12]), the number of gastrointestinal illnesses can be expected to increase using the following equation: $y = -150.5 + 423.5(\log x)$,
where y = illness rate per 100 000 persons exposed and x = number of *E. coli* organisms per 100 ml water ($x \geq 3$). If this formula is applied to the summer means of the numbers of *E. coli* organisms found in the Plankenbrug River, it follows that 2606.9 cases of gastrointestinal illness per 100 000 of exposed persons can be expected if recreational contact with the

water below Kayamandi takes place on a regular basis. The corresponding figure for Before Gilbeys is 2546.7 cases of gastrointestinal illness per 100 000 of the exposed population.

5.1.4.1 Effects of intervention of DANCED project

Over the five years of study, the pollution loads in the river followed the pattern expected in a winter rainfall climate, albeit at very high levels. The expected fluctuations between winter troughs and summer peaks over the first two years (1998 to early 2000) can be seen in Fig. 5.1.1. The reductions seen after that date can in large part be ascribed to the interventions in education and maintenance of sanitation systems during the DANCED project. The levels started rising as soon as the DANCED project came to an end (Fig. 5.1.1). The *E. coli* levels obtained at the sampling point "Below Kayamandi" for a few sampling occasions before the end of the DANCED project and the first sampling occasion three months after the project ended are depicted in Fig. 5.1.2. As soon as good maintenance together with the continual reminder of good sanitation behaviour provided by the education campaigns ceased, the level increased dramatically. This shows conclusively that upkeep of the sanitation facilities already in place in Kayamandi, when accompanied by encouragement towards better sanitation behaviour, can make a difference in a situation that many officials and inhabitants alike described as hopeless.

The information in Fig. 5.1.1 and Fig. 5.1.2 indicate that, even if no extra sanitation facilities are erected, education coupled with good maintenance of the present facilities can definitely make a difference to the pollution load in the Plankenbrug River, but that a sustainable effort should be made to continue with the strategy until better sanitation behaviour has become entrenched in the community. The pollution loads during the summer of 2001/2002 were the lowest summer values for the duration of the project. At least the decreased pollution loads during the campaigns showed that there is no substance to the often repeated opinion that inhabitants of poverty-stricken dense settlements cannot be induced to change their sanitation behaviour.

5.1.4.2 Other sources of pollution

Kayamandi is by no means always the major source of *E. coli* organisms in the river. Other sampling dates with anomalous results indicating sewage intrusion from sources other than Kayamandi were illustrated in Figs. 5.1.4 to 5.1.7.

In Fig. 5.1.5 the sharp drop in *E. coli* levels observed after sampling site 3 is almost certainly ascribable to the intrusion of winery effluent into the river at that point. There are wineries and a wine bottling plant situated on the river banks around that sampling site. It is known that such intrusions occur into the river at the Adam Tas Bridge. On many sampling occasions the candidate herself had noted a strong smell of fermentation in the water at that point and debris typical of winery waste (packaging material bearing the cellar logo's, wine bottle labels in large rolls ready for pasting, bottle sleeves, etc) were found in the river. The wineries concerned received warning letters from the Dept of Water Affairs and Forestry after an inspection by departmental officials found that cellar wastewater was channelled into stormwater drains. Despite the warnings, no improvement in the situation was observed over the five years of study.

The information presented in Fig. 5.1.5 to 5.1.7 clearly show that there are other points of entry for sewage into the Plankenbrug River. Large amounts of sewage has to be piped across the river in bulk carrier lines. In some instances the sewage entering the river below Kayamandi was several times larger than the load coming from Kayamandi itself. Kayamandi had always been regarded as the "obvious" source of faecal pollution in the Plankenbrug River. This assumption tended to undermine the vigilant observation of the actual situation. The local authority did not carry out regular inspections of the main sewage lines during the five years of study and the Chief Pollution Control Officer of the Dept of Water Affairs and Forestry (in the presence of the candidate) could not obtain any information on such inspections. This situation needs urgent attention, as systems failures such as these results suggest, should be rectified as soon as possible. Upgrading of the sewage system (if needed) as well as much more frequent monitoring of main sewage lines crossing the river should be instituted without delay to avoid future contamination.

If the sanitation systems along the Plankenbrug River continue to fail on such a large scale, it is reasonable to assume that the risk of the river eventually being contaminated by organisms such as *Vibrio cholerae* will increase. This will have a huge impact on the health status and economic activity of the region since tourism, agriculture and tertiary education are the three major enterprises sustaining the immediate district.

5.1.4.3 Model of temperature, rainfall and *E. coli* levels

The model generated in this study (Fig. 5.1.8) is not a statistical model in the classic sense, where theoretical values are generated in order to predict results under different conditions.

This is rather an accurate reflection of how the *E. coli* levels varied at the sampling point "Below Kayamandi" in relation to its two greatest contributing variables, temperature and rainfall. This was constructed as a statistical tool to use as a yardstick in subsequent sampling sessions in order to determine whether the pollution loads observed were deteriorating (given the temperature and/or rainfall). Since temperature and rainfall play such a crucial role in influencing *E. coli* levels in river water, a crude "inspection by eye" of values obtained a few weeks apart can give a very inaccurate picture of the changes observed. As can be seen from the large differences between the predicted and observed levels at the last two sampling occasions, the pollution levels were consistently higher than previously observed over the four years, given the temperature and rainfall. Based on the scientific observations of pollution levels, temperature and rainfall, it can therefore be said that the pollution situation in the Plankenbrug River is deteriorating.

At present, this mathematical model cannot be extrapolated to other climate situations and other river systems. It was developed on this specific river system and climate zone. It is not possible to distinguish at present between those factors contributing to the model that are unique to this specific situation and those factors that would be universal for other river systems inside the climate zone, or indeed outside of it. If such models could be developed after more catchment systems have been studied, it would greatly help to forecast where pollution levels are deteriorating without the need for many costly and onerous sampling rounds. This will facilitate the monitoring of the microbiological health of our river systems within the budget constraints facing South Africa as a low to middle income country with many other demands on its fiscal budget.

References to Substudy 1

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SUBSTUDY 2

Water Chemistry in the Plankenbrug River as Background to the Faecal Pollution Determinations

5.2.1 Introduction

There are few chemical constituents of water that can lead to acute health problems except through massive accidental contamination of a water supply.[1] Moreover, such water usually becomes undrinkable owing to unacceptable taste, odour and appearance. The fact that chemical contaminants are not normally associated with acute effects, place them in a lower priority category than microbial contaminants, the effects of which are usually acute and widespread.[1] Indeed, it can be argued that chemical standards for drinking water are of secondary consideration in a supply subject to severe bacterial contamination.[1]

The objective of this substudy was to determine the predictive ability of various combinations of the chemical parameters to indicate faecal contamination. The relationship between the parameters of river chemistry and faecal contamination in the dataset was explored. Of special interest was the predictive ability of various chemical parameters to indicate faecal contamination, since the data set is unique in its availability of chemical and microbiological determinations on the same samples.

The Department of Water Affairs and Forestry (DWAF) carry out regular water quality monitoring of major rivers as part of their mandate. In the Western Cape routine microbiological analyses are only carried out in rare instances, however. DWAF does not monitor for microbiological contamination except under exceptional circumstances, citing cost and technical complications. The chemistry determinations are used as a *de facto* indication of overall water quality. It was postulated that this approach has poor prognostic ability and this required investigation.

5.2.2 Methods

Analysing laboratories

For the first two years, the determinations were done at the laboratories of the Council for Scientific Research (CSIR) in Stellenbosch and paid for by own research funds and thereafter at the South African Bureau of Standards (SABS) in Rosebank under a Dept of Water Affairs and Forestry (DWAF) contract. The results of both the microbiological determinations and the chemistry analyses were shared with the relevant DWAF authorities. The present project provided the DWAF officials with the results of the microbiological analyses on a *quid pro quo* basis.

Collection of samples

During the first two years the samples were drawn in autoclaved sample bottles in exactly the same manner as for the microbiological samples. This represents higher requirements than normally employed for chemistry samples. The samples for chemical analyses were drawn immediately before the samples for microbiological analyses and transported on ice to the CSIR laboratory at Stellenbosch. The samples were delivered to the laboratory within 1 hour of sampling.

After the first two years, the samples for the chemistry analyses were drawn by the candidate according to the instructions given by DWAF and in sample bottles provided by DWAF. Samples were drawn at the same spot directly before those for the microbiological analyses. According to the instructions, the sample bottles had to be opened under water to let some water in, and then closed under water, the contents swirled around and then discarded. The same procedure had to be repeated and the bottle then filled, taking care always to open and close the bottle under water. The sample had to be taken with the open bottle about 30 cm under the surface (where possible) and facing the inflowing stream. Samples were transported on ice and given to the relevant DWAF official who then took it to the SABS in Rosebank. The results were sometimes only available weeks after sampling and samples got lost on occasion. Some of those were later located, but one set of data could not be retrieved.

The standard package of variables analysed for by the two different laboratories differed somewhat, but the 'core' variables remained the same. The levels of the following parameters were determined by the CSIR at Stellenbosch (May 1998 to March 2000): potassium (mg K/*l*), ammonia (mg N/*l*), nitrate and nitrite (mg N/*l*), orthophosphate (mg P/*l*), dissolved organic carbon (mg C/*l*), electrical conductivity (mS/m at 25°C) and pH (at 25°C). The SABS used a different 'standard package' of analyses and the water chemistry determinations carried out after March 2000 were: suspended solids (at 105°C in mg/*l*), free and saline ammonia (mg N/*l*), nitrate and nitrite (mg N/*l*), orthophosphate (mg P/*l*), dissolved organic carbon (mg/*l*), electrical conductivity (mS/m at 25°C), chemical oxygen demand (as mg O_2/*l*) and pH (at 25°C).

Water chemistry parameters are usually interpreted as being below certain set cut-off values (acceptable) or exceeding these values by increasing amounts, representing increasing levels of unacceptability. These cut-off values are closely linked to the intended water use. Different standards are in place for, e.g. drinking water quality, than for industrial use or irrigation.[2-11]. The following are a summary of these cut-off values (all values given as drinking water guidelines unless otherwise stated):

Potassium

South African Bureau of Standards[2]*:*

Ideal: <25 mg/*l* water

Acceptable: 25-50 mg/*l* water

Maximum allowable: >50-100 mg/*l* water

Water Quality Guidelines Domestic[3]

Class 1: 0-50 mg/*l* water = no effect

Class 2: 50-100 mg/*l* water

Class 3: 100-400 mg/*l* water

Class 4: >400 mg/*l* water

Suspended solids

SA Water Quality Guidelines (irrigation)[4]

Class 1: 0-<50 mg/*l* water (for clogging of drip irrigation systems)

Class 2: 50-100 mg/*l* water

Class 3 >100 mg/*l* water

Ammonia

SABS[2]

Ideal: <0.2 mg/*l* water

Acceptable (Class I): 0.2-1.0 mg/*l* water

Maximum allowable (Class II): >1.0 - 2.0 mg/*l* water

Nitrate+Nitrite

SABS[2]*:*

Ideal: <6 mg/*l* water

Acceptable: 6-10 mg/*l* water

Maximum allowable: >10-20 mg/*l* water

Water Quality Guidelines Domestic[3]

Class 1 (ideal): <6 mg/*l* water

Class 2 (good): 6-10 mg/*l* water

Class 3 (marginal): 10-20 mg/*l* water

Class 4 (poor or completely unacceptable): >20 mg/*l* water

Water Quality Guidelines Irrigation (nitrogen)[4]

Class 1: <5 mg/*l* water

Class 2: 5-30 mg/*l* water

Class 3: >30 mg/*l* water

Orthophosphate

SABS Drinking water standard[2]: No standard

SA Water Quality Guidelines[5] *Industry*

Category 1: 0-3 mg/*l* water (Target value)

Category 2: 0-5 mg/*l* water

Category 3: 0-5 (15?) mg/*l* water

Category 4: 0-25 mg/*l* water

Water Quality Guidelines Domestic Use[3]: No guidelines

Water Quality Guidelines Irrigation[4]: No guidelines

Dissolved organic carbon

SABS[2]

Ideal <5 mg/*l* water

Acceptable (Class I) 5-10 mg/*l* water

Max allowable (Class II): >10-20 mg/*l* water

Water Quality Guidelines Domestic Use[3]

1: 0-5 mg/*l* water

2: 5-10 mg/*l* water

3: 10-20 mg/*l* water

4: >20 mg/*l* water

Water Quality Guidelines Irrigation[4]: No guidelines

Electrical Conductivity

SABS[2] Ideal: <70 mSm/m

Acceptable: 70-150 mS/m

Maximum allowable: 150-370 mS/m

Water Quality Guidelines Domestic Use[3]: No guidelines

Water Quality Guidelines Irrigation[4]: No guidelines

Chemical Oxygen Demand

SABS[2]: No standard

SA Water Quality Guidelines[6] *Industry*

Category I: 0-10 mg/*l* water (Target value)

Category 2: 0-15 mg/*l* water

Category 3: 0-30 mg/*l* water

Category 4: 0-75 mg/*l* water

Water Quality Guidelines Domestic Use[3]: No guidelines

Water Quality Guidelines Irrigation[4]: No guidelines

pH at 25°C

SABS[2]:

Ideal: 6-9

Acceptable: 5-9.5

Maximum allowable: 4-10

Water Quality Guidelines Domestic[3]

Very poor to completely unacceptable: <4

Poor: 4-6

No significant health effect: 6-9

Marginal: 9-11

Very poor to completely unacceptable: >11

Water Quality Guidelines Irrigation[9]

Class 1: <6.5

Class 2: 6.5-8.4

Class 3: >8.4

E. coli

SABS[7]:(drinking water)

95% of samples: no organisms detected

Water Quality Guidelines Domestic[11]

Faecal coliforms

1 (ideal): 0 organisms per 100 m*l* water

2 (marginal): 0-10 organisms per 100 m*l* water

3 (poor, clinical infections common): 10-100 organisms per 100 m*l* water

4 (completely unacceptable, serious health effects common): >100 organisms per 100 m*l* water

Water Quality Guidelines Irrigation Crop Quality[4]

Class 1: <1 per 100 m*l* water

Class 2: 1-1000 per 100 m*l* water

Class 3: >1000 per 100 m*l* water

5.2.3 Results

Correlation between chemistry and *E. coli* levels

The r^2 values obtained on correlating the chemical parameters with *E. coli* levels are given in Table 5.2.1. (Note: $100r^2$ denotes the percentage of variation in *E. coli* levels explained by variation in the chemical parameter in question).

Table 5.2.1 Variation in *E. coli* levels explained by various chemical parameters

Chemical parameter	**r^2 with *E. coli* level**
Dissolved organic carbon (with log *E. coli*)	0.0474
Suspended solids	0.1525
Ammonia (with log *E. coli*)	0.5537
Nitrate and nitrite	0.5606
Nitrate and nitrite (with log *E. coli*)	0.5057
Chemical oxygen demand	0.5377

According to the standards listed above the number of samples exceeding the given levels are listed in Table 5.2.2 and 5.2.3.

Table 5.2.2 The number of samples on each sampling date during the period that 8 sampling sites were used that exceeded standards as specified by various sources

Sampling session	Sampling date	Ammonia	Nitrate+Nitrite	Dissolved organic carbon
1	04-05-98	5		1
2	29-06-98	1		1
3	17-08-98			1
4	28-09-98	1		2
5	08-11-98	1		6
6	07-12-98	4		1
7	25-01-99	2		5
8	01-03-99	4		7
9	12-04-99	5		7
10	17-05-99	5		
11	22-06-99	1		7
12	10-08-99			3
13	14-09-99			8
14	25-10-99	1		1
15	06-12-99	4		6
16	24-01-00	3		3
17	28-02-00	4	1	5
18	27-03-00	4		1
Cut-off value used		1 mg/*l* water	6 mg/*l* water	10 mg/*l* water
% of samples exceeding cut-off over total period		31,25%	0,69%	44,44%

There were no instances where potassium, orthophosphate, electrical conductivity and pH exceeded the standards used in the period specified.

Table 5.2.3 The number of samples on each sampling date during the period that 5 sampling sites were used that exceeded standards as specified by various sources

Sampling session	Sampling date	Suspended Solids	Ammonia	Nitrate+Nitrite	Dissolved Organic Carbon	Chemical Oxygen Demand
19	15-05-00		4		3	4
20	26-06-00		4		5	5
21	08-08-00		4		5	3
22	11-09-00		1		5	5
23	23-10-00		4		5	1
24	04-12-00	1	4		3	3
25	23-01-01		4		5	1
26	05-03-01		4		Missing*	1
27	23-04-01		4		5	4
28	28-05-01	1	4	1	5	4
29	23-07-01	1	1		5	3
30	03-09-01				5	1
31	15-10-01				5	
32	11-12-01		1		5	2
33	22-01-02				3	1
34	11-03-02		4		2	1
35	06-05-02	4			5	4
36	24-06-02		3		5	4
Cut-off value used		50 mg/l water	1 mg/l water	6 mg/l water	10 mg/l water	>30 mg/l water
% of samples exceeding cut-off over total period		7,7%	41,4%	1,1%	47,1%	52%

*Samples lost by the analysing laboratory

There were no instances where orthophosphate, electrical conductivity and pH exceeded the standards used during the sampling period.

The statistical relationships between *E. coli* levels (or the transformed logarithm) and the various chemical parameters are given in Fig. 5.2.1 to 5.2.4.

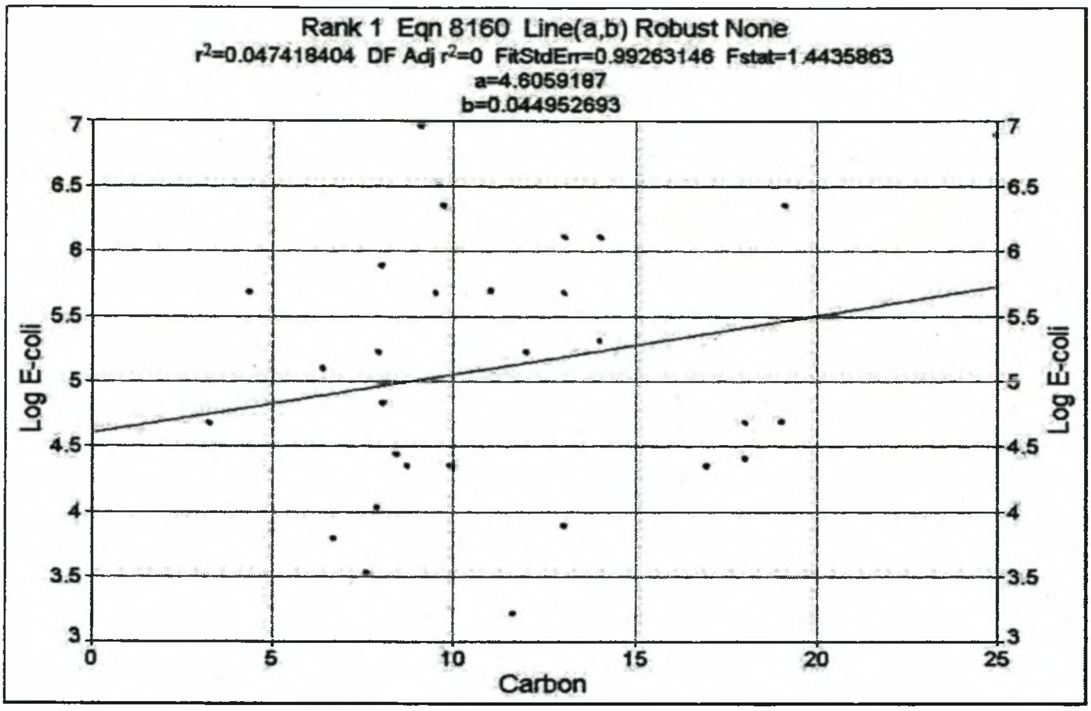

Fig. 5.2.1 Relationship of dissolved organic carbon with log *E. coli*

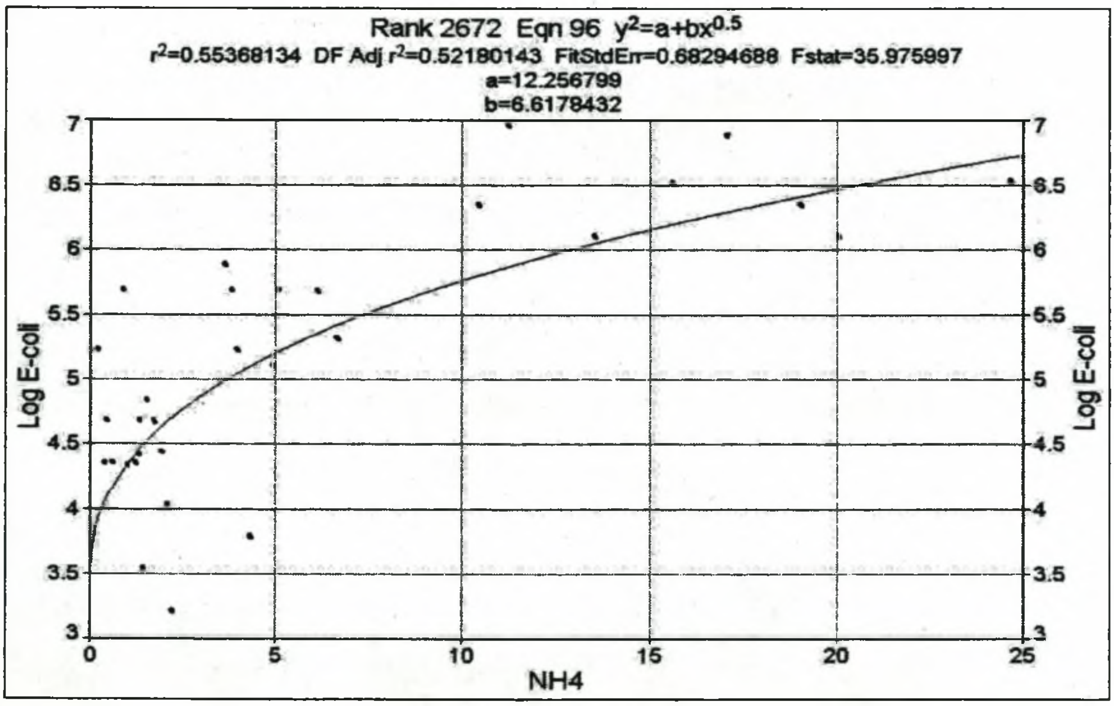

Fig. 5.2.2 Relationship of NH_4 with log *E. coli*

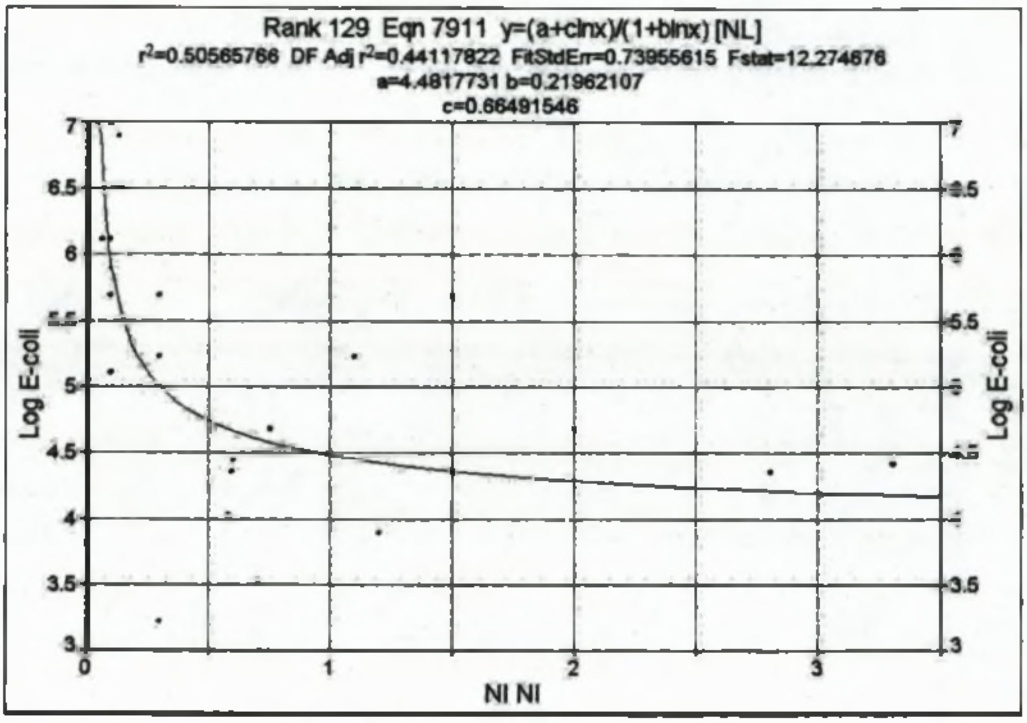

Fig. 5.2.3 Relationship of nitrites and nitrates with log *E. coli*

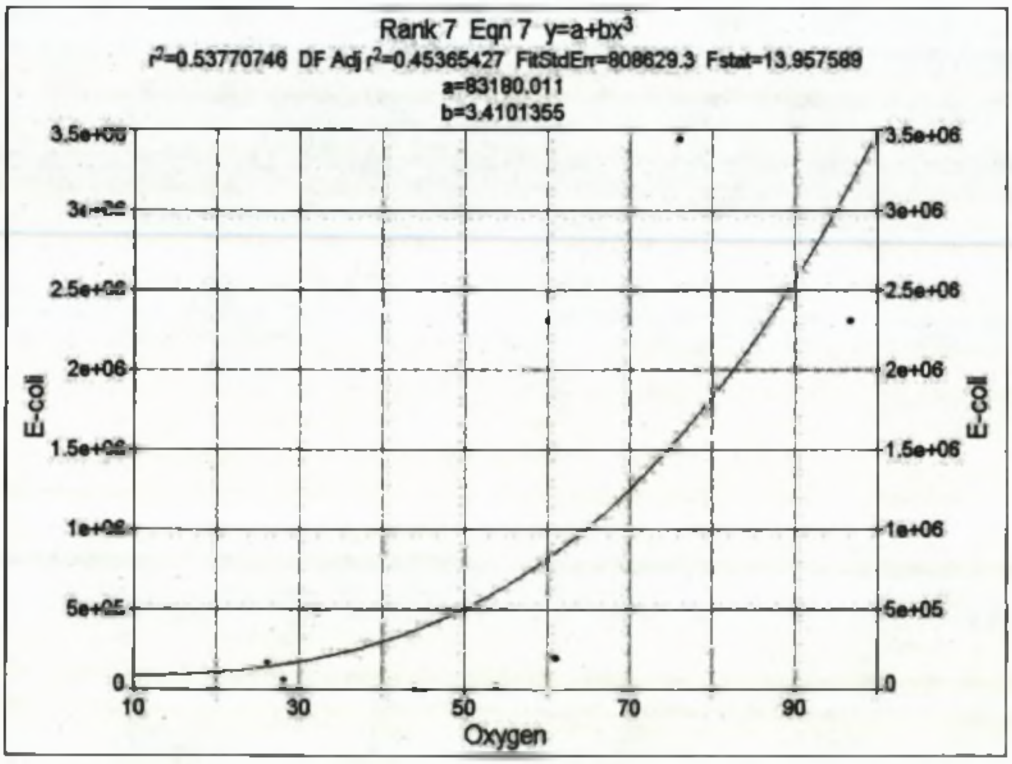

Fig. 5.2.4 Relationship of chemical oxygen demand with *E. coli*

5.2.4 Discussion

There were no instances where potassium (measured up to March 2000), orthophosphate, electrical conductivity and pH exceeded standards set by the various regulations that were used in this study. Suspended solids and nitrates and nitrites exceeded cut-off levels only on rare occasions. The impact of these parameters will not be discussed further.

Ammonia: Ammonia concentrations tend to be elevated in waters where organic decomposition takes place under anaerobic conditions. Ammonia is not toxic to man at the concentrations likely to be found in drinking water[2], but it does exert other effects. Elevated concentrations of ammonia can compromise the disinfection of water and can give rise to nitrite formation in distribution systems, which may result in taste and odour problems.

During the four years of sampling, ammonia levels were elevated above the cut-off concentration in 37.2% of total samples. This should be compared to the >90% of samples in this study that showed unacceptable *E. coli* levels (Fig 5.2.2). Ammonia can therefore not be used as a reliable surrogate predictor of microbiological pollution.

Dissolved organic carbon (DOC): DOC is the organic carbon present in water in the dissolved form, also referred to as that fraction able to pass through a 0.45 µm membrane filter.[3] The DOC content of water includes both low molecular weight volatile compounds and moderate to high molecular weight compounds. The presence of DOC can have adverse aesthetic implications (taste, odour and colour), which may be associated with both naturally occurring organic carbon and carbon originating from domestic or industrial effluent discharges. Elevated DOC may also affect light attenuation in rivers and streams, thus impairing the die-off of organisms sensitive to light.

Faecal pollution, and specifically *E. coli,* is supposed to show some association with dissolved organic carbon since the nutrients these organisms need are of an organic carbonaceous nature. This was not well supported by the present data as the DOC levels only exceeded the cut-off value in total on 45.4% of occasions. In contrast, it can be seen from Fig. 5.2.2 that all the sampling sites below the dense settlement of Kayamandi exceeded safe levels of *E. coli* on more than 90% of sampling occasions. This means that DOC was not a sufficiently reliable predictor of microbiological pollution (as indicated by *E. coli* levels) on which to base water quality monitoring.

Chemical oxygen demand (COD): The COD is the amount of oxygen required to degrade the organic compounds of water, mainly wastewater. The bigger the COD, the more oxygen the discharge into rivers demands from water bodies in order to break down the organic load it contains. As such it is a measure of water quality, but it has no direct health implications. No target water quality ranges are set for COD in the guidelines for drinking water[3], irrigation water[4], livestock watering[7], recreational water use[5], or aquaculture[6]. Only industrial water use has a set of guidelines[6]. COD is not a good predictor of the microbiological pollution levels as indicated by *E. coli* counts. COD was found to be elevated in 52% of samples taken, while the *E. coli* levels indicated a poor microbiological status in >90% of cases (Fig. 5.2.2).

Overall assessment of water chemistry: Viewed as an entire data set, the chemical parameters determined over the four years in this study showed a poor relationship with the information provided by the microbiological indicators.

The water chemistry parameters used in this study were those used in routine monitoring by the Department of Water Affairs and Forestry in the Western Cape. The samples were obtained in the same fashion as those taken by DWAF and analysed by the routine laboratories used by DWAF. According to the DWAF pollution control officials, microbiological analyses are too expensive and technically too difficult for DWAF to use as routine monitoring, mainly due to its meticulous sampling requirements and transport problems (e.g. short time allowed before arrival at laboratories and transport on ice). This study over four years has shown conclusively that such a policy carries a great risk of underestimating or even completely missing the true hazards associated with rivers subjected to uncontrolled waste discharge. None of the hazards uncovered by the microbiological assessments which have grave implications for human health, livestock watering, irrigation of edible crops, recreational water use, as well as hazards associated with aquatic ecosystems could have been identified by means of chemistry monitoring as implemented by DWAF. This then begs the question whether DWAF, as legal custodians of the water sources of a water-poor country, can afford to regard microbiological monitoring of a river catchment system as important as the Plankenbrug - Eerste River system as 'too expensive and too much trouble'.

In summary it can be said that, although the chemical parameters indicated unacceptable water quality in some instances, the overall picture presented by the chemical analyses are out of keeping with the dire situation revealed by microbiological monitoring.

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SUBSTUDY 3

Identification of the Most Likely Pathogens Involved in the Plankenbrug River by Additional Analyses of Water Samples

5.3.1 Introduction

Testing for every potential pathogenic organism in a river in order to monitor water quality is an expensive and technically problematic proposition. Thus, the concept of an indicator organism is used to indicate the possible presence of other disease-causing organisms. The coliform group of bacteria and specifically *Escherichia coli* are used as such indicators.[1,2] Once substantial numbers of *E. coli* are detected, it is prudent to assume that such water has been contaminated with faecal waste and that other, harmful pathogens are also present in significant numbers. Thus, the high *E. coli* numbers observed in the Plankenbrug River over the previous four years send a clear health warning.

The hugely elevated numbers of *E. coli* organisms found in the present study gave rise to the need to ascertain what other pathogens were present in the Plankenbrug river, so as to be better prepared for any health crises that may ensue. In other words, what other pathogens occur in the Plankenbrug River for which *E. coli* acts an indicator?

Besides the water in the river, which had already been shown to carry huge bacterial loads, the biofilms on the stones and other surfaces in the riverbed were also of epidemiological and clinical importance. Biofilms can be defined as communities of micro-organisms attached to a surface.[3] Micro-organisms undergo profound changes during their transition from planktonic organisms to cells that are part of a complex, surface-attached community. It is known that biofilm bacteria are significantly less susceptible to biocides than planktonic cells.[4] Micro-organisms growing in a biofilm are resistant to antimicrobial agents by one or more mechanisms.[5] Biofilms also provide a niche for the generation of resistant organisms.[5,6] Biofilms can form rapidly in raw or treated potable water, even in the presence of 1 to 2 mg/litre free chlorine residual.[7]

For these reasons, water and stones with visible biofilms from the Plankenbrug River were cultured to determine the clinically most important genera present. Where possible, the identification was taken down to species level. Due to the vast number of organisms present and the limited scope of the pilot study, it was not possible to take many of the analyses further.

5.3.2 Materials and methods

Water samples were collected on two occasions in the same manner as for enumeration of *E. coli*, described under Section 3.2.[8-10] The samples were obtained at the sampling points called "Below Kayamandi" and "Before Gilbeys" on 19 March 2002 and 15 April 2002. The sample run of 11 February 2002 was collected only from Below Kayamandi and was used as an initial pilot study.

Below the water surface stones with visible biofilms were also collected at the same points where the free-flowing water samples were taken on 19 March and 15 April 2002. The water was so polluted at these sampling points that all objects below the water surface (tins, branches, pieces of cement and brick and other rubbish) that were present for any length of time were covered in a grey slime. Only non-porous natural stones were collected, as the highly alkaline composition of lumps of cement (for example) may have altered the bioslime community growing on the surface. The stones were placed in airtight new plastic bags and sealed until sonication.

The water samples and the bagged stones were transported in coolbags and on ice (as previously described). The stones were sonicated within 15 minutes of collection at the Dept of Microbiology at the Stellenbosch campus in approximately 100 ml sterile deionised water for 6 minutes to loosen the biofilm and bring it into resuspension. The resultant water was carefully decanted into autoclaved sample bottles and immediately transported on ice to the Department of Medical Microbiology at Tygerberg Hospital where the analyses were carried out.

The water samples were thoroughly mixed and a mini most-probable-number determination, a faecal coliform determination and a confirmatory test for *E. coli* were carried out on all samples. After 24 h and vortex mixing, 1 ml water and 10 ml laurel tryptose broth (Oxoid) were inoculated onto plates or nutrient broth by means of a drop glass pasteur pipette (a) directly from the sample, and (b) after 48 h of incubation from the positive laurel tryptose broth tubes.

Any colony morphologically resembling a human pathogen was identified by routine microbiological techniques as follows:

A Blood agar plates: [Tryptose blood agar, Base: Biolab (Merck) to which horse blood was added] Samples were incubated aerobically at 35° in an atmosphere of 5% CO_2 for 20 to 24 hours, and anaerobically at 37°C for 24 to 48 hours.

B McConkey agar plates [McConkey agar base: Biolab (Merck) without crystal violet and with salt]

C Campylobacter agar plates [Columbia agar base (Oxoid) to which horse blood was added]. Samples were incubated in a micro-aerophyllic environment in an Oxoid plastic anaerobic jar at 37°C

D Salmonella and Shigella agar plates [SS agar Biolab (Merck)]

E XLD agar plates [Xylose lysine desoxycholate agar, Biolab (Merck)]

F Brain heart infusion broth [Biolab (Merck)] - A liquid infusion medium for the cultivation of most bacteriae

G Tetrathionate Broth [Tetrathionate broth base (Oxoid)]

H Mycobacterium

Aliquots of 30 ml water were taken directly from the sample bottles. These were centrifuged for 20 minutes at 3000 rpm. The samples were decontaminated with 4% NaOH + 4% $NaSO_3$ v/v and left for 20 minutes in an incubator at 37°C. The samples were then neutralized with PO_4 buffer pH 6.8 (equal volumes) and immediately centrifuged for 20 minutes at 3000 rpm. The supernatant was decanted and 0,5 ml of the deposit was inoculated into a Bactec 12B mycobacteria (Middlebrook 7H12) medium for culturing mycobacteria. The samples were then incubated at 37°C for 8 weeks and readings in the Bactec machine were done once a week until the samples were positive. When a positive reading was obtained, a Ziehl-Nielsen stain, positive for acid-fast bacilli, was performed. The positive sample was then sent to Groote Schuur Hospital for identification by means of a polymerase chain reaction method. This procedure was carried out on two sampling occasions (11 February 2002 and 19 March 2002).

The identities of the Group A and Group B streptococci were confirmed by appropriate testing, including Lancefield serogrouping.

Not all organisms were identified up to species or subspecies level. The aim was rather to get an overview of the types of organisms with potential implications for human disease present in the Plankenbrug River. Water samples were provided to Prof Maureen Taylor of the Department of Virology of Pretoria University for investigation of viral organisms and to Dr Wesaal Khan of the Department of Microbiobiology of Stellenbosch University for the investigation of the presence of *E. coli* O157H7. They will report on these investigations separately.

5.3.3 Results

The organisms identified in the samples taken on various occasions are listed in Tables 5.3.1 to 5.3.5.

Table 5.3.1 Organisms isolated from the water sampled below Kayamandi on 11 February 2002

β haemolytic Streptococcus Group A* (*S. pyogenes*)
Acinetobacter spp.
Citrobacter spp.
Coagulase negative staphylococci
Enterococcus faecalis
Escherichia coli (4 morphologically distinct colony types)
Klebsiella spp. including *K. pneumoniae, K. ozaenae*
*Mycobacterium intracellulare***
Proteus mirabilis, *P. vulgaris*
Providencia rettgeri
Pseudomonas spp. including *P. aeruginosa*
Staphylococcus aureus
Viridans group of streptococci

*This was confirmed as Lancefield Group A

**Identified by means of polymerase chain reaction by the Dept of Microbiology, University of Cape Town

Table 5.3.2 Organisms isolated from the water sampled on 19 March 2002

Water sample "Below Kayamandi"	**Water sample "Before Gilbeys"**
β haemolytic Streptococcus Group B* (*S. agalactiae*)	*Acinetobacter* spp.
Viridans group of streptococci	*Citrobacter* spp.
Acinetobacter spp.	Coagulase-negative staphylococci
Citrobacter spp.	*Enterobacter* spp.
Coagulase-negative staphylococci	*Enterococcus faecalis*
Enterobacter spp.	*Escherichia coli*
Enterococcus faecalis	*Klebsiella* spp.
Escherichia coli (4 morphologically distinct colony types)	*Proteus* spp. including *P. mirabilis*
Klebsiella spp.	*Providencia* spp.
*Mycobacterium intracellulare***	
Proteus spp. including *P. mirabilis*	

* These organisms were identified in two different cultures and confirmed as Lancefield Group B.

** Identified by means of polymerase chain reaction by the Dept of Microbiology, University of Cape Town

Table 5.3.3 Organisms isolated from biofilms on stones sampled on 19 March 2002

Stone sample "Below Kayamandi"	**Stone sample "Before Gilbeys"**
Acinetobacter spp.	*Citrobacter* spp.
Citrobacter spp.	Coagulase-negative staphylococci (in large numbers)
Coagulase-negative staphylococci	*Escherichia coli*
Enterobacter spp.	*Proteus* spp.
Enterococcus faecalis	*Pseudomonas* spp.
Escherichia coli	
Klebsiella spp.	
Proteus spp.	
Providencia spp.	
Viridans group of streptococci	
Yersinia spp.	

Table 5.3.4 Organisms isolated from the water sampled on 15 April 2002

Water sample "Below Kayamandi"	Water sample "Before Gilbeys"
Acinetobacter spp. including *A. lwoffii*	*Acinetobacter baumanii*
Bacillus spp. including *B. subtilis*	*Citrobacter* spp.
Citrobacter spp.	Coagulase-negative staphylococci
Coagulase-negative staphylococci	*Enterobacter cloacae*
Enterobacter cloacae	*Escherichia coli*
Escherichia coli	Gram-positive bacilli
Klebsiella pneumoniae	*Klebsiella ozaenae*
Klebsiella oxytoca	*Proteus* spp.
Proteus spp.	*Streptococcus* spp.
Enterococcus faecalis	

Table 5.3.5 Organisms isolated from biofilms on stones sampled on 15 April 2002

Stone sample "Below Kayamandi"	Stone sample "Before Gilbeys"
Acinetobacter spp. including *A. lwoffii*	*Acinetobacter baumanii*
Alcaligenes spp.	*Bacillus* spp. including *B. subtilis*
Bacillus subtilis	*Citrobacter* spp.
Citrobacter spp.	Coagulase negative staphylococci
Coagulase negative staphylococci	*Edwardsiella* spp.
Enterobacter spp. including *E. aerogenes*	*Enterobacter* spp.
Enterococcus faecalis	*Enterococcus faecalis*
Escherichia coli	*Escherichia coli*
Klebsiella spp. including *K. pneumoniae* and *K. oxytoca*	*Klebsiella* spp.
Proteus spp.	*Streptococcus* spp.
Providencia spp.	
Streptococcus spp.	
Viridans group of streptococci	

5.3.4 Discussion

Many of the organisms listed above also occur in the natural environment and are known to be able to survive in free-flowing surface water.[11-17] The numbers of these organisms in the Plankenbrug River were however greatly elevated above the levels normally encountered.

Only organisms that are potential human pathogens were listed in Tables 5.3.1 - 5.3.5 and not even all of these could be pursued to full identification. The range of potentially dangerous pathogens identified is another indication that this river is severely polluted and constitutes a health hazard as well as a danger to the environment.

One of the organisms isolated in February 2002, namely β haemolytic *Streptococcus* Group A, was a significant find. An extensive search of the Medline database of 11 million research articles yielded only nine references to haemolytic streptococci in association with water. All of these except one were related to water in treatment apparatus such as inhalation systems. Only one made mention of free flowing water in the environment.[18] The authors reported streptococcal disease in children from poor areas in Thailand reportedly being exposed to dirty water.[18] No direct connection was made between the water and the infections and the organisms were not isolated from the water in that study.

Diseases attributable to infection with β haemolytic *Streptococcus* Group A (*S. pyogenes*) and their byproducts include streptococcal sore throat, cellulitis, necrotizing fasciitis, infection of the upper respiratory tract with rapidly progressive pneumonia, local infection of superficial layers of skin (impetigo), especially in children, acute and subacute endocarditis, streptococcal toxic shock syndrome and the clinically overlapping syndrome of scarlet fever.[19] Other infections recorded include urinary tract infections and wound infections.[19] In all these clinical conditions, pre-existing disease affecting the immune system of the patient will cause more severe symptoms. The post-streptococcal diseases include rheumatic fever and glomerulonephritis.[19] Since there is a high TB and HIV infection rate as well as malnutrition in Kayamandi, many inhabitants can be classified as living with impaired immune systems. They are increasingly at risk of environmentally acquired infection with β haemolytic *Streptococcus* Group A.

The fact that β haemolytic *Streptococcus* Group A organisms have been isolated in a viable state from river water below Kayamandi is scientifically remarkable and its implications cannot be ignored. The improvement of the sewage disposal and the construction of informal slaughtering places to prevent sewage and blood from reaching the river in large quantities should receive urgent attention.

Bacillus subtilis was identified from the biofilm on the stones below Kayamandi on 15 April 2002. This pathogen is ubiquitous in the environment and is sometimes connected to bovine mastitis.[20] It is very resistant to conventional water treatment such as chlorine dioxide[21] and ozone[22] and is regarded as indicator of failed treatment of waste water.[23]

In conclusion it can be said that many potential pathogens able to cause serious diseases in humans were isolated from the water and biofilms on stones in the Plankenbrug River. This partial survey of pathogens other than *E. coli* contributes more information to the very serious picture of pollution and its potential impacts in this riverine environment.

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SUBSTUDY 4

The Ability of Organisms in the River Water to Survive Chlorination Treatment

5.4.1 Introduction

Chlorination of drinking water has been one of the most effective public health measures ever undertaken.[1] Chlorine has been successfully used for the control of waterborne infectious diseases for nearly a century. There are a number of alternatives to chlorination that are in active use in many parts of the world, but the risks associated with their by-products are even less well established than for chlorination.[1] Moreover, the use of these alternatives vary in their effectiveness and some require greater sophistication in their application. This can mean less protection to public health as a result of inappropriate application and control.

Sterilization is the complete elimination or destruction of all forms of microbial life[2,3] and is not achievable in the process of making water potable. Disinfection, on the other hand, describes a process that reduces or eliminates many or all pathogenic micro-organisms with the exception of bacterial endospores[2,3]. This process reduces the number of micro-organisms to a level that is not harmful to health.[3] Agents that kill all micro-organisms with the exception of bacterial endospores after exposure times shorter than those needed for sterilization (i.e. <45 minutes) are called high-level disinfectants. Intermediate level disinfectants may be cidal for tubercle bacilli, most viruses and fungi, but do not necessarily kill bacterial endospores.[2] Low-level disinfectants kill most vegetative bacteria, some fungi and some viruses within short exposure times (i.e. <10 minutes).[2] An antiseptic is an agent that prevents or arrests the growth or action of micro-organisms and is mostly used for preparations applied to living tissue.[2] Chlorination is usually employed as a low-level disinfectant to reduce the microbial burden in the water.[2]

The phenomenon that some pathogenic organisms survive water treatment with chlorination at conventional doses and contact times and enter the potable water reticulation system in a viable state is widely referred to as chlorination resistance in engineering and medical literature. This is not the same concept as is used in antibiotic resistance and should not be confused with the processes leading to antimicrobial resistance.

In many cases, protection of raw water sources from contamination is problematical and such water need to be treated to prevent the spread of pathogenic micro-organisms. The first-line processes known as 'conditioning of water for disinfection' are mainly coagulation, sedimentation and filtration. These processes render water suitable for the final barrier process, namely disinfection. Chlorine is by far the most commonly used disinfectant and in developing countries the use of chlorine is often the only affordable means of disinfecting drinking water.

Several factors influence the efficiency of disinfection with chlorine. These include pH and turbidity of the water, concentration of the chlorine and contact time.[4] Calculating the optimal contact time of water to be disinfected with chlorine in large water treatment works is a complex exercise. For small-scale users (such as farmers and small municipal treatment works) of local water sources (e.g. wells, rivers) there are guidelines issued by the World Health Organization[5] for optimal disinfection of water for drinking purposes. The contact time at a pH of less than 8 and a maximum turbidity of 1 NTU is given as 30 minutes.[5,6] Contact time should only be increased with due cognisance of the potentially harmful effects of over-chlorination,[1] but human health and safety should never be compromised.

There is increasing concern about the ability of landowners and smaller local authorities in the Western Cape to treat raw water obtained from rivers downstream from dense settlements. Should chlorine resistance be present to any significant degree in organisms occurring in free-flowing waters, this will imply that the ability to disinfect raw water from such polluted rivers is seriously impaired. The presence of chlorine resistant organisms in treated water is an indication that effective water treatment to inactivate pathogens may be ineffective.

The levels of chlorine resistance have not been determined in any of the river systems in the Eerste River catchment area. This is a sensitive topic from the standpoint of tourism, agriculture and contact of the local population with the river water. The health implications of the presence of such resistant organisms are considerable. Thus, the aim of this substudy was to establish the possible presence of organisms resistant to chlorine in the river below Kayamandi as indicators of environmental hazard. Organisms resistant to chlorine will also be an indication of whether small-scale treatment of the water downstream from the sources of pollution as encountered in the Plankenbrug River can be carried out successfully. If there is doubt about the ability of small-scale users such as farmers and small local authorities to treat the water, this will be a further indication of the extensive environmental damage inflicted by the pollution in the Plankenbrug river due to sanitation failures in the dense settlement of Kayamandi.

5.4.2 Materials and methods

E. coli was chosen as indicator organism for the determination of chlorination resistance.

The river was sampled downstream from Kayamandi ("Below Kayamandi"). The samples were collected in autoclaved sample bottles according to the guidelines set out by the South African Bureau of Standards[7] that incorporates the standard methods set out by the American Public Health Association, American Water Works Association and the Water Environment Federation.[8-10] The samples for this substudy were collected exactly as on all other sampling occasions and no sodium thiosulphanate was present in the sample bottles.

The standard methods to assess the resistance of organisms isolated from river water to chlorination disinfection were followed.[11,12] The samples were mixed thoroughly, filtered and divided in 5 equal samples of 225 ml each into clean sterile bottles. The rest of the water in the original sample bottle was used as a control sample with no chlorine added. This control sample was tested for faecal coliforms and *E. coli* according to the multiple tube method as described previously. All determinations in this study were done in duplicate.

Freshly manufactured Medisure® chlorine powder (Medichem, Tokai, South Africa) was used. The powder was weighed to four decimals of a gram and added to the sample water in the bottles so that concentrations formed a range of total chlorine: 0.1 mg/l; 0.3 mg/l; 0.4 mg/l, 0.5 mg/l and 0.6 mg/l. This range of concentrations was selected after consultation with the Chief Superintendent of the Cape Town water treatment. The concentration of available chlorine was verified by testing with a HACH 2000 spectrophotometer.

The bottles with water and chlorine mixture were left standing for 30 minutes. This is the minimum contact time for chlorination of small water sources (such as simulated in the present laboratory investigation) recommended by the World Health Organization[4] and adopted by many other countries.[5,6]

After 30 minutes, samples from each of the bottles of water and chlorine mixture were subjected to standard test for faecal coliforms and *E. coli* as previously described and the samples were incubated overnight at 37°C.

One (1.0) ml of the contents of each of the bottles of sample water from the river plus chlorine was added to 9.0 ml non-ionic ethoxylated sorbitan ester (Tween 80, Merck Schuchardt). These bottles were left covered on the laboratory bench for 30 minutes. The bottles were agitated from time to time during the 30 minutes.

One (1.0) ml of the contents of each bottle containing water and chlorine mixture were added to 9.0 ml brain heart infusion broth (Biolab Merck). These tubes were incubated overnight at 37°C.

River water and chlorine mixture from each bottle was also plated out on MacConkey agar plates (Biolab Merck), blood agar plates (tryptose blood agar, Biolab Merck) and brain heart infusion broth. The MacConkey agar plates and brain heart infusion broth tubes were incubated aerobically overnight at 37°C. The blood agar plates were incubated in a 5% CO_2 incubator overnight at 37°C.

From the river water and chlorine mixture 1.0 ml) to which was added Tween 80 (9.0 ml) and left standing on the bench for 30 minutes, MacConkey agar plates, blood agar plates and brain heart infusion broth were inoculated. The MacConkey agar plates and brain heart infusion broth tubes were incubated overnight at 37°C. The blood agar plates were incubated in an incubator containing 5% CO_2 gas at 37°C.

The bottles of river water and chlorine were left standing a further hour on the bench (total exposure 90 minutes). These bottles were vortexed initially and then manually agitated from time to time.

After the extra hour, a sample from each bottle containing river water and chlorine mixture was subjected to the standard determinations for faecal coliforms and *E. coli*. A sample from each bottle was also plated out again on MacConkey agar plates and brain heart infusion broth which were incubated aerobically overnight at 37°C and on blood agar plates which were incubated in an incubator containing 5% CO_2 gas at 37°C.

5.4.3 Results

After 30 minutes contact with chlorine

Table 5.4.1 *E. coli* organisms from water sampled "Below Kayamandi" on 11 June 2002 surviving after treatment with various chlorine concentrations for 30 minutes

Total chlorine concentration	Faecal coliforms per 100 ml surviving	*E. coli* per 100 ml surviving
0 (control)	27 810	27 810
0.1 mg/*l*	4 930	4 930
0.3 mg/*l*	792	792
0.4 mg/*l*	3 290	3 290
0.5 mg/*l*	0	0
0.6 mg/*l*	2	2

After 90 minutes contact with chlorine

Results obtained from organisms isolated from water sampled "Below Kayamandi" on 11 June 2002 after treatment with various chlorine concentrations as used in the previous experiment, but after a further 60 minutes (90 minutes in total) are depicted below.

Table 5.4.2 *E. coli* organisms surviving various chlorine concentrations after 90 minutes

Total chlorine concentration	Faecal coliforms per 100 ml surviving	*E. coli* per 100 ml surviving
0.1 mg/*l*	24	24
0.3 mg/*l*	12	7
0.4 mg/*l*	6	6
0.5 mg/*l*	0	0
0.6 mg/*l*	0	0

5.4.4 Discussion

An anomaly occurred in the results of the number of organisms surviving after 30 minutes of contact with the chlorine. At 0.3 mg/*l* chlorine, 792 *E. coli* organisms survived, while at

0.4 mg/l, 3 290 organisms survived - an increase of 315% over the previous concentration rather than the expected reduction. These determinations were done in duplicate. It is not known why more organisms survived at the higher concentration. It may have simply been a factor of coincidental sampling selection of more resistant organisms.

It is clear from the results that after 30 minutes' contact time with the chlorine, *E. coli* organisms survived up to the highest concentration used in this experiment. Even after 90 minutes of contact time, organisms still survived up to 4 mg/l total chlorine. If a disinfection system utilising 30 minutes' contact time is used to disinfect such water, then chlorine resistance will develop. The fact that organisms still survived up to the level just below optimal after 90 minutes of contact time, strengthens this conclusion. Water from the Plankenbrug River is therefore not suitable for disinfection with the ordinary methods available to small-scale users without increasing either the chlorine concentration and/or the contact time. This has implications for human health as well as for agriculture since irrigation water with a high chlorine concentration is phytotoxic to plants and affects animal health.

Local authorities aim to chlorinate bulk water supplies to a level of 0.5 mg/l water, but this concentration is very difficult to maintain over the entire length of the distribution line (personal communication: Chief Superintendent of the Cape Town water treatment works). If one keeps in mind that only 225 ml of river water was exposed to each concentration of chlorine, then the number of organisms that would have survived conventional chlorination of bulk water supplies sourced from the river would have been considerable.

Payment[13] evaluated transient failures or reductions in treatment efficacy in two water distribution systems in Canada. The experiments evaluated the survival, inter alia, of *E. coli* up to 0.7 mg/*l* total chlorine. His results suggested that the maintenance of a free residual concentration of chlorine in a distribution system did not provide a significant inactivation of pathogens, especially those represented by intrusions into the distribution system, or regrowth of organisms in biofilms along the distribution system. Cross-connections and back-flows can also introduce pathogens into the distribution system. Typically, those failures would result in infecting clusters of individuals, without eliciting the usual signs accompanying large outbreaks and thus remain undetected.[13] These findings are of particular relevance for local authorities and other water users needing to use water downstream from dense settlements such as the one in the present study.

Antiseptics and disinfectants are extensively used in e.g. health care settings for the disinfection of a variety of topical and hard-surface applications.[14,15] Although there is a wide variety of active ingredients found in these products, chlorine figures prominently amongst them. The widespread use of such agents have prompted discussion on the development of microbial resistance, in particular whether antibiotic resistance is induced by disinfectants.[14]

Different types of micro-organisms differ in their response to antiseptics and disinfectants.[14-18] This is hardly surprising in the light of their different cellular structure, composition and physiology. There has been some recent work done on extending the classification of resistance of micro-organisms.[18] The classification is now given as the following sequence[18]:

Descending order of resistance to antiseptics and disinfectants[18]

(examples in brackets):

1: Prions*
(Creutzfeldt-Jacob disease, bovine spongiform encephalopathy)
↓
2: Coccidia
(*Cryptosporidium*)
↓
3: Spores
(*Bacillus*, *C. difficile*)
↓
4: Mycobacteria
(*M. tuberculosis*, *M. avium*)
↓
5: Cysts
(*Giardia*)
↓
6: Small non-enveloped viruses
(polio virus)
↓
7: Trophozoites
(*Acanthamoeba*)
↓
8: Gram-negative bacteria (non-sporulating)
(*Pseudomonas*, *Providencia*)
↓
9: Fungi
(*Candida*, *Aspergillus*)
↓
10: Large non-enveloped viruses
(Enteroviruses, Adenoviruses)
↓
11: Gram-positive bacteria
(*S. aureus*, *Enterococcus*)
↓
12: Lipid enveloped viruses
(HIV, HBV)

[* NOTE: The conclusions on prions are not yet universally agreed upon.]

The first three entries at the top of the resistance flow chart were not investigated in the present study, nor were numbers 5, 7 and 9. These organisms should receive research attention. In the case of Coccidia such as Cryptosporidium, efforts to do research on these organisms are seriously hampered by the technical difficulties in identifying them from water samples and culturing them *in vitro*. Organisms from genera listed under numbers 3, 4, 8, and 11 were isolated from water from the Plankenbrug River and their antibiotic resistance should also receive research attention.

In the light of the increased chlorine resistance in *E. coli* noted in the present study and the increased antibiotic resistance to some antibiotics noted in the organisms surviving the chlorination treatment (see Table 5.5.2), the present preliminary study found support for concerns regarding induced antibiotic resistance in disinfection-resistant organisms.

Micro-organisms can adapt to a variety of physical and chemical conditions in the environment and reports of resistance[14-17] to extensively used antiseptics and disinfectants could have been predicted on theoretical grounds. The most significant survival mechanisms are clearly intrinsic, in particular the ability to sporulate, adaptation of pseudomonads, and the protective ability of biofilms.[14] In these cases the term resistance may be incorrect and "tolerance" may be more correct. Tolerance is defined as developmental or protective effects that permit micro-organisms to survive in the presence of an active agent.[14] Reports of resistance[14,18,20] have often paralleled issues such as inadequate cleaning, incorrect product use, or ineffective infection control practices and the contribution of these problems cannot be under-estimated. Chlorination, while initially lowering the total number of bacteria in sewage, may substantially increase the proportions of antibiotic-resistant potentially pathogenic organisms.[21] Furthermore, selective factors operating in the aquatic environment of a water treatment facility can act to increase the proportion of antibiotic-resistant members of the standard plate count bacterial population in treated drinking water.[22] The finding of possible chlorine resistant *E. coli* organisms in the present investigation is therefore a serious wake-up call. The present investigation was only a pilot study and large-scale investigations on more organisms should be instituted as a matter of urgency.

There are high requirements for asepsis and disinfection of public facilities (especially clinical settings such as hospitals), as well as for the disinfection of water and sewage. These matters should receive much more attention, especially if improper disinfection can also result in survival of antibiotic-resistant organisms. This situation causes a double jeopardy - our ability to eliminate these organisms from clinical settings are impaired as well as our ability to treat those persons infected by them. It is all the more worrying if the results of improper sanitation and disinfection are detected in free-flowing water, indicating that in restricted areas such as clinics, hospitals and water and sewage treatment works these organisms may be much more prevalent.

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SUBSTUDY 5

Antibiotic Resistance Patterns of Organisms in the River Water

5.5.1 Introduction

Antibiotic resistance is being found with increasing frequency in both pathogenic and commensal bacteria of humans and animals.[1] Antimicrobial resistance has become a major clinical and public health problem.[1,2] One traditional school of thought had been that it was primarily indiscriminate use of antibiotics that led to the phenomenon that most gram-positive and gram-negative bacteria continuously develop resistance to antibiotics in regular use.[2] However, the role of increased antibiotic resistance occurring in organisms surviving disinfection is realized more and more.[3] This constitutes a second group of causative factors in the development of resistance quite separate from the use of medication, injudicious or otherwise.

Antibiotic resistance is widespread in the environment because of uncontrolled discharge of urban and agricultural waste water.[4] Sewage treatment can significantly reduce the number of organisms in waste water, but also causes an increase in the proportion of resistant strains occurring because of phenomena that are not always well understood.[4,5] Surviving chlorine-tolerant bacteria seem to be antibiotic resistant in higher percentages than the chlorine-sensitive ones. [4-7] These significant increases in antibiotic resistance and multi-resistance have been observed in chlorinated effluent.[5,7]

Bacteria with intrinsic resistance to antibiotics are found in nature.[8] Such organisms may acquire additional resistance genes from bacteria introduced into soil or water and the resident bacteria may be the reservoir or source of widespread resistant organisms found in many environments.[8] According to a survey of 16 United States rivers at 22 sites[8], over 40% of the bacteria resistant to more than one antibiotic contained at least one plasmid. Ampicillin resistance genes, as well as other resistance traits, were identified in 70% of the plasmids. The most common resistant organisms in that survey were found to belong to the following genera: *Acinetobacter*, *Alcaligenes*, *Citrobacter*, *Enterobacter*, *Pseudomonas* and *Serratia*.

A survey of antibiotic resistance can be regarded as one of the more sophisticated measures of water quality as well as an indication of the impact of health-related organisms in environmental waters. With this in mind, surveys of antibiotic resistance were carried out on three different occasions on organisms obtained from the Plankenbrug River. On one of the occasions the organisms surviving the chlorine treatment during the study on chlorine resistance were also tested for antibiotic resistance.

5.5.2 Materials and methods

One hundred *E. coli* organisms collected at various sampling occasions prior to May 1999 from the two sampling sites "Below Kayamandi" and "Before Gilbeys" were selected for antibiotic sensitivity testing. In addition, some of the organisms identified during the sampling sessions of 19 March 2002 and 15 April 2002 were also subjected to tests to determine the patterns of sensitivity to various antibiotics. One hundred *E. coli* colonies were also subjected to sensitivity analyses during the March/April 2002 round of experiments as well as during the August 2002 sampling round. During the determinations for chlorine resistance in June 2002, the *E. coli* organisms surviving the chlorine treatment were also subjected to antibiotic sensitivity analyses.

Sensitivity testing was performed using the Kirby-Bauer disk diffusion method[9] according to the National Committee for Clinical Laboratory Standards (NCCLS) recommendations[10] using Mueller-Hinton broth (Mast) and Mueller-Hinton sensitivity agar plates (Mast). Colonies of the selected organisms were inoculated into Mueller-Hinton broth (Mast) and diluted with Mueller-Hinton broth (Mast) to 0,5 MacFarland. The colonies were planted out on Mueller-Hinton agar plates and paper disks (Davies Diagnostics) impregnated with the antibiotics were placed onto the seeded agar plates with sterile forceps. The seeded plates were allowed to dry for a few minutes with the tops in place and then incubated aerobically for approximately 18 - 24 hours at 35°C. The zones of inhibition were measured after incubation and the sensitivity/resistance determined based on NCCLS breakpoints.[10]

5.5.3 Results

The sensitivity patterns of various potential pathogens for the two rounds of sampling (before May 1999 and during 2002) are represented in Tables 5.5.1 to 5.5.7.

Table 5.5.1 Resistance patterns of 100 *E. coli* organisms collected at "Below Kayamandi" and "Before Gilbeys" before May 1999

Antibiotic	**Below Kayamandi (% resistant) n = 100**	**Before Gilbeys (% resistant) n = 100**
Amoxycillin	48%	44%
Cefuroxime	37%	9%
Co-trimoxazole	36%	42%
Gentamicin	4%	1%
Chloramphenicol	14%	14%
Ofloxacin	0%	0%

Table 5.5.2 Resistance patterns of *E. coli* in the Plankenbrug River during March/April 2002, June 2002 (chlorine resistant organisms) and August 2002

Antibiotic	**March/April 2002 % resistant** (n = 100)	**June 2002 (Survivors of chlorine treatment) % resistant** (n = 100)	**August 2002 % resistant** (n = 100)
Amoxycillin	**34%**	**65%**	**34%**
Co-trimoxazole	**26%**	**30%**	**20%**
Cefuroxime	0%	0%	0%
Gentamicin	2%	0%	0%
Ofloxacin	0%	-	4%
Ciprofloxacin	-	13%	-
Amoxycillin/Clavulanic acid	21%	9%	16%
Ceftazidime	0%	0%	0%
Cefazolin	15%	0%	6%

Table 5.5.3 Sensitivity of β haemolytic *Streptococcus* Group A as isolated from water sampled "Below Kayamandi" on 19 March 2002.

β haemolytic *Streptococcus* Group A	
Antibiotic	**Sensitivity**
Penicillin	Sensitive
Cefazolin	Sensitive
Co-trimoxazole	Resistant
Tetracycline	Sensitive
Erythromycin	Resistant
Vancomycin	Sensitive
Clindamycin	Sensitive
Cefuroxime	Sensitive

Table 5.5.4 Sensitivity patterns of potential pathogens isolated from water sampled "Below Kayamandi" on 15 April 2002.

Antibiotic	***E. cloacae***	***K. pneumoniae***	***A. lwoffii***	***K. oxytoca***
Ampicillin	R	R	R	R
Cefazolin	R	S	R	S
Co-trimoxazole	S	S	S	S
Gentamicin	S	S	S	S
Amikacin	S	S	S	S
Piperacillin	R	R	S	R
Cefuroxime	S	S	S	S
Ciprofloxacin	S	S	S	S
Ceftazidime	S	S	S	S
Cefoxitin	R	S	S	S
Cefotaxime	S	S	S	S
Amoxicillin/Clavulanic acid	S	S	S	S

S=sensitive, R=resistant

Table 5.5.5 Sensitivity patterns of potential pathogens isolated from biofilm on stone sample "Below Kayamandi" on 15 April 2002.

Antibiotic	*S. viridans*	*K. pneumoniae*	*A. lwoffii*	*K. oxytoca*
Ampicillin		R	R	R
Penicillin	S			
Cefazolin	S	S	R	S
Co-trimoxazole	R	S	S	S
Tetracycline	S			
Erythromycin	R			
Vancomycin	S			
Clindamycin	S			
Gentamicin		S	S	S
Amikacin		S	S	S
Piperacillin		R	S	R
Cefuroxime		S	R	S
Ciprofloxacin		S	S	S
Ceftazidime		S	S	S
Cefoxitin		S	S	S
Cefotaxime	S	S	S	S
Amoxicillin/Clavulanic acid		S	S	S

S=sensitive, R=resistant

Table 5.5.6 Sensitivity patterns of potential pathogens isolated from water sampled "Before Gilbeys" on 15 April 2002.

Antibiotic	***E. cloacae***	***A. baumanii***
Ampicillin	R	R
Cefazolin	R	R
Co-trimoxazole	S	R
Gentamicin	S	S
Amikacin	S	S
Piperacillin	R	S
Cefuroxime	S	
Ciprofloxacin	S	S
Ceftazidime	S	S
Cefoxitin	R	R
Cefotaxime	S	S
Amoxicillin/Clavulanic acid	R	R

S=sensitive, R=resistant

Table 5.5.7 Partial determination of sensitivity patterns of various organisms isolated from biofilm on stone sampled from "Before Gilbeys" on 15 April 2002.

Antibiotic	***A. baumanii***
Ampicillin	R
Cefazolin	R
Co-trimoxazole	R
Gentamicin	S
Amikacin	S
Piperacillin	S
Cefuroxime	R
Ciprofloxacin	S
Ceftazidime	S
Cefoxitin	R
Cefotaxime	S
Amoxicillin/Clavulanic acid	R

S=sensitive, R=resistant

5.5.4 Discussion

The resistance patterns for the *E. coli* organisms collected from water samples of the Plankenbrug River over a period of time shows that there are definite subpopulations of organisms freely occurring in surface water or biofilms in the river that are resistant to some of the commonly available antibiotics. In this respect such sensitivity surveys of organisms occurring in free-flowing water is often seen in environmental epidemiology as an oblique indicator of degradation of the environment due to human impact. This impact can come either from humans themselves or from animal husbandry. As far as could be ascertained there were no piggeries, or animal feedlots on the riparian farms above Kayamandi. The very low numbers of *E. coli* found in the river above Kayamandi for almost the entire duration of the study also support this (see Table 5.1.1, sampling years 1998 to 2000). It can therefore be concluded that animal husbandry could not have been a very large contributor to the observed resistance patterns.

From Table 5.5.2 it can be seen that for amoxycillin and co-trimoxazole an interesting phenomenon was observed. The organisms surviving the chlorination treatment showed increased resistance to the two antibiotics as well. This provides support for the contention that incomplete disinfection also makes an important contribution to the selection of antibiotic resistant strains.[11,12]

Antibiotic resistance analysis has been successfully used to identify sources of faecal coliforms in natural waters, especially from non-point source pollution.[13-16] This technique uses determination of antibiotic resistance against as many antibiotics as can be incorporated in the study (grouped into databases) and uses the statistical procedure of discriminant analysis to assess the sources of faecal contamination in natural waters. This promises to be a useful tool in the improvement of water quality. The present pilot study of resistance patterns occurring in natural waters is an essential first step in the setting up of such a monitoring system.

Residents of developing countries often carry antibiotic-resistant faecal commensal organisms.[17,18] Visitors to developing countries passively acquire antibiotic-resistant gut *Escherichia coli*, even if they are not taking prophylactic antibiotics, which suggests that they encounter a reservoir of antibiotic-resistant strains during travel.[19] Apparently healthy people in developing countries carry potentially pathogenic, antibiotic-resistant organisms asymptomatically.[20] Several factors, such as urban migration with crowding and improper sewage disposal, encourage the exchange of antibiotic-resistant organisms between people and the exchange of resistance genes among bacteria, thereby increasing the prevalence of resistant strains.[20]

This kind of survey needs to be carried out on a much wider scale in the rivers of the Western Cape that are contaminated by untreated sewage. It is an essential part of the picture of health impacts of poor sanitation and has been neglected in this region in the past. At present the impact of human activity in general on rivers and water supplies are very narrowly defined. In most cases, it reduces to the monitoring of a few chemical parameters. Without other sensitive indications such as antibiotic resistance of organisms in rivers, the consequences of such wide-ranging activities as agriculture, health services and sanitation cannot be fully assessed and remedial action cannot be taken in time before widespread damage sets in.

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5.6 Concluding Remarks to Chapter 5

It is clear from the evidence presented in this chapter as well as the findings announced in Chapter 4 that there is convincing evidence that the surroundings of the dense settlement of Kayamandi and the Plankenbrug River are seriously polluted. This pollution is mainly microbiological, while the chemical qualities of the water in the river are for the most part within acceptable ranges. A disproportionate burden of disease and adverse quality of life ensuing from inadequate sanitation are borne by the people of Kayamandi. This disproportion is partly based on race and/or income and reflects both inherited historical backlogs in services as well as the downward spiral of poverty.

The potential pathogens in the water will inevitably affect the whole of the greater catchment area of the Eerste River and the entire river system below the confluence of the Plankenbrug and Eerste Rivers are seriously affected.

The first lesson learnt from this in depth study of the nature and levels of pollution in this river and dense settlement is that effective diagnosis of the problem relies heavily on high quality environmental analysis.[1] High-technology interventions for effective remediation of any polluted river as well as the prevention of further pollution are costly.[2-4]

The legal issues regarding the downstream effects of such high levels of pollution are complex and have changed drastically in the previous decade. The wide-ranging nature of the effects of any pollution (varying from contamination of crops, disease effects in humans and animals to the contamination of farm dams and the damage to tourism) make the determination of liability a complex issue.[5] The legislative situation in South Africa has changed with the advent of the new political dispensation. In the past, many institutions would have considered it inconceivable that they be required to clean up contamination resulting from historic disposal of harmful substances, especially if the disposal had not been unlawful at the time. Yet, internationally, that is what is happening more and more.[5] The South African Cabinet adopted the White Paper on Basic Household Sanitation[6] in 2001 which put in place an improved national sanitation policy. This policy clearly affirms the principle of "polluter pays" and thus the local authorities allowing faecal pollution to enter a river unhindered and who make no efforts to address the situation will be in contravention of this requirement. Such cases have not been tested in court and it remains to be seen how serious the Government is in enforcing this policy. The increasing threat of parties outside the wider circle of state and semi-state administrations to seek redress for damages sustained because of polluted water may help to give impetus to the enforcement of the policies.

The purpose of environmental epidemiology is to acquire knowledge about the determinants and distribution of disease and to apply that knowledge to improve public health.[7] A key problem is therefore how much and what kinds of evidence are sufficient to warrant public health (typically preventative) actions?[7] It is vitally important that the environmental epidemiology should progress to the demonstration of the disproportionate *effects* of pollution rather than just the disproportionate *distribution* of pollution sources. At present the available resources cannot realize this progress and the low esteem with which environmental epidemiology is regarded within the traditional medical schools will make the road an uphill one.

The assessment of available evidence lays the foundation for the problem of complexity facing the discipline. Investigations reflect information from many levels of scientific understanding: molecular, cellular, tissue, organ systems, complete organisms (including humans), relationships between individuals and on to social and political processes that may impact on human health. The unraveling of these relationships should receive much more attention from South African academics, notably those in the health sciences, in order for the country to prevent the degradation of the environment and the backsliding of the economy that accompany large-scale pollution effects.

The discipline of environmental epidemiology should be developed and encouraged. The problems of studying correlated exposures and small individual relative risks are daunting and require experienced epidemiologists to avoid the pitfalls associated with so many pollution investigations. At present the study and diagnosis of local pollution problems seem to be the exclusive domain of the engineering profession, with help from basic scientists such as zoologists and botanists as sources of specialist input. Health issues are almost never included, although the preambles to many of these investigative briefs contain lofty references to health and well-being. Although more and better research is needed at all levels, it is crucially important to choose the most appropriate level of research for a particular problem. Only by conducting research at all levels and by developing further methods to combine evidence from these different levels can we hope to address the challenges facing environmental epidemiology today.[8]

References to Concluding Remarks

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ANNEXURE A - Sampling points along the Plankenbrug River

CHAPTER 6

Overall Conclusions and Recommendations

6.1 Overall conclusions

The studies described in the preceding chapters have generated a uniquely valuable and useful set of facts. No dense settlement in the Western Cape and its health effects on a river environment have been studied as intensively for as a long a period as the Plankenbrug has been for the last five years. No such studies could actually be traced. Under favourable conditions, such a set of facts would have been sufficient to overcome the inertia that allowed the pollution to get out of hand in the first place. This has unfortunately not been the case.

The picture emerging from the large amount of data available on this seriously polluted river is one of high health risk and grave environmental degradation. Apart from the serious shortcomings in the provision and maintenance of sanitation to the dense settlement of Kayamandi, the periodic failing of the sanitation system of the rest of the town of Stellenbosch also caused sporadic sewage intrusions into the river. These intrusions occurred immediately prior to at least a third of the sampling occasions, thus leading to the conclusion that the extent of the pollution load originating outside Kayamandi is considerable.

The findings of the substudies on identification of organisms and the chlorination resistance and antibiotic resistance of some of them, add weight to the 'diagnosis' of a community and a riverine environment that are under severe pressure. *E. coli* is seen as an indicator organism of fecal pollution of natural waters and the screen of actual organisms in the water of the Plankenbrug River gave a good indication of what range of pathogenic organisms are represented by high levels of *E. coli*. These organisms were not compatible with a healthy environment or with the safe use of such water in the agricultural areas beyond the urban boundaries of Stellenbosch.

The information arising from the community surveys which quantified and described the 'community at risk' in the dense settlement, provided a bleak picture of overcrowding, poverty, lack of education and ill health due, amongst others, to pollution. And yet, there also emerged clear indications of a widespread wish for more education on sanitation and a need to feel proud of the settlement and its people. These sentiments can be exploited in future education campaigns. The actual reduction in pollution levels of the river during the education campaigns and maintenance efforts was very encouraging and showed that relatively small investments in effort and money can result in significant improvements. All these different aspects of the situational analysis presented in this dissertation can be synthesized into an overall 'environmental diagnosis'. Not only the specific results obtained in these studies are obviously important. Equally important is the finding that studying these aspects over time provided a much more detailed and balanced conclusion than would have been possible with the traditional superficial analyses carried out in the past. It also emphasized the importance of microbiological investigations when assessing the pollution levels of river water, rather than the traditional chemical parameters used to determine the suitability of river water for irrigation.

The process of integration of the various pieces of information generated by the previously reported studies on aspects of hazard characterization and exposure assessment can be depicted schematically as follows:

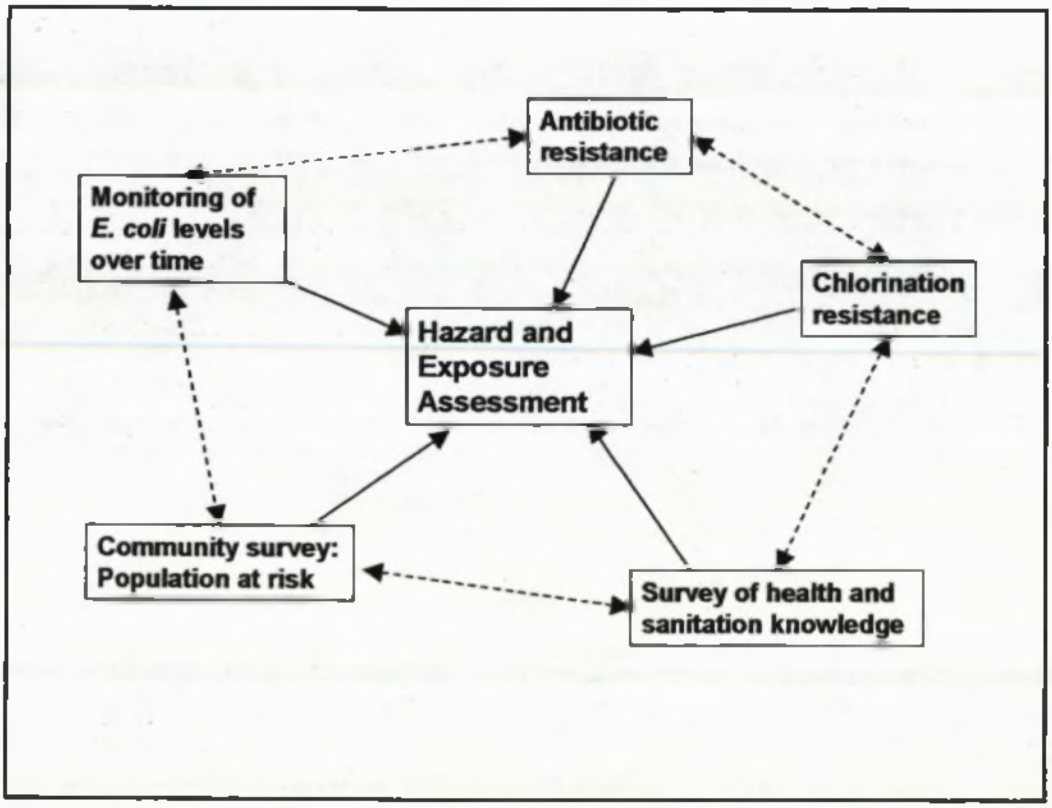


Fig. 6.1 Synthesis of various aspects of environmental assessment of risk regarding pollution of the Plankenbrug River.

The role of the supervising authorities in dealing with the situation of water pollution has been problematic up to this point and the impasse around the enforceability of the various pieces of legislation safeguarding our natural water sources needs sorting out without delay. There will always be a few officials or even entire local authority structures not complying with the minimum standards set out in the legislation. The present laissez-faire approach to those errant transgressors is sending the message that ignoring safety standards pays, since no legal action has to date been instigated against any of the local authorities in the Boland under the new legislative dispensation. The much-touted corporate governance approach where all disputes and transgressions are mediated and negotiated until the errant local authority sees the error of its ways, proved to be unworkable in practice. There seem to be an unwillingness to proceed to the next steps provided for in the various acts regarding transgressions.

On the whole, funding organisations see regular monitoring of microbiological water quality as a routine action with very few research benefits. This study has however shown the very opposite. If it were not for the monitoring over several seasons, the full picture of the sources and impact of this pollution would never have become known. The dense settlement of Kayamandi would have been viewed as the obvious, visible source of all the pollution, which is not the case. This would have resulted in inadequate measures to combat the pollution, trailing problems into the future.

The information obtained on the extent of the antibiotic resistance and resistance to chlorination should be viewed as only the beginning of such monitoring in the Eerste River Catchment Area. The Plankenbrug River forms only a part of the catchment, albeit a large donor of water pollution to the catchment. Indicators of water quality such as antibiotic resistance and resistance to chlorination as well as the health impact of pollution are much neglected - indeed absent - from all previous efforts to monitor the impact of human waste on this catchment area.

A thorough search was done to trace as many previous studies done on the Plankenbrug River or the Eerste River as possible. Some were uncovered by word of mouth from other scientists, but they all turned out to be small studies carried out by students for coursework and not of the extent or sophistication that provided credible conclusions. Many of these studies suffered from severe methodological flaws. Among the few that were done on a higher level, the one by Rossouw[1] can serve as an example. None of the studies however, considered any health impacts as a major variable and the few studies that did mention the determination of *E. coli*, only used it as an indicator of pollution with no associated impacts on health. No studies reported investigating any other pathogenic organisms, their antibiotic resistance or chlorination resistance.

There is reason for concern regarding the organisms identified as present in the river system. Although some of them are known to occur in free-flowing water even in pristine areas, the numbers of those organisms seen in the water at times resembled the situation in untreated sewage.

Antibiotic sensitivity in broad terms represents the ability of the health services to treat infections resulting from these organisms. It has been mentioned before the study started that there would probably not be very many organisms in free-flowing water exhibiting antibiotic resistance, but this turned out not to be the case. Further studies are needed to link the drug policies of the local health service points to the resistance patterns observed in the environment with a view to effecting changes if need be.

Chlorination resistance is of equal importance, but to a different sector of society. Water for both human consumption and agricultural use is becoming scarce and no source of water can be viewed as not needed or not important. Chlorination remains one of the easiest and cheapest options for bulk disinfection of large quantities of raw water. The fact that organisms survived the contact with chlorine even after 90 minutes of contact time is cause for concern. The further disquieting indication that those organisms surviving chlorine treatment may have a tendency towards increased resistance to some antibiotics at least carry serious implications for bulk water providers as well as the disinfection of hospitals, food manufacturers, etc.

Although the undertaking of community surveys and sanitation education programmes on a scale done in this study is rare and a luxury, the value of the information obtained shows that some efforts at enumeration of the community (e.g. a properly designed sample survey and community diagnosis) could be of immense value. At the start of the study, some so-called experts were of the opinion that no differences in the pollution levels in the river before and after the education campaigns and maintenance operation would be seen. Dramatic reductions in the levels were in fact recorded. Adding credibility of the reduction, those levels started rising again immediately after the campaigns and repairs were stopped. Regular determination of microbiological water quality is therefore a sensitive enough indicator in this scenario to monitor the interventions in sanitation and services in Kayamandi that are sure to follow on this study.

6.2 The long view - lessons from experience

6.2.1 Recognising the need for change

Sanitation and environmental health decisions reflect political, historical and economic considerations as well as the known facts about the impact of environmental exposures on health. On the whole, problems resulting from negative environmental conditions such as failing sanitation systems do not usually occur as a result of *intention*, much rather as a result of *inattention*.[2] Even the inattention that in the past allowed some tragic accidents to occur, such as the nuclear accident at Chernobyl, the Bhopal disaster or the Seveso tragedy, were not necessarily deliberate, callous or indifferent, nor were some of those situations inherently negligent.[2] *The inattention is usually due to a failure to see and respond adequately and timeously to what is often a new situation.*[2] New circumstances, new methods of investigation which provide a new slant on the extent of old problems, new detections of the extent of the crisis, all uncover the need for changing, adapting or terminating a well-established set of procedures. It can be called a *need* for change because to continue with the old established ways will allow the environmental health problems to grow. These new situations that require alteration to established ways of doing things create tension between established institutions and those bodies recognising the causes and extent of the problem. This has been demonstrated in many ways in the present study. The present unhelpful situation involving the Municipality of Stellenbosch on the one hand and the Department of Water Affairs and Forestry and the provincial Department of Environmental Affairs and Development Planning of the Western Cape on the other hand is a good example of the tension created by the need for change. The extent to which the amelioration of the sanitation crisis in Kayamandi has been resisted up to now means that changes must be required by or imposed by an outside authority if they are to occur. Only a political process is capable of such impositions and requirements.

Institutions created to oversee the provision of basic services to communities often see changes in their way of doing things as an obstacle to financial viability or to the provision of services to the rest of the town or area they serve. Such changes are then often covertly resisted. The local officials are merely trying to do their work as best they know how in the light of the way they define their "main task". In the case of the sanitation crisis in Kayamandi, the influx of new inhabitants to the settlement caused the scale of municipal activities to escalate to such an extent that it exceeded previous experience. Their established ways of dealing with the services and maintenance were no longer adequate.

As Kayamandi slowly re-established its internal community links and as the study uncovered the full extent and impact of the sanitation crisis, public awareness of the problem increased and the tolerance regarding pollution, poor services and resultant health problems decreased. Problems that have been overlooked in the past, or indeed not even acknowledged as existing, now stood out in sharper relief. The reaction of the officials to this overt and covert revelation of past neglect or poor planning was to follow a path of passive resistance (or inertia) and to employ blaming behaviour.

6.2.2 Unhelpful strategies or tactics in order to avoid the problem

Goldsmith[2] reviewed the epidemiological investigation of community environmental health problems and identified the following unhelpful "games" or strategies that the various stakeholders play in handling an environmental health problem like sanitation failure. These strategies postpone the resolution of the problem and escalate its effects. Notes on the present situation are provided.

"They" are polluting the environment

This is a strategy most often employed by officials and persons in authority who have the means at their disposal to do something about the problem, but who needs the motivation to do so. When action demands a change of attitudes or a change of established routines, the easiest escape option is to blame the most visible group of persons and to disregard the many other factors leading up to the causes of the problem. This attitude puts the 'blame' for the existing situation on a group or section of the community such as Kayamandi, without taking into account e.g. the lack of facilities at their disposal, the lack of proper maintenance of such facilities, the community's low education levels with concomitant ignorance, and so on. The biggest problem inherent in this attitude is that is takes away all incentive to change and perpetrates the unhealthy situation. The longer the officials deny their own involvement and responsibilities, the harder it becomes to get them to abandon this unhelpful attitude. This is the situation in the present sanitation crisis in Kayamandi.

Pollution is our privilege until "they" improve our services

On the other hand, the community of Kayamandi employs their own brand of unhelpful strategies. Their attitude, voiced at many community meetings, is that the present facilities are poor and they will change their ways and improve their sanitation behaviour only after the local authority installed a toilet per household (or any other similar target which is unattainable in the immediate future). This provides a comfortable justification for not having to change their environmentally unsustainable and unhealthy habits, even though most of them know that those habits are wrong. This attitude complicates the effectiveness of education campaigns and must be taken into account when such campaigns are designed.

We are complying with requirements and the new demands are unreasonable

In the past the local authority has quoted various stipulations and requirements of international bodies such as the World Health Organisation as justification for the present sanitation system. They claimed that the number of persons per toilet and the distance of these toilets to the furthest users in Kayamandi 'comply' with the international standards. These answers were obtained by denying the actual number of inhabitants living in Kayamandi and did not reflect the real situation in large parts of Kayamandi. In the past this was yet another reason stated at meetings for not needing to change the present system. It then also follows that any demands for more or improved services was seen as an unreasonable increase in standards.

These unrealistic demands will cost so much money that it is unattainable

The amount of money quoted at meetings as the minimum necessary to improve the sanitation situation in Kayamandi was not based on reasonable and detailed estimates. The strategy here is one of setting the cost of improvements sky-high and complying with the requirements as slowly and with as little initiative as the officials feel they can get away with without actually being fined or penalised. They have recognised that long court fights about compliance with legal requirements are costly and the deferment allows them to save on capital expenditure and save on the interest they have to pay. This amounts to a type of economic blackmail that should not be tolerated.

We have some of the best and most modern water laws in the world and there is no cause for alarm

This strategy is employed by the government departments who are the custodians of the various acts and regulations overseeing proper governance of water resources. It is rarely mentioned that setting high standards and inclusive ownership of our water resources commit the government departments to an adequate programme of enforcement and prevention to make sure that local authorities and other water users meet those standards. What counts is preventing the pollution from being a threat to the environment and the health of the population, and not elegantly formulated laws and regulations.

Another unhelpful strategy in this broad category is to establish monitoring programmes for pollutants of uncertain quality or applicability, instead of preventing their emission or discharge. Often the choice of variables monitored, the locations monitored and the sampling and methods of analysis are woefully inadequate, so that the numbers they generate do not mean anything. This however, gives the impression that something is being done. The data thus generated are not analysed or reacted to in any effective manner and the public is given a false sense of security. The routine river monitoring of the Department of Water Affairs and Forestry suffers from these problems, but their National Microbial Water Quality Monitoring Programme even more so. Inadequate sampling and wholly inadequate methods of analysis are employed with unreliable results. Municipal officials used these results in the past as "proof" that the pollution levels were decreasing to such an extent that no action was needed. Unfortunately those so-called low results were instances where methodological failures occurred. Repeated explanations to this effect, even by the DWAF officials running the programme, made no difference and this escapism still surfaces at almost every meeting.

These problems are too difficult and effective action would be too disruptive to our present way of doing things

The effect of this evasion tactic is to paralyse all efforts at improvement and to pass the problem on to subsequent budgets and subsequent generations of officials, who will be even less able to deal with the escalating effects of the crisis. All that inhabitants of affected poor communities can do to safeguard their families is to keep their children indoors since the streets are so polluted and to take elaborate precautions against disease transmission which is not feasible in a poverty-stricken community such as Kayamandi. Boiling water for instance is difficult for the resource-poor and burning of fossil fuels contribute to the smoky atmosphere and resultant respiratory diseases. Thus a spiral of events is triggered, dragging the community down more and more. Both the community and the officials are guilty of the unhelpful attitude embodied in this coping strategy and thus both parties need a change of attitude to escape the downward spiral. This is at present unattainable, given the very bad relations between the two stakeholders.

Sanitation and related health issues are 'lowly' matters and of little medical or academic standing

There is little recognition of the importance of sanitation as a research field in the world of health academics. The topic has very low prestige and although the link of sanitation to previously disadvantaged communities is recognised and sometimes exploited for short-term 'political' gain, there is little awareness of how improved sanitation can improve the heavy case load faced by the health services. The extensive associations of sanitation problems and resultant pollution with the burden of a wide number of diseases faced by all members of the population (not only the poor) are severely underestimated. The health professions are not very visible in this field, which is a regrettable state of affairs. The battle to obtain research money, the small allocations for health-related studies of sanitation failures countrywide, the lack of institutional interest, and declining research infrastructure are all systemic reasons why there are so few epidemiologically sound studies undertaken in this field. It is not easy to see how this problem should be addressed, but if one or more of the leading faculties of health in the country can take a courageous step and invest a realistic sum of money and staff in such research, this should greatly improve the status of such studies in South Africa.

The bottom line for a community-based study is not what has been learnt, but what action has been taken. We tend to assume that decisions can be informed by facts, which in turn will result in action. When the above unhelpful strategies are employed to avoid the situation rather than deal with it, providing objective facts can only help if those involved in the dispute and its solution are *willing to accept* the facts. The price of not doing so is very high for both opposing camps and this has been pointed out to them. It is up to them to find a way to co-operate rather than to keep conflict alive.

6.3 Recommendations regarding the pollution situation in the Plankenbrug River

Many recommendations with vague endpoints and absent identification of responsibility are doomed to failure. Thus, the following are rather framed in the spirit of suggestions from the viewpoint of a research scientist in the hope that the responsible authorities with the real power to make a difference will take them up.

Recommendation 1

Background: The present system of routine monitoring utilized by the Department of Water Affairs and Forestry is based almost exclusively on chemical parameters. This hides the serious impact of microbiological pollution and its concomitant dangers.

Recommendation: DWAF should seriously reconsider their policy of water monitoring and re-introduce microbiological monitoring in sensitive surface waters.

Recommendation 2

Background: There is at present an impasse where the Department of Water Affairs and Forestry cannot enforce the National Water Act of 1998 when the transgressor is a local authority because of constitutional obstacles and conflicts. The lack of enforceability makes a mockery of many concerned parties' efforts to reduce pollution, protect health and encourage economic growth. The strategy used in the past by both government and municipal officials was to denigrate those that report serious pollution simply because the authorities do not know how to deal with the situation.

Recommendation: Urgent attention should be paid to the legislative loopholes that allow local authorities to escape the levels of enforcing provided for in the various Acts guarding the integrity of our water sources. DAWF should also pay serious, high-level attention to their policy of solely concentrating on co-operative governance to the exclusion of enforcing water pollution legislation in cases of blatant dereliction of duty.

Recommendation 3

Background: The Provincial Department of Health has up to now not been engaged in a meaningful way in the process of solving these problems. The Provincial Department of Agriculture has likewise indicated to the candidate that the problem is a serious one and promised to follow up the initiative, but no constructive dialogue has as yet materialized, and the promised research funds have not been forthcoming either. The problem of sanitation failures in poor areas needs a strong central body to drive the process with inputs from major stakeholders. The Dept of Water Affairs and Forestry as custodians of the National Water Act is not equipped to be the central driver of this process on a local level. Maybe the Dept of Environmental Affairs of the province, which has shown encouraging willingness to become involved, could fulfill this co-ordinating role.
Recommendation: Urgent attention should be paid by the Provincial Cabinet to establishing an interdisciplinary Task Group to co-ordinate the actions needed to address the serious situation flowing from inadequate sanitation in informal settlements and the consequences of such water pollution. This task group should inter alia contaln health experts, agricultural experts as well as environmental and engineering experts in order to approach the problem in its totality.

Recommendation 4

Background: The community leaders in Kayamandi had in the past not been engaged in this crisis facing their constituents in a constructive or farsighted way. Withholding access to toilets in a struggle for resources, political divisions for short-term personal gains and lack of co-operation and favouritism for short-term political gain will not benefit the community and in the long run only do great harm. The vandalism that does occur can only be stopped effectively if all parties agree to help control these harmful practices from within the community. Vandalism is a great stumbling block to improving the situation and is used against the community of Kayamandi time and time again. It is the responsibility of the community of Kayamandi to find a negotiated way to stop this. Having said that, the local authorities involved in prosecuting such vandals when caught, should not shirk their responsibilities. Avoiding prosecution sends a very unhelpful message to persons contemplating stealing plumbing parts or just damaging public facilities.
Recommendation: The community leaders in Kayamandi should urgently review their approach to sanitation issues and education of the community. A negotiated settlement should be sought between all representatives from all political parties to exclude certain

issues from local political agendas. Such topics of exclusion for Kayamandi should include sanitation and health, education and proper maintenance of the public facilities. The local authority (officials as well as elected office-bearers) should form a Forum for the continuing discussion of the problems, incorporating advice from outside experts, so that progress made during the DANCED project should not be lost.

Recommendation 5

Background: The artisans recruited from the inhabitants of Kayamandi who were trained in plumbing, bricklaying and carpentry were very successful in undertaking maintenance of the sanitation facilities. Unfortunately the local authority did not see its way open to allowing them to compete for tenders to repair the toilet blocks once the DANCED project came to an end. This meant that the benefit to the whole of Kayamandi of these trained individuals was minimal. Only these individuals benefited personally. A scheme was also suggested and planned by the Kayamandi members of the Steering Committee during the DANCED project whereby households using a particular toilet block could contribute a very small amount of money each month into a pooled fund for the toilet block. Each family could then take turns to supervise the toilet block for a period (week or month) and get paid the money in the pool. This plan was met with great enthusiasm by the Kayamandi community members themselves. The local authority, in the person of the Deputy Mayor was also very much in favour of the scheme, but only if the municipality could collect all the money and control the process. It was pointed out to the municipality that they could not even collect the rates and service fees outstanding in Kayamandi. The scheme was never implemented after that setback.

Recommendation: Serious consideration should be given to broadening the skills base of the local inhabitants and a way has to be negotiated between the local authority (who is the owner of all the community ablution facilities in Kayamandi) and the inhabitants to institute a scheme of using local artisans as far as is possible. It is also necessary to implement some form of supervision over the toilet blocks to curb vandalism and the best way for this to work is to plan and implement a scheme whereby the users of the toilets are involved in keeping them clean and intact. The municipality is urged to pay urgent attention to this aspect.

Recommendation 6

Background: It is difficult to formulate suggestions regarding the desperately needed change of approach within the local authority, since so many efforts from so many sources, both governmental and unofficial, failed in the past four years. The new legislation regarding municipal structures and functioning should slowly begin to make changes in the entrenched way of operation within municipal structures, but the present pollution crisis cannot wait for such regulatory mills to grind slowly towards a solution.

Recommendation: The provincial authorities supervising the functioning of municipal structures should be very much more visible in the process of change of the operational approach employed by some local authorities.

Recommendation 7

Background: The University of Stellenbosch is both a source of expertise and a concerned party to the pollution situation. The management of the University failed to act when notified, and failed to even investigate the health warnings sent to them. The University is involved on many levels, some of its staff and students live in Kayamandi, many of its students come into recreational contact with the Plankenbrug River and the organisation is a major owner of real estate in the town. The lack of concern and the lack of willingness to even admit to the problem does not do it credit as a humanitarian institution that cares for its people and for the environment.

Recommendation: The present pollution in Kayamandi and the Plankenbrug River and the consequent health crisis is an opportunity for the University of Stellenbosch to show its commitment to the upliftment of a part of the community it serves. The University should use its position of influence far more positively than at present. An Environmental Forum of experts and interested parties affiliated to the University already exists and this body should get official encouragement to become involved in environmental issues. This Forum is a body of experts that the University could empower to do co-operative research into many aspects of sanitation and water pollution.

Recommendation 8

Background: The Faculty of Health Sciences in particular has not been actively involved in research at any level regarding the health problems connected to sanitation failures and pollution in general. At present, in many clinically orientated researchers' perception, the term "community-based" means moving the scene of research from the tertiary hospital to outlying clinics or primary care settings. This is a misconception. Real community-based research in the actual impoverished communities provides a much better insight into the powerful factors that shape the prevalence and incidence of disease in our environment.

Recommendation: The Faculty will find it well worth its while to invest more interest and support in the work of those scientists and clinicians who do community-based research and research into various aspects of sanitation or water pollution in particular. Public Health as a discipline and environmental epidemiology need to be strengthened as research efforts to alleviate the problems of pollution and poor sanitation should receive more encouragement. The positive image created by the willingness to take the problems of the severely disadvantaged members of the South African society on board as well as the huge potential for reducing the burden of morbidity and mortality facing the health services are investments that will be of great benefit to the Faculty.

6.4 Some suggestions for specific future research topics

1. There is an urgent need for research into the feasibility and practical applications of monitoring water quality in natural watercourses by means of microbiological determinations. Another need for future research in this category is to test for the presence of antibiotics in the river water.

2. More research needs to be done on antibiotic resistance of organisms in natural water sources and the possible impact of such resistance on health in the area as well as the possible adaptation of antibiotic drug policies of the local health service centers.

3. More research needs to be done about chlorination resistance of organisms reaching natural waters, either in a treated or untreated state. Especially the link between chlorination resistance and antibiotic resistance ought to receive urgent attention.

4. Research into the links between community behaviour, availability of sanitation services and receptivity to educational programmes should be expanded, especially for the local populations of impoverished people in dense settlements.

6.5 Collaboration established during the study

Invaluable collaboration was built up in this project with the following organisations:

1. Department of Water Affairs and Forestry (Western Cape) and especially the staff members of the Division for Water Quality. DWAF carried the cost of the chemical analyses of the Plankenbrug samples for four years.

2. Division of Agrometeorology of the Agricultural Research Council who carried out the analyses of pollution patterns in relation to weather data.

3. Department of Microbiology, University of Stellenbosch for the exchange of knowledge and experience in the field of environmental pollution. Ms Wesaal Khan, a doctoral student of the Department used some of the organisms isolated during the course of this study for further investigation.

4. Prof EP Jacobs, Chief Researcher, Institute for Polymer Science, University of Stellenbosch for collaboration on membrane technology used to remove pathogens from water.

5. The Kayamandi Steering Committee and the greater community of Kayamandi itself with whom valuable bonds have been established and from most of whom good co-operation had been received.

6. The Wildlife and Environment Society of South Africa, and especially Mr Stephen Finnemore, for sharing of previous data and correspondence on the river.

The research outputs generated by the various projects of the Dept of Water Affairs and Forestry, the Flemish Government grant, Project K5/1226 of the Water Research Commission, the Harry and Doris Crossley Foundation are recognized. Prof MB Taylor of the Dept of Medical Microbiology of the University of Pretoria did many analyses of the viral aspects of samples of polluted water from the Plankenbrug River as well as comparisons of these samples with other samples of well water used for irrigation of edible crops obtained in Venda. All the co-operative studies utilising information about the water from the Plankenbrug River are listed in Addendum A for reference purposes.

6.6 Capacity building

Much empowerment was done in the township itself. The project made a considerable difference to the lives of many people living in Kayamandi. Teams of unemployed persons living in Kayamandi were formally trained as artisans (plumbers, painters, carpenters and brick-layers) by the Department of Labour and their training paid for by the DANCED project. They helped to repair the toilet blocks as well as some of the public buildings like the Kayamandi Hall during their training. The idea was that these trained persons could help the local authority to maintain these facilities while turning their newly acquired skills to their own advantage in their spare time. Unfortunately, very little co-operation was received from the local authority and to date no tenders for repairs had been awarded to these artisans. The impetus of this empowerment scheme is fast being lost.

Teams of unemployed, matriculated persons from Kayamandi were also trained as community health educators in order for the education campaigns and surveys to be carried out. Many of these members have already found other jobs, which is wonderful; although it does mean that the task of training people in this role can never be regarded as completed. Ongoing attention to training is very much needed. The community health educators helped with many more aspects of their community life than just bringing sanitation messages across. They provided information on oral rehydration of their own accord; they reported children in distress (malnourished, neglected, ill without supervision etc) and generally provided an indispensable social service to their community. Although they were originally canvassed as volunteers, they were paid a small bonus each after their task was completed in order to encourage them to continue as well as to defray their expenses for meals, etc during the time they spent helping the project.

Teams of unemployed persons from Kayamandi, who had no other skills or job prospects, helped to clean the river. They were also paid a nominal amount for a meal and some soap to defray their expenses. They did a truly splendid job and "their" section of the river running next to Kayamandi had never been so clean and free of alien vegetation in decades. Out of their own accord, they went to speak to a shebeen owner on the riverbank who littered the riverbank with broken liquor bottles in order to stop the practice of throwing discarded glass over his fence. At least during their time as river cleaners, this practice was stopped. These aspects of the project were truly empowering and the lessons learnt from this part of the project should be carried out to the wider community in order to demonstrate how communities can be guided to help their own area much more than they themselves believe at present.

References to Chapter 6

1. Rossouw J. Populations and fate of faecal bacteria in contaminated water of the Eerste River below Stellenbosch. University of Stellenbosch, M Sc thesis. February 1999
2. Goldsmith JR. Environmental decisions: the impact of evidence. Ch. 22 in: Environmental Epidemiology: Epidemiological investigation of community environmental health problems. Boca Raton, Florida: CRC Press. 1986, p. 240-245

ANNEXURE A

Research outputs of the various projects associated with this study or those utilising samples from this study site

Reports:

1. Barnes JM. Important confidential health warning: Organisms identified from the Plankenbrug River. Report to the Municipality of Stellenbosch. 4 March 2002
2. Barnes JM. Water quality analyses of the Plankenbrug River. Report to Municipality of Stellenbosch, Dept of Water Affairs and Forestry, and Stellenbosch Hospital. 13 March 2002
3. Barnes JM, Taylor MB. Health risk assessment in connection with the use of microbial contaminated source waters for irrigation. Water Research Commission Report No K5/1226/0/1, 2003, pp. 99

Theses:

1. Naus T. The recovery and detection of hepatitis A virus and human astrovirus from irrigation waters and associated minimally processed foods. BSc (Hons) Research Report, Dept of Med. Virology, Univ. of Pretoria, Pretoria. 2001
2. Nadan S. Characterisation of astroviruses from selected clinical and environmental settings. M.Sc. Thesis, Dept of Medical Virology, University of Pretoria, Pretoria. 2002

Article in Journal

Nadan S, Walter JE, Grabow WOK, Mitchell DK, Taylor MB. Molecular characterization of astroviruses by reverse transcriptase PCR and sequence analysis: Comparison of clinical and environmental isolates. Applied and Environmental Microbiology 2003; 69(2): 747-753

Papers presented at conferences:

1. Barnes JM, De Villiers AS. Complex interaction between river pollution and a dense settlement along the Plankenbrug River. Paper presented at 44th Academic Research Day, Faculty of Medicine, Univ. of Stellenbosch, Tygerberg. August 2000

2. Barnes JM. Complex interaction of factors causing serious environmental pollution and health effects in a peri-urban dense settlement receiving clean municipal water. Paper presented at Joint Congress of the Infectious Diseases & Sexually Transmitted Diseases Societies of Southern Africa, Stellenbosch. December 2001
3. Nadan S, JE Walter, Grabow WOK, Taylor MB. The molecular detection and characterisation of astroviruses from human stool specimens and sewage. Paper presented at "Microbial Diversity" 12th Biennial Congress of the South African Society for Microbiology, Faculty of Health Sciences, University of the Free State, Bloemfontein. April 2002
4. Venter JME, Grabow WOK, Taylor MB (2002) Comparison of methods for the isolation and detection of hepatitis A virus in water samples. Paper presented at "Microbial Diversity" 12th Biennial Congress of the South African Society for Microbiology, Faculty of Health Sciences, University of the Free State, Bloemfontein. April 2002
5. Barnes, JM, Wassermann, E and Slabbert, MM. *Escherichia coli* as an indicator of microbiological water quality in the Plankenbrug River - what other pathogens does it indicate? Paper presented at the Annual Congress of the South African Society for Veterinary Epidemiologists, Pretoria. August 2003
6. Barnes, JM, Haasbroek, PD, Slabbert, MM and Huisamen, A. Monitoring *Escherichia coli* as indicator of faecal pollution of a river below a dense settlement - seasonal variation and correlation with chemistry and weather data. Paper presented at the Annual Congress of the South African Society for Veterinary Epidemiologists, Pretoria. August 2003

<u>Poster presentations at conferences:</u>

1. Kloppers W, Barnes JM. Implementation of a national strategy to manage water quality effects from densely populated settlements: Kayamandi model project. Poster presentation at 11th WISA Conf., Sun City. May-June 2000
2. Naus T, Grabow WOK, Taylor MB. The assessment of techniques for the recovery and detection of hepatitis A- and astroviruses from minimally processed foods. Poster presentation at Faculty Day, Faculty of Health Sciences, University of Pretoria, Pretoria. August 2001
3. Van der Linde M, Taylor MB, Grabow WOK, van Zyl WB. Occurrence of rotaviruses in selected water samples. Poster presentation at Faculty Day, Faculty of Health Sciences, University of Pretoria, Pretoria. August 2001

4. Venter JME, Grabow WOK, Taylor MB. Comparison of methods for the isolation and detection of hepatitis A virus from water samples. Poster presentation at Faculty Day, Faculty of Health Sciences, University of Pretoria, Pretoria. August 2001
5. Barnes JM, Slabbert MM, Huisamen A, Haasbroek PD, Liebowitz L. Seasonal variation of faecal pollution in the Plankenbrug River using Escherichia coli as an indicator organism - interpretational difficulties when assessing sanitation interventions. Poster presented at the IWA Health-Related Water Microbiology Symposium, Cape Town. September 2003
6. M.B. Taylor, S. Nadan, W.B. van Zyl, JME Venter, D. Pavlov, N. Potgieter, JM Barnes. Application of integrated-cell culture RT-PCRs to determine the occurrence of enteric viruses in irrigation water and associated minimally processed foods. Poster presented at the IWA Health-Related Water Microbiology Symposium, Cape Town. September 2003

Talks to professional bodies

1. Barnes JM. Report on the pollution problems of the Plankenbrug River. Presentation to the National Dept of Water Affairs and Forestry and the Department of Dept of Environmental Affairs of the Western Cape. Bellville. 12 August 2002
2. Barnes JM. Report on research findings regarding sanitation of Kayamandi and pollution problems in the Plankenbrug River. Presentation to the Technical Standing Committee of the Municipality of Stellenbosch. Stellenbosch. 1 October 2002
3. Barnes JM. Implications of the pollution of rivers due to failing sanitation to the tourism industry of the greater Stellenbosch area. Presentation to the Tourism Officers of the tourist offices and municipalities of Drakenstein, Franschhoek and Stellenbosch. 7 October 2002
4. Barnes JM. Implications of pollution of rivers below dense settlements on agriculture. Talk presented to "Bo-Bergrivier" Irrigation Board Committee. Paarl. 24 January 2003
5. Barnes JM. Serious environmental pollution and health effects arising from poor sanitation in dense settlements along river banks. Talk presented to Community Water Supply and Sanitation Division of the Water Institute of South Africa. Bellville. 7 May 2003
6. Barnes JM. River pollution due to bad sanitation. Talk presented at Consolidated Municipal Infrastructure Program (CMIP) workshop. West Coast Region at Saldanha. 23 – 24 October 2003

7. Barnes JM. River pollution due to bad sanitation. Talk presented at Consolidated Municipal Infrastructure Program (CMIP) Workshop. Boland / Overberg Region atArniston/Struisbaai. 30 – 31 October 2003
8. Barnes JM. River pollution due to bad sanitation. Talk presented at Consolidated Municipal Infrastructure Program (CMIP) Workshop. City of Cape Town Region at Paarl. 13 – 14 November 2003
9. Barnes JM. River pollution due to bad sanitation. Talk presented at Consolidated Municipal Infrastructure Program (CMIP) Workshop. Eden/Karoo Region at George. 27 – 28 November 2003

Reports in the Media

1. Anon. Kayamandi oefenlopie vir US se navorsing Die Burger. 17 November 1999, p. 8
2. Anon. Langtermynplan nodig vir besoedeling. Eikestadnuus 13 September 2002, p. 2
3. Anon. Project will divert polluted stormwater from river. Eikestadnuus. 25 October 2002
4. Bonthuys J. Eikestad-rivier 'n gesondheidsramp. Cholera-vrees: Munisiplaiteit kry ultimatum van die staat. Die Burger 23 Oktober 2002, p. 11
5. Editorial. Don't kill the messenger. Eikestadnuus. 4 October 2002, p. 8
6. Retief E. Besoedel - Rivier vuil en gevaarlik. Eikestadnuus, vol 32 13 September 2002, p.1
7. Retief E. Stappe nodig vir besoedelde rivier. Eikestadnuus. 4 October 2002, p. 2
8. Retief E. A little can make a big difference. Eikestadnuus. 11 October 2002, p. 7
9. Retief E. A clean Kayamandi, a cleaner river. Eikestadnuus. 22 November 2002. p. 9
10. Schumann C. Speedy action needed for Plankenbrug [Letter] Eikestadnuus. 27 September 2002, p. 6
11. Thom A. The story of a sick river. Cape Argus. 28 August 2002, p. 16
12. Van Zyl J. Hoe water, hoe kwater. Die Burger 23 Oktober 2002, p. 11

Radio talks

1. Barnes JM. SA FM: Interview on paper presented to Infectious Diseases Conference. 7 December 2001, 18h15 (Repeated Sunday 9 December 2001)
2. Barnes JM. SA FM: Interview with Sue Valentine June 19, 2002. Broadcast in three parts on SA FM (broadcasting dates not known)
3. Barnes JM. Matie FM Radio: Interview about the pollution in the Plankenbrug River. 12 September 2002 at 18h30

CHAPTER 7

Photographs of the Plankenbrug River and Kayamandi

Photograph 1

The Plankenbrug River during low flow conditions (summer) as it flows past Kayamandi on the outskirts of Stellenbosch. At this point the river has already received the discharge from several stormwater drains laden with faecal and other pollution.

Photograph 2

The Plankenbrug River below Kayamandi is overgrown, polluted with solid waste and the riparian housekeeping such as removal of alien invader plants is poor.

Photograph 3

Dense foam that does not abate for a considerable distance downstream points to chemical pollution (possibly with soaps and detergents) or material rich in certain kinds of proteins

Photograph 4

About 80% of the inhabitants of Kayamandi only have access to communal toilets which are not in a good state of repair. Vandalism contributes to this state of affairs, but a low level of maintenance aggravates the situation. At some of the communal blocks there are reported to be up to 40 users per toilet.

Photograph 5

The communal toilet blocks have taps and basins along the back wall. A similar state of disrepair is evident here. There are very few standing taps along the streets and service points such as this one is also the only source of water for most shack dwellers.

Photograph 6

Many of the toilets were in such a non-functional state that major renovations were necessary during the clean up and education campaigns described in this report. Note the lightweight materials used in construction.

Photograph 7

Due to the state of disrepair of the facilities, the environment is being polluted with sewage and this is spread over the ground surface by run-off, blowing of contaminated dust and rubbish and wandering animals.

Photograph 8

A workshop of sidewalk vendors and other small business entrepreneurs to find solutions for the large amount of solid waste and animal blood and offal reaching the river via the stormwater drains. The meeting was held in the newly renovated Community Hall, which was used as a practice project for the artisans trained by the DANCED project.

Photograph 9

One of the members of the Kayamandi community who received training in plumbing during the project. The plumbers who were trained were meant to help with the upkeep of the communal toilet facilities. Both men and women were trained.

Photograph 10

Community members being trained in the unblocking and repair of drains around the communal toilet blocks. All these trainees received their basic certificates from the training team of the Department of Labour.

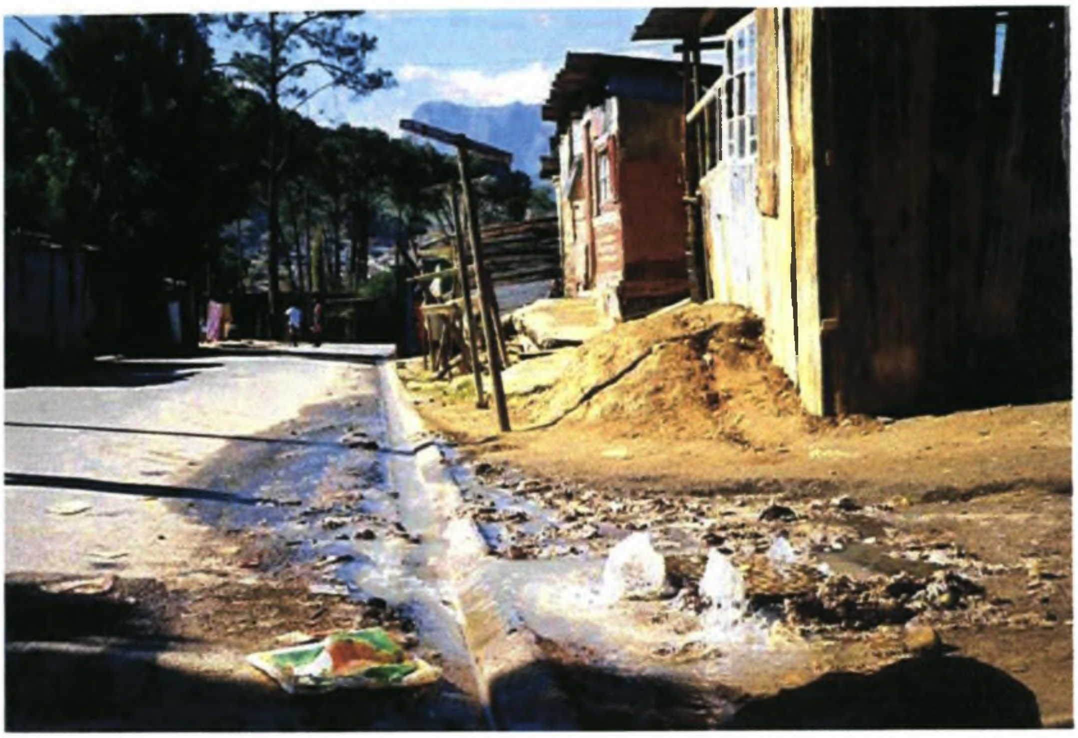
Photograph 11

This is the only way to one of the ablution blocks. What may look like random rubbish are actually the inhabitants' efforts to cover a perennially overflowing drain so that they can walk to the toilets.

Photograph 12

Uncollected solid waste accumulate at central points. This is also the playing ground for children.

Photograph 13



Overflowing drains are a common sight in the settlement. This one overflowed for many months and is on the way to the school.

Photograph 14

The large container for solid waste called a skip. These skips were not always emptied timeously and solid waste accumulated, causing the rubbish to wash into the stormwater drains, resulting in further blockages. These skips smell very badly, and attract flies and rummaging animals. The inhabitants do not want to live near them.