Correcting drawdowns for atmospheric pressure changes: an example from a semi-confined aquifer on Flinders Island.

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Abstract

During analysis of a fourteen day pump test conducted in a coastal aquifer on Flinders Island, unexpected drawdown fluctuations were found to be strongly related to atmospheric pressure changes. Correction for this effect made the results more amenable to standard pump test analysis.

INTRODUCTION

Tidal effects, barometric pressure changes, variations in pumping rate and longer term water level fluctuations may all be superimposed on the drawdown curve for pumped bores in coastal confined aquifers. Accurate analysis of the data requires their removal from the record, or at least their effect to be minimised, but often these short and long term variations go un-noticed and unaccounted for.

This report is the result of analysis of drawdowns from a fourteen day pump test made on an apparently unconfined coastal aquifer [FR048494] near Lady Barron on Flinders Island. Changes in water levels observed in seven observation bores were suspected and later proved to be related to changes in barometric pressure. This relationship, which indicates the aquifer is confined or semi-confined, has long been recognised elsewhere but although suspected has not previously been established for Tasmanian aquifers.

The pump test is described more fully in Cromer (1978) and was conducted on a set of shallow bores previously installed and briefly tested by Matthews (1978) during a general groundwater survey of the district.

The aquifer has been partly delineated by Matthews; Figure 1 shows its approximate limits. The sediments are probably Quaternary in age and consist of about 10 m of mainly brown medium-coarse grained well-sorted quartz sand overlying blue clay. A relatively impermeable layer of iron-oxide cemented and humic acid stained brown sand occurs generally between 0.9 m and 2.4 m below the surface. This material is not continuous; in some places it is absent (and the aquifer is unconfined) but in others it is replaced by a clay horizon.

Bores 1A and 1D (fig. 2) were pumped simultaneously for 14.2 days at an average combined rate of 155 m^3/day. Drawdowns accurate to the nearest millimetre were measured in each of the seven observation bores 1B, 1C, 11, 11A, 2A, 2B and 2C. Readings for bores 11 and 11A are listed in Appendix 2.

VARIATIONS IN ATMOSPHERIC PRESSURE

Continuous barographs are available from Pats River, 3 km north of Whitemark and 22 km north-west of the test site. These are the nearest available records, and although pressure changes between the two sites will differ in short-term details, their diurnal and larger trends should be similar. During the test, atmospheric pressure varied from 1002 - 1028 mb (10.210 - 10.475 m H_2O*). These changes are shown graphically in Figures 3(b) and 3(c), and are listed in Appendix 1.

* 1 mb = 0.01019 m H_2O.

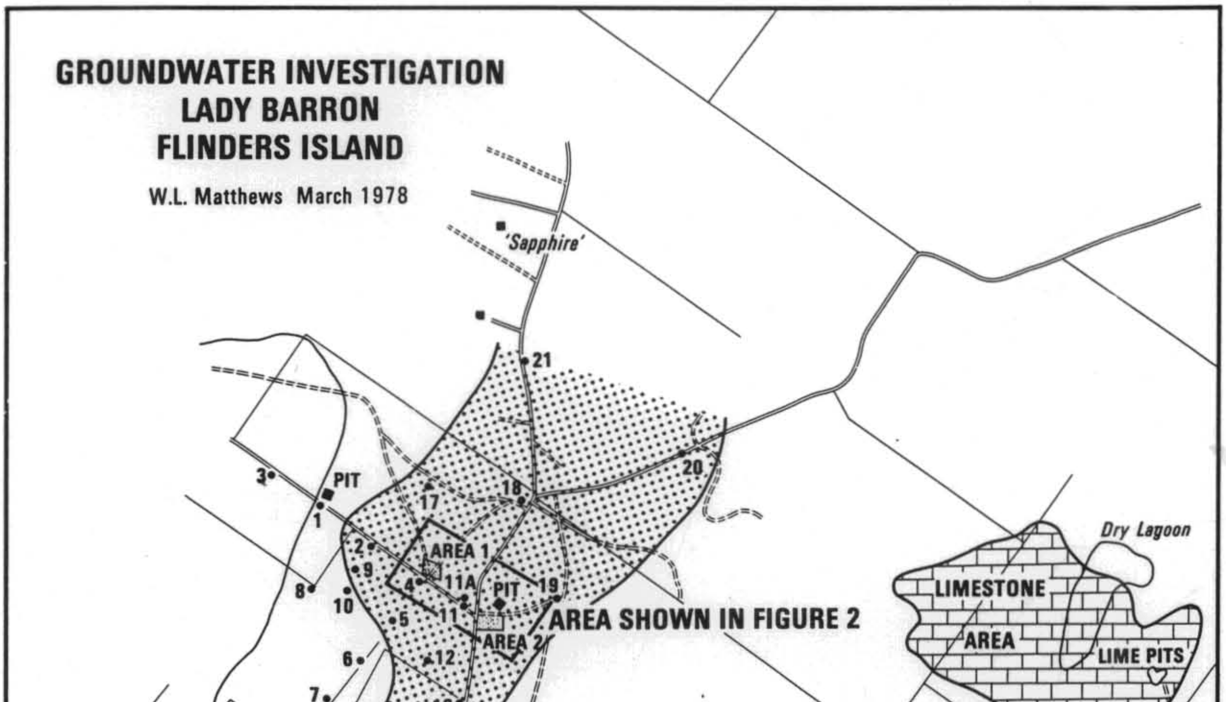
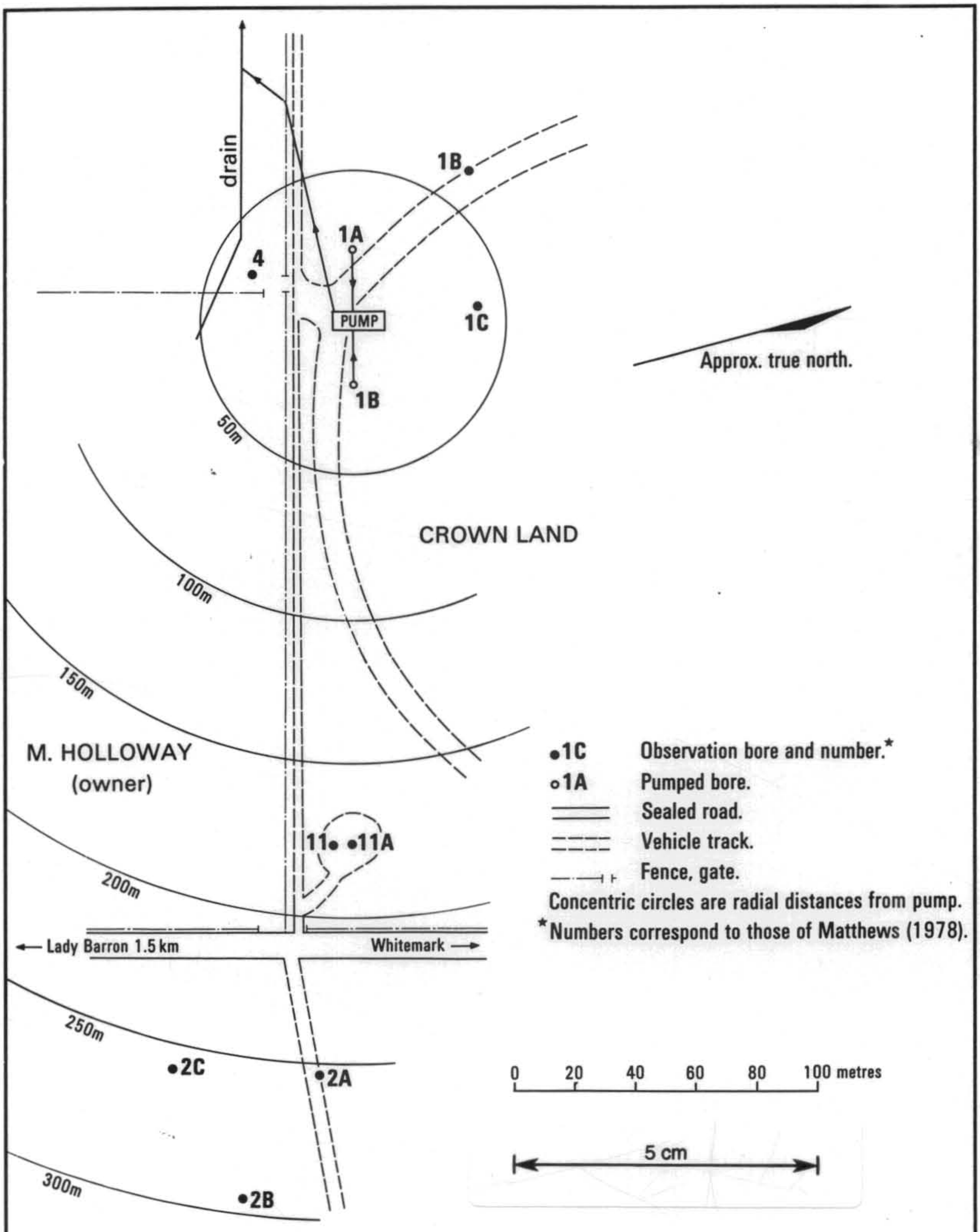

GROUNDWATER INVESTIGATION
LADY BARRON
FLINDERS ISLAND
W.L. Matthews March 1978
'Sapphire'
PIT
AREA 1
AREA 2
PIT
AREA SHOWN IN FIGURE 2
Dry Lagoon
LIMESTONE AREA
LIME PITS
Airstrip
Cemetery
A
B
VINEGAR HILL
100
80
60
40
20
North (Approx.)
Lady Barron jetty
Scotts Lagoon
5 Test hole
Areas of closely spaced holes
Pit dug with dragline
Road
Track
Area underlain by coarse sand
Contour (in metres)
0 250 500 metres
TASMANIA, DEPARTMENT OF MINES
4398

Figure 1



LOCATION OF PUMPED AND OBSERVATION BORES

Figure 2

Water level fluctuations due to atmospheric pressure changes are not usually recognised in bores tapping unconfined aquifers because the water table is a free surface at atmospheric pressure, and any pressure changes are distributed equally in the bore and aquifer. In confined or semi-confined aquifers, the pressure variations act not only on the free water surface in a bore, but also on the confining layer overlying the aquifer. This layer transmits the pressure change virtually undiminished, which is accommodated by both a change in stress in the elastic skeleton of the aquifer and by a change in water pressure in the pore spaces in direct contact with the confining bed. Thus a pressure differential is set up between the bore and the aquifer. Water level fluctuations will be observed in the bore and the ratio of the observed change in water level, Δh, to the corresponding change in pressure, Δp, both expressed in m H_2O, is known as the aquifer's barometric efficiency, *BE*:

$$BE = \Delta h/\Delta p$$

It is necessary to determine *BE* before removing barometric changes from drawdown readings.

Graphical calculation of BE

If Δh is plotted against Δp (fig. 4) *BE* is the inverse of the slope of the straight line of best fit through the points. If drawdown differences, Δs, are plotted against Δp instead, the line has an opposite slope because by convention $\Delta s = -\Delta h$. *BE*, however, is always positive. Ideally, Δh should be measured from hydrographs in bores removed from all the effects, but this was not possible at Lady Barron. Nevertheless, an inspection of drawdowns suggests that bore 2C is the least affected by pumping and that its $\Delta s/\Delta p$ plot would show the strongest correlation. This is verified in Figure 4, where the correlation coefficient is -0.93 (*i.e.* there is a strong inverse relationship between water levels, Δh, and Δp). The correlation (-0.73) is strong but less marked for observation bore 2A and complicated for observation bore 2B. [A large and unexplained increase in drawdown was recorded for this bore at about 7440 minutes. It is unlikely that the readings were incorrect; one possible explanation is a vertically upward shift in the plastic casing caused by artesian water pressure]. Correlation between Δh and Δp is improved for 2B if the readings are separated into two groups ±7440 minutes. For times less than 7440 minutes, the coefficient of -0.61 suggests reasonable inverse correlation, but an even stronger direct relationship (+0.66) between Δh and Δp for longer times is as yet unexplained.

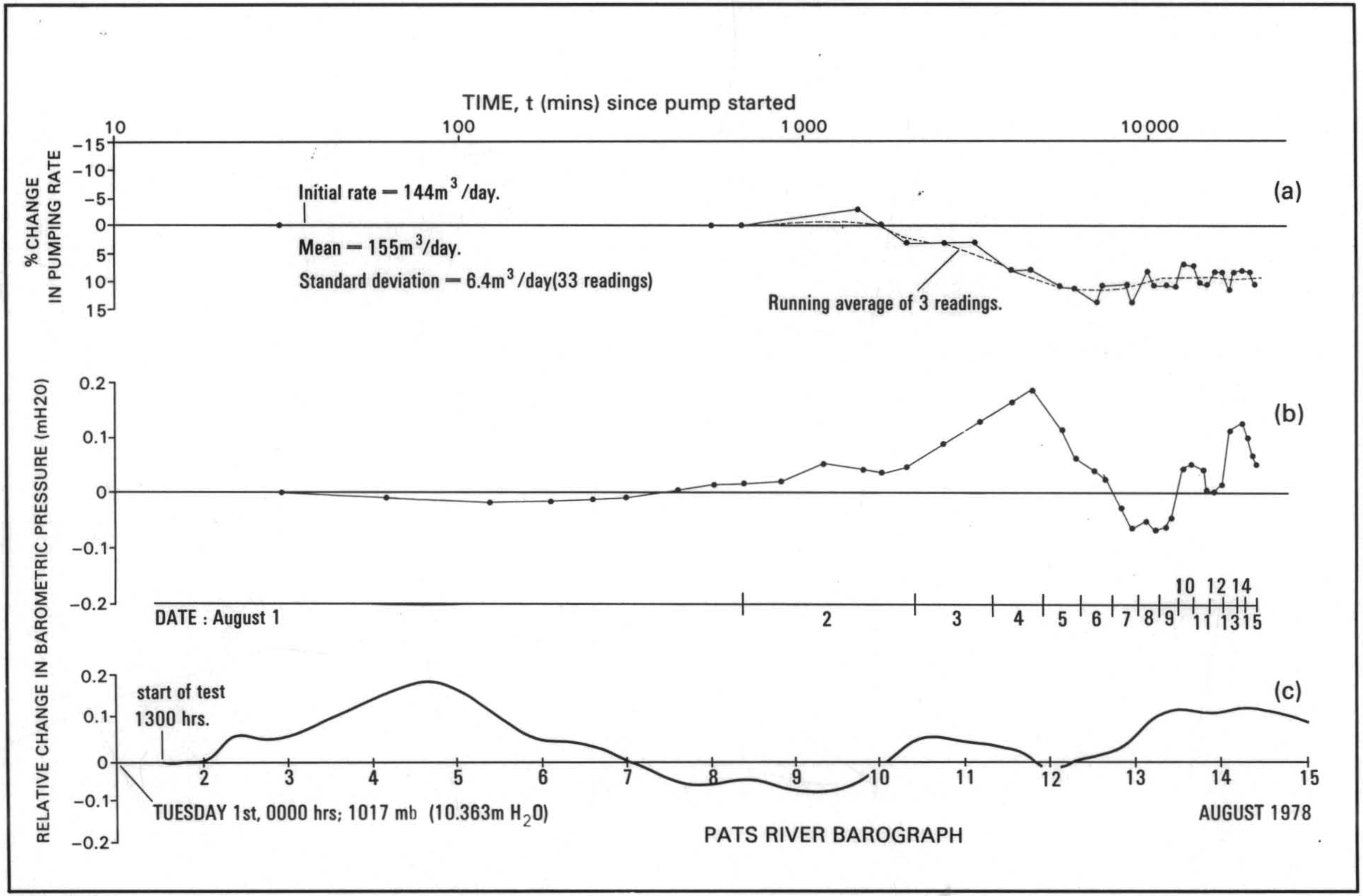
Since 2C shows the strongest relationship between Δh and Δp, a slope of -0.50 and barometric efficiency *BE* of 0.5 is considered reasonable for the aquifer.

Correcting for barometric pressure changes

Barometric pressure, p, for various times are listed in Appendix 1 and pressure differences, Δp, are calculated relative to the start of the pump test. The last column ($\Delta p \cdot BE$) represents the expected rise or fall in water level in the bore due to pressure changes. In normal hydrographs (unaffected by pumping) an increase in p causes a decrease in groundwater levels (and vice versa), and the adjusted water level (h') is therefore

$$h' = h \ (\Delta p \cdot BE) \quad (m)$$

Conversely, in pump tests where the sign convention is reversed and drawdowns (s) are measured, the adjusted drawdown (s') is;



TIME, t (mins) since pump started
10
100
1 000
10 000
% CHANGE IN PUMPING RATE
Initial rate — 144m³/day.
Mean — 155m³/day.
Standard deviation — 6.4m³/day(33 readings)
Running average of 3 readings.
(a)
(b)
(c)
RELATIVE CHANGE IN BAROMETRIC PRESSURE (mH20)
DATE : August 1
start of test
1300 hrs.
TUESDAY 1st, 0000 hrs; 1017 mb (10.363m H₂O)
AUGUST 1978
PATS RIVER BAROGRAPH

Figure 3

5 cm

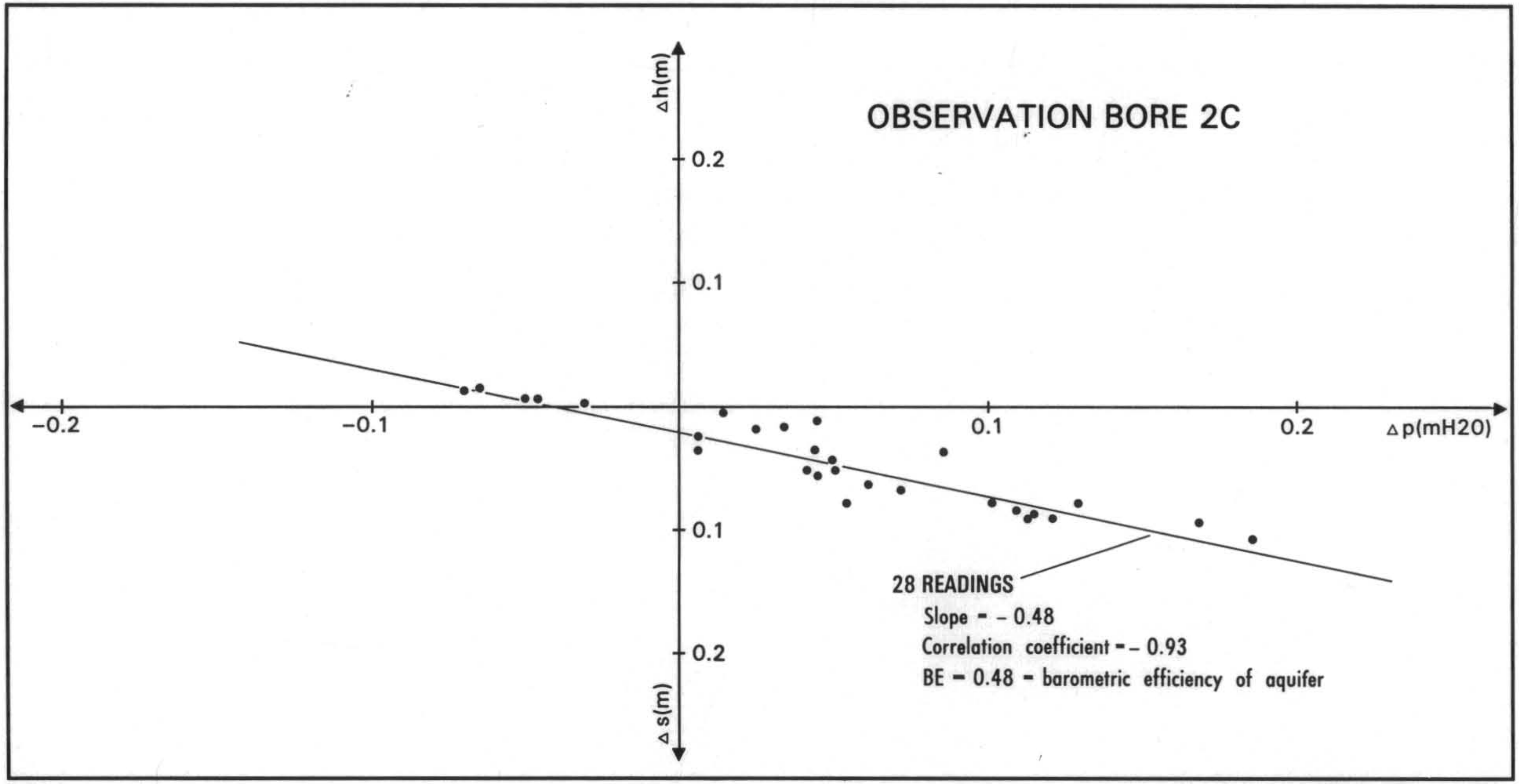


Figure 4

5 cm

33-6

6/11

$$s' = s - (\Delta p \cdot BE)$$

VARIATIONS IN PUMPING RATE

The pumping rate was initially set at 144 m^3/day but during the test varied from 140 - 164 m^3/day. The average rate was 155 m^3/day. Rates were measured from the time taken to fill a container of known volume (29*l*) and are probably accurate to ±4 m^3/day (±0.5 secs). In Figure 3a, the smoothed curve through the variation diagram is based on running averages of three readings.

Drawdown readings are easily adjusted for variation in pumping rate because in confined aquifers drawdown is directly and simply related to yield. If the pumping rate (Q) increases, excessive drawdowns are produced and these must be reduced by a simple fraction of Q, and vice versa. If Q_o is the initial pumping rate and Q_t is the pumping rate at time t, then s'' in Appendix 2 is given by

$$s'' = s' - (\Delta Q/Q_o)s' \quad (m)$$

where $\Delta Q = (Q_t - Q_o)$.

Log-linear graphs of (a) s vs t, (b) s' vs t and (c) s'' vs t for bores 11 and 11A are shown in Figure 5. In both cases there is a progressive smoothing of the curves from (a) to (c). The corrections are less noticeable for the remaining five bores but they generally allow straight lines of best fit to be drawn more accurately through the appropriate points and produce more reliable values for aquifer properties.

GENERAL CORRECTION EQUATION

It is apparent from Figure 5 that some other effects are influencing the drawdown readings. The properties of the aquifer vary from place to place and may account for some of the differences in effects between bores. The regional change in the water table is unknown but undoubtedly has an effect on readings. The variation in readings for bore 2B has already been referred to; an even more surprising rise in water level for bore 2A (not shown) is yet to be explained.

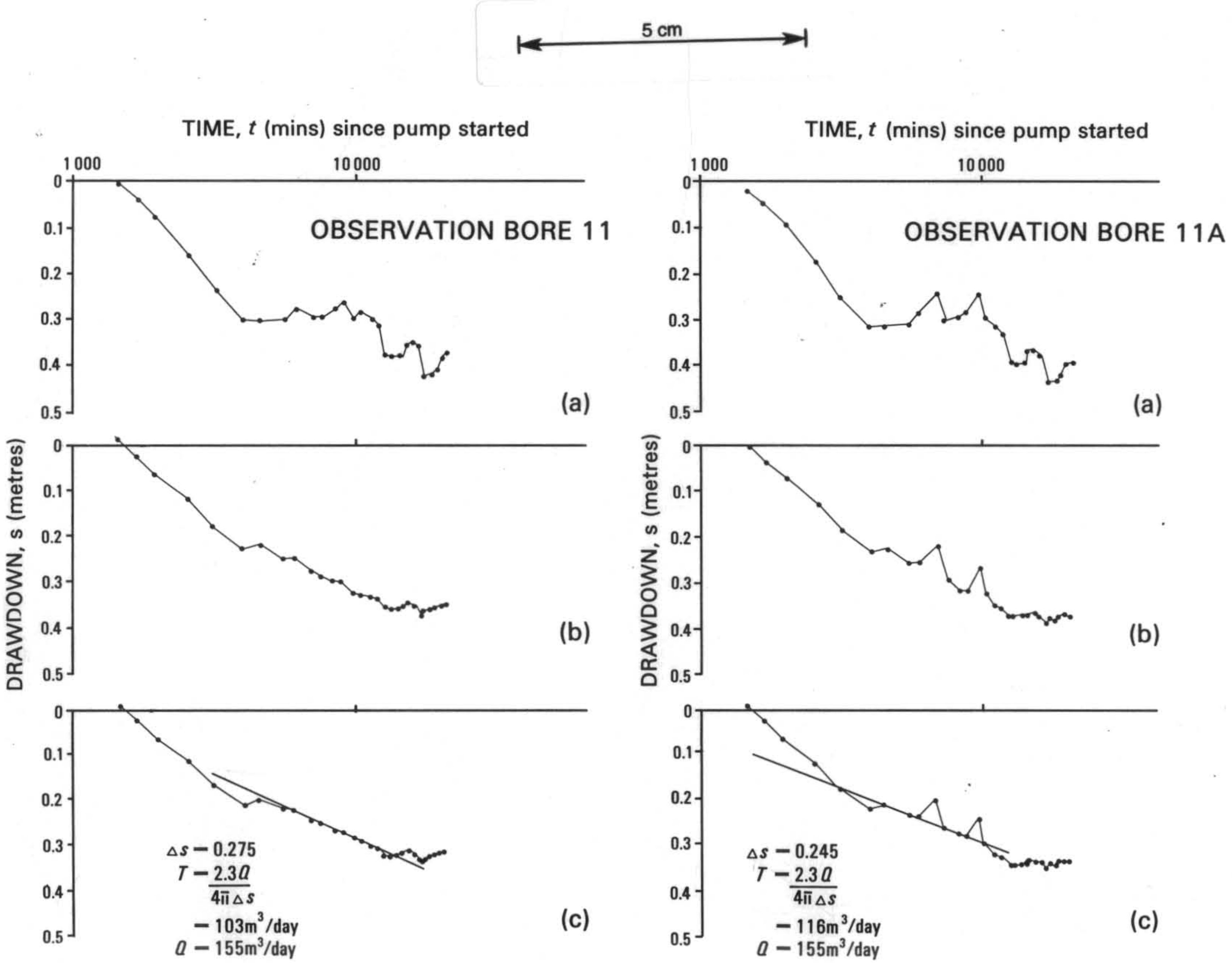
A general empirical equation which adjusts drawdown for most of the fluctuations (excluding earthquakes and similar) observed in confined aquifers may be written

$$s_{corr} = [s_{obs} - (\Delta p.BE) + (\Delta x.TE) + \Delta d]\ [1 - \Delta Q/Q_o]$$

	barometric changes	tidal effects	regional water-table changes	pumping changes

where at any time (and provided a consistent sign convention is used)

s_{corr} = fully adjusted drawdown
s_{obs} = observed drawdown
TE = tidal efficiency of aquifer = $(1-BE)$
Δx = relative elevation of tide above or below datum
Δd = relative elevation of regional water table gradient above or below datum



5 cm
TIME, t (mins) since pump started
1 000
10 000
OBSERVATION BORE 11
DRAWDOWN, s (metres)
0
0.1
0.2
0.3
0.4
0.5
(a)
(b)
(c)
△s = 0.275
T = 2.3Q / 4π△s
= 103m³/day
Q = 155m³/day
TIME, t (mins) since pump started
OBSERVATION BORE 11A
△s = 0.245
T = 2.3Q / 4π△s
= 116m³/day
Q = 155m³/day

Figure 5

REFERENCES

CROMER, W.C. 1978. Pump testing a confined coastal aquifer near Lady Barron, Flinders Island. *Unpubl.Rep.Dep.Mines Tasm.* 1978/34

MATTHEWS, W.L. 1978. Groundwater at Lady Barron, Flinders Island. *Unpubl. Rep.Dep.Mines Tasm.* 1978/8.

[29 September 1978]

APPENDIX 1

Barometric pressures for test period

Day	Time (hrs)	Time since pump started t (mins)	Barometric pressure* (mb)	p (m H_2O)	Cumulative pressure change Δp (m H_2O)	$(\Delta p \cdot BE)$ (m H_2O) x 0.5
August 1 1978	1300	0	1010.0	10.292	0.000	0.000
	1330	30	1009.5	10.287	-0.005	-0.003
	1400	60	1008.8	10.280	-0.012	-0.006
	1500	120	1008.5	10.277	-0.015	-0.008
	1600	180	1008.5	10.277	-0.015	-0.008
	1700	240	1009.0	10.282	-0.010	-0.005
	1800	300	1009.0	10.282	-0.010	-0.005
	2000	420	1010.5	10.297	0.005	0.003
	2200	540	1011.3	10.305	0.013	0.007
2	0000	660	1011.7	10.309	0.017	0.009
	0300	840	1012.5	10.317	0.025	0.013
	0800	1140	1015.0	10.343	0.051	0.026
	1330	1470	1014.0	10.333	0.041	0.022
	1700	1680	1013.5	10.328	0.036	0.018
	2200	1980	1014.5	10.338	0.046	0.023
3	0730	2550	1018.5	10.379	0.087	0.044
	1700	3120	1022.8	10.422	0.130	0.065
4	0730	3990	1026.5	10.460	0.168	0.084
	1700	4560	1025.2	10.477	0.185	0.093
5	0900	5520	1020.8	10.402	0.110	0.055
	1700	6000	1016.0	10.353	0.061	0.031
6	0900	6960	1014.2	10.335	0.043	0.022
	1700	7440	1012.5	10.317	0.025	0.013
7	0900	8400	1007.0	10.261	-0.031	-0.016
	1700	8880	1003.6	10.227	-0.065	-0.033
8	0900	9840	1005.1	10.242	-0.050	-0.025
	1700	10320	1003.0	10.221	-0.071	-0.036
9	0900	11280	1003.5	10.226	-0.066	-0.033
	1700	11760	1005.5	10.246	-0.046	-0.023
10	0900	12720	1014.5	10.338	0.046	0.023
	1430	13050	1014.9	10.342	0.050	0.025
	1530	13110	1015.2	10.345	0.053	0.027
11	0900	14160	1014.9	10.342	0.050	0.025
	1700	14640	1010.5	10.297	0.005	0.003
12	0900	15600	1010.5	10.297	0.005	0.003
	1700	16080	1011.5	10.307	0.015	0.008
13	0900	17040	1021.4	10.408	0.116	0.058
	1700	17520	1021.2	10.406	0.114	0.057
14	0900	18480	1022.0	10.414	0.122	0.061
	1700	18960	1020.0	10.394	0.102	0.051
15	0900	19920	1017.0	10.363	0.071	0.036
	1700	20400	1015.5	10.347	0.055	0.028

* 1 mb = 0.01019 m H_2O

APPENDIX 2

Observed and adjusted drawdown (m) for observation bores

s = observed drawdown; *s'* = *s* adjusted for barometric pressure change;
s" = *s'* adjusted for changes in pumping rate.

Time (mins) since pump started	Bore 11			Bore 11A		
	s	*s'*	*s"*	*s*	*s'*	*s"*
1140	*c* 0.0	*c* 0.0	*c* 0.0	*c* 0.0	*c* 0.0	*c* 0.0
1470	0.009	-0.013	-0.013	0.014	-0.008	-0.008
1680	0.040	0.022	0.022	0.043	0.025	0.025
1980	0.082	0.064	0.063	0.083	0.065	0.064
2550	0.164	0.120	0.116	0.168	0.124	0.120
3120	0.240	0.175	0.167	0.246	0.187	0.173
3990	0.307	0.223	0.211	0.312	0.228	0.215
4560	0.309	0.216	0.202	0.313	0.220	0.206
5520	0.301	0.246	0.223	0.308	0.253	0.229
6000	0.279	0.248	0.222	0.286	0.255	0.228
6960	0.299	0.277	0.247	0.240	0.218	0.194
7440	0.298	0.285	0.254	0.309	0.296	0.263
8400	0.284	0.300	0.267	0.295	0.311	0.277
8880	0.267	0.300	0.269	0.278	0.311	0.278
9840	0.298	0.323	0.289	0.241	0.266	0.238
10320	0.289	0.325	0.294	0.301	0.325	0.294
11280	0.300	0.333	0.303	0.319	0.352	0.320
11760	0.317	0.340	0.309	0.332	0.355	0.323
12720	0.384	0.361	0.329	0.400	0.377	0.343
13050	0.386	0.361	0.329	0.401	0.376	0.342
14160	0.383	0.358	0.326	0.398	0.373	0.339
14640	0.355	0.352	0.320	0.368	0.366	0.334
15600	0.350	0.347	0.314	0.369	0.366	0.331
16080	0.363	0.355	0.321	0.379	0.371	0.336
17040	0.430	0.372	0.337	0.443	0.385	0.348
17520	0.423	0.366	0.335	0.437	0.380	0.344
18480	0.422	0.361	0.329	0.441	0.380	0.346
18960	0.410	0.359	0.327	0.422	0.371	0.338
19920	0.388	0.352	0.320	0.405	0.369	0.336
20400	0.378	0.350	0.317	0.399	0.371	0.336