THE VALUE OF PUMPING TESTS
FOR THE ASSESSMENT OF GROUND-WATER SUPPLIES
IN SECONDARY AQUIFERS IN SOUTH AFRICA

J.F. ENSLIN and D.B. BREDENKAMP
Division of Hydrological Research, Department of Water Affairs,
Republic of South Africa

ABSTRACT

Ground-water supplies in the Republic of South Africa are obtained mainly from secondary aquifers.

Research, specially on scientific pumping tests, is being carried out to determine practical methods of assessing the safe yields of such aquifers.

Secondary aquifers at Rietondale Grass Research Station and some pumping tests are described.

The coefficient of transmissibility of the main conduit system, computed from pumping test data, is fairly accurate, but the coefficient of storage is generally much lower than the actual value.

The drillers' pumping test has been proved valuable for determining the maximum rate of pumping which can be maintained for long periods from boreholes located in certain types of aquifers.

Ground water is the only or major source of supply available for the development of the semi-arid and arid regions which cover 65% of the total area of 472,359 square miles of the Republic of South Africa, and is also used to a greater or lesser extent in the remaining, more humid, areas. According to the 1959-60 Agricultural Census 229,915 farm boreholes are equipped with windmills or engines with turbines or other types of pumps and used for domestic supplies, stock watering or irrigation. An additional 50,000 boreholes are being used in villages and towns. It is estimated that 15,000 of the boreholes are used mainly for irrigation.

It was also established by the census that the supplies from 28,540 boreholes decreased and that 5,077 boreholes dried up during the census year. As the drying-up of boreholes through overpumping may cause serious disruption of farming activities it is essential that assessments be made of the ground water resources and the safe yields of the separate supplies, to enable farmers and others to plan or control their abstraction with a view to preventing overpumping.

As a routine procedure the driller carries out a 7 or 9 hour pumping test on each borehole after completion, in order to determine the yield of the borehole at maximum drawdown. Accessory equipment of a boring machine usually includes a reciprocating test pump with a capacity of 2,000 to 4,000 gallons* per hour, which is operated by the drilling machine. The intake pipe and cylinder are generally inserted to a depth as near as possible to the bottom of the borehole and pumping takes place at maximum delivery. As the maximum yield of only 11% of the boreholes drilled in South Africa exceeds 2,000 gallons* per hour the driller is able to pump at a rate exceeding the maximum yield of the great majority of the boreholes. The pumping rate at the end of the test is regarded as the tested yield of the borehole. Often, if the delivery of a borehole is still decreasing noticeable near the end of the nine-hour test, the duration of the test is extended to establish equilibrium.

The public and farmers in general accept that it would be dangerous to pump continuously at the maximum tested yield, and many limit their pumping to 60% of

(*) Measures in Imp. gal. = 1.2 U.S. gal.
the tested yield for 10 to 12 hours per day.' Notwithstanding this safety measure large numbers of boreholes still dry up annually, as indicated by the census figures. It is therefore obvious that the routine method used by the boring contractor for establishing the safe pumping rate is not always very satisfactory.

All 1,200 boring contractors cannot be expected to be equipped for and able to carry out more scientific pumping tests. It would therefore be advantageous to determine under which conditions the drillers' tests can be accepted as reliable, how such conditions can be identified, and what the minimum requirements for such a test should be. Should conditions exist which make the drillers' test valueless, more scientific pumping tests have to be resorted to. However, the value and reliability of scientific pumping tests should also be proved for the hydrological conditions normally encountered in a particular country.

1. Secondary Aquifers

Most of the boreholes in the Republic are drilled in hard-rock formations which only hold water if they contain open fissures or are weathered (1,2). The aquifers in those formations consist of secondary interstices which have been formed by faulting and fracturing of the formations, weathering by chemical and mechanical processes or by the induration of clayey rocks by the intrusion of igneous dykes or sills. Such secondary aquifers have been described by Enslin (2). Unconsolidated granular sediments and deep sands are relatively scarce.

For the theoretical interpretation of a controlled pumping test by methods developed by Thiem, Theis, Jacobs and others the following characteristics concerning the aquifer are assumed to be satisfied:

a) The aquifer is isotropic and its permeability and coefficient of storage is constant in all directions.

b) The aquifer has infinite extent laterally and has a uniform thickness.

c) The radial flow to the borehole is uniform.

d) There is no leakage or recharge from adjacent aquifers or other sources.

It is evident that secondary aquifers do not extend indefinitely in all directions, do not normally give uniform permeability and storage capacity in depth or laterally and generally do not have uniform thicknesses, all characteristics which are assumed to hold if reliable theoretical interpretations of pumping tests are to be made.

The geohydrological conditions at Rietondale Grass Research Station, where a series of pumping tests have been carried out, illustrate some of the types of secondary aquifers encountered in South Africa.

2. Geohydrology of Rietondale

The Research Station lies between two ridges formed by the upper Daspooort quartzite of the Pretoria Series, Proterozoic age, which has been duplicated by an east-northeast to west-northwest striking fault. The general dip of the strata is 30°-32° North and the geological succession encountered between the two ridges, from north to south, as shown in Fig. 1-3, is as follows:

The contact zone between the quartzite (B) and the diabase north of the ridge is highly fractured and possibly faulted and forms a narrow linear aquifer.

The only rock exposures in the area are the quartzites forming the two prominent ridges and patches of the much less prominent quartzitic shale. The remainder of the Research Station, where the experimental plots are located, is covered by deep soil and sand.
GEOHYDROLOGICAL MAP of RIETONDALE GRASS RESEARCH STATION
AND ENVIRONS

IOBHOLE AND ELEVATION A M.S.L. OF GROUND WATER LEVEL
BOROHOLE IN USE
DIRECTION OF MOVEMENT OF GROUND WATER.
DIP OF STRATA
FAULT

SCALE

24 = 1 MILE

STRATA
SHALE AND VOLCSTONE
DABASE SILT
SHALE, MAJOR AQUIFER A32
QUARTZITE

STRATA
QUARTZITE SHALE
SHALE, MAJOR AQUIFER A32
LAVA
DYKE

FIG. 1
<table>
<thead>
<tr>
<th>Rock type</th>
<th>thickness in feet</th>
<th>Hydrological characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>quartzite (A)</td>
<td>300</td>
<td>aquifuge with slight fracturing</td>
</tr>
<tr>
<td>diabase sill</td>
<td>375</td>
<td>the weathered diabase forms a shallow aquifer</td>
</tr>
<tr>
<td>quartzitic shale</td>
<td>250</td>
<td>aquifuge</td>
</tr>
<tr>
<td>blue-grey shale</td>
<td>225</td>
<td>major aquifer No. 1</td>
</tr>
<tr>
<td>volcanic beds</td>
<td>1,200</td>
<td>the weathered lava forms a shallow aquifer</td>
</tr>
<tr>
<td>mudstone and black shale</td>
<td>200</td>
<td>aquiclude</td>
</tr>
<tr>
<td>diabase sill</td>
<td>200</td>
<td>very shallow aquifer of weathered diabase</td>
</tr>
<tr>
<td>shale</td>
<td>500</td>
<td>major aquifer No 2</td>
</tr>
<tr>
<td>diabase sill</td>
<td>300</td>
<td>very shallow aquifer of weathered diabase</td>
</tr>
<tr>
<td>quartzite (B)</td>
<td>300</td>
<td>same geological horizon as A.</td>
</tr>
</tbody>
</table>

Fig. 2.

SECTION THROUGH MAJOR AQUIFER No. 1
RIETONDALE.

Fig. 3.

SECTION THROUGH MAJOR AQUIFER No. 2
RIETONDALE.
The plots lie on slightly elevated ground which forms a local north-to-south watershed between the ridges. The water supply for domestic purposes, stock watering and supplementary spray irrigation of the plots is obtained from a number of boreholes located in the two major aquifers. Small supplies are also pumped from boreholes in the weathered diabase north of the laboratory.

Additional boreholes were drilled for the dual purpose of testing down-the-hole air drills in the various formations and for establishing observation boreholes. The geological logs of these boreholes have been used in the compilation of the geological map, Fig. 1, of the area. The dyke, which cuts across the No 2 major aquifer and forms its eastern boundary, had been traced magnetically by Mr. W. Simpson of the Geological Survey.

3. THE AQUIFERS AND CONTROLLED PUMPING TESTS AT RIETONDALE

The major aquifer No 1 which is formed by a shale horizon, 225 feet thick, is located immediately south of the laboratory. Movement of ground water is mainly along some highly permeable fissures; the bulk of the water is stored in a network of less permeable interstices.

The ground-water compartment is bounded by faults both on the east and the west, by the impervious quartzitic shale on the north and on the south partly by the lava and partly by mudstone and shale south of a fault contact.

The aquifer has a length of 6,000 feet and a width at surface of 350 feet. It is accepted that storage decreases with depth. The high-permeability fissures have been proved by the drilling to exist to depths of at least 400 feet below surface.

Borehole No 25, located in this compartment, has a maximum yield of 8,000 gallons per hour and is pumped at an average rate of 700,000 gallons per month. Recharge to this aquifer is mainly by leakage from the adjoining low permeability shale and mudstone, through and along the fault-plane. During 1962 the recharge, as determined by a water balance study amounted to 12,000,000 gallons. The specific yield of the aquifer as deduced from that study, is equal to $1.66 \times 10^{-2}$. Surplus water is lost to this compartment by effluent seepage at a spring located at its topographic lowest point, and which forms one of the sources of the stream west of Rietondale.

Controlled pumping tests were carried out on boreholes 25, 36 and 37, and very similar results were obtained in all the tests. The curves of the lowering of the ground-water levels in the observation boreholes during pumping from borehole No 25 and of their recovery after pumping was stopped, are given in Fig. 4. The semi-log time-drawdown curve for borehole No 38 and the computed coefficients are given in Fig. 5. The coefficient of transmissibility, $T = 6,560$ gallons per day per foot lowering of the water level, and the coefficient of storage $S = .00027$.

Two interesting points emerge from these pumping tests. Firstly, the semi-log plots of the time-drawdown curves are not straight lines. The increases in gradient with time indicate boundary conditions, and the later slight decrease, recharge. Secondly, the coefficient of storage determined from the pumping test is very much lower than that determined from the water balance study. The explanation offered is that the cones of water level depression and water level recovery only reflect the pressure or water level in the high-permeability fissures and is not affected by the water in the lower-permeability interstices where the bulk of the ground water is stored. It is therefore not possible to determine the storage coefficient of aquifer No. 1 or of any similar aquifers from drawdown or recovery curves of pumping tests. Total storage has, for such conditions, to be determined by water balance methods, which are often carried out in conjunction with pumping tests.
The major aquifer No 2, which is also formed by a shale horizon, lies further south between two diabase sills. Ground water is abstracted from three boreholes shown on the map. The main source of recharge of this aquifer is surplus water from an aquifer formed by a fault-zone along the contact between the quartzite and the diabase, further to the south. The ground water derived from influent seepage of rain on the quartzite ridge, collects in the fault-zone and then flows underground across
the diabase to the major aquifer, where some of it is pumped and some gave rise to a spring west of Rietondale. Since usage of this ground water from boreholes has increased, the spring has practically dried up.

Fig. 5.

Curves of the lowering of the water levels in observation boreholes during a pump test on borehole 27, and the recovery of the levels after pumping was stopped, are shown in Figure 6. The semi-log time-drawdown curve for observation borehole 32 is given in Fig. 7. These curves are similar to those given in Figs. 4 and 5. Boundary conditions are indicated. The computed transmissibility, $T = 3,010 \text{ gal./day/foot}$, and the coefficient of storage, $S = 0.000025$.

The diabase of the sill north of the laboratory is weathered to depths of 120 to 150 feet below surface and forms a shallow aquifer. The ground-water level in the central part of this aquifer is about 90 feet below surface and ground-water seepage takes place both towards the east and the west. Recharge is local and the surplus water leaks either into major aquifer No. 1 or is lost as effluent seepage into the streambed on the west.
4. General Conclusions

The following conclusions have been drawn concerning pumping tests on boreholes in secondary aquifers, as illustrated by the tests carried out on Rietondale:

1. The cones of dewatering spread very rapidly and very often reach the boundaries of the aquifer within such a short period after pumping commenced that there is hardly a straight line plot of the time-drawdown curve before the gradient is increased due to boundary effects.

2. The transmissibility computed from the pumping test data is that of the highly permeable conduits.

3. The feeding of water into these conduits from storage within the aquifer or outside of it could be considered as leakage or recharge of the aquifer.

4. The coefficient of storage computed from the pumping test is only that of the more permeable conduit or fissure system and the additional storage of the interstices with lower permeability generally is not reflected in the calculation. Often the computed storage is a minor part of the total storage for secondary aquifers, and could therefore be very misleading in assessing the ground-water supplies.

It is expected that the coefficient of storage computed from pumping tests in homogeneous original aquifers would generally reflect the total storage of that aquifer, but it is possible that for some cases the computed value could be appreciably lower than the actual storage.

![Fig. 6. Pumping Test, Borehole 27, Rietondale](image-url)
It would therefore appear that for the assessment of a water supply contained in a secondary aquifer the computed coefficient of transmissibility should reflect inflow into the borehole as a function of drawdown if corrections could be made for boundary conditions and feeding from low-permeability interstices and leakage into the conduits. The coefficient of storage should, however, not be accepted to reflect total storage of the aquifer without further determinations by the water balance method.

5. **THE DRILLERS' TEST**

As already stated, the drillers’ pumping test consists in pumping a borehole to maximum capacity, i.e. with drawdown to the intake pipe near the bottom of the borehole, continuously for seven or nine hours, and occasionally for a longer period,
and measuring the rate of pumping at the end of the test, which is given as the yield of the borehole. Although such a test is not accepted as scientific, its value and reliability will be discussed.

It has been observed that for a large number of such tests equilibrium is reached, that is, the up-to-then progressively decreasing rate of delivery of the borehole reaches a delivery rate which is maintained for the further duration of the tests, within a much shorter period than would have been expected for an aquifer for which the assumptions made for analysis by the non-equilibrium method are satisfied.

The explanation offered for this is as follows: The highly permeable conduit in which the borehole has been drilled has a very small storage capacity and the initial high rate of inflow into the borehole from this conduit rapidly decreases within a short period as the conduit is emptied. Inflow from the low-permeability interstices rapidly increases as the conduit is drained and very soon equals the decreasing rate of flow in the borehole, when equilibrium is established. The constant pumping rate thus equals the leakage into the conduit which flows into the borehole. This pumping rate generally can be maintained for an indefinite period, depending on the storage and annual recharge to the low-permeability aquifer.

Under such conditions the drillers' tested yield of a borehole, which reaches equilibrium before pumping stopped, is actually the maximum long term yield of the borehole and equals the safe yield of the borehole if storage and recharge are not the limiting factors.

It is estimated that equilibrium is established before the end of probably 50% of the 9-hour routine pumping tests carried out by boring contractors in the Republic of South Africa, and that for those tests the yields measured are reliable indications of the long term potentials of those boreholes. Pumping tests carried out at Cornelia (3) illustrate this type of condition very well. It is estimated that the storage of the highly permeable conduit at Cornelia is less than 5,000 gallons.

Should the storage of the system of permeable fissures be greater it may not be possible to establish equilibrium within 9 hours, or even within 72 hours, the usual maximum duration of longer tests. The yield of the borehole could then be much less than the maximum delivery of the borehole at the end of the test.

To illustrate: A particular borehole was tested for 72 hours and delivery at the end of the test was 6,000 gallons per hour. Equilibrium had not been established, however, and when the borehole was put into continuous use immediately afterwards, the yield progressively dropped and stabilised at 2,000 gallons per hour after 3 months of continuous pumping. The conduit system had a total storage of 10 million gallons. The rate of inflow into such fissures can, however, be established by an interrupted test (3).

In the limiting case of secondary aquifers, e.g. fault-zones, which are not hydraulically linked with larger storage in low-permeability interstices, the delivery will be progressively lowered during the course of a pumping test and the yield will fall to nil when the storage of the fault or fissure is completely drained. This is well illustrated by the pumping test of a farm borehole described by Enslin (3). The maximum yield at the commencement of the test was 2,500 gallons per hour and decreased to 2,200 g.p.h. after 10 hours, 400 g.p.h. after 50 hours and to about 100 g.p.h. after 200 ours, when the test was stopped.

It is accepted that, if the pumping rate is measured accurately and regularly during a routine pumping test by the drilling contractor, the data will be of great value in assessing ground-water supplies. Although conditions in secondary aquifers are seldom very favourable for analysing data of controlled pumping tests by the theoretical methods developed, and the coefficient of storage computed is very often misleading, research is being pursued to establish under which conditions it is possible to apply corrections or adjustments to the computed hydrological constants for use in assessing ground-water resources.
REFERENCES

