Strengthening Capacity in Environmental Physics, Hydrogeology and Statistics for Conservation Agriculture Research

CEPHaS Project Briefing

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AQUIFER PUMPING TESTS AT THE CONSERVATION AGRICULTURE EXPERIMENTS IN THE CEPHAS PROJECT

Background

Over a 3-year period that started in December 2018, an interdisciplinary network of researchers on the CEPHaS project embarked on an investigation at sites in Malawi, Zambia and Zimbabwe that generated quantitative data to better understand the impact of conservation agriculture (CA) vs conventional tillage (CT) practices on soil water dynamics and how this relates to groundwater recharge.

To enable the accurate estimation of groundwater recharge, hydraulic properties of the underground layer of rock/sediment that holds groundwater (aquifer) must be known, such as the rate of flow and volume of water that the aquifer can release from its storage. These hydraulic properties can be derived, for example, from pumping tests, which are field experiments in which a borehole is pumped for several hours to days at a controlled rate, and the resulting water level lowering (drawdown) during pumping and gradual increase (recovery) back to the initial levels after pumping is measured in one or more surrounding observation boreholes (see Figure 1). Once the data of the water level fluctuations is collected, mathematical models (type curves) are matched to the drawdown/recovery data through a procedure known as curve matching and used to estimate the aquifer properties of transmissivity, hydraulic conductivity and storativity.

Pumping tests using observation boreholes provide valuable information, but are rarely undertaken. Reasons for this include the absence of observation wells, which are an additional cost often left out in the project design, and sometimes a lack of skilled personnel with good understanding of the local and regional hydrogeological setting to conduct the test and interpret the results.

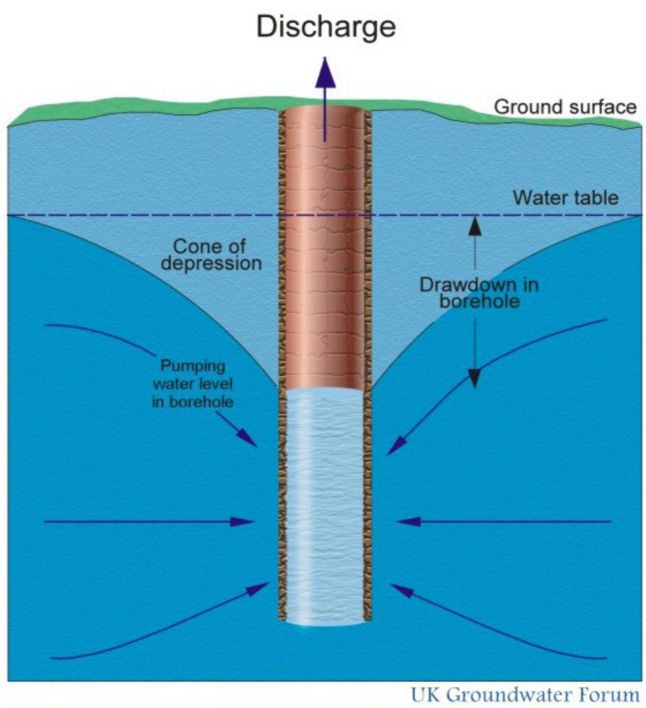


Figure 1 *The resulting cone of depression in the water table around a pumped borehole. Monitoring boreholes within the cone of depression will have a lowered water table, and this information can be used in pumping test analysis.*
(Source: http://www.groundwateruk.org/Image-Gallery.aspx).

The pumping test design and implementation

In Zimbabwe, the pumping test was conducted at the experimental field site in Domboshawa over the period 10–14 May 2021. The drilling of the boreholes for the entire field experiment was designed with the pumping test in mind. I.e., in addition to shallower monitoring boreholes (c.15 m depth), one deeper 'pumping borehole' was drilled to a depth of 33 m, so that it would obtain sufficient water from water-bearing fractures to allow for continuous pumping over multiple hours (Figure 2). The nearest observation boreholes were drilled 7 m and 10 m north and south of the pumping borehole under the assumption that this will be of sufficient proximity so that water levels in the observation boreholes are in the zone of influence (cone of depression, Figure 1) of the lowered water level in the pumping borehole. Other important parameters that were considered in planning for the test include: the best time of the year for pumping, the field equipment to pump the water (correct size submersible pump, power source and or generator), equipment for measurement and control of flow rates, measurement locations and schedules for collection of water levels, disposal of pumped water (outside of the experimental plot to avoid disturbance of ongoing soil moisture measurements) and the test duration.

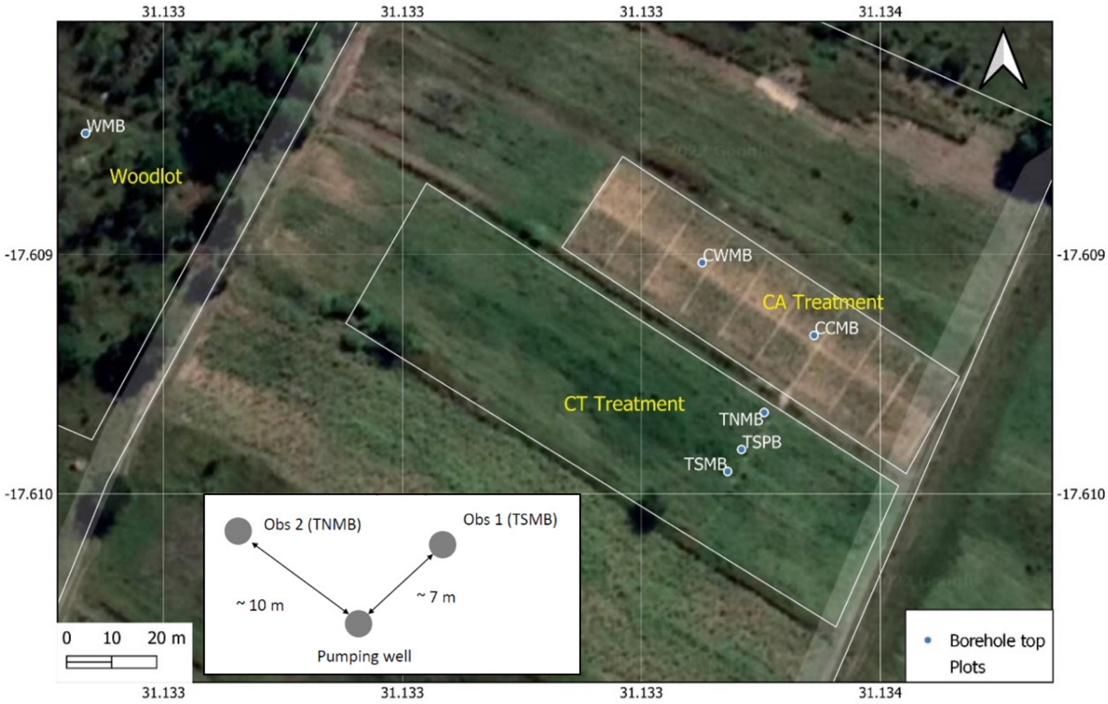


Figure 2
Detailed layout of the monitoring boreholes at the CIMMYT site in Domboshawa. Boreholes used in the pumping test were the pumping borehole (TSPB) and the observation boreholes TSMB and TNMB, as illustrated in the insert.

(Satellite map data: Google, Maxar Technologies)

The Zimbabwe pumping test was conducted for almost 12 hours from 9:05 am to 9:00 pm on 12/05/ 021. Before pumping started the static water level/rest water level was recorded in all boreholes. During the pumping test, the discharge (time to fill a 20L bucket) was recorded at regular intervals to confirm that the flow rate remained constant. The discharge rate in the pumping borehole was gated down from approx. 1.3 L/sec to 0.4 L/sec using two gate valves/ballcocks, one at the borehole head and a second at the pump discharge. After pumping was started, the depth to water was initially monitored manually every 1–2 minutes especially in the pumping borehole where the water levels were changing rapidly and then every 5 minutes after the water level became steady, moving to every 10–15–30 minutes and finally every 60 minutes in the last 3 hours of pumping. Automatic water level loggers were also used to monitor the water levels and these were set to record water levels at 1-minute intervals. The combination of manual and logged measurement was to obtain cross-validation of the observations.

Sample collection

Water samples (including major, minor and trace element chemistry, water isotopes and residence time tracers) were collected within the first few minutes of the pumping and within the last few minutes of pumping with the aim of analysing for any changes in water chemistry brought about by the extended pumping during the test.

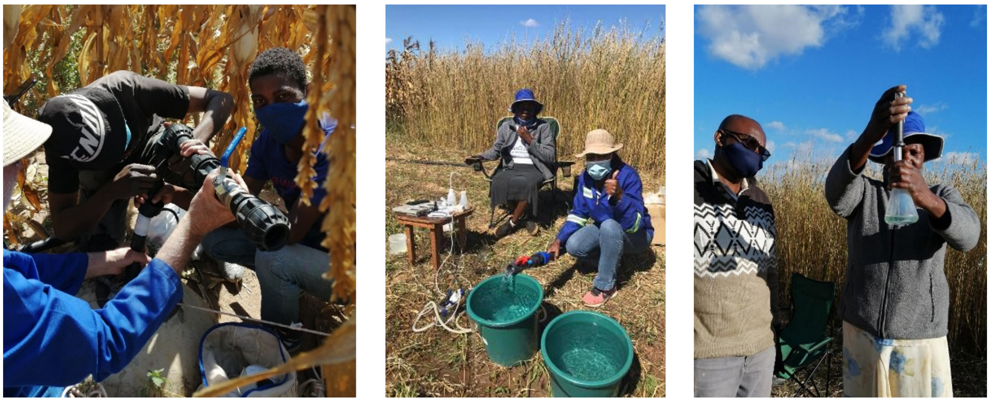
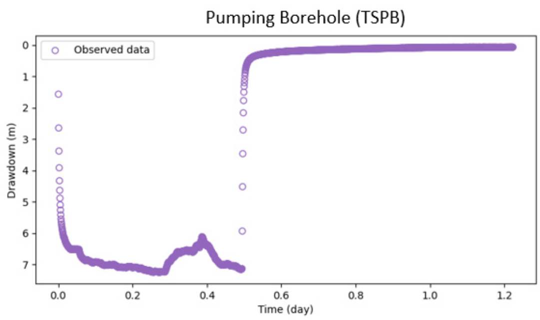


Figure 3 *Equipment installation, groundwater discharge rate monitoring sampling and field chemistry analysis during the Zimbabwe pumping test.*

(Photos: Daina Mudimbu)

Estimating aquifer properties

Data collected during the pumping test was analysed first by drawing simple drawdown and recovery curves and then analysing the drawdown data using 2 mathematical models; Theis and Jacobs solution for curve matching (Cooper & Jacob, 1946; Theis, 1935).



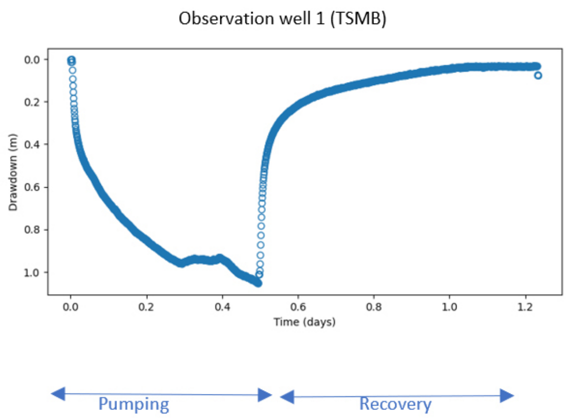
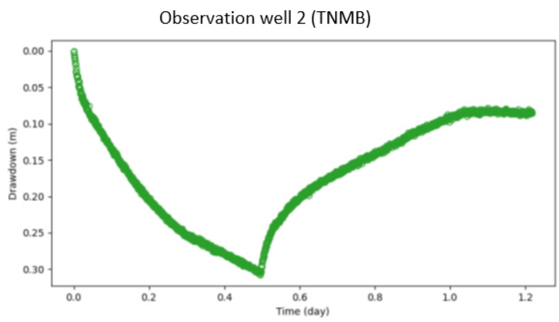


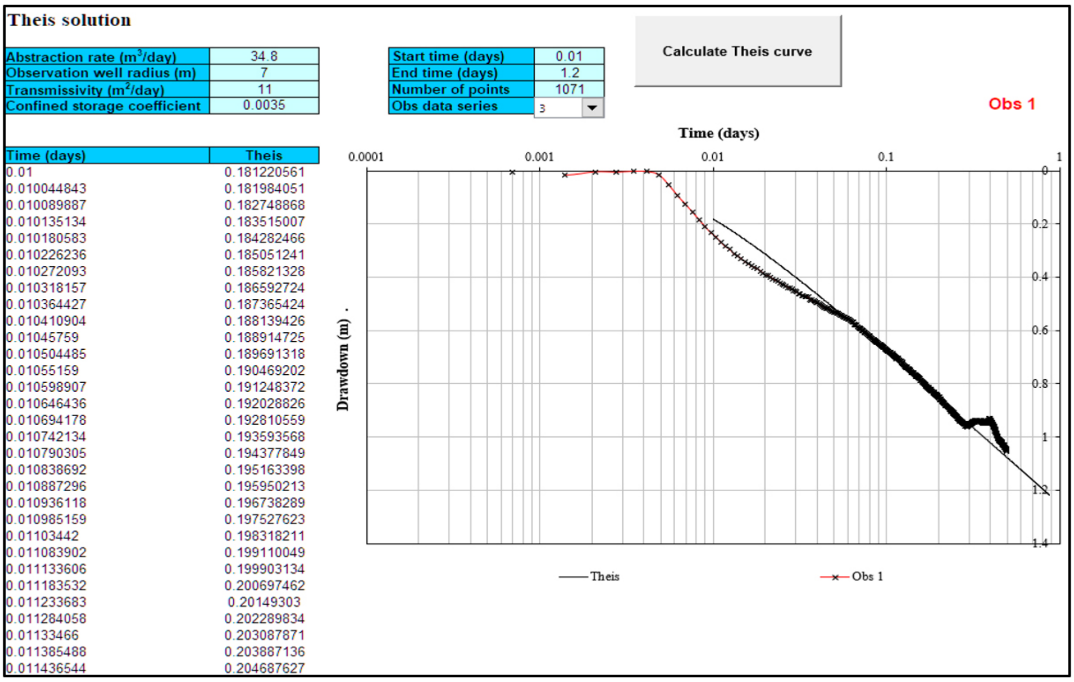
Figure 4 *Drawdown curves from the pumping test data.*

Notes:

- An interruption in pumping due to changes in power source can be seen the drawdown curves of TSPB and TSMB.
- Observation well 1 had a drawdown of about 1 m suggesting it to be more hydraulically connected to the pumping hole.
- Observation well 2 only had 0.3 m of drawdown and experienced a slower recovery.



From the curve matching (**Figure 4 and 5**) a range of values of the aquifer properties were obtained using the solutions from the observations and these were a transmissivity of 11–26 m^2/day and a specific yield ~0.4–2%. The obtained information from the pumping test will be used to further analyse and interpret the data collected during our 3-year hydrogeological investigation, e.g. the specific yield data in combination with analysis of annual water level fluctuation will be used to calculate the annual recharge (i.e. replenishment) of the groundwater body.



Theis solution

Abstraction rate (m^3/day)	34.8
Observation well radius (m)	7
Transmissivity (m^2/day)	11
Confined storage coefficient	0.0035

Start time (days)	0.01
End time (days)	1.2
Number of points	1071
Obs data series	3

Time (days)	Theis
0.01	0.181220561
0.010044843	0.181984051
0.010089887	0.182748868
0.010135134	0.183515007
0.010180583	0.184282466
0.010226236	0.185051241
0.010272093	0.185821328
0.010318157	0.186592724
0.010364427	0.187365424
0.010410904	0.188139426
0.01045759	0.188914725
0.010504485	0.189691318
0.01055159	0.190469202
0.010598907	0.191248372
0.010646436	0.192028826
0.010694178	0.192810559
0.010742134	0.193593568
0.010790305	0.194377849
0.010838692	0.195163398
0.010887296	0.195950213
0.010936118	0.196738289
0.010985159	0.197527623
0.01103442	0.198318211
0.011083902	0.199110049
0.011133606	0.199903134
0.011183532	0.200697462
0.011233683	0.20149303
0.011284058	0.202289834
0.01133466	0.203087871
0.011385488	0.203887136
0.011436544	0.204687627

Figure 5
Examples of curve matching using the 'Theis Solution' method. A free e-book for further reading on general groundwater principles can be accessed on http://www.groundwateruk.org/Default.aspx.

References

Cooper, H H, and Jacob, C E. (1946). A generalized graphical method for evaluating formation constants and summarizing well-field history. Eos, Transactions American Geophysical Union, 27(4), 526–534. https://doi.org/10.1029/TR027I004P00526

Theis, C. V. (1935). The relation between the lowering of the Piezometric surface and the rate and duration of discharge of a well using ground-water storage. Eos, Transactions American Geophysical Union, 16(2), 519–524. https://doi.org/10.1029/TR016I002P00519

WHO ARE WE?

We are soil scientists, agronomists, hydrogeologists, geo-physicists, statisticians and agricultural economists from the University of Zimbabwe, the University of Zambia, Lilongwe University of Agriculture and Natural Resources, the University of Nottingham, Rothamsted Research, Liverpool School of Tropical Medicine and the British Geological Survey. We are working with the Kasisi Agricultural Training Centre, Zambian Agriculture Research Institute, the Department for Agricultural Research Services (Malawi), and our commercial partner, Delta-T Devices (UK).

To find out more, visit our webpages at https://www2.bgs.ac.uk/CEPHaS and follow us on: twitter @CEPHaS_Soil

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