PRELIMINARY EVALUATION OF GEOHYDROLOGICAL CONDITIONS AT MOLENSTEEN PAN

by

ROBERT SCOTT AND FRANK HODGSON

SEPTEMBER 1991

EXECUTIVE SUMMARY

The following conclusions are drawn from this preliminary investigation into the feasibility of toxic waste disposal at the Molensteen Pan ash dump:

- Initial investigations indicate that no serious pollution of the aquifer around the ashing site has occurred during previous ashing operations.

- The ash, in its present state, has a significantly high permeability. The capability of the ash to immobilize a variety of toxic waste substances because of its unique chemical and physical properties, should therefore fully be utilized. Examples of such waste, are compounds with high heavy metal and fluoride content.

- Further detailed compatibility tests between a variety of wastes and the fly ash, as well as additional geohydrological investigations will be required to provide more detail before a final decision can be made on the suitability of this site for selected toxic waste disposal.

- The findings of this preliminary investigation should be discussed in detail with the Department of Water Affairs and Forestry, the Department of Health and the Department of the Environment before any further investigations are initiated.

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1 INTRODUCTION AND SCOPE OF INVESTIGATIONS

With the growing awareness for environmental conservation, the need for additional toxic waste disposal sites in the Vaal Triangle has increased over the past ten years. Suitable sites are not easy to select and most toxic sites in South Africa have to be lined with impermeable membranes.

Power station fly ash has unique characteristics, which could be used to immobilize waste, thus eliminating the need of impermeable membranes. These characteristics are:

- The high pH of the ash moisture, thus precipitating heavy metals.
- The high calcium content of the ash, thus binding waste high in fluoride content.
- The fine particle size of the ash, thus having a high surface retention capacity.
- The relatively low permeability of ash.
- The porcelanic character of the ash when exposed to air.
- The abundance of fly ash available at power stations and the ease with which trenches within the ash can be constructed.

In the Vaal Triangle, only two power stations exist where fly ash is available in abundance. These are the Lethabo and Kragbron Power Stations.

The Lethabo Power Station is located next to the Vaal River, close to Vereeniging. From the point of using its fly ash dump for toxic waste disposal, the proximity to the Vaal River and Vereeniging makes this site aesthetically unfavourable.

The Kragbron Power Station is located some 30 kilometres further south, next to the Taaibos Spruit. Some of the Kragbron's ash has been disposed of next to the Taaibos

Spruit, which also makes these dumps unfavourable for toxic waste disposal, because of possible public opposition.

Near Kragbron, another ash dump exists at Molensteen Pan (Figure 1), 4 km away from prominent surface drainage systems. The pan acts as a sump for water seeping through the ash dump and, in the past during active ash disposal, formed an ash water return dam.

At Eskom's request, this preliminary investigation was undertaken to determine the broad geohydrological characteristics at Molensteen Pan. The brief for this investigation was:

(i) Initial and follow-up meetings and discussions with Eskom.

(ii) Survey of available information on the topography, history of ashing, previous activities in the pan, stream flow, fountains, dams, geology, existing boreholes, wells and excavations. Sampling of surface and ground water for chemical analyses to determine the spread of pollutants, if any, at existing points.

(iii) Survey of other human activities in the area, which could be affected by pollution from the disposal of waste.

(iv) Perform geophysical tests to locate ground-water barriers. Drilling of boreholes at points as are determined by (ii) and (iii).
Log geological and geohydrological information from boreholes.
Perform tests in boreholes, such as permeability and water quality profiling.
Study rain-water penetration characteristics into the ash dam.

(v) Perform sampling from monitoring holes by pneumatic sampler.
Analyse for elements typically found within the ashing environment.

(vi) Enter all information into a computerized data base for processing and interpretation. Extract tables and graphs for report.

(vii) Report. If initial signs are positive, suggest follow-up geohydrological investigations, such as extension of the boreholes for ground-water quality monitoring, modelling of ground-water and pollution flow and final evaluation.

2 SITE DETAILS

Locality:

The Molensteen Pan fly ash dump is located about 10 km south-east of Sasolburg. It lies directly west of the Vereeniging - Koppies tarred road.

Topography:

The topography is undulating, with down gradients generally to the east. Molensteen pan lies north of and directly adjacent to the ash dump. Prior to ashing, all surface run-off from the now ash covered area, drained into the pan.

History of ashing:

Ashing commenced in mid eighties and continued until the power station was closed down temporarily in 1989. Ash was pumped from the power station as a slurry mixture of water and ash. At the ash dam, paddock walls were constructed with fine fly ash and the areas within the paddocks were filled by flooding, the excess water was decanted via penstocks into the pan. Water from the pan was returned to the power station to pump more ash.

Previous activities at the pan:

Various sources indicated that sandstone was previously mined from a quarry within the pan. The pan is presently full of water, and the dimensions of previous quarrying could not be determined. Sandstone presently outcrops on a ridge immediately north of the pan, where more recent sandstone quarrying has taken place.

Rainfall:

Bar charts, showing rainfall records over the past 30 years, are included in Figures 2 and 3. Average annual rainfall totals 650 mm.

Surface run-off:

In terms of safety for waste disposal within the ashing area of Molensteen Pan, surface run-off is of no concern, since the ash dam is located on a topographic high. Drainage is towards the pan and to the south, as indicated by the topographic divide in Figure 1.

Geology:

The area is underlain by 4 - 6 m of clayey soil and more than 150 m of Karoo sediments. The sediments comprise shale, sandstone and siltstone. A dolerite sill has intruded the sediments.

Existing boreholes:

A number of farm boreholes exist within the immediate vicinity of the ash dam and the pan (Figure 1). Details of their water chemistry and related information will be presented in Section 4.

Excavations:

The only excavations presently noticeable are north of the pan, where sandstone has been quarried. These excavations are not deep enough to interfere with the geohydrology of the pan and the ash dam.

Human activities in the area:

Permanent human activities of significance are restricted to farming. Distances to the nearest farm houses are indicated in Figure 1.

The existence of a tarred road immediately east of the Molensteen area, is an advantage in terms of access to the site.

3 FIELD TESTING

Geohydrological testing and data analysis during this investigation are as follows:

- Hydro census on farms.

- Drilling of three monitoring boreholes.
- Permeability pump testing of the monitoring holes.
- Sampling of monitoring holes and other water sources for chemical analyses.
- Water penetration characteristics on the ash dam.
- Data processing by means of HydroCom database software.

The results of this testing are included in the Figures in the back of this report and/or discussed in the text. They are as follows:

- Geohydrological logs (Figures 4 - 6).
- Results from chemical analyses (Tabled in Figure 7).
- Bar charts for water chemistry (Figures 8 - 15).
- Specialized chemical diagrams (Figure 16).
- Results from infiltration tests on top of the ash.

4 RESULTS FROM GEOHYDROLOGICAL TESTING

Hydro Census:

Positions of boreholes and other information points are indicated in Figure 1.

Several boreholes exist, which are presently being used for domestic supply within the vicinity of the ash dam and the pan. If toxic waste is to be disposed of at Molensteen Pan, consideration should be given to replace some of the closer water-supply boreholes.

Geohydrological logs:

Three boreholes were drilled during this investigation, specifically with the purpose of ascertaining the local geohydrological conditions. The positions of these holes are marked as B18, B19 and B20 in Figure 1. Detailed geohydrological logs are presented in Figures 6 to 8. The following conclusions can be derived:

- All three holes intersected Karoo sediments.

- Boreholes B18 and B19 intersected 4 - 6 metres of clayey soil. The underlying Karoo sediments are weathered to depths between 15 - 17 metres, as indicated by the brownish discolouration of the sediments. At greater depth, fresh and unweathered sediments and dolerite occur.

- Borehole B20 intersected 25 metres of clay, which is abnormally thick for the Kragbron area.

- Quantities of ground water intersected in these holes, rest water levels and transmissivity values (determined from analysis of pump-test data) are summarized below:

Borehole number	Depth water intersected (m)	Quantity (L/sec)	Water-level elevation	Transmissivity (m^2/day)
B14	36	0,1	1473	0,1
B18	18 - 30	0,1	1473	0,2
B19	9 - 17	0,8	1474	2,4
B20	44 - 50	1,0	1470	1,2

- All ground-water intersections were at significant depth, usually associated with the sandstone and sandstone/dolerite contacts.

- The ground-water table is shallow, ranging from 1 - 5 metres below surface. The conclusion can be drawn that the pan is surrounded by a higher ground-water level than the water level in the pan itself, which presently lies at 1470 mamsl. Seepage from the pan, through the strata to the east, is therefore not possible under present hydraulic conditions.

Chemical analyses:

The scope of chemical analyses done on water samples from the area was to determine the degree to which water from previous ashing operations had penetrated the aquifer. By mapping a possible pollution plume from previous ashing operations, an idea of existing flow paths through the strata could be obtained.

The results from the chemical analyses are tabled in Figure 7. The chemical constituents analysed for, are elements expected to be present in significant quantities in ash water at Molensteen Pan. A regional comparison of the sampled-water chemistry is given in two diagrammatic presentations; bar charts of some of the constituents (Figures 8-15), and an Expanded Durov diagram (Figure 16).

Bar charts are useful in identifying extreme values. Of particular importance are the bar charts for sodium and sulphate, because ash water has been known to contain significant quantities of these constituents.

The following is concluded:

- Both charts show contamination of the aquifer at borehole B18, i.e. to the east of the ash dam. This is ascribed to seepage from the ash dam, during past ashing operations. The other boreholes to the east are clean, except for B14, which has a high sodium content. This cannot be explained at this stage.

- The only other polluted borehole in the vicinity of the ashing area, is the pumping hole (B13) to the west of the pan. This contamination is ascribed to ingress of water from the pan, during intensive pumpage from the hole.

- The elevated sulphate levels on the farm Beltrim, south of the ashing area, cannot presently be attributed with certainty to ashing operations, because of its significant distance (1,5 km) from Molensteen Pan. In subsequent studies, this anomaly should be investigated and understood before a design philosophy for toxic waste disposal can be considered.

- Other than these anomalies, no evidence could be found of significant underground seepage from the ashing area, and the conclusion is drawn that subsurface flow, under present hydraulic conditions, is towards the pan.

- The Expanded Durov plot, which serves as a multi-variate tool for the evaluation of water chemistry, confirms the above conclusions.

Infiltration tests on top of the ash:

The results of ring infiltrometer tests done on top of the Molensteen ash dam, are presented below:

	Stable flow rate	Hydraulic conductivity	
	m^3/d	m/d	cm/s
Test 1	0,025	0,34	$3,9 \times 10^{-3}$
Test 2	0,017	0,24	$2,7 \times 10^{-3}$
Test 3	0,006	0,08	$9,5 \times 10^{-4}$
Test 4	0,021	0,29	$3,3 \times 10^{-3}$

These relatively high hydraulic conductivity values can be compared with typical values (cm/s) for:

Clean sand	- 10^{-5} - 10^{-2}
Marine clay	- 10^{-10} - 10^{-7}
Shale	- 10^{-11} - 10^{-7}

These high hydraulic conductivity values would preclude the disposal of liquids into the ash and show that any leachate produced from solid disposal would rapidly migrate through the ash, if not chemically retarted within the ash.

5 GENERAL DISCUSSION

The use of power station fly ash for the disposal of toxic waste, is technically viable because of the unique chemical properties of the ash. Through proper testing and field design, many toxic constituents can be isolated within an ash dump. In addition, a closed geohydrological environment is preferred, so that leachates, if any, cannot escape into the larger environment.

The Molensteen Pan ash dump seems to conform to the above requirement, since the ash dump and the adjacent pan presently constitute such a closed environment.

It should be stressed that the investigation has been undertaken from the point of view that toxic waste is disposed and contained within the fly ash. It is not intended that the pan should be used as a sump for leachates which emanate from the disposal site. The pan is merely a part of the closed system, acting as another safety measure.

Apart from using the pan as a safety measure, a trench could be dug between the ash dump and the pan, thus creating another front where seepage may be intercepted. It should be stressed that these extreme precautionary measures should not be part of the operational philosophy for containing the waste, but they are intended to indicate that other safety features are available to the designer.

In terms of the proximity of the ash dump to the pan, it may be considered as a constraint by some individuals. In such instances, consideration may be given to establish the toxic waste site on the open field, south of the Molensteen Pan ash dump. In such instance, ash from the Molensteen Pan dump will have to be conveyed, compacted and built up, thus creating a totally new facility for toxic waste disposal, south of the present dump. Disposal of toxic waste along the latter lines will not be significantly more expensive.

6 CONCLUSIONS

The following conclusions can be drawn from this preliminary investigation into the feasibility of toxic waste disposal at the Molensteen Pan ash dump:

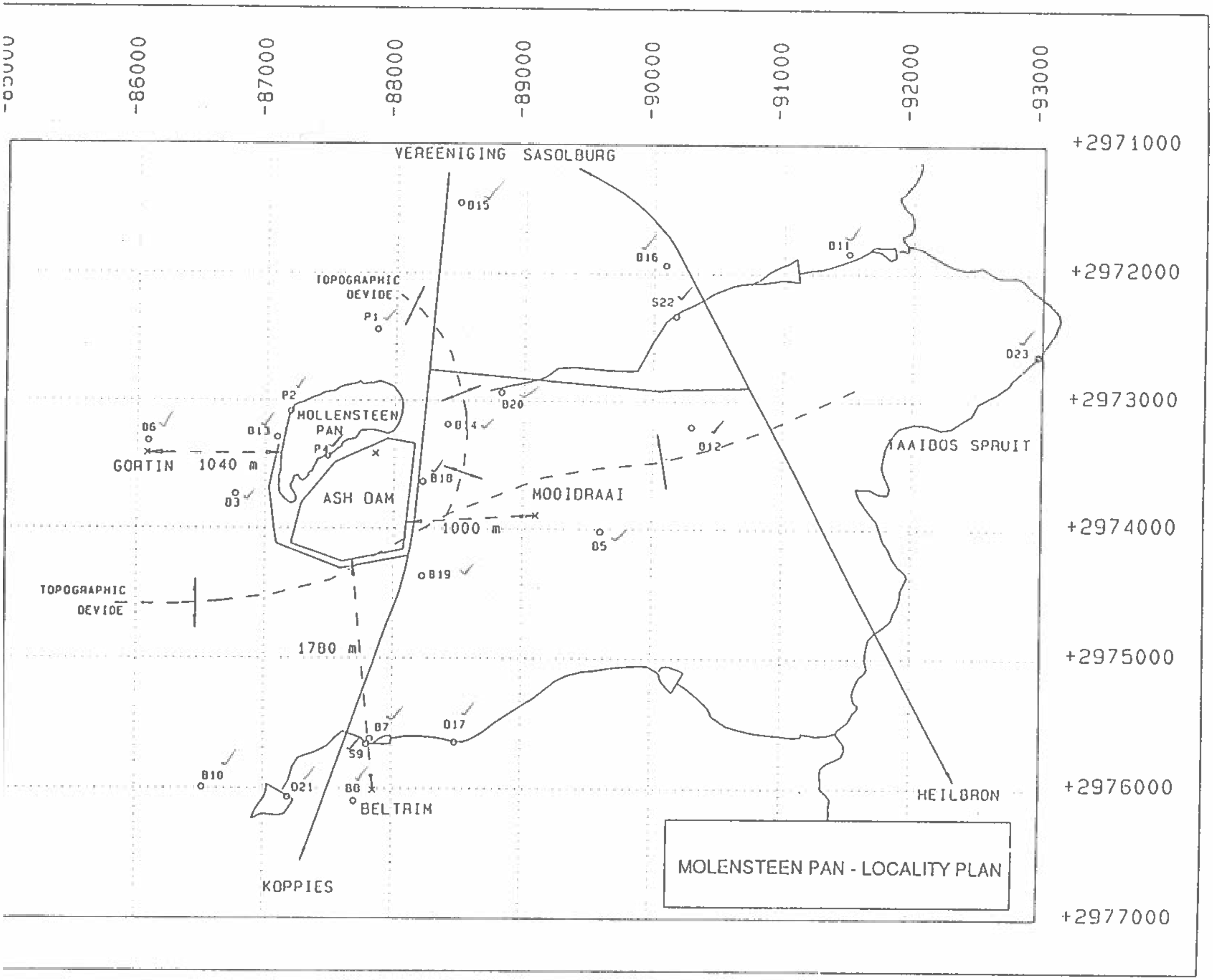
- Initial investigations indicate that no serious pollution of the aquifer around the ashing site has occurred during previous ashing operations.

- The ash, in its present state, has a significantly high permeability. The capability of the ash to immobilize a variety of toxic waste substances because of its unique chemical and physical properties, should therefore fully be utilized. Examples of such waste, are compounds with high heavy metal and fluoride content.

- Further detailed compatibility tests between a variety of wastes and the fly ash, as well as additional geohydrological investigations will be required to provide more detail before a final decision can be made on the suitability of this site for selected toxic waste disposal.

- The findings of this preliminary investigation should be discussed in detail with the Department of Water Affairs and Forestry, the Department of Health and the Department of the Environment before any further investigations are initiated.

FIGURE 1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-87000
-88000
-89000
-90000
-91000
-92000
-93000
+2971000
+2972000
+2973000
+2974000
+2975000
+2976000
+2977000
VEREENIGING SASOLBURG
D15
D16
D11
S22
TOPOGRAPHIC
DEVIDE
P1
D23
P2
HOLLENSTEEN
PAN
D20
D6
D13
D14
D12
P4
AAIBOS SPRUIT
GORTIN 1040 m
B18
ASH DAM
MOOIDRAAI
D3
1000 m
D5
B19
TOPOGRAPHIC
DEVIDE
1780 m
D7
D17
S9
D10
D21
B8
BELTRIM
HEILBRON
KOPPIES
MOLENSTEEN PAN - LOCALITY PLAN

FIGURE 2

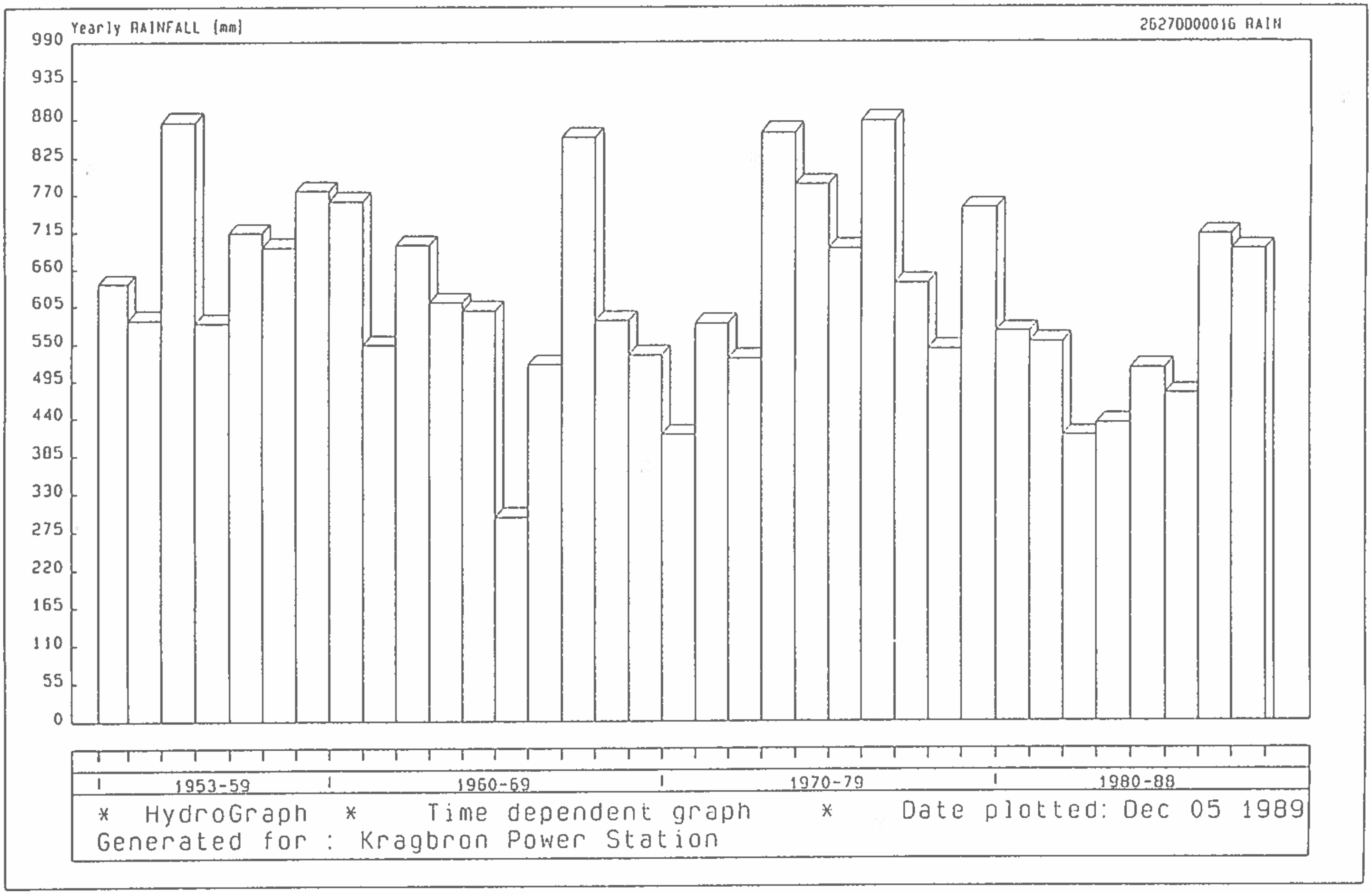
Yearly RAINFALL (mm)
26270000016 RAIN
990
935
880
825
770
715
660
605
550
495
440
385
330
275
220
165
110
55
0
1953-59
1960-69
1970-79
1980-88
* HydroGraph * Time dependent graph * Date plotted: Dec 05 1989
Generated for : Kragbron Power Station

FIGURE 3

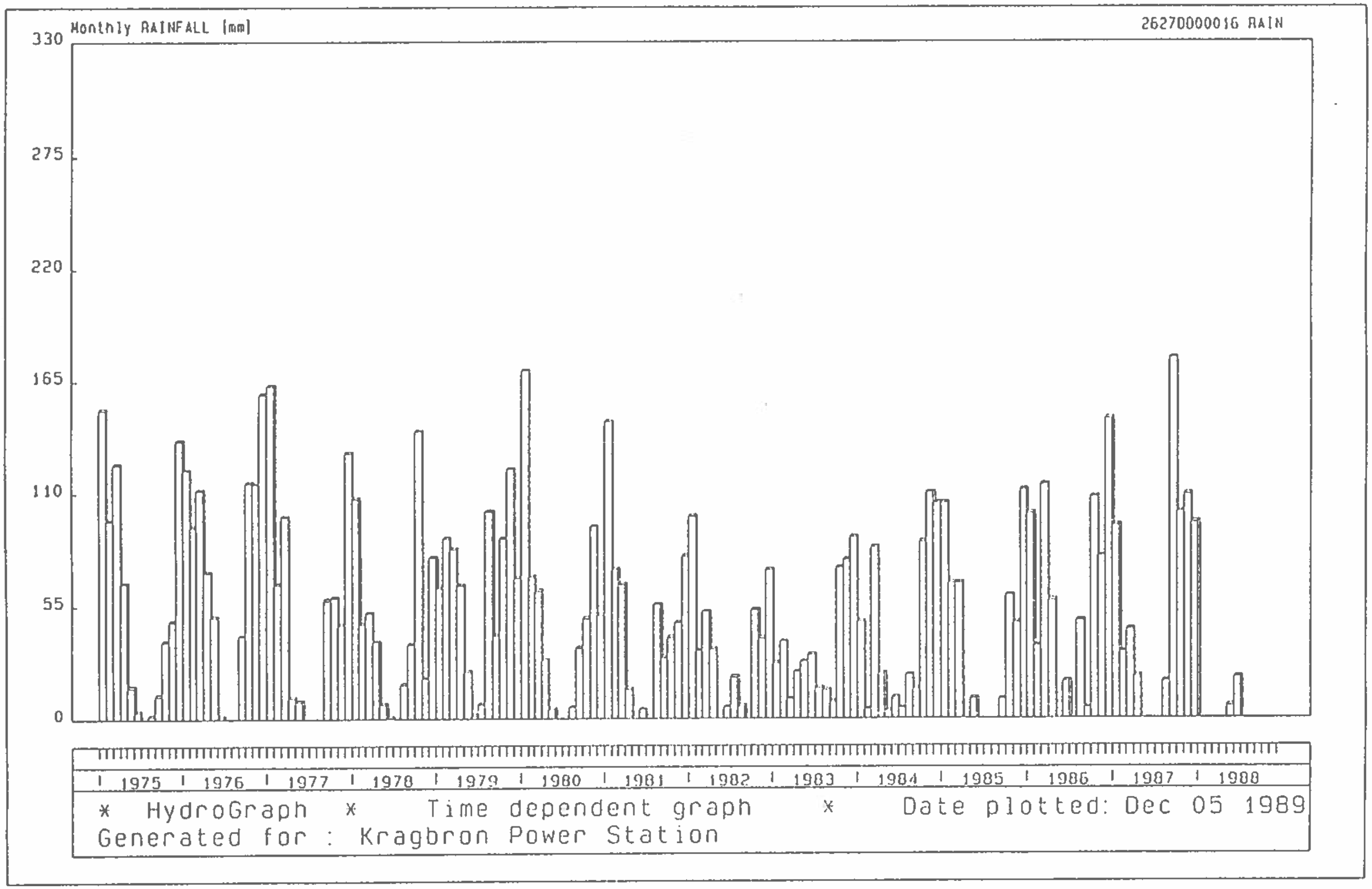
Monthly RAINFALL (mm)
26270000016 RAIN
330
275
220
165
110
55
0
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
* HydroGraph * Time dependent graph * Date plotted: Dec 05 1989
Generated for : Kragbron Power Station

FIGURE 4

* HydroBase * S I T E R E P O R T * DATE : 14 September 1991
Generated for : Molensteenpan Page 1

Site name : Mollensteen Pan Investigation
Notes :

Site ID: 2627DD00018

Number on map: B18

E-W coordinate : -88216.00
Ground Elevation: 1478.00 mamsl
Depth of Casing: 24.00 m
Logged by: IGS

N-S coordinate : 2973642.00
Collar Height: 0.25 m
Diameter of Hole: 160 mm
Date Drilled: 19910901

Depth (m) from	to	Thickness (m)	Description
Geology			
0.00	1.00	1.00	SOIL : fine grained; orange red; laminated; clayey.
1.00	4.00	3.00	GRAVEL, SILT AND CLAY : very coarse and very fine grained; orange brown; weathered; oolitic.
4.00	7.00	3.00	SANDSTONE : fine grained; yellowish orange; sandy; weathered.
7.00	11.00	4.00	SANDSTONE : fine grained; orange brown; micaceous; laminated.
11.00	15.50	4.50	SHALE : very fine grained; orange brown; clayey; weathered.
15.50	21.00	5.50	SILTSTONE : fine grained; grey; sandy. Wet bedding plane at 18m.
21.00	23.00	2.00	SANDSTONE : fine grained; grey; carbonaceous.
23.00	30.00	7.00	SANDSTONE : medium and fine grained; light grey; carbonaceous; weathered. Wet at 25m. Unweathered at 30m.
30.00	31.00	1.00	QUARTZITE : fine grained; white.
31.00	42.00	11.00	DOLERITE : fine crystalline; dark grey; fresh.
Geohydrology			
18.00	30.00	12.00	0.10 L/sec estimate yield

FIGURE 5

Site name : Mollensteen Pan Investigation
Notes :

Site ID: 2627DD00019

Number on map: B19

E-W coordinate : -88216.00
Ground Elevation: 1477.00 mamsl
Depth of Casing: 12.00 m
Logged by: IGS

N-S coordinate : 2974361.00
Collar Height: 0.25 m
Diameter of Hole: 160 mm
Date Drilled: 19910901

Depth (m) from	to	Thickness (m)	Description
Geology			
0.00	4.00	4.00	SOIL : fine grained; light brown; silty; clayey.
4.00	7.00	3.00	SILT : yellowish blue; weathered; clayey.
7.00	8.00	1.00	SAND AND SILT : fine grained; purple; laminated; weathered.
8.00	12.00	4.00	SANDSTONE : medium grained; light brown; weathered. Water strike at 8m and 12m.
12.00	13.00	1.00	SANDSTONE : medium grained; light brown; ferruginous; jointed.
13.00	15.00	2.00	SANDSTONE : fine grained; light brown; silty; weathered.
15.00	17.00	2.00	SANDSTONE : medium grained; light brown; slightly weathered.
17.00	31.00	14.00	DOLERITE : fine crystalline; dark grey; chloritic; jointed. Chloritic alteration and/or quartz deposition in joints and fractures.
Geohydrology			
9.00	17.00	8.00	0.80 L/sec estimate yield

FIGURE 6

```
===========================================================================
* HydroBase *  S I T E   R E P O R T  *        DATE : 14 September 1991
Generated for : Molensteenpan                                      Page 1
===========================================================================

Site name : Mollensteen Pan Investigation
Notes :
-------------------------------            ------------------------------
Site ID: 2627DD00020                       Number on map: B20
-------------------------------            ------------------------------
E-W coordinate    :  -88821.00             N-S coordinate : 2972932.00
Ground Elevation: 1473.00 mamsl            Collar Height: 0.25 m
Depth of Casing: 13.00 m                   Diameter of Hole:  160 mm
Logged by: IGS                             Date Drilled: 19910901
---------------------------------------------------------------------------
  Depth (m)  Thickness
  from   to   (m)               Description
---------------------------------------------------------------------------
Geology

  0.00   5.00  5.00 CLAY : light grey; oolitic.
  5.00   7.00  2.00 CALCRETE : very fine crystalline; white; solid.
  7.00  25.00 18.00 CLAY : orange brown; slightly oolitic. Occasional
                    pebbles of dolerite shale and sandstone up to
                    10mm in size.
 25.00  43.00 18.00 SHALE : light grey; micaceous; carbonaceous. This
                    unit is interlayered with thin sandstone bands
                    and thin sandy coal horizons.
                    The carbon content increases with depth.
                    A ferruginised fracture occured at 29m.
 43.00  50.50  7.50 SANDSTONE : very coarse grained; grey;
                    ferruginous; fractured. First water strike at
                    43m. 400l/h.
                    Second water strike at 46.5m in ferruginised
                    fractures, 1500 l/h.
 50.50  51.00  0.50 SHALE : greyish green; laminated. Varved shale
                    and grit.
 51.00  55.00  4.00 SHALE : greyish green.

Geohydrology

 44.00  50.50  6.50 1.00 L/sec estimate yield
---------------------------------------------------------------------------
```

* HydroBase * Chemistry Report * Date printed : 11 September 1991

Generated for : Molensteenpan Page 1

FIGURE 7

Sample number		MP1	MP2	MB3	MP4	MB5	MB6	MB7
Depth of sample	(m)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sample date		19910722	19910722	19910722	19910722	19910722	19910722	19910722
Sample time		0800	0000	0000	0000	0000	0000	0000
Date of analysis		19910728	19910728	19910728	19910728	19910728	19910728	19910728
Analytical laboratory		IGS	IGS	IGS	IGS	IGS	IGS	IGS
Aluminum	(mg/L)	0.13	0.40↑	0.29↑	0.42↑	0.35↑	0.39↑	0.40↑
Bicarbonate	(mg/L)	95	123	465	122	349	470	393
Bromide	(mg/L)	0.00	1.85	0.17	2.00	0.13	0.11	0.72
Calcium	(mg/L)	16	74	64	69	68	82	83
Calcium hardness	(mg/L)	40	185	160	172	170	205	207
Carbonate	(mg/L)	10	12	0	13	0	0	0
Chloride	(mg/L)	4	223	31	223	17	13	114
Electrical conductivity	(mS/m)	22.0	187.0↑	76.0↑	188.0↑	58.0	72.0↑	99.0↑
Fluoride	(mg/L)	0.5	1.7▲	0.3	1.8▲	0.2	0.3	0.4
Iron (total)	(mg/L)	0.24↑	0.11↑	0.06	0.21↑	0.06	0.21↑	0.06
Langelier index		0.08	0.56	0.17	0.58	0.23	0.14	0.41
Magnesium	(mg/L)	12	17	22	17	30	25	38
Magnesium hardness	(mg/L)	49	70	91	70	124	103	156
Manganese	(mg/L)	0.046	0.023	0.015	0.020	0.073↑	0.030	0.010
Methyl orange alkalinity	(mg/L)	94	121	381	122	286	385	322
Nitrate as nitrogen	(mg/L)	0.1	0.1	1.1	0.1	5.0	3.3	5.5↑
Nitrite as nitrogen	(mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.09
pH		8.69	8.60	7.68	8.65	7.81	7.53	7.90
Phenolphthalein alk.	(mg/L)	8	10	0	11	0	0	0
Phosphate	(mg/L)	0.46	0.58	0.33	0.00	0.00	0.22	0.33
Potassium	(mg/L)	4.5	29.9	13.0	29.1	11.0	19.8	10.8
Sodium	(mg/L)	18	355↑	82	331↑	29	51	87
Sulphate	(mg/L)	28	556↑	27	563↑	12	19	57
Total diss. solids (Σ)	(mg/L)	189	1393	710	1370	539	695	808
Σ Anions	(meq/L)	2.61	20.38	9.15	20.55	6.82	8.71	11.26
Σ Cations	(meq/L)	2.70	21.33	8.93	20.02	7.44	8.91	11.36
Ion-balance error	(%)	1.69	2.28	-1.22	-1.31	4.35	1.14	0.44

Selected standard : SA drinking water- humans

▲ = Exceeds max acceptable value ↓ = Below min guideline value

↑ = Exceeds max guideline value ▼ = Below min acceptable value

< = Below detection limit

* HydroBase * Chemistry Report * Date printed : 11 September 1991

Generated for : Molensteenpan

Page 2

FIGURE 7 (CONT)

Sample number		MB8	MD9	MB10	MB11	MB12	MB13	MB14
Depth of sample	(m)	0.000	0.000	0.000	0.000	0.000	0.000	1.050
Sample date		19910722	19910722	19910722	19910723	19910723	19910723	19910723
Sample time		0000	0000	0000	0730	0830	0000	1400
Date of analysis		19910728	19910728	19910728	19910728	19910728	19910728	19910728
Analytical laboratory		IGS	IGS	IGS	IGS	IGS	IGS	IGS
Aluminum	(mg/L)	0.45↑	0.95▲	0.35↑	0.27↑	0.25↑	0.40↑	0.10
Bicarbonate	(mg/L)	410	520	331	359	392	222	421
Bromide	(mg/L)	0.72	1.80	0.49	0.12	0.24	0.64	0.43
Calcium	(mg/L)	89	138	72	59	55	90	6
Calcium hardness	(mg/L)	222	345	180	147	137	225	15
Carbonate	(mg/L)	0	23	0	0	0	0	32
Chloride	(mg/L)	109	198	83	5	21	76	46
Electrical conductivity	(mS/m)	95.0↑	161.0↑	82.0↑	52.0	63.0	73.0↑	80.0↑
Fluoride	(mg/L)	0.3	0.9	0.3	0.1	0.2	0.2	1.8▲
Iron (total)	(mg/L)	0.06	0.33↑	0.10	0.06	0.16↑	0.06	0.29↑
[illegible]ngelier index		0.43	1.29	0.32	0.24	0.17	-0.16	0.42
Magnesium	(mg/L)	38	71↑	29	28	25	25	2
Magnesium hardness	(mg/L)	156	292	119	115	103	103	8
Manganese	(mg/L)	0.010	1.951▲	0.015	0.010	0.010	0.010	0.010
Methyl orange alkalinity	(mg/L)	336	464	271	294	321	182	399
Nitrate as nitrogen	(mg/L)	3.9	0.1	8.3↑	1.9	2.6	1.4	0.1
Nitrite as nitrogen	(mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pH		7.86	8.47	7.92	7.86	7.80	7.50	8.96
Phenolphthalein alk.	(mg/L)	0	19	0	0	0	0	27
Phosphate	(mg/L)	0.00	1.28	0.00	0.71	0.00	0.00	0.23
Potassium	(mg/L)	7.0	31.6	5.2	5.7	9.9	9.2	1.4
Sodium	(mg/L)	82	143↑	71	26	56	35	210↑
Sulphate	(mg/L)	38	207↑	37	11	15	107	4
Total diss. solids (Σ)	(mg/L)	791	1336	665	502	586	571	725
Σ Anions	(meq/L)	10.88	19.23	9.14	6.39	7.52	8.12	9.46
Σ Cations	(meq/L)	11.35	19.91	9.23	6.55	7.52	8.34	9.65
Ion-balance error	(%)	2.11	1.74	0.49	1.24	0.00	1.34	0.99

Selected standard : SA drinking water- humans

[illegible] = Exceeds max acceptable value ↓ = Below min guideline value

↑ = Exceeds max guideline value ▼ = Below min acceptable value

< = Below detection limit

* HydroBase * Chemistry Report * Date printed : 11 September 1991

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Page 3

FIGURE 7 (CONT)

Sample number		MB14/1	MB14/2	MB15	MB16	MD17	MB18/1	MB18/2
Depth of sample	(m)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sample date		19910903	19910903	19910723	19910723	19910723	19910902	19910902
Sample time		1410	1424	1530	1530	1630	1410	1427
Date of analysis		19910906	19910906	19910728	19910728	19910728	19910906	19910906
Analytical laboratory		IGS	IGS	IGS	IGS	IGS	IGS	IGS
Aluminum	(mg/L)	0.07	0.34↑	0.17↑	0.16↑	0.30↑	0.07	0.07
Bicarbonate	(mg/L)	420	404	342	172	79	467	388
Bromide	(mg/L)	0.48	0.47	0.00	0.16	1.03	0.95	0.86
Calcium	(mg/L)	4	4	44	36	31	47	47
Calcium hardness	(mg/L)	10	10	110	90	77	117	117
Carbonate	(mg/L)	24	35	16	0	0	10	36
Chloride	(mg/L)	46	43	9	5	144	94	80
Electrical conductivity	(mS/m)	82.0↑	79.0↑	53.0	41.0	71.0↑	120.0↑	107.0↑
Fluoride	(mg/L)	1.9▲	1.6▲	0.2	0.1	0.5	0.7	0.4
Iron (total)	(mg/L)	0.46↑	0.71↑	0.06	0.11↑	0.71↑	0.20↑	0.10
Langelier index		0.47	0.50	0.93	-0.62	-0.82	0.81	0.91
Magnesium	(mg/L)	1	2	28	20	13	23	21
Magnesium hardness	(mg/L)	4	8	115	82	54	95	86
Manganese	(mg/L)	0.010	0.010	0.010	0.010	1.735▲	0.246↑	0.074↑
Methyl orange alkalinity	(mg/L)	384	389	306	141	65	399	378
Nitrate as nitrogen	(mg/L)	0.1	0.3	0.5	9.7▲	0.1	7.9↑	6.3↑
Nitrite as nitrogen	(mg/L)	0.00	0.00	0.00	0.00	0.00	0.16	0.14
pH		9.21↑	9.23↑	8.66	7.50	7.74	8.48	8.58
Phenolphthalein alk.	(mg/L)	20	29	13	0	0	8	30
Phosphate	(mg/L)	0.53	0.20	0.00	0.00	0.00	0.32	0.28
Potassium	(mg/L)	1.0	1.0	11.2	7.0	23.1	7.0	7.4
Sodium	(mg/L)	207↑	181↑	39	21	83	193↑	157↑
Sulphate	(mg/L)	1	1	10	46	77	117	90
Total diss. solids (Σ)	(mg/L)	707	675	502	350	459	994	855
Σ Anions	(meq/L)	9.11	9.12	6.63	4.62	7.00	13.67	12.16
Σ Cations	(meq/L)	9.33	8.31	6.50	4.55	7.15	12.83	11.10
Ion-balance error	(%)	1.19	-4.65	-0.99	-0.76	1.06	-3.17	-4.56

Selected standard : SA drinking water- humans

▲ = Exceeds max acceptable value ↓ = Below min guideline value

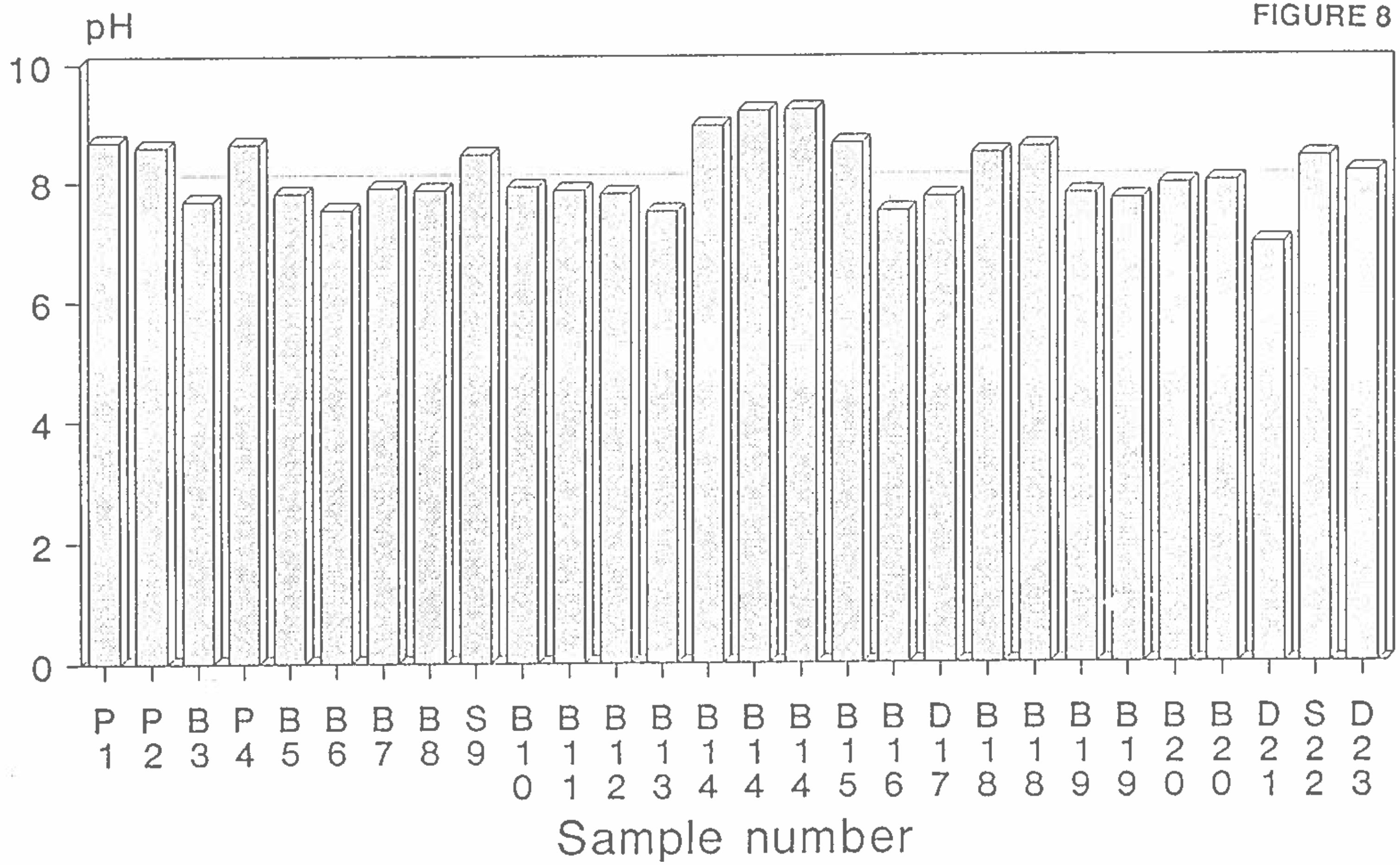
↑ = Exceeds max guideline value ▼ = Below min acceptable value

< = Below detection limit

Molenstein Pan

Water chemistry

FIGURE 8



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Water chemistry

FIGURE 9

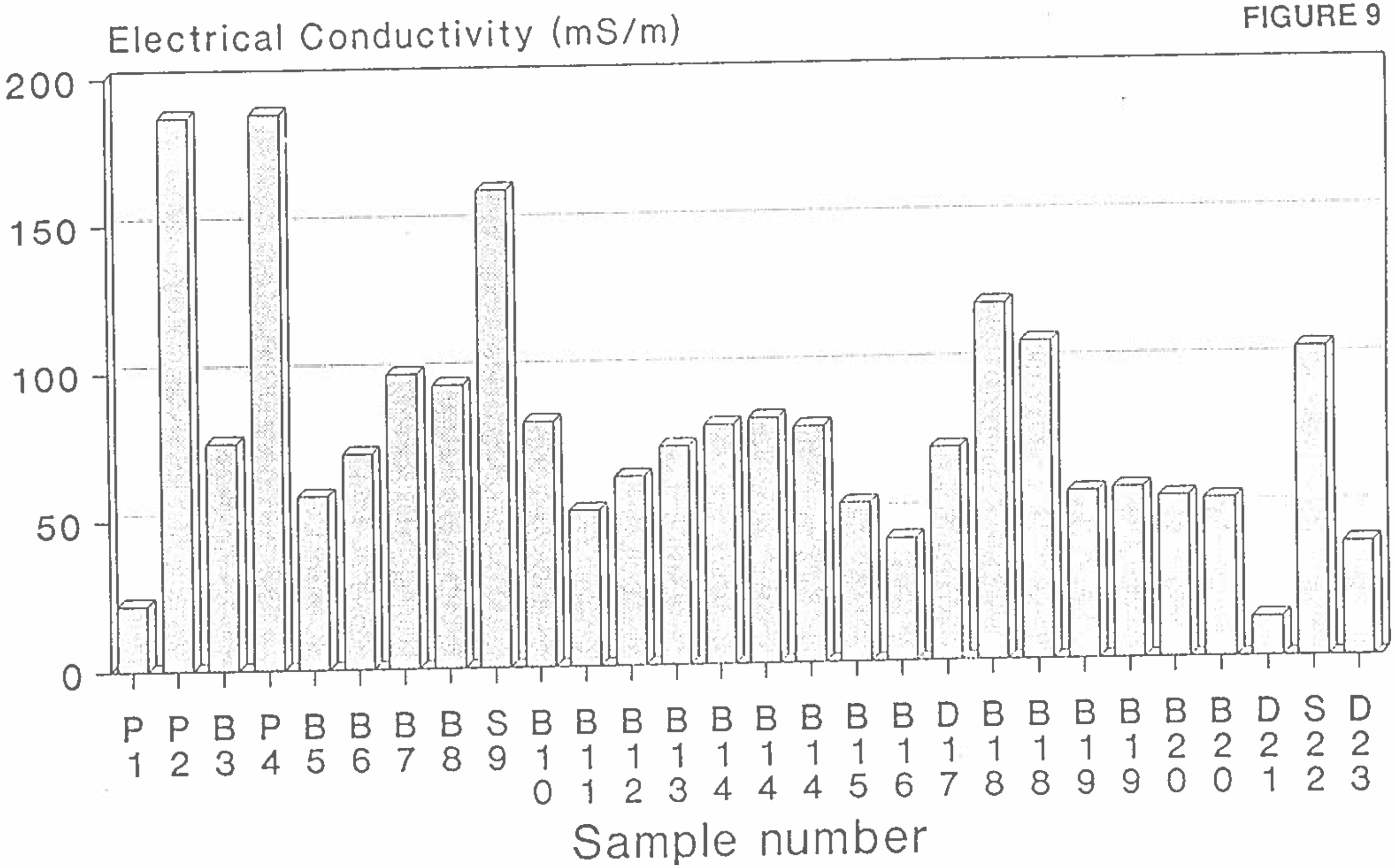

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FIGURE 7 (CONT)

Sample number		MB19/1	MB19/2	MB20/1	MB20/2	MD21	MS22	MD23
Depth of sample	(m)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sample date		19910903	19910903	19910902	19910902	19910827	19910828	19910905
Sample time		1010	1100	1010	1100	0000	0000	0000
Date of analysis		19910906	19910906	19910906	19910906	19910906	19910906	19910906
Analytical laboratory		IGS	IGS	IGS	IGS	IGS	IGS	IGS
Aluminum	(mg/L)	0.07	0.07	0.07	0.07		0.07	0.20↑
Bicarbonate	(mg/L)	339	332	333	338	51	737	126
Bromide	(mg/L)	0.24	0.22	0.22	0.20	0.17	0.25	0.21
Calcium	(mg/L)	63	65	41	38	14	70	26
Calcium hardness	(mg/L)	157	162	102	95	35	175	65
Carbonate	(mg/L)	0	0	0	0	0	2	0
Chloride	(mg/L)	26	22	22	22	8	7	39
Electrical conductivity	(mS/m)	56.0	57.0	54.0	53.0	13.0	104.0↑	38.0
Fluoride	(mg/L)	0.3	0.3	0.4	0.6	0.4	0.7	0.3
Iron (total)	(mg/L)	0.41↑	0.13↑	0.13↑	0.14↑		0.01	0.53↑
Langelier index		0.18	0.09	0.15	0.17	-2.06	1.10	-0.24
Magnesium	(mg/L)	18	18	17	14	6	77↑	13
Magnesium hardness	(mg/L)	74	74	70	58	25	317	54
Manganese	(mg/L)	0.300↑	0.032	0.020	0.028	0.133↑	0.398↑	0.287↑
Methyl orange alkalinity	(mg/L)	278	272	273	277	42	608	103
Nitrate as nitrogen	(mg/L)	1.5	1.8	0.2	0.3	0.5	0.1	0.2
Nitrite as nitrogen	(mg/L)	0.06	0.00	0.00	0.00	0.00	0.00	0.00
pH		7.79	7.70	7.96	8.00	6.96	8.41	8.15
Phenolphthalein alk.	(mg/L)	0	0	0	0	0	2	0
Phosphate	(mg/L)	0.35	0.00	0.00	0.00	0.00	0.00	0.00
Potassium	(mg/L)	6.1	6.5	2.0	1.9	6.8	2.1	4.9
Sodium	(mg/L)	38	37	68	70	8	76	43
Sulphate	(mg/L)	7	7	5	4	25	33	39
Total diss. solids (Σ)	(mg/L)	505	496	489	490	122	1006	293
Σ Anions	(meq/L)	6.56	6.35	6.22	6.30	1.64	13.09	4.00
Σ Cations	(meq/L)	6.46	6.51	6.46	6.15	1.72	13.21	4.41
Ion-balance error	(%)	-0.77	1.24	1.89	-1.20	2.38	0.46	4.88

Selected standard : SA drinking water- humans

▲ = Exceeds max acceptable value ↑ = Below min guideline value

[illegible] = Exceeds max guideline value ▼ = Below min acceptable value

< = Below detection limit

Molensteen Pan

Water chemistry

FIGURE 10

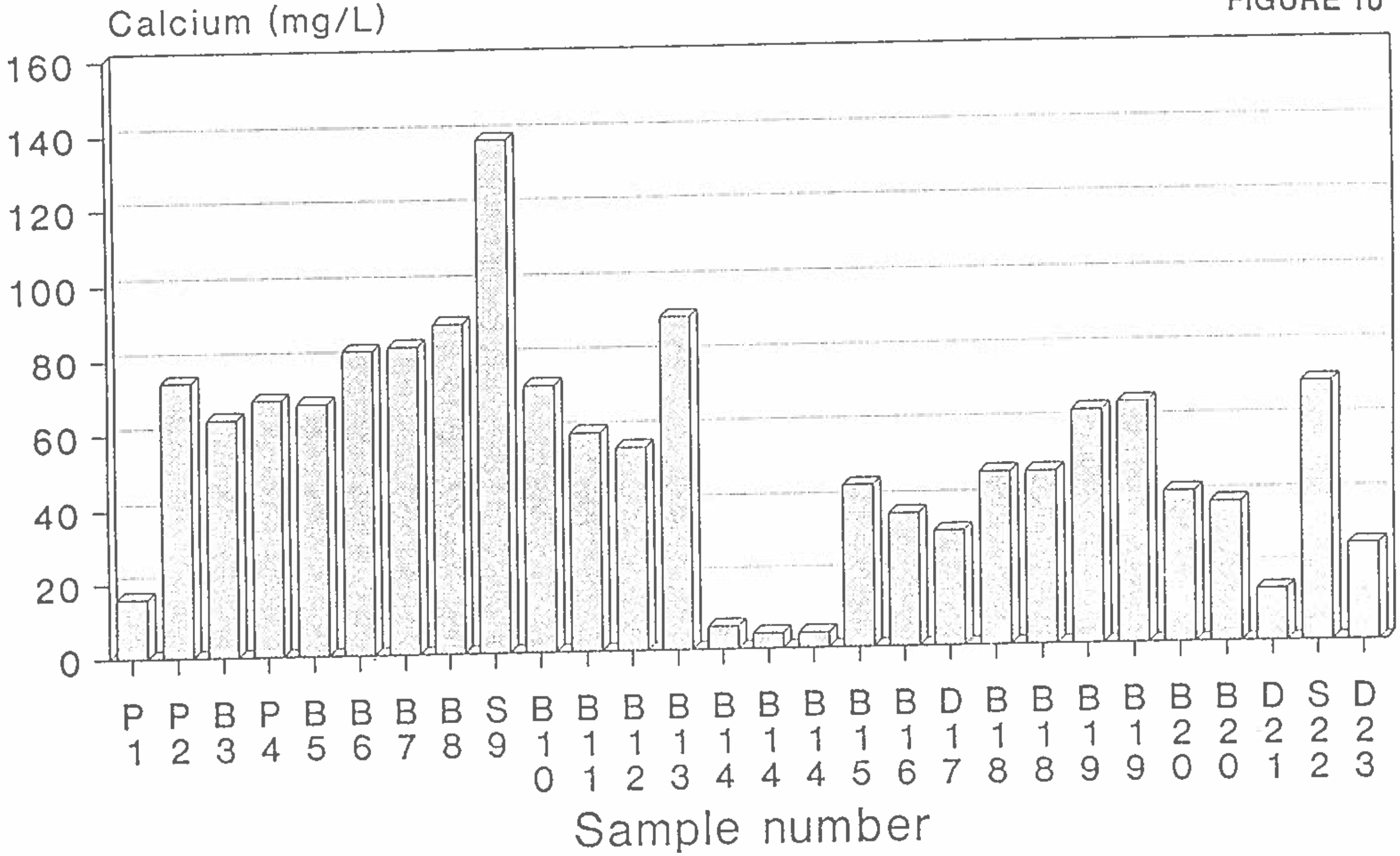

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FIGURE 11

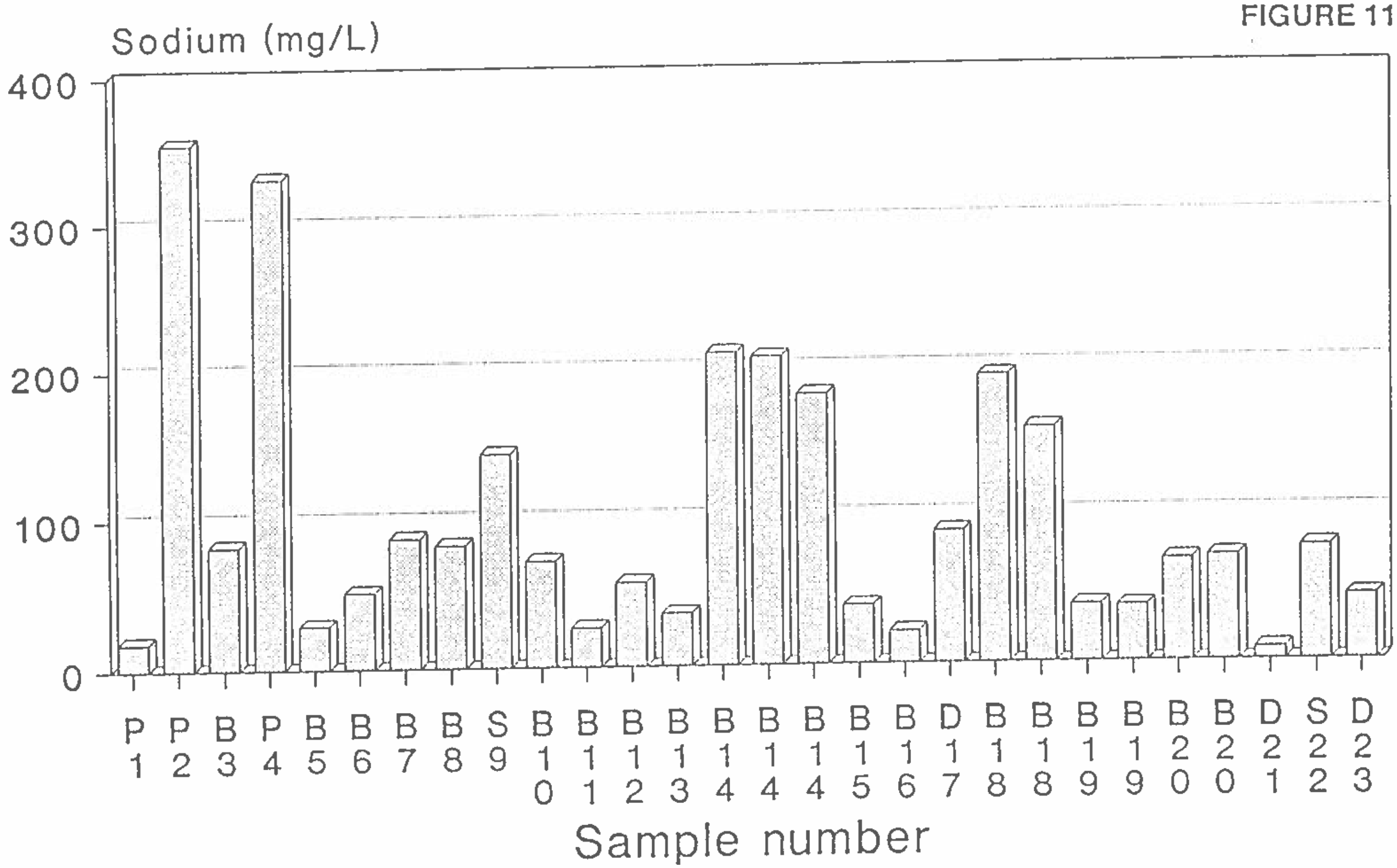

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FIGURE 12

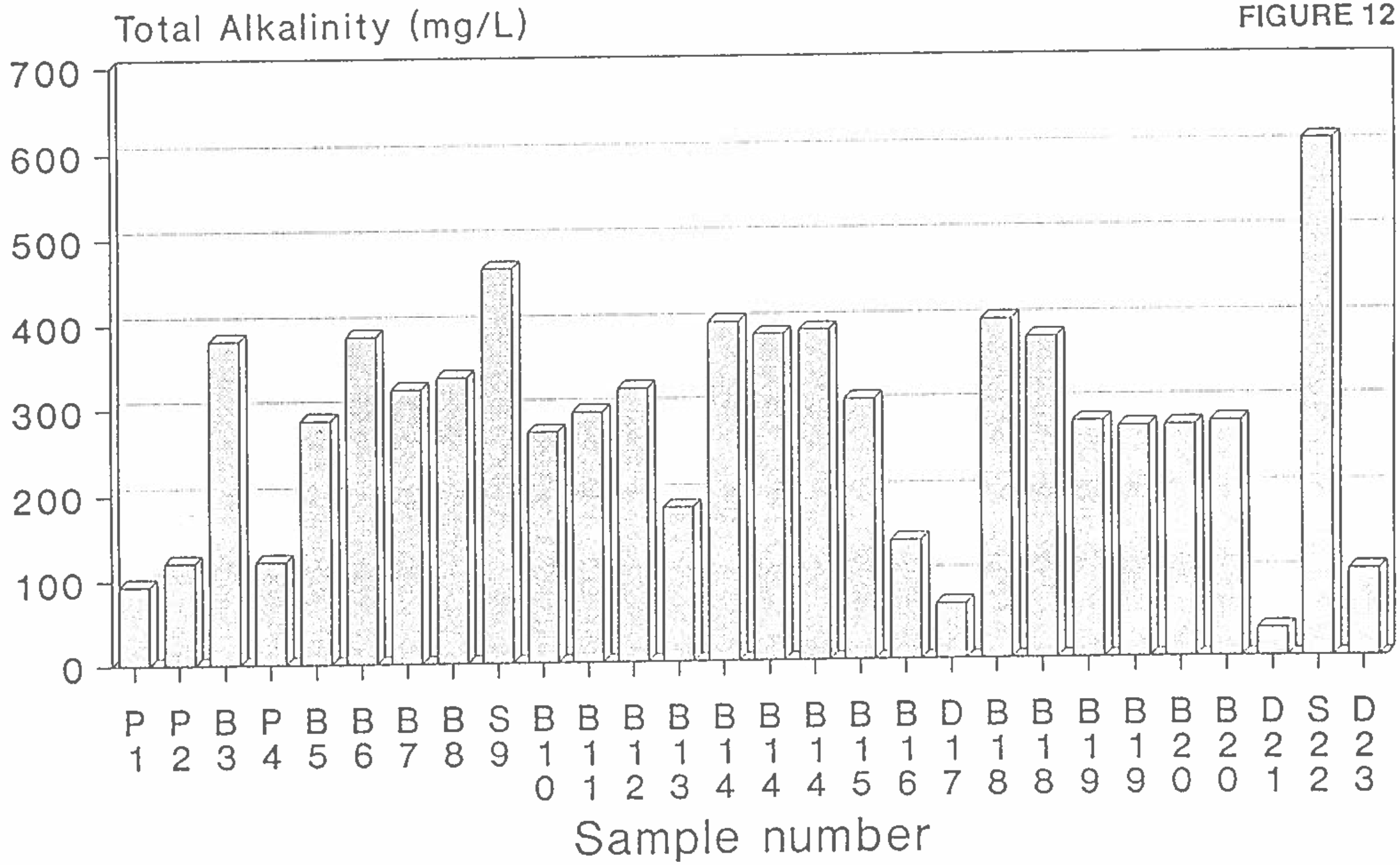

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FIGURE 13

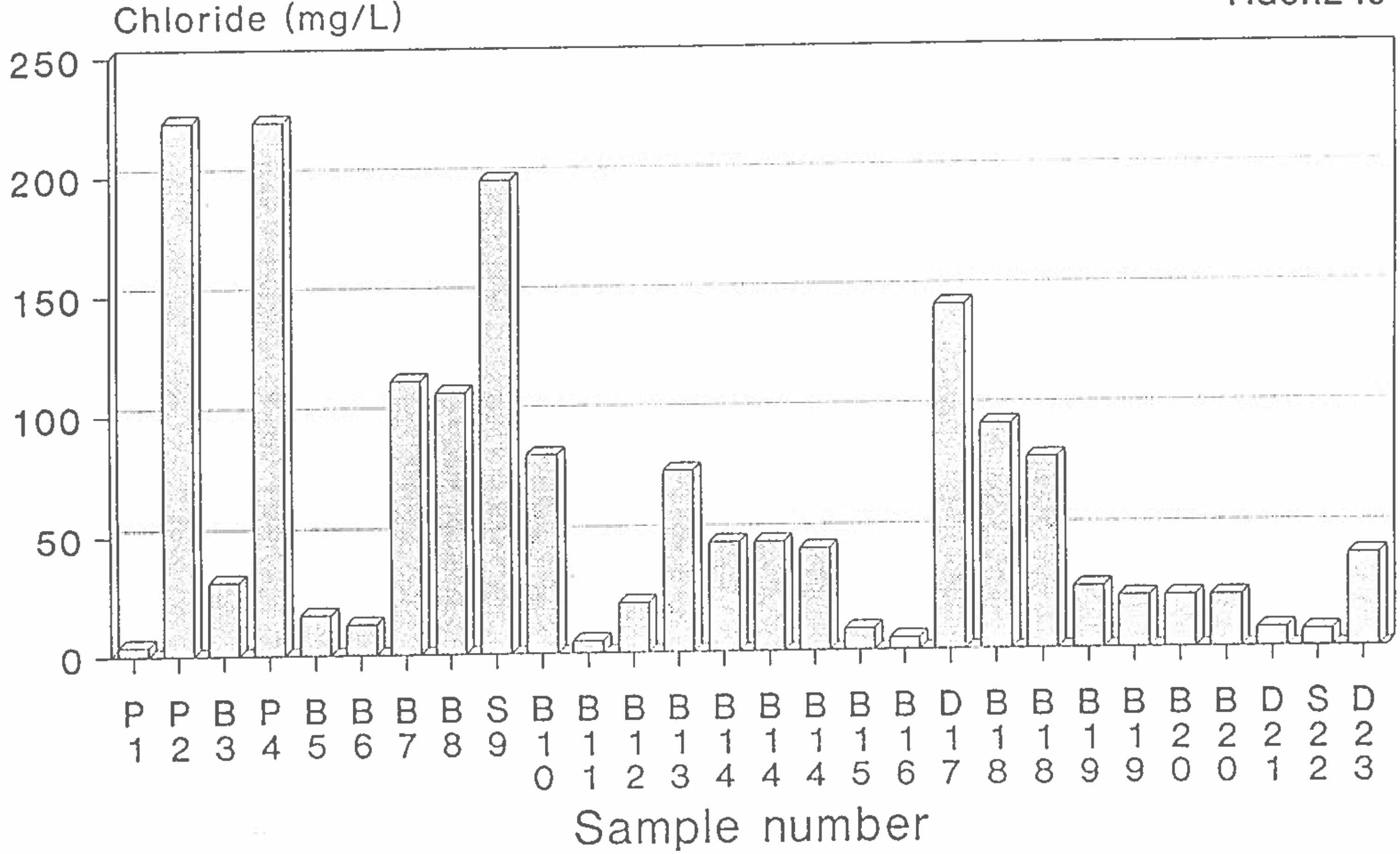

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FIGURE 14

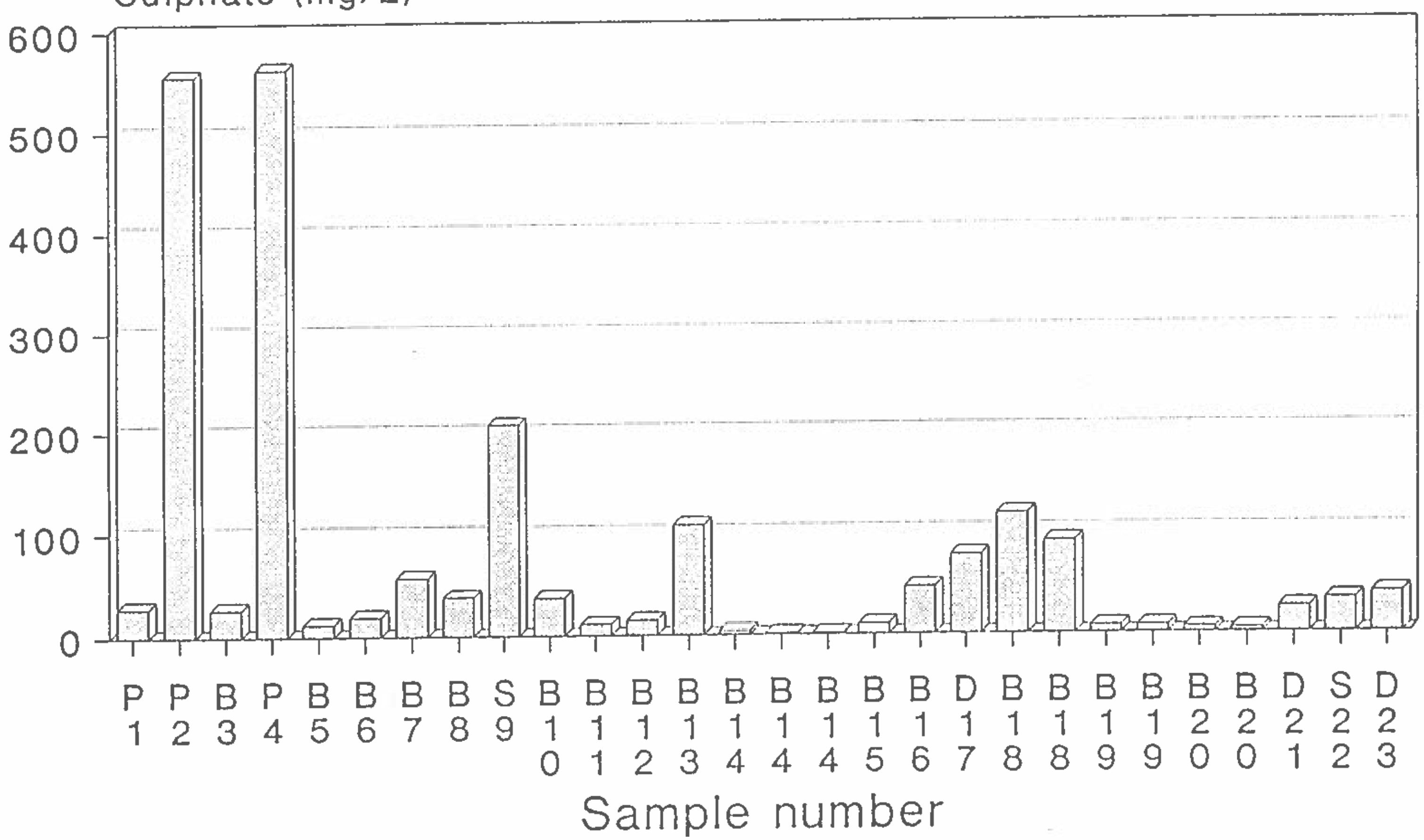

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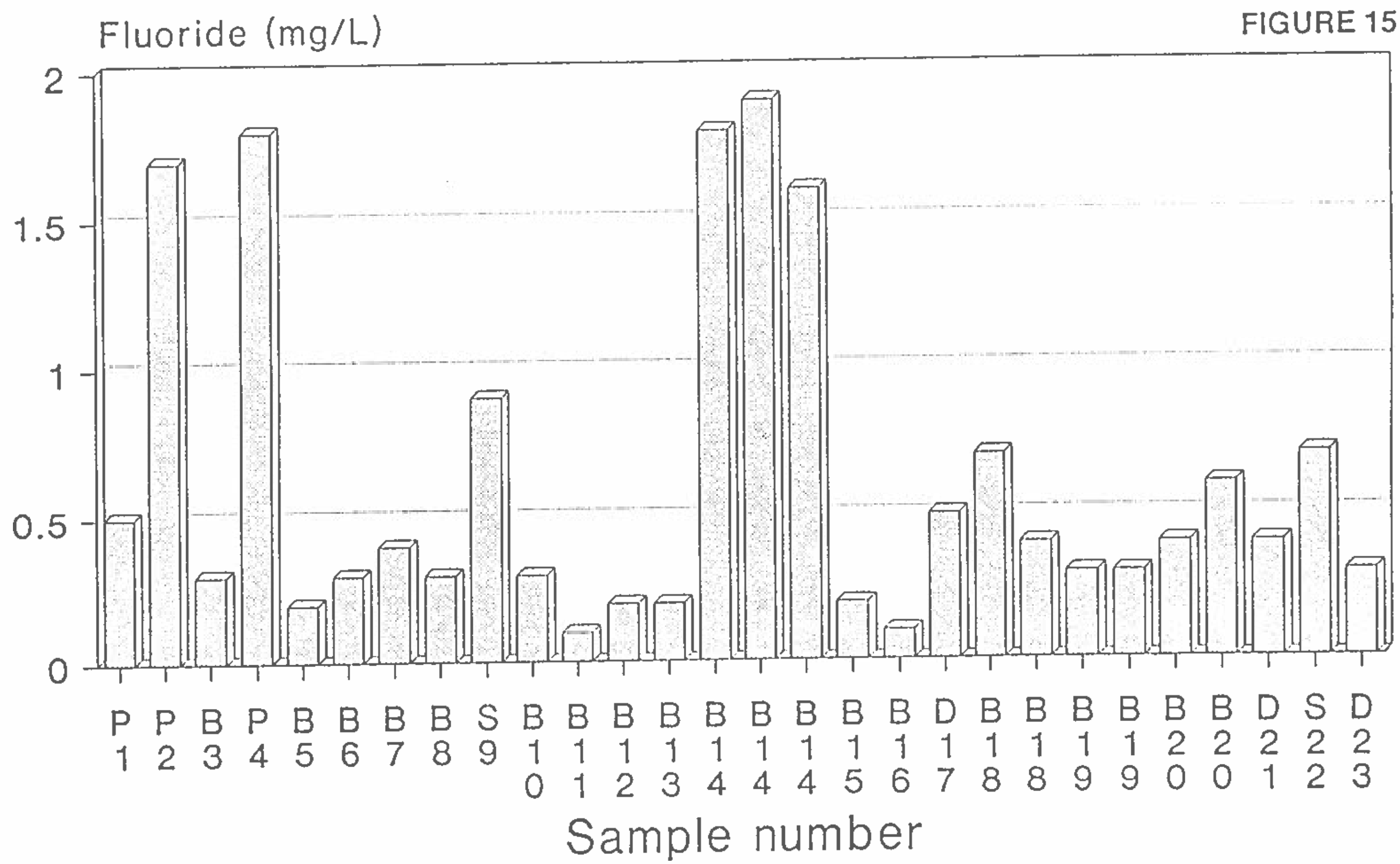
FIGURE 15



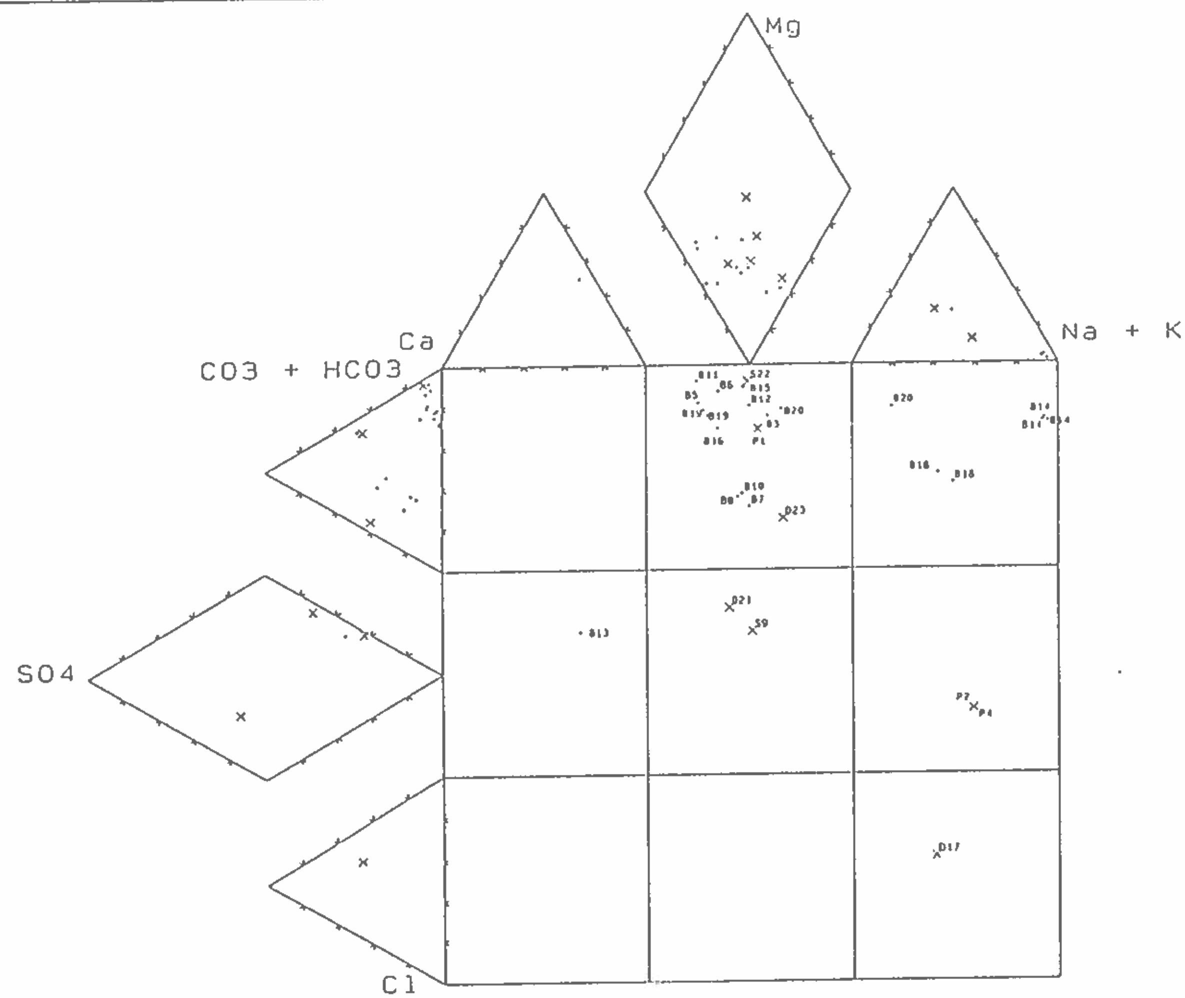


FIGURE 16

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