FIELD TESTING OF REAL-TIME CONTINUOUS FLOW AND WATER QUALITY MONITORING INSTRUMENTATION

G Matthews · M Fraser · TJ Coleman · D Salmon

WRC Report No. 1004/1/03

Water Research Commission

Field Testing of Real-Time Continuous Flow and Water Quality Monitoring Instrumentation

Report to the

Water Research Commission

by

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WRC Project No. 1004/1/03

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Executive Summary

Background

The need for monitoring of flow and water quality parameters in open channel flow systems on a continuous basis is now required with a greater frequency than in the past. The introduction of the Reserve in the National Water Act (1998) will require continuous monitoring to operate regulated water resource systems in accordance with the Instream Flow Requirements (IFR). Real time monitoring would also be useful in policing and managing the flood releases often specified as part of the IFR. Pressure is also being brought to bear on the mining and industrial sectors as well as local authorities to monitor waste discharges on a continuous basis. These monitoring requirements are often specified as permit conditions.

In 1996/97 the mines and power stations in the Witbank and Middelburg Dam catchments initiated a Managed Release Scheme to discharge saline mine water into the Klein Olifants and Olifants Rivers. The implementation of this scheme raised the question of the level and type of monitoring required to determine the available assimilative capacity in the dams and rivers in the catchments.

The Collieries had, with mixed results, previously installed continuous monitoring equipment and were reluctant to commit further expenditure without a full investigation of the merits and demerits of the water quality instrumentation offered by the equipment suppliers. Further, from the experience gained in the operation of the Managed Release Scheme, real-time communications would assist in timeous and accurate use of the available assimilative capacity.

There were several water quality instrumentation and communication system suppliers operating in South Africa. The communication systems included telemetry, cellular networks and satellites. Although specifications and brochures were available, little hard evidence regarding performance in the field and service backup was available. There was also a lack of guidelines with respect to the instrumentation operational requirements and the cost of operating continuous monitoring equipment.

This project was initiated to address this question and the general need to investigate the performance of available instrumentation and communication systems.

Study Objectives

- To identify the main suppliers and manufacturers of flow and water quality monitoring equipment in South Africa and Internationally.
- To undertake field tests of the equipment for a full hydrological year to investigate the reliability, accuracy and operating costs of the different manufacturers' equipment.
- To compare the performance of the different communication systems available.
- To report on any lessons learnt on the installation, operation, power requirements, calibration frequency and maintenance requirements of the equipment.

Project Approach

This project was jointly funded by the Water Research Commission (WRC) and the mines and power stations in the Witbank and Middelburg Dam Catchments. The project team consisted of personnel from Wates, Meiring and Barnard (Pty) Ltd and Anglo Coal Environmental Services. The team reported to the steering committee established by the WRC and to the controlled release scheme steering committee.

The overall approach adopted for the study consisted of 3 phases. The first phase was to identify the available equipment, communication systems and suppliers. Meetings were held with the suppliers and a terms of reference prepared and suppliers invited to participate in the project. The second phase dealt with the identification of the sites and installation of equipment. The third phase involved the testing of the equipment and communication systems under field conditions.

The approach to the third phase was to collect a base data set against which to compare the field measurements made by the instrumentation. This base data set was collected manually by Regen Waters Laboratory in Witbank. The parameters measured were pH, electrical conductivity, temperature and flow depth. These are the basic variables that are needed to manage the controlled release scheme and are associated with mining related pollutants.

Field installations

After the initial tender stage, there were 5 suppliers that were willing to participate in the project. The suppliers were ECOSAT (satellite communication), OTT, DDS, Groundwater Systems (Hydrolab probe), Prodesign (Greenspan probe) and Control and Monitoring Laboratories (YSI probe). Five existing Department of Water Affairs and Forestry weirs were selected in the Witbank and Middelburg Dam catchments at which to install the equipment. ECOSAT linked up with YSI and Hydrolab to provide satellite communications at two of the sites. The remaining three sites all had cell phone communication. A radio system was considered but it was found to be too expensive to install the necessary repeater stations to achieve communication between the sites and a central downloading point either in Witbank or the WMB offices in Midrand.

The CSIR was approached to provide background information on communication systems. Their report has been attached as Appendix A.

Results of field tests

The field data measured by the continuous monitoring equipment was compared to the base data set collected by Regen Waters. A number of comparative statistics were used to compare the data sets. The results of the analysis are listed in **Tables 1** to **4** for the different parameters measured.

Table 1 : Depth Statistics

	DDS		HYDROLAB		OTT		PRODESIGN		YSI	
	Regens	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**
Sample Size	42		86		126		100		67	
	Conservation Statistic									
Mean	0.031	0.033	0.469	0.539	0.171	0.170	0.537	0.565	0.160	0.154
% difference	-6.77		-15.00		0.69		-5.13		3.81	
Variance	0.001	0.001	0.320	0.315	0.040	0.038	0.306	0.347	0.018	0.021
% difference	-16.78		1.72		5.82		-13.45		-13.13	
Standard Deviation	0.005	0.005	0.566	0.561	0.201	0.195	0.553	0.589	0.135	0.143
% difference	-8.05		0.86		2.95		-6.52		-6.36	
	Regression Statistics									
Equation of Regression Line	Y=0.99X + 0.002		Y=0.95X + 0.086		Y=0.872 + 0.02		Y=1.03X – 0.013		Y=0.923X + 0.006	
Correlation Coefficient	0.920		0.960		0.900		0.970		0.620	
Coefficient of Determination	0.880		0.921		0.811		0.944		0.381	
Coefficient of Efficiency	0.880		0.905		0.794		0.972		0.361	
Coefficient of Agreement	0.970		0.979		0.946		0.985		0.742	

Table 2 : EC Statistics

	DDS		HYDROLAB		OTT		PRODESIGN		YSI	
	Regens	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**
Sample Size	42		86		126		100		67	
	Conservation Statistic									
Mean	196.03	144.04	54.170	51.986	115.460	115.206	70.669	65.822	54.814	49.809
% difference	26.52		4.03		0.22		6.86		9.13	
Variance	4665.03	2075.40	147.227	142.155	1669.505	1703.753	444.504	587.318	193.902	165.656
% difference	55.51		3.45		-2.05		-32.13		14.57	
Standard Deviation	68.30	45.56	12.134	11.923	40.860	41.277	21.083	24.235	13.925	12.871
% difference	33.30		1.74		-1.02		-14.95		7.57	
	Regression Statistics									
Equation of Regression Line	Y=0.53X + 39.23		Y=0.83X + 6.85		Y=0.972X + 3.04		Y=1.092X – 11.316		Y=0.839X + 4.020	
Correlation Coefficient	0.80		0.850		0.960		0.950		0.910	
Coefficient of Determination	0.64		0.719		0.925		0.902		0.831	
Coefficient of Efficiency	-1.18		0.656		0.924		0.855		0.648	
Coefficient of Agreement	0.88		0.915		0.980		0.974		0.952	

Table 3 : pH Statistics

	DDS		HYDROLAB		OTT		PRODESIGN		YSI	
	Regens	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**
Sample Size	42		86		126		100		67	
	Conservation Statistic									
Mean	7.573	7.442	8.203	8.119	-	-	7.882	7.858	8.084	8.018
% difference	1.73		1.02		-		0.30		0.81	
Variance	0.120	0.757	0.383	0.360	-	-	0.114	0.184	0.049	0.219
% difference	-530.28		6.16		-		-61.64		-347.68	
Standard Deviation	0.347	0.870	0.619	0.600	-	-	0.338	0.429	0.221	0.468
% difference	-151.05		3.13		-		-27.14		-111.58	
	Regression Statistics									
Equation of Regression Line	Y=2.01X – 7.75		Y=0.78X + 1.71		-		Y=0.721X + 2.173		Y=0.049X + 7.632	
Correlation Coefficient	0.800		0.810		-		0.570		0.020	
Coefficient of Determination	0.640		0.650		-		0.322		0.0006	
Coefficient of Efficiency	0.460		0.579		-		0.271		-0.224	
Coefficient of Agreement	0.880		0.886		-		0.685		0.024	

Table 4 : Temperature Statistics

	DDS		HYDROLAB		OTT		PRODESIGN		YSI	
	Regens	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**
Sample Size	42		86		126		100		67	
	Conservation Statistic									
Mean	-	-	19.155	19.758	19.028	19.956	19.455	19.899	18.908	18.584
% difference	-		-3.15		-4.88		-2.28		1.71	
Variance	-	-	16.090	19.628	9.733	11.538	16.248	17.289	14.405	26.182
% difference	-		-21.99		-18.54		-6.40		-81.75	
Standard Deviation	-	-	4.011	4.430	3.120	3.397	4.031	4.158	3.795	5.117
% difference	-		-10.45		-8.88		-3.15		-34.82	
	Regression Statistics									
Equation of Regression Line	-		Y=0.97X + 1.27		Y=0.9X + 2.82		Y=0.968X + 1.073		Y=0.832X + 2.856	
Correlation Coefficient	-		0.870		0.830		0.940		0.620	
Coefficient of Determination	-		0.764		0.684		0.880		0.381	
Coefficient of Efficiency	-		0.744		0.601		0.868		0.361	
Coefficient of Agreement	-		0.929		0.899		0.967		0.742	

Summary of costs

The capital and operating costs of the sites are listed in **Tables 5(a)** to **(d)**. The operating costs are site specific and the capital costs are in 1999 costs and should only be considered to be indicative.

Table 5(a) : Capital Costs of probes in 1999 prices

Supplier	Instrumentation	Cost (R)
Prodesign (Pty) Ltd	Greenspan CTDP 300	24 6414,00
	Multi-Functional Probe, (EC, pH, temperature, depth)	
	Vented cable, 30 m	1 232,00
	MA100 Interface	5 867,00
	Gcom "wasp"	2 187,00
	Equipment Enclosure	600,00
	Solar panels, frame and regulator	2 669,00
	102AH battery	499,00
	Total	37 695,00
Groundwater Systems CC	Hydrolab Minisonde	34 220,00
	Multi-functional probe (EC, pH temperature, depth)	-
	Data Logger	-
	Battery Pack	-
	Vented cable, 15 m	8 700,00
	Total	42 920,00
NB : Minisonde probe now replaced by "Quanta" probe		
Monitoring and Control Laboratories (Pty) Ltd (YSI)	YSI 600 XL Sonde	34 178,00
	Multi-functional probe (EC, pH, temperature, depth)	
	Total	34 178,00
Additional features, integral battery chambers, data logger etc. Prices available on request		
OTT Southern Africa (Pty) Ltd	Single function probe (EC and temperature)	4 500,00
	pH	No quote
	Water depth	11 425,00
	Data Logger	13 995,00
	Power Supply	1 610,00
	Total	31 530,00

Table 5(b) : Costs of the communication equipment

Supplier	Instrumentation	Cost (R)
Ecosat (Pty) Ltd	Leocell RDSU Satellite communicator	12 940,00
GSM Cellular Communications	Cellphone, Sim Card, modem, etc.	14 200,00

Table 5(c) : Costs for the master control station

Supplier	Specification	Cost (R)
Average Supplier Cost	Computer: 200 mHz Pentium, 64 MB Ram, 40 GB HDD, Read-write CD Rom, 3.5" stiffy drive, keyboard, mouse, ports for communication system, etc.	12 511,00
	Uninterrupted Power Supply	1 500,00
	Communication equipment : aerials, modems, disks, etc.	750,00
	Software : Windows NT4.0 Communication Software	8 700,00
	Total	23 461,00

Table 5(d) : Summary of operating costs

Site	Description of item included in cost	Average Monthly cost (R/month)
Prodesign at Wolwekrans weir – B1H005	8 visits to site at 287 km/trip at R2,50/km Cell phone calls to download data for an average of 40 minutes per call plus rental	R478 R252
Total		**R730**
Hydrolab/Ecosat at the Steenkoopspruit – B1H021	10 visits to site at 320 km/trip at R2,50/km Land line calls to download data for an average of 20 minutes per call plus rental Leosat fees	R667 R8 R217
Total		**R892**
YSI/Ecosat at Aangewys – B1H017	10 visits to site at 350 km/trip at R2,50/km Land line calls to download data for an average of 20 minutes per call plus rental Leosat fees	R729 R6,93 R217
Total		**R952,93**
DDS at B1H020	8 visits to site at 242 km/trip at R2,50/km Cell phone calls to download data for an average of 15 minutes per call plus rental	R403 R159
Total		**R562**
OTT at B1H002	6 visits to site at 262 km/trip at R2,50/km Cell phone calls to download data at an average 18 minutes/call. Rental costs carried by DWAF	R328 R108
Total		**R436**

Conclusions

The following conclusions can be made as a result of this study:

- If suitably maintained and powered, the instrumentation was generally found to perform well when compared to the base data collected by Regen Waters. The depth and EC readings compared particularly well for a number of the suppliers. There was generally more scatter for the pH and temperature readings when compared to the base data. The pH probes in particular required more attention in terms of maintenance than the other probes.

- A regular (about 2 weekly interval) manual measurement of gauge plates, EC and pH is required to provide a check on the instrument readings for calibration purposes. On average a monthly calibration and maintenance visit was found to be necessary.
- Vandalism and theft remain a major stumbling block in the use of continuous instrumentation and real time communication systems. Solar panels are the most sought after item. The YSI installation at B1H012, which did not have any communication system in place was not vandalised during its three months of operation.
- Lightning protection should be provided.
- The use of batteries as the sole power source was problematic. The batteries used at Aangewys did not last as long as expected. The suppliers were not always able to reach the site to change the batteries as often as required.
- Attention to detail in terms of the installation of equipment is important. This ranges from electrical connection to housing the cables in suitable conduits to limit vandalism. The provision of lightning protection falls in this category.
- At stages during the project, the project team got the impression in the case of ECOSAT, that the communication software was still being developed and had not been thoroughly tested. Only towards the end of the project did matters improve.
- Based on the results of this project, the Orbcom Satellite communication system will not be suitable for a real-time system for controlled release. The available data was often 3 hours to 2 days behind.
- Cell phone networks appeared to be the more favourable communication system. These systems were down at times but generally for less than a day. About 90% availability was achieved with the cell phone communication system.
- Besides DDS, the other suppliers are purely agents for the probes. Only limited repairs could be carried out locally. The probes having to be returned to the country of origin. The turnaround time varied between 4 to 6 weeks in the case of the Prodesign Greenspan probe. Although expensive, consideration should be given to a backup probe.

Recommendations

The following recommendations can be made as a results of this study :-

- If continuous monitoring is to remain a requirement of the regulatory authorities, consideration will have to be given to innovative ways of making continuous instrumentation safe in the field. Particularly if real time communication systems are to be installed with the associated power requirements.
- Other sources of power should be considered such as gas driven turbines, which are less conspicuous than the solar panels. These types of power sources can be housed within the instrumentation enclosure.
- Unfortunately the project budget and practical considerations prevented the investigation of a radio communication system. This means of communication should be considered if continuous real time monitoring is to be installed. Especially if an existing repeater station network is available on a mine or power station complex.
- Consideration should be given to a workshop with the mines and power stations to present the findings of this research.

Acknowledgements

This report emanated from a project funded by the Water Research Commission, mining industry and Eskom Power Stations entitled "Field Testing and Evaluation of Real-Time Continuous Flow and Water Quality Monitoring Instrumentation".

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

Mr HM du Plessis	Water Research Commission
Mr JB Conlin,	Eskom
Mr KL Gush,	CSIR, Mikomtek
Mr DE Simpson,	Umgeni Water
Mr R Schwab,	Department of Water Affairs and Forestry
Mr C Wendel,	Avgold
Dr J Kilani	Chamber of Mines
Mr SC Matseba	Department of Water Affairs and Forestry
Mr K Roux	CSIR, Mikomtek
Dr ML van der Walt,	Committee Secretary

The project team would like to thank the Steering Committee for its support and input to the project. In addition, the financial support and comments from the coal mines and power stations in the Witbank and Middelburg Dam catchments is gratefully acknowledged, in particular, the Kriel and Kleinkopje Collieries for their assistance in installing equipment.

The co-operation and participation of the instrumentation suppliers DDS, Prodesign, Ecosat, YSI, OTT and Hydrolab are gratefully acknowledged. The project team hopes that these suppliers gain some commercial returns for their efforts during the project.

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FIELD TESTING OF REAL-TIME CONTINUOUS FLOW AND WATER QUALITY MONITORING INSTRUMENTATION

1 INTRODUCTION

1.1 Background

The need for monitoring of flow and water quality parameters in open channel flow systems on a continuous basis is now required with a greater frequency than in the past. The introduction of the Reserve in the National Water Act (1998) will require continuous monitoring to operate regulated water resource systems in accordance with the Instream Flow Requirements (IFR). Real time monitoring would also be useful in policing and managing the flood releases often specified as part of the IFR. Pressure is also being brought to bear on the mining and industrial sectors as well as local authorities to monitor waste discharges on a continuous basis. These monitoring requirements are often specified as permit conditions.

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1.2 Objectives

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The approach to the third phase was to collect a base data set against which to compare the field measurements made by the instrumentation. This base data set was collected manually by Regen Waters Laboratory in Witbank. The parameters measured were pH, electrical conductivity, temperature and flow depth. These are the basic variables that are needed to manage the controlled release scheme and are associated with mining related pollutants.

2 ASSESSMENT OF AVAILABLE INFORMATION

2.1 Introduction

The review of the available literature for this project included :-

- Approaching the Department of Water Affairs and Forestry to determine the types of continuous instrumentation and real time communication systems used and the problems experienced with the systems;
- The assessment of the requirements for installation of equipment;
- An assessment of the available communication systems

An extensive literature covering most aspects of water monitoring exists. However details on continuous monitoring and information on continuous monitoring in the mine setting tend to be limited (for example Ward et al, 1990 and the Minerals Council of Australia (1997)) In South Africa the general approach has also been taken in the Department of Water Affairs Best Practice Guidelines for Water Monitoring. In an overview of Mine Water Management Practices in South Africa, Pulles et al (1995) recorded the lack of continuous monitoring in the mining industry, and where it occurs such monitoring has focused upon internal process water rather than natural stream courses. A concise coverage of continuous monitoring of acid rock drainage was produced by Fytas et al (1992). This study indicates what should be monitored, why continuous monitoring should be considered, equipment type and gives a monitoring strategy.

No publications were found on more specific requirements of instrumentation, installation and transmission of data.

2.2 Meetings with the Department of Water Affairs and Forestry

A series of meetings were held with the various Directorates of the Department of Water Affairs and Forestry. The Directorates included the hydrology section in the Mpumulanga Regional Office and the Department's head office in Pretoria. The meeting resulted in the following conclusions :-

- the flow measuring section has more or less standardised on the OTT equipment with cell phone communication. The OTT equipment consists of a logger and a separate depth probe or sensor;
- the water quality section prefers the more portable Sonde type equipment of YSI. This type of equipment has all the sensors and logging housed in a single compact and fully submersible unit. This type of equipment can be used to monitor specific discharges or rivers for short periods and can be easily moved to another site. There is also a wide selection of water quality parameters that can be monitored with this type of probe.
- Real time monitoring is undertaken within the Department for flood warning and management. A satellite communication system is used. The satellite system is the Meteosat system run by EUMETSAT. The use of the satellite time is free of charge as long as the data is available for use by the World Meteorological Organisation. The Department has a fixed time slot on the satellite. A station to communicate successfully with the satellite would cost about R100000. The expense is due to the accurate timing equipment required to make use of the fixed time slot. There is a delay of up to 1 hour before the data arrives at the Deparment's work stations.

The main problems the Department has found in operating the systems are :-

- theft and vandalism;
- electricity supply;
- regular maintenance is required.

2.3 Installation requirements

There are a number of guideline documents on the position where the flow depth has to be measured at a weir. The position varies according to the type of weir used for the flow measurement. The general requirement is the flow depth has to be measured in the pool beyond the drawdown curve at the weir.

This is in contrast to the desirable position for the measurement of the water quality parameters, which is generally in the flowing water at the low point in the weir. The possible reasons for this are:-

- the higher velocities at the low point of the weir prevent excessive fouling of the probes;
- the readings would be more representative of the water quality of the water flowing passed the point than readings taken in the pool. This would be particularly true of low flow conditions when stagnant areas could develop in the pool.

These requirements present problems in installing equipment. The use of the all-in-one Sonde type equipment would therefore be difficult. A separate stand alone probe would possibly have to be used for the depth measurement. The logging systems with the separate probes and loggers are possibly more suited to this type of installation.

The need to install the water quality probes in mid stream also poses installation problems. The instrumentation should be easily accessible to allow for removal of the probes for maintenance, calibration and repairs. This can involve extensive and expensive pipe work.

2.4 Available communication systems

The available communication systems include satellite, cell phones, land-lines and radio. Mikomtek, the communication section of the CSIR, was approached to assess the types of communication systems that are available. A copy of their report is included in Appendix A.

The report discusses the available technologies, evaluation of the suitability of the available technologies for a controlled release scheme and makes recommendations on the most suitable communication system.

The technologies discussed included:

- Fixed line/land line systems
- Cellular systems
- Digital Enhanced Cordless Telecommunication (DECT)
- Radio based Systems
- Satellite Systems

The guidelines costs provided in the report are summarised in **Table 2.4(a)** together with the advantages and disadvantages of the different systems. The costs are given in 1999 costs and must be considered as a guideline only.

The other issues discussed in the report include:

- Licensing requirements of the different systems
- Installation issues
- Sourcing, suppliers and training.

The overall recommendations were that a SCADA based radio or cell phone system would be best suited for a controlled release scheme in the Witbank area.

Table 2.4(a) : Summary of Costs and comments on communication systems from CSIR Report

System	Costs	Comments
Fixed line telephone	Capital R3000 – R5000/site Usage costs at Standard Telkom rates	• Relocation of equipment is difficult • Theft of copper wire • Telephone infrastructure needs to be in place • Communication not terrain dependent
Cellular	Capital cost R5000 – R10 000 Usage costs vary according to operator and airtime packages Typically R0,50 to R4/minute	• Portable allowing easy relocation of equipment • Coverage not always available
DECT	No costs provided	• Numerous base stations required in hilly terrain • Relocation easy if the radio equipment is within range of DECT base station • DECT base station has to be connected to a Telkom exchange
Radio	R6000/station R20000/repeater station Usage costs are license fee of about R50/annum	• Initial costs high but running costs lower than other systems • Numerous repeaters needed in hilly terrain • Power requirement high – need solar panels • License required
Satellite System	**Little Leo** R30000/station Licensing requirements not available **Geo stationing (VSAT)** R30000/station Licensing costs = R4000/month **Big Leo Satellite** Capital R13000 to R18000/station Usage = R12 to E36/minute **Meteosat** Capital Costs R60000 – R80000 Usage = 0	• Power requirements high – solar panels • Accessible in hilly terrain and forests • Some time delay in receiving data depending on system.

3 METHODOLOGY

3.1 Phase 1 : Identification of Suppliers, instrumentation and communication systems

3.1.1 Recruitment of Suppliers

The mining industry had already invested in continuous monitoring equipment with mixed results with regard to the accuracy and reliability of the instrumentation and service from the supplier. The investment in monitoring equipment and weir construction was substantial. There were a number of manufacturers and suppliers offering their equipment to the mining industry. The mines considered that field trials of the available instrumentation were necessary in order that informed buying decisions could be made in the future.

Possible suppliers of water quality instrumentation were discussed with the Department of Water Affairs and Forestry and the collieries. A list of suppliers was compiled and each was sent a guideline specification of the instrumentation and communication equipment required for the investigation.

In brief, the guideline specification detailed:

- The water quality and flow variables to be measured; conductivity (EC), pH, temperature and depth
- Required accuracy of measurement variables
- Real-time system requirements
- Data logging and communication methods
- Scanning intervals for water quality measurements
- Compatibility criteria for on-site and central control stations
- Remote re-programming of data format
- Potential expansion of site networks.

In reply, the Suppliers were asked to include full information on:

- Type of water quality instrumentation proposed e.g. separate or multi probes
- Hardware and Software available
- Preferred data communication system
- Transmission delays
- Operating and maintenance requirements
- On-site equipment installation requirements
- Response time to breakdowns
- Instrumentation Security
- Country of instrumentation manufacture
- Availability of spares
- Detailed user lists

Fundamental to the specification was a request for water quality instrumentation costs and an estimate of data transmission costs. The suppliers were requested to submit proposals before 25 February 1998.

3.1.2 Response from Suppliers

Suppliers who responded to the guideline specification were:

- Monitoring and Control Laboratories (Pty) Ltd (YSI)
- Digital Data Systems (Pty)Ltd (DDS)
- Prodesign (Pty) Ltd (Prodesign)
- OTT Southern Africa (Pty) Ltd (OTT)
- N & Z Instrumentation (Pty) Ltd (N & Z)
- Bateman Process Instrumentation Ltd (Bateman)
- Ecosat (Pty) Ltd (Ecosat)
- Groundwater Systems cc (Hydrolab)

Discussions were held individually and collectively with the suppliers to explain in more detail the purpose of the investigation. The river weir sites in the catchment were located in remote areas and the provision of electrical power and telephone links was not always possible. The water quality instrumentation and the communication equipment, therefore, required to be totally reliant on batteries and solar power.

N & Z Instrumentation withdrew from the project due to financial considerations and Bateman Process Instrumentation also withdrew after a company decision to concentrate on core business.

The project advisory team decided to issue a formal tender to the remaining suppliers.

3.1.3 Tender Adjudication

The tenders received from the suppliers were indicative of the cost to equip a weir site with water monitoring instrumentation and real-time communication equipment. The mine representatives on the Managed Release Committee were particularly insistent that, before any decision could be made to install additional monitoring equipment in their sub-catchments, field testing must be undertaken.

A full hydrological year, that was, from October 1998 to September 1999 was proposed to study the performance of each Tenderer's equipment during the seasonal variations of river quality and flow.

The cost of the tenderers' proposals to provide instrumentation exceeded the planned budget for the field-testing trials. The suppliers were asked to consider supplying the equipment free-of-charge for the period of the testing. The costs as originally supplied are listed in **Section 5** of this report.

The suppliers agreed on condition that:

- Cellular phone and satellite communication costs would be paid by the project
- All civil work necessary to install the equipment would be arranged by the project
- Data emanating from the project would be made available, without reservation, to all the participants in the project
- The water quality instrumentation and the communication equipment would be insured by the project

These conditions were agreed to and formal agreements were signed.

3.2 Phase 2 : Identification of sites and installation of equipment

3.2.1 Location of Sites

The location of sites are shown on **Figure 3.2.1**. The sites allocated to the suppliers are listed in **Table 3.2.1(a)**.

Table 3.2.1(a) : Sites allocated to suppliers

Supplier	DWAF No	Location	River
YSI/Ecosat	B1H017	Aangewys	Steenkoolspruit
Hydrolab/Ecosat	B1H021	Steenkoolspruit	Steenkoolspruit
Prodesign	B1H005	Wolwekrans	Olifants
DDS	B1H020	Koringspruit	Koringspruit
OTT	B1H002	Spookspruit	Spookspruit
YSI	B1H012	Middelburg Weir	Klein Olifants

The sites were at existing weirs where structures were available to house equipment. DDS (B1H020) and OTT (B1H002) already had operational systems at Koringspruit and Spookspruit. DWAF agreed to finance the installation of a conductivity probe at Spookspruit. Ecosat were required to install at Aangewys (B1H017) as the cell phone signal at the site was very weak. The balance of the sites were allocated at random.

At Aangewys (B1H017) and Steelkoolspruit (B1H021) the water quality instrumentation suppliers, YSI and Hydrolab, combined with the satellite communications equipment suppliers, Ecosat, to provide an operating system. The remaining suppliers, Prodesign, DDS and OTT made use of cellular telephone communications.

Each site was inspected by the suppliers, DWAF and the Project Advisory Team to approve the additional civil structures required to mount the equipment. Kriel Colliery and Kleinkopje Colliery agreed to provide the additional structures and labour necessary at Aangewys (B1H017) and Wolwekrans (B1H005), respectively.

In collaboration with WMB, YSI installed an additional probe at Middelburg Weir (B1H012). This installation did not include a communication system.

3.2.2 Description of Sites

(a) DWAF Weir B1H017 - Aangewys

Refer to **Figure 3.2.2(a)**.

The weir is situated in the Steenkoolspruit, several kilometres upstream of the opencast workings of Kriel Colliery. The weir lies in a deep cleft in the river. The northern side of the weir was unapproachable due to a steep hillside and the southern side only accessible through a marsh which could become impassable in the rainfall season. The steep hillside and the opencast spoils dumps made the reception and transmission of signals very unreliable and the most feasible method of communication was by satellite.

DWAF depth-instrumentation was housed in a concrete pillbox erected near the weir. Additional piping was erected by Kriel Colliery to accommodate the water quality monitoring instrumentation.

The weir was remote and there was no possibility of installing electrical power or telephone links.

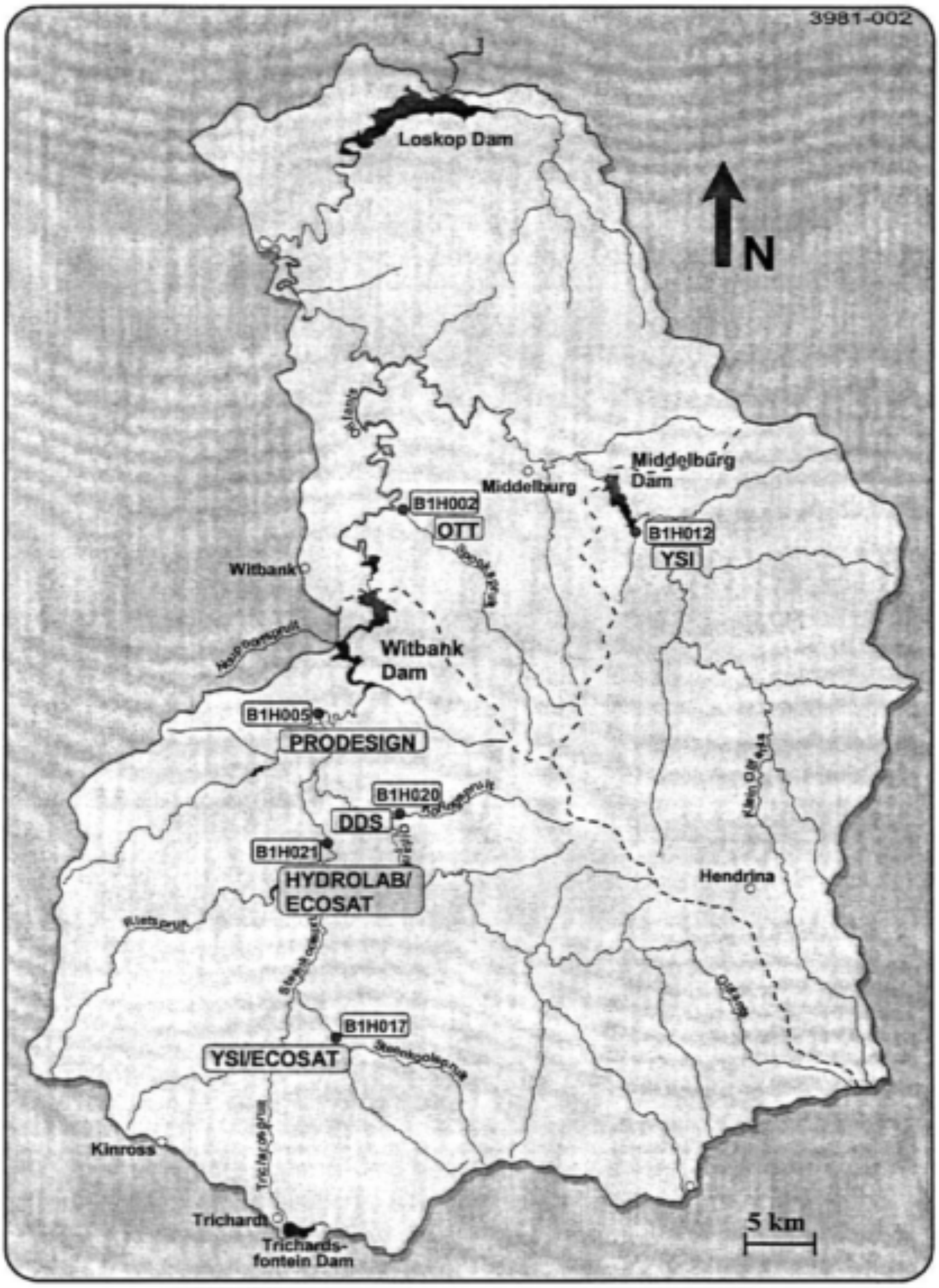

Figure 3.2.1 : Location of instrumentation monitoring points

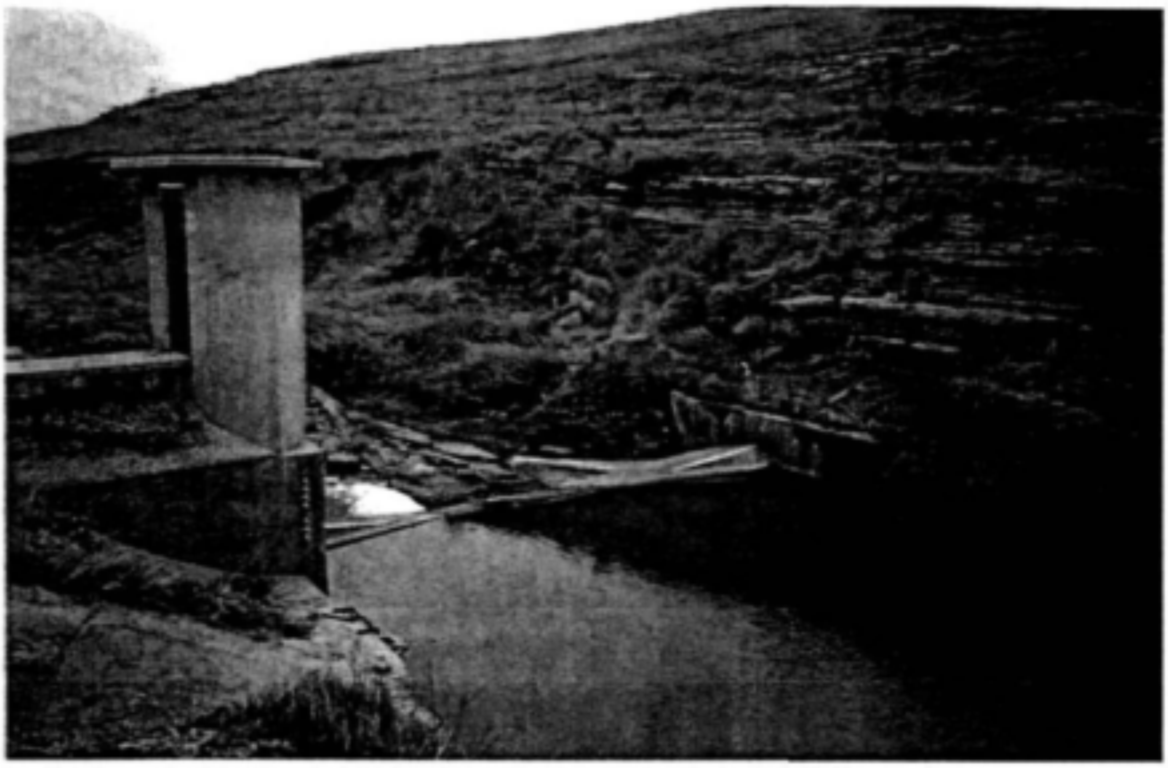

Figure 3.2.2(a) : Aangewys – B1H017 (Catchment Area = 387 km^2)

(b) DWAF Weir B1H021 - Steenkoolspruit

Refer to **Figure 3.2.2(b)**.

The weir is located downstream of Kriel Town near the point where the R547 road bridge crosses the Steenkoolspruit. The Department of Water Affairs and Forestry had erected a concrete pillbox above the level of the weir to accommodate depth-measuring instrumentation. The weir was accessible from the eastern side of the river. No electrical power or telephone links were available.

(c) DWAF Weir B1H005 - Wolwekrans

Refer to **Figure 3.2.2(c)**.

The weir is situated in a wide bend in the Olifants River downstream of Kleinkopje Colliery. Water is pumped from behind the weir to the Colliery. The DWAF instrumentation was housed in the weir superstructure. Electrical power was not available to drive the water quality instrumentation at the start of the field testing project but later in the project, due to vandalism, mains power was installed to obviate the need for solar panels. Telephone links were not available at the site.

Kleinkopje Colliery installed pipes to accommodate the water quality instrumentation.

(d) DWAF Weir B1H020 – Koringspruit

Refer to **Figure 3.2.2(d)**

The weir is located in the Koringspruit near to the confluence with the Olifants River. Electrical power or telephone links were not available.

DDS had already installed water flow instrumentation at the site. A cell phone communication system was installed at the site.

(e) DWAF Weir B1H002 - Spookspruit

Refer to **Figure 3.2.2(e)**.

The weir is positioned upstream of the R555 road bridge which crosses the Spookspruit. The stream discharges into the Olifants River downstream of Witbank Dam The DWAF instrumentation was housed in a concrete pillbox. OTT instrumentation, consisting of depth and temperature probes, was already installed at the weir. A conductivity probe was installed at the weir by DWAF.

(f) DWAF Weir B1H012 – Middelburg Weir

Refer to **Figure 3.2.2(f)**.

YSI installed instrumentation at the Middelburg Weir Site. No communication equipment was installed and data from the water quality probe was downloaded manually for inclusion in the project. A pipe with a locking cap was manufactured to house the Sonde YSI probe (See **Figure 3.2.2(f)**). The pipe was attached to the flank wall of the weir and was submerged in the water.

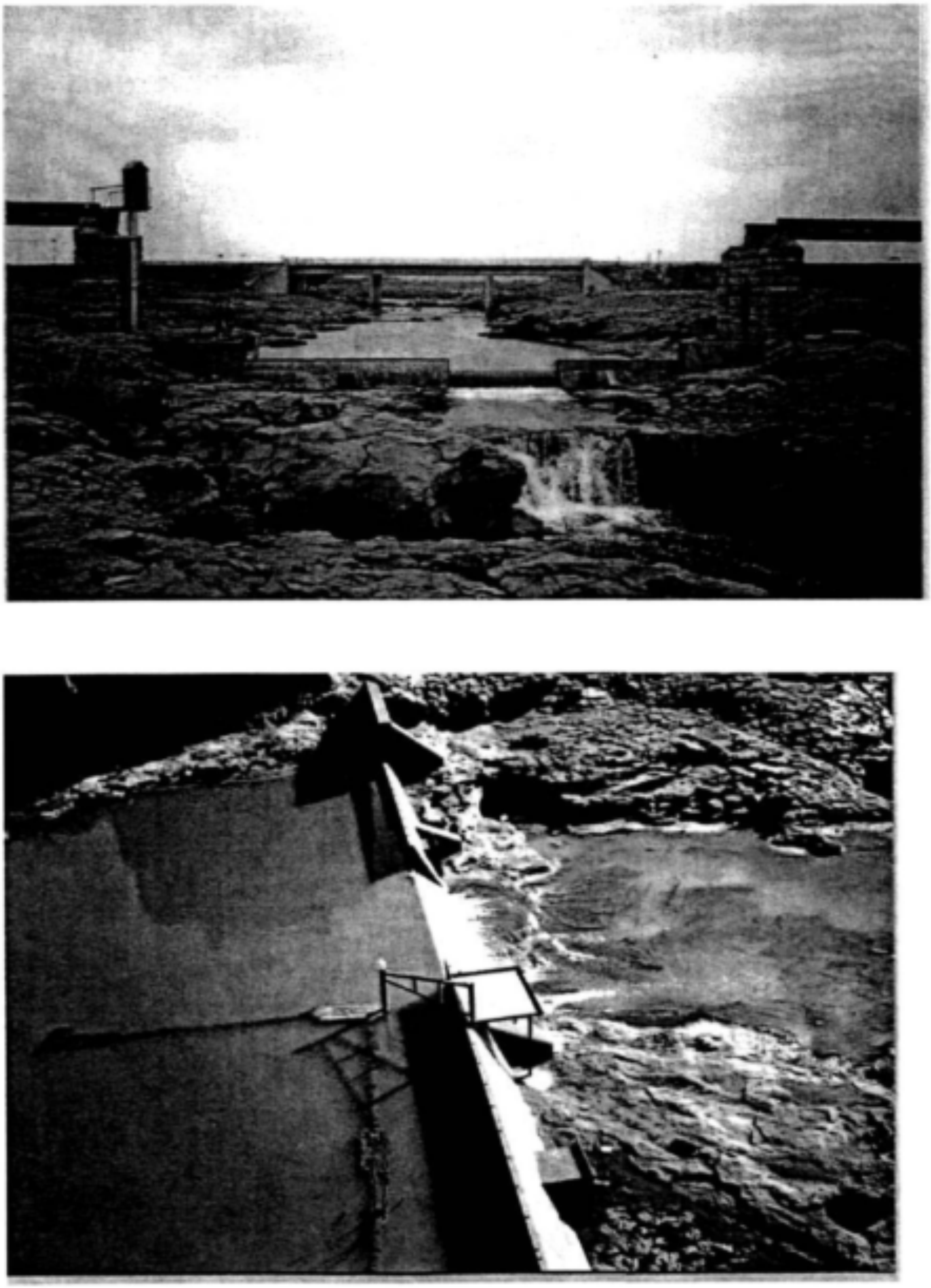

Figure 3.2.2(b) : Steenkoolspruit – B1H021 (Catchment Area = 1356 km^2)

Figure 3.2.2(c) : Wolwekrans – B1H005 (Catchment Area = 3256 km^2)

Figure 3.2.2(d) : Koringspruit – B1H020 (Catchment Area = 133 km²)

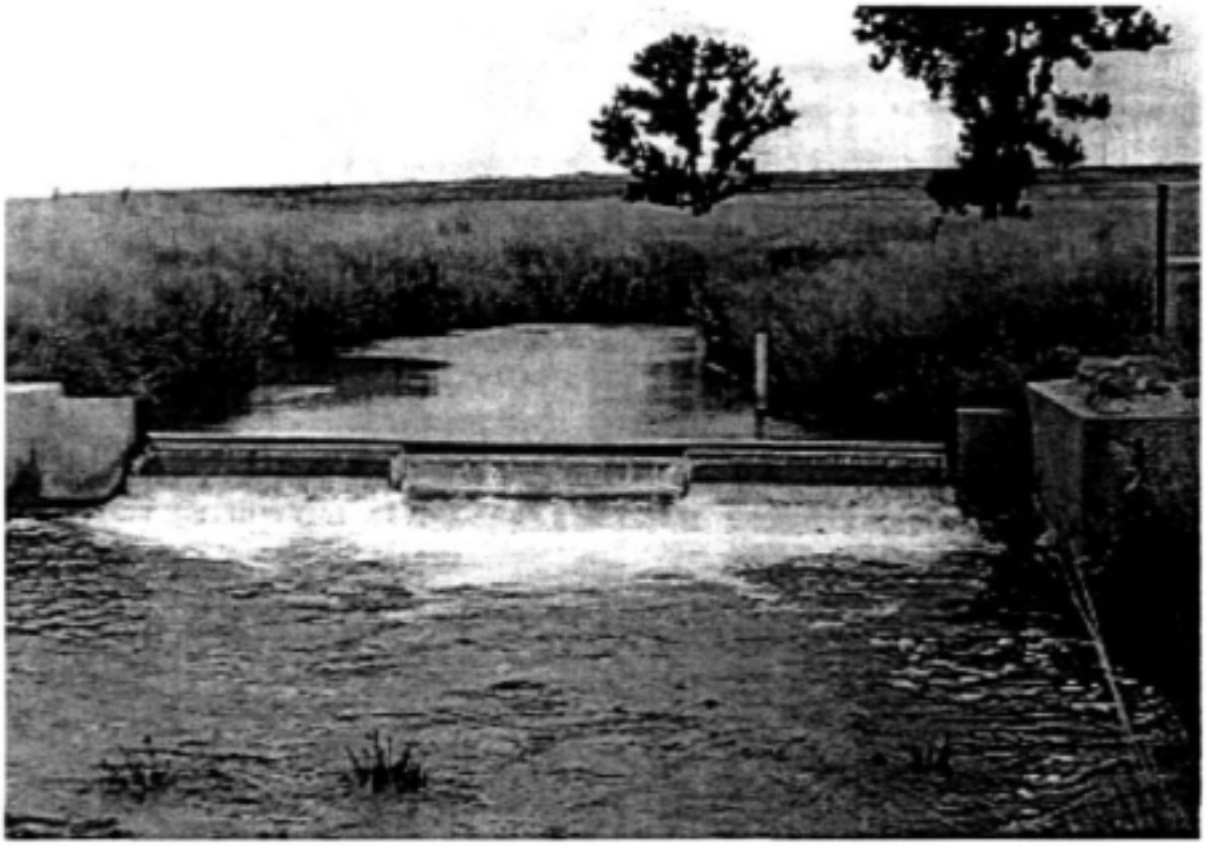

Figure 3.2.2(e) : Spookspruit – B1H002 (Catchment Area = 252 km²)

Figure 3.2.2(f) : Middelburg Weir – B1H012 (Catchment Area = 1053 km^2)

3.2.3 Control Station

A control station was established at the offices of WMB in Midrand, Johannesburg. Computers were installed by WMB and the appropriate modems supplied by the instrumentation and communication suppliers.

3.3 Phase 3 : Field Testing of Instrumentation

3.3.1 Test Procedures

The variables measured were pH, electrical conductivity (EC), temperature (°C) and the depth (metres) of the river flow. The following aspects of the instrumentation were tested:

- The accuracy of the data collected. The accuracy was assessed by the collection of manual grab samples at each test site for analysis by Regen Waters Laboratory in Witbank. The temperature and pH were measured in the field as close as possible to the probe.
- The reliability of the equipment. A record was kept of the down-time of the monitoring systems. The record also recorded the cause of the fault and the frequency of occurrence.
- The performance of the supplier in responding to instrument failures.
- The frequency that probes had to be re-calibrated
- A record of communication costs accrued between the test site and the control centre.
- Useful information was collected to produce guidelines for the installation and operation of monitoring equipment.

The data was downloaded in a weekly basis and all the results were sent to the suppliers. Each supplier was notified if there were any problems with the water quality data or communications network.

3.3.2 Testing of samples collected manually

Regen Waters Laboratory is an accredited chemical analysis laboratory located in Witbank, Mpumalanga. The laboratory was already under contract to the Controlled Release Steering Committee to take and analyse water samples when the project to field-test water quality instrumentation was initiated.

The inclusion of Regen Waters in the project was discussed with the instrumentation suppliers and all agreed to accept the analyses performed by the Laboratory as the control standard for the field-testing project.

In the event of a dispute between the suppliers and Regen Waters, arbitration would be referred to the National Standards of the CSIR.

3.3.3 Communication Systems

WMB commissioned Mikomtek, a division of the CSIR, to prepare a report on data communication systems available in South Africa. The report is comprehensive and discusses in detail the following aspects of communication systems:

- Communication Technologies
- System Costs
- System Suppliers
- Recommendations

Mikomtek recommends three modes of communication suitable for the water quality instrumentation investigation.

The Mikomtek report appears as Appendix A in this Document.

Satellite Communication

The Orbcomm Little Leo satellite system, supplied by Ecosat (Pty) Ltd, operates in South Africa and was chosen by the project team as the solution to the communication problem at the Aangewys site on the Steenkoolspruit River. The location of the site in a deep cleft in the surrounding terrain precluded the installation of cellular and radio communications. Satellite communication was also installed at the Steenkoolspruit site downstream of Kriel Town.

GSM Cellular Networks

The suppliers of the water quality instrumentation at Wolwekrans, Koringspruit and Spookspruit used cellular network communication systems.

Radio Communication Technology

Radio Technology was investigated by the project team as a possible link between the upper Olifants River Catchment and the data control centre at WMB offices in Midrand. Unfortunately, budgetary constraints and the possibility of vandalism to the repeater stations ruled out the testing of a long range radio communications system.

3.3.4 Instrumentation

The selection of the weir sites to accommodate the experimental water quality instrumentation was based upon the need to test the monitoring equipment on different levels of salinity, acidity, alkalinity and water depth. Temperature was almost constant between the sites and there was sufficient variation during a 24 hour period to test the temperature probes. The daily or weekly manual samples taken by Regen Waters provided comparative information on the performance of the test probes.

The placement of the probes in the river was determined by the topography of the weir. The probes were installed in or as near as possible to the natural flow of the river. At Wolwekrans weir, during April 2000 a severe 5 meter high flood swept away the pipes carrying the instrument cables. After the flood subsided, the monitoring of the pipes was strengthened and the assembly re-installed by Kleinkopje Colliery. The swinging arm assembly at Steenkoolspruit weir was changed to a rigid construction bolted to the weir.

3.3.5 Security of Installations

With the exception of the Spookspruit installation, all the other chosen sites were subject to repeated theft and vandalism. Solar panels, batteries, cabling and communication equipment were stolen from the sites resulting in excessive insurance claims. Eventually, it was decided to re-install the instrumentation from Aangewys, Steenkoolspruit and Koringspruit at Wolwekrans Weir to reduce the risk of vandalism. Even that apparently secure site was vandalised towards the end of the project.

Spookspruit weir, although easily visible from the main road, was situated near a farmhouse with large dogs having free range of the area. The close proximity of the farmhouse and the dogs obviously reduced the chance of vandalism.

With hindsight, the decision to test the instrumentation at varying water quality sites was not the wisest and one site should have been chosen which could have been guarded 24 hours per day.

4 RESULTS OF FIELD TESTING

4.1 Introduction

The results of the field testing are discussed for each set of instrumentation at each of the sites. The results discussed include the installation, commissioning and general problems that may have occurred at each site. The readings taken by the instrumentation are compared to the base data set collected manually by Regen Waters. The data sets are compared using a number of statistics as well as graphs. Finally a Table is presented summarising the statistics for the different instruments and sites.

The base data set was used as a means of assessing the performance of the continuous monitoring equipment. In determining the comparative statistics, the base data set was assumed to be correct. Errors could have been made in collecting the data manually, particular in taking the EC, pH and temperature readings close to the probe sensor positions as the water level did not always allow the required access. Thos should be kept in mind when viewing the statistics. Nonetheless, the base data set does provide a means of assessing the perf0ormance of the instrumentation.

The installation and commissioning of the water quality instrumentation and communication systems took approximately two months. Suppliers such as OTT and DDS had the obvious advantage of having systems already installed at the start of the project whereas the other suppliers had to cope with the design and erection of mounting structures, the problems of installation and comprehensive calibration and re-calibration procedures.

4.2 Description of Comparative Statistics

4.2.1 Definition of Statistics

Because visual comparison of the results could lead to subjectivity, the use of statistical measures were used to compare the goodness of fit of the probes readings with the manually collected base data set from Regen Waters. The general aims of the statistical analysis were to assess the following:

- If the probes values correspond as closely as possible to 1:1 relationship with the base data set.
- If the mean, variance and deviation of the probe and that of the base data were conserved.

A wide range of statistics were used to test the "goodness of fit". The statistics fall into two major categories, viz:

- conservation statistics
- regression statistics

For the various equations that follow, the following variables were used:

x_I	=	Base data set
y_I	=	Probe results
□	=	estimated value for the regression line of y on x
s	=	standard deviation
n	=	sample size

4.2.1.1 Conservation Statistics

Conservation of the mean

The mean is a measure of the central tendency of the data. It is given by

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

The objective function regarding the mean is expressed as a percentage difference between the means of the probe and base data set, i.e.

$$100.\frac{(\bar{x} - \bar{y})}{\bar{x}}$$

For a good correlation the value has to be minimised to zero.

Variance

Variance (V) is defined as the measure of dispersion relative to the scatter of the measured values about the mean. It is defined by the following equation:

$$V_x^2 = \frac{1}{n-1}\sum_{i=1}^{n} (x_i - \bar{x})^2$$

It is measured in squared units. For a good correlation the percentage difference between the probe and base data set variances should be minimised, i.e.

$$100.\frac{(V_x^2 - V_y^2)}{V_x^2}$$

Standard deviation

This is the measure of dispersion around the mean in original units, and is given by:

$$s_x = \sqrt{V_x}$$

The percentage difference of s_x for the probe and base data should be kept to a minimum for a good correlation, *viz.*

$$100.\frac{(s_x - s_y)}{s_x}$$

Coefficient of variation

It is the measure of relative dispersion and is independent of the units of measurement. It is given by the following equation:

$$z_x = \frac{s_x}{\bar{x}}$$

The objective function is to minimise the percentage difference between the coefficients of variation for both the probe and base values.

$$100.\frac{(z_x - z_y)}{z_x}$$

4.2.1.2 Regression Statistics

In the case of a simple linear regression analysis, two variables are of interest, namely the probe and base data sets. Linear regression by the least squares technique can be used to determine if the various values are comparable, i.e. follow a 1:1 ratio.

Correlation Coefficient

The correlation coefficient (r) is an index of the degree of association between the sets of data, i.e. the measure of the strength of the linear relationship between variables. The correlation coefficient is given by:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

The coefficient should be as close to unity for a good correlation.

Slope

The slope of the least-squares regression line represents the line denoting the change of the probe values relative to the change of the base data set values trends. The slope, b, is given by:

$$b = \frac{n\sum_{i=1}^{n}x_i y_i - \sum_{i=1}^{n}x_i\sum_{i=1}^{n}y_i}{n\sum_{i=1}^{n}x_i^2 - (\sum_{i=1}^{n}x_i)^2}$$

The aim is to obtain a slope as close as possible to 1 for a good correlation.

Y-intercept

The y-intercept is the point where the line crosses the y-axis and is defined by:

$$a = \frac{\sum_{i=1}^{n}y_i - b\sum_{i=1}^{n}x_i}{n}$$

A negative y-intercept is an indication of the probes values being less than the base data set for low magnitudes, whilst if it is positive it indicates that the probes values are greater than the base data set for the low magnitudes. The aim is to minimise the y-intercept to zero.

Coefficient of Determination

This coefficient is used for the measuring of the degree of association between the probe and base data values. The coefficient of determination is given by the following equation:

$$r^2 = \frac{\sum_{i=1}^{n}(y_i - \bar{y})^2 - \sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} = \frac{SSR}{SST}$$

A high r^2 value is indicative of a good degree of association. The r^2 value will always be less than 1 and greater than zero. Unity is indicative of a perfect correlation between the Regens and the probe values.

Coefficient of Efficiency

There may be a high degree of association with the probe and Regen values(i.e. high r^2), but the probe may be over- or underestimating systematically. It gives a good indication of the 1:1 fit between the probe and manual value. It is analogous to the coefficient of determination except that the manual value is substituted for the estimated probe value and is given by

$$E_e = \frac{\sum_{i=1}^{n}(y_i - \bar{y})^2 - \sum_{i=1}^{n}(y_i - x_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

The objective function is to maximise E_c to the value of r^2.

Coefficient of Agreement

$$A_i = 1 - \frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{\sum_{i=1}^{n}(|\hat{y}_i - \bar{y}| + |y_i - \bar{y}|)^2}$$

Reflects the degree to which probes values reflect the base data set.

Once again a perfect correlation is reflected by unity.

Conductivity depends on the water temperature, EC probes are generally temperature compensated for this reason. As can be seen for the Prodesign EC the values from the 19/03/1999 to the 28/06/1999 were not temperature compensated, when applying a the temperature compensation factor (**Table 4.2.2**) to these results it can be seen that they closely follow the base data set. It is important to note whether the probe is temperature compensated for measuring EC as results will be well below the actual readings.

4.2.2 Goodness of Fit Statistics for Base data set and Probe Values

The statistics were done on results obtained from the probe which had the closest associated time on the specific date the manual sample was taken. These associated results were then used for determining the goodness of fit statistics.

It must be noted that the sample size for each probe varies as it was sometimes impossible for Regen Waters to reach the site during flooding conditions. The sample size is also a direct result of when the probe was down and thus resulting in no value that corresponds to the base data on that day. The reasons for failure and the associated dates for the failures are discussed in **Section 4.4**.

4.3 YSI/Ecosat at Aangewys – B1H017

4.3.1 General Discussion on Performance

The weir site was located in a deep cleft in the surrounding terrain (see **Figure 3.2.2(a)**). The DWAF concrete pillbox contained two OTT depth measuring systems, one upstream of the weir and the other downstream. The YSI water quality probe was a multi-functional instrument which measured depth, electrical conductivity (EC), pH and temperature. The distance of the pillbox from the centre of the weir was approximately 6 metres but any structure which located the probe exactly in the centre of the main river flow would have been vulnerable to flood conditions. Engineers from Kriel Colliery decided to mount a vertical pipe 1 metre from the pillbox such that the probe was positioned as near as possible to the weir overflow. Regen Waters took manual samples near to the position of the YSI probe. No adverse effects to the mounting structure were observed during the floods of January 2000.

Communication difficulties between the YSI probe and the Leocell logging unit were experienced at this site. The communication protocol problems occurred despite testing in the laboratory before installation. The problem tended to occur after the power had been removed from the system. The Leocell Engineers eventually diagnosed the problem as a software protocol error.

The main problem at the Aangewys site was the security of the instrumentation. The site was repeatedly vandalised, batteries and the Leosat communications module were stolen. The DWAF padlock on the door of the pillbox was broken, possibly with a crowbar. The locking mechanism was replaced and strengthened by DWAF. A farmer, resident in the area of the weir, was also plagued by vandals but was unable to apprehend the miscreants.

During the period of high river flows in the river, access to the site through the wetlands to the south of Aangewys was impossible. The scheduled replacement of batteries and the re-calibration of probe elements was interrupted by flooding.

The dates and reasons for the downtime at the installation are listed in **Table 4.3.1(a)**.

Table 4.3.1(a) : Periods and reasons for downtime at the YSI/Leosat installation at B1H017

Supplier	Period	Comments
YSI/ Ecosat	26/02/99	Probe installed
	30/05/99 – 10/06/99	Failure of satellite communications
	07/10/99 – 11/12/99	Flat battery caused lack of compatibility between probe and Leocell logger. Units returned to Potchefstroom for investigation.

Supplier	Period	Comments
	11/02/00 – 01/03/00	Lightning damage to Leocell Unit. Leocell unit and probe returned to Potchefstroom for repair and re-programming

4.3.2 Comparison to Base Data Set

A plot of the data measured by the YSI/Ecosat system is shown in **Figure 4.3.2(a)**. The base data is shown as discrete points on the graphs. The graphs show that the EC, depth and to a lesser extent the temperature follow the trends indicated by the base data set. This is supported by the regression analysis and comparative statistics given in **Figure 4.3.2(b)** and **Table 4.3.2(a)** respectively. The outliers in the pH which occurred during June 1999 were not included in the regression analysis. The high pH values occurred during and soon after the failure of the Leosat communication system.

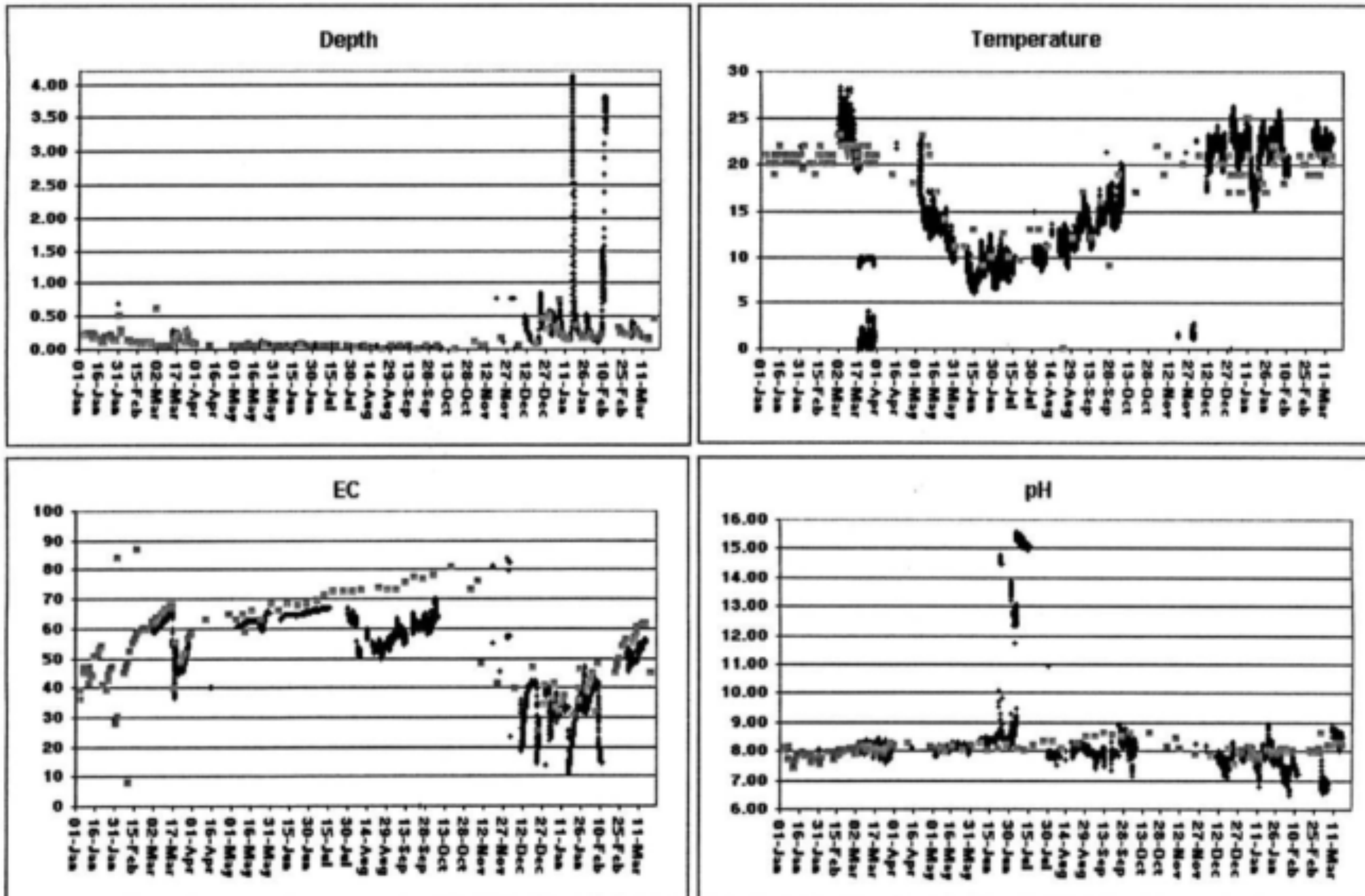

Figure 4.3.2(a) : Comparison of base and continuous monitoring data from YSI/Ecosat system at B1H017

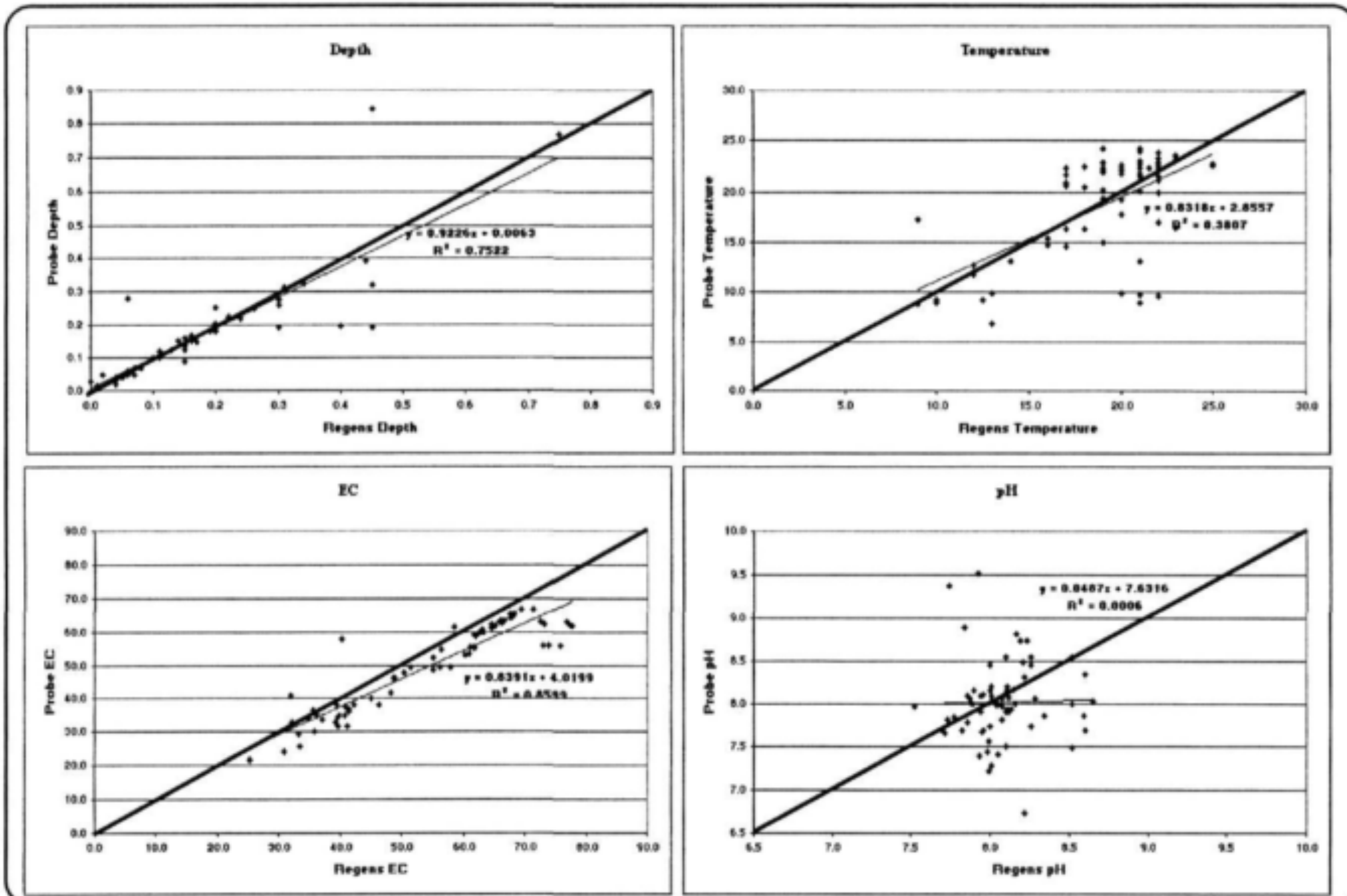

Figure 4.3.2(b) : Linear Regression Analysis for YSI/Ecosat at B1H017

Table 4.3.2(a) : Comparative statistics for YSI probe data at B1H017

	Depth		EC		pH		Temperature	
	Base	Probe	Base	Probe	Base	Probe	Base	Probe
Sample Size	67							
	Conservation Statistic							
Mean	0.160	0.154	54.814	49.809	8.084	8.018	18.908	18.584
% difference	3.81		9.13		0.81		1.71	
Variance	0.018	0.021	193.902	165.656	0.049	0.219	14.405	26.182
% difference	-13.13		14.57		-347.68		-81.75	
Standard Deviation	0.135	0.143	13.925	12.871	0.221	0.468	3.795	5.117
% difference	-6.36		7.57		-111.58		-34.82	
	Regression Statistics							
Equation of Regression Line	Y = 0.923X + 0.006		Y = 0.839X + 4.020		Y = 0.049X + 7.632		Y = 0.832X + 2.856	
Correlation Coefficient	0.87		0.91		0.02		0.62	
Coefficient of Determination	0.752		0.831		0.0006		0.381	
Coefficient of Efficiency	0.745		0.648		-0.224		0.361	
Coefficient of Agreement	0.925		0.952		0.024		0.742	

4.4 Hydrolab/Ecosat at Steenkoolspruit – B1H021

4.4.1 General Discussion of Performance

Groundwater Systems installed a multi-functional Minisonde water quality probe at the Steenkoolspruit weir. Satellite communications were supplied by Ecosat. The initial survey of the weir identified Steenkoolspruit as an ideal location for the water quality instrumentation testing. The weir was easily accessible from the road and the DWAF steel structure provided an excellent housing for the power supplies and communications equipment.

Ecosat engineers designed and installed a swinging-arm mount for the Minisonde which allowed access during the re-calibration of the probe. Ecosat also erected a platform alongside the probe to provide a convenient working area.

The probe was positioned in the main flow of the river and the depth measurement facility of the Minisonde was calibrated with respect to the DWAF depth measuring installation. Initially the functioning of the water quality probe was affected by an accumulation of algae on the probe apertures but the covering of the probe with a silk stocking reduced the problem.

The signals from the probe were conveyed via a multi-cored cable to the Leosat communication equipment located in the DWAF structure. The signal cable was exposed and not protected in a steel conduit.

During the course of the project the possible lack of strength of the swinging-arm mount was discussed. WMB felt that the structure would not be able to withstand a medium to high flood. The suppliers agreed and replaced the structure with a mounting arrangement rigidly bolted to the top of the weir.

Security of equipment at Steenkoolspruit posed a problem. The site was visible from the road and on several occasions batteries and solar panels were stolen. After the customised signal cable was stolen from the site in December 1999, it was agreed to relocate the instrumentation to Wolwekrans Weir.

The history of the downtime at the site is given in **Table 4.4.1(a)**.

Table 4.4.1(a) : Periods and reasons for downtime at the Hydrolab/Ecosat installation at B1H021

Supplier	Period	Comments
Hydrolab /Ecosat	22/02/99	Probe installed
	11/08/99 – 19/08/99	Flat battery. No data logged.
	07/10/99 – 31/10/99	Flat battery. No data logged
	12/12/99 – 24/02/00	Cable vandalised on site, probe moved to Wolwekrans weir
	01/03/2000	Probe reinstalled at Wolwekrans weir

4.4.2 Comparison to Base Data Set

The plot of the data measured by the Hydrolab/Ecosat system is shown in **Figure 4.4.2(a)** with the base data shown as discrete points on the graphs. The EC and depth reading compared well with the base data set. This is shown by the limited scatter around the 1:1 lines on the regression plots shown in **Figure 4.4.2(b)** for the EC and depth readings.

The scatter for the pH and the temperature is greater than for the EC and the depth measurements. The comparative statistics are shown in **Table 4.4.2(a)**.

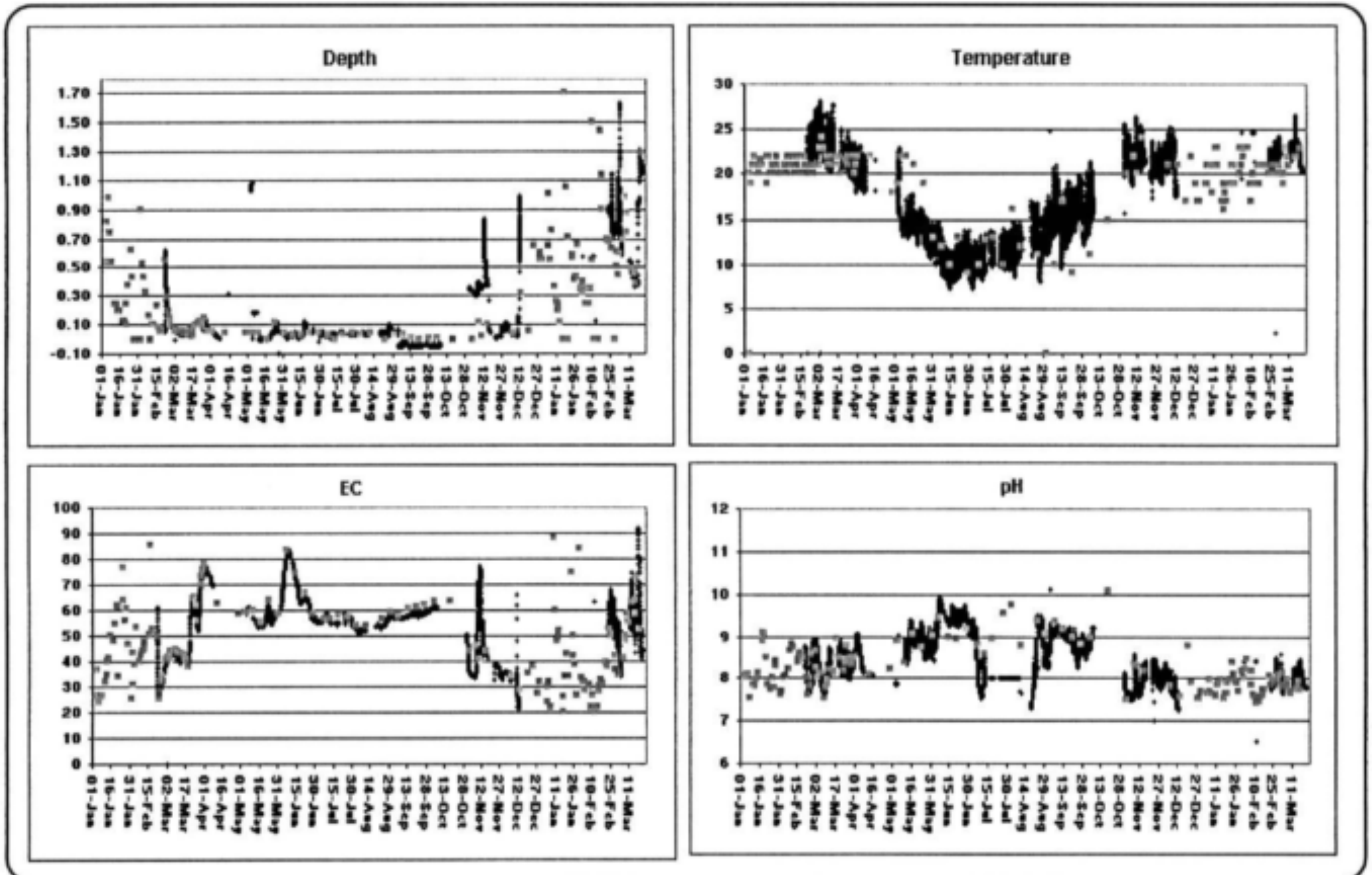

Figure 4.4.2(a) : Comparison of base and continuous monitoring data from Hydrolab/Ecosat system at B1H021

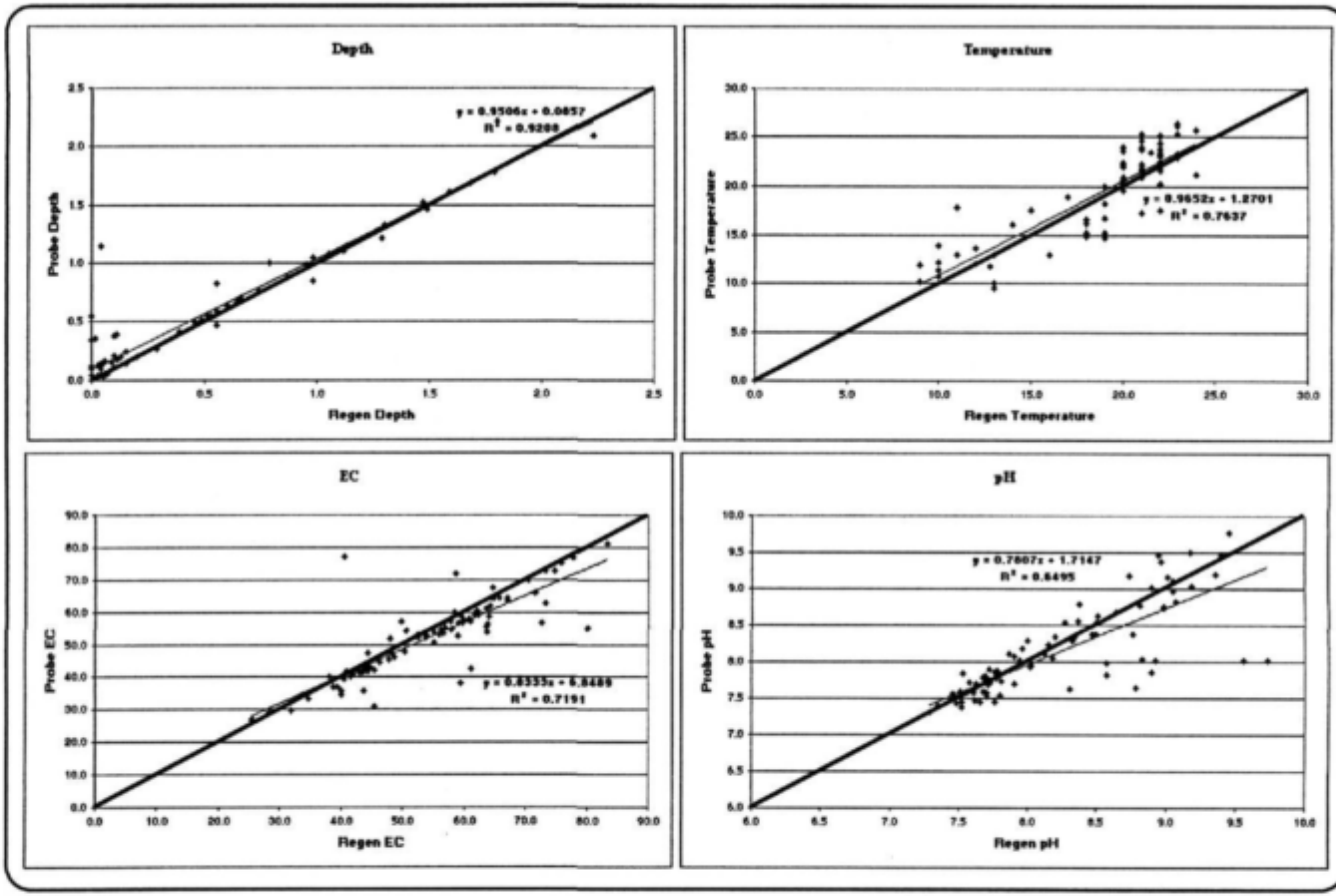

Figure 4.4.2(b) : Linear Regression Analysis for Hydrolab/Ecosat at B1H021

Table 4.4.2(a) : Comparative Statistics for Hydrolab data at B1H021

	Depth		EC		pH		Temperature	
	Base	Probe	Base	Probe	Base	Probe	Base	Probe
Sample Size	86							
	Conservation Statistic							
Mean	0.469	0.539	54.170	51.986	8.203	8.119	19.155	19.758
% difference	-15.00		4.03		1.02		-3.15	
Variance	0.320	0.315	147.227	142.155	0.383	0.360	16.090	19.628
% difference	1.72		3.45		6.16		-21.99	
Standard Deviation	0.566	0.561	12.134	11.923	0.619	0.600	4.011	4.430
% difference	0.86		1.74		3.13		-10.45	
	Regression Statistics							
Equation of Regression Line	Y = 0.95X + 0.086		Y = 0.83X + 6.85		Y = 0.78X + 1.71		Y = 0.97X +1.27	
Correlation Coefficient	0.96		0.85		0.81		0.87	
Coefficient of Determination	0.921		0.719		0.650		0.764	
Coefficient of Efficiency	0.905		0.656		0.579		0.744	
Coefficient of Agreement	0.979		0.915		0.886		0.929	

4.5 Prodesign at Wolwekrans Weir – B1H005

4.5.1 General discussion of performance

Prodesign installed a Greenspan multi-functional probe and cellphone communications system at Wolwekrans weir. The probe was positioned near the outflow from the weir. Kleinkopje Colliery installed a pipe running from the top of the weir structure to beneath the water level. The data logger, power supplies and cellphone communication system were located in a secure lockable compartment on top of the weir concrete structure. A solar panel provided back-up to the battery power supply.

Security at the Wolwekrans weir was adjudged to be good with the added advantage of the close proximity of Kleinkopje Colliery and regular patrols by the Colliery security personnel. In addition, the water pumps which supplied water to the Colliery operations were regularly serviced and inspected by the Maintenance Department.

In August 1999, the Greenspan probe failed and in the opinion of the Prodesign Engineers and the Greenspan Manufacturers in Australia, the failure was due to vibrations from the suction intakes of the water pumps. The pumps stopped and started several times per day according to the Colliery demands. A polystyrene collar was designed to protect the replacement probe and prevent further vibration damage.

Difficulties were experienced by Prodesign with the cellphone communications system. Periodically the transmitting link would break down and the problem was traced to the electronic card linking the data logger to the transmission system. During the periods of the malfunction, the data logger was downloaded manually and data was transferred to the project monitoring facility at WMB.

On 18 November 1999, the replacement probe was struck by lightning. The instrument was sent to Australia for repair and re-installed at Wolwekrans in January 2000.

Due to the high incidence of vandalism at the Steenkoolspruit and Koringspruit installations, the decision was made to transfer the instrumentation of these two sites to Wolwekrans weir. Additional pipes were installed by Kleinkopje colliery and a mains supply was also installed at Wolwekrans. The installation of the mains supply obviated the need for solar panels as normal mains battery chargers could be used. Before the installation of the mains cable was completed, the solar panels supplying the DWAF depth measuring equipment and the Prodesign installation were stolen. Regular-irregular visits of the colliery security personnel had been arranged with the Colliery but the vandals were able to evade the patrols.

In early January 2000 the level of the Olifants River started to rise and a major flood with a peak of 748 m^3/s rising to a height of 5 metres swept through the Wolwekrans Weir on 17 January. Severe damage was caused to the water quality probe pipes and one pipe was washed away. Flood-bourn trees or debris had torn the pipes from their mountings. The flood subsided fairly quickly and Kleinkopje Colliery was able to replace the bent and lost pipes within a few days.

DDS decided to install a multi-functional probe. of their own design, at Wolwekrans but by the end of the instrumentation project, the results were not available.

Wolwekrans weir was considered to be a relatively secure site but the mounting of visible equipment such as solar panels attracted the attention of thieves. The record of downtime is shown in **Table 4.5.1(a).**

Table 4.5.1(a) : Periods and reasons for downtime at the Prodesign installation at B1H005

Supplier	Period	Comments
Prodesign	19/01/99	Probe installed
	08/09/99 – 18/09/99	Probe damaged by vibration. Returned to Australia. Original probe re-installed
	30/09/99 – 14/10/99	Loss of data. Transmission Failure
	17/11/99 – 16/02/00	Original probe damaged by lightning.
	18/02/00	Solar panel stolen

4.5.2 Comparison to Base Data Set

The Greenspan probe performed particularly well in the measurement of flow depth. This is shown in the plots in **Figure 4.5.2(a)** and in the linear regressions shown in **Figure 4.5.2(b)**. The comparative statistics listed in **Table 4.5.2(a)** also support the plots. Like the other probes, the scatter around the 1:1 line is higher for temperature and pH than for the EC and flow depth.

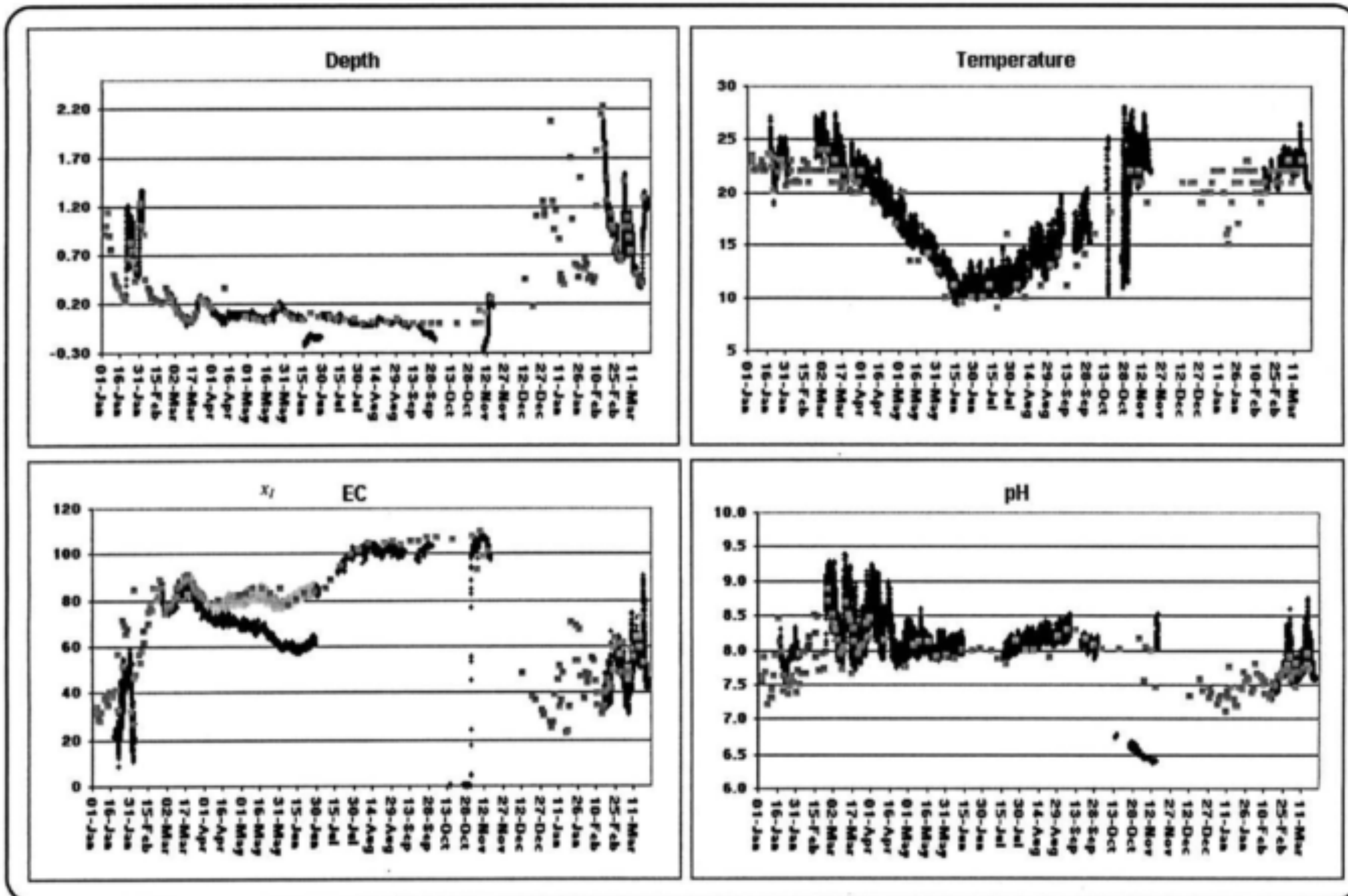

Figure 4.5.2(a) : Comparison of base and continuous monitoring data from Prodesign system at B1H005

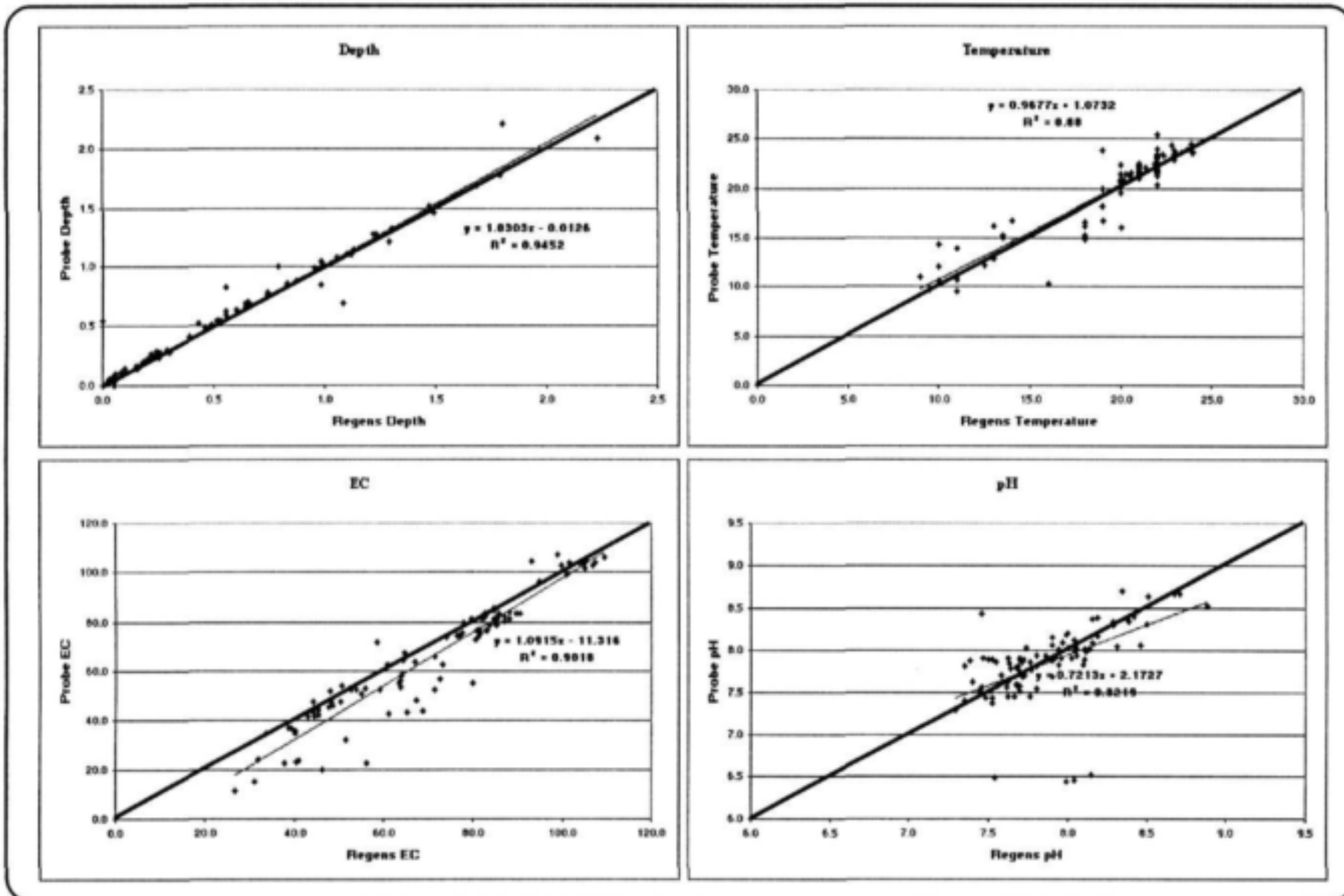

Figure 4.5.2(b) : Prodesign – Linear Regressions

Table 4.5.2(a) : Comparative Statistics for Prodesign data at B1H005

	Depth		EC		pH		Temperature	
	Base	Probe	Base	Probe	Base	Probe	Base	Probe
Sample Size	100							
	Conservation Statistic							
Mean	0.537	0.565	70.669	65.822	7.882	7.858	19.455	19.899
% difference	-5.13		6.86		0.30		-2.28	
Variance	0.306	0.347	444.504	587.318	0.114	0.184	16.248	17.289
% difference	-13.45		-32.13		-61.64		-6.40	
Standard Deviation	0.553	0.589	21.083	24.235	0.338	0.429	4.031	4.158
% difference	-6.52		-14.95		-27.14		-3.15	
	Regression Statistics							
Equation of Regression Line	Y = 1.03X – 0.013		Y = 1.092X – 11.316		Y = 0.721X + 2.173		Y = 0.968X + 1.073	
Correlation Coefficient	0.97		0.95		0.57		0.94	
Coefficient of Determination	0.944		0.902		0.322		0.880	
Coefficient of Efficiency	0.972		0.855		0.271		0.868	
Coefficient of Agreement	0.985		0.974		0.685		0.967	

4.6 DDS at Koringspruit – B1H020

4.6.1 General discussion of performance

At the beginning of the instrumentation investigation, the DWAF weir was equipped with DDS depth measuring equipment from which river flow information was computed. Unlike other installations, Koringspruit did not possess a convenient concrete structure to house additional instrumentation. Separate electrical conductivity (EC) and pH probes were installed by DDS. A temperature probe was not installed.

From the start of the project, the DDS installation was beset with problems. The cellphone link-up between the DDS data logger and the cellphone service provider did not operate properly. The transmission aerial was positioned incorrectly and the battery capacity was inadequate. Solar panels were installed to maintain the required capacity but after the theft of the solar panels, there was insufficient battery capacity to maintain regular transmission. The data was downloaded manually.

The instrumentation was vandalised on several occasions. Solar panels, batteries, the cellphone and eventually the metal cabinet containing the instrumentation was stolen. DDS management was convinced that the theft of equipment from site was more than simple vandalism. On the occasion that the cellphone was stolen, the Simcard was used in another phone. DDS was unable to establish the identity of the user.

It was decided to relocate the DDS instrumentation to Wolwekrans Weir to give the supplier an equal opportunity to perform in the instrumentation investigation. However, the installation at Wolwekrans weir was not carried out successfully. After the probes were washed away in January 2000, DDS essentially abandoned the project. The record of downtime is shown in **Table 4.6.1(a)**.

Table 4.6.1(a) : Periods and reasons for downtime at the DDS installation at B1H020

Supplier	Period	Comments
DDS	04/03/99	Probe installed
	27/07/99 – 12/08/99	Cell phone stolen from site. Reinstalled 12/08/99
	26/08/99	Cell phone stolen from site. Probe operation.
	22/09/99	Probe stolen from site.

4.6.2 Comparison to Base Data Set

Due to the theft and vandalism problems experienced at site, there was a limited data set available for analysis. The available data is shown plotted on **Figure 4.6.2(a)** with the results of the linear regression analysis in **Figure 4.6.2(b)**. The comparative statistics are listed in **Table 4.6.2(a)**. The data measured by the DDS equipment followed the general trends of the base data set. However, the data showed a large variation around the general trend line.

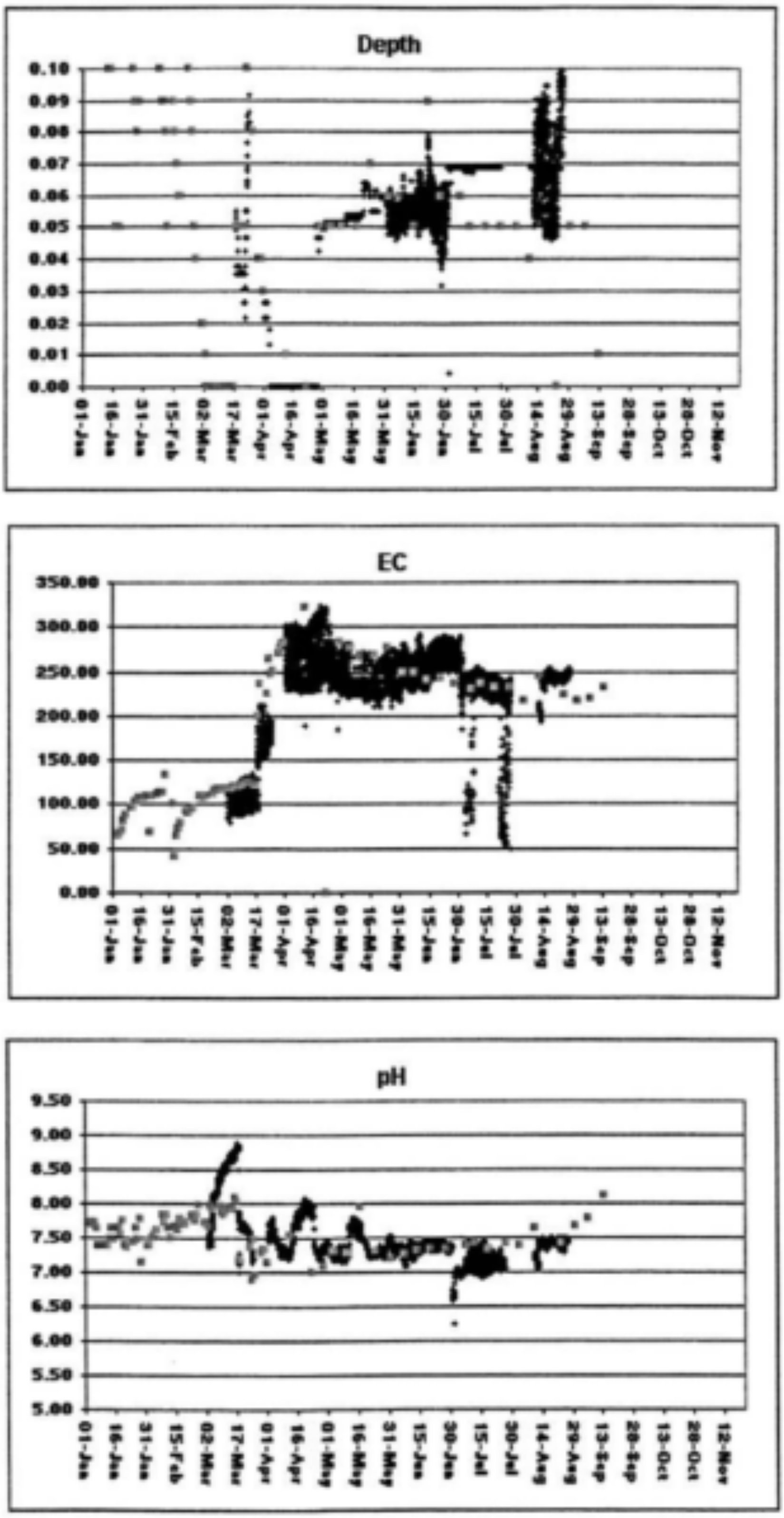

Figure 4.6.2(a) : DDS Probes Historic Results

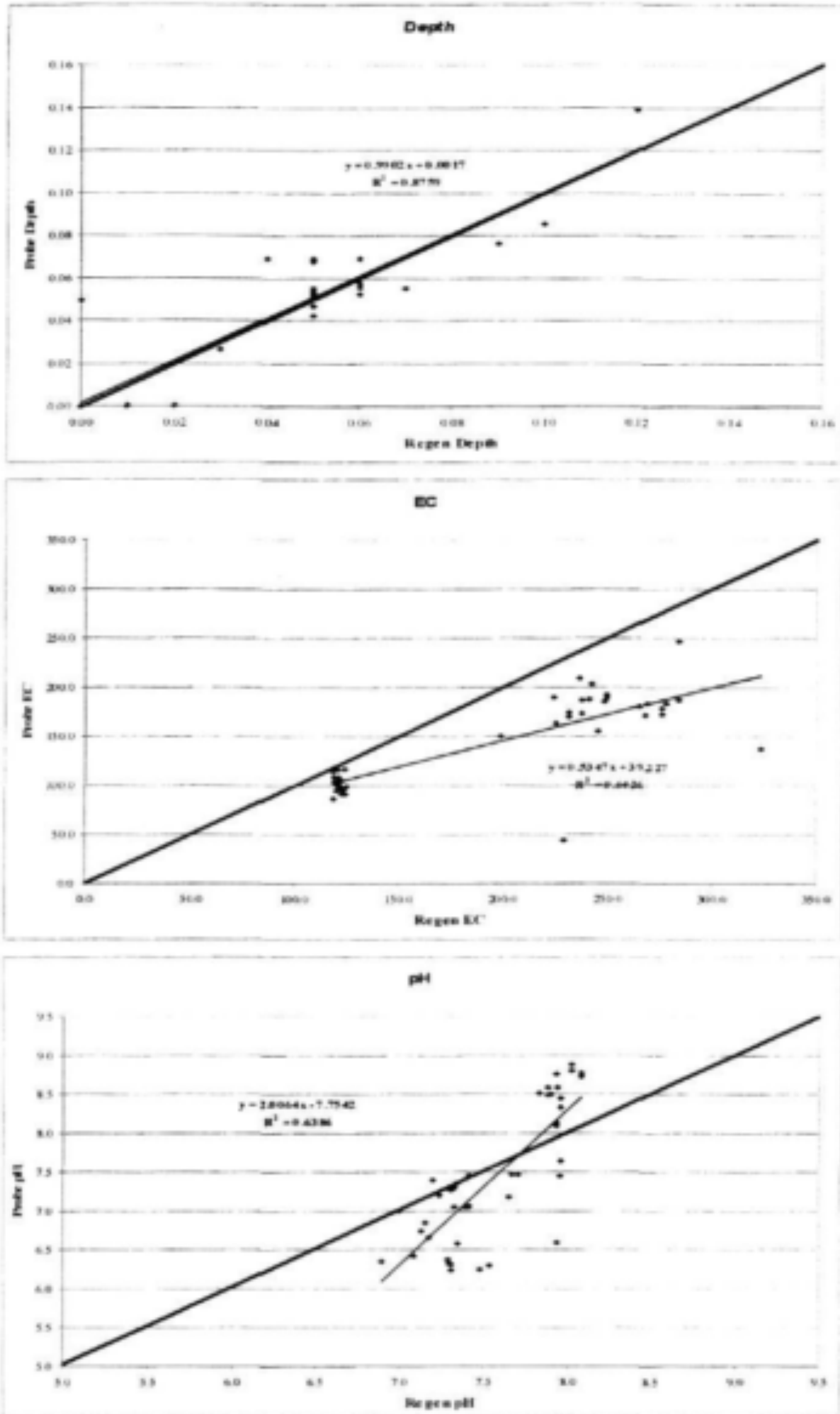

Figure 4.6.2(b) : DDS – Linear Regressions

Table 4.6.2(a) : Comparative Statistics for DDS data at B1H020

	Depth		EC		pH		Temperature	
	Base	Probe	Base	Probe	Base	Probe	Base	Probe
Sample Size	42							
	Conservation Statistic							
Mean	0.031	0.033	196.03	144.04	7.573	7.442	-	-
% difference	-6.77		26.52		1.73		-	
Variance	0.001	0.001	4665.03	2075.40	0.120	0.757	-	-
% difference	-16.78		55.51		-530.28		-	
Standard Deviation	0.005	0.005	68.30	45.56	0.347	0.870	-	-
% difference	-8.07		33.30		-151.05		-	
	Regression Statistics							
Equation of Regression Line	Y = 0.99X + 0.002		Y = 0.53X + 39.23		Y = 2.01X – 7.75		-	
Correlation Coefficient	0.92		0.80		0.80		-	
Coefficient of Determination	0.88		0.64		0.64		-	
Coefficient of Efficiency	0.88		-1.18		0.46		-	
Coefficient of Agreement	0.97		0.88		0.88		-	

4.7 OTT at Spookspruit – B1H002

4.7.1 General discussion of performance

The site was equipped with OTT depth and temperature probes at the beginning of the project. DWAF purchased an OTT electrical conductivity probe which was installed by OTT at the weir.

The additional instrumentation, including a cellphone link was installed in the DWAF concrete pillbox. Underground cables for the separate water quality probes were used between the pillbox and the weir.

The performance of the EC probe initially caused difficulties. The Regen Waters measurement showed that the OTT probe was under-reading. Several visits to the site to carry out EC surveys using hand held portable probes were undertaken. A number of samples were also taken to Regen Waters for testing. There were disagreements concerning the accuracy and calibration of the types of equipment used. Discussions were held with the Regen Waters Laboratory personnel and OTT finally accepted the method and instruments used to measure the electrical conductivity. The installation was finally inspected and a faulty probe cable due to a cut in the cable was discovered.

OTT was requested to install a pH probe at the site. OTT at the time of the project did not have a suitable probe available which could be used with confidence. Since the completion of the project, OTT have a pH probe available for use with OTT equipment.

Security at Spookspruit was never violated due to the nearness of the local farmer's house and the guard dogs which roamed freely in the area, night and day. The record of downtime is shown in **Table 4.7.1(a)**.

Table 4.7.1(a) : Periods and reasons for downtime at the OTT installation at B1H002

Supplier	Period	Comments
OTT	12/07/99 – 04/08/99	No conductivity data. Faulty probe cable.

4.7.2 Comparison to Base Data Set

The plots of the base data and the data measured using the OTT equipment is shown plotted in **Figure 4.7.2(a)** and the linear regressions in **Figure 4.7.2(b)**. The comparative statistics are given in **Table 4.7.2(a)**. Once the initial cable problems were solved, the instrumentation performed well.

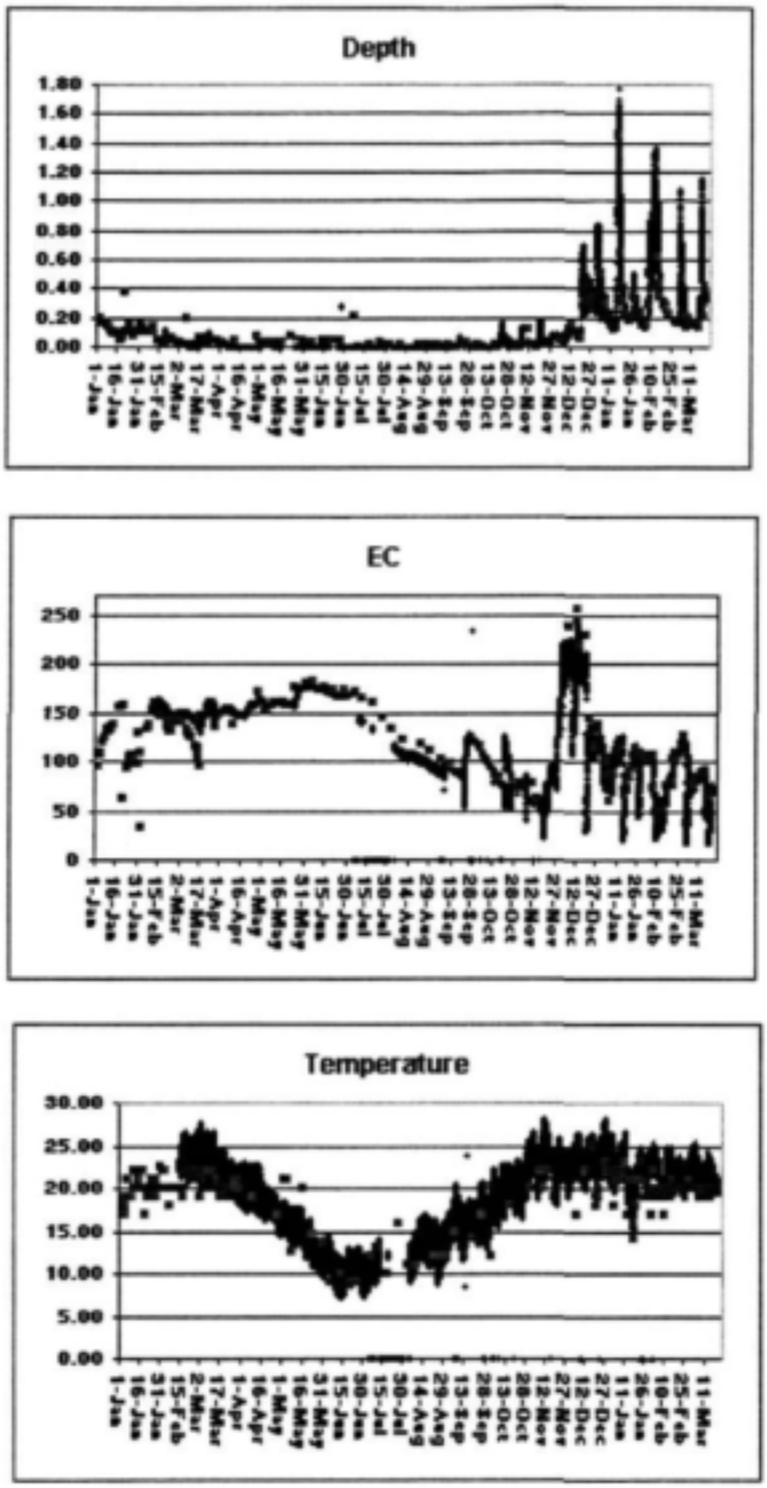

Figure 4.7.2(a) : OTT Probes Historic Results

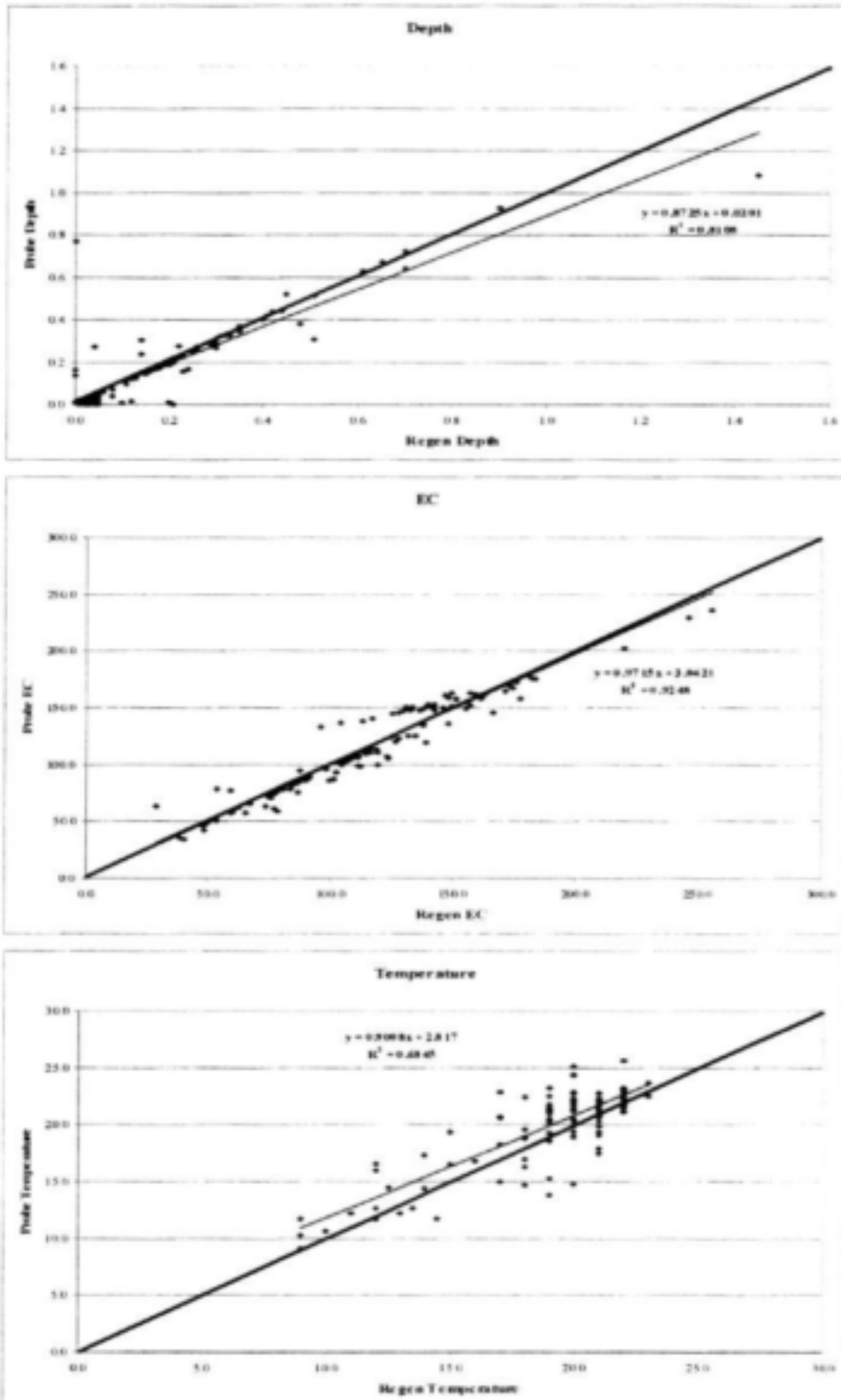

Figure 4.7.2(b) : OTT – Linear Regressions

Table 4.7.2(a) : OTT Probe : Statistics

	Depth		EC		pH		Temperature	
	Base	Probe	Base	Probe	Base	Probe	Base	Probe
Sample Size	126							
	Conservation Statistic							
Mean	0.171	0.170	115.460	115.206	-	-	19.028	19.956
% difference	0.69		0.22		-		-4.88	
Variance	0.040	0.038	1669.505	1703.753	-	-	9.733	11.538
% difference	5.82		-2.05		-		-18.54	
Standard Deviation	0.201	0.195	40.860	41.277	-	-	3.120	3.397
% difference	2.95		-1.02		-		-8.88	
	Regression Statistics							
Equation of Regression Line	Y = 0.872X + 0.02		Y = 0.972X + 3.04		-		Y = 0.9X +2.82	
	0.90		0.96		-		0.83	
Coefficient of Determination	0.811		0.925		-		0.684	
Coefficient of Efficiency	0.794		0.924		-		0.601	
Coefficient of Agreement	0.946		0.980		-		0.899	

4.8 Middelburg – B1H012

4.8.1 General discussion of performance

During the project, YSI requested permission to install an additional multi-functional probe on the Klein Olifants River at the entrance to the Middelburg Dam. No communications equipment was integrated with the water quality probe and data was downloaded by YSI on a regular basis.

The metal pipe casing was designed and built by WMB. The casing was bolted to the main structure of the weir near the overspill section.

In the past, DWAF instrumentation at the weir had been vandalised but YSI felt that the design, size and relative smallness of the casing above water would be less obvious to vandals. The padlock which locked the top-cap of the assembly was partially covered by the top-cap and made illegal entry difficult.

The YSI probe was installed in January 2000 and performed without interruption until the end of the project.

4.8.2 Comparison of Base Data Set

The base data is shown plotted in **Figure 4.8.2(a)** together with the data measured using the YSI probe.

4.9 Summary of Comparative Statistics

The comparative statistics listed in the tables in **Sections 4.3** to **4.8** are combined in **Tables 4.9(a)** to **4.9(d)** to allow for the comparison of the results between suppliers for the parameters measured.

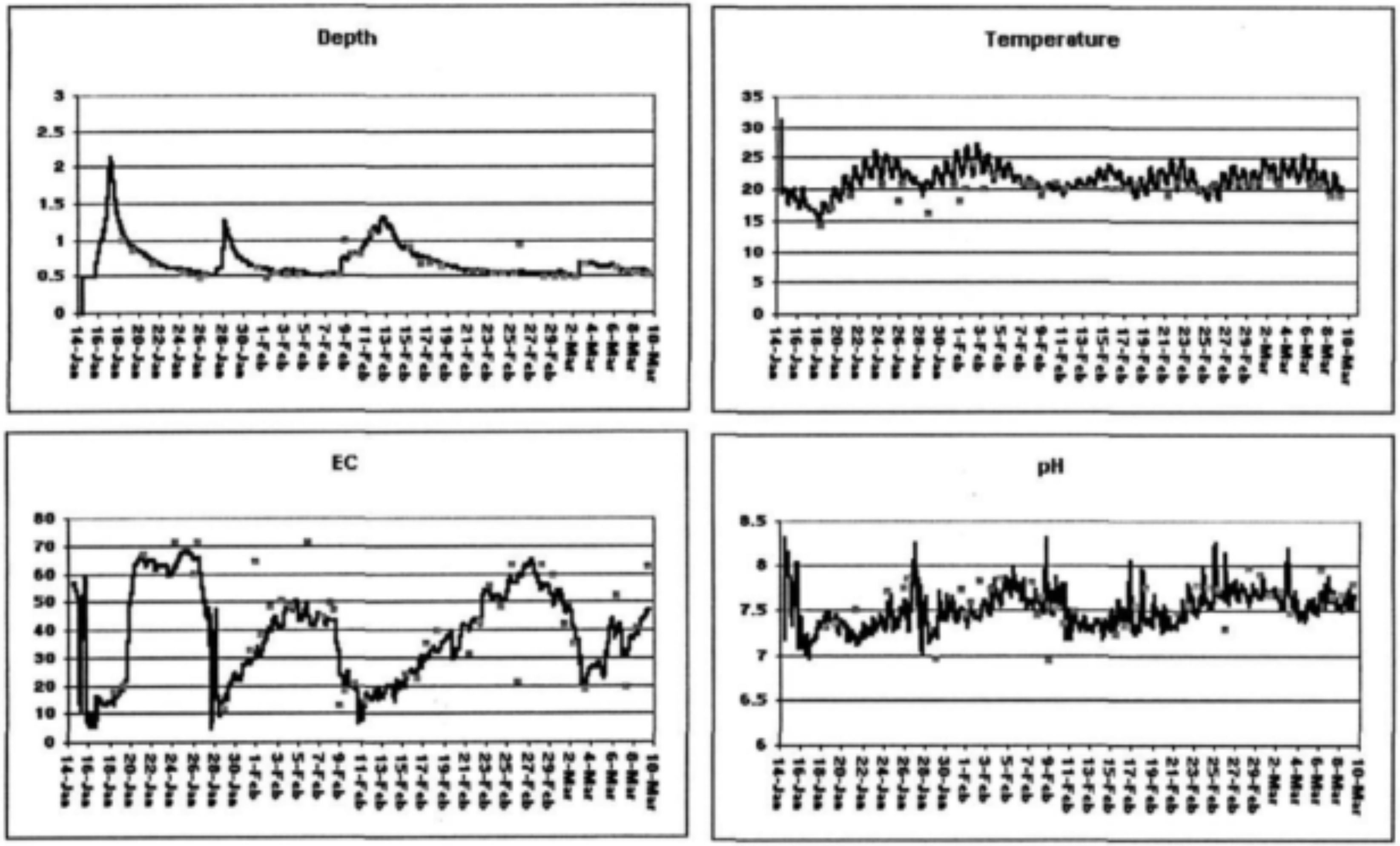

Figure 4.8.2 : YSI Probes (Middelburg Weir – B1h)12) Historic Results

Table 4.9(a): Depth Statistics

	DDS		HYDROLAB		OTT		PRODESIGN		YSI	
	Regens	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**
Sample Size	42		86		126		100		67	
	Conservation Statistic									
Mean	0.031	0.033	0.469	0.539	0.171	0.170	0.537	0.565	0.160	0.154
% difference	-6.77		-15.00		0.69		-5.13		3.81	
Variance	0.001	0.001	0.320	0.315	0.040	0.038	0.306	0.347	0.018	0.021
% difference	-16.78		1.72		5.82		-13.45		-13.13	
Standard Deviation	0.005	0.005	0.566	0.561	0.201	0.195	0.553	0.589	0.135	0.143
% difference	-8.05		0.86		2.95		-6.52		-6.36	
	Regression Statistics									
Equation of Regression Line	Y=0.99X + 0.002		Y=0.95X + 0.086		Y=0.872 + 0.02		Y=1.03X – 0.013		Y=0.923X + 0.006	
Correlation Coefficient	0.920		0.960		0.900		0.970		0.620	
Coefficient of Determination	0.880		0.921		0.811		0.944		0.381	
Coefficient of Efficiency	0.880		0.905		0.794		0.972		0.361	
Coefficient of Agreement	0.970		0.979		0.946		0.985		0.742	

Table 4.9(b): EC Statistics

	DDS		HYDROLAB		OTT		PRODESIGN		YSI	
	Regens	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**
Sample Size	42		86		126		100		67	
	Conservation Statistic									
Mean	196.03	144.04	54.170	51.986	115.460	115.206	70.669	65.822	54.814	49.809
% difference	26.52		4.03		0.22		6.86		9.13	
Variance	4665.03	2075.40	147.227	142.155	1669.505	1703.753	444.504	587.318	193.902	165.656
% difference	55.51		3.45		-2.05		-32.13		14.57	
Standard Deviation	68.30	45.56	12.134	11.923	40.860	41.277	21.083	24.235	13.925	12.871
% difference	33.30		1.74		-1.02		-14.95		7.57	
	Regression Statistics									
Equation of Regression Line	Y=0.53X + 39.23		Y=0.83X + 6.85		Y=0.972X + 3.04		Y=1.092X – 11.316		Y=0.839X + 4.020	
Correlation Coefficient	0.80		0.850		0.960		0.950		0.910	
Coefficient of Determination	0.64		0.719		0.925		0.902		0.831	
Coefficient of Efficiency	-1.18		0.656		0.924		0.855		0.648	
Coefficient of Agreement	0.88		0.915		0.980		0.974		0.952	

Table 4.9(c): pH Statistics

	DDS		HYDROLAB		OTT		PRODESIGN		YSI	
	Regens	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**
Sample Size	42		86		126		100		67	
	Conservation Statistic									
Mean	7.573	7.442	8.203	8.119	-	-	7.882	7.858	8.084	8.018
% difference	1.73		1.02		-		0.30		0.81	
Variance	0.120	0.757	0.383	0.360	-	-	0.114	0.184	0.049	0.219
% difference	-530.28		6.16		-		-61.64		-347.68	
Standard Deviation	0.347	0.870	0.619	0.600	-	-	0.338	0.429	0.221	0.468
% difference	-151.05		3.13		-		-27.14		-111.58	
	Regression Statistics									
Equation of Regression Line	Y=2.01X – 7.75		Y=0.78X + 1.71		-		Y=0.721X + 2.173		Y=0.049X + 7.632	
Correlation Coefficient	0.800		0.810		-		0.570		0.020	
Coefficient of Determination	0.640		0.650		-		0.322		0.0006	
Coefficient of Efficiency	0.460		0.579		-		0.271		-0.224	
Coefficient of Agreement	0.880		0.886		-		0.685		0.024	

Table 4.9(d): Temperature Statistics

	DDS		HYDROLAB		OTT		PRODESIGN		YSI	
	Regens	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**	**Regens**	**Probe**
Sample Size	42		86		126		100		67	
	Conservation Statistic									
Mean	-	-	19.155	19.758	19.028	19.956	19.455	19.899	18.908	18.584
% difference	-		-3.15		-4.88		-2.28		1.71	
Variance	-	-	16.090	19.628	9.733	11.538	16.248	17.289	14.405	26.182
% difference	-		-21.99		-18.54		-6.40		-81.75	
Standard Deviation	-	-	4.011	4.430	3.120	3.397	4.031	4.158	3.795	5.117
% difference	-		-10.45		-8.88		-3.15		-34.82	
	Regression Statistics									
Equation of Regression Line	-		Y=0.97X + 1.27		Y=0.9X + 2.82		Y=0.968X + 1.073		Y=0.832X + 2.856	
Correlation Coefficient	-		0.870		0.830		0.940		0.620	
Coefficient of Determination	-		0.764		0.684		0.880		0.381	
Coefficient of Efficiency	-		0.744		0.601		0.868		0.361	
Coefficient of Agreement	-		0.929		0.899		0.967		0.742	

5 INSTRUMENTATION COSTS

5.1 Introduction

The capital and operating costs for the equipment used during the project are presented in this section. The capital costs include the costs of purchasing the probes and loggers as well as the installation costs. The operating costs include the communication costs and the site visits to calibrate and maintain the site.

5.2 Capital costs

The costs of purchasing the probes and communication equipment in 1999 prices are listed in **Table 5.2(a)** and **Table 5.2(b)** respectively. The prices of the equipment depend on factors such as the number of units purchased, exchange rates and cable lengths. The prices given in the Tables should only be considered to be indicative. In **Table 5.2(c)**, the costs of the computer equipment required at the master station for downloading data remotely has also been included.

Table 5.2(a) : Capital Costs of probes in 1999 prices

Supplier	Instrumentation	Cost (R)
Prodesign (Pty) Ltd	Greenspan CTDP 300 Multi-Functional Probe, (EC, pH, temperature, depth)	24 6414,00
	Vented cable, 30 m	1 232,00
	MA100 Interface	5 867,00
	Gcom "wasp"	2 187,00
	Equipment Enclosure	600,00
	Solar panels, frame and regulator	2 669,00
	102AH battery	499,00
	Total	37 695,00
Groundwater Systems CC	Hydrolab Minisonde	34 220,00
	Multi-functional probe (EC, pH temperature, depth)	-
	Data Logger	-
	Battery Pack	-
	Vented cable, 15 m	8 700,00
	Total	42 920,00
NB : Minisonde probe now replaced by "Quanta" probe		
Monitoring and Control Laboratories (Pty) Ltd (YSI)	YSI 600 XL Sonde	34 178,00
	Multi-functional probe (EC, pH, temperature, depth)	
	Total	34 178,00
Additional features, integral battery chambers, data logger etc. Prices available on request		

Supplier	Instrumentation	Cost (R)
OTT Southern Africa (Pty) Ltd	Single function probe (EC and temperature)	4 500,00
	pH	No quote
	Water depth	11 425,00
	Data Logger	13 995,00
	Power Supply	1 610,00
	Total	31 530,00

Table 5.2(b) : Costs of the communication equipment

Supplier	Instrumentation	Cost (R)
Ecosat (Pty) Ltd	Leocell RDSU Satellite communicator	12 940,00
GSM Cellular Communications	Cellphone, Sim Card, modem, etc.	14 200,00

Table 5.2(c) : Costs for the master control station

Supplier	Specification	Cost (R)
Average Supplier Cost	Computer: 200 mHz Pentium, 64 MB Ram, 40 GB HDD, Read-write CD Rom, 3.5" stiffy drive, keyboard, mouse, ports for communication system, etc.	12 511,00
	Uninterrupted Power Supply	1 500,00
	Communication equipment : aerials, modems, disks, etc.	750,00
	Software : Windows NT4.0 Communication Software	8 700,00
	Total	23 461,00

The average capital cost for the equipment required for a station is about R50200 (excl VAT). The installation costs for the Aangewys, Wolwekrans and Steenkoolspruit sites averaged about R12000. These costs included the installation of pipe work at existing weirs to house Sonde type equipment. The DDS and OTT equipment was already installed at the Koringspruit and Spookspruit respectively. Representative costs were therefore not available.

5.3 Operating Costs

The operating costs include the costs of site visits and weekly phone calls to download the data. The costs for the ECOSAT satellite communication were not specified as ECOSAT provided an overall data management service. The communication was from WMB to the server at ECOSAT in Johannesburg. The costs are summarised in **Table 5.3(a)**. For further costs, see the CSIR report in **Appendix A**.

Table 5.3(a) : Summary of operating costs

Site	Description of item included in cost	Average Monthly cost (R/month)
Prodesign at Wolwekrans weir – B1H005	8 visits to site at 287 km/trip at R2,50/km	R478
	Cell phone calls to download data for an average of 40 minutes per call plus rental	R252
Total		**R730**
Hydrolab/Ecosat at the Steenkoopspruit – B1H021	10 visits to site at 320 km/trip at R2,50/km	R667
	Land line calls to download data for an average of 20 minutes per call plus rental	R8
	Leosat fees	R217
Total		**R892**
YSI/Ecosat at Aangewys – B1H017	10 visits to site at 350 km/trip at R2,50/km	R729
	Land line calls to download data for an average of 20 minutes per call plus rental	R6,93
	Leosat fees	R217
Total		**R952,93**
DDS at B1H020	8 visits to site at 242 km/trip at R2,50/km	R403
	Cell phone calls to download data for an average of 15 minutes per call plus rental	R159
Total		**R562**
OTT at B1H002	6 visits to site at 262 km/trip at R2,50/km	R328
	Cell phone calls to download data at an average 18 minutes/call. Rental costs carried by DWAF	R108
Total		**R436**

6 CONCLUSIONS

The following conclusions can be made as a result of this study:

- If suitably maintained and powered, the instrumentation was generally found to perform well when compared to the base data collected by Regen Waters. The depth and EC readings compared particularly well for a number of the suppliers. There was generally more scatter for the pH and temperature readings when compared to the base data. The pH probes in particular required more attention in terms of maintenance than the other probes.
- A regular (about 2 weekly interval) manual measurement of gauge plates, EC and pH is required to provide a check on the instrument readings for calibration purposes. On average a monthly calibration and maintenance visit was found to be necessary.
- Vandalism and theft remain a major stumbling block in the use of continuous instrumentation and real time communication systems. Solar panels are the most sought after item. The YSI installation at B1H012, which did not have any communication system in place was not vandalised during its three months of operation.
- Lightning protection should be provided.
- The use of batteries as the sole power source was problematic. The batteries used at Aangewys did not last as long as expected. The suppliers were not always able to reach the site to change the batteries as often as required.
- Attention to detail in terms of the installation of equipment is important. This ranges from electrical connection to housing the cables in suitable conduits to limit vandalism. The provision of lightning protection falls in this category.
- At stages during the project, the project team got the impression in the case of ECOSAT, that the communication software was still being developed and had not been thoroughly tested. Only towards the end of the project did matters improve.
- Based on the results of this project, the Orbcom Satellite communication system will not be suitable for a real-time system for controlled release. The available data was often 3 hours to 2 days behind.
- Cell phone networks appeared to be the more favourable communication system. These systems were down at times but generally for less than a day. About 90% availability was achieved with the cell phone communication system.
- Besides DDS, the other suppliers are purely agents for the probes. Only limited repairs could be carried out locally. The probes having to be returned to the country of origin. The turnaround time varied between 4 to 6 weeks in the case of the Prodesign Greenspan probe. Although expensive, consideration should be given to a backup probe.

7 RECOMMENDATIONS

The following recommendations can be made as a results of this study :-

- If continuous monitoring is to remain a requirement of the regulatory authorities, consideration will have to be given to innovative ways of making continuous instrumentation safe in the field. Particularly if real time communication systems are to be installed with the associated power requirements.

- Other sources of power should be considered such as gas driven turbines, which are less conspicuous than the solar panels. These types of power sources can be housed within the instrumentation enclosure.

- Unfortunately the project budget and practical considerations prevented the investigation of a radio communication system. This means of communication should be considered if continuous real time monitoring is to be installed. Especially if an existing repeater station network is available on a mine or power station complex.

- Consideration should be given to a workshop with the mines and power stations to present the findings of this research.

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APPENDIX

CSIR Report on Communication Systems

Technology Survey

Remote Water Pollution Monitoring

DETAILS

Document Title:	Technology Survey
Project:	Remote Water Pollution Monitoring
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Executive Summary

As part of the Witbank Dam project, Wates Meiring and Barnard requested the CSIR to produce a report that would inform their project team on technologies available that can be used for remote monitoring. The larger project is about the controlled release of pollution water.

This document outlines and describes a number of technologies available that could be used for remote monitoring, including:

- Satellite (LEO, VSAT and MeteoSAT)
- GSM Cellular
- Trunking
- Wireless Data
- Private Radio
- HF

For each technology grouping a first order evaluation of system cost is done.

Finally, a recommendation is made as to which system will be most suitable for serving the specific project.

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DEFINITION OF TERMS AND ACRONYMS

Band	This is a contiguous range of frequencies that are grouped together for convenience or because of some technical characteristic.
GSM	Global System for Mobile communications
HF	High Frequency
ISM Band	Industrial, Scientific and Medical band
LEO	Low Earth Orbiting Satellite
VSAT	Very Small Aperture Terminal (Satellite)
SCADA	Supervisory Control And Data Acquisition

1 INTRODUCTION

Wates, Meiring and Barnard approached the CSIR for assistance in the evaluation of remote monitoring or telemetry technologies. Stakeholders in the Witbank dam project are the Department of Water Affairs, Water Research Council, local Mining Industry and the local authorities.

In the Witbank dam catchment area the water pollution level is monitored at a number of pre-determined locations, typically in a river feed close to a factory, industrial area or mine. Monitoring the PH, temperature levels, rainfall levels and such parameters, the change in *pollution can be analysed and also forecasted. To control the release of pollution water, the* monitoring is done on a continuous basis.

The purpose of this study is to investigate different technology options that are available in South Africa that can be used to provide cost-effective telecommunications for remote monitoring. . The parameters and/or assumptions made were:

- The main function of the system is to relay information from the monitoring stations to a central collection point. The ability to send data back to the monitoring stations is secondary.
- The frequency and size of data is typically not more than 50 bytes every 15 minutes per station.
- About 13 stations need to be served in the catchment area.
- Cost should be kept to an absolute minimum
- Security and power are very important factors to consider. In most cases solar power will be used.
- In terms of reliability and latency, a delay of up to 24 hours between measurement and final reception of the signal can be tolerated.

The initial application of this study is to deploy a system in the Witbank dam catchment area. Although this study can find broader application in national deployment, a more in-depth evaluation and system design would be recommended for such a case.

A number of systems were tested over the last two years on the Witbank dam project. Other consulting engineer firms also executed similar projects to the Witbank dam project. These inputs combined with other research done by the CSIR in the telecommunications industry forms the basis of this report.

This report is structured into three sections covering

1. A general discussion of technologies available
2. An evaluation of specific systems/networks/solutions implemented with these technologies.
3. Other issues to consider in acquiring a system.
4. Recommendation of which system to use.

2 TECHNOLOGY OVERVIEW

2.1 Telephone based systems

2.1.1 Fixed line / Land line systems

A fixed line system requires an existing telephone infrastructure in the area. Each set of monitoring equipment would be connected via a modem.

Comments

Monitoring terminals are fixed in a specific location and cannot be relocated easily

Copper wire theft in remote areas is a real problem, increasing the probability of loss of communication for long periods.

The initial telephone infrastructure needs to be in place.

If the infrastructure is in place, communication is not terrain dependant or susceptible to signal fading as is the case with a wireless system.

More information:

http://www.telkom.co.za

2.1.2 Cellular systems

Where cellular services exist, these tend to be of better quality and greater reliability than traditional landline services. The digital GSM standard is currently the only system in use in South Africa.

Typical system requirements for remote monitoring are:

- A PC with a Type II or III PCMCIA Card capability (for telephone handsets without built in RS-232 ports). Desktops can use PCMCIA cards via an additional adapter card.
- A PCMCIA cellular telephone data card with cable (plugs into the laptop's PC card slot). The card used will depend to some extent on the brand and model of the handset used. Also, some of the newer handsets have a built in RS-232 serial port and do not require a PCMCIA card, simply plugging directly into the serial port of the computer.
- A cellular phone handset with data capability.
- Applications software (which often is packaged with the data card).

Comments

Very portable and mobile, allowing easy relocation of equipment.

This technology is currently suitable for voice and low speed data. Coverage is not available in many rural areas and cannot be guaranteed in mountainous areas where the equipment is situated in clefts or valleys.

The GSM MoU Association's website provides detailed information about GSM network operators worldwide. Details include tariffs, services, roaming and coverage. The website can be found at: http://www.gsmworld.com/gsminfo/gsminfo.htm

More Information: http://www.gsmdata.com, http://www.gsmworld.com, http://www.cdg.org and http://www.cellular.co.za

2.1.3 Digital Enhanced Cordless Telecommunications (DECT)[1]

DECT is a flexible digital radio access standard for cordless communications in residential, corporate and public environments. It caters for voice and data traffic.

DECT was designed to provide fixed access wireless service in high demand areas while still providing the facilities of advanced communication networks.

Telkom is using DECT fairly extensively for the provision of telephone service in rural areas. In a typical scenario, a DECT base station is located on a hillside near a small rural village. Telephones are linked to wireless transmitters, which relay information back to the base station, which in turn communicates with the nearest telephone exchange (often via microwave link)

Radio Technology

The DECT standard delivers high speech quality and security, high system capacity, with low risk of radio interference.

Dynamic Channel Selection / Allocation (DCS/DCA) is a DECT capability that ensures that the best of the available radio channels is always used. This happens when a cordless phone is in standby mode, as well as throughout a call. This capability ensures that DECT can coexist with other systems in the same frequency band but still provide high-quality, robust and secure communications for users.

Applications

1. **WLL:** DECT technology provides a high-quality radio alternative to wired subscriber local loops.

Comments:

DECT is geared towards providing fairly high-density telephone coverage as a replacement for fixed line access. In South Africa the DECT base station would have to be connected to a Telkom exchange (possibly via a fairly expensive microwave link).

Coverage for WLL applications (from base station to remote) is between 5 to 16 km depending on terrain. In a hilly environment such as the Witbank catchment area, this could prove to be costly as more than one base station would be required.

Provided the terminal radio equipment is within range of the DECT base station unit, the relocation of equipment is not a problem.

More information: DECT Forum. http://www.dect.ch

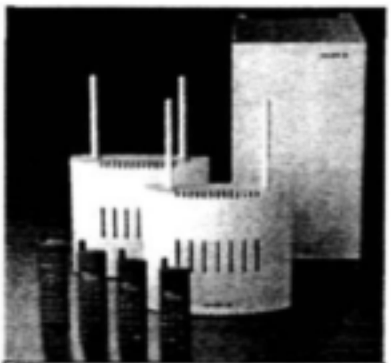

Figure 2: DECT Equipment

[1] formerly known as Digital European Cordless Telephone

2.2 Radio based systems

2.2.1 Private Telemetry / SCADA systems

The walkie-talkie is an example of a Land Mobile Radio (LMR) system. LMR also includes Citizens Band (CB) radios, and other two-way radio systems. LMR operates in the UHF and VHF frequency bands and usually operates either as single or dual frequency systems. Single frequency systems are simplex in operation and are not constrained by any usage tariffs. Sometimes infrastructures known as "parrot repeaters" are also used to provide some form of store and forward type of messaging.

In dual frequency systems, units transmit on frequency f_1 and receive on frequency f_2. The repeaters receive on f_1 and automatically transmit on f_2.

Good transmission ranges (20 – 45km) from outstations can be achieved with the use of directional Yagi antennas.

A repeater is an radio station that receives on a frequency and re-transmits the same signal on a different frequency. Repeaters are usually located on mountain tops, towers, skyscrapers, etc. because their main purpose is to provide a wide area coverage to stations operating in VHF and UHF frequencies. Repeaters mostly have a range of about 20 to 30 km, depending on location. The power supplied would be much higher than for portable equipment and solar panels or generators would mostly supply the power. In Africa it has been found that such installations are very prone to theft, damage or sabotage.

2.2.2 Community Repeaters

Repeater systems, use mobiles, portables, control stations, and a repeater to give all the radios more range. If it is necessary that every radio in the system be able to talk to and hear every other radio in the system and there are significant impediments such as long distances, walls, electrical noise, rocky terrain etc., the repeater is the way of overcoming the problem. The cost of installing and maintaining a repeater may be too great a burden for a single company or organization ("user") to sustain, for which case there are in most areas community repeaters. Community repeaters are owned and maintained by a communications company and the use of the repeater is rented out on a monthly basis to a number of users.

2.2.3 Public Data Networks

These are networks established and operated by a telecommunications administration, or a recognised private operating agency, for the specific purpose of providing data transmission services for the public. Organisations will generally provide turnkey solutions, using their own choice of equipment, hiring out the service to the public. In remote areas, the costs are likely to be very high. Examples of organisations providing public data networks are Telkom and WBS.

2.2.4 Trunking Radio Networks

Trunked radio systems are those which share a small number of radio channels among a larger number of users. The physical channels are allocated as needed to the users who are assigned logical channels. The users only hear units on the same logical channel. This uses the available resources more efficiently since most users do not need the channel 100% of the time.

When a trunked radio user wishes to talk with someone on the same logical channel, the mobile radio sends a data signal to the controller requesting a channel. The controller responds with a physical channel number. The requesting radio switches back to receive long enough to hear this information. At the same time, all the other radios see the same data. Those with the same logical channel selected, follow to that physical channel. They then use that channel just like any other two-way radio would.

In South Africa, an example is the Motorola SmartZone trunked radio system

Trunked radio systems are costly to build and maintain, beyond the resources of most users to own, but because many users can share a system, the shared cost of doing so can be quite reasonable. Trunked systems generally charge users a flat monthly rate for each radio to be used on the system, plus a small charge for each minute the user is actually talking on the system.

2.2.5 HF Radio

HF frequencies allow communications well beyond the horizon. Bandwidth of these systems is very low, partly because of problems with interference in these wavebands, and also because they are used extensively for international radio broadcasting. Time-of-day and sunspot activity are particularly important factors in the ability of the HF bands to support long distance communications and a good selection of frequencies, spread throughout the HF bands is critical to maintaining reliable communications.

General Comments

Factors to consider include whether the system has agents operating in South Africa, as well as companies with the highest market share in SA. Local agents and operators will mean lower costs in the long run, even if initial costs are considerably higher. Generally, the initial costs for HF systems are high. No costs are incurred while communicating data, but there will be annual HF radio license fees. No import tax is payable in South Africa on HF equipment.

Each unit could be either stationary or be set up as a transportable system. Relocating a system should pose very few problems.

2.3 Satellite Systems

In this category many exciting new systems are being commissioned or will be put into service by early next decade. These developments will probably put pressure on the existing satellite-based offerings to drop prices.

Satellites are generally classified according to the orbits they occupy. Geosynchronous Earth Orbit (GEO) is approximately 36 000 km above the earth. Low Earth Orbit (LEO) is below 2 000 km and Medium Earth Orbit (MEO) is somewhere between LEO and GEO at approximately 10 000 km. Satellites generally orbit either above or below the Van Allen[2] radiation belt (1 500 to 10 000 km).

2.3.1 Geo-Stationary Satellites (VSAT)

The VSAT is a small bi-directional earth station that may be used to deliver integrated data, voice and video services via GEO Satellites. VSATs are mainly used as a replacement for leased line networks and is ideal for centralised computer networks. Medium to large geographically dispersed businesses often find that VSATs are cost justified when compared to terrestrial alternatives.

VSAT links are often employed in two fundamentally different ways: The term mesh topology is used to describe point-to-point connectivity between all stations and is usually applied to either temporary connections or dedicated links to connect pairs of earth stations. Star topology has a single hub that connects to all the stations in a point-to-multipoint fashion.

It is extremely difficult to estimate the various costs involved in implementing a VSAT communications solution. This is mainly due to the fact that there are numerous options and services available from various service providers. Also, one finds that the costs involved depend heavily on the topology of the planned network, the access technology chosen and the number of sites.

Telkom SA and Transtel are service providers in South Africa providing VSAT services.

2.3.2 Small Low Earth Orbiting Satellites (Little-LEO)

VitaSat is an example of a Little LEO satellite system, which are mainly used as store and forward type data and messaging systems.

VITA has been operating an experimental LEO satellite network using a satellite that has been carrying daily e-mail between several stations and VITA (where there is an Internet gateway in operation) for some years. Work continues with that satellite to bring it the level of functionality where VITA and others can use it. Plans to develop and use a Cape Town gateway are dormant awaiting further development.

VITA is also working on a totally separate effort which, when implemented, will make such communications much easier in the future. The idea is to co-ordinate a "virtual constellation" of low orbiting satellites already in orbit and to permit much greater utility through the development of a multi-satellite earth terminal which will cost a fraction of the current technology with a much higher degree of user "friendliness." It will be some months before this system is operational. (Exact time scale not known.)

Comments:

As the new VITAsat system is expected soon and the old platform will not be suitable for use for that, it would not be wise to invest in this system now. It does seem however that the new system

[2] energetic ionised particles may damage solar cells and other solid-state components

will warrant investigating when available. It seems possible that the initial costs for hard and software might be high.

A system deployed at a specific station would be static, but could be redeployed elsewhere with ease.

2.3.3 Big Low Earth Orbiting Satellites (Big-LEO)

Motorola's Iridium project – to provide global cellular services – consists of 66 LEO satellites; each weighing 689 kg and in an orbit of 780 km above the earth. Iridium is selling its satellite system as a backup network for cellular providers. Iridium subscribers will have their calls routed over the traditional cellular network when possible, but over the Iridium network if they are out of the range of cellular stations.

Figure 2: Motorola Dual Mode Handset for Iridium

Comments:

- Solar charger panels which stand-alone and can fold into a briefcase for use in the bush will be available. A preliminary expectation of the cost of this solar charger is about R4500.
- A data interface as on cell phones is available on the terminals.
- Forests (and foliage) and rain is not expected to be a problem when communicating.
- Itemised billing will provide details about the duration of each call. Additionally, some of the phones may have counters on them to determine minutes of usage.

2.3.4 MeteoSAT

The Meteosat satellite series are controlled by the World Meteorological Organisation (WMO) and operated by EUMETSAT, an intergovernmental organisation of 16 European states. The satellite is geostationary and located approximately 37000km above the earth over the equator at 0 degrees longitude.

Possibilities exist for the use of a number of the Meteosat channels free of charge, provided the data is made available to the WMO and the meteorological community. Enquiries should be directed to the WMO.

The Department of Water Affairs and Forestry (DWAF) has used the Meteosat system (for hydrological data collection) since the early 1990's. Each hydrological station communicates with the satellite at a designated time every hour. Mr Stefan Van Biljon of DWAF raised the following points:

- In comparison with an earlier Meteorburst system, the Meteosat system provided a saving of R2.6 million for the provision of communication for DWAF's dam water monitoring equipment.
- Meteosat ground equipment, however, is very expensive, proving to be four or five times more expensive than a cellular system.
- Remote sites are prone to vandalism and theft, with solar panels being a prime target. This has resulted in the decommissioning of at least two stations in recent years.

One channel that has been allocated to DWAF is being used temporarily by a SADAC country. Channel availability should be discussed with DWAF as well as WMO.

2.3.5 *Other future Satellite Systems*

Teledesic

Teledesic has an "Internet in the sky" vision at $9 billion cost. Teledesic will have 288 satelites in 12 longitudinal planes with 24 each operating under 1400km altitude. Teledesic will support millions of simultaneous users on fixed and mobile services.

Teledesic will begin offering service in 2003.

Comments:

Teledesic's laptop-size terminals are fixed, although it will be possible to transport them. Global coverage is envisaged

Teledesic is still under development. Teledesic will develop alliances with service provider partners in countries world-wide, rather than marketing directly to end-users. Teledesic will enable service providers to extend their networks; both in terms of geographic scope and in the kinds of services they can offer.

More Information: http://www.teledesic.com

SkyBridge

SkyBridge is a satellite-based system designed to provide global access to interactive, multimedia communications. Built around a constellation of 80 low earth orbit satellites, SkyBridge will provide the communications infrastructure for broadband services, including Internet access and high speed data communications. SkyBridge will also provide narrowband services and infrastructure links.

Services are expected to begin being rolled out by the end of 2001.

More Information: http://www.skybridgesatellite.com/c.htm

3 SYSTEM COST EVALUATION

The following cost comparisons are rough guidelines only, and exclude costs of civil engineering works, land purchase costs, manpower costs, maintenance costs etc. All these must also be taken into account when evaluating the overall cost of the system.

3.1 Fixed Line Telephone System

Capital costs per site: approximately R3, 000 – R5, 000 (this includes a R1000 modem)

Usage costs: Standard Telkom rates (R0.02 – R0.15 per minute local call)

see: http://www.telkom.co.za/tariffs/

3.2 Cellular Systems

Capital costs per site: approximately R5, 000 – R10, 000 (this includes a R1000 PC card)

Usage costs:

- voice – from R0.50 to R4.00/min (varies according to operator and airtime packages)
- data charges are the same as voice charges or less.

Recurring costs: R100 to R300/month rental

3.3 Private radio (Scada systems)

Capital cost:

- Per outstation: R6,000 for radio with a modem
- Up to 3 x repeaters to provide overall coverage: R20,000 per repeater station, including masts and antennas.

Usage costs:

- Licensing – R50 per annum

3.4 HF Radio

Purchase cost per site: R12, 000 – R40, 000

Running cost: R50 –R200 per month

3.5 Satellite Systems

3.5.1 Little Leo Satellite

At the moment a system is available at a discounted R30, 000 instead of R60, 000.

There are also licensing fees to be paid.

3.5.2 Geo-stationary Satellites

VSAT costs.

Capital costs: R30,000+ per station.

Licensing costs: Only Telkom is allowed to provide VSAT services in South Africa. Rental from Telkom is currently in the order of R4,000 per month.

3.5.3 Big-Leo Satellite

Connection fee: approximately R600.

Customer equipment (the handset – which looks much like a traditional cell phone) costs:

- R13, 000 for the Kyocera Iridium only terminal or
- R18, 000 for the Motorola dual mode terminal.

Usage costs:

- Iridium to Iridium calls within a country will be charged at about R12.00/min
- Iridium to PSTN calls will be charged at about R36.00/min.

Recurring costs: R600/month.

3.5.4 MeteoSAT Satellite

Capital costs: R60, 000 – R80, 000

Satellite usage costs: 0

Licensing costs:

3.5.5 Teledesic Satellite

The Teledesic system's low orbit enables the use of small, low-power terminals and antennas. The laptop-size terminals will mount flat on a rooftop and connect inside to a computer network or PC. Service providers will set end-user rates, but Teledesic expects rates to be comparable to those of future urban wireline services for broadband access

4 TECHNOLOGY SUPPLIERS

4.1 Own infrastructure

Technology	System / Supplier	Contacts
Private Radio	ProDesign	http://www.prodesign.co.za
	Spectrum	
	Lieberman / DAKA	http://home.global.co.za/~lieberma/dakahome.htm
	Alcom Systems	telephone (011) 807-7551
	Siemens	http://www.siemens.co.za/
HF Radio	Trans RSA	telephone (012) 6610361

4.2 Operator based infrastructure

Technology	System / Operator / Service Provider	Additional Notes
Telephone	Telkom	http://www.telkom.co.za
Cellular	Ott	
	DDS	http://www.ddsystems.co.za/
Trunking	Fleetcall	fleetcall@global.co.za
	Q-Trunk	http://www.q-trunk.co.za/
	One-2-One	
Wireless Data	SwiftNet	http://www.cellular.co.za/fastnet.htm
	WBS	telephone (011) 2340320
Little LEO satellite	Orbcomm	http://www.orbcomm.net/
	EcoSAT	
	VITA	
Big LEO satellite	Iridium	
V-SAT	Inmarsat (Telkom)	
MeteoSAT		http://www.eumetsat.de/ http://www.wmo.ch

5 OTHER ISSUES

5.1 General Issues

Questions that should be asked if towers need to be put up include:

- Who owns the land where the tower has to be located?
- How secure is the intermediate infrastructure?
- Are there any schemes that can be harnessed to prevent theft and vandalism of that infrastructure?

Cellular phones are very easily stolen due to their portability and high resale demand, and are not easily traced. Some insurance against theft may be required.

Another issue is how heavy equipment (such as VSAT dishes, solar panels, etc.) will be transported to the site, especially in remote areas with inaccessible sites?

It is unwise to rely on systems that are currently under development and have not been tested in the market. They may not work as expected or have other problems associated with them.

5.2 Sourcing and Training

When purchasing equipment externally, the following points should be considered:

- Customs duty
- Tax
- Transportation costs
- Power supply compatibility
- Training of personnel on the equipment

Purchasing support equipment necessary to keep communications equipment running can be fraught with 'hidden costs'.

A case in point is the purchase of solar generators capable of supplying 260 VA continuously. Some vendors tend to quote for parts instead of the entire infrastructure[3]. So there are many non-obvious costs. A solar power installation at that rating would have a solar panel, battery, inverter and regulator. This would cost about R60, 000. The solar panel would however require a steel superstructure fore the correct mounting of the solar panel. Various protection mechanisms are also necessary: for example to prevent a damaged inverter from damaging other components through 'back voltage'. In addition, lightning protection and cabling costs can push up the total price by a further R5, 000.

[3] The 'component-provider' versus 'system-provider' marketing approach

5.3 Regulation and licensing

The transportation of voice on networks that 'cross' public property is in most cases prohibited, especially if this is viewed as a bypass of existing public telecommunications infrastructure.

Some things to be mindful of:

- Is the transmission frequency in a band permitted by the regulator (when purchasing equipment from foreign countries)?
- Is a license required? And if so, is there a fee? (All satellite systems have to be licensed. There are two types of licenses – a usage license, which the customer has to obtain, and an operator's license.)
- Any fixed (point to point) communication can only be provided by Telkom as per the Telecommunications act. There are, however, other options where operators of mobile systems (Vodacom, MTN, WBS, etc.) could deploy their equipment in a fixed manner. Exception to the rule is also made when it is a telemetry (data only) application with point to multipoint linking.

6 RECOMMENDATIONS

Given all the options available, the MeteoSat option will be the most cost-effective long-term solution. This is, however, not a viable option due to the limit placed on the number of stations in any specific region.

The next best option is either cellphone or private SCADA based systems. With a cellphone system the variable cost is higher, but a network operator maintains the network. With a SCADA system the initial costs are higher, especially if repeaters have to be installed, but the variable cost is close to zero. Maintenance and support will be provided by the supplier of the equipment on a support contract or when required.

For the SCADA system, a license would be required. The wireless data operators can also provide a similar system without the licensing difficulties. Discussions are currently underway to further investigate the feasibility of this option.

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8 APPENDIX A: A WIRELESS TECHNOLOGY PRIMER...

8.1 Frequency

The higher the frequency the greater the potential data rate, but also the greater the impact of the environment (rain, dust, terrain, etc.) on the transmission. From VHF frequencies, radio line of sight is required to communicate. Lower frequencies generally require larger antennas. Transmission frequency is the primary determinant of the propagation properties of the signal. Frequencies often used in wireless communications are in the following bands:

Table 8-1: Frequency Band Characteristics

Band Name	Range	Comments
VLF (Very Low Frequency)	3 – 30 kHz	The earth and the ionosphere act as a waveguide. Used in submarine communications.
LF (Low Frequency)	30 – 300 kHz	Waves can travel through the surface of large objects like the earth as the earth acts as a conductor. Ionospheric effects can cause interference.
MF (Medium Frequency)	0.3 – 3 MHz	
HF (High Frequency)	3 – 30 MHz	Ionospheric propagation is dominant, so long distance communication is possible. Much interference and fading is experienced through the shifting of the ionospheric layers and sunspots.
VHF (Very High Frequency)	30 – 300 MHz	Ionospheric waves can be neglected (except for interference). Lower VHF frequencies can adapt somewhat to the terrain, so communication over distances of 100 km is possible. At the higher VHF and all UHF frequencies, communication is possible mainly in strictly line of sight conditions. Rain is generally not a problem.
UHF (Ultra High Frequency)	0.3 – 3 GHz	
SHF (Super High Frequency)	3 – 30 GHz	Rain, obstacles, and atmospheric attenuation become serious problems here.
EHF (Extremely High Frequency)	30 – 300 GHz	
Infrared	0.1– 1000 THz	Not capable of penetrating walls and other opaque objects or media such as dense fog or rain. This communication is weakened by strong light on the transmitter.

The range of frequencies in the VLF to EHF band is normally referred to as the "Radio Spectrum." The frequency spectrum, being a scarce resource, is highly controlled by the various national regulatory bodies who have designated particular frequencies for particular applications. Operations on those particular frequencies often require a license or are already allocated to a particular user. The license is usually only given after presentation of the technical specifications of the equipment to be used.

Microwave Frequencies

Microwave frequencies can be used for terrestrial line-of-sight communications but are especially used in satellite communications.

As frequencies increase antenna dish sizes can become smaller. Higher frequencies are also subject to increased fading due to rain and atmospheric loss and reduced ability to adapt to local terrain.

Microwave frequencies are divided into bands that are commonly designated by letters. Some characteristics and comments about these bands are provided in Table 8-2.

Table 8-2: Microwave Frequency Band Characteristics

Band	Freq. Range [GHz]	Comments
L	1 – 2	Effectively no rain attenuation but the ionosphere can introduce a rapid fading called ionospheric scintillation. This band represents a regulatory challenge and not a technical one. There are more uses and users for this spectrum than there is spectrum to use. Additional spectrum will be opened up as terrestrial users are migrated out.
S	2 – 4	Inherently low background noise level and suffers less from ionospheric effects than L band.
C	4 – 8	This is the most heavily developed and used piece of the satellite spectrum. Service characteristics are excellent because of modest amount of fading from rain and ionospheric scintillation. The large size earth station antenna is a drawback.
X	8 – 12.5	Military usage dominates. X band can provide service quality on par with C band, but commercial users will find the equipment costs to be higher due to the thinner market.
Ku	12.5 – 18	Spectrum allocations here are more plentiful than in C band. Digital Direct To Home (DTH) services such as DIRECTV use this band. VSATs and DTH receivers must anticipate more rain attenuation, but this can be countered by increasing satellite radiated transmission power.
K	18 – 26.5	
Ka	26.5 – 40	From a technical standpoint, Ka band has many challenges. The biggest is the heavy attenuation due to rainfall. Spectrum is abundant in this band and new services opt for this band for this reason and the high data bandwidths that it promises.

8.2 Power

At the same transmission power, higher frequencies tend to travel shorter distances than lower frequencies. Increasing power tends to improve the clarity and range of the received signal. The regulator in the operating license specifies limits on transmitter power.

8.3 Antenna

Antenna design affects transmission and reception of signals. Transmission range can be increased for the same power and frequency if a highly directional antenna is directed toward a receiver's antenna. Omnidirectional antennas allow point-to-multipoint communications, but a penalty is paid in terms of reduced range (and signal clarity as distance increases from the transmitter).

8.4 Modulation

Modulation techniques concern how information is to be carried on the base frequency and affects the ability of a transmission to be accurately detected in an electromagnetically noisy environment. They also affect the cost of the associated equipment.

8.5 Multiple Access

Multiplexing techniques govern sharing of the medium between multiple users. Examples of multiplexing techniques are TDMA (Time Division Multiple Access), FDMA (Frequency Division Multiple Access) and CDMA (Code Division Multiple Access).

8.6 Wireless Local Loop (WLL)

WLL is not a technology per se, but instead is an application of radio technology to extend the Public Switched Telecommunications Network (PSTN). A local loop contains the facilities that connect a customer's premises to the local telephone exchange. Traditionally, the local loop consists of pairs of copper wire to provide the connections and a significant investment in the PSTN has been made in this regard. But copper wire takes an appreciable amount of time to lay down, is subject to lightning damage and can be stolen. WLL is a wireless alternative for the local loop. Advantages of WLL are rapid deployment, less susceptibility to service disruption due to theft and better economic viability for sparsely populated areas.

8.7 Costs

The cost of using a technology to the user consists of three parts: capital costs, usage costs and recurring costs. Capital costs refer to things such as the cost of the equipment, installation costs, transportation costs, labour costs, etc. to set up communications equipment to operate in a specified way. Usage costs is totally depend on how much the technology is used and is often specified in terms of $/min or a $/kbyte charge. Recurring charges often appear as service charges ($/month) and occur only if an independent service provider is involved in the provision of telecommunication services.

8.8 Capacity

The capacity of a system is the amount of information it can carry, the direction it can carry it in and the type of information it can carry. The amount of information is often specified in bits per second (b/s) for digital systems or the number of circuits used for analogue systems. The flow direction can be simplex, duplex, half-duplex, symmetric or asymmetric. The information type can be analogue (e.g. voice, video) or digital (data, digitised voice), real-time or non-real-time.

8.9 Latency

Latency describes the amount of elapsed time before the receiver obtains sender transmitted information. Telephone conversations tend to be handicapped by latency greater than about 300 ms. Email is not much affected by latency.

8.10 Mobility

This term refers to the speed at which a communications device can be moved while still maintaining communications. Cellular phones for example have high mobility.

8.11 Coverage

This term refers to the area of use and can be a range or a geographic area.

8.12 Suitability

This is a term that is application subjective. The suitability of a technology is determined by the requirements of the user.

8.13 Technology Categorisation by Frequency

Table 8-3 provides an indication of the frequencies used by some technology options and how they may be classified. The table is not meant to be an exhaustive radio spectrum band allocation reference. A more comprehensive band allocation may be obtained from the following references: [SAgazette] and [USfreq].

Table 8-3: Technology Options According to Frequency

System	Frequency
HF Radio	1.6 – 30 MHz
Community repeaters	VHF and UHF frequencies for Walkie Talkies.
Tel. Line Extenders	144 – 174 MHz 403 – 430 MHz 450 – 470 MHz
Little LEO systems	137 – 138 MHz 148 –149.9 MHz 400.15 – 401 MHz
Public Trunking	Mobile Tx = 254 – 259.4 MHz (MPT1327) Base Tx = 262 – 267.4 MHz (MPT1327) Or Mobile Tx = 413.7625 – 417.625 MHz Base Tx = 423.7625 – 427.625 MHz
Terrestrial Cellular	824 – 849 MHz (CDMA and AMPS) 869 – 894 MHz (CDMA and AMPS) 890 – 915 MHz (GSM) 935 – 960 MHz (GSM)
Digital PMR[4] (trunk radio)	Mobile Tx[5] = 876 – 880 MHz Base Tx = 921 – 925 MHz
Cordless Telephone	864.1 – 868.1 MHZ (CT2) 914 – 915 and 959 – 960 MHZ (CT1)

[4] PMR is Private Mobile Radio
[5] Tx stands for Transmit

System	Frequency
Satellite Phone	Inmarsat mini-M Tx = 1.6GHz; Rx = 1.5 GHz GlobalStar Tx = 1.61 - 1.6265 GHz; Rx = 2.4835 - 2.5 GHz Iridium Tx = 1.616 - 1.626 GHz; Rx[6] = 1.616 - 1.626 GHz
Inmarsat B	Tx = 1.6265 – 1.6465 GHz; Rx = 1.5250 –1.5450 GHz
Terrestrial Cellular	1.710 – 1.785 GHz (GSM) 1.805 – 1.885 GHz (GSM) 1.850 – 1.910 GHz (GSM and CDMA) 1.930 – 1.990 GHz (GSM and CDMA)
Cordless Telephone	1.880 – 1.900 GHZ (DECT) 1.895 – 1.918 GHZ (PHS)
Teledesic	Tx = 28.6 - 29.1 GHz; Rx = 18.8 – 19.3 GHz

[6] Rx stands for Receive

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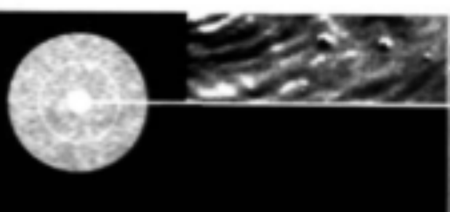

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