EXPOSURE OF GENERIC COATING SYSTEMS IN RAW SOUTH AFRICA DAM WATERS

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WRC Report No. 381/2/99
ISBN No. 1 86845 533 5
ISBN Set. 1 86845 534 3

EXECUTIVE SUMMARY

An exposure program was undertaken over a period of three years to evaluate the performance of various metals, alloys and coatings in South African Dam Waters. A total of 2250 coupons were exposed in three dams, namely the Vaal and Roodeplaat Dams in Gauteng and the Kleinplaas Dam in the Western Cape. The purpose of the exposure program was to evaluate the suitability of various generic coating systems for immersed applications in raw South African Dam Waters and the results will therefore not refer to specific coating brands. Strict control was exercised over the preparation of the panels in order to avoid any dispute at the end over the application of the coatings and the coatings were applied by the manufacturers themselves. Specimens were exposed at three levels in each dam, namely splash zone, totally immersed and in the mud/silt zone. The splash zone was found to be a particularly corrosive environment. The performance of the organic coatings on mild steel panels was good whereas the galvanised, zinc and aluminium metals-sprayed coupons that had been coated performed poorly. Consequently, duplex systems are not recommended for use under immersed conditions in South African Dam Waters. Microbial corrosion due to sulphate reducing bacteria was also evident at all levels and in all the dams.

ACKNOWLEDGEMENTS

The report resulted from a research project funded by the Water Research Commission entitled:

"EXPOSURE PROJECT OF GENERIC COATING SYSTEMS IN RAW SOUTH AFRICAN DAM WATERS"

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

Mr J.N. Bhagwan	-	Water Research Commission (Chairman)
Mrs C.M. Smit	-	Water Research Commission (Committee Secretary)
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Mr J.C. Geldenhuys	-	Rand Water

The financial support of the WRC made the entire project possible, and is acknowledged with thanks. Contributions from the steering committee members are also gratefully acknowledged.

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LIST OF ABBREVIATIONS

CSIR	-	Council for Scientific and Industrial Research
DWAF	-	Department of Water Affairs and Forestry
MPE	-	Multipurpose Epoxy
ND	-	No Defects
ppm	-	Parts Per Million
S.A	-	South Africa
WRC	-	Water Research Commission

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VAAL DAM

(SAMPLES AFTER 36 MONTHS EXPOSURE)

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1. INTRODUCTION

Many methods are used for corrosion protection of steel structures in contact with raw water. It has been found cost effective to use protective materials for both internal and external surfaces. A large number of options are available when coatings are selected. It would benefit contractors and manufacturers to perform coating selection according to specified guidelines so that possible mistakes could be avoided. Also of benefit is the evaluation of the exact conditions under which the coating must operate.

According to a survey conducted by Upfill-Brown and Stead (1) in South Africa, approximately 55% of all pipes produced annually were small bore (diameter below 150mm). Of these, very few were bitumen or solvent-based epoxy coated or lined, and about one third were galvanised. Of the larger bore pipes, 14% were protected by bitumen or solvent-based epoxy.

However, some pipe materials under current use have suffered from a number of problems. Steel trunk mains often leak due to internal corrosion or external corrosion. Tuberculation of unlined steel mains increases the frictional force (and thus the cost of transporting water) and a deterioration in water quality due to the presence of micro-organisms and corrosion products. The bitumen used as a lining on some steel pipes degrades with time and can then allow corrosion of the underlying steel pipe to take place.

This project aimed at evaluating the performance of a number of coatings commonly used as protective materials in water storage facilities steel structures in dams and water distribution systems.

The objectives of the project were as follows:

- To evaluate the performance of various coatings in raw waters.
- To determine important water parameters that affect the selection of correct coatings.

2. MATERIALS AND METHODS

2.1 TEST SITES AND FACILITIES

Test sites used for this project (K5/381) were as follows:

- Kleinplaas Dam (Stellenbosch)
- Roodeplaat Dam (Pretoria)
- Vaal Dam (Vereeniging)

2.2 EXPERIMENTAL PROCEDURE

Pontoons for raw water:

The performance of various coatings was evaluated after exposure in raw waters in the three dams.

Specimens were supported in test racks attached to a floating pontoon. The specimens were exposed at three levels in each dam. The top level was in the splash zone (with half the specimen being immersed), the second level was approximately three metres below the surface (depending on the thermocline) and the third level was in the mud or silt zone of the dams.

The test specimens were 150 mm x 100 mm in size and were manufactured from 3 mm mild steel plate. A 12 mm hole drilled into each specimen facilitated suspension of the specimen in the test rack. A weld was made on one face of the coupon to approximate a fabricated construction.

The mild steel, 3CR12 and galvanised steel coupons were received by the CSIR and distributed to the coating manufacturers for the application of the various coating systems. The zinc and aluminium sprayed coupons were obtained by the coating manufacturers directly from the subcontractors who applied the metal coatings.

In the case of the mild steel and 3CR12 reference systems, 12 coupons were exposed at each level. The galvanised, zinc-sprayed and aluminium-sprayed reference systems were exposed in sets of six coupons at each level. The systems consisting of organic coatings were also exposed in sets of six specimens at each level. At each inspection stage a visual examination was conducted. As with the metallic coatings, two of the six coupons were removed at 12, 34 and 36 month intervals. Adhesion tests were conducted on reference panels before exposure and also on the panels after removal from the dams.

The zinc and aluminium specimens were supplied by African Zinc Mills and Hullett Aluminium respectively. The participating organisations for the project included: African Zinc Mills, Hullett Aluminium, Middleburg Steel and Alloys (now Columbus Stainless) Department of Water Affairs, AECI, Plascon and Chemrite Coatings. The range of materials tested is summarised in Table 1.

In order to ensure that the organic coatings were applied to the coupons satisfactorily, this task was the responsibility of the individual coating manufacturers. The galvanising of the coupons was done in collaboration with the South African Hot Dip Galvanising Association while the zinc and aluminium metal sprayed coatings were applied by the Department of Water Affairs and Forestry under the supervision of the CSIR's Tribology and Surface Engineering Programme. The participants were notified as to when and where the metal spraying was done in order for them to make arrangements to apply their sealant coatings in accordance with the DWAF specification.

2.2.1 Water Quality Analysis

At each dam site water for analysis was taken at the three levels at which the specimens were exposed. The water analyses at the Roodeplaat and Vaal Dams were carried out by the Department of Water Affairs personnel while the analysis of water from the Kleinplaas Dam was carried out by the Ground water Programme of Environmentek of the CSIR based in Stellenbosch. The water analyses were conducted on a monthly basis.

The water quality variables monitored included: pH, temperature and dissolved oxygen which were measured immediately at the dams, whereas the conductivity, calcium, chloride, sulphate, total alkalinity and dissolved organic carbon were determined later in the laboratory.

After each evaluation, a report was issued to the parties concerned. As the purpose of this programme was to evaluate the performance of generic systems, the Water Research Commission received a report in which no mention of brand names was made. The participating coating companies each received a report containing results of the evaluation of their products only.

2.2.2 Evaluation of Samples

Where applicable the evaluation was carried out as per **International Standard ISO 4628 "Paints and Varnish"** - Evaluation of degradation of paint coatings (2). Adhesion was subjectively evaluated by cross cutting the paint coating at 60° and removing the coating with a knife-point. If pieces of the coating could be removed, the adhesion was graded as poor (p), while if only small chips of the coating could be flaked off the adhesion was graded as good (g). Where no deterioration could be seen on the panel the grading was designated ND.

The surface morphologies of the corroded metallic specimens i.e. carbon steel, aluminium, 3CR12 and metallic coated specimens were visually examined.

2.2.3 Samples Identification

The following code served to identify the specimens.

1st letter	=	Dam	**K**	=	Kleinplaas
			R	=	Roodeplaat
			V	=	Vaal Dam

2nd letter	=	Substrate	**M**	=	Mildsteel
			G	=	Galvanised
			Z	=	Zinc metal sprayed
			Al	=	Aluminium metal sprayed
			C	=	3CR12 pickled and passivated
			E	=	3CR12 blast cleaned and passivated
3rd letter	=	Supplier			
4th letter	=	Coating Type	**E**	=	Epoxy
			M	=	Multipurpose epoxy
			V	=	Vinyl

TABLE 1: Summary of alloys and coatings for dam water exposure

BASE ALLOY	SURFACE PREPARATION	METALLIC COATING	ORGANIC COATING		
			AECI	CHEMRITE	PLASCON
Mild Steel	Abrasive Blasted	None	Vinyl Epoxy M.P.E.	Epoxy M.P.E.	Vinyl Epoxy M.P.E.
Mild Steel	Abrasive Blasted	Galvanised	Vinyl Epoxy		Vinyl Epoxy
Mild Steel	Abrasive Blasted	Zn Sprayed	Vinyl Epoxy		Vinyl Epoxy
Mild Steel	Abrasive Blasted	Al Sprayed	Vinyl Epoxy M.P.E.		Vinyl Epoxy M.P.E.
3CR12	Pickled/Passivated	None	Vinyl Epoxy M.P.E.		Vinyl Epoxy M.P.E.
3CR12	Blasted/Passivated	None	Vinyl Epoxy M.P.E.		Vinyl Epoxy M.P.E.

3. RESULTS

3.1 PANELS FROM KLEINPLAAS DAM (36 MONTHS EXPOSURE)

TABLE 2: Unpainted Panels -Surface (Metallic Materials)

PANEL IDENTIFICATION	CONDITION
KM 7	Severe corrosion
KM 8	Severe corrosion
KG 4	Galvanising stripped at water line on front of panel - more extensive attack on rear of panel
KZ 4 Sealed	Severe corrosion
KA 4 Sealed	ND
KC 7	ND
KC 8	ND
KGAV 4	Galvanising extensively attacked
KZAV 4	ND
KAAV 4	ND

ND = No defects

TABLE 3: Epoxy Painted Panels - Surface (Non-metallic lining/coatings)

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
KMAE 4	g	0	ND
*KMCP 4	g	0	ND
KMPE 4	g away from blisters	$d_2S_4 + d_3S_2$	
KGAE 4	g	0	ND
KGPE 4	delaminated	delaminated	white corrosion under coating
KZAE 4	g	0	ND
KZPE 4	g	0	small patellas of delamination at the edge
KAAE 4	g	0	ND
KAPE 4	g	d_4S_2	
KCPE 4	g away from blisters	d_2S_4	
KEAE 4	g	0	ND
KEPE 4	g	0	ND

* Code varies

ND = No defects

TABLE 4: Multipurpose Epoxy Painted Panels - Surface (Non-metallic lining/coatings)

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
*KMCE 4	g	0	ND
KMPM 4	g away from blisters	d_3S_3	
KAAM 4	g	0	ND
KAPM 4	delamination	delamination	white corrosion
KCAM 4	g	0	ND
KCPM 4	g	0	ND
KEAM 4	g	0	ND
KEPM 4	g	0	ND

*** Code varies**
ND = No defects

TABLE 5: Vinyl Painted Panels - Surface (Non-metallic lining/coatings)

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
KMPV 4	g undercoat	Intercoat d_4S_3	
KGPV 4	g undercoat	Intercoat d_2S_5	
KZPV 4	g undercoat	Intercoat d_2S_4	
KAPV 4	g undercoat	Intercoat d_2S_3	
KCPV 4	g undercoat	Intercoat d_2S_4	
KEPV 4	g	0	ND

ND = No defects

TABLE 6: **Unpainted Panels -Middle (Metallic Materials)**

PANEL IDENTIFICATION	CONDITION
KM 23	Extensive severe corrosion with pitting
KM 24	Extensive severe corrosion with pitting
KG 12	Galvanising stripped / extensive large pitting
KZ 12 Sealed	Corrosion at edges with under creep
KA 12 Sealed	Extensive white corrosion
KGAV 12	Patches (15 mm diam.) of corrosion
KZAV 12	White corrosion under sealing
KAAV 12	Extensive white corrosion
KC 23	Odd deep pits
KC 24	Deep pitting at mounting / odd deep pit

NB: Middle - exposure position

TABLE 7: **Epoxy Painted Panels - Middle (Non-metallic lining/coatings)**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
KMAE 12	g	0	ND
*KMCP 12	g	0	ND
KMPE 12	g away from blisters	d_5S_4 in patches + d_2S_5	
KGAE 12	delamination	delamination	white corrosion
KGPE 12	delamination	delamination	white corrosion
KZAE 12	g	0	ND
KZPE 12	g	0	delamination from the edge
KAAE 12	delamination	delamination	white corrosion
KAPE 12	delamination	delamination	white corrosion
KCPE 12	g	d_2S_4	
KEAE 12	g	0	ND
KEPE 12	g	d_2S_5	

*** Code varies**
ND = No defects

TABLE 8: **Multipurpose Epoxy Painted Panels - Middle (Non-metallic lining/coatings)**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
*KMCE 12	g	0	ND
KMPM 12	g away from blisters	$d_2S_2 + d_2S_4$	
KAAM 12	delaminated	delaminated	white corrosion
KAPM 12	delaminated	delaminated	white corrosion
KCAM 12	g	0	ND
KCPM 12	g	0	ND
KEAM 12	g	0	ND
KEPM 12	g	0	ND

* Code varies
ND = No defects

TABLE 9: **Vinyl Painted Panels - Middle (Non-metallic lining/coatings)**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
KMPV 12	g	d5S2	
KGPV 12	g	d2S4	
KZPV 12	g	0	under creep from the edge
KAPV 12	g undercoat	delamination of top coats	
KCPV 12	g	d_2S_4	
KEPV 12	g	1 S4	

* Code varies
ND = No defects

TABLE 10: **Unpainted Panels - Bottom (Metallic material)**

PANEL IDENTIFICATION	CONDITION
KM 33	Extensive severe corrosion
KM 34	Extensive severe corrosion
KG 17	Extensive corrosion with pitting
KZ 17 Sealed	Slight white corrosion
KA 17 Sealed	Extensive white corrosion
KGAV 17	Galvanising removed / Extensive corrosion and pitting
KAAV 17	Extensive white corrosion
KZAV 17	White patches under sealing
KC 33	Deep pitting at mounting
KC 34	Deep pitting at mounting. Near mounting pit has penetrated the specimen, white patches under sealing

TABLE 11: **Epoxy Painted Panels - Bottom**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
KMAE 17	g	0	ND
*KMCP 17	g	0	ND
KMPE 17	g away from blisters	d_5S_2 in patches + d_2S_4	corroded under blisters
KGAE 17	delaminated	delaminated	white corrosion
KGPE 17	delaminated	delaminated	white corrosion
KZAE 17	g	0	ND
KZPE 17	g	0	under creep from the edge
KAAE 17	delaminated	delaminated	white corrosion
KAPE 17	delaminated	delaminated	white corrosion
KCPE 17	extensive blistering	d_4S_4	
KEAE 17	g	0	ND
KEPE 17	g away from blisters	d_3S_4	

*** Code varies**
ND = No defects

TABLE 12: **Multipurpose Epoxy Painted Panels - Bottom**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
KMAM 17	g	0	ND
*KMCE 17	g	0	ND
KMPM 17	g away from blisters		
KAAM 17	delamination	delamination	white corrosion
KAPM 17	delamination	delamination	white corrosion
KCAM 17	g	0	ND
KCPM 17	g	0	delamination from pit at the edge
KEAM 17	g	0	ND
KEPM 17	g	0	ND

*** Code varies**
ND = No defects

TABLE 13: **Vinyl Painted Panels - Bottom**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
KMPV 17	undercoat g	d_5S_2	
KGPV 17	P	$d_5S_2 + d_3S_5$	
KAPV 17	undercoat g	$d_5S_3 + d_2S_5$	under creep from the edge
KZPV 17	undercoat g	d_3S_5	
KCPV 17	P	d_2S_4	
KEPV 17	P	d_2S_5	

*** Code varies**
ND = No defects

3.2 PANELS FROM ROODEPLAAT DAM (36 MONTHS EXPOSURE)

TABLE 14: **Unpainted Panels -Surface**

PANEL IDENTIFICATION	CONDITION
RM 5	General corrosion
RM 6	General corrosion
RG 3	Severe corrosion with zinc removed / oval deep pitting
RZ 3 Sealed	Slight white corrosion
RA 3 Sealed	White corrosion above water line Panel sound below water line
RC 5	ND
RC 6	ND
RGAV 3	Slight white corrosion
RZAV 3	Slight white corrosion
RAAV 3	White corrosion / slight red corrosion

ND = No defects

TABLE 15: **Epoxy Painted Panels - Surface**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
RMAE 3	g	0	ND
*RMCP 3	g	0	ND
RMPE 3	g away from blisters	d_3S_4	rust under blisters
RGAE 3	P	delamination	white rust under coating
RGPE 3	delaminated	delaminated	white rust under coating
RZAE 3	g	d2 S4	
RZPE 3	g	0	ND
RAAE 3	g	0	ND
RAPE 3	g	0	delamination from the edge
RCPE 3	g	0	ND
REAE 3	g	0	ND
REPE 3	g away from blisters	d3 S4	

*** Code varies**
ND = No defects

TABLE 16: Multipurpose Epoxy Painted Panels - Surface

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
*RMAM 3	g	0	ND
RMCE 3	g	0	ND
RMPM 3	g away from blisters	$d_2S_2 + d_2S_4$	
RAAM 3	g	0	ND
RAPM 3	P	patch of delamination	delamination from edge
RCAM 3	g	0	ND
RCPM 3	g	0	ND
REAM 3	panel suspect	panel suspect	
REPM 3	g	0	ND

*** Code varies**
ND = No defects

TABLE 17: Vinyl Painted Panels - Surface

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
RMPV 3	undercoat g	Intercoat d_2S_4	Sound
RGPV 3	undercoat g	Intercoat d_2S_4	Sound
RZPV 3	undercoat g	Intercoat d_2S_4	Sound
RAPV 3	undercoat g	Intercoat d_2S_4	under creep from edge
RCPV 3	undercoat g	Intercoat d_2S_4	Sound
REPV 3	P	0	Sound

TABLE 18: Unpainted Panels -Middle

PANEL IDENTIFICATION	CONDITION
RM 13	Overall corrosion
RM 14	Overall corrosion
RG 7	White deposit - No defects
RZ 7	Complete failure with extensive white corrosion, red corrosion and pitting
RA 7	ND
RGAV 7	Complete destruction of galvanised coating with pitting corrosion
RZAV 7	Few patches of white corrosion
RAAV 7	White deposit with very small patches of white corrosion
RC 13	White deposit - No defects
RC 14	White deposit - No defects
RC 15	White deposit - No defects

ND = No defects

TABLE 19: **Epoxy Painted Panels - Middle**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
RMAE 7	g	0	ND
*RMCP 7	g	0	ND
RMPE 7	g away from blisters	$d_4S_2 + d_2S_4$	rust under blisters
RGAE 7	P	patchy delamination	
RGPE 7	delaminated	delaminated	white corrosion
RZAE 7	g	odd S4	under creep from the edge
RZPE 7	g	0	under creep from the edge
RAAE 7	delaminated	delaminated	white corrosion
RAPE 7	delaminated	delaminated	white corrosion
RCPE 7	g	$1S_5$	ND
REAE 7	g	0	ND
REPE 7	g away from blisters	d_3S_4	

*** Code varies**
ND = No defects

TABLE 20: Multipurpose Epoxy Painted Panels - Middle

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
RMAM 7	g	0	ND
RMCE 7	g	0	ND
RMPM 7	g away from blisters	d_3S_2 + d_3S_4	rust under blisters
RAAM 7	delaminated	delaminated	white corrosion
RAPM 7	delamination	delamination	white corrosion
RCAM 7	g	0	ND
RCPM 7	g	0	ND
REAM 7	defective panel	defective panel	
REPM 7	g	0	ND

* Code varies
ND = No defects

TABLE 21: Vinyl Painted Panels - Middle

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
RMPV 7	undercoat g	few S_5	corrosion at the edges and the weld
RGPV 7	P	odd S_5	corrosion at the edges
RZPV 7	g	intercoat	failures at the edges with white corrosion
RAPV 7	g	d_3S_4	under creep from the edge
RCPV 7	P	d_2S_5	
REPV 7	g	0	ND

ND = No defects

TABLE 22: Unpainted Panels -Bottom

PANEL IDENTIFICATION	CONDITION
RM 29	Overall corrosion
RM 30	Overall corrosion
RZ 15	Under creep from the edge
RA 15	Red corrosion
RGAV 15	Pits up to 15 mm diameter Corrosion at the edges
RZAV 15	Spots of corrosion. Overall condition good
RAAV 15	Extensive white corrosion
RC 29	Pitting under mounting No defects on open panel
RC 30	Pitting under mounting No defects on open panel

TABLE 23: **Epoxy Painted Panels - Bottom**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
RMAE 15	g	0	ND
*RMCP 15	g	0	ND
RMPE 15	g	very few S_2	corrosion at the edges
RGAE 15	P	d_2S_2	
RGPE 15	P	delamination	
RZAE 15	g	0	ND
RZPE 15	g	0	ND
RAAE 15	delaminated	delaminated	white corrosion
RAPE 15	delaminated	delaminated	white corrosion
REAE 15	g	0	ND
RCPE 15	g	0	ND
REPE 15	g	0	ND

*** Code varies**
ND = No defects

TABLE 24: Multipurpose Epoxy Painted Panels - Bottom

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
RMAM 15	g	0	ND
*RMCE 15	g	0	ND
RMPE 15	g	0	corrosion at an edge
RAAM 15	delaminated	delaminated	white corrosion
RAPM 15	delaminated	delaminated patch	white corrosion
RCAM 15	g	0	ND
RCPM 15	g	0	ND
REAM 15	g	0	ND
REPM 15	g	0	ND

* Code varies
ND = No defects

TABLE 25: Vinyl Painted Panels - Bottom

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
RMPV 15	undercoat g	odd S_5 intercoat	corrosion at edges
RGPV 15	undercoat g	d_5S_3 intercoat	under creep and severe edge corrosion
RZPV 15	undercoat g	$1S_5$	slight corrosion at one edge
RAPV 15	undercoat g	odd large 20mm	under creep from edges
RCPV 15	undercoat g	1 15mm	uncovered at edges
REPV 15	undercoat g	Intercoat d_3S_3	

3.3 PANELS FROM VAAL DAM (36 MONTHS EXPOSURE)

TABLE 26: **Unpainted Panels - Surface**

PANEL IDENTIFICATION	CONDITION
VM 3	Severe overall corrosion and pitting below waterline.
VM 4	Severe overall corrosion and pitting below waterline.
VG 2	ND
VZ 2	ND
VA 2	Very slight corrosion at corner.
VC 3	ND
VC 4	ND
VGAV 2	ND
VZAV 2	ND
VAAV 2	Overall white corrosion and odd spots showing initiation of red corrosion.

TABLE 27: **Epoxy Painted Panels - Surface**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	**BLISTERING**	**GENERAL**
VMAE 2	g	O	ND
*VMCP 2	g	O	ND
VMPE 2	g away from blistering	Blisters below waterline d_4 S_4	Corrosion under blisters
VGAE 2	P	O	
VGPE	Complete delamination	Delaminated	White corrosion under coating
VZAE 2	g	O	ND
VZPE 2	g	O	ND
VAAE 2	g	O	ND
VAPE 2	g	O	ND
VCPE 2	g away from blisters	d_3 S_4	
VEAE 2	g	O	ND
VEPE 2	g away from blisters	d_4 S_4	
VZAE 2	g	O	ND

*** Code varies**

TABLE 28: Multipurpose Epoxy Painted Panels - Surface

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
VMAM 2	g	O	ND
*VMCE 2	g	O	Corrosion at edge
VMPM 2	g away from blisters	d_4 S_3	Corrosion under blisters
VAAM 2	g	O	ND
VAPM 2	g away from blisters	d_5 S_5 in a patch	White corrosion under blisters
VCAM 2	g	O	ND
VCPM 2	g away from blisters	d_2 S_4	
VEAM 2	g	O	ND
VEPM 2	g away from blisters	d_2 S_4	

* Code varies

TABLE 29: Vinyl Painted Panels - Surface

PANEL IDENTIFICATIO N	CONDITION		
	ADHESION	BLISTERING	GENERAL
VMPV 2	Primer g	Intercoat d_1 S_5	Alligatoring at surface
*VGPV 2	Adhesion loss from two spots 10 x 10 mm and 10 x 5 mm	Intercoat d_3 S_4	Alligatoring at surface
VZPV 2	Primer g	Intercoat d_2 S_4	Alligatoring at surface
VAPV 2	Primer g	Intercoat d_4 S_5	Alligatoring at surface
VCPV 2	Primer g	Intercoat d_2 S_4	Alligatoring at surface
VEPV 2	Primer g	Intercoat d_2 S_4	Alligatoring at surface

TABLE 30: Unpainted Panels - Middle

PANEL IDENTIFICATION	CONDITION
VM 19	Overall corrosion with deep pitting
VM 20	Overall corrosion with deep pitting
VG 10	Dark colour ND
VZ 10 sealed	Corrosion on edges and weld
VA 10 sealed	General corrosion white and red
VC 19	ND
VC 20	ND
VGAV 10	ND
VZAV 10	Light white corrosion
VAAV 10	Overall white corrosion

TABLE 31: **Epoxy Painted Panels - Middle**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
VMAE 10	g	O	ND
*VMCP 10	g	O	ND
VMPE 10	g away from blistering	$d_2 S_4 + d_3 S_2$	Corrosion under blisters
VGAE 10	P	O	
VGPE 10	Complete delamination	Delaminated	White corrosion
VZAE 10	P	O	Not corroded
VZPE 10	g	O	Slight corrosion at edge
VAAE 10	Extensive delamination	Delaminated	White corrosion
VAPE 10	Large (10 - 20 mm) contagious blisters over whole surface		White corrosion
VCPE 10	g	$d_2 S_3$	
VEAE 10	g	O	ND
VEPE 10	g away from blisters	$d_3 S_4$	

* **Code varies**

TABLE 32: **Multipurpose Epoxy Painted Panels - Middle**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
VMAM 10	g	O	ND
*VMCE 10	g	O	ND
VMPM 10	g away from blisters	d_3 S_4	
VAAM 10	Extensive contagious blistering S_4	d_5 S_4	White corrosion
VAPM 10	Extensive delamination		White corrosion
VCAM 10	g	O	ND
VCPM 10	g	O	ND
VEAM 10	g	O	ND
VEPM 10	g	O	ND

* Code varies

TABLE 33: **Vinyl Painted Panels - Middle**

PANEL IDENTIFICATION	CONDITION		
	ADHESION	BLISTERING	GENERAL
VMPV 10	Primer g Intercoat poor	Intercoat d_1 S_5 + d_5 S_1	
VGPV 10	Primer g Intercoat poor	Intercoat d_1S_5	
VZPV 10	Primer g	Intercoat d_2 S_2	
VAPV 10	P	Intercoat d_5 S_3 + few large 40 - 50 mm	Corrosion under primer in patches
VCPV 10	Primer g	Intercoat d_1 S_5	
VEPV 10	Primer g	Intercoat d_3 S_5	

The final set of specimens was removed from the Vaal dam in June 1997 after approximately 36 months exposure. Specimens from the other two dams i.e. Roodeplaat and Kleinplaas were removed in December 1996 after 36 months of exposure. The results of the evaluation of the specimens after their period of exposure were shown in Tables 1 to 33. The tables show the results according to their sites of exposure, the positions in the dam and the various type of coatings - evaluations according to an **ISO Standard 4628 "Paints and Varnish"**. The coatings on the various specimens and the surface appearance of non-coated specimens were visually examined for all possible defects such as blistering, adhesion and cracks.

3.4 VISUAL EXAMINATION

Figure A: Exposure racks assembly on-site.
Note: Completed exposure racks with float (**A3** and **A4**).

Figure B: Completed pontoon floating on-site.
Note: Floats in line attached to the pontoon (**B4**).

Figure C: Exposure sites i.e. Kleinplaas and Roodeplaat Dams.

Figure D: Specimens as arranged in the exposure racks after removal from the dam.

Figure E: Specimens from Roodeplaat dam before cleaning. Note the build up of algae and white deposit.

Figure F: Specimens from Roodeplaat dam before cleaning. In figures **F2, F3** and **F4** note the red/brown corrosion where coatings have failed.

Figure G1: Intercoating blistering in a vinyl coating.

Figure G2: Intercoating blistering in a vinyl coating and large blisters at the edge of the specimen.

Figure G3: In specimen **RPM7** note the fine blisters.

3.5 COMPARATIVE RESULTS OF SITES, POSITION AND COATINGS

TABLE 34: Unpainted

SPECIMEN	KLEINPLAAS	ROODEPLAAT	VAAL
SURFACE			
G	Severe Corrosion	General Corrosion	Severe Corrosion
Z	Stripped at water line	Severe pitting	ND
A	ND	Slight	ND
C	ND	Slight at water line	Slight
E	ND	ND	ND
MIDDLE			
M	Extensive Severe Corrosion with pitting	General Corrosion	General Corrosion and Pitting
G	Galvanizing stripped and large pits	White deposit	Corrosion at edge
Z	Edge Corrosion	Complete failure	General Corrosion
A	Severe Corrosion	ND	
C	Odd deep pits	ND	ND
E	Deep pits at mount		
BOTTOM			
M	Severe Corrosion	General Corrosion	
G	Extensive and pitting	Large pits	
Z	Slight Corrosion	Under creep	
A	Extensive corrosion	Red corrosion	
C	Pitting at mount	Pitting at mount	
E	Pitting at mount		

TABLE 35: **Epoxy Painted - Surface**

SPECIMEN	KLEINPLAAS	ROODEPLAAT	VAAL
M1	ND	ND	ND
M2	ND	ND	ND
M3	Blistering	Blistering	Blistering
G1	ND	White Rust	Poor Adhesion
G3	Failed	White Rust	Delaminated
Z1	ND	Blistering	ND
Z3	Edge Delamination	ND	ND
A1	ND	ND	ND
A3	Blistering	Edge Delamination	ND
C3	Blistering	ND	Blistering
E1	ND	ND	ND
E3	ND	Blistering	Blistering

TABLE 36: **Epoxy Painted - Middle**

SPECIMEN	KLEINPLAAS	ROODEPLAAT	VAAL
M1	ND	ND	ND
M2	ND	ND	ND
M3	Blistering	Blistering	Blistering
G1	White Corrosion	Delamination	Poor Adhesion
G3	White Corrosion	White Corrosion	Delaminated
Z1	ND	Under Creep	Poor Adhesion
Z3	Edge Delamination	Under Creep	Under Creep
A1	White Corrosion	White Corrosion	White Corrosion
A3	White Corrosion	White Corrosion	White Corrosion
C3	Blistering	ND	Blistering
E1	ND	ND	ND
E3	Blistering	ND	Blistering

TABLE 37: Epoxy Painted - Bottom

SPECIMEN	KLEINPLAAS	ROODEPLAAT	VAAL
M1	ND	ND	
M2	ND	ND	
M3	Blistering	Blistering	
G1	White Corrosion	Blistering	
G3	White Corrosion	Delamination	
Z1	ND	ND	
Z3	Under Creep	ND	
A1	White Corrosion	White Corrosion	
A3	White Corrosion	White Corrosion	
C3	Blistering	ND	
E1	ND	ND	
E3	Blistering	ND	

TABLE 38: Multipurpose Epoxy Painted - Surface

SPECIMEN	KLEINPLAAS	ROODEPLAAT	VAAL
M1		ND	ND
M2	ND	ND	Corrosion at edge
M3	Blistering	Blistering	Blistering
A1	ND	ND	ND
A3	Delamination	Delamination from edge	Blistering
C1	ND	ND	ND
C3	ND	ND	Blistering
E1	ND		ND
E3	ND	ND	Blistering

TABLE 39: **Multipurpose Epoxy Painted - Middle**

SPECIMEN	KLEINPLAAS	ROODEPLAAT	VAAL
M1	ND	ND	ND
M2	ND	ND	Corrosion at edge
M3	Blistering	Blistering	Blistering
A1	Delamination	Delamination and Corrosion	White Corrosion
A3	Delamination	Delamination and Corrosion	Delamination and Corrosion
C1	ND	ND	ND
C3	ND	ND	ND
E1	ND		ND
E3	ND	ND	ND

TABLE 40: **Multipurpose Epoxy Painted - Bottom**

SPECIMEN	KLEINPLAAS	ROODEPLAAT	VAAL
M1	ND	ND	
M2	ND	ND	
M3	ND	Corrosion at edge	
A1	Delamination	Delamination and Corrosion	
A3	Delamination	Delamination and Corrosion	
C1	ND	ND	
C3	Delamination from edge	ND	
E1	ND	ND	
E3	ND	ND	

There was a massive build-up of biological constituents and chemical compositions on the samples before cleaning. The condition of surfaces of the samples was clearly visible on cleaned samples. The exposure in raw water of the dams is aggressive to both coated and uncoated samples irrespective of their positions (levels) in the dam. The mass loss of the uncoated carbon steel coupons after 36 months was 70.71 (top) and 88.56 (bottom) at Vaal Dam, 43.67, 148.16, 70.09 for top, middle and bottom at Roodeplaat Dam respectively and 66.42, 129.68 and 129.46 for top, middle and bottom at Kleinplaas Dam respectively. All values in μm/yr.

3.6 WATER QUALITY ANALYSIS

The results of the corrosion species and indices are shown graphically in Figure 1 to 18 from the different exposure sites i.e. Kleinplaas Dam, Vaal Dam and Roodeplaat Dam respectively.

Figures 1 to 6 are the graphical representations of samples exposed at Kleinplaas Dam. The chloride concentrations at various positions in the dam were actually higher during the dry seasons as well as the sulphates and calcium concentrations. The dissolved oxygen concentration in Kleinplaas Dam were between 8 and 8.5 ppm in the middle and top of the dam as compared to lower concentration in the bottom of the dam. The solubility of oxygen decreases with a rise in temperature and deoxygenation often occurs at the bottom of the dam. The Langelier Index was always negative at Kleinplaas Dam. Higher Langelier Index levels were also noticed during the dry seasons. The value was more negative, implying that the water was capable of dissolving any calcium carbonate with which it came into contact. The chloride and sulphate levels at Kleinplaas Dam fluctuated in a narrow zone between 7 - 15 ppm and 1 - 3 ppm respectively.

Figures 7 to 12 are graphical representations of results from Vaal Dam. The concentrations of chlorides, and sulphates were not showing a clear trend according to the seasons. The calcium concentration was between 8 ppm and 12 ppm. The chloride levels at the Vaal Dam varied between 3 and 8 ppm whilst the sulphate levels fluctuated between 4 - 27 ppm. The Langelier Index fluctuated between -2.1 and 0.3. The same trend observed in Kleinplaas Dam was noticed at the Vaal Dam as far as the dissolved oxygen concentration is concerned. The corrosion indices were also not showing a particular trend.

Figures 13 to 18 are graphical representations from Roodeplaat Dam. The chloride concentrations were between 40 ppm and 60 ppm with no obvious seasonal trend. The same trend was noticed with sulphate and calcium concentrations. The highest levels of chlorides were detected at Roodeplaat Dam where the level fluctuated in a narrow band between 38 - 60 ppm and the sulphate levels between 10 - 45 ppm. The corrosion indices were also not showing a particular trend. The above results confirm the fact that no two dams will show similar results as noticed also from the effect of water on both the coated and non-coated samples.

Chlorides and sulphates make up most of the corrosive species found in waters. In general, the concentration of dissolved chlorides is greater than that of sulphates. High levels of chlorides can cause localised corrosion of alloys relying on passive film for protection e.g. stainless steels. The most important dissolved gases from a corrosion point of view are oxygen and carbon dioxide.

The water analysis carried out reinforces the fact that water composition varies seasonally and relying on one sample taken at a particular point of time may lead to erroneous conclusions being drawn. In general, there was little variation in chloride, sulphate and calcium levels and the Langelier Index.

4. DISCUSSION

4.1 CORROSIVE NATURE OF THE RAW WATER OF THE DAMS

An examination of the uncoated metal panels from the various dams showed that for specimens exposed in the middle of the dams, the specimens from Kleinplaas were most severely corroded.

The "Middle" specimens were chosen because:

- at the surface the wet/dry conditions that exist are not common for many structures in the water supply situation and

- the "bottom" specimens from Vaal dam after 3 years were lost in floods).

From the water analyses carried out, the Langelier Index has been calculated for the three dams. While the Langelier Index in itself is not considered a reliable measure of the corrosive nature of water, it is indicative of the ability of a water to form scale.

The Langelier index for the water from Kleinplaas dam was negative. The index for water from Roodeplaat dam has been generally positive while the index for water from Vaal dam has been generally negative but never near as negative as that of the water from Kleinplaas.

4.2 THE PERFORMANCE OF THE PAINT COATINGS

4.2.1 Epoxy Resin Paint

4.2.1.1 On Mild Steel

The performance of the epoxy resin paints of two suppliers on mild steel was good with no major defects. The material from a third supplier tended to form blisters. When these blisters were larger than 2mm diameter, the steel under the blisters was generally corroded.

4.2.1.2 On Galvanised Steel, Zinc Metal Sprayed Steel and Aluminium Metal Sprayed steel

One supplier did not recommend that their material be applied over these substrates. The performance of the other two materials was generally poor with some specimens delaminating with corrosion of the metal under the coatings. These defects were not always immediately obvious and some failures were only found when the adhesion of the coating was evaluated. In other instances the failures were obvious with massive blistering and white corrosion (plus red corrosion of the steel) of the metal applied to the steel.

4.2.2 Multipurpose Epoxy Resin Paint

4.2.2.1 On Mild Steel

Three suppliers prepared panels. The performance of the panels from two suppliers was good while the material from the third supplier tended to form blisters.

4.2.2.2 On Metal Coated

Two suppliers prepared panels on aluminium metal sprayed steel. The performance of the coatings was generally poor with delamination and white corrosion products.

4.2.2.3 On 3CR12

Two suppliers prepared panels. The performance of the coatings was generally good. The material from one supplier showed blistering on a few panels. Some pitting of the 3CR12 panels occurred when submerged in water.

4.2.2.4 On 3CR12 Steel Pickled and Passivated and Blast Cleaned

Two suppliers prepared panels. The one material showed blistering but without corrosion under the blisters.

In some instances the 3CR12 material showed pitting.

4.2.3 Vinyl Paint

4.2.3.1 On Mild Steel, Galvanised Steel, Metal Sprayed Steel and 3CR12

One supplier prepared panels. On all the panels intercoat blistering occurred. On the metal sprayed panels some failures of the entire system with corrosion of the substructure occurred on the panels from the "surface", alligatoring of the exposed coating occurred.

5. CONCLUSIONS

After three years exposure in Vaal, Kleinplaas and Roodeplaat Dams the following conclusions are drawn:

1. The splash zone is a particularly corrosive environment.

2. Certain anomalies occurred indicating the need for the exposure of at least triplicate panels. However such action would have made the exposure programme unwieldy

3. The galvanised, zinc and aluminium metal-sprayed coupons that had been coated performed poorly. Complete failure in most cases occurred at the metal/coating interface and was due to corrosion products being generated on the metal surface, destroying the adhesion. The use of duplex systems under immersed conditions in South African Dam waters is therefore not recommended.

4. The performance of unpainted metal coated panels has varied with some unanticipated severe failures.

5. The performance of organic coatings on mild steel panels has been good.

6. The performance of generic coatings from different manufacturers varies.

7. Where 3CR12 panels are completely exposed, the resistance to corrosion has been excellent but sometimes where oxygen is excluded e.g. at mountings, deep pitting has occurred.

8. Microbial corrosion due to sulphate-reducing bacteria was evident at all dams and at all levels.

9. The use of mass loss results as a measure of corrosivity is unreliable when the predominant form of corrosion is localised. In this study, low corrosion rates were recorded for carbon steel based on mass loss but extensive localised corrosion of panels had occurred.

10. Some variation in performance of generic coatings between different manufacturers was evident, but will not be discussed.

6. RECOMMENDATIONS

- It is recommended that an extension of this project is necessary to look at newer materials entering the market.

- The WRC should print a booklet summarising the main findings of this study and include colour photographs showing types of failures and guideline on how to build up such a database.

7. REFERENCES

1. Upfill Brown, S.H. and Stead, G.R. - The Corrosion Protection of Steel Pipelines by Organic Coatings and Lining Materials. Part 2. Corrosion and Coatings South Africa, June 1983.

2. International Standard - ISO 4628/1 to 6 (1982).

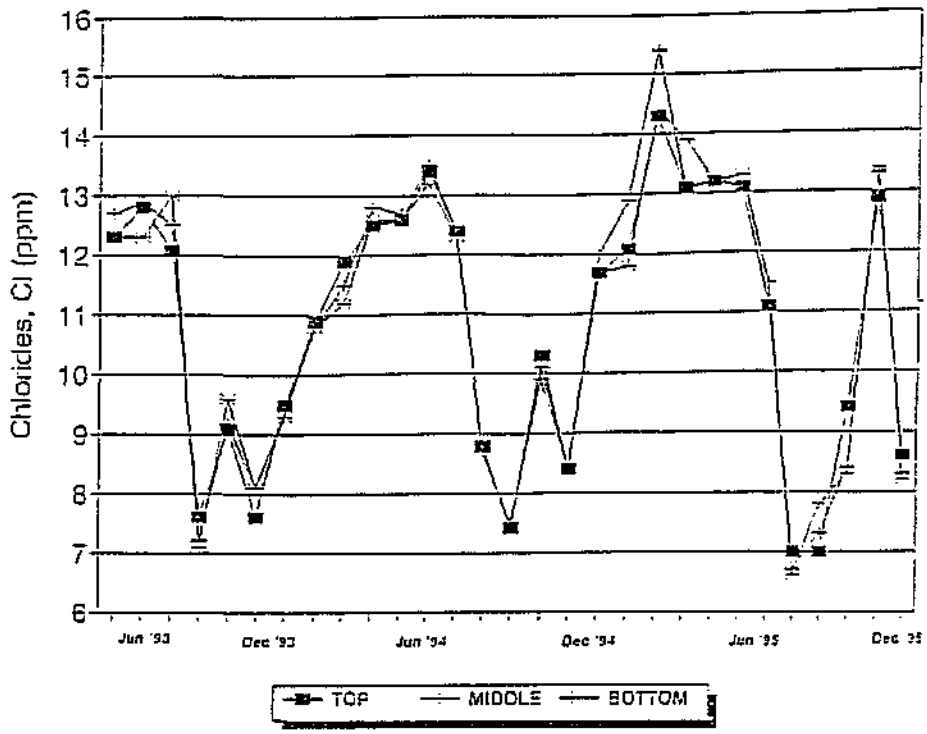

Figure 1: **Chloride** concentration (ppm) from Kleinplaas Dam at three levels, during June 1993 - December 1995.

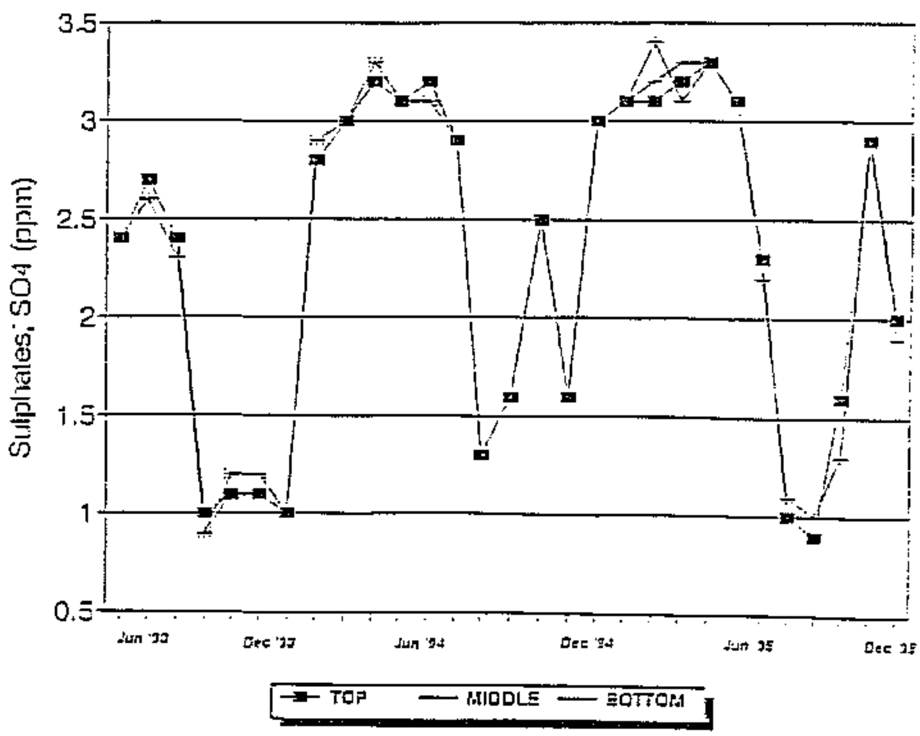

Figure 2: **Sulphate** concentration (ppm) from Kleinplaas Dam at three levels, during June 1993 - December 1995.

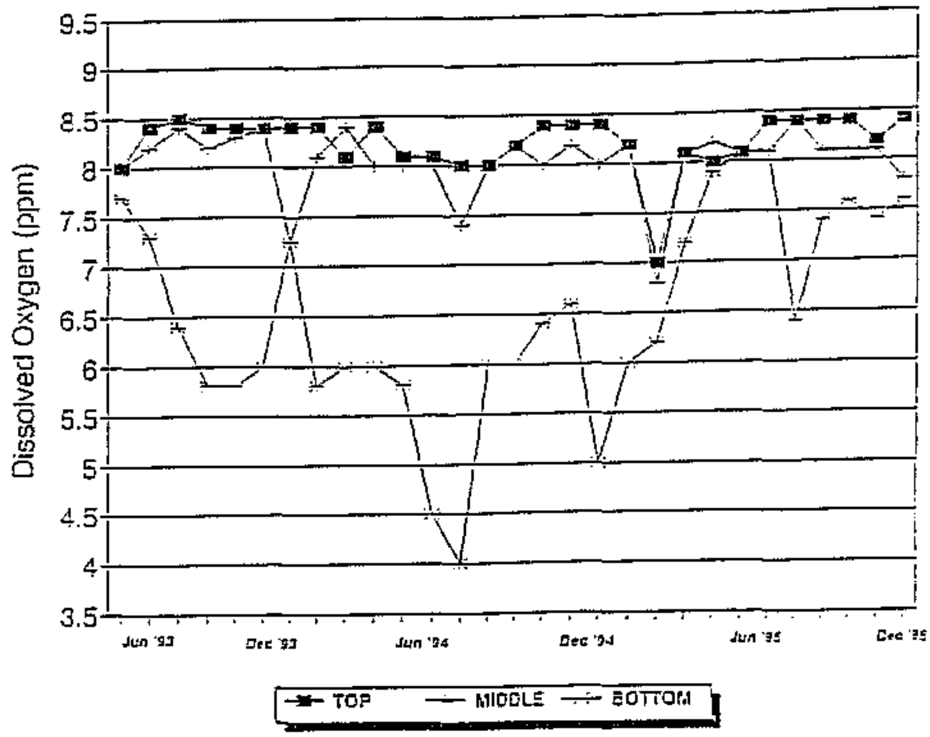

Figure 3: **Dissolved Oxygen** concentration (ppm) from Kleinplaas Dam at three levels during June 1992 - December 1995.

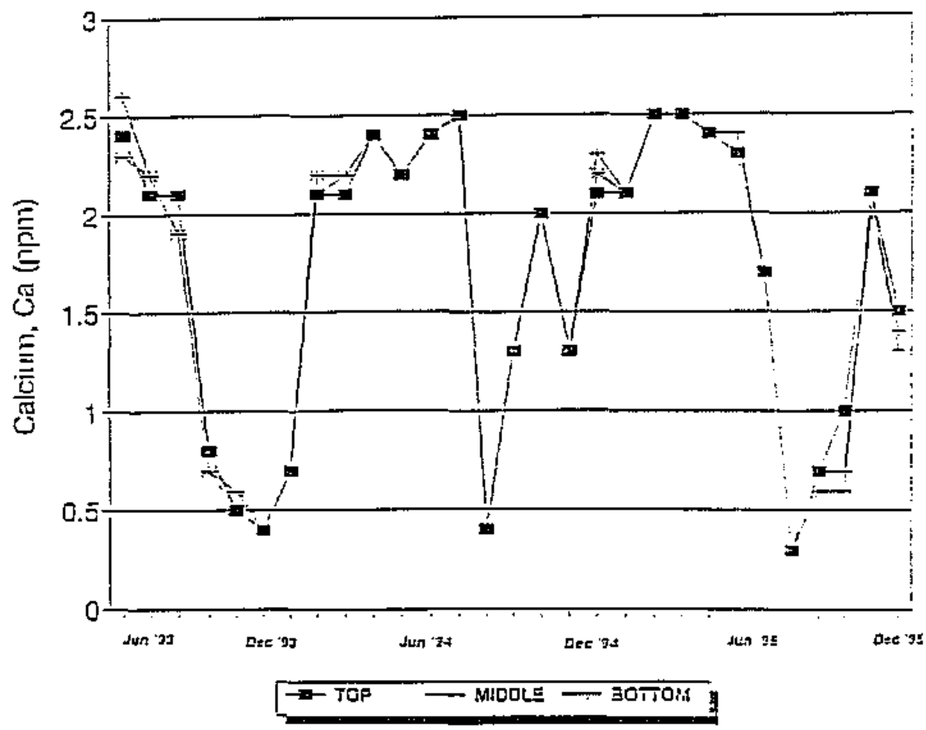

Figure 4: **Calcium** concentration (ppm) from Kleinplaas Dam at three levels during June 1993 - December 1995.

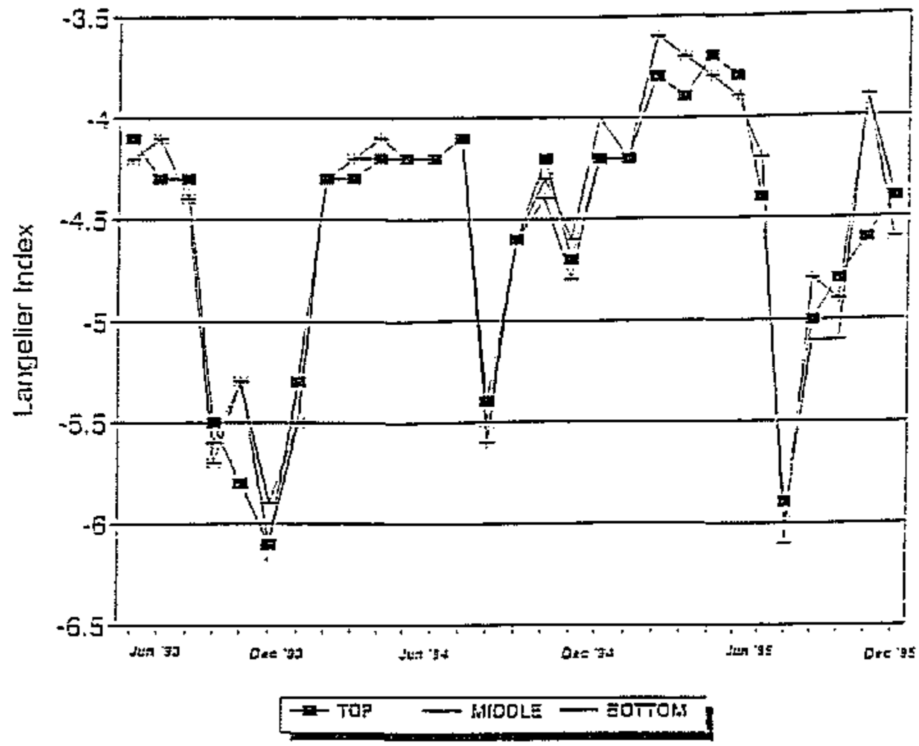

Figure 5: **Langelier Index** from Kleinplaas Dam at three levels during June 1993 - December 1995.

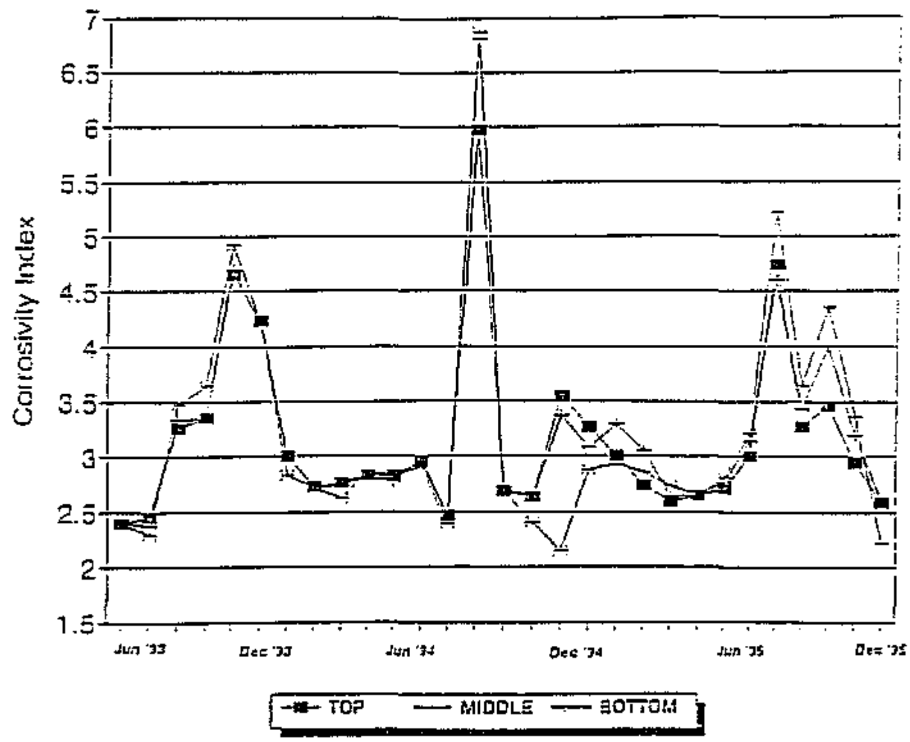

Figure 6: **Corrosivity Index** from Kleinplaas Dam at three levels during June 1993 - December 1995.

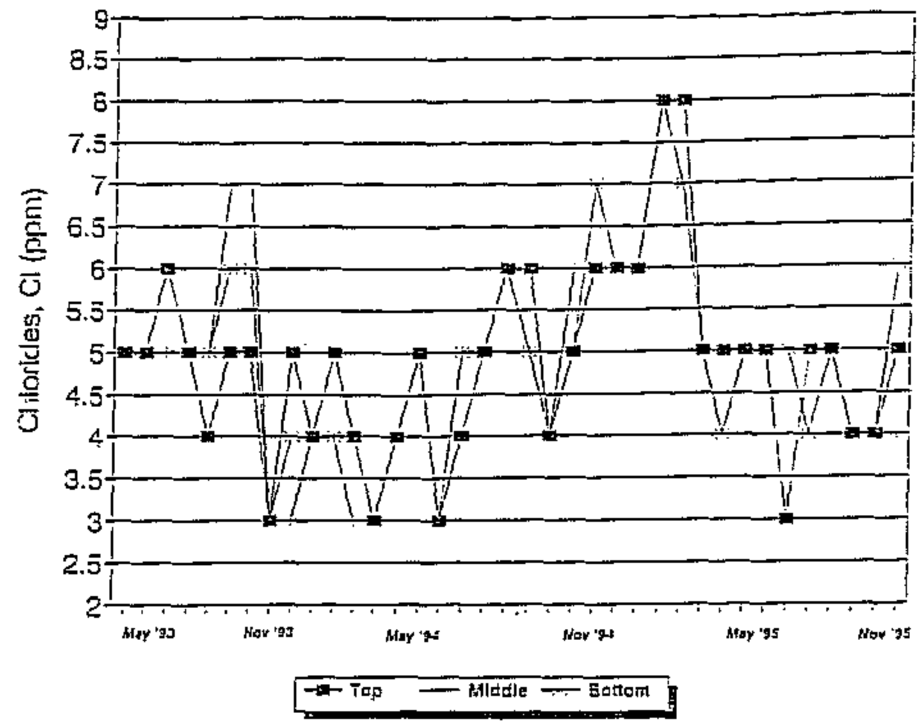

Figure 7: **Chloride** concentration (ppm) from Vaal Dam at three levels during May 1993 - November 1995.

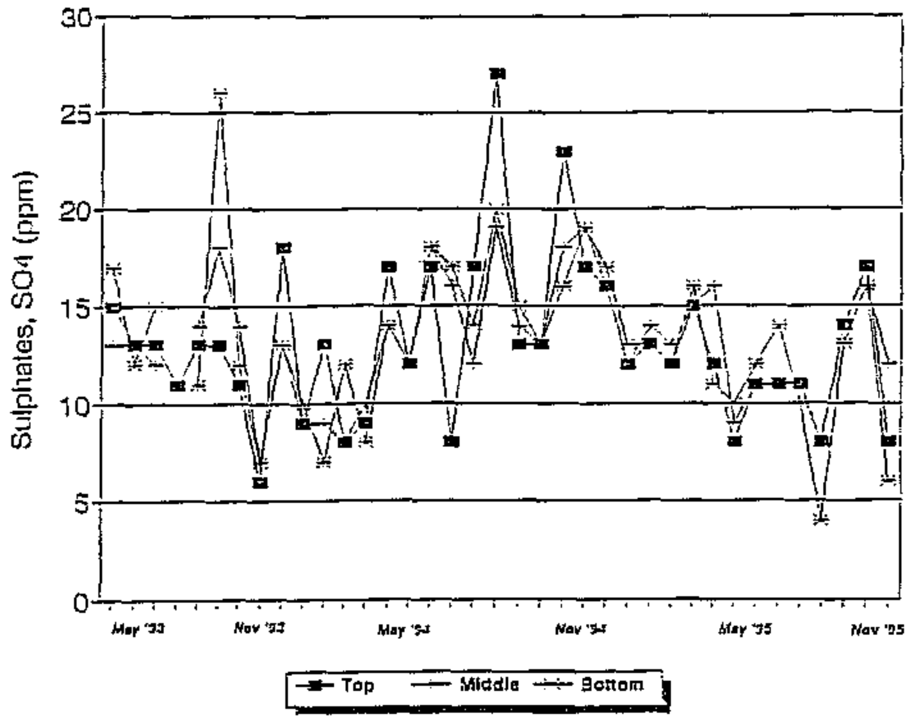

Figure 8: **Sulphate** concentration (ppm) from Vaal dam at three levels during May 1993 - November 1995.

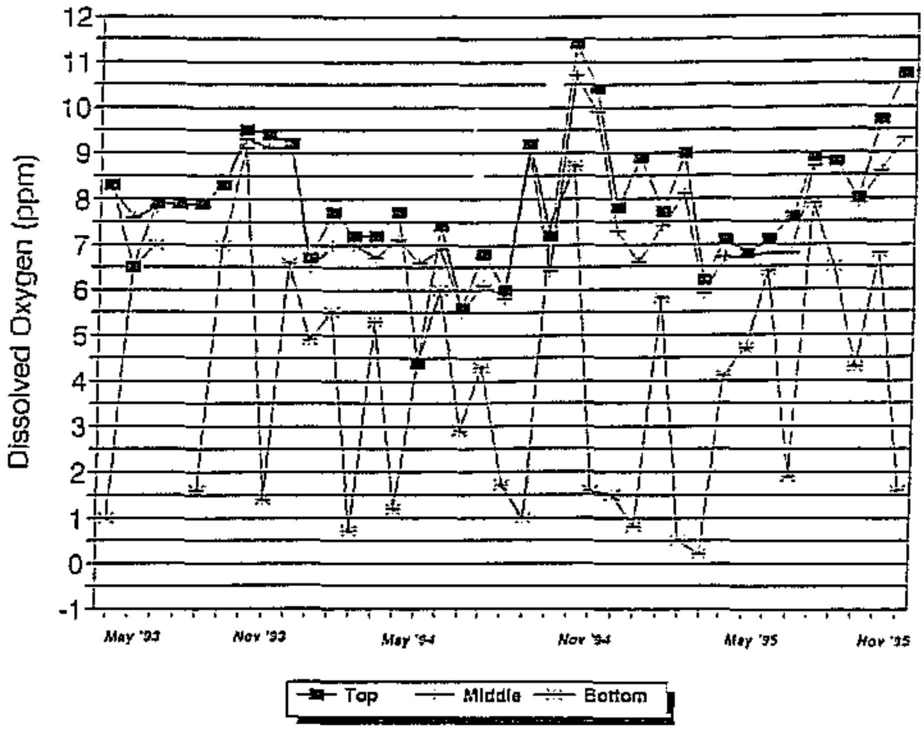

Figure 9: **Dissolved Oxygen** concentration (ppm) from Vaal Dam at three levels during May 1993 - November 1995.

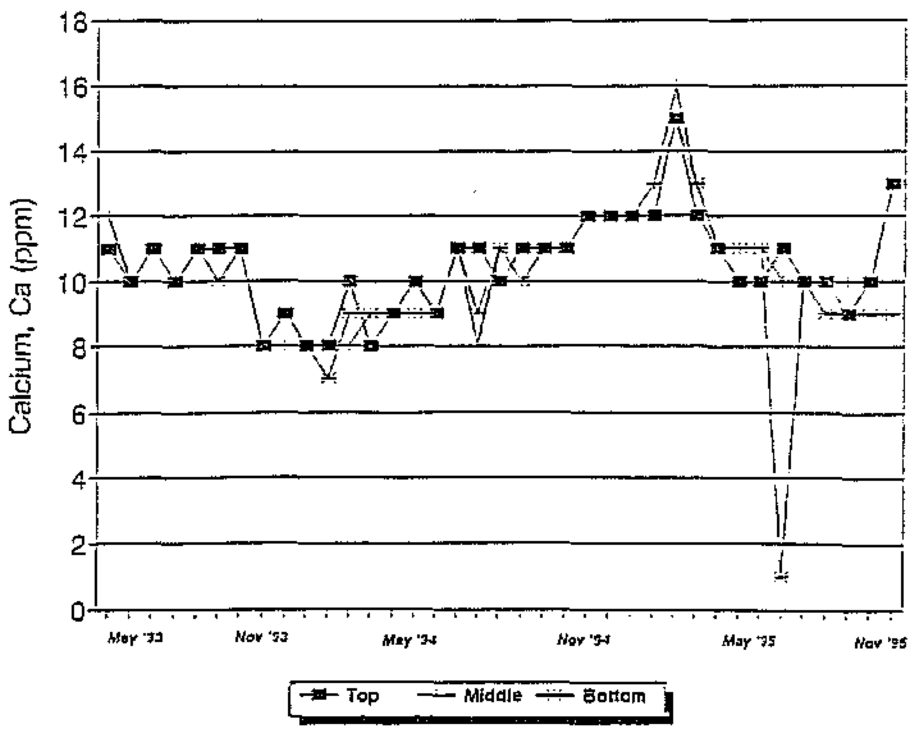

Figure 10: **Calcium** concentration (ppm) from Vaal Dam at three levels during June 1993 - November 1995.

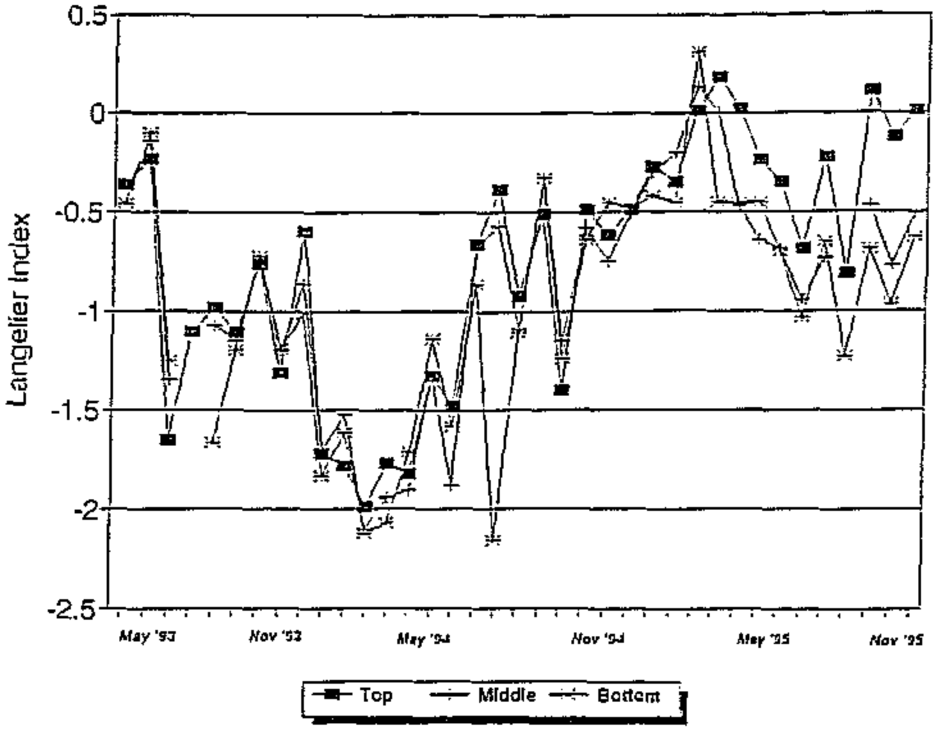

Figure 11: **Langelier Index** from Vaal Dam at three levels during May 1993 - November 1995.

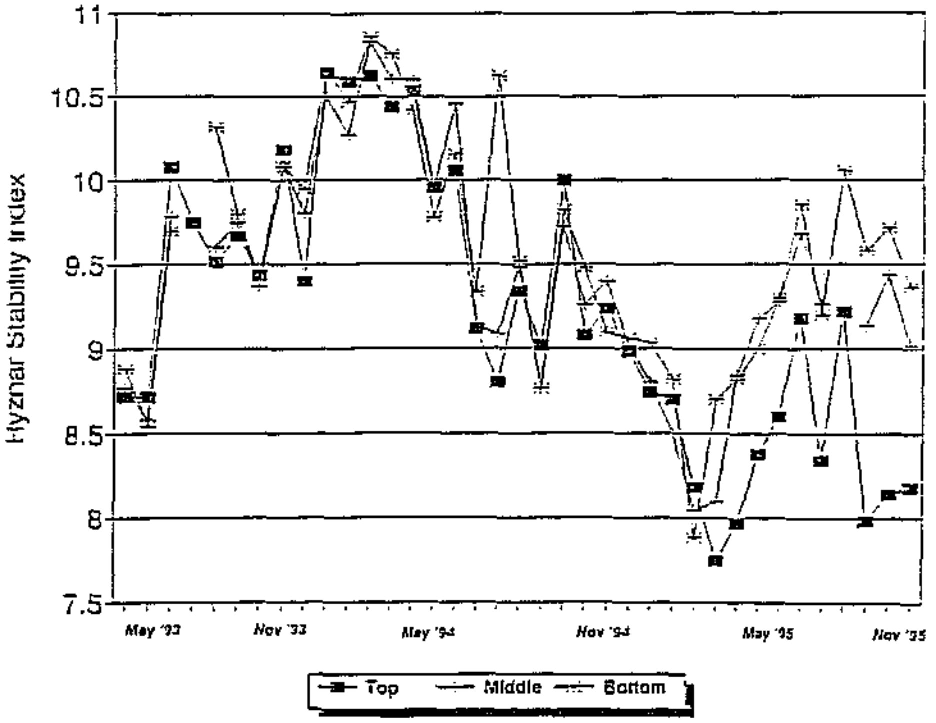

Figure 12: **Ryznar Index** from Vaal Dam at three levels during May 1993 - November 1995.

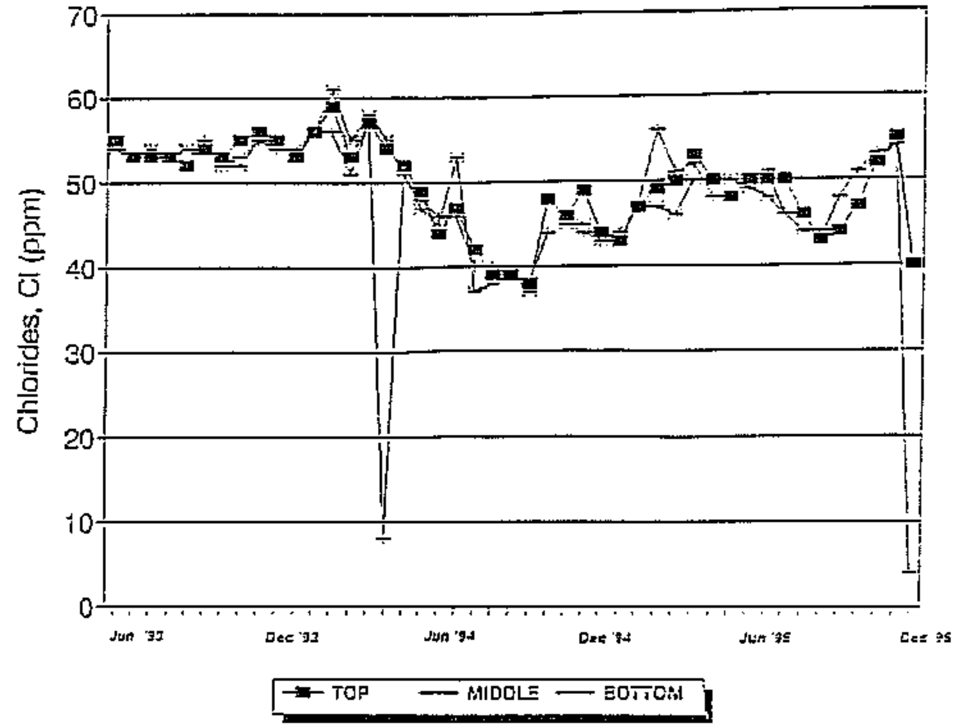

Figure 13: **Chloride** concentration (ppm) from Roodeplaat Dam at three levels during June 1993 - December 1995.

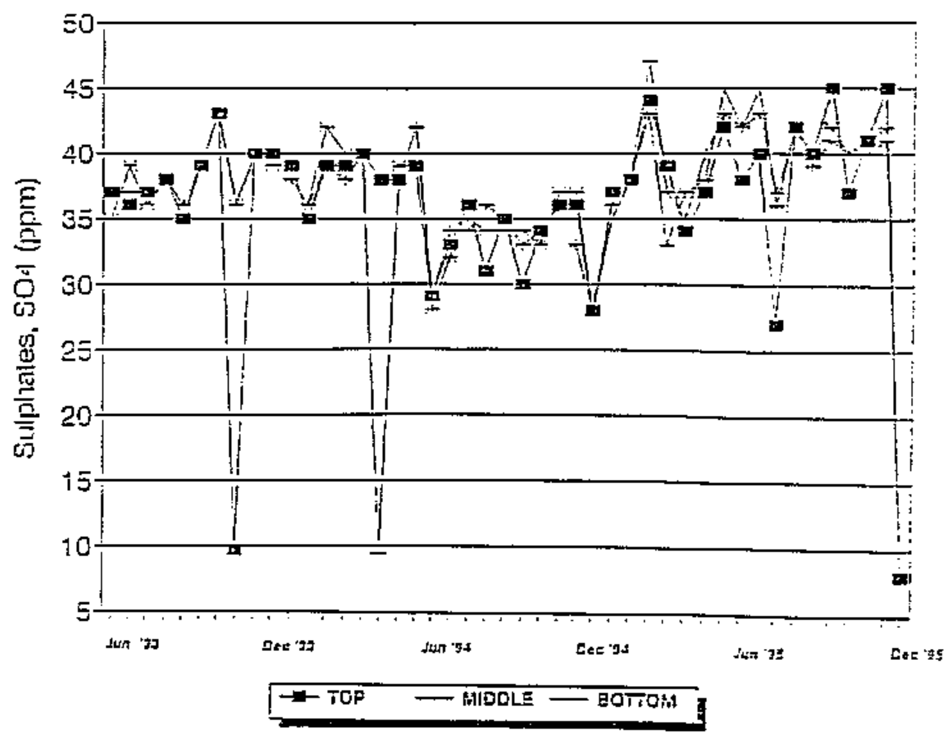

Figure 14: **Sulphate** concentration (ppm) from Roodeplaat Dam at three levels during June 1993 - December 1995.

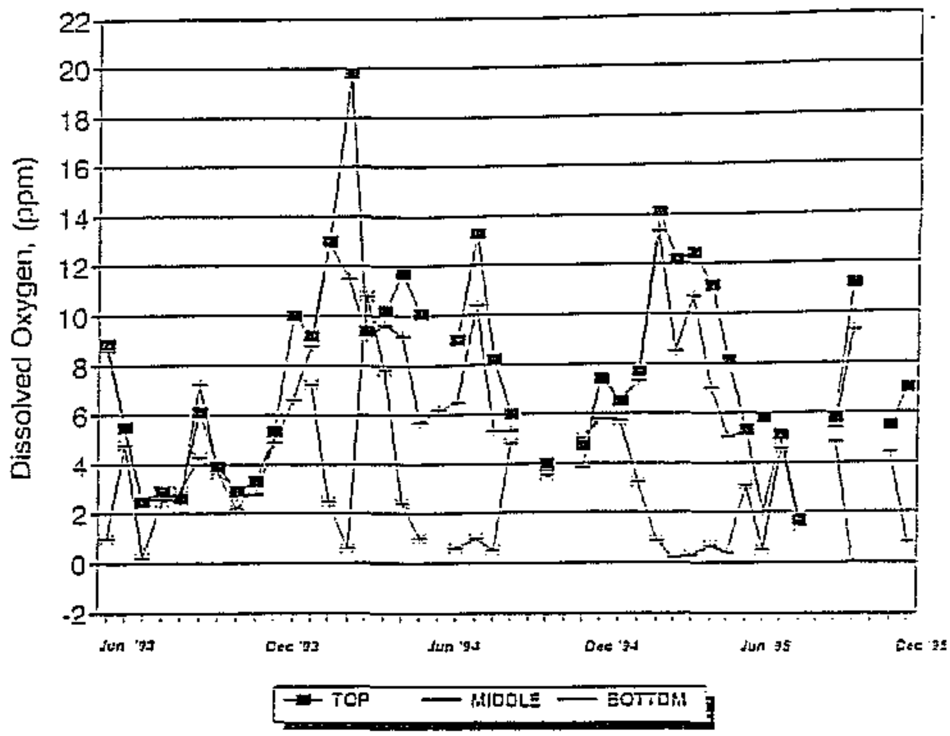

Figure 15: **Dissolved Oxygen** concentration (ppm) from Roodeplaat Dam at three levels during June 1993 - December 1995.

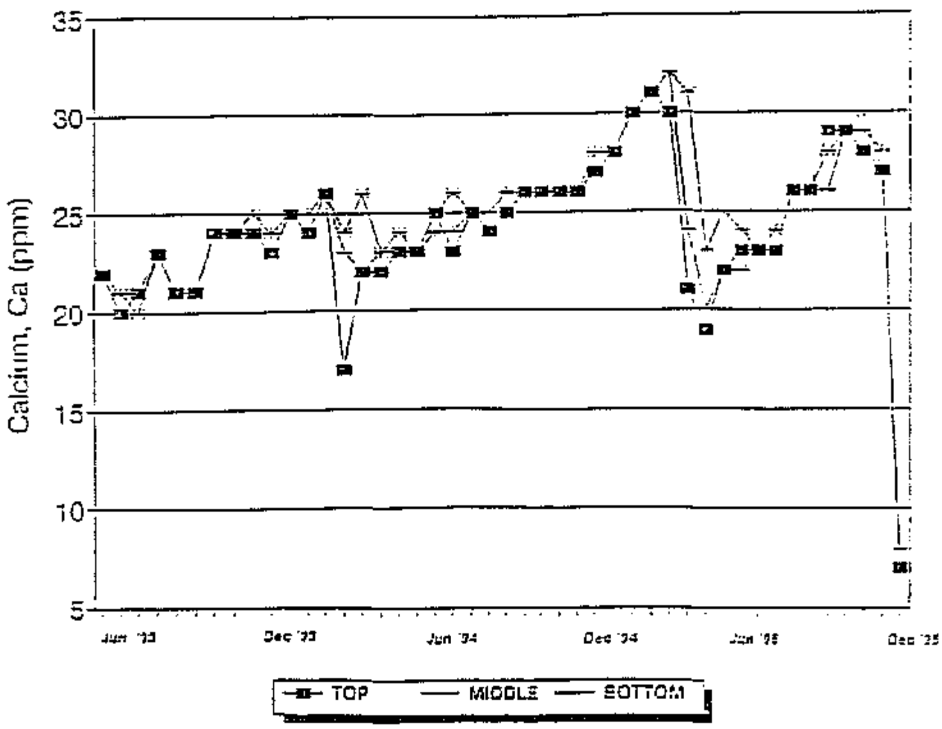

Figure 16: **Calcium** concentration (ppm) from Roodeplaat Dam at three levels during June 1993 - December 1995.

PHOTOGRAPHS