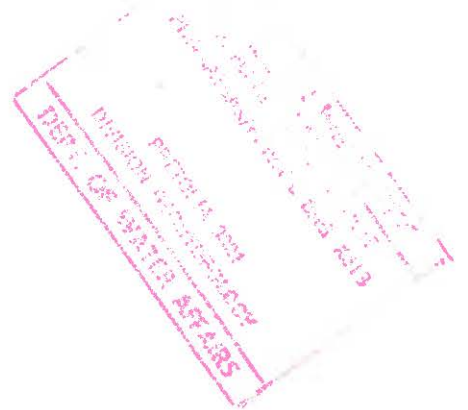


DEPARTMENT OF WATER AFFAIRS  
HYDROLOGICAL RESEARCH INSTITUTE



GROUNDWATER QUALITY  
CAPE FLATS GROUNDWATER DEVELOPMENT  
PILOT ABSTRACTION SCHEME

by

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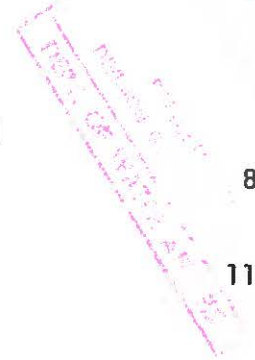
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1. INTRODUCTION

1.1 Background

During the past two decades a number of intensive investigations into the use of the Cape Flats aquifer as a potential water resource have been undertaken. These investigations were initiated by the Cape Provincial Administration in 1966 as a result of predicted future water shortages in the Cape Town metropolitan area. Further research by the National Institute for Water Research, funded by the Water Research Commission, was carried out during the 1970's. These studies focused on the feasibility of reclamation, storage and abstraction of water from the Cape Flats aquifer. The main emphasis of these investigations was on the definition of hydrogeological parameters; the use of sewage as a recharge medium and the generation of a model capable of simulating conditions in the aquifer under certain operating strategies.

By 1980 the emphasis had shifted away from the concept of re-use of reclaimed water to the exploitation of the natural groundwater. Proposals for a pilot groundwater abstraction scheme were made and drilling of the boreholes commenced in late 1982. The Cape Flats Groundwater Development Pilot Abstraction Scheme, as it later became known, was situated in the eastern portion of a high transmissive zone located just north east of the Mitchells Plain Sewage Treatment Works.

The scheme consisted of 10 production boreholes and 18 observation boreholes. In an agreement reached the project was to be undertaken jointly by the Department of Water Affairs and the Municipality of Cape Town.

After an initial period in which the boreholes were located, drilled, developed and tested, large scale, almost uninterrupted groundwater abstraction commenced in May 1985 and was completed in April 1988.

A logical consequence of the quantification of the groundwater in this portion of the Cape Flats was the investigation of the groundwater quality. This task was undertaken jointly by the City of Cape Town Engineer's Department, the Hydrological Research Institute and the National Institute for Water Research.

## 1.2 Purpose and scope

The purpose of this study was to monitor the groundwater quality in order to establish ambient groundwater quality in the study area. Also to detect any possible changes in quality of the abstracted groundwater during the operation of the Pilot Abstraction Scheme.

This report summarizes existing groundwater quality data and attempts to indicate the suitability of this groundwater as a potable water supply source.

It is not within the scope of this report to attempt a hydrogeochemical interpretation of the data.

## 2. LOCATION AND DESCRIPTION OF STUDY AREA

The study area (Figure 1) comprises only a small portion of the sand covered coastal plane known as the Cape Flats. The area under consideration consists of approximately 49 km<sup>2</sup>. The approximate boundaries are Weltevreden and Swartklip roads in the west and east respectively. The southern boundary is defined by the coast line extending from Strandfontein to Wolfgat, the northern boundary is just south of Phillipi.

The area under investigation is almost entirely urbanized. Surface water features are notably absent, with the exception of structures associated with the Mitchell's Plain sewage treatment works in the western portion of the study area. Agriculture is practiced in the north western sector of the area. The land surface slopes gradually upward from the coast line to a maximum altitude of approximately 50 m.a.m.s.l.

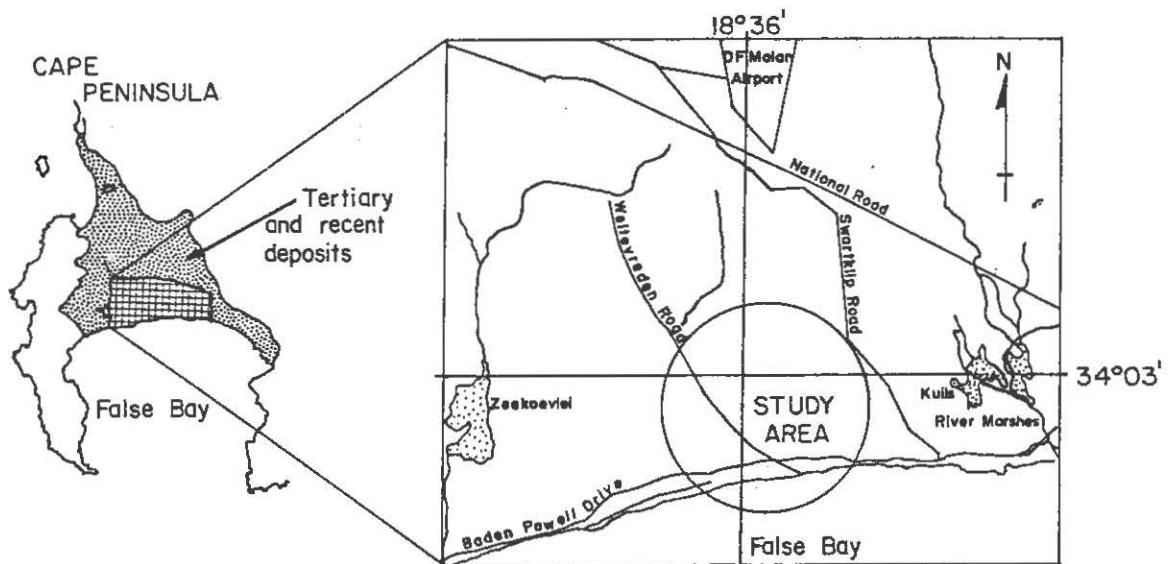


Figure 1: Location of study area.

The climate is typically Mediterranean, the rainy period being from May to September. Based on 22 years rainfall data from a gauging station at D.F. Malan Airport (north of study area) a mean annual rainfall of 509 mm was calculated, the range being from 344 to 751 mm/a (Gerber, 1980).

Based on 31 years of rainfall data from Zeekoeivlei (west of study area) a mean of 665 mm/a was calculated. Seasonal sub-series plots of data clearly indicate that the lowest mean rainfall occurs in November, December and January, and the highest in June and July. Temperatures range from approximately 11°C in winter to 20°C in summer (Henzen, 1973).

Natural recharge of groundwater in the Cape Flats takes place during the rainy season from April to September, with very little occurring during the summer months (Gerber, 1980; Henzen, 1973).

Recent work done within the study area by van Doolaege and co-workers (1989, in press) shows correlation of rainfall with recharge. Water levels have been monitored for both production and observation boreholes. It has been estimated that replenishment in the southern part of the Cape Flats aquifer is approximately  $60 \times 10^6 \text{ m}^3$  per year, and that more than 80% of this amount is lost by evapo-transpiration (Gerber, 1981).

No major point sources of pollution other than the sewage works and possibly the agricultural area in the north west are known to exist within the study area.

## 2.1 Previous investigations

The hydrogeology of the Cape Flats aquifer has been investigated extensively during the past two decades by a number of parties. Comprehensive investigations by Henzen (1973), Gerber (1976 and 1980) and more recently by van Doolaege and co-workers (in press) define the hydrogeological characteristics of the Cape Flats aquifer. The latter study focuses on the study area, specifically the Cape Flats Groundwater Development Pilot Abstraction Scheme.

## 2.2 Geology and hydrogeology

The aquifer itself consists of cenozoic deposits, the deposits consist predominantly of shelly calcareous and quartzone sands with lesser amounts of calcrete, gravel, clay and peat lenses. Sedimentation of these horizontally stratified deposits occurred in a shallow sea environment. Subsequent sedimentation took place during a marine regression and deposition progressed to intermediate beach and finally aeolian environments. Of particular interest is the calcareous deposits which appear to be more predominant in a narrow strip near the coastline.

Based on work done by van Doolaeghe and co-workers a number of lithological units have been recognised and mapped. Elevation of bedrock has been obtained from both drilling records (van Doolaeghe, 1989, in press) and geophysical studies (Meyer, 1980), the maximum depth reached during drilling was 19 m below m.a.m.s.l. The bedrock topography wedges gradually towards the north.

The lithostratigraphic units from top to bottom are as follows: the Bredarsdorp formation which consists of the Witzand, Langebane Limestone (locally known as the Wolfgat) and Springfontyn members. The above three members are composed of shelly and calcareous sands; calcrete and fine calcareous sand; and quartzone sands with peaty and calcareous clay lenses respectively. The Springfontyn and Witzand members are generally not found together and it has been suggested that decalcification of the latter by groundwater action resulted in the Springfontyn member. The Bredarsdorp formation is underlain by the Varswater formation which consists of the Calcareous Sand Member (CSM) and the Shelly Gravel (or Strandfontein) Member (SGM). The former consisting of fine to medium, often silty sand and shell fragments, and the latter comprising heavily weathered shell fragments and shelly sands. The basal aquifer unit, the Elandsfontyn formation is made up of fine to coarse

clayey sands and peat, peaty clay layers are prominent. Malmesbury group metasediments (age 600 to 700 my) form the basement on which the above units rest. This sequence has generally been described as a geosynclinal succession of sedimentary and high grade metamorphic rocks of marine origin.

Van Doolaege (1989, in press) states that the aquifer in the area under consideration varies from semi-unconfined to semi-confined. Details with regard to hydrogeologic parameters obtained during the Pilot Abstraction Scheme may be obtained from van Doolaege (1989, in press). Hydrogeologic parameters relating to the Cape Flats aquifer as a whole may be obtained from Gerber (1976 and 1980) and from Henzen (1973).

It has been suggested that the sands of the Witzand and Springfontyn members are by far the most important units from a production point of view. The hydrogeological models proposed may be found in works by van Doolaege and Gerber.

Varswater formation sediments form the aquifer when the highly transmissive Bredarsdorp sediments are absent. The CSM and SGM however have relatively low conductivities the net result being that Varswater formation sediments, act as the dominant bottom aquitand whenever Bredarsdorp formation sediments are present. The Elandsfontyn formation may be considered as an aquitand. The Malmesbury group has generally been regarded as an impervious basement but this may not be the case.

Water level measurements indicate that the general groundwater flow direction is towards the coast and that steeper piezometric gradients occur nearer the coast than further inland. The presence of a groundwater mound in the southwest of the study area may be a reflection of leakage from the maturation ponds at the Mitchells Plain Sewage Treatment Works.

### 3. WATER QUALITY

The investigation of the groundwater quality in the Cape Flats aquifer was undertaken jointly by the Hydrological Research Institute and the Directorate: Geohydrology of the Department of Water Affairs.

Due to an apparent shortage of manpower at the time of inception of the scheme (1985), it was decided that the National Institute for Water Research, funded by the Water Research Commission, in Cape Town would be responsible for the sampling of the 18 observation boreholes at a frequency of four times a year.

The Cape Town City Engineer's Department undertook to sample the 10 production boreholes on a monthly basis. The analyses of the above-mentioned samples were undertaken by the Hydrological Research Institute and the Cape Town City Engineer's Department.

In addition to this routine monitoring programme, samples were taken and analysed for microbiological and organic contamination by the National Institute for Water Research and the Hydrological Research Institute respectively.

#### 3.1 Data collection and methods

##### 3.1.1 Sampling and analysis

Figure 2 shows the location of the 10 production boreholes and 18 observation boreholes in the study area where water quality samples were collected.

Borehole drilling and construction details are summarized in Table 1. A table giving the various borehole identifiers and their longitude and latitude are given in Table 2.



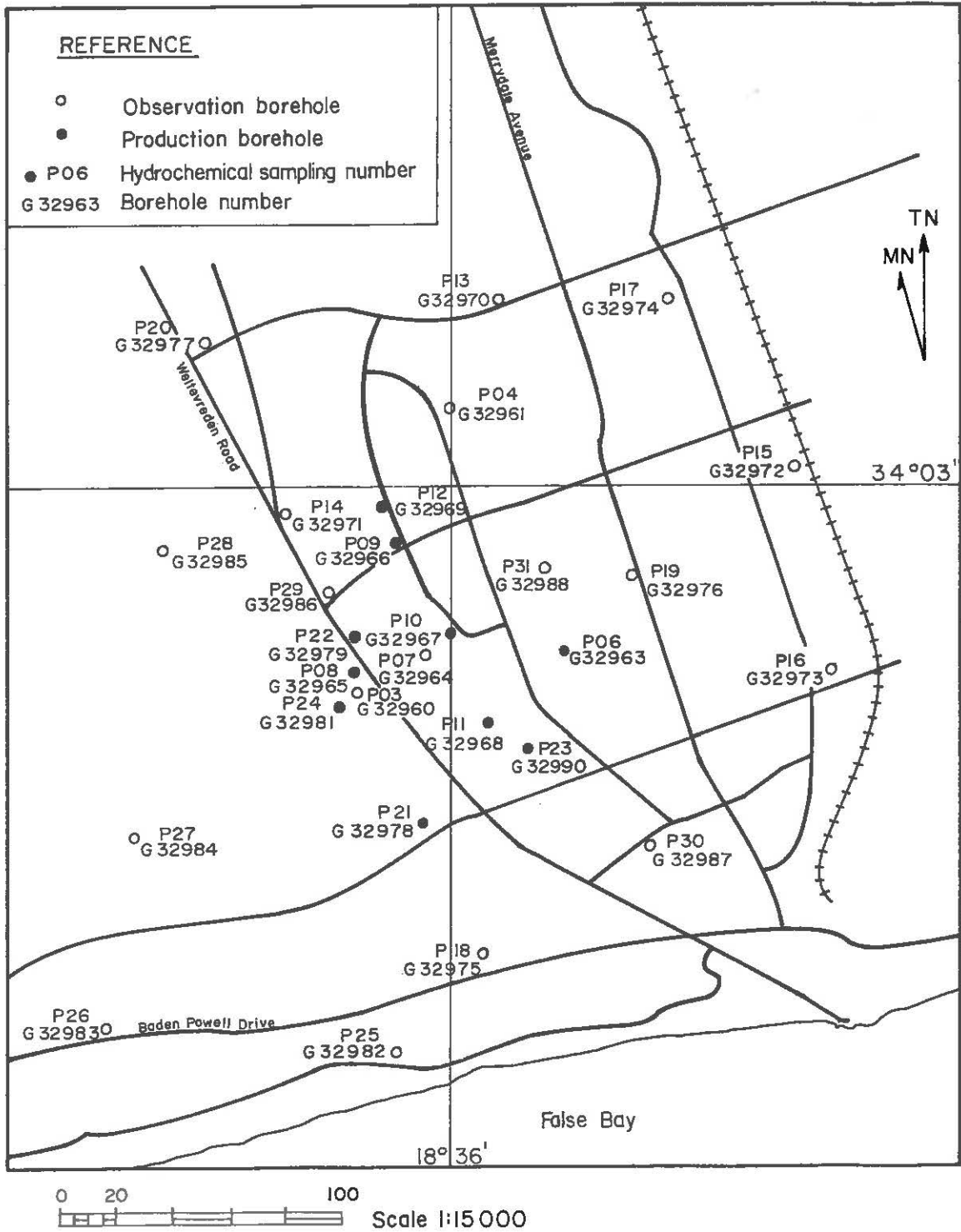


Figure 2: Cape Flats groundwater development pilot abstraction scheme location of hydrochemical sampling stations.

Table 1: Information pertaining to observation and production boreholes.

Ref. No.	Lithostratigraphic unit, thickness in m						Bedrock elevation m.a.m.s.l.	Drilling depth (m)	Water* level (m)	Collar elevation m.a.m.s.l.
	Witzand Member	Wolfgat Member	Springfontyn Member	CSM	SGM	Elandsfontyn formation				
P03	7	0	19	0	5	4	-15,2	350	4,250	19,800
P04	18	0	0	8	11	0	-9,4	40,0	6,595	27,610
P06	9	0	12	4	5	0	-10,6	36,0	3,940	19,366
P07	0	0	22	0	11	0	-12,0	33,6	3,920	21,040
P08	6	0	20	0	7	0	-13,1	33,0	4,250	19,854
P09	0	0	8	18	2	0	-3,5	28,0	5,710	24,460
P10	16	0	9	0	7	0	-8,2	32,0	7,310	23,768
P11	15	0	13	3	5	0	14,1	35,5	7,320	21,871
P12	1	0	19	6	12	0	12,0	39,0	6,120	26,015
P13	8	10	0	0	10	8	-8,9	39,0	3,745	27,076
P14	0	0	20	4	4	0	-2,4	24,0	4,640	25,649
P15	18	0	0	7	3	3	-6,7	33,0	4,440	25,319
P16	14	0	0	10	2	0	-4,6	26,5	4,590	21,433
P17	0	15	0	6	0	7	-0,9	28,0	2,245	27,150
P18	6	0	5	0	16	0	0,6	28,0	3,020	27,622
P19	0	0	9	11	6	0	0,0	26,0	7,700	26,009
P20	0	0	15	4	8	0	3,7	30,0	6,440	30,700
P21	0	0	8	11	9	0	77,4	41,0	5,911	18,624
P22	0	0	11	16	8	0	-13,0	35,1	4,730	21,977
P23	0	0	11	16	8	0	74,4	36,0	6,940	20,605
P24	10	0	19	3	6	0	-16,1	37,8	5,290	21,929
P25	4	0	6	0	14	0	-18,3	24,0	2,060	5,750
P26	10	0	15	14	2	0	-19,1	42,0	12,395	21,903
P27	11	0	16	12	0	0	-12,0	39,0	10,485	26,965
P28	6	0	20	4	6	0	-10,5	36,0	3,275	25,544
P29	4	0	19	1	6	0	-5,2	30,0	5,300	24,516
P30	12	0	0	13	14	0	-9,8	39,0	15,010	29,164
P31	2	0	9	11	8	0	-6,7	30,0	5,145	23,267

CSM - Calcareous Sand Member.

SGM - Shelly Gravel (Strandfontyn) Member.

\*Water level below collar April 1983.

(modified from Van Doolaege *et al.*, in press).

Table 2: Station reference data.

Ref. No.	Station No.	Borehole	Longitude	Latitude
P03	G2003	G32960	18°35'39"	34°03'37"
P04	G2004	G32961	18°36'00"	34°02'51"
P05	G2005	G32962	18°35'46"	34°03'13"
P06	G2006	G32963	18°36'05"	34°03'05"
P07	G2007	G32964	18°35'55"	34°03'30"
P08	G2008	G32965	18°35'40"	34°03'35"
P09	G2009	G32966	18°35'47"	34°03'12"
P10	G2010	G32967	18°36'04"	34°03'27"
P11	G2011	G32968	18°36'04"	34°03'39"
P12	G2012	G32969	18°35'47"	34°03'06"
P13	G2013	G32970	18°35'08"	34°03'06"
P14	G2014	G32971	18°36'04"	34°02'31"
P15	G2015	G32972	18°37'06"	34°02'25"
P16	G2016	G32973	18°37'16"	34°03'30"
P17	G2017	G32974	18°36'42"	34°02'28"
P18	G2018	G32975	18°36'10"	34°04'18"
P19	G2019	G32976	18°36'36"	34°03'18"
P20	G2020	G32977	18°35'00"	34°02'36"
P21	G2021	G32978	18°35'55"	34°04'00"
P22	G2022	G32979	18°35'40"	34°03'27"
P23	G2023	G32990	18°36'16"	34°03'44"
P24	G2024	G32981	18°35'33"	34°03'38"
P25	G2025	G32982	18°36'42"	34°04'25"
P26	G2026	G32983	18°34'00"	34°04'41"
P27	G2027	G32984	18°35'00"	34°04'00"
P28	G2028	G32985	18°35'00"	34°03'06"
P29	G2029	G32986	18°35'30"	34°03'18"
P30	G2030	G32987	18°36'42"	34°04'00"
P31	G2031	G32988	18°36'16"	34°03'12"

Production borehole pumping rates have been schematically represented in Figure 3.

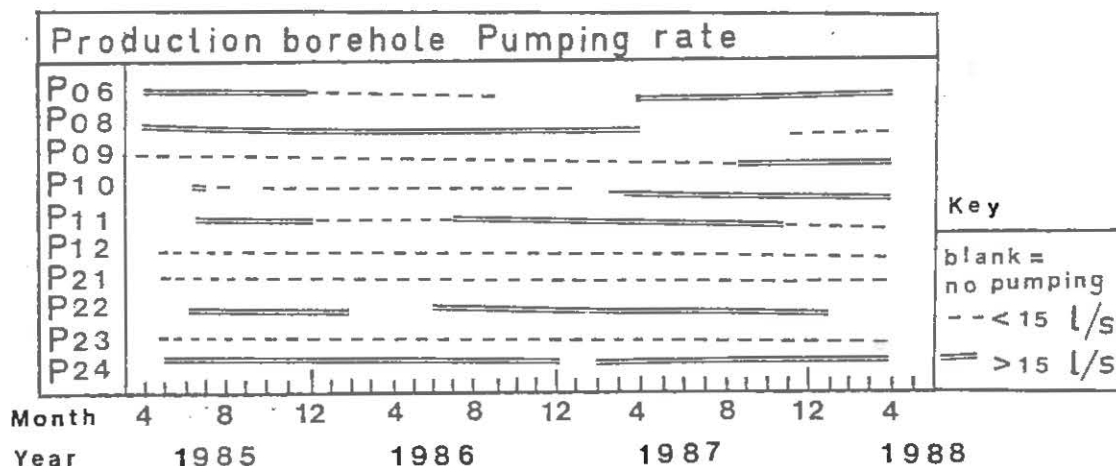


Figure 3: Production borehole pumping rates.

In order to minimize additional variations of chemical data which may have arisen due to sampling procedures, a definite protocol was established for the collection and preservation of samples. These procedures were consistently adhered to throughout the monitoring programme.

An investigation into the effects of well installation, purging and sampling techniques on the representativeness of the data obtained from samples is beyond the scope of this report.

Sampling from production boreholes was carried out during everyday pumping operations by means of a sampling tap. During periods in which pumping had been suspended, pumps were restarted and allowed to run for several minutes prior to sampling. This resulted in the well being flushed or purged, the samples taken then reflected aquifer and not well water quality. As soon after sampling as possible, total alkalinity, pH, conductance, UV and turbidity were measured. These determinations were made by the City of Cape Town Engineer's Department.

In view of the relatively long delay between sample collection and analysis (normally in the order of four to six weeks) and the consequent potential changes in chemical composition it was decided where available to use data provided by the City of Cape Town Engineer's Department. Analyses for pH and total alkalinity were undertaken by this organization with very little delay and probably represent actual conditions in the aquifer.

Anomalously low values for many variables noted in samples collected on the 25/06/86 are consistent with anomalously high values of certain trace elements (barium, zinc and aluminium) and were considered to be outliers.

Prior to sampling from observation boreholes, pumps were started and the boreholes purged until a constant conductivity was achieved, only then was a sample taken.

During each routine sampling episode three samples were collected in 350 ml polyethylene bottles. The samples to be analysed for major inorganic, physical and nutrient constituents were preserved with 1 ml (6 mg/l) mercuric chloride solution. The two remaining samples on which trace metal determinations were to be made were preserved with nitric and sulphuric acids.

None of the samples were filtered directly after sampling, prior to chemical analysis.

A number of boreholes were sampled for microbiological quality in February 1986 by the National Institute for Water Research, CSIR (Belville).

Samples were also taken and analysed by the Hydrological Research Institute, for trihalomethanes. These samples were collected in 25 ml glass bottles, the bottles being filled and closed to exclude air. No filtration or preservation was carried out.

### 3.1.2 Results

The results of the aforementioned sampling programme are given in Tables 3 and 4, and in Appendix B.

All hydrochemical data collected prior to and during the operation of the Cape Flats Development Pilot Abstraction Scheme are presented in Appendix A.

The following comments are applicable to the data. In all the tables the concentrations are expressed in milligrams per litre (mg/l) except for conductivity, pH, UV, turbidity and colour. Conductivity and pH are expressed in millisiemens per metre and pH units respectively. Turbidity in NTU's, UV in absorbance units, and colour in units on the platinum-cobalt scale. The determinands have been expressed as follows: total alkalinity as  $\text{CaCO}_3$ ;  $\text{SiO}_2$  as Si;  $\text{PO}_4$  as P and  $\text{NO}_3$  as N. Total dissolved salts have been calculated by summation of the individual anion and cation concentrations.

In the Appendices the asterisks denote missing values. Values for total alkalinity, pH, turbidity, UV and colour were supplied by the City of Cape Town Engineer's Department.

All values have been reported, even values below detection limits. Table 5 (Appendix A) shows water quality variables and detection limits. Values appearing to represent outliers were resubmitted for analysis, if consistent these values were included.

Table 3 shows microbiological quality of water from observation boreholes sampled on 13th February 1986. The results were supplied by the National Institute for Water Research, CSIR, Belville.

Results of trihalomethane (THM) determinations are reported in Table 4, these analyses were carried out by the Hydrological Research Institute. Analyses were made using gas/liquid chromatography. These values are in micrograms per litre.

### 3.2 Status of groundwater quality

A hydrochemical interpretation of the data is not within the scope of this report. The intention of this report is merely to summarize data obtained during the period in which the Cape Flats Development Pilot Abstraction Scheme was in operation.

#### 3.2.1 Spatial variations in groundwater quality

Comparisons of groundwater quality among samples obtained from production boreholes for the period August 1985 to April 1988 were done by means of box plots (Figure 4a to 4n, Appendix A). Statistical summaries of water quality variables of all boreholes have been computed and are presented in Table 6 (Appendix A) as have statistical data pertaining to all the samples taken, Table 7 and 8, Appendix A).

The median and percentile values were used as a method of comparison for a number of reasons. Water quality data and specifically groundwater quality data has frequently been shown to be non-normally distributed being bounded at zero and highly skewed to the right. (Helsel, 1987; Harris *et al.*, 1987). In addition the data may exhibit both seasonality and serial correlation. Thus the commonly used parametric statistical methods based on the assumption of an underlying normal distribution and of large sample size are often inappropriate. Data pertaining to trace metals is often characterized by less than detection limit values.

The use of distribution free statistics has been chosen. Presentation of the data using box plots gives an indication of the nature of the underlying population (i.e. its distribution).

Statistical terms used in summarizing the water quality data are defined as follows:

MAXIMUM is the largest value in a group of measurements.

MINIMUM is the smallest value in a group of measurements.

MEDIAN is the value of middle measurement of an uneven number of ordered measurements, or the mean of the middle two measurements when there are an even number of measurements.

THE 10th PERCENTILE is that value in a group of measurements below which 10% of the total number of measurements occur. (Similarly for the 5th, 95th, etc).

MEAN is the sum of a number of measurements divided by the number of measurements.

STANDARD SKEWNESS is the third moment about the mean divided by the cubed standard deviation. It tests for significant deviations from the normal distribution. It has been suggested that for large samples, values of greater or less than +2 or -2 for the skewness coefficient may indicate that the data departs significantly from a normal distribution.

Figures 4a to 4n are box and whisker plots of concentrations of water quality variables for production boreholes and may be found in Appendix A as may Tables 6 and 7.

#### Water quality variables

##### Total dissolved salts (Figure 4c and Tables 6 and 7)

Dissolved salts represent the major cations and anions and have been calculated from analyses as explained previously. The median values for TDS from production boreholes range from 566 mg/l (P24) to a maximum of 763 mg/l (P21). The median concentration range for all boreholes is from 278 mg/l to 887 mg/l. Average values usually fall on the lower side of the median except in P09 in which the effect of high values during the initial period of pumping are seen. The greatest range of TDS values noted in production boreholes are in P09 and P11 and the smallest in P23 and P24. Observation boreholes have



an extremely large range in TDS, from 218 mg/l in P13 to 1 161 mg/l in P20. P20 has an average of 975 mg/l this is by far the highest value. This is possibly a reflection of its position in relation to the agricultural area in Phillipi. Water level measurements taken at this borehole indicate that it is beyond the sphere of influence of the pumping operation and hence variability of concentration is a result of "natural effects". During three sampling episodes on the 25/6/86, 17/9/86 and 21/1/87 very low TDS values were observed in all boreholes, the reason for this sudden drop in concentration does not appear to be related to either changes in pumping, water levels or rainfall. Bulk TDS values appear to be normally distributed.

Figure 5 illustrates the relationship between TDS and conductivity. A simple least squares linear regression was performed. A correlation coefficient of 0,864 and R-squared value of 74% were calculated. The estimated regression line and 95% confidence and prediction limits have been superimposed.

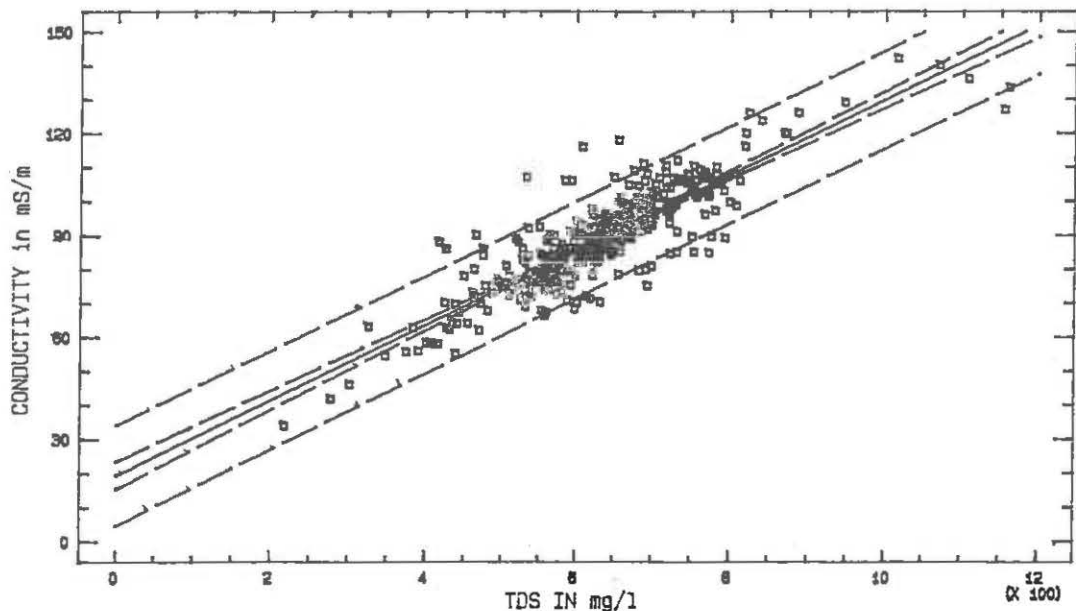


Figure 5: Relation of conductance to total dissolved salts Cape Flats aquifer 1985-1988.

#### pH (Figure 4a and Tables 6 and 7)

pH values range from 5,8 to 8,5 pH units, however more than 90% of all values lie in the range 7,5 to 8,5 pH units. Measurements of pH below 7 are extremely rare and are limited to one sampling episode on the 25/6/86. The value of 5,8 was recorded at P08 on 25/6/86 but is not consistent with other values observed at that borehole. The low values may be as a result of very heavy rainfall in early June. However, the values measured the following year after heavy rainfall were not significantly different from the median.

Observation borehole P20 is a noticeable exception in terms of pH, having values ranging from 6,78 to 6,79 pH units compared to values of between 7 and 7,5 for all other boreholes. P20 is situated in the extreme north west of the study area.

#### Sodium (Figure 4d and Tables 6 and 7)

Sodium salts are extremely soluble and there appear to be few precipitation reactions controlling the amounts of sodium in solution as is the case with calcium (Hem, 1970). The dominant processes controlling its occurrence are probably dispersion and absorption-desorption mechanisms.

The contamination or intrusion of the water body by saline waters does not appear to be a problem in this case (with the possible exception of P25). Median concentrations of sodium for three of the four boreholes closest to the False Bay coast line are below 62 mg/l. The borehole closest to the coast line (approximately 300 m) P25, has a median sodium concentration of 88 mg/l. Furthermore none of the above-mentioned boreholes show any response to the large scale abstraction of groundwater by the production boreholes during the period 1985 to 1988. The presence of a low transmissive zone (Varswater sediments) in the coastal zone and steep piezometric gradients have already been mentioned.

A minimum and maximum sodium concentration of 22 and 113 mg/l respectively and a median value of 61 mg/l was observed for the 403 samples taken during the period August 1985 to April 1988. The distribution of values appear to be normal with 90% of the values falling within the range 40 to 94 mg/l.

Five of the production boreholes, namely P08, P09, P10, P22 and P24, have median sodium concentrations of below 60 mg/l. These boreholes are situated in the central western portion of the production well field and characteristically lack sediments from the Wolfgat Member and Elandsfontyn formation. The largest ranges in concentration were observed in samples taken from P09 and P11.

Of all the boreholes monitored P31 has the highest median sodium concentration, 100 mg/l, in this case sodium replaces calcium as the dominant cation.

It has been suggested that the dominance of chloride, sodium and potassium ions over calcium and bicarbonate ions in the central and central northern portions of the study area could be explained by the presence of a wide interdual and vlei-like area prior to the urban development.

#### Calcium (Figure 4e and Tables 6 and 7)

The median calcium concentration for the 403 samples taken and analysed during the three year sampling period was 103 mg/l. A maximum concentration of 230 mg/l was measured in P20, this value although high when compared to other values is fairly characteristic of that borehole. The median concentration of P20 is 189 mg/l. The highest median concentrations observed in all boreholes were in P20, P12 and P14 all of which are located in the extreme north west of the study and consist primarily of Springfontyn and to a lesser extent of SGM sediments. Both lithostratigraphic units contain large amounts of calcareous material. The relatively high concentrations of both calcium and sulphates in the north west may also be related to the agricultural activities in this area (either through fertilization or soil amelioration).

It is worth noting that 90% of all concentrations of calcium fall within the range 66 to 130 mg/l. The relatively small spread of median values of production boreholes may be seen in Figure 4e. The largest range occurred in P09 and P11. Calcium appears to be the principal cation with the possible exception of P31.

#### Magnesium (Figure 4f and Tables 6 and 7)

Ninety percent of all magnesium concentrations lie within the range 8 to 17 mg/l magnesium. The median value is 12 mg/l. Both production and observation boreholes show very limited ranges in magnesium concentrations. In only two cases (P20 and P16) are median values greater than 15 mg/l. These boreholes being situated in the extreme north west and north east of the study area respectively.

#### Potassium (Figure 4g and Tables 6 and 7)

Concentrations of potassium range from 0,6 to 8,2 mg/l with a median value of 1,9 mg/l and a mean of 2,3 mg/l. The reason for the large difference between mean and median is a result of the positively skewed distribution. The majority of production boreholes (all but P21) show very small ranges in values and concentrations generally do not exceed 3 mg/l with the exception of what appear to be outliers in P06 and P09. Production borehole (P21) and observation borehole (P25) have median concentrations of 5,7 mg/l - a possible explanation for this is that they are situated down gradient (water levels) from the sewage treatment works. The presence of groundwater mound in this vicinity may be due to leakage from the maturation ponds and canals carrying sewage waste to the sea. The possibility exists that P25 is (or was in the past) influenced to some extent by the intrusion of saline waters.

### Hardness (Table 7)

A median hardness of 309 mg/l as  $\text{CaCO}_3$  was calculated for all samples collected during the three year sampling period. Ninety percent of all values fall between 213 and 378 mg  $\text{CaCO}_3$ /l. Production boreholes have hardness values ranging from 284 mg/l in P24 to 368 mg/l in P12. Most values are however close to 320 mg/l. The observation boreholes exhibit a much wider range namely 205 in P03 to 573 in P20.

### Alkalinity (Figure 4h and Tables 6 and 7)

Median concentrations range from 250 to 390 mg/l (as  $\text{CaCO}_3$ ) in the production boreholes. The higher value measured comes from P21 and this borehole has a median concentration of 390 mg/l (as  $\text{CaCO}_3$ ). The majority of production boreholes show distributions of TAL which are skewed toward higher values with the notable exceptions of P21, P23 and P24.

### Sulphate (Figure 4i and Tables 6 and 7)

Sulphate concentrations range from 0 to 326 mg/l, the median concentration for all the samples is 45 mg/l. The production boreholes have a range of 18 to 125 mg/l, this is if the outliers are excluded. In all but three cases (P09, P11 and P12) the range in concentration from the 95th to the 5th percentile is less than 50 mg/l. Observation boreholes P20 and P14 have median sulphate concentrations greater than 100 mg/l while median values of less than 20 mg/l were observed in P15 and P28.

Both P20 and P14 (highest sulphate values) occur in the north west of the study area and are comprised chiefly of Springfontyn, CSM and SGM sediments. While P15 and P28 (lowest sulphate values) are found in the extreme eastern part of the study area. The presence of higher concentrations of sulphate in the north west is probably also related to the use of gypsum or ammonium sulphate in the agricultural areas near Phillipi.

#### Chloride (Figure 4j and Tables 6 and 7)

A maximum chloride concentration of 211 mg/l was observed in P31. The median concentrations of chloride in observation boreholes exhibit a large range in results, from 50 mg/l (P19) to 190 mg/l (P31). The range of median concentrations in production boreholes is much narrower, 90% of all results lie within the range 73 to 164 mg/l. The smallest ranges being found in P10, P24, P21 and P22.

#### Fluoride (Tables 6 and 7)

Fluoride concentrations in groundwater with a high calcium content are fairly rare. The natural concentration of fluoride appears to be limited by the solubility of fluoride (Hem, 1970). In only one instance was a concentration of greater than 0,4 mg/l observed, 0,7 mg/l in P08, this value is not consistent with other observations made at this borehole.

#### Nitrate (Figure 4k and Tables 6 and 7)

Most nitrates in natural waters are derived from organic sources or from industrial and agricultural chemicals. Although small amounts may be present in certain rocks the contribution is probably insignificant.

The median nitrate concentration of all the samples is 1,53 mg/l  $\text{NO}_3$  as N, a maximum and a minimum of 19 and 0 mg/l respectively, were observed. Production boreholes P09, P12 and P22 have values not exceeding 1 mg/l. These boreholes are situated in the north western corner of the production well field. Nitrate concentrations in P08, P10, P24 and P21 rarely exceed 4 mg/l. A single observation of 17,4 mg/l recorded in P21 is not consistent with the other results obtained for this borehole and is probably an outlier. In some cases sampling episodes have been identified in which nutrient values are significantly lower than the expected value, these



observations may be related to sampling techniques or the failure to preserve samples. Fortunately it was possible to check certain values against data obtained from the Cape Town City Engineer's Department. Although the data sets are not exactly the same similarities are observed. (Figure 6a).

Production boreholes P06, P11 and P23 show the largest range in results and also the highest median values, namely 5,1 mg/l. All three boreholes lie within the south eastern sector of the production well field. Observation boreholes in the extreme eastern portion of the study area (all beyond the influence of the production boreholes) P16, P17, P19 and P30 have a high median nitrate concentration. The range being from 5,9 mg/l (P30) to 15,25 mg/l  $\text{NO}_3$  as N (P16).

Silica (Figure 4l and Tables 6 and 7)

Silica (as Si) ranges in concentration from 1 to 17,5 mg/l with a median concentration of 4,1 for 403 samples. Both the minimum and maximum concentrations appear to be outliers. It is noted that 90% of all values fall within the range 3,4 to 5,4 mg/l. Samples taken from production boreholes show very little spread of results, median concentrations range from 3,9 to 4,9 mg/l. Distribution of silica values appear to be normal. Only observation borehole P20 exhibits an above average median concentration. P20 is situated in the extreme north west of the study area.

Ammonia (Figure 4m and Tables 6 and 7)

Concentrations of ammonia range from 0 mg/l to 31,9 mg/l. The median value for all samples is 0,1 mg/l. Ninety five percent of all observations have concentrations of less than 0,6 mg/l and in fact seventy five percent of all observations are lower than 0,19 mg/l. The distribution is highly skewed towards higher values.

A closer look at the data reveals the following: The maximum concentration observed in P09 is 20,2 mg/l, this result is almost definitely an outlier and if not excluded biases the results. P20 and P22 both indicate slightly higher median concentrations than the median values for all samples. One obvious exception is P21 in which the ammonia concentration ranges from a minimum of 0,4 to a maximum of 31,89 mg/l.

This result suggests that appreciable nitrification is apparently not taking place. The location of borehole P21 is down gradient of the Mitchell's Plane Sewage Treatment Works. Leakage from the maturation ponds and canals is supported by both hydrogeological and chemical evidence, high concentrations of potassium, phosphate, Kjeldahl nitrogen, dissolved organic carbon and relatively high UV absorbance have also been noted in this borehole.

It has been suggested that the disposal of treated sewage effluent from an activated sludge plant may not be detrimental to the aquifer. However, leachates from sludge drying beds should not be permitted to reach the aquifer (Tredoux, 1983).

#### Phosphate (Figure 4n and Tables 6 and 7)

Phosphate concentrations range from 0 to 1,35 mg/l as P with a median value of 0,011 mg/l. The highest median concentration of 0,187 mg/l was observed in P21. As previously mentioned this borehole is situated near the sewage treatment works. The only other location where concentrations greater than 0,1 mg/l were observed was in P09 and here only on two occasions.



### Colour

Colour (expressed in units on the platinum-cobalt scale) may result from the presence of humus and peaty materials, industrial wastes and natural metallic ions. The colour number is determined by purely empirical methods and has no direct chemical significance. Colour of 2 was observed for all but 4 of the samples taken. Colour of 5 was noted in boreholes P20 and P31 in February 1986 and in P27 and P29 in August 1986.

### Turbidity and UV

In ninety percent of the cases turbidity was below ~16 NTU's (Nephelometric turbidity units) and the median value was 4 NTU's. Notably higher values were observed in P20, P21, P31 and P29. The median value in P29 being 43 NTU's.

UV determinations have been made in order to indicate the amount of dissolved organic substances such as humic and fulvic acids. In most cases samples collected have absorbances of less than 0,2 with the exception of P21, P27, P25 and P20. Production borehole P21 has values ranging from 0,17 to 0,41 absorbance units, increasing in value throughout the period of pumping.

### Microbiological quality (Table 3)

Unfortunately only one set of analyses is available for the observation boreholes (Table 3). Coliform or faecal coliform bacteria have been used as indicators of pollution. The coliform group is made up of a number of bacteria. Total coliform bacteria have been associated with faeces of warm-blooded animals and with soil. Total coliform counts are used as indicators of overall bacteriological quality. Undisinfected secondary effluent contains numerous micro-organisms including faecal coliforms.

Although no limits have been suggested for the raw water quality objectives for potable water use, the following have been recommended for drinking water (Kempster *et al.*, 1980). Faecal coliforms minimum and maximum of 0,0 and 2 000 counts respectively and total coliforms 0,1 and 50 000 counts respectively. Both limits are expressed as counts/100 ml and apply before chlorination.

In the majority of cases observation boreholes containing the highest counts occur in the north and north east of the study area.

Table 3: Microbiological quality - observation boreholes (sampled 13/2/86)

Station Reference	Borehole No.	Total Coliforms	Faecal Coliforms
P07	G32964	108	56
P13	G32970	780	688
P14	G32971	520	0
P15	G32972	0	0
P16	G32973	296	268
P17	G32974	36	24
P18	G32975	0	0
P19	G32976	16	12
P20	G32977	1 500	0
P25	G32983	0	0
P28	G32985	0	0
P29	G32986	0	0
P31	G32988	0	0

Analyses supplied by National Institute for Water Research, Belville.

## Trihalomethane formation potentials (Table 4)

The THM formation potential is the maximum concentration of THM which could form on excessive chlorination of the water and is essentially an indication of the concentration of precursors present in the raw water.

Formation potentials for both P20 and P21 consistently showed concentrations of above 400 and 200 micrograms per litre respectively. Observation borehole P20 is located in the extreme north west of the study area while production borehole P21 is situated down gradient of the sewage treatment works in the southern portion of the study area.

Table 4: Trihalomethane analyses  
(Concentrations in micrograms per litre).

Borehole No.	Date				
	23/07/86	13/08/86	18/02/87	24/06/87	07/10/87
	Instantaneous THM's (Totals) Formation Potential (Total)				
P04		1,06	4,02		0,27
		138	29		176,
P06	5,5		3,3	4,24	
	30		34	228	
P07		1,67	5,06		0,14
		126	188		165
P08	2,4		2,7	2,83	
	150		129	370	
P09	1,1		1,69	7,69	
	156		49	26	
P10	5,1		0,84	0,89	
	133		179	131	
P11	4,1		4,84	6,8	
	130		8	126	
P12	1,7		0,39	5,92	
	129		194	180	
P13		1,77	1,56		0,17
		91	14		116
P14		0,64	4,96		0,15
		358	24		325
P15		0,45	2,26		0,42
		68	61		71

Table 4: (Continuous).

Borehole No.	Instantaneous THM's (Totals) Formation Potential (Total)				
	Date				
	23/07/86	13/08/86	18/02/87	24/06/87	07/10/87
P16		1,63 155	2,68 88		1,23 196
P17		4,64 68	4,52 7		0,15 75
P18		5,99 173	4,03 7		0,13 212
P19		21,33 171	9,89 32		8,53 165
P20		1,35 724	4,14		0,12 431
P21	5,1 209		4,62	2,58 294	
P22	1,7 140		2,30 15	5,05 130	
P23	2,5 180		2,55 17	0,75 194	
P24	0,17 142		1,74 92	6,03 97	
P25		3,82 388	1,4 146		0,09 331
P26		2,32 169	1,35 149		0,09 337
P27		4,43 336	1,63 201		0,10 283
P28		4,48 385	4,41 11		0,13 349
P29		2,89 199	4,96 5,02		0,10 206
P30		2,98 131	3,01 133		3,35 176
P31		4,82 62	2,79 38		0,45 224

### 3.2.2 Temporal variations in groundwater quality

Time series plots of individual water quality variables, water levels, pumping rates and rainfall data were used to assess changes in water quality over the period August 1985 to April 1988.

Only data from production boreholes were analysed as it was considered unrealistic to try and define trends in quality in observation boreholes taking into account what appears to be large natural fluctuations of fewer than 10 data points.

Numerous problems were encountered when attempting to study changes in the water quality. Amongst these were the following: comprehensive data records during only part of the period of abstraction (August 1985 to April 1988) exist for only 10 production boreholes; the availability of data prior to large scale abstraction of groundwater was limited and interpretation was complicated by the fact that different sampling and preservation techniques were used. In addition pumping rates of production boreholes varied during the three year period, with periods of no abstraction being recorded at times in certain boreholes. Obviously hydrogeological parameters such as the different conductivity and transmissivity of different aquifer units resulted in different quantities of water being abstracted from different lithostratigraphic units.

Various authors have shown that seasonality of some water quality variables exist, especially in shallow unconfined aquifers (Harris *et al.*, (1987)). However, seasonality was not observed in any of the groundwater quality variables, even though definite periods of recharge were observed. Henzen (1973) in an extensive thesis on the Cape Flats aquifer concludes that no seasonality in concentration of water quality variables exists. Even if any was present within the study area for any or all the determinands this would have been obliterated by the intensive pumping and resulting homogenization of water quality from different horizons.

The suggestion has been made by various authors that only quarterly samples are required in order to guarantee independence of samples. It was however considered impractical to do this especially taking cognizance of the fact that limited data was available and that detailed statistical analysis was not attempted.

The differences in concentrations of water quality variables amongst boreholes in the study area are large. It is for this reason that only data pertaining to the boreholes sampled during the pilot abstraction scheme have been used to obtain an idea of background quality before pumping. The notion of a regional background quality was not acceptable. The large variations may be seen by comparison of nitrate values during the drilling of boreholes.

Time series plots of some but not all water quality variables may be seen in Figures 6a-6l (Appendix B).

#### Total dissolved salts

Decreasing concentrations of total dissolved salts (TDS) were observed during the pumping period. P06 shows a decrease from ~680 mg/l to ~635 mg/l. Very low values were observed during a period of no pumping from October 1986 to March 1987, this decrease in pumping rate was accompanied by an increase in water level. Decreasing TDS concentrations were also observed in P09, P11, P12 and P23. Decreased pumping rate in P11 from January to June 1986 appears to have resulted in a slight increase in TDS during the same period, once pumping resumed the general decrease appears to have continued. In only one case was an increase in TDS observed in P24.

TDS values have been calculated by summing the major anions and cations. A detection limit of 1 mg/l has been estimated and in all of the above cases trends observed are to be considered as real and not due to random fluctuations.

Of special significance are the sampling events of 17/9/86 and 21/1/87, samples taken on these dates exhibit extremely low TDS concentrations. The reason for this is unknown and no significant changes in pumping rates, water levels or especially heavy rains occurred prior to these sampling episodes.

In many cases the large ranges in concentrations noted in the previous section are due to the increase or decrease in concentration during the three year period.

#### Sodium

During the three year period (1985 to 1988) in which the abstraction scheme was in operation decreasing concentrations in sodium were noted in six of the ten production boreholes. Although decreases of approximately 20 mg/l were noted in most cases, these are large in comparison to the small variability observed between successive results. Extremely low concentrations were noted in P11, P12 and P21 during the sampling event 21/1/87. Although insufficient data points exist to make conclusive statements regarding trends in observation boreholes, decreases in sodium concentration possibly exist in P19 and possible increasing concentrations exist in P28 and P18.

#### Magnesium

Magnesium concentrations appear to remain constant throughout the period of pumping with the possible exception of P06, concentrations of 15 mg/l were observed during May 1985 and dropped to 11 mg/l by April 1988.

#### Silica

Silica content in all but one of the production boreholes remained constant during the three year period. Time series plots of silica in P21 indicates that the concentration increased during this period, data obtained prior to August 1985 support these observations.

### Chloride

Increases in chloride concentrations were observed in only one of the production boreholes during the three year period. An initial increase in P23 during 1985 to mid 1987 was followed by a decrease in the latter part of 1987 and early 1988. Decreases in chloride were observed in P06, P08, P09, P10, P14, P12 and P22. P09 exhibits an increase in concentration in 1988, this may be due to an increased pumping rate during that period.

### Sulphate

Time series plots of sulphate concentration for production boreholes are almost all characterized by large fluctuations or variations in concentration during the first year of pumping. This variation in concentration appears to have decreased somewhat in some boreholes during the latter part of the pumping episode. Increases in sulphate concentrations were observed in the period 1985 to 1988 in boreholes P21, P24 and P10. The initial increase in P10 was followed by a decrease during the latter part of 1987 and early 1988. Decreases in sulphate concentration were observed in P08, P09 and P23. The initial rapid decreases in P09 became less dramatic in the latter part of 1986. Amongst the observation boreholes P18 shows an increase in sulphate. P18 appears to be beyond the influence of the drawdown due to pumping.

The sulphate values obtained during the initial sampling periods and during drilling are often very different to those taken during the period August 1985 to April 1988. However in certain cases P08 and P09 values taken during the operation are consistent with trends observed prior to August 1985.



## Nitrate

Time series plots of nitrate show both increases and decreases in concentration during the period 1985 to 1988. Increases in concentrations have occurred in P06 and P10, these observations are consistent with data obtained during drilling, pump testing and the initial period of pumping. During the period in which no pumping took place in P06 a decrease in nitrate concentration was observed. Very low nitrate concentrations are common to samples collected on the 22/4/87, with the exception of P23, the reason for this is unknown. P08 may exhibit a decrease in nitrate concentration after an initial increase. Although the nitrate concentration in P09 remains constant throughout much of its history, it appears to be showing an increase towards the end of 1987 and the beginning of 1988. This could be as a result of increased pumping during that period.

## Kjeldahl Nitrogen, Total Phosphorus and Ammonia

Chemographs of Kjeldahl nitrogen (KN), total phosphorus (TP) and ammonia ( $\text{NH}_4$ ) all exhibit very little variation about the median value, they are, however, often very different in their order of magnitude. Both KN and ammonia show no systematic changes in concentration with the exception of P24 and P21. P24 shows a slight change in ammonia concentration with concentrations increasing during the period of pumping.

P21 however, shows large changes in both KN and  $\text{NH}_4$ , the former increasing from ~7 to ~25 mg/l and the latter a marked increase from ~5 to ~20 mg/l. Total phosphorus shows an increase from 0,2 mg/l (August 1985) to 1,8 mg/l (March 1988). Data obtained prior to pumping are not consistent with these observations and in fact show P21 to contain very little  $\text{NH}_4$ . This may be as a result of the sampling and preservation methods used. No preservatives were used prior to August 1985. It seems inconceivable that  $\text{NH}_4$  concentrations can increase from 0,07 mg/l on the 27/6/85 to 5,43 mg/l less than two months later, unless poor quality water was being "drawn in" from a nearby pollution source e.g. sewage treatment works.

Pumping of and water levels in the production borehole P21 remained fairly constant. The closest observation borehole P18 (apparently outside the sphere of influence of the pumping operation) showed an elevated water table from June to September each year. Chemographs of TP, KN, and  $\text{NH}_3$  for borehole P21 exhibit increased variability of these concentrations during the periods of highest rainfall i.e. April to September.

### 3.3 Water quality type

The dissolved salts composition of water consists primarily of the principal cations; sodium, calcium, magnesium and potassium and the principal anions; chloride, fluoride, sulphate, nitrate and bicarbonate. Groundwater is classified according to its TDS concentration as follows (Robinove, 1958 as reported by Hem, 1970).

Table 9a: Types of water.

Name	Concentration of TDS in mg/l
Fresh water	<1000
Moderately saline water	3000 - 10000
Very saline water	10000 - 35000
Brine	>35000

Ninety five percent of all samples collected have TDS concentrations that fall below 790 mg/l. Only borehole P20 has concentrations exceeding 1 000 mg/l. The groundwater in the study area (with the exception of P20) is thus classified as fresh.

A similar simple classification of water this time based on hardness (Sawyer, 1960) is as follows:

Table 9b: Types of water (hardness).

Name	Hardness range (mg/l of CaCO <sub>3</sub> )
Soft water	0 - 75
Moderately hard water	75 - 150
Hard water	150 - 300
Very hard water	>300

With a median hardness of 309 (mg/l as CaCO<sub>3</sub>) it is evident that the water ranges from hard to very hard (distribution of data is fairly symmetrical about the median value).

Relative proportions of the major anions (bicarbonate, sulphate, chloride, fluoride and nitrate) and cations (calcium, magnesium, sodium and potassium) have been displayed on a number of trilinear (Piper) diagrams (Figure 7a-7c). Waters of similar ionic proportions, and thus similar character, plot near one another. It must be kept in mind that in order to facilitate presentation of data in such a manner, potassium and sodium have been grouped together as have fluoride, sulphate and chloride. The one disadvantage of such a presentation is that waters with highly different TDS values may plot on the same point.

The concept of hydrochemical facies developed in the 1960's enables one to conveniently refer to water compositions by identifiable groups or categories. Figure 8 is divided into a number of subdivisions which represent zones of cation and anion concentrations, these district zones are hydrogeochemical facies.

Figure 7a is a trilinear plot of all groundwater quality data sampled from production boreholes during the three year period of the operation of the pilot abstraction scheme.

The dominant cation is calcium with fewer samples exhibiting calcium and sodium as dominant cations. Most variability with respect to relative proportions of cations is introduced by changes in calcium, sodium and potassium concentrations.

Although most cation data from production boreholes plot in a small area. P06 and P21 plot in a position indicating a higher proportion of sodium and potassium ions. This may reflect the decrease in sodium during the period 1985 to 1988 in these boreholes. The decreasing calcium concentration and concomitant increase in both sodium and potassium explain the change of water in P21 from a calcium to a sodium and calcium dominated water during the three year period. The majority of samples show the dominant anion as being bicarbonate with fewer samples exhibiting bicarbonate and chloride nature.

Firstly apart from samples taken from P06 and P09 there appears to be very little change in the relative proportions of anions during the three year pumping period. The changes of composition of waters from P09 is explained by the large decreases in sulphate concentration. Secondly P09, P07 and P06 appear to represent end member compositions. P09 and P12 contain the largest relative percentage sulphates, P21 and P24 the greatest  $\text{HCO}_3$  (and least Cl) and P06 and P23 the highest percentage chloride. P06 and P23 are situated in the western portion of the production well field, P09 and P12 in the northern and P21 and P24 in the southwestern portion. This phenomenon is supported to some extent by data from observation boreholes, (Figure 7b).

In general, waters are classified as follows; the majority of samples are of a calcium bicarbonate water type with fewer samples of the type calcium, sodium, bicarbonate and chloride.

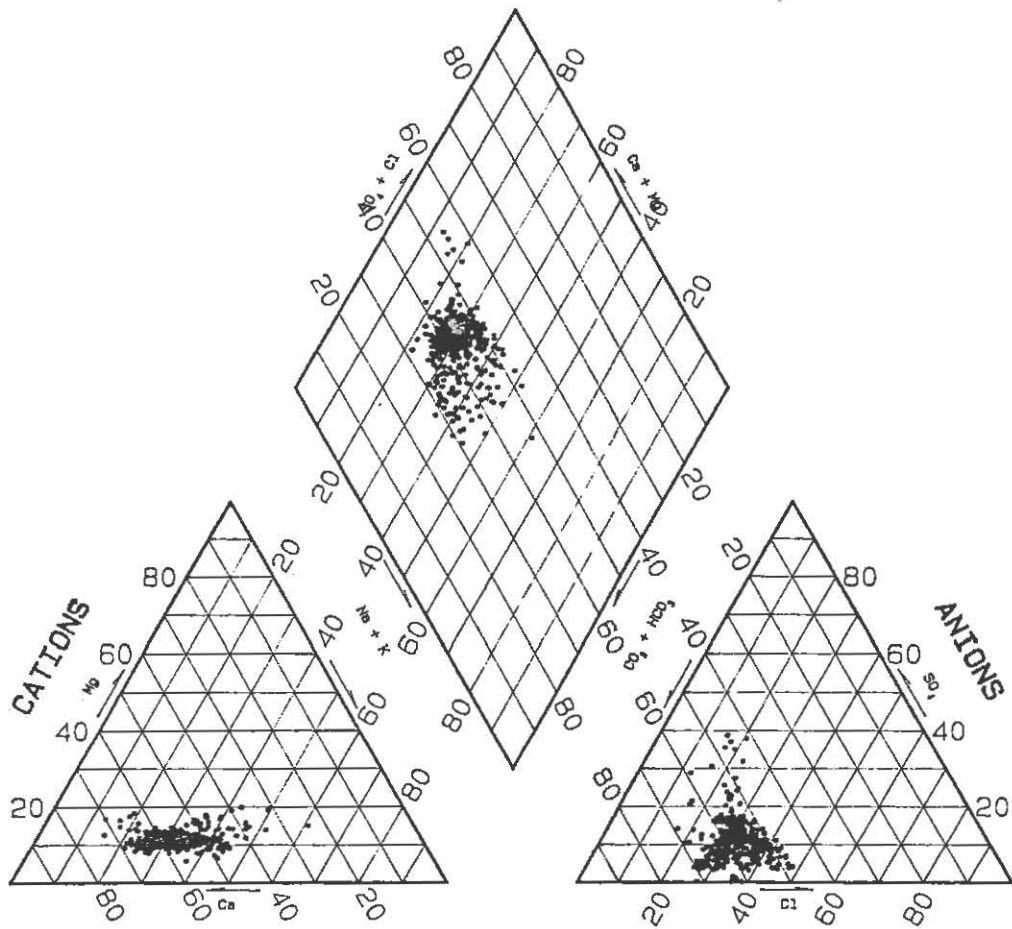


Figure 7a: Trilinear plot of groundwater quality data from production and observation boreholes.

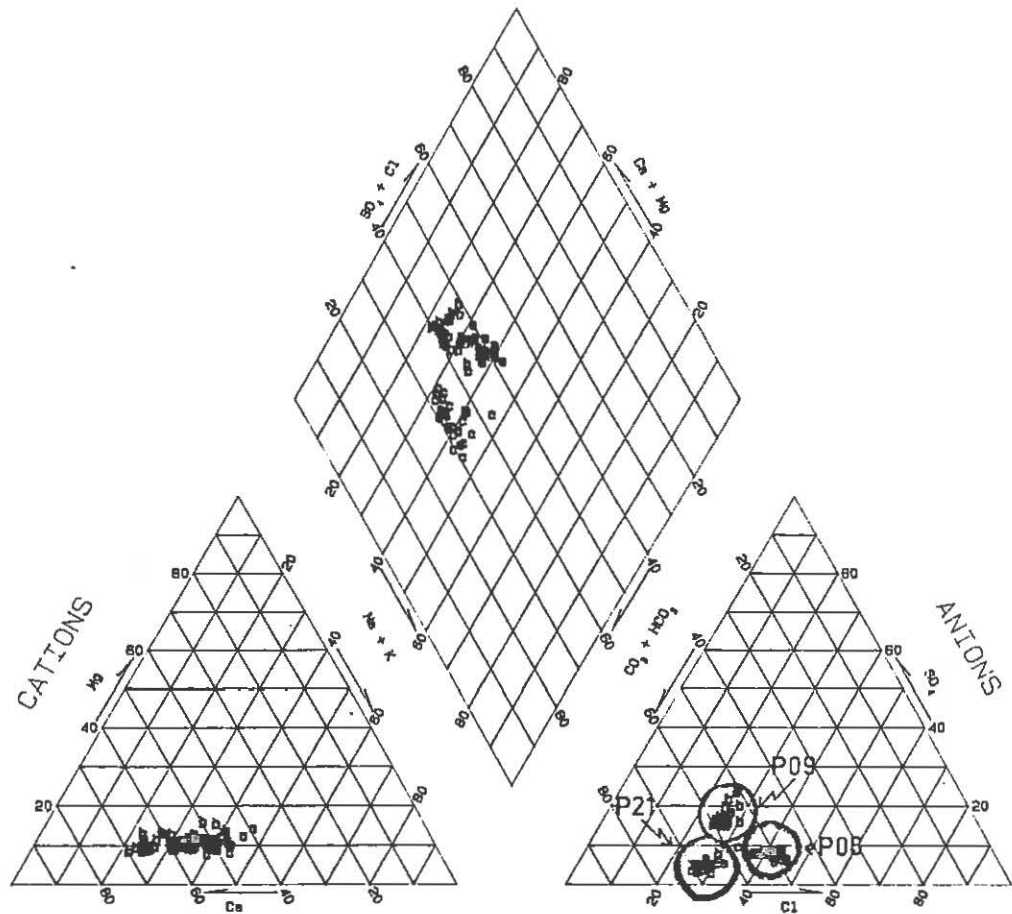


Figure 7b: Trilinear plot of groundwater quality data from selected production boreholes in the Cape Flats aquifer - P06, P09 and P21.

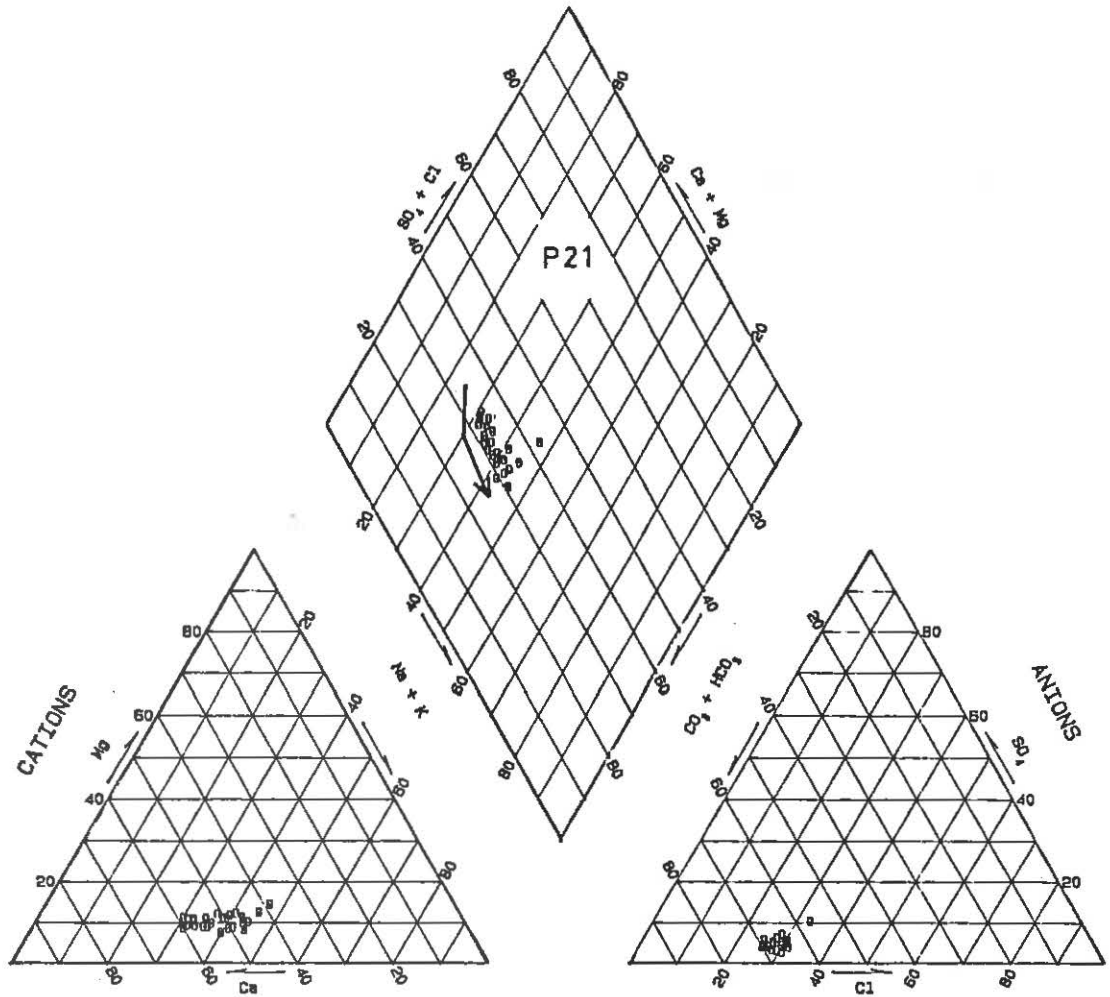


Figure 7c: Trilinear plot of groundwater quality data from P21 the arrow indicates the trend of increased potassium and sodium during the period of abstraction.

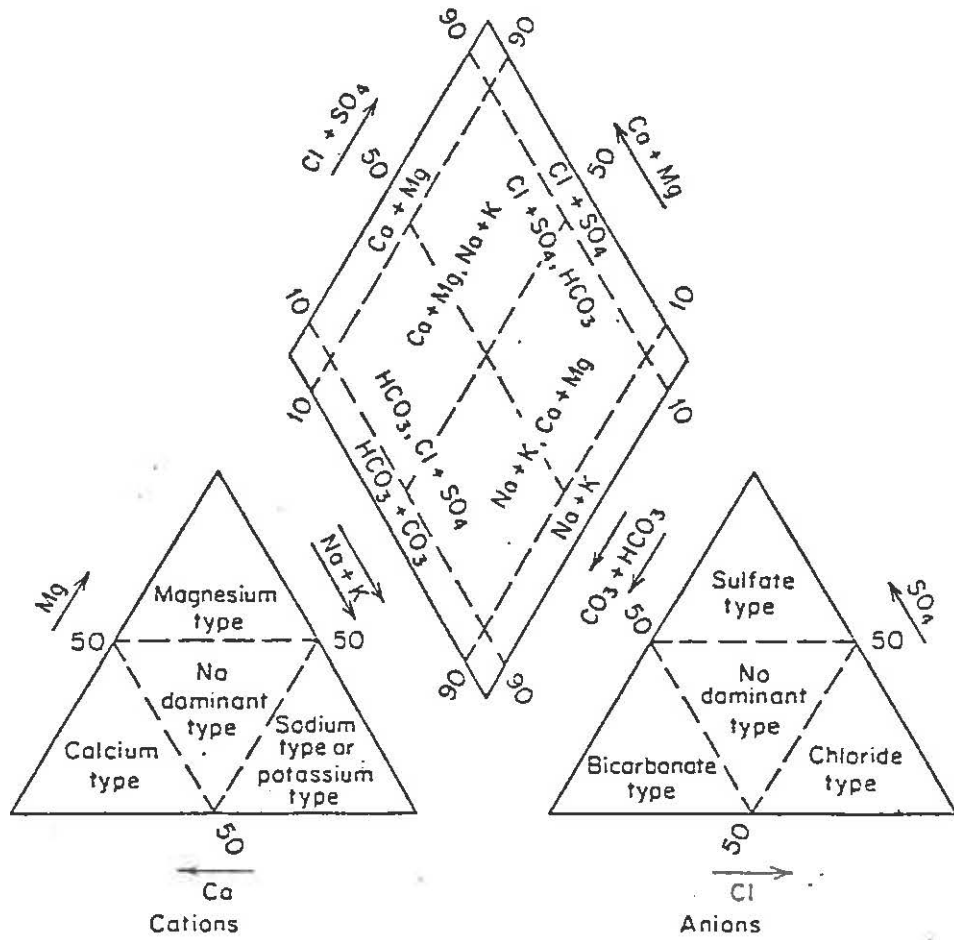


Figure 8: Piper diagram for classification of cation and anion facies.



Of all the samples taken from production boreholes over the period 1985 to 1988 only those from P21 exhibit a water type different to the rest. P21 plots on the trilinear diagram away from the other production boreholes, the position reflects the high sodium, potassium, carbonate and bicarbonate content (Figure 7c).

Samples collected from borehole P21 plot along a line, this illustrates the changing relative concentrations of the major ions. Increases in potassium and sodium and a concomitant decrease in calcium concentration result in the composition of the water from borehole P21 moving away from that of the other production boreholes and of its original composition. It is interesting to note that this is without the contribution of Kjeldahl nitrogen and ammonia which are known to increase dramatically from 1985 to 1988.

#### 3.4 Utilization of groundwater

The uses of groundwater may be many and varied. The success of the use of such water depends on the efficient abstraction of an acceptable quality of water. The chemical, biological and physical quality of the groundwater not only dictate the use and treatment but also the long-term efficiency of the system.

Chemical, physical and biological quality can exert a number of constraints on the groundwater system, amongst these are; corrosion, reduction of yield and the development of unacceptable water quality. The electrochemical nature of corrosion its causes and effects are well documented as are the processes leading to clogging of equipment. The occurrence of unacceptable water quality may arise because of a number of factors, for example pollution by agriculture or industry or incorrect groundwater management (e.g. the over-abstraction resulting in intrusion by saline waters, etc).

Users of water generally fall into one of the following categories: drinking or domestic, agricultural or industrial. Comprehensive water quality criteria for each of these uses have been published both internationally and locally (Train, 1979; Kempster et al., 1980 and Kempster and Smith, 1985). Criteria used in this report have been obtained from Kempster and Smith, 1985, Kempster and van Vliet, 1988.

It should be remembered that water quality criteria are only a guideline for estimating the quality of the sample.

Water quality criteria obtained from Kempster and Smith, 1985 have been denoted by "(NIWR/SABS)".

The following conventions have been used:

- P50 - percentile fifty, the mean of the water quality should comply with the recommended limit.
- P90 - percentile ninety the ninetieth percentile should not exceed the maximum limit.
- P100 - percentile one hundred the crisis limit, this value should not be exceeded by any of the data.

When making decisions as to the suitability or fitness of use of the groundwater in terms of its use as a potable water supply source, based on water quality, cognizance must be taken of a number of factors. For example median TDS values noted in P20 exceed the maximum allowable limit for drinking water (NIWR/SABS) however it is evident from water level measurements that this borehole is at this stage beyond the influence of the pumping scheme. Based on geohydrological data, predictions on the effect of pumping will have to be made. On this basis decisions will have to be made as to whether or not water of poor quality will effect the overall quality at some time in the future. Cognizance must also be taken of trends in concentration observed thus far.

Note that the raw water quality objectives proposed by Kempster and van Vliet, 1988 relate to water that is to be treated in conventional water treatment processes i.e. the removal of suspended solids and the disinfection with for example chlorine. Processes such as removal of hardness by lime softening and zeolite or ion exchange systems are not considered.

pH (aesthetic/physical) P50, P90 and P100 have the limits of 6 to 9, 5,5 to 9,5 and 4 to 11 pH units respectively (SABS/NIWR). pH values observed are well within the P50 limits, namely within the range of 6 to 9, with the exception of one value 5,8 (P08, 25/6/85) which is an outlier. Knowledge of pH is important as it influences corrosiveness of the water and efficiency of certain treatment processes.

Conductivity and total dissolved salts (aesthetic/physical). Since the relationship between conductivity and TDS has not been established for this water, the two are treated separately.

Conductivity P50, P90 and P100 limits are 70, 300 and 400 mS/m respectively (NIWR/SABS). The maximum conductivity value, in an observation borehole, was 142 mS/m, the median value was 89,5 and the 90th percentile 106 mS/m. The maximum value observed in a production borehole was 123 mS/m.

A very approximate conversion factor calculated from bulk statistical median values indicate that  $TDS (mg/l) = EC(mS/m) \times 7,1$ . This factor, however, often results in up to 20 mg/l difference between calculated and observed TDS values. The factor is obviously dependent on the specific composition of the water. TDS values for P50, P90 and P100 have been suggested as 500, 2 000 and 2 700 mg/l respectively. Median, 90th percentile and maximum concentrations observed were 633, 754 and 1 161 mg/l respectively. The final decision as to the acceptability of the water for a particular use, however, should be based on the concentration of the individual determinands.

Total hardness (non-toxic). The suggested limits (NIWR/SABS) for P50, P90 and P100 are 20 to 300; 0 to 650 mg/l and 0 to 1 300 mg/l (as  $\text{CaCO}_3$ ) respectively. Values for water obtained during the sampling period have a median, 90th percentile and maximum of 309, 360 and 705 mg/l respectively. Although limits of hardness of less than 100 mg/l have been suggested to prevent excessive accumulation of scale in pipes the recommended limit (P50) for drinking water has been set at 300 mg/l (as  $\text{CaCO}_3$ ).

Magnesium (non-toxic). P50, P90 and P100 values of 70, 100 and 200 mg/l (NIWR/SABS) respectively have been suggested. The maximum observed concentration was 33 mg/l.

Sodium (non-toxic). P50, P90 and P100 values have been set at 100, 400 and 800 mg/l respectively (NIWR/SABS); median, 90th percentile and maximum values of 61, 83 and 113 mg/l were observed. It must be noted however that in only three boreholes do concentrations exceed 100 mg/l, in both observation boreholes P16 and P31 these high values are representative of the quality. However, in production boreholes P06 the single value above 100 mg/l appears to be an outlier in addition to this sodium concentration appears to have decreased during the three year period.

Calcium (non-toxic). P50, P90 and P100 values of 150, 200 and 400 mg/l respectively have been suggested (NIWR/SABS). It has been suggested that at present the calcium limits for raw water be unspecified. A maximum concentration of 230 mg/l was observed (P20) a median of 103 and 90th percentile of 123 mg/l were calculated. The second highest concentration with the exception of P20 was 158 mg/l in P09. Ninety percent of all values for production boreholes are below 132 mg/l.

Potassium (non-toxic). Limits of P50 = 200, P90 = 400 and P100 = 800 mg/l (NIWR/SABS) have been proposed. The maximum value observed was 8,2 mg/l.

Sulphate (non-toxic). P50, P90 and P100 raw water limits of 200, 600 and 1 200 mg/l respectively have been proposed by Kempster and van Vliet (1988). Sulphates at higher than 250 mg/l may affect taste, may have a laxative effect, and may enhance corrosivity of water. A maximum sulphate concentration of 326 mg/l was observed and median and 90th percentile values of 45 and 80 mg/l respectively were calculated. In only one borehole do any of the concentrations exceed the recommended limit of 200 mg/l. P20 has a median of 282 mg/l.

Chloride (non-toxic). P50, P90 and P100 are given as 250, 600 and 1 200 mg/l (NIWR/SABS). A maximum, 90th percentile and median of 211, 134 and 120 mg/l respectively were observed.

Fluoride (moderate toxicity). Criteria are as follows P50 = 1; P90 = 1,5 and P100 = 3 mg/l (NIWR/SABS). Maximum, 90th percentile and median concentrations of 3, 0,2 and 0,1 mg/l were measured. Both the highest concentrations of fluoride 3 mg/l (P17) and 0,7 mg/l (P08) are not consistent with other observations at these boreholes.

Silica (as Si) (non-toxic) no limits have been set. The only concern is a possible contribution to boiler scale.

Nitrates (as N) (moderately toxic). Although relatively non-toxic to adults large concentrations may be harmful to infants. Limits of nitrate concentrations as N have been set at P50 = 6; P90 = 10 and P100 = 20 mg/l (NIWR/SABS). Median, 90th percentile and maximum concentrations of 1,53; 6,07 and 19,4 mg/l  $\text{NO}_3$  as N have been observed. In only three boreholes does nitrate concentration exceed 10 mg/l. (P16, P19 and P21). P21 (a production borehole) is situated in the southern part of the production well field close to the sewage treatment works. P21 has a maximum nitrate concentration of 17,4 mg/l.

Ammonia (aesthetic/physical). The ammonia limits for drinking water are as follows P50 = 1; P90 = 2 and P100 = 4 mg/l (NIWR/SABS). A maximum concentration of 31,1 mg/l, a median of 0,1 and 90th percentile of 0,4 mg/l were observed. In only three cases is the crisis limit exceeded, namely in P06, P09 and P21. In the first two the values appear to be spurious. In P21 high ammonium concentrations are common and during the three year pumping period an increase from ~5 to ~20 mg/l was observed.

Phosphate (non-toxic). Maximum, median and minimum limits of 0,20, 0,10 and 0,06 mg/l (as P) have been suggested by Kempster et al. (1980). A median and 90th percentile of 0,011 and 0,044 mg/l  $PO_4$  as P have been calculated. Values of greater than 1 mg/l were recorded at P21 on four occasions and once at P09. High phosphate values appear to be more prevalent towards the latter part of 1987 and early 1988 in P21.

Turbidity (aesthetic/physical). The criteria for raw water turbidity values are source specific and during treatment these values may be altered to varying degrees. The disinfection by chlorination is affected by the presence of particulate matter. Recommended, maximum permissible and crisis limits (P50, P90 and P100) have been suggested as 1,0, 5,0 and 10,0 NTU's (NIWR/SABS). Values obtained during the sampling period have a median, 90th percentile and maximum of 4, 15,9 and 87 NTU's. Production boreholes exhibit large ranges in turbidity.

Colour (aesthetic). A recommended limit of 20 Pt units has been suggested for drinking water. No limits have been recommended for raw water. No value measured during the sampling period exceeds 5 pt units.

Table 10 summarizes these variables which exceed limits for drinking water.

Table 10: Exceedence of selected drinking water quality criteria - production boreholes.

Determinand	Recommended Limit	Maximum Permissible	Crisis Limit
pH	None	None	None
Conductivity	All	None	None
Total Dissolved Salts	All	None	None
Sodium	None	None	None
Calcium	None	None	None
Magnesium	None	None	None
Potassium	None	None	None
Sulphate	None	None	None
Chloride	None	None	None
Fluoride	None	None	None
Nitrate (as N)	None	None	None
Ammonia	P21	P21	P21
Phosphate (as P)	P09, P21	P09, P21	P09, P21
Total Phosphorus (as P)	P21	P21	None
Dissolved Organic Carbon	P21	None	None
Turbidity	P08, P09, P10 P11, P21, P22, P24	P08, P10, P11 P12, P22, P24	P06, P08, P09 P11, P21, P24
Colour	None	None	None
Total Alkalinity (as CaCO <sub>3</sub> )	All	None	None

Water Quality Criteria for Drinking Water:  
Obtained from Kempster *et al.*, 1985

Only the production boreholes in which the 'recommended' limits are exceeded are noted.

In summary, as far as the acceptability of the water from the production boreholes for potable use is concerned, it can be stated that overall the water quality is suitable for use. There are two exceptions, however. The first is borehole P21, near the sewage works, which is heavily contaminated with ammonia and is definitely unacceptable for use as potable water. The second is borehole P20, which has a salinity in excess of 1 000 mg/l, making it undesirable for potable use.

### Trace elements

Water quality variables in this section include the metals; Al, Cr, Pb, Zn, Ba, Cd, Cu, Mn, Co, Fe, Ni, V, and Sr as well as the metalloids As and B.

The determination of trace elements is primarily for: the possible identification of ore bodies; determination of the genesis and geochemistry of water; as traces for origin, age and velocity and direction of flow and finally the possible effects of use of the water and identification of sources of pollution. However, of special interest to this report are the trace metals for which limits have been set in drinking water standards and the possible use of these elements as indicators of pollution.

The collection, preparation and preservation of samples, may affect the concentration of certain trace metal constituents in the water as may the procedures and materials used to construct the well and collect the sample. Detection limits and the distribution of data are especially important when attempting to statistically summarize the data and even more so when applying any statistical tests.

Trace metals in groundwater (with the exception of iron) generally occur in concentrations of 1 mg/l or less. The reasons for such low concentrations are generally due to the adsorption of these constituents on clay minerals and on hydrous oxides of manganese, iron and organic matter as well as low solubilities of source minerals.

Time series plots of trace metal elements are presented in Figures 9a to 9d, Appendix C.



The maximum, mean and median aluminium concentrations observed were 1,07; 0,09 and 0,056 mg/l respectively. Of the 403 samples taken ~30% were below detection limit. The maximum value of 1,0 mg/l was recorded in P18 from a sample taken in February 1988, this value appears to be an outlier. The distribution appears to be highly skewed towards the higher values. Of particular interest was the fact that no aluminium was detected in any of the samples taken between March and July 1987.

Recommended, maximum and crisis limits for Al of 0,15; 0,5 and 1 mg/l have been suggested (NIWR/SABS). Ninety five percent of all values measured do not exceed 0,4 mg/l. Concentrations above 0,4 mg/l are especially evident from samples collected on the 25th of June 1986. High concentrations have been observed in 7 out of the 10 production boreholes in samples collected on this date, pH values for this date are also low.

High concentrations of chromium in waters are probably as a result of pollution. Of the 403 samples analysed for chromium approximately 90% showed no chromium and of the 10% of values showing some chromium approximately ~5% of the values were below the detection limit of 0,005 mg/l. Although toxic in high concentrations chromium is an essential nutritional element. The recommended, maximum permissible and crisis limits are 0,1; 0,2 and 0,4 mg/l respectively. The maximum observed concentration was 0,063 mg/l.

In 84% of all samples taken no lead was detected. The maximum concentration observed was 0,856 mg/l. In many cases samples taken in February 1986 have concentrations of lead close to 0,5 mg/l.

Arsenic in solution may be removed in conventional purification processes. However, if only chlorination is carried out little or no decrease in arsenic concentration can be expected. Raw water and drinking water criteria of P50 = 0,1; P90 = 0,3 and P100 = 0,6 mg/l have been suggested (NIWR/SABS). A maximum arsenic concentration of 0,209 mg/l and a median concentration of <0,1 mg/l were observed for all samples. Only 3% of all data shows any arsenic at all and these values are often below the detection limit. Arsenic concentrations of greater than 0,1 mg/l were only observed on six occasions, all of these samples were taken in February and March 1986.

Cadmium is generally rare in natural water but may be present as a result of industrial pollution. The limits suggested are as follows P50 = 0,01; P90 = 0,02 and P100 = 0,04 mg/l (NIWR/SABS). Kempster and van Vliet (1988) suggest that cadmium may be associated with particular matter and that if waters are highly alkaline or turbid raw water quality objectives should be P50 = 0,02; P90 = 0,04 and P100 = 0,08 mg/l. Of all the samples taken the maximum value was 0,13 and the 90th percentile, 0,004 mg/l. Only 9% of all samples analysed showed any cadmium at all, of these ~5% are below detection limit. It is interesting to note that all values exhibiting cadmium concentrations of greater than or equal to 0,01 mg/l were taken in February 1986.

A maximum and median concentration for copper of 0,146 and 0,001 mg/l were recorded. In only one instance was the concentration of copper greater than 0,1 mg/l this was 0,146 mg/l in P23. Copper may be toxic in high concentrations and impart a taste to the water. The recommended limits are P50 = 0,5; P90 = 1,0 and P100 = 2,0 mg/l.

The maximum and median concentrations observed for manganese were 0,044 and 0,004 mg/l respectively. The recommended, maximum permissible and crisis limits have been set at 0,05, 1 and 2 mg/l respectively (NIWR/SABS). Kempster and van Vliet (1988) suggests that the raw water quality objectives should be P50 = 0,1; P90 = 2 and P100 = 4 mg/l. Maximum limits have been based on aesthetic considerations.

The maximum concentration of boron measured was 0,895 mg/l. The median and 95th percentile were 0,07 and 0,127 mg/l respectively. Of the 10 boreholes sampled on the 25th June 1986 seven have boron concentrations greater than 0,5 mg/l on this day. Both P16 and P20 have consistently high concentrations of boron, namely 0,1 and 0,2 mg/l. Recommended, maximum and crisis limits are 0,5; 2,0 and 4,0 mg/l respectively.

Suggested criteria for cobalt in drinking water are as follows P50 = 0,25; P90 = 0,5 and P100 = 1 mg/l (NIWR/SABS). Only 15% of samples analysed show any cobalt at all. The 95th percentile and maximum values are 0,009 and 0,105 mg/l respectively.

Iron is strongly associated with suspended particulate matter and therefore raw water quality objectives of P50 = 0,5; P90 = 5 and P100 = 10 mg/l have been proposed by Kempster et al. (1988). Criteria for drinking water (NIWR/SABS) are half these values. The median value for all samples collected during the three year period was 0,663 mg/l. A maximum value of 22,9 mg/l was recorded in P09 on the 25th June 1986. The 95th percentile value is 3,29 mg/l and although values of 10 and 15 mg/l were recorded, these are usually not consistent with the other data from those boreholes. Production boreholes have median values falling between 0,112 (P06) and 1,999 (P21). Both P29 and P20 exhibit anomalously and consistently high iron concentrations ~5 and 3 mg/l respectively.

The maximum, median and 90th percentile concentrations for strontium are 4,38; 1,50 and 1,91 mg/l respectively. Time series plots show remarkably consistent strontium concentrations for all the production boreholes. On only one occasion was a value of below 1 mg/l recorded in the production boreholes. Maximum and minimum values of 10 and 2 mg/l respectively have been proposed by Kempster et al. (1980).

#### 4. CONCLUSIONS

Some aspects of groundwater quality in part of the Cape Flats Aquifer have been described. Data used was obtained from a groundwater quality monitoring network run concurrently with the operation of the Cape Flats Development Pilot Abstraction Scheme.

Samples were collected and analysed by the Hydrological Research Institute, the City of Cape Town Engineer's Department and the National Institute for Water Research.

Although groundwater quality data exists for a period prior to the commencement of the Pilot Scheme it is very sparse. Data that does exist was collected and handled in a number of different ways.

During the Groundwater Development Pilot Abstraction Scheme purging of boreholes was carried out and this procedure allowed a sample representative of aquifer and not the well water quality to be collected. Results obtained from the Hydrological Research Institute and Cape Town Engineers Department illustrate the need for the measurement of certain water quality variables to be made with as little delay as possible. This is especially evident for pH and TAL.

Insufficient data exists to establish ambient groundwater quality in the study area prior to pumping.

Large ranges in water quality variables were observed in most cases. Much but not all of the variability or spread of data was as a result of spurious results, some was due to changes in concentrations during the three years of operation of the scheme. Data and statistical summaries of data presented in this report reflect conditions in the aquifer over the three year period.

Due to the fact that much of the data was obtained from pumping production boreholes and since these samples represent a homogenized or integrated water from many different lithological units, water classification based on lithologies was not possible. The concentration of certain water quality variables appears to be related to the position of the borehole. For example P20 located just south of a highly agriculturalized area in the north of the study area has exceptionally high sulphate, calcium, TDS concentrations and low pH.

Concentrations of TDS range from 218 (P13) to 1 161 mg/l (P20) and the median value was 633 mg/l. A number of production boreholes exhibit decreasing TDS concentrations (P06, P08, P09, P11, P12 and P23). An increase was observed in P24.

pH ranges from 5,8 to 8,5. P20 is the exception in terms of pH in that pH values are consistently low.

Sodium concentrations range from 22 to 113 mg/l. The median is 61 mg/l. Production boreholes located in the central western portion of the study area have the lowest median sodium concentrations. Decreases in sodium during the abstraction period were noted in 6 of the 10 production boreholes. A very small range in magnesium concentration was noted (8 to 17 mg/l). Only 2 boreholes namely P20 and P16 exhibit median magnesium concentrations of greater than 15 mg/l.

Calcium ranges in concentration from 16 (P03) to 230 (P20) with a median value of 103 mg/l. High calcium concentrations occur in boreholes situated in the northwest of the study area (P20, P12 and P14).

The concentration of silica is consistently low with a median of 4,1 mg/l. Only samples taken from P21 show an increase during the 3 year abstraction period. Potassium ranges in a concentration from 0,6 to 8,2 mg/l with a median of 1,9. Only P21 and P25 have median concentrations above 5 mg/l. In only one case (P21) was there an increase in potassium.

Total alkalinity values obtained from the Cape Town Engineer's Department were used. The range in values increases from 250 to 390 mg/l as  $\text{CaCO}_3$ . P21 is the exception with consistently high values being recorded.

Sulphate ranges in concentration from 0 to 326 mg/l. The median value is 45 mg/l. Boreholes P20 and P14 in the northwestern part of the study have median concentrations of greater than 100 mg/l while P15 and P28 located in the extreme eastern part have median concentrations of less than 20 mg/l. Increasing sulphate in P21, P24 and P10 and decreases in P08, P09 and P23 were observed.

Chloride concentrations range from 17 mg/l in P15 to 211 mg/l in P31. The median concentration is 102 mg/l. Decreases in concentration were noted in all the production boreholes with the exception of P21 and P24 in which no trend was observed and P23 in which an initial increase was followed by a decrease.

Fluoride shows a very small range and in all but one case concentrations are less than 0,4 mg/l.

Nitrate concentrations have a median value of 1,39 mg/l. Production boreholes in the northwestern portion of the well field have concentrations of less than 1 mg/l, while those in the southeast have median concentrations of 25,1 mg/l (P06, P11 and P23). Observation borehole P16 has an exceptionally high median nitrate concentration of 15 mg/l. Increases were observed in P06 and P10.

Ammonia ranges from 0 to 31 mg/l. Both P22 and P20 have high median concentrations. P21 is again the exception with values ranging from 0,4 to 31 mg/l. P21 also has extremely high values for Kjeldahl nitrogen and total phosphorus. Increases in ammonia, Kjeldahl nitrogen and total phosphorus are observed in P21 during the 3 year period. In addition these water quality variables show increased variability during the winter months in this borehole.

Phosphates range from 0 to 1,35 with a median concentration of 0,187 mg/l in P21.

Colour is constant at two units on the platinum-cobalt scale.

Trihalomethane data although sparse indicates consistently high formation potentials in P20 and P21.

Microbiological data exists only for observation boreholes. Values from boreholes in the north and north eastern portion of the study area appear to be the highest.

Trace element analyses include determinations on Al, Cr, Pb, Zn, Ba, Cd, Cu, Mn, Co, Fe, Ni, V, Sr, As and B. These determinations have been used predominantly as indicators of pollution. Only in very few cases are limits for drinking water exceeded, these should be examined individually.



Boreholes in the western portion of the production well field are characterized by high chloride. In the northern sector sulphates predominate and in the eastern part bicarbonate ions are predominant. In general the groundwater is predominantly of a calcium bicarbonate type with fewer samples being classified as calcium, sodium, bicarbonate and chloride type. The water is generally fresh with median TDS concentrations of below 800 mg/l with the exception of P20. Waters are hard to very hard.

The Cape Flats aquifer being unconfined to semi-confined and shallow in places is very susceptible to pollution. It has been shown that the presence of waste disposal sites and sewage treatment maturation ponds have resulted in pollution of groundwater in parts of the Cape Flats. The contamination of groundwater by leakage from maturation ponds at the Mitchells Plain Sewage Treatment Works in the south of the study area has been confirmed. Borehole P21 has high concentrations of ammonia, total alkalinity, potassium, total dissolved salts, Kjeldahl nitrogen, phosphates, total phosphorus, and dissolved organic carbon. Large increases in concentration from 1985 to 1988 occur in this borehole. Evidence of leakage is supported by groundwater level data. The effects on groundwater quality of increasing urbanization may also be cause for concern.

The presence of a low transmissive zone in the vicinity of the coastline, may to some extent act as a barrier against intrusion of seawater.

Drawdown cones based on water levels during the operation of the scheme indicate different spheres of influence. The drawdown appears to be a maximum in summer. It is obvious that in order to maintain the quality of water at a certain level care must be taken not to operate the scheme at a rate that leads to the abstraction of poor quality water e.g. P20. The dilution introduced may however still render the final quality of water abstracted acceptable.



The poor water quality in production borehole P21 presents a problem if water is to be abstracted in the future. In terms of macro-inorganic constituents and nutrients. The quality of water from this borehole is unacceptable for use as drinking water, without extensive purification. The problems associated with cessation of abstraction from this hole and the influence of the quality of neighbouring production boreholes must be analysed from a hydrogeological view point. A possible solution would be the continued abstraction until such a time that reduction of pollution (which will ultimately destroy the potential use of the aquifer) from the sewage works could be facilitated. It is important that microbiological quality of production boreholes be examined in order to determine the extent of contamination.

Water quality has been compared with raw and drinking water quality objectives. Production borehole P21 has concentrations of ammonia, phosphate, total phosphate and turbidity values that exceed recommended, maximum permissible and crisis limits for drinking water. P09 shows a unacceptably high concentration of total phosphate. A number of production boreholes show high turbidity values, all production boreholes have median, TDS, alkalinity and conductivity values which exceed the recommended limits.

## 5. RECOMMENDATIONS

If further exploitation of the groundwater is envisaged it is suggested that monitoring of boreholes close to the coast line be done in order to timeously detect the possible intrusion of seawater into the aquifer. It is also recommended that boreholes in the northwest and northeast be monitored.

Further sampling of production boreholes for microbiological and organic quality is suggested, particularly borehole P21. This would be useful in determining changes in the extent of contamination in that area.

Monitoring of boreholes for water quality would obviously take place regularly from production boreholes if the groundwater was to be utilized. The monitoring of some of the observation boreholes for groundwater quality is considered appropriate. It is suggested that observation boreholes P20, P13, P15, P16, P30, P25, P26, P27 and P28 be sampled at a frequency of approximately 4 monthly intervals. These boreholes are all beyond the present sphere of influence of the pumping activities.

In addition the sampling of borehole P31 and P18 are recommended. Observation boreholes exhibiting changes of groundwater level that may be as a result of pumping activities should also be sampled.

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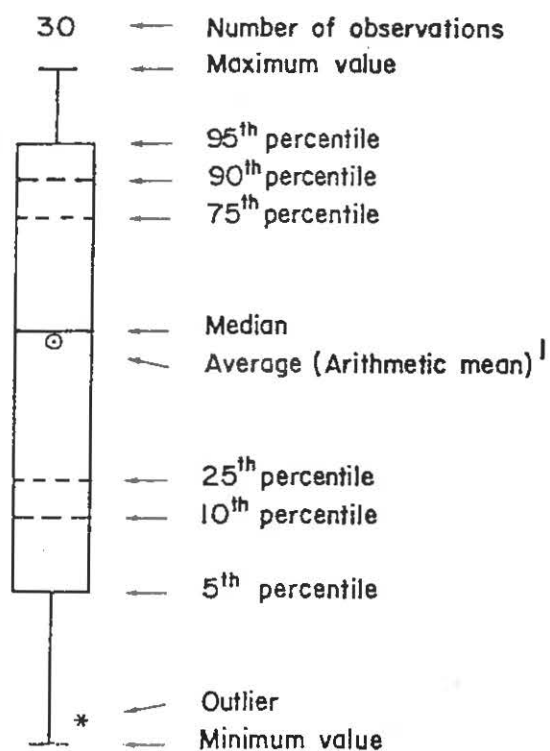
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APPENDIX A

EXPLANATION

\* **OUTLIER** : Value is greater than the 75th percentile or less than the 25th percentile by more than three times the interquartile range

1 Geometric mean for pH

Water quality objectives - all limits from Kempster et. al. (1985) except where specified

All detection limits from H.R.I. laboratory

Values obtained from City of Cape Town Engineers Department

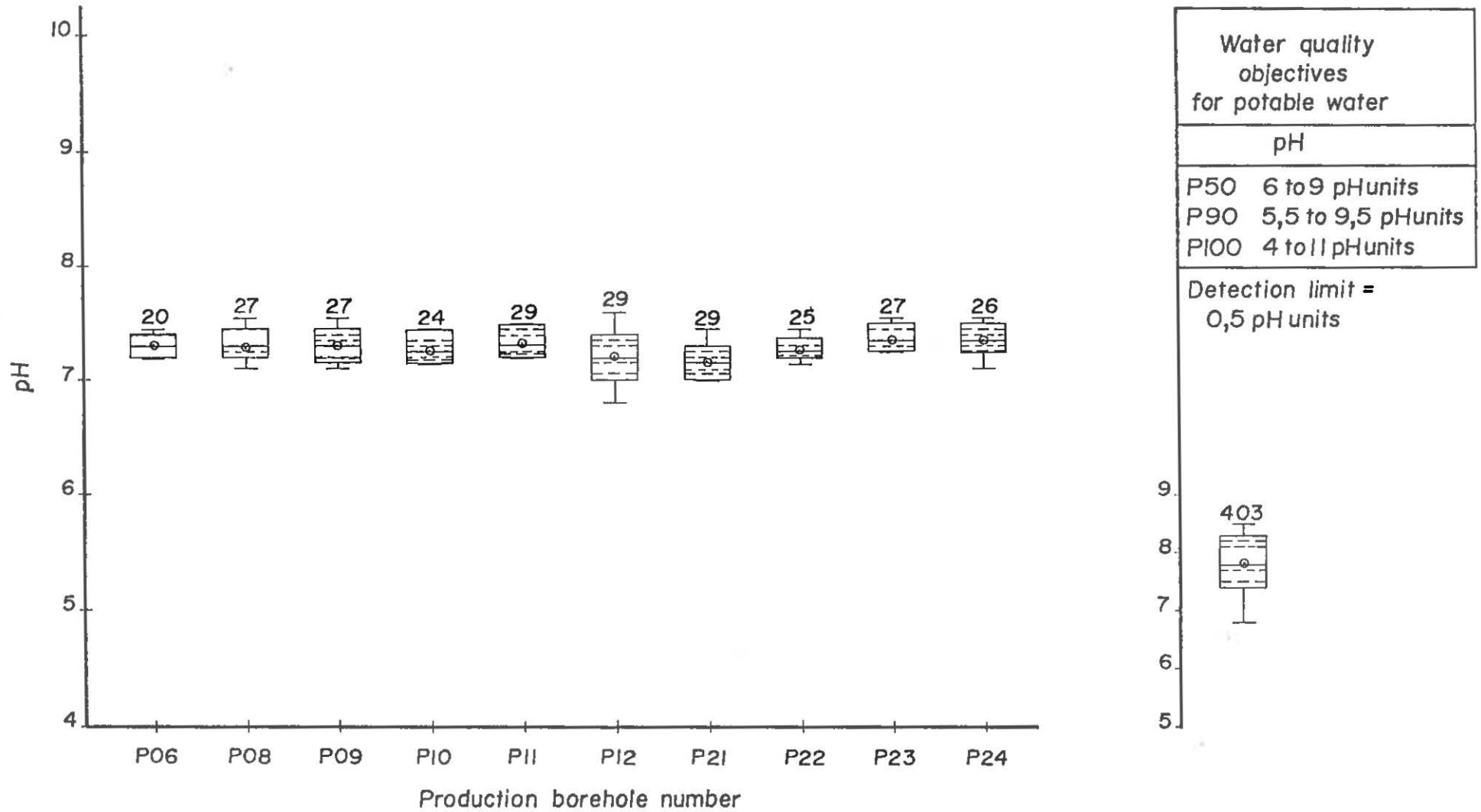


Figure 4a: Box and whisker plots of concentrations of pH - production boreholes.

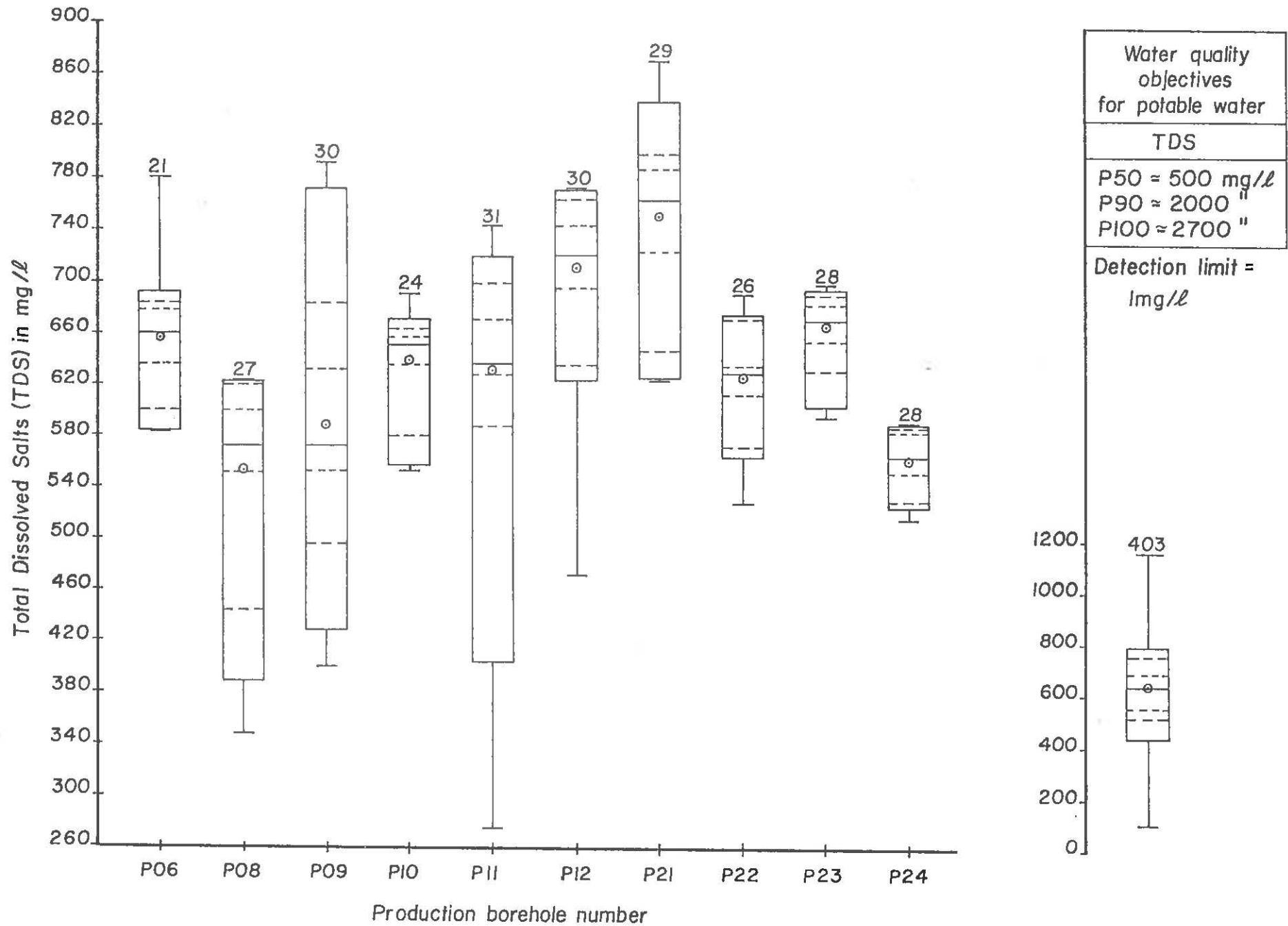
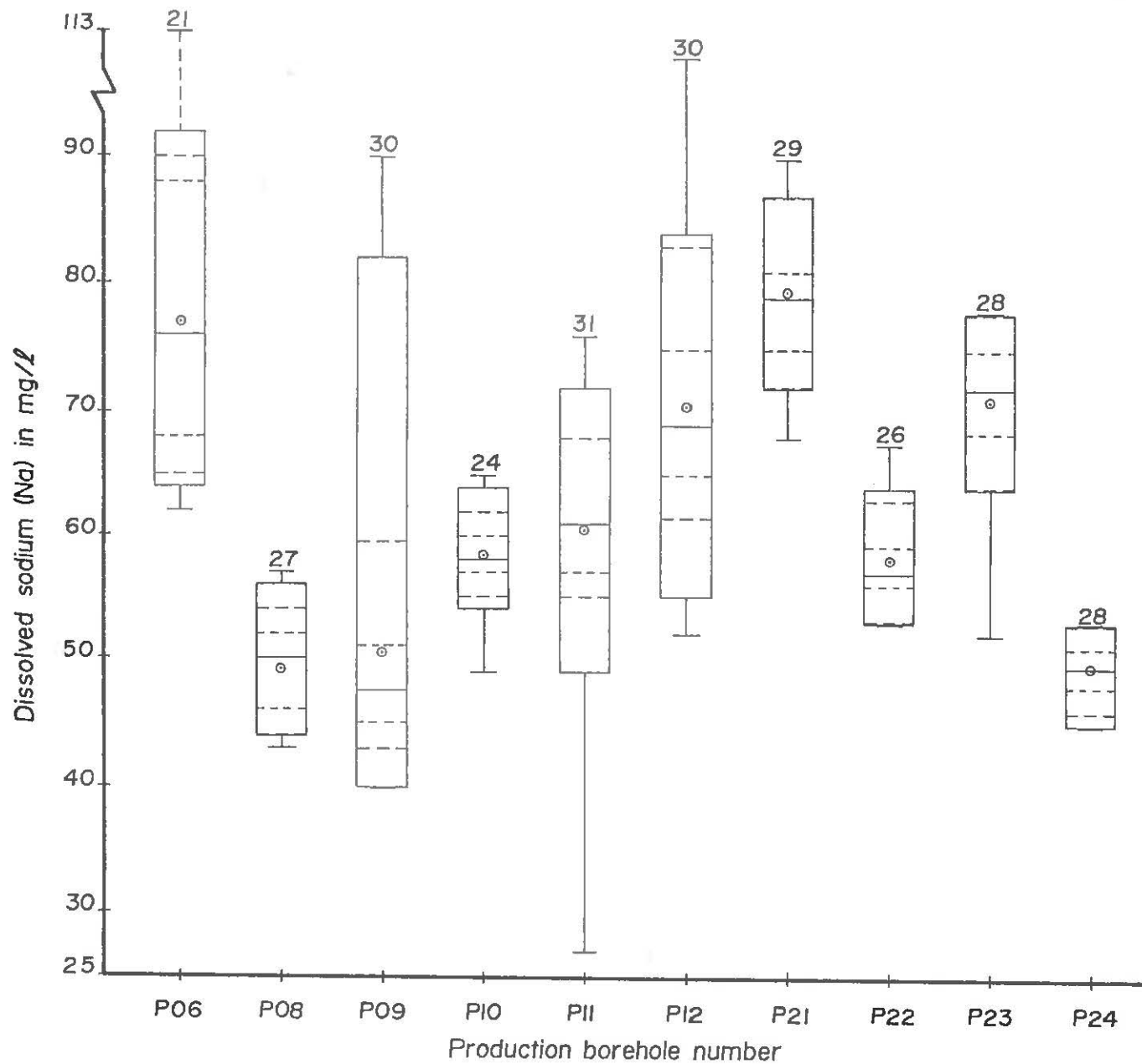


Figure 4c: Box and whisker plots of concentrations of TDS - production boreholes.





Water quality objectives for potable water	
Na	
P50	= 100 mg/l
P90	= 400 "
P100	= 800 "
Detection limit = 2mg/l	

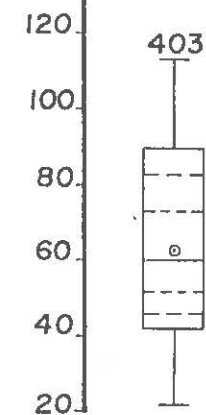


Figure 4d: Box and whisker plots of concentrations of sodium - production boreholes.

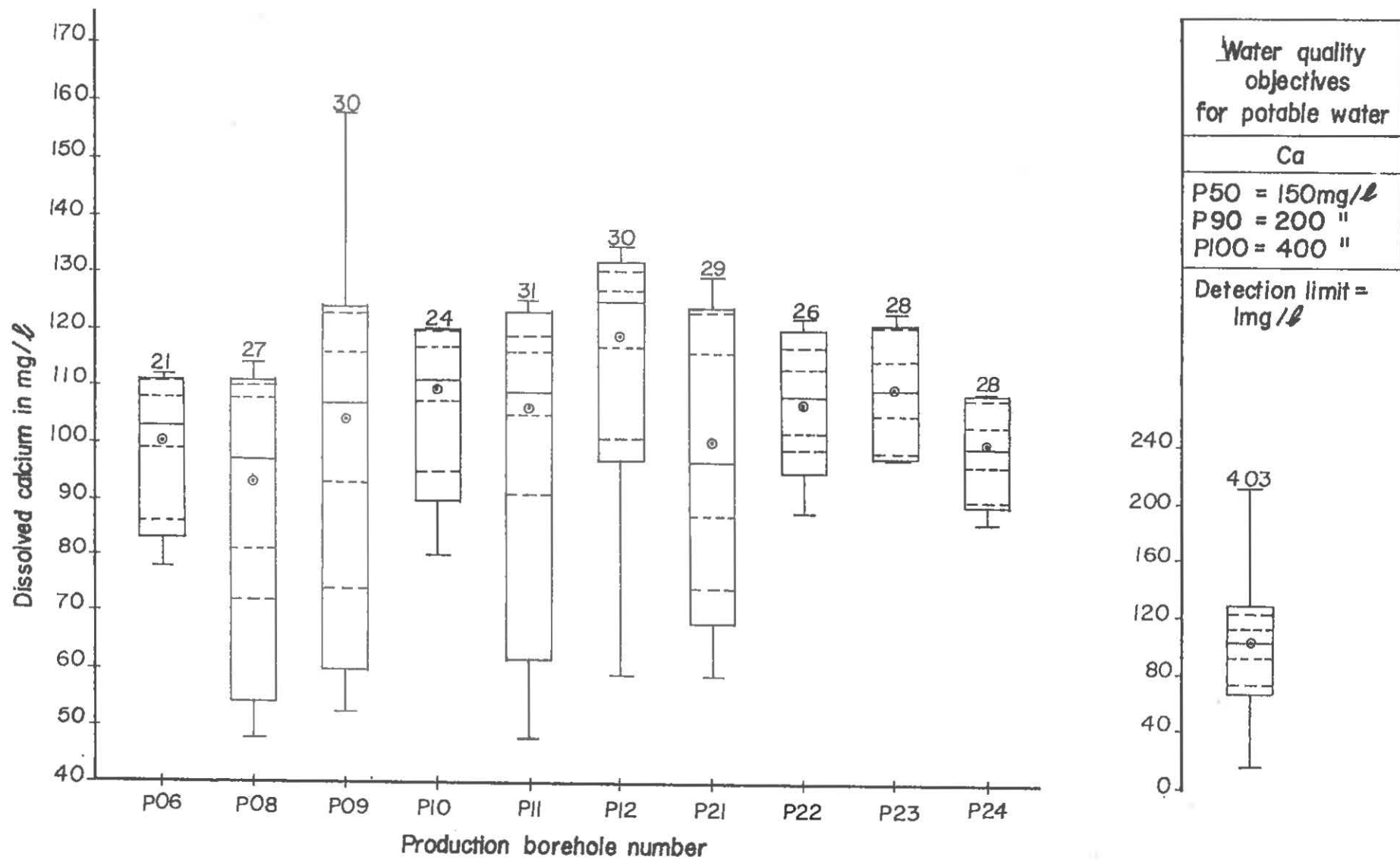


Figure 4e: Box and whisker plots of concentrations of calcium - production boreholes.

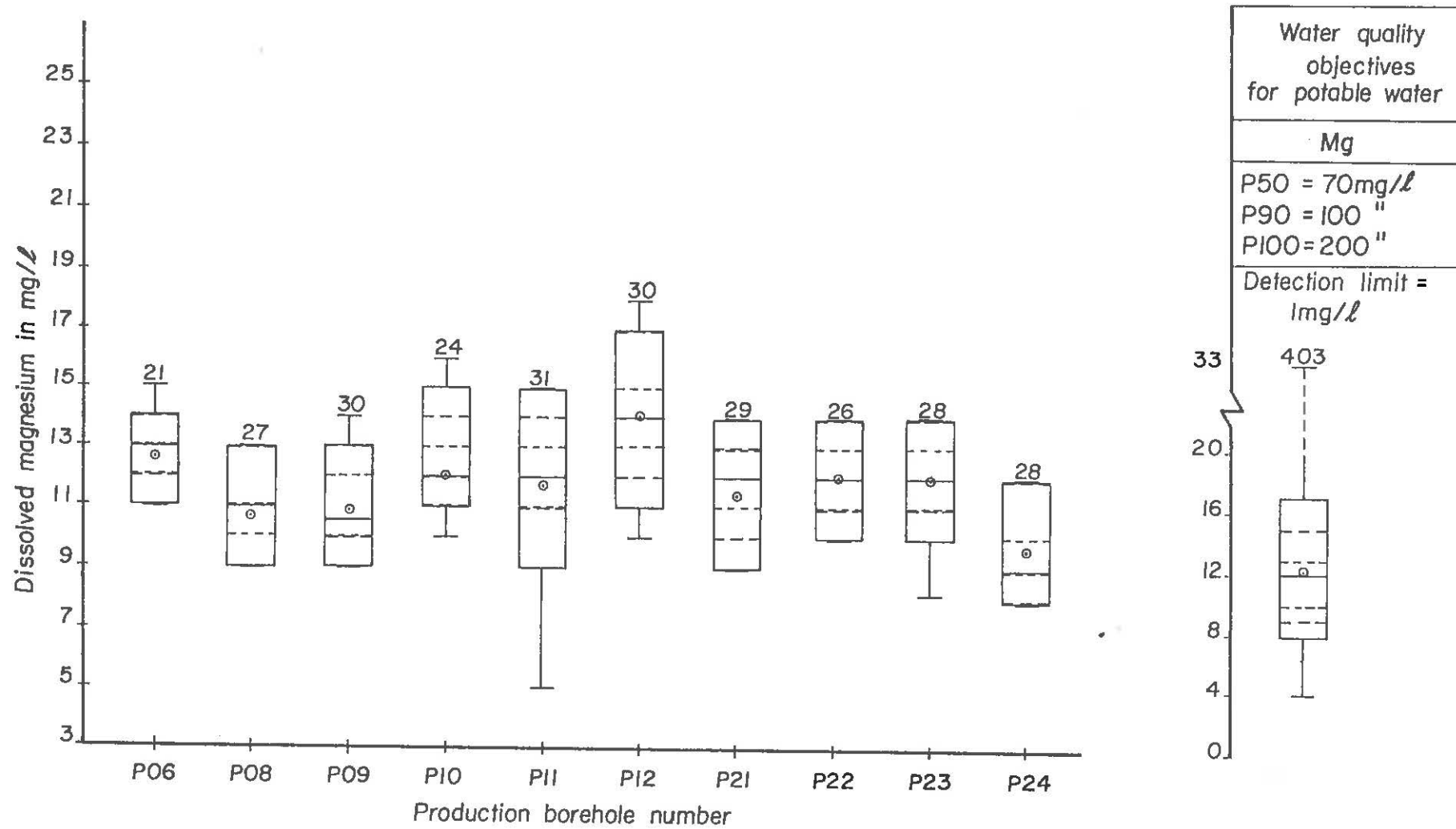


Figure 4f: Box and whisker plots of concentrations of magnesium - production boreholes.

Water quality objectives for potable water
K
P50 = 200 mg/l
P90 = 400 "
P100 = 800 "
Detection limit = 0,3 mg/l

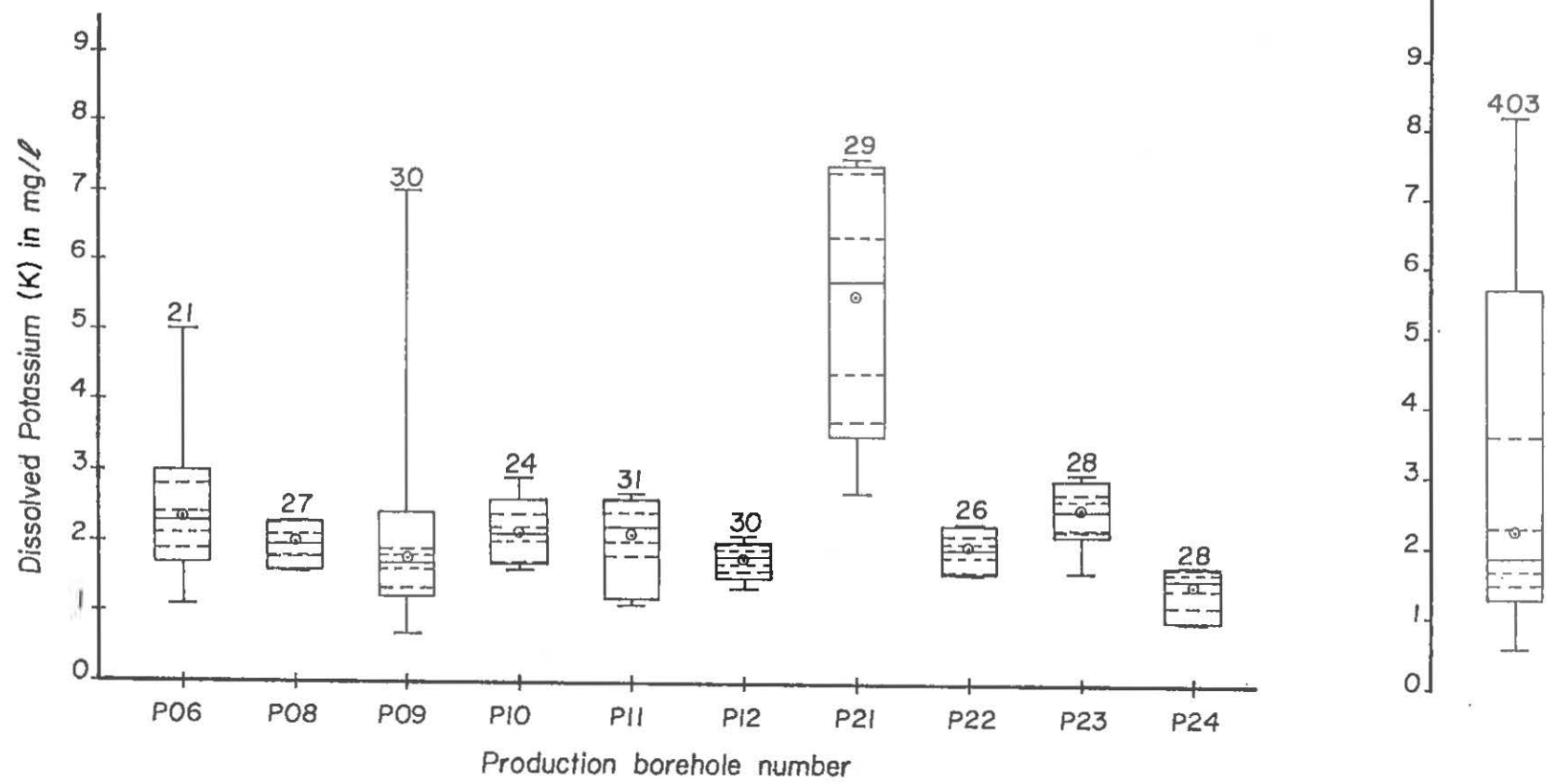
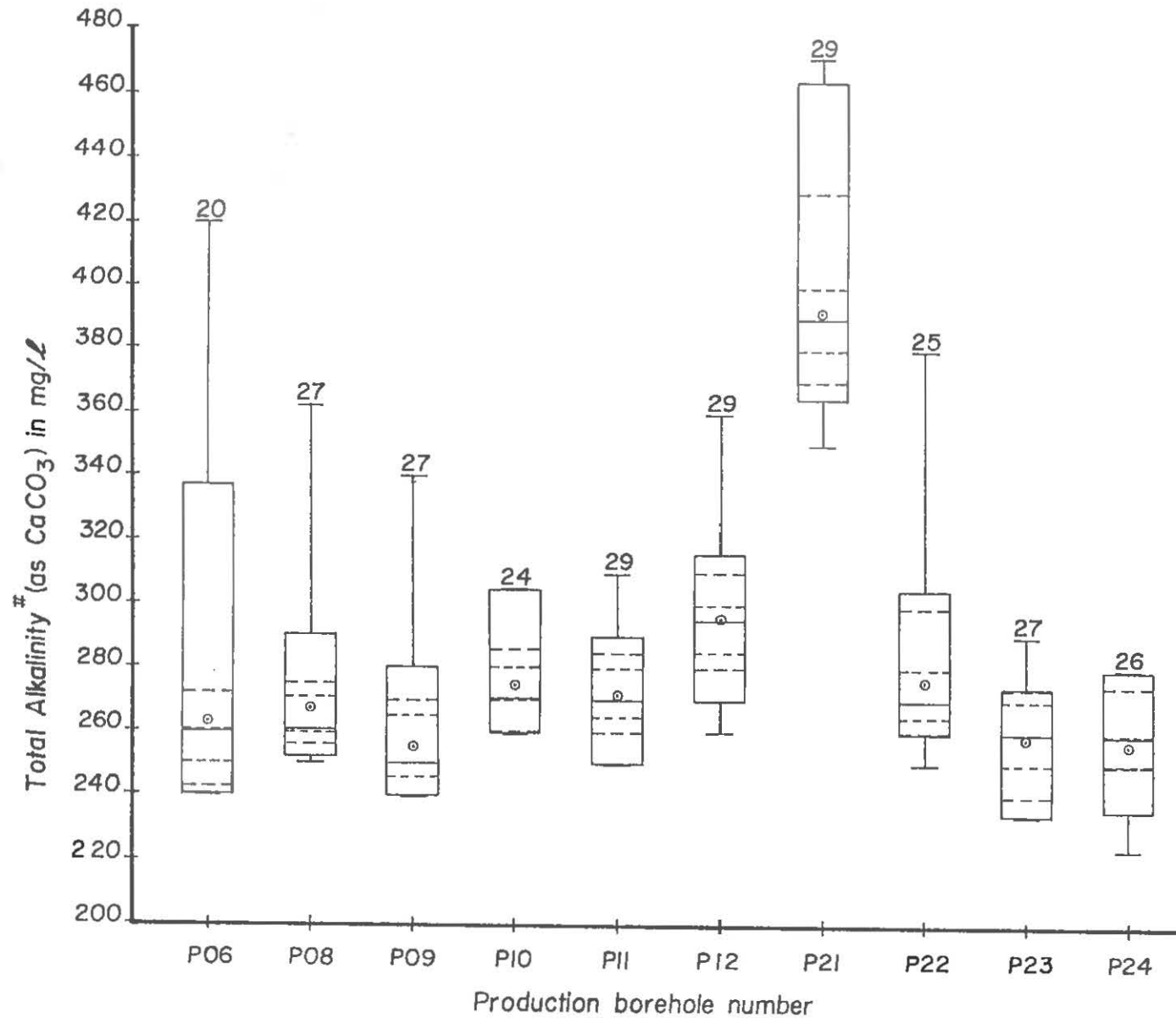


Figure 4g: Box and whisker plots of concentrations of potassium - production boreholes.

# Values obtained from City of Cape Town Engineers Department



Water quality objectives for potable water
TAL
P50 = 30mg/l *
P90 = 500 "
P100 = 500 "

\* Kempster et al (1980)

Figure 4h: Box and whisker plots of concentrations of total alkalinity - production boreholes.

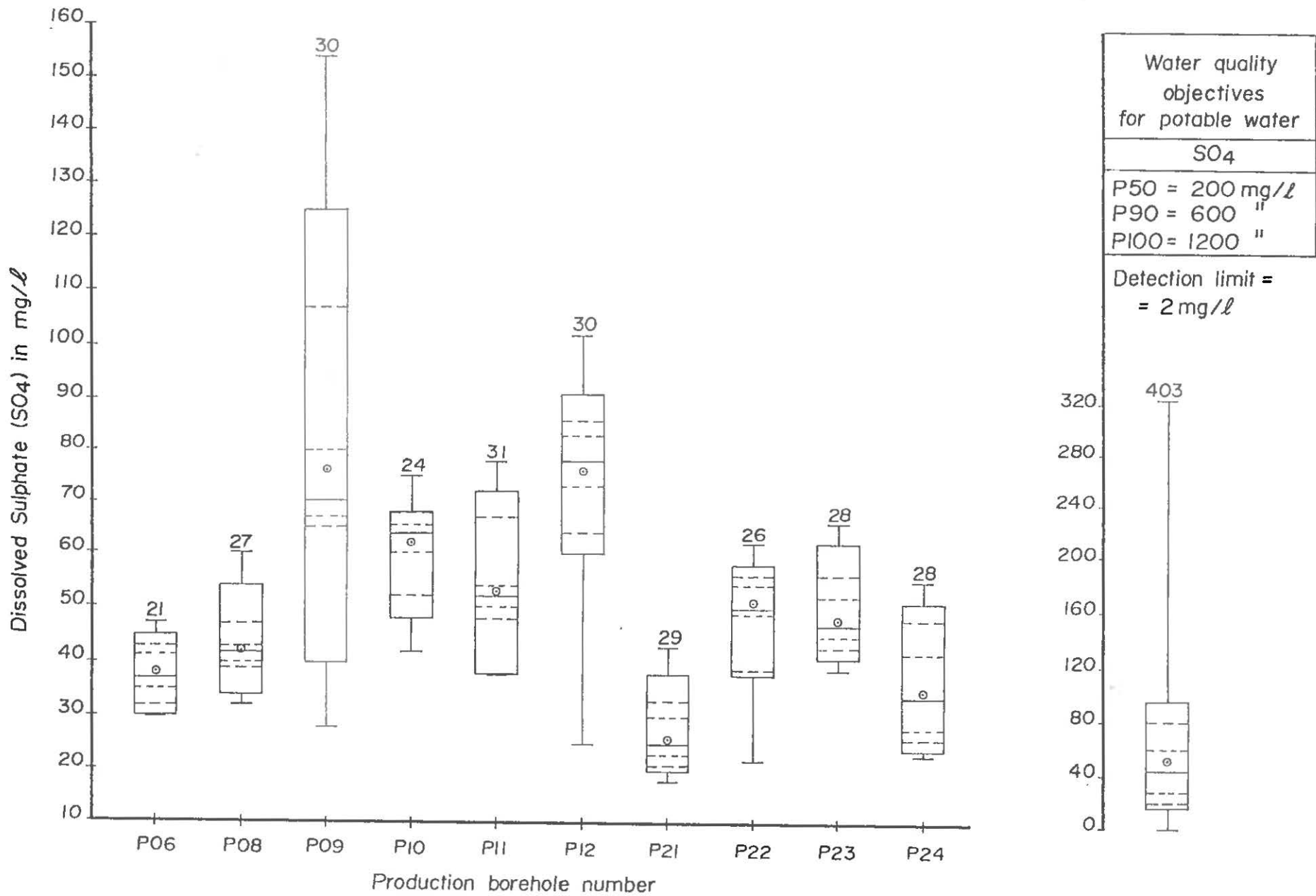


Figure 41: Box and whisker plots of concentrations of sulphate - production boreholes.

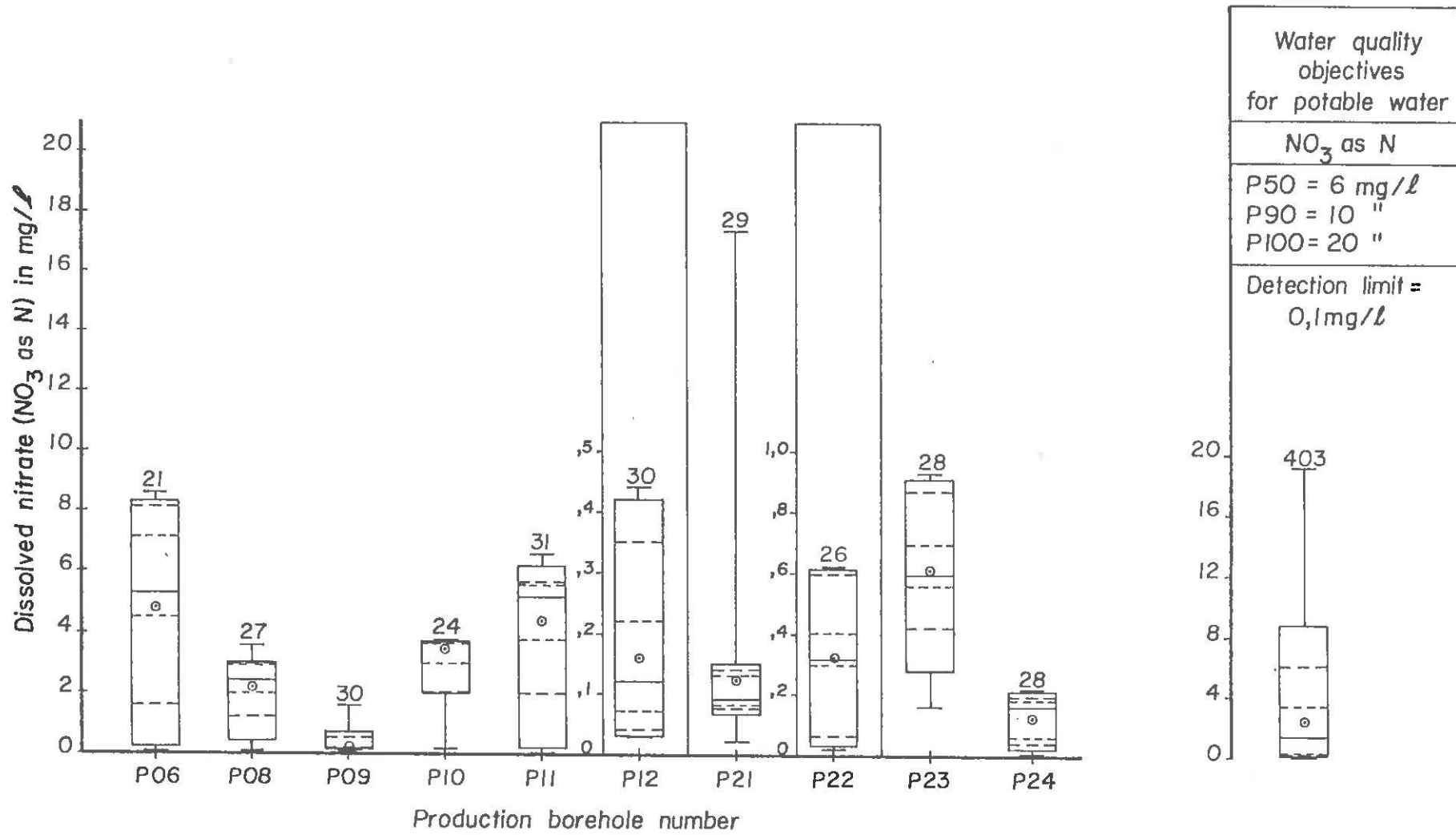
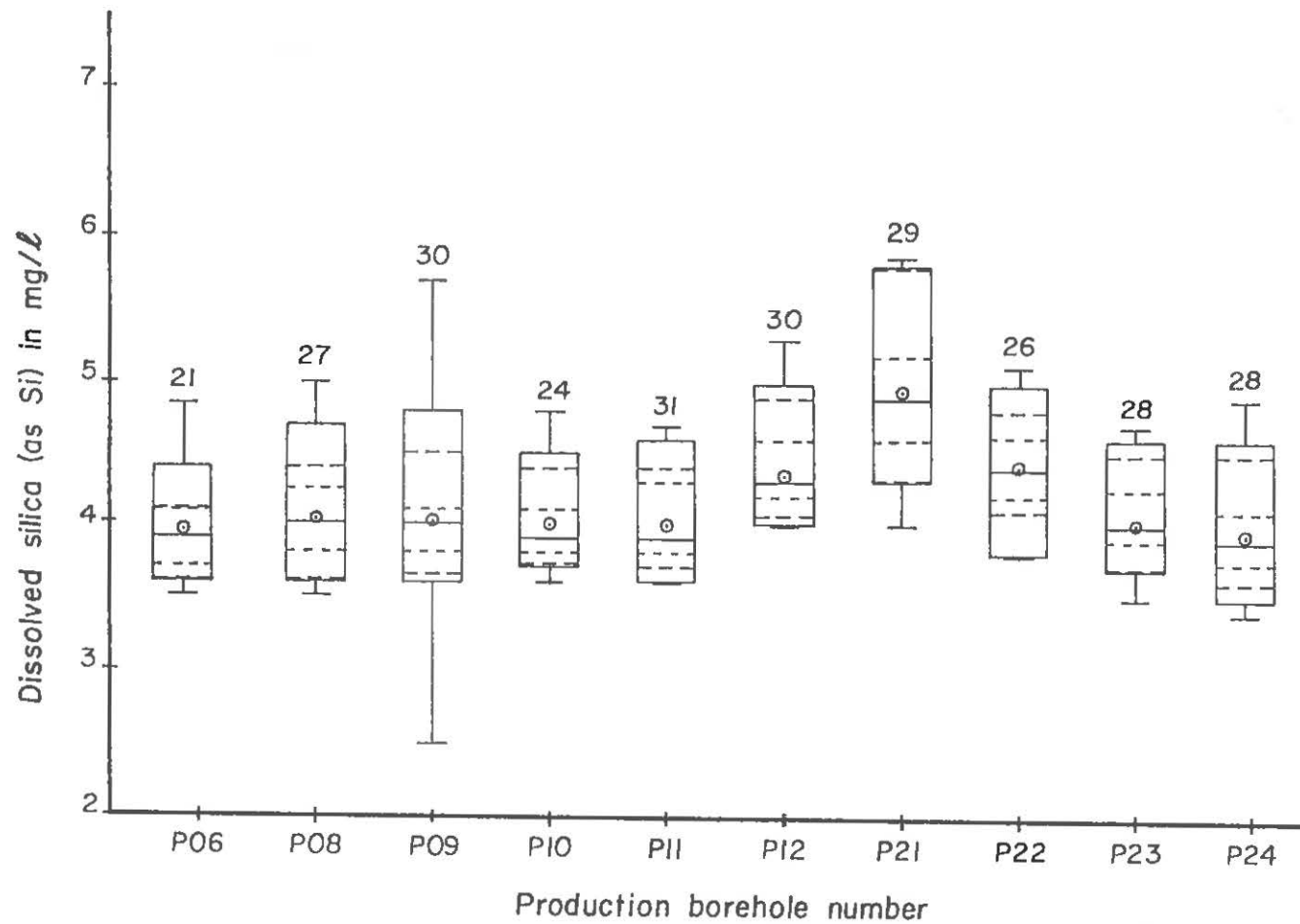


Figure 4k: Box and whisker plots of concentrations of nitrate - production boreholes.



Water quality objectives for potable water
SiO <sub>2</sub> (as Si)
None
Detection limit = 0,4 mg/ℓ

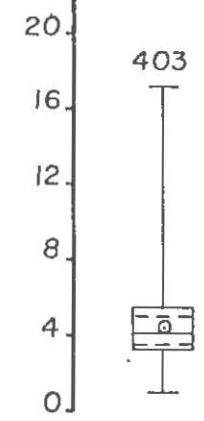


Figure 41: Box and whisker plots of concentrations of silica - production boreholes.



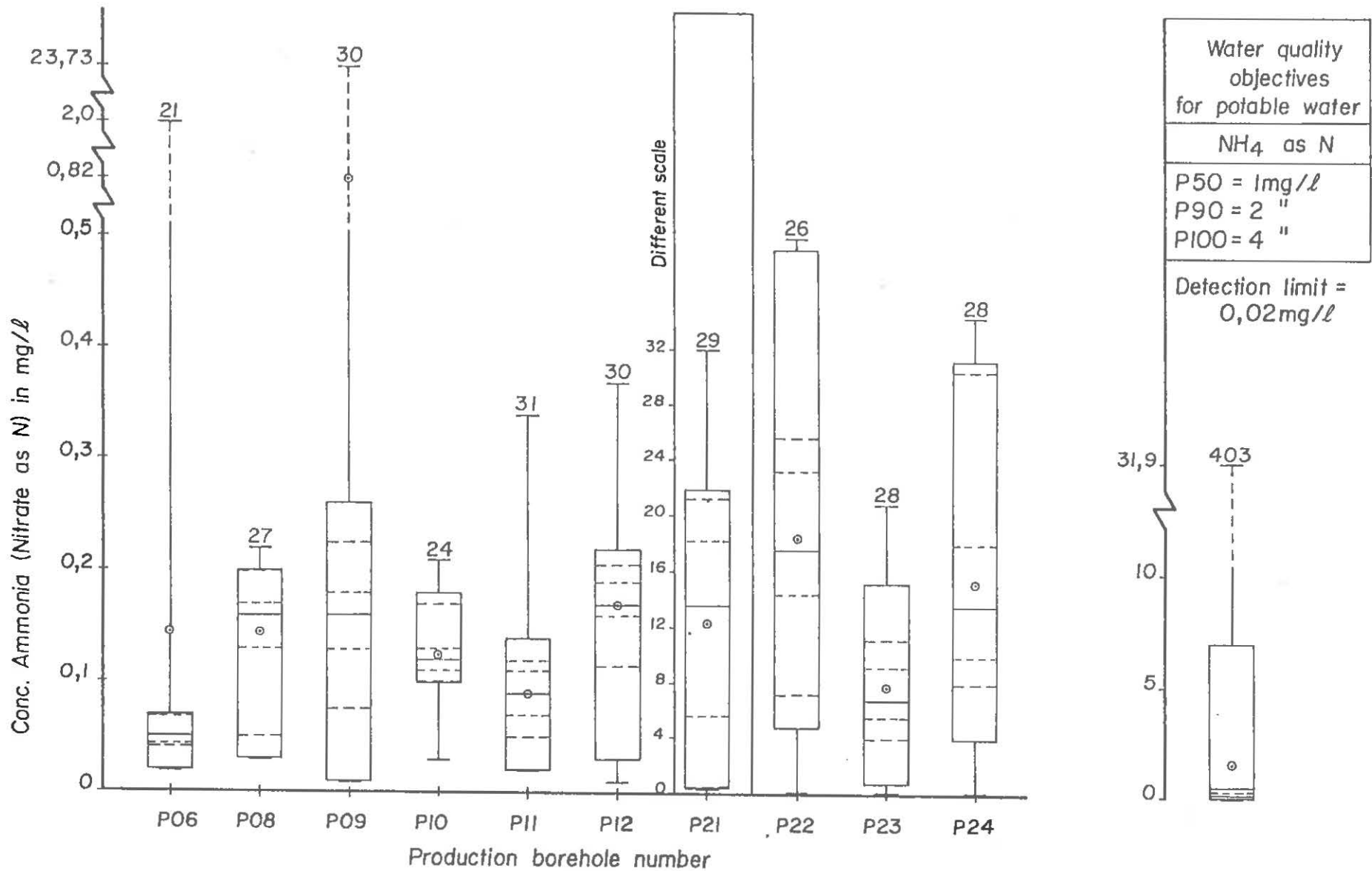


Figure 4m: Box and whisker plots of concentrations of ammonia - production boreholes.

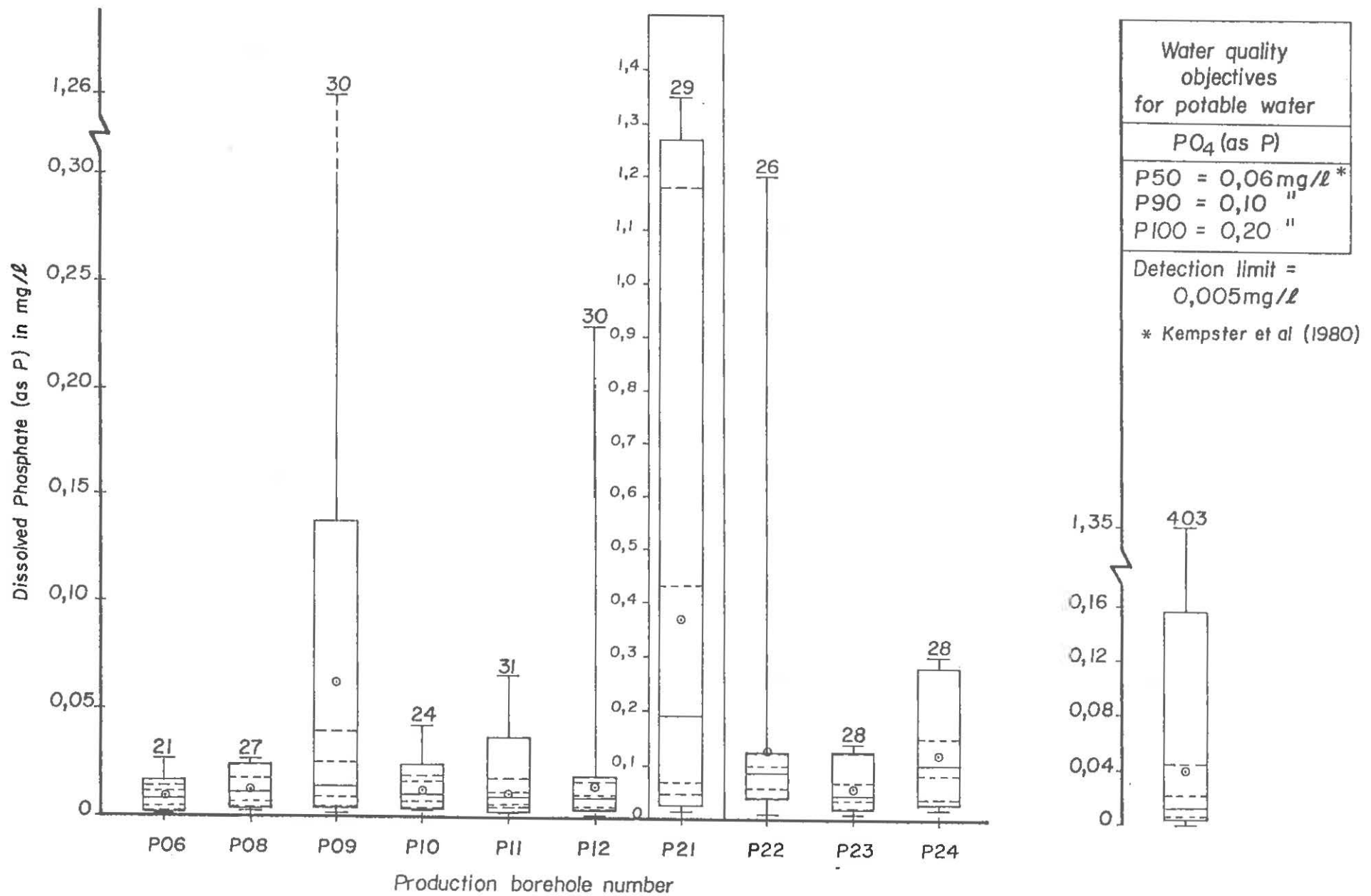


Figure 4n: Box and whisker plots of concentrations of phosphate - production boreholes.

Table 5: Water quality variables and detection limits.

Determinand	Detection limit	Unit	Determinand	Detection limit	Unit
pH	0,5	pH units	Aluminium Al	<0,100	mg/l
Conductivity		millisiemens per metre	Arsenic As	<0,100	mg/l
Total dissolved salts	1	mg/l	Barium Ba	<0,004	mg/l
Sodium Na	2	mg/l	Boron B	<0,002	mg/l
Calcium Ca	1	mg/l	Beryllium Be	<0,001	mg/l
Magnesium Mg	1	mg/l	Cadmium Cd	<0,005	mg/l
Potassium K	0,3	mg/l	Cobalt Co	<0,020	mg/l
Total Alkalinity TAL	4	mg/l CaCO <sub>3</sub>	Chromium Cr	<0,005	mg/l
Chloride Cl	3	mg/l	Copper Cu	<0,005	mg/l
Fluoride F	3	mg/l	Iron Fe	<0,020	mg/l
Nitrate+Nitrite NO <sub>3</sub>	0,02	mg/l N	Lead Pb	<0,050	mg/l
Silica SiO <sub>2</sub>	0,4	mg/l S	Manganese Mn	<0,001	mg/l
Ammonia NH <sub>4</sub>	0,02	mg/l N	Nickel Ni	<0,020	mg/l
Phosphate PO <sub>4</sub>	0,005	mg/l P	Strontium Sr	<0,001	mg/l
Total Phosphorus TP	0,005	mg/l P	Titanium Ti	<0,001	mg/l
Kjeldahl Nitrogen KN	0,04	mg/l N	Vanadium V	<0,002	mg/l
Dissolved Organic Carbon DOC	0,1	mg/l C	Zinc Zn	<0,004	mg/l
Sulphate SO <sub>4</sub>	2	mg/l	Zirconium Zr	<0,001	mg/l
Turbidity	0,1	NTU	Zirconium Zr	<0,020	mg/l

Table 6: Statistical summary of water quality variables.

Determinand	PO <sub>4</sub>						TP					
	Statistic						Statistic					
Ref. No.	N	Min	Max	Med	Av	Sk	N	Min	Max	Med	Av	Sk
P03	2	0	0,015	0,008	0,008		2	0,021	0,023	0,023		
P04	7	0	0,032	0,030	0,006		7	0	0,189	0,034	0,061	
P06*	21	0	0,028	0,008	0,088	3,005	21	0,009	0,064	0,020	0,024	3,550
P07	6	0	0,006	0,002	0,002	0,575	6	0,003	0,010	0,005	0,008	
P08*	27	0,003	0,027	0,012	0,013	0,734	27	0,012	0,477	0,034	0,074	6,598
P09*	30	0,003	1,26	0,015	0,063	12,018	30	0,016	1,49	0,04	0,112	11,308
P10*	24	0,003	0,042	0,011	0,013	3,948	24	0,014	0,081	0,031	0,035	4,236
P11*	31	0,001	0,065	0,010	0,012	7,450	31	0,01	0,073	0,029	0,032	3,427
P12*	30	0	0,233	0,008	0,016	12,014	30	0,01	0,282	0,023	0,044	6,808
P13	9	0	0,030	0,003	0,006		9	0,006	0,061	0,013	0,020	
P14	8	0	0,043	0,004	0,012		8	0,012	0,061	0,016	0,030	
P15	8	0	0,014	0,006	0,006		8	0,004	0,02	0,009	0,01	
P16	7	0,001	0,025	0,003	0,007		7	0,006	0,035	0,023	0,022	
P17	8	0,001	0,015	0,006	0,007		8	0,001	0,019	0,010	0,010	
P18	8	0,001	0,033	0,010	0,014		8	0,01	0,102	0,034	0,039	
P19	7	0	0,008	0,003	0,003		7	0,003	0,03	0,012	0,041	
P2	8	0	0,033	0,007	0,010		8	0,006	0,097	0,031	0,0350	
P21*	29	0,011	1,350	0,187	0,365	3,316	29	0,17	1,78	0,58	0,80	1,667
P22*	26	0,003	0,300	0,022	0,032	10,264	26	0,007	0,36	0,040	0,054	9,692
P23*	28	0,003	0,035	0,012	0,014	2,337	28	0,009	0,301	0,026	0,040	9,762
P24*	28	0,005	0,076	0,027	0,029	2,887	28	0,019	0,369	0,054	0,073	7,864
P25	7	0,005	0,047	0,010	0,019		7	0,012	0,215	0,014	0,052	
P26	7	0,003	0,044	0,004	0,010		7	0,008	0,080	0,009	0,021	
P27	6	0,003	0,034	0,020	0,020		6	0,012	0,074	0,030	0,040	
P28	8	0,003	0,053	0,006	0,017		8	0,006	0,720	0,011	0,123	
P29	8	0	0,052	0,007	0,008		8	0,003	0,052	0,011	0,021	
P30	6	0,001	0,028	0,011	0,011		6	0,006	0,096	0,021	0,030	
P31	8	0	0,032	0,002	0,006		8	0,002	0,070	0,006	0,017	

Determinand	KN						DUC					
	Statistic						Statistic					
Ref. No.	N	Min	Max	Med	Av	Sk	N	Min	Max	Med	Av	Sk
	2	0,38	0,54	0,46	0,46							
	77	0,07	0,23	0,15	0,14		7	0,7	3,1	1,2	1,46	
	21	0,11	2,65	0,27	0,43	6,638	21	0,7	2,9	1,5	1,60	0,947
	6	0,10	0,25	0,16	0,17		6	1,4	2,8	2,3	2,2	
	27	0,20	0,71	0,38	0,39	2,119	27	0,8	2,9	1,9	1,92	0,185
	30	0,18	23,73	0,30	1,11	12,233	30	0,6	4,1	1,7	1,81	2,656
	24	0,12	0,74	0,32	0,35	1,946	24	0,9	3,25	1,8	1,89	1,001
	31	0,11	0,72	0,33	0,34	1,650	31	0,4	4,3	1,9	2,01	2,239
	30	0,19	1,34	0,29	0,35	8,539	30	0,7	3,1	1,7	1,80	0,282
	9	0,05	0,26	0,14	0,14		7	0,8	5,0	1,6	2,0	
	8	0,12	1,79	0,21	0,44		8	2,1	1,9	3,25	3,1	
	8	0,10	1,30	0,19	0,40		8	0,1	3,7	0,9	0,5	
	7	0,01	0,57	0,28	0,45		7	0,9	3,1	2,7	2,6	
	8	0,04	0,25	0,13	0,15		8	1,5	6,2	1,3	1,5	
	8	0,12	0,37	0,24	0,38		8	1,6	5,9	2,5	2,9	
	7	0,06	0,26	0,38	0,18		7	1,5	5,9	2,4	2,9	
	8	0,42	1,52	1,18	0,18		8	2,2	7,7	4,8	4,6	
	29	3,56	37,98	19,11	17,21	0,7513	29	2,2	7,7	5,8	5,79	-1,308
	26	0,23	0,82	0,46	0,46	1,478	26	0,7	5,3	2,2	2,08	3,474
	28	0,15	0,82	0,31	0,34	3,715	28	0	5,7	1,8	1,96	3,455
	28	0,18	0,67	0,36	0,37	1,509	28	0,5	5	1,8	1,92	3,635
	7	0,26	0,81	0,31	0,44		7	3,7	6,7	4,4	4,2	
	7	0,10	0,41	0,14	0,17		7	2,0	4,2	2,4	2,6	
	6	0,14	0,80	0,10	0,28		6	1,6	4,1	3,3	3,1	
	8	0,18	1,11	0,30	0,45		8	2,7	6,9	3,1	3,7	
	8	0,25	0,67	0,52	0,47		8	2,1	4,2	4,2	2,9	2,8
	6	0,12	0,62	0,25	0,29		6	1,1	3,0	1,7	1,9	
	8	0,95	0,31	0,18	0,16		8	0,8	4,3	1,5	1,7	

1) \*Production boreholes.  
 2) All values in milligrams per litre except pH and conductivity which are in pH units and millisiemens per meter respectively.  
 3) N-number of measurements, Med-median, Max-maximum, Min-minimum and SK-Standardized skewness.

Table 6: (Continued)

Determinand	F						NO <sub>3</sub>					
	Statistic						Statistic					
Ref. No.	N	Min	Max	Med	Av	Sk	N	Min	Max	Med	Av	Sk
P03	2	0	0,2	0,1	0,1		2	0,04	0,12	0,08	0,08	
P04	7	0,1	0,1	0,1	0,1		7	0	3,5	0,64	1,10	
P06*	21	0	0,3	0,2	0,17	0,755	21	0	8,64	5,37	4,86	0,525
P07	6	0,1	0,2	0,1	0,12		6	0,04	0,42	0,11	0,18	
P08*	27	0	0,7	0,1	0,16	6,508	27	0,01	3,46	2,4	2,24	-2,715
P09*	30	0	0,3	0,2	0,16	7,228	30	0,02	1,69	0,17	0,25	8,860
P10*	24	0	0,3	0,2	0,17	0,387	24	0,02	3,88	3,54	3,20	-4,969
P11*	31	0,1	0,3	0,2	0,16	1,294	31	0	6,62	5,19	4,50	-3,507
P12*	30	0	0,3	0,1	0,13	2,721	30	0,03	0,44	0,12	0,16	2,320
P13	9	0,1	0,3	0,1	0,12		9	0,14	2,64	0,76	0,88	
P14	8	0,1	0,2	0,15	0,15		8	0,01	0,31	0,09	0,12	
P15	8	0,1	0,2	0,15	0,15		8	0,54	1,65	0,99	1,03	
P16	7	0,1	0,2	0,1	0,13		7	11,07	19,4	75,25	15,26	
P17	8	0	3	0,1	0,45		8	1,29	3,28	2,14	2,27	
P18	8	0	0,2	0,1	0,1		8	0,04	2,61	1,4	1,46	
P19	7	0	0,2	0,1	0,1		7	8,15	14,94	9,82	10,20	
P20	8	0	0,3	0,1	0,14	0,563	8	0,02	0,58	0,16	0,213	
P21*	29	0	0,3	0,1	0,14	-0,063	29	0,51	17,44	1,80	2,42	5,150
P22*	26	0	0,3	0,1	0,14	1,327	26	0,02	0,62	0,35	0,34	-0,783
P23*	28	0	0,4	0,15	0,16	1,904	28	1,69	9,31	5,87	6,22	-0,507
P24*	20	0	0,4	0,15	0,16	2,709	20	0,03	2,17	1,61	1,327	-1,990
P25	7	0	0,3	0,2	0,16		7	0,03	0,41	0,16	0,19	
P26	7	0,1	0,2	0,1	0,13		7	0	0,05	0,04	0,03	
P27	6	0,1	0,3	0,15	0,17		6	0,03	0,26	0,22	0,18	
P28	8	0	0,2	0,1	0,11		8	0	0,3	0,02	0,065	
P29	8	0	0,2	0,1	0,13		8	0	0,1	0,015		0,025
P30	6	0,1	0,2	0,1	0,12		6	4,73	8,31	5,9	6,32	
P31	8	0	0,2	0,1	0,11		8	0	0,34	0,05	0,10	

Table 6: (Continued)

	SiO <sub>2</sub>					NH <sub>4</sub>						
	Statistic					Statistic						
N	Min	Max	Med	Av	Sk	N	Min	Max	Med	Av	Sk	
	2	1,1	4,4	2,8	2,8		2	0,25	0,27	0,26	0,26	
	7	3,4	4,6	4	3,97		7	0,01	0,07	0,03	0,03	
	21	3,5	4,8	3,9	3,92	2,234	21	0,02	2,08	0,05	0,15	8,556
	6	4,2	5,3	4,7	4,68		6	0,01	0,07	0,04	0,04	
	27	3,5	5	4	4,00	2,326	27	0,03	0,22	0,16	0,15	-2,867
	30	2,5	5,7	4	4,01	1,264	30	0,01	20,24	0,16	0,82	12,243
	24	3,6	4,8	3,9	3,99	2,277	24	0,03	0,21	0,12	0,13	0,003
	30	3,6	4,7	3,9	3,40	1,603	31	0,02	0,34	0,090	0,092	7,019
	30	4	5,3	4,3	4,38	2,538	30	0,01	0,37	0,17	0,17	0,440
	9	2,3	4,7	3,6	3,67		9	0,02	0,06	0,03	0,04	
	8	3,0	3,4	3,4	4,90		8	0,21	0,44	0,03	0,12	
	7	3,2	4,4	4,2	43,46		8	0,02	0,06	0,03	0,04	
	8	3,9	4,9	4,1	4,18		8	0,02	0,06	0,03	0,03	
	7	3,4	5	3,6	4,00		8	0,02	0,07	0,02	0,04	
	8	4,2	7,5	6,7	6,50		8	0,02	0,08	0,03	0,036	
	29	4,0	5,9	7,5	6,7	0,789	29	0,04	1,89	3,87	12,15	
	26	3,8	5,1	4,4	4,42	0,242	26	0	0,50	0,22	0,23	1,364
	28	3,5	4,7	4	4,04	0,909	28	0	0,26	0,09	1,0	2,776
	20	3,4	4,9	3,9	3,90	1,638	20	0	0,43	0,17	0,19	1,800
	7	3,8	4,2	3,8	3,91		7	0,03	0,41	0,15	0,15	
	7	1,0	4,9	3,9	3,63		7	0,01	0,16	0,03	0,05	
	6	5,0	17,5	5,3	7,38		6	0,01	0,06	0,03	0,03	
	8	4,3	5,6	4,5	4,78		8	0,01	0,96	0,06	0,23	
	8	4,5	5,4	4,7	4,75		8	0,02	0,49	0,24	9,22	
	6	3,4	3,9	3,6	3,62		6	0	0,09	0,04	0,04	
	8	4,1	5,1	4,3	4,38		8	0	0,09	0,03	0,03	

Table 6: (Continued)

Determinand	TALCC					
	Statistic					
Ref. No.	N	Min	Max	Med	Av	Sk
P03						
P04	6	270	420	275	301,3	
P06*	20	240	400	260	263,2	7,214
P07*	6	280	318	296	298,3	
P08*	27	250	362	260	267,7	8,449
P09*	27	240	305	250	255,7	3,419
P10*	24	260	305	270	275,2	2,753
P11*	28	250	309	270	272,21	1,354
P12*	29	260	360	295	295,2	3,161
P13	7	220	320	230	244,3	
P14	7	260	435	390	306,3	
P15	7	176	270	190	199,4	
P16	7	305	410	320	331,4	
P17	7	238	370	260	269,0	
P18	7	260	290	270	272,9	
P19	4	220	300	233	246,3	
P20	7	250	530	400	399,4	
P21*	29	350	472	390	393,0	3,988
P22*	25	250	380	270	277,4	6,533
P23*	27	235	290	260	258,2	0,312
P24*	26	225	280	260	257,7	-0,582
P25	6	248	320	278	280,5	
P26	6	248	290	258	261,3	
P27	6	250	270	264,5	263,2	-0,881
P28	6	300	500	343	362,5	
P29	7	202	335	339	309,1	
P30	5	202	225	221	218,6	
P31	7	270	400	285	303,7	

Table 6: (Continued)

	SO <sub>4</sub>					Cl					
	Statistic					Statistic					
N	Min	Max	Med	Av	Sk	N	Min	Max	Med	Av	Sk
2	4	39	21,5	21,5		2	113	117	115	115	
7	22	110	41	53,6		7	94	134	118	118,1	
21	130	47	37	37,9	0,118	21	104	207	130	135,5	2,215
6	37	46	40	40,3		6	95	111	109	106	
27	32	60	42	42,6	0,2061	27	76	109	86	85,4	1,869
30	29	154	70	76,4	3,160	30	72	107	81	83,0	2,311
24	42	75	63	61,7	-2,330	24	91	102	95	95,3	1,587
31	138	77	52	53,5	2,430	31	50	127	101	100,3	-3,370
30	24	101	80,5	77,5	-4,727	30	85	154	112,5	117	1,129
9	40	60	47	49,4		9	39	92	84	76,6	
8	99	174	129	132		8	56	103	91	86,9	
8	12	21	14,5	15,1		8	17	86	84	82,6	
7	32	47	40	39,7		7	86	185	146	142	
8	16	23	20	19,6		8	130	157	149	147,9	
8	25	54	36,5	37,5		8	94	109	99,5	100,5	
7	44	76	46	51,7		7	45	64	50	51	
8	192	326	282,5	271,5		8	61	133	103,5	103	
29	18	43	26	26,9	2,340	29	98	122	109	108,8	0,513
26	23	62	57,5	50,1	-4,165	26	98	116	102	103,7	2,346
28	39	66	48	48,8	2,489	28	99	132	120	118,8	-0,670
28	23	55	34	35,8	1,142	28	81	96	86	87	1,752
7	34	49	40	40,3		7	115	120	118	117,4	
7	20	32	25	24,9		7	101	116	104	105,3	
6	14	31	25,5	23,7		6	81	90	85	85,7	
8	0	7	4,5	3,9		8	123	149	139	138,3	
8	19	35	24,5	25,6		8	106	120	115	115,4	
6	25	32	29	28,8		6	91	116	105,5	103,5	
8	20	27	21,5	22,6		8	160	211	190	187,6	

Table 6: (Continued)

Determinand	Na						Ca					
	Statistic						Statistic					
Ref. No.	N	Min	Max	Med	Av	Sk	N	Min	Max	Med	Av	Sk
P03	2	62	69	65,5	65,5		2	16	117	66,5	66,5	
P04	7	62	80	69	70,4		7	56	131	77	87,9	
P06*	21	62	113	76	77,5	2,057	21	78	112	103	100,6	
P07	6	55	62	60,5	59,5		6	69	109	92,5	90,8	
P08*	27	43	57	50	49,3	-1,209	27	48	114	97	93,2	
P09*	30	40	90	47,5	50,3	5,947	30	53	158	107	103,9	
P10*	24	49	65	58	58,4	-0,946	24	80	120	111	109,6	
P11*	31	27	76	61	60,6	-4,666	31	48	125	109	106,3	
P12*	30	52	98	69	70,7	1,656	30	59	135	124,5	119,2	
P13	9	22	54	49	45,4		9	38	100	90	84	
P14	8	31	57	53,5	51,25		8	74	151	131,5	128	
P15	8	42	46	44,5	44,38		8	43	74	69,5	67,1	
P16	7	64	100	94	91,3		8	52	135	113	96,6	
P17	8	73	95	88	86,6		8	32	94	92,5	82,6	
P18	8	52	76	61,5	62,5		8	44	102	85	83,6	
P19	7	31	44	35	36,4		7	79	122	96	96,6	
P20	8	29	64	53,5	51,5		7	91	230	189	187,1	
P21*	29	68	90	78	78,3	0,735	29	59	129	97	99,7	
P22*	26	53	67	57,5	58,2	1,671	26	88	122	108,5	107,2	
P23*	28	52	78	72	71,1	-3,599	28	97	123	109,5	109,7	
P24*	28	45	53	49,5	49,5	-0,372	28	86	109	99	99,5	
P25	7	74	92	88	86,9		7	80	112	89	89,9	
P26	7	57	61	58	58,7		7	58	98	93	86,6	
P27	6	46	53	47,5	48		6	67	98	97	92	
P28	8	67	81	74	74,4		8	41	145	103,5	101,1	
P29	8	62	69	67,5	66,8		8	53	118	82,5	86,3	
P30	6	58	63	60	60,5		6	69	98	90	88	
P31	8	87	112	100	99		8	66	111	98	93,8	

Table 6: (Continued)

	Mg						K					
	Statistic						Statistic					
N	Min	Max	Med	Av	Sk	N	Min	Max	Med	Av	Sk	
2	7	12	9,5	9,5		2	2,2	4,3	3,3	3,25		
7	10	14	12	11,9		7	1,5	1,9	1,8	1,75	-1,081	
21	11	15	13	12,7	0,667	21	1,1	5,0	2,3	2,38	4,350	
6	7	16	15	13,5		6	1,7	2,2	2,0	1,96		
27	9	13	11	10,7	1,128	27	1,6	2,3	1,9	1,96	0,232	
30	9	14	10,5	10,9	1,464	30	0,7	7,0	1,7	1,84	10,769	
24	10	16	12	12,4	2,240	24	1,6	2,9	2,1	2,13	1,353	
31	5	15	12	11,8	-2,937	31	1,1	2,7	2,2	2,13	-2,380	
30	10	18	14	14,1	-0,227	30	1,4	2,1	1,8	1,78	-0,691	
9	4	12	9	9,2		9	0,6	2,3	1,8	1,69		
8	8	16	13	12,8		8	1,0	2,0	1,9	1,79		
8	8	10	9	9		8	1,5	2,0	1,95	1,85		
7	15	22	17	17,9		7	1,9	2,6	2,5	2,4		
8	9	14	11	11,1		8	1,0	1,3	1,1	1,11		
8	9	13	9,5	10,3		8	1,5	2,0	1,9	1,83		
7	9	14	12	11,7		7	2,7	8,0	2,8	3,66		
7	15	33	24,5	24,8		8	2,0	3,8	3,5	3,38		
29	9	14	12	11,69	-0,233	29	2,7	7,5	5,7	5,53	-0,703	
26	10	14	12	12,0	0,489	26	1,6	2,3	1,9	1,90	0,559	
28	8	14	12	11,6	1,407	28	1,6	3,0	2,4	2,40	-0,786	
28	8	12	9	9,6	1,320	28	0,9	1,7	1,5	1,42	-1,706	
7	7	10	8	8,6		7	2,5	8,2	5,7	5,1		
7	8	11	10	9,6		7	1,5	1,8	1,7	1,67		
7	4	13	10	9,5		6	1,2	6,4	1,5	2,3		
8	9	21	15,5	15,8		8	1,3	2,8	1,8	1,81		
8	12	17	13,5	14,3		8	1,6	2,1	1,8	1,85		
6	8	14	9,5	10,3		6	1,7	2,3	2,1	2,07		
8	11	18	13,5	14		8	1,6	1,8	1,8	1,74		

Table 6: (Continued)

Determinand	pHCCC					
	Statistic					
Ref. No.	N	Min	Max	Med	Av	Sk
P03						
P04	6	6,09	7,40	7,30	7,26	
P06	20	7,6	7,5	7,3	7,3	-0,005
P07						
P08	27	7,13	7,53	7,32	7,32	-0,135
P09	27	7,13	7,54	7,31	7,30	0,754
P10	24	7,17	7,48	7,29	7,28	1,305
P11	28	7,76	7,54	7,32	7,34	0,413
P12	29	6,81	7,60	7,23	7,23	-1,042
P13	1	7,24	7,39	7,36	7,33	
P14	7	7,24	7,39	7,36	7,33	
P15	7	7,39	7,63	7,53	7,51	
P16	7	6,98	7,22	7,06	7,08	
P17	7	7,22	7,46	7,30	7,32	
P18	7	7,12	7,35	7,23	7,23	
P19	7	7,21	7,52	7,44	7,40	
P20	7	6,79	6,87	6,81	6,82	
P21	29	7,13	7,13	7,13	7,13	0,857
P22	25	7,14	7,45	7,29	7,29	-0,221
P23	27	7,23	7,53	7,35	7,37	0,867
P24	26	7,0	7,54	7,36	7,35	1,079
P25	6	7,10	7,31	7,28	7,24	
P26	6	7,23	7,73	7,29	7,36	
P27	6	7,29	7,50	7,33	7,25	
P28	6	7,05	7,20	7,16	7,14	
P29	7	7,09	7,24	7,14	7,15	
P30	5	7,21	7,25	7,35	7,31	
P31	7	7,11	7,48	7,25	7,25	

Table 6: (Continued)

Conductivity						TDS					
Statistic						Statistic					
N	Min	Max	Med	Av	Sk	N	Min	Max	Med	Av	Sk
2	45,9	88,5	76,2	67,2		2	302	657	479,5	479,5	
7	78	104	86	87,0		7	475	732	571	580,6	
21	85	109	94	94,8	0,353	21	585	781	660	658,1	1,299
6	76	92	83	85,3		6	505	654	587	567,7	
27	54,4	91,1	78	78,1	-2,231	27	348	626	574	554,5	-3,578
30	58,2	107	81,1	82,2	0,536	30	401	793	574	587,6	0,715
24	78,1	96,8	90,1	89,9	-2,169	24	551	690	649	640,5	-3,262
81	41,7	107,7	90,4	81,1	-4,835	31	278	745	638	633,4	-6,389
30	69,9	110,3	100,2	99,5	-4,078	30	472	776	722	710	-5,290
9	33,9	84	73	69,4		9	218	566	536	489,8	
8	62,7	103	96	91,4		7	384	792	720	688,5	
8	55,1	64	62,9	61,6		8	326	455	433	420,5	
7	76	126	118	111,9		7	493	887	782	7,3,6	
8	78,4	96	92	90,3		8	417	670	627,5	605,4	
8	55,6	88	81,9	77,7		8	375	642	565,5	549,3	
7	62	84	72	72,7		7	450	646	541	538,6	
8	86	142	131,2	12,67		8	475	1161	1043	975,3	
29	81	123,7	105	104,2	-0,671	29	632	872	763	753,8	-1,299
26	70,3	99,5	87,4	87,3	-1,217	26	531	692	627,5	623,9	-1,423
20	78	101,1	97	95,1	-4,207	28	598	700	670	665,7	-2,556
28	67,3	89	79,3	78,9	-0,886	28	519	593	566	564,4	-1,293
7	75,1	93	90	88,2		7	607	694	633	643,7	
7	70,1	86	79,8	79,4		7	426	602	552	470,9	
6	58	78	74,4	61,8		6	417	564	452,5	523,8	
8	67,9	100	98	93,8		8	439	808	686	574,9	
8	80,9	96	89	88,7		8	466	699	613	604,3	
6	72,1	83	79	78,2		6	463	614	564	556,3	
8	89,5	116	109,2	106,4		8	594	751	691	684,0	



Table 7: Statistical summary of water quality variables - all data.

Determinand	N	Maximum	Minimum	Mean*	Median	Percentiles				Standardized skewness
						95	90	10	5	
pH <sup>#</sup>	403	8,5	5,8	7,82	7,8	8,3	8,2	7,5	7,4	-12,052
Conductivity	403	142	33	89,1	89,5	109,3	106	73	67,3	0,961
Total Dissolved Salts TDS	403	161	218	630	633	788	754	510	441	4,523
Sodium Na	403	113	22	62,9	61	90	83	46	44	4,354
Calcium Ca	403	230	16	102,3	103	129	123	74	66	7,601
Magnesium Mg	403	33	4	12,03	12	17	15	9	8	17,465
Potassium K	403	8,2	0,6	2,31	1,9	5,7	3,6	1,5	1,3	21,260
Sulphate SO <sub>4</sub>	403	326	0	51,95	45	99	80	22	18	31,515
Chloride Cl	403	211	17	105,2	102	149	134	80	76	8,481
Fluoride F	403	3	0	0,50	0,1	0,3	0,2	0,1	0	114,157
Nitrate NO <sub>3</sub>	403	19,4	0	2,40	1,53	8,46	6,07	0,04	0,02	18,033
Silica SiO <sub>2</sub>	403	17,5	1	4,25	4,1	5,4	5	3,6	3,5	59,025
Ammonia NH <sub>4</sub>	403	31,89	0	1,047	0,12	6,6	0,39	0,02	0,02	38,316
Phosphate PO <sub>4</sub>	403	1,35	0	0,043	0,011	0,55	0,044	0,002	0,001	54,491
Total Phosphorus TP	403	1,78	0	0,102	0,03	0,52	0,189	0,009	0,009	37,181
Dissolved Organic Carbon DOC	403	7,7	0	2,41	2	5,8	4,5	1,1	0,8	13,189
Ultra Violet	372									
Turbidity	359	87	0,1	7,58	4	27	15,9	0,4	0,3	26,621
Total Alkalinity TAL <sup>#</sup>	403	386	61	225,6	226	326	277	168	132	
Hardness	403	705	68	305	309	378	360	233	213	-0,072

\*Geometric mean for pH.

<sup>#</sup>Total alkalinity and pH - from Hydrological Research Institute.

Table 8: Statistical summary of minor and trace constituents  
(all concentrations in milligrams per litre).

Determinand	N	Maximum	Minimum	Mean	Median	Percentile 95
Aluminium Al	403	1,070	0	0,090	0,056	0,306
Arsenic As	403	0,209	0	0,003	0	0
Barium Ba	403	1,961	0	0,078	0,033	0,113
Beryllium Be	403	0,127	0	0,0004	0	0
Boron B	403	0,895	0	0,087	0,071	0,127
Cadmium Cd	403	0,013	0	0,001	0	0,004
chromium Cr	403	0,063	0	0,001	0	0,003
Cobalt Co	403	0,105	0	0,002	0	0,009
Copper Cu	403	0,146	0	0,007	0,001	0,030
Iron Fe	403	22,99	0	1,153	0,663	3,290
Lead Pb	403	0,856	0	0,030	0	0,072
Manganese Mn	403	0,044	0	0,005	0,004	0,011
Nickel Ni	403	0,100	0	0,005	0	0,028
Strontium Sr	403	4,382	0	1,567	1,500	2,230
Titanium Ti	403	0,015	0	0,001	0	0,007
Vanadium V	403	0,012	0	0,001	0	0,003
Zinc Zn	403	1,304	0	0,057	0,022	0,150
Zirconium Zr	403	1,390	0	0,010	0,003	

APPENDIX B

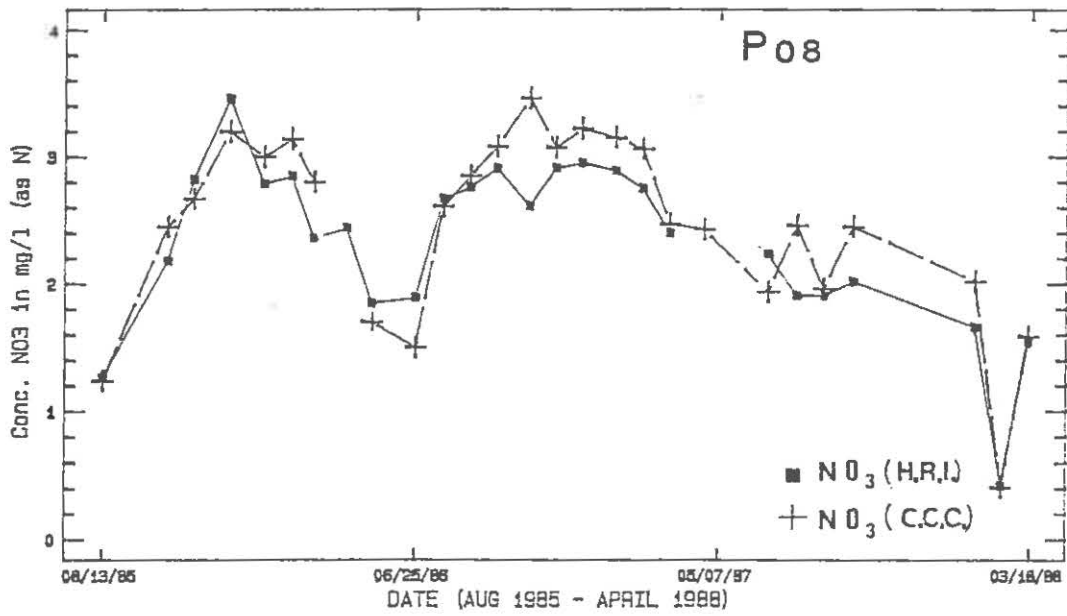
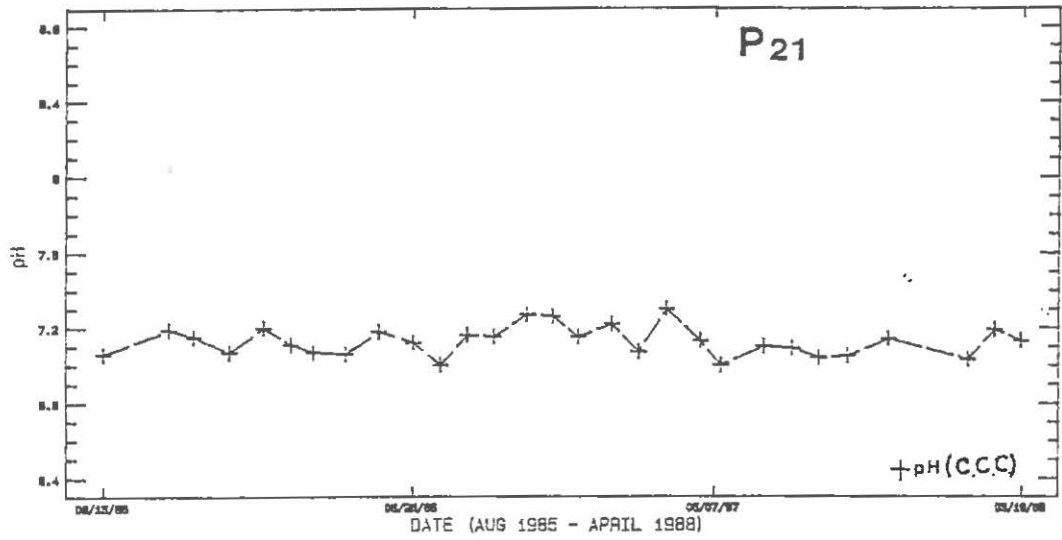


FIG.6a : CHEMOGRAPHS OF NITRATE AND pH FROM P21 AND P08  
- RESULTS FROM H.R.I. AND C.C.C.

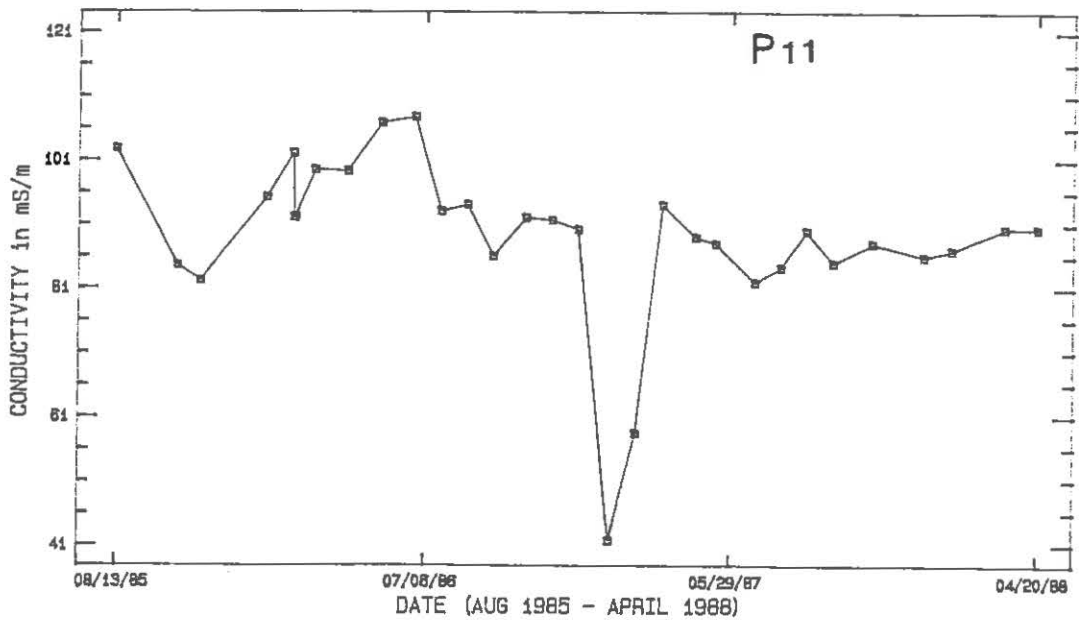
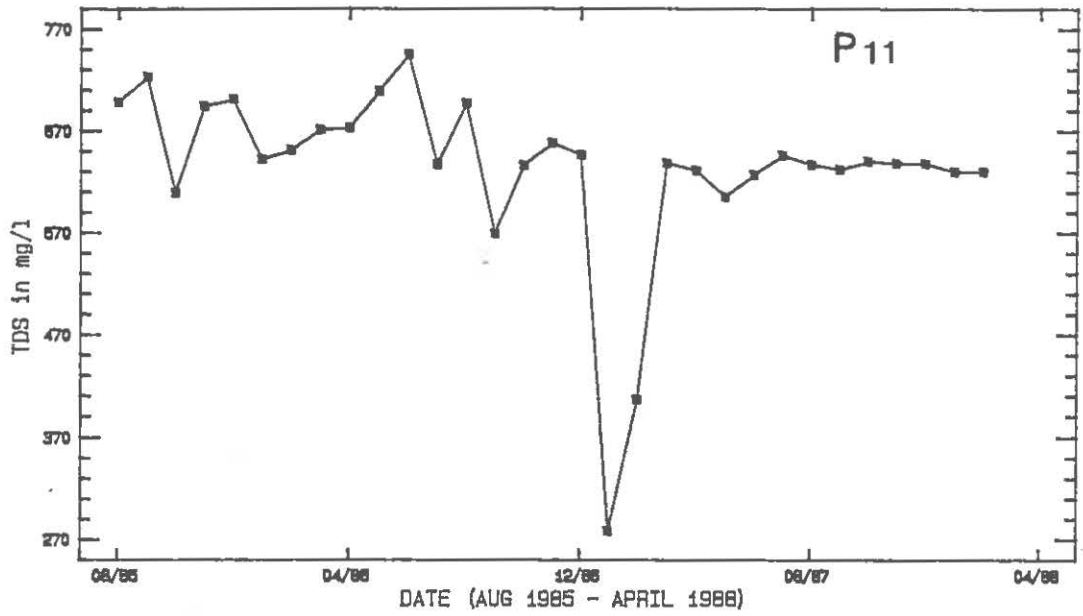
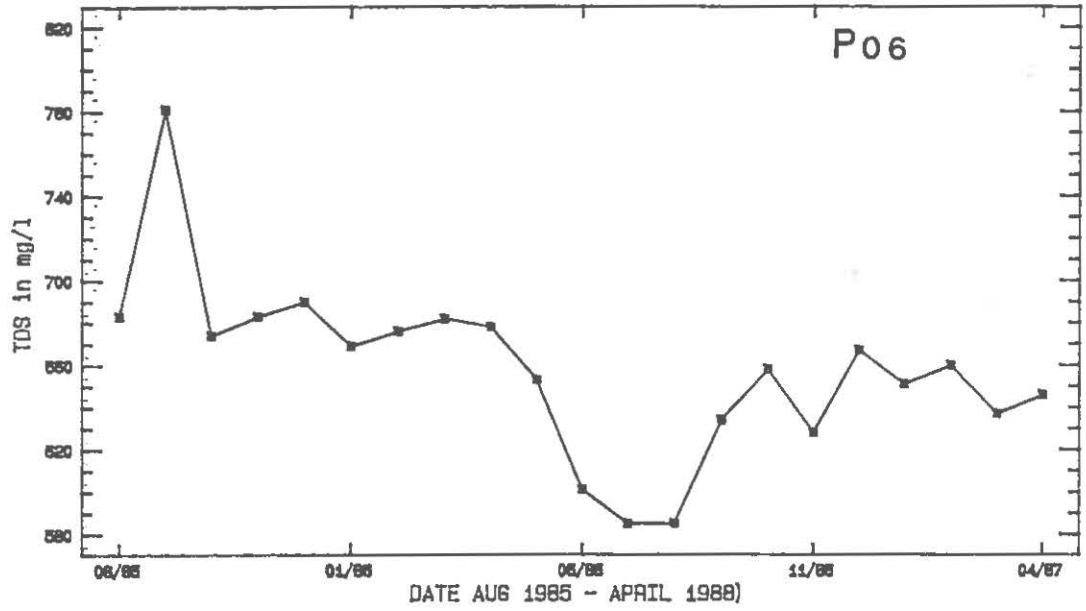


FIG.6b : VARIATIONS IN TDS AND CONDUCTIVITY FROM SELECTED PRODUCTION BOREHOLES

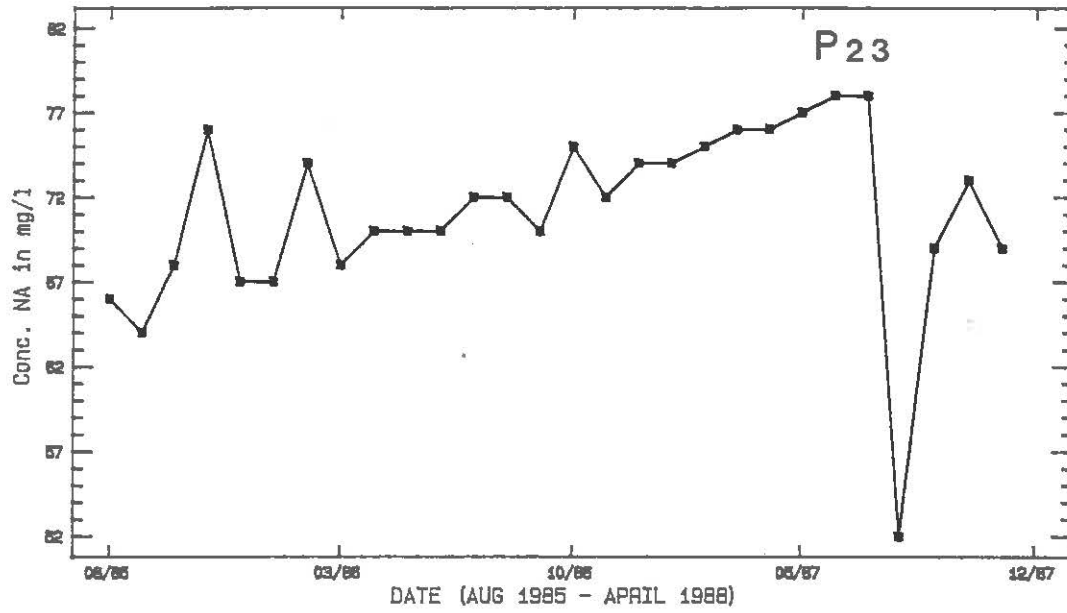


FIG.6c : VARIATIONS IN SODIUM CONCENTRATION FROM SELECTED PRODUCTION BOREHOLES

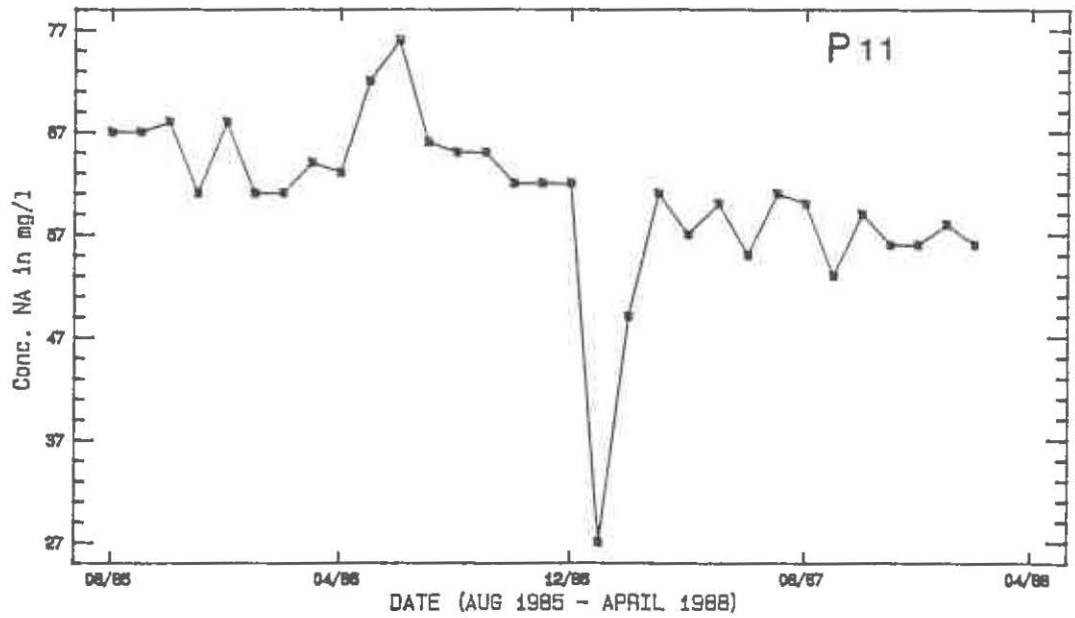
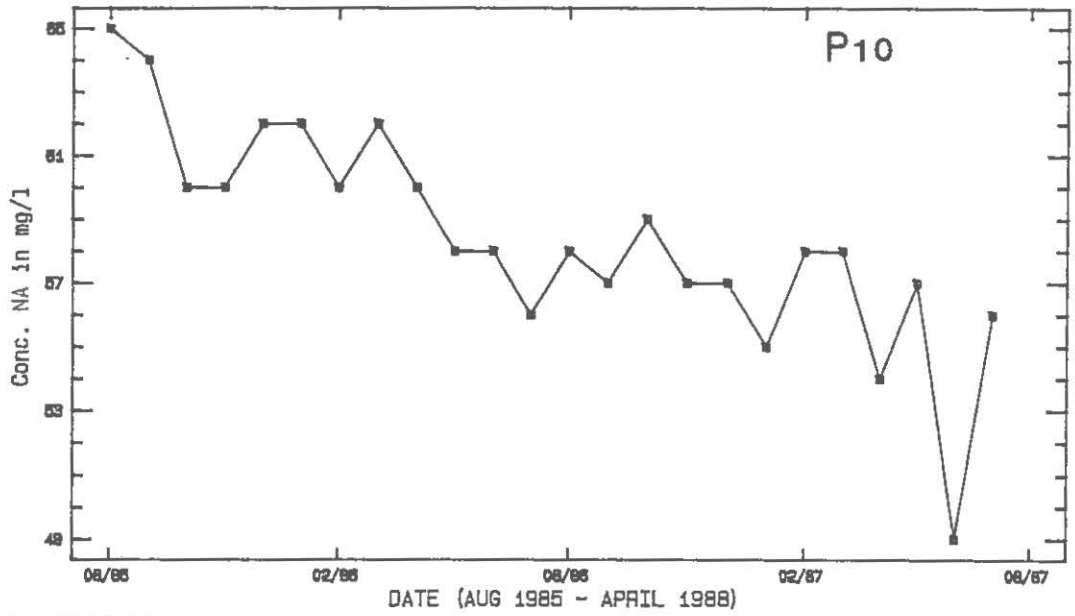
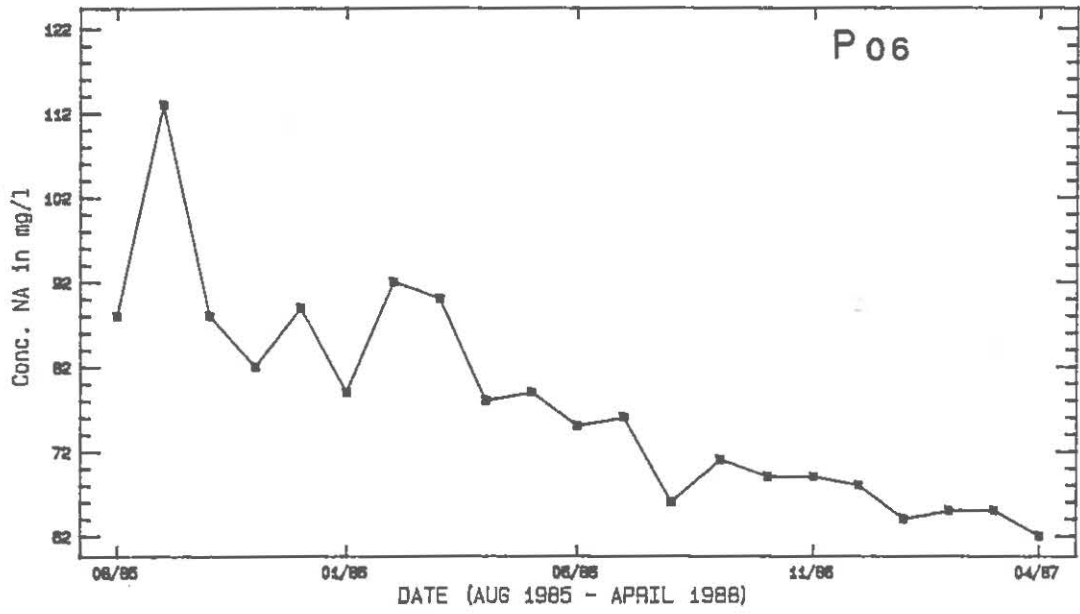


FIG.6d : VARIATIONS IN SODIUM CONCENTRATION FROM SELECTED PRODUCTION BOREHOLES

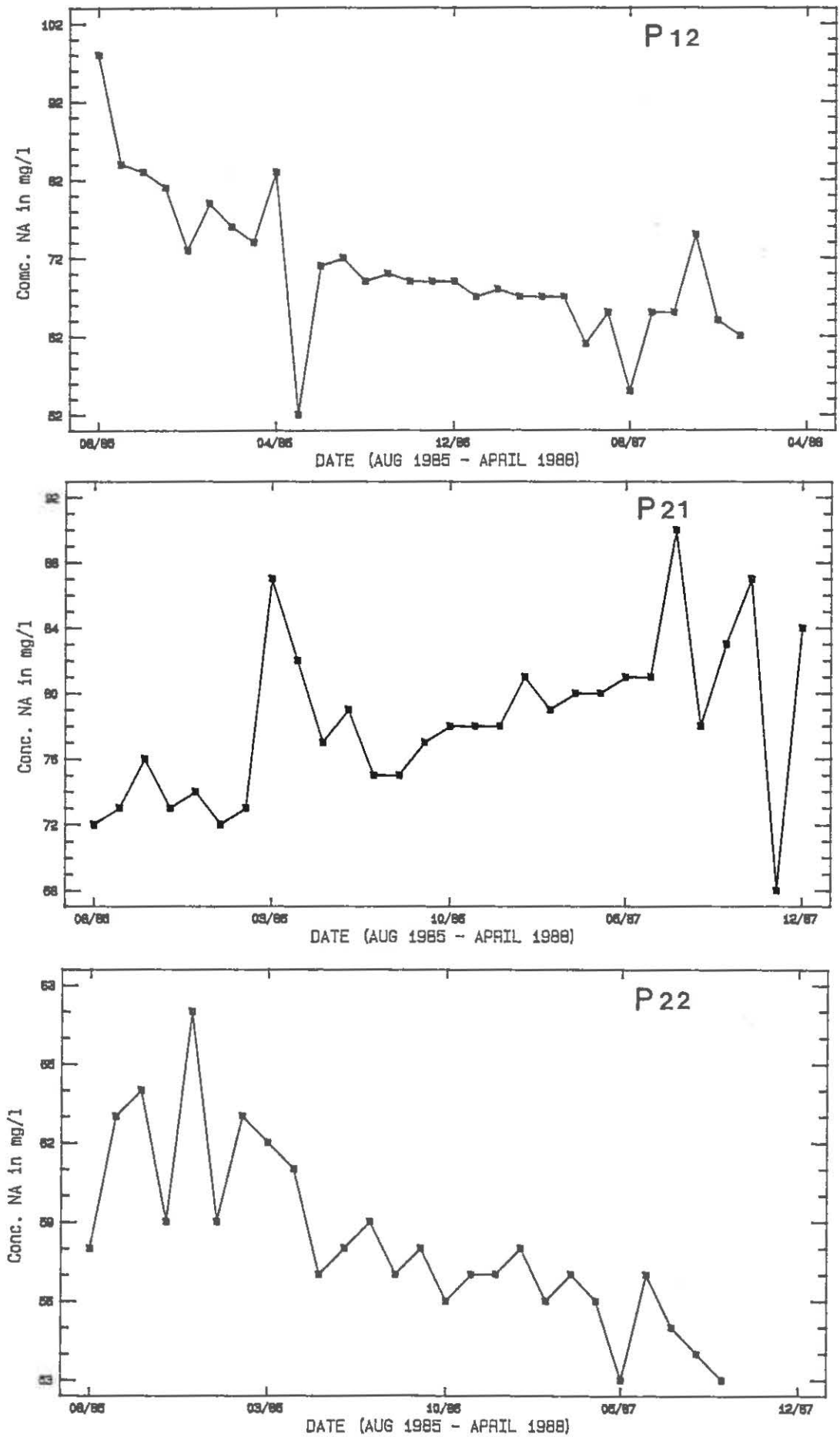


FIG.6e : VARIATIONS IN SODIUM CONCENTRATION FROM SELECTED PRODUCTION BOREHOLES



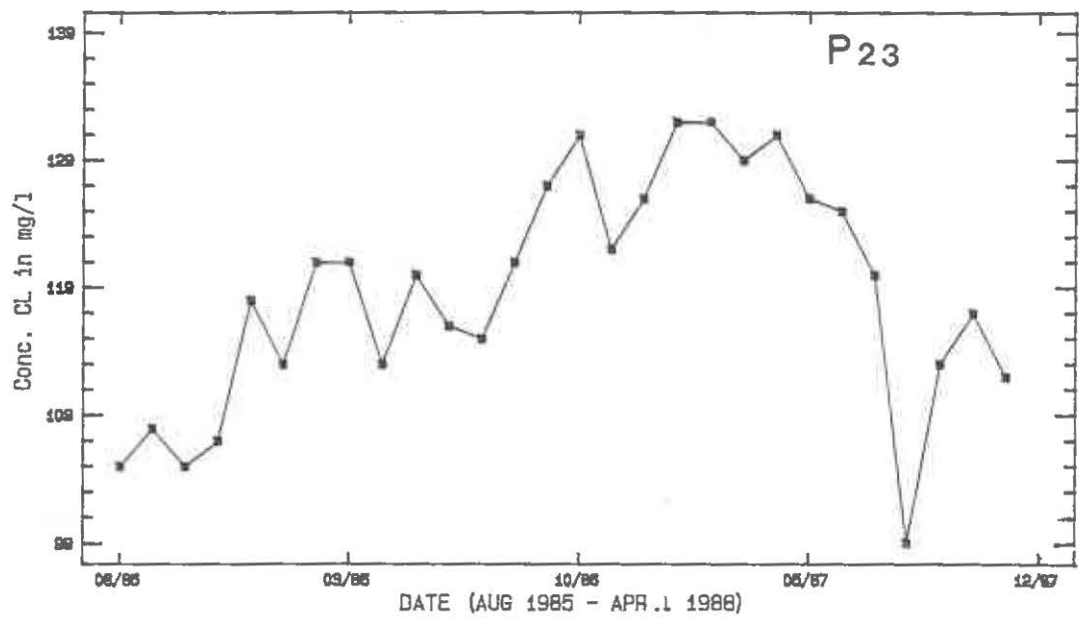


FIG.6f : VARIATIONS IN CHLORIDE CONCENTRATIONS FROM SELECTED PRODUCTION BOREHOLES

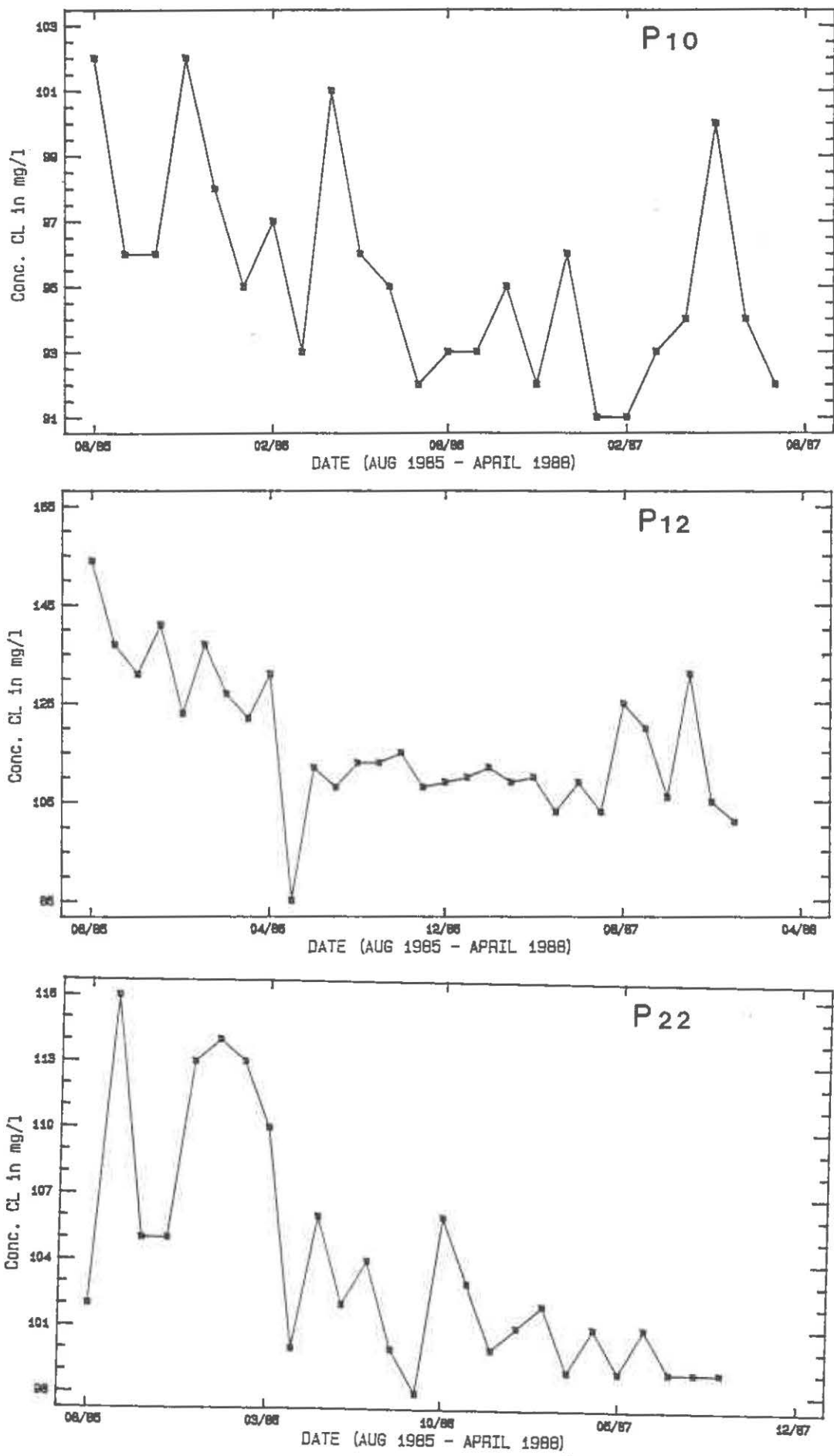


FIG. 6g : VARIATIONS IN CHLORIDE CONCENTRATIONS FROM SELECTED PRODUCTION BOREHOLES

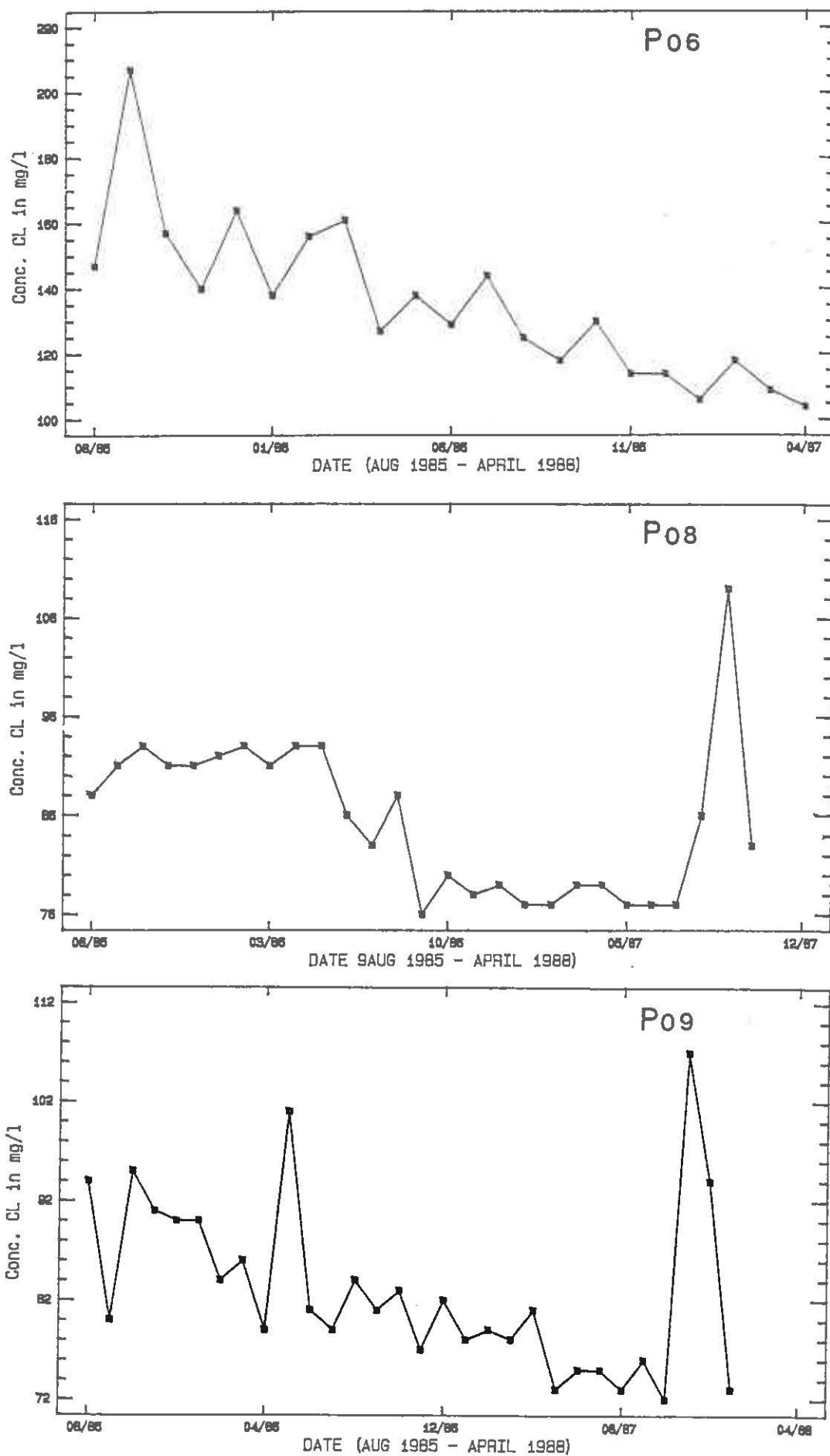


FIG.6h : VARIATIONS IN CHLORIDE CONCENTRATIONS FROM SELECTED PRODUCTION BOREHOLES

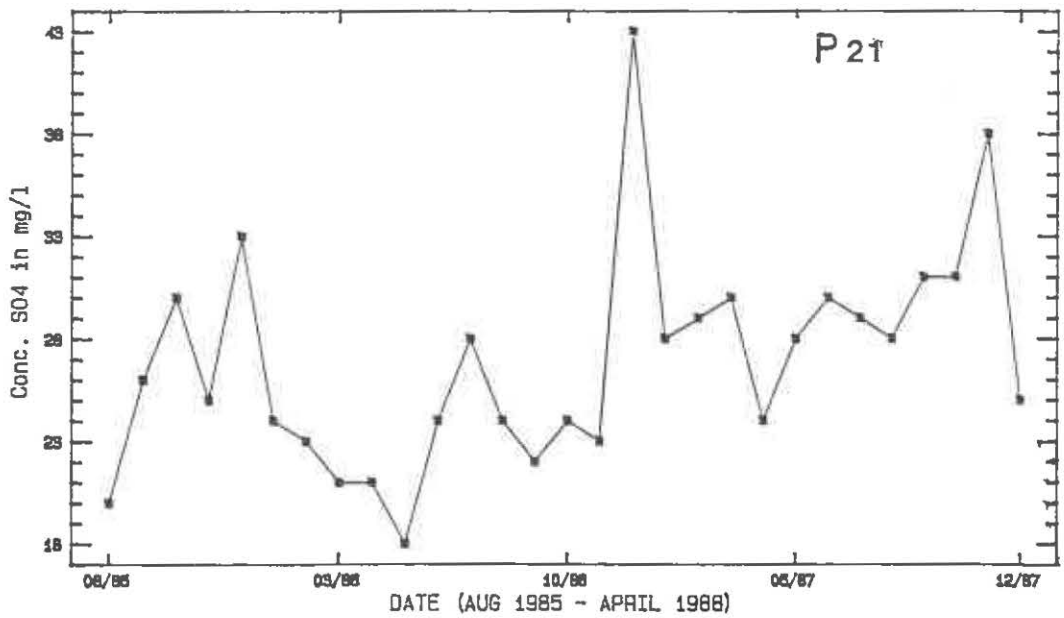
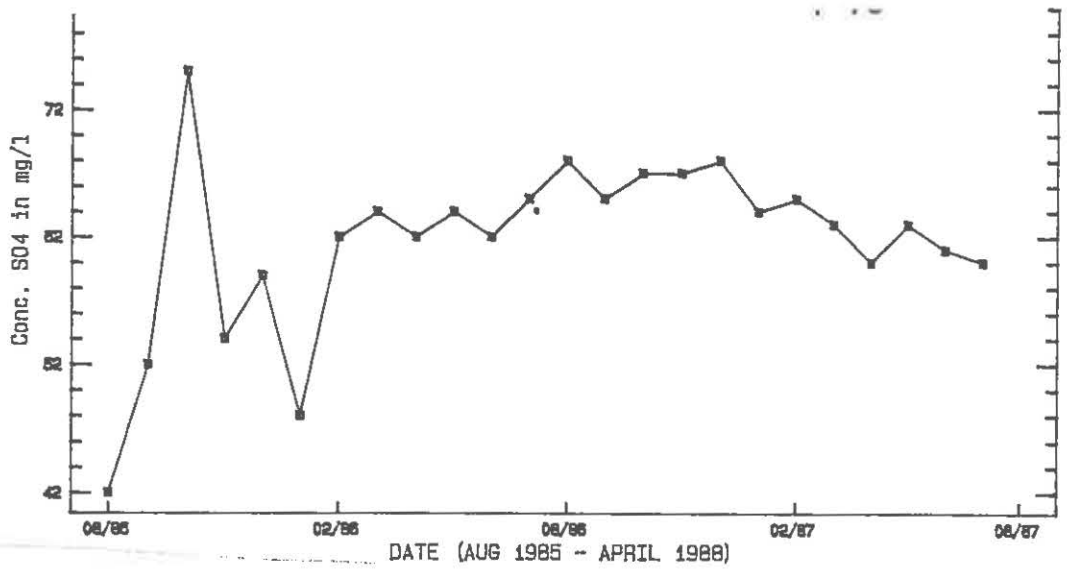
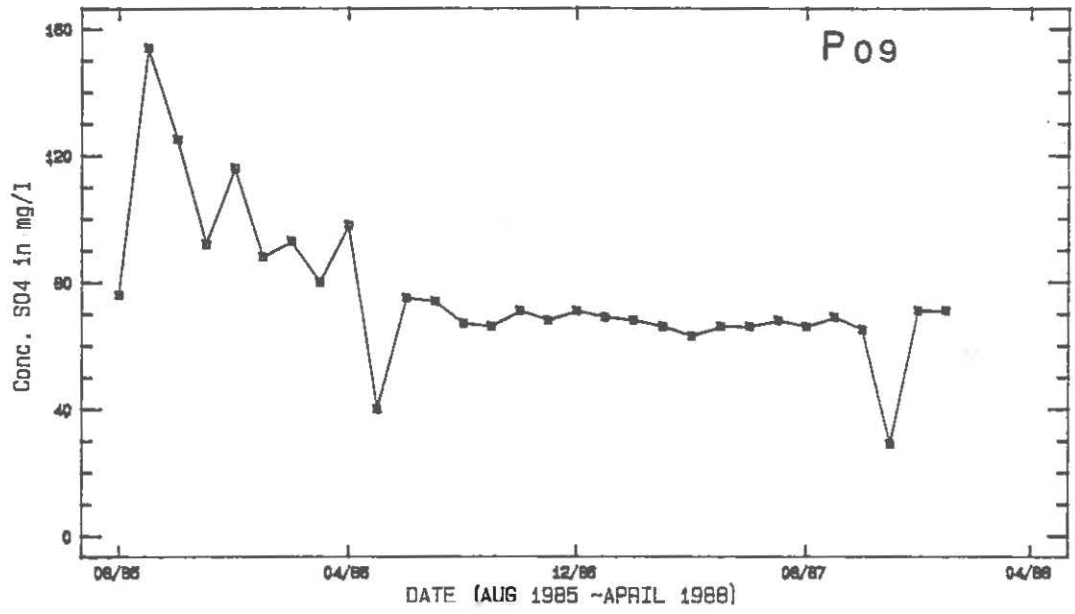


FIG.6i : VARIATIONS IN SULPHATE CONCENTRATIONS FROM SELECTED PRODUCTION BOREHOLES

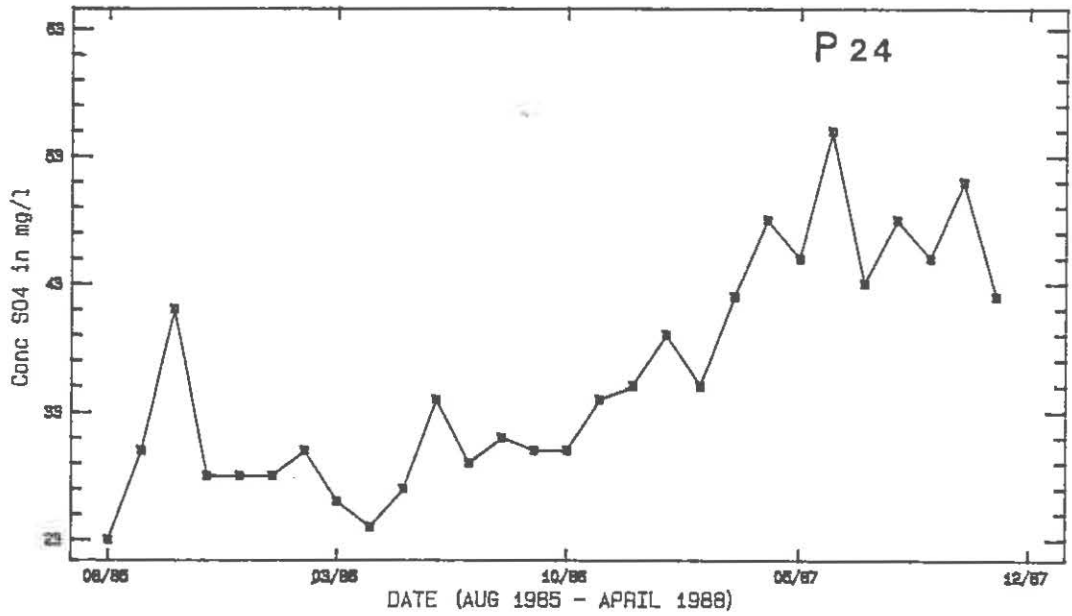
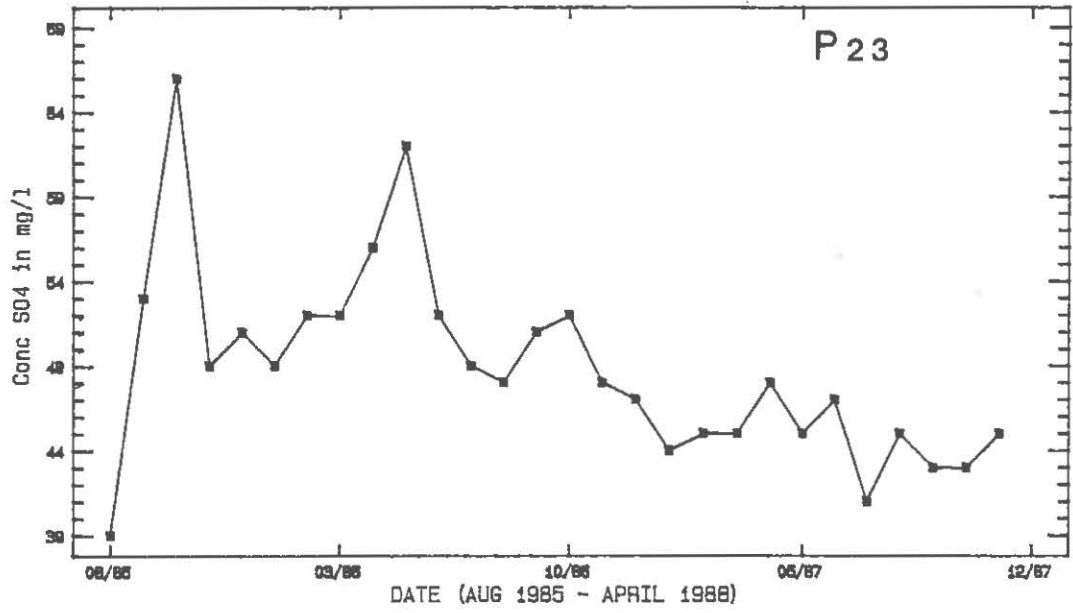


FIG.6j : VARIATIONS IN SULPHATE CONCENTRATIONS FROM SELECTED PRODUCTION BOREHOLES

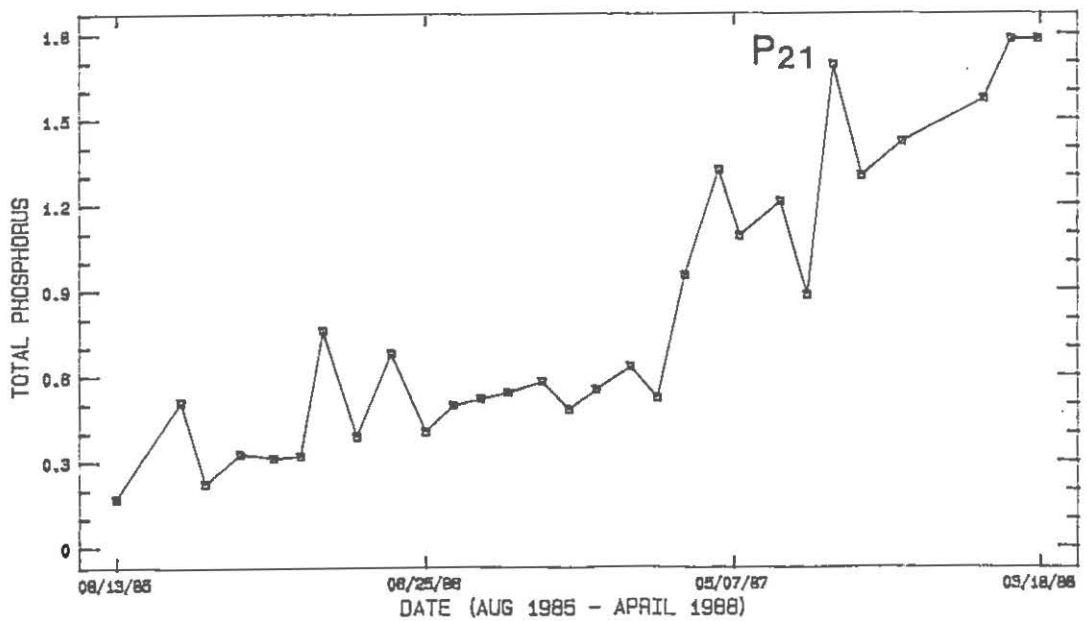
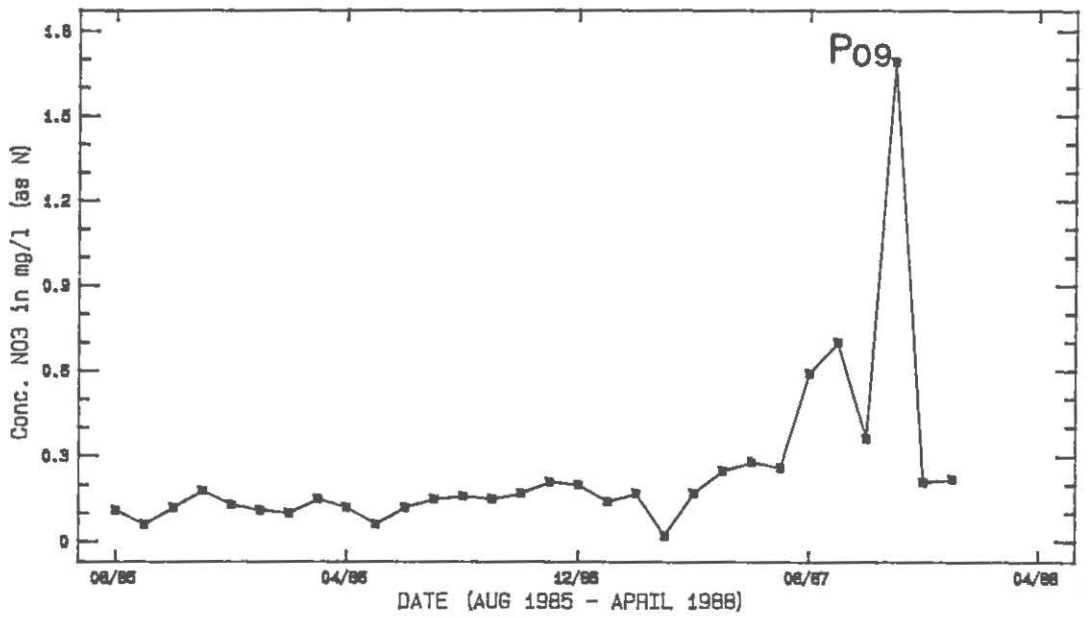
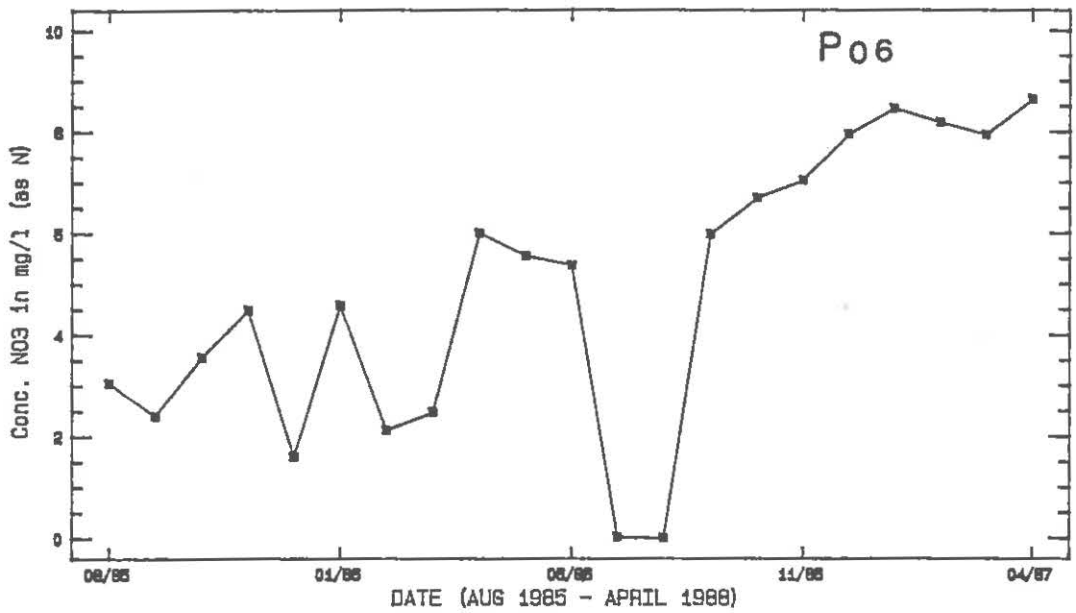


FIG.6k : VARIATIONS IN NITRATE AND TOTAL PHOSPHORUS CONCENTRATIONS FROM SELECTED PRODUCTION BORE HOLES

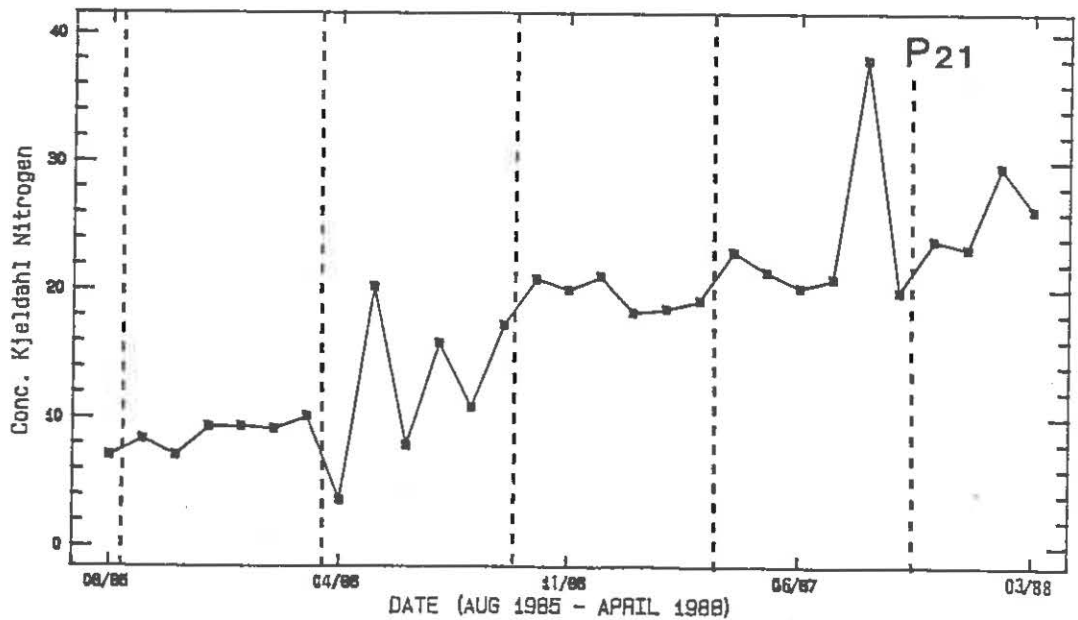
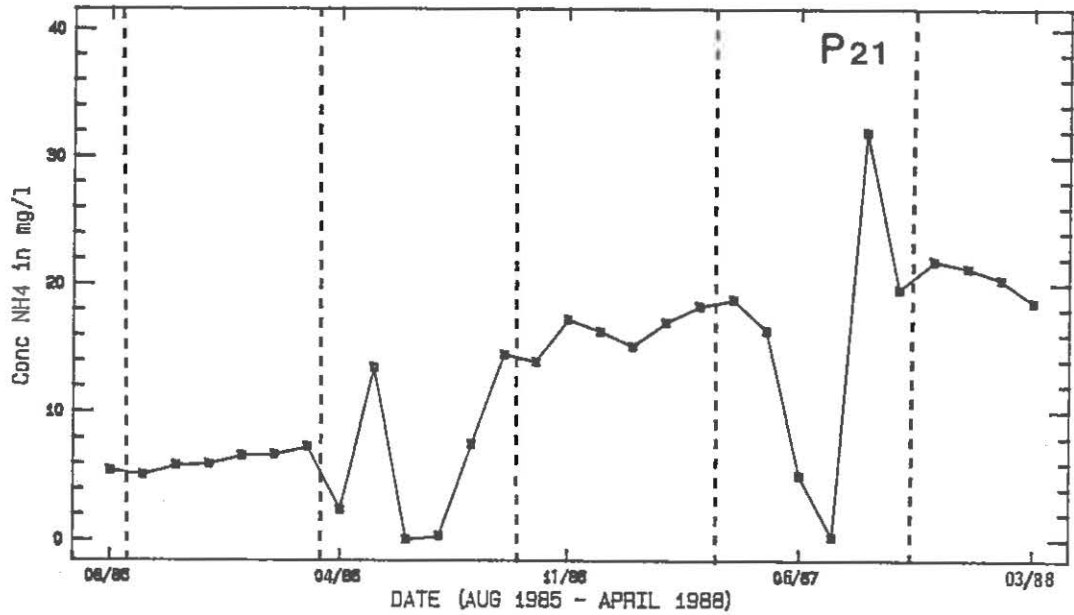
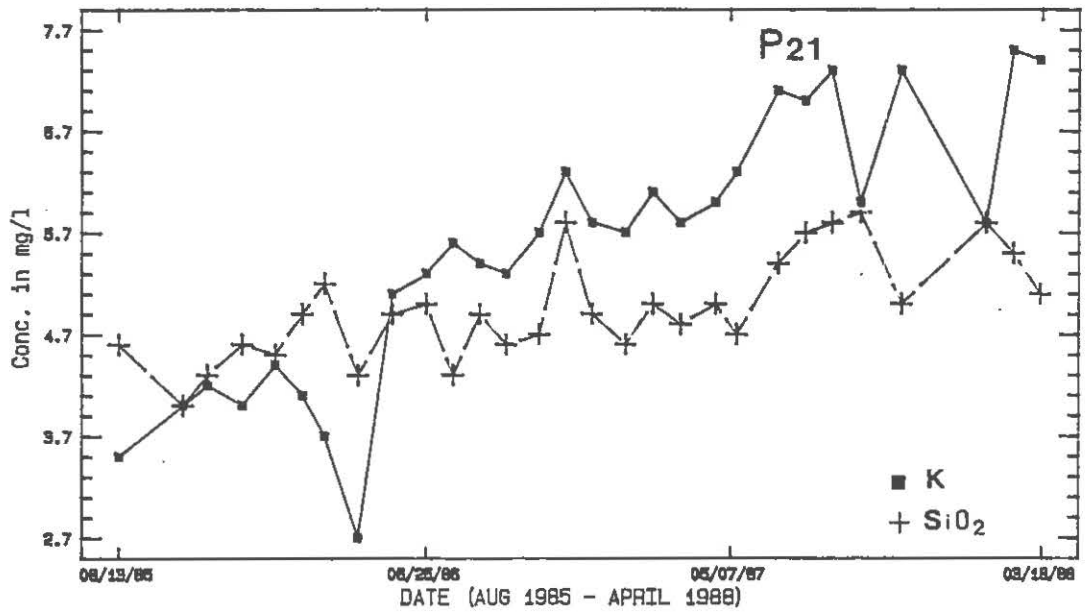


FIG.61 : VARIATIONS IN POTASSIUM, SILICA, AMMONIUM AND KJELDAHL NITROGEN CONCENTRATIONS FROM SELECTED PRODUCTION BOREHOLE NO. P21

APPENDIX C



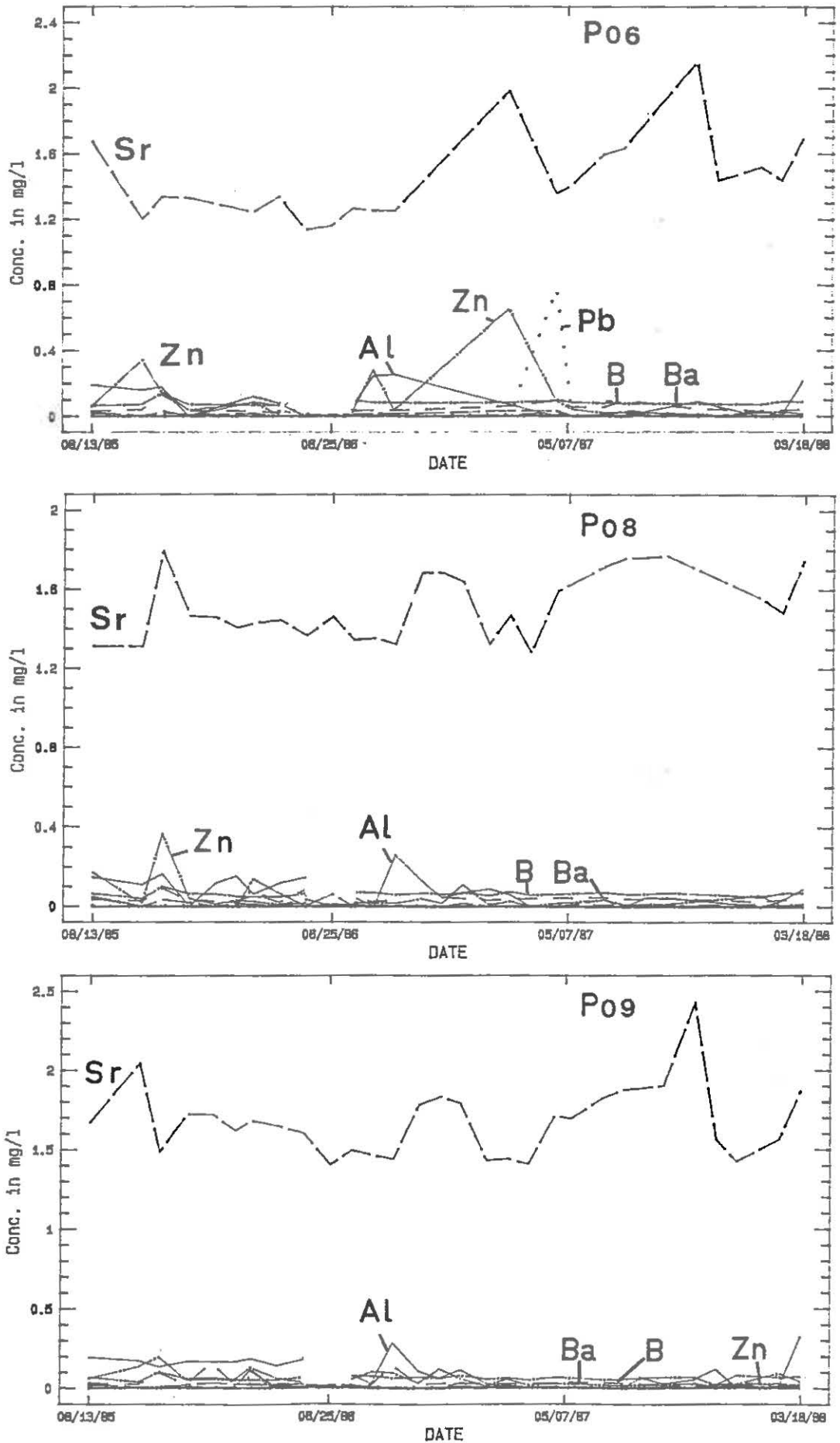


FIG.9a : TIME SERIES PLOTS OF MINOR AND TRACE CONSTITUENTS  
- PRODUCTION BOREHOLES

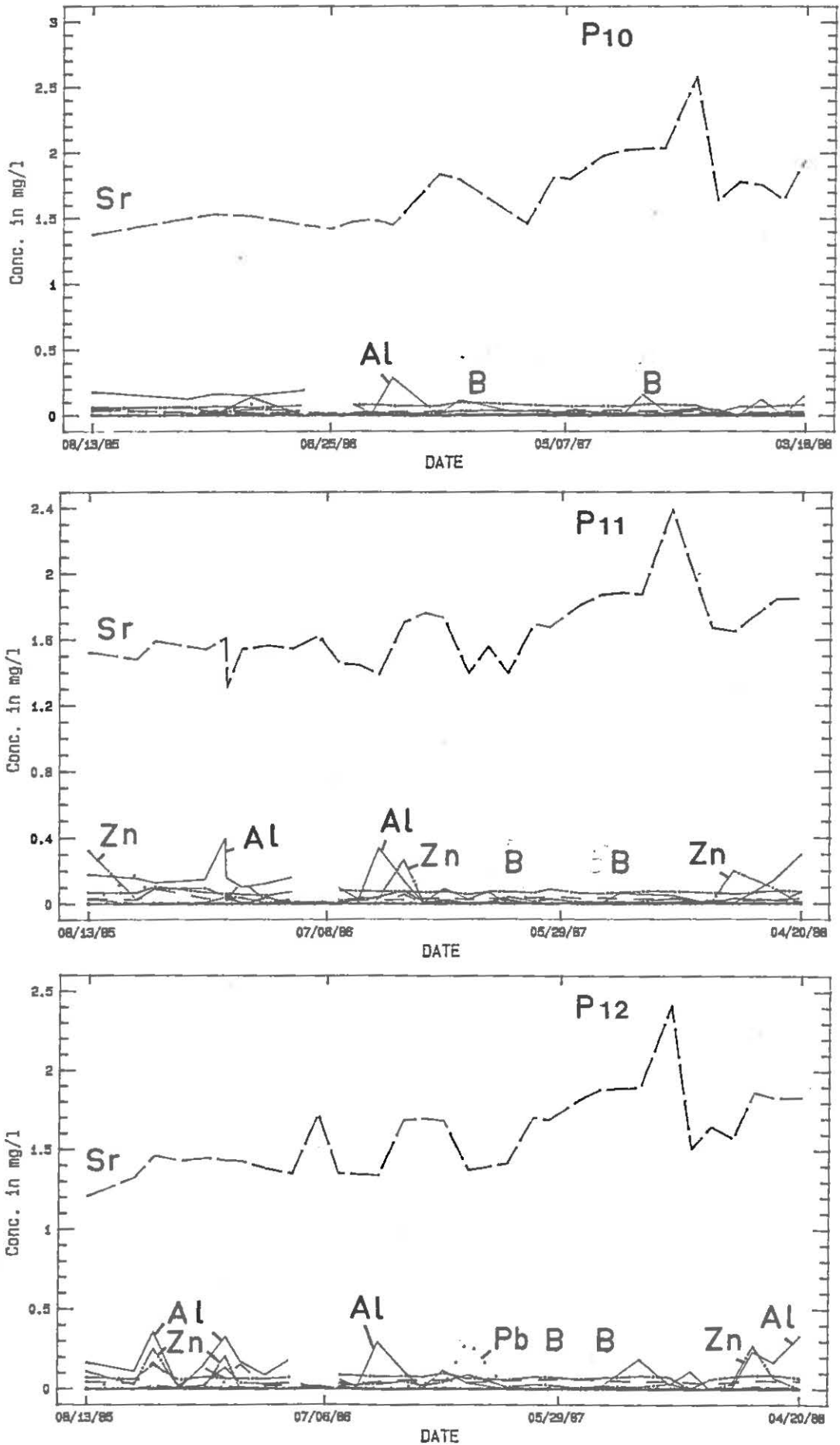


FIG.9b : TIME SERIES PLOTS OF MINOR AND TRACE CONSTITUENTS  
- PRODUCTION BOREHOLES

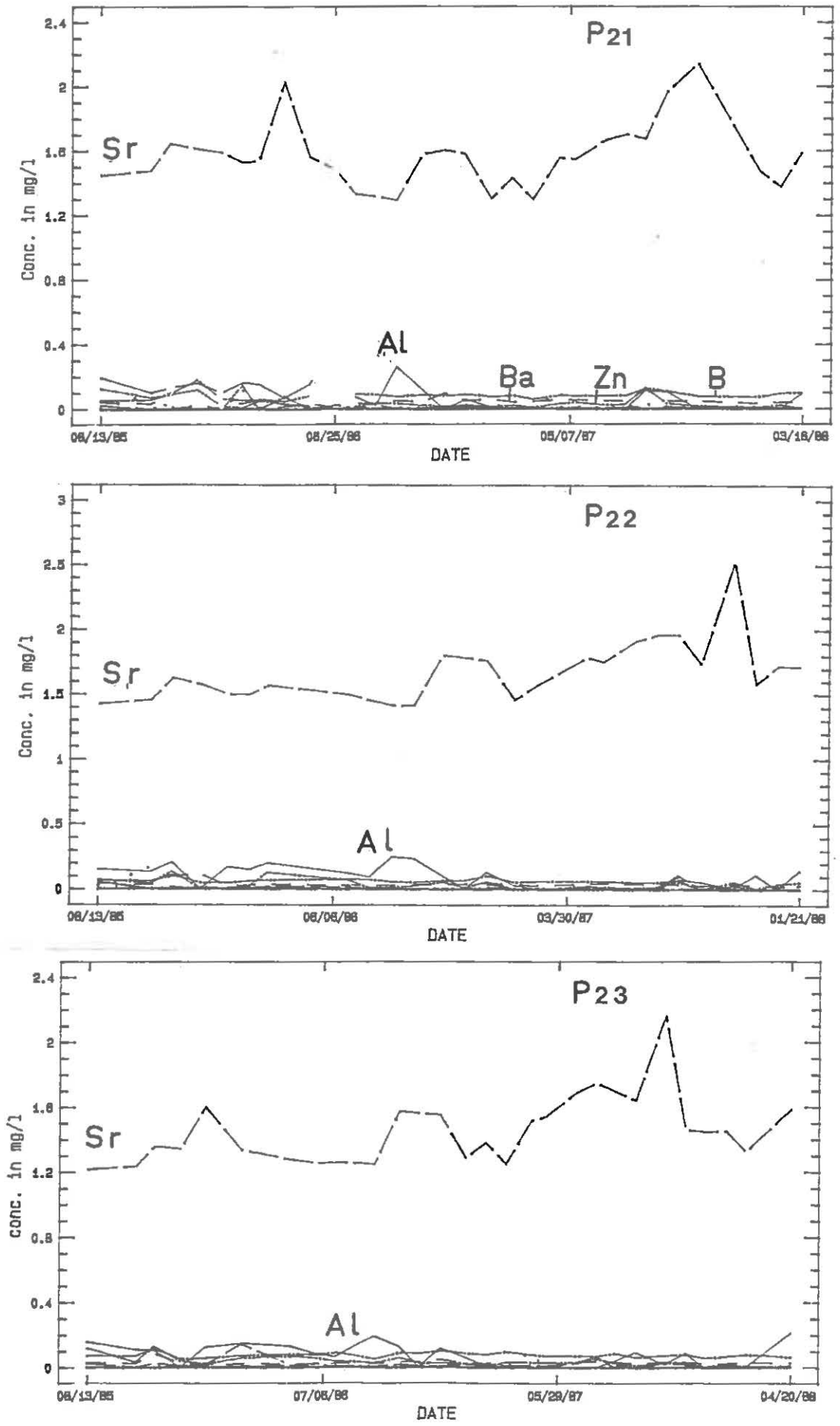


FIG.9c : TIME SERIES PLOTS OF MINOR AND TRACE CONSTITUENTS  
 - PRODUCTION BOREHOLES

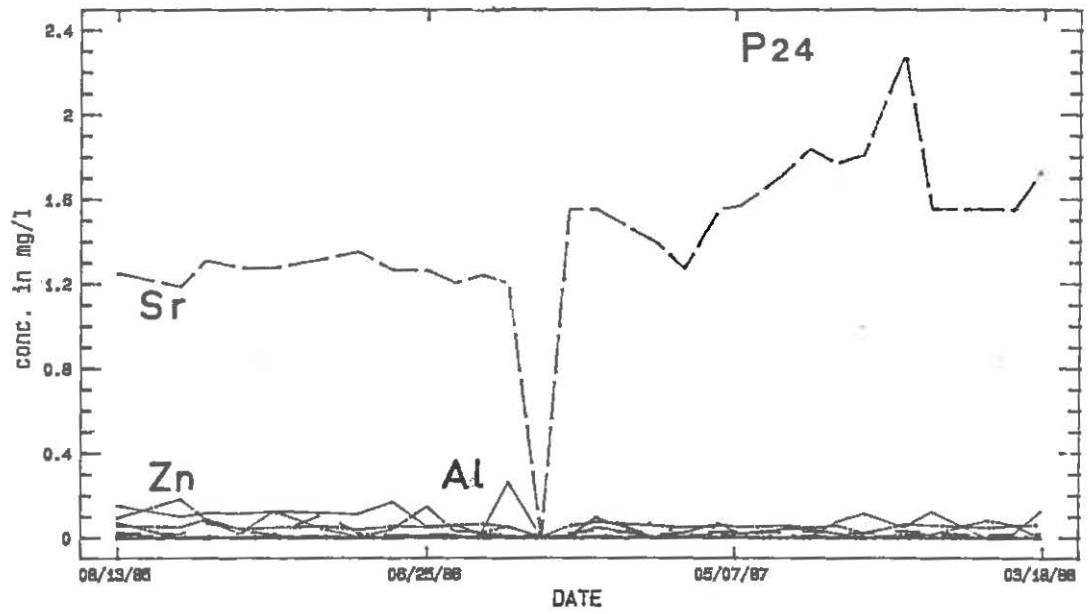


FIG.9d : TIME SERIES PLOTS OF MINOR AND TRACE CONSTITUENTS  
- PRODUCTION BOREHOLES