MINISTRY OF IRRIGATION AND WATER DEVELOPMENT

NATIONAL WATER DEVELOPMENT PROGRAM

(AFRICAN DEVELOPMENT FUND SUPPORTED COMPONENT)

CONSULTANCY SERVICES FOR ESTABLISHMENT OF WATER RESOURCES MONITORING SYSTEM

SITUATION AND NEEDS ASSESSMENT REPORT
Annexure 5:
Recommendation of Equipment Needs

Report No 03/106334

July 2011

aurecon

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1. Introduction

The Report on the Present Situation and Needs Assessment (Aurecon, Report No 03/106334, June 2011) gives a comprehensive assessment of the current state of the monitoring system and practices in the water resources department of the Ministry of Irrigation and Water Development. The functions underlying the water resources monitoring system in Malawi is generally in a poor condition affecting the integrity of some of the data. A serious shortage of operational budgets and capacity are experienced in all divisions where monitoring must be done as a routine function to ensure continuity and integrity of data management. An overview of the needs assessment was given with proposals to improve the situation.

The consultant team was requested to provide initial high level priorities to improve the service delivery of the Water Resources Monitoring System for Surface Water, Groundwater and Water Quality Services Divisions to stakeholders in the ministry and other ministries. The high level priorities identified in this document can only be fully refined to the level of individual instruments or activities once the present monitoring infrastructure has been reconciled with the updated monitoring system design. On request a report is herewith presented on the equipment required for the water resources monitoring systems as already identified during the needs assessment. It is important that some of this equipment must be acquired. This however should be seen as complementary to the operational needs and capacity building required to ensure effective monitoring of the water resources in Malawi.

Workshops were held with the respective divisions to finalise priorities of needs including processes and equipment. These proposed priorities and costing of the equipment have been further investigated and are detailed in this supplementary report as Annexure 5 to the Present Situation and Needs Assessment.

The needs of equipment are highlighted but where it is an integral part of a bigger activity, these were added as well. The needs are grouped according to the respective functions of Surface water monitoring, Water Quality Services, Groundwater monitoring and the crosscutting Management Information System.

All the price and cost estimates in this report exclude taxes and delivery costs and these will have to be added to the quoted prices to arrive at the total cost for these equipment. For the items available in South Africa this would include cost of delivery from South Africa to Malawi, while for certain items these costs are ex-works in the country of manufacture, such as the USA. All costs are based on July 2011 costs.

It was very difficult to obtain exact equipment requirements (numbers) for some of the tools, so the quotes are included here to give an indication of cost. Many of the quotes were obtained from suppliers in Malawi but a few of the items are only available in South Africa. In these cases the costs were converted to Malawi Kwacha at a rate of ZAR 1 = 22 MWK, the exchange rate in beginning of July 2011. Some of the costs vary by quite substantial amounts, but it is recommended where it is stated that the price difference is according to quality, that the more expensive item is procured as these will have a significantly longer life span.

2. Surface Water Monitoring

2.1 Overview of Surface Water Needs Assessment

The priority needs as assessed and discussed in workshops with the personnel are outlined in Table 2.1. Although gauge readers, staff and transport are the most urgent issues to deal with, this report concentrates on the capital and equipment needs. Transportation is now hired from a central vehicle department for the Malawi government and thus vehicles are not procured for the exclusive use of the Ministry anymore. The first four priorities have been included in Table 2.1 to emphasise their importance, as they are essential for the success of any of the other spending.

The most urgent equipment requirements include in descending order: equipment and consumables for maintenance of stations, survey equipment where necessary depending on the district, safety equipment for staff, new flow gauging equipment to replace the problematic Wagtech flow meters, digital cameras, maintenance of high flow gauging equipment (depending on the type of flow meters that are purchased) and upgrading of certain identified stations to automatic recorder stations, possibly with telemetry.

Table 2.1 Recommended priorities for budget allocation

Priority	Priority for budget allocation for equipment and operations
1	Budget to pay the gauge readers a decent wage or honorarium
2	Budget to hire the required staff per district
3	Transport (one 4x4 and motorcycle per district)
4	Budget for fuel and maintenance of vehicles
5	Procurement of everyday consumables and equipment for maintenance of stations
6	Procurement of new survey equipment where necessary
7	Procurement of safety equipment for staff
8	Procurement of new flow gauging equipment (flow meters and tapes) for each district to replace the problematic Wagtech meters
9	Procurement of digital cameras, rechargeable batteries and chargers to record the state of stations
10	Procurement or maintenance of high flow gauging equipment including bridge cranes, winches, cables and the refurbishment of cableways
11	Upgrade certain stations to automatic level recorder stations and possibly with telemetry

Equipment needs were summarised by district and are presented in Table 2.2. As mentioned previously, the state of transportation is shown in this table to highlight the urgency of this issue even though it is outside the scope of equipment and capital items. Each district should have permanent access to one 4x4 and one motorcycle.

Table 2.2 Equipment needs summarised by district

District	Transportation		Survey Equipment	Flow gauging			Safety equipment	Office equipment	General maintenance	
	4x4	Motorbike		Flow meter	Tape	High flow equipment for bridges			Consumables	Tools
Northern Region										
Chitipa	1 new 4x4 required	Maintenance required	Generally OK	New flow meter required	OK	Requires maintenance	New safety equipment required	Require new digital camera	Require gauge plates, angle irons, paint, cement	Require various new tools
Karonga	Maintenance required	1 new motorbike required	New tripod required	New flow meter required	Require new tape	Require new winch and cable	New safety equipment required	Require new digital camera	Require angle irons, paint, cement	Require various new tools
Rumphi	1 new 4x4 required	Maintenance required	Generally OK	New flow meter required	Require new tape	Generally OK	New safety equipment required	Require new digital camera	Require gauge plates, angle irons, paint, cement	Require various new tools
Mzimba & Nkhata Bay	1 new 4x4 required	1 new motorbike required	Generally OK	New flow meter required	Generally OK	Requires maintenance	New safety equipment required	Require new digital camera	Generally OK	Generally OK
Central Region										
Kasungu	Maintenance required	Maintenance required	Generally OK	New flow meter required	Require new tape	Generally OK	New safety equipment required	Require new digital camera	Require angle irons	Require various new tools
Nkhotakhota	1 new 4x4 required	Maintenance required	Generally OK	New flow meter required	Generally OK	Generally OK	New safety equipment required	Require new gauge reader books and digital camera	Require gauge plates, angle irons, paint, cement	Require various new tools
Lilongwe	Maintenance required	1 new motorbike required	Generally OK	New flow meter required	Generally OK	Generally OK	New safety equipment required	Require new gauge reader books and digital camera	Generally OK	Require various new tools
Ntcheu	1 new 4x4 required	Maintenance required	Generally OK	New flow meter required	Require new tape	Generally OK	New safety equipment required	Require new gauge reader books and digital camera	Generally OK	Generally OK
Southern Region										
Blantye & Zomba	Maintenance required	1 new motorbike required	New dumpy level, tripod and staff required	New flow meter required	Require new tape	Require new winch, cable and bridge crane (derrick)	New safety equipment required	Require new digital camera	Require gauge plates, angle irons, paint, cement	Require various new tools
Thyolo	1 new 4x4 required	1 new motorbike required	Generally OK	New flow meter required	Require new tape	Require new winch, cable and bridge crane (derrick)	New safety equipment required	Require new digital camera	Require angle irons, paint, cement	Require various new tools
Ngabu	1 new 4x4 required	1 new motorbike required	New dumpy level, tripod and staff required	New flow meter required	Generally OK	Require new winch, cable and bridge crane (derrick)	New safety equipment required	Require new digital camera	Require gauge plates, angle irons, paint, cement	Require various new tools

2.2 General tools and consumable equipment

Quotes were obtained for various general tools and consumables and are presented in Table 2.3. These are priorities 5, 7 and 9 in Table 2.1. It was very difficult to obtain exact equipment requirements (numbers) for these tools, so the quotes are included here to give an indication of cost. Many of the quotes were obtained from suppliers in Malawi but a few of the items are only available in South Africa. In these cases the costs were converted to Malawi Kwacha at a rate of ZAR 1 = 22 MWK, the exchange rate at beginning of July 2011. Some of the costs vary by quite substantial amounts, but it is recommended where it is stated that the price difference is according to quality, that the more expensive item is procured as these will have a significantly longer life span.

Table 2.3 Equipment estimates based on quotes obtained in July 2011

Item	Description	Units	Malawian suppliers Blantyre and Lilongwe (MWK)						South African suppliers Cape Town (MWK)			Comments
			Builders Whole-sale	LMD	Rainbow paints	Actor supplies	Bio Clinical Partners	Game	OTT SA	Zero Indus-tries	The Fishing Specia-list	
1	**Tools**											
1.1	Slasher	No.	950	875								Price difference due to quality
1.2	Panga	No.	500	295								Price difference due to quality
1.3	Pick	No.	1 850	3 050								Price difference due to quality
1.4	Shovel	No.	1 850	1 850								Price difference due to quality
1.5	Wheelbarrow	No.	14 500	12 950								Price difference due to quality
1.6	2 lb hammer	No.	600	2 250								Price difference due to quality
1.7	14 lb hammer	No.	2 700	11 750								Price difference due to quality
1.8	Hacksaw	No.	800	2 850								Price difference due to quality
1.9	Spirit level	No.	550	795								Price difference due to quality
1.10	Shifting spanner	No.	995	1 850								Price difference due to quality
1.11	3" Paint brush	No.		475				1 300				
2	**Consumables**											
2.1.1	First aid kit (small)	No.				5 300	6 900					Choice of size
2.1.2	First aid kit (medium)	No.					8 500					Choice of size
2.1.3	First aid kit (large)	No.					11 500					Choice of size
2.2	80mm x 80mm angle irons	2 m lengths		21 000								
2.3	White paint	5 litre tin	2 600	3 500				4 060				
2.4	Red paint	5 litre tin	12 475		13 500							
2.5	Cement	50 kg pocket		3 000								
2.6	Gauge plates	1.5 m							6 600			Only supplier in South Africa
3	**Safety equipment**											
3.1	Gum boots	Pair	2 000	2 850		2 600						
3.2	Raincoat	No.	1 100	1 850		1 700						
3.3	Life jacket (medium)	No.								11 200		
3.4	Waders										8 700	
3.5.1	Nylon tent, mosquito proof (2 man)	No.						6 000				Choice of size
3.5.2	Nylon tent, mosquito proof (3 man)							15 000				Choice of size
3.5.3	Nylon tent, mosquito proof (4 man)							22 500				Choice of size
3.6	Backpack - 50 litres size	No.						6 500				
3.7	Camp beds	No.						32 600				
3.8.1	Plastic road cones (large)	No.		4 850								Choice of size
3.8.2	Plastic road cones (medium)	No.				3 500						Choice of size
4	**Extras**											
4.1	Digital camera	No.						42 000				
4.2	Laptop computer	No.						150 000				Comments

2.2.1 Gauge plates

An estimate of the number of gauge plates that need replacement at all the surface water stations was made, based on the information gathered during the field trips. Table 2.4 detailed the total number of gauge plates that should be installed in the gauging network per Region and District.. Table 2.5 provides the number of gauge plates that currently need to be replaced.

Based on the estimate of gauge plates that need replacement plus the desired stock levels, the number of gauge plates that can be purchased can be calculated. The cost of each gauge plate was quoted at MWK 6,600 by OTT SA, the only supplier of gauge plates in South Africa.

Table 2.4 Estimate of total number of gauge plates that should be installed in the network

Region and District	0 - 1.5	1.5 - 3	3 - 4.5	4.5 - 6	6 - 7.5	7.5 - 9	9 - 10.5	10.5 - 12	Other markings	No Data	Totals
Central	**59**	**50**	**33**	**17**	**5**	**2**	**2**		**7**	**1**	**175**
Kasungu	11	11	9	3	2	1	1		1		**39**
Lilongwe	25	19	11	6	2				1		**64**
Nkhotakota	13	12	10	7	1	1	1				**45**
Ntcheu	10	8	4	2	1				5	1	**30**
Northern	**42**	**37**	**26**	**8**	**2**				**1**	**3**	**116**
Chitipa	8	8	8	3	1						**28**
Karonga	10	9	7	4	2					3	**32**
Mzimba	13	9	6								**28**
Nkhata Bay	3	3	2	1					1		**10**
Rumphi	8	8	4	1							**21**
Southern	**44**	**38**	**30**	**12**	**6**	**3**	**3**	**2**			**138**
Blantyre	12	11	10	2	2	2	2	1			**42**
Ngabu	11	11	8	4	2	1	1	1			**39**
Thyolo	12	9	6	4	2						**33**
Zomba (Blantyre)	9	7	6	2							**24**
Grand Total	**145**	**125**	**89**	**37**	**13**	**4**	**5**	**2**	**8**	**4**	**428**

Table 2.5 Estimate of gauge plates that need to be replaced, based on field trips

Region and District	Total Open Stations	Inspected Stations	No Data	0 - 1.5	1.5 - 3	3 - 4.5	4.5 - 6	6 - 7.5	7.5 - 9	9 - 10.5	10.5 - 12	Other gauge plate markings	Totals
Central	**55**	**43**	**1**	**27**	**23**	**20**	**11**	**4**	**1**	**2**			**88**
Kasungu	11	10		6	6	6	2	1	1	1			**23**
Lilongwe	19	14		11	7	7	5	2					**32**
Nkhotakota	11	5		3	3	3	2			1			**12**
Ntcheu	14	14	1	7	7	4	2	1					**21**
Northern	**42**	**21**	**3**	**16**	**11**	**11**	**4**	**1**				**1**	**44**
Chitipa	8	4		3	2	2	1	1					**9**
Karonga	12		3	3	2	2	1						**8**
Mzimba	10	5		3	2	2							**7**
Nkhata Bay	4	4				1	1					1	**3**
Rumphi	8	8		7	5	4	1						**17**
Southern	**39**	**35**		**22**	**21**	**17**	**7**	**4**	**3**	**3**	**2**		**79**
Blantyre	11	9		7	5	5	2	1	2	2	1		**25**
Ngabu	9	9		6	6	7	1	2	1	1	1		**25**
Thyolo	10	10		6	6	2	2	1					**17**
Zomba (Blantyre)	9	7		3	4	3	2						**12**
TOTALS	**136**	**99**	**4**	**65**	**55**	**48**	**22**	**9**	**4**	**5**	**2**	**1**	**211**

2.3 Survey equipment

Together with general tools, consumables and safety equipment for staff, the other urgent requirement is for replacement of survey equipment in certain districts. The districts and their survey equipment needs are given in Table 2.2. Each district should have an automatic level, staff and tripod. These are essential to allow the checking of levels of gauge plates off bench marks and the setting out of additional bench marks.

Quotations for survey equipment were obtained from two suppliers in South Africa (Table 2.6), as there is no supplier of survey equipment in Malawi.

Table 2.6 Quotations received for survey equipment, prices in Malawi Kwacha

Description	Units	Cost from various suppliers (MWK)	
		J Allen Instrument Services, Cape Town, South Africa	GB Survtek, Cape Town, South Africa
Automatic level "Pro-Shot AL-24"	No.	17 600	23 430
Automatic level "Nikon AX-2S"	No.	37 180	37 180
Tripod	No.	7 480	12 100
Staff (5m, 5 sections)	No.	4 400	9 680
50m tape	No.	5 500	10 560
100m tape	No.	13 200	23 980

Based on the quotes in Table 2.6, a cost estimate for re-equipping the districts in need of new survey equipment is given in Table 2.7. Discussions with the supplier revealed that there is very little difference in quality between the two manufacturers of survey levels so the cheaper manufacturer was selected.

Table 2.7 Cost estimates for replacing all missing survey equipment

Item	Description	Units	Quantity	Rate (MWK)	Cost (MWK)
1.1	Automatic level "Pro-Shot AL-24"	No.	2	17 600	35 200
1.2	Tripod	No.	3	7 480	22 440
1.3	Staff	No.	2	4 400	8 800
1.4	50m tape	No.	6	5 500	33 000
1.5	100m tape	No.	6	13 200	79 200
TOTAL					**178 640**

2.4 Flow meters

The next-most urgent equipment that needs to be procured is flow meters to replace the ageing Braystoke and problematic Wagtech flow meters.

Various suppliers were contacted in South Africa and abroad for both the Doppler-type meters and for other more traditional type meters including propeller and electro-magnetic meters. The suppliers who were contacted are listed in Table 2.8. More detail one each flow meter is given in Tables 2.9 to 2.14.

Table 2.8 Summary of flow meters, suppliers and manufacturers

Supplier	Manufac-turer	Flow meter	Opera-tion principle	Flow depth range (m)	Flow velocity range (m/s)	Operating tempera-ture (˚C)	Recom-mended training time	Capital cost of instruments only (MWK)	Training cost	Advantages	Disadvantages
GeoWater South Africa	Global Water Instrumen-tation, USA	Flow Probe FP211 (1.5-5m extension)	Propeller	0.05 - 5	0.1 – 6.1	-20 – 70	2 days	185 460	Provided by Aurecon	Cheap Velocity read-out on display	Not a very accurate instrument for low-flow measurements. (Soupir et al (2009)) Design does not include a wading rod to set height of meter above streambed. Not for gauge flows deeper than 5m and not practical for use off a cableway or bridge
GeoWater South Africa	Marsh-McBirney, USA	Flo-Mate 2000	Electro-magnetic	0.05 - 25	-0.15 – 6	0 – 50	8 days, including follow up at 6 months	1 492 480	Provided by Aurecon	Calibration is easy No moving parts Velocity read-out on display Rugged	According to Soupir et al (2009) this is the most accurate instrument for low-flow measurements but none of the Doppler meters were tested in that study.
OTT SA South Africa	OTT, Germany	Universal Current Meter C31	Propeller	0.05 - 25	0.025 – 10		8 days, including follow up at 6 months	7 541 820	Provided by Aurecon	Rugged Staff have experience with propeller meters already	Will require rehabilitation of cableways
OTT SA South Africa	OTT, Germany	Qliner	Doppler	0.45 – 20	-10 – 10	-5 – 35	8 days, including follow up at 6 months	3 575 000	968 000	Frequency = 1 MHz Can give results more accurate than the instruments that rely on the traditional velocity-area method	Maximum operating temperature is only 35 ˚C which in Malawi is regularly exceeded Requires use of a tag line which limits the size of river that can be gauged unless there is a suitable bridge or cableway.
Moncon South Africa	Sontek, USA	M9	Doppler	0.20 – 30	-20 – 20	-5 – 45	8 days, including follow up at 6 months	7 172 000	739 200	The maximum operating temperature is 45 ˚C which occurs less often in Malawi Wide depth range Recommended by RSA Department of Water Affairs Proven Southern African track record No cableways necessary	Maximum operating temperature is 45 ˚C which is exceeded in certain areas of Malawi frequently
Teledyne RDI Europe France	Teledyne RDI, USA	Streampro	Doppler	0.15 – 7	-2 – 2	-4 – 40	4 days	7 692 150	1 875 000	Frequency – 600 kHz for RiverRay Combination of instruments allows for wide range in depths No cableways necessary	Requires both instruments to be able to gauge both shallow and deep flows Maximum operating temperature is 40 ˚C which is exceeded in certain areas of Malawi frequently
Teledyne RDI Europe France	Teledyne RDI, USA	Riveray	Doppler	0.30 - 40	-5 – 5	-5 – 45					

2.4.1 Propeller meters

Propeller meters measure velocity by placing a propeller in the water stream and measuring the speed at which the propeller is turning. Propeller meters measure velocity at the point where the propeller is situated. The technique to measure flow in rivers using propeller meters is called the velocity-area method, where velocities are measured at various points across a river's cross-section (located perpendicular to the flow direction and in a river reach where the flow lines are parallel), and the velocity at each point is multiplied by the area around it half-way to the next measuring point.

Propeller meters have in the past been used in Malawi and the advantage of these meters includes the fact that the staff has experience with them and that the measuring technique takes place over fairly long time spans so that fluctuation of flows can be averaged out during measurements. The drawbacks though of these meters is that a network of cableways is required to undertake high flow measurements, unless a suitable bridge is located near to the structure from which to undertake these measurements. The measurement technique takes the reading over a period of time so that if the flow rate is quickly decreasing or increasing then an incorrect flow reading can be obtained. In addition, to obtain accurate flow measurements using these meters the cross-section of the river must be split up into a large number of sections. Many sources state that at least 25 sections are required to obtain an accurate estimate of the flow and it is often not done in the field.

The choice of a hydraulically suitable site is critical to accurate results. In deep water, measurements should be done at both 20% and 80% of the depth at each section, while in shallower water one measurement at 60% of the depth is generally sufficient. Thus accurate measurement using propeller meters is generally time-consuming and requires a good knowledge of hydraulics by the operators.

The suppliers for propeller meters contacted were OTT SA and GeoWater, both based in South Africa. The cost estimates from both these suppliers do not include training. Training could be provided by Aurecon if either of these instruments were selected.

The cost estimate for the Global Flow Probe is in Table 2.9. The Global Flow Probe was the cheapest of all the instruments investigated, but it also gives the least accurate results according to Soupir et al (2009). One of the major drawbacks of this instrument is that it does not include a wading rod, thus no methodical method is followed to gauge flow. The manufacturer merely states that the user should move the flow probe through the river cross-section until a constant velocity is read out on the display. This instrument is not suitable for large rivers.

Table 2.9 Cost estimate for Global Flow Probe propeller flow meter (supplier GeoWater)

Item	Description	Cost (MWK)
1.1	New Flow Probe FP211 (1.5-5m extension) with carry case	185,460
TOTAL		**185,460**

The cost estimate for the OTT C31 propeller meter is in Table 2.10. This appears to be a good quality propeller meter, and the table includes all the equipment that would be required both for high and low flow gauging in large and small rivers. If propeller meters are desired then it is recommended to select the OTT C31.

Table 2.10 Cost estimate for OTT C31 propeller flow meter (supplier OTT SA)

Item	Description	Cost (MWK)
1.1	C31 Current Meter on wading rod	
1.2	C31 Current meter body	523 380
1.3	Tools incl. propeller oil	17 160
1.4	Ground pin long for 125 mm propeller	5 720
1.5	Propeller No. 1, brass, 125 mm dia., 0.25 m pitch (0.025 - 5 0 m/s)	200 200
1.6	Calibration BARGO up to 2.5 m/s	62 920
1.7	Velocity tables BAREL for calibration BARGO	14 300
1.8	Connecting cable 111/110, 4 m long	34 320
1.9	OTT Z400 with flow computation feature	240 240
1.10	Instrument case aluminium	68 640
1.11	Wading rod 20 mm dia., 3m long in 3 sections	171 600
1.12	Relocating device HERES	128 700
1.13	Canvas bag for wading rods	34 320
1	**SUM for wading rod use**	**1 501 500**
2.1	C31 Current Meter cable suspended	
2.2	Intermediate piece	42 900
2.3	Stabiliser tail piece (1.4 m long in 2 sections with tail fin)	280 280
2.4	Instrument case for above items (including space for current meter and propellors)	157 300
2.5	Middle piece 25 kg with watertight ground feeler	715 000
2.6	Carrying case	100 100
2.7	Middle piece 50 kg with watertight ground feeler in carrying case	929 500
2.8	Carrying case	100 100
2.9	Cable 111/200 from winch to counter set, 2.5 m long	25 740
2.10	Single drum winch 25 to 50 kg with safety clutch	1 278 420
2.11	Safety crank for single drum winch	91 520
2.12	Carrying case for single drum winch, current meter cable and connection cable	128 700
2.13	Current meter cable 111/454, 25 m long, type D5 galvanised, with thimble and plugs, installed on winch	171 600
2.14	Movable trolley, aluminium, portable incl. pulley for jib for maximum 50 kg weight	509 080
2.15	Middle piece 100 kg with watertight ground feeler for use in cableway installations	1 315 600
2.16	Carrying case	128 700
2.17	Bearing plate for mounting the winch on a jib	65 780
2	**SUM for bridge and cableway equipment**	**6 040 320**
SUM TOTAL for all current meter equipment required		**7 541 820**

2.4.2 Electro-magnetic meters

Electromagnetic meters work by the principle that a magnetic field set up in a flowing water stream creates a voltage which can vary with velocity. By measuring the voltage a velocity can be determined.

Electromagnetic meters are used in a similar manner to propeller meters, whereby they also measure velocity at a point only. The velocity-area method is also used to determine flow and the number of measurement points, depth of measurement and choice of site are equally critical. The advantage of these meters over propeller meters is that these meters have no moving parts and are robust. In addition they do not need to be re-calibrated.

The only supplier of this type of flow meter in South Africa is GeoWater (based in South Africa) who supply the Marsh McBirney Flo-Mate 2000 (Table 2.11). According to Soupir et al (2009) this flow meter is the best all-round flow meter for low flow gauging, out of the flow meters that they tested (however they did not test the Doppler type meters discussed in the next section). This flow meter is suitable for both low and high flow gauging on large and small rivers, but the light finned weight would limit the velocities that can be gauged at high flows, compared to those that could be gauged using the OTT C31 propeller meter. The quote also did not include a winch, tackle or bridge crane. This instrument may not be well suited to very large and fast flowing rivers during high flows. The cost does not include training, which could be undertaken by Aurecon.

Table 2.11 Cost estimate for Marsh McBirney Flo-Mate 2000 electromagnetic flow meter (supplier GeoWater)

Item	Description	Cost (MWK)
1.1	Flo-Mate 2000 with detachable cable connection to water resistant display unit, with 6m cable, universal sensor mounting, padded carry case & manual	1 030 700
1.2	Metric Top Setting wading rod set (with 3 wading rods of 600mm each)	213 620
1.3	Additional cable for the Flo-Mate 2000 (25 m)	44 000
1.4	Suspension cable kit with 6.8 kg finned weight and hanger (excludes stainless steel cable)	176 660
1.5	Suspension stainless steel cable (25 m)	27 500
TOTAL		**1 492 480**

2.4.3 Doppler meters

Historically gauging of flow has been done using the meter types described above in conjunction with the velocity-area method. Propeller meters and the velocity-area method have been used for well in excess of 100 years, some sources state as long as 185 years. However in the last 15 years a new technology using ultrasonic technology and the Doppler effect has become available and although at first there were many issues with this technology, the technology has now improved sufficiently.

Various types of Doppler meters are available in the market place. The three main types available for streamflow gauging are:

- The first type measures point velocity and therefore relies on the velocity-area method as described previously for electro-magnetic and propeller meters, and which would then subject these meters to all the same limitations as those velocity meters. None of these meters were priced as they are more expensive than the above mentioned propeller and electro-magnetic type flow meters.
- The second type are pulled across a river on a small boat along a tag line, where a reading is taken by the instrument at each regularly spaced tags on the line and an average velocity for each tag point representing the average velocity in that section below the meter is used to determine a total velocity for the section. The drawback of this type of flow meter is that it requires a tag line which would be challenging or even impossible to set up on wide rivers. Gauging can be done off bridges but there are not always suitable bridges at all stations,

therefore various cableways would need replacement or maintenance. They however have the advantage of making gauging of smaller rivers far faster and more accurate than traditional meters and the velocity-area method. OTT (Germany) produce a flow meter which works on this principle.

- The third types track the bottom as they are moved across the river thereby enabling them to determine a flow for the section in one pass without any stops while also being independent of any tag line. This also means that they can be attached to both a small custom-made boat for small rivers and to a full-size boat with a driver for large rivers. For situations where the bed is also moving, such as what is common in Malawi especially in the rainy season, a GPS is attached to the instrument thereby allowing the position of the boat to be determined at all times via the GPS. The huge advantage of this technology is the speed at which gaugings can be done and the fact that cableways are no longer necessary at each gauging station. Both Sontek (USA) and Teledyne RDI (USA) produce this type of flow meters.

For the second and third types, site selection for flow gauging is still critical to the accuracy of the measurement, but the measurement itself is more accurate than that of a propeller meter. Another big advantage is that these two Doppler systems automate many of the decisions that would otherwise need to be made, reducing the risk of human error in the gauging process. The methodology is more forgiving than with propeller or electromagnetic meters as the meter can compensate for velocities measured at angles not perpendicular to the cross-section across the river and because the velocity is measured at numerous points in the cross-section both in the vertical and horizontal planes.

The third type of Doppler meter is the most sophisticated - the instrument is moved across the river perpendicular to the flow direction (although it is not necessary for it to be exactly perpendicular as the instrument can account for flow direction as well) and it then divides the river cross-section into numerous cells for each of which a velocity is measured. This third type of flow meter can (depending upon the manufacturer) measure flows from relatively shallow flows to deep flows, thus allowing one instrument to be used to measure both low and high flows.

The lower the frequency of the sound emitted, the greater the penetration of the sound waves through moving sediment to the real bottom of the river. Thus the lowest frequency Doppler options have been selected for each option.

The cost estimate for the second type of flow meter (Q liner supplied by OTT SA in South Africa), which requires a tag line, is given in Table 2.12. The cost estimate includes the cost of two training courses given by the supplier. This Doppler meter works at 1 MHz.

Table 2.12 Cost estimate for Doppler flow meter (supplier OTT SA)

Item	Description	Cost (MWK)
1.1	Q liner doppler meter (up to 20m depth)	3,575,000
1.2	5 days initial training, including flights, accommodation, food	583,000
1.3	3 days refresher course after 6 months including flights, accommodation, food	385,000
TOTAL		**4,543,000**

The cost estimates for the two competing Doppler systems which have bottom tracking capability are given in Table 2.13 and Table 2.14. Both the cost estimates include for training held by the supplier. Note that the supplier for Teledyne RD Instruments is based in France while the supplier for Sontek (Moncon) is based in South Africa.

Table 2.13 Cost estimate for Doppler flow meter (supplier Moncon)

Item	Description	Cost (MWK)
1.1	Sontek River Surveyor M9 (medium depth water 0.2 - 35 metres)	4,840,000
1.2	Telemetry with DGPS using bottom tracking and DGPS as reference	1,650,000
1.3	Oceanscience Group riverboat tri-maran (to mount equipment onto)	682,000
1.4	5 days initial training, including flights, accommodation, food	440,000
1.5	3 days refresher course after 6 months including flights, accommodation, food	299,200
TOTAL		**7,911,200**

Discussions with staff at South Africa's Department of Water Affairs (Dr Pieter Wessels) who run the South African surface water monitoring network, recommended that Malawi should adopt the Doppler technology due to its superior accuracy and they recommended that Sontek should supply the instruments, as the service delivered to them has been good. Sontek have also supplied these flow meters to other Southern African countries including Mozambique and Zambia.

Two separate flow meters would be required if the option supplied by Teledyne RD Instruments was selected as the StreamPro can only measure flows up to 7 m depth.

Table 2.14 Cost estimate for Doppler flow meter (supplier Teledyne RD Instruments)

Item	Description	Cost (MWK)
1.1	StreamPro ADCP without Pocket PC (up to 7m depth)	2,467,500
1.2	RiverRay Phased Array 600Khz	3,975,000
1.3	Training on site 4 days, including flights, accommodation, food	1,875,000
1.4	*OPTION: StreamPro Compass(required for rivers with a moving bottom)*	262,500
1.5	*OPTION: Hemisphere A100 Smart Antenna DGPS for RiverRay (required for rivers with a moving bottom)*	537,150
1.6	*OPTION: StreamPro GPS Kit (required for rivers with a moving bottom)*	450,000
TOTAL		**9,567,150**

2.4.4 Recommendation for purchase of new flow meters

It is recommended that the Sontek River Surveyor M9 is purchased if new flow meters are desired, as there is already wide ranging experience with this flow meter throughout Southern Africa. The supplier also obtained a good recommendation from the South African Department of Water Affairs (DWA). A major advantage of these flow meters is that there will be no need to rehabilitate any of the cableways in the country as would be the case with all the other flow meters except the Teledyne RDI StreamPro / RiverRay option. In addition this instrument is according to the DWA very accurate.

It is recommended that if these new flow meters are purchased, one flow meter is acquired first for each region as a pilot and tested for a while and any issues are sorted out with the supplier. After this, the balance of the flow meters could be purchased.

2.4.5 Alternatives to the Purchase of New Flow Meters

An alternative to purchasing new flow meters is to contract one of the suppliers to undertake the flow gauging themselves. Sontek were approached to provide as estimate to undertake the river gauging under contract instead of this being done in-house, but unfortunately the quotation was not received in time for this report.

The advantages of this would be that the flow gauging could be undertaken by the experts quickly and efficiently. The disadvantage would be that no development of the Malawian staff would be achieved and that the Malawian staff would not be familiar with the issues that were encountered during certain gaugings that could later explain anomalies in the rating curves and data.

2.5 Flow gauging stations

Some of the primary flow gauging stations could be upgraded as part of an equipment replacement program, but it is recommended to first spend available funds on the equipment discussed in the previous sections.

The South African Department of Water Affairs was consulted on the cost of new gauging stations that include a gauging weir, automatic logger and telemetry. Recent costs ranged from MWK 480 000 000 for a 200 m wide weir on poor foundations in the Orange River, to MWK 370,000,000 for a 75 m wide weir in Lesotho, to MWK 77 000 000 for a 32 m wide weir on good foundations in the Olifants River in the Western Cape Province.

The cost of installing automatic equipment is about MWK 22 000 000 according to the South African Department of Water Affairs, including the house, loggers, telemetry via satellite etc. Gauge plates are still required at these weirs together with a gauge reader to provide a backup to the automatic system and to check that the automatic system is working correctly.

If it is desired to upgrade certain stations to these state of the art installations, it is then recommended to firstly target the SADC-HYCOS stations which have already been through a rigorous selection process and are therefore key stations both nationally and internationally.

2.6 Data loggers

A quotation for setting up an automatic station including telemetry via GSM (mobile phone network) was also obtained. These estimates are given in Table 2.15. These estimates exclude the cost of installation.

Table 2.15 Cost estimate for Automatic Level GSM/SMS Logger (supplier 4water)

Item	Description	Cost (MWK)
1.1	Cello GSM Data logger	280 324
1.2	Interface cable	19 229
1.3	Control Centre	354 201
1.4	Data input cable	48 070
1.5	Cello maintenance kit	15 400
1.6	Cello hanging bracket	2 152
1.7	Cello big top lid p/antenna	35 419

Item	Description	Cost (MWK)
1.8	User replaceable battery pack	21 504
1.9	Multi-channel data input box	31 877
1.10	10-way.mil.spec plug & box	15 940
2.1	CTE9000 4-20mA depth level transmitter	99 934
2.2	CTE9000 4-20mA cable per meter	2 620
2.3	CTE9000 4-20ma cable hanger	9 362
3.1	Metrolog 4-20mA backup logger	103 729
3.2	Metrolog 4-20mA 10.w.spec plug & box	16 446
TOTAL		**1 056 205**

This data logger needs a SIM card to operate and an agreement with one of the cellular phone networks in Malawi would be required. In addition many stations are located where there is no cell phone reception and these stations would require satellite telemetry equipment.

3. Groundwater Monitoring Systems

The Needs Assessment Report (Aurecon, April 2011) and the associated Workshop (June 2011) made the following recommendations with regard to the maintaining and strengthening of the National Groundwater Monitoring Network (NGMN):-

- To maintain the current network in terms of rehabilitation and monitoring by water monitoring assistants (WMAs) and personnel of MoIWD
- To increase the network from the current 24 to +/- 100 boreholes at the rate of 20 per annum
- Professionally test pump existing and new network boreholes to get T, S and SC values.
- To map ground water quality distribution and produce National Map
- Upgrade the Central Water Laboratory in terms of analytical equipment and sustainable procedures
- To manage measured monitoring data centrally by MoIWD (NGMN database)
- Set up of Standard Operating Procedures for the relevant stakeholders
    - in relation to contractors and consultants that construct/supervise new network boreholes
    - in relation to MoIWD and WMAs in data collection, management and reporting
    - in relation to Water Resources Board (WRB) in controlling and issuing water rights for boreholes

Some of these are Government-maintained services that require equipment to be purchased in addition to training and improvement of operational activities. In relation to network expansion / rehabilitation, ground water quality mapping and obtaining aquifer values through test pumping, the services of Consultants and Contractors for drilling and test pumping are required. Indeed, in terms of expanding the NGMN it is highly recommended that a consultant be appointed to firstly finalise the positions and secondly manage (with MoIWD) the drilling of the first new batch of boreholes. All of these are quantified and costs estimated in this report.

3.1 Rehabilitation and Monitoring of Existing Boreholes

3.1.1 Rehabilitation of Existing Boreholes

The report “Field Review of 35 Water Monitoring Boreholes’’ annexed to the Needs Assessment Report (Aurecon, May 2011) details four boreholes vandalised and filled with stones. These are beyond repair and need to be officially abandoned. Replacement will be contained in the proposed NGMN expansion (Section 3.2).

Of the 31 good monitoring boreholes 26 are urgently in need of cover plates with locks to prevent vandalism. The existing boxes will have to be broken and replaced with similar cover plates including a hinged lid / frame with a stout lock. Locks should have at least 3 keys. Down the hole, logging has been planned using casing penetrating probes so as to log the geology of the existing monitoring boreholes.

3.1.2 Monitoring of Existing Boreholes

The WMAs make the measurements at the monitoring boreholes and MoIWD have to check, coordinate and plan. The following is required to sustain this process:-

- Equipment. Motorcycles, helmets, gloves, cell phones, SIM cards, water level meters, plumb lines, GPS's, pH and EC meters, Iron checker discs, laptops, memory sticks.
- Equipment. Automatic water level recorders including data capture units and transfer cables. Barometric pressure measuring equipment and laptops

To automate water level determinations requires quite a lot of sophisticated equipment, training and procedure. Automatic recorders record at 1 – minute intervals and are accurate to +/- 25cm without pressure correction and +/- 5cm with pressure correction. It is clear that for meaningful results barometric pressure corrections are required together with accurate elevation of the borehole collars (see Section 3.2) . This will still require the WMA to visit the site at periodic intervals (e.g., every 6-months) to pull out the recorder and download the data to a field data recorder. This will then be downloaded to a laptop at the Water Office and the raw data compensated for pressure variation over the corresponding period using data from an automatic pressure recorder mounted at the Water Office. This cannot be done centrally in Lilongwe as pressure correction is a local rather than a regional correction.

For the automation process to be initiated at the 31 existing monitoring sites the following items are budgeted:-

- 31 automatic water level data loggers with Kevlar suspension cords (one at each site)
- 20 portable Data Capture Units with USB data cable (one for each district Water Office / WMA)
- 20 barometric pressure loggers with USB data cable (one for each district Water Office)
- 20 laptops for capturing and correcting water level and pressure data (one for each district Water Office)
- Contract for the initial installation at 31 sites and for the training of the WMAs, etc

The envisaged quantities and costs are captured in Table 3.1 and summarised in Table 3.6.

Table 3.1 Costs for automation process to be initiated at the 31 existing monitoring sites

Item	Description	Unit	Quantity	Rate (MWK)	Amount (MWK)
1 .0	Equipment for WMAs				
1 .1	Motorcycles (e.g. Suzuki 125TF) with helmet, gloves and wind jacket	Item	12	750 000	9 000 000
1 .2	Automatic Water Level Recorders: Brand: Solinist. Range: Levelogger Gold LT with temperature and depth sensors. Models: F15/M5, F30/M10, F100/M30, F330/M100. Accessories: Kevlar suspension rope (100m).	Item	31	200 000	6 200 000
1 .3	Portable Data Capture Units for each Water Office: Brand: Solinist. Model: Leveloader Gold. Accessories: Standard Communication package (optical read-out unit, CD with manual and software for USB communication)	Item	20	400 000	8 000 000
1 .4	Barometric Pressure Loggers for each Water Office. Brand: Solinist. . Model: Barologger Gold M1.5/F5	Item	20	200 000	4 000 000
1 .4	Laptops with memory sticks for each water Office (to process the water level data)	Item	20	100 000	2 000 000
1 .5	Water level dippers - 100m	Item	20	80 000	1 600 000
1 .6	Cell phone with SIM card	Item	20	7 500	150 000
1 .7	Mobilisation of down the hole logger	Lump	1	2 500 000	2 500 000
1 .8	Miscellaneous stationery	Lump	1	300 000	300 000
	Sub total				33 750 000
2 .0	Equipment for MoIWD				
2 .1	EC stick meters with calibrant	Item	20	30 000	600 000
2 .2	pH stick meters with calibrant	Item	20	30 000	600 000
2 .3	Iron checker discs	Item	20	20 000	400 000
2 .4	Stop watches	Item	20	6 000	120 000
2 .5	Laptops with memory sticks	Item	6	100 000	600 000
2 .6	GPS hand held e.g. Garmin	Item	6	80 000	480 000
2 .7	Water level dippers - 100m	Item	6	80 000	480 000
2 .7	Borehole plumb lines - 100m	Item	6	50 000	300 000
	Sub total				3 580 000
3 .0	Contract to down the hole log and then secure 26 Existing Monitoring Sites				
3 .1	Dismantle existing box structure and remove material from site	Bore-hole	26	20 000	520 000
3 .2	Build new box 0.75 x 0.75m x 0.6m deep with reinforcing, cast or plastered brick with inset steel frame with hinged and locking lid, Heavy duty padlock.	Bore-hole	26	100 000	2 600 000
3 .3	DTH log to determine geology	Bore-hole	26	215000	5 590 000
	Sub total				8 710 000
4 .0	Contract to install 31 automatic water level loggers - existing boreholes				
4 .1	Calibration / Installation of Levelogger Gold LT in monitoring boreholes with test data download inclusive of mobilisation and incidentals	Bore-hole	31	80 000	2 480 000
4 .2	Training of WMA's, Water Office staff in data capture / download / barometric pressure adjustments and transmission to headquarters of water level data inclusive of mobilisation and incidentals	Bore-hole	20	200 000	4 000 000
	Sub total				6 480 000
4 .0	**Total (Item 1-4)**				**52 520 000**

3.2 Expanding the NGMN with 20 new boreholes per annum

It is proposed to expand the NGMN in steps of 20 new boreholes per annum. This expansion involves two main components:-

- Equipment. Extra items as already listed in Section 3.1.2
- Professional Services. Ground water consultant and, siting, drilling and test pumping contractor(s) and a surveyor.

Consultancy services would be firstly engaged to identify the position and the priority of the 76 boreholes to be drilled in the overall programme. Thereafter the same consultancy or another would be engaged to manage and supervise:-

- The geophysical siting of 20 boreholes at the recommended and prioritised points
- The drilling of 20 boreholes with three sites chosen for two piezometer / observation boreholes
- The test pumping of the 6 selected sites with piezometers
- Installation of the new batch of automatic water level recorders
- Determination of an accurate collar elevation on 31 old and 20 new sites – in order to ensure that the groundwater contour map becomes accurate (not so at present).

The consultant would log the boreholes and assign intersections to Malawi lithological position, analyse the pumped well and observation well data for hydraulic parameters and produce a professional report.

The envisaged quantities and costs are captured in Table 3.2 and summarised in Table 3.6.

Table 3.2 Needs and Costs for expanding the NGMN with 20 new boreholes per annum

Item	Description	Unit	Quantity	Rate (MWK)	Amount (MWK)
1.0	**Equipment for WMAs to monitor 20 extra sites**				
1.1	Motorcycles (e.g. Suzuki 125TF) with helmet, gloves and wind jacket	Item	3	750 000	2 250 000
1.2	Automatic Water Level Recorders	Item	31	200 000	6 200 000
1.3	Water level dippers - 100m	Item	3	80 000	240 000
1.4	Cell phone with SIM card	Item	3	7 500	22 500
1.5	Miscellaneous stationary	Lump	1	300 000	300 000
	Sub total				**9 012 500**
2.0	**Consultancy to design and research the position for 76 monitoring sites**				
2.1	Consulting Hydrogeologist	Month	2	2 000 000	4 000 000
2.2	Flights	Item	1	100 000	100 000
2.3	Technician	Month	2	300 000	600 000
2.4	GIS Map production	Lump	1	150 000	150 000
2.5	Per diem (consultant and assistant for accommodation etc)	Day	60	20 000	1 200 000
2.6	km (visiting the targets for geological confirmation)	km	6000	100	600 000
2.7	Reporting	Lump	1	100 000	100 000
	Sub total				**6 750 000**

Item	Description	Unit	Quantity	Rate (MWK)	Amount (MWK)
3.0	**Geophysical Contract to geophysically site 20 Monitoring boreholes**				
3.1	Site using EM profiling (minimum 2km at 25m stations) plus at least 4 Resistivity Soundings at each site to an AB spread of 200m minimum. Peg best site. Report. Inclusive of hydrogeologist, equipment, technicians, accommodation and per diems	Bore-hole	20	180 000	3 600 000
3.2	km (visiting the targets for geological confirmation	km	3000	100	300 000
	Sub total				**3 900 000**
4.0	**Consultancy Contract to coordinate/supervise contractors: Drilling at 20 sites and piezometers at 6 sites and test pumping at 6 sites. Pumping test analysis for hydraulic parameters T, S etc. Correlation of the 20 sites according to Malawi geological succession. Report.**				
4.1	Consulting Hydrogeologist	Month	4	2 000 000	8 000 000
4.2	Flights	Item	1	100 000	100 000
4.3	Technicians (3) local	Month	12	180 000	2 160 000
4.4	Lithological log production	Lump	1	150 000	150 000
4.5	Per diem (consultant for accommodation etc)	Day	120	15 000	1 800 000
4.6	Per diem (Technicians for accommodation etc)	Day	360	4 000	1 440 000
4.7	Transport (full time supervision of sites with at least 2 vehicles)	km	12000	100	1 200 000
4.8	Reporting	Lump	1	200 000	200 000
					15 050 000
5.0	**Drilling Contract for the Construction of 20 new boreholes with extra piezometer / observation borehole at 6 sites and professional pump testing at these 6 sites**				
5.1	**Construction of 20 boreholes**				
5.1.1	Mobilisation / demobilisation (including rigging up / down, site clearing, tidying and movement between sites	Lump	1	4 000 000	4 000 000
5.1.2	Drilling to a finishing diameter of 8" / 203mm to intersect main aquifer but not exceeding 100m	Meter	2000	12 000	24 000 000
5.1.3	Supply and insert PVC casing at 4" / 100 mm ID (uPVC class 10)	Meter	1010	3 500	3 535 000
5.1.4	Supply and insert PVC screen at 4" / 100mm ID, factory slotted (0.75mm)	Meter	1000	4 000	4 000 000
5.1.5	Supply centralisers for 100mm OD PVC - one per 3m length	Bore-hole	20	30 000	600 000
5.1.6	Supply and install PVC end cap on both ends	Bore-hole	40	2 000	80 000
5.1.7	Supply and insert washed, rounded gravel, 3-6mm (i.e. sieved)	Bore-hole	20	200 000	4 000 000
5.1.8	Develop borehole until water is clean and silt free (minimum 4 hours)	Bore-hole	20	50 000	1 000 000
5.1.9	Build, reinforced, plastered box with hinged, locking lid with lock (0.75 x 0.75 x 0.6m deep)	Bore-hole	20	120 000	2 400 000
	Sub total				**43 615 000**
5.2	**Construction of 6 piezometers at 6 of the monitoring sites**				
5.2.1	Drilling to a finishing diameter of 6" / 150mm to intersect main aquifer but not exceeding 100m	Meter	600	10 000	6 000 000
5.2.2	Supply and insert PVC casing at 2" / 50 mm ID (uPVC Class 10) slotted on site	Meter	605	2 000	1 210 000
5.2.3	Supply and install PVC caps on both ends	Bore-hole	12	1 500	18 000
5.2.4	Supply and insert washed, rounded gravel, 3-6mm (i.e. sieved)	Bore-hole	6	100 000	600 000

Item	Description	Unit	Quantity	Rate (MWK)	Amount (MWK)
5.2.5	Develop borehole until water is clean and silt free (minimum 4 hours)	Bore-hole	6	50 000	300 000
5.2.6	Build, reinforced, plastered box with hinged, locking lid with lock (0.75 x 0.75 x 0.6m deep)	Bore-hole	6	120 000	720 000
	Sub total				**8 848 000**
5.3	**Pumping Test.** Pump at 80m depth capable of **5** l/second, discharging 100m from borehole. One dipper access tubes per pumped borehole (25mm ID). Water level measurements at pumped borehole and one piezometers simultaneously (requiring 2 dippers), Flow rate measurements at point of discharge in calibrated containers. Gate valve at discharge point to control and maintain constant flow rate. Foot valve on pump.				
5.3.1	Mobilisation / demobilisation (including rigging up / down, site clearing, tidying and movement between sites	Lump	1	2 000 000	2 000 000
5.3.2	Step Test (5 x 100 minute steps with 1 x 100 minute recovery step)	Bore-hole	6	150 000	900 000
5.3.3	Constant Discharge Test (48 hour with discharge maintained constant within +/- 5%)	Bore-hole	6	450 000	2 700 000
5.3.4	Recovery Test (24 hour)	Bore-hole	6	150 000	900 000
5.3.5	2 x 1 liter samples for laboratory analysis for major ions, refrigerated (CWL)	Bore-hole	6	15 000	90 000
5.3.6	On site measurement of e-coli and streptococci by CWL	Bore-hole	6	25 000	150 000
	Sub total				**6 740 000**
	Sub total (Item 5.1 - 5.3)				**59 203 000**
6.0	**Surveying contract to accurately determine the collar elevation of 31 old and 20 new boreholes**				
6.1	Determine the Z elevation coordinate to an accuracy of 0.5m relative to the National Datum. Report. Inclusive of survey team, equipment, accommodation and per diems	Bore-hole	51	100 000	5 100 000
6.2	km (visiting the sites and the national beacons, etc)	km	3000	100	300 000
	Sub total				**5 400 000**
7.0	**Contract to install 20 automatic water level loggers - new boreholes**				
7.1	Calibration / Installation of Levelogger Gold LT in new monitoring boreholes with test data download inclusive of mobilisation and incidentals	Bore-hole	20	80 000	1 600 000
	Sub total				**1 600 000**
8.0	**Total (Item 1-7)**				**100 915 500**

Since the stratigraphic position of the existing 35 monitoring boreholes was not determined by logging of drill chips at the time of drilling it has been suggested by the MoIWD that these boreholes be geophysically logged. This is possible but it is likely to be very expensive as more than one geophysical sonde will have to be run in each hole (to measure different physical parameters) and thereafter the geophysical profile correlated and interpreted against documented SADC data. The outcome would probably be subjective and not free of uncertainty. Additionally this would only be feasible in the boreholes drilled through sedimentary sequences (Karoo and alluvial) and would not make sense in boreholes drilled into metamorphic basement. It is suggested that before embarking on such an expensive exercise, the consultant that is appointed to position the planned 76 monitoring boreholes also fully investigates the available drilling data and site positions for the 24 existing monitoring sites. It may be possible to assign stratigraphic positions (and aquifer type) to the sites based on this data and site observations (outcrop etc).

3.3 Preparation of a National Groundwater Quality Distribution Map

The preparation of a national groundwater quality distribution map should be a highly prioritised assignment as such preparation is cost effective and serves the nation in planning rural water programmes and general development programmes.

The envisaged quantities and costs are captured in Table 3.3 and summarised in Table 3.6. A highly experience groundwater consultant would need to be employed by the MoIWD. The consultancy could be split into three components:-

- Desk study. Assembly and input of all existing ground water hydrochemical data into a database
- Field Survey. Collection of samples from 500 boreholes widely distributed and carefully selected. Input of new data into the data base
- Map and report production. National and 1: 250,000 scale maps. Integration of the hydrochemical database into the NGMN Database

The envisaged quantities and costs are captured in Table 3.3 and summarised in Table 3.6.

Table 3.3 Needs and Costs for Preparation of a National Groundwater Quality Distribution Map

Item	Description	Unit	Quantity	Rate (MWK)	Amount (MWK)
1.0	**Consultancy to research and prepare the NGQD Map**				
1.1	**Desk study**				
1.1.1	Consulting Hydrogeologist	Month	1	2 000 000	2 000 000
1.1.2	Flights	Item	1	100 000	100 000
1.1.3	Technicians (1)	Month	1	300 000	300 000
1.1.4	Per diem (Consultant for accommodation etc)	Day	30	15 000	450 000
1.1.5	Per diem (Technicians for accommodation etc)	Day	30	4 000	120 000
1.1.6	km (data gathering from regional centers)	km	3000	100	300 000
1.1.7	Desk study report with 1st version database and proposed methodology of Field Survey	Lump	1	200 000	200 000
	Sub total				**3 470 000**
1.2	**Field survey to measure water quality and collect samples for laboratory analysis from 500 reference boreholes spread the length and breadth of Malawi**				
1.2.1	Consulting Hydrogeologist	Month	4	2 000 000	8 000 000
1.2.2	Flights	Item	1	100 000	100 000
1.2.3	Technicians (3)	Month	12	300 000	3 600 000
1.2.4	Per diem (Consultant for accommodation etc)	Day	120	15 000	1 800 000
1.2.5	Per diem (Technicians for accommodation etc)	Day	360	4 000	1 440 000
1.2.7	km (visiting the sites for sampling)	km	12000	100	1 200 000
1.2.8	Obtaining pumped water sample with electric pump and generator (minimum 20 minutes)	Bore-hole	500	15 000	7 500 000
1.2.8	2 x 1 liter samples for laboratory analysis for major ions, refrigerated (CWL)	Bore-hole	500	15 000	7 500 000

Item	Description	Unit	Quantity	Rate (MWK)	Amount (MWK)
	Sub total				**31 140 000**
1.3	**Preparation of Map Set and Report, integration of hydrochemical data into the NGMN database. Maps should contour groundwater salinity (in TDS and or EC units). Groundwater types should also be depicted as well as the aquifer types and the groundwater contours as abstracted from the NGMN datasets.**				
1.3.1	Consulting Hydrogeologist	Month	1	2 000 000	2 000 000
1.3.2	GIS Expert / Cartographer	Month	1	2 000 000	2 000 000
1.3.3	Flights	Item	2	100 000	200 000
1.3.4	Technicians (1)	Month	1	300 000	300 000
1.3.5	Per diem (Consultant / GIS Expert for accommodation etc)	Day	60	15 000	900 000
1.3.6	Per diem (Technicians for accommodation etc)	Day	30	4 000	120 000
1.3.7	km (visiting the sites for sampling)	km	2000	100	200 000
1.3.8	Input of data to the NGMN database	Day	20	40 000	800 000
1.3.9	GIS Map production. - National Map, (laminated)	Map	100	10 000	1 000 000
1.3.10	GIS Map production. National Map and 1:250,000 Map Set (thick paper) in tubes	Map set	50	7 500	375 000
1.3.11	Final report to accompany the maps	Report	150	25 000	3 750 000
	Sub total				**11 645 000**
2.0	**Total (Item 1.1 - 1.3)**				**46 255 000**

3.4 Upgrade of the Central Water Laboratory Equipment

The Central Water Laboratory (CWL) provides the vital service of determining whether water from boreholes is fit for intended purpose (e.g. drinking, farming or industrial processes) in terms of its chemical and biological make-up. The information feeds into a database which is used by planners and to create the National Groundwater Quality Distribution Map. The size and coverage of the database would feed from the WRB which would make the provision of a water sample analysis compulsory for any borehole abstraction application and subsequent abstraction right.

With this in mind the Laboratory should be modernized with up-to-date analytical equipment and technique. Training of the staff in the use of new equipment is required. The Laboratory should also be comprehensively stocked with chemicals, reagents and calibrants sufficient to last 1-2 years and the staff given additional training on how to execute stock-takes and restocking inventories and processes and how to ensure 100% reinvestment of generated analytical income.

The equipment needs and costing are outlined in Section 4.

3.5 Establishing and Sustaining the NGMN Database

This data base would contain all the positional, construction, water quantity and quality data as well as users and the respective WRB water abstraction details.

In addition to equipping the NGMN database with an office (at MoIWD) and a full range of electronic equipment, staff salaries would be supported (3 member team for 24 months) and a consultant would be deployed. This consultancy would consist of an initial 1-month input followed by 2 monitoring visits each of 2 weeks duration at month 12 and month 24 of the programme. During the first visit the consultant and the appointed staff team would:-

- Make operational the database
- Initiate data input formats and set data input target dates (e.g. per district)
- Draw up the mandate of the NGWM database
- Define the roles and responsibilities of the database staff members
- Define the Standard Operation Procedures (SOPs) of each staff member
- Define the data capture chain from WMAs to NGMN database

The subsequent visits would be for monitoring progress and to address problems and procedural bottlenecks should they occur. The envisaged quantities and costs are captured in Table 3.4 and summarised in Table 3.6.

Table 3.4 Needs and Costs for Establishing and Sustaining the NGMN Database

Item	Description	Unit	Quantity	Rate (MWK)	Amount (MWK)
1.0	**Provision of Equipment for NGMN Database**				
1.1	Computers - fastest, high RAM and HDD, large screen, keyboards, mouse etc	Item	2	300 000	600 000
1.2	Computers - fastest, high RAM and HDD, large screen, keyboards, mouse etc	Item	1	250 000	250 000
1.3	Digitiser (A0)	Item	1	2 000 000	2 000 000
1.4	Scanner (A4)	Item	1	100 000	100 000
1.5	Scanner (A0)	Item	1	1 500 000	1 500 000
1.6	Plotter (A0) + 3 sets of toners	Item	1	2 500 000	2 500 000
1.7	Printer (A3) + 6 sets of toners	Item	1	300 000	300 000
1.8	Printer (A4) + 6 sets of toners	Item	1	250 000	250 000
1.9	External hard disc drive (1 terrabyte or larger)	Item	1	100 000	100 000
1.10	Memory sticks 1 gbyte	Item	6	20 000	120 000
1.11	Surge protection and uninterrupted power supply	Item	2	200 000	400 000
1.12	Database software and access key	Item	2	1 000 000	2 000 000
1.13	Printing paper all sizes	Lump	2	100 000	200 000
1.14	Office furniture	Lump	2	750 000	1 500 000
1.15	Agent to install and configure	Days	2	100 000	200 000
	Sub total				**12 020 000**
2.0	**Provision of staff to man the NGMN (2-year support programme before taken on by MoIWD).**				
1.2.1	Manager	Month	24	100 000	2 400 000
1.2.2	Assistant	Month	24	70 000	1 680 000
1.2.3	Secretary	Month	24	40 000	960 000
1.2.4	Cleaner	Month	24	20 000	480 000
	Sub total				**5 520 000**
3.0	**Consultancy to set up and train the staff of the NGMN Office**				
3.1	Consultant	Month	2	2 000 000	4 000 000
3.2	Data input technician	Month	2	2 000 000	4 000 000
3.3	Flights	Item	2	100 000	200 000
3.4	Per diem (Consultant for accommodation etc)	Day	60	25 000	1 500 000
3.5	Per diem (Data input technician for accommodation etc)	Day	60	15 000	900 000
3.6	km (office support)	km	1000	100	100 000
3.7	Final report including Job Descriptions, Roles and Responsibilities, SOPs	Lump	1	200 000	200 000
	Sub total				**10 900 000**

Item	Description	Unit	Quantity	Rate (MWK)	Amount (MWK)
4.0	**Consultancy to monitor the operation of the NWMN at month 13 and 25 (2 weeks each).**				
3.1	Consultant	Month	1	2 000 000	2 000 000
3.2	Data input technician	Month	1	2 000 000	2 000 000
3.3	Flights	Item	2	100 000	200 000
3.4	Per diem (Consultant for accommodation etc)	Day	30	25 000	750 000
3.5	Per diem (Data input technician for accommodation etc)	Day	30	15 000	450 000
3.6	km (office support)	km	1000	100	100 000
3.7	Monitoring reports with recommendations (for each trip)	Lump	1	100 000	100 000
	Sub total				**5 600 000**
4.0	**Total (Item 1 - 4)**				**34 040 000**

3.6 Set-up and Train Stakeholders in Standard Operations Procedures (SOPs)

The training of the staff of the NGMN database has already been covered in Section 3.5.

What remains is the training of the WMAs and the staff of the WRB. A consultant would be engaged for this process. The training of the WMAs could be done in workshops located in the three regions. Measurements at a live site would be included as well as the procedure for sending water level measurements via cell phone and internet. The training of the WRB staff would occur at the board premises.

The envisaged quantities and costs for Set-up and Training in Standard Operations Procedures are captured in Table 3.5 and summarised in Table 3.6.

Table 3.5 Needs and Costs for Set-up and Training in Standard Operations Procedures

Item	Description	Unit	Quantity	Rate (MWK)	Amount (MWK)
1.0	**Consultancy to Trains Stakeholders in Standard Operations procedures**				
1.1	**Standard Operations Procedures for WMA's**				
1.1.1	Consultant	Month	1	2 000 000	2 000 000
1.1.2	Flights	Item	1	100 000	100 000
1.1.3	Per diem (Consultant for accommodation etc)	Day	30	25 000	750 000
1.1.4	Hire of workshop venue including allowances and transport for participants. Includes trip to live monitoring site, sending data via cell phone internet.	Work-shop	3	1 000 000	3 000 000
1.1.5	Vehicle hire	Month	1	450 000	450 000
1.1.5	km (office support)	km	2000	100	200 000
1.1.6	Final report including Job Descriptions, Roles and Responsibilities, SOPs	Lump	1	200 000	200 000
	Sub total				**6 700 000**
1.2	**Standard Operations Procedures for WRB Staff**				
1.2.1	Consultant	Month	1	2 000 000	2 000 000
1.2.2	Flights	Item	1	100 000	100 000
1.2.3	Per diem (Consultant for accommodation etc)	Day	30	25 000	750 000
1.1.5	Vehicle hire	Month	1	450 000	450 000
1.2.4	km (office support)	km	1000	100	100 000
1.2.5	Final report including Job Descriptions, Roles and Responsibilities, SOPs	Lump	1	200 000	200 000
	Sub total				**3 600 000**
3.0	**Programme support of district WMAs and central**				

Item	Description	Unit	Quantity	Rate (MWK)	Amount (MWK)
	WRB in relation to the NGMN				
3.1	**Support of District WMA's**				
3.1.1	WMA salaries for new positions (estimated at 15 positions for 24 months each)	Month	360	30 000	10 800 000
3.1.2	Motorcycle running costs	Month	360	8 000	2 880 000
	Sub total				**13 680 000**
3.2	**Programme support of district WMAs and central WRB in relation to the NGMN**				
3.2	**Support of WRB**				
3.2.1	WRB salaries for new positions (estimated at 2 positions for 24 months each)	Month	48	60 000	2 880 000
	Sub total				**2 880 000**
4.0	**Total (Item 1 - 3)**				**26 860 000**

3.7 Summary of Groundwater Monitoring Requirements

Strengthening the groundwater component of water resource management has been divided into six components covered by the six sub-sections above. Equipment for monitoring WMAs, operational procedures, expertise input (consultants) and contractors (siting, drilling and test pumping), the NGMN database office and equipment and support in the form of new staff have been elaborated and cost estimated in some detail.

The existing boreholes in the network need lockable cover plates put in place lest they are vandalised beyond repair. MoIWD also request that the network and all subsequent phases of expansion are fully automated with data loggers. For the required precision to be met then the data from these loggers (or pressure transducers) will have to be corrected for variation in atmospheric pressure via barometric pressure recorders mounted at the district Water Offices. Also to maintain the required precision the collar elevation of the boreholes will have to be surveyed with differential GPS survey.

In particular the expansion of the NGMN by 76 new boreholes is recommended in annual batches of 20. These will be carefully selected and sited and properly logged against Malawi stratigraphy (unlike the existing monitoring boreholes). In each batch of 20 boreholes, 6 will be selected for piezometer construction and these will be used to observe the aquifer hydraulic behaviour to pump testing on the adjacent borehole. These tests will generate the aquifer parameters needed to begin the process of modelling the national ground water resource.

To manage water resources is not only to demarcate the aquifers and their hydraulic properties but also to map the distribution of ground water quality. The opportunity must be seized to also map the quality of the national ground water resource and to link the generated information into the NGMN database.

Table 3.6 summarises the various cost elements as discussed in the sections above. It should be noted that only the 31 existing and first annual batch of 20 new monitoring boreholes have been included. This will bring the MGMN up to 51 sites. Two or three further campaigns will be required to bring it up to the planned 100 sites. These latter campaigns must also be budgeted.

Table 3.6 Summary of Cost Estimates for Groundwater Monitoring Needs

Item	Description	Amount (MWK)
1.0	Rehabilitation Works and Monitoring Equipment for Existing NGMN Boreholes	
1.1	Equipment for WMAs	33 750 000
1.2	Equipment for MoIWD	3 580 000
1.3	Contract to secure existing monitoring boreholes	8 710 000
1.3	Contractor to install 31 automatic water level recorders borehole and train WMAs	6 480 000
	Sub total	**52 520 000**
2.0	**Expanding the NGMN by 20 boreholes per annum (1st year costs)**	
2.1	Equipment for WMAs to monitor 20 extra sites	9 012 500
2.2	Consultancy to design and research the position for 76 monitoring sites	6 750 000
2.3	Geophysical Contract to geophysically site 20 monitoring boreholes	3 900 000
2.4	Consultancy Contract to coordinate/supervise contractors:	15 050 000
2.5	Contractors to drill 20 sites 6 with piezometers and conduct 6 pumping tests	59 203 000
2.6	Contractors to survey 51 borehole sites for elevation above mean sea level	5 400 000
2.7	Contractor to install 20 automatic water level recorders borehole	1 600 000
	Sub total	**100 915 500**
3.0	**Preparation of a National Groundwater Quality Distribution Map**	
3.1	Consultancy desk study	3 470 000
3.2	Consultancy field survey and sampling programme	31 140 000
3.2	consultancy to produce the groundwater quality map set	11 645 000
	Sub total	**46 255 000**
4.0	**Establishing and sustaining the NGMN Database**	
4.1	Equipment	12 020 000
4.2	Provision and support of staff to man the NGMN database	5 520 000
4.3	Consultancy to set up and train the NGMN staff	10 900 000
4.4	Consultancy monitor the NGMN at month 12 and 24	5 600 000
	Sub total	**34 040 000**
5.0	**Set up train (in SOPs) and support the NGMN Stakeholders**	
5.1	Consultancy: Standard Operations Procedures for WMAs	6 700 000
5.2	Consultancy: Standard Operations Procedures for WRB officers	3 600 000
5.3	Programme support of district WMAs in relation to the NGMN	13 680 000
5.4	Programme support of central WRB in relation to the NGMN	2 880 000
	Sub total	**26 860 000**
6.0	Total (Item 1-6)	260 590 500

4. Water Quality Services Division

An important step in the updated water quality monitoring design is to prioritise the water quality constituents to be tested for each programme (quality of surface and groundwater, pollution control). The instrumentation and methods required for these analytical tests can then be identified and protocols and good laboratory practices developed.

The monitoring chain undertaken by the Water Quality Services Division can broadly be divided into three activities:

- Water sampling and field measurements
- Analysis of water samples
- Data storage, information generation and dissemination

In the absence of a Strategic Water Laboratory Quality Plan this document will assume the use of low level technology that will provide accurate results at an acceptable cost per analysis. This recommendation was influenced by:

- The absence of a scientifically based strategic plan that links the purpose of monitoring, with levels of detection of specific variables and frequency of sampling
- Limited funds for maintenance, reagents and other consumables
- Challenging after sails service
- Limited analyst skill
- Limited Good Laboratory Practise actions by present staff
- Poor laboratory infrastructure
- Challenging sampling actions

4.1 Water sampling and field measurements

Funding for the collection of routine water quality and pollution control samples and for field measurements is required to cover the following:

- Operational costs – these are expenses associated with travel to the sampling sites, securing vehicles for the sampling trips, fuel for the vehicles, subsistence and travel allowances for the staff undertaking sampling, consumables used during the sampling trip, etc. Funding for the operational costs at present appears to be the biggest constraint to Water Quality Services Division performing their duties. Field sampling is the first link in the monitoring chain and if it fails due to the shortage of funds, the whole monitoring programme is compromised.

- Field instrumentation – In-situ measurements are undertaken at monitoring points and the instruments required include an Electrical Conductivity Meter, pH meter, Turbidity Meter, Dissolved Oxygen Meter, instrument for measuring residual chlorine, and equipment for appropriate microbial analysis. According to the laboratory staff the current field instruments urgently need to be serviced and recalibrated. In future robust multi-parameter (e.g. DO, EC, pH, temperature) instruments need to be purchased with long cables (30m) to facilitate measurements from bridges and for profile measurements in dams and lake Malawi (near shore sampling). The Millipore microbial monitoring equipment is in a questionable state and alternative options to monitor bacteriological water quality are recommended.

- Sampling equipment – Sampling equipment includes sampling bottles, cooler boxes, ice bricks, buckets, field note books, marker pens, sampling staffs, etc. Sampling equipment is regarded as consumables to be funded from the operational budget as sampling bottles and cooler boxes need to be replaced from time to time. It appears that, in general, the sampling equipment of the laboratories is adequate for the task at hand. However consideration should be given to regularly replace sampling bottles and to prevent cross-contamination between bottles used for river and groundwater sampling and those used for pollution control.

4.2 Field sampling equipment

Although the field equipment of the three laboratories was marginally serviceable, the equipment is old, and in many cases requires maintenance. It is therefore recommended that consideration be given to upgrade most of the field sampling equipment and to use the old equipment as backup equipment (after these have been serviced).

a) Water temperature

Water temperature must be measured in the field because a water sample will gradually reach the same temperature as the surrounding air. Temperature is measured with:

- A glass thermometer, either alcohol/toluene filled or mercury filled with 0,1 °C graduations, or
- An electronic thermometer.

The glass thermometer is impractical for field work because it can easily break during transport unless it has a protective metal sheath. In most cases the electronic thermometer is an integral part of a dissolved oxygen meter, pH meter or electrical conductivity meter and is therefore dealt with below. Temperature readings should be accurate within 0,1 °C.

b) Electrical conductivity and total dissolved salts

Conductivity (or electrical conductivity or specific conductance) is a measure of the amount of dissolved salts in the water. It is measured in milli-Siemens per meter (1 mS/m = 10 µS/cm = 10 µmhos/cm). A standard factor is generally used to converts an EC measurement into a total dissolved solids (TDS) concentration (mg/l). Conductivity is temperature dependent and most meters have automatic temperature correction. If a meter is not equipped with automatic temperature correction the temperature must be recorded along with the EC measurement. EC meters can either be a pen type pH meter or combination, or it can be a unit with a sensor attached to a reader unit via a cable. The length of the cable can vary depending on the application. Standard cables vary in length between 1,5m – 3m but if a measurement from a bridge is required then a 10m cable or longer is required. Conductivity solution with a known conductance is required for the calibration of these instruments.

Indicative costs for portable EC and Temperature meters are given in Table 4.1:

Table 4.1 Costs for portable EC and Temperature meters **{** *XE "Table 4.1 Summary of Cost Estimates for Groundwater Monitoring Needs"* **}{** *XE "Table 4.1 Summary of Cost Estimates for Groundwater Monitoring Needs"* **}**

Type	Example model	Indicative cost (MK)
Pen type	Hanna HI 98311	30 690
	Lovibond EC meter	?
	WTW 3210 COND meter with 1m cable	124 970
	WTW 3210 COND meter with 3m cable	199 630
	WTW 3210 COND meter with 10m cable	210 450
Calibration solutions	Conductivity solution (1413 µS/cm, 500ml)	3 430

c) pH meters

The pH of water should, if possible, be measured in the field. pH can be measured either with pH indicator paper, liquid colorimetric indicators, and electronic meters. pH indicator paper is simple and inexpensive but not very accurate because it relies on the subjective judgement of the user. The most commonly used field measurements are electronic, battery powered, portable meters that give measurements with an accuracy of ± 0,05 pH units. These can be pen type pH meters or combination pH and EC pen type meters, or it can be units with a sensor attached to a reader unit via a cable. The length of the cable can vary depending on the application. Standard cables vary in length between 1,5m – 3m but if a measurement from a bridge is required then a 10m cable or longer is required. Buffer solutions with known pH values are required for the calibration of these instruments. Indicative costs for portable pH meters are given in Table 4.2:

Table 4.2 Costs for portable pH meters

Type	Example model	Indicative cost (MWK)
Pen type	Hanna HI 98128	30 700
	Lovibond tester	?
Portable pH meter with cable & sensor	Hanna HI 991001	?
	Lovibond pH meter	?
	WTW PH 3210 pH meter with 1m cable	117 800
	WTW PH3210 pH meter with 3m cable	130 200
	WTW PH1970i pH meter with 10m cable	438 970
Calibration solutions	Buffer pH 4.01 500ml or Buffer pH 7.01 500ml	1 100

Type	Example model	Indicative cost (MWK)
	Storage solution	1 760

d) Multi Parameter EC and pH meters

Many instrument companies manufacture multi-parameter meters that combines different sensors into one instrument and allows the user to simultaneously measure EC/TDS/pH and water temperature. The advantage of these instruments is that two or three parameters can be measured with one instrument.

Indicative costs of these instruments are given in Table 4.3:

Table 4.3 Costs for Multi Parameter EC and pH meters

Type	Example model	Indicative cost (MK)
Pen type	Hanna Combo pH/EC/TDS tester HI 98129	41 700
	TEST35 EC/pH meter	39 050
Portable pH/EC/TDS meter with cable & sensor	Hanna Portable EC/TDS/°C meter HI 99300N	54 900
	YSI ProPlus 1030-4 with 4m cable	270 600
	YSI ProPlus 1030-10 with 10m cable	279 400
	Lovibond SensiDirect 150 EC/pH meter with 1m cable	163 900

e) Dissolved oxygen meters

Two main methods are used to measure dissolved oxygen in water. The first is the Winkler method and the second is by means of an electronic meter. The Winkler method requires the addition of three chemical reagents to a water sample making it quite impractical for field measurements. The majority of monitoring programmes rely on electronic instruments for DO measurements. There are two primary types of dissolved oxygen sensing technologies available: the optical based sensing method which is commonly referred to as luminescent and the Clark electrochemical or membrane-covered electrode. Within these two types of technologies, there are slight variations available.

Indicative costs of these Dissolved oxygen instruments are given in Table 4.4:

Table 4.4 Cost of Multi Parameter EC and pH meters

Type	Example model	Indicative cost (MK)
Portable DO meters	Hanna HI 9146N-04 Potable DO/temperature meter with 4m cable	153 890
	YSI ODO-4 Pro Optical DO and temperature meter (4m cable)	252 560
	YSI ODO-10 Pro Optical DO and temperature meter (10m cable)	266 200
	WTW OXI 3210 with 1m cable	234 060
	WTW OXI 3210 with 3m cable	267 600

	WTW OXI 3210 with 10m cable	279 270
	Lovibond Sensodirect 150 DO/EC/pH meter	203 060

f) Multi parameter DO/EC/pH meters

Many instrument companies manufacture multi-parameter meters that can simultaneously measure DO/EC/TDS/pH and water temperature.

Indicative costs of Multi parameter DO/EC/pH meters are given in Table 4.5:

Table 5.5 Costs of Multi parameter DO/EC/pH meters

Type	Example model	Indicative cost (MK)
Portable DO/EC/pH meters	YSI Proplus Quattro 4 DO/EC/Temp & pH meter (4m cable)	470 360
	YSI Proplus Quattro 4 DO/EC/Temp & pH meter (10m cable)	479 160
	Hanna HI9828/4 multi-parameter meter (4m cable)	505 890
	Hanna HI9828/4 multi-parameter meter (20m cable)	549 890
	WTW Multi 340I DO/EC/Temp and pH meter	438 988

g) Turbidity

A turbidity meter measures light scatter with the light source and sensor set at 90 degree angle. It is an indicator of the amount of suspended material in the water. There is no direct conversion from turbidity to suspended sediment because the relationship between the two is a function of the sediment characteristics of a specific region. Suspended sediment concentrations are gravimetrically determined.

Indicative costs of turbidity meters are given in Table 4.6:

Table 6.6 Costs of turbidity meters

Type	Example model	Indicative cost (MK)
Portable turbidity meter	Hanna portable meter and carry case	197 890
	Lovibond Turbicheck turbidity meter	178 640
	Hach portable turbidity meter	?

h) Free chlorine

When conducting compliance water quality monitoring of the final water of water treatment plants, it is important to measure the turbidity and free chlorine in the water. Free chlorine is measured in a potable photometer and requires reagents for the tests. Gel turbidity standards should be purchased to check the turbidity meter on a daily basis (if used in the laboratory), and liquid turbidity standards should be purchased to calibrate the instrument when required.

Indicative cost of a turbidity and free/total chlorine meter is given in Table 4.7:

Table 7.7 Cost of a turbidity and free/total chlorine meters

Type	Example model	Indicative cost (MK)
Portable turbidity and chlorine photometer	Hanna HI 93414 Turbidity and free/total Cl2 meter	307 890
	Free chlorine reagents (100 tests) (MK44 per test)	4 400
	Total chlorine reagents (100 tests) (MK44 per test)	4 400
Portable chlorine meter	Lovibond MD100 Photometer chlorine meter	107 360
	Hach chlorine meter	?

4.3 Recommendations with regard to field instruments

a) Field monitoring equipment

It is recommended that the field monitoring equipment of the three laboratories be upgraded. A number of options are given in Table 4.8 with respective advantages and disadvantages:

Table 8.8 Advantages and disadvantages of different types of field monitoring equipment

Instrument type	Advantages	Disadvantages
Pen type EC/pH /Temp meters	Easy to use and carry around Cheaper than other types Well suited for quick inspections good as a backup when field instruments are not available	Not as robust as other field meters Accuracy is questionable Easy to mislay due to their size Not well suited for direct measurements in a river, better to collect a sample and measure in container
Single parameter EC, pH or DO meters with standard cable & probe	Generally robust for field measurements Sensor and cable suitable for in-situ measurements If an instruments is defective other measurements are not compromised	Combined cost of Individual instruments is more expensive than one multi-parameter instrument More equipment to carry to a sampling site
Multi-parameter EC/pH/temp meters	Generally robust for field measurements Multiple measurements with one instrument Sensor and cable suitable for in-situ measurements Fewer instruments to carry to a sampling site	Measurements may be compromised when one sensor is defective

b) Notes on the selection of suitable field equipment:

1. Robust - Field instruments should be sturdy and preferably rubberised, waterproof or at least splash proof and the cables should be robust with sturdy, waterproof connectors. The

waterproofness is indicated by the IP code or NEMA rating of an instrument. Laboratory instruments are not suitable for field use but field instruments can be used in a laboratory.

2. Displays - Displays should be legible in direct sunlight with a large font size.
3. Accuracy - Make sure the meter can provide the level of accuracy and precision that is required by the specific monitoring objectives. For example, although a pH meter may display readings to two decimal places, an examination of the specifications may reveal that the meter is only accurate to within ± 0,2 pH units.
4. Temperature compensation – Field measurements need to be temperature corrected. Cheaper meters do not provide temperature corrected measurements. Furthermore, DO measurements require concurrent measurements of temperature for correct calibration and use. Some DO meters perform these measurements and corrections automatically while others require the use of separate equipment to measure temperature.
5. Sensor housing - Sensors should have a sturdy protective housing to prevent damage when using it in a fast-flowing stream or stream with lots of stones and rocks.
6. Power supply - Portable instruments should use conventional batteries which can be replaced in the field.
7. One hand operations – one-hand operations is an advantage when the sensor is lowered into the water with the other hand.
8. Lifespan of membranes – Instruments that use membranes that have a long lifespan is preferred over instruments that require membranes that need to be replaced frequently.
9. Cable length – A longer cable length is an advantage when monitoring from a bridge or dam wall. This is also an advantage if vertical water quality profiles (changes in quality with depth) are recorded in reservoirs but it is also bulky and provide space problems when doing analysis in a beaker.
10. Calibration solutions – It is highly advisable to use the equipment supplier's calibration solutions to calibrate DO, EC and pH meters rather than making up solutions. This removes one source of error in the field measurements.

Experience with field equipment has shown that YSI and Hach equipment are probably the best options to consider. Hanna and Lovibond equipment has been found to be less reliable and too fragile for heavy field work in remote areas, and their backup service was unsatisfactory.

c) Care of electronic field instruments

- Improper use or storage can damage field equipment. Storing equipment for extended periods of time with batteries installed can cause damage if the batteries leak.
- Many pH probes use a porous glass or ceramic tip that must be kept moist while stored or the reference solution or gel will dry out and the probe will need replacing. Proper storage solution or tap water must be used for storing pH probes; and not distilled or deionised water, as the reference gel or solution will be diluted and the probe will need replacement sooner.
- Most DO probes also require moist storage conditions to prevent the membrane from drying out. For storing DO probes, distilled water is preferred.

- It is highly recommended that a mandatory annual training session be arranged for all staff using the meters to ensure correct use of the instruments. All staff involved in monitoring should know how to calibrate and troubleshoot problems with the field instruments.

d) Reservoir monitoring

At present the water quality monitoring programme is focused on river monitoring and pollution monitoring. Once these programmes have been rehabilitated, consideration should be given to monitoring the in-lake water quality of key water supply reservoirs.

In water supply reservoirs, especially where water is released through a bottom outlet, it is important to understand the impact of thermal and oxygen stratification. If thermal and oxygen stratification occurs on a seasonal frequency, then there might be significant differences in the water quality of the surface and bottom waters. Under low or no dissolved oxygen conditions in the bottom waters, iron and manganese may leach from the sediments and these may cause problems in potable water treatment plants. In key water supply reservoirs it becomes important to monitor longitudinal zonation in the dam (water quality differences along the length of the dam), and vertical stratification (water quality differences with depth). The monitoring of reservoirs require samples to be collected at least at the surface and bottom layers, and vertical DO and EC/pH profiles, near the water abstraction point.

Water quality monitoring on reservoirs require a small fold-up inflatable boat with a small outboard motor, and DO/EC/pH meters with a long (20-30m) cable length. The inflatable boat should be small enough so that two persons can carry and erect it at the water's edge.

Two types of water samples are collected in a reservoir. The one is a discrete depth sample and the other is an integrated water sample:

- A Kemmerer or Van Dorn water sampler is commonly used to collect water at a specific depth. These devices are cylindrical tubes with stoppers at each end. After the sampler has been lowered to the desired depth (marked on the lowering line), the sampler slides a weight (called a messenger) down the line. When the messenger reaches the sampler, it hits a trigger mechanism and the two stoppers snap shut, trapping the sample of water from that depth. The sampler is then hauled back into the boat and the sample water poured into a container.
- An integrated sample combines water from a range of depths in the water column. It is essentially a mixture of point samples designed to represent more of the photic zone (light penetration zone) than a single sample. The simplest way for samplers to collect an integrated sample is to use a hose and bucket. Basically, a measured length of hose is weighted on one end and then lowered into the reservoir. While the hose descends, it collects a vertical column of water. By plugging the surface end and then bringing the lowered end to the surface with a line, an intact column of water can then be emptied into a bucket and a sample drawn for laboratory analysis.

The additional equipment required for reservoir sampling therefore include:

- Small portable inflatable boat
- Outboard motor (15 hp)
- Fuel tank
- Anchor & anchor rope
- Oars
- Life jackets
- Van Dorn or Kemmer water sampler & rope
- Hose pipe integrated sampler (if required)
- DO/EC/pH meter with a 20-30m cable

Indicative costs of a small inflatable boat and other equipment are given in Table 4.9:

Table 9.9 Costs of a small inflatable boat and appropriate equipment

Type	Example model	Indicative cost (MK)
Boat	Portable inflatable boat, 3,1m with floor boards	330 000
Outboard motor	15hp outboard motor	440 000 - 572 000
	8hp outboard motor	440 000 - 484 000
Life jackets	SABS Approved life jacket	4 400
Discrete depth sampler	Van Dorn sampler	50 820
Hosepipe sampler	Hosepipe, weight and rope	2 200

In terms of priorities, the reservoir monitoring has a lower priority than the river monitoring. Once the river monitoring programme is running smoothly, consideration can be given to expand the programme to include in-lake reservoir water quality monitoring. Sampling from a boat has implications for samplers as they need training in the handling of small water craft as well as water safety training.

e) Field sampling equipment suppliers in South Africa

Listed below in Table 4.10 are field equipment suppliers in South Africa. In most cases they are the local agents for the equipment and stock consumables for the calibration of the equipment as well as spares. They can service and undertake most repairs when required. It is only in exceptional cases that instruments need to returned to the manufacturers.

Table 10.10 Listed of field equipment suppliers

Company	Contact details	Agents for
Monitoring and Control Laboratories Contact: Mr Peter Wigzel www.moncon.co.za	Tel: +27 11 327 6254 Fax: +27 11 327 6530 Email: pwigzel@moncon.co.za PO Box 890266 Lyndhurst Johannesburg 2106	YSI equipment www.ysi.com
Aqualytic environmental & laboratory www.aqualytic.co.za	Tel: + 27 12 664 4333 Fax:+ 27 12 664 4777 Email: anna@aqualytic.co.za	HACH www.hach.com

Company	Contact details	Agents for
	P.O. Box 682 Irene 0062 Pretoria	
Labotec www.labotec.co.za	Tel: +27 11 315 5434 Fax: +27 11 315 5882 Email: sales@labotec.co.za PO Box 6553 Halfway House Johannesburg 1685	WTW Equipment www.wtw.com
Hanna Instruments www.hannainst.co.za	Tel: +27 11 615 6076 Fax: +27 11 615 8582 Email: hanna@hanna.co.za PO Box 1646 Bruma 2026 Johannesburg	Hanna Instruments www.hannainst.com
Selectech www.selectech.co.za	Tel: +27 11 475 8565 Fax: +27 11 475 8530 Email: sales@selectech.co.za PO Box 532 Allensnek 1737 Johannesburg	Lovibond www.lovibond.com

4.4 Laboratory analysis

The Laboratory Strategy will determine the level of sophistication and atomisation required to meet the water quality information needs by different Ministries and other users. Funding for the analysis of samples arriving at the laboratory should therefore focus on low level technology that will provide accurate results at a lower cost per result compared to high level technology that is only cost effective at large number of samples and variables analysed for on a daily basis (for example 70 samples per day, seven days per week, 300 days per year, on which 20 different metals have to be analysed):

- Analytical instrumentation – Analytical instruments refers to UV/Visible spectrophotometers, pH meters, turbidity meters, etc. Surveys of equipment found that many of the instruments have failed, require repairs or need to be serviced. Other instrument priorities such as flame photometer, atomic adsorption spectrophotometer, Gas Chromatographs, HPLC, can only be finalised once the monitoring programmes have been revised, the priority constituents identified, and the appropriate analytical methods have been determined on with the laboratories (an output from the Laboratory Strategic Session)..
- Other equipment – Other equipment refers to fridges, incubators, water stills, hot plates, stirrers, analytical balances, steam baths, filtration units, autoclaves, ovens, etc. Inspections found that some were in a state of disrepair. The supporting equipment priorities can only be finalised once the monitoring programmes have been revised, the priority constituents identified, and the appropriate analytical methods have been agreed on with the laboratories.
- Glassware – Glassware and other consumables refers to pipettes, flasks, etc. used in chemical analysis tests. Glassware should be viewed as consumables as these are subject to breakages.

- Reagents – Reagents refer to chemical reagents that the laboratory requires to undertake the testing of water samples. It also refers to reagents for test kits. These have an expiry date and should be replaced on the expiry date. Reagents are viewed as consumables and a proper stock control system need to be instituted to ensure that there is always a sufficient supply of in-date reagents required for the analyses to be undertaken. It must be noted that glassware and reagents are depended on the analytical methods used. Costs estimates for these items can only be done based on the outcome of the proposed strategic laboratory session.
- Building infrastructure –Building infrastructure refer to laboratory buildings. Some of the buildings are in a poor state with leaking roofs. There was also evidence of unsafe electrical connections in some of the laboratories. The analytical instruments are very delicate and should not be exposed to dripping water or faulty electrical connections that can cause costly damage. Many of the instruments require a constant temperature working environment. It is highly recommended that general maintenance of the laboratory buildings be improved to create an environment conducive to accurate analysis results. It is also recommended that the provision of air-conditioning to the laboratories be considered.
- The Northern Region Water Quality Laboratory has not been constructed yet even though plans for its construction were drawn up a number of years ago. This severely affects the service that the Division can provide in the northern region of Malawi. It is recommended that serious consideration be given to securing funding for a laboratory facility in Mzuzu. It will be of paramount importance to attend to the above infrastructure faults and proposals before even considering putting new instrumentation onto site.
- Procedures – Procedures refer to analysis protocols, stock control procedures, good laboratory practices, health and safety procedures, etc. Many of these will be updated or developed as part of the current project to ensure that good practices are embedded or reinforced in the laboratories and that the accurate and credible analysis results are produced. This is important to secure the needed equipment in time to embed the procedures with the use of the equipment.

Operating budget must be made available for consumables for the laboratories to undertake the required analyses, and to service and maintain instrumentation. This includes the replacement of expired reagents, purchase of reagents, replacement of broken glassware, repair of defective instruments, and servicing of existing instruments.

The medium term budget requirements for instrumentation can only be finalised when the update of the monitoring programme has advanced to the point where the chemical, microbiological and biological tests have been agreed upon by the Ministry.

4.5 Laboratory equipment

From the list of water quality variables provided by the Ministry, the water quality variables are prioritised into three groups:

- Group 1: the real critical / minimum that have to be analysed irrespective if the specific information need,

- Group 2: those that provide important information for general water quality management, and
- Group 3: those that provide specific information in dedicated / specific water quality monitoring projects or programmes.

The requirements for each of these groups are detailed in terms of the capital and consumable budget required to perform accurate analysis and to report correct results of 50 samples per month.

4.5.1 Group 1: Minimum requirements for all analyses

These water quality variables do provide very basic and fundamental information regarding the water quality status of the water and should be the minimum performed by any authority. The financial implications to monitor these variables on 50 samples per month are set out in Table 4.11.

Table 11.11 Group 1. Minimum requirements for all analyses

Water Quality Variable	Capital requirement		Consumable requirement		Reagent Cost		
	Item	Cost (MWK)	Item	Unit	Unit cost (MWK)	MWK/ result	MMK/ 50 samples
Chemical / Physical							
Electrical conductivity (mS/m)	Hach Sension EC5 Basic EC Meter	138 600	Calibration liquid	500	3080	6,16	308
pH (with temperature probe and compensation)	Hach Sension pH1 Basic pH Meter Portable	121 000	Buffers for calibration	500	4400	8,80	440
Free and Total Chlorine (mg/L)	Hach PCII Portable Pocket Colorimeter Free & Total	129 800	DPD Free Chlorine	100	6930	69,30	3 465
		0	DPD Total Chlorine	100	6930	69,30	3 465
		0	Gel standards	7000	44000	6,29	314
Sample transport containers	Cooler Boxes & Ice Packs	66 000					
Turbidity (NTU)	Hach2100Q Portable Tubidity Meter 0 -1000 NTU	286 000	Gel standards	7000	77000	11,00	550
COD	HACH DRB 30 PLACE REACTOR 220v	303 600	COD VIALS HR 20-1500mg/l	150	57200	381,33	19 067
Microbiology							
E. coli & coliforms (Colilert Quantitray)	Quantitray sealer	814 550	Quantitray Trays (0 - 2400 cfu/100 ml)	100	25960	259,60	12 980
	6 Watt UV Lamp	37 840	100 ml sterile vessel	200	23540	117,70	5 885

Water Quality Variable	Capital requirement		Consumable requirement		Reagent Cost		
	Item	Cost (MWK)	Item	Unit	Unit cost (MWK)	MWK/ result	MMK/ 50 samples
	UV Viewing cabinet	59 400	Growth media	200	128260	641,30	32 065
	Hach incubator	297 000					
	Generator						
TOTALS		**2 253 790**					**78 539**

Note:

- The pH, Electrical conductivity, Temperature and Turbidity instruments used during the sampling trip can also be used in the laboratories. This will cut the capital requirement significantly.
- There is no need to do other bacteriological analysis other than E. Coli and Total coliforms except in cases where a specific quality requirement has to be monitored. The Colilert technology is the most suitable as it limits possible contamination to a minimum.
- Chemical Oxygen Demand (COD) is an excellent indicator of chemical and biological pollution. Given the complexity of the Biological Oxygen Demand method and the high variability in results, it should not be done on a routine basis – only for a specific purpose.

4.5.2 Group 2: Requirements for General Water Quality Management

The variables listed in Table 4.12 provide more detail on the chemical composition of the water. It will also indicate specific pollution and if monitored frequently over a period of some years provide information regarding seasonal or long term changes. The analyses associated with these variables are expensive and should be motivated by the specific aims of a monitoring programme.

The technology available to analyse these specific water quality variables, varies from very simple basic colorimetric methods (mainly for a small number of samples per month) to highly sophisticated and automated technology which can only be implemented in high sample volume laboratories where low levels of detection are required. Specialist skills levels are also required to operate and maintain these instruments.

As a start, the laboratory should only focus on the colorimetric technology to analyse for most of these variables. The autotitrator can be considered for a combination of tests (Alkalinity, Conductivity, pH) and will provide accurate information.

Table 12.12 Group 2 Water Quality Variables and Associated Capital and Consumable Costs

	Capital requirements	Consumable requirements	Reagent Cost

Water Quality Variable	Item	Cost (MWK)	Item	Unit	Unit cost (MWK)	MWK/ result	MWK/ 50 samples
Chemical / Physical							
Chloride as Cl	HACH DR2700 Vis Spectro-photometer	633 600	Chloride RGT SET 0.1-25mg/l	100	20240	202	10 120
Sulphate as SO4			Sulfate RGT PP 2-70mg/l	100	8580	86	4 290
Ammonium as N (Low range)			AMMONIA RGT SET 0.02-2.5mg/l	250	22660	91	4 532
Ammonium as N (High range)			Ammonia RGT SET HR 0.4- 50mg/l	50	29370	588	29 370
Nitrate and Nitrite as N			Nitrate RGT SET HR 0.1- 30mg/l	100	11440	115	5 720
Nitrite as N			Nitrite RGT PP 0.002 – 0.3mg/	100	10054	100	5 027
Total Phosphate as P			Phosphonates RGT SET 0.02 – 125mg/l	100	25300	253	12 650
Ortho-Phosphate as P			Phosphorus RGT SET 0.02 – 2.5mg/l	100	9020	90	4 510
Flouride as F			Fluoride/ SPADNS RGT 0.02 -02mg/l	250	11330	45	2 266
Calcium as Ca			Calcium reagent	100	16500	165	8 250
Magnesium as Mg			Magnesium reagent	100	16500	165	8 250
Manganese as Mn			Manganese RGT SET HR 0.1-20mg/l	100	19580	196	9 790
Iron as Fe			Iron RGT PP 0.02-3mg/l	100	8624	86	4 312
Silica as Si			Silica RGT SET HR 1- 100mg/l	100	23980	240	11 990
Hardness as CaCO3	Calculation from Mg and Ca results						
Alkalinity as CaCO3	888 Titrando / Touch Control Methrom Autotitrator	3 212 000					
Electrical conductivity			Calibration liquid	500	3080	6	308
pH			pH buffers	500	4400	9	440
Temperature (sample)							
Sodium as Na			Standard & Probe	2500	187000	75	3 740
	Selective ion electrode	187 000					
	TOTALS	**4 032 600**			**19 439**	**2 512**	**125 565**

4.5.3 Group 3: Requirements for dedicated / specific water quality monitoring projects or programmes

This group include a few variables that should either be considered in a few year's time or do required highly specialised skills and capital intensive instrumentation:

In Africa, Radioactivity analysis in water can only be done the Pelindaba laboratory in South Africa. It is suggested that samples be send to this laboratory.

Barium should only be performed when a specific monitoring programme can motivate it. Together with pesticides & herbicides as well as oil and grease these samples should be sent to a competent laboratory in the mean time.

It is also suggested that Chlorophyll a analysis be postponed for the mean time. If required urgently, the laboratory would be able to use the spectrophotometer identified in Group 2.

4.5.4 Cost implications:

Table 4.11 and Table 4.12 indicate the capital costs for the basic technology. The consumable costs were calculated based on 50 samples per month. Table 4.13 provides a summary of the capital and consumable totals for both these groups.

Table 13.13 Capital and Consumable costs based on 50 samples per month

Group	Costs (MWK)	
	Capital Cost	MWK/ 50 samples
1	2 253 790	78 539
2	4 032 600	125 565
Total	**6 286 390**	**204 104**

From the table it is evident that a minimum of MWK 78 500 will be required on a monthly basis to analyse for the basic water quality variables. This is about 3,5 times the amount presently provided by the ministry for the sampling programme. It is of paramount importance to ensure that these resources are available to prevent "unnecessary" capital being spent.

It is also important to note that these costs are applicable to one laboratory only. If needed all three laboratories in Malawi can be issued with this basic set of instrumentation as a start. A strategic decision may then be to only provide high level technology for the main laboratory. This decision will however have to be informed by the proposed strategic workshop and plan.

4.6 Data storage, information generation and dissemination

Funding for data storage, information generation and dissemination is required to cover the following:

- Desktop PCs – Chemical and biological analysis data needs to be stored on computer and in hard copy formats. There is an urgent need to replace the desktop PC in the Central Water Laboratory (Lilongwe) and to install a dedicated water quality database for the storage and verification of analysis results. The database for the storage of analysis data should be common to all three laboratories. There is also an urgent need to purchase a desktop PC for the same purpose for the Southern Region Water Quality Laboratory. Each desktop PC should be equipped with a printer, a facility to backup data, and a UPS to prevent accidental data loss during a power failure. Until the Northern Region Water Quality Laboratory is constructed, the analysis data should be stored on the laptop of the head of the laboratory.

It is envisaged that the water quality analysis data stored at the laboratories will be uploaded from time to time to HYDSTRA which will be the central data repository of all the surface water, groundwater, and pollution quality data.

Indicative costs of equipping the laboratories with desktop personal computers are given per unit in Table 4.14:

Table 14.14 Costs of desktop personal computers per unit

Type	Example model	Indicative cost (MK)
Desktop PC and peripherals	Mid-level desktop PC	110 000
	LED screen	22 000
	Laser printer	19 800
	UPS	11 000
	Microsoft Office 2010	44 000

This equipment can be purchased from suppliers in Malawi.

5. Management Information System (MIS) Needs

During the Situation and Needs Assessment Phase of the project, the following recommendations with regard to priority needs for Management Information Systems were identified.

5.1 Network infrastructure

5.1.1 Background

The 2002 situation assessment commented on the piecemeal acquisition of computer hardware, software and peripherals without the benefit of an overall needs assessment to guide the development of IT infrastructure. The lack of basic housekeeping (setting up and using archiving facilities and procedures to ensure protection of software, hardware and data – i.e. virus checking) was also noted. At the time of the previous assessment, networking was not available.

Some progress has been achieved since then, including extension of the GWAN to service the MoIWD and the installation of a LAN in Tikwere House. The LAN has an anti-virus server and is also used for the MoIWD's Financial Management Information System (FMIS). There are no data or application servers (except for the FMIS), which means that data are stored on individual PCs, leading to data loss and data duplication.

The LAN and the GWAN are not connected. It appears that the GWAN is used by MoIWD personnel primarily for internet and email access. The exception is the HYDSTRA server, which is connected to the GWAN and located in Tikwere House. (There are plans to move the server to the Government IT Centre.) The Central and Southern Laboratories are not connected to the GWAN. The connection of the laboratories to the network is a priority, will substantially improve data security, and will make data transfer between the laboratories and the MoIWD a possibility.

The MoIWD and WRB are reliant on Government IT services for support and network upgrades. External priorities influence resource allocation, and it is not a given that the Ministry will be allocated the resources that are required to upgrade their networks to a level that is suitable for the MIS that is being developed for this project. To influence and speed up this process, it is recommended that a focussed short term consultancy to assess the current state of the network, and to design and cost the network upgrades that are required.

5.1.2 Short-term Consultancy for Network Re-design and Implementation

The purpose of the consultancy is to produce the following:

- A rationalised, scaleable re-design of the existing LAN and relevant components of the GWAN which will include application, database and web servers dedicated for use by MoIWD and WRB users
- Extension of the GWAN to the Central and Southern Laboratories
- Data protection measures, including backup and anti-virus systems
- Reliable internet access for the servers that will host MIS applications
- A programme for implementation that matches MIS roll-out
- IT support personnel requirements within the Ministry
- Detailed costing for the above.

- Supervision of the procurement and supervision, testing and signing off of the installation process

The network re-design must meet the following requirements:

A. System Architecture

1. The proposed network design must support TCP/IP and future IP protocols (IPV6 as well as IPV4) as defined by networking industry standards.
2. The proposed network design must describe the technical architecture for the MoIWDs network, identifying all compatible hardware platforms and environments.
3. The proposed network design must describe any other special hardware, software, network or other system requirements
4. The proposed network design must provide detailed technical specifications for all hardware (routers, switches, servers, workstations, telephone line hook-up, etc.) to support the proposed network WAN design and the MoIWD internal LAN.
5. Each remote site location (Central and Southern Laboratories) must either have a 10/100 switched Ethernet LAN or greater. If not, these sites must be equipped with additional cabling, hardware and installation to connect to the WAN.
6. The final proposed network design must describe the network design's fault tolerant, redundancy, and disaster recovery features.

B. Hardware

7. The final network design document will describe all hardware requirements to support the network design proposed. The document must include:
    a. Any required upgrade to current hardware, including routers, MCU, servers, software, video conference codecs, etc.
    b. Any hardware upgrade required to support vendor system based on projected growth requirements. Vendor must specify the square footage floor space and/or rack space requirements as well as electrical, cooling, and power backup requirements for hardware proposed.
8. The vendor must specify recommended manufacturer, model number, description, and quantity for all required hardware items.

C. Communications / Network

9. The final network design document must describe all communication/network requirements to support the proposed network design.

D. Software

10. Any software solutions proposed as part of the network design must meet the following minimum requirements.
    a. All documents must be delivered in either Microsoft Office 2007 or Microsoft Visio 2003.

b. The workstation software must run in a Microsoft Windows XP, SP3 operating system environment at a minimum. Describe when the software will run on Microsoft 7 operating system.

c. The software proposed must be compatible with TCP/IP network protocol and Ethernet network topology.

d. The server software proposed must be compatible with Windows Server 2008, IBM AIX, Red Hat Linux or z/OS operating systems. The software's proposed server operating system must be defined.

11. The process for sign-on and password management for the proposed software must be described.

The envisaged cost of the consultancy is included in the schedule shown in Table 5.1. A provisional lump sum has also been set aside for the network upgrade costs, but this is highly speculative, and must be refined as part of the consultancy.

Table 5.1 Re-design and rationalising of the LAN and sub-components of the GWAN

Item	Description	Unit	Quan-tity	Rate (MWK)	Provisional Amount (MWK)
1.0	**Consultancy to (a) re-design and rationalise the LAN and sub-components of the GWAN, (b) provide detailed specifications and costing, (c) prepare procurement documentation, (d) supervise procurement and installation**				
1.1	Malawi based Computer Network Engineer with number of years experience in Wide Area Network design	months	4	2 944 000	11 776 000
1.2	km (visiting WAN sites)	km	3000	100	300 000
1.3	Per Diem (accommodation away from Lilongwe)	day	5	20 000	100 000
	Sub total				**12 176 000**
2.0	**Provisional amounts for procurement and installation (dependent on 1.0)**				
2.1	Installation contract	months	2	1 840 000	3 680 000
2.2	Web server, including operating system (Minimum Windows Server 2003)	item	1	1 000 000	1 000 000
2.3	Application server, including operating system (Minimum Windows Server 2003)	item	1	1 000 000	1 000 000
2.4	Database server, including operating system (Minimum Windows Server 2003)	item	1	1 000 000	1 000 000
2.5	Database and networking software	Lump	1	4 600 000	4 600 000
2.6	Networking hardware (routers, switches, telephone line hook-ups, etc.)	Lump	1	4 600 000	4 600 000
	Sub total				**15 880 000**
	Total (Items 1 - 2)				**28 056 000**

5.2 Immediate Needs for MIS Implementation

5.2.1 Surface Water

The Surface Water Division has made a decision in principle to migrate their data management systems from HYDATA to HYDSTRA. To complete the change-over, the following short to medium term interventions would be required:

- Migration of the master HYDATA database and missing records in the six "child" databases to HYDSTRA. This process will include checking of station IDs and ensuring that as much of the primary data that is available from various sources is migrated. A system of quality codes must also be introduced
- A review and update of the existing Standard Operating Procedures (SOPs) for data capturers
- Refresher training in HYDSTRA. It is recommended that the training consist of two parts:- a field course in flow measurement, and training in the operation of HYDSTRA.
- Importantly, back-up procedures and equipment to protect the server must be put in place to secure the surface water database. The cost of this will be orders of magnitude smaller than the time cost of the human resources that are required to computerise and manage the surface water data. There is an immediate need for an uninterrupted power supply (UPS) and a backup device for the HYDSTRA server.
- Ensure that the data collection procedures, from field to Office, are in place. All incoming data should be registered (this could be done in a spreadsheet)
- Currently only gauge plate readings are being used in data processing even though mechanical chart data exists. An effort should be made to obtain a digitizer so that this information can be updated in HYDSTRA. Chart data is more reliable than gauge plate readings and should be the preferred data source being used.
- Electronic data from the HYCOS stations should be stored in HYDSTRA - not the case at the moment. (no electronic data was made available in previous visits).
- An IT person should be identified and trained to maintain the proper running of HYDSTRA
- An administrator in the Hydrology Department also needs to trained in the day to day maintenance of the system (backups, etc)

Migration to HYDSTRA and operationalising of the system form part of the current assignment. The immediate priority need is to safeguard the HYDSTRA installation. Provisional costs for this, and the provision of a digitiser are provided in part 1 of Table 5.2.

5.2.2 Water Quality and Pollution Monitoring Systems

MIS related needs that were identified as part of the Situation and Needs Assessment Phase are to:

- Develop a good laboratory management system to ensure confidence in the analysis data produced by the laboratories.
- Develop a central water quality information system for storing and managing the water quality and pollution monitoring data.
- GWAN network links to provide for data transfers between the Ministry and the Central and Southern Laboratories (Section 5.1)

The immediate needs are as follows:

a) Upgrading of the computer in the Central Laboratory and provision of backup facilities.

b) As an interim measure, the DBase III system should be replaced by an MS Access database and software to continue population of the database. The new system should provide for partial and full chemical analyses.

c) Regular transfers of analysis results from the water quality monitoring point network to a centralised database at the Ministry. It is proposed that this data is stored in the HYDSTRA system and that a HYDSTRA Water Quality license be purchased to provide trend analysis and reporting abilities. The main advantage of this approach is the integration of water quality and water volume data in a single database.

Provisional costs of upgrading the computer, to provide backup facilities, and to purchase the required HYDSTRA licences are given in part 2 of Table 5.2. The conversion of the DBASE III system and development of a data capturing interface forms part of the current assignment.

5.2.3 Groundwater

MIS requirements for the groundwater component relate to the selection of software and databases. Selection of these have not been finalised, but for the purposes of provisional costing, it is assumed that the requirements will be as follows:

- Purchase of a HYDSTRA Groundwater license to provide for the centralised storage of borehole construction and pump test data, borehole chemistry and water level time series.
- Purchase of WISH (Windows Interpretation System for Hydrogeologists) software licences for data interpretation, analysis and mapping.

A further need that has been identified is upgrading of ArcGIS licences in the department. This is a cross-cutting requirement that is equally applicable to other divisions in the Ministry.

Provisional costs of the above are listed in part 3 of Table 5.2.

5.2.4 Water Resources Board

The priority MIS need that was identified for the Water Resources Board is the first phase design and development of a Permitting System, comprised of an Application Tracking and Evaluation module, and a Water Permit Processing module. The development of this system forms part of the current assignment. Other MIS related needs are cross-cutting issues such as network access to application, database and web servers (dealt with in Section 5.1), upgrading of GIS licences, and links to the surface, groundwater and water quality databases.

Table 5.2 Immediate Needs for MIS Implementation

Item	Description	Unit	Quantity	Rate (MWK)	Provisional Amount (MWK)
1.0	**Surface Water MIS**				
1.1	A0 Digitiser tablet and software (GTCO Calcomp or similar)	item	1	2 000 000	2 000 000
1.2	HYDSTRA Application Server and operating system (Minimum Windows Server 2003)	item	1	1 000 000	1 000 000
1.3	Uninterrupted Power Supply and batteries	item	1	575 000	575 000
1.4	Network Attached Storage (NAS) Backup - RAID 5, 4 disk system, 1TB active storage	item	1	460 000	460 000
1.5	Computer technician to install and configure 1.1 - 1.4	days	5	100 000	500 000
	Sub total				**4 535 000**
2.0	**Water Quality and Pollution Monitoring MIS**				
2.1	Laboratory PC and operating system fastest, high RAM and HDD, large screen, keyboards, mouse. Windows 7	item	1	600 000	600 000
2.2	Uninterrupted Power Supply and batteries	item	1	575 000	575 000
2.3	USB External Drive (1TB) with backup software	item	1	115 000	115 000
2.4	Computer technician to install and configure 2.1 - 2.3	days	5	100 000	500 000
2.4	HYDSTRA WQ Module (1 license, AUD$ 5000)	item	1	828 000	828 000
	Sub total				**2 618 000**
3.0	**Groundwater MIS**				
3.1	HYDSTRA GW Module (1 license, AUD$ 5000)	item	1	828 000	828 000
3.2	WISH desktop licences (4 no. @ USD 500 / seat)	item	4	80 500	322 000
	Sub total				**1 150 000**
4.0	**Common MIS requirements**				
4.1	ArcGIS 10 (2, ArcEditor, 6 ArcView) concurrent licences	lump	1	9 200 000	9 200 000
4.2	ArcGIS Introductory training (8 people)	item	8	345 000	2 760 000
4.3	Flights for ArcGIS training instructors (2)	item	2	161 000	322 000
4.4	Per Diem for ArcGIS training instructors (accommodation, etc.)	item	10	13 800	138 000
4.5	HYDSTRA WQ and GW installation and configuration by specialist	days	5	11 500	57 500
4.3	Flights for HYDSTRA specialist	item	1	161 000	161 000
4.4	Per Diem for HYDSTRA specialist (accommodation, etc.)	item	5	13 800	69 000
	Sub total				**12 707 500**
	Total (Items 1 - 4)				**21 010 500**

6. References

Aurecon, April 2011. Report No 03/106334. Situation and Needs Assessment Report as part of a consultancy entitled "Consultancy Services for Establishment of Water Resources Monitoring System" for Ministry of Irrigation and Water Development, National Water Development Program

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