MINISTRY OF AGRICULTURE, IRRIGATION AND WATER DEVELOPMENT

Standard Operating Procedure for Aquifer Pumping Tests

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1.0 GENERAL INFORMATION

1.1 Purpose

The purpose of this document is to give guidance in the performance of pumping tests for hydrogeological studies and to provide recommended quality assurance and quality control (QA/QC) procedures.

This document does not cover pumping tests conducted for the purpose of determining whether a ground water zone is capable of producing a sufficient amount of yield for water supply purposes.

1.2 Application

The procedures contained in this document are to be used when performing pumping tests to evaluate hydraulic characteristics of aquifer(s).

In the event that the field personnel determine that any of the procedures described in this section are inappropriate, inadequate or impractical for specific circumstances and that another procedure must be used for any aspect of test pumping, the variant procedure will be documented, along with a description of the circumstances requiring use of alternative procedure.

1.3 Scope

This document describes procedures for performing pumping tests suitable for various aquifers in Malawi. It will facilitate the acquisition of accurate data for hydrogeological aquifer characterisation.

All personnel designing and performing pumping tests are required to be familiar with the procedures provided herein.

1.4 Background

A pumping test is a field procedure used to determine the in-situ hydraulic properties of water-bearing horizons and define the overall hydrogeologic setting. It involves the withdrawal of measured quantities of water from pumping (or test) borehole(s) and observing the water level response over time in the pumping borehole and observation boreholes close by.

The purpose of this test is to determine the hydraulic parameters of the aquifer system for quantifying water resources and in groundwater resource management. If measurements are made on nearby springs, it may also be possible to determine the impact of pumping on surface water features.

The following aquifer characteristics can be obtained from pumping test data, using graphical analysis or computer programs such as WISH:

1) Hydraulic conductivity (K_h and/or K_v).
2) Transmissivity (T).
3) Storativity (S) for confined aquifers.
4) Specific yield (Sy) for unconfined aquifers.
5) Yield.
6) Hydraulic connection between aquifer units.
7) Boundary conditions.
8) The cone of influence of a pumping well in an extraction system.

Test pumping shall comprise three types of tests:

1) Calibration test.
2) Step test.
3) Constant rate test and recovery.

1.5 Groundwater division SOPs

The following documents form part of the series of standard Operating Procedures for best management practices in groundwater management:

Document No.	**Title**
GW01/2012	Standard Operating Procedure: Drilling and Construction of National Boreholes
GW02/2012	**Standard Operating Procedure for Aquifer Pumping Tests**
GW03/2012	Standard Operating Procedure for groundwater level monitoring
GW04/2012	Standard Operating Procedure for groundwater sampling
GW05/2012	Standard Operating Procedure for operation and management of the national groundwater database
GW06/2012	Standard Operating Procedures: Water Use Permitting
GWD – 07/2012	Standard Operating Procedure: Drilling and Construction of Production Boreholes

All official copies of the division's documents are kept, in electronic format and hard copies, by the office of the Deputy Director – Groundwater Resources

1.6 Definitions of terms

Aquifer	A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs.
Constant pumping rate	A pumping rate that does not vary by more than ±10%.
Cone of depression	Cone of depression (or "influence") is the draw-down of the water table or potentiometric surface that happens when a borehole/well is pumped. The drawdown cones of two wells close together may overlap so that if the wells are pumped simultaneously they will compete with each other for available groundwater (well interference).
Development	The act of repairing damage to a formation i.e. cleaning out the clay and silt introduced during the drilling process as well as the finer part of the aquifer directly around the well screen to increase borehole permeability. It is carried out to maximize well yield by increasing the rate of water movement from the aquifer into the borehole. The types of well development include chemical, air development, jetting and surging.
Discharge area	Zone in which groundwater leaves the ground either as a spring or into a water body.
Drawdown	A measure of the amount of lowering of the water level in a well when pumping is in progress i.e. a change in water level due to an external stress such as pumping.
Formation	A laterally continuous rock unit with a distinctive set of characteristics that make it possible to recognize and map from one outcrop or well to another. It is the basic rock unit of stratigraphy
Groundwater	Water stored in water-bearing underground geologic formations.

Hydraulic conductivity	The volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angle to the direction of flow.
Hydrogeologic	Those factors that deal with subsurface waters and related geologic aspects of surface waters.
Hydrogeology	The subject dealing with the occurrence, characterization and movement of water below the earth's surface.
Observation well	A borehole drilled in a selected location for the purpose of observing parameters such as water levels and for the collection of water samples.
Permeability	The ability of an aquifer or water-bearing formation to allow water to pass through it. Permeability is also known as effective porosity because it is a function of interconnected saturated pore spaces.
Permeable	Permitting the flow of water or other liquids.
Recovery	The period just after a pump is shut down when the water level in the borehole returns to a pre-pumping level.
Specific yield	Volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table.
Static water level	Static water level is the level at which water stands in a well when the water level is at equilibrium with atmospheric pressures). It is a measure of the depth from the ground surface or from a known measuring point to the water level.
Storativity	Volume of water released from storage by a confined aquifer per unit surface area of aquifer per unit decline in hydraulic head normal to surface.
Transmissivity	The product of hydraulic conductivity and saturated thickness.
Valve	A device that allows water to move in only one direction. A valve at the bottom of each cylinder holds the column of water in the rising main while the plunger is being pushed down after each upstroke. A one-way valve in the plunger allows water to flow through the plunger while it is being pushed down.

Water table	The top of the zone in which all pore spaces or fissures are totally filled with water.
Well	A hole drilled or dug into the ground to extract liquid. Drinking water wells must be deep enough to reach far below the water table or they may have no water during the dry season when the large of recharge causes the water table to fall.
Well screen	A filtering device used to keep sediment from entering a well.
Yield	The amount of water that is produced when a pump is operated for a fixed number of full strokes.

1.7 Health and safety

Proper safety precautions must be observed when performing pumping tests. A health and safety plan must be prepared prior to field work and must be followed during testing. The plan should address all potential and known hazards.

The following personal protective clothing (PPE) is recommended, as a minimum requirement, at all test pumping sites for health and safety reasons:

- Hard hat.
- Eye protection.
- Hearing protection.
- Dust protection.
- Gloves.

Workers stationed and working greater than 3m above ground level will also be provided with and made to wear fall protection harnesses.

The testing site shall be fully marked with a barrier tape that clearly denotes and encompasses the work site and have warning signs in English stating the recommended PPE to be worn within the work area.

All non-designated personnel are to be kept away from and out of the work site for safety reasons.

2.0 EQUIPMENT AND TOOLS

The following equipment and tools must be available on site before commencement of the testing.

1) Pump (submersible or positive displacement pump) and its accessories.
2) Electronic data logger(s) (if available).
3) Water level meter (dip meter) – the number depends on the total number of boreholes to be monitored, including the pumping borehole.
4) Measuring tapes.
5) Stopwatch or watch with a second hand.
6) Tape measure.
7) Semi log graph paper.
8) Laptop computer.
9) Pen and/or pencil.
10) Calculator.
11) Data recording sheets for each of the tests stated above and recovery test data forms.
12) Daily activity logs.
13) Weir
14) Water flow meter
15) Any PPE listed or required for the site.

3.0 PROCEDURE

3.1 Pre-operation activities

1) Confirm, from borehole completion records or the drilling team, if the boreholes for pump testing are ready and have been properly developed. Shut down all pumping boreholes within the radius of influence (generally 500m) of the test borehole for at least 24 hours prior to the test.
2) Measure static water levels at the pumping and observation boreholes at least daily for one week prior to the start of test pumping. If on-site or nearby pumping cannot be stopped due to system supply needs or other factors, this must be noted and discussed as it relates to the test accuracy.
3) Mobilise for test pumping with all the relevant pumping test equipment, appropriate operating manuals, and information on equipment modifications necessary to conduct the tests.

4) Check the equipment for proper functioning.
5) All equipment should be steam cleaned or cleaned using high-pressure hot water, if appropriate, prior to and at completion of testing at each site to ensure that no contamination is transported from the sampling site.
6) Measure and record the static water level and borehole depth at the pumping borehole.
7) Install the pump at the specified installation depth, at least 10m above the bottom of the borehole to avoid mud ingress into the pump. Either a submersible pump or positive displacement pump, approved by the Project Manager, shall be used for pumping tests. The positive displacement pump is recommended because it has more or less a constant flow regardless of the system pressure or head.
8) Install a flow meter, if available, in the discharge line of the pumping well to accurately measure and monitor the volume of discharge.
9) The pump rising main must be fitted with a non-return valve, after the flow meter.
10) Install sufficient pipe to transport the discharge from the pumping well, a distance of at least 200m away from the area, to prevent infiltration of extracted water into the pumped zone.
11) Ensure all transducers, flow meters, and other equipment used in conducting pumping tests are properly calibrated before use.

3.2 Calibration test

1) Perform a calibration test comprising up to four (4) fifteen (15) minute steps to determine engine RPM required to establish borehole yields and drawdowns for different pumping rates. The water should be discharged away from the pumping well in a down slope direction and at sufficient distance to eliminate the water recharging the aquifer during the test.
2) Allow the borehole water level to recover to 90% of the original water level before the next test.

3.2 Step test

1) Step drawdown tests shall be conducted to predict well yields, evaluate well performance, predict groundwater inflow zones and estimate a suitable well yield for constant rate test. These tests will consist of a minimum of four continuous tests, during which the test borehole is progressively pumped at increasing fractions of the proposed discharge rates, while recording water levels or drawdown in the borehole.

2) The minimum length of time for each discharge rate shall be 1 hour to ensure that there is an observable change in water level in the borehole/well. The minimum yield shall be determined by the blow out yield and a general guideline is 1.0 litre/second. For boreholes with blow out yields lower than 1l/s, a slug tested is recommended.
3) The test shall begin with the lowest pumping rate and end with the highest rate.
4) At the end of the test, allow the borehole water level to recover whilst recording the water levels before performing the constant rate test. The recovery should be monitored for 24 hours or until 90% recovery (whichever is earlier).

Table 2 shows the data sheet for use when performing step tests.

Table 1 Step tests data sheet

WATER DEVELOPMENT AND IRRIGATION, GROUNDWATER DIVISION, P/BAG 390, LILONGWE									
			PUMP TEST RESULTS						
Locality:				**TA:**		**District:**			
BH. No :				**Description of the Datum:**					
Water rest level (mbgl):				**Static water level (mbgl):**					
Date of Test:				**Time:**					
Pump Set at:				**Tested by:**					
			STEP DRAWDOWN TEST						
Time since test started (min)	**Pumping water level(m)**	**Drawdown (meters)**	**Pumping water level(m)**	**Drawdown (m)**	**Pumping water level(m)**	**Drawdown (m)**	**Pumping water level(m)**	**Drawdown (m)**	**Recovery (m)**
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
12									
14									
16									
18									
20									
25									
30									
35									
40									
45									
50									
55									
60									
70									
80									
90									
100									
Discharge rate (L/s)									

3.3 Constant discharge test

The constant discharge test (CDT) is a test that is used widely to determine the hydraulic properties of the aquifer and to identify nearby hydrologic boundaries such as streams or dykes. One or more observation wells installed at appropriate distances from the pumping

well are used to record data during the test, because accurate drawdown data from the pumped well are normally difficult to obtain. The steps for performing CDT test are:

1) Ensure the water level in the pumped well has fully recovered from the step drawdown test prior to the test.
2) Measure the static water level in the test borehole and all observation boreholes at the beginning of the test.
3) Commence the test using a constant discharge rate determined by the step drawdown test, for a minimum period of 24 hours.
4) Water level measurements in the pumping borehole and all observation boreholes shall be measured according to the schedule in Table 3.
5) Measure the discharge rate at intervals set out in Table 3 in order to determine the average discharge rate for the test.
6) Water quality samples shall be collected during the last hour of pumping for chemical and bacteriological analysis. The Chemical analysis should determine primarily the TDS, pH, sulphates, fluoride, nitrates, chloride, electric conductivity and iron. The bacteriological test should determine the total coliform and the E. coli. Refer to the Water sampling SOP for specific sampling parameters.
7) Collect water levels during recovery i.e. the period after pump shut down, using the same time intervals as the CDT test (Table 3) until either 90% recovery has been attained or a period of time equivalent to the pumping period has passed. Measurement should begin at least one minute prior to pump shutdown, in both the pumping and observation boreholes. Recovery data shall be used to check the results from the actual pumping test.

Table 2 Constant discharge (CDT) & Recovery data sheet

WATER DEVELOPMENT AND IRRIGATION,GROUNDWATER DIVISION, P/BAG 390, LILONGWE								
			PUMP TEST RESULTS					
Locality:				**TA:**		**District:**		
BH. No :				**Description of the Datum:**				
Water rest level (mbgl):				**Static water level (mbgl):**				
Date of Test:				**Time:**				
Pump Set at:				**Tested by:**				
			MAIN TEST					
Time since test started (min)	**Pumping water level(m)**	**Drawdown (m)**	**Q (L/sec)**	**Time since test started (min)**	**Pumping water level(m)**	**Drawdown (m)**	**Q (l/Sec)**	**Recovery (m)**
1				300				
2				330				
3				360				
4				420				
5				480				
6				540				
7				600				
8				660				
9				720				
10				780				
12				840				
14				900				
16				960				
18				1020				
20				1080				
25				1140				
30				1200				
35				1260				
40				1320				
45				1380				
50				1440				
55				1500				
60				1600				
70				1700				
80				1800				
90				1900				
100				2000				
110				2100				
120				2200				
135				2300				
150				2400				
165				2500				
180				2600				
195				2700				
210				2800				
240				2880				
270								

4.0 Quality Assurance and Quality Control (QA AND QC)

1) A qualified Hydrogeologist shall design and supervise all test pumping activities.
2) Water discharged during the test shall be discharged away (a distance of at least 200m) from the pumping well in a down slope direction and at sufficient distance to eliminate the water recharging the aquifer during the test.
3) All data collected during the test shall be recorded on the prescribed data sheet. The frequency of each measurement shall be as prescribed on the data recording sheet. The tolerance in measurement acceptable for the step drawdown and constant discharge test are:

Pumping rate	± 10% of the designated rate
Water levels	± 0.5cm
Time	±1 minute
Period of recovery (after CDT)	90% recovery or 24hrs (whichever is first)

4) Completed test data sheets/forms shall be handed to the Field Hydrogeologist at the end of each test. Water level measurements or drawdown shall be plotted against time on semi-log paper during the test by the Filed Hydrogeologist during tests to ensure enough drawdown within the pumping well is achieved (at least 75% of available drawdown).
5) All field employees shall be properly trained to conduct test pumping work.
6) Routine field audits to evaluate how well employees follow procedures shall be performed.

5.0 REFERENCES

The following documents were consulted in the preparation of this SOP:

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