REPORT TO THE WATER RESEARCH COMMISSION

A HYDROLOGICAL INVESTIGATION OF THE STORMWATER RUNOFF FROM THE KHAYELITSHA URBAN CATCHMENT IN THE FALSE BAY AREA, SOUTH WESTERN CAPE

by

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EXECUTIVE SUMMARY

South Africa has not escaped the demographic phenomenon of rapid urbanization experienced by developing countries. The rapid acceleration in urbanization over the last decade may be attributed to a large extent to the growth of the "Black" African community, especially since the abolition of influx control and collapse of the "Apartheid" system. The urban Black population is expected to treble within 20 years and much of this urbanization will be in the form of informal settlements around the existing metropolitan areas. Many of these people live in overcrowded tin shanties with no running water or ablution facilities. In an effort to combat this problem, the authorities are attempting to upgrade the existing settlements and to establish site-and-service schemes. Unfortunately even these semi-controlled areas become overcrowded and the basic services provided inevitably prove inadequate. It is thus highly probable that any stormwater runoff originating in these catchments will be polluted. Many studies have been done in First World type urban catchment but the findings from these may not necessarily be applicable in Third World type catchments in Africa, especially considering the African culture and way of life.

The Division of Water Technology, CSIR, recognised the need for an indepth geohydrological investigation of urban stormwater runoff from Third World type catchments and proposed the present study to the Water Research Commission. The objective of the study was to assess the magnitude of the stormwater contamination, identify pollution sources and assess its resultant effect on the receiving water body. Three aims were established to meet these objectives, namely:

1. to identify the hydrological processes taking place within the urban catchments and the role of each process in contributing to the contamination of the stormwater runoff with special emphasis on the microbiological contaminants;

2. to investigate the gradual accumulation effect versus shockloading impact of chemical and microbiological pollutants on the marine environment around Monwabisi Resort;

3. to evaluate the WITWAT hydrological simulation model in a Third World urban catchment in the winter rainfall zone of South Africa.

The study was initially for a two year period, but was later extended for a further year in order to assess the changes in stormwater quality originating in two sub-catchments undergoing different types of Third World urban development.

THE STUDY AREA

Khayelitsha, a new township of some 0.3 million people on the northern shores of False Bay, was selected as a study area. Designed as a high density black township, Khayelitsha serves as a typical example of present low income type urban development in South Africa. Although development was still in the initial stages, the stormwater runoff was already contaminated and considered a major source of pollution to False Bay. The urban development has taken place on an unconfined sandy aquifer that forms part of the Cape Flats Aquifer. The catchment may be divided into a number of sub-catchments with a dual stormwater drainage system down the centre of the catchment. The catchment is of an entirely residential nature and contains organised squatter housing with minimal services (shacks with communal water supply points and bucket latrines), serviced sites (shacks with waterborne sewerage and stormwater drainage), and formal housing (permanent structures).

THE HYDROLOGICAL NETWORK AND DATA ACQUISITION

All available data on the catchment was acquired from the relevant Government Departments and Project Engineers, and an extensive review of existing urban stormwater literature undertaken. An initial field reconnaissance showed that the hydrological monitoring network would have to be on a macro scale. Both the nature of the catchment and the poor security situation discouraged the establishment of any permanent monitoring equipment/structures within Khayelitsha. The constantly changing state of the urban development with its deviations from the masterplan meant that the network had to be modified from time to time. The highly volatile security situation continually disrupted field work and resulted in the exclusion of certain sub-catchments from the study.

Initially a network of five rain gauges (two Casella natural siphon rainfall recorders and three standard raingauges) was established. Problems were, however, experienced with the standard raingauges in Khayelitsha and these were abandoned while a third Casella natural siphon rainfall recorder was added.

A flow gauging station was established downstream of the final stormwater detention basin immediately before the stormwater outfall discharge point on the beach. Although this site was not ideal it was the only available site along the main stormwater outfall pipe. The large amounts of sand and debris in the stormwater system and continual blocking of the system made gauging elsewhere impossible. Similar problems were experienced with the siting of a continuous salinity monitoring system and this was finally installed just upstream of the final detention basin.

Five sites were initially selected for water quality monitoring in order to assess the magnitude of the stormwater contamination and identify possible source areas. The samples were collected on a monthly basis and analyzed for both chemical and microbiological parameters. A fairly wide range of parameters were selected in order to obtain as much information as possible. The main sampling programme consisted of both storm event sampling and the sampling of 11 selected sites during specific weather conditions (e.g.) dry summer periods, dry winter periods and wet winter periods. Sampling involved the taking of a grab sample. Storm event sampling was done on the main stormwater outfall upstream of the final detention basin. The sampling had to be done manually during daylight hours as the security situation did not allow for the installation of automatic samplers. The sampling interval was initially brief to ensure maximum data acquisition during the early stages of the storm in order to monitor the first flush effect. Two of the sub-catchments monitored underwent urbanization during the study period and provided a "before" and "after" scenario. The sub-catchments represent the two major types of controlled Third World urban development, namely, formal housing and serviced sites.

A laboratory mixing experiment and inner-surfzone sampling was undertaken at the stormwater outlet east of Monwabisi Resort in order to assess the effects on the receiving water body. The surf samples were taken at doubling intervals up to 200 m on either side of the outfall on a receding surf. Samples were analysed for trace metals, nutrients and microbiological indicator organisms.

STUDY RESULTS

The urban stormwater runoff originating in Khayelitsha catchment was found to be polluted throughout the year. The pollution was predominantly of a microbiological nature with correspondingly high concentrations of nutrients and organics. Table A provides a comparison of typical stormwater quality during stormflow and base-flow conditions for different landuses (types of housing). The trace metal pollutant loads were low in comparison with most First World type urban catchments reflecting the lack of industry and motor vehicles. The high salinity values being as a result of saline groundwater. The best quality stormwater originated in the sub-catchments containing formal housing, although these sub-catchments had slightly higher trace metals loads. The serviced site sub-catchments consistently produced the worst stormwater quality.

The sandy nature of the catchments, small effective impervious surface area and low intensity rains experienced resulted in very little overland flow. Interflow and groundwater flow were the dominant runoff processes and resulted in a large baseflow component throughout the year. Rapid interflow being the major contributor to stormflow, hence the lack of a first flush effect. The highly porous nature of the sands enables pollutants to be carried down by infiltrating water to produce contaminated subsurface flow. The effect of this is seen in the high pollutant concentrations in the baseflow and sub-catchments with no stormwater runoff system. The reduced concentrations during stormflow are due to rapid interflow. The pollutant loads, however, are greatest during stormflow due to the increased discharge volumes

The major source of pollution was litter and faecal contaminants that abound throughout the catchment. The high population density, poor living conditions and general lack of environmental awareness ensure ongoing pollution generation far in excess of that experienced in First World type urban catchments. The ongoing violence and periodic strikes in Khayelitsha adversely affect the basic services provided. Extended periods of unrest result in the complete collapse of services

TABLE A

A COMPARISON OF WATER QUALITY DURING STORMFLOW AND BASEFLOW CONDITIONS FOR DIFFERENT LANDUSES

Determinands	Shacks		Serviced sites		Core area		Total output		Beach outfall	
	Storm	Base	Storm	Base	Storm	Base	Storm	Base	Storm	Base
F. coliforms per 100 ml	1.2×10^5	3.9×10^3	2.7×10^5	5.8×10^4	2.2×10^4	1.5×10^3	3.4×10^4	4.3×10^4	3.0×10^4	1.2×10^4
F. streptococci per 100 ml	9.9×10^3	$1.1\ \ 10^3$	3.9×10^3	1.8×10^4	6.1×10^4	9.2×10^2	6.1×10^3	5.1×10^3	1.4×10^4	6.3×10^2
Coliphage per 10 ml	2.0×10^3	1.6×10^2	5.4×10^2	6.3×10^3	7.0×10^0	4.0×10^0	2.0×10^3	1.8×10^3	3.7×10^2	1.2×10^3
K	19.9	11.9	15.4	15.7	13.3	14.0	10.4	10.1	8.4	10.2
Na	198	170	134	140	131	137	194	197	144	202
Ca	232	198	122	125	136	143	129	127	92	127
Mg	49	75	47	49	35	36	44	43	31	45
NH_4-N	1.86	0.47	2.38	4.21	1.09	1.06	0.36	0.39	0.50	0.19
SO_4	298	426	195	194	93	94	165	179	114	181
Cl	291	234	164	185	191	210	278	291	194	290
Alk ($CaCO_3$)	412	449	372	376	436	437	351	343	267	343
NO_4-N	22.8	1.33	13.6	12.7	4.05	3.23	9.93	9.23	7.14	9.05
P	<0.05	<0.05	0.10	0.28	<0.05	<0.05	<0.05	0.09	0.06	<0.05
Cd	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	<0.02	0.08	<0.02	0.02	<0.02	0.05	<0.02	0.01	<0.02	0.01
Fe	0.36	0.36	0.41	0.58	1.74	2.19	0.64	0.48	0.23	0.25
Pb	0.02	0.07	0.02	<0.03	0.03	<0.03	0.06	<0.03	0.02	<0.03
Zn	0.02	0.01	<0.02	0.03	<0.02	0.01	0.05	0.01	<0.02	0.01
DOC	13.7	12.8	14.2	12.9	17.8	16.1	12.2	10.8	10.9	9.2
EC (mS/m)	230	215	158	160	154	160	185	190	138	190
pH	6.7	6.7	7.0	7.0	6.9	6.8	7.0	7.0	7.2	7.0
TDS (Calc)	1472	1376	1011	1024	986	1024	1184	1216	883	1216

units = mg/L

stormflow = 54 hours rainy weather
baseflow = 8 days dry weather

and the accumulation of garbage, blocking of drains and local dumping of bucket latrines. The worst pollution recorded during the study occurred during times of unrest. The provision of additional infrastructure, as in the serviced site sub-catchments did not necessarily reduce the pollution problem. In fact, the installation of water-borne sewerage and stormwater systems facilitated the removal of pollutants from the catchment and increased the contamination resulting from the sub-catchments. Where parks, playing fields and open spaces are provided these areas have been inundated with shacks, with a resultant increase in pollution. All forms of urbanization involving shacks result in contamination of the water leaving the catchment, either as surface or subsurface flow. The magnitude of the contamination appears to depend more on the population density than degree of infrastructure provided.

The final stormwater detention basin northeast of Monwabisi Resort functioned as a pollution reduction mechanism during baseflow conditions, but was not as effective during storm events due to the short retention time. Microbiologically the stormwater runoff entering the sea during winter was unacceptable even after initial dilution. During baseflow conditions the levels were lower, but even so, direct contact recreation should not take place within at least 100 metres of the stormwater outfall. The inner surfzone sampling showed that in most cases the concentration of dissolved nutrients and trace metals during baseflow conditions are within the limits specified. During storm conditions, however, the limits are regularly exceeded. Dilution studies indicated that through mixing with seawater the trace metals posed no serious problem with regard to the short term impact on the marine environment. The long term impact from lead could, however, be substantial due to accumulation in sediments and aquatic organisms.

The constant unrest and Third World nature of the urban area resulted in conditions that made hydrological research extremely difficult. Hydrological equipment normally used for taking field measurements was found to be unsuitable for Khayelitsha conditions. With the result that the accuracy and coarse scale (time increment) of much of the hydrological data, made simulation with a sophisticated computer model like WITSKM of limited value, especially with regard to model evaluation. This component of the study was therefore not pursued.

CONCLUSION

The study achieved two of the three objectives proposed, namely:

1. to identify the hydrological processes taking place within the urban catchments and the role of each process in contributing to the contamination of the stormwater runoff with special emphasis on the microbiological contaminants;

2. to investigate the gradual accumulation effect versus shockloading impact of chemical and microbiological pollutants on the marine environment around Monwabisi Resort;

Although the study had to be undertaken on a more macro-scale than initially envisaged the main issues could still be investigated. The study was the first of its type in South Africa and produced valuable information on stormwater quality and hydrological processes in a sandy Third World urban catchment. This was the first major attempt at investigating the source area of contaminated water entering False Bay. The results will, however, not only benefit authorities in the South Western Cape, but throughout the coastal area. Many results are also applicable to the townships on the Highveld, although these catchments receive conventional rain and have different geological settings.

The third objective of the study involving the evaluation of a South African hydrological simulation model could not be attained. The data required for such an operation could not be collected in the Khayelitsha catchment under the present conditions. Hopefully with the changing political climate in South Africa such studies will become possible in the future. Even so, great care will have to be taken in selecting a study area, as underground stormwater systems in Third World type catchments provide unique problems with regard to flow gauging.

RECOMMENDATIONS

Third World type urbanization, with its informal housing and "shanty towns", is very much part of South Africa and will continue to play a major role in this country for many years to come. It is thus vital that the research continues in these catchments, as well-proven engineering solutions from First World communities are not always applicable to Third World urban areas.

Future research should include:

a) Groundwater contamination as a result of Third World type urbanization especially in the case of unconfined sandy aquifers;

b) Stormwater contamination in a Third World urban catchment in the summer rainfall zone (an area that experiences convectional rainfall).

c) Groundwater as a practical water supply for informal settlements.

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The Steering Committee responsible for this project consisted of the following persons:

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TERMINOLOGY

Definitions of some specific terms used in this report:

First World type urbanisation - formal urban development as seen in developed countries of the Western world, e.g. Europe and the USA

Third World type urbanization - urban development common to under-developed countries of the world. People living in shacks generally outnumber those living in conventional housing

Black townships - urban areas/suburbs developed during the Apartheid era, exclusively for occupation by the Black peoples of South Africa

Coloured townships - urban suburbs developed during the Apartheid era, exclusively for occupation by the "coloured" community [a mixed race that is mostly the product of miscenegation between indigenous Khoikhoin, White settlers and the Black tribes]

CHAPTER 1

INTRODUCTION

South Africa has not escaped the world-wide post-war demographic phenomenon of rapid urbanization and predictions are that the urban population in South Africa could almost double by the year 2000 (Spies, 1987). The rapid acceleration in urbanization over the last decade may be attributed to a large extent to the growth of the "Black" community, especially since the abolition of influx control in 1986. More than 40 per cent of all "Blacks" now reside in urban areas, and these numbers are expected to treble within 20 years (Van Niekerk, 1990). This influx has contributed to the ethnic diversity and economic disparities found in South African cities. This particular mix of interdependent First and Third World communities creates unique problems to urban authorities.

The change in the urbanization pattern has led to the development of large low-cost, high-density urban areas to cater for the rapid urbanization at the expense of the traditional low density urban developments. Unfortunately the Third World nature of this urbanization has resulted in gross overcrowding and the development of vast informal settlements around the existing metropolitan areas. The very nature of these settlements results in virtually no sanitation or concept of basic hygiene among the community and not only presents a considerable problem for the people but also for the environment. In an effort to combat this problem the authorities are attempting to upgrade the existing settlements and establish site-and-service schemes. Unfortunately even these semi-controlled areas become overcrowded and the basic services provided inevitably prove inadequate. The situation is made increasingly difficult by the heightened aspirations of the community as a result of exposure to First World living conditions, both through the media and via the work place.

The changing nature of urban development in South Africa poses new problems with regard to the pollution threat to the environment. Typical high-cost, low-density urban areas have sophisticated infrastructure and the pollution threat is mainly from point sources which may be monitored and controlled. Low-cost, high-density urban areas have less sophisticated infrastructure with the result that the pollution source is more diffuse and difficult to identify and control. Any water leaving these urban catchments will act as a vector for the transport of pollutants and viruses. This is especially true in those areas experiencing political unrest as it often leads to the complete collapse of services. The result is the accumulation of garbage and blocking and overflow of bucket latrines and sewerage systems.

The virtually uncontrolled influx of people from rural areas has been particularly felt in the Cape Peninsula where a spate of urban development has taken place on the Cape Flats to the north of False Bay. Existing plans indicate that within the next decade the entire northern shoreline will have been developed for residential and recreational purposes (Figure 1). Khayelitsha is the latest "Black" township development along the coastline and by 1990 had an "official" population of 320 000 with an expected population of some 750 000 by the turn of the century.

As with other areas of a similar nature in South Africa a certain degree of "urban squalor" has occurred with shanty communities in and around the planned township.

The Cape Flats development does not only have the normal urbanization problems, but also a serious pollution problem. The urban catchments generate considerable volumes of water which discharge into the surf zone of False Bay through sewage outlets, stormwater outlets, rivers and natural seepage. This is of great concern as the shoreline discharges tend to remain trapped within the surf zone over relatively long distances resulting in low dilutions (CSIR, 1991). The authorities are able to control that portion of waste water which constitutes sewage, as this is treated before disposal, but the remaining outflow receives no such treatment and if polluted will have detrimental effects on False Bay.

Research in the Northern Hemisphere and Australasia has shown that the pollutant load in stormwater runoff is comparable to that in sewage effluent and that it may actually contain more micro-organisms than secondary treated effluent (Cordery, 1977). Field and Turkeltaub (1981) have found that typical suspended solids concentrations in runoff usually exceed the concentrations found in raw municipal sewage, that biological oxygen demand levels are approximately equal to those of secondary effluents and that faecal coliform counts far exceed the concentrations considered safe for water contact. Initial surveys undertaken in the False Bay area confirm these findings (Augoustinos and Kfir, 1990; Brown *et al.*, 1989; Wright, 1990). A comprehensive study of the entire bay indicates that at present the seawater in the immediate vicinity of the shoreline discharges does not comply with Water Quality Criteria for the South African Coastal Zone (CSIR, 1991).

1.2 Problem statement

It is a well established fact that urban development creates many potential pollution sources, both point and non-point/diffuse sources. Urban hydrologists have studied urban stormwater runoff quality problems for many years and several major research projects have been undertaken in South Africa (Simpson, 1986; Stephenson *et al.*, 1986; Kloppers, 1989). The vast majority of these studies have, however, concentrated on First World type catchments with the result that little is known about Third World urban catchments.

As much of the present and future urban development in South Africa is of the Third World type, there is an urgent need to investigate the potential magnitude of any water contamination from these areas and to determine the processes involved. This would be particularly beneficial in the Southwestern Cape where the new development areas around False Bay appear to pose a definite health risk (CSIR, 1991). The new township of Khayelitsha is not only a typical example of this type of urbanization, but has also been identified as a major contributor of polluted runoff.

1.3 Study objective

The Division of Water Technology, CSIR, recognised the need for such an in-depth hydrological investigation of urban stormwater runoff from a typical Third World type catchment and proposed the present study to the Water Research Commission. The objective of the study was to assess the magnitude of the storm-water contamination, identify pollution sources and assess its resultant impact on the receiving water body. Three aims were established to meet these objectives, namely:

1. To identify the hydrological processes taking place within the urban catchment and the role of each process in contributing to the contamination of the stormwater runoff with special emphasis on the microbiological contaminants.

2. To investigate the gradual accumulation effect versus shockloading impact of chemical and microbiological pollutants on the marine environment around Monwabisi Resort.

3. To evaluate the WITWAT hydrological simulation model in a Third World urban catchment in the winter rainfall zone of South Africa.

The Khayelitsha urban catchment was selected as a study area as it was in the process of being developed and contained all the different types of Third World type urbanization found in South Africa.

CHAPTER 2

2. DESCRIPTION OF KHAYELITSHA CATCHMENT

2.1 Location

Khayelitsha is situated centrally along the northern shoreline of False Bay some 25 km southeast of Cape Town (Figure 1). The township is bound on the northern side by the N2 freeway and on the southern side by Baden-Powell Drive and False Bay (Figure 2). On the eastern side the township as planned will extend across Baden-Powell Drive to Macassar, a mixed income area serving the Somerset West/ Strand node. The western side is bordered by land occupied in the north by Swartklip Products (Armscor), in the south west by a solid waste disposal site and cemetery and by Swartklip Road. The areas to the immediate north west between Khayelitsha and the N2 freeway still houses the South African Cape Corps and a wetland area which forms part of the Kuils River drainage system.

2.2 Topography

Khayelitsha was developed on a site comprised of high, vegetated dunes with a large central low-lying area. The dunes occurred, in south-east/north-west tending series that varied between 40 and 50 metres in height. The central lowlying area contained a series of interconnected vleis which formed part of the Kuils River flood plain. The Kuils River itself runs along the northern boundary through an area of natural wetlands. During periods of high flow, water from the river overflowed and filled the interconnected depressions and vleis in the central area. This central area would remain flooded for many weeks after the river had subsided, as there was no natural outlet to the sea.

As the catchment was urbanized so the terrain was levelled and today only the dunes in the south remain (Plate 1). The extent of the earthworks was in the order of 10 000 m^3/ha (VKE, 1984). The topography in the urbanized part of the catchment features very gentle gradients inwards towards an artificial drainage system down the centre of the catchment. This will be described in section 2.6. The Kuils River drainage system remains, but was channelized to avoid any flooding of the urban area.

2.3 Climate

The Cape Peninsula experiences a typical Mediterranean climate with hot dry summers and wet winters. The average daily temperatures range from 22 °C in summer to 11 °C in winter. The weather pattern being controlled by the annual north-south migration of the earth's wind and pressure belts. During summer a ridge of high pressure connecting the South Atlantic and southern Indian Ocean anticyclonic cells extends across the peninsula and results in hot, cloudless days. Conditions are often windy with the "south-easter" frequently reaching gale force strengths. During the winter the area comes under the influence of the moving cyclones and associated fronts of the west-wind belt to the south. The succession of fronts being responsible for much of the rain received. On average 97 raindays are experienced per annum with an annual average rainfall of 508 mm.

D.F. Malan Airport weather station is the closest comprehensive meteorological station to the study area. The rainfall data from this station for the periods 1990/91 is summarized in Appendix A while the graph in Figure 3 illustrates the highly seasonal trend. The wet season is from mid-April to September (Schultze, 1984).

2.4 Geology

Khayelitsha, located in the south-eastern portion of the Cape Flats, is characterized by sediments of the Cenozoic Sandveld Group (Table 1) overlying bedrock shales and greywacke of the Malmesbury Group. A great many boreholes were drilled in the eastern Cape Flats during the late 1970's and used by Wessels and Greeff (1980) to map the local geology (Figures 4 and 5). The sand deposits vary in thickness from less than 15 metres in the north to more than 30 metres in the central and southwestern area, while the bedrock elevation over much of the area is below mean sealevel.

TABLE 1

CAPE PENINSULA LITHOSTRATIGRAPHY

SANDVELD GROUP	Witzand Formation*	Recent
	Langebaan Formation	Pleistocene
	Velddrif Formation	Pleistocene
	Springfontyn Formation*	Pleistocene
	Varswater Formation	Pliocene
	Elandsfontein Formation*	Miocene
FALSE BAY DOLERITES	(e.g. Logies Bay dyke)	Jur-Cretaceous
TABLE MOUNTAIN GROUP	Pakhuis Formation	Silurian
	Peninsula Formation	Silurian
	Graafwater Formation	Ordovician
	Cape Point Intrusive	Precamb-Cambrian
CAPE GRANITE SUITE	Cape Peninsula Batholith	Precamb-Cambrian
MALMESBURY GROUP	Sea Point Formation*	Late Proterozoic
	Bloubergstrand Fm*	Late Proterozoic

*not yet approved by SACS

(From Hartnady and Rogers, 1990, p4)

The geology of the area is very much a reflection of global climatic changes and a result of the pronounced glacioeustatic effects felt during the late Cenozoic. The Varswater Formation is of marine origin and consists of highly fossiliferous, phosphate-bearing, muddy, very fine quartzose sand. The Springfontyn Formation in contrast is aeolian in nature and consists of fine to medium quartzose sand. The Velddrif Formation which is best seen at the foot of the coastal cliffs, is a patchy deposit of poorly consolidated intertidal and estuarine sediments. This is overlain by the crossbedded, semi-consolidated alienates of the Langebaan Formation. The calcretised upper surface of this unit forms the cliffs seen along the shoreline and extends across the entire study area. The final geological unit, namely the Witzand Formation, formed during the Last Glacial when equatorward compression of the climatic belts caused excessive winds which resulted in an extensive system of parabolic, vegetation-bound coastal dunes (Hartnady and Rogers, 1990).

2.5 Geohydrology

The Khayelitsha area forms part of the Cape Flats coastal aquifer. The Cenozoic sand deposits represent an unconfined coastal aquifer which has for many years been considered as a valuable groundwater resource (Vandoolaeghe, 1984). A major Water Research Commission study in the late 1970's (Wessels and Greeff, 1980) examined the possibilities of artificially recharging water from the Eerste River System in the present Khayelitsha area. The study showed that such a project was feasible.

The sandy nature of the catchment provides for high infiltration rates and no natural runoff occurs. The rate of natural recharge is thus high and much of the present study area has a saturated sand thickness of between 20 and 25 metres (Wessels and Greeff, 1980). The aquifer is, however, not homogeneous as the calcrete and clay horizons act as semi-pervious layers (Figure 6). The calcrete layer occurs throughout the area (Figure 5) and is responsible for exceptionally high groundwater levels during winter. In the northeast where the calcrete is exposed on the surface it causes ponding of the water and surface run-off. The upper unit of the aquifer is also recharged by the Kuils River in the vicinity of SACC. The development of dune ridges in the past forced the river to flow in an easterly direction and make a 90 ° turn in its natural course. This has led to an area of natural wetlands which recharges the aquifer from the northeast. The research by Wessels and Greeff (1980) indicated that 37 % of the groundwater flow occurred in the upper unit and 63 % in the lower unit of the aquifer. The weathered nature of the upper Malmesbury shales and resultant clay appears to isolate the sandy aquifer from the underlying units and possible secondary aquifers. Using these figures it was calculated that in the order of 8 L/s and 13.5 L/s of water flowed out to sea per kilometre. This gives an approximate annual total groundwater discharge from the catchment of $6.85 \times 10^6 m^3$.

The groundwater quality varies substantially over the catchment as illustrated in the salinity contour plan produced by Wessels and Greeff (1980) (Figure 7). The boreholes used to produce the contour plan all penetrated the bedrock. Table 2 gives a summary of the groundwater quality in selected boreholes as indicated in Figure 7. The poor quality water is attributed to the Malmesbury shales.

Concentrations are often higher in those areas where the bedrock is close to the surface and evapotranspiration has a major influence on the concentration. The better quality groundwater is found in those areas recharged by the Kuils River. The groundwater is, however, of an exceptionally saline nature in the central area as a result of the old vlei/marsh area. The vertical groundwater quality variations (Figure 6) reflect the effect of the semi-pervious calcrete layer on infiltration and presence or absence of clay.

TABLE 2

A SUMMARY OF GROUNDWATER QUALITY FROM SELECTED BOREHOLES

Determinands	Boreholes				
	1	2	3	4	5
K as mg/L	2.0	10.0	21.0	5.0	2.3
Na as mg/L	325	1080	413	410	40
Ca as mg/L	185	180	81	175	47
Mg as mg/L	180	90	66	45	9
Cl as mg/L	490	1785	680	820	47
SO_4 as mg/L	740	105	176	160	22
Alk ($CaCO_3$) as mg/L	380	375	276	300	200
Fe as mg/L	1.2	2.0	1.6	1.1	1.5
E.C. as mS/m	275	520	247	250	55
pH	7.8	7.7	7.8	7.3	7.6

*Borehole location shown in Figure 7 (After Wessels and Greeff, 1980)

The water quality in the Kuils River is highly dependent on human activity as the sewage effluent from 5 wastewater treatment plants enters the river. The effluent is responsible for much of the baseflow whereas urban stormwater runoff is a major contributor to peak flows during winter. In general the oxygen demand of the sewage effluents is not excessive and the self-purification which takes place in the vlei areas (wetlands) assists in ensuring that the water quality does not deteriorate.

2.6 Urban development

The township of Khayelitsha was designed specifically to cater for the influx of Black people to the Cape Peninsula. The target population was considered to earn under R4 000 per annum, have a high dependency ratio, an initial priority for food, followed by transport to place of work and finally shelter. The housing was therefore aimed at providing a range of formats which would not overburden the occupant financially, but allow for gradual upgrading (VKE, 1984). The final outcome was a high density black urban area serving the greater Cape Town Metropolitan Area.

The proposed structural plan for Khayelitsha is shown in Figure 2 and the present extent of urbanization illustrated in Plate 1. The incremental approach adopted by the developers included four different types of housing options:

a) *Organised squatter housing with minimal services*

In this option the developers provided a skeletal road system, a limited number of communal water supply points and a system of bucket latrines. Housing being the basic do-it-yourself squatter shack. These areas have inevitably degenerated into uncontrolled shanty towns with very high population densities and crime rates. Site C, most of the open land around the perimeter of Town 1, and the area between Town 2 and the Kuils River have this style of urbanization (Figure 2). More than 30 % of the population live in these areas and the number of shacks far exceeds the official figure of 23 654. Plate 2 depicts a typical view of one such area.

b) *Serviced sites or the starter option*

With this option the developers provided a basic infrastructure and plots on which private individuals could erect housing of a prefabricate/temporary nature. The main roads are tarred and both waterborne sewage and storm-water drainage is provided. Each plot has a flushing toilet and single water supply point. Such an area is illustrated in Plate 2. This type of urban development covers the largest area in Khayelitsha and appears to be the only way of rapidly accommodating vast numbers of people. Areas with this type of housing include Town 1 (Village 3 and 4), Town 2 (Village 2a and 4c) Town 3 (Villages 3, 4 and 5) and represent more than 50 % of the population. Unfortunately the older settlements of this type have become the most congested, the most filthy and usually the most dangerous areas. The shacks are so close together that walking between them is difficult and all sense of order (planned structure) has long since disappeared. Plate 2 gives some idea of this disorder in Town 1, Village 4.

c) *Core housing*

These areas are fully developed by the authorities and private enterprise, with tarred roads, a stormwater network, waterborne sewage, metered water and formal housing (permanent structures). Although the houses are constructed from recognised building material they are small and provide only the basic core around which future extensions may be made (Plate 2). Portions of Khayelitsha which may be defined as core areas are Town 1 (Villages 1 and 2) and Town 2 (Villages 1, 3, 4a and 4b). Officially there are 16 826 formal housing units [Lingelethu West Planning Dept., 1991].

d) *Higher income housing*

This type of housing is targeted at the higher income bracket. All the normal infrastructure is provided but no on-plot services are included. Private individuals are expected to acquire the services of private contractors to build houses as requested by the individual. To date no such areas have been established although Town 4 is reserved for such housing (Figure 2).

Development began in the mid-1980's and by 1989 Site C and Town 1 were complete. Although the "official" population was 210 000 the actual figure was probably far higher. By 1990 the official figure was 320 000 and the population at present is likely to be in the order of 500 000 people. Figures 8 and 9 illustrate the extent of urban development over a period of 4 years.

In 1990 the local authorities were forced to admit that the initial structural planning for the development of Khayelitsha was outdated and had failed to meet expectations. According to Mr Graham Lawrence, the town clerk, much of this could be blamed on "bureaucratic inefficiency".

Much of the recent development has been of the "serviced sites" option as this provides the quickest, most cost effective way of controlling urbanization. Efforts were made during 1991 to move people from the overcrowded shack areas to the new serviced sites in Towns 2 and 3. This exercise was not totally successful as shacks still remain along the north-eastern perimeter and Site C remains as crowded as ever. Although the core areas contain schools, privately-run nutritional centres, clinics, a few filling stations and minor shops, Khayelitsha remains very much a residential township. With no supermarkets or banks, most residents shop in Mitchell's Plain, although small businesses are now booming throughout Khayelitsha.

Like all other South African townships Khayelitsha has experienced considerable political unrest and is considered the most dangerous township in the Cape Peninsula . Police reports indicate that more than 250 people were murdered in 1989 alone. The most violent areas being the shack settlements where there is rampant unemployment. One Argus reporter went as for as to state that "his experiences in townships on the Reef pale into insignificance when compared to those in Khayelitsha". The taxi wars which raged throughout 1991 caused further complications and often led to total turmoil in the township for weeks on end.

The outcome of this unrest and violence is that terror-stricken residents dismantle their ramshackle shanties and move to new areas literally overnight. This continuous movement of people makes township management almost impossible. A common occurrence during periods of unrest is for hundreds of shacks to be torched in one night leaving thousands of people homeless. The security threat to municipal workers coupled with municipal strikes and straight forward sabotage of sewage pipes often results in a complete breakdown in services. The result is that sewage overflows from bucket latrines and out of sewers to produce scenes of cars driving "axle-deep in muck".

2.7 Stormwater system

The stormwater system for Khayelitsha was designed with an eye to removing urban runoff, controlling the high groundwater table and providing protection against flooding by the Kuils River (VKE, 1984). In its natural state most of the catchment has no natural outlet either to the sea or to the Kuils River. The Illudas stormwater drainage model was used during the design stages and Figure 10 illustrates the main elements of the system. The system allows for the disposal of stormwater originating from all the western area and part of the eastern area into the sea. The balance, comprising about one third of the catchment discharges into the Kuils River.

Two main collector drains run in a south-south easterly direction through the centre of the catchment, before entering the main outfall conduit that drains into a detention basin upstream of the coastal outlet. The system is entirely below ground except for a short section of open channel between Site C and the detention basin (an existing natural depression) north of Town 1. The main collector drains are box sections over most of the route while the minor system feeding into them consists of open jointed pipes allowing for groundwater seepage into the system.

The original topography was regraded to allow general drainage to the main collector drains, with secondary valleys draining to the secondary collectors. The system was designed to cope with floods of up to 100 year recurrence interval, while excess water would be held in temporary storage areas (VKE, 1984). These areas are located along the main collector drains and double-up as parks and sportsfields. The final retention basin which covers an area of 60 000 m^2 provides for both flood control and pollution reduction through settling and dilution.

2.8 Sewerage System

Most of Khayelitsha has waterborne sewage except for Site C and the other shack areas where a nightsoil bucket system is in use. The sewerage system runs in parallel with the stormwater system with two pump stations and one sewage works (Zandvliet wastewater treatment plant). One pump station is in the centre of Khayelitsha, while the second is on the coast south of the stormwater detention basin. By not using pit latrines, septic tanks and soakaways the authorities attempted to avoid any possible pollution of the groundwater. The close proximity of the sewerage pipelines to the stormwater system does, however, have the potential for contamination of the stormwater, especially in the final detention basin as the sewerage line runs across the basin.

CHAPTER 3

STORMWATER QUALITY

3.1 The Runoff Cycle

The runoff cycle describes the distribution of water and the paths it follows, from when it precipitates to when it reaches the stream/river channel. The fact that rainfall on the land surface is spasmodic and irregular in space, time and amount, whereas the resultant runoff from the land surface is comparatively constant indicates that the cycle is not simple. This contrast is largely due to the great storage capacity of the surface layers of the earth which ensure that excess rainfall is held back and only gradually released.

Figure 11a provides a very simple interpretation of this rather complicated cycle. Only recently have hydrologists begun to understand the processes involved in the cycle and still have a long way to go before all the processes are fully understood. The relative magnitude of the various components/processes in the cycle depend on the physical features and conditions of the land as well as the characteristics of the storm. When the precipitation reaches the earth's surface it may be intercepted by vegetation and lost through evapotranspiration, infiltrate through the soil surface, or collect in surface depressions. When the available interception and depression storage are completely exhausted and when the rainfall intensity at the soil surface exceeds the infiltration capacity of the soil, overland flow begins. Overland flow travels over the surface of the earth towards a stream channel either as quasi-laminar sheet flow or in small trickles and minor rivulets. Once the overland flow reaches the stream channel it is called surface runoff. The runoff process may be summarized as shown in the diagrammatic representation.

The water which infiltrates the soil surface may either percolate down through the soil layer and become groundwater, or it may move laterally through the upper soil horizons towards the stream channel as interflow. Interflow may either be as unsaturated flow or as shallow perched saturated flow above the main groundwater level. There may thus be several levels of interflow below the surface corresponding to textural changes between horizons and to the contact between weathered material and bedrock. Some interflow does not discharge directly into the stream channel, but comes to the surface at some point between the stream and catchment divide and may then move as overland flow (dotted line in Figure 11a). Experimental evidence suggests that interflow may in fact account for up to 85 % of the total runoff (Ward, 1975). This realization has led to the variable source/dynamic watershed/partial area concept and a kinematic approach in hydrological model derivation.

It can thus be concluded that quickflow, or direct runoff, is the sum of channel precipitation, surface runoff and rapid interflow. This runoff component clearly represents the major runoff contribution during storm periods.

When urbanization takes place within a catchment many of the natural hydrological processes are streamlined. The infiltration capacity is considerably reduced as the precipitation is caught by buildings, roads, cement walkways, etc. after which it is passed through drainage systems which have been designed to dispose of it into nearby streams as rapidly as possible. The urban drainage process is illustrated in Figure 11b. The greater the degree of urbanization the more the infiltration capacity is reduced resulting in a larger percentage of the precipitation becoming overland flow and thus quickflow (direct runoff).

Urbanization thus, not only produces larger volumes of surface runoff, but concentrates the runoff more rapidly (Overton and Meadows, 1976; Douglas, 1983; Simpson and Stone, 1988). It must, however, be remembered that although urbanization reduces infiltration spatially, by collecting the stormwater runoff, it boosts the potential for infiltration at selected sites (Lerner, 1990). If this water, once collected and concentrated, is not rapidly removed from the catchment it will artificially induce infiltration.

In the case of the Khayelitsha urban catchment the processes differ somewhat from that seen in First World type urban catchments. The Third World nature of the urban development and sandy nature of the catchment favour maximum infiltration and minimum overland flow. Figure 12 illustrates the runoff cycle for two common types of urban development in Khayelitsha. Because of the flat, sandy nature of the catchment any precipitation will either infiltrate or become depression storage. In the squatter camp areas there are no roads and drainage systems and all the water eventually evaporates or infiltrates. In the serviced site areas only the main roads (tarred) are connected to the stormwater system and thus contribute to overland flow. Other impervious surfaces such as the shacks/houses initially collect and concentrate the precipitation only to have it infiltrate in the surrounding sands.

The effective impervious surface in the Khayelitsha catchment is in the order of only 25 % of the total area, as much of the township consists of shacks and small free standing housing units. This means that infiltration is the dominant hydrological process and subsurface flow the major contributor of stormwater runoff. With the result that peak flows should be both delayed and reduced, while baseflows are increased. This has important repercussions on the stormwater's ability to act as a transport path of substances in the urban environment.

3.2 Stormwater quality in general

Apart from peak flows, urbanization also affects the stormwater runoff quality. The high concentration of population, commerce and industry in urban areas results in large scale production of waste material and pollutants. Precipitation and the resultant runoff loosen, suspend and then transport the pollutants within the stormwater discharge. Thus although stormwater is not a pollutant, it serves as a vector for the pollutants. The range of pollutants may vary greatly and includes those demanding oxygen, nutrients, solids fractions, heavy metals, bacteria, hydrocarbons and pesticides (Weatherbe and Novak, 1977). Research in North America has indicated that approximately half of the 129 listed US Environmental Protection Agency's priority pollutants have been detected in urban stormwater runoff. These include a number of mutagenic substances with a potential for entering the biological food chain (Field, 1985).

Not only is urban stormwater runoff capable of containing a wide range of pollutants, but it is also known to have high concentrations. For example, Cordery (1977) found that in comparison with raw sewage, the stormwater from a sandy urban catchment in Sydney contained the equivalent of 60 % of the suspended solids, 7 % of the BOD, 19 % of the phosphate and 5 % of the ammonia. The fact that raw sewage is treated, whereas stormwater is not, can therefore often mean that stormwater is more polluted than treated sewage effluent. Similar results have been obtained by Field and Fan (1981); Field and Turkeltaub (1981); and Gutteridge *et al.* (1981). Both Weatherbe and Novak (1977), and Qureshi and Dutka (1979) have shown that microbiologically stormwater runoff may be more contaminated than dilute raw sewage. A recent study along the False Bay coastline has shown that urban stormwater outfalls contribute far greater microbiological pollution than the sewage effluent outfalls originating in the same urban area (Augoustinos and Kfir, 1990).

The pollution potential of stormwater runoff is not just by way of the high concentration of specific pollutants/constituents, but also from the resultant effect caused by the interaction between different constituents. An example is the detrimental effect which increased concentrations of heavy metals have on the decomposition of organic matter. Heavy metals are a form of toxicity to the bacteria and reduce their decomposition activities. The large volumes discharged by stormwater systems also result in a shock loading effect in the receiving water body.

The concentration of pollutants may be relatively consistent during baseflow conditions, but varies dramatically during storm events (rainfall event). At the beginning of a storm event those pollutant particles lying loose on impervious surfaces are quickly suspended and transported by the incipient overland flow. This results in a "first flush" effect when the volume of stormwater is still relatively minimal, but the concentration of pollutants is very high. The concentration then decreases until the peak flows resulting from the storm event scour/remove the compacted particles in the catchment (Mance and Harman, 1978; Hoffman *et al.*, 1982; Simpson, 1986; Hvitved-Jacobson *et al.*, 1987). An Australian study by Cordery (1977) suggested that most of the pollution is removed from the catchment by the first 10 to 20 mm of rain, provided fairly high intensity occurs and thereafter continued rain removes only minor amounts.

This suggests a relationship between pollutant load and the antecedent dry period. One school of thought (Weatherbe and Novak, 1977; Randal *et al.*, 1978; Urbonas and Tucket, 1980; Colwill *et al.*, 1984; Sartor *et al.*, 1984; Simpson, 1986) believes that pollutant build-up on land surfaces and the subsequent washing off of these pollutants is related in some way to the duration of the dry period preceding the storm event. Another school (Whipple, *et al.*, 1977; Bedient *et al.*, 1980; Mance and Harman, 1987) believes the length of the antecedent dry period and the magnitude of the previous storm event have little affect on the mass of pollutants discharged. It is rather the characteristics of the current storm event that have a dominant influence. Barkdoll *et al.*, (1977) suggest that the similarity in shape between hydrographs and pollutographs indicates that flow is the dominant factor influencing pollution loads.

Although the presence of the first flush effect has been well established by urban hydrologists - Helsel *et al.*, (1979) for example, found that in the United States 90 % of all storm events analysed in commercial catchments showed a first flush effect, with an 80 % rate for residential catchments - it does not necessarily include all pollutants. Microbial populations in fact do not reflect a first flush effect, but rather increase with flows and then remain at high concentrations for long periods after the flow has once again subsided (Qureshi and Dutka, 1979; Wright, 1990).

3.3 Pollution Sources

The source of pollutants carried by stormwater runoff may be either specific - a point source - or diffuse - a non-point source. A survey undertaken by Wanielista (1979) indicated that 80 % of the time urban stormwater quality is determined by non-point source pollution. Simpson (1986) grouped the sources into three main categories, namely, atmospheric fallout, erosion of the catchment and materials imported from outside the catchment. Two processes enable the stormwater to collect and transport the pollution. As water is a good solvent for many substances it is able to transport soluble substances from both the atmosphere and urban surfaces. Secondly raindrops, when hitting a surface, are a very good erosive agent, thus creating the possibility of transporting particulate substances.

The atmosphere acts as a pollutant source both as dry weather fall out and rainfall washout. Simpson *et al.* (1978) ascribed 51 % of the suspended solids, 35 % of the phosphorous, 80 % of the nitrogen and 43 % of the lead found in stormwater runoff in a Natal urban catchment to atmospheric deposition. Other studies by Malverson *et al.* (1984); Ebbert and Wagner (1987) and Ng (1987) have confirmed that precipitation is a source of both nitrogen and phosphorous, while Green *et al.* (1986) found a strong correlation between lightning activity and nitrate levels. These studies established that most atmospheric pollutants are washed out at the beginning of rainfall events and thus the amount of rain and intensity thereof, has little bearing on the amount of pollution.

Research in both the United Kingdom (Ellis and Dochinger, 1978) and the United States (Randal *et al.*, 1978; Gutteridge *et al.*, 1981) suggests that although the source of atmospheric pollutants may be site specific, the fallout/washout is relatively uniform over metropolitan areas. Heaney and Sullivan (1971) estimated that approximately 70 % of the material found on street surfaces in Chicago could be attributed to atmospheric fallout.

The role of motor vehicles as a source of pollutants has been well established (Bardoll *et al.*, 1977; Goettle, 1978). Exhaust emissions contribute lead to atmospheric fallout, while wear-products that collect on the road surface contribute both metals and hydrocarbons (Wigington *et al.*, 1983). The importance of vehicle omission to atmospheric fallout was demonstrated in a West German town by Goettle (1978). All traffic was prohibited for a period of days and it resulted in an 85 % reduction in concentrations of lead, carbon monoxide and nitrous oxides. Much of the pollution found on roads is of a fine nature and almost 90 % is found within 0.3 metres of kerb, (Gutteridge *et al*, 1981). It is these pollutants found near the kerb, in catchpits of the road drainage system, that contribute to the first flush effect (Mance and Harman, 1978).

The land use practised in a catchment is important as it not only affects the erosion potential, but also determines the types of materials imported into the catchment. The pollution loads from industrial and commercial catchments appear to produce the greatest concentrations of pollutants (Overton and Meadows, 1976; Polls and Lanyon, 1980; Gutteridge *et al.*, 1981). Industry serves as a major polluter by way of leaching from open stockpiles of raw materials, finished products and process wastes; accidental spillage and leakage; and illegal flushing. The pollutants include oils, lubrication, toxic material and heavy metals. Commercial areas generally have the highest degree of imperviousness and produce pollutants such as lead, rubber compounds, oil and suspended solids.

Residential catchments are largely responsible for providing organics, bacteria and nutrients to the stormwater runoff. These originate from litter, plant material and human and animal excreta. The most important organic elements are carbon, hydrogen, oxygen and nitrogen which give rise through the action of aerobic bacteria to carbon dioxide, water and nitrate. The process depletes the stormwater oxygen content and provides energy for increased bacterial growth (Overton and Meadows, 1976). Nutrients such as nitrogen and phosphorous which cause eutrophication in the receiving water body also originate from fertilizers used in gardens, parks and sport fields. Pesticides are another major pollutant which originate from gardening practices.

Gutteridge *et al.*, (1981) found that there appears to be no difference between old and newly developed residential catchments, but rather that the quantities of pollutants produced vary according to the economic standard of the suburb. These findings are a confirmation of a study by Charachlis *et al.*, (1978) which found that a low income suburb in Houston produced substantially more pollution than an adjacent middle class suburb. What is important, is whether new construction is taking place in a catchment. Ellis (1976) found that in catchments where construction is taking place or soil erosion is rife, the suspended sediment contains substantial clay which acts as excellent sorbents for trace metals. Suspended solids such as concrete, ash, brick and aggregate components are also highly absorbent and may pick up aerosol metal ions, grease and detergents and accumulate them in benthal sludges.

There are thus numerous diffuse pollution sources in an urban catchment other than the obvious point sources. All the sources ultimately contribute to the accumulation of pollutants on the catchment surface from where they are removed by the first flush of stormwater. The runoff must, however, have sufficient transport capacity and this will vary with the runoff intensity, the topology of the area, etc. Pollutants may thus be transported from one area within the catchment to another without necessarily reaching the main stormwater system and receiving waterbody. Some parts of the catchment may therefore act as a "sink", accumulating substances and becoming pollution sources for runoff events of greater intensity (Svensson, 1989).

3.4 Third World type urban catchments

As most urban hydrological studies have been in the "developed countries" of the world the research has concentrated on First World type urbanization. Conditions in the developing countries are, however, totally different as the systems dealing with water and sanitation are generally of a rudimentary nature. It has been estimated by the World Health Organization that water and sanitation improvements in such communities could reduce the overall incidence of infant and child diarrhoea by 24 % and total infant and child mortality by over 50 % (IAWPRC, 1991).

Most of these areas are effectively residential and have very little commercial or industrial activity of a formal nature. This, coupled with the general lack of infrastructure and poor sanitation, results in a shift in emphasis when considering potential contaminants. Toxins, such as, heavy metals, pesticides and herbicides become less important, whereas, organics, nutrients, bacteria and pathogenic micro-organisms become important. The major source of pollutants must undoubtly be litter and faecal contamination from both human and domestic animals.

Even in those townships where regular refuse collection takes place there is a generally untidy appearance with extensive litter and informal dumps. Residents either dispose of their refuse by burning or in pits on the property or more commonly dump their refuse in the road or closest open area (public space). Residents also often make use of the sewer system (both sewage and stormwater) to dispose of their refuse and this results in blockages and spillages which posses a further health threat. Unfortunately untidy, unclean and unhygienic conditions limit opportunity for increased living standards and have a desensitising effect. It then becomes more difficult to change attitudes towards dumping and littering (Reilly and van der Merwe, 1990). The virtually uncontrolled presence of domestic animals and informal trading adds considerably to the pollution threat.

It is thus clear that Third World type urbanization not only poses a health threat to the urban community within the catchment but also to the adjacent areas. Any water leaving such catchments would be likely to be polluted and a carrier of the classic water borne diseases such as cholera, typhoid, infections hepatitis, shigellosis and diarrhoea.

CHAPTER 4

METHODOLOGY

4.1 Research Framework

The possible contamination of the marine environment in False Bay has received substantial public attention and much research has been done on the marine environment (Engelbrecht and Tredoux, 1989; Brown *et al.*, 1989; Augoustinos and Kfir, 1990; Idema and Kfir, 1990; CSIR, 1991). This work has identified stormwater runoff as one of the major contributors to the pollution load in False Bay, but has not investigated the actual pollution source. In fact urban stormwater quality from the Third World type urban communities remains very much of an unknown factor.

This study is therefore aimed at filling the gap in the research knowledge. Research is concentrated on urban stormwater runoff quality from the Khayelitsha catchment and attempts to address the following issues:

a) What type of pollution does a Third World type urban catchment produce?

b) Are the hydrological process different from that of a First World type urban catchment?

c) Do different types of urban development produce different types of contaminants.

d) What is the magnitude of the pollution?

e) What effect does the "polluted" stormwater have on the receiving waterbody?

4.2 Study Approach

One of the most unusual characteristics of water is its ability to dissolve a greater range of substances than any other liquid (Driscoll, 1986). This coupled with the random nature of water quality makes water quality monitoring a complex exercise (Fetter, 1980; Ward and Loftis, 1986). It was therefore decided to adopt a system's perspective as this avoids the common practice of gathering data for an entire "shopping list" of variables at great cost. Figure 13 summarises the general approach taken during the study.

Unlike most other urban hydrological investigations this study had the added constraint of a security problem. The poor security situation within the catchment had a direct bearing on both the network design and sample collection activities. Certain security problems were foreseen at the outset of the study, but nothing like what was experienced. The situation deteriorated to such an extent that many areas of the catchment could not be visited at all and others for extended periods of time. The unpredictable nature of the unrest made planning extremely difficult.

4.3 Network Design

Network design has received considerable research attention since the early 1970's (Montgomery and Hart, 1974; Beckers and Chamberlain, 1974; Kazmann, 1981; Sander *et al*, 1983). This information was used in determining sample locations, frequency and water quality variables to be measured in the study area. It was obviously not practical to study all the hundreds or thousands of potential chemical compounds in water, physical water quality variables and various biological species. For example, more than 450 chemical components have been identified as important in water quality problems (Sanders *et al*., 1983). It was therefore necessary to apply a hierarchical ranking system to identify those water quality variables at the top, which have aggregated effects of all the other water quality variables. Table 3 provides a summary of water quality variables used in other monitoring networks and those selected for this study. The water quality variables selected for this study cover the main groups of water quality criteria, namely: physico-chemical parameters; organic content; content of solids; nutrient content; toxins; and microbiological indicators.

TABLE 3

WATER QUALITY VARIABLES ANALYSED FOR IN OTHER URBAN HYDROLOGICAL STUDIES

Variables	Three Anchor Bay Kloppers (1989)	Three Anchor Bay Wright *et al.* (1987)	Atlantis Wright (1991)	Pinetown Study Simpson (1986)	Johannesburg Green *et al.* (1986)	Present Study
Physical			EC	EC suspended solids	EC suspended solids	EC
Inorganic major ions			calcium magnesium sodium potassium alkalinity sulphate chloride pH	sulphate chloride	bicarbonate sulphate chloride pH	Calcium magnesium Sodium potassium alkalinity sulphate chloride pH
Trace metals	zinc lead iron manganese chromium cadmium copper		zinc lead iron manganese chromium cadmium copper	zinc lead iron manganese chromium cadmium copper		zinc lead iron cadmium copper
Organic	Hydrocarbon		DOC	COD		DOC
Nutrients			nitrate ammonia orthophosphate	nitrate phosphate	nitrate	nitrate ammonia phosphate
Micro-biological		faecal coliform faecal Streptococci coliphages	total coliforms faecal coliform faecal Streptococci coliphages			faecal coliform faecal Streptococci coliphages

An initial field reconnaissance showed that the monitoring network would have to be on somewhat of a regional scale. Both the nature of the catchment and the poor security situation discouraged the establishment of any permanent monitoring structures within Khayelitsha. The different sub-catchments were studied in conjunction with the stormwater network and different types of urban development in order to site the water quality monitoring stations. The monitoring network is illustrated in Figures 14 and 15.

A network of five raingauges (two Casella natural-siphon rainfall recorders and three standard rain gauges) was established. The standard raingauges were sited in Khayelitsha itself while the Casella gauges were sited on either side of the catchment in safe areas (Swartklip Explosives Factory and SACC). The gauges within the catchment and on the coast proved unsuccessful due to vandalism, unreliable operators and continuous clogging during sandstorms. The strong south-easterly winds and disturbed sand dunes result in the movement of large quantities of fine sand across the catchment. A third Casella natural-siphon rainfall recorder was later added to the network and sited at the Zandvliet Sewage Works.

Flow gauging proved a major problem as the stormwater system, which is some 2 metres below the surface, contains large quantities of sand, rubble and garbage. This material continuously blocked the system causing false water levels and flooding of the system. Blockage of the grid upstream of the detention basin frequently resulted in the water level rising more than 2 metres in the main outfall conduit. Unfortunately it was only in the latter part of 1991 that this grid was checked and cleaned on a regular basis and even then weeks could pass between cleaning. Flow gauging was therefore only done at the weir on the final detention basin. The water level was recorded on a continuous chart recorder and the height of the water above the weir converted to flow volumes. The data was, however, of a coarse nature and the resolution was in the order of 30 minutes.

Five sites were initially selected for water quality monitoring in order to assess the magnitude of the stormwater contamination and help determine the best sampling sites to identify possible source areas (Figure 14). The final water quality sampling sites during the main part of the project are shown in Figure 15 and may be summarized as follows:

K1 - to monitor any stormwater runoff from Site C, an area of shacks, bucket latrines and no stormwater system. The sample was collected in the collector basin on the southern edge of Site C where the future connection with the existing stormwater system will be.

K2 - to monitor the stormwater runoff from the established core housing between Site C and the Swartklip Road. This site also represents any stormwater runoff that may enter the system from outside the Khayelitsha catchment. The sample was collected at the start of the open channel.

K3 - to monitor the water quality in the underground stormwater system of an established serviced-site sub-catchment. The sample was collected along the main outfall conduited 2 metres below ground.

K9 - to monitor the surface runoff entering the stormwater system from the central, temporary storage area in an established serviced-site sub-catchment. The sample was collected where the surface runoff enters the main stormwater conduit. This represents the same manhole as sample station K3 and drains the same sub-catchment, giving a comparison between the two types of stormwater drainage from the same landuse.

K5 - to monitor an established core-housing sub-catchment that has a low urban density and functional infrastructure. The sample was collected from the secondary stormwater conduit just before it joins the main conduit.

K6 - to monitor a developing core-housing sub-catchment. The sample site was on a secondary conduit more than 3 metres below surface. This station enabled a sub-catchment to be monitored as formalized urbanization took place. The sub-catchment was also selected as a comparison could be made between stormwater, irrigation water and groundwater.

K4 - to monitor the effect of establishing serviced-site type housing in a catchment. This station sampled a sub-catchment during all the stages of urban development, that is of the serviced-site type and is the equivalent of K6.

K10 - this site monitored the subsurface water quality in the sub-catchment feeding sample station K4. The sample was collected in the Town 3 (village 3) detention basin which intersects the calcrete layer and thus collects all the upper-subsurface water.

K11 - this site is in the same manhole as K4 and monitored the subsurface water collected in the stormwater system draining the area adjacent to the Kuils River System. This site was representative of the subsurface recharge effect from the river.

K7 - to monitor all the urban stormwater runoff originating in Khayelitsha catchment except for that from Town 3. The site is at the point where the main outfall conduit enters the coastal detention basin.

K8 - to monitor the stormwater quality at the final point along the stormwater network where it discharges onto the beach $\pm$ 1 000 km east of Monwabisi Resort. This being the same site that was sampled in previous False Bay reports such as Augoustinos and Kfir (1990) and CSIR (1991).

between the sample and cap. Care was taken not to touch the neck or lip of the bottle or the thread of the cap. Once collected the sample was immediately stored in a "cool box" and transported to the laboratory within six hours. Sampling of the marine environment (receiving waterbody) took place in the surf zone opposite the Monwabisi stormwater discharge (K8 in Figure 15). Samples were collected during low tidal conditions and approximately 20 cm below surface during the morning hours. Samples were taken at doubling intervals up to 200 m on either side of the outfall on a receding surf. Salinity was measured with a portable optical refractometer.

The one-off sampling of groundwater in the shallow, small diameter boreholes involved a somewhat more complex procedure. The borehole had first to be purged of its stagnant water before a sample could be taken. The stagnant water was not representative of the aquifer as a whole and the hydraulic properties, geology and construction details had to be considered for each individual borehole in order to decide on purging times and rates. The temperature, pH, and EC of the water was monitored regularly during purging and sampling only began once the EC had stabilized. Garrett (1988) found that for many monitoring wells, field parameters stabilize after three well volumes have been purged. During the present study it was found that when using the Division of Water Technology 3-stage submersible electric centrifugal pump, the boreholes had to be purged for about eleven minutes at the rate of $0.17\ L.s^{-1}$. Care had to be taken as the borehole could suffer physical change if purging rates exceeded development rates. When the sample was collected care was taken to ensure that no air remained in the bottle once the sample had been collected, as exposure of the groundwater to atmos-pheric oxygen and loss of carbon dioxide could affect the water chemistry enough to initiate changes in the equilibrium.

4.5 Laboratory Analysis

Laboratory analysis is a complex and specialized activity as it involves the analysis for many water quality variables with several alternative procedures. It also includes operational procedures such as the handling and flow of samples in the laboratory, quality control and the recording of analytical results. This part of the study was undertaken by the Analytical Services Programme staff of the Division of Water Technology, CSIR.

The water quality variables analysed included physical variables (temperature, electrical conductance, turbidity and pH), inorganic chemical variables (major ions and trace metals), organic chemical variables (dissolved organic carbon), nutrients (forms of nitrogen and phosphorous) and microbiological variables. The physical variables were determined in the field as they are unstable and change with time. All other variables were analysed in the laboratory using the methods recommended by Standard Methods for the Examination of Water and Wastewater (APHA, 1985).

The analysis of trace metals is relatively expensive and was therefore only done for selected elements and only when considered necessary. The great number of man-made organic compounds and high analytical costs meant that none were included in this study. As carbon serves as a key element in natural organic compounds it

A single site, namely K7, was selected for storm event sampling and continuous water quality monitoring (Figure 15). A site could not be selected inside the township itself because of the difficulty in gauging flow and for security reasons. This site ensured that all the stormwater runoff originating in 90 % of the present catchment was monitored. The continuous water quality monitoring was accomplished by measuring salinity in the form of electrical conductivity (EC). This was done using a Lektratek conductivity probe and Flowtra data logger which was housed in a security box inside the fenced-off stormwater discharge structure. Groundwater monitoring sites were restricted to the Town 2 (Villages 1 and 2a) sub-catchments. The old WRC/CSIR boreholes used in the Wessels and Greeff (1980) study could not be located, but the old data was available. Thirteen small diameter boreholes were, however, drilled during the early construction phase (1989) and sampled. These boreholes were later destroyed during further construction and subsequent urban development.

4.4 Sample Collection

Sample collection involved both the gauging of stormwater discharges and rainfall, and the collection of water quality samples. Quality control was vigorously applied during sample collection activities as sampling is recognised as one of the most error prone sections of any monitoring programme. Analytical results are only as good as the samples they are testing. Many guidelines for sampling and sample preservation are available and in this study those proposed by Kempster and Smith (1985) and Weaver (1992) were used.

Sampling consisted of "grab" samples at the selected sites, even though "grab" sampling has been considered as unreliable for studying temporal variations (Daniel *et al.*, 1978). The security situation made it impractical to use automatic sampling equipment and manual sampling is also preferable when undertaking microbiological analysis. This meant that storm event sampling was done manually and was restricted to rainfall events that occurred during daylight hours. The sample interval was initially brief to ensure maximum data acquisition during the early stages of the hydrograph. Thus being able to monitor any "first flush" effect that may be present. The routine sampling programme was geared towards specific weather conditions. By sampling under similar conditions one variable was removed from the equation and a comparison could be made between the different landuses and over time. Specific weather conditions chosen were: periods of dry weather in both summer and winter; and periods of typical wet weather both in winter and summer.

All samples were collected in plastic bottles which were first washed with 10 per cent HCl, rinsed with tap water and finally rinsed with distilled water. In the field, the bottle was again rinsed twice with the water to be sampled. No special sampling procedure such as filtering in the field was required for the major ions and nutrients, whereas samples to be analysed for trace metals were both filtered and acidified in the field. The samples were acidified using nitric acid to ensure that the metals remain in solution. In the case of microbiological sampling the bottles were glass and sterilized in the laboratory before sampling. The bottle was not rinsed in the field, but filled directly from the source, allowing for a small air space was used as an indicator variable and total concentrations of dissolved organic carbon (DOC) were monitored. Dissolved organic carbon as carbon was determined by automated infrared carbon dioxide measurement following potassium persulphate and ultra-violet digestion (CSIR, 1974).

Microbiological organisms were analysed for as water may act as the transmitting medium for a wide variety of disease-causing organisms which generally originate from human waste (Cabelli *et al.*, 1983; Borrego *et al.*, 1990). The pathogenic micro-organisms, however, appear intermittently in natural waters at low concentrations and present techniques available for the selective recovery and enumeration are complex and costly. It is therefore standard practice to analyse for other micro-organisms which share the same habitats. A number of researchers (Bonde, 1974; Kenard and Valentine, 1974; Grabow *et al.*, 1984; Borrego *et al.*, 1990) have confirmed this correlation between indicator organisms and the presence of pathogens. Indicator micro-organisms selected in the present study were faecal coliforms, faecal *Streptococci* and coliphages. No analysis was done for viruses, because an earlier study by Idema and Kfir (1990) has already shown that the Khayelitsha stormwater contains high levels of viruses (including hepatitis A and rotavirus). As the cost of such analysis is extremely high it was decided to use coliphage as an indicator as recommended by Vaughn *et al.* (1975); Olivieri (1981); Idema and Kfir (1990). The faecal coliforms and faecal *Streptococci* were analysed per 100 mL using the membrane filter technique (APHA, 1985) with dehydrated mEndo agar bes, mFC agar and *mEntercococcus* agar respectively. A modified double-layer-agar method (Grabow *et al.*, 1984) was used for plaque assays of coliphages. Coliphages were counted after incubation for 16 hours at 37 °C. Faecal coliforms were counted after incubation for 16 hours at 45 °C. Faecal *Streptococci* were incubated for 48 hours at 45 °C.

The laboratory mixing experiment was undertaken in the Ematek laboratories of the CSIR in Stellenbosch and Figure 16 illustrates the layout of the laboratory equipment. Two 250 mL glass bottles, interconnected by a tap, was used as the mixing vessel. The one bottle contained urban stormwater and the other seawater. Mixing took place when the tap was opened. Water was pumped from the seawater bottle at a constant rate and collected in 10 ml fractions, using a LKB Ultrorac 7000 fraction collector. The salinity of each fraction was measured with an AO optical refractometer.

Dissolved nutrients (nitrate, nitrite, ammonium, reactive phosphate and reactive silicate) were filtered through 0,45 μm Millipore filters prior to analyses according to a modification of the methods described by Mostert (1983). Trace metals (copper, lead and zinc) were analysed by flameless atomic absorption spectroscopy, using a Varian Techtron GTA95 Graphite Tube Atomizer.

4.6 Data Handling

Data handling consisted of acquiring and collection of all required water quality data. Much of the data could be transferred directly from the CSIR laboratories, but other data, such as meteorological and flow records had to be created from the collected field charts. Once the data was received it then had to be sorted, evaluated and verified for accuracy. Wherever possible this was done while loading the data in the database. In many cases the data had been collected at different levels of resolution and had to be manipulated into a compatible form.

4.7 Data Analysis

Data handling and data analysis are closely linked as data analysis often requires the rapid manipulation of large amounts of data. The multiplicity of variables which determine water quality, and the broad spectrum of management requirements combine to create a formidable obstacle in obtaining precise information from the database (Sanders *et al.*, 1983). There are a great number of techniques which may be used to analyse water quality data and in this study efforts were concentrated on the more general techniques, as these are most often used for coarse scale (time and/or space) analysis of water quality conditions (Hirsch *et al.*, 1982; Smith *et al.*, 1982; Sanders *et al.*, 1983).

4.8 Information Utilization

This was the final activity and involved the interpretation of information extracted from the data during data analysis activities. It included determining the format in which the interpreted information would be presented/reported.

The activity was undertaken in a number of phases. The first phase was a literature study on all aspects of urban stormwater hydrology including all previous work done in the False Bay area/Cape Flats aquifer. The second phase concentrated on the stormwater quality in the Khayelitsha catchment and this is reported in Chapter 5. The third phase looked at the receiving waterbody and is reported in Chapter 6. The final phase was a comparison of the results with other South African urban studies and constitutes Chapter 8.

CHAPTER 5

KHAYELITSHA STORMWATER QUALITY

5.1 The initial survey

Initially a monthly routine sampling programme was undertaken in order to define the extent of the microbiological contamination and the most probable source areas, that is geographical areas and not hydrological processes. The sampling sites are shown in Figure 14. The samples were analysed for three microbiological indicator organisms and salinity as measured by electrical conductivity. A more complete chemical analysis was done on a seasonal basis. These results are summarized in Tables 4, 5 and 6.

The sampling showed that microbiologically the entire stormwater system was polluted with concentrations exceeding levels defined for both drinking purposes (Kempster *et al.*, 1985) and direct contact recreation (Lusher, 1984). Although the criteria for direct contact recreation, are intended for the marine and estuarine environments, they are used in this study for stormwater to obtain some perspective on the water quality. Water within the stormwater system could according to the criteria pose a serious health threat if ingested by humans or if the stormwater canal and detention basins are used for direct contact recreation purposes (e.g. kids swimming).

Although the entire urban catchment was microbiologically polluted it appeared to be at its worst at site KS1 which represented runoff from Site C and the core housing immediately west of Site C. This was somewhat confusing as although the Site C shanty area had the potential for being the greatest pollution source, there was no surface runoff and any water entering the stormwater canal had to filter through the upper sand horizon (Figure 12a). This suggested that either the core housing type sub-catchment provided more pollution than suspected or that the sands were highly porous and were not filtering out the pollution originating in the squatter areas, resulting in groundwater contamination. The KS2 samples indicated that the older service-site sub-catchments were also prominent sources of pollution. With the addition of stormwater from an established core housing sub-catchment (KS3) the water quality surprisingly often deteriorated. Only during the wet season was there any dilution, probably due to the greater percentage surface runoff in these catchments (Figure 12b).

The salinity as measured by electrical conductivity showed a distinct spatial variation within the catchment (Table 5). As the lower values occurred closer to the sea the trend was opposite to that which may have been expected for a coastal catchment in which the prevailing wind is landwards. The trend did, however, correspond to both the groundwater salinity (Figure 7) and population density. A comparison between KS4 and KS5, before and after the final detention basin, indicated a substantial reduction in salinity.

TABLE 4

INITIAL ROUTINE MICROBIOLOGICAL ANALYSIS OF KHAYELITSHA STORMWATER

Faecal coliforms (per 100 mL)

Month	KS1	KS2	KS3	KS4	KS5
April	8.0×10^{2}	7.3×10^{2}	1.4×10^{4}	7.9×10^{3}	3.2×10^{3}
May	1.8×10^{5}	5.4×10^{5}	1.7×10^{5}	3.6×10^{5}	4.2×10^{4}
June	3.5×10^{6}	8.1×10^{5}	1.0×10^{6}	1.2×10^{4}	2.5×10^{3}
July	4.3×10^{5}	1.2×10^{4}	1.1×10^{5}	7.1×10^{6}	2.5×10^{4}
August	7.5×10^{5}	5.3×10^{5}	3.9×10^{5}	4.0×10^{5}	2.8×10^{5}
September	3.1×10^{6}	1.2×10^{4}	1.2×10^{4}	2.9×10^{5}	2.0×10^{3}
October	1.1×10^{3}	2.4×10^{2}	7.9×10^{4}	1.9×10^{5}	1.5×10^{3}
November	1.1×10^{5}	2.1×10^{3}	4.3×10^{3}	1.1×10^{4}	1.3×10^{3}
December	4.7×10^{3}	2.8×10^{3}	1.6×10^{6}	7.0×10^{5}	7.0×10^{3}
January	5.5×10^{4}	1.0×10^{4}	6.0×10^{4}	4.6×10^{3}	5.1×10^{3}
February	1.2×10^{5}	3.0×10^{3}	1.2×10^{4}	2.1×10^{4}	1.8×10^{4}
March	4.9×10^{6}	7.0×10^{2}	2.7×10^{4}	2.2×10^{5}	6.0×10^{3}

Faecal streptococci (per 100 mL)

Month	KS1	KS2	KS3	KS4	KS5
April	8.3×10^{2}	3.6×10^{1}	1.6×10^{3}	1.2×10^{3}	2.2×10^{2}
May	1.2×10^{4}	1.7×10^{4}	8.4×10^{3}	6.9×10^{3}	3.4×10^{2}
June	5.6×10^{3}	1.5×10^{4}	8.1×10^{3}	6.2×10^{2}	6.0×10^{2}
July	2.8×10^{4}	1.9×10^{2}	1.1×10^{4}	2.7×10^{4}	2.5×10^{2}
August	1.5×10^{5}	1.5×10^{5}	1.7×10^{5}	1.4×10^{5}	9.9×10^{4}
September	3.9×10^{4}	6.0×10^{2}	1.1×10^{2}	1.2×10^{2}	2.0×10^{1}
October	5.0×10^{2}	6.0×10^{1}	3.2×10^{4}	5.4×10^{4}	7.0×10^{3}
November	7.3×10^{3}	2.6×10^{2}	2.4×10^{3}	1.0×10^{3}	2.0×10^{1}
December	2.1×10^{3}	7.6×10^{2}	2.0×10^{5}	2.9×10^{3}	0.8×10^{1}
January	3.9×10^{3}	1.3×10^{3}	5.6×10^{3}	1.3×10^{3}	6.7×10^{1}
February	9.6×10^{3}	1.6×10^{2}	9.4×10^{3}	1.5×10^{3}	7.0×10^{1}
March	1.5×10^{5}	1.2×10^{2}	2.5×10^{3}	2.5×10^{3}	1.0×10^{1}

Coliphage (per 10 mL)

Month	KS1	KS2	KS3	KS4	KS5
April	1.6×10^{3}	0.6×10^{1}	2.0×10^{1}	7.8×10^{1}	5.4×10^{1}
May	2.8×10^{3}	3.6×10^{3}	2.3×10^{3}	3.3×10^{3}	8.4×10^{3}
June	3.0×10^{2}	2.3×10^{2}	2.7×10^{2}	3.8×10^{2}	3.7×10^{2}
July	3.9×10^{3}	5.5×10^{2}	1.8×10^{2}	7.6×10^{3}	3.7×10^{2}
August	1.5×10^{4}	7.1×10^{3}	4.0×10^{3}	1.1×10^{4}	1.2×10^{4}
September	9.6×10^{4}	5.2×10^{2}	1.8×10^{2}	1.4×10^{4}	8.0×10^{2}
October	1.9×10^{3}	4.0×10^{1}	5.0×10^{2}	2.4×10^{2}	5.9×10^{2}
November	1.0×10^{3}	8.2×10^{2}	1.0×10^{2}	4.3×10^{2}	5.0×10^{2}
December	7.0×10^{2}	1.3×10^{1}	6.9×10^{2}	1.4×10^{2}	3.8×10^{1}
January	2.0×10^{2}	9.4×10^{1}	4.2×10^{2}	1.4×10^{2}	9.0×10^{1}
February	1.7×10^{3}	3.0×10^{1}	5.4×10^{1}	1.0×10^{2}	9.7×10^{2}
March	2.6×10^{3}	2.6×10^{1}	2.4×10^{2}	5.1×10^{2}	1.8×10^{2}

TABLE 5

SALINITY VALUES MEASURED DURING INITIAL ROUTINE SAMPLING

Sampling Date	Number of rain free days prior to sampling date	Sampling points				
		KS1	KS2	KS3	KS4	KS5
April	21 days	325	190	135	220	210
May	4 days (2.1 mm)	275	200	145	230	180
June	14 days	265	111	139	230	215
July	5 days (1.4 mm)	280	195	134	210	215
August	(20 mm during preceeding 24 hours)	121	154	84	83	92
September	7 days (25 mm)	290	180	132	220	180
October	4 days (1.7 mm)	295	175	124	205	175
November	4 days (2.8 mm)	300	180	130	195	175
December	30 days	310	180	128	205	175
January	4 days (5.2 mm)	305	175	118	180	165
February	3 days (3.6 mm)	305	175	71	170	160
March	21 days	290	165	118	180	165

Salinity measured as Electrical Conductivity in mS/m

The chemical analysis (Table 6) reflected the Third World nature of the catchment - very low trace metal concentrations and higher NH_4-N, NO_x-N and DOC concentrations. Those areas containing shacks were the greater sources of pollution. The higher concentrations occurring during the drier months suggested that baseflow was a major contributor of contaminants. It was, however, more likely a reflection of reduced volumes of stormwater discharged during summer and although concentrations were higher total pollution loads were less. Obviously different trends occurred in those sub-catchments with formal housing as the addition of stormwater from these areas had a diluting effect.

A number of conclusions could be made from the initial routine sampling:

a) the stormwater runoff was polluted throughout the drainage system;

b) the major form of pollution was of a microbiological nature;

c) sampling on a routine basis was of limited value;

d) landuse appeared to have an effect on the resultant stormwater quality;

e) subsurface flow/groundwater appeared to have an influence on the chemical quality of the stormwater;

f) the final detention basin was effective in reducing pollution.

TABLE 6

INITIAL ROUTINE CHEMICAL ANALYSIS OF KHAYELITSHA STORMWATER

Sample Pt	KS1			KS2			KS3			KS4			KS5		
Season	Winter	Spring	Summer	Winter	Spring	Summer	Winter	Spring	Summer	Winter	Spring	Summer	Winter	Spring	Summer
K mg/L	9.8	16.8	14.3	7.8	15.5	15.7	8.4	8.9	4.9	8.8	10.1	7.8	8.7	9.4	8.6
Na mg/L	286	302	365	96	168	162	102	90	43	288	262	212	275	213	209
Ca mg/L	193	229	211	79	130	128	132	135	75	129	128	101	102	98	66
Mg mg/L	53.1	57.5	62.5	31.1	56.0	56.5	43.6	40.9	18.8	55.7	52.3	39.0	52.3	44.8	38.9
NH_4-N mg/L	0.72	3.20	0.43	0.72	1.80	1.16	0.50	0.45	0.10	0.26	0.69	0.11	0.05	0.12	0.35
Cd mg/L	<0.01	0.02	<0.02	<0.01	0.01	<0.02	<0.01	0.01	<0.02	<0.01	<0.01	<0.02	<0.01	<0.01	<0.02
Cu mg/L	<0.02	0.01	<0.02	<0.02	<0.01	<0.02	<0.02	<0.01	<0.02	<0.02	<0.01	<0.02	<0.02	0.02	<0.02
Fe mg/L	0.330	0.379	0.079	1.700	0.455	0.375	0.390	0.318	0.361	0.330	0.242	0.258	0.070	0.091	0.014
Pb mg/L	0.02	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.64	<0.02
Zn mg/L	0.17	<0.02	<0.02	0.13	<0.02	<0.02	0.06	<0.02	0.02	0.02	<0.02	0.05	0.02	<0.02	0.03
SO_4 mg/L	242	306	223	122	184	215	213	171	96	187	193	132	175	138	143
Cl mg/L	480	495	629	128	207	209	126	115	62	420	381	290	387	309	299
ALK ($CaCO_3$)	306	428	391	199	366	375	299	315	167	355	368	293	304	292	218
NO_x-N mg/L	19.40	19.30	23.03	10.50	17.18	14.87	9.75	8.01	2.97	6.70	7.21	4.21	5.20	6.10	3.34
P mg/L	<0.05	0.15	<0.05	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
ABS 545 n	0.015	0.013	0.013	0.013	0.005	0.007	0.005	0.005	0.012	0.006	0.008	0.011	0.006	0.007	0.023
ABS 275 n	0.599	0.993	0.859	0.349	0.509	0.521	0.392	0.393	0.29	0.574	0.624	0.473	0.559	0.589	0.759
ABS 254 n	0.771	1.272	1.089	0.451	0.660	0.674	0.510	0.508	0.372	0.755	0.814	0.618	0.730	0.769	0.99
DOC mg/L	10.2	15.3	16.6	6.3	11.0	11.8	9.9	8.8	7.1	10.2	11.5	11.9	8.1	10.6	12.8
EC mS/m	265	290	305	111	180	175	139	132	71	230	220	170	215	180	160
pH	7.9	8.0	6.7	7.9	8.0	6.9	8.0	8.0	7.5	8.3	8.0	7.2	8.4	8.2	7.5
TDS mg/L	1723	1856	1952	722	1152	1120	904	845	454	1495	1408	1088	1398	1152	1024

ABS = UV absorbance Scan

5.2 The main survey

The findings of the initial survey provided a valuable insight into the catchment characteristics and helped with the formulation of the main sampling programme. This programme is fully described in Chapter 4. The results are summarized in Appendix B and represent sampling throughout the catchment during both dry and wet weather conditions. These results may be further summarized (Tables 7 and 8) giving the average quality for the different types of landuse. Khayelitsha is a low income residential catchment and thus different landuse types relate merely to housing and population density (as described in Section 2.6). Dry weather conditions relate to the baseflow, while wet weather conditions concentrate largely on interflow (especially rapid interflow) and to a lesser extent groundwater flow. The differentiation between "old" and "new" distinguishes between those areas urbanized prior to and post 1990.

5.2.1 *Undeveloped sub-catchments*

The undeveloped sub-catchment represents an area that has the normal urban infrastructure, but as yet has no houses or human occupancy. The stormwater system is thus fed by surface runoff from the roads and interflow from the upper 5 metres of the aquifer.

The microbiological counts were high in comparison with the chemical analyses. This water quality suggested a mixture of groundwater and interflow as a result of irrigation of the "grassed" open areas above the stormwater outfall pipe. The area immediately surrounding the stormwater outfall pipe acted as a natural conduit for any subsurface flow and a portion of this water then seeped into the pipe through the open joints.

5.2.2 *Controlled squatting sub-catchments*

In those areas of controlled squatting there is no infrastructure and stormwater sampling was confined to the main drainage point on the edge of such a sub-catchment. Plates 2 and 3 illustrate such "catching" basins.

The stormwater runoff showed a fairly constant quality with obvious signs of pollution. The higher chemical concentrations during dry weather conditions reflected the importance of the baseflow component as illustrated in Figure 12. During wet conditions rapid interflow took place and concentrations dropped to reflect this influx of shallow subsurface water. No overland flow was observed other than on a few highly compacted tracks, even during the most intensive storms. Although ponding occurred this only results in depression storage and increased evaporation and delayed infiltration.

The pollution reflected by the microbiological counts is of concern as this was in water that had filtered through several metres of sand. The sample represented water seeping into the stormwater catchpits some 2 metres below groundlevel and not semi-stagnant water already in the catchpit. During wet conditions increased flow meant that sampling could be done as the water left the catchpit and entered the stormwater outfall pipe. The high microbiological counts and DOC concentrations from these samples (Table 8) probably reflect direct contamination of the water in the catchpits (Plate 3) and surface depressions.

TABLE 7

AVERAGE STORMWATER QUALITY FOR DIFFERENT LANDUSES DURING DRY WEATHER CONDITIONS

Determinand	Undeveloped sub-catchment	Controlled squatting	Serviced Sites		Core Housing		Total Catchment
			Old	New	Old	New	
F.coliforms per 100 ml	1.4×10^4	2.5×10^5	4.0×10^6	2.0×10^7	1.4×10^3	1.1×10^6	5.0×10^4
F.streptococci per 100 ml	7.6×10^3	3.9×10^4	8.5×10^3	2.4×10^5	1.0×10^3	6.9×10^3	5.8×10^3
Coliphage per 10 ml	2.4×10^1	1.1×10^7	6.4×10^3	5.8×10^3	6.0×10^1	1.0×10^1	3.5×10^2
K mg/L	3.9	12.8	17.1	15.8	11.4	2.6	8.3
Na mg/L	14	72	58	96	136	13	184
Ca mg/L	34.1	155.6	125.4	132.7	123.3	29.0	114.6
Mg mg/L	3.5	36.6	53.0	29.2	33.7	2.8	41.6
NH_4-N mg/L	<0.05	0.5	3.10	2.62	0.49	0.06	0.23
So_4 mg/L	28	161	185	69	76	18	138
Cl mg/L	24	87	190	108	188	21	256
Alk ($CaCO_3$) mg/L	72	440	390	488	380	71	326
NO_3-N mg/L	0.30	1.45	10.37	<0.05	2.30	0.26	6.25
P mg/L	<0.05	<0.05	0.22	0.48	<0.05	0.06	0.05
pH (20deg C)	8.2	6.8	7.0	6.9	7.0	8.2	7.1
DOC mg/L	7.7	19.7	13.7	44.6	14.8	7.3	12.8
EC mS/m	28	129	165	118	139	24	165
TDS (Calc) mg/L	179	826	1056	755	890	154	1056
Hardness as $CaCO_3$ mg/L	100	539	525	452	413	86	450
Cd mg/L		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu mg/L		0.03	<0.02	<0.02	<0.02	<0.02	<0.02
Fe mg/L		1.99	0.85	0.67	1.69	1.02	0.42
Pb mg/L		0.06	0.05	<0.05	<0.05	0.06	<0.05
Zn mg/L		0.17	<0.02	0.03	<0.02	0.03	<0.02

The lack of adequate ablution facilities in the squatter areas was a direct source of faecal pollution. Although bucket latrines were provided these often only served as point sources of pollution. During periods of unrest and strikes the buckets remained uncollected and local disposal took place. In such areas ablution took place wherever possible, irrespective of the health risk.

5.2.3 *Serviced site sub-catchments*

The stormwater quality showed that the serviced site sub-catchments were the most polluted landuse type. This was a direct result of the pollution caused by over-crowding and the Third World life-style of the inhabitants. The type of pollution was essentially of a faecal nature, of both human and animal origin. Micro-biological indicator levels often approached those found in raw sewage which was not surprising considering that much of the remaining open area (the very light and very dark portions in Town 1, Village 3 and 4, Plate 1) was used for ablution purposes. Although each plot was originally supplied with a toilet (waterborne sewerage) these subsequently proved inadequate, as plots became inundated with shacks (Plate 2). A major source of pollution during the study period was the sewerage system itself. During unrest periods blockages occurred and sewage overflowed into the streets resulting in highly polluted stormwater as illustrated in Figure 17.

TABLE 8

AVERAGE STORMWATER QUALITY FOR DIFFERENT LANDUSES DURING WET WEATHER CONDITIONS

Determinand	Undeveloped sub-catchment	Controlled squatting	Serviced Sites		Core Housing		Total Catchment
			Old	New	Old	New	
F.coliforms per 100 ml	5.3×10^3	1.5×10^6	4.5×10^6	7.5×10^5	1.5×10^3	2.4×10^4	4.9×10^6
F.streptococci per 100 ml	1.7×10^4	5.8×10^5	2.0×10^5	2.8×10^5	9.2×10^3	5.5×10^3	2.9×10^5
Coliphage per 10 ml	1.3×10^2	1.2×10^4	2.1×10^4	5.8×10^3	0.4×10^1	1.3×10^1	2.2×10^3
K mg/L	0.6	11.3	16.1	14.1	10.1	1.7	10.1
Na mg/L	1	15	154	134	116	8	169
Ca mg/L	14	38	122	121	108	24	107
Mg mg/L	0.6	3.8	53.1	35.3	28.3	1.9	36.1
NH_4-N mg/L	<0.05	0.41	4.06	0.52	0.61	0.05	0.75
So_4 mg/L	3	22	170	90	77	10	130
Cl mg/L	2	19	211	170	176	11	240
Alk ($CaCO_3$) mg/L	35	112	368	435	358	63	300
NO_3-N mg/L	<0.05	0.30	12.40	0.19	0.90	0.16	6.5
P mg/L	<0.05	0.75	0.81	0.61	<0.05	<0.05	0.20
pH (20deg C)	8.8	7.9	7.0	6.9	7.0	8.5	7.1
DOC mg/L	1.3	15.2	22.6	48.4	17.5	3.2	14.7
EC mS/m	8	32	158	143	124	18	156
TDS (Calc) mg/L	49	202	1101	916	794	112	998
Hardness as $CaCO_3$ mg/L	38	111	511	466	387	64	407
Cd mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Fe mg/L	<0.05	0.36	0.41	0.06	1.74	0.02	0.64
Pb mg/L	<0.05	<0.05	<0.02	<0.05	0.03	<0.05	0.06
Zn mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.05

A further source of pollution was the litter and garbage dumped throughout the urban area. Plate 3 illustrates this source of pollution in the serviced site areas. This pollution source had negligible effect during dry weather conditions, but acted as a reservoir of potential pollutants for storm periods when a first flush effect could be expected. The large quantities of drift sand in Khayelitsha were responsible for blocking stormwater inlet points for much of the year and this helped to create a build up of material until storm events of high enough intensity occurred to flush the catchment.

In the older well established serviced site areas there was an increase in microbiological pollution during wet periods, whereas in the newer areas the count remained consistently high throughout the year.

The chemical parameters decreased during periods of wet weather. It was also observed that during dry weather conditions the newer areas had higher microbiological counts, but roughly the same during wet weather conditions. This possibly was as a result of the blocked stormwater inlets in the older subcatchments which did not allow many of the pollutants to enter the stormwater system, unlike the new areas where the stormwater system remained relatively sediment free.

The gross overcrowding in these serviced site catchments often resulted in unplanned changes to the existing drainage system. In Town 1 Village 4, for example, the central stormwater detention basin system (the white areas in Figure 2) became a densily populated shack area with no planned ablution facilities (compare Plate 1 to Figure 2). Any water draining from this low-lying area would thus be expected to be highly polluted especially during the wet season. Table 9 shows a comparison between the stormwater draining off this central squatter area and that in the main stormwater outfall pipe draining the whole sub-catchment. The results confirmed the expected trends, with the surface water (K9) being of a better quality during the drier summer months, but not necessarily so during the wet months. The amount of pollution produced in the sub-catchment is probably constant throughout the year, but the vastly reduced volumes of runoff during the summer means that less pollution is washed out especially by the surface drainage in the central area. The fact that the water also passed through a marsh-like area before entering the stormwater system helped reduce pollution during baseflow conditions. With the greater volumes of water during winter there was more potential for washing out of the accumulated pollutants especially in the central area. This was clearly reflected in the microbiology, NH_4-N, NO_x-N and P concentrations, especially of the surface drainage (K9). The effect that decreasing runoff volumes had was illustrated in the August sampling, as this represented a period of drying out within the sub-catchment. The sample collected on 7 August 1991 was 5 days after the last period of rain and 13 August 1991 a further 6 days later. The K9 results reflected the decreasing surface flow while the K3 sample indicated a further source of pollution in the system. Thus different drainage systems within the same sub-catchment gave different stormwater qualities.

TABLE 9

A STORMWATER QUALITY COMPARISON IN A WELL ESTABLISHED SERVICED SITE SUB-CATCHMENT

Determinand	12/03/91		23/04/91		07/06/91		05/07/91		07/08/91		13/08/91		22/10/91		19/11/91	
	K3	K9	K3	K9	K3	K9	K3	K9	K3	K9	K3	K9	K3	K9	K3	K9
F. coliforms per 100 ml	2.2×10^4	4.4×10^3	6.7×10^4	3.3×10^2	4.5×10^5	9.7×10^4	1.0×10^7	1.0×10^6	4.0×10^4	1.1×10^6	3.1×10^7	6.4×10^5	2.0×10^4	1.4×10^5	1.3×10^5	1.5×10^7
F. streptococci per 100 ml	3.0×10^7	6.0×10^3	6.8×10^7	7.2×10^3	2.0×10^5	1.1×10^5	1.3×10^6	2.1×10^5	8.5×10^3	1.6×10^6	3.5×10^5	5.8×10^3	4.3×10^7	1.4×10^4	2.1×10^4	6.0×10^2
Coliphage per 10 ml	2.8×10^1	2.0×10^1	2.2×10^1	2.2×10^1	2.1×10^4	1.7×10^3	2.6×10^4	2.3×10^4	6.4×10^2	1.5×10^5	7.3×10^4	1.8×10^4	5.1×10^4	5.4×10^3	8.4×10^2	9.8×10^1
K mg/L	14.1	3.6	14.1	7.6	21.6	17.3	16.1	14.8	20.2	17.9	19.4	12.7	19.4	10.8	15.6	2.7
Na mg/L	163	146	170	141	142	63	60	48	181	86	158	90	174	88	166	103
Ca mg/L	134.8	199.6	132.5	181.4	109.4	60.0	62.9	62.0	141.8	112.0	117.8	143.0	130.9	124.5	122.1	173.2
Mg mg/L	56.6	89.8	55.7	76.6	40.3	16.2	13	13.3	53.0	29.1	45.2	41.7	53.1	39.2	53.1	65.1
NH_4-N mg/L	2.53	0.11	2.35	0.12	4.06	1.12	6.32	8.85	3.74	17.09	13.18	2.07	2.92	1.21	1.51	0.18
SO_4 mg/L	209	430	212	369	139	66	49	44	190	118	157	160	170	135	183	305
Cl mg/L	208	166	227	171	201	77	76	62	241	96	199	103	233	94	238	97
Alk ($CaCO_3$) mg/L	390	477	395	450	349	206	230	232	414	419	402	429	423	420	368	474
NO_3-N mg/L	9.58	6.11	11.93	7.31	10.43	0.95	0.93	0.20	18.70	11.27	11.27	3.56	13.18	1.73	7.14	1.81
P mg/L	0.06	0.11	<0.05	0.07	0.81	0.58	0.99	1.32	0.30	3.27	1.20	0.69	0.22	0.51	0.13	0.14
pH (20 °C)	6.9	6.7	6.9	6.7	7.0	7.5	7.4	7.4	6.9	6.9	7.0	6.8	6.9	6.9	7.9	6.7
DOC mg/L	10.3	15.5	13.7	18.2	22.6	20.0	16.7	15.6	18.6	28.0	29.8	19.7	16.6	18.6	31.1	20.5
EC mS/m	170	195	180	190	155	76	75	69	195	126	165	132	180	123	172	157
TDS (Calc) mg/L	1088	1248	1152	1216	992	486	480	442	1248	806	1056	845	1152	787	1101	1005
Hardness as $CaCO_3$ mg/L	570	868	560	768	439	216	210	210	572	399	480	529	546	472	523	701
Cd mg/L	<0.01	<0.01	<0.01	<0.01												
Cu mg/L	<0.02	<0.02	<0.02	<0.02												
Fe mg/L	1.10	0.07	0.50	<0.05												
Pb mg/L	0.05	0.04	<0.05	<0.05												
Zn mg/L	0.02	<0.02	<0.02	<0.02												

12/03/91 & 23/04/91 Typical dry autumn
06/06/91 & 05/06/91 Typical wet winter
07/08/91 & 13/08/91 Typical dry winter
22/10/91 & 19/11/91 Typical dry summer

K3 - Main Stormwater outfall
K9 - Surface drainage

5.2.4 *Core housing sub-catchments*

Stormwater in sub-catchments containing core housing was by far the best quality of all the landuse types. The water from these sub-catchments served to help dilute the more polluted water from the serviced site areas. Microbiologically the quality was consistent whether originating from a well established area or a new area and irrespective of weather conditions (Tables 7 and 8). The chemical analyses showed more of a contrast, with the more established areas producing higher concentrations. The differences are seen in the NH_4-N, NO_x-N, DOC, K and trace metal concentrations as might be expected for such catchments.

The reduced pollution in the core housing areas is a reflection of the lower population density and slightly higher living standards. The main source of pollution was litter and garbage which collected in the gutters and catchpits (Plate 3). As with all the other areas stormdrain inlets and gutters became blocked with sand and this often resulted in ponding of water and accumulation of pollutants. The chemical analysis was thus more appropriate for detecting pollution. The main source of stormwater runoff was subsurface flow and during rainfall events only the streets contributed to overland flow. The drainage from individual houses invariably soaked into the sand surrounding the buildings as gutters and paved yards were not connected to the street drainage and hence the stormwater drainage system. The reduced amount of pollutants on individual plots meant that the sands were more effective in filtering the infiltrating water. Even the stormwater detention basins were better kept (maintained as sport fields) and contained less litter than other areas.

5.2.5 *The stormwater - groundwater quality relationship*

Groundwater flow is an important component of the natural runoff cycle and together with interflow is responsible for the greater proportion of stormwater runoff in a Third World urban catchment (section 3.1). In the case of the Khayelitsha catchment subsurface geology is responsible for promoting interflow at the expense of groundwater flow. The calcrete layer and clay lenses that extend throughout the aquifer (Figure 5) form natural barriers to vertical infiltration. Although not impermeable, these layers do result in a greater horizontal flow vector than vertical flow vector (Figure 6). Thus water infiltrating in the catchment has a tendency to flow downgradient within the upper unit of the Cape Flats Aquifer. As the stormwater drainage system is between 2 and 4 metres below the surface and designed to "control the high groundwater table" (VKE, 1984) it is likely to drain a large percentage of the subsurface flow above the calcrete layer. Ideally any pollution transported by the infiltrating water should be filtered out as it passes through the unsaturated zone. The purification/change in water quality takes place by means of a number of processes, namely, filtration, dilution, physico-chemical and biological processes (Hofkes and Visscher, 1986). Factors affecting these processes in the upper zone at Khayelitsha include the calcareous nature of the sand unit and the high groundwater level over large areas of the catchment.

Table 10 provides a water quality comparison between different types of water in a sub-catchment in which borehole data was available. The deep borehole intersected the Malmesbury Shales and sampled the lowermost unit of the aquifer, while the shallow borehole stopped above the main clay layer (~ 13 m depth) and thus sampled the middle unit (Figure 6). The stormwater sampled represented baseflow collected 3.5 to 4 m below surface at a time when no overland flow was present, but irrigation was taking place. The borehole and stormwater drain samples thus represented the three different units in the aquifer. From the sample analyses it was clear that the water in the upper unit was of a different quality to that of the lower units. The stormwater baseflow must therefore represent interflow which resulted from the irrigation taking place on the sport fields. The slight increase in concentrations indicated the chemical changes that took place as the water infiltrated through the calcareous sands above the calcrete layer. It is interesting to note that the water quality in the deeper unit appeared to have deteriorated over a 12 year period prior to the people actually moving in to the sub-catchment. This can, however, only be substantiated by further sampling.

A sampling exercise undertaken in one of the new serviced site sub-catchments (Town 3 villages 3 and 5) also served to illustrate how the water quality differed between the subsurface and surface environment, both of which contributed to the stormwater runoff. Table 11 summarizes the sampling results. Village 3 (Sample K4) was occupied prior to sampling whereas the occupation of Village 5 (Sample K11) only began in October 1991. The type of urbanization was identical, but at different stages of completion. Village 5 is, however, closer to the Kuils River wetland system which is responsible for the recharge of substantial quantities of water into the aquifer during the wet season. The presence of the calcrete layer close to the surface (Figure 5) results in elevated groundwater levels and flooding in any lowlying areas. The stormwater detention basin (K10) situated on the north-eastern edge of Village 3 and between the two villages intersects the calcrete layer and as such collects subsurface flow and not stormwater. The water draining off this basin then flows into the stormwater system and combines with that from Villages 3 and 5.

The higher microbiological counts from K4 and K11 distinguished the surface water component polluted by urban development, from that of the subsurface water recharged largely from the river system. The decrease in counts for K11 during the dry season probably reflected the increasing influence of the groundwater component. This is supported by the chemical trend. The increasing NH_4-N concentration in K4 and K11 suggests the increasing affect of urbanization and accompanying pollution. The SO_4 trend in the detention basin shows the results of falling groundwater levels and the drying out of the basin floor.

Sampling therefore showed that subsurface water quality, whether interflow or groundwater affects the stormwater quality. The lower two units of the aquifer are unlikely to have any affect on the stormwater, but the upper unit was the main source of baseflow. The level of the groundwater table determines whether this occurs as interflow or groundwater flow. Indications are that the calcrete layer helps retain any possible groundwater contamination in the upper unit of the Cape Flats Aquifer.

TABLE 10

SURFACE WATER - GROUNDWATER QUALITY COMPARISON

Determinand		Deep borehole (pre-urban development)	Deep borehole (start of urban development)	Shallow borehole (during urban development)	Irrigation water (present)	Stormwater baseflow (Present)
K	mg/L	2.3	3.3	1.7	1.2	7.8
Na	mg/L	40	86	101	7	18
Ca	mg/L	47	82	101	20	42
Mg	mg/L	9.0	22.2	21.8	1.9	3.4
NH_4-N	mg/L	-	<0.05	<0.05	<0,05	0.07
SO_4	mg/L	22	35	30	22	45
Cl	mg/L	192	143	188	18	30
Alk ($CaCO_3$)	mg/L	200	238	255	29	71
NO_x-N	mg/L	-	<0.05	<0.05	<0.05	2.10
P	mg/L	-	<0.05	<0.05	<0.05	<0.05
pH (20deg C)		7.6	7.3	7.2	8.8	8.1
DOC	mg/L	-	-	6.6	2.6	10.7
EC	mS/m	55	98	116	17	30
TDS (Calc)	mg/L	352	627	742	106	189
Hardness as $CaCO_3$	mg/L	-	298	-	59	120

TABLE 11

A STORMWATER QUALITY COMPARISON IN A NEWLY ESTABLISHED SERVICED SITE SUB-CATCHMENT

Determinand		Oct 91 K4	Oct 91 K10	Oct 91 K11	Nov 91 K4	Nov 91 K10	Nov 91 K11	Jan 92 K4	Jan 92 K10	Jan 92 K11
F. coliforms per 100 ml		6.6×10^6	2.2×10^2	3.9×10^5	7.5×10^6	2.9×10^4	2.5×10^5	2.0×10^7	1.5×10^3	2.9×10^4
F. streptoccoci per 100 ml		2.5×10^4	8.4×10^3	5.5×10^3	2.8×10^5	4.4×10^3	1.9×10^3	2.4×10^5	2.1×10^3	1.7×10^3
Coliphage per 10 ml		7.1×10^2	0	1.5×10^2	5.8×10^3	0	1.3×10^3	5.8×10^3	0	8.4×10^1
K	mg/L	12.7	14.1	11.2	15.1	13.8	10.7	15.8	18.1	10.7
Na	mg/L	130	229	169	137	359	180	96	338	185
Ca	mg/L	110.2	84.7	125.8	145.0	108.6	127.7	132.7	114.5	133.7
Mg	mg/L	33.5	72.0	39.4	38.1	103.0	42.4	29.2	101.9	44.6
NH_4-N	mg/L	0.32	<0.05	<0.05	1.72	0.07	0.13	2.62	0.05	0.18
SO_4	mg/L	88	54	67	91	149	81	69	116	76
Cl	mg/L	165	344	268	176	546	282	108	533	289
Alk ($CaCO_3$)	mg/L	406	497	386	475	577	405	438	622	418
NO_x-N	mg/L	0.32	<0.05	9.90	0.07	0.00	7.67	<0.05	<0.05	9.51
P	mg/L	0.18	0.08	0.05	1.03	0.16	0.10	0.48	<0.05	<0.05
pH (20deg C)		7.0	7.0	6.9	6.8	6.8	6.9	6.9	6.8	6.9
DOC	mg/L	22.2	32.1	17.9	75.7	38.3	27.7	44.6	26.0	17.0
EC	mS/m	134	190	165	152	275	175	118	260	170
TDS (Calc)	mg/L	858	1216	1056	973	1760	1120	755	1664	1088
Hardness as $CaCO_3$	mg/L	413	508	476	519	695	493	452	706	517

K4 Village 3
K10 Detention basin
K11 Village 5

High groundwater levels : Oct and Nov 91
Low groundwater levels : Jan 92

5.2.6 *The effects of urbanization*

Increased urbanization of a Third World nature can be expected to result in increased pollution, as unlike First World urbanization the increasing population density is not necessarily accompanied by improved infrastructure and living conditions. In theory the provision of serviced site areas to eliminate uncontrolled squatting should improve conditions and reduce pollution especially that of a faecal nature. In practice, however, as shown in Khayelitsha (Tables 7 and 8) this is not the case, as serviced site areas merely became controlled squatter areas. Figure 18 shows total stormwater quality trends for selected parameters over a period of 30 months. Data collected during rainfall events was not included in the graphs. The decreasing salinity trend possibly indicates an increase in overland flow and/or rapid interflow with respect to delayed interflow and groundwater flow. This is reflecting the large area receiving irrigation water and mains water. The other graphs, especially that of DOC and NH_4-N, show an increase in concentrations since early 1991 (22 months) which coincides with the movement of people into the new serviced site sub-catchments (Town 2 Village 2A and Town 3 Village 3, 4 and 5). This suggests that any form of new Third World urban development causes increased pollution and pollution is related more to population density than type of housing.

Two sub-catchments, one containing core houses (K6) and one with serviced sites (K4) were monitored as development and occupation took place. Sampling began on completion of the stormwater system and before occupation took place. The results are summarized in Table 12 and show the effects of "serviced site" type urbanization on stormwater quality. People began moving into the sub-catchment in August 1991 and this resulted in an immediate increase in nutrient concentration, followed later by increased microbiological counts. Occupation of the "core house" sub-catchment (K6) was a lot slower and is still taking place. In this sub-catchment there was no significant change in stormwater quality. This probably reflects the better living conditions and more importantly the lower population density.

The study thus suggests that any form of urban development that involves shacks/ informal houses will be detrimental to the quality of the stormwater runoff. The provision of water and waterborne sewerage does not necessarily mean less pollution, but can even increase the stormwater pollution by providing additional means for transporting the pollutants.

5.3 Storm event analysis

The continuous monitoring of stormwater quality could only be undertaken at one locality (Figure 15) and involved salinity as measured by electrical conductivity. Unfortunately due to the design of the stormwater drainage system and nature of the flow a continuous record could not be obtained during summer. Summer base-flow conditions gave very low water levels which resulted in the monitoring equipment periodically being exposed from the stormwater and producing "zero" values. As measurements were taken every 15 minutes and averaged over an hour it

TABLE 12 (continued)

THE EFFECTS OF URBAN DEVELOPMENT ON STORMWATER QUALITY IN TWO SUB-CATCHMENTS

15/10/91		22/10/91		19/11/91		29/01/92		14/05/92		27/07/92		09/11/92	
K4	K6	K4	K6	K4	K6	K4	K6	K4	K6	K4	K6	K4	K6
5.4×10^4	1.1×10^4	6.6×10^6	2.4×10^4	7.5×10^6	2.0×10^4	2.0×10^7	8.9×10^6	5.0×10^7		7.0×10^4	2.0×10^4	1.2×10^5	
4.2×10^3	6.9×10^3	4.2×10^3	6.9×10^3	2.8×10^5	1.9×10^2	2.4×10^5	3.0×10^5	8.0×10^5		1.4×10^4	3.5×10^4	3.9×10^4	
1.9×10^3	1.0×10^1	1.9×10^3	1.0×10^1	1.9×10^3	1.3×10^1	5.8×10^3	4.0×10^2	1.9×10^5		4.0×10^2	1.0×10^2	3.3×10^3	
11.2	4.3	12.7	2	15.1	1.2	15.8	7.8	17.2		10.2	1.6	8.2	
172	17	130	6	137	8	96	18	298		107	10	99	
123.1	34.5	110.2	22.7	145.0	24.6	132.7	42.4	63.5		114.7	24.6	79.4	
41.5	3.8	33.5	1.7	38.1	2.3	29.2	3.4	37.9		29.8	1.9	23.9	
0.29	<0.05	0.32	<0.05	1.72	0.07	2.62	0.07	22.23		0.72	0.17	0.07	
73	21	88	10	91	20	69	45	75		57	8	51	
268	27	165	7	176	17	108	30	499		173	16	151	
388	83	406	63	475	49	438	71	309		344	58	264	
8.19	0.26	0.32	0.16	0.07	0.00	<0.05	2.10	<0.05		2.23	0.22	0.05	
0.52	0.06	0.18	<0.05	1.03	0.01	0.48	0.05	4.10		0.30	0.06	0.07	
6.9	8.1	7.0	8.4	6.8	8.5	6.9	8.1	7.3		7.0	8.4	7.3	
19.4	7.3	22.2	5.2	75.7	3.2	44.6	10.7	28.3		18.9	4.9	13.0	
165	30	134	17	152	20	118	30	190		122	18	104	
1056	189	858	106	973	128	755	189	1216		781	115	666	
478	102	413	64	519	71	452	120	315		409	69	297	
						<0.01	<0.01			<0.01	<0.01	<0.01	
						<0.02	<0.02			<0.02	<0.02	<0.02	
						0.67	1.02			0.45	0.30	0.40	
						<0.05	1.02			<0.05	<0.05	<0.05	
						0.03	0.03			0.03	0.02	<0.02	

TABLE 12 (continued)
LEGEND

Weather Conditions

23/04/91	2 week dry period
06/06/91	1 day wet period (25 mm)
05/07/91	2.5 days wet period (44 mm)
07/08/91	1 week dry period
13/08/91	2 week dry period
15/10/91	2 week dry period
22/10/91	1 day wet period (5 mm)
19/11/91	1 day wet period (6 mm)
29/01/92	2 week dry period
14/05/92	1 week dry period
29/07/92	1 day wet period (6 mm)
09/11/92	1 day wet period (2 mm)

Extent of Urbanization

Date	K6	K4
01/04/90	0.05	0.00
01/10/90	0.15	0.00
01/04/91	0.30	0.00
01/10/91	0.43	0.90
01/04/92	0.50	1.00
01/10/92	0.55	1.00

Landuse types

K4	Serviced sites
K6	Formal housing

TABLE 12
THE EFFECTS OF URBAN DEVELOPMENT ON STORMWATER QUALITY IN TWO SUB-CATCHMENTS

Determinand	23/04/91		06/06/91		05/07/91		07/08/91		13/8/91	
	K4	K6	K4	K6	K4	K6	K4	K6	K4	K6
F. coliforms per 100 ml	5.2×10^4	1.4×10^4	3.4×10^4	1.4×10^4	3.6×10^4	5.3×10^3	2.4×10^4	1.7×10^3	6.6×10^5	2.9×10^3
F. Streptoccoci per 100 ml	1.7×10^3	7.6×10^3	3.4×10^4	3.0×10^4	2.1×10^4	1.7×10^4	8.2×10^2	8.0×10^0	6.0×10^2	2.1×10^3
Coliphage per 10 ml	4.8×10^2	2.4×10^1	3.8×10^2	1.3×10^2	3.4×10^2	1.3×10^2	3.8×10^1	6.0×10^1	7.7×10^3	1.0×10^1
K mg/L	8.2	3.9	4.9	1.9	1.5	0.6	12.6	1.1	17.4	2.6
Na mg/L	105	14	61	8	8	1	178	8	271	13
Ca mg/L	85.6	34.1	56.6	26.3	19.4	14.2	142.5	24.4	168.0	30.0
Mg mg/L	25.8	3.5	15.2	1.9	2.2	0.6	42.9	1.8	53.0	2.7
NH_4-N mg/L	0.16	<0.05	0.08	0.10	0.13	<0.05	0.44	0.09	0.59	0.06
SO_4 mg/L	66	28	38	6	4	3	99	15	130	19
Cl mg/L	162	24	93	11	12	2	283	12	381	22
Alk ($CaCO_3$)mg/L	253	72	162	72	53	35	414	55	467	71
NO_x-N mg/L	7.33	0.30	4.44	0.24	0.38	<0.05	12.68	0.10	18.80	0.26
P mg/L	0.10	<0.05	0.05	<0.05	<0.05	<0.05	0.071	<0.05	0.07	0.10
pH (20 °C)	8.3	8.2	7.6	8.3	8.5	8.8	6.9	8.4	6.7	8.2
DOC mg/L	13.4	7.7	9.2	4.2	6.6	1.3	23.0	2.8	20.2	7.0
EC mS/m	111	28	73	19	16	8	185	19	235	24
TDS (Calc) mg/L	710	179	467	118	99	49	1184	118	1504	154
Hardness as $CaCO_3$ mg/L	320	100	204	74	58	38	532	68	638	86
Cd mg/L	<0.01	<0.01								
Cu mg/L	<0.02	<0.02								
Fe mg/L	0.06	0.2								
Pb mg/L	<0.05	<0.05								
Zn mg/L	<0.02	<0.02								

resulted in many incorrect values. A further problem was the blocking of the stormwater grid as the subsequent clearing thereof caused scouring of the sands on the drain floor and substantial lowering of the water level. The problems experienced with the monitoring equipment at this site are discussed in Section 4.3.

The continuous salinity trends as recorded during the 1991 rainy season are summarized in graphical form in Appendix C. The graphs indicate that during base-flow conditions the salinity (here used as a general indicator of water quality) remained relatively consistent. Rainfall events and the resultant stormflow conditions were the major causes of variation in the stormwater quality. This is clearly illustrated in the salinity trend during September (Figure 19). A comparison between the rainfall totals for each storm event and the resultant stormwater quality variation indicates that the type of rain (intensity thereof) is more important than the actual total amount received. Winter frontal systems typically give extended periods of soft soaking rain that cause minimal overland flow in a sandy catchment, but result in significant rainfall totals. The salinity trends do show some changes in stormwater quality that are not related to storm event, but rather to other factors in the catchment. The May graph (Figure 19) shows two such periods followed by the effect of the first major frontal system of the rainy season. Periods of poorer quality stormwater could be correlated directly to periods of unrest in Khayelitsha and the collapse of municipal services in different sectors of the catchment.

Storm event sampling was undertaken to further investigate the stormwater quality variations during peak flow conditions. The sampling was aimed at detecting any "first flush" effect and the methodology is discussed in Chapter 4. Although sampling only took place at one site (Figure 15) it represented the total stormwater discharged from the urban area. A storm/rain event was taken as a period of continuous precipitation without a break lasting more than 3 hours as defined by Simpson and Kemp (1982). It was, however, often difficult to clearly delineate storm events in the study area as the frontal systems which dominate the Cape weather may result in up to 2 weeks of almost continuous drizzle with intermittent showers. The nature of the rain meant that most storm event sampling covered the rising limb of the stormwater hydrograph, but it seldom covered the recession curve much beyond the inflection point. As discussed in Chapter 3, delayed interflow is a major contributor to Khayelitsha's runoff. A further limitation during sampling was that most storms began either late in the afternoon or at night. This was a problem as for security reasons automatic samplers could not be used and manual sampling could only be done during daylight hours.

The sampling results from 3 storm events are discussed in this section. In each case the results are summarized in graphical form in 3 figures. The first figure briefly describes the storm event hydrologically within the broader time scale (5 days) while the next two figures concentrate on the 10 hour sampling period. Sampling was initiated as soon after the rain began as possible to ensure at least one background value before any stormflow occurred.The storm event of 10 July 1991 (Figures 20, 21 and 22) represents a typical winter frontal system in which rain continued intermittently for 1.5 days at varying intensities. The storm can be divided into 5 episodes of which the first two were considered to constitute a single storm event (covering 6 hours). Sampling was discontinued when the next episode of rain began and the recession curve of the hydrograph never reached baseflow levels. Both the hydrograph and salinity trend correlate extremely well with the rainfall pattern. The chemical results (Figure 22) show similar trends between the different parameters except for trace metals and pH. This supports the earlier decision to use salinity (EC in this case) as a general indicator of stormwater quality. The trends gave no indication of a first flush effect as the water quality variation recorded between the 40 and 100 minute interval was a response to the different rainfall intensity (see Figure 21). The trace metals (Iron and Zinc) showed increasing concentrations with the initial rains (0-45 minutes and 90-150 minutes) and first peak in the hydrograph. The subsequent peak (after 330 minutes) resulted in no significant variation in concentration indicating that all the readily available trace metals were washed out during the first runoff episode. The peak concentrations between 260-310 minutes could not be correlated with additional rain or increased runoff, and probably represent a "parcel" of water from one particular sub-catchment. As this trend is not seen with any of the other chemical parameters it suggests a very specific source of metal pollution. The microbiological indicator trends showed an immediate increase in counts as soon as the storm began. Counts increased throughout the rising limb of the hydrograph, but either stabilized or decreased after peak flow. The trends suggest that the greater the discharge the higher the microbiological counts.

The storm event of 28 August 1991 (Figures 23, 24 and 25) was a typical late winter storm that began with soft rain that later became more intense, followed by soft intermittent rain. It was only the more intense rain which resulted in peak flows as the softer rain merely produced interflow and thus elevated baseflow levels. The salinity trend for the 5 day period accurately reflects the rainfall pattern and shows an increase in salinity just before the storm event. This should not be thought of as a possible first flush effect as it occurred before any rise in the hydrograph and was not identified in the storm event sampling (Figure 25). The increased salinity also extended over several hours. The chemical results clearly reflect the initial rain followed by soft drizzle and then the more intense rain which produced the peak flow. The DOC trend, unlike the other parameters, showed an increase during the initial soft rain. Cleaning of the drain on the previous day could have resulted in the loosening of organic material which then washed out with the slight increase in discharge that resulted during the soft rain. The microbiological indicators showed increased counts as the stormwater flow increased with immediate stabilization and decreases in counts once the hydrograph had peaked. The Coliphage counts appear to be more dependent on discharge rates than the faecal coliform counts.

The Third example, that of 11 September 1990 (Figures 26, 27 and 28) represents storm events during which gentle rain occurs fairly uniformly throughout the storm-event. Unlike the previous example there was no period of medium intensity rain. Unfortunately in this situation the storm event sampling missed the initial stages of the rising limb, but gave better coverage of the recession curve. No continuous salinity monitoring was undertaken during 1990 and as such no data is available. The chemical trends show that the rain, although of low intensity, caused water quality changes of the same extent as that of higher intensity rain. The subsequent rain which was also of low intensity did not however have a similar effect. The buffering effect seen after 165 minutes and delayed return to normal concentration levels reflects the larger component of delayed interflow that results during soft rain. The trend in the ammonia concentration is similar to the trend in microbiological counts and shows minor variation during the storm, but significant increases once the runoff had substantially subsided. This was not observed during other storm events and may represent washoff from a particular faecal source and an accumulative effect.

The storm event sampling failed to detect any first flush effect and except for the faecal and trace metal pollution the stormwater quality improved due to stormflow conditions. The lack of first flush effect may have been due to the sampling being too infrequent (15 minutes) or the initial rise in water level not being detected until after the first flush of water had passed. The large storm drain size (3 m x 2 m) and wave action in the drain made it difficult to detect minute rises in water level. The continuous electrical conductivity monitoring should at some stage, however, have detected a first flush effect.

5.4 Pollutant loads

One of the most useful sets of data in water quality monitoring is pollutant loads as these act as a summary value for both water quality and water quantity variables. The difficulties experienced in accurately measuring the discharges in the stormwater system made the calculation of pollution loads extremely difficult. It was not possible to make a comparison between sub-catchments as only the total stormwater discharge could be measured. Table 13 provides average pollutant loads during summer and winter baseflow conditions. Average values were used for both the water quality variables and the discharge, and the loads represent the cumulative loads per day. A comparison with the results in Tables 7 and 8 show that although baseflow concentrations are higher in summer it is during winter that the greater pollution load is added to the receiving water body.

The pollutant load contributed by stormflow is clearly illustrated in the graphs contained in Figures 29 and 30. The figures show concentration (EC), discharge and resultant pollutant load (TDS) trends for September (rainy season) and April (dry season) respectively. These show that although the concentrations are dramatically reduced during storm events, the increased discharge volumes result in larger pollutant loads. The average storm event, such as that of 10/11 July 1991 (Figures 20-22, Section 5.3), contributes loads of approximately 44 000 Kg (TDS) which is triple that of the average summer baseflow (Table 13). Such additions of pollutants during storm events could have a detrimental shock loading effect on the receiving water body.

TABLE 13

AVERAGE DAILY POLLUTANT LOADS FOR SELECTED PARAMETERS FOR THE KHAYELITSHA URBAN CATCHMENT DURING BASEFLOW CONDITIONS (IN kg/day)

Parameter	Summer	Winter
Potassium	70	160
Sodium	1590	2630
Calcium	990	1670
Magnesium	360	560
Sulphate	1190	2020
Alkalinity	2810	4670
Chloride	2200	3730
Total dissolved salts	9120	15520
Zinc	-	0.8
Lead	-	0.9
Iron	3.6	9.9
Copper	-	-
Calcium	-	-
Nitrate	54.0	99.5
Ammonia	2.0	11.7
Orthophosphate	0.4	3.1

CHAPTER 6

IMPACT OF POLLUTED RUNOFF ON RECEIVING WATER BODY

6.1 General criteria

The runoff cycle (Figure 11) illustrates how surface runoff inevitably ends in a receiving water body such as a river or lake and eventually the ocean. Under natural conditions these water bodies are in the long term able to absorb the fluctuations in runoff volumes and quality (i.e.) a natural balance is maintained. Human activity, however, is inclined to amplify the fluctuations and place unrealistic demands on a receiving water body's assimilation capacity. This is especially true when coastal authorities consider the ocean as a limitless sink.

Concern about the pollution effect of urban stormwater runoff has increased over the past decade and the pollution problems have shifted the objectives of many European water agencies to optimise operational performance in terms of receiving water impact. The effect of stormwater runoff on receiving water can be twofold:

1. a short term shockloading impact, where the pulsed discharge of large volumes of pollutants can result in acute poisoning of organisms and depletion of the oxygen supply; and

2. a long term accumulation impact, where the sustained discharge of poor quality runoff water can lead to the accumulation of pollutants in the sediments and aquatic organisms (Arnell *et al.*, 1984; Hogland *et al.*, 1984; Svensson, 1989).

An important immediate effect of stormwater runoff is bacterial and viral pollution which pose a health risk and restrict water resource use, recreational use and fishing use of the receiving water (Field and Turkeltaub, 1981). Certain organic chemicals, pesticides and some heavy metals like cadmium are also acutely toxic to aquatic life and will have a severe impact on the population diversity of the receiving ecosystem. Depletion of the dissolved oxygen supply caused by the bacterial breakdown of organic material can also destroy sensitive species of fish and aquatic organisms and can result in anaerobic conditions with objectionable end products (Field and Turkeltaub, 1981; Simpson, 1986).

Pollutants that can have a long term impact include heavy metals, pesticides and persistent organics. These compounds have the potential for toxicity to aquatic life through accumulating in sensitive areas and also through bio-accumulation. Enclosed water bodies with long retention times tend to concentrate trace metals and organics in supernatant and bottom sediments. These compounds can cause depletion of the oxygen supply or they can become available through resuspension, resulting in the disruption of the ecosystem. Large inputs of nutrients can also cause eutrophication, a process manifested by excessive aquatic weed and algal growth (Field and Turkeltaub, 1981; Moore *et al.*, 1988).

A protection policy for the management of receiving water bodies is therefore essential. These policies fall along a continuum from maintaining water quality at its natural background levels to setting levels only as stringent as needed to protect the current and anticipated uses of the water body. This can result in three types of policy:

Non-degradation -	the criteria selected seek to protect the water quality at natural levels
Limited degradation -	the criteria aim to maintain water quality at as high a level as possible while allowing contamination up to protection (critical) levels
Differentiated protection -	protection criteria are only enforced on those water bodies that have present or possible future uses.

The present South African water quality policy is moving towards environmental quality objectives rather than published ambient standards (Braune and Hodgson, 1991). In order to get some perspective on the potential impact of stormwater runoff from a Third World urban catchment on the marine environment, the concentration of pollutants present in the stormwater must be evaluated against the receiving water quality criteria which is linked to certain beneficial uses (Lusher, 1984).

In the case of dissolved nutrients the criteria states that for all beneficial uses, water should not contain nutrients and other biostimulants in concentrations that are capable of causing excessive or nuisance growth of algae or other aquatic plants or deletions reductions in dissolved oxygen. For all marine biological purposes ammonia should not exceed 0,6 ppm (Lusher, 1984).

In the case of trace metals the following concentrations are recommended for all beneficial uses except mining and cooling water:

copper	5.0 $\mu g\ 1^{-1}$
lead	12.0 $\mu g\ 1^{-1}$
zinc	25.0 $\mu g\ 1^{-1}$

These levels must be attained in the sea upon completion of initial dilution.

Microbiological criteria are linked to specific beneficial uses:

Beneficial use No 2. Direct contact recreation (swimming, diving, windsurfing etc.)

	Maximum acceptable count
Faecal coliforms per 100 ml	100 (50 %)
	400 (90 %)
	2000 (99 %)

Beneficial use No 4. Collection of filter feeders for food.

	Maximum acceptable count
Faecal coliforms per 100 ml	15 (50 %)
	45 (90 %)

(X%) = percentage of samples to comply with given count.

Field and Pitt (1990) have found that most beneficial uses are adversely affected by urban runoff. Most of the problems occur over long periods of time and are not associated with individual runoff events, making cause and effect relationships difficult to study.

6.2 Final detention basin

The coastal detention basin represents the first receiving water body for the Khayelitsha stormwater runoff. The entrance and exit points to the basin were sampled 13 times and the results are shown in Figure 31. As expected the discharge canal ("entrance" sample) contained the highest concentration of faecal organisms. Exceptions occurred during the wet season when prolonged rain eventually reduced bacteria numbers through dilution, and "older", more polluted water was still held in the main section of the basin.

The greatest relative drop in bacteria counts occurred during baseflow conditions and low waterlevels in the basin. The presence of egyptian geese, coots, terns and Hartlanbs gulls on the basin was an additional source of faecal organisms, but was not significant enough to distort the main trend. During baseflow conditions the retention time may be measured in days resulting in increased exposure to sunlight and accelerated die-off of the micro-organisms (Pike *et al.*, 1970; Bellair *et al.*, 1977).

It can thus be concluded that as a pollution reduction feature the coastal detention basin was effective. The abundant growth of aquatic macrophytes such as Potamogeton and Lemna without doubt enhance the "self purification" by providing a suitable milieu for retaining and in a way filtering the stormwater. In this way the removal/breakdown of these intestinal micro-organisms is promoted by processes such as predation, completion and solar irradiation, the latter probably being a key factor (Borrego and Romero, 1983). The abundant growth of aquatic plants and large accumulation of settled plant debris indicates that nutrients are taken up from the stormwater.

6.3 The inner-surf zone

Routine sampling of the stormwater discharged on the beach near Monwabisi (K8 in Figure 15) showed that in most cases the concentration of dissolved nutrients and trace metals measured during baseflow conditions were within the limits specified. However, during storm conditions these limits were regularly exceeded. In the case of the microbiological pollutants the limits were exceeded during both baseflow and storm conditions. In another CSIR study (Idema and Kfir, 1990) it was found that the stormwater also contained viruses, including both hepatitis A and rotavirus. Table 14 summarizes the microbiological data over a period of 1 year and illustrates the seasonal variation.

As a general rule the bacterial count under different weather conditions were as follows:

	Faecal coliforms	Faecal Streptococci
Rain	$10^5 - 10^7$	$10^3 - 10^5$
Dry	$10^2 - 10^4$	$10^1 - 10^3$

The seasonal variation was found to be closely related to rainfall and counts increased dramatically after rain in the catchment and levels persisted for a number of days thereafter. Mean faecal coliform numbers during winter were about 35 times higher than during summer. Another important factor which contributed towards low bacterial counts in summer was the increased exposure of stormwater runoff to irradiation by sunlight as a result of the detention pond just upstream of the outfall.

TABLE 14

MICROBIOLOGICAL ANALYSIS OF THE STORMWATER RUNOFF DISCHARGED FROM KHAYELITSHA
(Sample Station K8)

Month	Faecal Coliforms (per 100 ml)	Faecal Streptococci (per 100 ml)	Coliphage (per 10 ml)
April	3.2×10^3	2.4×10^2	5.4×10^1
May	4.2×10^4	3.44×10^2	8.4×10^3
June	2.5×10^3	6.0×10^2	3.7×10^2
July	2.5×10^4	2.5×10^2	3.8×10^2
August	2.9×10^5	9.9×10^4	1.2×10^4
September	2.0×10^3	2.0×10^1	8.0×10^2
October	1.5×10^3	7.0×10^3	5.9×10^2
November	1.3×10^3	2.0×10^1	4.9×10^2
December	7.0×10^3	0.8×10^1	3.8×10^1
January	5.1×10^3	6.7×10^1	9.0×10^1
February	1.8×10^4	7.0×10^1	9.7×10^2
March	6.0×10^3	1.0×10^1	1.8×10^2

The environmentally undesirable levels of harmful and toxic elements found in stormwater runoff do not necessarily mean that treatment is essential to avoid degradation of the environment. A decision on how to handle this problem should be based on the potential dilution of urban runoff in the receiving marine environment, which in many cases may result in dilution to well below toxic levels (Simpson and Stone, 1988).

The samples collected in the surf zone (Appendix D) indicated that immediately upon entering the surfzone, stormwater showed a reduction of two to three orders of magnitude. Despite this, the area in the immediate vicinity of the outlet, did not comply with the microbiological health criteria. The bacterial counts did, however, decrease fairly rapidly on either side of the outfall up to a distance of approximately 100 m. The distribution pattern or pollution plume geometry was strongly influenced by wind strength and direction. Studies elsewhere along the False Bay coastline confirmed that achievable dilutions with shoreline discharges are very limited and that discharge water is transported along the coastline rather than out to sea (CSIR, 1991).

6.4 Laboratory mixing study

The dilution behaviour in the marine environment of different chemical (trace metals and dissolved nutrients) and microbiological (faecal coliforms and faecal Streptococci) parameters were determined. From these results the impact of stormwater runoff from a Third World urban settlement was determined in terms of shock loading or gradual accumulation.

6.4.1 *Dissolved nutrients*

The results of the dilution experiments for dissolved nutrients are given in Figure 32. Dissolved nutrient versus salinity plots showed a linear relationship for all nutrients measured. When conservative behaviour of a constituent is established, its distribution pattern in the surf zone can be described in terms of actual dilution (salinity is not always used as the dilution index) by the following equation:

$$\frac{C_x = C_{eff} + A . C_{sea}}{A+1}$$

where:

C_x	=	constituent concentration at given salinity x
C_{eff}	=	constituent concentration in effluent
C_{sea}	=	constituent concentration in sea-water
$A + 1$	=	dilution

In this way the extent of nutrient enrichment over distance along the surf zone can be determined if the actual dilution is known. Therefore, used in conjunction with water quality criteria, this information would be of great value to managers in evaluating the feasibility for discharging an effluent into the surf zone, especially in areas where the background levels in the receiving water has already been elevated through other discharges.

Receiving water quality criteria for dissolved nutrients, except in the case of ammonium, are not well defined for False Bay. Identification of such criteria for specific areas, related to their beneficial uses, need to be established in order to effectively apply the above findings to water quality management plans. In the case of ammonium, the concentration was already within water quality criteria limits at a salinity of 6 ppt and required no further dilution.

6.4.2 *Trace metals*

The results of the dilution experiments for trace metals are given Figure 33. Copper showed linear dilution with salinity. The concentration of copper was already within water quality criteria limits at a salinity of 10 ppt. Therefore, although the concentration of copper in stormwater runoff from this catchment exceeded the water quality criteria limits at times, the dilution of this metal in the marine environment would normally result in sub-toxic levels. Copper was therefore considered to have a minimal impact on the receiving marine environment.

Extensive removal of lead occurred during the mixing of stormwater runoff and seawater. The mechanism of lead removal was probably that of flocculation and precipitation as the ionic strength increased along the mixing gradient (Hunter, 1983). At a salinity of 5 ppt almost all of the lead was already removed from the water column, indicating that the levels of lead would be back to background levels within a short distance from this stormwater outlet and the levels in the marine environment would be well below toxic levels. However, this metal tends to accumulate in the bottom sediments where it could be harmful to benthic organisms and be taken up in the food chain. It can also become available through resuspension at some later stage. Therefore, the shockloading impact of lead in stormwater runoff from this catchment is considered to be minimal although the long term impact could be substantial.

The dilution of zinc was very similar to that of copper in that a linear dilution pattern was followed with the levels of zinc back to water quality criteria limits at a salinity of 10 ppt. Therefore, although the concentration of zinc in stormwater runoff from this catchment also exceeded the water quality criteria limits at times, the dilution of zinc in the marine environment would normally be well below toxic levels. Zinc was therefore also considered to have a minimal impact on the receiving marine environment.

6.4.3 *Microbiological indicators*

According to Engelbrecht (1990) the initial dilution is the most important factor in determining the survival rate of the bacteria in the marine environment. More than 90 % of the bacteria are eliminated at this stage and the bacterial counts are much lower than the counts estimated when assuming linear dilution. Therefore, the actual dilution needed to ensure that bacterial counts are within the water quality criteria limits can be much lower than the estimated physical dilution due to the initial die-off. Irradiation by sunlight is also considered an important factor for ensuring that die-off takes place after the initial dilution. Other factors determining the die-off or survival of micro-organisms are discussed by Engelbrecht (1990). These include pressure, temperature, organic content, salinity, osmotic shock, sedimentation, competition for food, predation, adsorption, inorganic coagulation, flocculation and catalytic breakdown.

After initial dilution (and 90 % removal) bacterial counts during rain events were still much higher than the limits set by the receiving water quality criteria (Lusher, 1984). During dry weather the bacterial counts were more acceptable after initial dilution. However, the collection of filter feeders for food use should be prohibited in the vicinity of the stormwater outfall at all times.

6.5 Conclusions

Dissolved nutrients in stormwater run-off from Khayelitsha showed linear dilution patterns for all nutrients measured which can be described, in terms of dilution, by the following equation:

$$\frac{C_x = C_{eff} + A.C_{sea}}{A+1}$$

where:

C_x = constituent concentration at given salinity x
C_{eff} = constituent concentration in effluent
C_{sea} = constituent concentration in sea-water
$A + 1$ = dilution

Identification of water quality criteria for dissolved nutrients for specific areas, related to beneficial uses, need to be established in order to set up a proper water quality management plan for this area.

The levels of copper, lead and zinc measured in stormwater runoff from Khayelitsha were found to be sufficiently diluted during the mixing with sea-water not to have any serious, immediate impact on the marine environment. However, in the case of lead the long term impact resulting from its accumulation in sediments and aquatic organisms could be substantial.

The numbers of faecal coliforms and faecal Streptococci around Khayelitsha stormwater outfall were unacceptable during winter even after initial dilution. During summer factors such as low rainfall, high solar radiation, predation and competition for food contributed towards lower bacterial counts. However, direct contact recreation should not take place within 100 metres on either side of the stormwater outfall. The collection of filter feeders for food use should be prohibited in this area at all times.

As a general rule it can be said that there is a health risk associated with swimming, bathing and the collection of seafood near the discharge point. The discharge, however, has no apparent effect on the Monwabisi Resort area and poses no health risk to it. As the amount of water discharged increases so, however, will the impact area. One advantage is that the large discharges of stormwater are sporadic and occur mostly during winter when recreational usage of the beach is limited.

CHAPTER 7

APPLICATION OF A RUNOFF MANAGEMENT MODEL

7. Introduction

During the development of an urban area engineers are faced with the task of constructing a stormwater reticulation network to remove the higher recurrence interval runoff events from the catchment as quickly and cost effectively as possible. Very often in order to achieve this the natural drainage channels are enlarged and lined to cope with the increased runoff due to urbanization. This type of functional engineering structure is, however, finding less favour with a more environmentally conscious public (Stephenson, 1989). Today more sophisticated techniques such as computer simulation models that are capable of accounting for most of the physical processes involved in the rainfall runoff process are extensively used. A great many models are available and one such model, ILLUDAS, was used with the initial planning of Khayelitsha (VKE, 1984).

WITWAT a model that employs the kinematic method of flow routing with the option of using time-shift routing in conduits was developed especially for South African conditions and use on a micro-computer by Green and Stephenson (1984). One of the initial objectives of the project was to try and apply this model in Khayelitsha as this catchment is both of a Third World nature and in the winter rainfall zone of South Africa. During the project, however, it came to light that Stephenson (1989) had developed WITSKM to overcome shortcomings in the WITWAT model. This model uses modules to represent the components that go to make up a stormwater drainage system and thus provides more flexibility and versatility. It was thus decided that WITSKM would be more appropriate in the Khayelitsha catchment especially as it contains a subsurface flow component.

7.2 WITSKM model

WITSKM is a single event model designed for IBM compatible micro-computers. The program includes an editor for increased efficiency during the process of data input and editing. A modular approach was adopted and allows for the modelling of flow over impermeable and permeable surfaces, aquifers, pipes, trapezoidal channels, compound channels and detention/retention storage facilities. A system of module numbers is used to determine the connectivity and the modules to which overflows should be routed in the simulation of dual drainage systems. The Gren-Ampt infiltration model is used in the aquifer modules as the parameters for this model can be physically measured. The kinematic routing approach is used for the routing of flows over permeable and impermeable surfaces as well as through pipes and channels. The kinematic equations are solved by the Muskingham-Cunge routing method. WITSKM contains no evaporation component and the aquifer module caters only for the routing of subsurface flow once the aquifers are saturated (Coleman & Stephenson, 1990).

7.3 Discussion

In the case of the Khayelitsha study the following input data was required to test the model:

Time data:	Time interval	
	Simulation duration	
	Rainfall duration	
Rain data:	Rainfall intensities	
Module data:	Width of catchment	Width of channel
	Length of catchment	Maximum flow depth
	Manning of catchment	Width of aquifer
	Slope of catchment	Length of aquifer
	Pipe length	Depth of aquifer
	Pipe slope	Aquifer slope
	Pipe roughness	Height of water table
	Pipe diameter	Moisture content
	Length of channel	Porosity
	Channel bed slope	Suction head
	Channel roughness	Permeability

The accuracy and value of the simulation depends greatly on the accuracy of the input data. Obviously estimates can be used for these parameters and this is often the route which engineers are forced to take. The number of sub-catchments and modules into which the catchment is divided depends largely on the input data available and the objective of the simulation.

In the case of the Khayelitsha catchment it was generally not possible to obtain measurements for many of the required parameters. Initially five rain gauging stations were established, but it proved impossible to get reliable and continuous data from within the urban area. Eventually only three rain gauges located outside the catchment were used. As these used casella chart recorders with weekly charts the data had a minimum 15 minute increment. Figure 34 shows how the rainfall pattern during a single storm varied between the three raingauges (Figure 15 shows the location of each raingauge). Information regarding the stormwater drainage network was obtained from the original structure plans. The accuracy of the information could not be ascertained and was of a fairly coarse scale. Parameters such as bed slope and roughness varied continuously as the drains were permanently filled with sand, debris and garbage. The flow never appeared great enough to clear the drains. Parameter values could thus only be guesstimates at the best of times.

Initially it was thought that the aquifer parameters could be obtained from published reports from earlier research and actual field measurements. This proved false as the borehole data from the Wessels and Greeff (1980) report could not be satisfactorily correlated and the coarse scale of this study did not provide the more detailed aquifer dimensions required for modelling. Attempts to relocate the old boreholes to take field measurements proved unsuccessful. Even those shallow boreholes drilled immediately prior to the commencement of the present study had been destroyed and lost as possible monitoring sites. Again to run the model guesstimates would have to be used for many of the aquifer parameters.

The most important field measurement, namely, discharge volumes proved the largest stumbling block. Actual measured discharge volumes form the basis against which the model simulation is judged/compared. Discharge measurements could not be made within the stormwater drainage network because of the structural design and more importantly the large amount of sand, debris and garbage present in the system at all times. Continual blockages throughout the system especially during stormevents led to phenomenal changes in flow depth. Flow gauging equipment used in other urban catchments such as Atlantis and Stellenbosch proved useless in Khayelitsha. As stated in Chapter 4 flow gauging could only be done at one site and even this was not completely satisfactory. This station measured the total flow leaving the final (coastal) detention basin and because of the scale of operations was at a fairly coarse time interval (increments smaller than 1 hour were not possible). During the summer months (baseflow conditions) the detention basin was drained of as much water as possible to create maximum storage capacity for the new rainy season. This was done by means of two large valves which meant that the water bypassed the flow gauging equipment and no accurate discharge volumes could be measured. Although discharge volumes could be estimated to give average daily and monthly values it was not possible to obtain accurate values at the required sensitivity level. Appendix D contains monthly graphs of the discharge volumes from Khayelitsha for the period covered by the study.

7.4 Conclusion

The accuracy and coarse scale (time increment) of the input data for the Khayelitsha urban catchment makes simulation with a model such as WITSKM of limited value. Using coarse data in a sophisticated computer model is of no value with regard to model evaluation. The level of confidence placed in such results would be no greater than those when using more simple methods like the rational method with its wide margins of error. It would thus be an injustice to the model to attempt to evaluate it using such poor input data. It was therefore decided at an early stage of the project (see progress reports) that the third objective of the project would not be attained.

The exercise has shown that the use of sophisticated models and evaluation thereof, common in hydrological studies of First World type urban catchments, is not necessarily applicable in Third World type urban catchments. The sensitivity level required for most modern models is difficult to obtain in catchments like Khayelitsha under the present unstable conditions found in South Africa.

CHAPTER 8

COMPARISON OF RESULTS WITH OTHER URBAN STUDIES

8.1 Introduction

Several urban stormwater studies have been undertaken in South Africa and provide a background for comparison purposes. Figure 32 indicates the location of these studies. The earlier studies concentrated on First World type catchments and on stormwater runoff models. Stephenson *et al.* (1986) looked at two largely residential catchments in Johannesburg which fall within the summer rainfall region. Montgomery Park catchment (1053 ha) represented a low density residential suburb with some commercial and light industrial activity, plus a solid waste disposal site. Whereas the Hillbrow catchment (67.2 ha) represented a high density residential area with some commercial activity. Simpson (1986) concentrated on a smaller (19.5 ha) catchment in Pinetown which, although also in the summer rainfall region, experienced different rainfall patterns from that of the Johannesburg catchments. This catchment also contained commercial, light industrial and residential activity. In the winter rainfall region Kloppers (1989) made a comparative study of the stormwater quality in the Three Anchor Bay catchment (152 ha) and Mitchell's Plain (1375 ha). The former being a low density, middle class residential and the latter a medium density working class "coloured" township. A further study by Wright (1991) concentrated on Atlantis an industrial town of 140 factories developed exclusively for the "coloured" community (70 000 people).

Several studies, begun subsequent to this investigation, involve Black Townships in the Johannesburg, Durban and Port Elizabeth areas. A study by Wimberley (1992) attempts to determine the effect of the runoff from Alexandra Township on the water quality of the Jukskei River by way of water and pollutant mass balances. In Durban, Simpson & Coleman (1992) are collecting runoff water quality, flow and rainfall data in the Shembe catchment (560 ha Black residential area containing low cost housing and informal settlements) in order to test the WITSKM runoff management model. In Port Elizabeth Goschen (1990, pers comm.) has investigated the quantity and quality of urban runoff from Motherwell Township as part of a larger Swartkops estuary study.

A common problem experienced in all the Third World Type urban catchments (Shemba, Motherwell and Alexandria) has been the inability of researchers to collect the required (hoped for) hydrological field data. Intensive hydrological monitoring with the aid of modern equipment is general not possible due to poor security within the catchments.

8.2 Discussion

The Khayelitsha study differed from most other South African studies in that it looked at a classic Third World type urban catchment containing formal housing, site and service and squatter camp areas. The main emphasis of the study was on water quality especially with regard to microbiological aspects and sampling was not only restricted to the total stormwater runoff leaving the catchment. Unlike the other studies the hydrological and engineering aspects received less attention, except for a proposed attempt to test the existing runoff management model WITSKM. Because of the nature of the catchment and security problems experienced, the study had to be undertaken on a more coarse scale than originally planned. Where other studies could involve intensive monitoring and small efficient networks this was not possible in Khayelitsha.

Unfortunately no standard set of water quality variables has been used in the South African studies. Table 15 contains a summary of average stormwater quality in the different areas (Figure 32) as compared to Khayelitsha. Initially only the Southwestern Cape studies tested for microbiological indicators and the results are remarkably similar. This is somewhat surprising as Three Anchor bay is a highly urbanized, upper income catchment and thus expected to have less faecal contamination. The reason for this is probably that the Three Anchor Bay catchment is largely impervious and pollution thus accumulates during storms giving highly polluted stormflow. In Khayelitsha, however, the lack of overland flow means that many pollutants are filtered out in the sands giving a fairly uniform poor quality runoff throughout the year irrespective of whether its baseflow or stormflow conditions. Khayelitsha thus has more pollution within the catchment, but thanks to the sandy nature of the area, not all this pollution finds its way into the final stormwater runoff. The microbiological results from the Alexandra study are not used in this report as an upper detection limit of 1800 for faecal coliform counts (Wimberley, 1992) is really meaningless when considering stormwater runoff from such a catchment. Values in excess of 10 (cfu/100 ml) should be expected during stormflow conditions especially as overland flow comprises some 77 % of the total stormflow. The nutrient concentrations in Alexandra vary significantly with very high concentrations at times (NO_x-N = 52.5 mg/L&NH_4-N = 32.5 mg/L). This level of contamination is only comparable to that of the worste shack areas in Khayelitsha. The results from Motherwell are similar to the formal housing of Khayelitsha and suggest a certain amount of uniformity within the coastal zone.

Khayelitsha stormwater has substantially higher concentrations of salts than the other catchments. This trend is not necessarily due to pollution from the urban environment, but rather as a result of subsurface water quality. Groundwater quality prior to urban development showed high salinities and significant lateral variation within the catchment. A comparison of phosphate levels between the different studies shows that the sandy catchments, where subsurface flow constitutes a large component of the stormwater runoff, have low concentrations due to adsorption during the passage through the soil/sand. The nitrate concentration is similar to that of the other lower income urban catchments. The very high Montgomery Park value is anomalous and probably due to leaking sewage as it represents baseflow concentrations. The trace metal concentrations in Khayelitsha are insignificant in comparison to the First World type catchments and reflect the lack of industry and motor vehicles.

TABLE 15

A COMPARISON BETWEEN KHAYELITSHA STORMWATER QUALITY AND OTHER SOUTH AFRICAN STUDIES

Determinand		Khayelitsha*				Johannesburg							Atlantis[7]		
		Shacks	Serviced sites	Formal housing	Total	Montgomery park[1]	Hillbrow[1]	Alexandria[2]	Pinetown[3]	Shembe[4]	Three Anchor Bay[5,6]	Mitchells Plain[5,3]	Residential	Industrial	Motherwell[8]
F.coliforms per 100 ml		1.2×10^5	2.7×10^5	2.2×10^4	3.4×10^4						2.6×10^5	4.1×10^4			5.4×10^4
F.Streptococcus per 100 ml		1.0×10^4	3.9×10^3	6.1×10^4	6.1×10^3						2.3×10^4	2.5×10^3			3.7×10^4
Coliphage per 10 ml		2.0×10^3	5.4×10^6	7.0×10^6	2.0×10^3						2.0×10^2	1.3×10^2			4.0×10^2
K	mg/L	19.9	15.4	13.3	10.4								7.7	5.2	
Na	mg/L	198	134	131	194								98	163	
Ca	mg/L	232	122	136	129								38.4	62.5	
Mg	mg/L	49	47	35	44								13.8	19.8	
NH_4-N	mg/L	1.86	2.38	1.09	0.36			24.54		0.50		0.20	0.11	<0.1	
SO_4	mg/L	298	195	93	165			90	21				61	83	
Cl	mg/L	291	164	191	2.78	31	120	87	9				158	236	
Alk ($CaCO_3$)	mg/L	412	372	436	351	61	145						75	107	
NO_3-N	mg/L	22.8	13.6	4.05	9.93	21.5	<0.1	2.88	2.79	4.84		8.98	5.12	<0.1	5.2
P	mg/L	<0.05	0.10	<0.05	<0.05			3.68	0.57	2.39		0.02	0.05	0.10	0.28
pH (20deg C)		6.7	7.0	6.9	7.0	7.8	6.9			7.4			8.1	7.9	8.3
DOC	mg/L	13.7	14.2	12.9	12.2								9.4	36.5	
EC	mS/m	230	158	154	185	63	106	109		37			80	118	5
TDS (Calc)	mg/L	1472	1011	986	1184	405	772	801					512	755	
Cd	mg/L	<0.01	<0.01	<0.01	<0.01				<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Cu	mg/L	<0.02	<0.02	<0.02	<0.02				0.042	0.179	0.101	0.018	<0.01	0.040	
Fe	mg/L	0.360	0.410	1.740	0.640			2.13	6.348		5.051	3.574	0.346	1.320	
Pb	mg/L	0.020	0.020	0.030	0.060			0.20	0.280	0.560	0.540	0.097	0.031	0.070	
Zn	mg/L	0.020	<0.02	<0.02	0.050				0.404	0.658	0.839	0.081	0.019	0.385	

Source of Data

1 Stepehnson and Green (1988)
2 Wimberly (1992)
3 Simpson (1986)
4 Simpson and Coleman (1992)
5 Kloppers (1989)
6 Wright (1987)
7 Wright (1991)
8 Mackay (1992)

*Typical stormflow quality during winter (samples after 54 hours of rainy weather)

8.3 Conclusions

Khayelitsha stormwater quality differs from the other First World type catchments in three basic ways, namely: consistently high microbiological contamination; high salt concentrations; and low trace metal concentrations. Except for salinity the Khayelitsha stormwater quality is similar to the other Third World type urban catchments with the only major difference being the lack of a first flush effect. The baseflow component of stormwater runoff is a major source of pollution in Third World type urban catchments unlike the First World catchments where the first flush appears to be the major problem. The geological setting and nature of the urban development are key parameters causing different stormwater qualities between catchments.

CHAPTER 9

CONCLUSIONS

The Khayelitsha urban catchment was selected as a study area to:

- asses the magnitude of stormwater contamination;
- identify pollution sources; and
- assess resultant effects on receiving water bodies, in Third World type urban areas.

Khayelitsha contained all the features typical of Third World type urbanization taking place in South Africa. Unfortunately the constant political unrest and ongoing taxi war hampered the study as equipment could not be installed in the catchment and field work was severely restricted. The study thus had to be undertaken on a more regional scale with the emphasis on water quality, rather than hydrological modelling.

A number of conclusions may be drawn from the study:

a) Stormwater runoff originating in Khayelitsha urban catchment is polluted throughout the year. The pollution is predominantly of a microbiological nature with correspondingly high concentrations of nutrients and organics.

b) No significant first flush effect is present and trace metal pollutant loads are low in comparison with First World type urban catchments.

c) The salinity of the stormwater runoff is relatively high and is largely as a result of saline groundwater.

d) The sandy nature of the catchment, small effective impervious surface area and low intensity rains experienced in the Cape, result in very little overland flow. Interflow and groundwater flow are the dominant runoff processes. Rapid interflow is the major contributor to stormflow hence the lack of a first flush effect.

e) The highly porous nature of the sands allows pollutants to be transferred from the surface to the subsurface flow. This results in relatively high pollutant concentrations in the baseflow. The stormflow has reduced concentrations due to the rapid interflow component, but large pollutant loads due to the increased discharge volumes.

f) The major source of pollution is litter and faecal contaminants that abound throughout the catchment. The high population density, poor living conditions and general lack of environmental awareness ensure ongoing pollution generation far in excess of that experienced in First World type urban catchments.

g) The ongoing violence and periodic strikes in Khayelitsha adversely affect the basic services provided. Extended periods of unrest result in the complete collapse of services and the accumulation of garbage, blocking of drains and local dumping of bucket latrines. The worst pollution recorded during the study occurred during times of unrest.

h) The provision of additional infrastructure, as in the serviced site sub-catchments, does not necessarily reduce the pollution problem. In fact the installation of waterborne sewerage and stormwater systems facilitate the removal of pollutants from the catchment and increase the contamination resulting from these sub-catchments. Where parks, playing fields and open spaces have been provided these areas have been inundated with shacks, with a resultant increase in pollution.

i) Where formal housing occurs the pollutant loads are greatly reduced especially during baseflow conditions. The concentrations being similar to First World residential catchments. These catchments produce higher concentrations of trace metals than the other sub-catchments reflecting the higher income group and resultant increase in motor traffic.

j) The final stormwater detention basin northeast of Monwabisi Resort functions as a pollution reduction mechanism during baseflow conditions. This is not the case during storm events when the retention time is too short.

k) The inner-surfzone sampling showed that in most cases the concentration of dissolved nutrients and trace metals during baseflow conditions are within the limits specified. During storm conditions, however, the limits are regularly exceeded.

l) Dilution studies indicate that through mixing with seawater the trace metals pose no serious problem with regard to the start term impact on the marine environment. The long-term impact from lead could, however, be substantial due to its accumulation in sediments and aquatic organisms.

m) Microbiologically the stormwater runoff entering the sea during winter is unacceptable even after initial dilution. During baseflow conditions the levels are lower, but even so, direct contact recreation should not take place within 100 metres of the stormwater outfall.

n) The continuing unrest and Third World nature of the urban area results in conditions that make hydrological research extremely difficult. Hydrological equipment normally used for field measurements are not suitable for Khayelitsha. Hydrological studies in Third World urban catchments in South Africa at present have to be on a more macro-scale then those in First World type catchments.

The study has achieved two of the three objectives proposed, namely:

1. to identify the hydrological processes taking place within the urban catchment and the role of each process in contributing to the contamination of the stormwater runoff with special emphasis on the microbiological contaminants;

2. to investigate the gradual accumulation effect versus shock loading impact of chemical and microbiological pollutants on the marine environment around Monwabisi Resort.

Although the study had to be undertaken on a more macro-scale than initially envisaged the main issues, as outlined in Section 4.1, could be investigated and answered. The general results from this study are applicable to any other sandy catchment within the South African coastal zone.

The third objective of the study, involving the evaluation of a South African hydrological simulation model, could not be attained and efforts had to be abandoned after the initial simulations investigations. The data required for such an operation could not be collected in the Khayelitsha catchment under the present conditions. Hopefully with the changing political climate in South Africa such studies will become possible in the future. Even so great care will have to be taken in selecting a study area, as underground stormwater systems in Third World type catchments provide unique problems with regard to flow gauging.

CHAPTER 10

RECOMMENDATIONS

Third World type urbanization, with its informal housing and "shanty towns" is very much part of South Africa and will continue to play a major role in this country for many years to come. It is thus vital that the engineering community continue to study these urban catchments, as well proven engineering solutions from First World communities are not always applicable to Third World urban areas. Future research should include:

a) groundwater contamination as a result of Third World type urbanization;

b) stormwater contamination in a Third World urban catchment in the summer rainfall zone (an area that experiences convectional rainfall);

c) groundwater as a practical water supply for informal settlements.

Site specific recommendations include the following:

a) Bucket latrines should be phased out as soon as possible, and no pit latrines allowed at all.

b) Garbage collection must be improved to avoid indiscriminate dumping.

c) Streets should be cleared of sand to ensure that the stormwater drainage system remains open.

d) Stormwater grids should be cleared on a weekly basis and after each storm.

e) Stormwater detention basins and flood control facilities should be cleared of squatters.

f) The number of people occupying each plot should be controlled in accordance with the services provided (i.e. number of toilets).

g) Routine sampling should continue at the main stormwater outfalls.

h) Bathing should be prohibited in the vicinity of the stormwater outfall east of Monwabisi Resort.

CHAPTER 11

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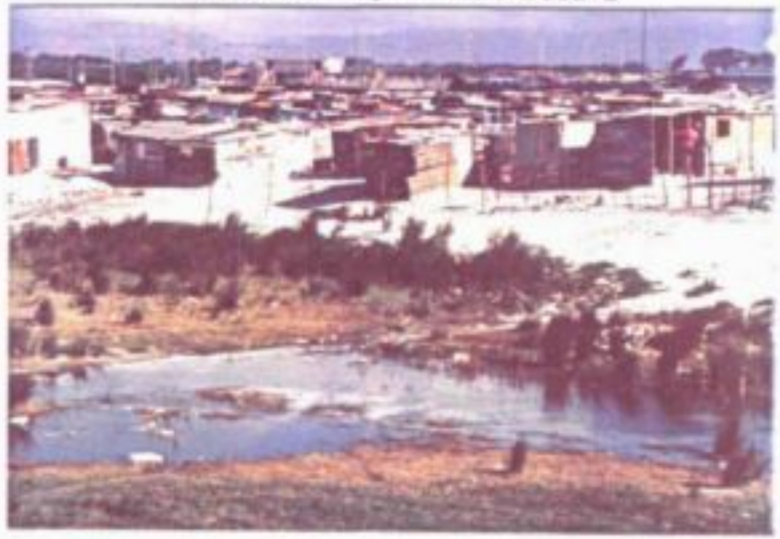
PLATE 1 THE KHAYELITSHA CATCHMENT

CORE HOUSING

ORGANIZED SQUATTER HOUSING



SERVICED SITES (BEFORE OCCUPATION)

SERVICED SITES (ONCE OCCUPIED)

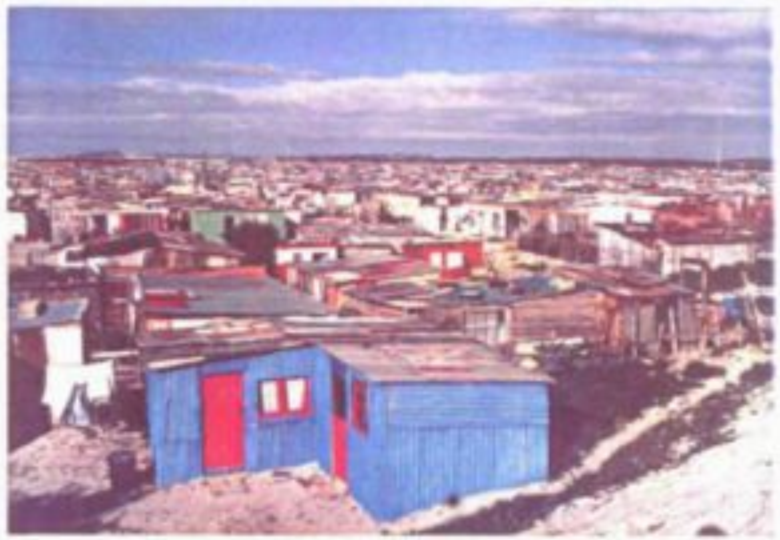


PLATE 2 DIFFERENT TYPES OF URBAN DEVELOPMENT IN THE KHAYELITSHA CATCHMENT

CORE HOUSING AREA

STORMWATER DETENTION BASIN & SUMP

SERVICED SITE AREA

PAVEMENT & PARK AREA

PLATE 3 TYPICAL SOURCES OF POLLUTION IN THE KHAYELITSHA CATCHMENTS

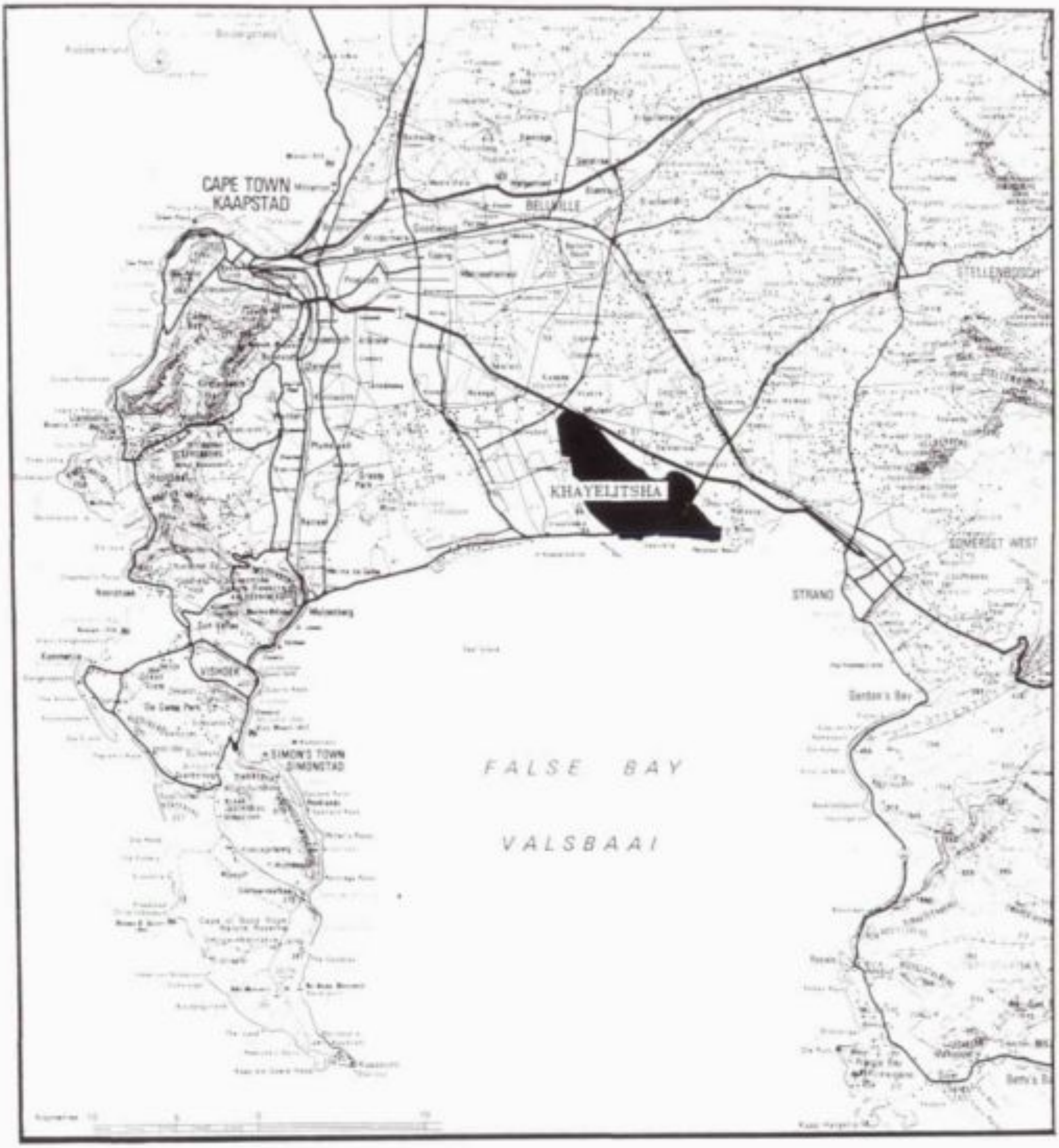


Figure 1 Location Plan

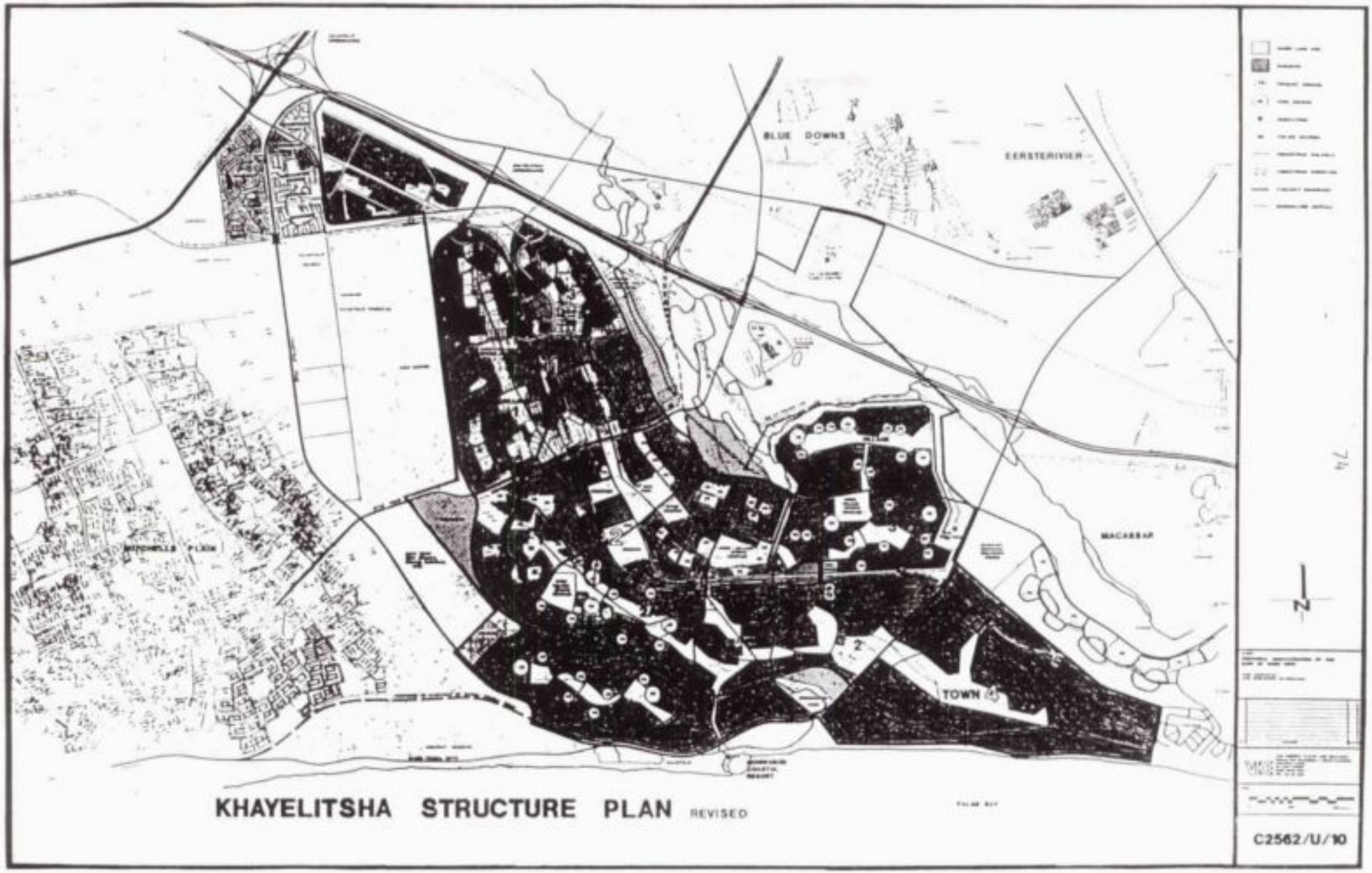


Figure 2 Khayelitsha structural plan

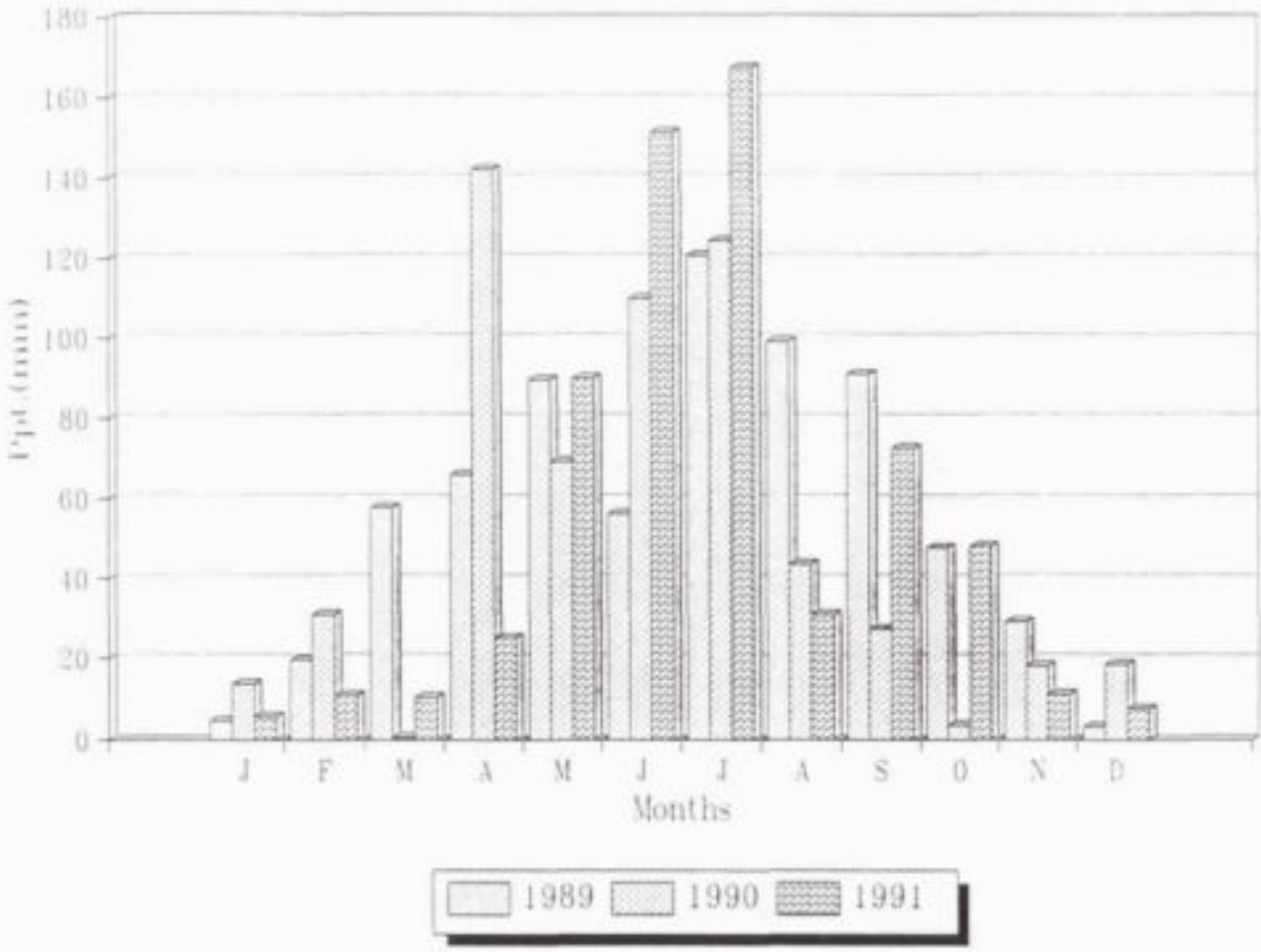


Figure 3 Monthly rainfall trend at DF Malan Airport

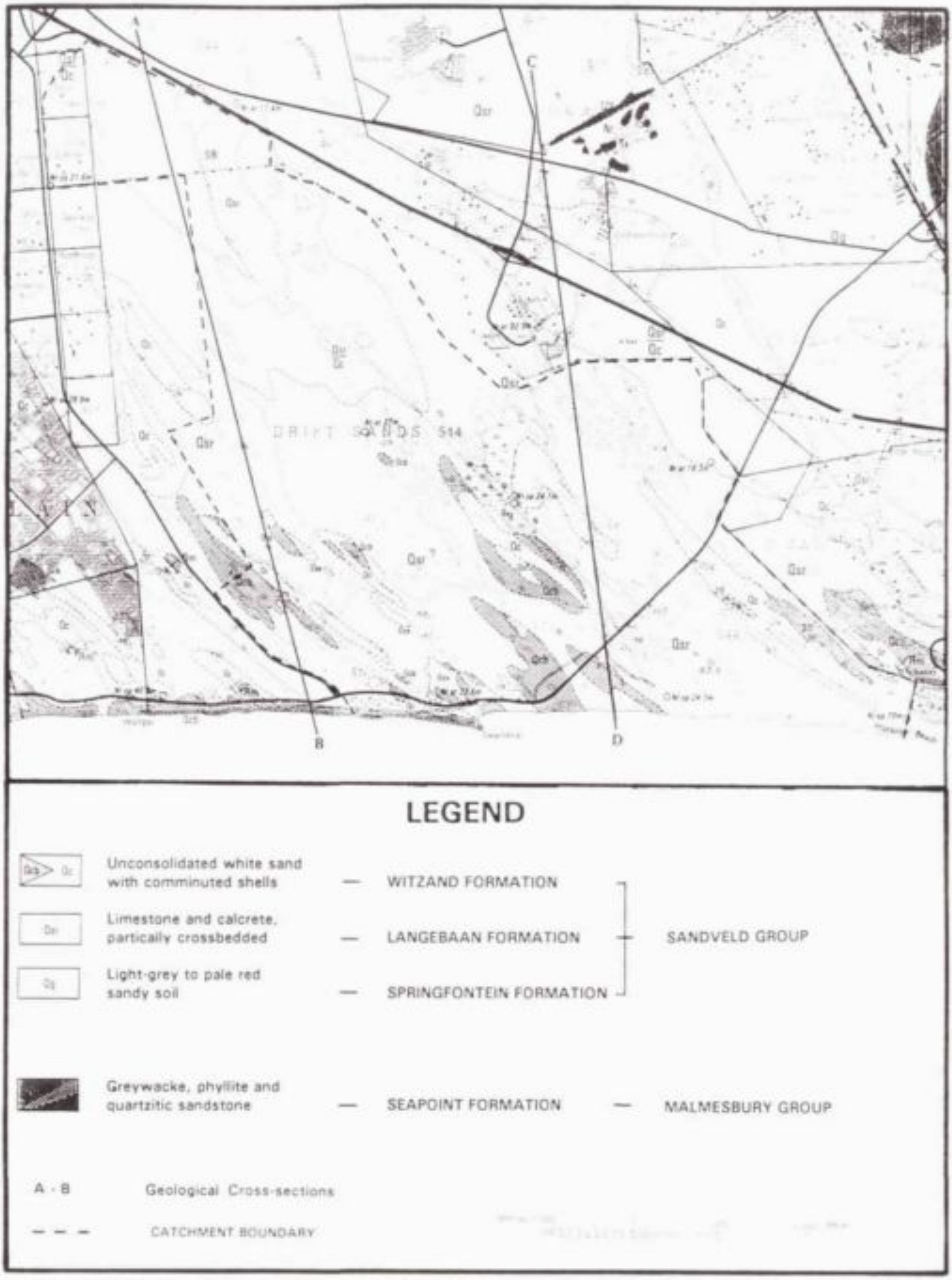


Figure 4 Geology of the southeastern Cape Flats

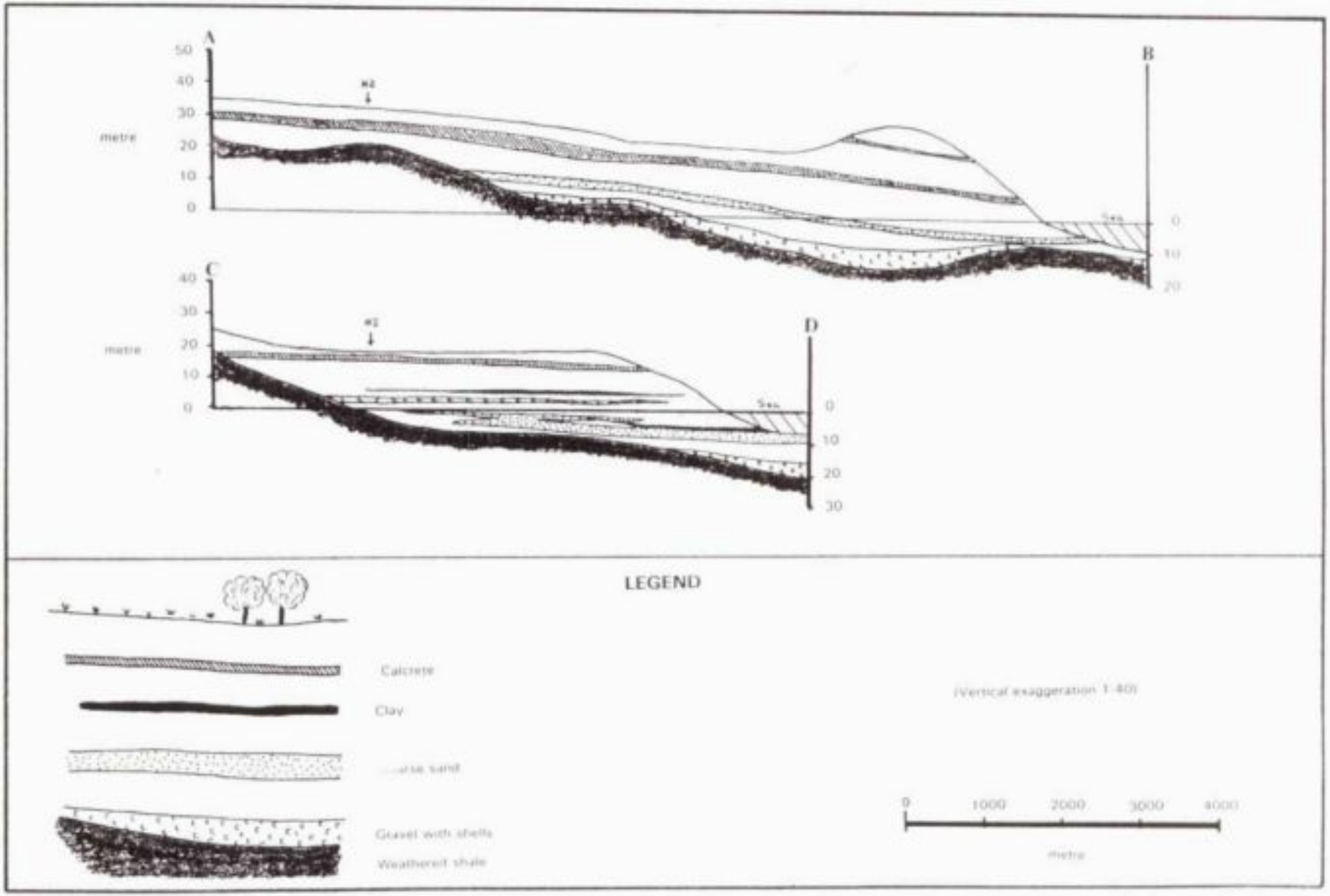


Figure 5 **Geological cross-sections of the Khayelitsha catchment**

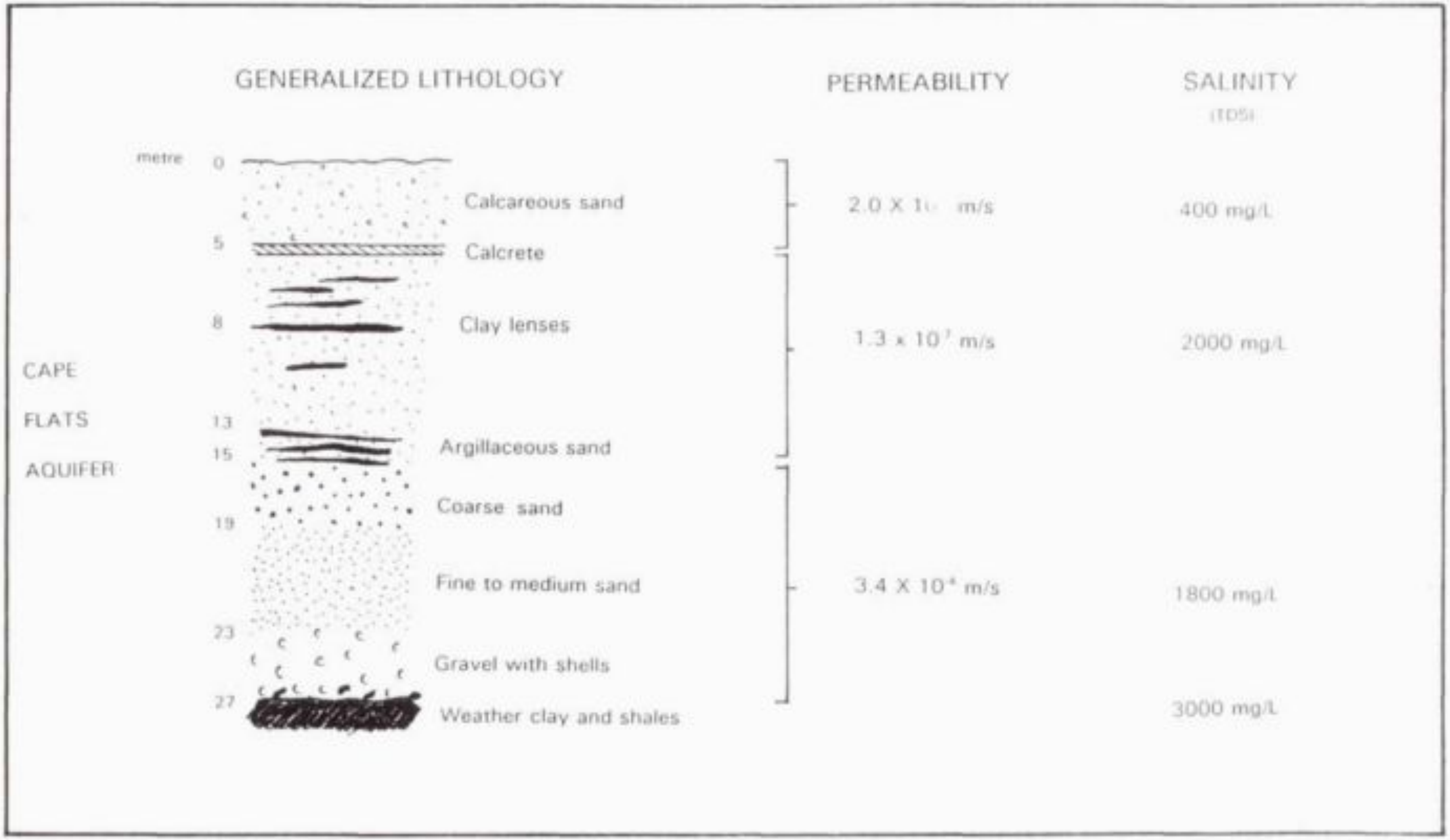


Figure 6 A generalized geological log showing the three units within the aquifer and their typical geohydrological characteristics

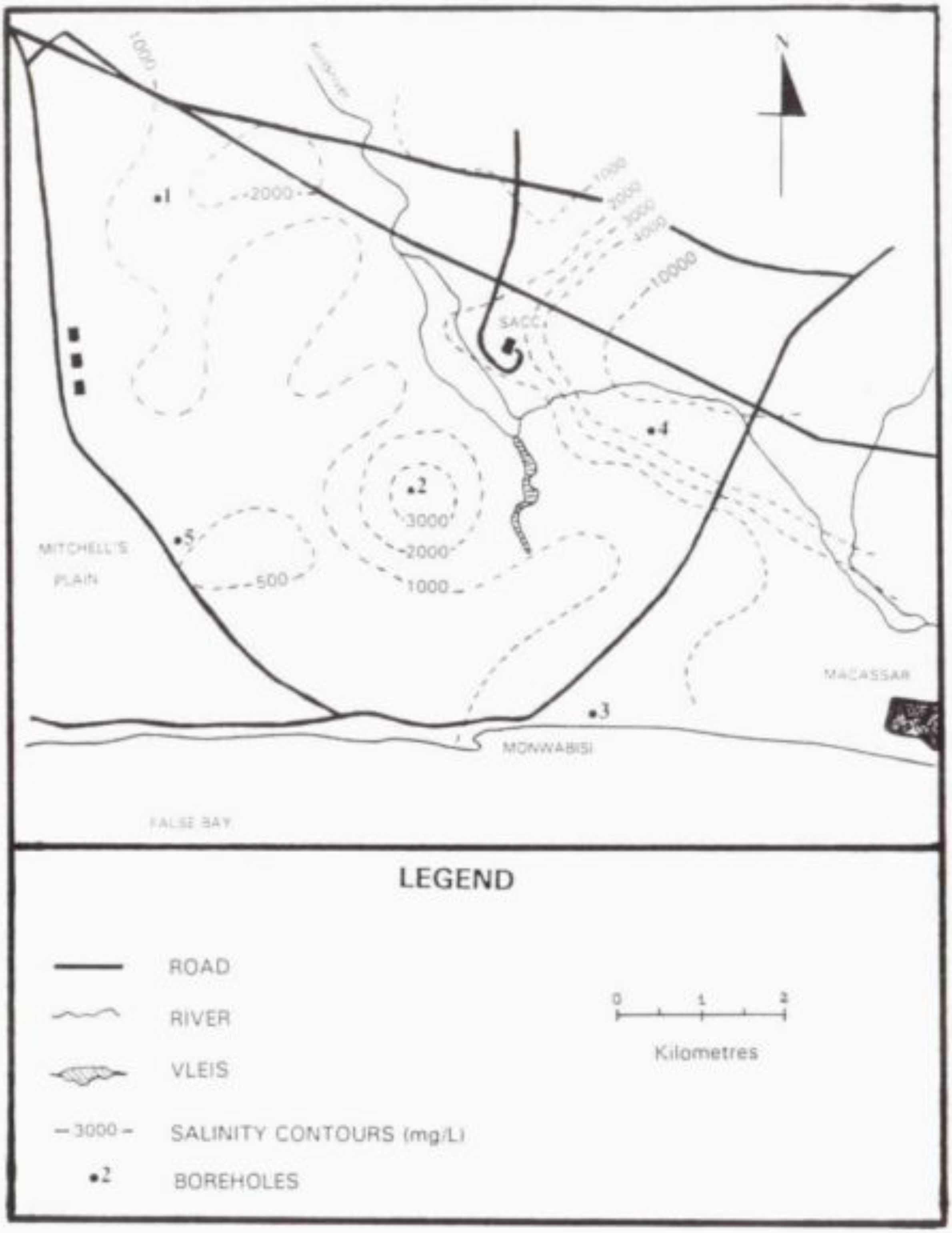
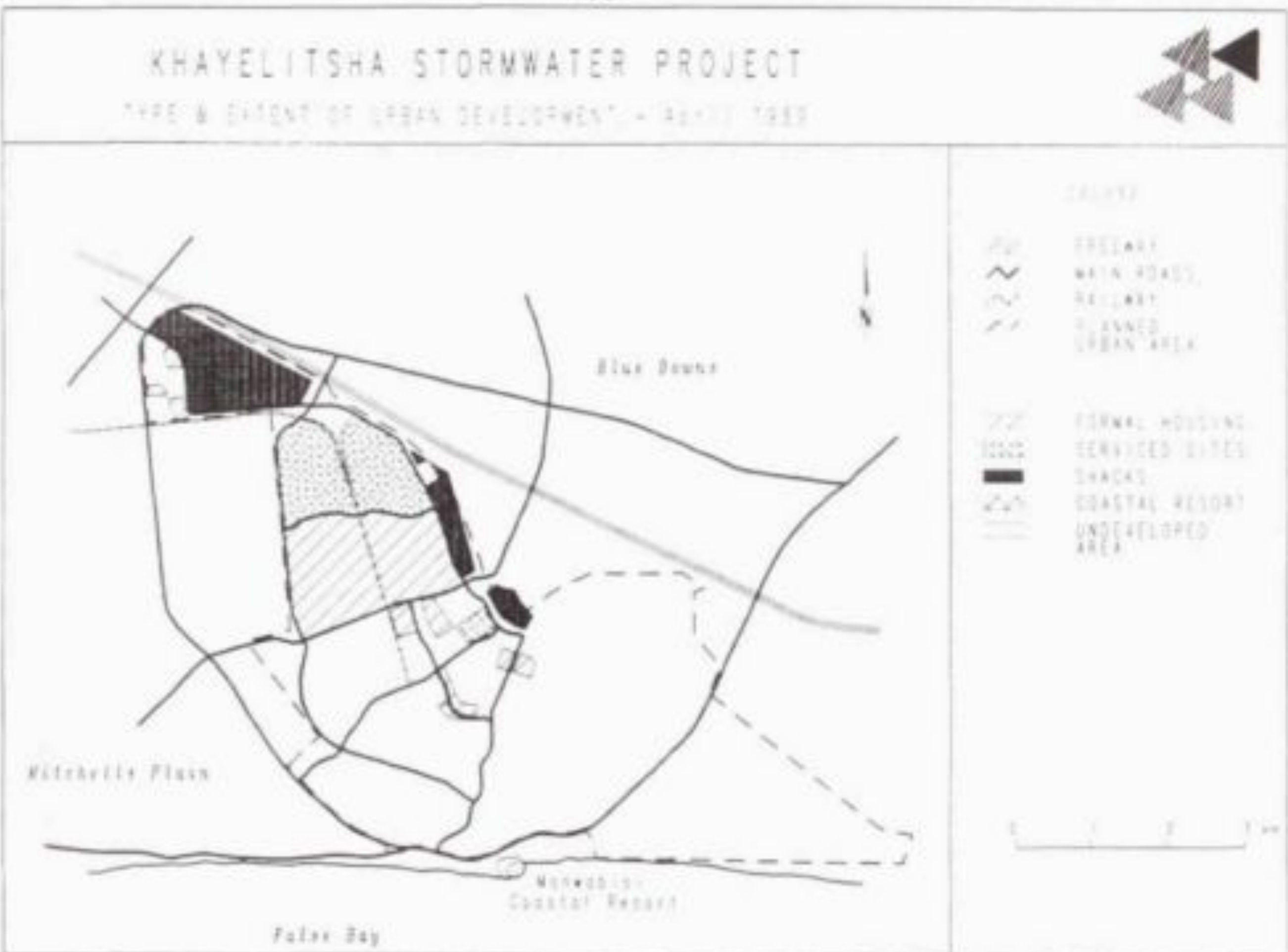


Figure 7 Groundwater salinity contour plan



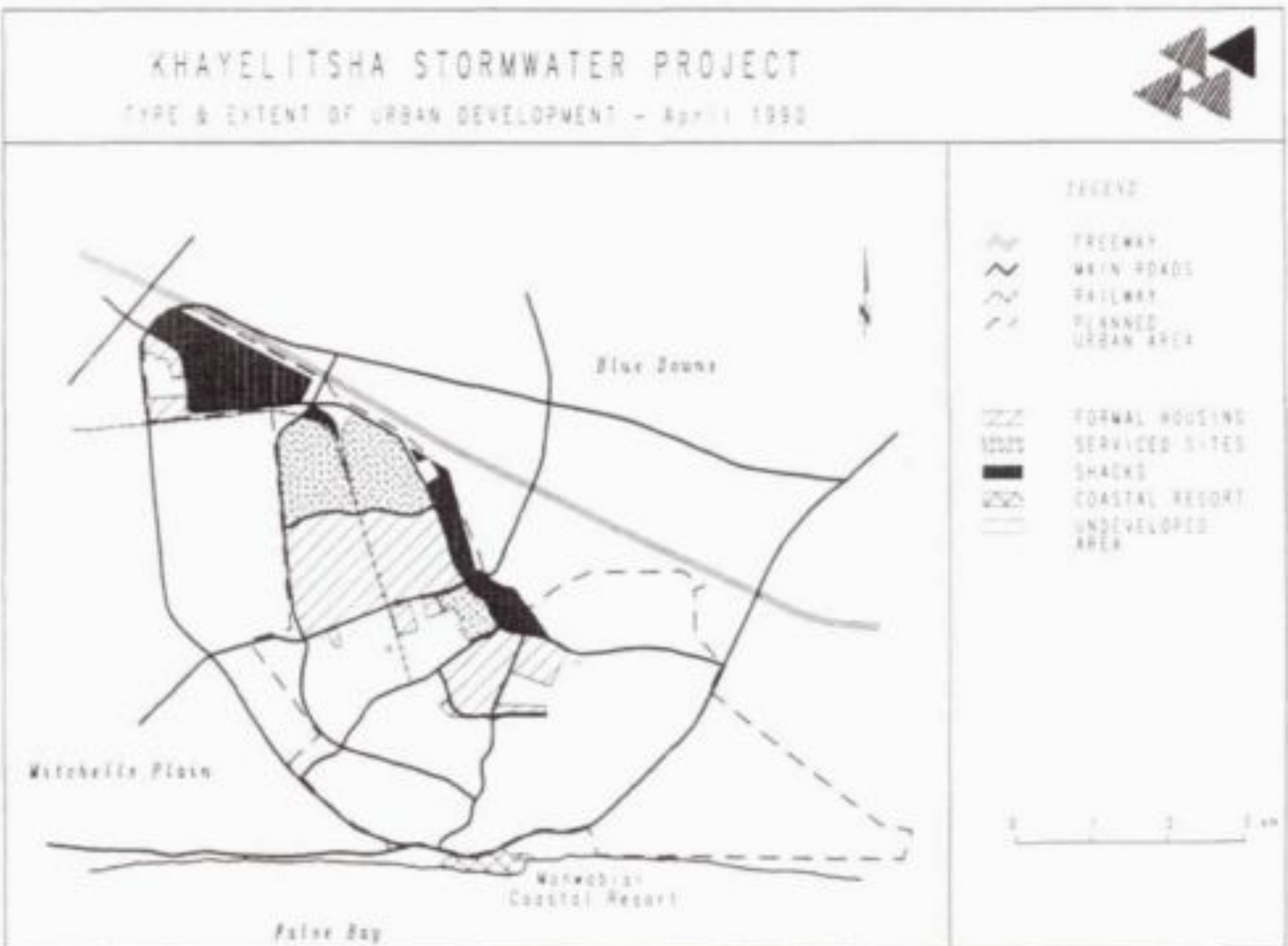
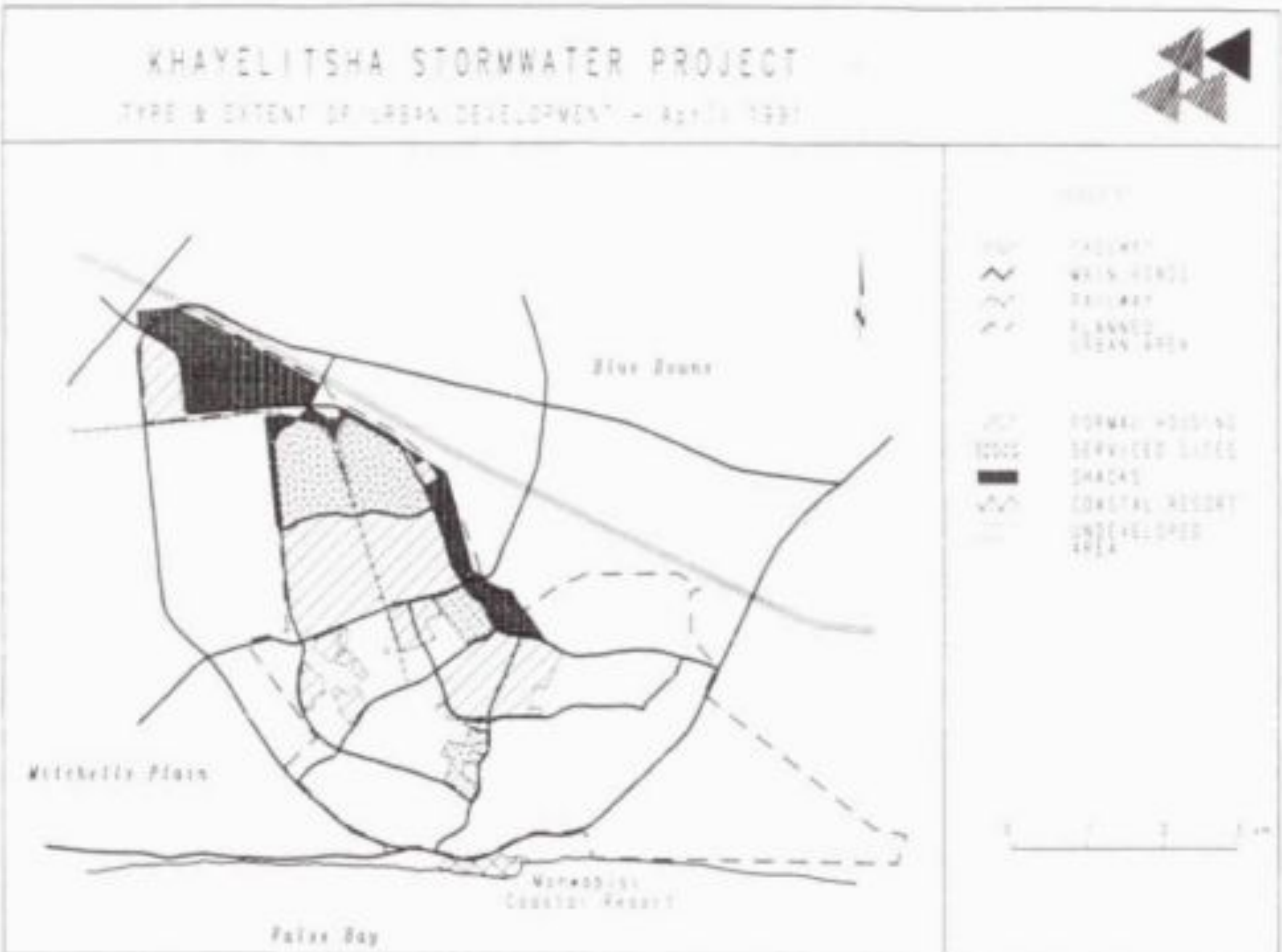


Figure 8 Urban development 1989/1990



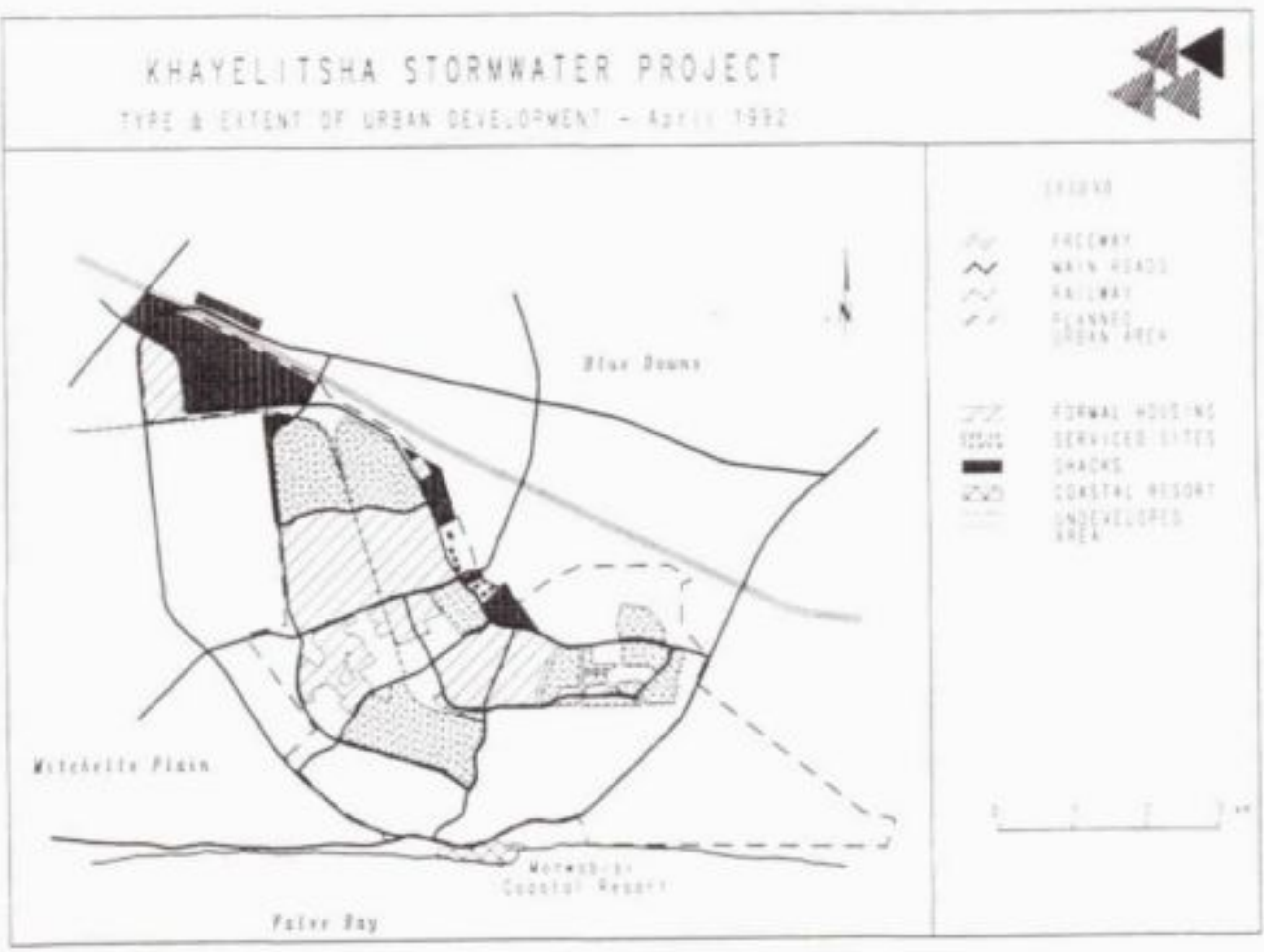


Figure 9 Urban development 1991/1992

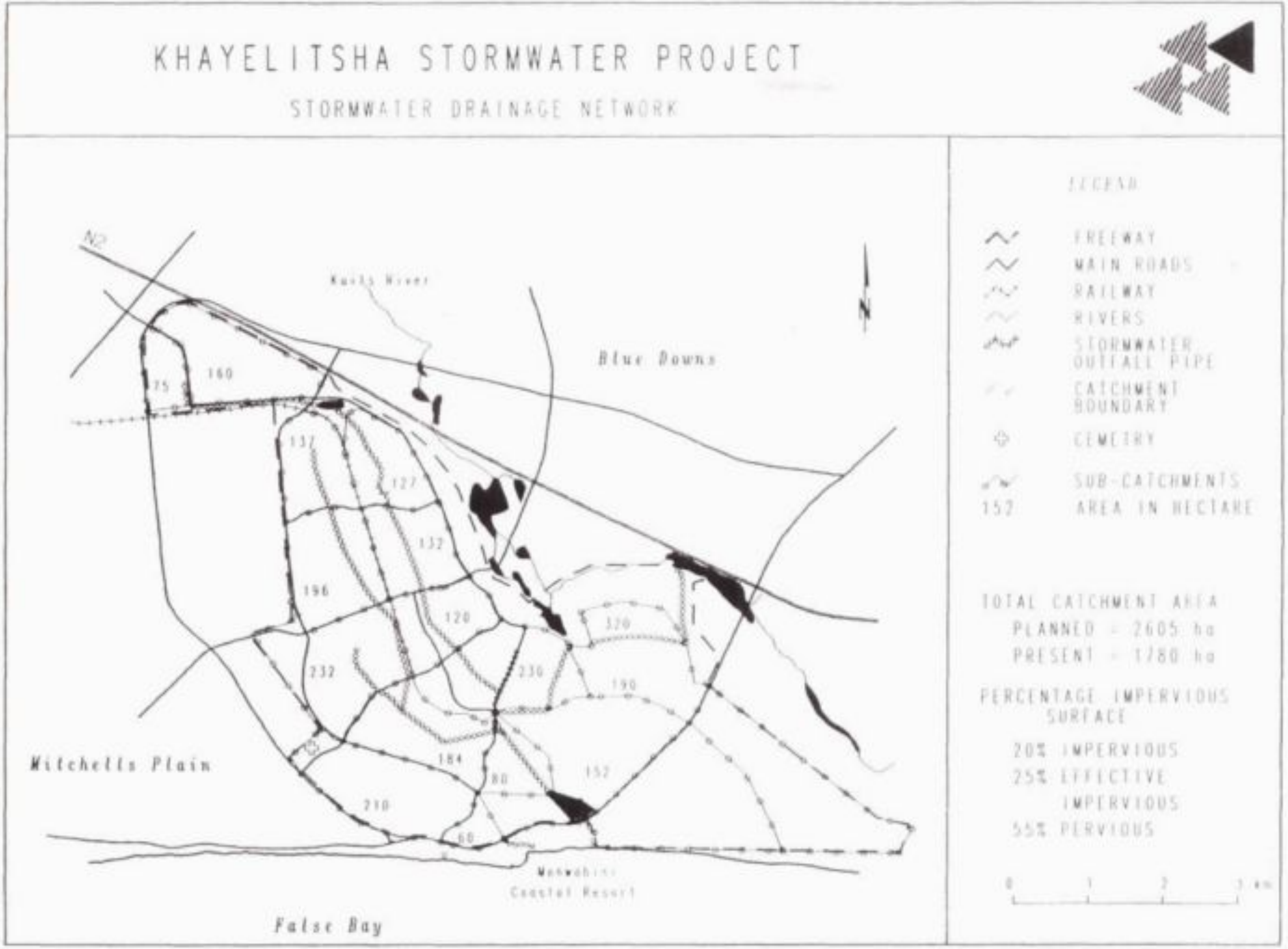
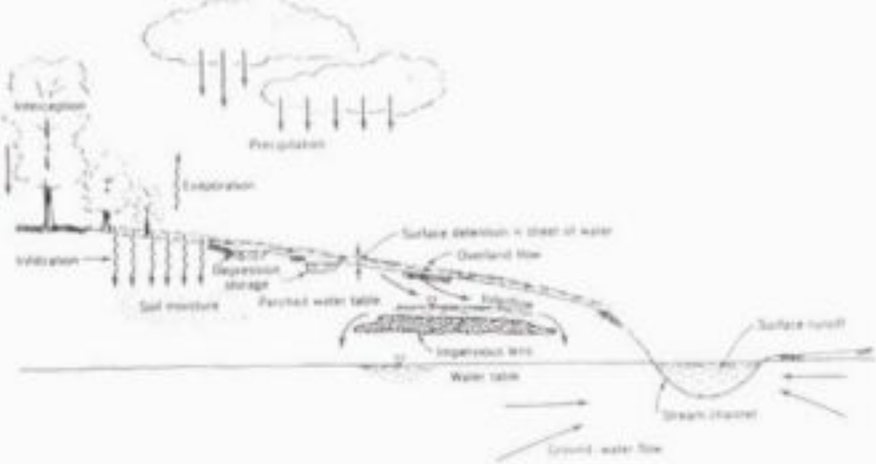
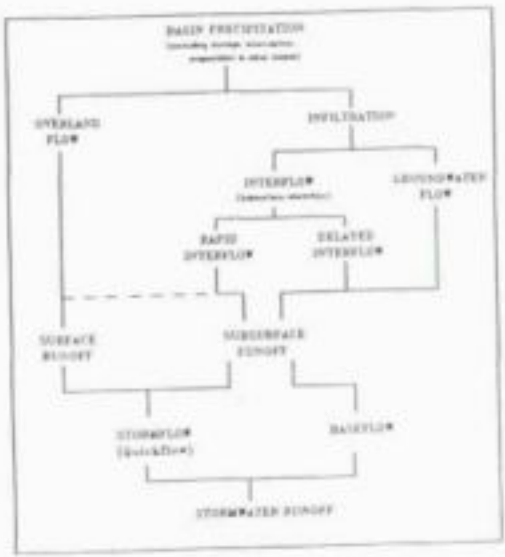


Figure 10 Khayelitsha stormwater drainage system

NATURAL CATCHMENT

1st WORLD URBAN CATCHMENT





DIAGRAMMATIC REPRESENTATION OF THE RUNOFF PROCESS

DIAGRAMMATIC REPRESENTATION OF THE RUNOFF PROCESS

Figure 11 The runoff cycle in a natural and urbanized catchment

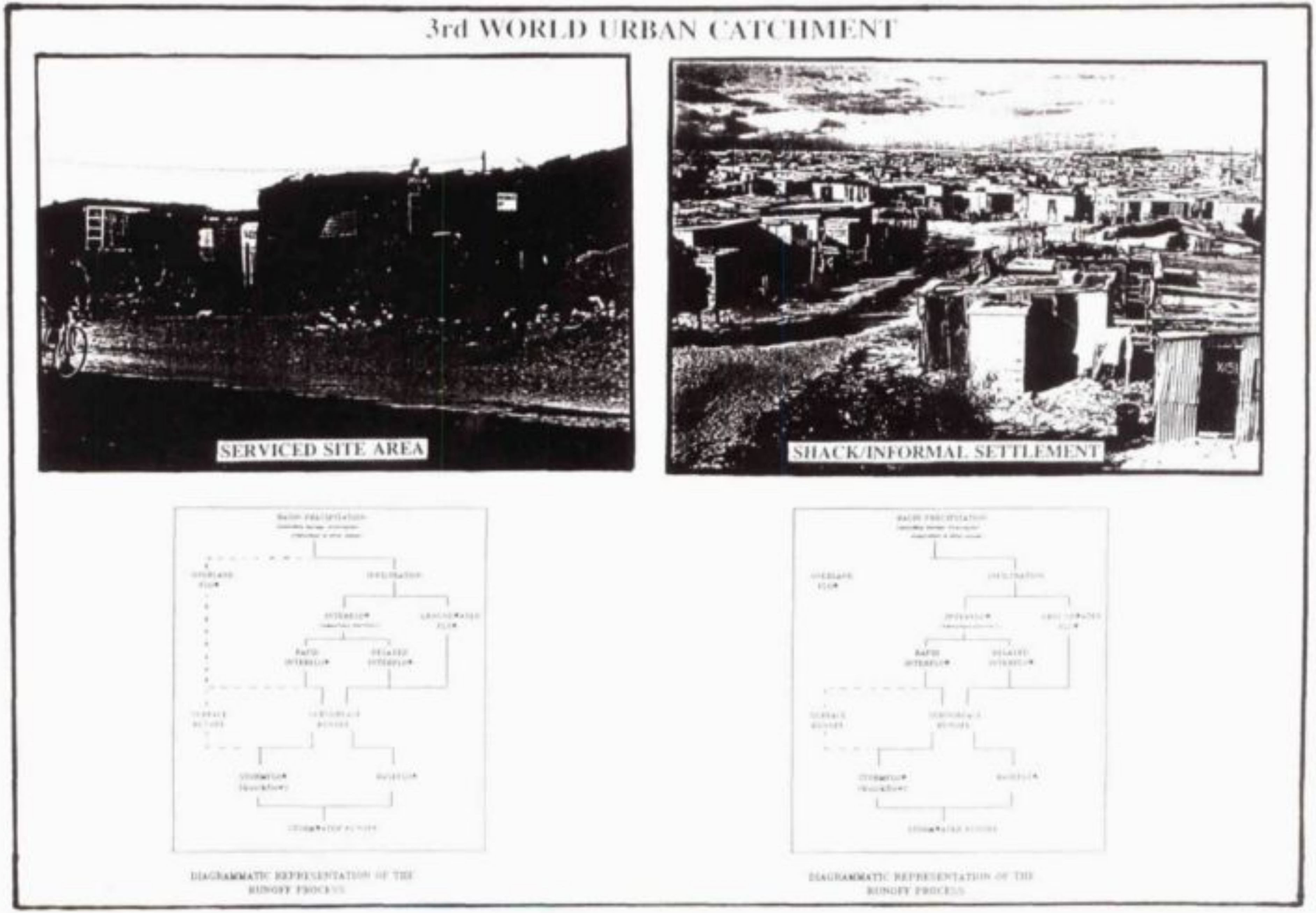


Figure 12 The runoff cycle in a Third world type urban catchment

Figure 13 The monitoring system based on the operational activities involved in the flow of information through a monitoring system (After Sanders *et al.*, 1983)

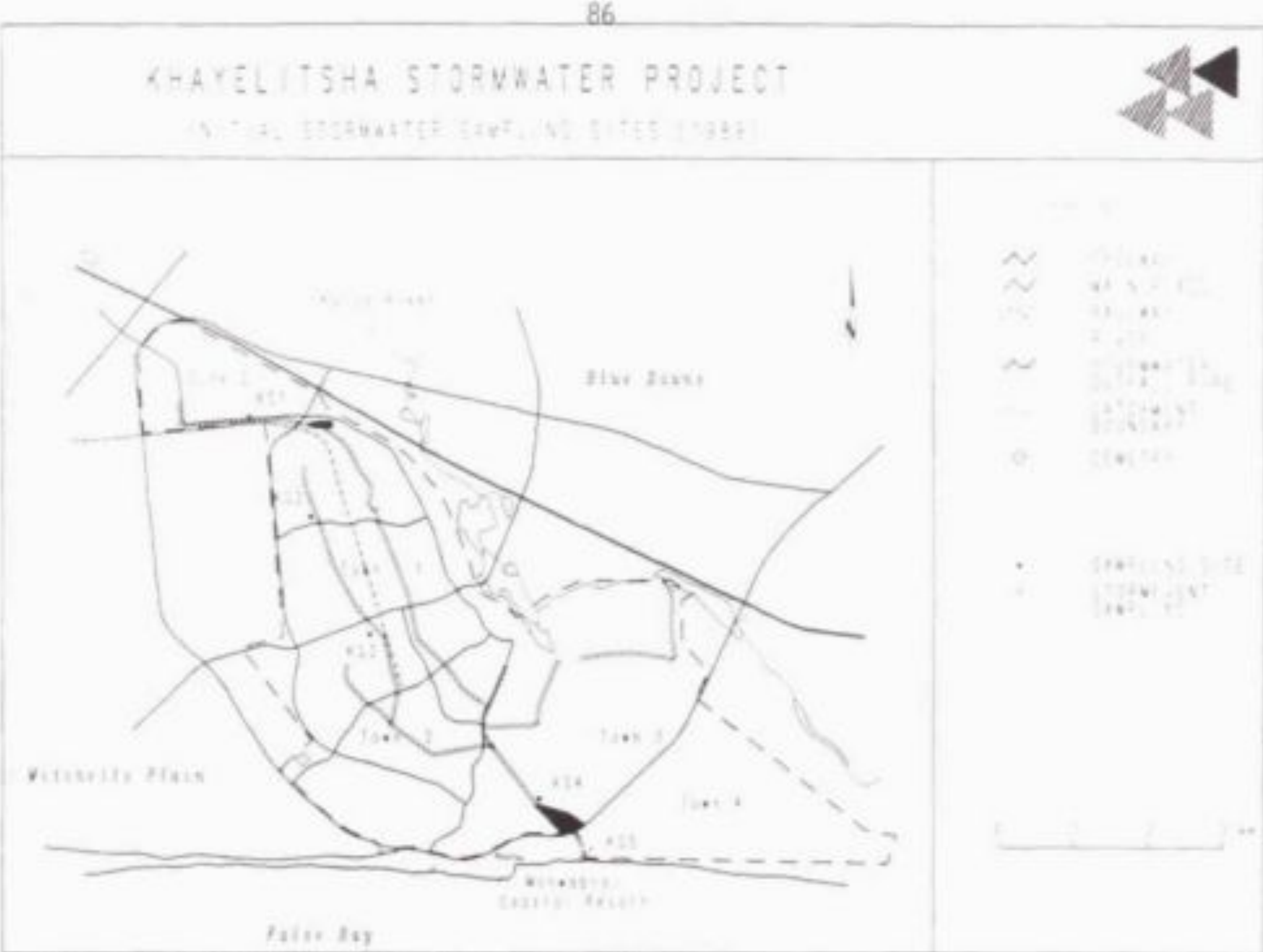


Figure 14 The initial stormwater sampling sites

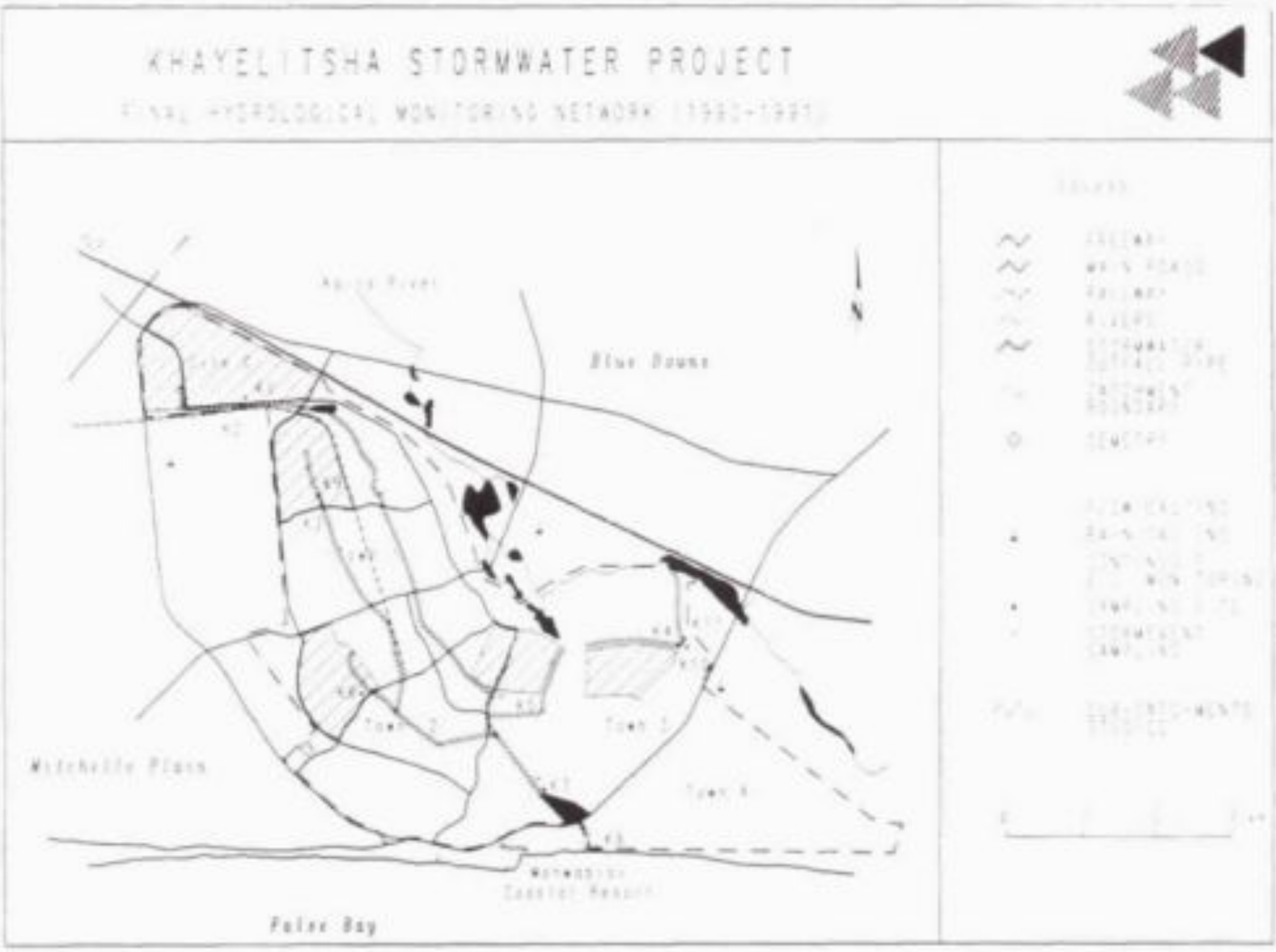


Figure 15 Final hydrological monitoring network

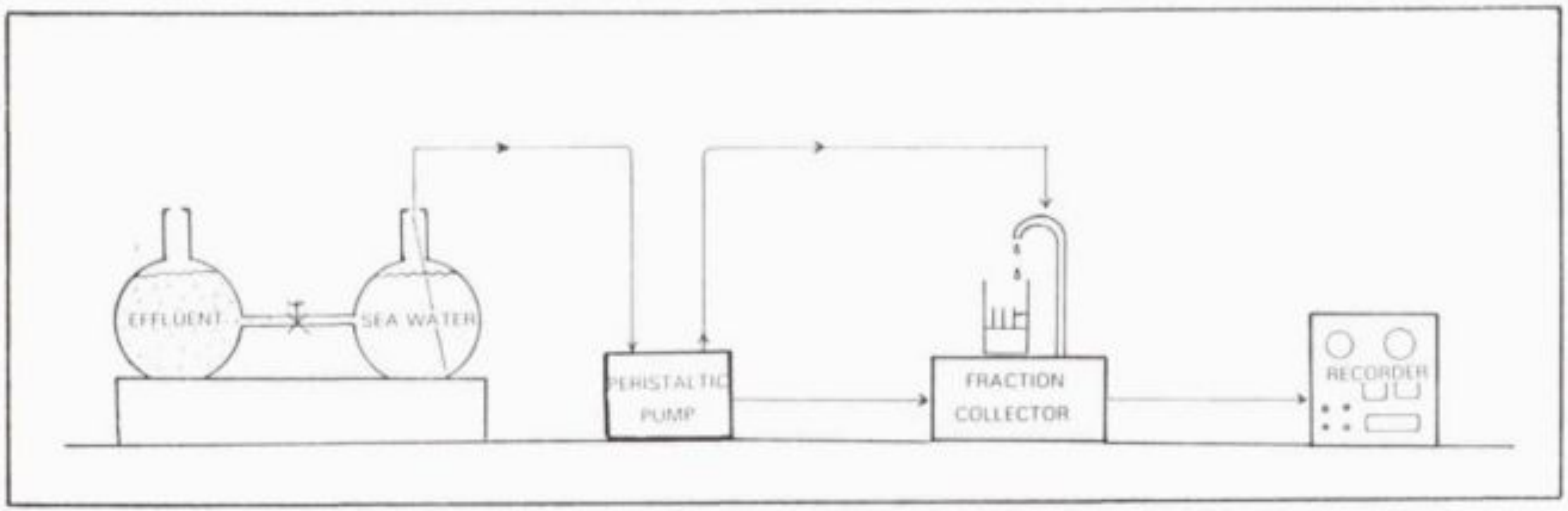


Figure 16 Laboratory setup for chemical mixing experiments

SEWAGE CRISIS . . . Father Heinz Schneider, Roman Catholic priest for Site B, Khayelitsha, surveys the sewage overflow from blocked pipes yesterday. Some homes could be flooded by waste.

Picture: OBED ZILWA

Determinand		Normal conditions*	Unrest condtions**
K	mg/L	13.1	20.9
Na	mg/L	139	118
Ca	mg/L	119.2	88.6
Mg	mg/L	49.2	32.8
NH_4-N mg/L		5.21	42.55
SO_4	mg/L	173	111
Cl	mg/L	192	152
Alk ($CaCO_3$	mg/L	386	424
NO_x	mg/L	7.97	8.55
P	mg/L	0.22	6.15
Cd	mg/L	<0.01	<0.01
Cu	mg/L	0.02	0.02
Fe	mg/L	1.37	1.06
Pb	mg/L	<0.02	0.02
Zn	mg/L	0.02	0.06
DOC	mg/L	12.5	66.8
EC	mg/L	160	152
pH	mg/L	7.0	7.1
TDS	mg/L	1024	973
Hardness as $CaCo_3$ mg/L		500	356
F. coliforms per 100ml		4.2×10^5	1.8×10^{12}
F. streptococci per 100 ml		1.4×10^4	4.1×10^7
Coliphage per 10 ml		5.3×10^3	1.4×10^5

** 03/12/90
* 22/01/91

Figure 17 Typical stormwater quality in a serviced site sub-catchment during periods of unrest

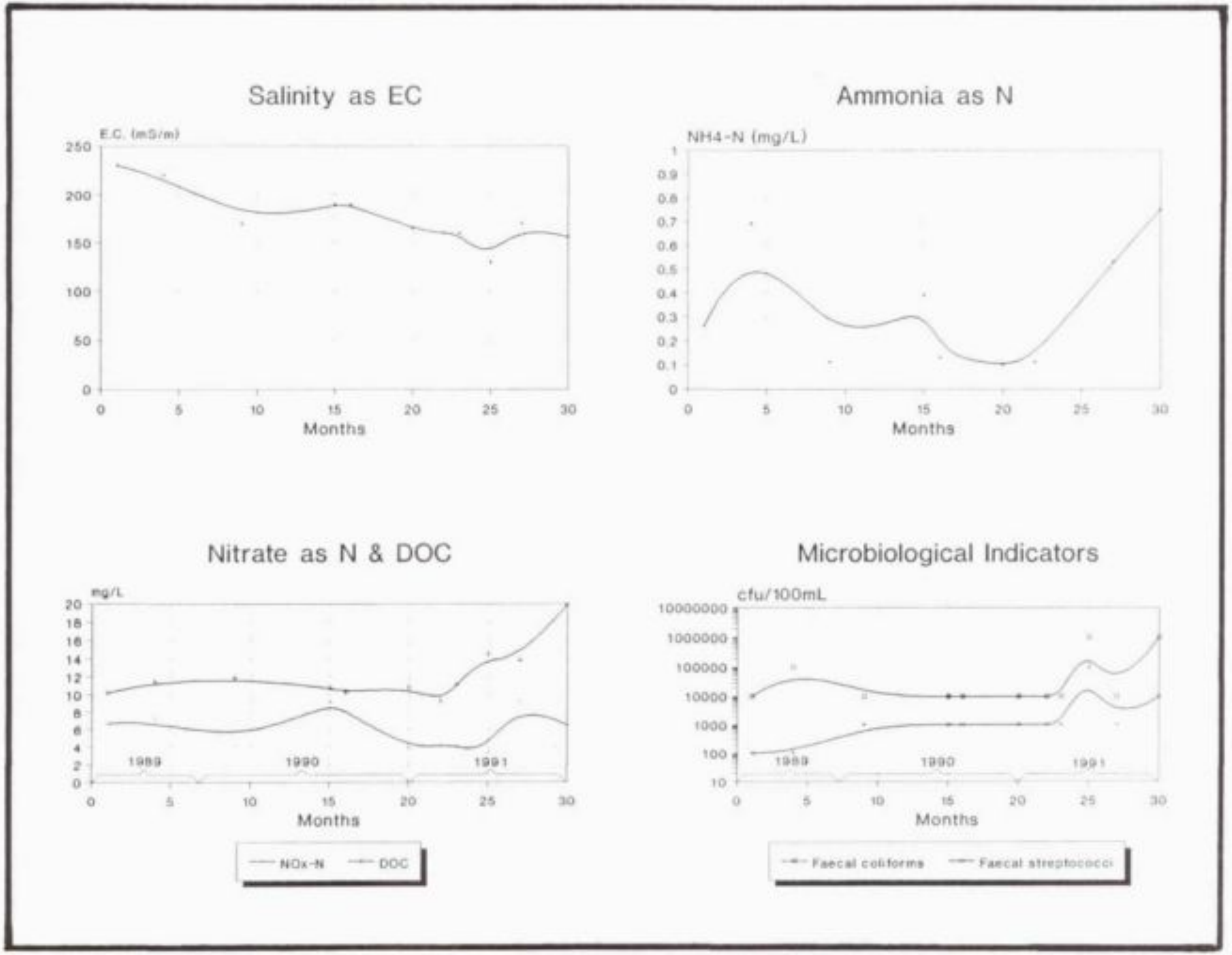
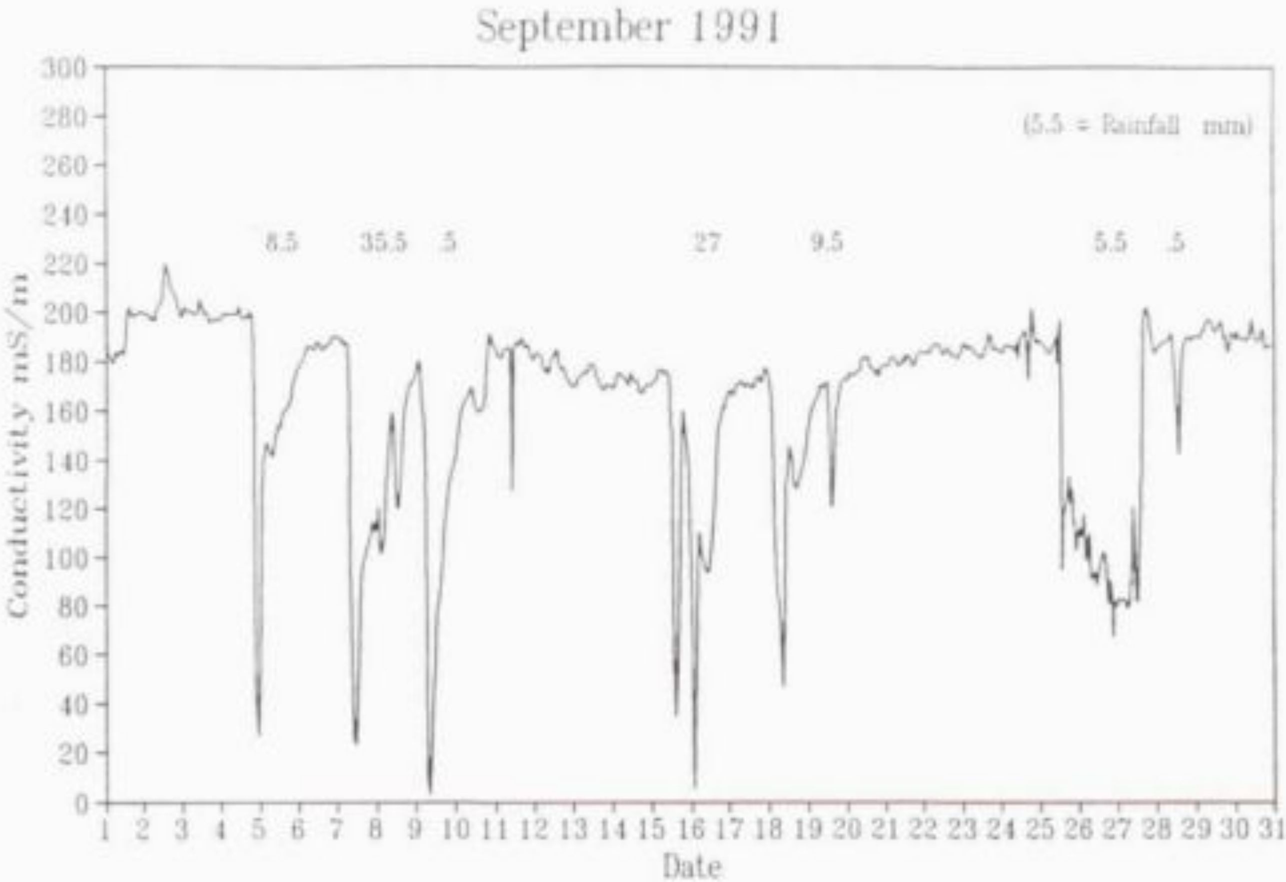


Figure 18 Selected stormwater quality trends for Khayelitsha urban catchment: June 1989 - Nov 1991



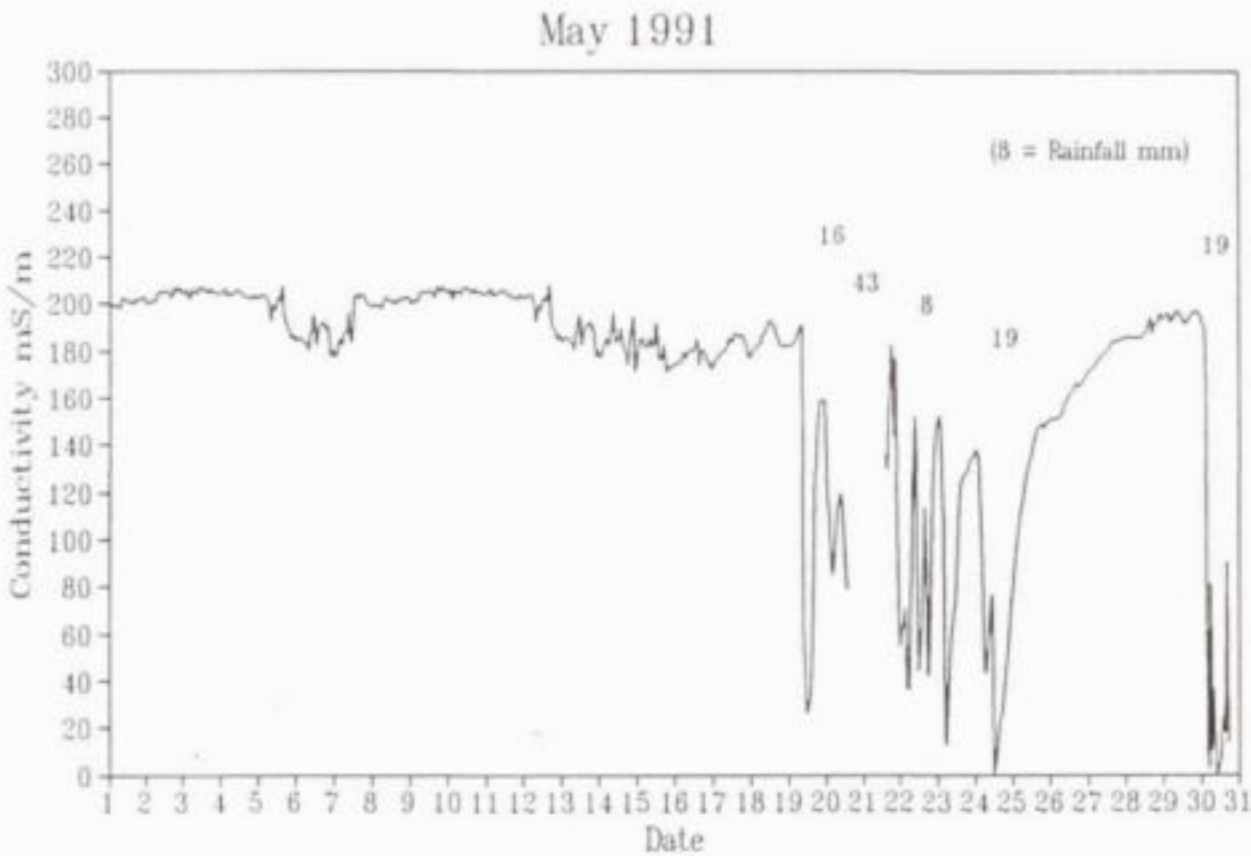
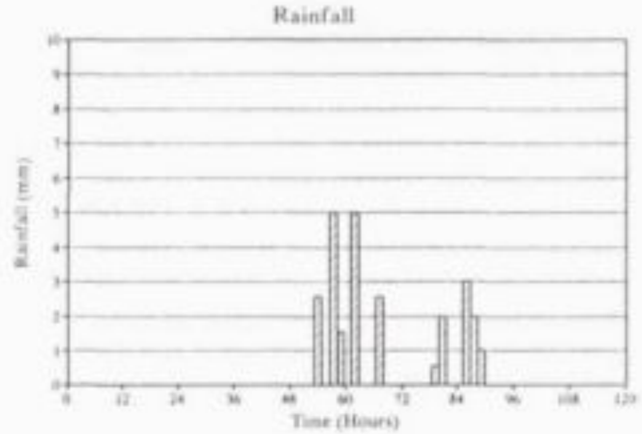
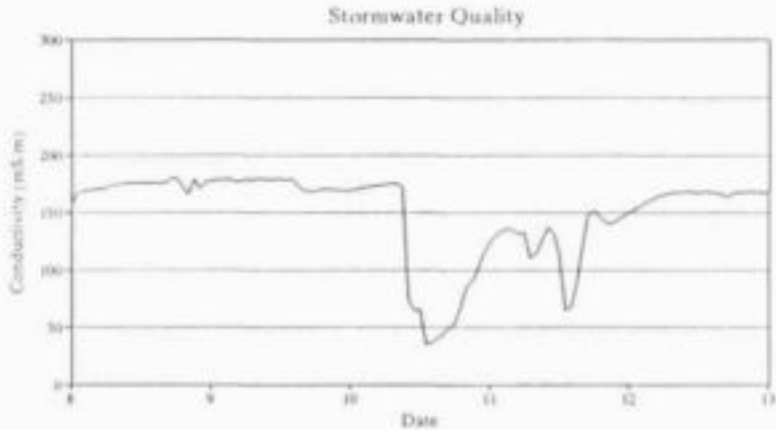
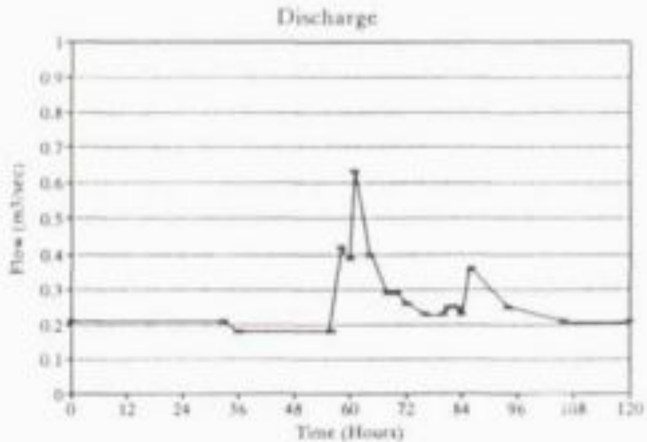


Figure 19 Stormwater salinity trends as monitored at site 7 during May and September 1991







Notes

10 July 1991	
Stormevent Type	Typical frontal weather with westerly winds
Length of Stormevent	32 hours
Total Rainfall	22 mm
Nature of Rain	Five rainfall episodes with the most intense rain during episodes 1 and 2
Time to previous rainevent	4 days
Previous Rainevent	61 mm over 72 hours

Figure 20: Stormevent analysis: Hydrological data 8 - 12 July 1991

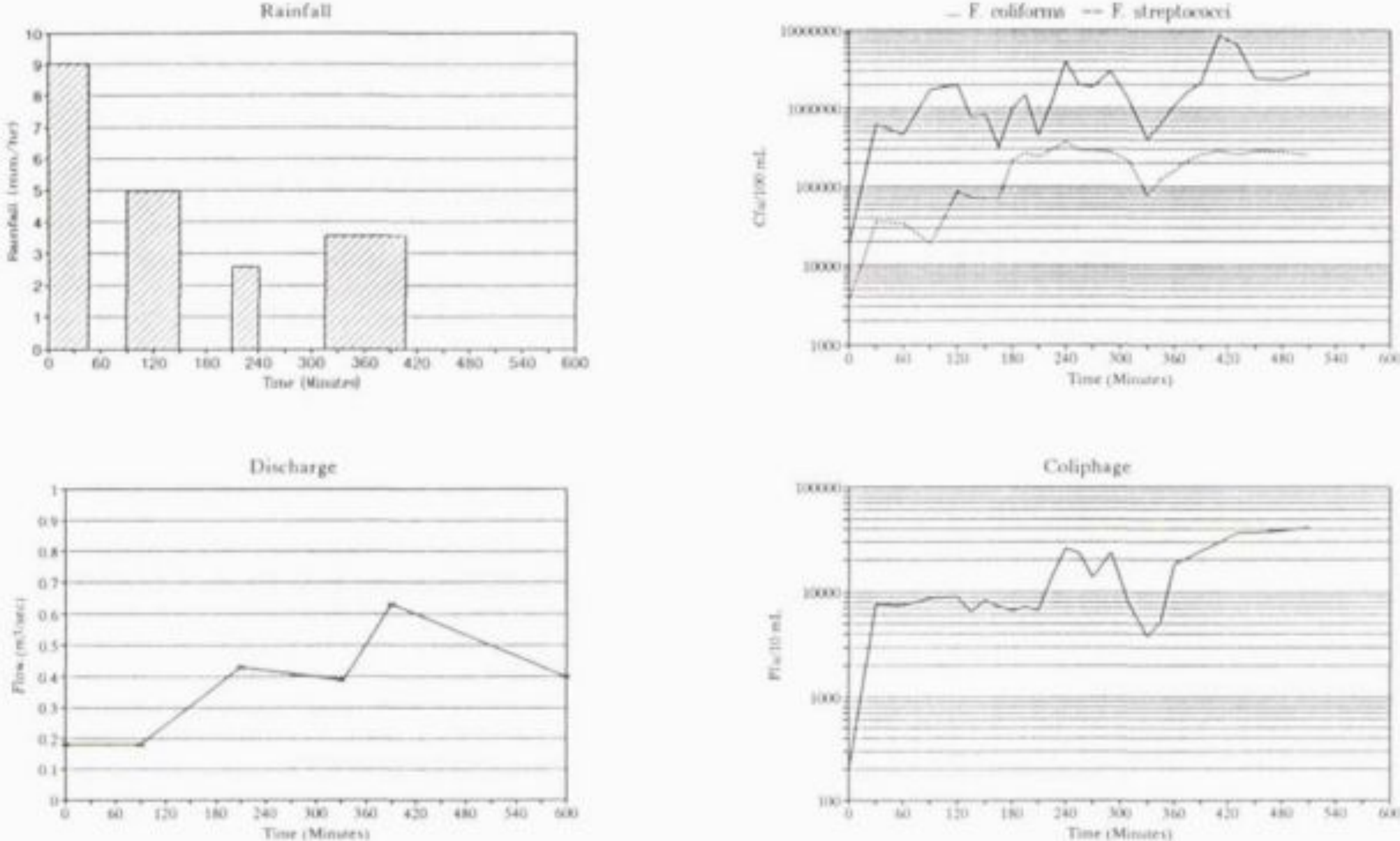


Figure 21: Stormevent analysis 10 July 1991 - Hydrological and microbiological data

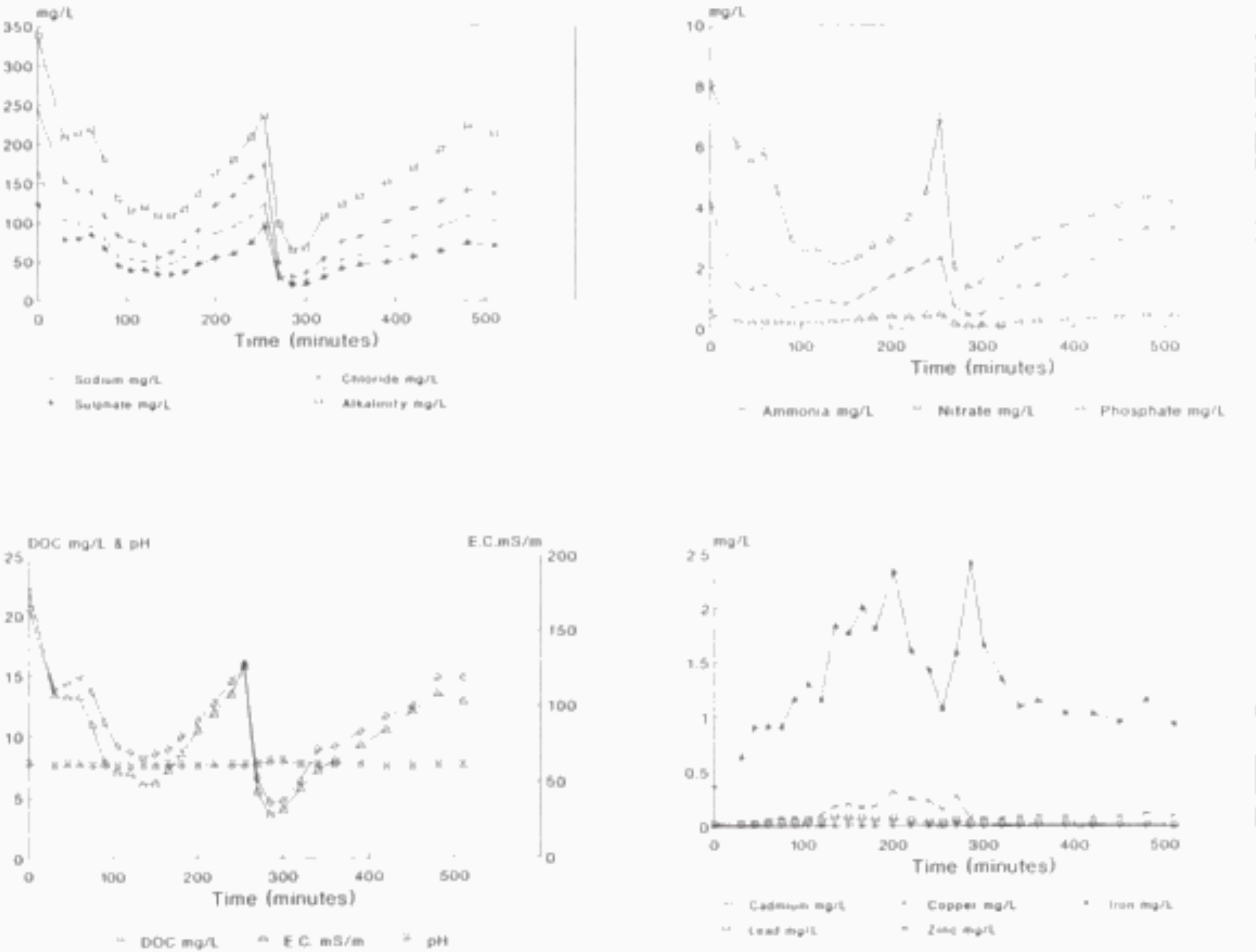
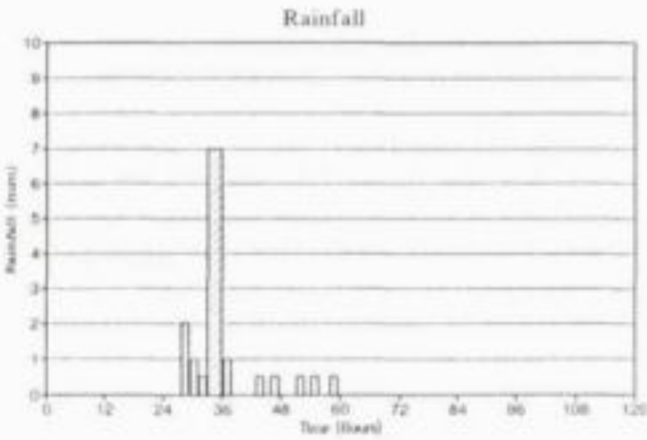
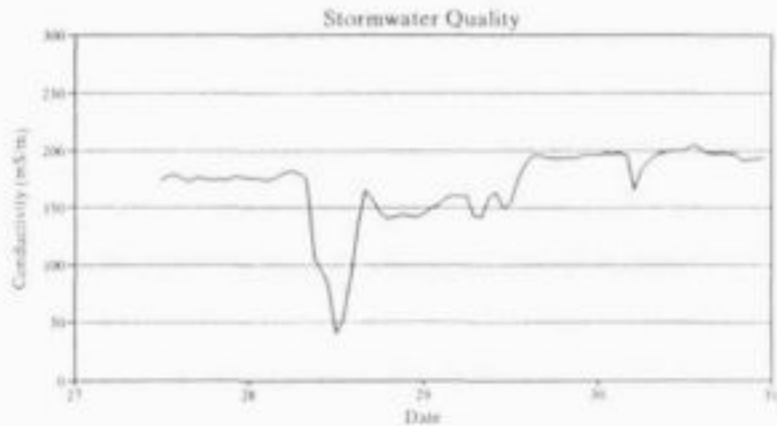
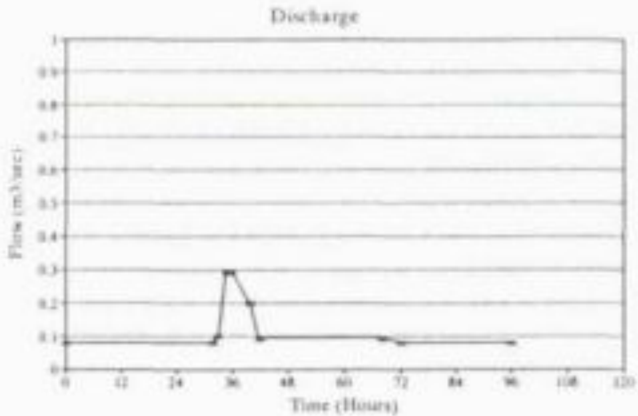


Figure 22 Stormevent analysis 10 July 1991: Chemical analysis







Notes

28 August 1991	
Stormevent Type	Late winter frontal system with westerly winds
Length of Stormevent	27 hours
Total Rainfall	15 mm
Nature of Rain	Five hours moderate intensity rain followed by 22 hours of soft intermitten rain
Time to previous rainevent	3 days
Previous Rainevent	3.5 mm over 24 hours

Figure 23: Stormevent analysis Hydrological data 27 - 30 August 1991

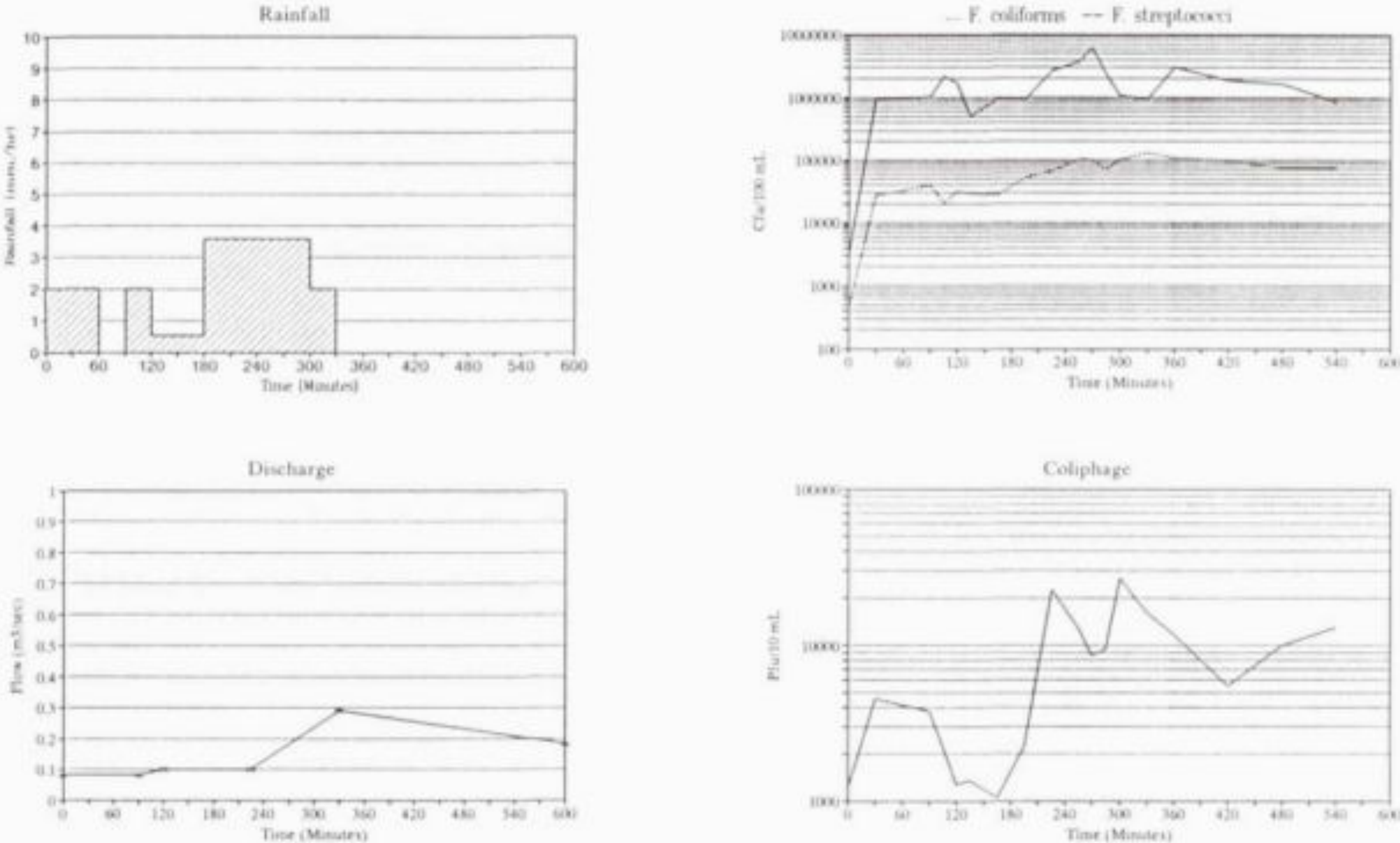


Figure 24: Stormevent analysis 28 August - Hydrological and microbiological data

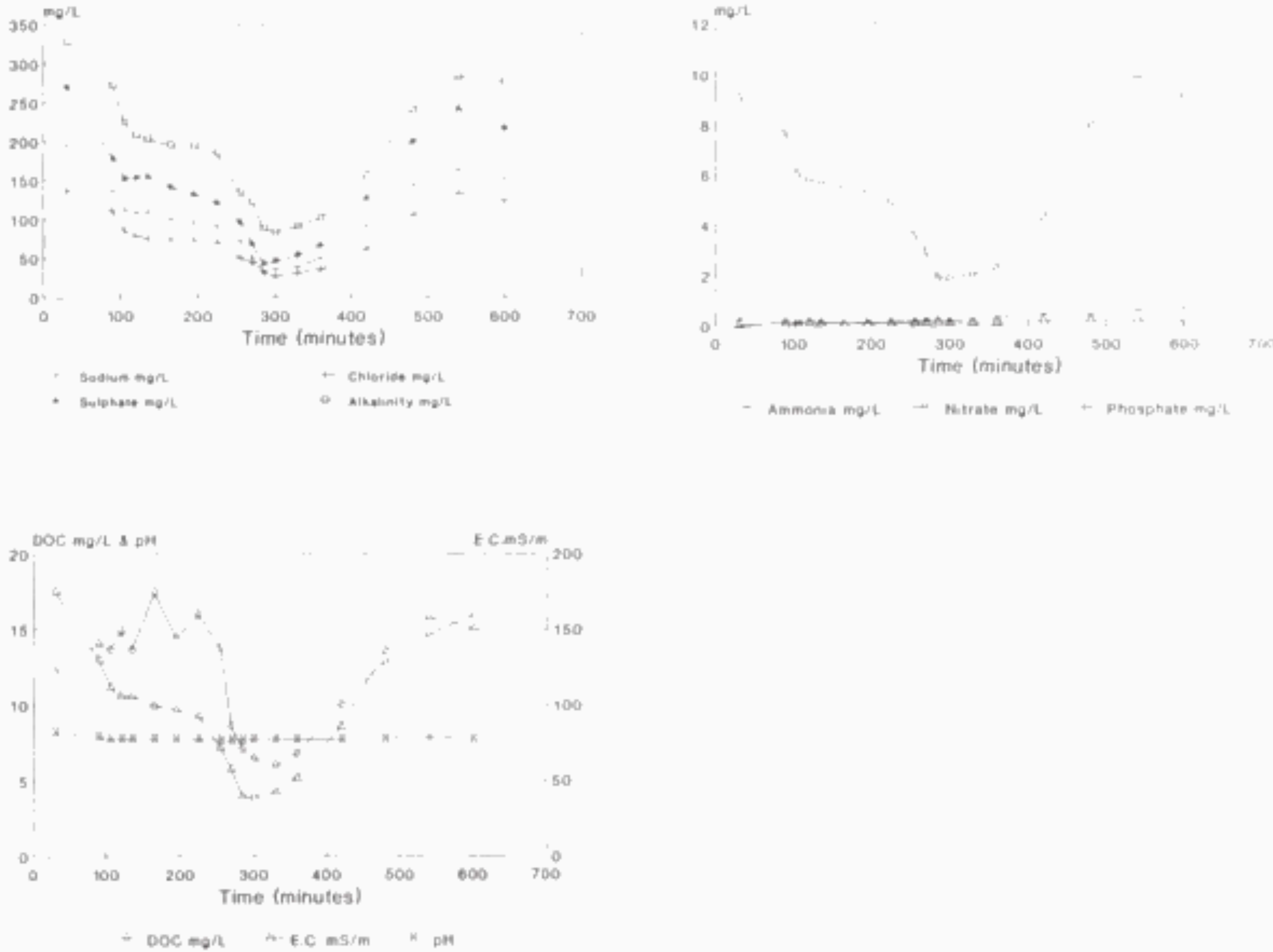
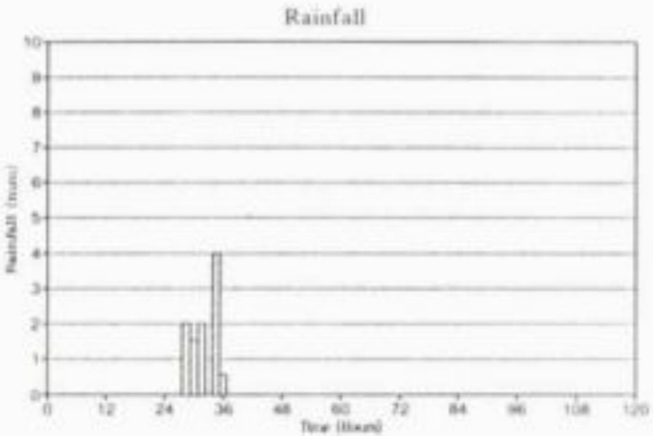
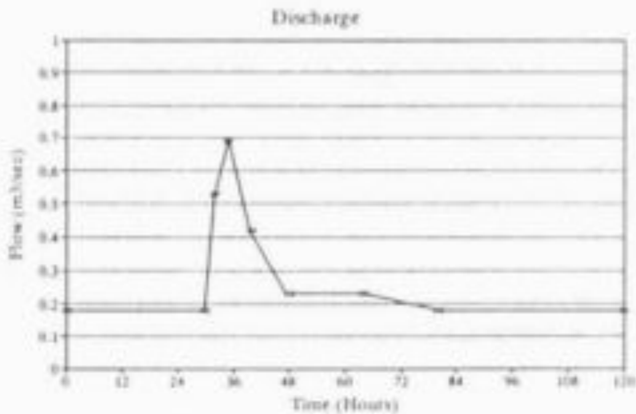


Figure 25 Stormevent analysis 28 August 1991: Chemical analysis





Notes

11 September 1991	
Stormevent Type	Early spring shower - cold front with southwesterly winds
Length of Stormevent	5 hours
Total Rainfall	13 mm
Nature of Rain	Gentle rain fairly uniformily distributed over stormevent
Time to previous rainevent	5 days
Previous Rainevent	4 mm in short intense storm

Figure 26: Stormevent analysis Hydrological data 10 - 14 September 1991

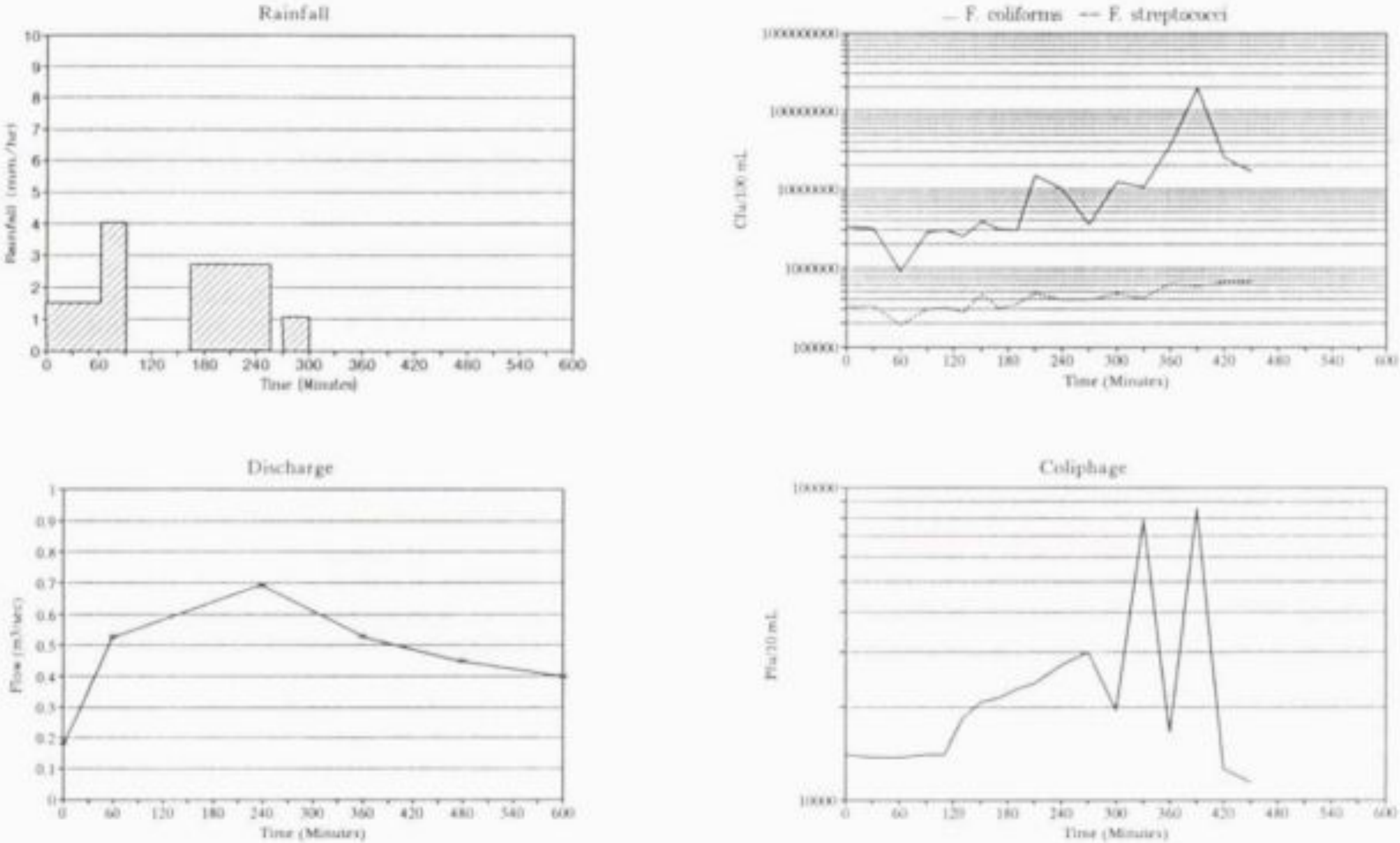


Figure 27: Stormevent analysis 11 September 1991 - Hydrological and microbiological data

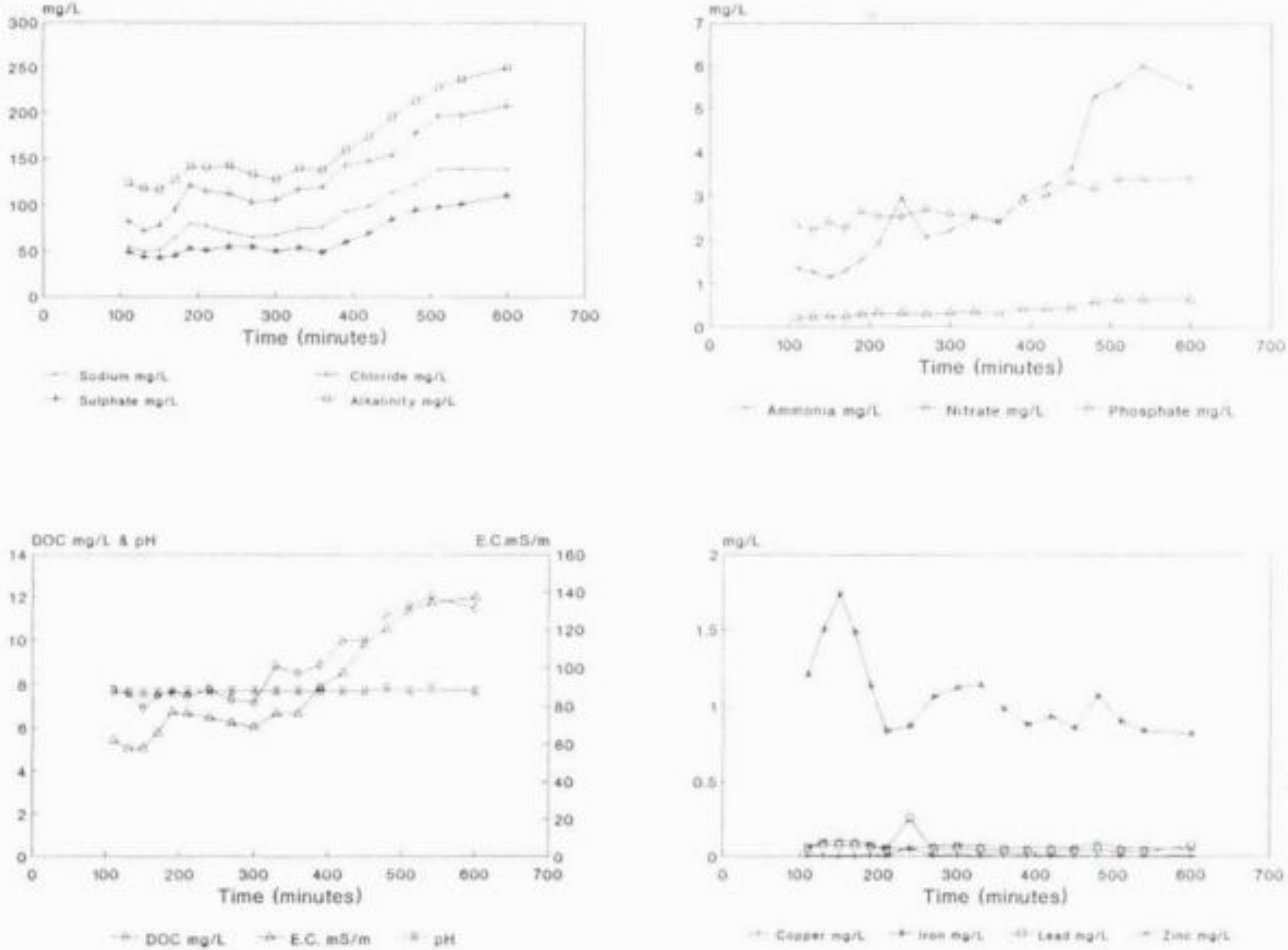


Figure 28 Stormevent analysis 11 September 1990: Chemical analysis

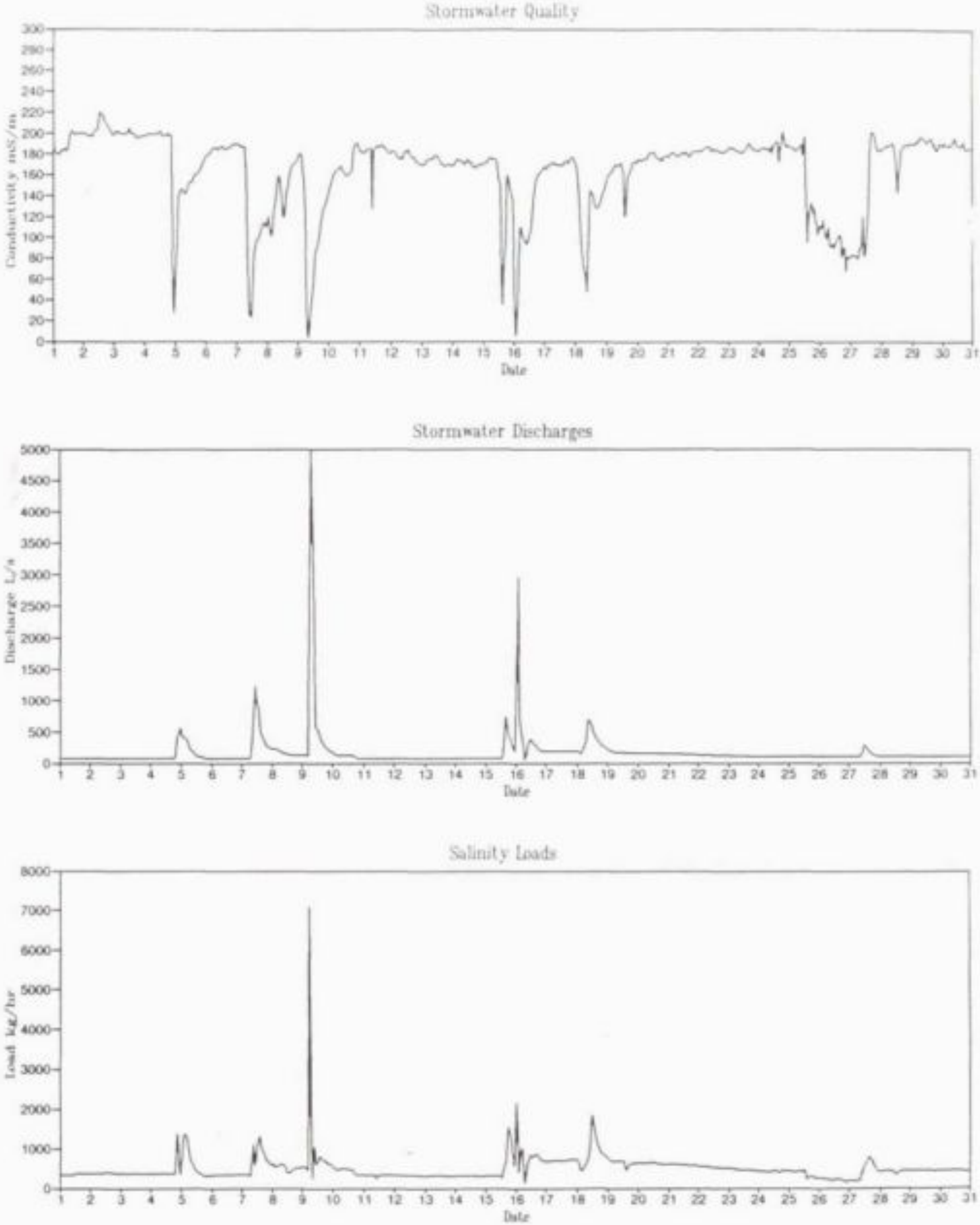


Figure 29 A summary of stormwater concentration, pollutant load and discharge trends during a wet month (September 1991)

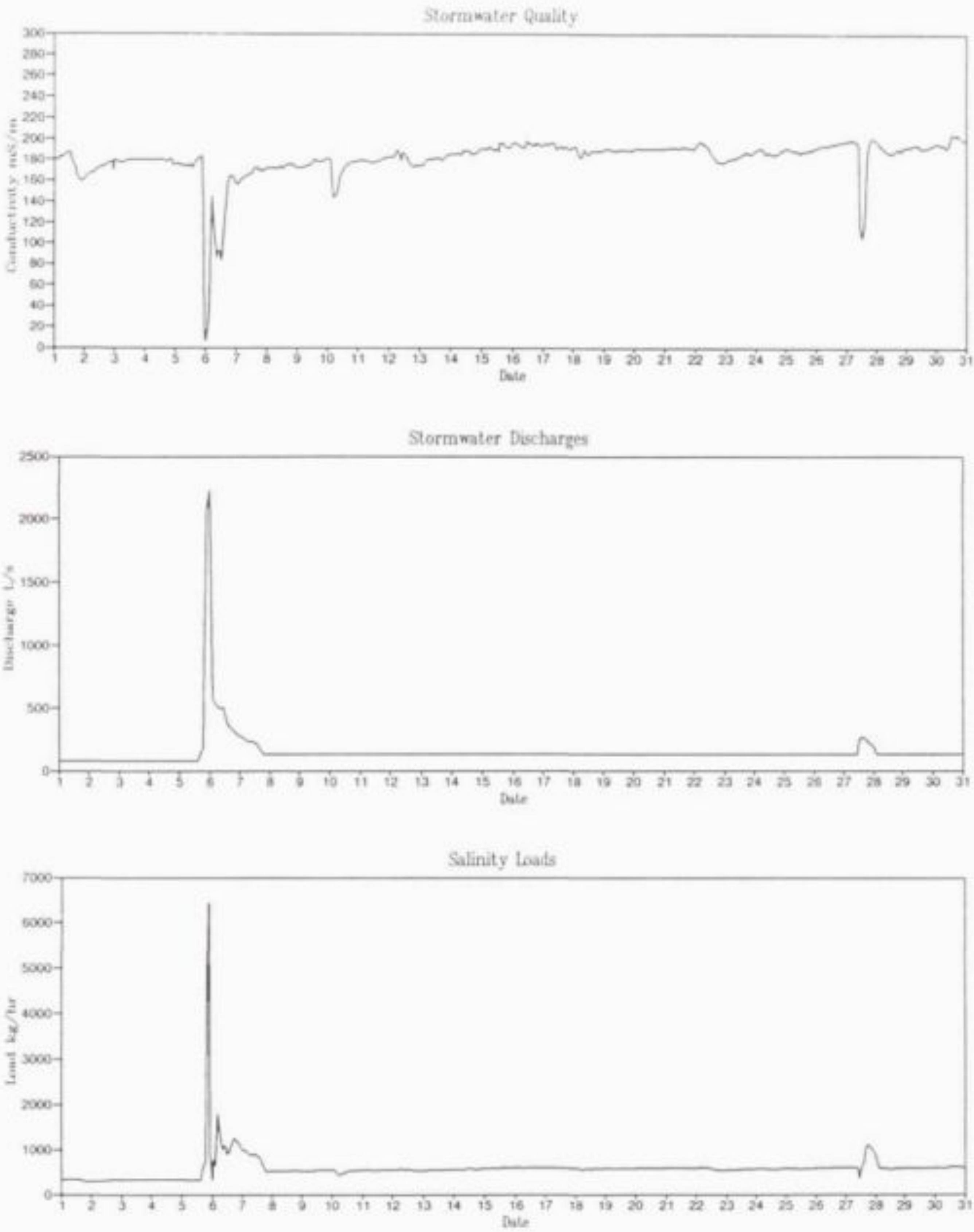
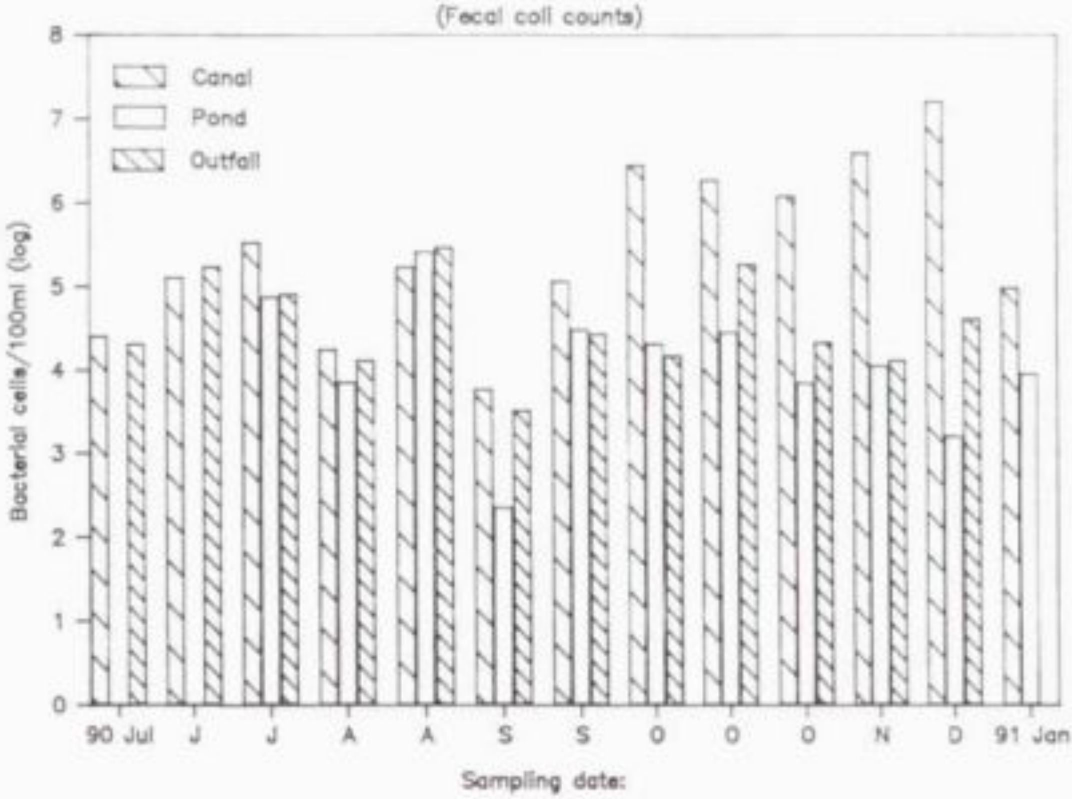


Figure 30 A summary of stormwater concentration, pollutant load and discharge trends during a dry month (April 1991)



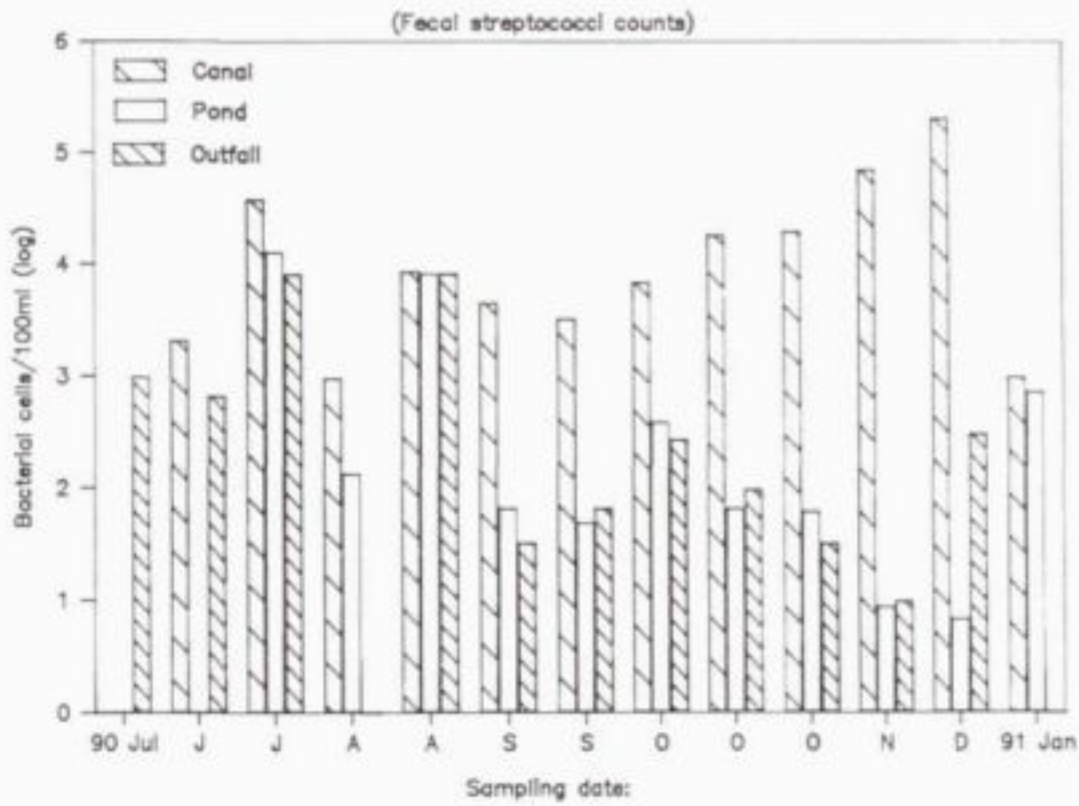


Figure 31 Microbiological results from stormwater sampling before, in, and after the final stormwater detention basin

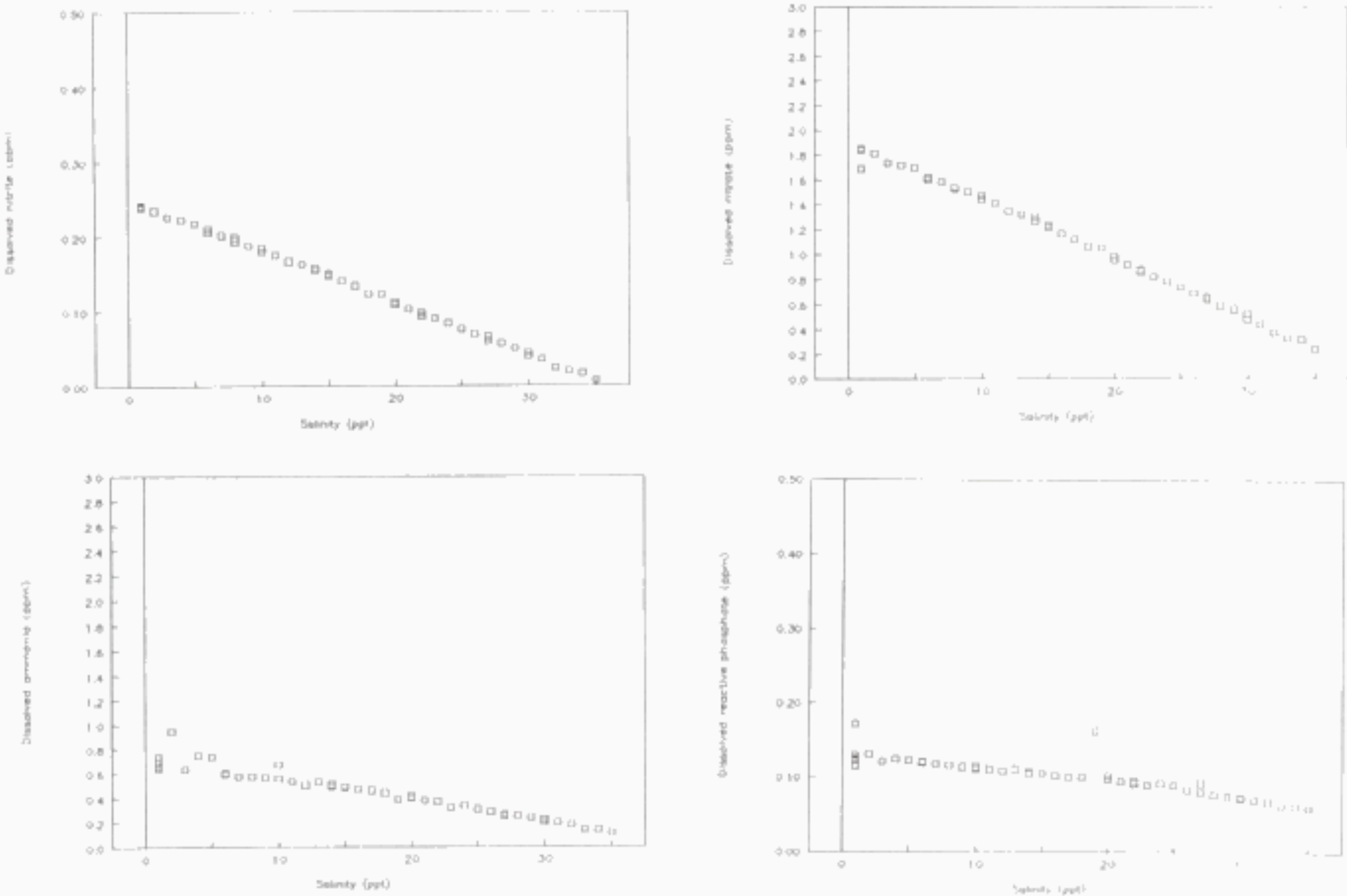


Figure 32 Dissolved nutrient dilution experiment results

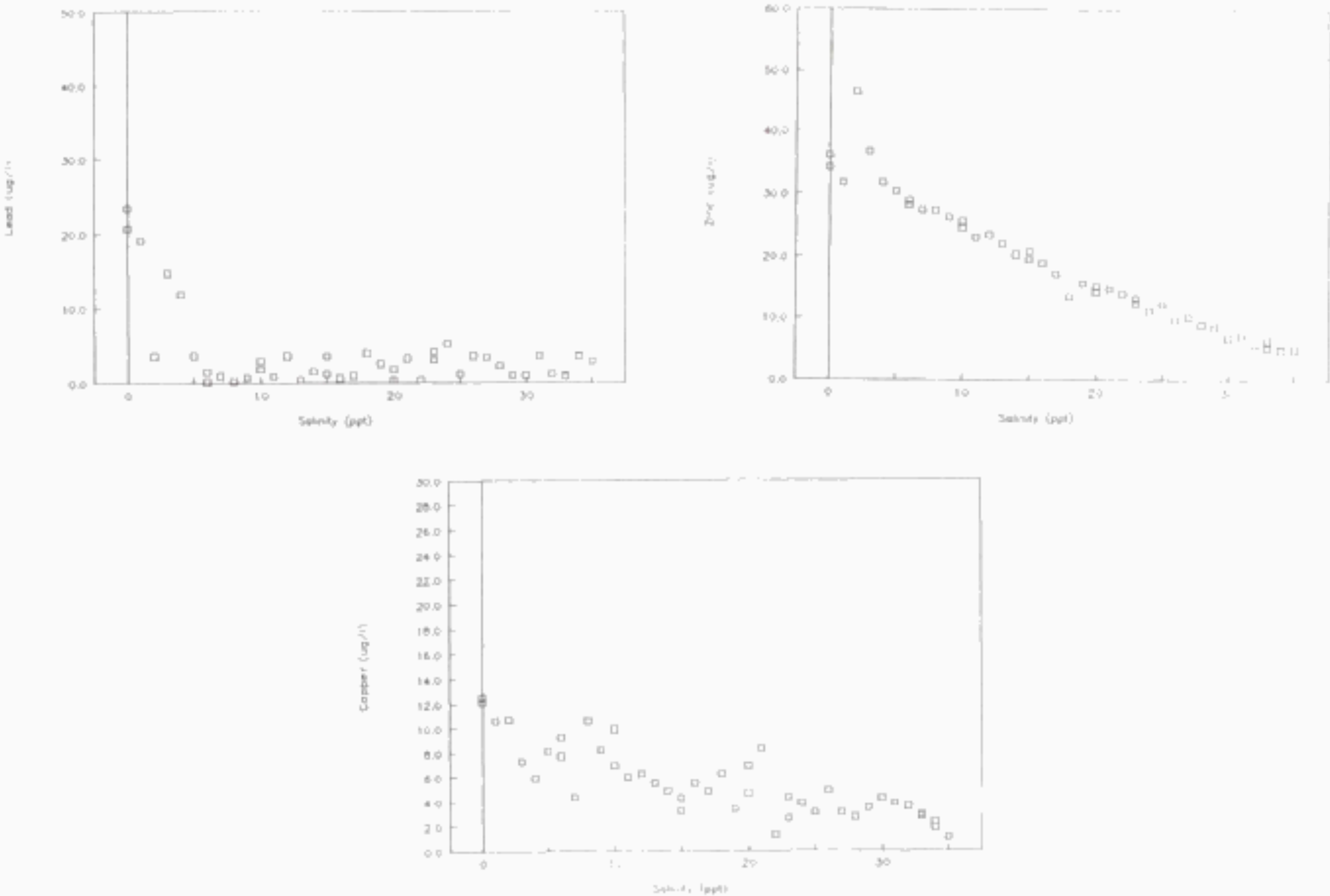


Figure 33 Trace metal dilution experiment results

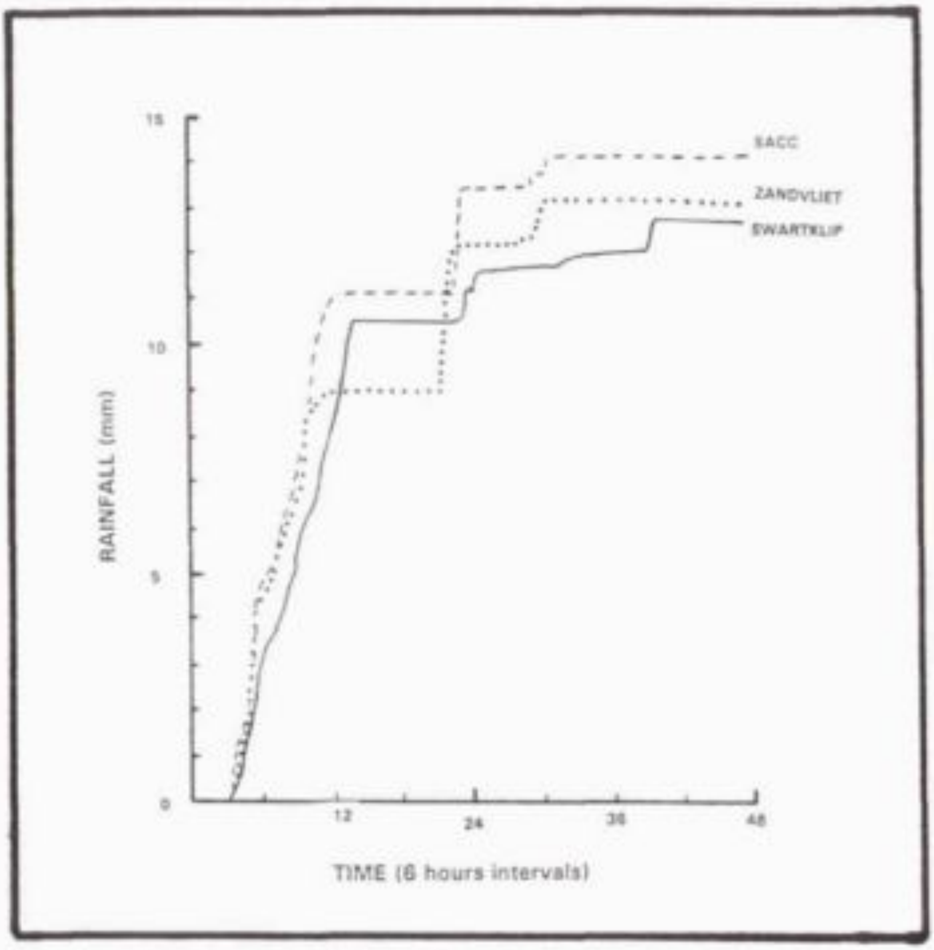


Figure 34 Variation in the rainfall pattern during a single storm as recorded at 3 sites around Khayelitsha urban catchment

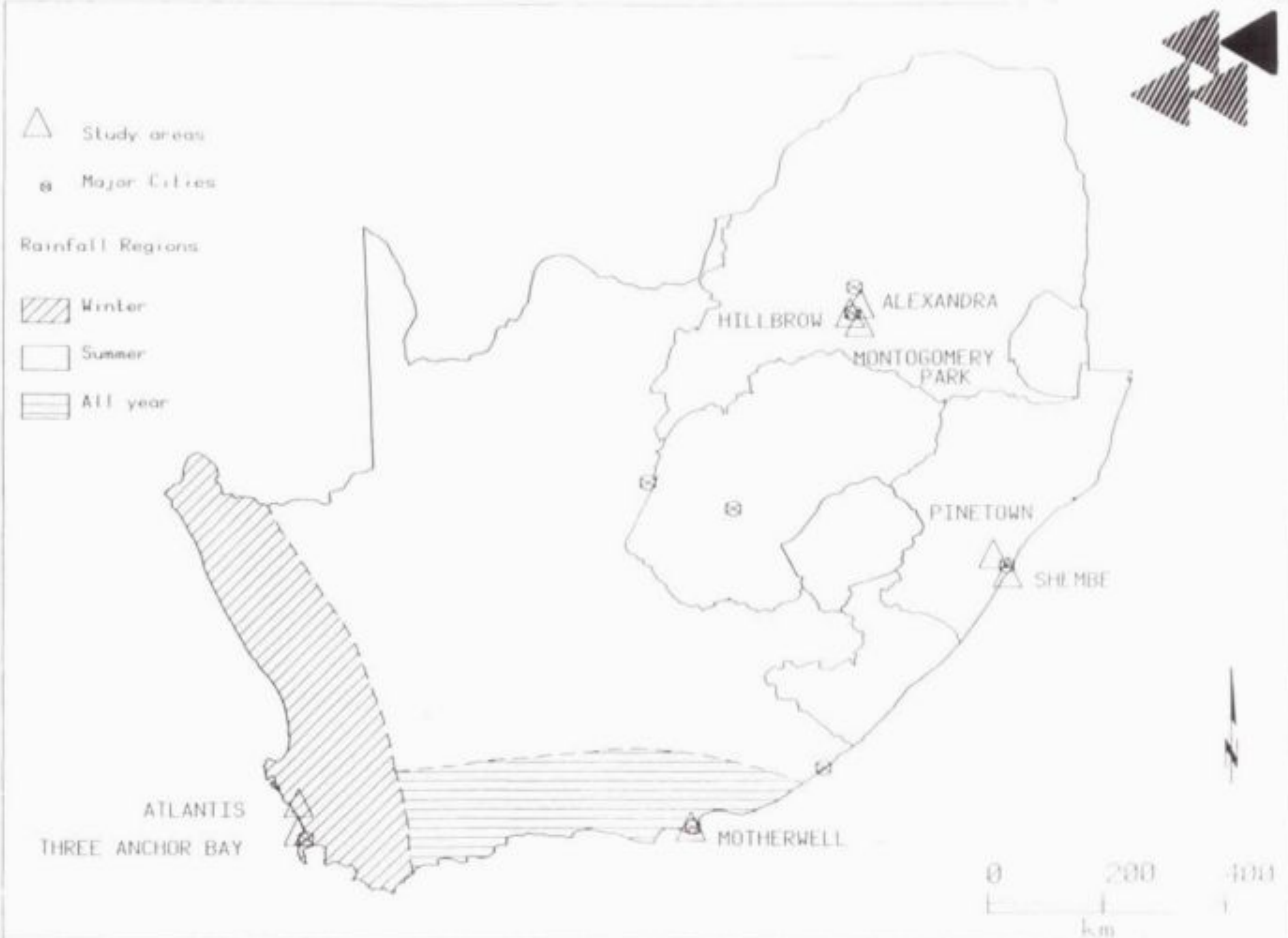


Figure 35 The location of other [illegible] African urban hydrological studies used for comparative purposes

APPENDIX A

RAINFALL DATA

a) DF Malan

b) SACC, Swartklip Explosives and
Zandvliet Sewage Works
[Data available from Watertek, CSIR, Stellenbosch]

1989

	J	F	M	A	M	J	J	A	S	O	N	D
1	-	0	62	-	-	99	0	123	6	5	-	-
2	-	3	-	-	-	28	115	-	13	0	-	0
3	-	-	-	-	2	-	0	-	293	-	-	-
4	0	-	-	-	-	10	147	-	77	37	-	0
5	1	-	-	-	-	-	-	-	40	7	-	-
6	-	-	-	-	-	2	-	-	4	-	-	-
7	-	-	-	-	-	-	-	-	-	9	-	-
8	-	-	-	-	-	-	-	16	-	210	-	-
9	-	-	-	0	5	-	0	17	-	-	-	-
10	-	1	-	-	137	-	80	18	-	-	-	-
11	-	-	0	-	53	-	21	10	-	-	-	-
12	-	1	122	-	22	-	-	103	-	-	-	-
13	-	15	153	14	-	-	-	19	-	-	-	-
14	-	-	18	0	-	-	-	48	-	49	-	-
15	-	-	0	-	-	-	45	207	12	0	0	-
16	-	-	-	-	-	-	153	5	-	-	-	-
17	-	-	-	-	147	-	100	-	157	-	295	-
18	-	-	-	-	13	-	48	-	23	-	-	-
19	-	0	-	154	-	0	-	17	68	-	-	13
20	14	-	-	165	8	-	-	9	188	16	-	9
21	-	-	-	302	5	56	-	0	-	1	-	1
22	-	-	-	24	-	15	-	3	0	37	-	-
23	-	3	-	-	-	2	-	-	2	-	-	7
24	-	64	-	-	-	-	43	18	0	-	-	-
25	-	0	-	-	-	155	286	7	-	-	-	-
26	-	-	-	-	-	25	80	243	-	89	-	0
27	-	-	-	-	-	3	-	1	-	17	-	-
28	-	112	-	-	-	38	-	100	27	-	-	-
29	-		134	-	-	112	-	27	-	-	-	-
30	0		88	-	6	17	88	0	-	-	0	-
31	32		0		498		-	-		-		-
TOT	47	199	577	659	896	562	1206	991	910	477	295	30

1990

	J	F	M	A	M	J	J	A	S	O	N	D
1	2	-	-	-	117	4	-	36	-	-	-	-
2	-	-	-	-	74	76	1	0	-	-	-	-
3	-	-	-	-	12	300	185	3	-	-	-	-
4	-	-	-	-	-	184	227	-	-	-	-	-
5	35	-	-	9	4	5	-	-	41	-	-	-
6	10	-	-	-	-	-	-	-	-	-	-	-
7	0	-	-	-	-	20	-	2	-	-	-	-
8	-	-	-	-	-	20	70	54	0	-	-	-
9	-	-	-	-	-	19	77	140	-	-	-	-
10	-	-	-	0	-	13	0	54	34	0	0	6
11	-	-	-	136	-	-	140	0	100	-	67	-
12	-	-	-	15	-	-	29	-	0	0	-	23
13	-	-	-	48	-	-	2	-	-	-	52	0
14	-	-	-	-	-	-	-	-	-	8	53	-
15	-	17	-	-	-	17	64	-	0	14	-	-
16	-	21	-	-	-	3	0	-	60	-	-	103
17	-	0	-	45	-	0	112	-	32	-	-	-
18	25	-	-	6	-	-	47	98	-	-	-	0
19	26	164	-	0	355	-	3	25	-	-	-	-
20	-	110	-	-	85	68	-	-	-	-	-	-
21	-	-	-	276	34	60	-	-	-	-	-	-
22	-	-	-	188	1	-	-	-	-	3	1	10
23	-	-	-	46	-	-	12	26	-	-	1	1
24	-	-	-	6	-	-	9	-	-	-	-	43
25	2	-	-	40	-	-	0	-	-	-	-	-
26	1	-	3	50	-	-	33	-	-	-	-	-
27	-	-	-	321	-	0	-	0	-	-	-	-
28	-	-	-	17	10	310	87	-	8	-	-	-
29	-		-	111	-	2	20	-	-	10	-	-
30	34		-	107	-	-	72	-	-	-	8	-
31	5		4		-		53	-		-		2
TOT	140	312	7	1421	692	1101	1243	438	275	35	182	188

1991

	J	F	M	A	M	J	J	A	S	O	N	D
1	-	-	-	-	-	-	-	26	-	0	-	
2	-	3	7	-	0	-	-	87	-	-	-	
3	-	-	31	0	-	-	55	1	-	-	-	
4	-	-	-	-	-	-	90	-	128	-	-	
5	-	-	-	174	-	116	425	-	0	-	-	
6	-	-	0	42	-	134	30	-	5	-	80	
7	40	-	-	-	-	2	10	-	156	-	1	2
8	-	-	-	-	-	-	-	-	64	-	-	
9	-	-	-	0	-	-	23	-	57	-	-	
10	-	-	2	0	-	-	155	-	-	9	-	
11	-	-	-	-	-	-	43	-	-	-	-	
12	-	0	-	-	-	5	-	-	4	-	-	
13	-	0	-	-	-	-	-	-	2	-	-	
14	-	-	-	-	-	-	-	0	-	19	-	
15	5	-	-	-	-	-	-	20	177	0	-	
16	-	16	-	-	-	-	-	8	1	-	-	
17	-	70	-	-	-	60	-	-	25	-	-	
18	-	-	-	-	0	94	-	-	65	301	1	43
19	-	-	-	-	108	2	-	-	0	-	18	30
20	-	-	65	0	15	-	-	7	-	-	4	
21	-	-	-	-	127	120	0	-	-	15	-	
22	-	-	-	-	215	134	15	-	-	4	-	
23	-	16	-	4	126	422	170	-	0	-	-	
24	-	4	-	-	145	247	2	18	-	-	-	
25	1	-	-	-	-	-	300	9	0	-	-	
26	0	-	-	-	0	-	84	0	5	-	-	
27	-	-	-	34	0	-	-	6	26	-	8	
28	-	0	-	-	0	-	-	120	2	-	-	
29	-		1	-	1	70	62	8	-	135	-	
30	-		-	-	162	108	19	1	8	-	-	
31	12		-		-		193	-		-		
TOT	58	109	106	254	254	899	1514	1676	311	725	483	75

APPENDIX B

KHAYELITHSA STORMWATER QUALITY DATA

a) Summer baseflow conditions

b) Winter baseflow condtions

c) Stormflow condtions

Khayelitsha Stormwater Quality

SAMPLING STATION : K 1 SAMPLING CONDITION : Wet period

DETERMINAND	Winter			Summer	
	10/07/90	06/06/91	05/07/91	22/10/91	19/11/91
F. coliforms (cfu/100mL)	1.2E+05	1.5E+06	9.0E+05		
F. Streptococci (cfu/100mL)	9.9E+03	5.8E+05	4.6E+05		
Coliphage (pfu/10mL)	2.0E+03	1.2E+04	9.0E+03		
K mg/L	19.9	11.3	5.9		
Na mg/L	198	15	8		
Ca mg/L	232.0	38.2	23.6		
Mg mg/L	49.2	3.8	1.6		
NH4-N mg/L	1.86	0.41	2.16		
SO4 mg/L	298	22	8		
Cl mg/L	291	19	9		
Alk (CaCO3) mg/L	412	112	79		
NOx-N mg/L	22.79	0.30	<0.05		
P mg/L	<0.05	0.75	0.57		
DOC mg/L	13.7	15.2	7.5		
EC mS/m	230	32	19		
pH (20°C)	6.7	7.9	8.3		
TDS (calc) mg/L	1472	202	122		
Hardness as CaCO3 mg/L	781	111	66		
Cd mg/L	<0.01				
Cu mg/L	<0.02				
Fe mg/L	0.36				
Pb mg/L	0.02				
Zn mg/L	0.02				

Khayelitsha Stormwater Quality

SAMPLING STATION : K1 SAMPLING CONDITION : Winter dry period

DETERMINAND	DATE			
	08/08/90	04/09/90	07/08/91	13/08/91
F. coliforms (cfu/100mL)	3.9E+03	2.5E+05		
F. Streptococci (cfu/100m	1.1E+03	4.0E+04		
Coliphage (pfu/10mL)	1.6E+02	1.0E+02		
K [illegible]L	11.9	12.8		
Na mg/L	170	72		
Ca mg/L	198.3	155.6		
Mg mg/L	75.3	36.6		
NH4-N mg/L	0.47	0.5		
SO4 mg/L	426	161		
Cl mg/L	234	87		
Alk (CaCO3) mg/L	449	440		
NOx-N mg/L	1.33	1.45		
P mg/L	<0.05	<0.05		
pH (20°C)	6.7	19.7		
DOC mg/L	12.8	129		
EC mS/m	215	6.8		
TDS (calc) mg/L	1376	826		
Hardness as CaCO3 mg/L	805	539		
Cd mg/L	<0.01	<0.01		
Cu mg/L	0.08	0.03		
Fe mg/L	0.36	1.99		
Pb mg/L	0.07	0.06		
Zn mg/L	0.01	0.17		

Khayelitsha Stormwater Quality

SAMPLING STATION : K2　　　SAMPLING CONDITION : Summer dry period

DETERMINAND	DATE			
	03/12/90	22/01/91	12/03/91	23/04/91
F. coliforms (cfu/100mL)	6.8E+05	3.2E+06	3.9E+08	5.1E+06
F. Streptococci (cfu/100mL)	1.2E+04	1.8E+04	2.9E+05	2.6E+04
Coliphage (pfu/10mL)	1.1E+04	2.6E+04	1.7E+04	3.2E+04
K mg/L	13.2	11.8	9.6	9.7
Na mg/L	237	243	181	190
Ca mg/L	190.6	146.3	114.8	155.1
Mg mg/L	51.1	40	29.4	37.8
NH4-N mg/L	0.73	7.42	10.07	0.91
SO4 mg/L	259	119	103	170
Cl mg/L	366	368	277	293
Alk (CaCO3) mg/L	382	374	314	358
NOx-N mg/L	1.92	15.92	8.52	12.47
P mg/L	0.07	0.95	0.89	0.12
pH (20°C)	6.8	6.9	7.1	6.9
DOC mg/L	13.5	15.3	11.5	12.6
EC mS/m	230	215	165	185
TDS (calc) mg/L	1472	1376	1056	1184
Hardness as CaCO3 mg/L	686	530	408	543
Cd mg/L	<0.01	<0.01	<0.01	<0.01
Cu mg/L	<0.02	0.02	<0.02	0.02
Fe mg/L	0.76	0.12	0.16	0.11
Pb mg/L	0.02	0.02	0.06	<0.05
Zn mg/L	<0.02	<0.02	0.02	0.03

Khayelitsha Stormwater Quality

SAMPLING STATION : K 2 SAMPLING CONDITION : Wet period

DETERMINAND	Winter			Summer	
	10/07/90	06/06/91	05/07/91	22/10/91	19/11/91
F. coliforms (cfu/100mL)	1.8E+04	1.6E+06	1.4E+07	1.5E+06	2.8E+06
F. Streptococci (cfu/100m	1.3E+03	2.2E+05	6.5E+05	2.0E+04	1.6E+05
Coliphage (pfu/10mL)	1.6E+02	1.6E+04	1.9E+04	2.4E+04	3.9E+04
K mg/L	11.1	9.8	9.0	19.1	12.1
Na mg/L	176	126	57	194	180
Ca mg/L	206.0	93.8	60.2	199.6	126.5
Mg mg/L	77.8	23.0	10.0	47.2	34.7
NH4-N mg/L	0.54	1.06	3.87	1.10	1.03
SO4 mg/L	433	121	53	282	178
Cl mg/L	243	193	83	283	273
Alk (CaCO3) mg/L	467	205	160	385	256
NOx-N mg/L	2.35	7.72	2.26	23.10	8.24
P mg/L	<0.05	0.32	0.45	0.11	0.23
DOC mg/L	16.0	15.4	11.7	15.3	23.8
EC mS/m	220	129	71	215	170
pH (20°C)	6.7	7.3	7.6	6.8	7.1
TDS (calc) mg/L	1408	826	454	1376	1088
Hardness as CaCO3 mg/L	835	329	192	693	459
Cd mg/L	<0.01				
Cu mg/L	0.02				
Fe mg/L	0.38				
Pb mg/L	0.05				
Zn mg/L	<0.02				

Khayelitsha Stormwater Quality

SAMPLING STATION : K2 SAMPLING CONDITION : Winter dry period

DETERMINAND	DATE			
	08/08/90	04/09/90	07/08/91	13/08/91
F. coliforms (cfu/100mL)	1.8E+05	7.4E+05	2.4E+05	2.5E+05
F. Streptococci (cfu/100mL)	3.7E+03	2.1E+04	9.3E+03	3.2E+03
Coliphage (pfu/10mL)	2.4E+03	2.4E+03	2.3E+04	3.7E+03
K mg/L	13.0	18.1	15.7	19.6
Na mg/L	286	201	249	192
Ca mg/L	201.8	254.8	196.3	228.3
Mg mg/L	52.3	55.9	47.2	48.4
NH4-N mg/L	0.50	1.45	1.63	1.49
SO4 mg/L	216	409	218	283
Cl mg/L	490	287	400	281
Alk (CaCO3) mg/L	382	415	393	402
NOx-N mg/L	29.50	16.92	26.10	28.20
P mg/L	<0.05	<0.05	0.13	0.07
pH (20°C)	6.8	6.6	6.8	6.7
DOC mg/L	9.7	14.1	19.7	17.8
EC mS/m	275	245	245	225
TDS (calc) mg/L	1760	1568	1568	1440
Hardness as CaCO3 mg/L	719	867	684	770
Cd mg/L	<0.01	<0.01		
Cu mg/L	0.02	<0.02		
Fe mg/L	0.23	0.39		
Pb mg/L	<0.03	0.04		
Zn mg/L	0.02	<0.02		

Khayelitsha Stormwater Quality

SAMPLING STATION : K3 SAMPLING CONDITION : Summer dry period

DETERMINAND	DATE			
	03:12:90	22:01:91	12:03:91	23:04:91
F. coliforms (cfu/100mL)	1.8E+12	4.2E+05	2.0E+04	6.7E+04
F. Streptococci (cfu/100mL)	4.1E+07	1.4E+04	3.0E+02	6.9E+02
Coliphage (pfu/10mL)	1.4E+05	5.3E+03	2.8E+01	2.2E+01
K mg/L	20.9	13.1	14.1	8.2
Na mg/L	118	139	163	105
Ca mg/L	88.6	119.2	134.8	85.6
Mg mg/L	32.8	49.2	56.6	25.8
NH4-N mg/L	42.55	5.21	2.53	0.16
SO4 mg/L	111	173	209	66
Cl mg/L	152	192	208	162
Alk (CaCO3) mg/L	424	386	390	253
NOx-N mg/L	8.55	7.97	9.56	7.33
P mg/L	6.15	0.22	0.06	0.1
pH (20°C)	7.1	7	6.9	7.3
DOC mg/L	66.8	12.5	10.3	13.4
EC mS/m	152	160	170	111
TDS (calc) mg/L	973	1024	1088	710
Hardness as CaCO3 mg/L	356	500	570	320
Cd mg/L	<0.01	<0.01	<0.01	<0.01
Cu mg/L	0.02	0.02	<0.02	<0.02
Fe mg/L	1.06	1.37	1.1	0.06
Pb mg/L	0.02	<0.02	0.05	<0.05
Zn mg/L	0.06	0.02	0.02	<0.02

Khayelitsha Stormwater Quality

SAMPLING STATION : K 3

SAMPLING CONDITION : Wet period

DETERMINAND	Winter			Summer	
	10\07\90	06\06\91	05\07\91	22\10\91	19\11\91
F. coliforms (cfu/100mL)	2.7E+05	4.5E+05	1.0E+07	2.0E+04	1.3E+05
F. Streptococci (cfu/100mL)	3.9E+03	2.0E+05	1.3E+06	4.3E+02	2.1E+04
Coliphage (pfu/10mL)	5.4E+02	2.1E+04	2.6E+04	5.1E+03	8.4E+02
K mg/L	15.4	21.6	16.1	19.4	15.6
Na mg/L	134	142	60	174	166
Ca mg/L	122.0	109.4	62.9	130.9	122.1
Mg mg/L	47.5	40.3	13.0	53.1	53.1
NH4-N mg/L	2.38	4.06	6.32	2.92	1.51
SO4 mg/L	195	139	49	170	183
Cl mg/L	164	201	76	233	238
Alk (CaCO3) mg/L	372	349	230	423	368
NOx-N mg/L	13.57	10.43	0.93	13.18	7.14
P mg/L	0.10	0.81	0.99	0.22	0.13
DOC mg/L	14.2	22.6	16.7	16.6	31.1
EC mS/m	158	155	75	180	172
pH (20°C)	7.0	7	7.4	6.9	7.0
TDS (calc) mg/L	1011	992	480	1152	1101
Hardness as CaCO3 mg/L	501	439	210	546	523
Cd mg/L	<0.01				
Cu mg/L	<0.02				
Fe mg/L	0.41				
Pb mg/L	0.02				
Zn mg/L	<0.02				

Khayelitsha Stormwater Quality

SAMPLING STATION : K3 SAMPLING CONDITION : Winter dry period

DETERMINAND	DATE			
	08/08/90	04/09/90	07/08/91	13/08/91
F. coliforms (cfu/100mL)	5.8E+04	2.9E+05	4.0E+04	3.1E+07
F. Streptococci (cfu/100mL)	1.8E+04	1.0E+04	8.5E+03	3.5E+05
Coliphage (pfu/10mL)	6.3E+03	3.9E+03	6.4E+02	7.3E+04
K mg/L	15.7	15.1	20.2	19.4
Na mg/L	140	147	181	158
Ca mg/L	125.4	125.1	141.8	117.8
Mg mg/L	495.0	51.7	53.0	45.2
NH4-N mg/L	4.21	3.10	3.74	13.18
SO4 mg/L	194	185	190	157
Cl mg/L	185	176	241	199
Alk (CaCO3) mg/L	376	386	414	402
NOx-N mg/L	12.72	10.37	18.70	11.27
P mg/L	0.28	0.06	0.30	1.20
pH (20°C)	7.0	6.9	6.9	7.0
DOC mg/L	12.9	13.7	18.6	29.8
EC mS/m	160	165	195	165
TDS (calc) mg/L	1024	1056	1248	1056
Hardness as CaCO3 mg/L	517	525	572	480
Cd mg/L	<0.01	<0.01		
Cu mg/L	0.02	<0.02		
Fe mg/L	0.58	0.61		
Pb mg/L	<0.03	0.03		
Zn mg/L	0.03	<0.02		

Khayelitsha Stormwater Quality

SAMPLING STATION : K4 SAMPLING CONDITION : Summer dry period

DETERMINAND	DATE			
	03/12/90	22/01/91	12/03/91	23/04/91
F. coliforms (cfu/100mL)	1.8E+12	4.2E+05	2.0E+04	6.7E+04
F. Streptococci (cfu/100mL)	4.1E+07	1.4E+04	3.0E+02	6.9E+02
Coliphage (pfu/10mL)	1.4E+05	5.3E+03	2.8E+01	2.2E+01
K mg/L	1.2	14.1	3.9	8.2
Na mg/L	9	232	53	105
Ca mg/L	25	127.7	50.4	85.6
Mg mg/L	2.4	58.6	13.6	25.8
NH4-N mg/L	0.86	0.15	0.13	0.16
SO4 mg/L	25	96	41	66
Cl mg/L	16	333	82	162
Alk (CaCO3) mg/L	50	418	133	253
NOx-N mg/L	0.3	19.45	3.73	7.33
P mg/L	0.11	<0.05	<0.05	0.1
pH (20°C)	8.5	6.9	7.8	7.3
DOC mg/L	5.6	17.7	5.9	13.4
EC mS/m	21	205	60	111
TDS (calc) mg/L	973	1312	384	710
Hardness as CaCO3 mg/L	356	560	182	320
Cd mg/L	<0.01	<0.01	<0.01	<0.01
Cu mg/L	0.02	0.02	<0.02	<0.02
Fe mg/L	1.06	0.05	0.05	0.06
Pb mg/L	0.02	0.02	0.04	<0.05
Zn mg/L	0.06	0.06	<0.02	<0.02

Khayelitsha Stormwater Quality

SAMPLING STATION : K 4　　　　SAMPLING CONDITION : Wet period

DETERMINAND	Winter			Summer	
	10\07\90	06\06\91	05\07\91	22\10\91	19\11\91
F. coliforms (cfu/100mL)		3.4E+04	3.6E+04	6.6E+06	7.5E+06
F. Streptococci (cfu/100mL)		3.4E+04	[illegible]	2.5E+04	2.8E+05
Coliphage (pfu/10mL)		3.8E+02	3.4E+02	7.2E+02	5.8E+03
K mg/L		4.9	1.5	12.7	15.1
Na mg/L		61	8	130	137
Ca mg/L		56.6	19.4	11.2	145.0
Mg mg/L		15.2	2.2	33.5	38.1
NH4-N mg/L		0.08	0.13	0.32	1.72
SO4 mg/L		38	4	88	91
Cl mg/L		93	12	165	176
Alk (CaCO3) mg/L		162	53	406	475
NOx-N mg/L		4.44	0.38	0.32	0.07
P mg/L		0.05	<0.05	0.18	1.03
DOC mg/L		9.2	6.6	22.2	75.7
EC mS/m		73	16	134	152
pH (20°C)		7.6	8.5	7.0	6.8
TDS (calc) mg/L		467	99	858	973
Hardness as CaCO3 mg/L		204	58	413	519
Cd mg/L					
Cu mg/L					
Fe mg/L					
Pb mg/L					
Zn mg/L					

Khayelitsha Stormwater Quality

SAMPLING STATION : K4 SAMPLING CONDITION : Winter dry period

DETERMINAND	DATE			
	08/08/90	04/09/90	07/08/91	13/08/91
F. coliforms (cfu/100mL)		1.3E+02	2.4E+04	6.6E+05
F. Streptococci (cfu/100mL)		8.0E+00	8.2E+02	6.0E+02
Coliphage (pfu/10mL)		0	3.8E+01	7.7E+03
K mg/L		17.3	12.6	17.4
Na mg/L		223	178	271
Ca mg/L		175.8	142.5	168
Mg mg/L		59.3	42.9	53.0
NH4-N mg/L		0.15	0.44	0.59
SO4 mg/L		99	99	130
Cl mg/L		315	283	381
Alk (CaCO3) mg/L		524	414	467
NOx-N mg/L		26.85	12.68	18.80
P mg/L		<0.05	0.07	0.07
pH (20°C)		6.7	6.9	6.7
DOC mg/L		19.2	23.0	20.2
EC mS/m		225	185	235
TDS (calc) mg/L		1440	1184	1504
Hardness as CaCO3 mg/L		683	532	638
CaCO3 mg/L				
Cd mg/L		<0.01		
Cu mg/L		<0.02		
Fe mg/L		0.13		
Pb mg/L		0.03		
Zn mg/L		<0.02		

Khayelitsha Stormwater Quality

SAMPLING STATION : K5 SAMPLING CONDITION : Summer dry period

DETERMINAND	DATE			
	03/12/90	22/01/91	12/03/91	23/04/91
F. coliforms (cfu/100mL)	1.4E+03	2.4E+04	4.8E+03	3.7E+04
F. Streptococci (cfu/100mL)	1.0E+03	1.4E+04	5.1E+02	4.1E+03
Coliphage (pfu/100mL)	6.0E+01	1.8E+01	1.2E+01	0
K mg/L	11.5	8.9	8.6	9.8
Na mg/L	139	108	113	136
Ca mg/L	123.3	95.4	99.7	113.5
Mg mg/L	33.8	25.9	25.7	30.6
NH4-N mg/L	0.49	0.24	0.32	0.32
SO4 mg/L	85	64	71	82
Cl mg/L	188	157	161	205
Alk (CaCO3) mg/L	386	296	289	352
NOx-N mg/L	2.67	2.03	1.92	1.4
P mg/L	<0.05	<0.05	<0.05	<0.05
pH (20°C)	6.9	7.2	7.2	7
DOC mg/L	16	12.5	10.5	14.8
EC mS/m	146	115	117	139
TDS (calc) mg/L	934	736	749	890
Hardness as CaCO3 mg/L	447	345	355	409
Cd mg/L	<0.01	<0.01	<0.01	<0.01
Cu mg/L	<0.02	<0.02	<0.02	<0.02
Fe mg/L	1.45	1.36	1.44	2.17
Pb mg/L	<0.02	<0.02	0.04	<0.05
Zn mg/L	<0.02	<0.02	<0.02	<0.02

Khayelitsha Stormwater Quality

SAMPLING STATION : K 5 SAMPLING CONDITION : Wet period

DETERMINAND	Winter			Summer	
	10\07\90	06\06\91	05\07\91	22\10\91	19\11\91
F. coliforms (cfu/100mL)	2.2E+04	5.1E+03		1.9E+03	1.1E+05
F. Streptococci (cfu/100mL)	6.1E+04	4.8E+03		2.7E+02	3.4E+03
Coliphage (pfu/10mL)	7.0E+00	1.8E+01		6.0E+00	4.4E+01
K mg/L	13.3	10.1		3.2	9.5
Na mg/L	131	116		33	110
Ca mg/L	136.0	108.1		41.1	108.7
Mg mg/L	35.3	28.3		8.2	28.1
NH4-N mg/L	1.09	0.41		0.11	0.51
SO4 mg/L	93	77		28	65
Cl mg/L	191	171		48	158
Alk (CaCO3) mg/L	436	336		119	347
NOx-N mg/L	4.05	0.88		0.46	1.38
P mg/L	<0.01	<0.05		<0.05	0.01
DOC mg/L	17.5	15.2		5.1	18.9
EC mS/m	154	126		43	124
pH (20°C)	6.9	7.1		7.9	7.0
TDS (calc) mg/L	986	806		275	794
Hardness as CaCO3 mg/L	484	386		136	387
Cd mg/L	<0.01				
Cu mg/L	<0.02				
Fe mg/L	1.74				
Pb mg/L	0.03				
Zn mg/L	<0.02				

Khayelitsha Stormwater Quality

SAMPLING STATION : K5 SAMPLING CONDITION : Winter dry period

DETERMINAND	DATE			
	08/08/90	04/09/90	07/08/91	13/08/91
F. coliforms (cfu/100mL)	1.5E+03	1.6E+04	5.6E+02	8.0E+01
F. Streptococci (cfu/100mL)	9.2E+02	5.7E+03	8.9E+01	1.9E+01
Coliphage (pfu/10mL)	4.0E+00	1.8E+01	0	0
K mg/L	14.0	13.2	12.6	11.0
Na mg/L	137	153	178	108
Ca mg/L	143.2	146.7	142.5	118.1
Mg mg/L	35.6	38.3	42.9	28.7
NH4-N mg/L	1.06	0.72	0.44	1.14
SO4 mg/L	94	92	99	56
Cl mg/L	210	207	283	145
Alk (CaCO3) mg/L	437	449	414	388
NOx-N mg/L	3.23	3.28	12.68	2.50
P mg/L	<0.05	<0.05	0.07	<0.05
pH (20°C)	6.8	6.8	6.9	7.0
DOC mg/L	16.1	16.0	23.0	15.8
EC mS/m	160	165	185	125
TDS (calc) mg/L	1024	1056	1184	800
Hardness as CaCO3 mg/L	504	524	532	413
Cd mg/L	<0.01	<0.01		
Cu mg/L	0.05	<0.02		
Fe mg/L	2.19	2.02		
Pb mg/L	<0.03	0.02		
Zn mg/L	0.01	<0.02		

Khayelitsha Stormwater Quality

SAMPLING STATION : K 6 SAMPLING CONDITION : Wet period

DETERMINAND	Winter			Summer	
	10/07/90	06/06/91	05/07/91	22/10/91	19/11/91
F. coliforms (cfu/100mL)	7.1E+01	1.4E+04	5.3E+03	2.4E+04	2.1E+04
F. Streptococci (cfu/100mL)	5.0E+01	3.0E+04	1.7E+04	5.5E+03	1.9E+02
Coliphage (pfu/10mL)	0	4.0E+01	1.3E+02	1.3E+01	0
K mg/L	1.0	1.9	0.6	2.0	1.2
Na mg/L	5	8	1	6	8
Ca mg/L	21.0	26.3	14.2	22.7	24.6
Mg mg/L	1.1	1.9	0.6	1.7	2.3
NH4-N mg/L	0.05	0.10	<0.05	<0.05	0.07
SO4 mg/L	11	6	3	10	20
Cl mg/L	8	11	2	7	17
Alk (CaCO3) mg/L	48	72	35	63	49
NOx-N mg/L	<0.05	0.24	<0.05	0.16	0.00
P mg/L	<0.05	<0.05	<0.05	<0.05	0.01
DOC mg/L	2.4	4.2	1.3	5.2	3.2
EC mS/m	15	19	8	17	20
pH (20°C)	8.5	8.3	8.8	8.4	8.5
TDS (calc) mg/L	96	118	49	106	128
Hardness as CaCO3 mg/L	57	74	38	64	71
Cd mg/L	<0.01				
Cu mg/L	<0.02				
Fe mg/L	<0.02				
Pb mg/L	0.02				
Zn mg/L	<0.02				

Khayelitsha Stormwater Quality

SAMPLING STATION : K6 SAMPLING CONDITION : Winter dry period

DETERMINAND	DATE			
	08/08/90	04/09/90	07/08/91	13/08/91
F. coliforms (cfu/100mL)			1.7E+03	2.9E+03
F. Streptococci (cfu/100mL)			8.0E+00	2.2E+03
Coliphage (pfu/10mL)			6.0E+00	1.0E+00
K mg/L			1.1	2.6
Na mg/L			8	13
Ca mg/L			24.4	30
Mg mg/L			1.8	2.7
NH4-N mg/L			0.09	0.06
SO4 mg/L			15	19
Cl mg/L			12	22
Alk (CaCO3) mg/L			55	71
NOx-N mg/L			0.10	0.26
P mg/L			<0.05	0.10
pH (20°C)			8.4	8.2
DOC mg/L			2.8	7.0
EC mS/m			19	24
TDS (calc) mg/L			118	154
Hardness as CaCO3 mg/L			68	86
Cd mg/L				
Cu mg/L				
Fe mg/L				
Pb mg/L				
Zn mg/L				

Khayelitsha Stormwater Quality

SAMPLING STATION : K6 SAMPLING CONDITION : Summer dry period

DETERMINAND	DATE			
	03/12/90	22/01/91	12/03/91	23/04/91
F. coliforms (cfu/100mL)				1.4E+04
F. Streptococci (cfu/100mL)				7.6E+03
Coliphage (pfu/10mL)				2.4E+01
K mg/L				3.9
Na mg/L				14
Ca mg/L				34.1
Mg mg/L				3.5
NH4-N mg/L				<0.05
SO4 mg/L				28
Cl mg/L				24
Alk (CaCO3) mg/L				72
NOx-N mg/L				0.3
P mg/L				<0.05
pH (20°C)				8.2
DOC mg/L				7.7
EC mS/m				28
TDS (calc) mg/L				179
Hardness as CaCO3 mg/L				100
Cd mg/L				<0.01
Cu mg/L				<0.02
Fe mg/L				0.2
Pb mg/L				<0.05
Zn mg/L				<0.02

Khayelitsha Stormwater Quality

SAMPLING STATION : K 7   SAMPLING CONDITION : Wet period

DETERMINAND	Winter			Summer	
	10\07\90	06/06/91	05\07\91	22\10\91	19\11\91
F. coliforms (cfu/100mL)	3.4E+04	4.9E+06	7.4E+05		1.8E+06
F. Streptococci (cfu/100)	6.1E+03	2.9E+05	5.7E+05		4.8E+04
Coliphage (pfu/10mL)	2.0E+03	2.2E+04	5.2E+03		9.0E+04
K mg/L	10.4	10.1	3.7		8.9
Na mg/L	194	142	41		169
Ca mg/L	129.0	79.0	34.9		107.3
Mg mg/L	43.7	27.0	8.4		36.1
NH4-N mg/L	0.36	<0.05	0.96		0.75
SO4 mg/L	165	104	29		127
Cl mg/L	278	206	57		235
Alk (CaCO3) mg/L	351	244	108		308
NOx-N mg/L	9.93	3.35	1.55		6.50
P mg/L	<0.05	0.50	0.19		0.12
DOC mg/L	12.2	14.5	5.6		19.9
EC mS/m	185	130	46		156
pH (20°C)	7.0	7.3	8		7.1
TDS (calc) mg/L	1184	832	291		998
Hardness as CaCO3 mg/L	501	309	122		417
Cd mg/L	<0.01				
Cu mg/L	<0.02				
Fe mg/L	0.64				
Pb mg/L	0.06				
Zn mg/L	0.05				

Khayelitsha Stormwater Quality

SAMPLING STATION : K7 SAMPLING CONDITION : Winter dry period

DETERMINAND	DATE			
	08/08/90	04/09/90	07/08/91	13/08/91
F. coliforms (cfu/100mL)	4.3E+04	5.0E+04	4.9E+04	3.8E+04
F. Streptococci (cfu/100mL)	5.1E+03	5.7E+03	7.6E+03	1.4E+04
Coliphage (pfu/10mL)	1.8E+03	3.5E+02	1.5E+03	5.3E+03
K mg/L	10.1	8.3	9.8	9.9
Na mg/L	197	208	178	181
Ca mg/L	127.3	128.6	120.3	120.6
Mg mg/L	43.1	45.6	37.9	39.4
NH4-N mg/L	0.39	0.13	0.53	0.71
SO4 mg/L	179	171	140	129
Cl mg/L	291	291	250	256
Alk (CaCO3) mg/L	343	353	335	334
NOx-N mg/L	9.23	8.08	9.33	9.98
P mg/L	0.09	<0.05	0.10	0.14
pH (20°C)	7.0	7.0	7.0	7.0
DOC mg/L	10.8	10.3	13.8	14.8
EC mS/m	190	190	170	165
TDS (calc) mg/L	1216	1216	1088	1056
Hardness as CaCO3 mg/L	495	509	456	464
Cd mg/L	<0.01	<0.01		
Cu mg/L	0.01	<0.02		
Fe mg/L	0.48	0.35		
Pb mg/L	<0.03	0.03		
Zn mg/L	0.01	<0.02		

Khayelitsha . ormwater Quality

SAMPLING STATION : K7   SAMPLING CONDITION : Summer dry period

DETERMINAND	DATE			
	03\12\90	22\01\91	12\03\91	23\04\91
F. coliforms (cfu/100mL)	1.9E+07	2.4E+04	6.5E+04	6.4E+04
F. Streptococci (cfu/100mL)	4.4E+05	2.0E+03	2.9E+03	8.3E+03
Coliphage (pfu/10mL)	9.2E+04	4.6E+02	1.9E+02	3.2E+02
K mg/L	10.1	8.1	8	7.6
Na mg/L	188	192	189	181
Ca mg/L	106.7	105.2	113.5	106.7
Mg mg/L	38.4	39.[illegible]	40.4	37.8
NH4-N mg/L	7.9	0.1	0.11	<0.05
SO4 mg/L	131	129	138	131
Cl mg/L	253	271	253	260
Alk (CaCO3) mg/L	354	318	327	318
NOx-N mg/L	2.48	3.89	4.25	4.09
P mg/L	1.14	0.08	<0.05	<0.05
pH (20°C)	7.1	7.1	7.1	7.1
DOC mg/L	15.5	10.8	9.3	11.1
EC mS/m	170	165	160	160
TDS (calc) mg/L	1088	1056	1024	1024
Hardness as CaCO3 mg/L	425	424	450	422
Cd mg/L	<0.01	<0.01	<0.01	<0.01
Cu mg/L	<0.02	<0.02	<0.02	<0.02
Fe mg/L	0.35	0.42	0.51	0.35
Pb mg/L	<0.02	<0.02	0.05	<0.05
Zn mg/L	<0.02	<0.02	0.02	<0.02

Khayelitsha Stormwater Quality

SAMPLING STATION : K 8 SAMPLING CONDITION : Wet period

DETERMINAND	Winter			Summer	
	10\07\90	06\06\91	05\07\91	22\10\91	19\11\91
F. coliforms (cfu/100mL)	3.0E+04	1.6E+06	2.0E+05		3.4E+03
F. Streptococci (cfu/100mL)	1.4E+04	1.1E+05	2.4E+04		2.4E+01
Coliphage (pfu/10mL)	3.7E+02	1.7E+04	2.6E+04		3.2E+01
K mg\L	8.4	6.5	9.5		8.7
Na mg/L	144	98	131		185
Ca mg/L	92.0	59.8	89.2		72.7
Mg mg/L	31.2	19.7	27.9		38.4
NH4-N mg/L	0.50	2.43	3.65		0.11
SO4 mg/L	114	72	93		139
Cl mg/L	194	139	190		266
Alk (CaCO3) mg/L	267	187	267		243
NOx-N mg/L	7.14	1.92	4.96		4.32
P mg/L	0.06	0.36	0.44		0.01
DOC mg/L	10.9	11.2	13.7		12.4
EC mS/m	138	96	130		152
pH (20°C)	7.2	7.6	7.2		7.4
TDS (calc) mg/L	883	614	832		973
Hardness as CaCO3 mg/L	358	231	337		339
Cd mg/L	<0.01				
Cu mg/L	<0.02				
Fe mg/L	0.23				
Pb mg/L	0.02				
Zn mg/L	<0.02				

Khayelitsha Stormwater Quality

SAMPLING STATION : K8 SAMPLING CONDITION : Winter dry period

DETERMINAND	DATE			
	08/08/90	04/09/90	07/08/91	13/08/91
F. coliforms (cfu/100mL)	1.2E+04	6.6E+02	2.0E+05	2.4E+04
F. Streptococci (cfu/100mL)	6.3E+02	1.7E+02	2.0E+03	3.5E+02
Coliphage (pfu/10mL)	1.2E+03	4.2E+02	4.1E+03	1.8E+03
K mg/L	10.2	9.0	10.7	9.8
Na mg/L	202	218	180	186
Ca mg/L	127	111.9	119.2	121.2
Mg mg/L	44.7	46.1	38.0	40.6
NH4-N mg/L	0.19	0.08	1.07	0.68
SO4 mg/L	181	177	141	127
Cl mg/L	290	310	257	267
Alk (CaCO3) mg/L	343	312	340	343
NOx-N mg/L	9.05	6.55	9.31	9.72
P mg/L	<0.05	<0.05	0.15	0.09
pH (20°C)	7.0	7.1	7.0	7.0
DOC mg/L	9.2	9.6	14.3	14.9
EC mS/m	190	185	170	170
TDS (calc) mg/L	1216	1184	1088	1088
Hardness as CaCO3 mg/L	501	469	454	470
Cd mg/L	<0.01	<0.01		
Cu mg/L	0.01	<0.02		
Fe mg/L	0.25	0.22		
Pb mg/L	<0.03	0.03		
Zn mg/L	0.01	<0.02		

Khayelitsha Stormwater Quality

SAMPLING STATION : K8 SAMPLING CONDITION : Summer dry period

DETERMINAND	DATE			
	03/12/90	22/01/91	12/03/91	23/04/91
F. coliforms (cfu/100mL)	6.8E+02	1.2E+03	8.5E+03	4.9E+03
F. Streptococci (cfu/100mL)	2.0E+01	2.8E+02	2.7E+02	2.5E+02
Coliphage (pfu/10mL)	1.5E+04	3.3E+02	9.8E+02	2.4E+01
K mg/L	9.6	8.3	8.2	8.1
Na mg/L	187	194	212	206
Ca mg/L	95.8	96	97.8	83.2
Mg mg/L	37.3	39.4	42.2	39.6
NH4-N mg/L	3.06	0.38	0.24	0.1
SO4 mg/L	131	132	143	134
Cl mg/L	256	282	295	283
Alk (CaCO3) mg/L	302	306	302	272
NOx-N mg/L	3.69	2.51	2.87	1.98
P mg/L	0.99	0.13	<0.05	<0.05
pH (20°C)	7.2	7.2	7.2	7.3
DOC mg/L	15.6	11.5	8.8	10.1
EC mS/m	160	165	170	160
TDS (calc) mg/L	1024	1056	1088	1024
Hardness as CaCO3 mg/L	393	402	418	371
Cd mg/L	<0.01	<0.01	<0.01	<0.01
Cu mg/L	<0.02	<0.02	<0.02	<0.02
Fe mg/L	0.26	0.26	0.49	0.17
Pb mg/L	<0.02	<0.02	0.04	<0.05
Zn mg/L	<0.02	<0.02	<0.02	<0.02

APPENDIX C

CONTINUOUS SALINITY (EC) MONITORING DATA

[Full data set available from Watertek, CSIR, Stellenbosch]

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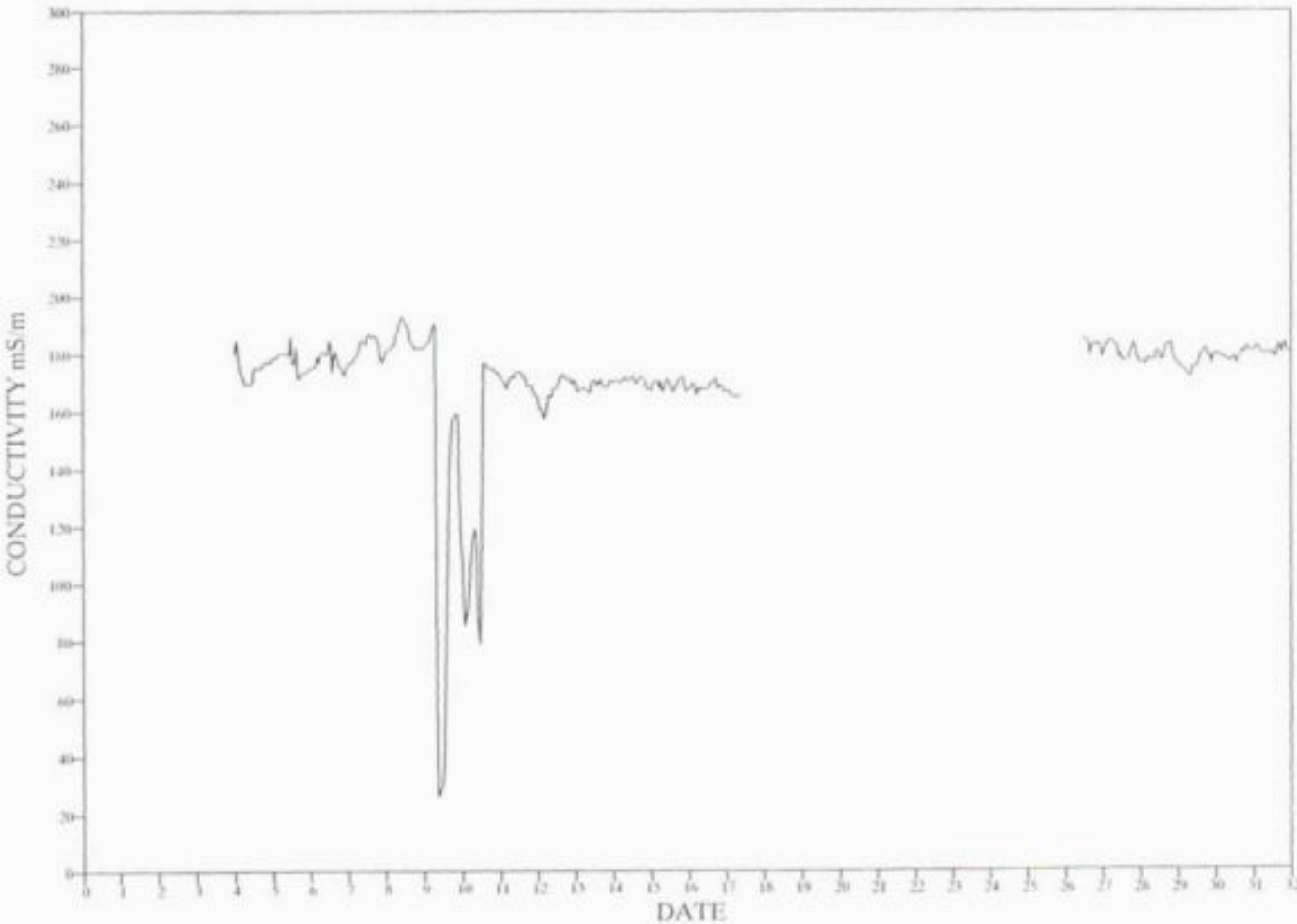

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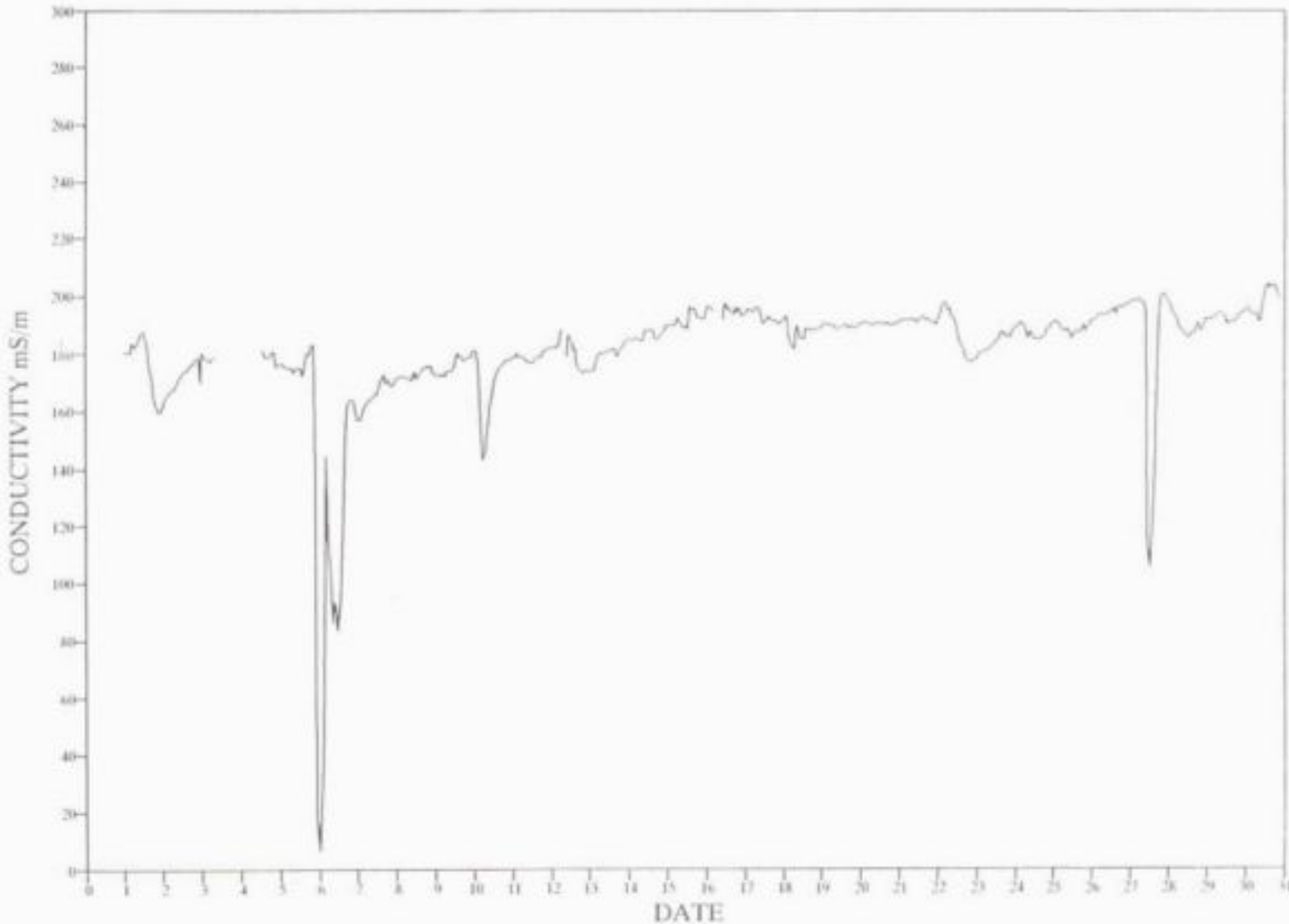

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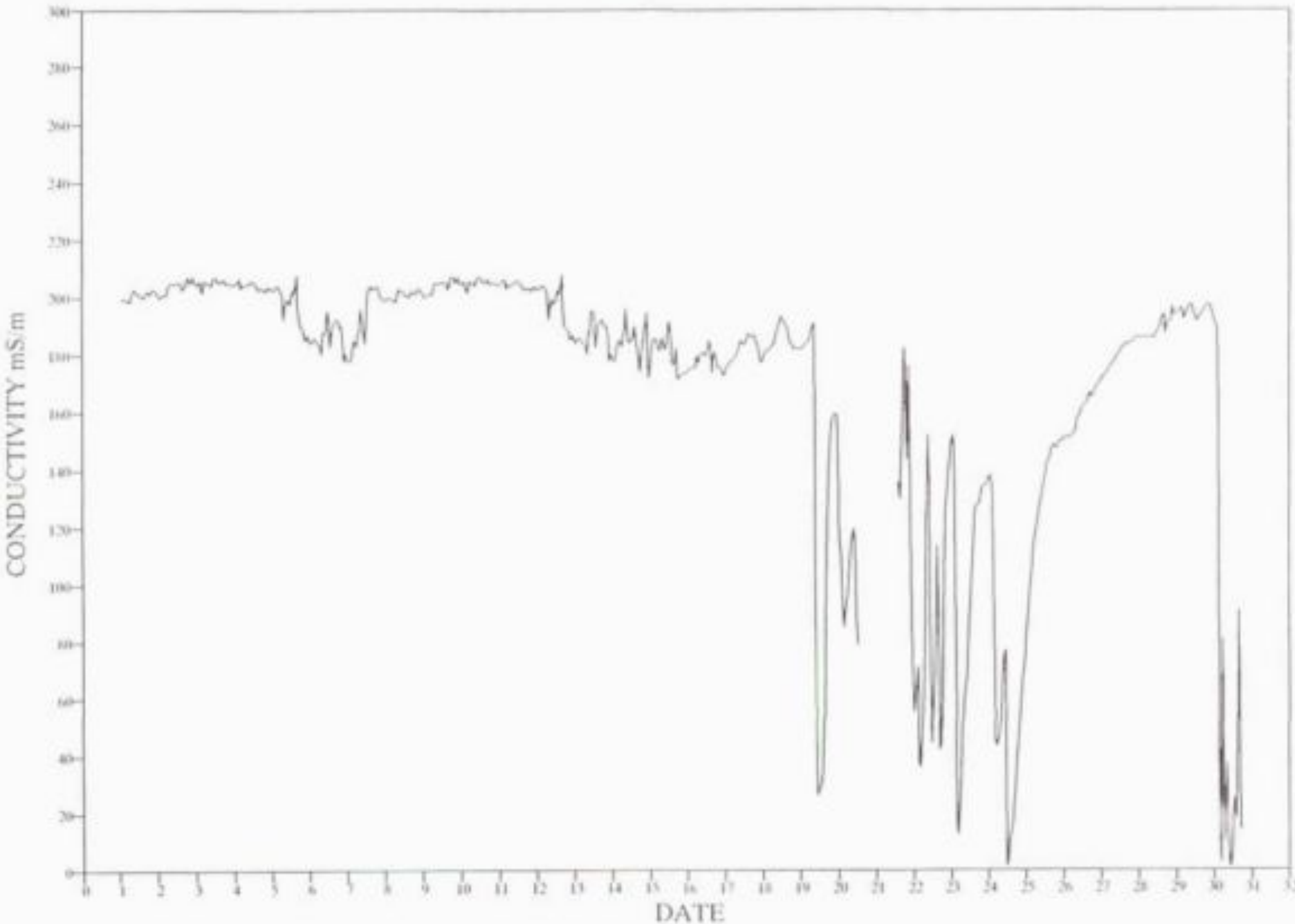

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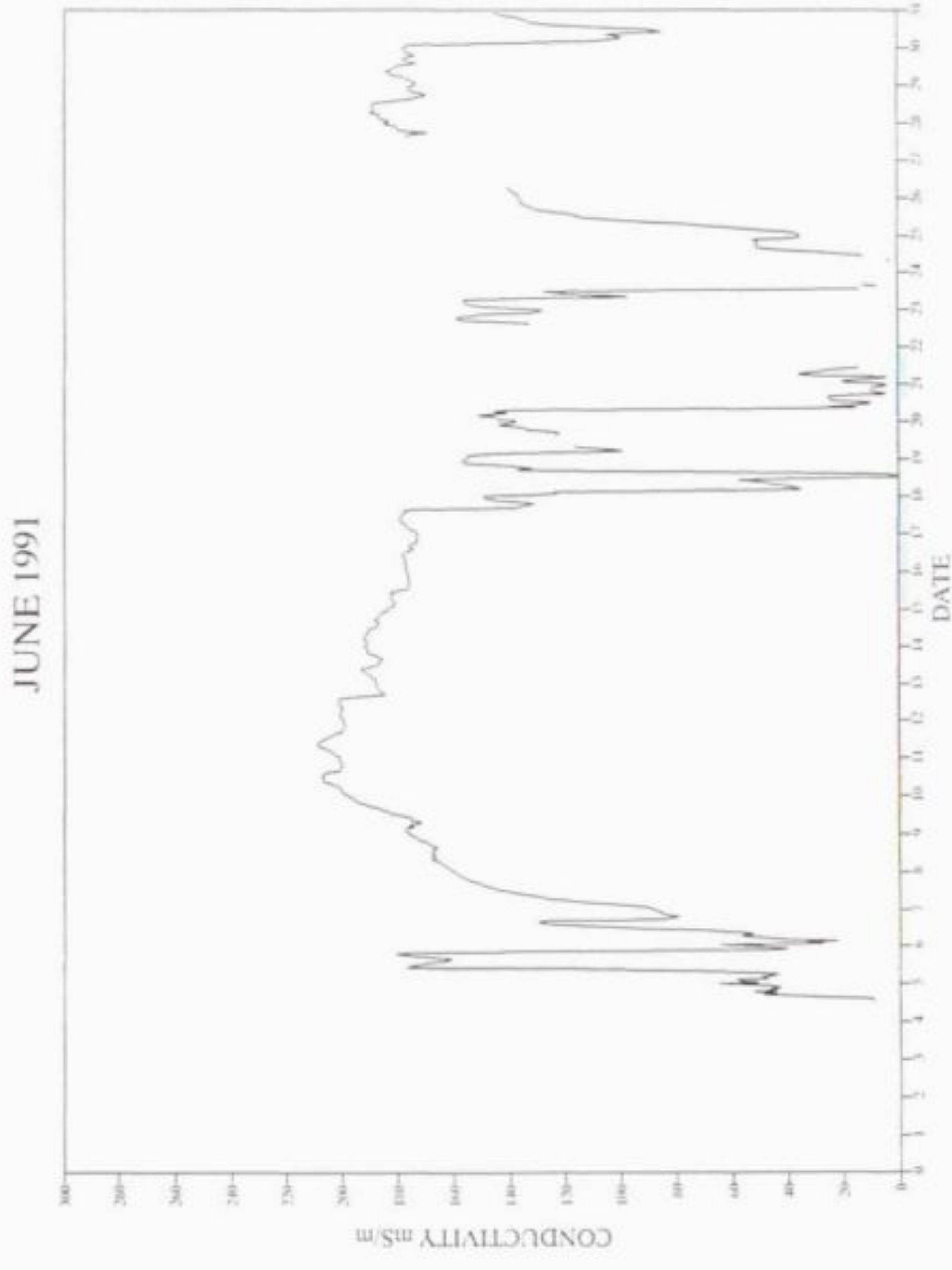

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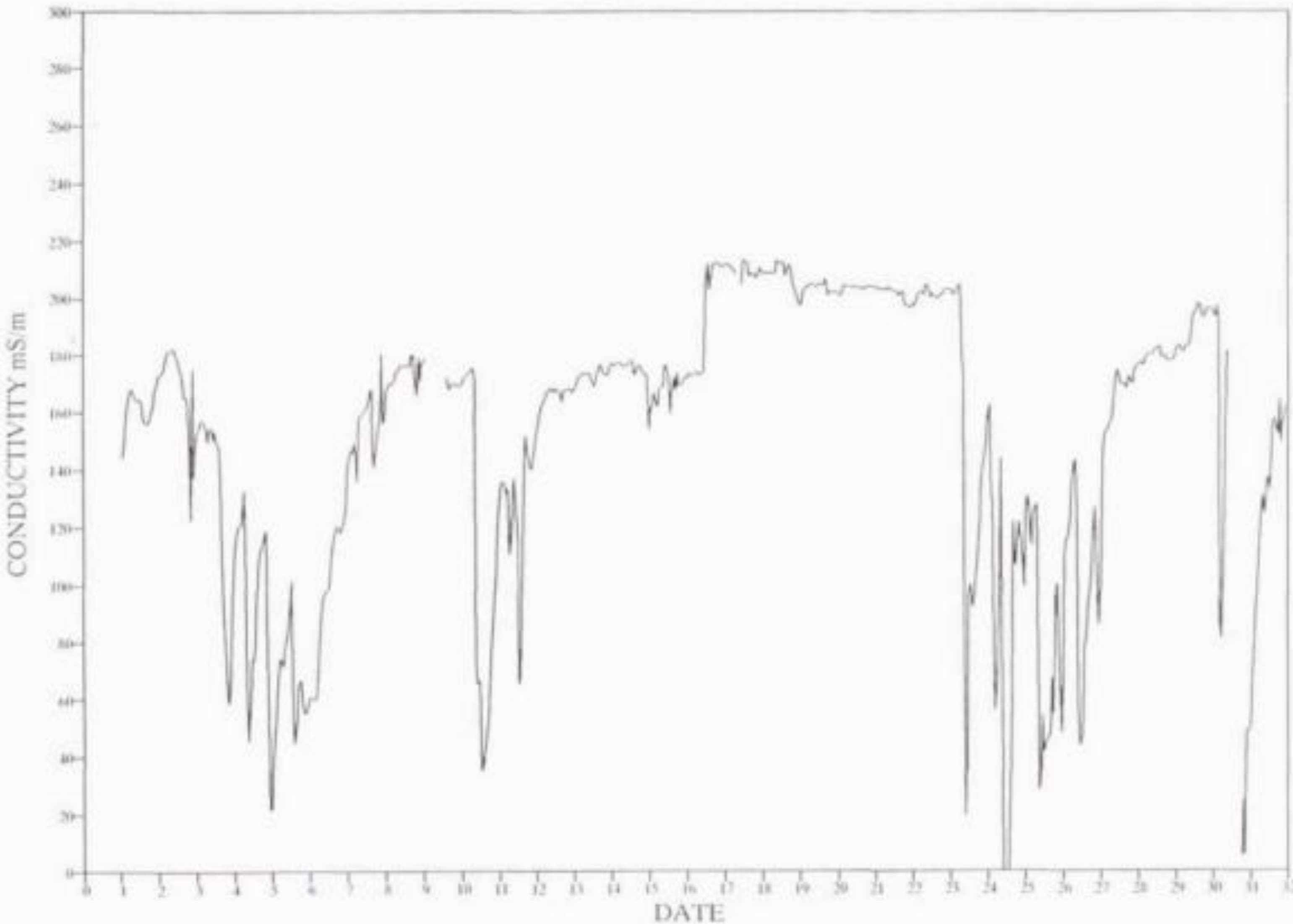

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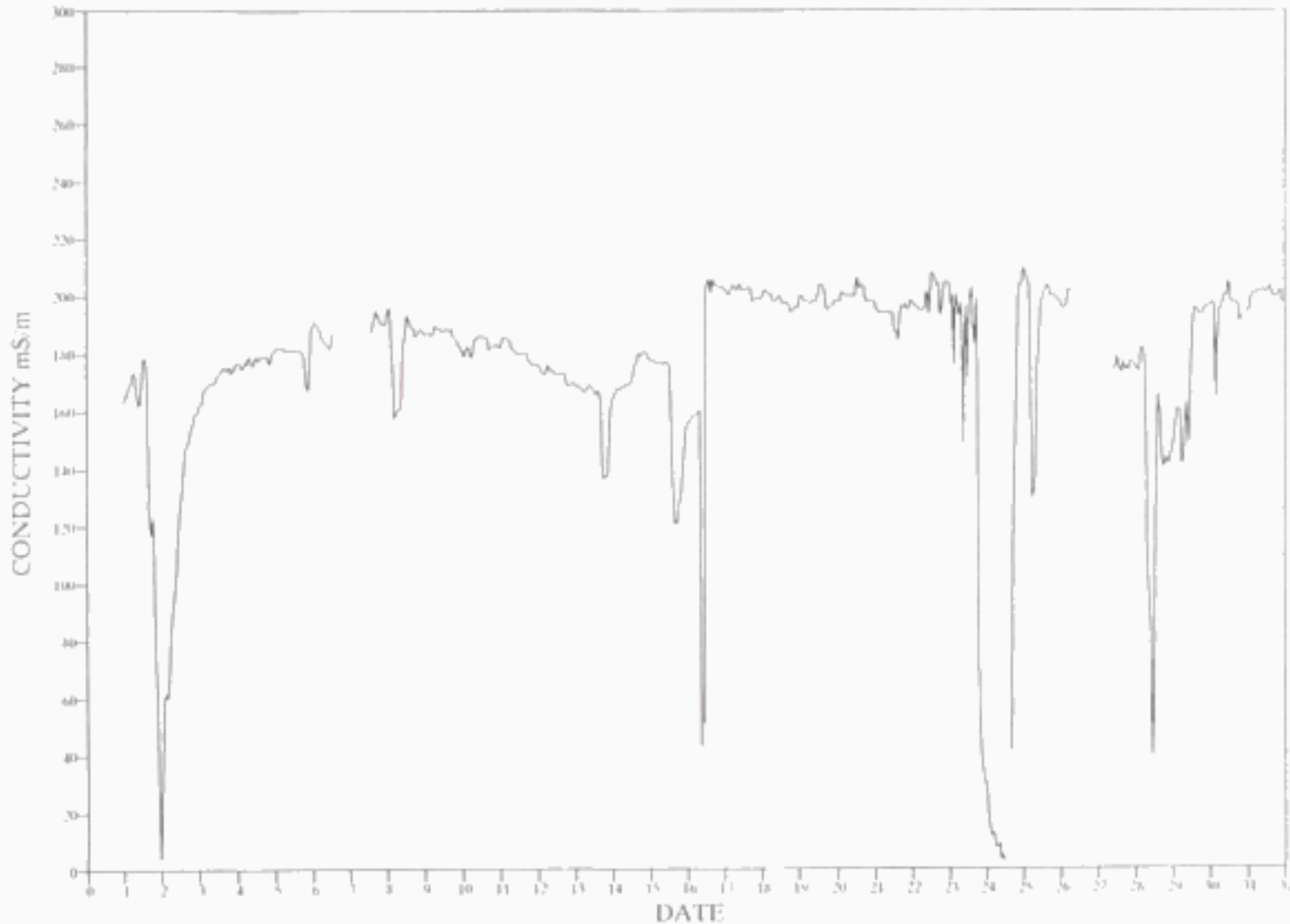
AUGUST 1991



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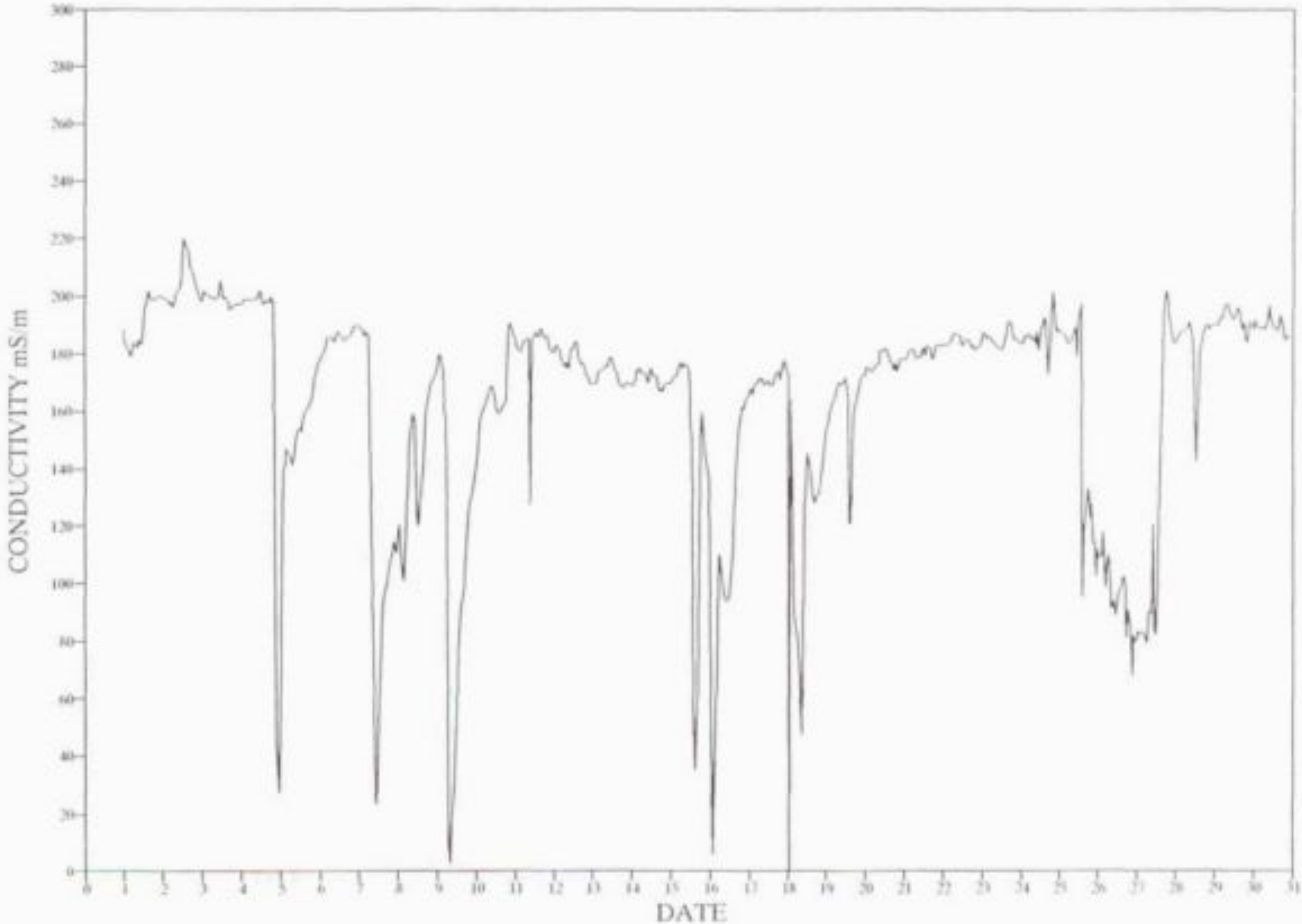

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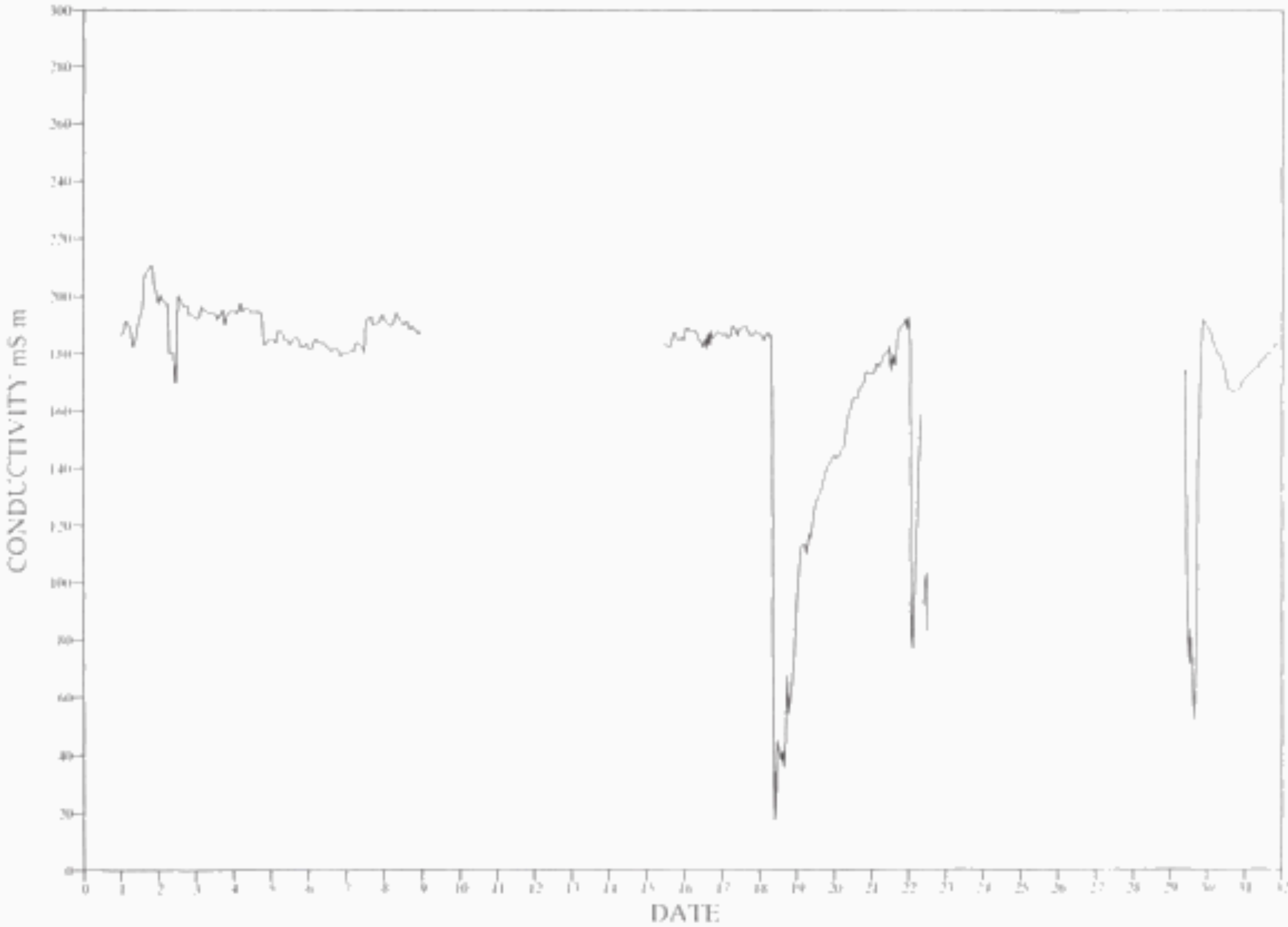
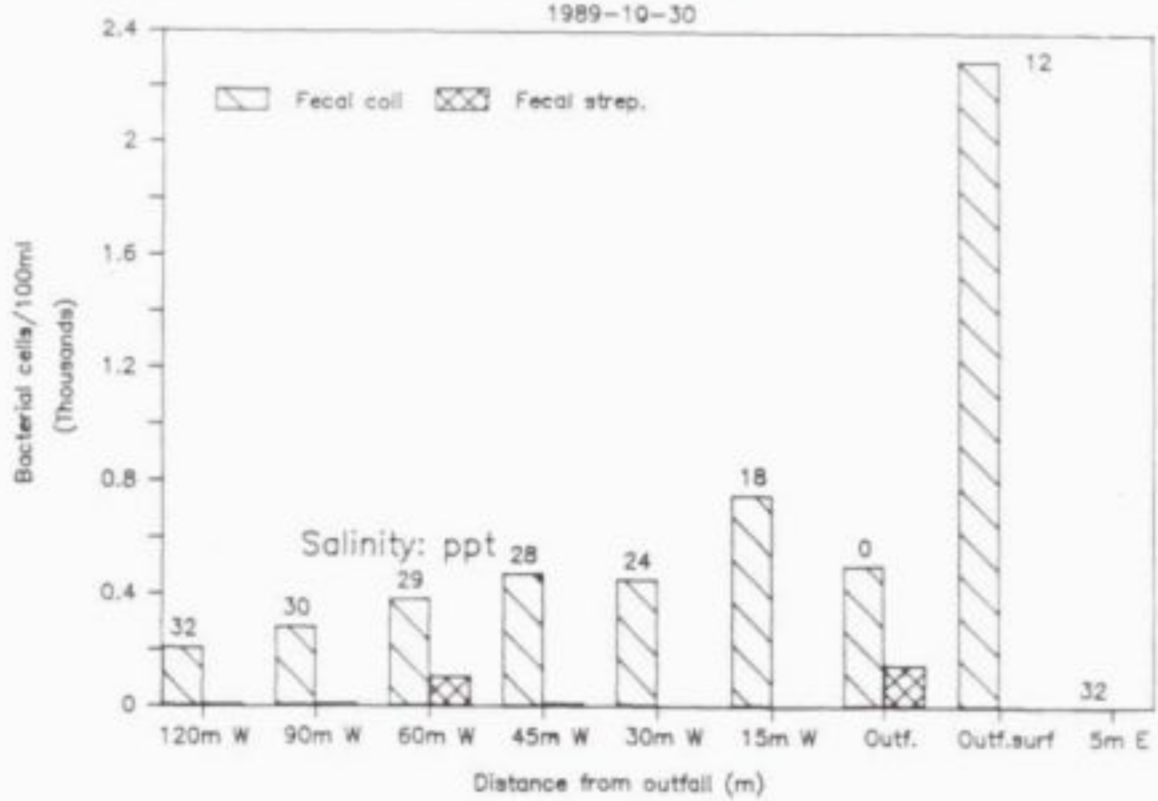
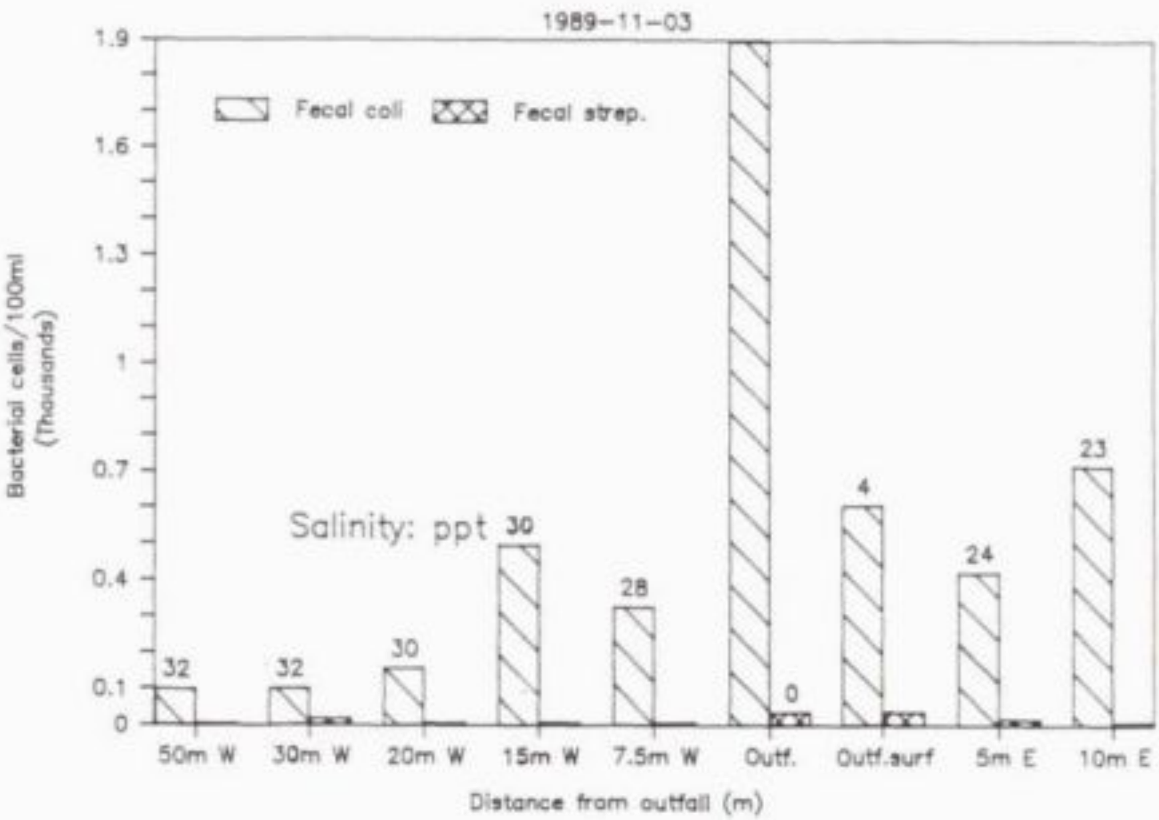


A P P E N D I X D

MICROBIOLOGICAL QUALITY OF THE STORMWATER ON ENTERING THE SURFZONE

MONWABISI STORMWATER OUTFALL





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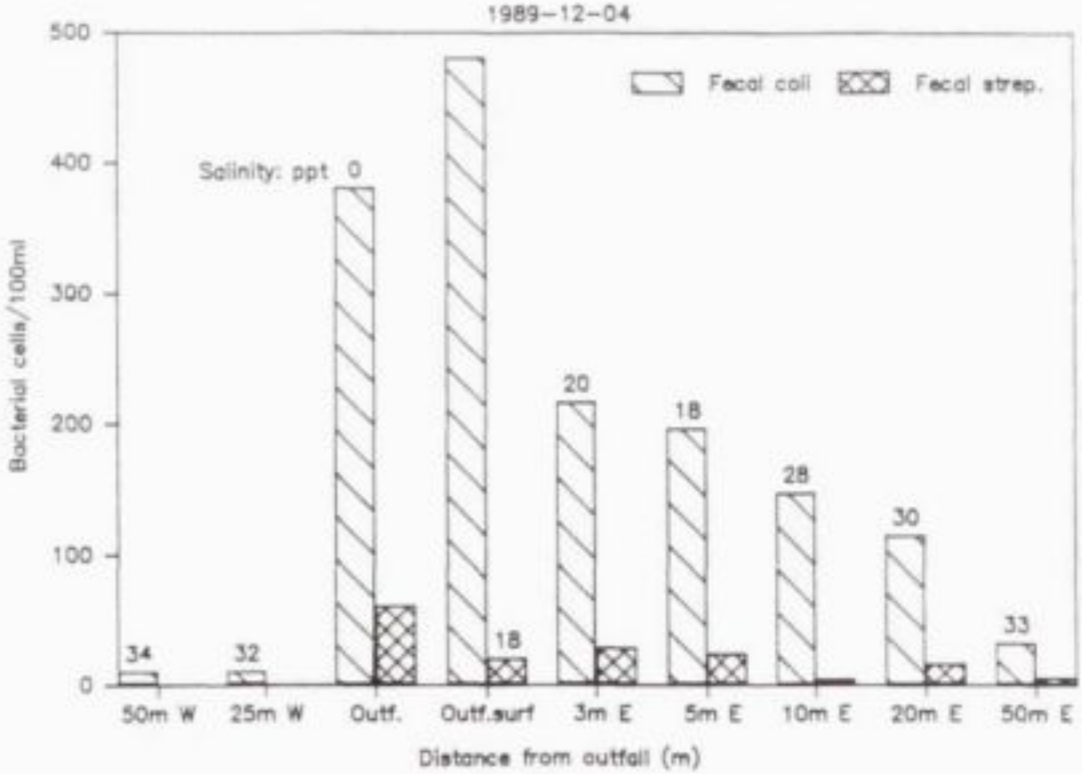

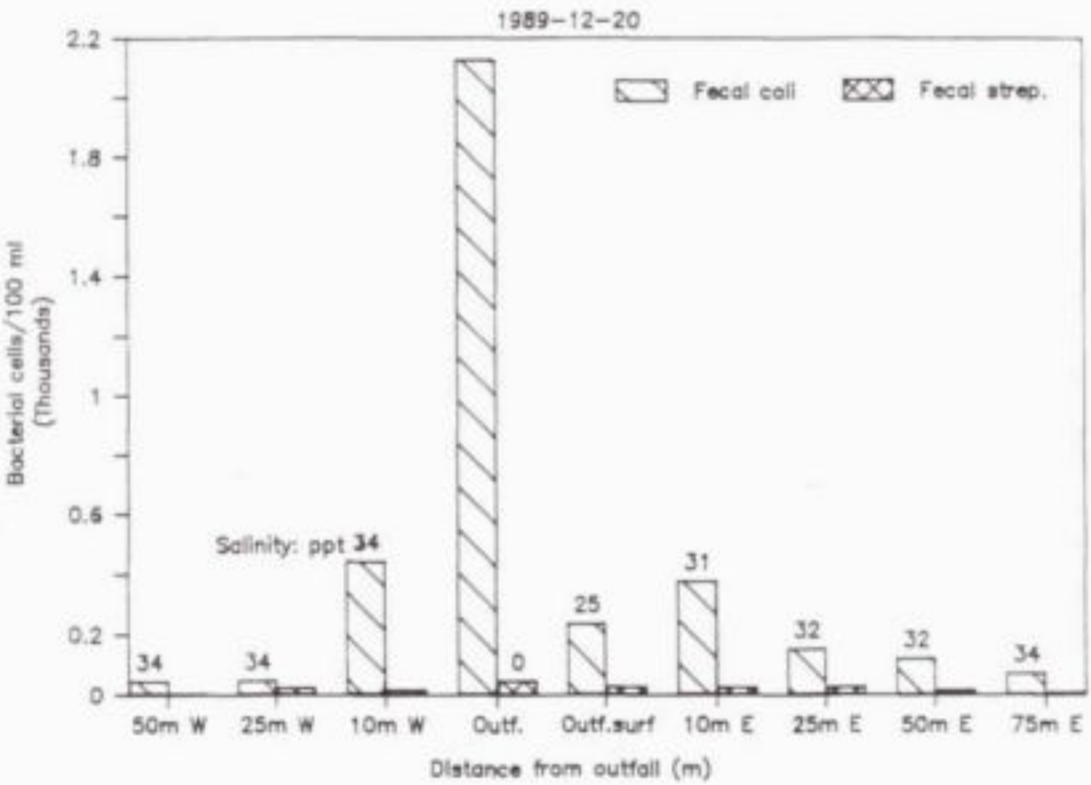

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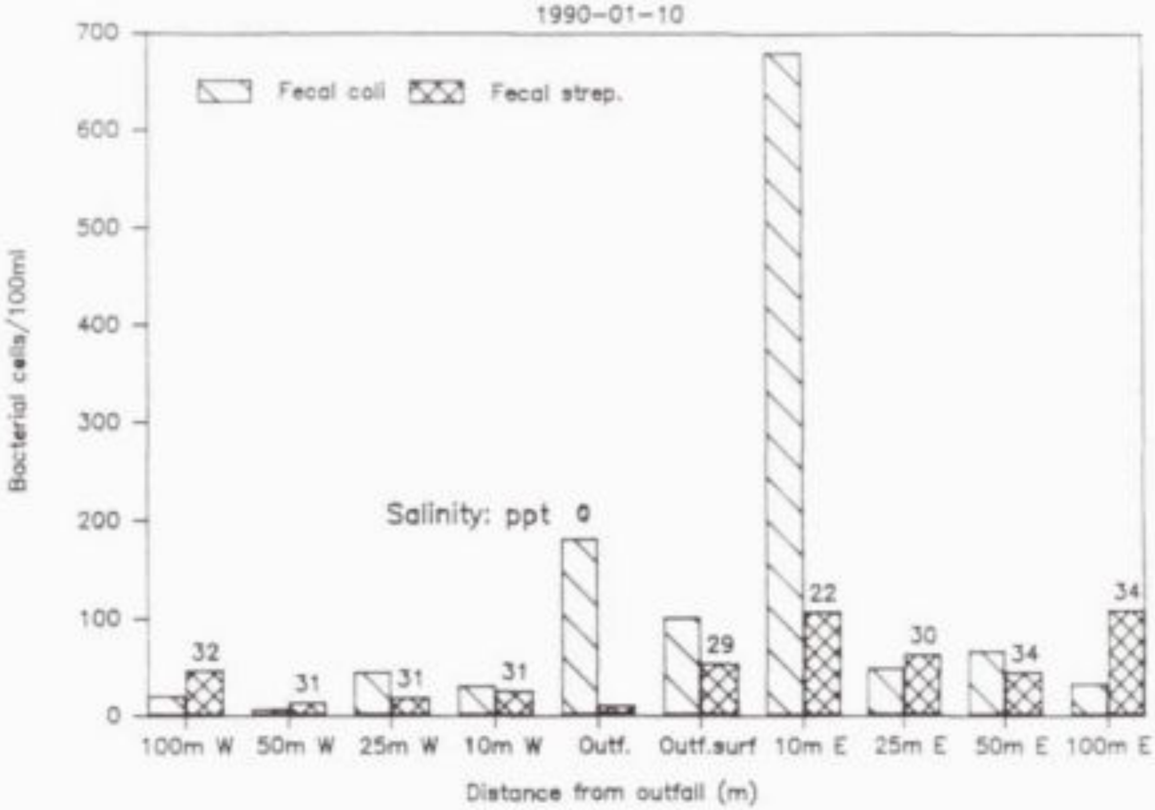

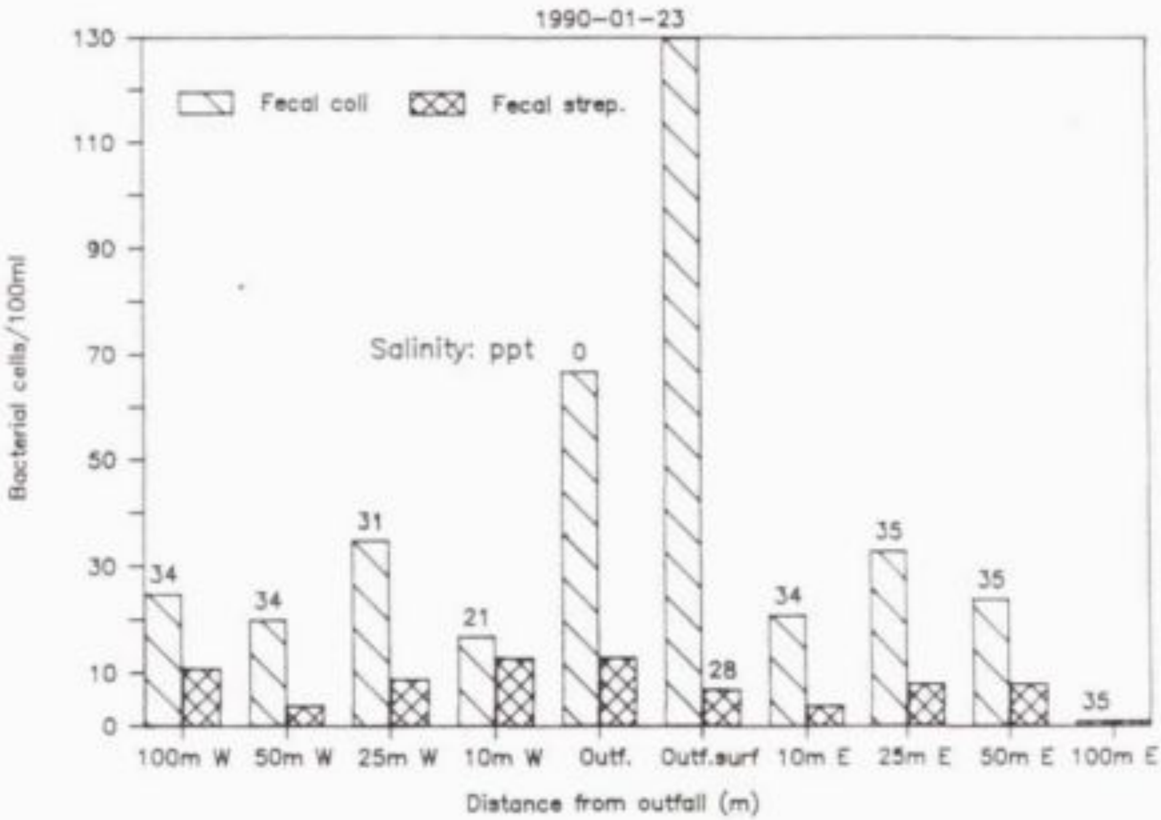

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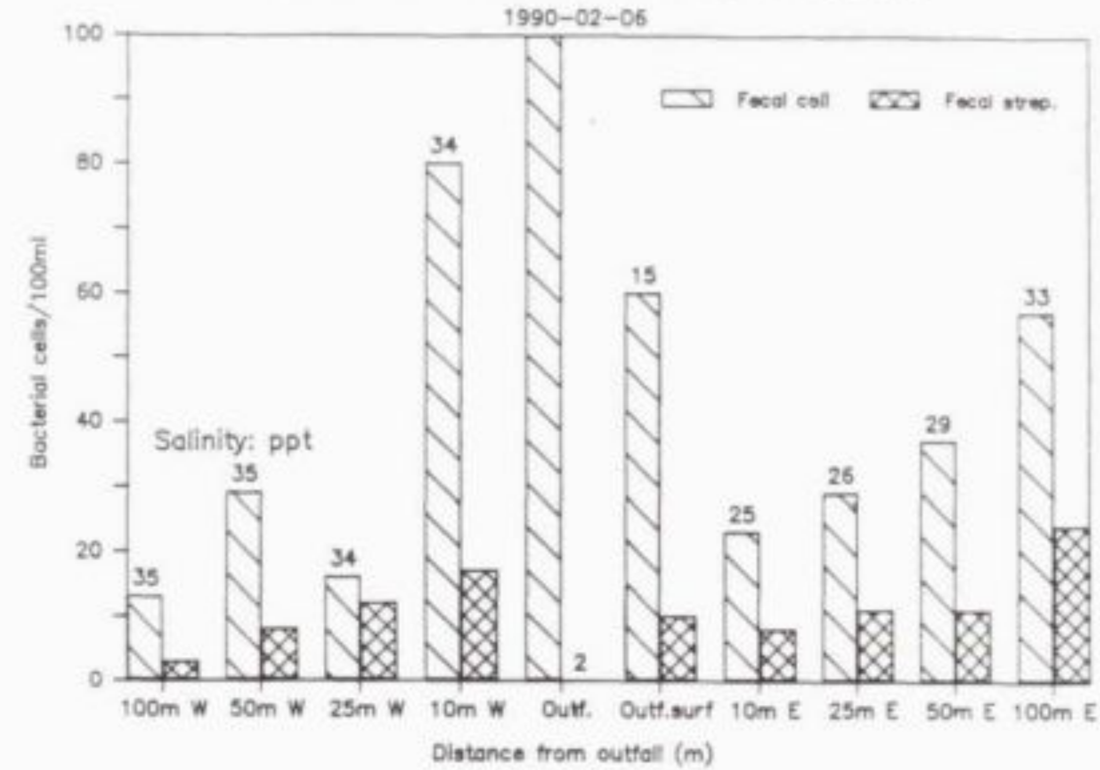

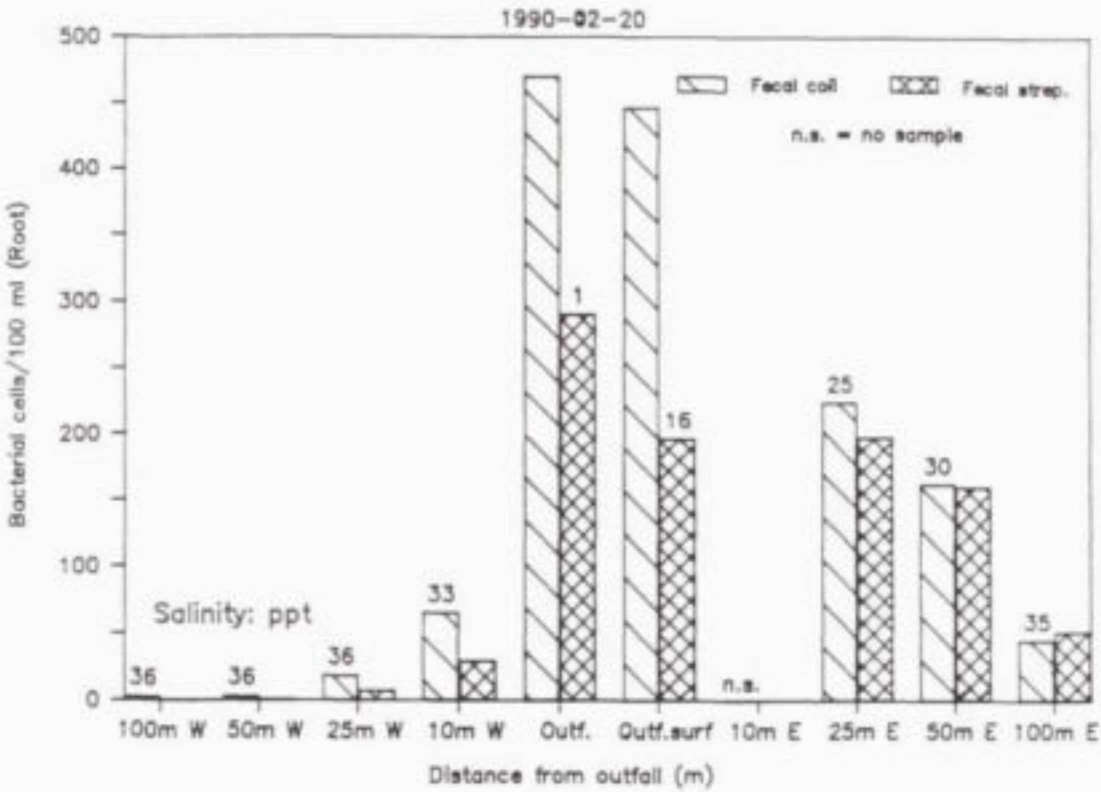

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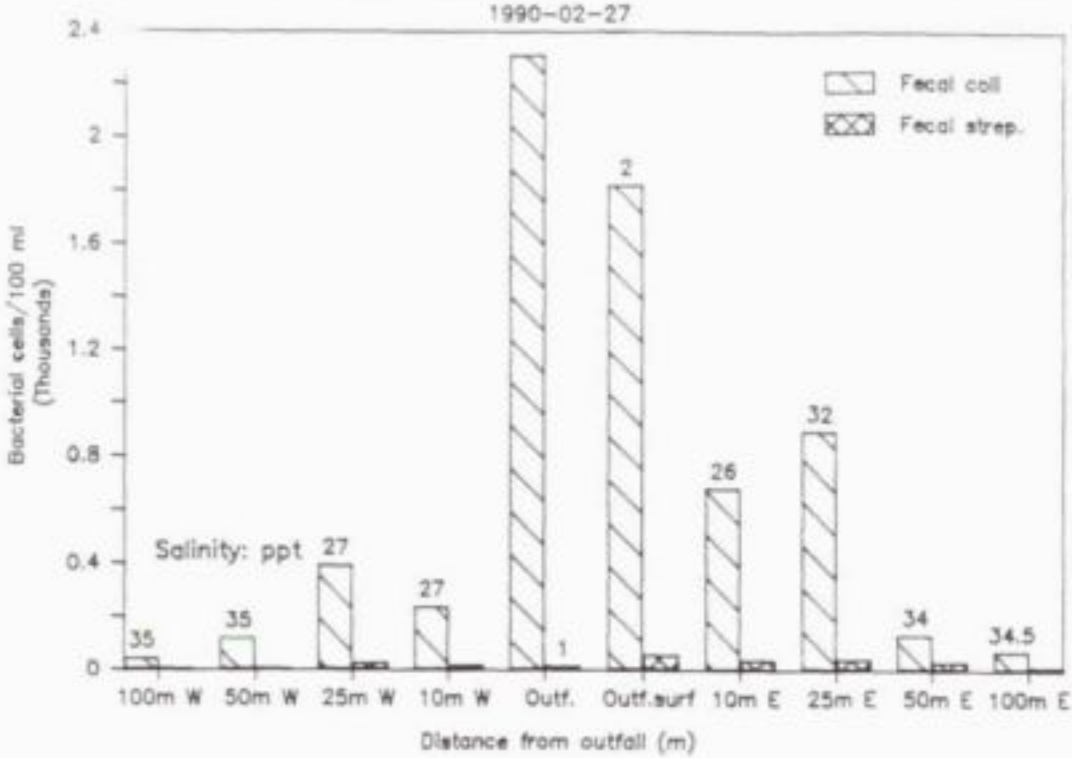

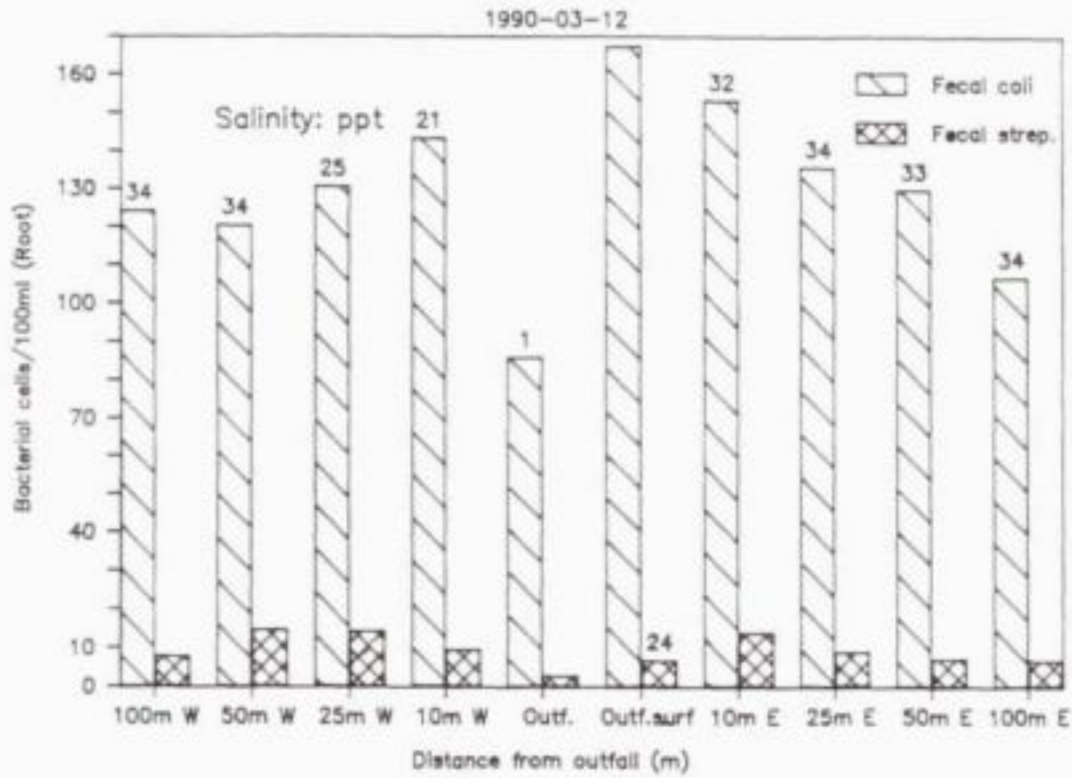

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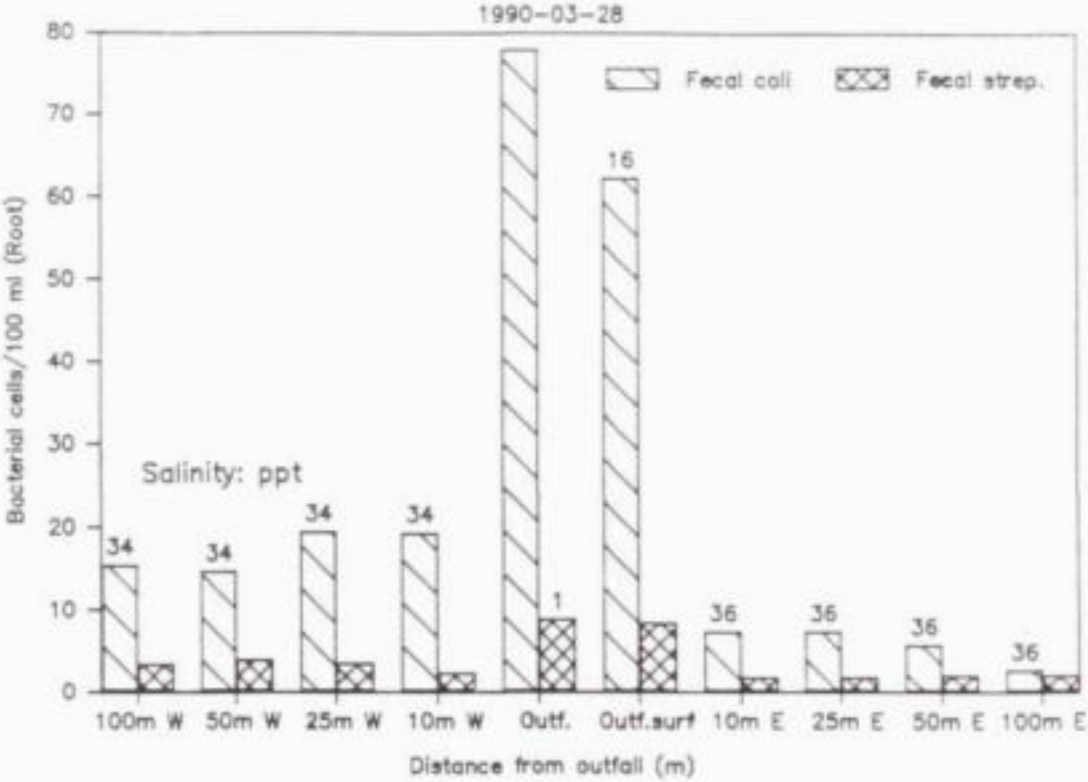

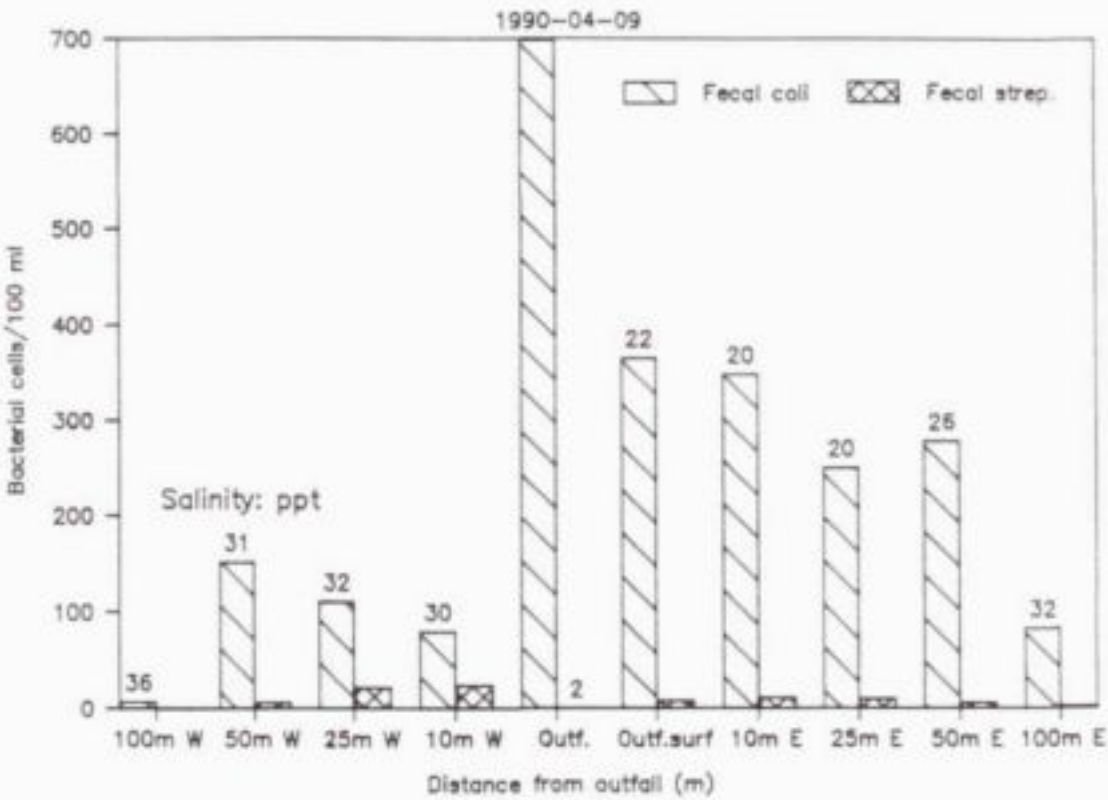

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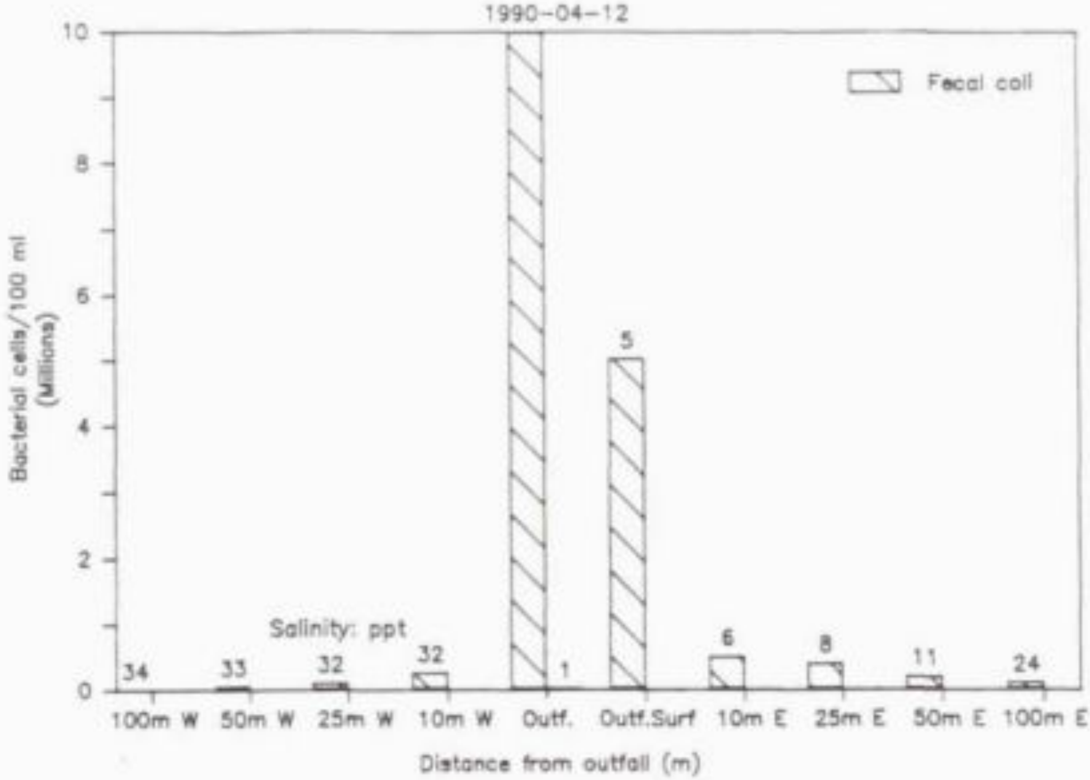

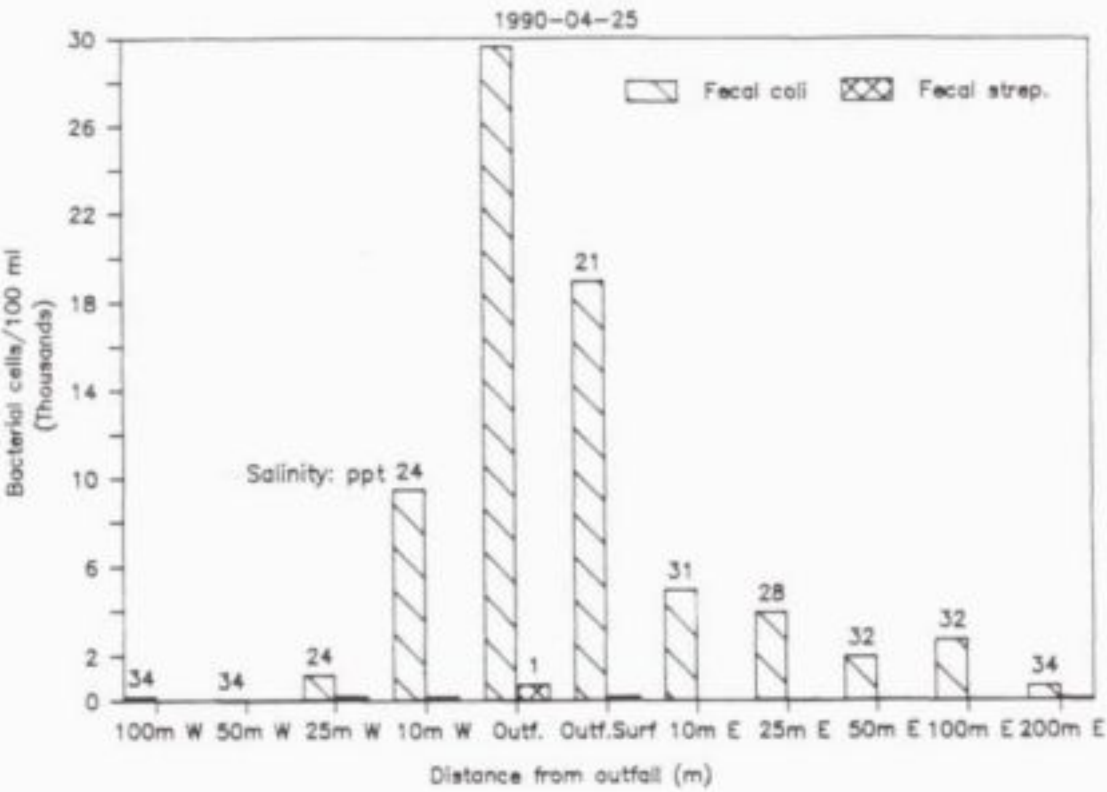

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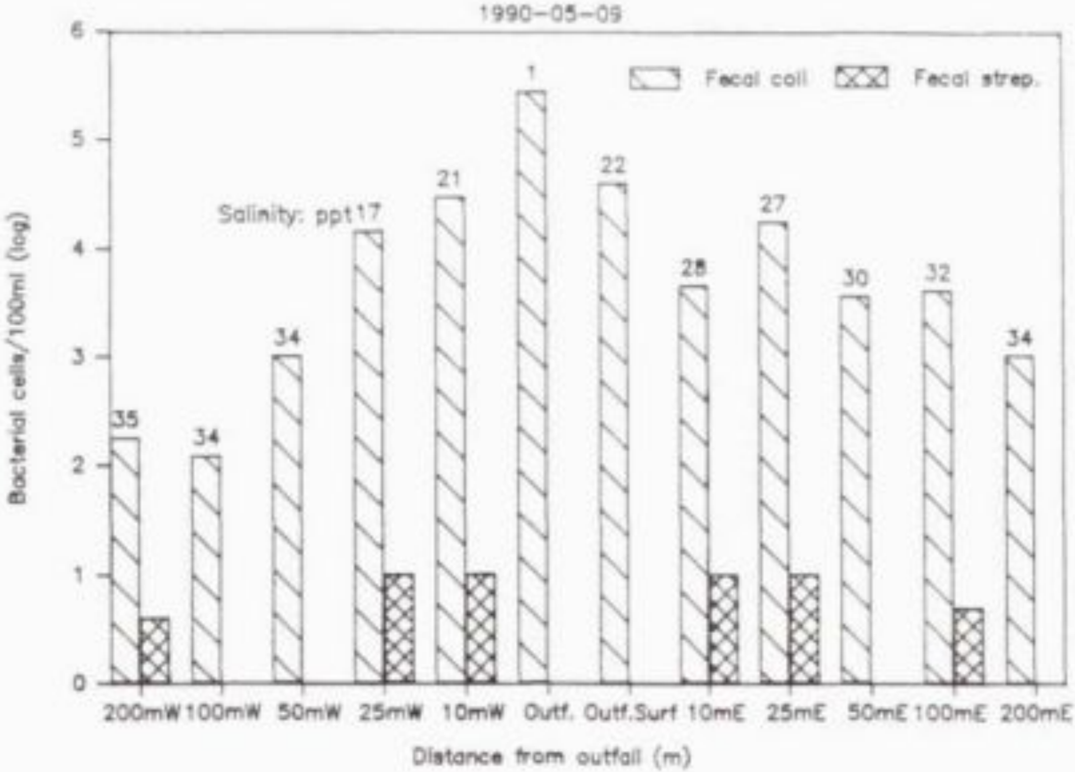

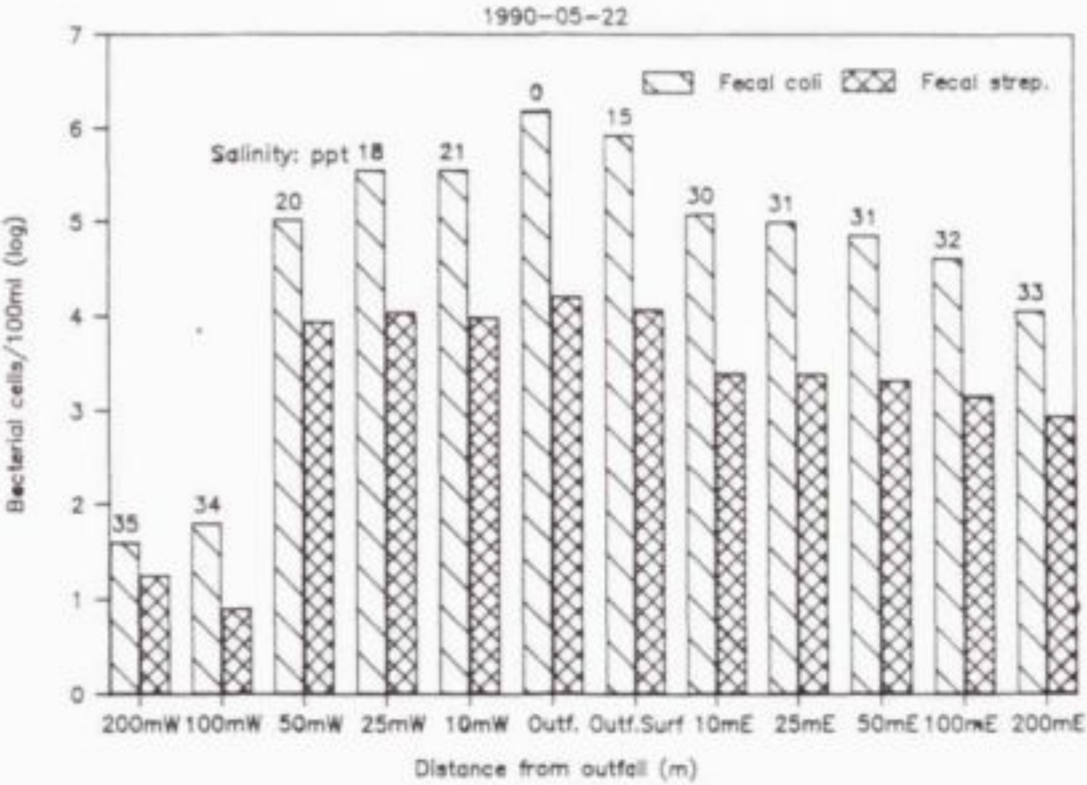

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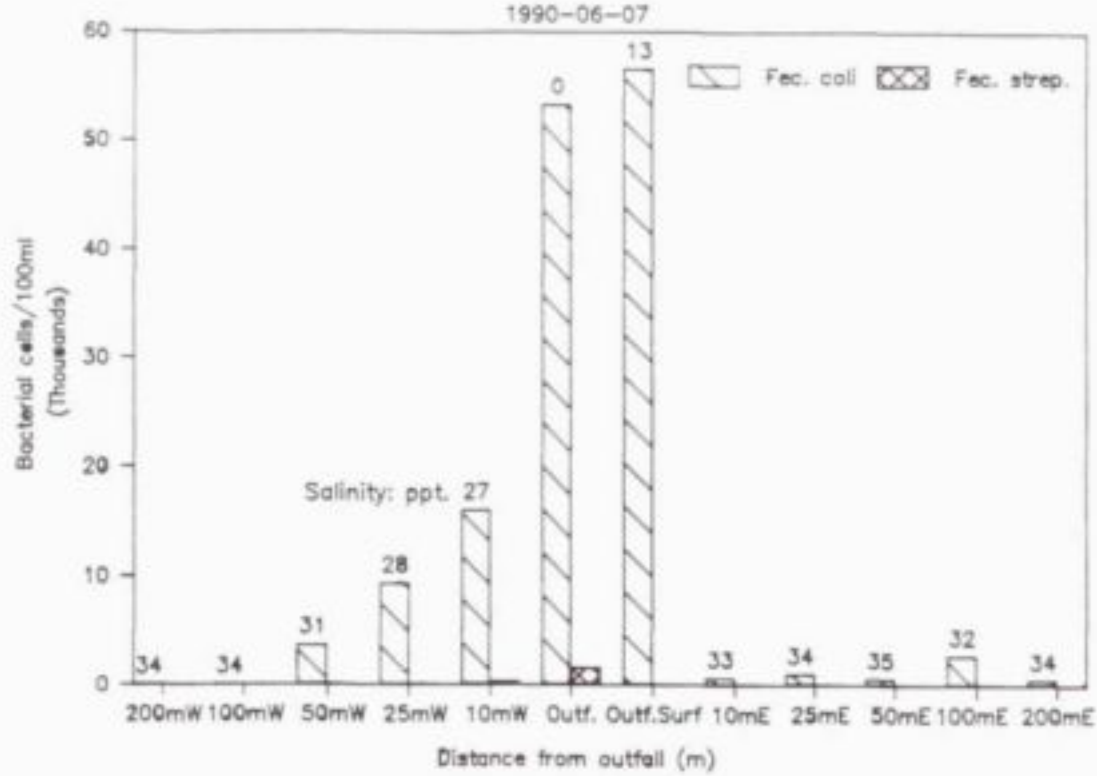

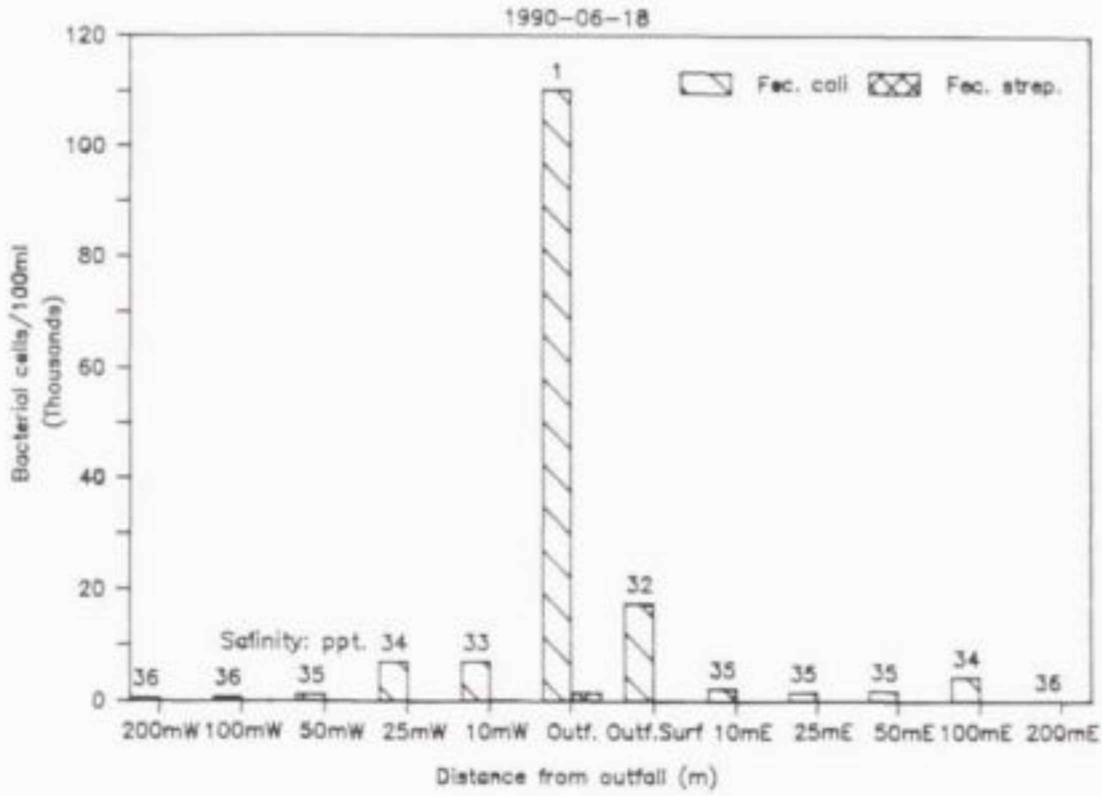

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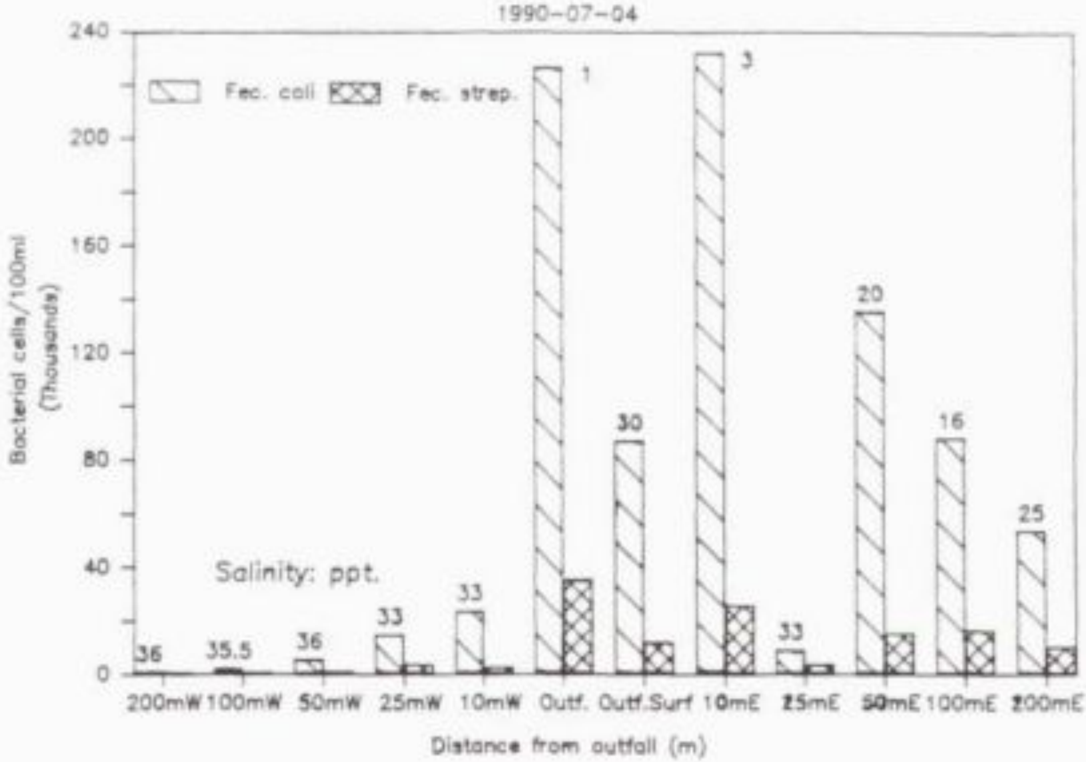

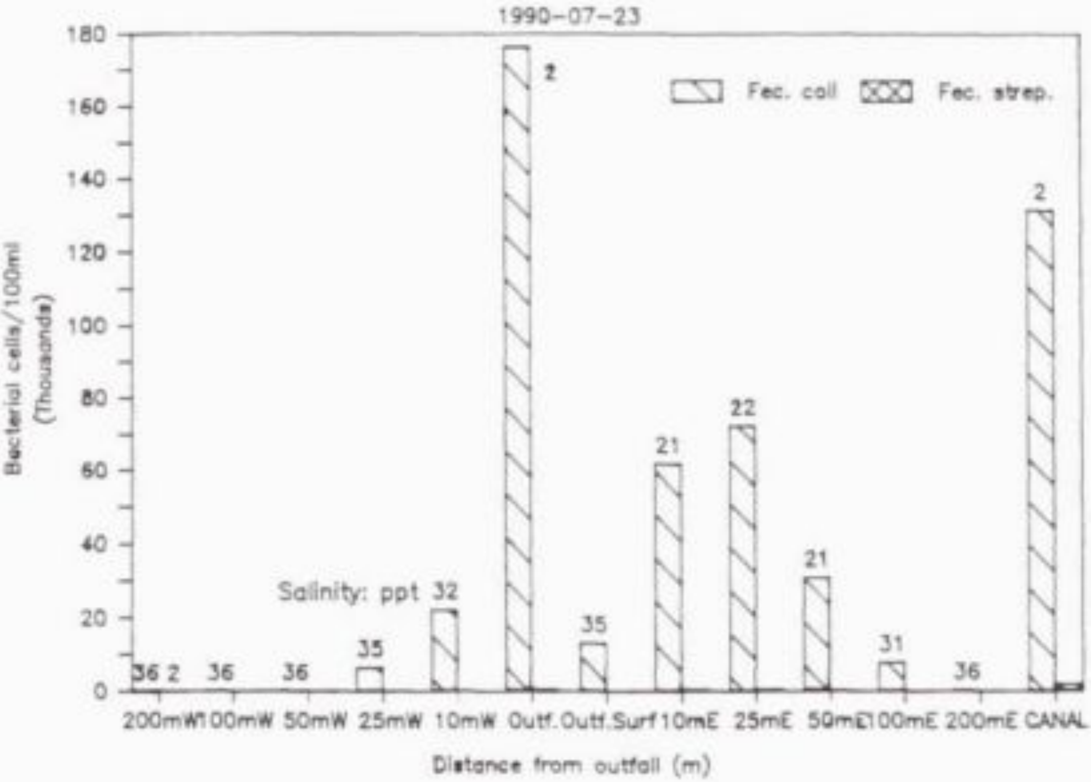

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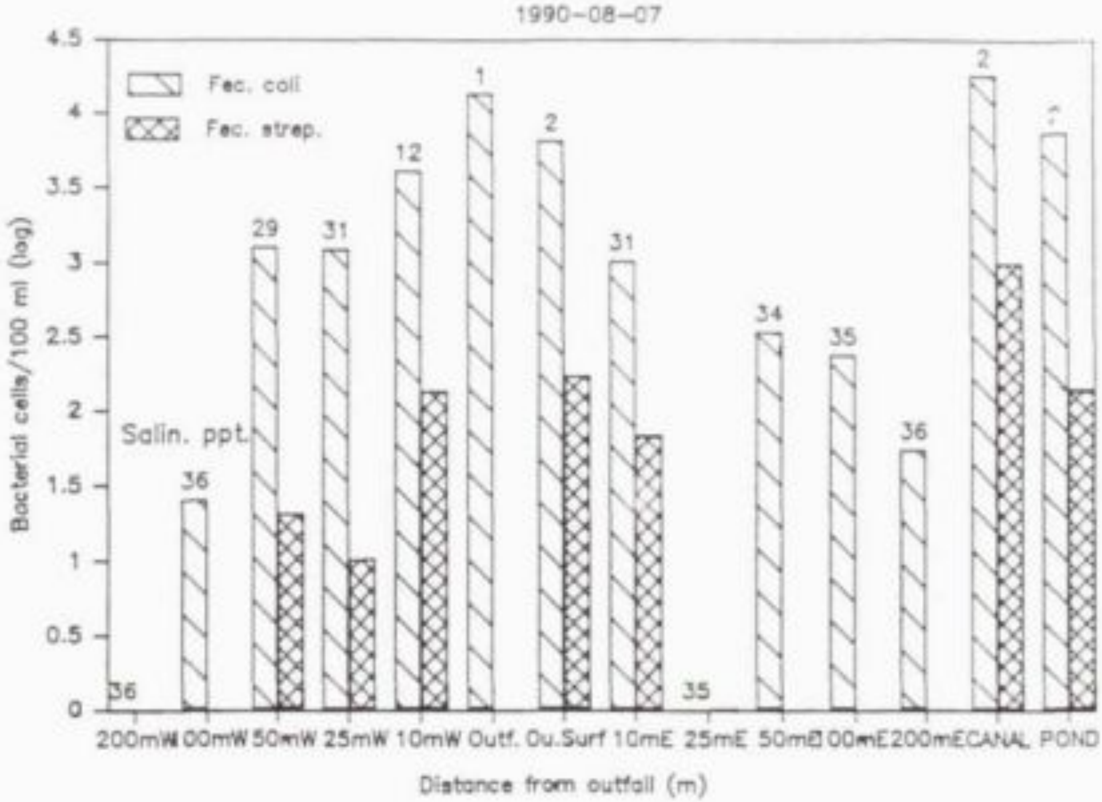

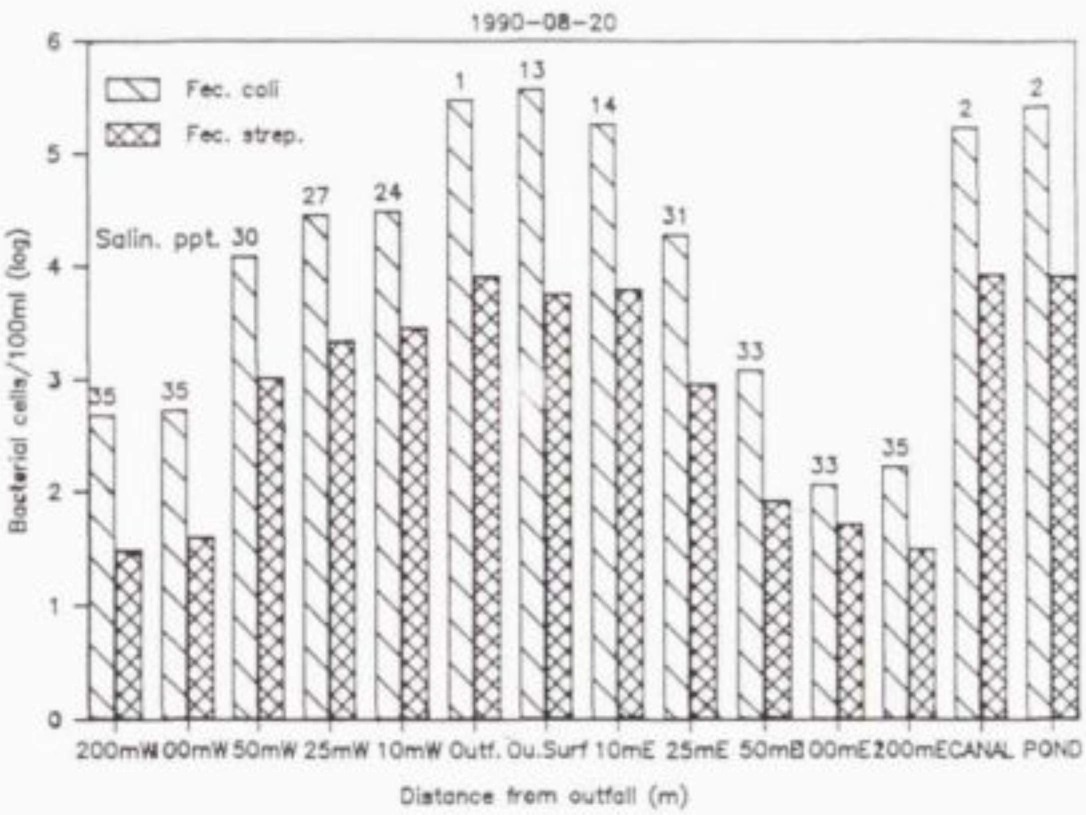

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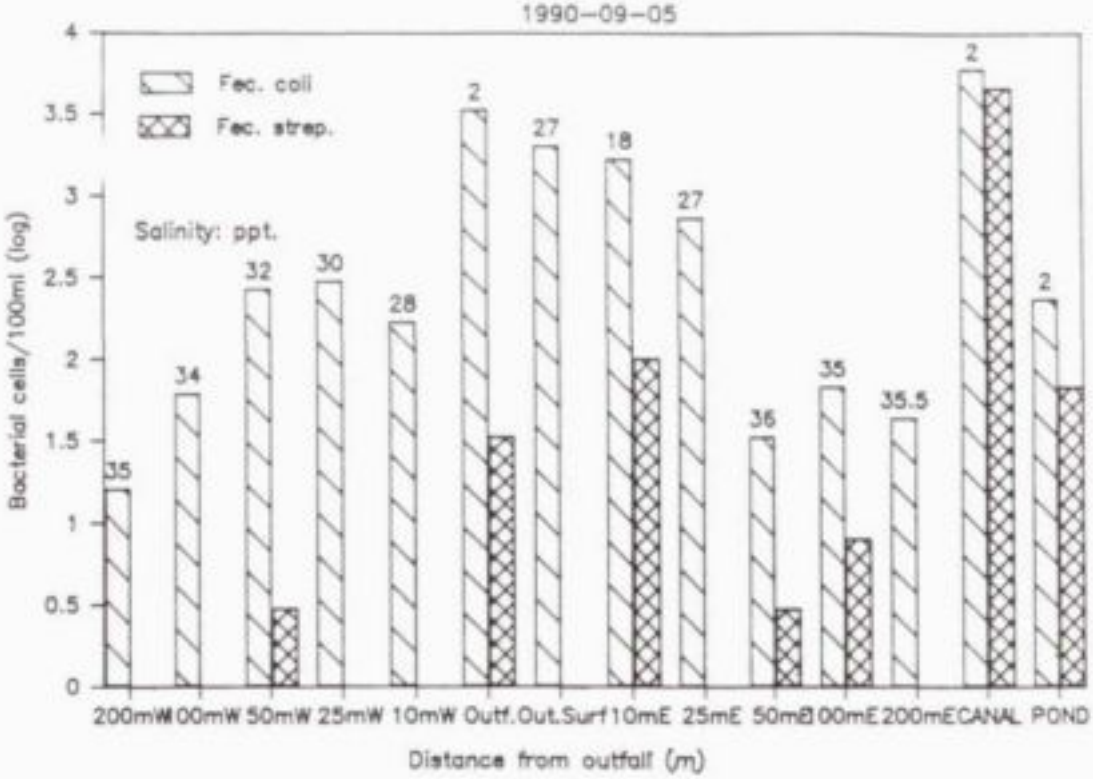

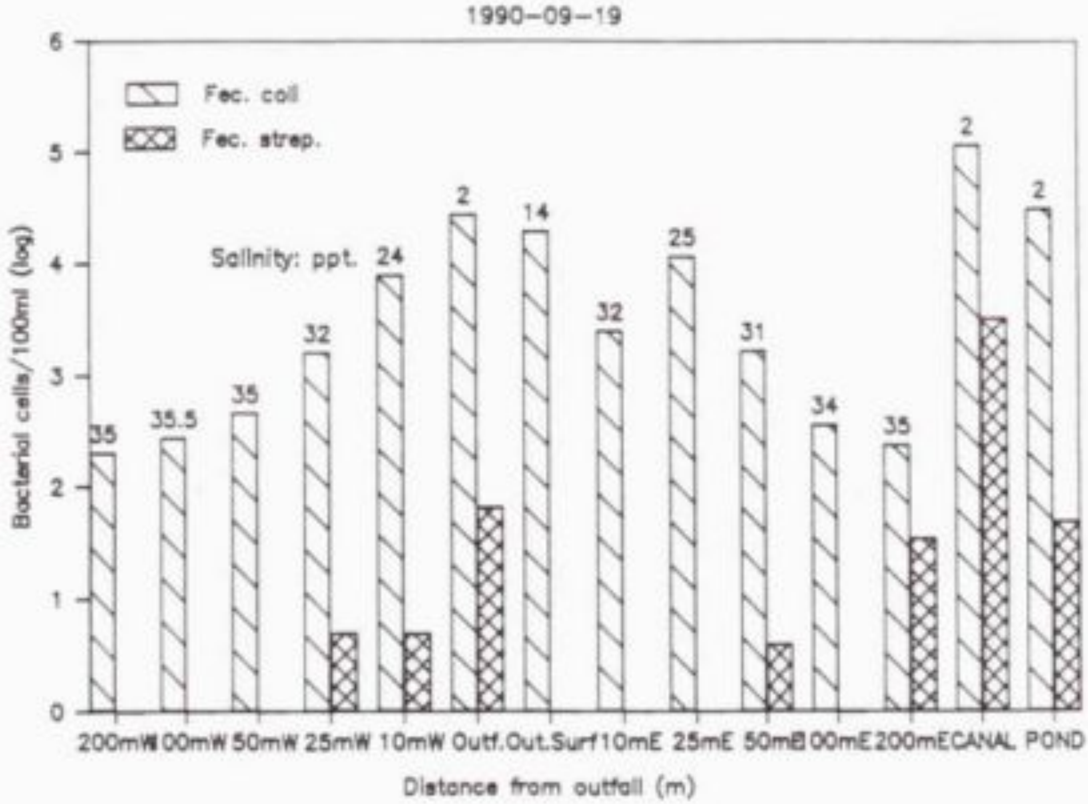

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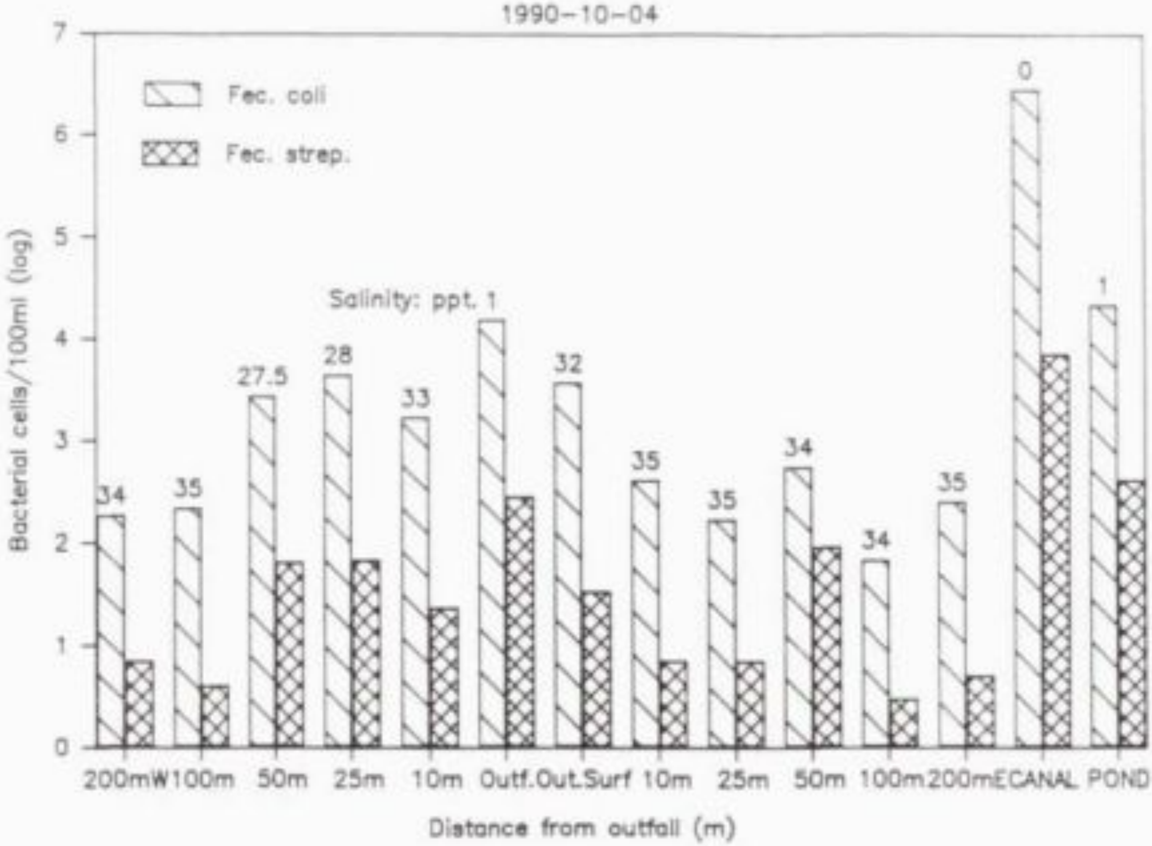

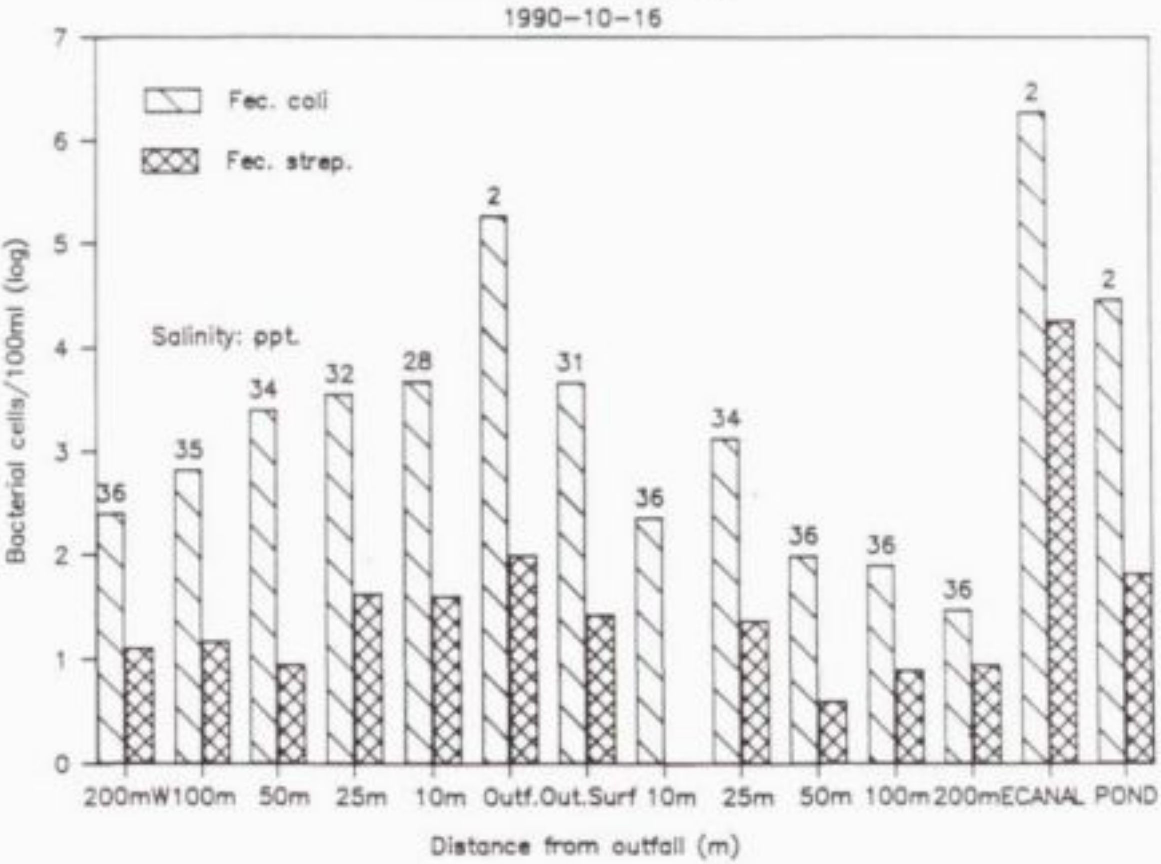

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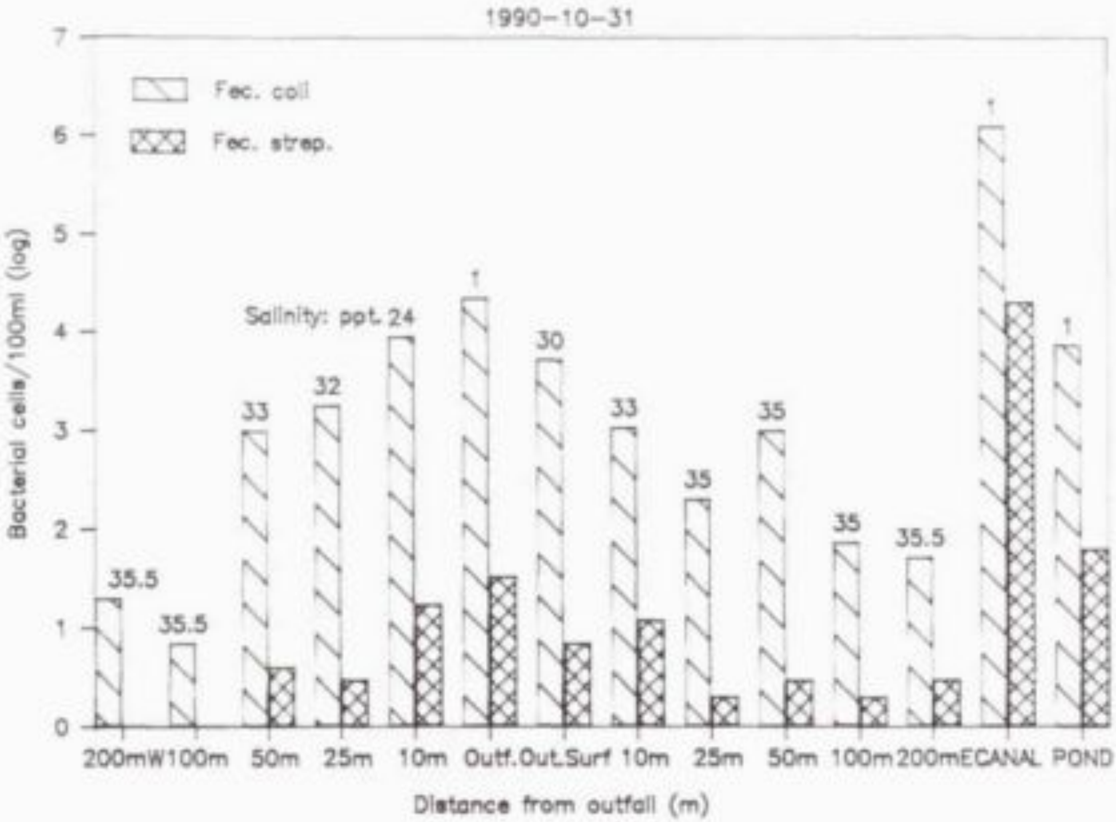

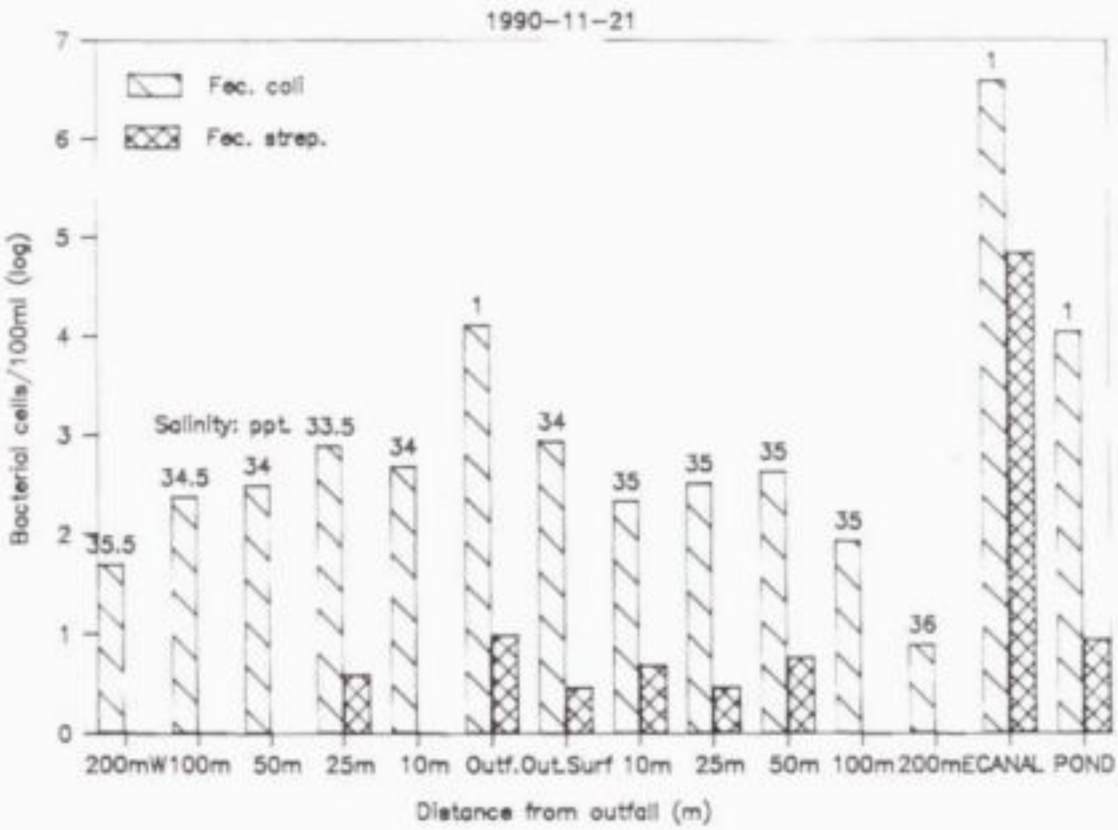

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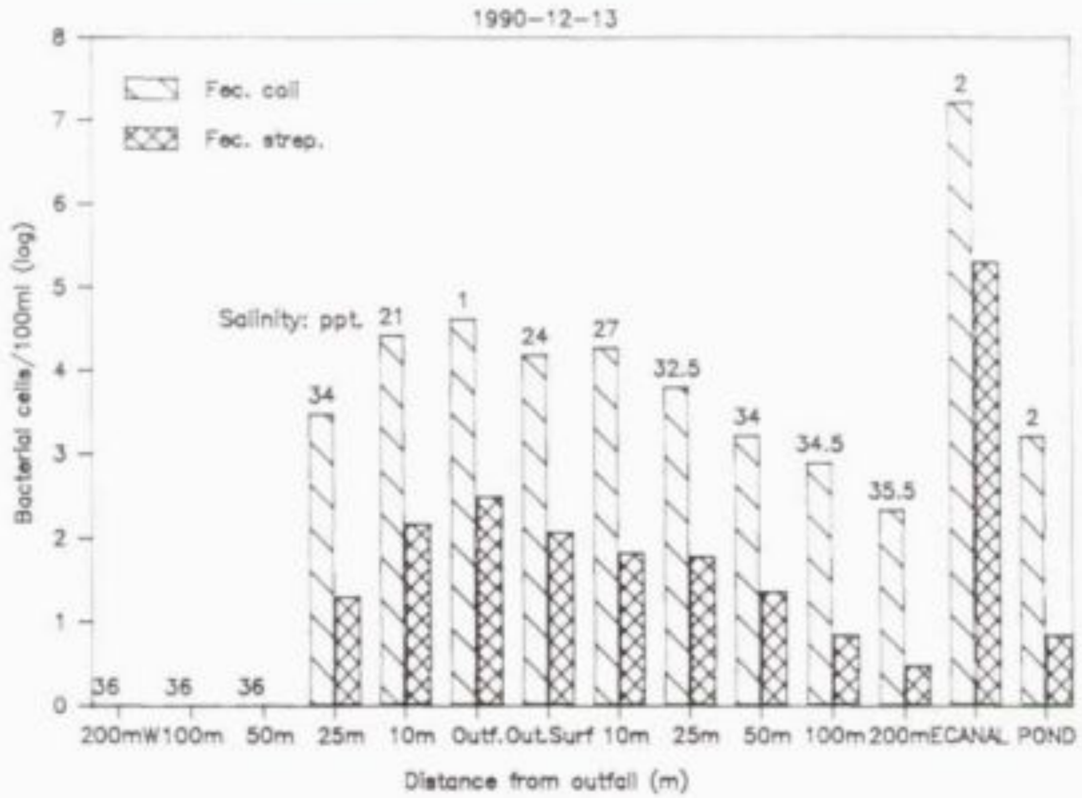
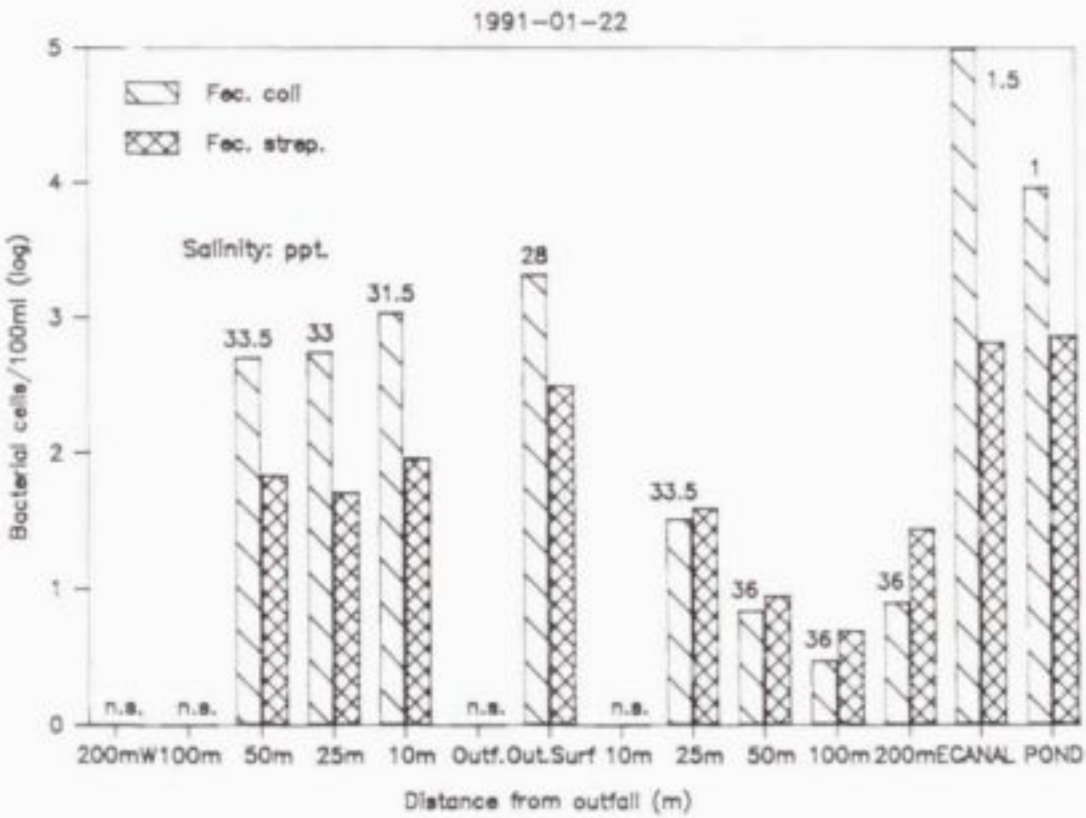


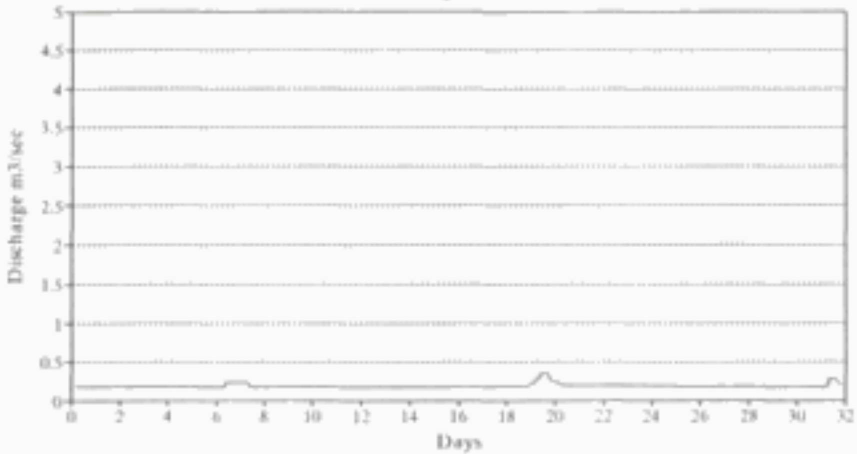


APPENDIX E

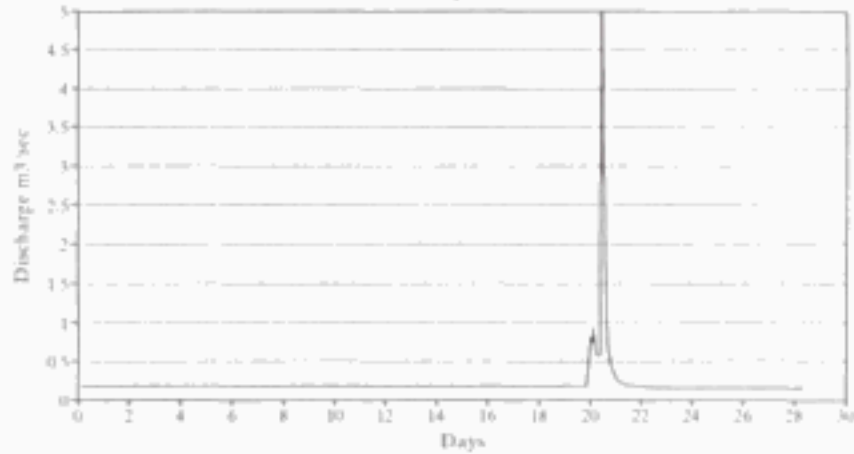
KHAYELITSHA DISCHARGE DATA

[Full data set available from Watertek, CSIR, Stellenbosch]

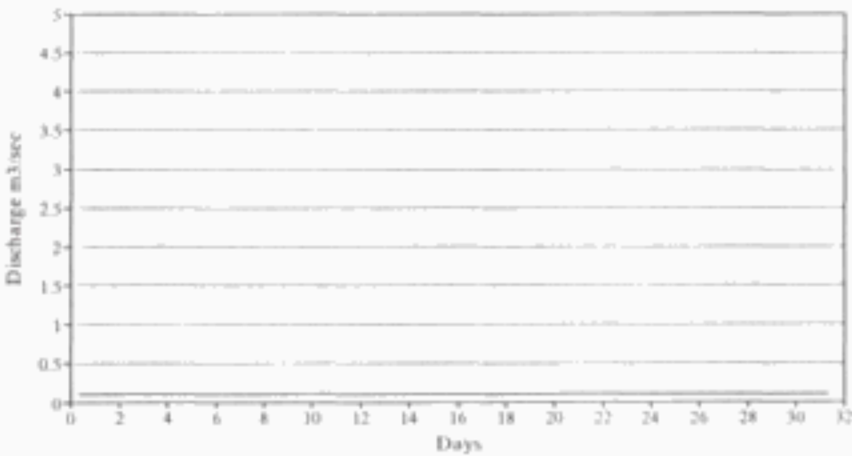
January 1990



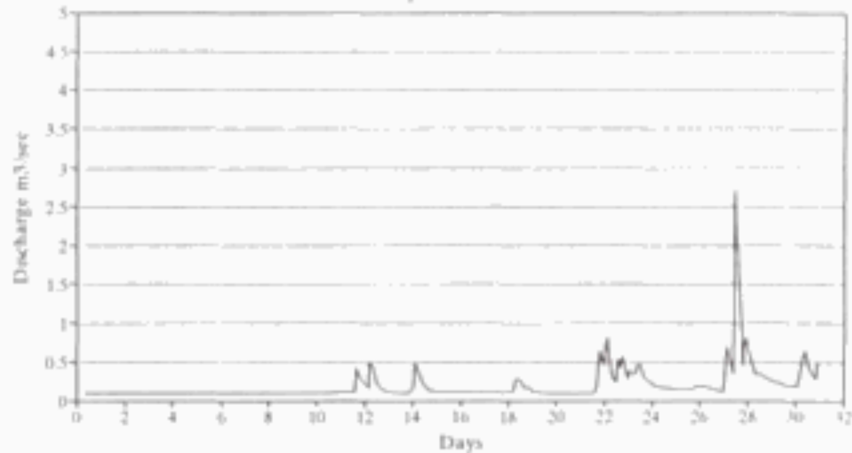
February 1990



March 1990



April 1990



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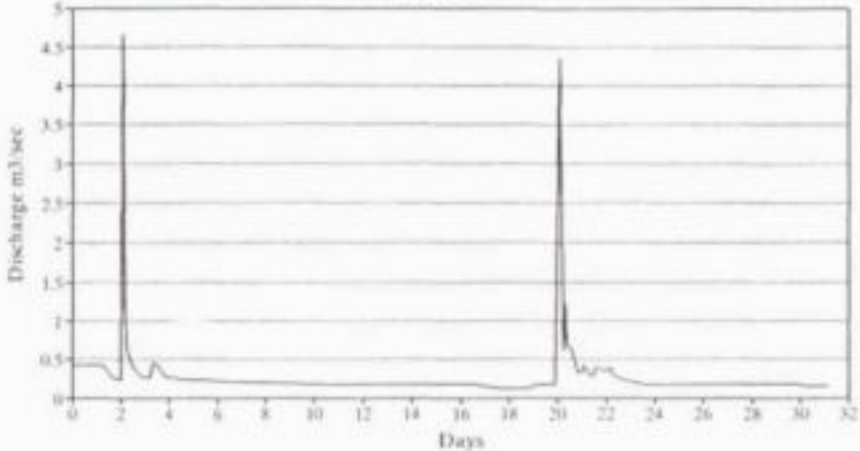
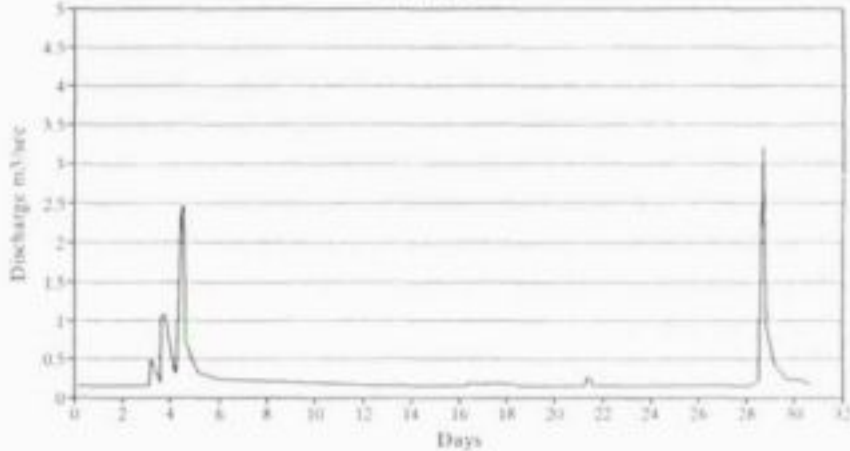
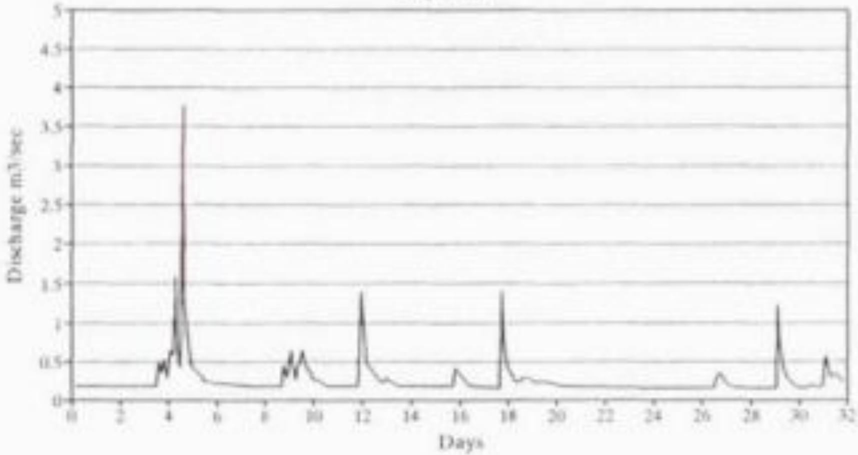


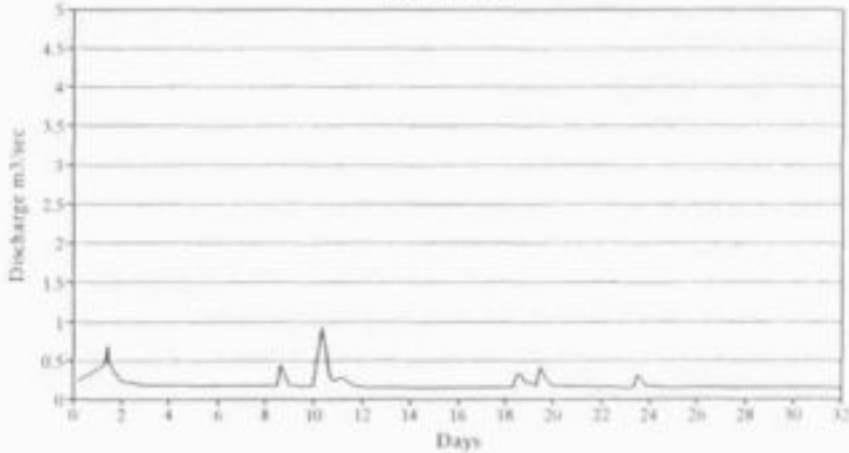
June 1990

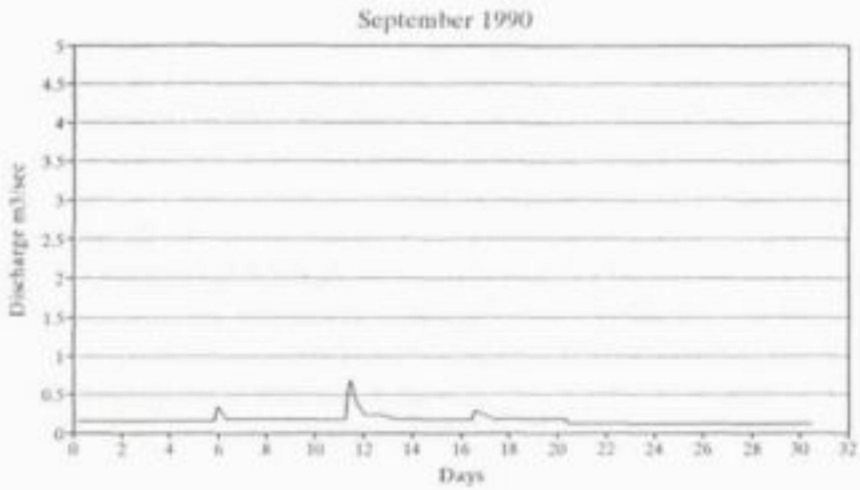


July 1990

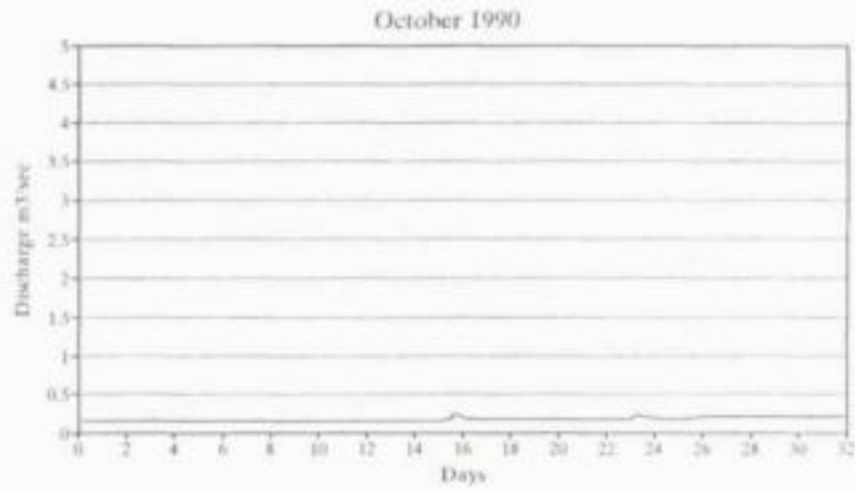


August 1990

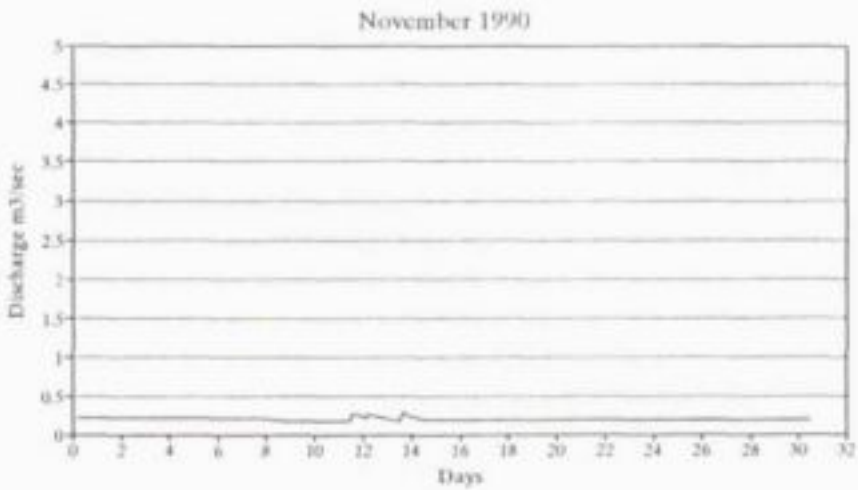




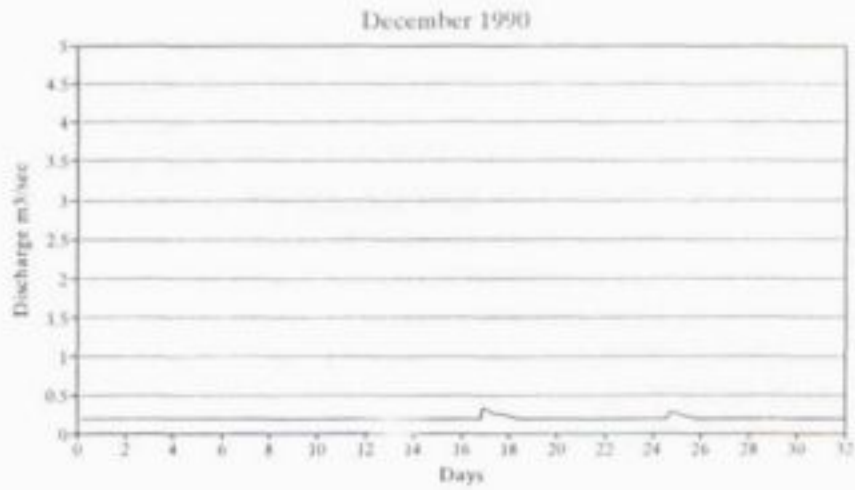
September 1990
Discharge m3/sec
Days



October 1990
Discharge m3/sec
Days

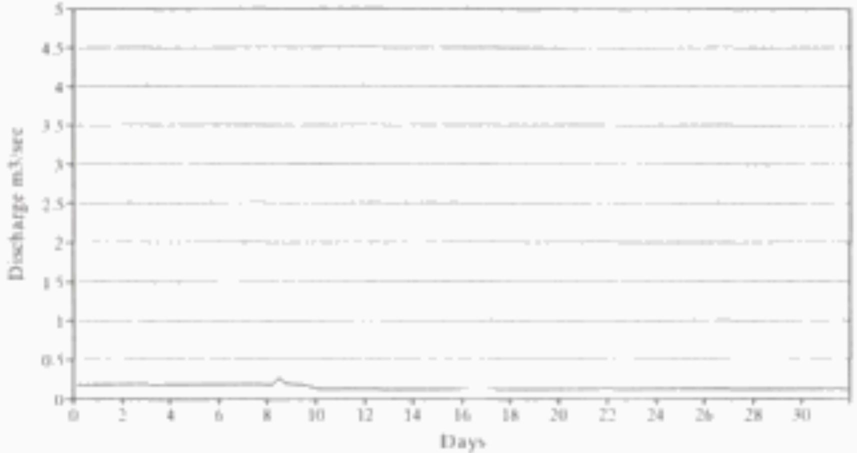


November 1990
Discharge m3/sec
Days

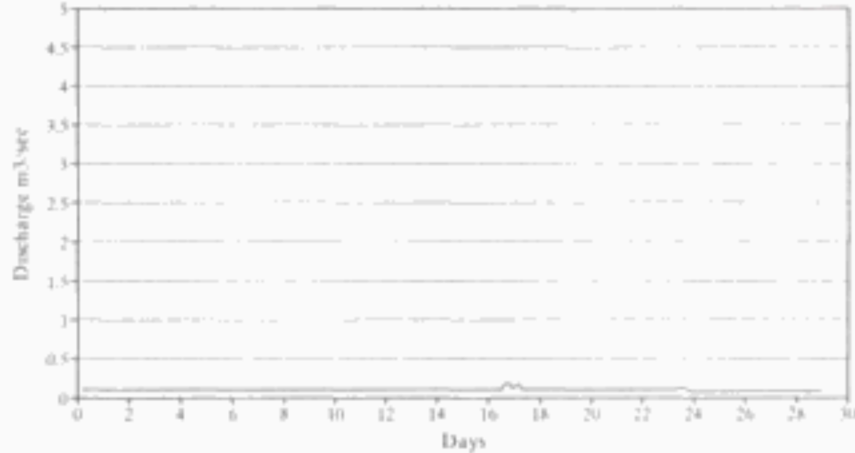


December 1990
Discharge m3/sec
Days

January 1991



February 1991



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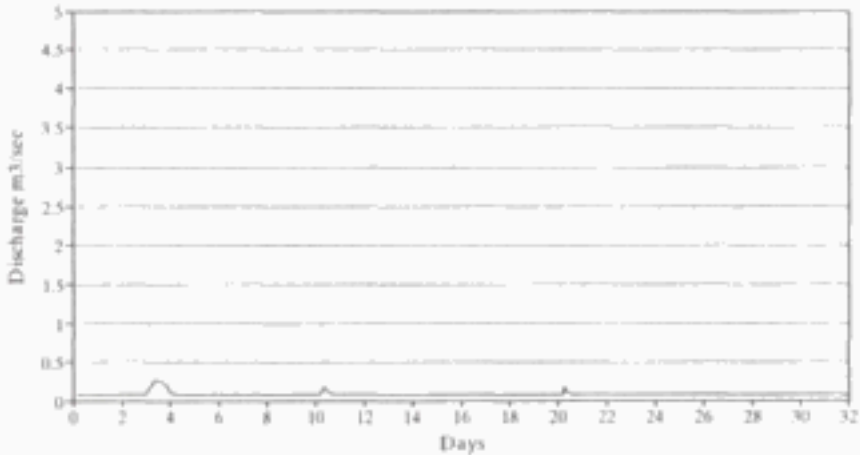

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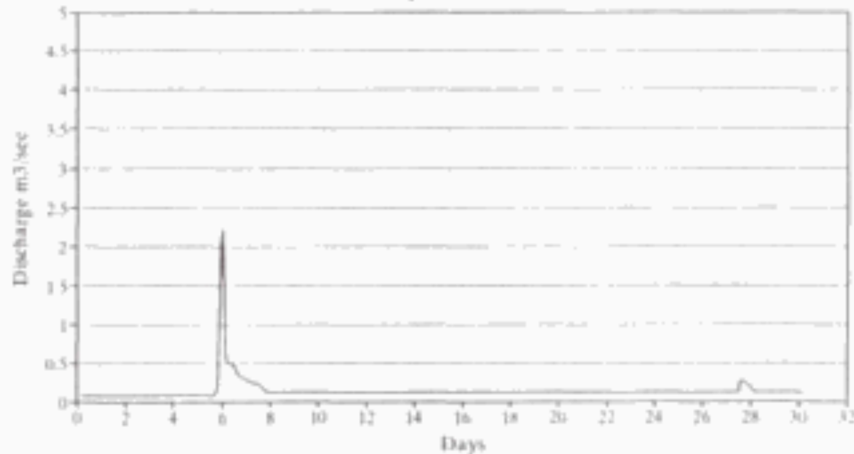

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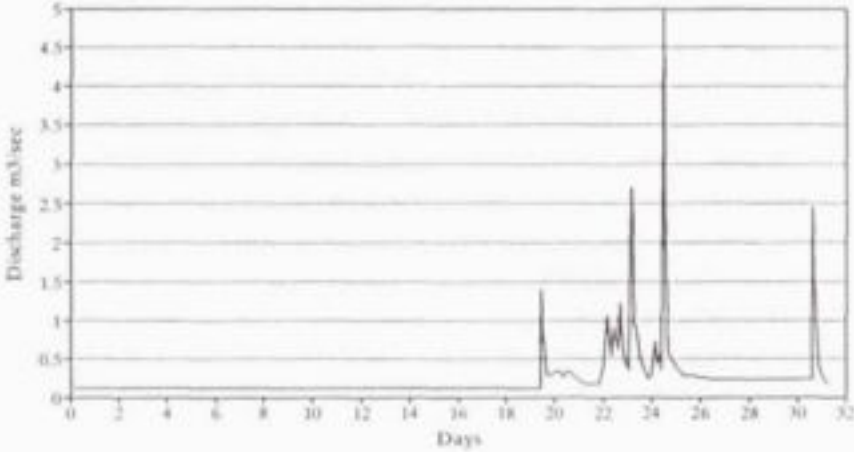

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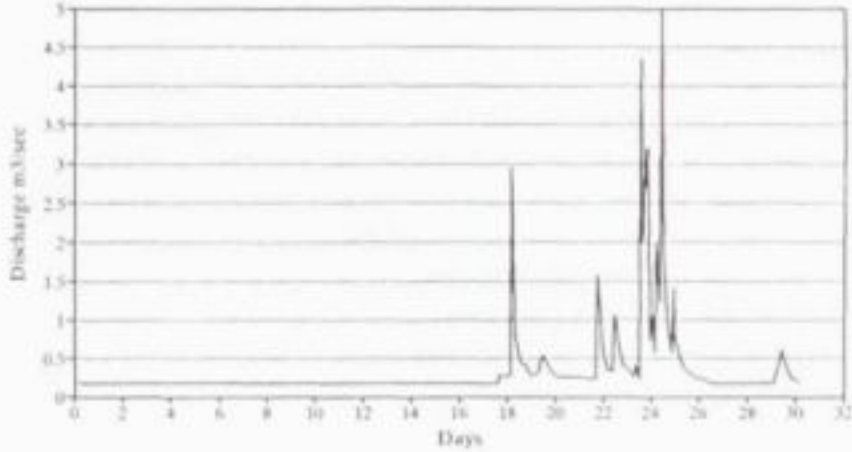
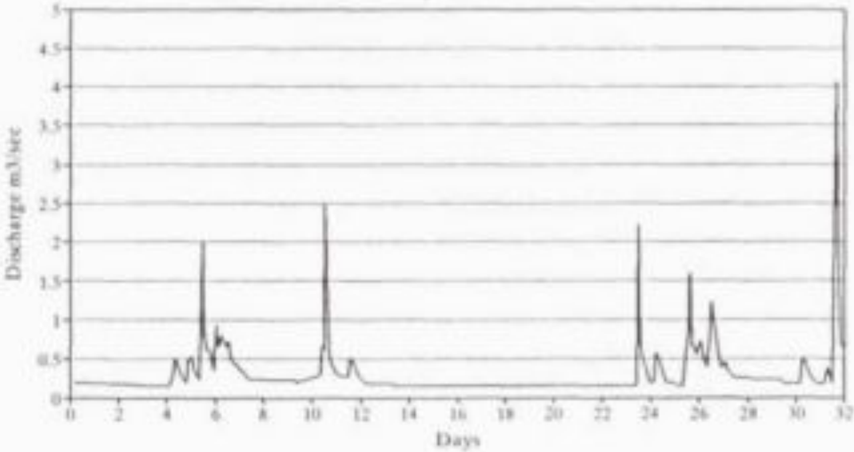
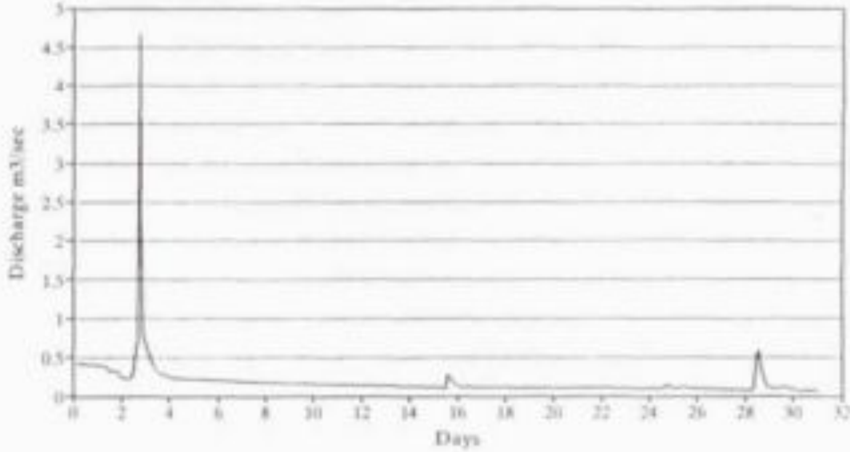


July 1991



August 1991



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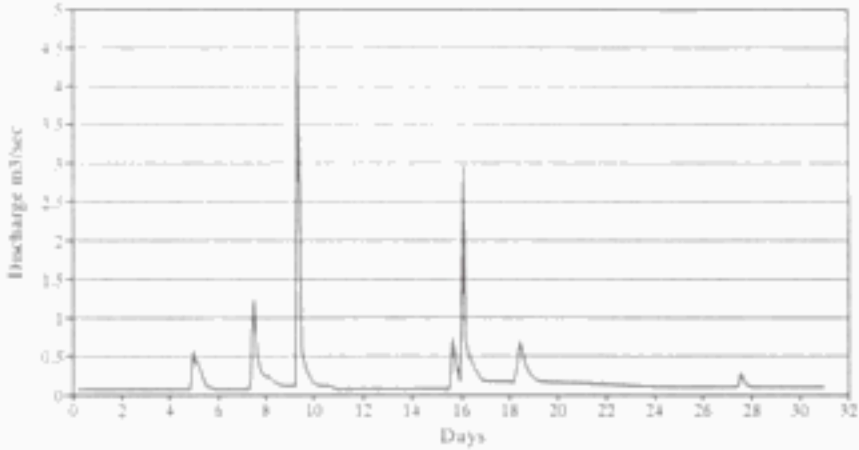

October 1991