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Final Report on Application of Collector Well Well Systems to Sand Rivers Pilot Project

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EXECUTIVE SUMMARY

Aims of the Study

This pilot study was undertaken with the primary aim of assessing the application of collector well systems to abstraction of groundwater from sand-rivers in Botswana. Such a study is required to understand:

1. the drilling and construction techniques required for installation of collector well systems into sand river deposits,

2. the geological and hydrogeological nature of sand river deposits.

Study Inputs

Some 45 laterals were constructed within 10 well shafts excavated at riverside locations in north-eastern Botswana. The well shafts were excavated at suitable sites by the Department of Water Affairs. The collector well laterals were drilled using BGS drilling equipment with the assistance of DWA staff and equipment. The hydrogeological and geological aspects of the sand river and collector well, at each site were evaluated by BGS and DWA staff, using a series of techniques developed by BGS for evaluation of alluvial sediments and large diameter wells elsewhere in the world.

Results

This pilot study, which was primarily of an engineering nature, successfully investigated application of the collector well system to abstraction of groundwater from sand rivers. The criteria used as a basis for this study were based upon the conclusions drawn about the physical characteristics of sand-rivers from earlier, much more extensive studies. Laterals were drilling through the weathered basement rocks of the sand river bank into sand river alluvial sediments using air hammer or rotary drilling with mixed results. Drilling using the telescoped jetting method was successful within coarse sands, where laterals were installed to 20 m from the well shaft, but not in fine sands and silts. Drilling methods appropriate for specific sediment lithologies may need and/or a new approach involving dewatered trench systems used to ensure installation of appropriately screened and gravel packed laterals.

The DWA/BGS study also demonstrated that the geological and hydrogeological characteristics of sand-rivers are more complex than previously thought. Novel techniques were employed to recognise and quantify groundwater flow through sand river sediments at the end of the dry season, sediment permeabilities and susceptibility of screen slots to blockage - the latter being determined from formation grain size distributions. Test pumping indicated rates of flow along laterals to the collector wells. Some indication of potential short to long term sustainable discharge rates were obtained from these data, although abstraction rates and water levels have to be monitored for at least one year if reasonable estimates of the sustainability of such systems are to be made. Detailed investigations need to be made of sand rivers, including weathering of the underlying basement strata and the nature of channel sediments to ensure that laterals are constructed within water-productive sand layers. Geophysical methods such as ground penetrating radar used with the penetration probe and sampling device can be used to local suitable target zones.

The sustainable yield of a sand river system depends upon:

- the recharge it receives and its distribution with time
- the geometry of the sand river deposits
- the geometry of the collector well, shaft and adits
- the hydraulic properties of the sand river
- the upstream use of the sand river groundwater resources

A generalised digital model should be produced of the groundwater system of a sand river. A subroutine for simulating different patterns of recharge should be developed. The model could be used to examine long term sustainable yield and design of collector well laterals. Data acquired from the long term monitoring of sites located on each of the three classes of sand rivers identified will be required to prove such a model.

Scope for Additional Work

This type of study produces information of relevance not only to hydrogeologists but also to those concerned with water supply in semi-arid environments. The study has highlighted the need for detailed understanding of the sedimentology of sand rivers and the main factors controlling the modes of sediment deposition and diagenesis. The installation of production collector well systems should now be undertaken, with BGS involvement, within a process type project. This will ensure the further development of collector well abstraction systems appropriate for each class of sand river.

1. INTRODUCTION

1.1 Situation and Visit Objectives

The British Geological Survey (BGS) was contracted by the Department of Water Affairs (DWA), Botswana, within the "Application of Collector Wells to Sand-rivers Pilot Project, Botswana", to evaluate methods of collector well construction for abstraction of groundwater from sand-river systems in north-eastern Botswana. Geological and hydrogeological aspects of sand-river deposits were also studied.

In sparsely vegetated semi-arid environments erosion of colluvium by storm-water surface runoff is accelerated by climate change, deforestation and overgrazing (Owen, 1989). In such environments ephemeral river channels become choked with ribbon like sand and gravel deposits, derived from land-surface erosion (Bond, 1967). Crowley (1983) and Graf (1988), among others, describe alluvial sediment accumulations along ephemeral river channels in semi-arid environments. Referred to as sand-rivers in north-eastern Botswana, these ephemeral streams occupy steep-sided channels with flat floors that are underlain by alluvial sands up to 10 m thick (Figure 1). According to Lister (1987) such channels were eroded into basement rocks during pluvial periods; to be latterly infilled with alluvium derived from the erosion of surrounding basement rocks during drier periods (Nord, 1985).

The geology of north-eastern Botswana, as described by Bennett (1971), Crockett et al (1974), Litherland (1975), and Key (1976) is dominated by rocks of the Precambrian Basement Complex. These include rocks of the Tati Schist belt and the Limpopo Mobile Belt, all intruded by numerous Karroo age WNW trending dolerite dykes. Weathered Precambrian granites and high grade metamorphic granitic gneisses and amphibolites are the main sources of the sand, gravel and clay deposits that infill the sand-rivers. The trends of river courses within north-eastern Botswana are affected by geological features such as joints, faults and outcrops of harder rocks such as dolerite dykes.

The ephemeral sand-rivers of north-eastern Botswana are major sources of groundwater, in an area that receives 450-1210 mm of rainfall per annum. These elongate alluvial deposits are recharged by short lived flash floods, the result of isolated storm rainfall events. Annual maximum temperatures range from 24°C to 35°C resulting in high surface evaporation losses. Since capillary rise through the surface sands is only effective to about 1.1 m below the sand-river surface, sands below that level can remain saturated throughout the year, with water continuing to flow downstream through this saturated zone. Such sand-river aquifers are important sources of water for village use and stock watering in an area underlain by basement rocks with poor aquifer properties.

Wikner (1980) and Nord (1985) recognised major, intermediate and minor sand-river systems in north eastern Botswana. They assessed the groundwater development potential of these systems, based on river gradient, river cross section area, aquifer permeabilities and formation transmissivities. Unfortunately they did not study the impact of palaeo-environmental and anthropogenic processes upon patterns of sand-river alluvial sediment deposition.

Attempts have been made to develop the groundwater resources of these deposits using boreholes, well point systems and large diameter wells sunk into the river-sands and boreholes located within bank side fissure zones that intersect sand-river courses. Temporary abstraction points include hand excavated shallow pits for abstraction of small quantities for cattle watering purposes, mechanically excavated large pits for abstraction of large quantities of water for road construction purposes, as from the Ntshe River (Fig 2), and well points for village domestic supply. These abstraction systems are vulnerable to damage during large flood events. Therefore a cheap reliable system, safe from the

Figure 1. A typical sub-minor sand-river, the Tati at Masunga

Figure 2. Water abstraction for rural road construction from a mechanically dug hole in the bed of the Ntshe sand-river

effects of flooding but with sufficient storage capacity to satisfy the increasing requirements of a village supply system is required. The present and projected water demands for the main villages in the North Eastern Botswana are listed in Table 1.

Village	Pop 91	Pop 97	Yield 97 m^3/day	Demand 97 m^3/day	Pop 2007	Demand 2007 m^3/day	Shortage	Remarks 1:50 000 sheet number
Botalaote	344	428	57	64	616	92	yes	Supplies Makaleng and Sebina
Butale	531	661	53	99	951	142	yes	2027D1
Gambule	947	1178	20	176	1695	254	yes	2027C2
Gulubane	805	1002	44	150	1441	216	yes	2027C4
Jackalasi 1	1207	1501	12	224	2159	323	yes	2027D1
Ditladi	334	416	106	62	599	90	ok	
Jackalasi 2	1039	1293	23	193	1860	278	yes	2027D3
Kalakamati	678	844	35	126	1214	182	yes	2027C2
Kgari	688	856	44	128	1232	184	yes	Connected to Ramokgwebana
Letsholathebe	718	893	38	134	1285	192	yes	2027C2
Makaleng	1071	1334		199	1919	287		2027C4 fed from Mambo, Butale
Malambakwena	742	923	95	138	1328	199	yes	2027C2
Mambo	578	719	134	108	1033	155	ok	2027C4
Mapoka	1583	1969	90	295	2832	414	yes	2027D1
Masingwaneng	558	694		104	999	150		2027C4 fed from Mambo
Masukwane	788	980	40	147	1410	211	yes	
Masunga	1554	1933	216	475	2780	683	yes	2027C2
Tshesebe	1145	1422	88	350	2048	503	yes	2027D1
Matshelagabedi	1293	1608	546	241	2313	346	yes	2127B1
Matsiloje	841	1046	80	157	1505	225	yes	2127B4
Mbalambi	466	580	60	87	835	125	yes	Bh 3195
Moroka	1138	1416		212	2037	305		2027D1 supplied by WUC
Mosojane	1245	1545	44	231	222	332	yes	2027D1
Nlapkwane	1920	2388	140	357	3435	514	yes	2027D1
Pole	319	397	11	60	571	85	yes	2027D1
Ramokgwebane	1353	1683	42	414	2421	595	yes	2027D1

Village	Pop 91	Pop 97	Yield 97 m^3/day	Demand 97 m^3/day	Pop 2007	Demand 2007 m^3/day	Shortage	Remarks 1:50 000 sheet number
Sechele	606	754		113	1085	162		2027C4 connected with Mambo
Sekakangwe	948	1179	23	176	1696	254	yes	
Senyawe	1318	1640	52	245	2359	353	yes	2027D3
Shashe Bridge	601	748		112	1076	161		2127A4 supplied from Tonota
Tati Siding	2420	2988		447	4298	643		2127A4 supplied by WUC
Temashanga	1683	2093	43	313	3010	450	yes	2027C4
Nzwenshambe	1274	1585	54	237	2280	341	yes	2027C2
Matenge	432	538	53	81	774	116	yes	2027C4
Siviya	1231	1531	220	229	2202	329	yes	2027D3
Kachane	350	436		65	628	94		RVN
Tsamaya	1563	1944	72	291	2796	418	yes	2027D3

Table 1. Village water demand projections and consumption figures.

Dam construction on sand-rivers is an expensive option. The Shashe River has been dammed for provision of water supply to Francistown and Selebi Phikwe, and the Motloutse River has recently been dammed at Letsibogo near Mmadinare, to supply water into the north-south pipe line that will transmit water to Gaborone. Further dam construction for the north-south pipeline is planned at sites on the Limpopo and Lower Shashe rivers. Such major works can not be economically undertaken for rural water supply. The impact of dams upon down-stream flow and village water supply systems has still to be assessed.

BGS developed the collector well system as a cheap but sustainable method of abstracting groundwater from weathered basement rocks and alluvial sediments. Drilling systems were developed for the installation of laterals within collapsing alluvial formations. The results of these studies have been applied to the water bearing sand-rivers of north-eastern Botswana, where well-shafts have been sunk into stream banks located above normal flood level. Essentially, a 2.2 m diameter, corrugated steel sheet lined well-shaft is excavated into basement rock adjacent to a sand filled incised sand-river channel, to a depth below the base of the channel, as defined by sand probing. Boreholes are drilled horizontally from this well-shaft, at depths designed to intercept water bearing sands within the sand-river. As originally conceived, laterals were to be drilled to intercept permeable coarse grained sediments thought to be located along the base of a sand-river channel. The well-shaft then acts as a reservoir from which water can be abstracted continuously, or during several periods of pumping, to supply the requirements of local communities.

A pilot study undertaken to assess the application of collector well systems to abstraction of groundwater from sand-rivers in Botswana has recently been completed. As part of an on-going village water supply project of the Government of Botswana, ten 2.2 m diameter well-shafts have been sunk by the DWA, one each at Chadibe, Borolong, Mathangwane, Matshelagabedi, Gulubane and Francistown Prison, and two at both Tobane and Masunga (Figure 3). An aim of the pilot project was the conversion of these large diameter well-shafts into collector well systems.

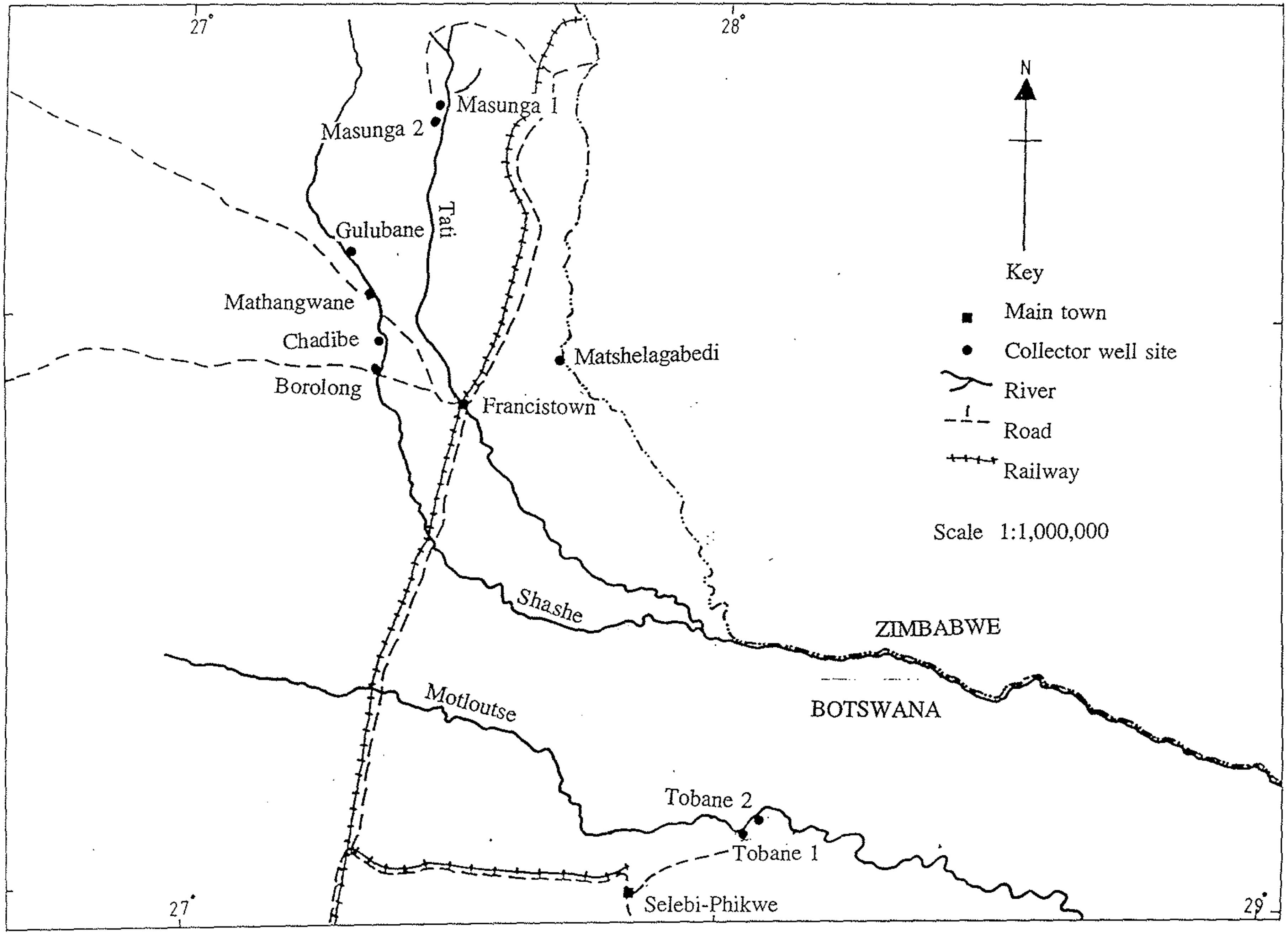


Figure 3. Collector well site location map

The pilot project included four short visits undertaken by BGS personnel to drill laterals and test newly completed collector wells, as well as assess the hydrogeological nature of sand rivers, between 1991 and 1997. The results and analysis of data collected during these periods of field work are presented within the following BGS reports:-

- Herbert, R (1992)
- Davies J, Herbert R and Rastall P (1995a)
- Davies J, Herbert R and Rastall P (1995b)

The main results of this project have been summarised and presented as a paper at the 30th International Geological Congress, China (Herbert R, Barker J A, Davies J and Katai O T 1997).

The drilling and test-pumping methods used were modified during the pilot study to take into account of the complex nature of sand-river sedimentation. Methods were also devised to better assess the hydraulic properties of sand-river alluviums, permitting determination of stream flow towards the end of the dry season, permeability of sediments, and recognition of 1 in 100 year major flood event depth of channel scour.

During the 13 July to 3 August 1997 a BGS hydrogeologist based at Francistown visited collector well sites at Gulubane and Matshelagabedi. During 6 July to 23 August a BGS contract driller undertook works at Gulubane, Matshelagabedi and Tobane. The objectives of this visit were:

- To drill and test a series of laterals at the Gulubane and Matshelagabedi collector well sites (additional drilling of laterals was undertaken at Tobane 1).
- Attempt dewatering of a trench part-way across the Shashe River to extend a shallow lateral, by installation of screen sections by hand, across the river at shallow depth.
- Assess the nature of the BGS research programme using additional data acquired.

This report describes work undertaken, data collection and analysis during this field visit; present the results of the recent studies, and describe the field methodologies and analytical methods developed during the pilot project. Recommendations for future work are listed and briefly discussed.

1.2 Summary of Works Undertaken During Recent Visit

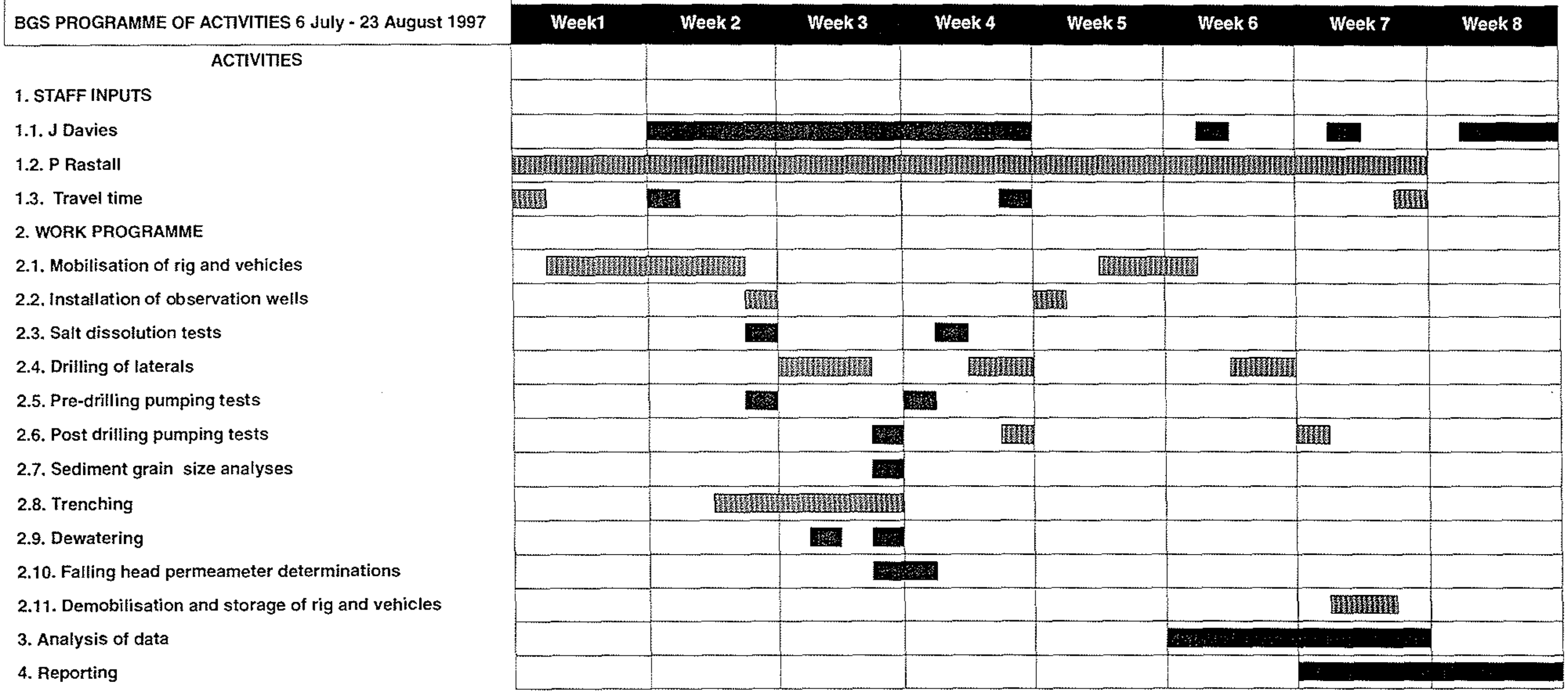
The BGS programme of activities undertaken during the period 6th July to 23rd August 1997 are summarised in bar chart form (Table 2); works undertaken by BGS at the Gulubane, Matshelagabedi and Tobane 1 collector well sites are summarised below; detailed movements of BGS staff are described in an itinerary (Appendix A).

1.2.1 *Works Undertaken at Gulubane*

(a) A drawdown/recovery pumping test was undertaken on the Gulubane well-shaft. Within the 9.85 m deep well-shaft the rest water level was 6.71 (mbtoc) before pumping. The well-shaft was emptied in 82 mins at a discharge rate of 2.8 l/sec. Average inflow into the well-shaft during drawdown was 0.04 l/sec. The water level recovered to 8.72 m after 1246 mins, at an average inflow rate of 0.045 l/sec.

TABLE 2

BGS PROGRAMME OF ACTIVITIES 6 July - 23 August 1997



(b) A JCB was used to excavate a dewatering trench 10 m wide, across the Shashe river normal to the bank where the well-shaft is located. The base of the trench was excavated to the water table 1.35 m below the sand-river surface (mbsrs). Three observation wells were installed 14 m, 24 m, and 34 m from the river bank adjacent to the well-shaft, in a line normal to the longitudinal axis of the river.

(c) The JCB was also used to excavate a geological inspection trench about 3 m wide across the Shashe River downstream of the dewatering trench. A series of photographs were taken of the trench sides and sand samples taken for grain size determinations.

(d) Four laterals were drilled from the well-shaft, three at 8.85 m below top of casing (mbtoc) (4.2 mbsrs) and one at 7.09 mbtoc (2.44 mbsrs). All four produced water, the largest flow, 2 l/sec, being recorded from lateral No. 4.

(e) Grainsize analyses were undertaken of 14 sand samples obtained from the geological inspection trench. These were obtained at 5 m intervals along the trench at depths of 1 m and 1.75 mbtsr. A nest of twenty two sieves, a motorised shaker and an electronic balance were used to undertake the grainsize analyses.

(f) Falling head permeability tests were undertaken upon 8 sand samples obtained from the dewatering and geological trenches. A simple falling head permeameter tube was manufactured and used for these determinations. This equipment with notes explaining its use was passed on to DWA field staff for their future use.

(g) Three salt dilution flow tests were undertaken, one at each of three observation boreholes located along the dewatering trench. These observation boreholes were screened to depths of 1.83 m, 2.24 m and 2.17 m below the water table respectively.

(h) A drawdown/recovery pumping test was undertaken on the Gulubane collector-well. Within the 9.85 m deep collector-well the rest water level was at 6.11 m before pumping. The collector-well was pumped dry in 102 mins at a discharge rate of 6.2 l/sec. Average inflow into the collector-well during drawdown was 3.6 l/sec. The collector-well water level recovered to 6.38 m in 100 mins, an average inflow rate of 2.5 l/sec for the recovery stage.

(i) An attempt was made to dewater the trench at the end adjacent to the collector-well site using two diaphragm pumps, located within perforated 200 l drums, each producing 6 l/sec. A drawdown of more than 1 m was achieved. A similar attempt to dewater the central part of the trench produced a drawdown of 0.5 m, insufficient to uncover the end of lateral No. 4 located about 1 m below the rest water level.

(j) The drilling and test-pumping equipment were moved to the Matshelagabedi site on completion of works at the Gulubane site.

1.2.2 Works Undertaken at Matshelagabedi

(a) A drawdown/recovery pumping test was undertaken on the Matshelagabedi well-shaft. Within the 8.7 m deep well-shaft the rest water level was at 2.87 mbtoc before pumping. The well-shaft was emptied in 62 mins at a discharge rate of 6.2 l/sec. The average inflow into the well-shaft during drawdown was 0.93 l/sec. The water level recovered to 4.06 mbtoc in 310 mins, at an average inflow rate of 0.90 l/sec during recovery.

(b) Four laterals were drilled from the well shaft, three at 5.00 mbtoc (3.48 mbsrs) and one at 4.00 mbtoc (2.48 mbsrs). Three of the four laterals produced water, each flowing at 0.5 l/sec.

(c) Falling head permeability tests were undertaken upon two samples obtained from holes dug for lithological survey and emplacement of an observation borehole, the latter installed by jetting with compressed air.

(d) One salt dissolution flow test was undertaken at the observation borehole, located 33 m from the collector well, within the Zimbabwean side of the Ramokgwebana River. This observation borehole was screened to a depth of 1.25 m below the water table. The very slow response measured is indicative of very low formation permeability and/or a very low through-flow rate.

(e) A drawdown/recovery pumping test was undertaken on the Matshelagabedi collector-well after drilling all four laterals. Within the 8.7 m deep collector-well the rest water level was at 2.90 mbtoc before pumping. The collector-well was emptied in 100 mins at a discharge rate of 6.8 l/sec. Average inflow into the collector-well during drawdown was 3.46 litres/second. The water level recovered to 3.16 mbtoc in 190 mins, at an average inflow rate of 1.66 l/sec.

(f) The drilling and test-pumping equipment were moved to the Tobane 1 collector-well site on completion of works at the Matshelagabedi site.

1.2.3 *Works Undertaken at Tobane 1*

(a) Five additional laterals were drilled from the collector well, three at 6.00 mbtoc (4.00 mbsrs), one at 5.50 mbtoc (3.50 mbsrs), and one at 5.00 mbtoc (3.00 mbsrs). Two of the five laterals produced small quantities of flowing water.

(b) A drawdown/recovery pumping test was undertaken on the Tobane 1 collector-well after drilling of laterals. Within the 8.2 m deep collector-well the rest water level was at 4.8 (mbtoc) before pumping. The well was emptied in 31.6 mins at a discharge rate of 6.7 l/sec. Average inflow into the well during drawdown was 0.94 l/sec. The water level recovered to 6.58 (mbtoc) in 250 mins, at an average inflow rate of 0.31 l/sec.

(c) The drilling and test-pumping equipment were moved to the Tonota stores for storage on completion of works at the Tobane 1 collector well site.

1.2.4 *Reporting to DWA*

Progress and findings were described to a DWA project review group. Results of drilling, test-pumping, dewatering and ancillary exercises were described. The meeting concluded that:

(a) An adequate well point dewatering system was required if extension of laterals across sand-river channels at shallow depths is to be successful.

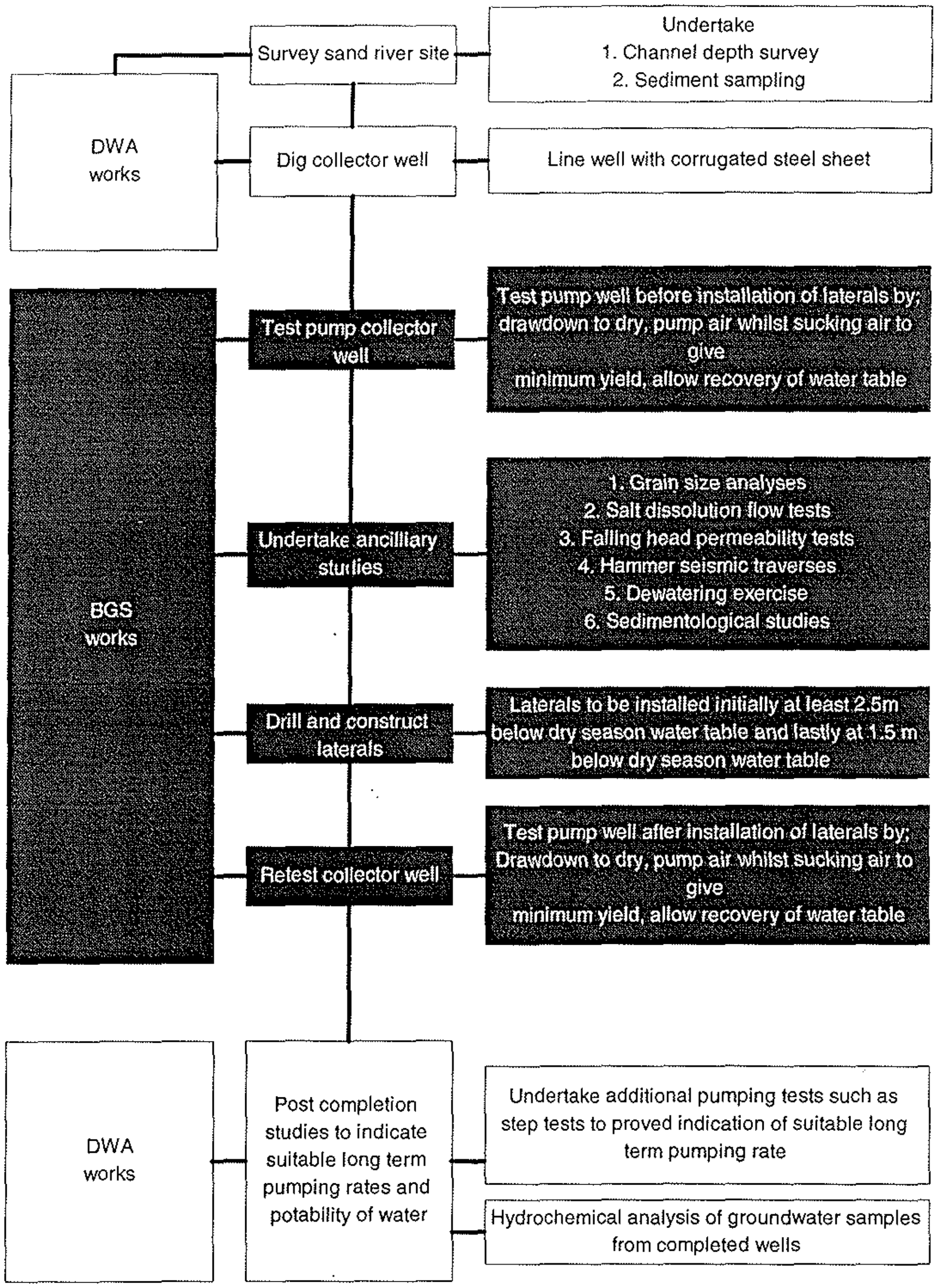


Figure 4. Flow chart of activities undertaken

(b) A ground penetrating radar system is needed to adequately determine lithological variations with depth across sand rivers

(c) The refurbished BGS rig or a new drilling rig to is needed to undertake the drilling of collector well laterals on a production basis. DWA requested clarification of the current status of the BGS rig and equipment, and a quote for the purchase of a new rig. DWA also requested an estimate of the current cost per metre of drilling laterals. A quote for a replacement drilling rig is presented in Appendix B.

(d) DWA declared the pilot project stage of the project ended. The meeting concluded that much remains to be resolved about the hydrogeology of sand-rivers but that these factors could be studied during the production collector well phase.

2. STUDIES UNDERTAKEN

The primary aim of the pilot project was 'to assess the application of collector well systems to abstraction of groundwater from sand-rivers in Botswana'. Methods of collector well construction, and drilling and installation of laterals were evaluated at sites selected by DWA. Short term studies were undertaken at these sites, using methods devised, to assess the viability of a collector well system use. The studies included determination of the hydraulic characteristics of the sand-river channel adjacent to the collector well as well as the hydraulic nature of the collector well. Several of these methods are novel and have not previously been applied to the study of sand-rivers. They are described section "2.4 Ancillary Studies" below. Short term visits were undertaken at the end of the annual dry season, when water levels and flow rates along sand-river channels were at their lowest. The results of these studies indicated the complex nature of sand-river sediment infill.

Within this joint project some site activities are undertaken by DWA personnel and some by BGS personnel with the assistance of DWA staff. These activities are itemised in a flow diagram (Figure 4) and described below.

2.1 Sand-river Channel and Sediment Infill Survey

DWA staff use sand probing and sediment sampling methods introduced by Nord (1985) and Wikner (1980) to determine sand river channel shape, sediment infill depth and variations in sediment lithology with depth. These methods are used to locate water bearing alluvial sands suitable for development, and sites for well-shaft excavation, adjacent to target villages. River channel dimensions determined at each of the test sites are presented in Table 3.

Site	River name/ river size	Channel max. depth (m)	Channel depth range (m)	Channel width (m)	Channel saturated cross section area (m^2)
Borolong	Shashe/Minor	3.65	1.8-3.65	65	117
Chadibe	Shashe/Minor	5	3-5	60	220
Mathangwane	Shashe/Minor	5	3.5-5	60	180
Masunga 1	Tati/Sub-minor	4.5	3-4.5	38	45
Masunga 2	Tati/Sub-minor	5	3.5-5	47	100
Tobane 1	Motloutse/Major	10.5	8-10.5	165	1071
Tobane 2	Motloutse/Major	10	6-10	120	765
Gulubane	Shashe/Minor	10	9-10	44	173
Matshelagabedi	Ramokgwebana/ Intermediate	10	9-10	52	270

Table 3. Sand-river channel dimensions determined at collector well sites.

2.2 Well-shaft Excavation

At each site DWA staff excavate a 2.2 m diameter well-shaft into the river bank, from a point close to the sand river channel but above flood level, to a depth below the base of the sand-river infill. The diameter of the well-shaft is large enough to allow installation of a 2 m diameter ARMCO corrugated galvanised steel sheet tube; based upon designs and methods developed by BGS in Zimbabwe to minimise time taken to excavate and construct a well-shaft. Boulders of dolerite and unweathered basement complex rocks can hinder excavation and steel tube emplacement, the use of explosives may be required to effect their removal. Where possible, excavation should be undertaken where sufficient depth of weathered basement has been proven by trial drilling. Lithological samples should be collected at regular depth intervals during excavation and described. The degree of weathering, incidence of fracture zones and groundwater inflow zones should also be recorded. Following insertion of the well casing the annulus between the casing and the shaft wall should be gravel packed to stabilise the casing. The status of each test site shaft pre-lateral installation is presented in Table 4.

Site	Well depth (mbtoc)	Rest water level (mbtoc)	Notes - status pre-lateral installation
Borolong	9.5	8	Dry
Chadibe	n/r	n/r	Dry
Mathangwane	11	5.6	Dry, backfilled to 9 m above dolerite boulders
Masunga 1	12	4.9	Low inflow
Masunga 2	9	3.8	Moderate inflow, dug into fissure zone
Tobane 1	8.4	4.2	Moderate inflow
Tobane 2	11	7.5	Moderate inflow
Gulubane	10.1	6.1	Very low inflow
Matshelagabedi	8.7	2.9	Moderate inflow, dolerite boulders caused casing to settle from vertical

Table 4. Well-shaft dimensions and condition on excavation at test sites.

2.3 Test Pumping of Well-shaft Pre-installation of Laterals

The well-shaft is test pumped before erection of drilling equipment. Either an air operated centrifugal pump (Figure 5a) or an air operated diaphragm pump (Figure 5b), both of nominal 6 l/sec capacity, is used to empty the well-shaft. Water levels are monitored at 1-2 min intervals, and discharge levels determined at 10 min intervals, during the drawdown phase. On pumping all storage water from the well-shaft, if significant inflow occurs, the pump is left to operate for several minutes during which time it will pump a mixture of air and water. The discharge rate of water pumped should be that of inflow of water into the well-shaft. Pumped water should be discharged at a point sufficiently distant from the well-shaft to preclude its recharge to the sand-river during the test and subsequent recovery. The pump is then switched off and removed from the well-shaft, the water level being left to recover. Water level measurements during the recovery phase are taken, initially at 1 minute intervals for the first 4 or 5 hr then at 5 or 10 min intervals until at least 75% of the drawdown has recovered.

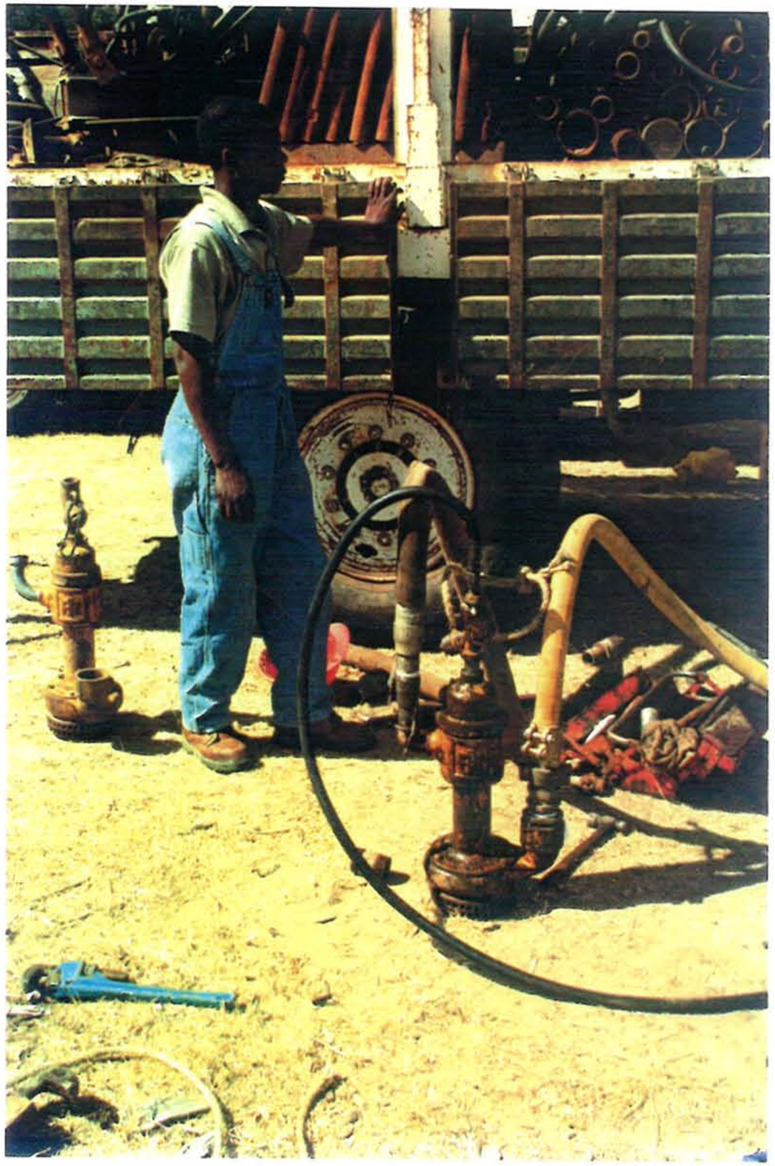
The total volume of water pumped during the drawdown phase is calculated. The volume of the well-shaft emptied during the test, i.e. the volume of water in storage, can then be deducted from the total amount pumped to produce the volume of water that flowed into the well-shaft during the drawdown phase of the test. The latter volume, in litres, can then be divided by the pumping period in seconds to produce an average inflow rate in litres/second (l/sec). Similarly the volume of well-shaft filled during the recovery phase divided by the period of recovery provides an average inflow rate during the recovery period. The rates of inflow during the drawdown and recovery phases should be approximately the same, but their calculation is dependent upon the apparent radius of the well-shaft. By varying the apparent radius of the well-shaft to equalise the drawdown and recovery inflow rates calculated an effective well-shaft radius can be produced that takes into account the open volume behind the casing that is drained and then refilled during the drawdown/recovery test. The inflow rate calculated should be approximately the same as the rate of inflow determined during pumping after the well-shaft has been emptied of stored water. The calculated inflow rate and effective well-shaft radius can then be applied to the test pumping data obtained after installation of the laterals.

2.4 Ancillary Studies

The methods described below are used to determine the hydraulic and physical characteristics of the sand-river channel and the alluvial sediment infill.

2.4.1 *Grain-size Analysis*

Since the lateral screens are installed by jetting from the well-shaft, no lithological returns are produced to guide the driller or hydrogeologist as to the nature of the sediments that the laterals are installed within. Some indication of sediment variation with depth and with distance across the channel is needed if factors such as failure of lateral installation or lateral screen blockage are to be avoided. Sediment samples can be obtained by pitting and trenching from above the water table and to a maximum of 0.5 m below the water table. Hence the importance of sediment samples obtained from greater depths during the probing survey and the grain size analyses produced. Grain-size distribution analyses are used to define the proportions of major and minor grain-size components, used to provide first indications of sediment permeability, screen slot size and potential screen blockage problems. The last is most important as, since gravel pack material cannot be installed around the screen, a natural pack must be developed. Therefore the potential for fine matrix movement through coarse grained framework, and the potential for that frame work to collapse, needs to be assessed. The range of sieve sizes used during earlier visits and those of the new set used during the last visit are shown in Table 5.



5a Air operated centrifugal pump

5b Air operated diaphragm pump

Figure 5. Compressed air operated pumps used for dewatering and test pumping well -shafts and collector wells

Old set (1995 studies)		New set (1997 studies)	
phi scale	**Sieve size mm**	**phi scale**	**Sieve size mm**
-2.7	6.7	-2.7	6.7
-2.3	5.1	-2.4	5.6
-2.2	4.75	-2.2	4.75
-1.75	3.35	-1.75	3.35
-1.5	2.8	-1.5	2.8
-1.25	2.3	-1.25	2.3
-1	2	-1	2
		-0.75	1.7
		-0.5	1.4
-0.25	1.18	-0.25	1.18
		0	1
		0.25	0.85
		0.5	0.71
0.75	0.6	0.75	0.6
		1	0.5
1.25	0.425	1.25	0.425
		1.5	0.355
1.75	0.3	1.75	0.3
		2	0.25
		2.25	0.212
0.275	2.75	2.5	0.18
3.75	0.075	3	0.125
	pan		pan

Table 5. The ranges of sieve sizes used during the 1995 studies and during the 1997 visit.

Driscoll (1986) describes methods of assessing the degree of sorting of sediments by calculation of an uniformity coefficient, and observing the shape of cumulative % weight distribution curves. The Uniformity Coefficient is defined by dividing the 60% grain size by the 10% grain size. Homogeneous sediments have an uniformity coefficients of 1-1.5, poorly sorted sediments have uniformity coefficients >3. He also describes use of grain-size analysis data to determine screen slot size. For mixed fine to coarse grained sediments Driscoll recommends that the 60% grain size be used to determine the slot size of screen emplaced against a mixed sediment without a gravel pack.

Where samples have bimodal distributions then a method developed by Kovaks (1981), as described in Davies et al (1996), is used to determine the potential for fine matrix movement through a coarse sediment framework, framework collapse and screen blockage, as well as better defining the screen slot size required. The two parts of a bimodal distribution are assessed about an inflection point. The diameters of the 15% (D15C)and 50% (D50C) elements of the coarse segment, and the 15% (D15F), 50% (D50F) and 85% (D85F) elements of the fine segment are then determined. According to the "Kovaks suffusion criteria for bimodal strata" the following conditions may occur:-

If D15F>D15C/4 (**A1**)
yes - fines will not move through coarse grained framework

If D85F>D15C/4 (**A2**)
yes - formation is stable

If D50F<D50C/4 **(A3)**
yes - formation will not collapse

If no to the above criteria (**A1, A2** and **A3**) - formation will collapse therefore do not screen.

If 'no' to only **A1** then fines will move through the coarser framework material but formation will not collapse. Also the gravel pack should then be designed to be appropriate for the coarse fraction only.

Where F - fine fraction of layer of formation
C - coarse fraction of layer of formation

2.4.2 *Salt Dilution Flow Tests*

For water supplies from sand-rivers to be sustainable, flow through the sand infill needs to occur throughout the year thus ensuring that water is not being removed from storage alone towards the end of the dry season. Therefore the presence of flow towards the end of the dry season needs to be recognised and evaluated.

Hall (1993) describes how the rate of salt dilution measured down an observation borehole can be used to determine the rate of water flow through an alluvial aquifer. Application of this method is described in Herbert et al (1997). Flow along a sand river can thereby be recognised and evaluated at the critical end of a dry season period.

This test requires the installation of 50 mm diameter screened observation boreholes, drilled to suitable depths into the saturated zone of a sand-river. Various methods of installation have been attempted including:

1. Jetting with compressed air
2. Hammering or driving using a jack hammer (Figure 6a).
3. Pushing in with a heavy weight e.g. the back hoe bucket of a JCB (Figure 6b).

Initial attempts at jetting, using too high an air pressure, resulted in burst air hoses. An alternative, the jack-hammer system, was used to install the majority of observation boreholes to 1-1.5 m below the water table (Figure 6a). In practise, installation to depths >1.5m below the water table was not practical due to sand locking. Problems were experienced with plastic screens splitting and sand locking of the drive pipe within the disposable steel tip. To achieve even these depths installation had to be undertaken within a trench or a pit excavated to the water table. The tips were not truly disposable as they were needed for the drilling of subsequent observation boreholes and laterals, and therefore had to be recovered on completion of testing. At the Gulubane site three observation boreholes were rapidly installed to depths >2 m by pushing steel screens using the back bucket of a JCB (Figure 6b).

The salt dilution flow test requires use of a PhOX conductivity bridge with a sonde located at the end of a 5 m cable, a water level dipper tape, a stopwatch and a bag of common salt (Figure 7a). At each observation borehole the groundwater water conductance is measured at a suitable depth for monitoring. Following the addition of 100-300 gm of common salt, the groundwater in the borehole was agitated to ensure that the salt is dissolved. The sonde is then emplaced within the screened section of the borehole at the pre-determined depth, measured using an attached water level dipper tape, and the rate of dilution of the salt solution monitored by measuring the groundwater conductance at one minute intervals for a period of 1 hr (Figure 7b). The Darcy velocity of flow along the sand-

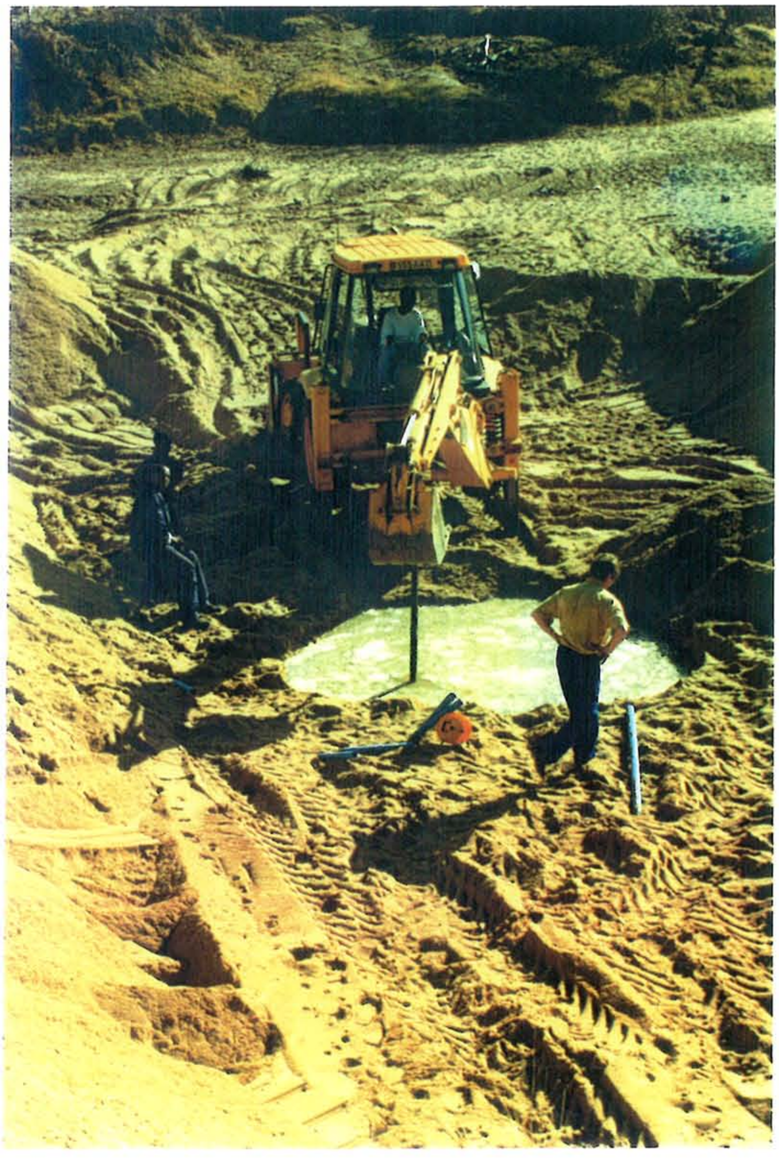


Figure 6.
Methods of observation borehole installation

6a Using a jack hammer at Tobane I

6b using the back bucket of a JCB at Gulubane

7a. Basic equipment

7b Equipment in use at Gulubane

Figure 7. Salt dilution flow test equipment

river aquifer is then determined from the rate of decline in salt concentration as described in Herbert et al 1997. Flow rates can be determined at discrete depths within the upper saturated zone using this method. These results are then applied to the cross section area of the channel to determine approximate flow rates that are of the correct order of magnitude. End of dry season sand river flow rates calculated for the full saturated cross sections at each site by salt dilution flow test are summarised in Table 6.

	Estimated flow rate along channel	
Site	m^3/day	l/sec
Mathangwane	101	1.2
Masunga 1	59	0.7
Masunga 2	44	0.5
Tobane 1	442	5.6
Tobane 2	455	5.3
Gulubane	206	2.4
Matshelagabedi	137	1.6

Table 6. Summary of channel flow rates calculated from salt dilution flow tests at test sites.

2.4.3 *Falling Head Permeameter Tests (from Davies and Herbert, 1990)*

This method describes determination of vertical permeabilities for formations composed of clean, unconsolidated, nonindurated alluvial sediments. The 1 kg samples collected are totally uncemented and have undergone only a very small degree of compaction. It is considered that if disturbed samples of sufficient thickness are placed within a test cylinder of large enough diameter then realistic vertical permeability values can be determined within a crude falling head permeability apparatus. For this purpose a simple falling head permeameter apparatus was constructed (Figure 8).

The experimental procedure is as follows:-

(a) The permeameter tube and the retaining mesh are thoroughly cleaned

(b) A sample is emplaced within the lower part of the tube to a level below that of the hydrometer tube inlet

(c) The base of the tube is placed firmly upon a plastic sheet underlain by a sheet of foam rubber to stop water flowing out of the tube

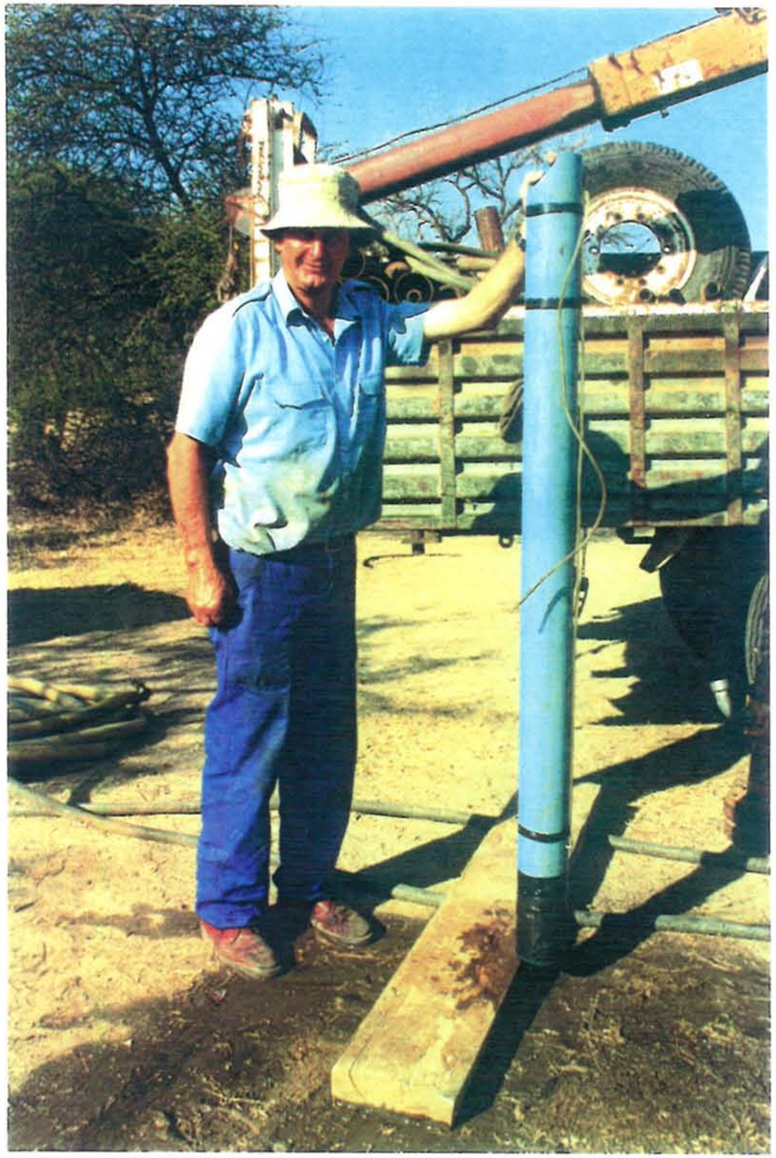
(d) Water is poured into the tube completely filling it

(e) The distance between the top of the tube and the surface of the sediment plug is measured to determine the thickness of the latter

(f) The full tube is lifted permitting the water to flow through the plug of sediment

(g) Ensure that the clear plastic hydrometer tube is clear of sediment before the water level has dropped to level H_0. Start the stopwatch on the level reaching level H_0.

(h) Stop the stop watch when the water level falls to level H_1 and record the time interval t.



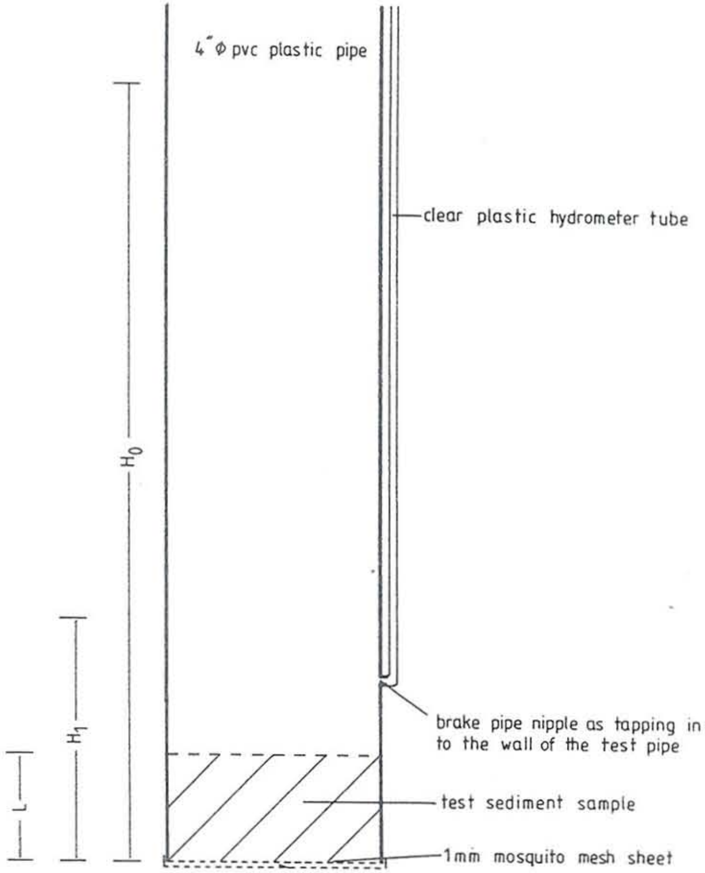


Figure 8. Falling head permeameter apparatus

(i) Calculate the vertical permeability of the sample under test by relating the time taken for the water level to drop from H_0 to H_1 to the thickness of the sediment sample using the expression below .

The method of analysis is as follows:-

Assuming quasi-steady-state Darcian flow through the sample, the following formula can be used to determine the permeability/hydraulic conductivity, K, of the samples put into the permeameter:

$$K = \frac{L}{t} \ln \frac{H_0}{H_1}$$

The value of In H_0/H_1 was made common to every test.

where L is the thickness of the sediment sample used (usually 10-15 cm) and t is the time taken for the water level to drop in the permeameter tube from level H_0 to level H_1.

2.4.4 *Hammer Seismic Studies*

Wikner (1980) and Nord (1985) recognised that the probing method used to define the shape and nature of sand-river channels was slow and labour intensive. They attempted to use surface resistivity surveys as an alternative but these failed to provide sufficiently accurate data to be of general use. Noting the marked seismic velocity contrast between the sand-river channel infill and the underlying basement rock, BGS proposed the use of an ABEM Miniloc hammer seismic system to define the depth and nature of the infill/country rock boundary. The system was not sensitive enough to recognise changes within the sediment infill.

The use of this system to investigate thicknesses of weathered bedrock in southern Zimbabwe as possible sources of groundwater is described by Davies (1994). The ABEM MINILOC system is a lightweight 3 geophone/channel seismograph system used to conduct shallow refraction surveys. Survey results are produced and analysed in the field on a liquid crystal display that can be down loaded to a printer to produce a hard copy. The system includes a control box, three geophones with connecting cables, a trigger unit with connecting cable, a 7.5 kg steel plate and a 7.5 kg hammer (Figure 9a). The system is easily man portable. A two or three man crew is required, one to strike the plate, one to place the triggering device and third to operate the data collection system (Figure 9b). When the latter system is set to automatic the third man is not required. Typical seismic velocities for formations met in Botswana and Zimbabwe are presented in Table 7. The depth of penetration of the system is limited to about 20 m. The seismic data produced can readily be used to identify the thickness of the sand/regolith layer, depth to the bedrock and the nature of the bedrock. The nature of vertical fracture zones can be identified, i.e. whether they are tight or open.

9a. Seismic system components

9b. Equipment in use at Masunga

Figure 9.

Hammer siesmic equipment

Material	Seismic velocity range
Dry Loose Soil	300-1000 m/sec
Clays	1600 m/sec
Saprolite	1800-2500 m/sec
Saprock	2200-3000 m/sec
Weathered Granite/Gneiss	3000-4000 m/sec
Fractured Granite/Gneiss	3500-4500 m/sec
Massive Granite Gneiss	4500-6000 m/sec
Air	330 m/sec
Water	1450 m/sec

Table 7. Typical seismic velocities of lithological formations and media met in NE Botswana.

Hammer seismic studies were undertaken at Mathangwane, Masunga and Tobane to confirm depths to bedrock/thickness of sand determined by the probing studies. The analyses indicate depths to channel base that correlate well with depths obtained from dynamic probe traverses at Masunga and Mathangwane. Spurious results were obtained at Tobane indicating that improved correlation of results needs to be undertaken before this system can provide satisfactory depths to saturated zone and bedrock where very thick sand layers are present.

More recent attempts at using geophysical survey methods to define the depth and nature of the channel/bedrock interface, the nature of the sediment infill and location of the water table within sand river channels or similar deposits include:

As part of a study of "Subsistence Irrigation from Shallow Aquifers", Ekstrom et al (1996) investigated shallow alluvial aquifers along the ephemeral Umzingwane River in Zimbabwe. The geophysical DC-resistivity traversing and imaging method was used to map the geology, with the aim of finding out how different geological boundaries affect the size of the alluvial aquifers. Generally the resistivity results indicated alluvium thicknesses of more than 20 m at some places. The DC-resistivity method worked satisfactorily in the investigated environment but it was not supplemented with data from drilling, therefore the reliability of the interpreted geology results are open to question.

Numerous attempts have been made in the UK and else where to use the ground penetrating radar (GPR) survey method to study the composition of modern alluvial sediments along present day river channels. An example is provided in Davies et al (1995a) of a GPR traverse across the Tati River south of Francistown. Bedding features within the sediment infill, the sediment filled channel/bedrock boundary and the water table can be discerned from the radar image produced.

2.4.5 *Dewatering Exercise*

Studies of sand-river sediments at Masunga indicate that the 1 in 100 year depth of channel scour during major flood episodes lies at about 1.5 m below the sand-river surface (Herbert et al, 1997). Therefore laterals emplaced at 1 m below the dry season water table level i.e. 2.5 m below the sand-river surface should be well below the scour level of even major flood events. If water continues to flow down stream to an abstraction site during the dry season the water level is unlikely to decline by more than 0.5 m. Therefore the installation of laterals at 1-2 m below the dry season water table level would appear to be an attractive option considering they would probably be emplaced within medium to coarse sands. Herbert (1985) devised a "rolling" groundwater control system using parallel lines of well points between which the water table could be lowered sufficiently to permit the excavation of a trench without the side walls collapsing to permit extension of a lateral drilled from a collector well at shallow depth to be extended by hand coupling of screened sections (Appendix C).

In the absence of well point abstraction systems the use of 6 l/sec capacity diaphragm pumps enclosed in perforated 200 l drums was attempted within a wide trench excavated to the water table at the Gulubane site but without much success. If the system described by Herbert (1985) were successfully installed then it would be possible to:

- undertake detailed geological investigation of sediments below normal water table level by trenching.
- install larger diameter laterals made up of screen with appropriate slot size and gravel pack surrounds below the depth of scour, by hand. Such laterals, acting as drains, could be laid across the full width of the stream using the rolling system of overlapping parallel series of well points described.

2.4.6 *Sedimentology of Sand-river Alluvium*

As indicated in Table 3, the thickness of sand-river channel sediments varies from 5 m in minor river channels to 10 m in major channels. Sediments infilling sand-river channels are studied via exploration pits, sand abstraction pits and trenches dug into the sand-river surface. Unfortunately these are 1-1.5 m deep, excavated to the water table. When excavated below the water table the sides become unstable and liable to collapse. Typically the upper 1 m is composed of successive fining upward cycles of very mixed, cross-bedded fine to coarse sands and gravels. Below this sequence occurs a fairly homogeneous medium to coarse sand that could coarsen upwards in a manner described by Crowley (1983) and observed in the Masunga Sand pit (Figure 10a and interpretation in Figure 10b). Deeper sediments could be exposed within trenches dug within dewatered zones as indicated above.

C^{14} radio-carbon dating of organic material obtained from a sand pit at Masunga indicates deposition at about 50 years BP. These data were use to infer a 1 in 100 year depth of channel scour during major flood events of about 1.3 m.

The need for detailed study of alluvial sediments within the saturated zone of a sand river remains. Earlier studies at Masunga indicated complex sediment distributions, sediments from the upper 1-2 m, the limit of normal investigation, being potentially different from those at greater depths. The trench dug for construction of the Letsibogo dam across the Motloutse River presented an ideal site for such a detailed study of sand river composition.

Silty sediments encountered during drilling of laterals at Tobane and Matshelagabedi indicate the presence of lower permeability, more indurated fined grained clayey sediments at depth, indicative of sediments deposited during more pluvial periods. Sediments such as this are exposed within the main channel upstream of the Matshelagabedi collector well site. Weakly cemented orange-red sediments have been noted occurring at about 2 m below sand-river surface in dewatering pits excavated into the Umzingwane River at Cawood Ranch in south western Zimbabwe, and in a water abstraction pit in the main channel of the Save River at Gudo's Pool in south east Zimbabwe. At Cawood Ranch the farm owner related how his great grand father had, nearly 100 years ago, observed hippos in the muddy reed beds then occurring in the adjacent Umzingwane River, at a site where the channel is now choked with sand.

2.4.7 *Other Studies*

Detailed levelling of the sand river surface (at 10 m intervals) and water table (at 100 m intervals) was undertaken between the Masunga I and II collector wells (Figure 11). A gradient of 0.005 for the sand river surface and a water table gradient of 0.0013 were determined. Levelling of the water table

Figure 10a. Section through sand infill within the Tati sand-river at Masunga.

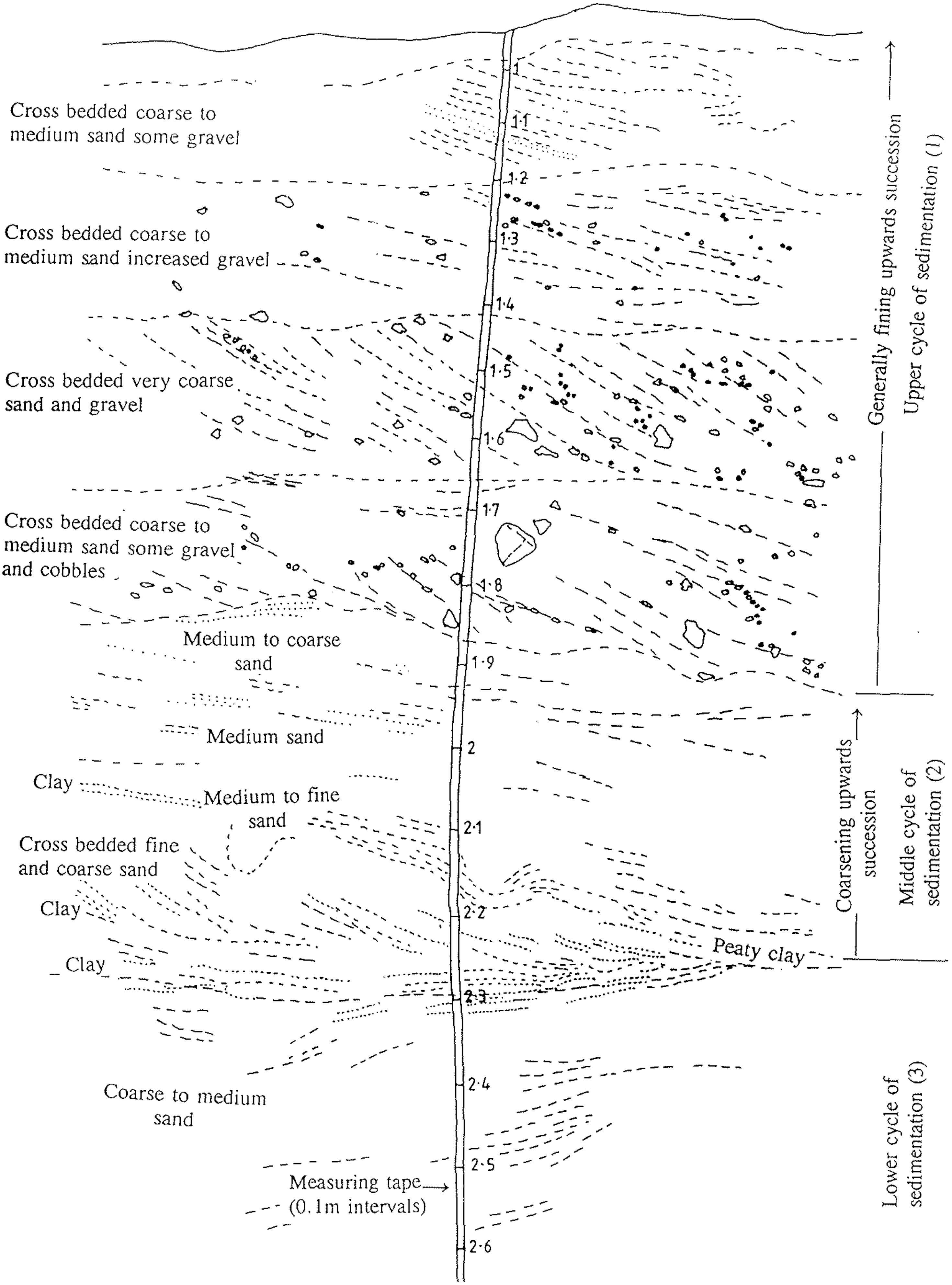


Figure 10b. Interpretation of section in Figure 10a showing main sedimentary structures and decimetre scale.

Figure 11. Levelling sand river surface gradient and water table along the Tati sand-river between Masunga I and Masunga II collector wells.

necessitated the digging of a series of shallow exploration pits to the water table between available groundwater abstraction pits. The water levels produced indicated the effects of abstraction and hard rock outcrops acting as dams upon a depressed water table at the end of the dry season.

There is a profound need to monitor water levels, before pumping and abstraction rates at collector well systems, and relate these to rainfall/recharge events, and flow rates down stream if the long term sustainability of sand-river abstraction sites are to be accurately evaluated. Such monitoring has been initiated at Masunga by Andersen (1996).

In addition the future need to assess the influence of points of recharge and potential contamination, as occurring upstream of the Masunga collector well No. 2 where sewage pond outflows directly recharge into the Shashe River, must not be ignored.

2.5 Drilling and Construction of Laterals

The drilling system as presently used requires the drilling of a 100 mm diameter access bore through the well-shaft casing and weathered/solid river bank formation into the channel sands. If clayey material is met then that formation is cased off with 100 mm steel pipe. As far as is practical each lateral is constructed using blank 50 mm diameter casing through the bank formations and slotted screen within the channel sands.

During the pilot study laterals were constructed using following variety of construction components (Figures 12 and 13):-

2" (50 mm) plastic or steel wash down shoe - outer thread as 2" (50 mm) PVC/steel casing, inner thread 36.5 mm left hand disposable tip
2" (50 mm) flush joint blank pipe PVC 0.5 m lengths
2" (50 mm) flush joint blank pipe steel 0.5 m lengths
2" (50 mm) flush joint plank pipe thermoplastic (blue) 0.5 m lengths
2" (50 mm) flush joint slotted pipe PVC 0.5 m lengths with 0.5 mm slots
2" (50 mm) flush joint slotted pipe steel 0.5 m lengths with 0.5 mm slots
2" (50 mm) flush joint slotted pipe thermoplastic (blue) 0.5 m lengths with 0.5 mm slots
3" (75 mm) flush joint blank steel pipe 0.5 m lengths
4" (100 mm) flush joint blank steel pipe 0.5 m lengths
¾" (18 mm) flush joint bank steel adductor pipe 0.5 m lengths
¾" (18 mm) flush joint bank steel adductor pipe sub with left hand male thread

The drilling equipment package used included a Hydroquest 2 m drilling rig (Figure 14) designed to drill 30 m deep boreholes using 73 mm diameter rock bits on 50 mm OD drill rods, or using a down the hole hammer with 70 mm button bit. The rig was mounted on a circular frame that fitted within a 2 m diameter well-shaft permitting the rig to be moved 360° in its horizontal mode. The rig operation is controlled from a hydraulically operated console mounted alongside or above the rig. A hydraulic power pack, mounted on the rear of the crane truck provides power for the operation of the rig (Figure 15). The following drilling rods, subs, drilling bits and ancillary items are required for the efficient operation of the rig:-

50 mm x 0.75 m taper thread drill rods - 40 No.
73 mm hard formation rock roller drill bits - 3 No.
73 mm tungsten carbide drag bit - 1 No.
60 mm valveless DTH hammer - 1 No.
70 mm diameter hammer button bits - 4 No.

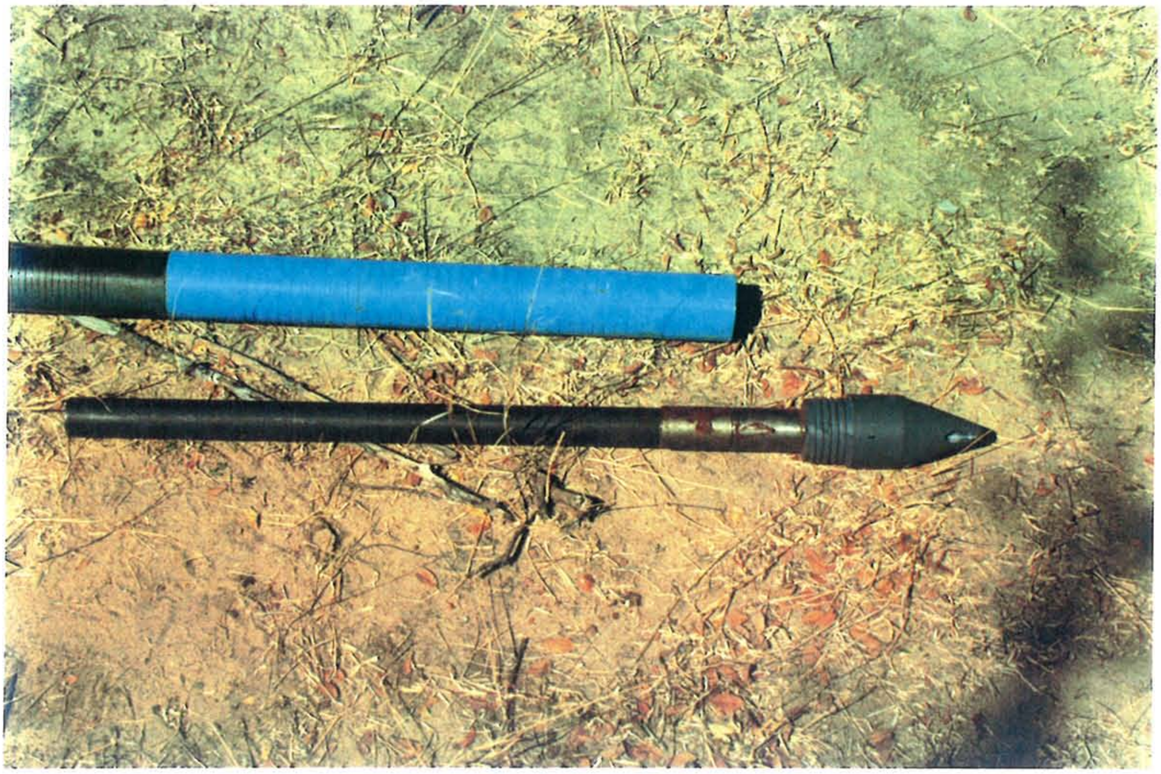


Figure 12. Blue thermoplastic and black pvc slotted 2" diameter screens above steel adductor pipe connected to a 2" diameter diposable point via a left hand threaded connector. The 2" screen slides over the adductor pipe and is screwed onto the rear thread of the point.

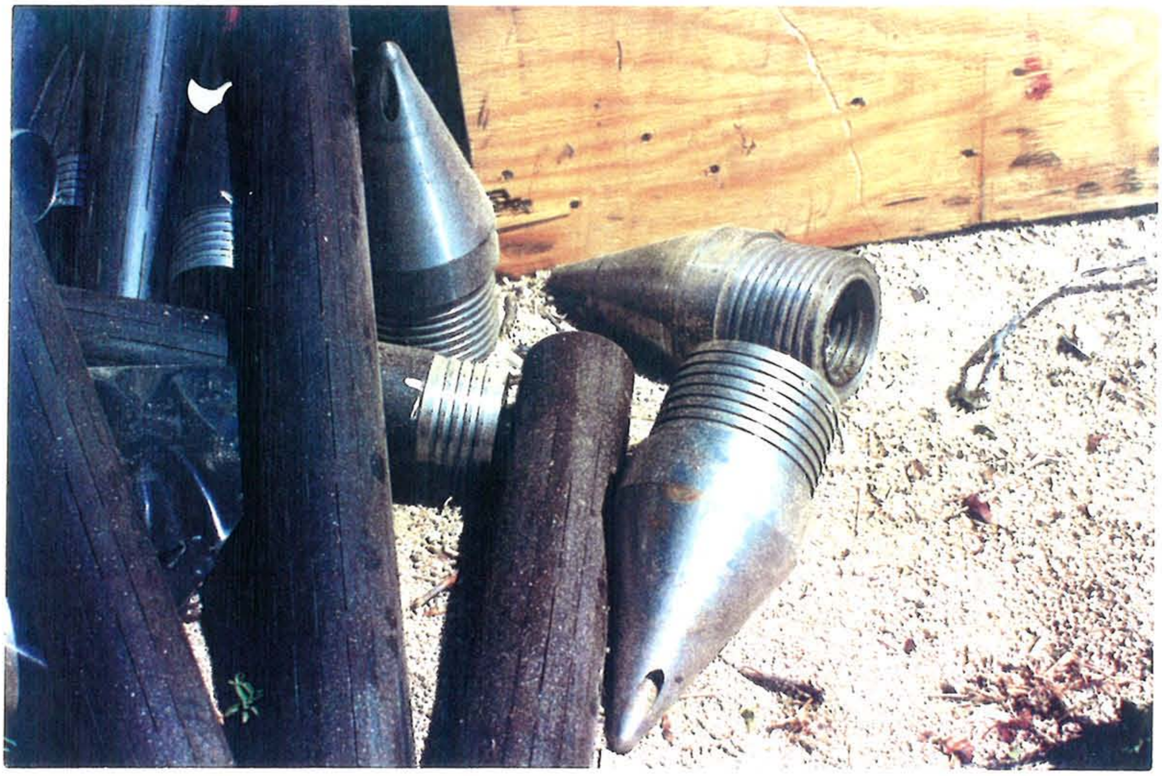


Figure 13. Steel 2" diameter vertically slotted screens with steel disposable wash-down points

Figure 14. Horizontally mounted Hydroquest 2 rig on circular base plate with jacks for mounting within a 2 m diameter well-shaft. Note cradle with drill rods and drilling bits to left of rig.

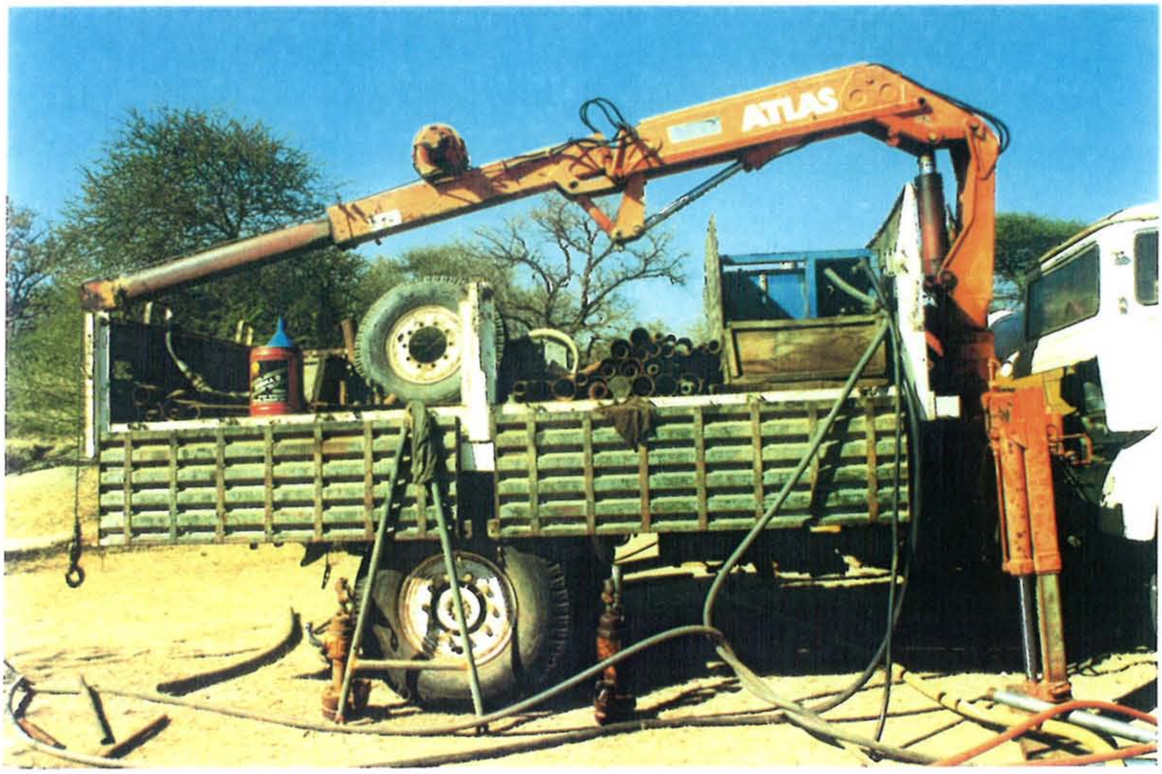


Figure 15. Rear of 4x4 Bedford crane truck with hydraulic power pack for the rig mounted on the rear of the truch. Note winch mounted on extendable hoist arm, and 4" diameter temporary steel pipe on back of truck..

Sub adapter - drill rods to hammer - 1 No.
Sub adapter - drill rods to rock bits - 1 No.
Ancillary equipment - kibble, drill rod cradle, hydraulic hoses, lay flat hoses, timbers, dewatering pumps, necessary spares etc.
Compressed air for the operation of dewatering pumps and the drilling element of the rig is provided from two compressors provided by the DWA (Figures 16 and 17).

The complete drilling system is transported to site on a Bedford 'M' series 4x4 truck with crane fitted with winch (Figure 15). A Landrover is required for transport of the driller and crew to and from site.

A quote for the provision of a new drilling system and crane truck is presented in Appendix B

The procedures for drilling rig emplacement and operation during lateral installation are as follows:

1. Pump well shaft dry and clean well base using kibble, suspended on hydraulic winch located on crane truck, to remove debris (Figure 18).

2. Emplace timbers in well to locate drill at required depth for lateral drilling.

3. Locate rig in the well shaft with hydraulic controls box ensuring beforehand that the crane truck has been located close enough to the well side to allow the crane operator to work the hydraulic controls on the side of the truck whilst observing activity down the well (Figure 19).

4. Ensure that the two compressors are fully operational and that hydraulic oil and fuel reservoirs have been topped up.

5. The hydraulic hoses for operation of rig and pump as well as the discharge hose from the pump need to be secured to avoid pipe creep down the well side during drilling operations.

6. When the two man crew are lowered down the well ensure that they have hard hats, ear mufflers and safety goggles to hand, and that all tools are tied to the base of the rig to avoid them being lost in the flooded hole beneath rig base level.

7. Drill pipe, drilling bits and necessary tools are lowered down the well on a special cradle. These include a drag bit, a down the hole hammer and bit and sufficient NW drill pipe to allow initial drilling through the river bank into the channel sands.

8. Use clusterite tipped U100 coring bit to drill through the shaft casing and obtain a core of the shaft wall rock (Figure 20).

9. Drill out through the bank material using the drag bit to drill soft to medium formations and the down the hole hammer to drill hard formations. When drilling dry, hard formations much dust can be generated. The crew must wear respirators under such conditions as it may take several hours to drill through hard formations into the channel sands. On reaching the channel sands and water entering the lateral, drilling is halted and the drill string removed (Figure 21). The rods and drilling bits are stacked in the cradle and withdrawn from the well.

10. The kibble containing a known quantity of blank 2" (50 mm) pipe, slotted 2" (50 mm) pipe, adductor pipe and tools required for coupling these pipes are passed down the well. The first two lengths of screen, two lengths of adductor pipe, disposable point and left hand threaded adductor pipe sub connector are made up and also passed down the well on the kibble. Must

Figure 16. Large capacity Atlas Copco 350 l/sec, 20 bar compressor, used to supply compressed air for drilling and jetting in pipe.

Figure 17. Small capacity 110 lb/in^2, 125 cfm compressor, used to supply air for dewatering pump operation.

Figure 18.
Clearing out debris from base of well-shaft with a kibble prior to erection of the drilling rig. Note the Shashe minor size sand-river at Gulubane.

Figure 19.
Lowering the rig down the Masunga well-shaft. Note the position of the winch operator and the truck. The operator is able to observe what is happening down hole whilst operating the winch controls.

Figure 20. Initial drilling through the well-shaft casing using a U100 core bit faced with tungsten carbide clusterite chips. Note rig positioned upon a stack of timbers

Figure 21. Drilling lateral into water bearing unconsolidated materials. Note drilling crew must wear water proofs and safety glasses during this operation.

unsure that the left hand threaded connection between the adductor pipe and the disposable point is fairly loose thus ensuring ease of uncoupling on cessation of pipe jetting.

11. The crew of driller and assistant use the drill head to push screens/blank pipe and adductor rods into the channel sand formation. 0.5 m length of adductor pipe is coupled first (Figure 12). The next length of screen is slid over the adductor pipe and coupled up, the assembly is then pushed further in through the hole (Figure 22). When the effect of sand locking becomes apparent, only then use compressed air through the adductor pipe and disposable tips jets to jet in the screen and casing. Do not rotate the screen. A maximum amount of 10 m of screen should be coupled on followed by sufficient plank pipe to insert the lateral to a maximum length of 23-25 m beyond which the effects of sand locking become to great for the screen to be safely emplaced further. During jetting much water can be blown out of the lateral with sand and gravel chips (Figure 21). Therefore it is essential that the crew members operating the rig wear water proofs, gum boots and safety goggles.

12. On achieving maximum lateral emplacement, a distance that can only be adjudged by an experienced operator, when the screen cannot be pulled or pushed further without risk of fracturing the screen or central adductor pipe, the central adductor pipe is turned in a clockwise direction to dissengage the left hand thread at the end of the pipe from the disposable point. The adductor pipe is withdrawn from the lateral, the number of lengths withdrawn being noted, and they are stacked in the kibble. On completion the kibble, adductor pipes and pipe handling tools are withdrawn from the well.

13. The rig is then repositioned by rotating the unit on its base to the next lateral drilling position and the above procedure is repeated. Periodically during drilling excess inflow water is pumped from the well.

14. If the has to be emplaced at a higher level the rig has to be lifted from the well to allow emplacement of additional timbers. Prior to rig removal the well should be pumped dry to ensure that the timber stack does not float and move. Add the required timbers and re-erect the rig in the well.

During the pilot project 45 laterals were drilled at nine collector well sites (Table 8). Two methods of installing lateral screens into river sands have been attempted used:

1. Using the telescoped method slotted steel screen of 88.9 mm diameter was jetted into river sands, using a central adductor tube and disposable end tip, with compressed air as the flushing medium (Figure 12). On reaching the required distance the adductor pipe was back screwed from the disposable tip leaving the screen in place. Difficulties were experienced where ridges of hard rock had to be drilled within the river sands using down the hole hammer equipment. Location of screens within these remote holes with the basal sand sequence proved to be very difficult if not impossible. While this system of screen emplacement proved to be successful at Masunga and Mathangwane within coarse sand sequences difficulties were experienced at Tobane where the silty sands encountered passed through the screen slots causing sand locking problems. These resulted in failure to unscrew the central adductor pipe that ultimately resulted in the shearing and loss of some of the adductor pipe and screen.

Figure 22. Installation of 2" screens and pipes.

Location	Lateral details-drilled depth (mbtoc) x lateral length (metres), discharge, screen lengths		Discharge/ drawdown rate pre laterals	Discharge/ drawdown rate post laterals
Borolong	1) 8.75x26 dry 2) 8.5x26 flowing 3) 8.5x17 dry	4) 8.5x17 dry 5) 8.5x25 dry 6) 8.75x16 low flow	Dry	45 m^3/day for 450 min, drawdown of 0.50 m
Chadibe	1) ?x23 low flow 2) ?x7 low flow	3) ?x7 low flow	Dry	45 m^3/day, drawdown of 0.28 m
Mathan-gwane	1) 8.7x13.5 dry 2) 8.4x3.4 dry 3) 8.4x3.4 dry	4) 7.7x30.4 flowing, 0-20 steel 5) 7.7x20.3+ flowing, 0-20 steel	Dry	21.6m^3 in 130 min, recovery to 75% <3 hr
Masunga 1	1) 7.9x28.5 dry 2) 6.9x23.3 dry 3) 5.8x21.8 flowing 0-20 steel	4) 5.8x29.3 dry 5) 5.8x24.8 dry 6) 5.3x23.3 flowing, 0-19 PVC, 19-24 steel	Not tested	32.6m^3 in 154 min, recovery to 75% <3.5 hr
Masunga 2	1) 7.7x27.8 flowing, 0-20 PVC, 20-25 steel 2) 7.7x27.8 flowing, 0-20 PVC, 20-25 steel 3) 6.3x15.4 flowing, 0-12 steel	4) 6.3x15.4 flowing, 0-13 steel 5) 6.3x13.1 dry	3.3 l/s for 1 hr, drawdown 2.2 m	24.8m^3 in 46 mins recovery to 75% 6 hr.
Tobane 1a	1) 7.2x6.8 dry 2) 7.2x45.8 flowing, 0-15 PVC, 15-25 steel	3) 7.2x44 flowing, 0-15 PVC, 15-25 steel	4 l/sec for 60 min, drawdown 3.3 m	14.5 m^3 in 32 min, recovery to 75% >360 min
Tobane 1b	1) 6x15 dry 2) 5x16 dry 3) 6x24 flowed but stopped	4) 6x25 flowing 5) 5.5x25 flowing	4 l/sec for 60 min, drawdown 3.3 m	6.7 l/sec for 32 min, drawdown 3.14 m, inflow 0.94 l/sec
Tobane 2	1) 9.8x30 flowing 2) 9.8x9+ flowing	3) 9.8x9+ flowing 4) 9.8x9+ flowing	2.8 l/sec for 60 min, drawdown 2.53 m	22.5m^3 in 40 min, recovery to 50% after 360 min
Gulubane	1) 8.85x15 flowing, 12.5-15 PVC 2) 8.85x17 flowing, 13-17 PVC	3) 8.85x17.5 flowing, 13-17 PVC 4) 7.09x19 flowing, 8-19 PVC	2.8 l/sec for 77 min, drawdown 2.79 m, inflow 0.3 l/sec	6.3 l/sec for 102 min, drawdown 3.74 m, inflow 3.6-4.25 l/sec
Matshel-agabedi	1) 5.00x10.5 dry 2) 5.00x17 flowing	3) 4.00x10 flowing, 0-10 PVC 4) 4.00x10 flowing, 0-10 PVC	6.5 l/sec for 60 min, drawdown of 5.75 m, inflow of 0.9 l/sec	6.9 l/sec for 100 min, drawdown 5.60 m, inflow 3.5 l/sec

Table 8. Laterals drilled and constructed at test sites during the pilot project.

2. The duplex system utilised blank outer steel casing of 3" (75 mm) diameter within which was located plastic screen with a disposable tip. On reaching the required distance the outer casing was pulled back exposing the inner 2" (50 mm) screen. When used at Tobane this system also failed due to silty sand flowing into the annulus between the outer casing and inner screen, sand locking the screen to the casing.

The methods of drilling and emplacement of screens within sand formations need further refinement before use in geological conditions as met at Tobane to enable use to be made of the groundwater resources there.

2.6 Retest Collector Well after Installation of Laterals

On completion of drilling of laterals, the drilling rig, ancillary equipment and timbers are removed from the collector well and the water level allowed to fully recover before the collector well can be test pumped. An air operated diaphragm pump of nominal 6 l/sec capacity is used to empty the collector well to dryness. Water levels are monitored at 1-2 min intervals and discharge rate determined at 10 min intervals. On pumping out the collector well, the pump is left to operate for several minutes during which time it will pump a mixture of air and water, the amount of water pumped being equal to the inflow of water into the collector well. The pump is then switched off and the well water level left to recover. Water level measurements are taken initially at 1 min intervals for the first 4 or 5 hr then at 5 or 10 min intervals until at least 75% of drawdown has recovered. The yield of an individual lateral may be determined by noting the time taken to fill a 3 or 5 gallon (13.5 or 22.5 l) bucket suspended beneath the out flow from the respective lateral. When measuring the yields of laterals beware of leakage in the annual space between the lateral and the drilled hole through the bank material.

The total volume of water pumped during the drawdown phase is calculated using measured discharge rates during the drawdown phase and appropriate time intervals. The volume of the collector well emptied during the test, i.e. the volume of storage water calculated using the effective radius apparent from the pre-lateral installation pumping test, can then be deducted from the total amount pumped to produce the volume of water that flowed into the collector well during the drawdown phase of the test. The latter volume, in litres, can then be divided by the pumping period in seconds to produce an average inflow rate in litres/second. Similarly the volume of collector well filled during the recovery phase divided by the period of recovery provides an average inflow rate during the recovery period. The rates of inflow during the drawdown and recovery phases should be approximately the same, but their calculation is dependent upon the apparent radius of the collector well. The inflow rate calculated should be approximately the same as the rate of inflow determined during pumping after the well-shaft has been emptied of stored water. The inflow rate and effective well-shaft radius calculated during the pre-lateral installation test can then be compared with these test pumping data obtained after installation of the laterals. Data from both tests, plotted on arithmetic graphs, are compared to show differences/improvements in yield/drawdown/recovery characteristics.

Herbert (1992) attempted to analyse test pumping data derived from Chadibe and Borolong using the methods of Pappadopolos and Cooper, and Rushton and Singh. Poor data fits were produced, and so the data could not be analysed using these methods. Analyses of recovery data using the Theis recovery method produced inconclusive results. It is concluded that aquifer parameters of the channel sands cannot be determined using test pumping data obtained from collector wells. Such data is dominated by storage in the well, rates of flow along laterals, and possible inflow from behind the well casing be that at leakage through the bedrock of from the annular space between the lateral and the bedrock. Herbert et al (1997) concluded that the best way to interpret the behaviour of large diameter wells with high storage is to compare rates of recovery of water levels after pumping. This is because normal rates of pumping greatly exceed the rates at which the aquifer can replenish the well during the drawdown phase. It is only during the recovery phase that the contribution of the aquifer can be accurately determined. Herbert et al (1997) describes a method of calculating a 'lateral parameter' that, once determined ,can be used to predict drawdown and recovery of water level within the well during different pumping regimes.

2.7 Undertake Completion Studies

Additional studies that could be undertaken by DWA staff include the following.

2.7.1 *Additional Pumping Tests - Step Tests*

Step drawdown/recovery tests, with more than six steps need to be undertaken on each collector well after completion. To be effective these time consuming tests should be undertaken at various river water level stages during the year to indicate how much water can be contributed to the collector well from the upper and lower parts of the channel infill sequence.

2.7.2 *Hydrochemical Analysis of Water Samples*

Water samples need to be obtained from the upper and lower parts of the saturated channel infill during the initial channel survey stage. The major and minor ion contents will indicate the state of the water in the sand i.e. recently recharged waters should have low specific electrical conductance, acidic pH, high Eh and be of $Ca(HCO_3)_2$ type. Older waters obtained from the basal parts of the channel may well have higher SEC, alkaline pH and low Eh be of $NaHCO_3$ type with moderate total dissolved iron content. Water samples should then be obtained on collector well completion for comparative purposes. Introduction of acidic oxygenated water into the basal stagnant parts of the channel may result in flocculation of dissolved iron oxides in the ferric form, with their deposition as a weak cement, thus reducing sediment permeability. Analyses of water samples are undertaken at a DWA laboratory.

3. RESULTS

3.1 Gulubane

3.1.1 *Survey of Sand-river Site*

At Gulubane the upper reaches of the Shashe sand river conform to the minor form of sand-river in the classification of Nord (1985) and Wikner (1980). At the site of the collector well the Shashe River is 46.6 m wide. The collector well is located on the left bank of the river 2.5 km north west of Gulubane and 1 km south of Madwaleng (Figure 23), about 6 m from the edge of the channel where the ground surface is 4.25 m above the sand-river surface. The DWA probed survey indicates that the channel base lies at 10 m below the sand-river surface (Figure 24). The rest water level was 1.34 m below the sand-river surface. A saturated channel cross section of 173.3 m^2 was determined. Depth sediment samples were latterly obtained from augered holes at intervals across the river bed. The grain size analyses of these samples are presented in Appendix E. The lithological variations noted with depth agree with those noted from the geological trench reported below.

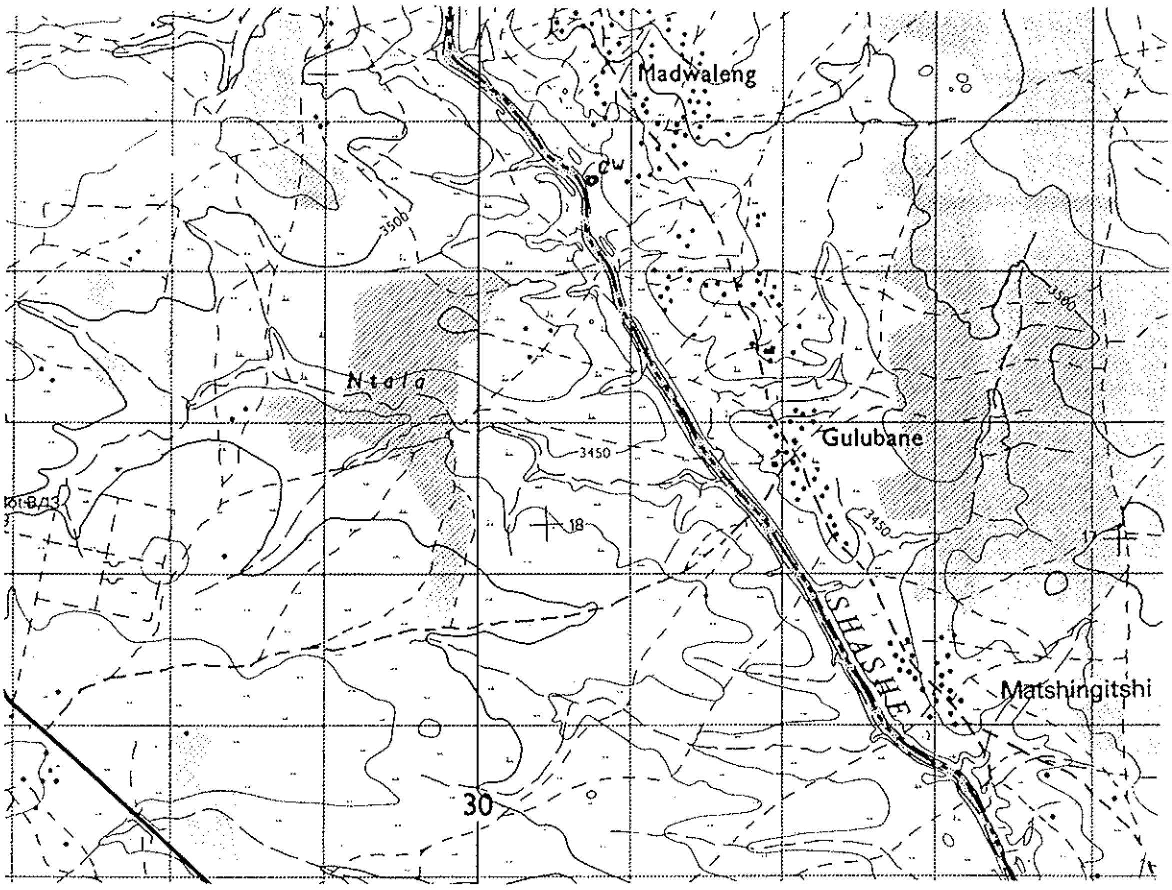


Figure 23. 1:50 000 scale location map of the Gulubane collector well site.

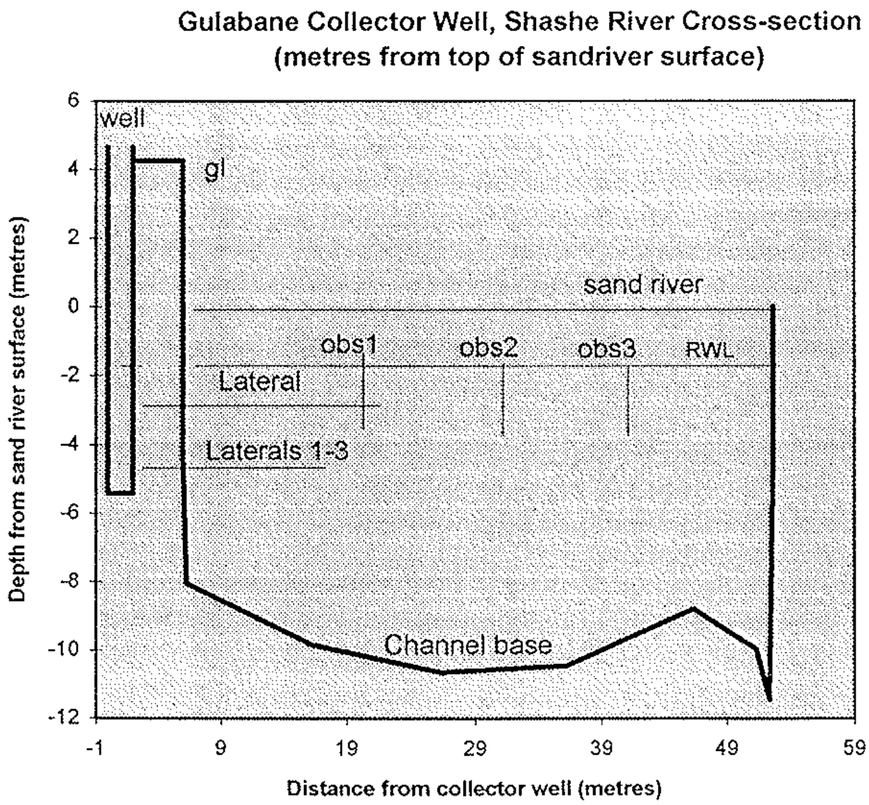


Figure 24. Probed cross section across Shashe River at Gulubane site showing location of laterals, observation boreholes and collector well.

3.1.2 *Well-shaft Excavation*

The 2.2 m diameter well-shaft was excavated to 10 m below top of casing, 5.3 m below sand-river surface level. The well-shaft located excavated adjacent to a vertical dyke of hard quartz feldspar rock (Figure 25) through which laterals had to be drilled to reach the sand-river channel. The lithological log of the shaft has not been reported. The well shaft was cased with a corrugated galvanised steel sheet tube set at vertical. The casing had not been gravel packed at the time of drilling. The top of the well-shaft is located above normal river flood level.

3.1.3 *Pre-lateral Installation Pumping Test*

Prior to installation of timbers and rig the shaft was test pumped at a discharge rate of 2.8 l/sec for 77 min, by which time the well had been pumped dry. The rest water level before pumping was 6.705 mbtoc, a drawdown of 2.79 m being achieved during the test. Pumping was continued for five minutes using the compressed air driven diaphragm pump, which is capable of pumping a mixture of water and air. During this time water was pumped at a rate of 0.3 l/sec, this being the rate of water inflow into the well shaft from the formation around the shaft casing. An average inflow rate of 0.04 l/sec was calculated from the drawdown data (Figure 26). The residual drawdown was 2.015 m after 1246 minutes, a recovery of 27.6%, during which time an average inflow rate of 0.045 l/sec was determined (Figure 27). The slow recovery and inflow rates are indicative of little hydraulic connection between the well-shaft and the sand-river channel and the general very low permeability of the weathered basement rocks. An effective well-shaft diameter of 2.78 m was calculated from the test pumping data. The test pumping and recovery data are tabulated in Appendix D.

3.1.4 *Ancillary Studies*

3.1.4.1 Sediment grain size analyses

Fourteen sediment samples obtained from the geological inspection trench were sieved through a nest of 22 sieves. Samples 1a to 7a were obtained from fairly homogeneous sand formations located 1.75 m below the sand river surface, about 0.5 m below the water table. They appear to be representative of the formation penetrated by Lateral No. 4. Samples 1b to 7b were obtained from very mixed, cross bedded sand and gravel formations that were recently deposited. The results are tabulated in Appendix E. Cumulative weight % grain size distribution curves for each of the samples sieved are presented in Figures 28 and 29. Data required for determination of the uniformity coefficient of each sample are presented in Table 9. Uniformity coefficients for samples 1a-7a vary between 2.2 and 3.1, indicative of mixed sediments. In contrast the uniformity coefficients for samples 1b-7b vary between 2.3 and 4.3, indicative of mixed to poorly sorted sediments. The average screen slot size for the sediments analysed appears to be 1mm, except sample 6b which indicates a slot size of 2mm.

Sample No.	Distance from left bank (m)	Depth (m)	10% grain size (mm)	60% grain size (mm)	Uniformity coefficient	Screen slot size (mm)
1a	2	1.75	0.4	0.98	2.5	1
2a	5	1.75	0.4	1	2.5	1
3a	10	1.75	0.32	1	3.1	1
4a	15	1.75	0.32	1	3.1	1
5a	20	1.75	0.4	1.1	2.2	1
6a	25	1.75	0.4	1.08	2.7	1
7a	30	1.75	0.33	1.02	3.1	1

Figure 25. Quartz-feldspar dyke cropping out upstream of the Gulubane test site.

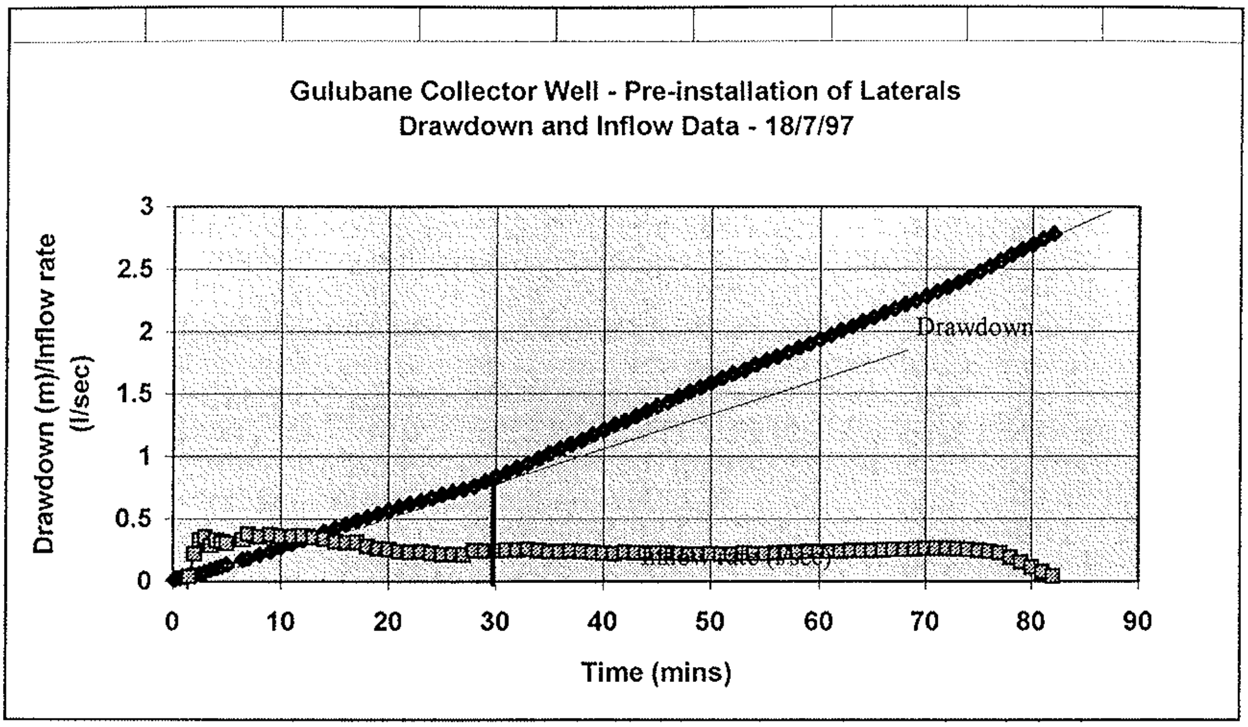


Figure 26. Pre-installation of laterals test pumping data, Gulubane well-shaft

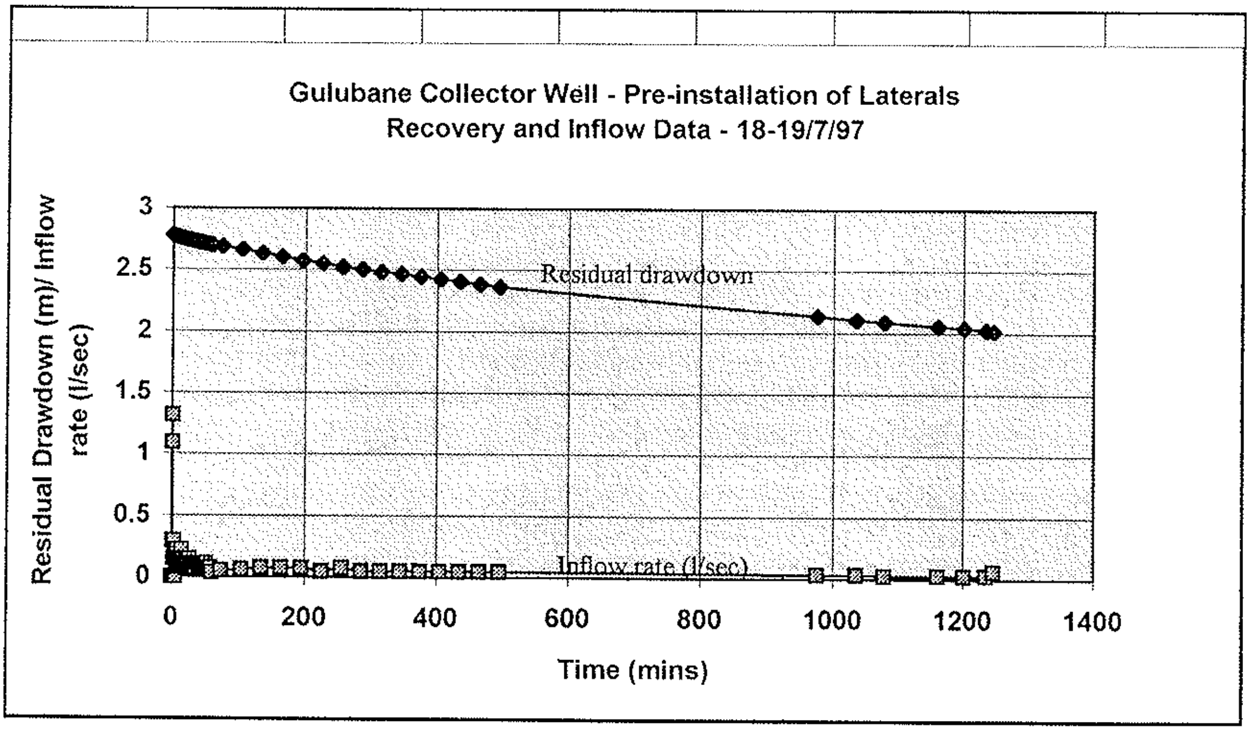


Figure 27. Pre-installation of laterals recovery data, Gulubane well-shaft

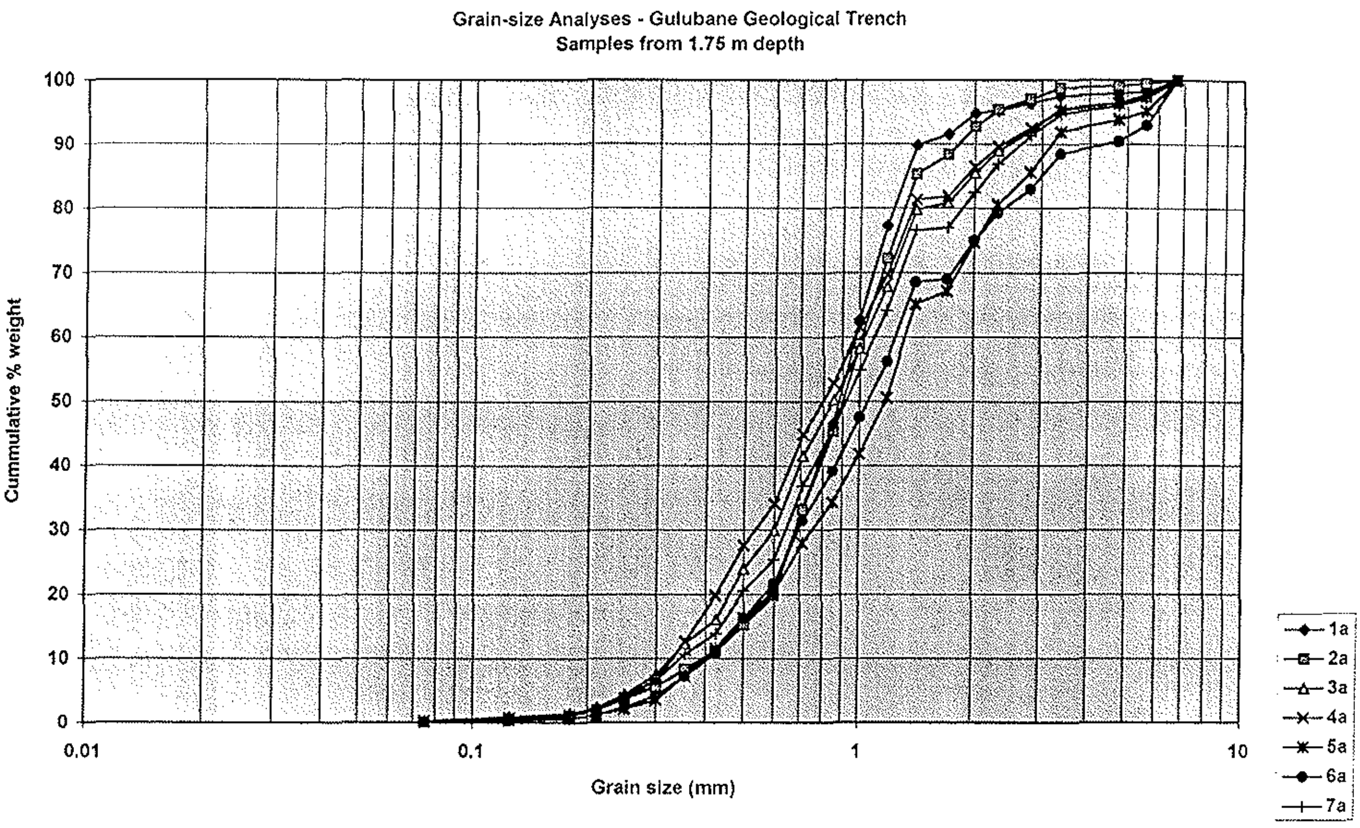


Figure 28. Grain size cummulative % weight curves, Gulubane. Samples 1a-7a from 1.75 m depth

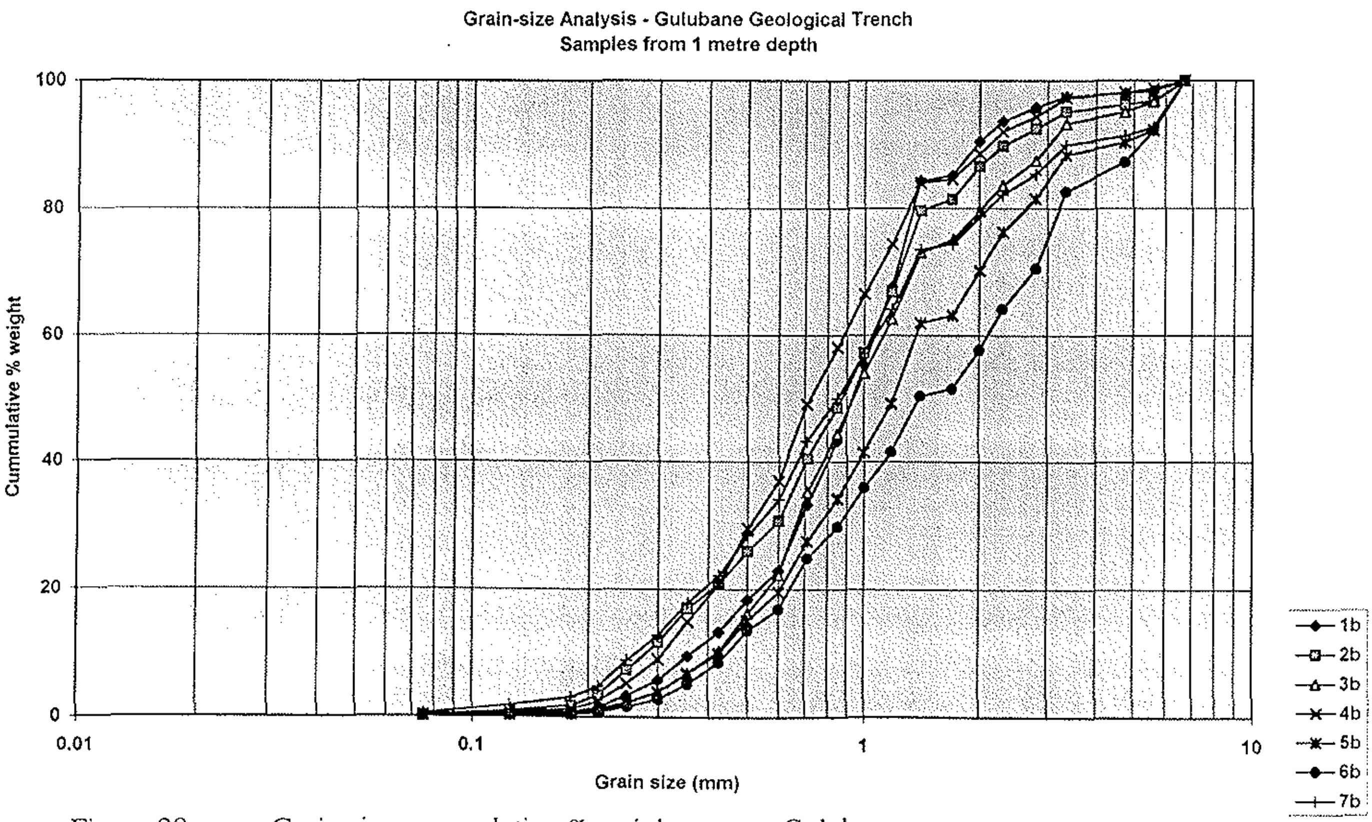


Figure 29. Grain size cummulative % weight curves, Gulubane. Samples 1b-7b from 1.00 m depth

Sample No.	Distance from left bank (m)	Depth (m)	10% grain size (mm)	60% grain size (mm)	Uniformity coefficient	Screen slot size (mm)
1b	2	1	0.46	1.05	2.3	1
2b	5	1	0.3	1.05	3.5	1
3b	10	1	0.46	1.1	2.4	1
4b	15	1	0.31	0.89	2.9	1
5b	20	1	0.46	1.15	2.5	1
6b	25	1	0.48	2.05	4.3	2
7b	30	1	0.028	1.05	3.8	1

Table 9. Determination of sample uniformity coefficients and suitable screen slot sizes

3.1.4.2 Kovaks analysis for sediment stability

The general shape of the cumulative % weight grain size distribution curves indicates bimodal grain size distributions. Therefore analysis for sediment stability according to the method of Kovaks was undertaken upon the grain size analysis data. This analysis assesses the potential for sediment framework collapse and/or movement of fine matrix material towards a well screen during pumping, with potential for screen blockage.

The distribution curves of sediment samples 1a-7a are presented on Figure 28, basic data required for the Kovacs analysis obtained from these curves being presented in Table 10a. The results of the analysis are shown in Table 10b. As can be seen from these results most of the sediments tested are stable. Fine matrix sediments will tend to pass through the coarse sediment framework in sands 3a, 4a and 5a. Within these formations, given sufficient fluid velocities, fines will be carried towards the bore hole screens where, if the slot size is too small to allow their passage into the borehole they will block the screen slots.

No.	Inflection point %	D15C		D50C		D15F		D50F		D85F	
		%	mm	%	mm	%	mm	%	mm	%	mm
1a	90	91.5	1.3	95	2.0	13.5	0.44	45	0.84	76.5	1.2
2a	85	87.3	1.7	92.5	2.0	12.8	0.44	42.5	0.80	72.5	1.2
3a	80	83.0	1.9	90	2.5	12.0	0.35	40	0.70	68	1.2
4a	82	84.7	1.9	91	2.5	12.3	0.35	41	0.68	69.7	1.2
5a	65	70.3	1.8	82.5	2.4	9.8	0.41	32.5	0.80	55.3	1.2
6a	68	72.8	1.4	84	3.0	10.2	0.43	34	0.74	57.8	1.3
7a	77	80.5	1.2	88.5	2.5	11.6	0.36	38.5	0.71	65.5	1.3

Table 10a. Basic data derived from cumulative % weight distribution curves of samples 1a-7a as required for Kovaks analysis.

No.	A1	A2	A3	Notes
	Is D15F>D15C/4	Is D85F>D15C/4	Is D50F<D50C/4	
1a	0.44>3.25 yes	1.1>0.33 yes	0.44<0.5 yes	Formation stable
2a	0.44>0.42 yes	1.2>0.42 yes	0.44<0.5 yes	Formation stable
3a	0.35>0.46 no	1.2>0.46 yes	0.35<0.63 yes	Fines will pass through framework
4a	0.35>0.48 no	1.2>0.48 yes	0.35<0.63 yes	Fines will pass through framework
5a	0.41>0.45 no	1.2>0.45 yes	0.41<0.6 yes	Fines will pass through framework
6a	0.43>0.35 yes	1.3>0.35 yes	0.43<0.75 yes	Formation stable
7a	0.36>0.30 yes	1.25>0.30 yes	0.36<0.63 yes	Formation stable

Table 10b. Results of Kovaks analysis on samples 1a-7a.

The distribution curves of sediment samples 1b-7b are presented on Figure 29, basic data required for the Kovacs analysis obtained from these curves are presented in Table 11a. The results of analyses are shown in Table 11b. These results show that only the sand formation at 5b is entirely stable. Fine matrix sediments will tend to pass through the coarse sediment framework in all of the other test sediments. Within these formations, given sufficient fluid velocities, sediment fines will be carried towards the bore hole screens where, if the slot size is too small to allow their passage into the borehole they will block the screen slots. These poorly sorted and very mixed sediments are modern, recently derived from the erosion of soils and weathered basement. Fortunately all these sediments occur above the water table.

No.	Inflection point %	D15C		D50C		D15F		D50F		D85F	
		%	mm	%	mm	%	mm	%	mm	%	mm
1b	84	86.4	1.8	92	2.1	12.6	0.40	42.0	0.84	71.4	1.3
2b	80	83.0	1.8	90	2.3	12.0	0.30	40.0	0.70	68.0	1.3
3b	73	77.5	1.9	86.5	2.4	11.0	0.43	37.5	0.75	62.0	1.2
4b	84	86.4	1.8	92.0	2.3	12.6	0.31	42.0	0.64	71.4	1.1
5b	62	67.7	1.4	81.0	2.8	9.3	0.42	31.0	0.77	52.7	1.3
6b	50	57.5	2.0	75.0	3.0	7.5	0.40	25.0	0.70	42.5	1.2
7b	73	77.5	2.0	86.5	3.0	11.0	0.28	37.5	0.62	62.0	1.2

Table 11a. Basic data derived from cumulative % weight distribution curves of samples 1a-7a required for Kovaks analysis.

No.	A1	A2	A3	Notes
	Is D15F>D15C/4	**Is D85F>D15C/4**	**Is D50F<D50C/4**	
1b	0.4>0.45 no	1.3>0.45 yes	0.84<0.53 no	Fines will pass through framework
2b	0.3>0.45 no	1.3>0.45 yes	0.7<0.58 no	Fines will pass through framework
3b	0.43>0.48 no	1.2>0.48 yes	0.75<0.6 no	Fines will pass through framework
4b	0.31>0.45 no	1.1>0.45 yes	0.64<0.58 no	Fines will pass through framework
5b	0.42>0.35 yes	1.25>0.35 yes	0.77<0.7 no	Formation stable
6b	0.4>0.50 no	1.2>0.5 yes	0.7<0.75 yes	Fines will pass through framework
7b	0.28>0.49 no	1.2>0.49 yes	0.62<0.75 yes	Fines will pass through framework

Table 11b. Results of Kovaks analysis on samples 1a-7a.

3.1.4.3 Salt dilution flow tests

Salt dilution flow tests were undertaken at three observation boreholes at the Gulubane test site. Details of three observation boreholes installed, using a JCB at intervals along the main trench are presented in Table 12a. Following salt emplacement dilution was monitored at 1 min intervals for at least 60 min. The results are presented as a series of graphs on Figure 30. Late time data have been used for gradient calculations required for determination of Darcy velocity in each case. Using these data applied to the channel saturated cross section area possible down channel flow rates are calculated (Table 12b). If flow takes place through the entire saturated section then water flows through the system at 2.38 l/sec (205.6 m^3/day). If flow only occurs through the upper 2 m of the saturated section the a water flow rate of 1.30 l/sec (112.7 m^3/day) occurs. Using the salt dilution flow data average permeabilities for the saturated channel sediments of 148-207 m/day have been calculated (Table 12b).

Observation Bh No.	Obs Bh 1	Obs Bh 2	Obs Bh 3
Distance from collector well (m)	20	30	40
Borehole depth (mbtoc)	2.5	2.5	2.5
Borehole top (mbsrs)	0.66	1.06	1.05
Water level (mbtoc)	0.68	0.28	0.29
Water level (mbsrs)	1.34	1.34	1.34

Table 12a. Details of observation boreholes installed at the Gulubane test site.

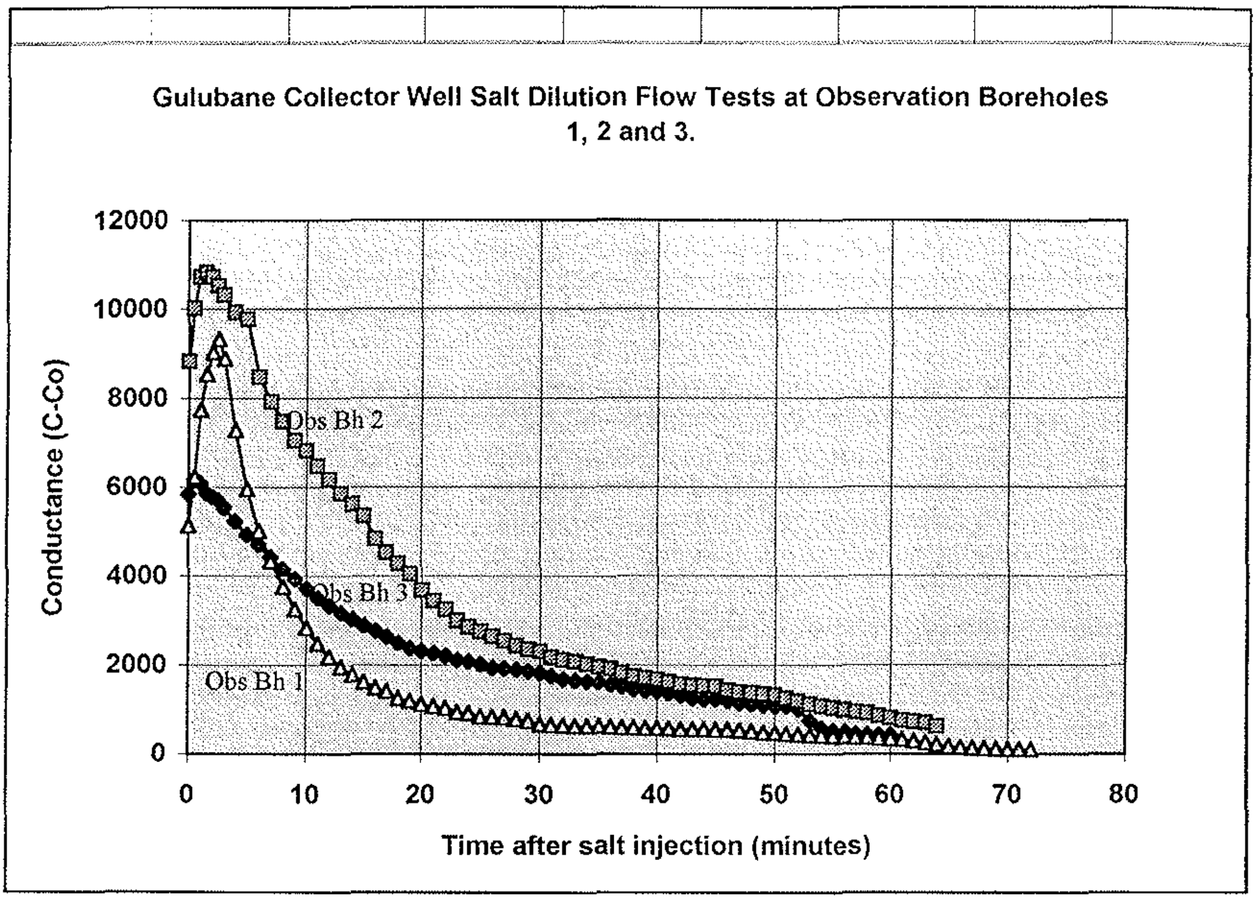


Figure 30. Salt dilution flow tests, Gulubane, graphs of the results.

Obs Bh No.	Darcy velocity (m/day)	Cross section area (m^2)	Discharge (m^3/day)	Discharge (l/sec)	Permeability (m/day)
To probed depth of channel					
Obs Bh 1	1.11	18 x 3.5	70.1	0.81	148
Obs Bh 2	1.55	10.5 x 4.5	65.6	0.76	207
Obs Bh 3	1.11	18 x 3.5	69.9	0.81	148
		Totals	205.6	2.38	
Top 2 m of saturated zone					
Obs Bh 1	1.11	18 x 2	40.1	0.46	148
Obs Bh 2	1.55	10.5 x 2	32.6	0.38	207
Obs Bh 3	1.11	18 x 2	40.0	0.46	148
		Totals	112.7	1.30	

Table 12b. Results of analysis of salt dilution flow test data from the Gulubane test site.

3.1.4.4 Falling head permeameter tests

Using the falling head permeability apparatus described in section 3.4.3. the vertical permeability of 8 sediment samples obtained from the geological and dewatering trenches at the Gulubane test site were determined (Table 13). The samples obtained from below the water table in the geological trench produced permeabilities of 90.5-183 m/day. Samples obtained from beneath the water table in the dewatering trench also produced high K values. That obtained from more than a metre below the water table using the back bucket on the JCB (sample No. 8) produced a permeability of 215.7 m/day. This sample was obtained from the area and depth of installation of the screened portion of lateral No. 4, which may explain the high discharge rate observed from this lateral. The permeabilities obtained correlate very well with those obtained from the salt dilution flow test data.

Sample No.	Location	Date	l (m)	t (sec)	K (m/day)
1	Gulubane 2a	30/7	0.10	69.5	162.7
2	Gulubane 3a	30/7	0.09	79.5	128
3	Gulubane 4a	30/7	0.09	67	151.9
4	Gulubane 5a	30/7	0.11	67.5	183.9
5	Gulubane 6a	30/7	0.09	112.5	90.48
6	Gulubane 7a	30/7	0.12	100	135.7
7	Gulubane dewatering trench	26/7	0.18	120	169.7
8	Gulubane dewatering JCB bucket deep	26/7	0.205	107.5	215.7

Table 13. Results of falling head permeability determinations on sediments from the Gulubane test site.

$K = \frac{1}{t} \times$ ... = 1.308

1.10 = 1.375 H_0 = H_1 = 0.375

1.25 1.5
0.25 1.4
1.42

1.38 = 1.29
1.40 = 1.25

3.1.4.5 Dewatering exercise

Results of work undertaken at Masunga indicated that the depth of channel scour during 1 in 100 year floods probably only reached a depth of 1.3 m below the sand-river surface. At Masunga near surface very poorly sorted, recent sediments occurred down to a depth of about 1 m below which occurred either coarsening upward sediments of medium to coarse well sorted sediments. By the end of the dry season a sand-river water table would probably decline to about 1.5 mbsrs. Advantage could be taken of natural flow in the river if a lateral could be emplaced within the medium to coarse river sands, at a depth of 2.5 m below sand-river surface and 1 m below the dry season water table. Using current drilling technology a lateral could only be drilled to about 10 m beyond the channel bank into the river sands. Extension of a shallow lateral by the coupling of additional screen sections by hand would require the excavation of a trench to 1.5 m below the present water table. To achieve this a zone would need to be dewatered across the channel. Herbert (1986) proposed a method utilising well point systems to dewater part of the channel, sufficient to allow excavation of part of the required trench.

A JCB was hired to excavate a 10 m wide trench across the sand river to the water table 1.35 mbsrs (Figure 31). In the absence of suitable well point abstraction system equipment a system was rigged up utilising 200 litre drums with perforated ends within which were to be place 6 l/sec capacity dewatering pumps.

Within the base of the wide trench the JCB was used to sink the 200 l capacity drums into the sands below the water table (Figure 32), the suction pumps could then pump water out of the sumps created thereby creating localised cones of depression. When two sumps, each with a pump, were established then extra drawdown could be achieved between them as the cones combine with each other.

Difficulty was experienced in sinking the drums deep enough in very permeable river sands. Adjacent to the river bank a drawdown of 1 m was achieved after only a short period of pumping. When pumping was attempted within the central part of the channel at the end of lateral No. 4 a drawdown of only 0.5m was achieved (Figure 33). Difficulties were also experience with the stability of the JCB. Therefore the attempt was abandoned.

The method of dewatering attempted failed due to:

- low number of abstraction points
- high permeability of the sediments
- instability of standing area of the JCB

There is a need to try this exercise again but using a well point dewatering system as recommended by Herbert.

During the dewatering exercise much sand was removed from the trench area beneath which laterals were installed which probably made lateral installation much easier. The drilling of lateral No. 4 beneath the deepened part of the trench demonstrated how a lateral could be developed by air since fine sediments were carried upward into the water filled channel above the lateral, as indicated by the turbidity of the channel water. Use of drilling foam could further improve development.

3.1.4.6 Sedimentology of sand river alluvium

A JCB was used to excavate a trench about 2 m wide across the Shashe River downstream of the dewatering trench to permit geological inspection of sediment above the water table (Figure 34). A series of photographs were taken of the trench sides and sand samples taken for grain size and

Figure 31. Excavation of main dewatering trench to water table at Gulubane.

Figure 32.
Initial attempt at dewatering the trench at Gulubane using dewatering pumps located within perforated 200 l drums. Using JCB rear bucket to dig in the drum.

Figure 33.
Second attempt at dewatering the trench at Gulubane using dewatering pumps in perforated 200 l drums located in the central part of the trench.

Figure 34. Excavation of geological inspection trench to water table at Gulubane.

permeability determinations from 1.00 m and 1.75 m below the sand-river surface. Logs of sediment variations with depth were recorded at 15 m and 20 m from the collector well end of the trench, these are presented below.

Geological log at 15 m

Depth (m)	Lithology
0.00 - 0.27	Very mixed top of cycle, fine to medium sand and gravel
0.27 - 0.44	Very mixed fine to coarse sand and gravel, cross bedded
0.44 - 0.60	Very mixed fine to coarse sand and gravel, cross bedded with a silty base to the cycle
0.60 - 0.95	Fining upwards cycle of cross bedded medium to coarse grained sand with gravel at base, medium to fine sand at top.
0.95 - 1.22	Cross bedded medium to coarse grained sand

Geological log at 20 m

Depth (m)	Lithology
0.00 - 0.26	Mixed top cycle of fine to coarse dry sands some cross bedding
0.26 - 0.39	Mixed cross bedded cycle of fine to coarse grained sands and gravels
0.39 - 0.49	Mixed cycle fine to coarse sands and gravels
0.49 - 0.79	Fining upwards cross bedded very mixed fine to coarse sands and gravels with coarse fragments up to 1-2" across.
0.79 - 0.96	Mixed cross bedded fine to coarse sands and fine gravels
0.96 - 1.22	Well sorted cross bedded medium to coarse sands.

A series of fining upward cross bedded poorly sorted fine to coarse sands and gravels occur above 1.00 m depth below the sand-river surface as between the 29-33 m section of the trench (Figure 35). Below that level cross bedded medium to coarse sands occur. The water table occurred at a depth of 1.34 mbsrs along the trench. Wood fragments and insect body fragments were recovered at 0.79 m in the 20 m section for possible C^{14} radio-carbon dating.

3.1.5 *Drilling and Construction of Laterals - Gulubane Collector Well (Figure 24)*

The first three laterals were drilled at a depth of 8.85 m below the top of casing (4.2 mbsrs). In each case the lateral had to be drilled through 1 m of hard quartz-feldspar dike rock using a down the hole hammer with a 4" diameter bit. The laterals were then drilled through several metres of clayey weathered bedrock using a 4" diameter drag bit out into channel sand. 50 mm blank casing and screen was then jetted to a distance of 15 m in lateral No.1, to a distance of 17 m in lateral No. 2 and to a distance of 17.5 m in lateral No. 3. All three laterals produced water at a flow rate of 0.5 l/sec (Figure 36 and Table 14). During screening of first lateral the jetting pipe joint sheared, The left hand thread connector to disposable tip and two jetting pipes were lost. The rig was raised by a metre for the drilling of lateral No. 4, to 7.09 mbtoc (2.44 mbsrs). As with the first three this lateral was initially drilled through a very hard quartz band, thence through weathered basement rock before entering the channel sands. 50 mm diameter PVC slotted screen and blank casing was jetted to a depth of 19 m. Water flowed from this lateral at the rate of 2 l/sec (Figure 36).

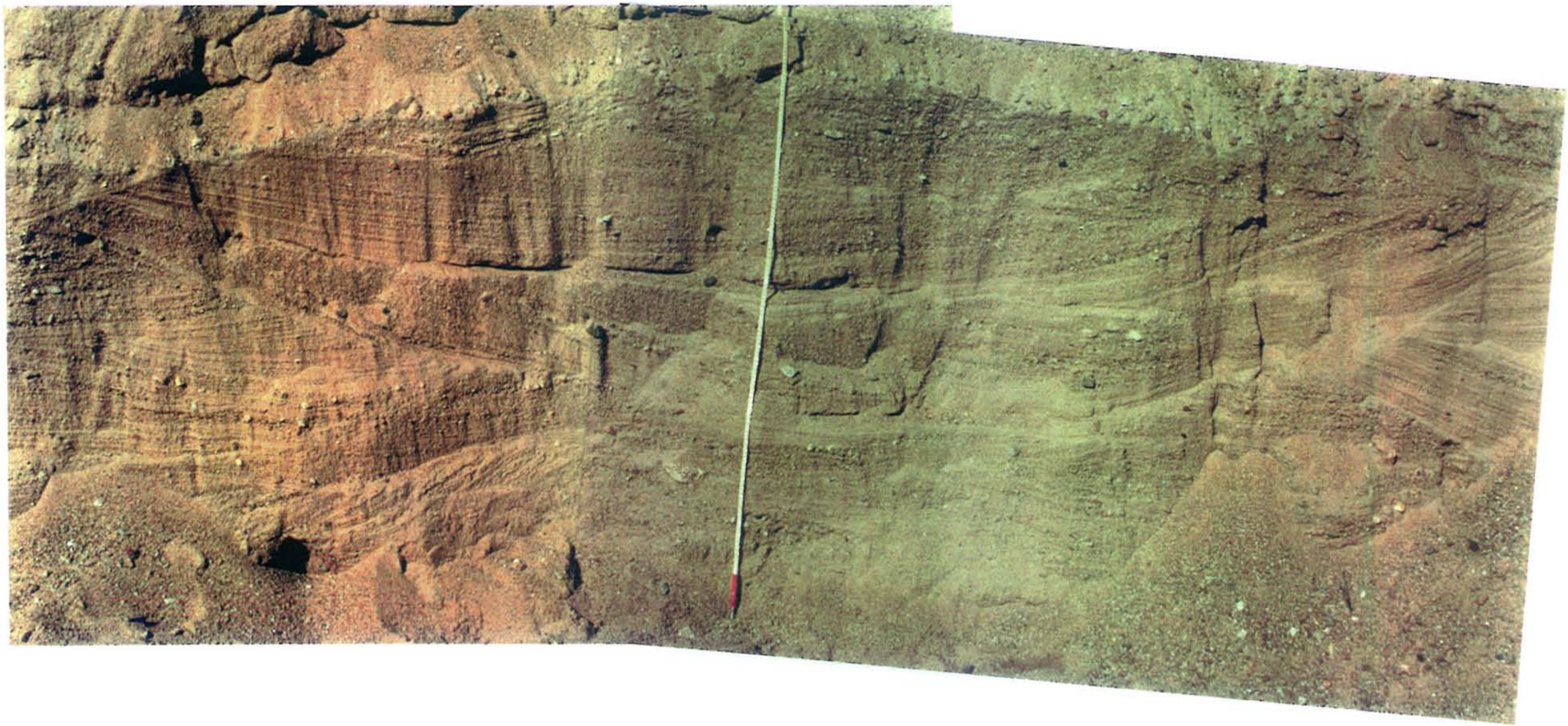


Figure 35. Geological section at 29-33 m along geological trench, Gulubane.

Figure 36. Flowing laterals within the completed Gulubane collector well.

Lateral details (drilled depth/metres, discharge, casing/screen lengths)	Discharge rate pre laterals	Discharge rate post laterals
(1) 8.85 x 15 flowing, 0-12.5 PVC blank, 12.5-15 PVC screen	Total inflow of 0.045 l/sec	0.5 l/sec
(2) 8.85 x 17 flowing, 0-13 PVC blank, 13-17 PVC screen		0.5 l/sec
(3) 8.85 x 17.5 flowing, 0-13 PVC blank, 13-17.5 PVC screen		0.5 l/sec
(4) 7.09 x 19 flowing, 0-8 PVC blank, 8-19 PVC screen		2 l/sec Total inflow of 3.6 to 4.25 l/sec

Table 14. Details of laterals drill from the Gulubane collector well

3.1.6 *Post-lateral Installation Drawdown/Recovery Pumping Test - Gulubane Collector Well*

At the start of the drawdown phase the rest water level was 6.11 m in the completed collector well 27/7/97. The well was pumped to dry, a drawdown of 3.74 m resulted after 102 min of pumping at an average discharge rate of 6.27 l/sec, a total volume of 38.4 m^3 being pumped. Pumping of inflow water and air was continued after this time, an inflow rate of 4.25 l/sec being measured. An average inflow rate of 3.6 l/sec was determined from the drawdown data (Appendix D and Figure 37).

During the recovery phase rapid water level recovery to a residual drawdown of 0.272 m was noted by 100 min, a recovery of 92.72%, 75% recovery to 0.935 mbtoc achieved after 68 min, an average inflow of water into the well of 2.53 l/sec being recorded (Appendix D and Figure 38). Linear recovery occurred between the base of the well at a residual drawdown of 3.75 m and the bottom laterals at a residual drawdown of 2.5 m in 20 min with an inflow rate of 4.4 l/sec. Between the bottom laterals at a residual drawdown of 2.5 m and the top lateral at a residual drawdown of 1 m linear recovery took 43 min at an inflow rate of 2.4 l/sec. Above the upper lateral recovery was logarithmic with the rate of inflow declining from 3 l/sec to less than 1 l/sec by a residual drawdown of 0.272 after 100 min of recovery. This collector well could be continuously pumped at 3 l/sec (259 m^3/day).

Comparison of arithmetic plots of the drawdown/recovery data derived from pumping tests undertaken before and after installation show a marked increase in inflow rate and recovery rate within the collector well (Figure 39). Prior to lateral installation it took nearly 80 min to pump the well-shaft dry at a discharge rate of 2.8 l/sec. Recovery was extremely slow, only 27.6 % recovery had occurred after 1246 min. After lateral installation it took 100 min pumping at 6.3 l/sec to empty the collector well. In contrast recovery was extremely fast, with 92.7% recovery after only 100 min.

3.1.7 *Completion Studies*

Current water demand is estimated to be 150 m^3/day (1.7 l/sec) of which 44 m^3/day (0.5 l/sec) are obtained from a borehole located between Gulubane village and the Shashe River. Demand for 2007 estimated to be 216 m^3/day (2.5 l/sec). The collector well system should be capable of supplying all of this projected future requirement. Stepped discharge/ drawdown/ recovery test-pumping needs to be undertaken upon this collector well system at different channel water stage levels during the year. The results of these tests coupled with data obtained from long term monitoring of abstractions and water levels should be used to judge the long term sustainability of the resource.

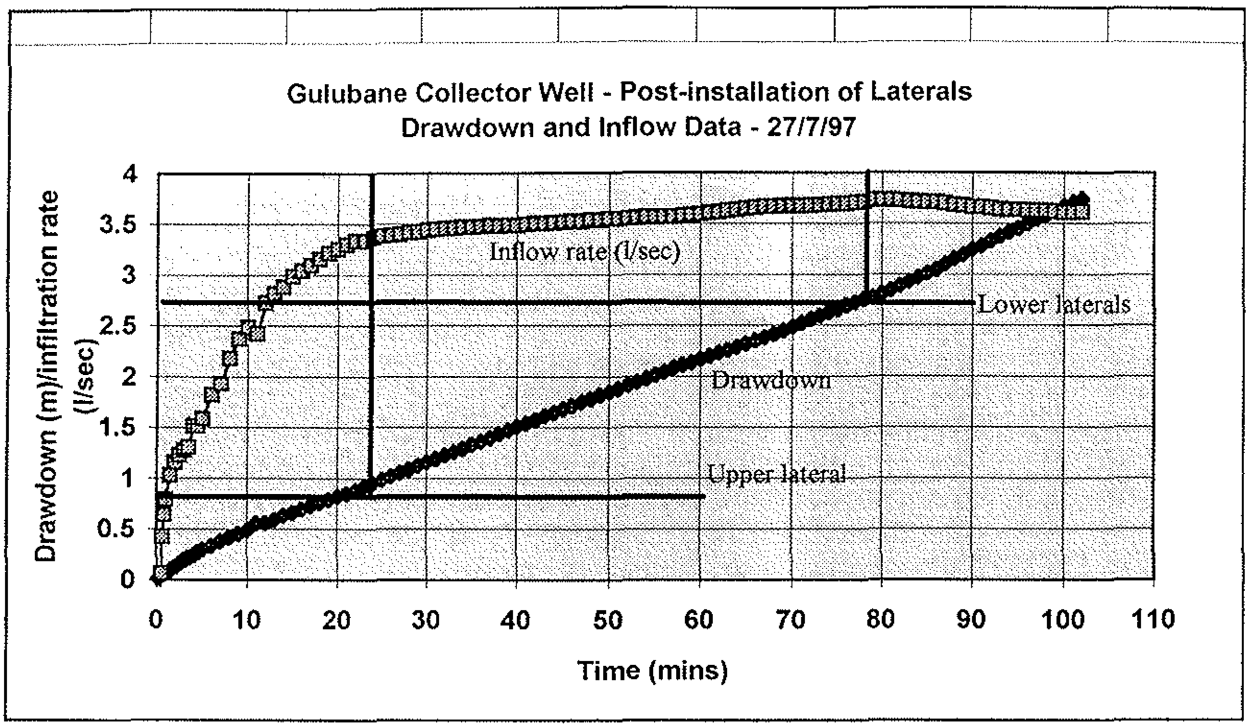


Figure 37. Post-installation of laterals test pumping data, Gulubane collector well

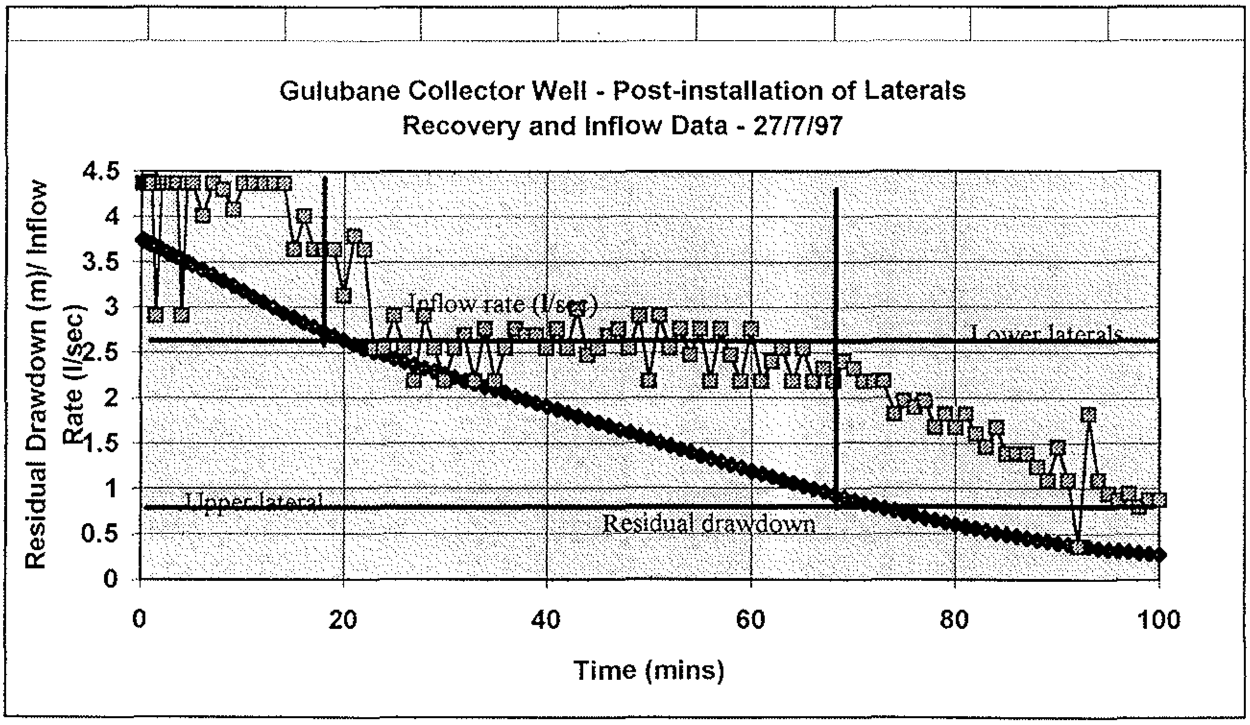


Figure 38. Post-installation of laterals recovery data, Gulubane collector well

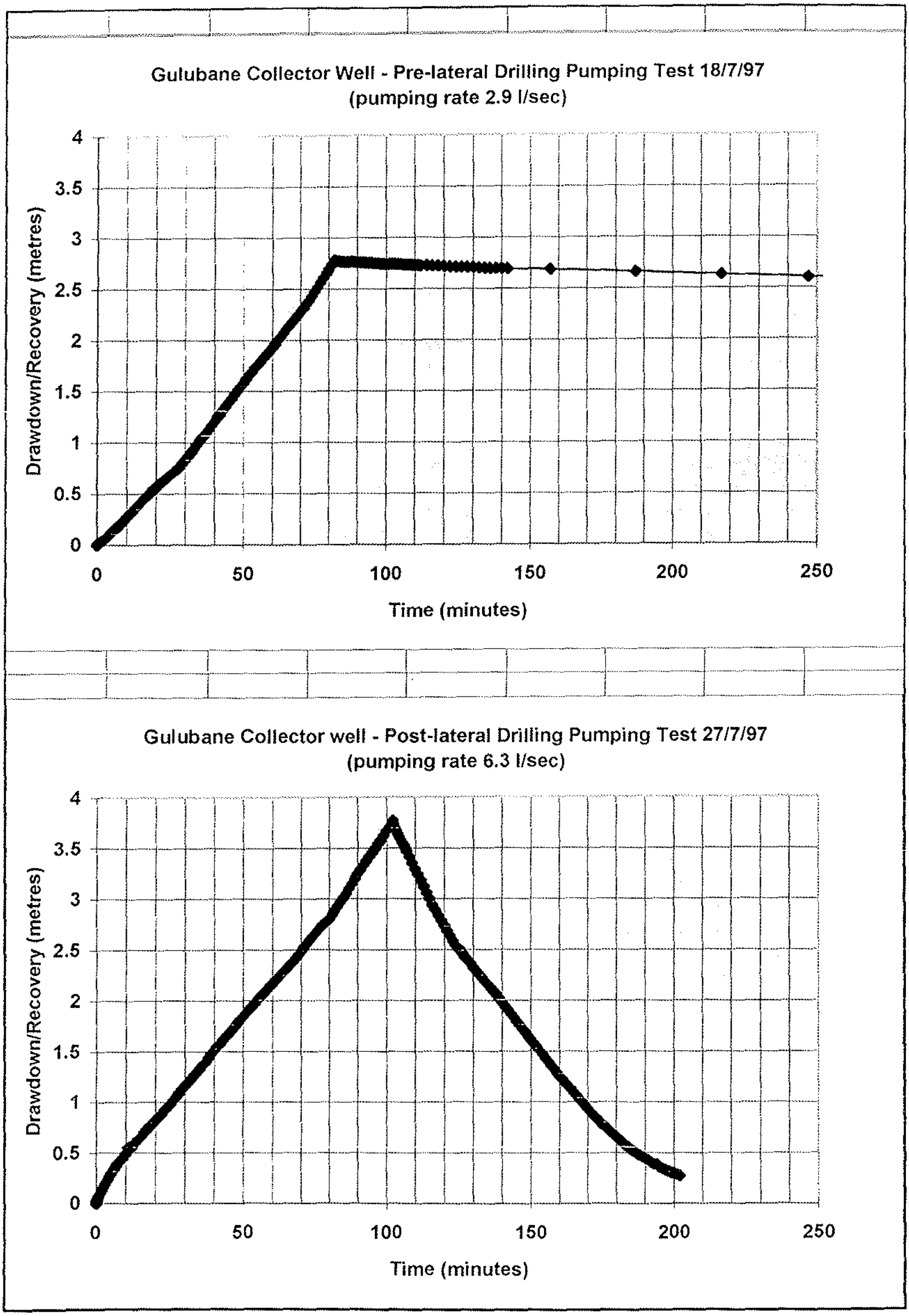


Figure 39. Comparative plots of pre and post lateral installation drawdown/recovery test pumping data, Gulubane collector well.

3.2 Matshelagabedi

3.2.1 *Survey of Sand-river Site*

The collector well site is located 5 km NNE of Matshelagabedi on the upper reaches of the Ramokgwebana sand-river (Figure 40). There the Ramokgwebana sand-river is 52.7 m wide, and is of intermediate size according to the classification of Nord (1985) and Wikner (1980). The collector well is located on the right bank, on the Botswana side of the river, 3.8 m from the edge of the channel. The DWA probed survey indicates that the channel base lies between 9 m and 10 m below the sand-river surface (Figure 41). The rest water level was 1.35 m below the sand-river surface, and a saturated channel cross section of 269.6 m^2 was determined. Depth sediment samples were latterly obtained from augered holes at intervals across the river bed. The grain size analyses of these samples are presented in Appendix E. The lithological variations noted with depth indicate a marked reduction in sediment grain size below 2 m depth, results that correlate well with drilling problems experienced during the installation of the lower laterals as described below. If these results had been available earlier maybe the well shaft would not have been constructed at this site. The grain size analyses obtained indicate that the laterals will probably block with time reducing well yield.

3.2.2 *Excavation of Well-shaft (Figure 42)*

The 2.2 m diameter well-shaft was excavated to 10 m below the level of the sand-river surface through a sequence of sands, consolidated clayey sands and dolerite boulders. The lithological log of the well-shaft has not been reported. The well-shaft lining of corrugated steel sheet hung up on dolerite boulders during excavation. Attempts to straighten the well-shaft to bring the casing back to vertical failed, the base of the well remaining 1 m from vertical. That the well-shaft was back-filled with sediment during flood events when the casing was over-topped, as indicated by the base of the well-shaft now lying at 7.19 mbsrs. Since the well-shaft sides slope to such an extent, difficulties were experienced with emplacement of timbers used to locate the rig at depths required for lateral drilling. The awkward positioning of the hydraulic controls rendered operation of rig difficult.

3.2.3 *Pre-lateral Installation Pumping Test*

Prior to installation of timbers and rig the well-shaft was test pumped at a discharge rate of 6.5 l/sec for 60 minutes, by which time the well-shaft had been pumped dry (Figure 43). Pumping was continued for several minutes using the compressed air driven diaphragm pump, which is capable of pumping a mixture of water and air. During this time water was pumped at a rate of 1.1 l/sec, this being the rate of water inflow into the well-shaft from the formation around the casing. An average inflow rate of 0.9 l/sec was calculated from the drawdown data (Figure 43). Water level recovery, within the well-shaft, was monitored for 310 min during which time an average inflow rate of 0.9 l/sec was determined (Figure 44).

3.2.4 *Ancillary Studies*

3.2.4.1 Salt dilution flow tests

Using compressed air, an observation borehole was jetted into the bed of the Ramokgwebana River at 33.1 m from the collector well, through the base of a 1.35 m deep exploration pit, dug to the water table (Table 15). The observation borehole was constructed using 50 mm diameter slotted steel pipe with a disposable well jetting point.

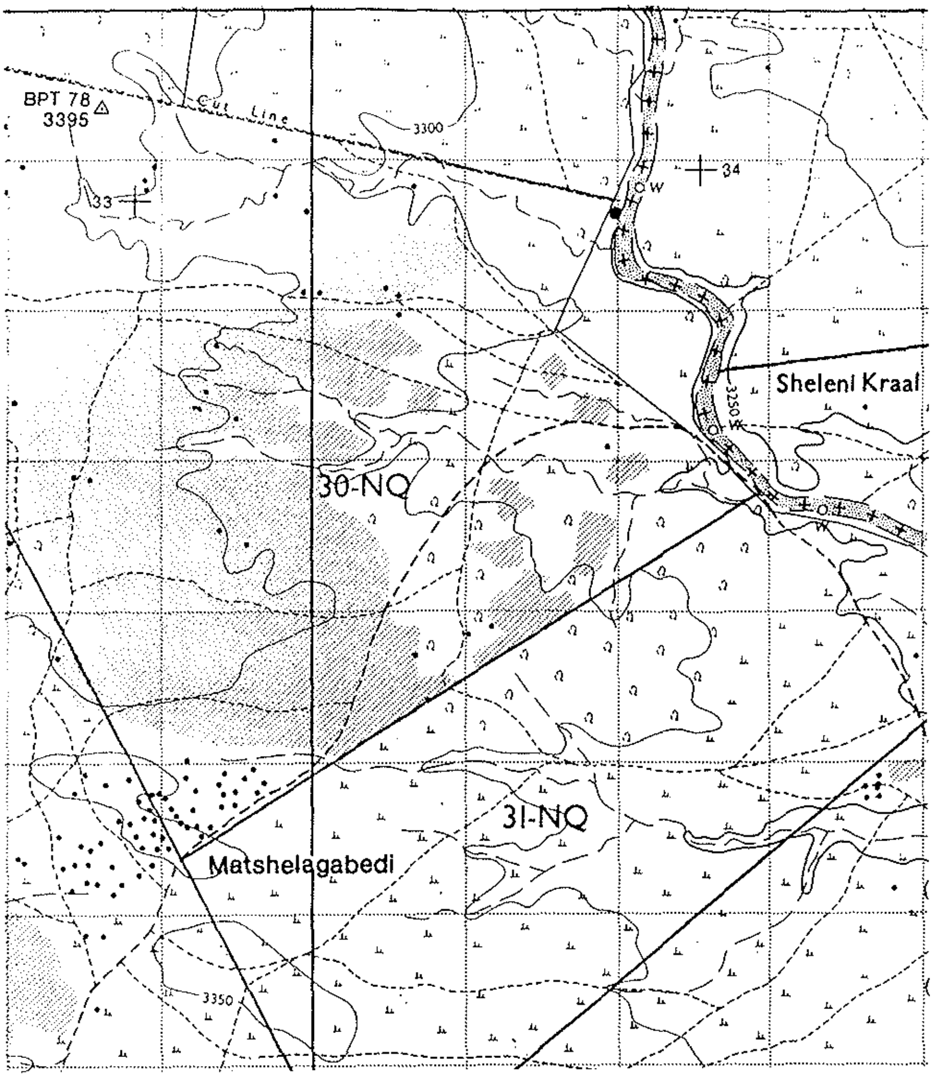


Figure 40. 1:50 000 scale location map of the Matshelagabedi collector well site.

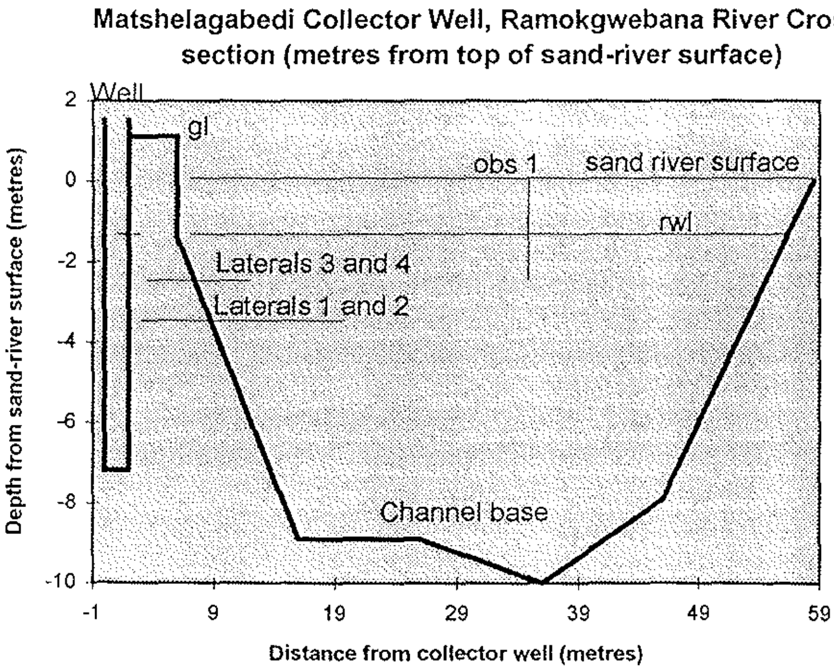


Figure 41. Probed cross section across Ramokgwebana River at Matshelagabedi site showing location of laterals, observation boreholes and collector well

Figure 42. River bank well-shaft location, Matshelagabedi

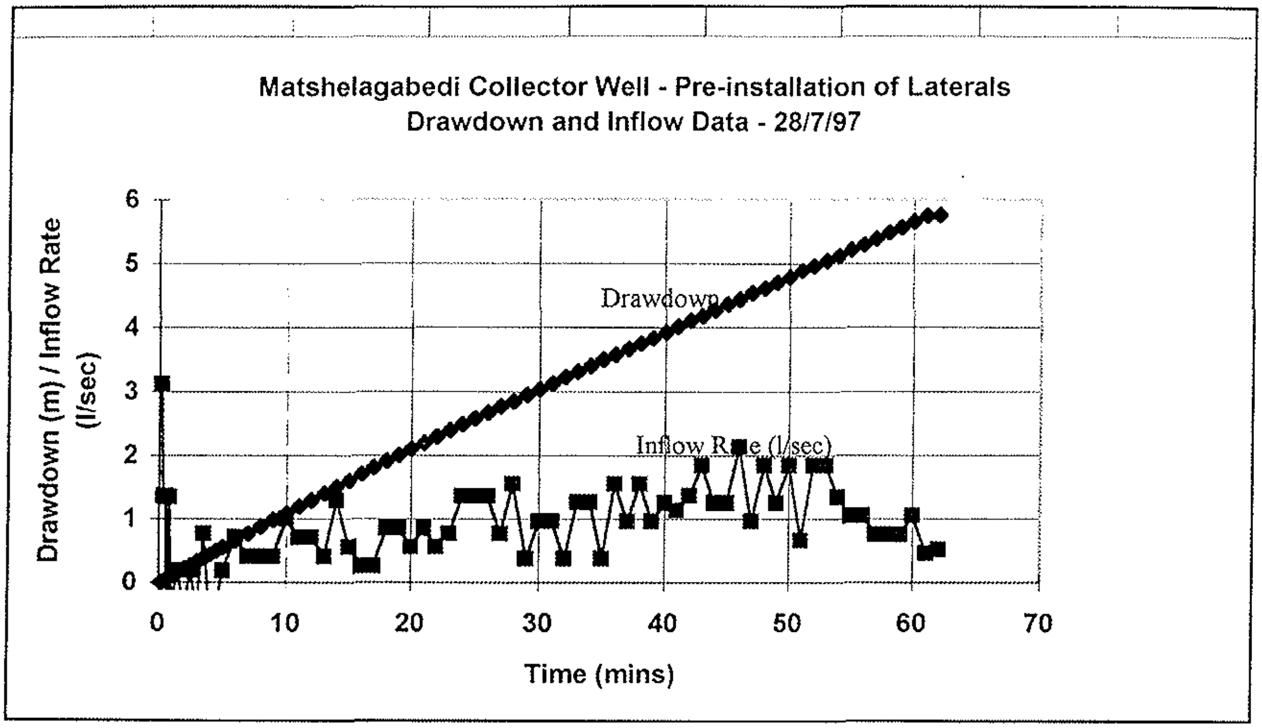


Figure 43. Pre-installation of laterals test pumping data, Matshelagabedi well-shaft

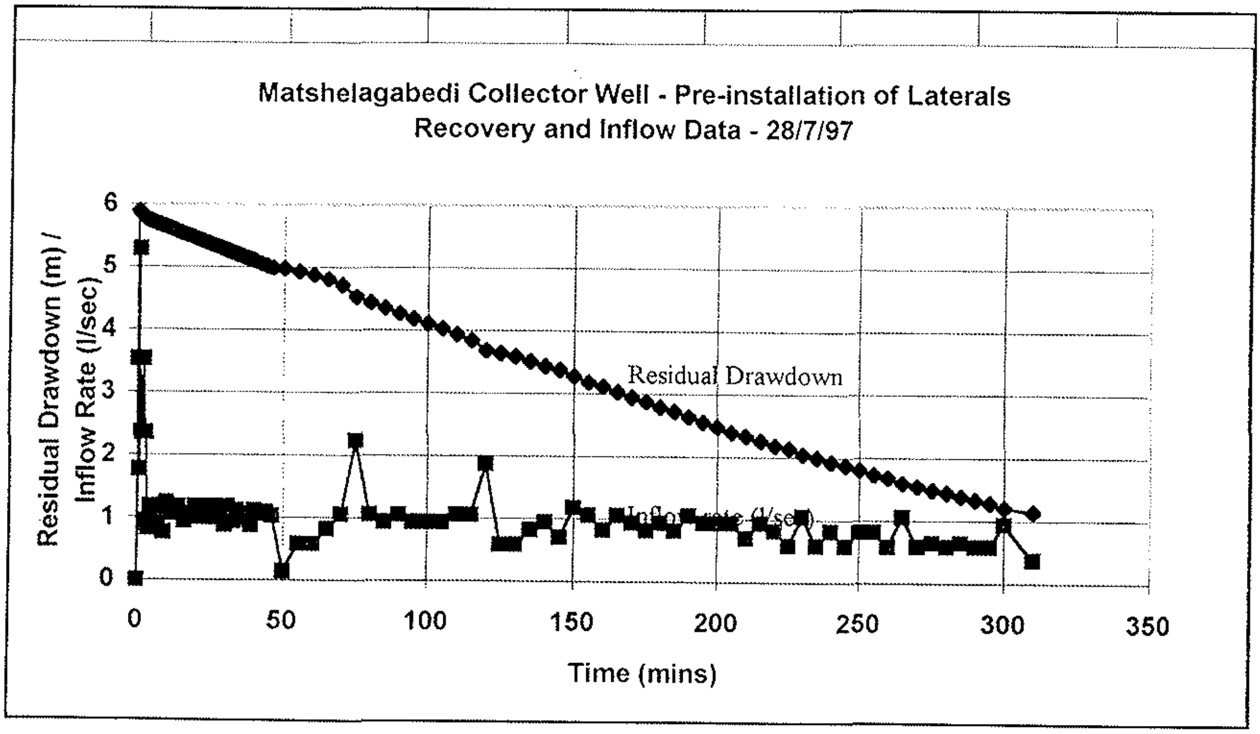


Figure 44. Pre-installation of laterals recovery data, Matshelagabedi well-shaft

Observation Bh No.	Obs Bh 1
Distance from collector well (m)	33.1
Borehole depth (mbtoc)	2.5
Borehole top (mbsrs)	0.10
Water level (mbtoc)	1.25
Water level (mbsrs)	1.35

Table 15. Observation borehole details at the Matshelagabedi collector well site.

An initial salt dilution flow test was attempted on 29/7/97 with the changes in conductance being monitored at 1 m below the water table (2.25 mbtoc). At that depth no reduction in conductance was discerned even after 60 minutes of monitoring. Therefore the change in conductance with depth below the water table at 100 mm intervals was therefore determined. A marked increase in conductance was recorded at 1.6 mbtoc. Below that depth conductance increased from 1000 μS to 9000 μS (Figure 45). The borehole was logged again the following day by which time the depth at which conductance was seen to increase had dropped to 1.8 mbtoc, conductance rising from 500 μS at that depth to 7500 μS at the base of the hole. Therefore a zone of higher flow occurs through high permeability sediments between 1.2 and 1.8 mbtoc, above lower permeability sediments. A salt dilution test was therefore undertaken monitoring conductance in the fast zone at 1.55 mbtoc. The results of this test are presented in Appendix F and summarised in Table 16. The less permeable horizons below 1.8 metres below the sand-river surface may represent older more indurated sediments, as observed existing at similar depths within sand-rivers of similar size in southern Zimbabwe.

Two estimates of flow rate along the channel have been produced (Table 16). The first uses a gradient of 0.0025 and the full saturated cross section of the channel, a flow rate of 1.58 l/sec (136.9 m^3/day) being calculated. The second uses a gradient of 0.003 and the upper 2 m of the saturated cross section, a flow rate of 0.59 l/sec (50.8 m^3/day) being calculated. The results of this test highlight the necessity for a full understanding of the geomorphological history of the sand-river channel sediment infills.

Obs Bh No. 1	**Darcy velocity (m/day)**	**Cross section area (m^2)**	**Discharge (m^3/day)**	**Discharge (l/sec)**	**Permeability (m/day)**
To probed depth of channel and gradient of 0.0025	0.51	269.5	136.9	1.58	203
Top 2 metres of saturated zone and gradient of 0.003	0.51	50 x 2	50.8	0.59	169

Table 16. Result of salt dilution flow test at the Matshelagabedi collector well obs bh No. 1.

3.2.4.2 Falling head permeameter tests

An exploration pit was sunk to the water table within the sand channel some 9.6 m from the collector well. Two sediment samples were obtained from this pit, the first at a depth of 1 m and the second at a depth of 0.3 m below the water table (1.7 mbsrs). Falling head permeameter tests were conducted upon these samples and the results are produced in Table 17. The results produced are in very good agreement with the permeabilities produced from the salt dilution flow test of 170 - 200 m/day.

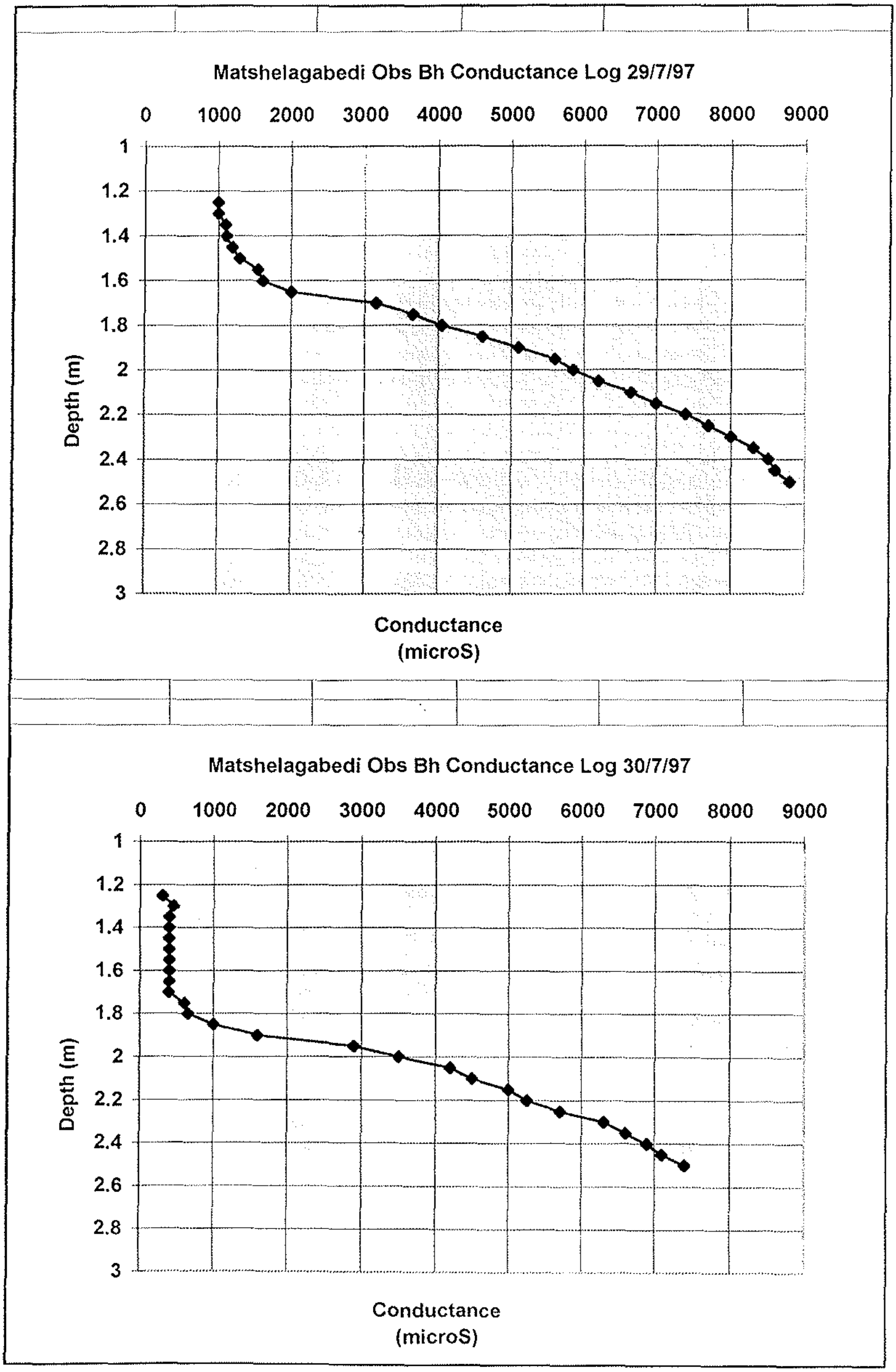


Figure 45. Salt dilution flow test graphs, Matshelagabedi observation borehole

Sample No.	Location	Date	l (m)	t (sec)	K (m/day)
9	Matshelagabedi litho-hole 1 m	29/7	0.185	101	207.2
10	Matshelagabedi litho-hole 1.7 m	30/7	0.195	128	172.3

Table 17. Falling head permeameter test results from the Matshelagabedi collector well site.

3.2.4.3 Sedimentology of sand river alluvium

Above the water table unconsolidated cross bedded poorly graded mixed medium to coarse sands and gravels were noted within the exploration pits sunk at distances of 9.6 m (Figure 46) and 33.1 m from the collector well. The possible presence of lower permeability semi-consolidated alluvium at depths greater than 1.8 mbsrs are indicated by the results of conductance logging within an observation borehole. Semi consolidated, older alluvial sediments seen to crop out within the main river channel about 1 km upstream (Figure 47) of the collector well site, may be similar to the less permeable sediments that occur below the water table adjacent to the collector well site. Detailed studies of the sediments in the channel at the collector well site need to be undertaken.

3.2.5 *Drilling and Construction of Laterals*

During the drilling of the first lateral at a depth of 2.2 m below the water table, the tungsten carbide cutting shoe used to cut a 100 mm hole through the shaft casing cut through into the consolidated clayey medium sands that forms the well wall, a cored sample of the formation being retrieved (Figure 48). Drilling was continued through this dry consolidated formation using a 100 mm diameter drag bit into the channel sands. 50 mm screen was then jetted to a depth of 10.5 m. The jetting pipe broke during the installation of this lateral leaving 7 x 0.5 m lengths of pipe in the lateral, which was dry on completion. The second lateral was drilled to the left of the first. The lateral was drilled through dry, fairly hard clayey sand using a 100 mm drag bit, into the channel sands. The initial hole was cased with 100 mm steel casing through which PVC screen and casing was jetted to a depth of 17 m. Initially very muddy water flowed from this lateral at the rate of about 1.5 l/sec. During dewatering of the well prior to drilling the following morning the well was being pumped at 5.5 l/sec, the second lateral continuing to flow at about 1.5 l/sec, producing extremely muddy water, for about 43 min when the flow from the lateral suddenly stopped. The lateral was re-developed by jetting with air, finally producing 0.5 l/sec of very muddy water (Figure 49). The rig was repositioned at a level of 2 m below the water table. Two laterals were drilled at that level, with screen jetted out to 10 m in each case. Both of these laterals produces clear water at the rate of 0.5 l/sec(Table 18). The second lateral continued to flow at a rate of 0.5 l/sec, finally clearing of sediment after a further 24 hr after jetting.

Lateral details (drilled depth(mbtoc)/length (m), discharge, casing/screen lengths (m)	Inflow rate pre lateral installation	Inflow rate post lateral installation
(1) 5.00 x 10.5 dry	0.9 l/sec	dry
(2) 5.00 x 17 flowing		0.5 l/sec
(3) 4.00 x 10 flowing, 0-10 PVC screen, 0-1.5 x 4" steel		0.5 l/sec
(4) 4.00 x 10 flowing, 0-10 PVC screen, 0-1.5 x 4" steel		0.5 l/sec
		total inflow of 2.7 l/sec

Table 18. Details of laterals drill from the Matshelagabedi collector well

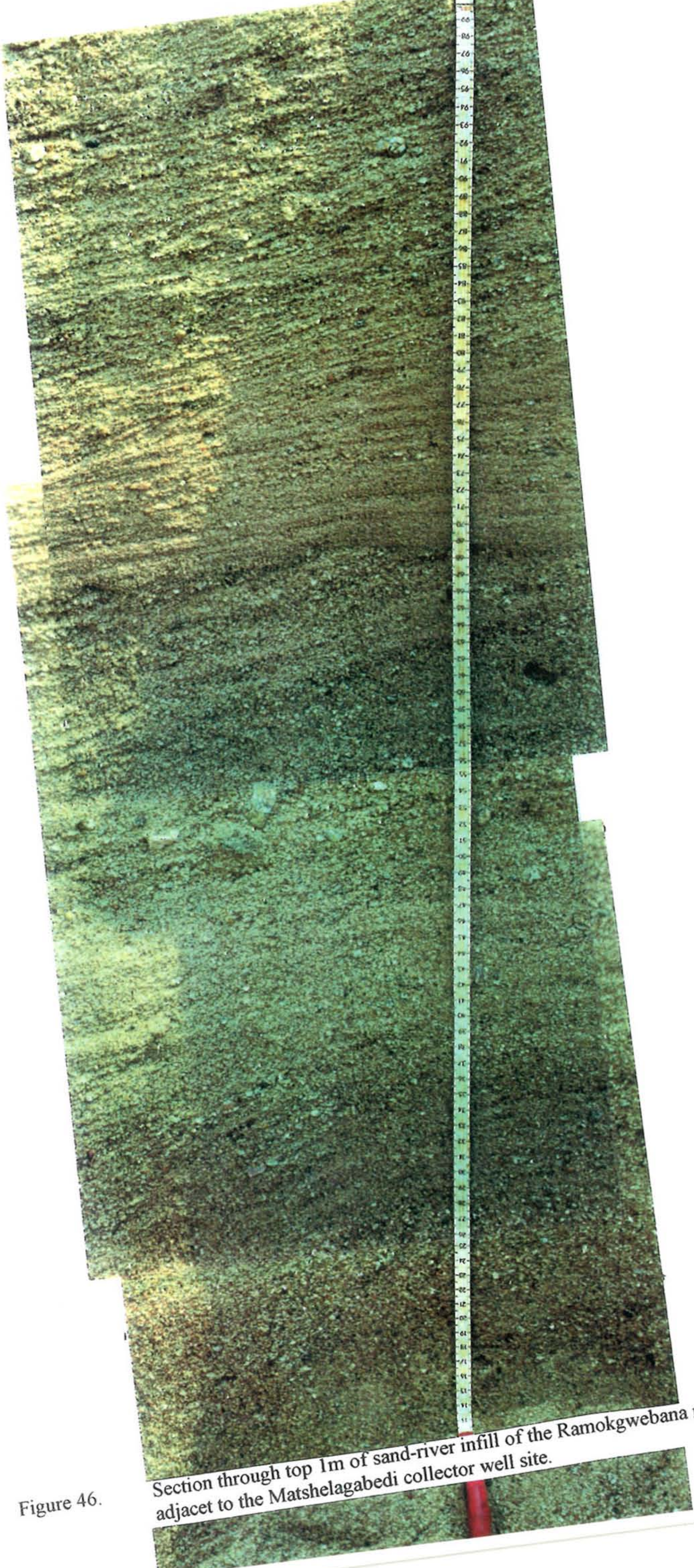


Figure 46. Section through top 1m of sand-river infill of the Ramokgwebana river adjacet to the Matshelagabedi collector well site.

Figure 47. Semi-consolidated, older alluvial sediments cropping out along Ramokgwebana River 1 km upstream of collector well site.

Figure 48. Core of sandy siltstone obtained from the weathered bank of the Ramokgwebana River at Matshelagabedi.

Figure 49. Water flow from second lateral heavily charged with silt, Matshelagabedi.

3.2.6 *Post-lateral Installation Drawdown/Recovery Pumping Tests*

The completed collector well was retested on 3/8/97 when the well was pumped to dry at a discharge rate of 6.9 l/sec in 100 min. Pumping of inflow water and air continued after this time, an inflow rate of 2.7 l/sec being measured. An average inflow rate of 3.5 l/sec was determined from the drawdown data. During the drawdown phase the rate of inflow is seen to fall from 3.8 l/sec to less than 2 l/sec, a decline that may be due to screen blockage in one or more of the laterals. (Appendix D and Figure 50).

Water level recovery was monitored for 190 min during which time an average inflow of water into the well of 1.7 l/sec was recorded, nearly twice the pre-lateral installation inflow rate (Appendix D and Figure 51). During the recovery phase the water level recovered linearly from 8.52 m to the lower laterals at 5.1m in 83 min at an inflow rate of 2.4 l/sec. Between the lower laterals at 5.1 m and the upper laterals at 4.09 m the water level recovered linearly in 28 min at inflow rate of 2 l/sec. Above 4.09 m recovery occurred at an exponential rate with inflow declining rapidly from 2 l/sec at 120 min to 0.2 l/sec at 190 min. This collector well could be continuously pumped at 2-3 l/sec.

Comparison of arithmetic plots of the drawdown/recovery data derived from pumping tests undertaken before and after installation show an increase in inflow rate and recovery rate within the collector well (Figure 52). Prior to lateral installation it took nearly 60 min to pump the well-shaft dry at a discharge rate of 6.5 l/sec. Recovery was fairly fast recovery to about a 1 m of residual drawdown occurring by 310 min. After lateral installation it took 100 min of pumping at 6.9 l/sec to empty the collector well. In contrast recovery was fast, with 88.4% recovery after 190 min (Figure 52).

3.2.7 *Completion Studies*

Water supply demand by the year 2007 is estimated to be 346 m^3/day (4 l/sec). The collector well system should be capable of supplying up to 75% of this demand at least in its present form. However the initial salt dilution flow test indicates that yields could decline if water levels fall to the levels of the lower permeability layers at 1.8 m below the sand-river surface. Additional probing surveys need to be undertaken to indicate the distribution of any lower permeability layers with depth across the channel cross section. Additional stepped discharge/ drawdown/ recovery test pumping needs to be undertaken upon this collector well system. The results of these tests coupled with data obtained from long term monitoring of abstractions and water levels should be used to judge the long term sustainability of the resource.

3.3 Tobane

Initial studies at the Tobane 1 collector well site were undertaken during 1995 and reported in Davies et al (1995b). During the latest visit, undertaken at the request of DWA, additional laterals were drilled and constructed within the Tobane 1 collector well by the BGS driller who subsequently re-tested the collector well. The drilling and construction of additional laterals and test pumping results are described and commented upon here.

3.3.1 *Drilling and Construction of Additional Laterals*

According to the criteria of Wikner (1980) and Nord (1980) the Motloutse River at Tobane belongs to the major class of sand-river (Figure 53). Initial drilling results proved the existence of fine grained sandy sediments at depth in the channel at shallow depth. Drilling of laterals at shallower depths was undertaken to intercept coarser sediments. Unfortunately similar fine grained sandy sediments were also encountered in the latest series of laterals drilled. Only three of the five laterals drilled producing

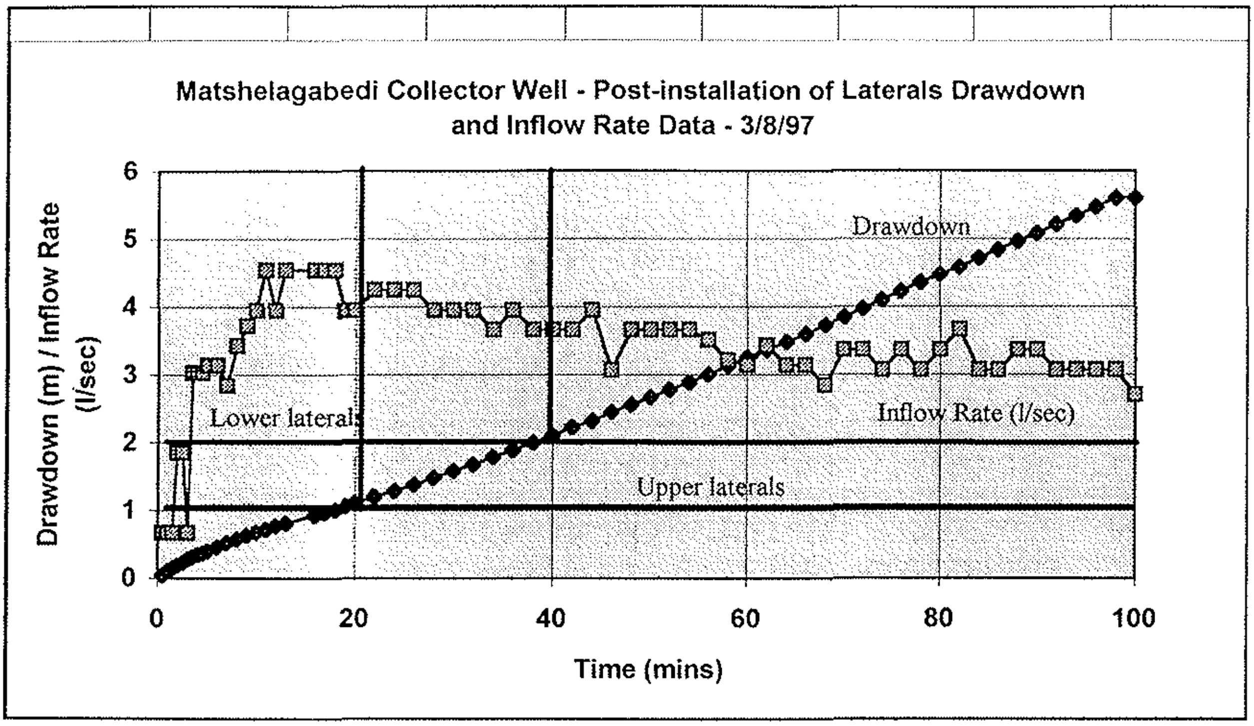


Figure 50. Post-installation of laterals test pumping data, Matshelagabedi collector well

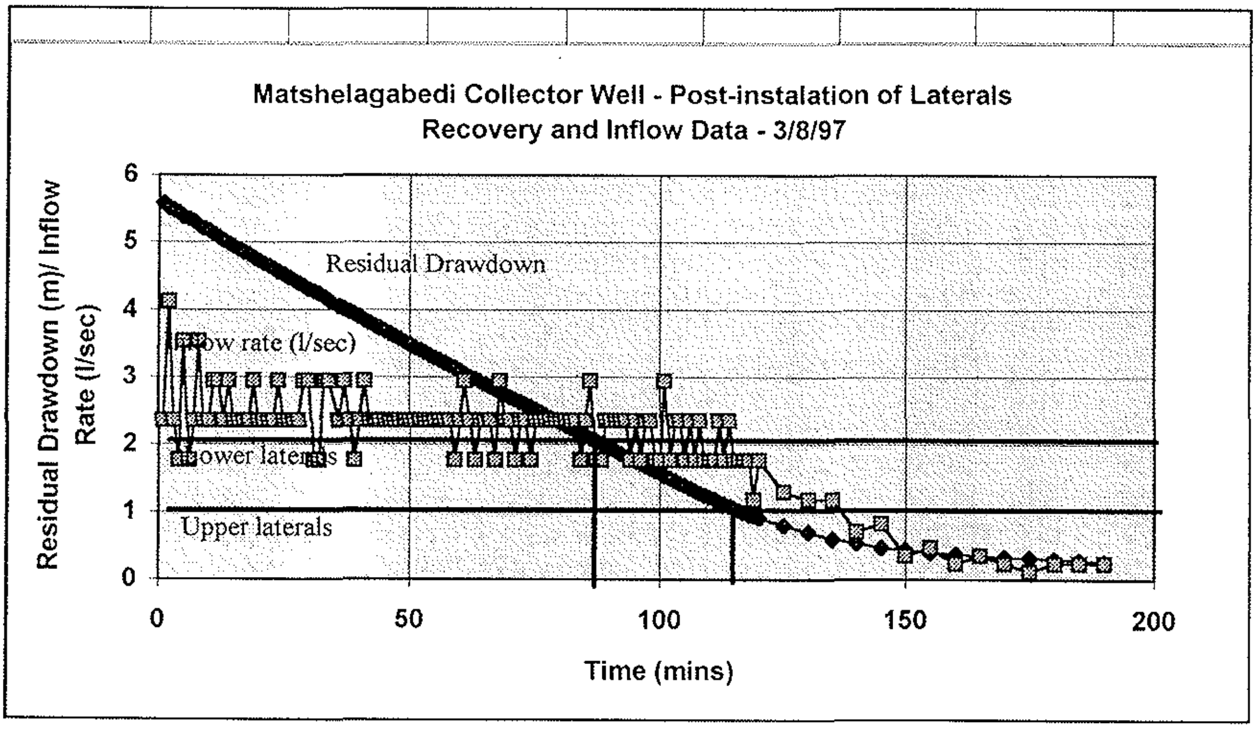
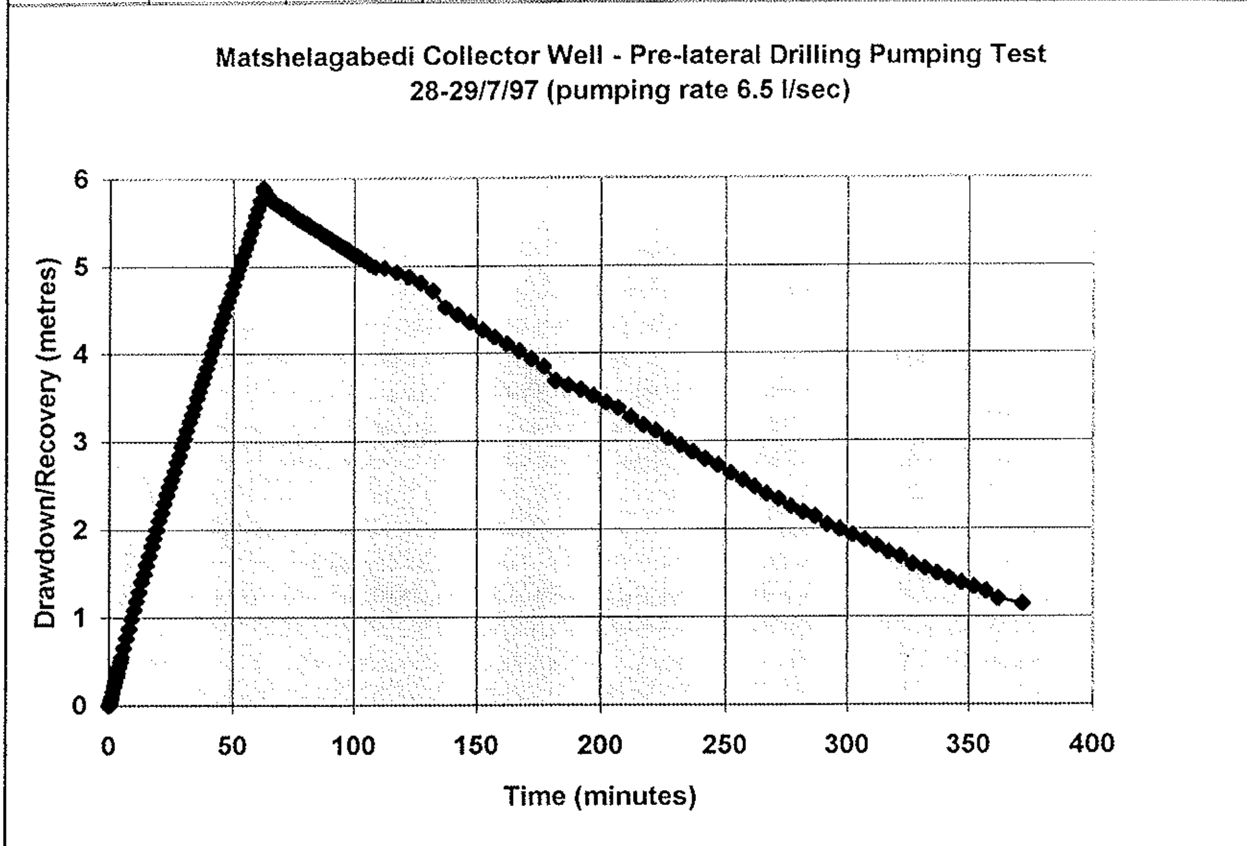


Figure 51. Post-installation of laterals recovery data, Matshelagabedi collector well



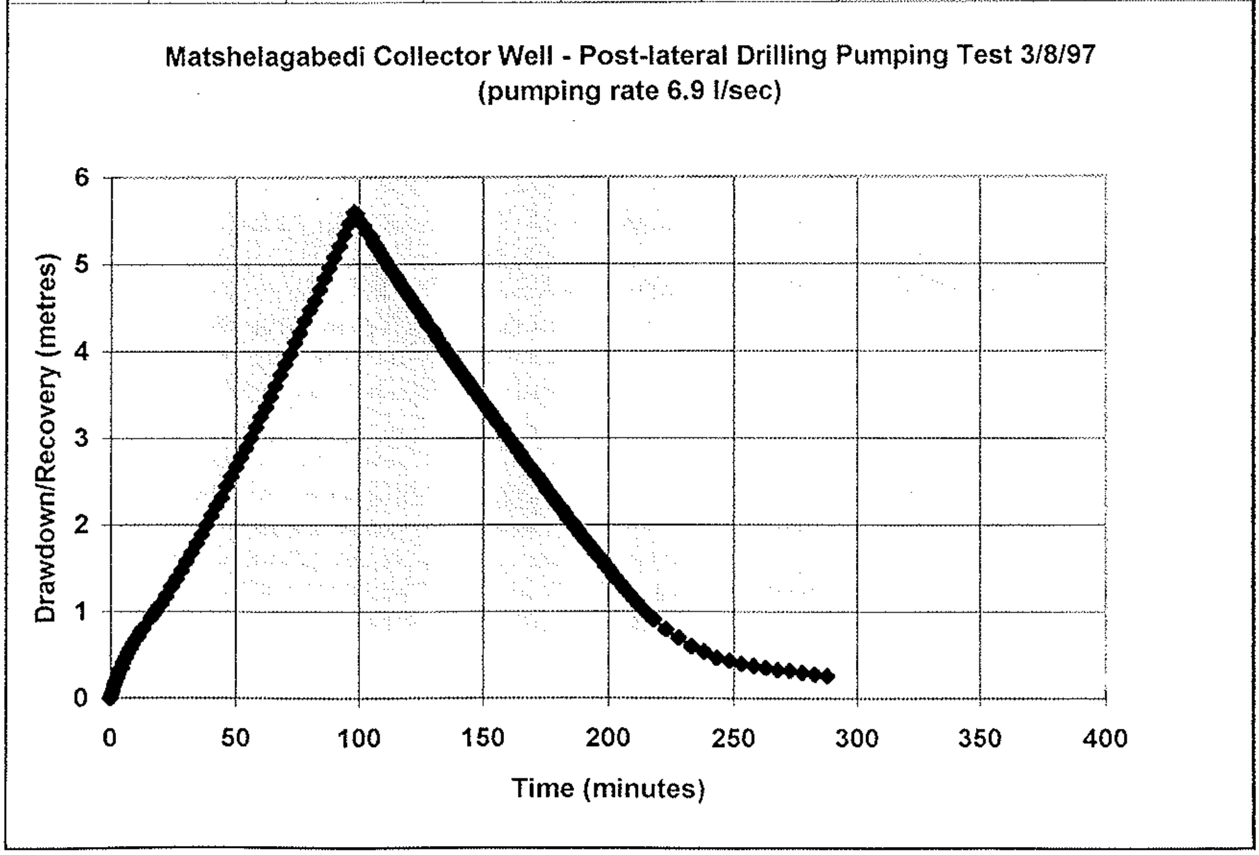


Figure 52. Comparative plots of pre and post lateral installation drawdown/recovery test pumping data, Matshelagabedi collector well.

Figure 53. A typical major sand-river, the Motloutse sand-river at Tobane I collector well

flows of water on completion, and of these one latterly dried up. Details of the laterals drilled are presented in Table 19.

Lateral details (drilled depth/metres, discharge, casing/screen lengths)	Discharge rate pre laterals	Discharge rate post laterals
(1) 6x15 dry	dry	Inflow rate of 0.94 l/sec
(2) 5x16 dry	dry	
(3) 6x24 flowed but stopped	dry	
(4) 6x25 flowing	not determined	
(5) 5.5x25 flowing	not determined	

Table 19. Additional laterals drilled and constructed at Tobane 1 collector well.

3.3.2 *Post-lateral Installation Drawdown/Recovery Pumping Tests*

The collector well was re-tested on 18/8/97 on completion of lateral construction and removal of rig and ancillary equipment from the collector well. The rest water level prior to the test was at 4.8 mbtoc. The collector well was pumped at 6.7 l/sec for 32 min, until the collector well was emptied. Inflow rate at the end of the drawdown phase was 0.99 l/sec, an overall average inflow rate of 0.94 l/sec being determined for the drawdown phase (Figure 54). During the recovery phase a recovery of 43.2 % to a residual drawdown level of 1.78 m had been reached after 250 minutes, an average inflow rate of 0.31 l/sec being determined (Figure 55). The drawdown/discharge characteristics of the collector well seem to have deteriorated since first tested in August 1995 (Figure 56). In addition the rate of recovery is slower than that determined on 26/8/95 (Figure 57). This deterioration could be due to:

- blockage of screen slots by fine sediments reducing inflow
- reduced availability in the most permeable near surface layers as indicated by a marked decline in water levels, possibly due to the upstream damming of the Motloutse River at Letsebogo.

or a combination of both of the above.

4. DISCUSSION

During the pilot project ten well-shafts were sunk by DWA and nine of these were converted to collector wells by a BGS team with varying success.

Wikner (1980) and Nord (1985) concluded from their probe surveys of sand-rivers of north eastern Botswana that:

- coarse sediments occur at the top and base of channel infill deposits, and that a range of sediment sizes occur between,
- only certain parts of the main sand-rivers were large enough to have groundwater development potential,
- these sand-rivers could be grouped into three categories according to channel size.

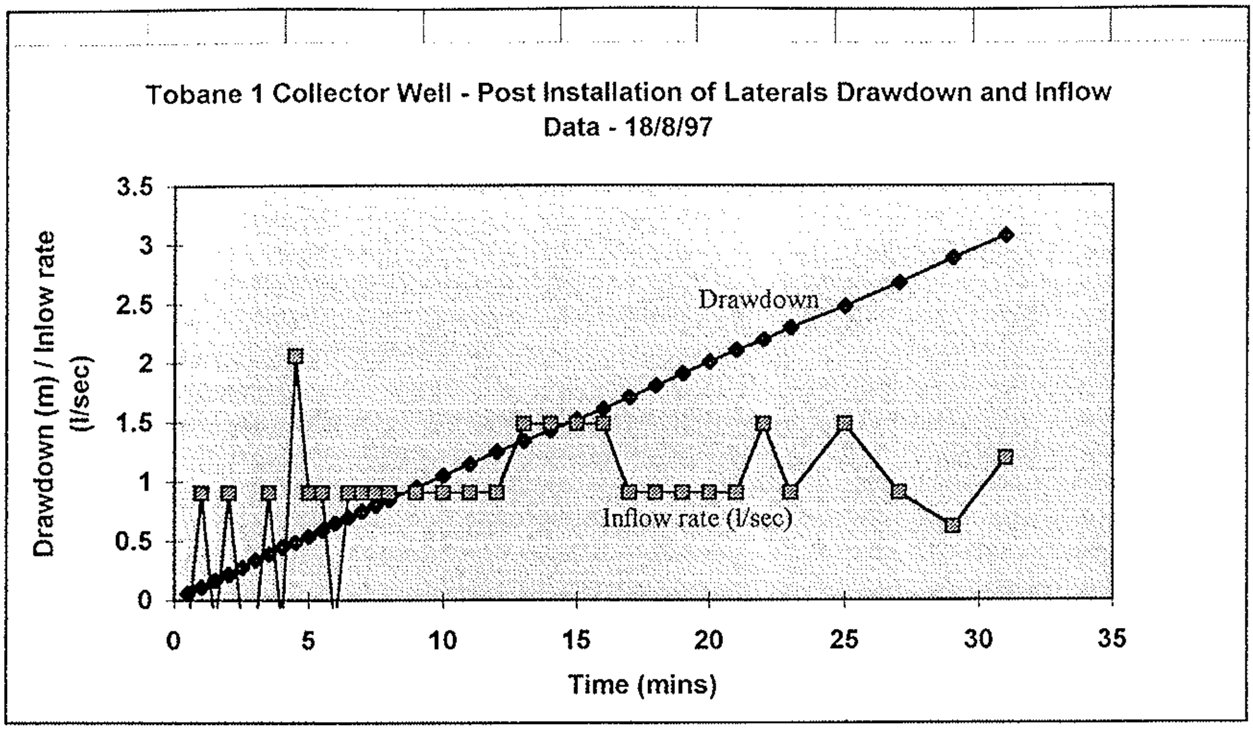


Figure 54. Post-installation of laterals test pumping data, Tobane I collector well

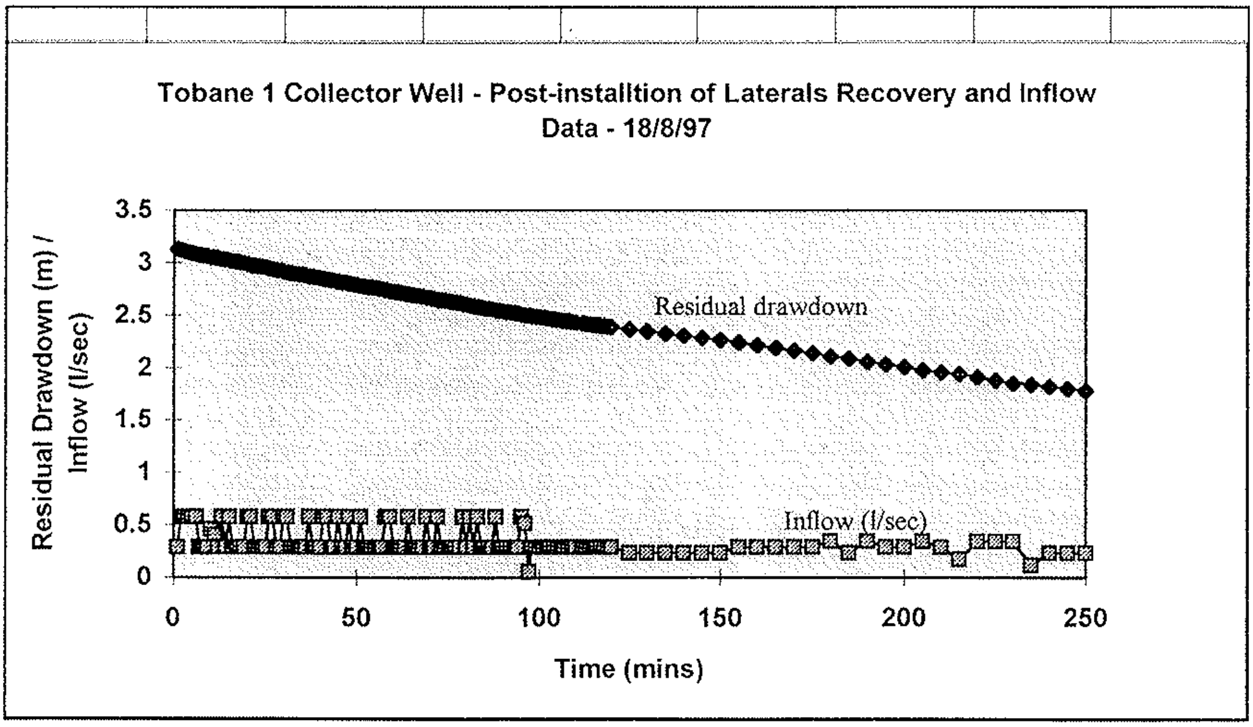


Figure 55. Post-installation of laterals recovery data, Tobane I collector well

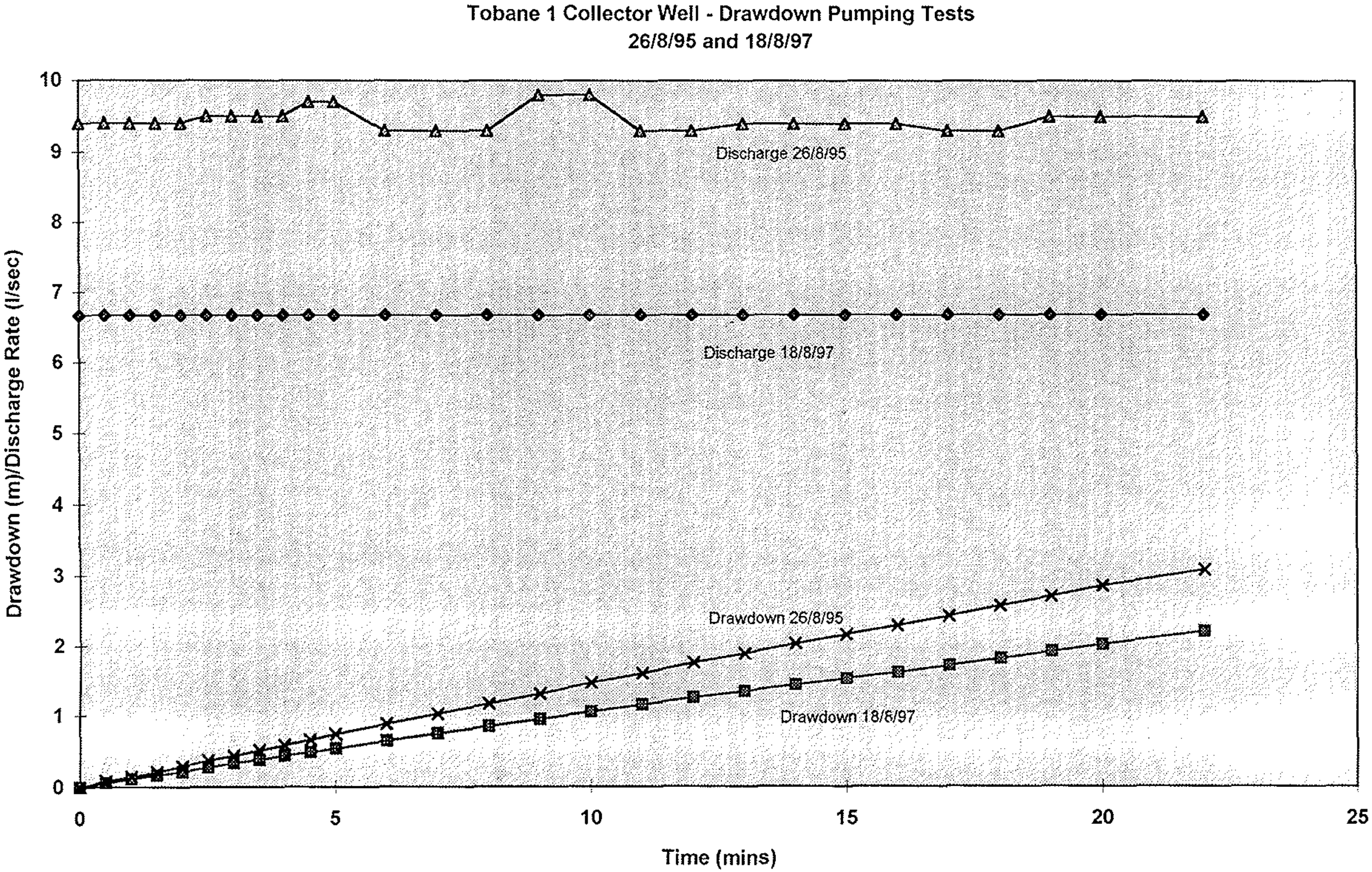


Figure 56. Comparative plots of drawdown/discharge test pumping data, Tobane I collector well.

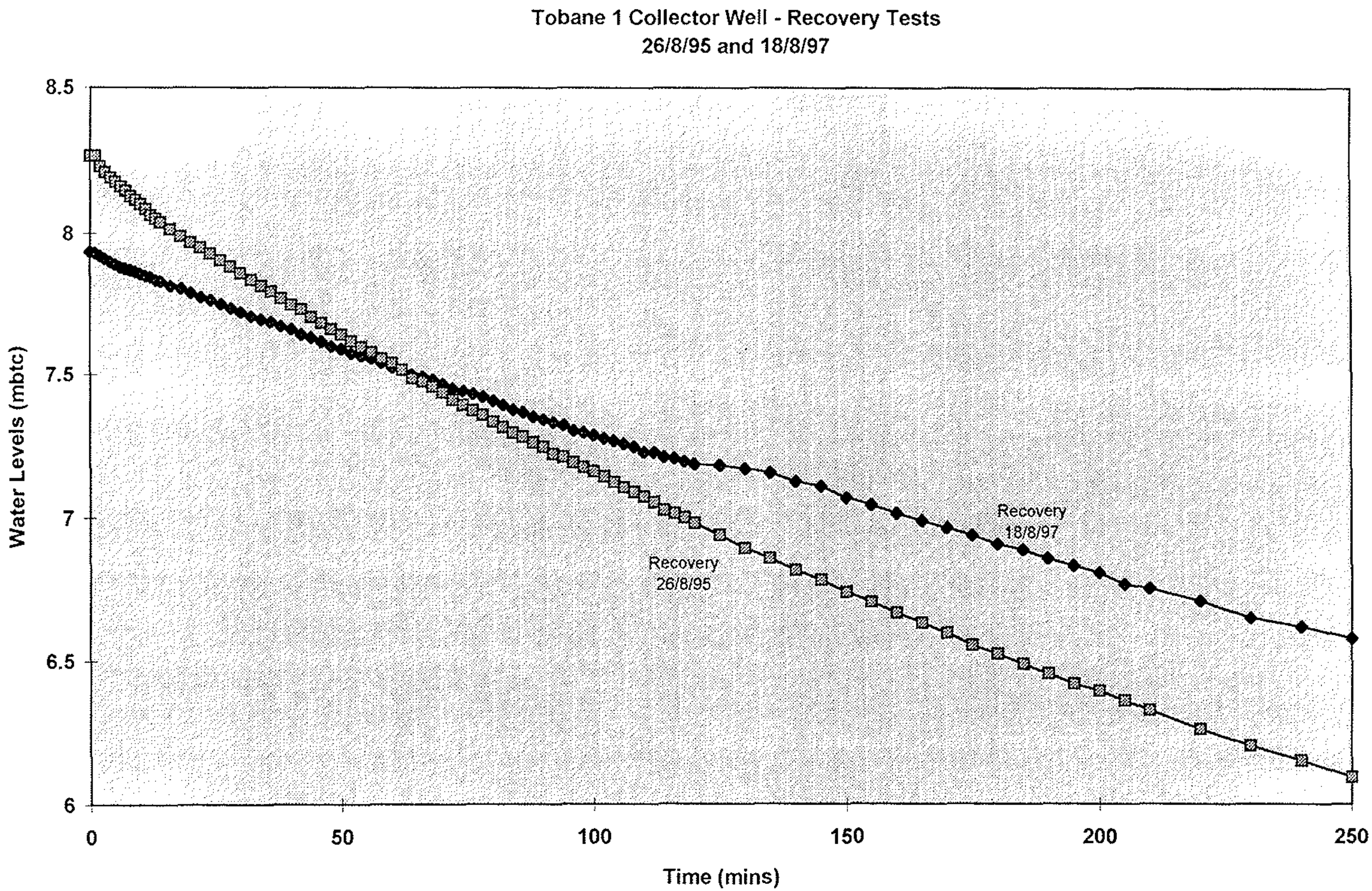


Figure 57. Comparative plots of recovery test data, Tobane 1 collector well.

The above conclusions were used as criteria for the initial application of collector wells for the development of sand-river water resources. Laterals were to be drilled and constructed into the coarse basal sediments recognised by Wikner and Nord. The main limitation was the 25-30 m maximum length of lateral that could be installed.

Therefore, according to these criteria, the main requirements were:

- knowledge of the depth of the channel to determine apparent depth to basal sands and gravels
- that the well-shaft be sunk to a depth greater than the depth of the channel and in the river bank at a location as close as possible to the channel but that was high enough to avoid flooding.

Lateral construction using the above criteria were first attempted at Chadibe and Borolong on the Shashe River. At these sites problems were encountered with the variable nature of the sand infill/bedrock interface. Several of the laterals, when drilled encountered pinacles of hard rock between pockets of sand, making the installation of casing and screen extremely difficult. In addition pockets of clayey weathered material were encountered within the interface horizon. Dry or poor yielding laterals were drilled in consequence. Attempted use of the telescoped drilling system at these two sites produced mixed results.

Similar problems were encountered during lateral construction at the two collector wells at Masunga. These are located at the very end of a minor river and are therefore atypical as there is insufficient stream length available upstream to provide groundwater drainage throughout a year. Studies undertaken at and between these sites did produce insight into the nature of sediment deposition within sandriver channels. Several laterals were thereby installed at the Masunga collector wells.

Of the other sites developed, Gulubane is located along the upper reaches of the Shashe River. In this area of apparent minor development potential, the river has good flow, sediment formation and upstream drainage characteristics. At Matshelagabedi the Ramokgwebana river is of intermediate development size, but the river channel appears to occupied with partially indurated older sediments below mixed upper recent sediments. The two collector wells at Tobane are located on the Motloutse River that has apparent major development potential. However, thick fine alluvial sands occur beneath shallow coarse grained mixed recent sediments within a wide channel. Such a channel could be split into a major central channel with minor channels either side within which finer sediments have been deposited during pluvial periods, all now masked by recent coarse sediments. The above results emphasis the importance of understanding sediment distribution and structure along rivers of different sizes and therefore development potential if they are to be effectively developed using the collector well system or any other system that involves the emplacement of drainage laterals at depths across sand-rivers.

Initial site surveys undertaken by DWA staff includes a traverse of probing sites across a sand-river channel at 10 m intervals. This system allows determination of the depth to bedrock at each site, allowing construction of a channel base profile. The equipment also permits collection of sand samples at specific depths. A cross section showing the distribution of sediments within a channel should thereby be compiled. Unfortunately these data were not made available to BGS staff during the project. Without such knowledge of sediment distribution application of appropriate drilling and lateral construction methods is difficult, as was experienced at the Tobane collector well sites. However, geophysical survey methods have been developed that produce images of sediment distribution with depth across a sand-river channel. Potentially the correlation of ground penetrating radar traversing with sediment probing and depth sampling will be the most effective way of investigating sediment structure, thickness, lithology and water content in the future.

The age of sediment deposition is still imperfectly understood. The C^{14} radio-carbon dating of organic materials from the Masunga site have indicated the very recent nature of the near surface coarse grained very mixed sediments, 1 to 1.5 m thick, that blanket the channel infill sediments along most valleys. The deposition of these sediments are indicative of possible changes in local climatic patterns during the not too recent past and to the influence of possible anthropogenic influences, including population movements into the area (Tapela, 1982), upon vegetation patterns that has resulted in massive erosion of top soils throughout the north-eastern Botswana region. Such anthropogenic changes could, themselves have contributed to climatic change in the area.. The age of underlying sediments, which from the extremely limited understanding of their characteristics, appear to have been deposited under pluvial conditions, is unknown.

As well as investigating the derivation of sediments within sand-river channel methods have been devised during the pilot project to assess the hydraulic and lithologic characteristics of these sediments.

- A salt dilution flow test has been used to recognise the presence, rate of and quantity of groundwater flow down channel through inflow sediments at the end of the dry season.

- A falling head permeameter apparatus has been used to determine the approximate permeabilities of disturbed samples of unconsolidated and uncemented sediments.

- A method following on the work of Kovaks was applied to grain size analyses data to recognise the potential for suffusion to take place adjacent to screened sections of laterals that could cause screen blockage.

The 2 m diameter well-shafts are converted into collector wells by the drilling of horizontal laterals connecting the well-shaft with saturated sediments within the adjacent sand-river channel. The application of telescoped and duplex methods of drilling and constructing laterals into sand-rivers were investigated. Mixed results were obtained, these depending to a great deal upon which type of river site was investigated.

Best results were achieved using the telescoped method of drilling/construction in the coarse grained sediments of minor rivers, as at Gulubane. Within this situation laterals with up to 10 metres of screen can be jetted out into coarse sands to 23 metres before sand locking halts further progress. Unfortunately the use of 0.5 mm slot screen may have resulted in progressive screen blockage with mobilised sediment matrix fines at Masunga where yields have reportedly declined with collector well use. Larger slot sized screens need to be used in the future. Attempts to use the duplex method failed due to sand locking of 50 mm screens within the outer 88 mm temporary steel pipe.

At Matshelagabedi within an intermediate sand-river environment screens were successfully jetted out to 20 m or more but water flowing through the laterals initially carried a very large silt content. This silt content could result in the sudden cessation of flow from a lateral. The silt content only cleared after a day or so of lateral flow.

At the Tobane sites, within a major sand-river environment, laterals were easily jetted out into finer sediments for distances up to 25 m. Unfortunately the fine sediments flowed through the 0.5 mm slots sand locking the adductor pipe within the screened section of the lateral. This problem highlights the need to understand the distribution of sediments within all sizes of sand rivers with depth if effective laterals are to be constructed.

Initial attempts to install longer laterals across a sand-river channel at Gulubane, at shallow depths below the apparent depth of channel flood scour, failed due to a lack of appropriate dewatering equipment. Such methods are technically feasible and maybe the best way of installing longer laterals within intermediate and major sand-river environments where larger diameter laterals with necessary gravel packs can be installed within dewatered trenches.

Assessment of the hydraulic characteristics of collector wells requires comparison of drawdown/yield/recovery characteristics of the well-shaft before lateral installation and of the completed collector well. Need to equate rates of inflow during pumping and recovery by calculating a nominal well radius by iteration. Once a nominal flow rate and effective well radius have been worked out from the results of the initial test (inflow rate should approximately equate with rate of pumping when pump is sucking air on emptying the well) these factors can be applied to the test pumping data obtained after installation of the laterals. Using the effective well radius the inflow rates can be calculated and compared to those obtained prior to installation of the laterals. Application of test pumping analytical techniques such as those of Papadopolos and Cooper as well as Rushton and Singh have provided little in the way of useful data, as had application of the Theis method to recovery data. Herbert et al concluded that one needed to understand the component parts of the drawdown and recovery curves as occurring below lateral level and above lateral level. They attempted to apply a lateral factor to try to predict collector well flow conditions with differing head conditions in the adjacent sand river. Some success has been achieved with this approach.

To fully understand the flow regime along sand-river channels and the sustainability of water supplies abstracted via collector wells long term monitoring of water levels, water abstractions, as well as rainfall and river flow events must be recorded if any meaningful modelling of such systems can be undertaken. This will be particularly important downstream of new major dam sites, as at the Letsebogo Dam site where as well as understanding the nature of the sand river at the dam site itself there is an urgent need to understand and assess the impact of the Letsebogo dam site upon abstraction systems down stream.

Before production collector well drilling can be undertaken the nature of the drilling system and ancillary equipment requirements need to be assessed. At present the BGS vehicles and rig system need to be thoroughly overhauled. The Landrover is now nearly 16 years old and has just lost use of 5th gear. It requires replacement. The 4x4 crane truck is of even older vintage, in excess of 25 years old. This requires a replacement brake master cylinder and the linkage engaging low and high ratio four wheel drive is u/s. The body work is in poor condition and the unit needs replacement. The drilling rig and hydraulic motor both require overhaul and upgrading. The four dewatering pumps need urgent replacement as their pumping efficiency have declined due to erosion of component parts. Compressor units were supplied by DWA. All 2" diameter casing and screen has been used and so a stock of suitable blank pipe and screen needs to be purchased. DWA may be able to use the BGS drilling rig to construct collector wells in the short term but procurement of a new drilling system more appropriate for lateral construction in all types of sand river system must be considered. A quotation for such a system is presented in Appendix B.

5. RECOMMENDATIONS AND CONCLUSIONS

5.1 Site Investigation

The sediment morphology of sand river channels is complex. Detailed investigations need to be undertaken a series of typical sand river channels, including weathering patterns within the underlying basement strata and the nature of the channel infill sediments including age of deposition. In order to determine the maximum yields at each collector well site, the geometry and lithology of the sand river must be determined as the collector well adits must be drilled into the most water-productive layers of the sand river. Ground penetrating radar or perhaps automatic resistivity imagery techniques could be used to quickly produce detailed channel cross-section images. These could be used to identify target points where the DWA penetration probe and sampling device can be used to confirm depths and sediment distributions interpreted from the geophysical data and provide sediment samples for sieving analysis to determine sand properties. This approach should provide the detailed data require for optimum location of laterals installation and reduce the number of man days spent investigating each channel section, and the number of sections needed to be investigated in detail. This option should be investigated.

5.2 Drilling

The laterals are usually constructed by drilling through the weathered basement rocks of the sand river bank and out into the sand river alluvial sediments, which may be clays, silts or sands. Drilling through weathered basement and into semi-consolidated beds like silty sands is no problem, air hammer or rotary drilling can be used. To date success in drilling into the unconsolidated material has been mixed. Some success has been had using telescoped jetting. However, further work is needed to fully determine the capabilities of other drilling methods available such as moling within finer silty sands. The drilling method used should be appropriate for the sand lithology to be developed. Therefore in the short term, the BGS drilling rig should be overhauled and used to drill the initial production collector wells, but a rig of more appropriate design should be procured, capable of inserting laterals by moling as well as jetting. Two new drill strings are considered. A special GRP screened well strong enough to be jetted directly in place and a Duplex system consisting of PVC screen emplaced within temporary steel casing are both strong candidates for better results. The installation of longer and larger diameter laterals are required in intermediate and major sand river environments within dewatered trench systems. Installation of appropriate gravel packs and screen slot sizes can be used within such systems.

5.3 Determining Sustainable Yields by Modelling Studies

The sustainable yield of a sand river system depends upon:

- the recharge it receives and its distribution with time
- the geometry of the sand river deposits
- the geometry of the collector well, shaft and adits
- the hydraulic properties of the sand river
- the upstream use of the sand river groundwater resources

It is recommended a generalised digital model be constructed of the groundwater system of a sand river. A subroutine for simulating different patterns of recharge should be developed. The model could be used to examine the issues, which decide the long term sustainable yield and the factors which affect efficient design of the collector well adits. The model will need to be proven against observations of long term behaviour of collector-well sites, as at Masunga. For this purpose long term monitoring should be initiated at three more sites, one on each of the main classes of sand rivers. Development of the Gulubane, Matshelagabedi and Tobane sites is recommended and that monitoring of collector well and sand-river behaviour be started at these sites as quickly as possible.

In conclusion, the pilot study, which was primarily of an engineering nature, successfully investigated application of the collector well system to abstraction of groundwater from sand rivers. The criteria used for these studies were based upon the conclusions drawn about the physical characteristics of sand-rivers from earlier, much more extensive studies. Although not the primary purpose of the pilot project, the DWA/BGS study has demonstrated that the characteristics of sand-rivers are more complex than previously thought. The study has highlighted the need for detailed understanding of the sedimentology of sand rivers and the main factors controlling the modes of sediment deposition and diagenesis. The installation of production collector well systems should now be undertaken, with BGS involvement, within a process type project. This will ensure the further development of collector well abstraction systems appropriate for each class of sand river.

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Natural Environment Research Council

TECHNICAL REPORT WD/98/2C
Hydrogeology Series

Technical Report WD/98/2C

Final Report on Application of Collector Well Well Systems to Sand Rivers Pilot Project APPENDICES

J Davies, P Rastall and R Herbert

This report was prepared for the Department of Water Affairs, Republic of Botswana

<u>*Bibliographic Reference*</u>

Davies J, Rastall P and Herbert R 1998
Final Report on Application of Collector Well Systems to Sand Rivers Pilot Project. APPENDICES
British Geological Survey Report WD/98/2C

Keyworth, Nottinghamshire

British Geological Survey 1998

APPENDIX A: ITINERARY

Detailed BGS staff movements during the last fieldwork period in Botswana:

July

6. Mr Rastall travelled via London (Heathrow) to Gaborone flight BA55, departed at 22.05.

7. Mr Rastall arrived in Gaborone at 12.00 noon.

8. Mr Rastall flew to Francistown on Air Botswana's morning flight.

9-15 Mr Rastall organised equipment and vehicles. Overhauled the project Landrover and Bedford truck. Brake master cylinder was u/s on the latter. Serviced the rig and checked spares, stocks of screen, casing, stores and equipment held at the DWA Francistown and Tonota stores. Organised insurance for the two vehicles. Moved equipment to the first collector well site at Gulubane. Contacted DWA field officers.

13 Mr Davies travelled from London (Heathrow) to Gaborone flight BA55, departed at 22.05.

14 Arrived Gaborone at 12.00 noon. Contacted the DWA office.

15. To DWA where met Mr Katai. Discussed the proposed work programme and content of the last report. Passed on copy of bibliography on disk to Katai. Positive response received from Mr Katai about possible joint TDR project to look at the nature of sand rivers. Problems reported with the laterals at Masunga blocking up. Flew to Francistown on Air Botswana flight BP044. Met by Peter Rastall at Francistown.

16 Persistent problems with brake master cylinder (BMC) on the Bedford truck. The inside of the cylinder was too badly scored with rust, had the cylinder reamed out. Visited the Gulubane collector well site. The JCB was being used to dig the dewatering trench. Returned to Francistown.

17 To the DWA stores to collect hammer seismic equipment. To Gulubane where used JCB to install 2 observation wells. Returned to Francistown to collect the repaired BMC but found one of the plastic fluid reservoirs was badly cracked and leaking.

18 To DWA stores at Tonota from where transferred drilling equipment to the drilling site at Gulubane. Geological trench dug by JCB, 3rd obs Bh inserted. Undertook initial pumping test on collector well followed by a recovery test, recovery was monitored throughout the night. Returned to Francistown.

19 To Gulubane where undertook salt dilution tests upon three observation wells. Drilling equipment prepared. Large compressor U/S due to lack of engine and hydraulic oil. Returned to Francistown to purchase ancillary equipment and enter data into computer.

20 To Gulubane where undertook survey of geological trench and collected sediment samples for grain size analysis. The large compressor repaired and three 44 gallon drums were perforated. Drilling equipment was erected in collector well. Drilling of the first lateral was begun, through hard band of white quartz feldspar rock. Returned to Francistown.

21 Public Holiday, to Gulubane where repaired wiring problems with large compressor. During screening of first lateral, a jetting pipe joint sheared therefore lost left hand thread connector to disposable tip and two jetting pipes. Photographed part of the geological trench. JCB used to deepen the dewatering trench below the water table across half of the river adjacent to the collector well. Repositioned rig within the well and started drilling the second lateral. Returned to Francistown.

22 Public holiday, to Gulubane where collector well had been dewatered. Completed drilling out second lateral. Logged several sections in geological trench. Attempted dewatering of the main trench using diaphragm pump set in perforated 200 litre drum, but insufficient perforations. Increased number of perforations and tried again. Managed to lower the water level by 0.75 metre by pumping at 6 l/sec. Increased the density of perforations in two more drums. Returned to Francistown.

23 Arranged manufacture of left hand thread jetting pipe subs in Francistown. To Gulubane where levelled in the river water level and the collector well. Back-filled part of geological trench. Attempted dewatering trench using two pumps, pumping at 12 l/sec and managed the lowering of water level by more than 1 metre. Returned to Francistown to obtain additional equipment and left hand threaded subs.

24 To Gulubane where completed the construction of second lateral. Moved rig and undertook drilling and construction of third lateral. Removed rig from the hole. Assessed sieving equipment and dried sediment samples. Returned to Francistown.

25 Transported timbers from Tobane to Gulubane. Dewatered collector well and set up rig in the hole. Initiated drilling of fourth lateral. Undertook the grain size analysis sieving of 10 sediment samples at Francistown.

26 To Gulubane where dewatered the collector well. Constructed a falling head permeameter test rig. The testing of sediment samples from the dewatering trench produced high permeability results. Drilled and constructed 4th lateral and removed drilling equipment. Dewatered the collector well and undertook a recovery test. Dewatering of the central part of the trench attempted to locate the end of the 4th lateral but could only lower water level by 0.5 metre although pumping water from the trench at the rate of 12 l/sec. Returned to Francistown.

27 To Gulubane where undertook a drawdown/recovery pumping test on the collector well. Packed up drilling equipment. Moved equipment to next site at Matshelagabedi on the Ramokgwebana river. Left equipment and small compressor at the drilling camp. Inspected access to the collector well site. Returned to Francistown where undertook grain size analysis of 4 sediment samples.

28 To Matshelagabedi where moved drilling equipment to site. Undertook a drawdown/recovery pumping test on the collector well. Attempted to jet observation well into central area of the river. Returned to Francistown.

29 To Matshelagabedi where large compressor was moved to site. Jetted in observation well and undertook salt dilution test. Dewatered collector well and erected rig upon a stack of timbers in the well shaft. Started drilling first lateral. Returned to Francistown.

30 To Matshelagabedi where undertook repeat salt dilution test on observation well. Dewatered the collector well and drilled/constructed first lateral. Lost 5 lengths of jetting pipe due to joint fracture. Repositioned rig and drilled/constructed second lateral. Undertook falling head permeability tests on six samples. Returned to Francistown.

31 To Matshelagabedi where during monitoring of dewatering of well the flow of very muddy water (about 1 l/sec) from second lateral suddenly ceased. Redeveloped this lateral by jetting with air and re-established flow at a reduced rate (0.5 l/sec). Extracted observation well from river sediments. Transported timber from Tonota to site. Noted occurrence of palaeo-alluvial sediments as a gravel/sand-bank one kilometre upstream of site. Reset drilling rig in well at a higher position. Returned to Francistown where discussed results of the project with Douglas. Passed grain size sieve analysis and falling head permeameter equipment to him.

August

1. To Gaborone on Air Botswana flight BP41. To DWA where discussed the collector wells project with Mr Katai. At 13-45 returned to DWA where with the Deputy Director of DWA, Mr Jay and Mr Katai reviewed the project and the way forward. Contacted Mr Rastall who had drilled and constructed a third lateral at Matshelagabedi, which had the same discharge rate as that of the second. The water flowing from the second lateral had cleared. Obtained a quote from CJ Engineering re the manufacture of steel disposable tips for the drilling of up to six laterals at Tobane.

2 Departed from Gaborone to London (Heathrow) on BA flight 054. Fourth lateral drilled and constructed in Matshelagabedi collector well.

3 Arrived at London (Heathrow). A drawdown/recovery pumping test was carried out on the Matshelagabedi collector well.

3-10 Mr Rastall transferred equipment to the Tobane 1 collector well site, experienced problems with mobilisation of rig, equipment and vehicles from Matshelagabedi to Tobane.

10-17 Mr Rastall undertook the drilling of five laterals at Tobane 1 collector well and undertook a drawdown/recovery pumping test on completion. All remaining screen and casing were used at Tobane. DWA promised to supply sediment grain-size analysis data from the Gulubane, Matshelagabedi and Tobane sites.

17-20 Vehicles, rig and equipment moved from Tobane to Tonota and Francistown stores for storage.

21 Mr Rastall travelled from Francistown to Gaborone on Air Botswana flight BP41.

22 Mr Rastall departed from Gaborone for London (Heathrow) on BA flight 054.

23 Mr Rastall arrived at London (Heathrow).

APPENDIX B: DRILLING EQUIPMENT QUOTE

Demco

DRILLING EQUIPMENT THERMOPLASTIC CASINGS AND SCREENS SEWER RELINING PIPE

Units 11 and 12, Star Industrial Park, Bodmin Road, Wyken, Coventry, West Midlands, CV2 5DB
Telephone: (01203) 602323 Fax: (01203) 602116

Quotation

For the attention of	: Mr Jeff Davies	Sheet	: 1 of 4
Company	: British Geological Survey	Date	: 22.8.97
Tel Number	:	Quote No	: 8625
Fax Number	: 01491692345	Your Ref	:

Thank you for your enquiry, we now have pleasure in quoting the following:-

Item No.	Description	Quantity	Unit Price	Total Price
1	<u>Hydroquest 2m Drilling Rig.</u> To drill 30m deep boreholes using 73mm diameter rock bits on 50mm OD drill rods, or using a D.T.H. hammer with 70mm button bit.	1	Unit	76415.00

Suitable for operation in 2m diameter wells up to 20m deep.

As per following specification:

Rotation : 0-1000ft 1bf (0-138 kgf.m) Infinitely variable 0-100 rpm. Infinitely variable.

Feed/Retract : 0-2200 1bf (0-1000 kgf) Infinitely variable. 0-9.8 ft/min (0-3m/min) Infinitely variable.

Drill Stroke : 3'3" (1.0m) Wire rope feed/retract with Hydraulic Cylinder operation.

Drill Head : Hydraulic Motor drive with spring-loaded sliding sub-adapter for easy making/breaking of drill pipe joints in any plane. Hinged to swing clear of centre line for inserting casings. C/w water/air circulation swivel.

Drill Rods : 50mm OD X 0.75m. Taper thread connections. Specifically designed for horizontal drilling.

Drill Table : 100mm diameter casing capacity. Bushed to suit drill rods.

Breakout : Hydraulic ram operated to assist in breaking drill pipe joints.

Demco

DRILLING EQUIPMENT THERMOPLASTIC CASINGS AND SCREENS SEWER RELINING PIPE

Units 11 and 12, Star Industrial Park, Bodmin Road, Wyken, Coventry, West Midlands, CV2 5DB
Telephone: (01203) 602323 Fax: (01203) 602116

Quotation

For the attention of	: Mr Jeff Davies	Sheet	: 2 of 4
Company	: British Geological Survey	Date	: 22.8.97
Tel Number	:	Quote No	: 8625
Fax Number	: 01491 692345	Your Ref	:

Description

The Hydroquest 2m is comprised of 3 portable units, connected together by hydraulic hoses with quick release connectors.

Drill Frame:

To be mounted on a base frame which enables mast to be rotated to enable drilling to be carried out in any horizontal direction, with the ability to angle the borehole up or down. To prevent the frame moving/lifting during drilling operations it must be securely anchored. Drill table, Rotary Drill Head and Breakout to be removable.

Control Console:

To be a free standing unit containing all of the controls for the hydraulic system, enabling the drilling to be carried out, and monitored from one position.

Power Pack:

2 wheeled trailer mounted unit, to consist of air-cooled diesel engine (nominal 20 hp (15 kw)) with electric start, driving two section hydraulic pump through an over-centre clutch. Incorporating hydraulic tank and filters.

The Power Pack can be positioned away from the Drill frame and Controls as its only link is by hydraulic hoses.

If required the unit can be left on the support vehicle.

Item	Description	Quantity	Unit	Total
2.	Drilling Equipment			
2.1	50mm x 0.75m taper thread drill rods.	40	No	
2.2	73mm diameter drill bits.			
a)	Hard formation rock roller	3	No	
b)	Drag bit - tungsten carbide.	1	No	

Demco

DRILLING EQUIPMENT *THERMOPLASTIC CASINGS AND SCREENS* *SEWER RELINING PIPE*

Units 11 and 12, Star Industrial Park, Bodmin Road, Wyken, Coventry, West Midlands, CV2 5DB
Telephone: (01203) 602323 Fax: (01203) 602116

Quotation

For the attention of	: Mr Jeff Davies	Sheet	:	3 of 4
Company	: British Geological Survey	Date	:	22.8.97
Tel Number	:	Quote No	:	8625
Fax Number	: 01491 692345	Your Ref	:	

2.3	60mm valveless DTH hammer.	1	Each	
2.4	70mm diameter hammer button bits	4	Each	
2.5	Sub adapter. Drill rods to hammer	1	No	
2.6	Sub adapter. Drill rods to rock bits.	1	No	
2.7	Tool kit for drilling rig.	1	Each	
Total items 2.1 - 2.7 as listed				6808.00
2.8	Manufacturer's spares set for drilling rig. Either as a percentage or as an itemised list at your options.	Extra	A/R	
3.1	Crane Truck comprising :-	1	No	35710.00
a)	Reconditioned Bedford 'M' Series double drop side diesel 4 x 4 truck. This vehicle is ex-Ministry, fully overhauled and prepared to MOT testing and plating standard. c/w tow hitch. 9650 Kg. g.v.w. Includes painting to customers colour.			
b)	Above fitted with hydraulic loading crane including vehicle stabiliser feet, reinforcing sub chassis. Crane fitted behind cab. C/w safety hook. Whole unit fully tested and supplied with works test certificate.			

Demco

DRILLING EQUIPMENT THERMOPLASTIC CASINGS AND SCREENS SEWER RELINING PIPE

Units 11 and 12, Star Industrial Park, Bodmin Road, Wyken, Coventry, West Midlands, CV2 5DB
Telephone: (01203) 602323 Fax: (01203) 602116

Quotation

For the attention of	:	Mr Jeff Davies	Sheet	:	4 of 4
Company	:	British Geological Survey	Date	:	22.8.97
Tel Number	:		Quote No	:	8625
Fax Number	:	01491 692345	Your Ref	:	

c) Above crane fitted with 1000kg capacity hydraulic winch with 25m of wire rope. Tested and certified.

3.2 Recommended spares for crane truck. Either as a percentage or as an itemised list at your option. Extra A/R

Notes:

All of the above prices are pound sterling, nett, excluding VAT, ex-works Coventry UK unpacked, based on the specification indicated. For 2 units there will be a price reduction of 2.5%.

Delivery: To be agreed.

Terms: To be agreed.

Validity: Our quotation is open for acceptance within 30 days.

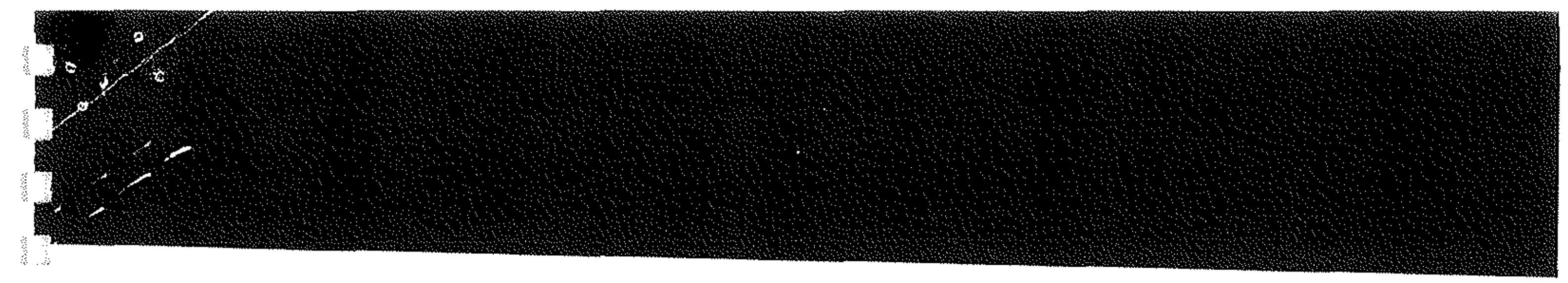
Demco standard Terms and conditions apply.

We trust that our offer meets with your requirements and look forward to hearing from you.

....

M A Park

APPENDIX C :
THE DESIGN OF A "ROLLING" GROUNDWATER CONTROL SYSTEM, R Herbert (1985)



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The design of a "rolling" groundwater control system

by R. HERBERT*, BSc, PhD, FGS

*Principal Scientific Officer, British Geological Survey, and Hydrogeological Advisor to ODA.

Abstract

A "rolling" dewatering system is defined as two parallel lines of wells installed at a rate to match the movement of the centre of construction for which dewatering is required. As the centre of construction moves forward the first wells installed are gradually shut down as they become more distant from the centre of dewatering. This kind of dewatering installation is useful for construction of sewers, canals, tunnels, etc. where a high water table exists.

A program is written for the hand-held programmable T159 calculator, which predicts the performance of such dewatering installations.

It is shown that, depending on the diffusivity (T/S) of the aquifer, spacing between wells can be gradually increased as time progresses and economies in dewatering costs can be made. Criteria are developed to test this possibility.

An example is given of the design of a dewatering system required for the construction of a canal in Bangladesh.

1. Definition of a "Rolling" Dewatering System

Fig. 1 shows what is meant by a Rolling Dewatering System. Two parallel, closely spaced lines of wells are used to assist construction of long lines of sewers, tunnels and canals. For small scale jobs, well points are often used, elsewhere large capacity, deep tubewells must be employed. The dewatering system is designed to lower the water table between the wells so that excavation can continue dry. If a long line of dewatering is required then only a few of the wells are pumped at any one time. The centre of the dewatered zone is "rolled" forward to keep pace with construction. This reduces the number of pumps required and hence the capital cost of the dewatering system.

Referring to Fig. 1:

- At any one time two sets of wells contained within a constant length λ_3 will be situated around the line of construction such that forward rate of construction V_w is equal to the forward rate of movement of the centre of λ_2
- The first two wells in each line are spaced $\Delta\lambda_1$ apart and the spacing is increased by a constant factor F such that the spacing between nth pair of wells is given by:

$$\Delta\lambda_n = F\Delta\lambda_{n-1} = F^{n-1}\Delta\lambda_1 \qquad \dots (1)$$

At first the two sets of wells are stationary for t_0 where $t_0 = (\lambda_2/V_w.2)$ This means the wells at the centre of λ_2 will each pump for the same period, λ_2/V_w as all the dewatering wells to their right hand side.

Plate 1 shows one such system in operation. In this case well points are being used in an urban situation.

2. The general solution

The aim is to calculate the drawdown at any point X, Y caused by a rolling system of wells at any time t_1, since start of pumping the first well:

Where $t_1 = t_0 + t$

t = time since start of movement of rolling system

t_0 = time the first set of pumping wells remain stationary (see below for further clarification)

2.1 Assumptions

- The aquifer is homogeneous and infinite, having a transmissivity, T, and specific yield S_y.
- The wells are fully penetrating, fully screened and have a constant discharge per well, Q.
- It is required to lower the water table along a straight line of length L by s_{TOTAL}.

2.2 The mode of solution

The option of having a gradually increasing spacing between wells was considered, Equation 1, because in certain situations fewer wells will be required in the later stages of construction than earlier. This is because pumping from the earlier wells (since closed down) can have a residual effect on groundwater levels further along the line L. The importance of this option is discussed in more detail in section 3.

The dewatering system is symmetrical about the line, $y = 0$, see Fig. 1, and so only one line of wells needs to be considered. The first well is located at $x = 0$, $y = \lambda_3/2$, and the drawdown at the centre of the line of dewatering installation x^1, y, at time t, should be doubled.

$$x^1 = [V_w \times (t - t_0) + \lambda_2/2], \; y = 0 \qquad \dots (2)$$

The drawdown at distance r from a well pumping at rate Q for time t_2 is given by the Theis equation (3)

$$s_r = (Q/4\pi T) \cdot W(u) \qquad \dots (3)$$

In Equation 3, $W(u)$ is a well tabulated function of u, Todd (1959)

$$u = r^2S/4Tt_2 \qquad \dots (4)$$

The total drawdown at x^1, Fig. 1, at t_1 is solved using Image Well theory, Todd (1959)

At time t_1 all wells to the left of $x = (\lambda_1 + \lambda_2)$, where Equation 5 applies, are pumping wells.

$$\lambda_1 = V_w(t_1 - t_0) \qquad \dots (5)$$

All wells to the left of $x = \lambda_1$, are image wells pumping at $-Q$. The drawdowns of each real and image well are summed to give the total drawdown at x^1.

2.3 The program written for the T159

Fig. 2 gives the flow chart used to construct a simple digital program written for the T159. As stated above the aim of the program is to calculate the drawdown at a general point X, Y caused by a rolling system of wells at any time t_1. To do this the following steps are used and are summarised on the flow chart of Fig. 2.

(a) Key data is entered

(b) Initial values for key variables are calculated

(c) The position of the centre of the dewatering front is calculated

(d) Each well is considered in turn until all wells which have played a part in dewatering during time t_1 have been considered and the drawdowns associated with each well are summed.

The program is listed on Fig. 3. In this program $W(u)$ is calculated using a polynomial approximation as described in Herbert (1978).

3. Example of the use of the program

3.1 The problem

A 20km canal, 100m wide was to be constructed in the alluvium of Bangladesh. The water table was above the base of the canal and construction was to be dry. A rolling well system was to be used to dewater the line of the canal. Allowing for berms, two lines of wells 200m, λ_3 apart were to be used. The wells were to be typical irrigation wells, having a 2cusec yield and being effectively fully penetrating. Construction was to be completed in 225 days, one dry season, thus the rate of advance of the centre of construction and dewatering, V_w, would have to be $(20\,000 + \lambda_2/2)/225$. For convenience of construction purposes, λ_2 is chosen as 5km, thus V_w was 100m/day. The transmissivity and storage coefficient, T and S, of the aquifer were 12 000m/day and 0.13 respectively. The drawdown required was 10.0m.

3.2 Solutions run

Several solutions were run on the computer. Table 1 lists the results.

Solutions 1 and 2 illustrate one short cut to running the program on the T159. If only the number of wells, N_w, is varied then the geometry of the dewatering system is unchanged and the drawdown achieved at the centre is proportional to the number of wells used. Thus, solution 2 gives half the drawdown of solution 1. Similarly, solution 4 indicates that to achieve 10m drawdown at the centre of two lines of wells a well spacing of 100m is necessary and 500 wells in total will be required.

Solutions 3 and 4 calculate the drawdowns at two positions equivalent to the centre of the rolling installation as it moves along the 20km line. It is interesting to note that drawdowns do not get significantly larger as time goes on so there is no residual effect from the now, closed-down, distant earlier wells.

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The above results are in contrast to the results from solutions 5, 6 and 7. For these solutions S was changed to .0013 and for a constant well spacing, $F = 1.0$, the drawdowns at the centre of the rolling system gradually became bigger, showing that for this aquifer less wells were needed as time went on to achieve the same drawdown.

The contrast in behaviour between solutions 5, 6 and 7 and 2, 3 and 4 is explained as follows:

Boulton (1965) has shown that after long times the radius of influence caused by a well, R_w is given by Equation 7:

$$R_w = 1.5\sqrt{Tt_2/S} \quad \ldots (7)$$

Hence the rate of movement of R_w is given by:

$$V_R = R_w/t_2 = 1.5\sqrt{T/St_2} \quad \ldots (8)$$

The rate of movement of the rolling system is V_w and when $V_w > V_R$ for a particular well at a particular time then the drawdown of the well will no longer be "felt" at the dewatering front.

For solutions 1, 2, 3 and 4, the time t_2 when $V_w = V_R$ is 20.7 days. For solutions 5, 6 and 7 $V_w = V_R$ at 2 070 days. These calculations explain the difference in performance of a rolling system in different aquifer types and in particular why the drawdown in solution 7 is 31% greater than that for solution 5.

Solutions 8, 9, 10 and 11 illustrate how values chosen for F and $\Delta\lambda$ effect the drawdown values. Reducing $\Delta\lambda$ increases drawdowns at early times, small x^1, while increasing F reduces drawdowns at late times, large x^1. Careful selection of F and $\Delta\lambda$ will allow the number of wells required to be minimised.

4. Conclusions

A computer program, suitable for use on the T159, has been written, which can predict the drawdowns caused by a rolling dewatering system.

In aquifers with high diffusivities (T/S), fewer wells are needed with the passage of time. The program allows this effect to be studied and the minimum number of wells to be identified.

Acknowledgements

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References

Todd, D.K. (1959): "Groundwater Hydrology". John Wiley & Sons, New York

Herbert, R. (1978): "Programs for the T159 suitable for hydrogeologists overseas", British Geological Survey Report No. WD/OS/78/40. December

Boulton, N.S. (1965): "The discharge to a well in an extensive unconfined aquifer with constant pumping level", Journal of Hydrology, 3, 129-130

SYMBOLS USED

Symbol	Description	*Dimensions*
F	constant used to calculate spacing between wells	—
N_w	number of wells at any one time t	—
L	length of dewatering line	L
λ_2	distance along dewatering line including all pumping wells	L
λ_1	distance moved in time t by rolling system	L
$\Delta\lambda$	spacing between first two wells	L
λ_3	spacing between two lines of wells	L
Q	discharge of a single well	L^3/T
s_r	drawdown caused by one well at distance r	L
$s_{TOTAL} = s$	total drawdown caused by all wells	L
t	time after start of movement of rolling system	T
t_1	$t + t_0$	T
t_0	time first wells remain stationary	T
t_2	time of pumping real or image well	T
T	transmissivity	L^2/T
S_y	specific yield	—
V_w	rate of movement required of centre of dewatering	L/T
x^1, y	centre of dewatering installation	L
X, Y	general coordinates relative to first well at 0,0	L
$x_{n,o}$	position of well being considered in program	

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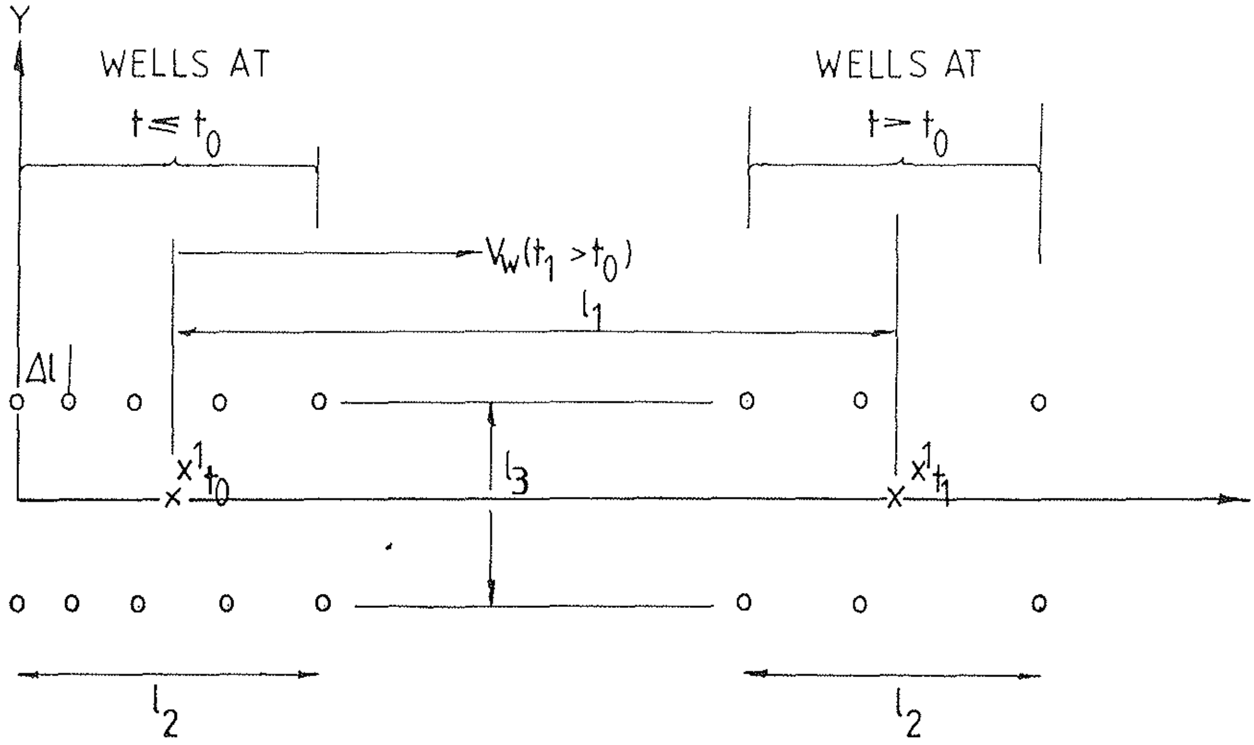
TABLE I: RESULTS OF ROLLING DEWATERING SYSTEM STUDIES

Sol'n No.	DATA ENTERED						RESULTS		No. of Wells required for 10.0m drawdown
	S	X	Y	t_1	F	$\Delta\lambda$	*Total No. Wells analysed*	*Drawdown (m) at XY from 1 line of wells*	
1	·13	2 500	100	50	1·0	100	75	4·99	500
2	·13	2 500	100	50	1·0	200	38	2·47	
3	·13	12 500	100	125	1·0	200	75	2·68	
4	·13	22 500	100	225	1·0	200	126	2·66	
5	·0013	2 500	100	25	1·0	200	26	7·87	
6	·0013	12 500	100	125	1·0	200	75	9·59	
7	·0013	22 500	100	225	1·0	200	126	10·34	
8	·0013	2 500	100	25	1·01	150	29	8·86	
9	·0013	22 500	100	225	1·01	150	99	6·10	
10	·0013	22 500	100	225	1·005	150	123	8·34	
11	·0013	2 500	100	25	1·005	150	32	9·49	

Constants for all Solutions entered into program $T = 12\ 000$ m/d $Q_{well} = 7\ 344$ m³/d $\lambda_2 = 5\ 000$ m $V_w = 100$ m/d $t_0 = 25$ d



n.b. Fig. shows position of wells at time $t_1 = 0$ to $t_1 = t_0$ and at general time $t_1 > t_0$.

After t_0, centre of dewatering wells moves at rate V_w

The spacing between first two wells is $\Delta \ell$

The spacing between nth pair of wells is $F.\Delta \ell_1$

Fig. 1. Rolling Dewatering System (Nomenclature).

APPENDIX D: TEST PUMPING AND RECOVERY DATA

Pumping test 18/07/97

Gulubane Collector Well

Pumping test before drilling of laterals

Rest water level 6.705 mbtoc

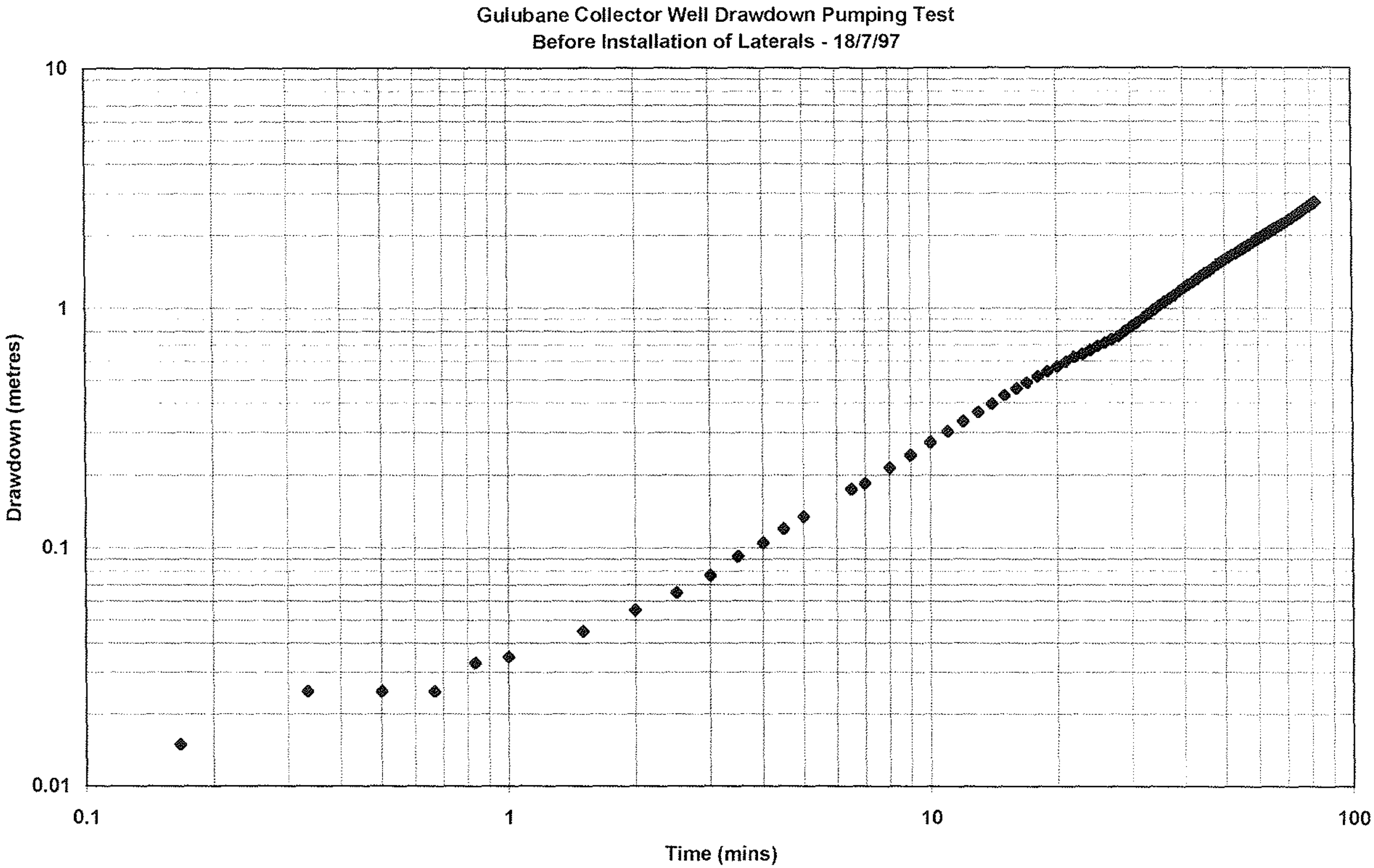
Well depth 10.08 mbtoc

Top of casing 0.4 magl

Start of test 13:03

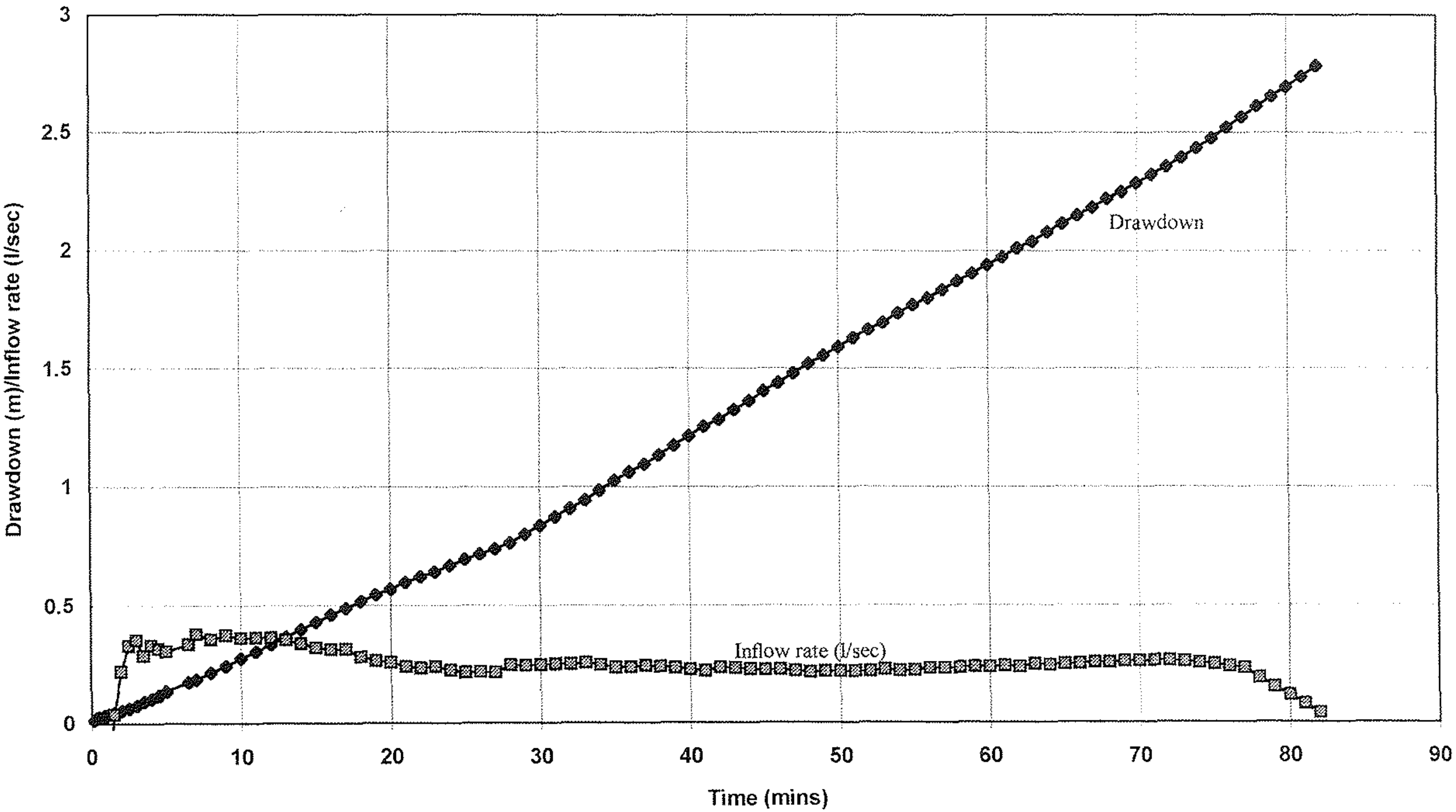
Time mins	PWL metres	Drawdown metres	Cummulative vol pumped m3	Pumping rate l/sec	Volume pumped m3	Cummulative volume m3	inflow rate l/sec
0	6.71	0.005		2.22222	0		
0.1666667	6.72	0.015	0.06549402	2.22222	0.0222	0.02222222	-4.3272
0.3333333	6.73	0.025	0.1091567	2.22222	0.0222	0.04444444	-3.2356
0.5	6.73	0.025	0.1091567	2.22222	0.0222	0.06666667	-1.4163
0.667	6.73	0.025	0.1091567	2.22222	0.0223	0.08893333	-0.5053
0.833	6.738	0.033	0.14408684	2.22222	0.0221	0.11106667	-0.6607
1	6.74	0.035	0.15281938	2.22222	0.0223	0.13333333	-0.3248
1.5	6.75	0.045	0.19648206	2.22222	0.0667	0.2	0.0391
2	6.76	0.055	0.24014474	2.22222	0.0667	0.26666667	0.221
2.5	6.77	0.065	0.28380742	2.22222	0.0667	0.33333333	0.3302
3	6.782	0.077	0.33620264	2.22222	0.0667	0.4	0.3544
3.5	6.798	0.093	0.40606292	2.22222	0.0667	0.46666667	0.2886
4	6.81	0.105	0.45845814	2.38095	0.0714	0.53809524	0.3318
4.5	6.825	0.12	0.52395216	2.38095	0.0714	0.60952381	0.3169
5	6.84	0.135	0.58944618	2.38095	0.0714	0.68095238	0.305
6.5	6.88	0.175	0.7640969	2.38095	0.2143	0.8952381	0.3363
7	6.89	0.185	0.80775958	2.38095	0.0714	0.96666667	0.3784
8	6.92	0.215	0.93874762	2.38095	0.1429	1.10952381	0.3558
9	6.948	0.243	1.06100312	2.5641	0.1538	1.26336996	0.3748
10	6.98	0.275	1.2007237	2.5641	0.1538	1.41721612	0.3608
11	7.01	0.305	1.33171174	2.5641	0.1538	1.57106227	0.3627
12	7.04	0.335	1.46269978	2.5641	0.1538	1.72490842	0.3642
13	7.072	0.367	1.60242036	2.5641	0.1538	1.87875458	0.3543
14	7.103	0.398	1.73777466	2.38095	0.1429	2.02161172	0.3379
15	7.135	0.43	1.87749524	2.38095	0.1429	2.16446886	0.3189
16	7.165	0.46	2.00848328	2.38095	0.1429	2.30732601	0.3113
17	7.193	0.488	2.13073878	2.38095	0.1429	2.45018315	0.3132
18	7.223	0.518	2.26172682	1.92308	0.1154	2.56556777	0.2813
19	7.25	0.545	2.37961606	1.92308	0.1154	2.68095238	0.2643
20	7.275	0.57	2.48877276	1.92308	0.1154	2.796337	0.2563
21	7.303	0.598	2.61102826	1.92308	0.1154	2.91172161	0.2386
22	7.328	0.623	2.72018496	1.92308	0.1154	3.02710623	0.2325
23	7.348	0.643	2.80751032	1.83486	0.1101	3.13719797	0.2389
24	7.375	0.67	2.92539956	1.83486	0.1101	3.24728971	0.2235
25	7.4	0.695	3.03455626	1.83486	0.1101	3.35738146	0.2152
26	7.422	0.717	3.13061416	1.83486	0.1101	3.4674732	0.2159
27	7.445	0.74	3.23103832	1.83486	0.1101	3.57756494	0.2139
28	7.47	0.765	3.34019502	2.94118	0.1765	3.75403553	0.2463
29	7.508	0.803	3.5061132	2.94118	0.1765	3.93050612	0.2439
30	7.544	0.839	3.66329885	2.94118	0.1765	4.10697671	0.2465
31	7.58	0.875	3.8204845	2.94118	0.1765	4.2834473	0.2489
32	7.616	0.911	3.97767015	2.89855	0.1739	4.45736034	0.2498
33	7.65	0.945	4.12612326	2.89855	0.1739	4.63127338	0.2551
34	7.691	0.986	4.30514025	2.89855	0.1739	4.80518643	0.2451
35	7.732	1.027	4.48415724	2.89855	0.1739	4.97909947	0.2357

36	7.768	1.063	4.64134288	2.89855	0.1739	5.15301251	0.2369
37	7.802	1.097	4.789796	2.89855	0.1739	5.32692556	0.242
38	7.84	1.135	4.95571418	2.89855	0.1739	5.5008386	0.2391
39	7.88	1.175	5.1303649	2.89855	0.1739	5.67475164	0.2326
40	7.92	1.215	5.30501562	2.89855	0.1739	5.84866469	0.2265
41	7.96	1.255	5.47966634	2.89855	0.1739	6.02257773	0.2207
42	7.99	1.285	5.61065438	2.98507	0.1791	6.20168221	0.2345
43	8.03	1.325	5.7853051	2.98507	0.1791	6.38078669	0.2308
44	8.07	1.365	5.95995582	2.98507	0.1791	6.55989116	0.2272
45	8.11	1.405	6.13460654	2.98507	0.1791	6.73899564	0.2238
46	8.145	1.44	6.28742592	2.85714	0.1714	6.91042421	0.2257
47	8.185	1.48	6.46207664	2.85714	0.1714	7.08185278	0.2198
48	8.225	1.52	6.63672736	2.89855	0.1739	7.25576583	0.2149
49	8.26	1.555	6.78954674	2.89855	0.1739	7.42967887	0.2177
50	8.296	1.591	6.94673239	2.89855	0.1739	7.60359191	0.219
51	8.335	1.63	7.11701684	2.89855	0.1739	7.77750496	0.2158
52	8.37	1.665	7.26983622	2.85714	0.1714	7.94893353	0.2177
53	8.4	1.695	7.40082426	2.85714	0.1714	8.1203621	0.2263
54	8.44	1.735	7.57547498	2.85714	0.1714	8.29179067	0.2211
55	8.475	1.77	7.72829436	2.85714	0.1714	8.46321924	0.2227
56	8.505	1.8	7.8592824	2.85714	0.1714	8.63464781	0.2308
57	8.54	1.835	8.01210178	2.85714	0.1714	8.80607639	0.2322
58	8.575	1.87	8.16492116	2.85714	0.1714	8.97750496	0.2335
59	8.608	1.903	8.309008	2.85714	0.1714	9.14893353	0.2373
60	8.645	1.94	8.47055992	2.85714	0.1714	9.3203621	0.2361
61	8.678	1.973	8.61464676	2.85714	0.1714	9.49179067	0.2397
62	8.717	2.012	8.78493122	2.85714	0.1714	9.66321924	0.2361
63	8.745	2.04	8.90718672	2.98507	0.1791	9.84232372	0.2474
64	8.785	2.08	9.08183744	2.98507	0.1791	10.0214282	0.2447
65	8.82	2.115	9.23465682	2.98507	0.1791	10.2005327	0.2477
66	8.855	2.15	9.3874762	2.98507	0.1791	10.3796372	0.2505
67	8.888	2.183	9.53156304	2.98507	0.1791	10.5587416	0.2555
68	8.924	2.219	9.68874869	2.85714	0.1714	10.7301702	0.2553
69	8.955	2.25	9.824103	2.85714	0.1714	10.9015988	0.2603
70	8.99	2.285	9.97692238	2.85714	0.1714	11.0730273	0.261
71	9.025	2.32	10.1297418	2.85714	0.1714	11.2444559	0.2617
72	9.06	2.355	10.2825611	2.85714	0.1714	11.4158845	0.2623
73	9.099	2.394	10.4528456	2.85714	0.1714	11.5873131	0.259
74	9.14	2.435	10.6318626	2.85714	0.1714	11.7587416	0.2538
75	9.182	2.477	10.8152458	2.85714	0.1714	11.9301702	0.2478
76	9.227	2.522	11.0117279	2.85714	0.1714	12.1015988	0.239
77	9.272	2.567	11.20821	2.85714	0.1714	12.2730273	0.2305
78	9.317	2.612	11.404692	0.2963	0.0178	12.2908051	0.1893
79	9.36	2.655	11.5924415	0.2963	0.0178	12.3085829	0.1511
80	9.4	2.695	11.7670923	0.2963	0.0178	12.3263607	0.1165
81	9.445	2.74	11.9635743	0.2963	0.0178	12.3441385	0.0783
82	9.49	2.785	12.1600564	0.2963	0.0178	12.3619162	0.041
		Average inflow rate l/sec =			0.041		



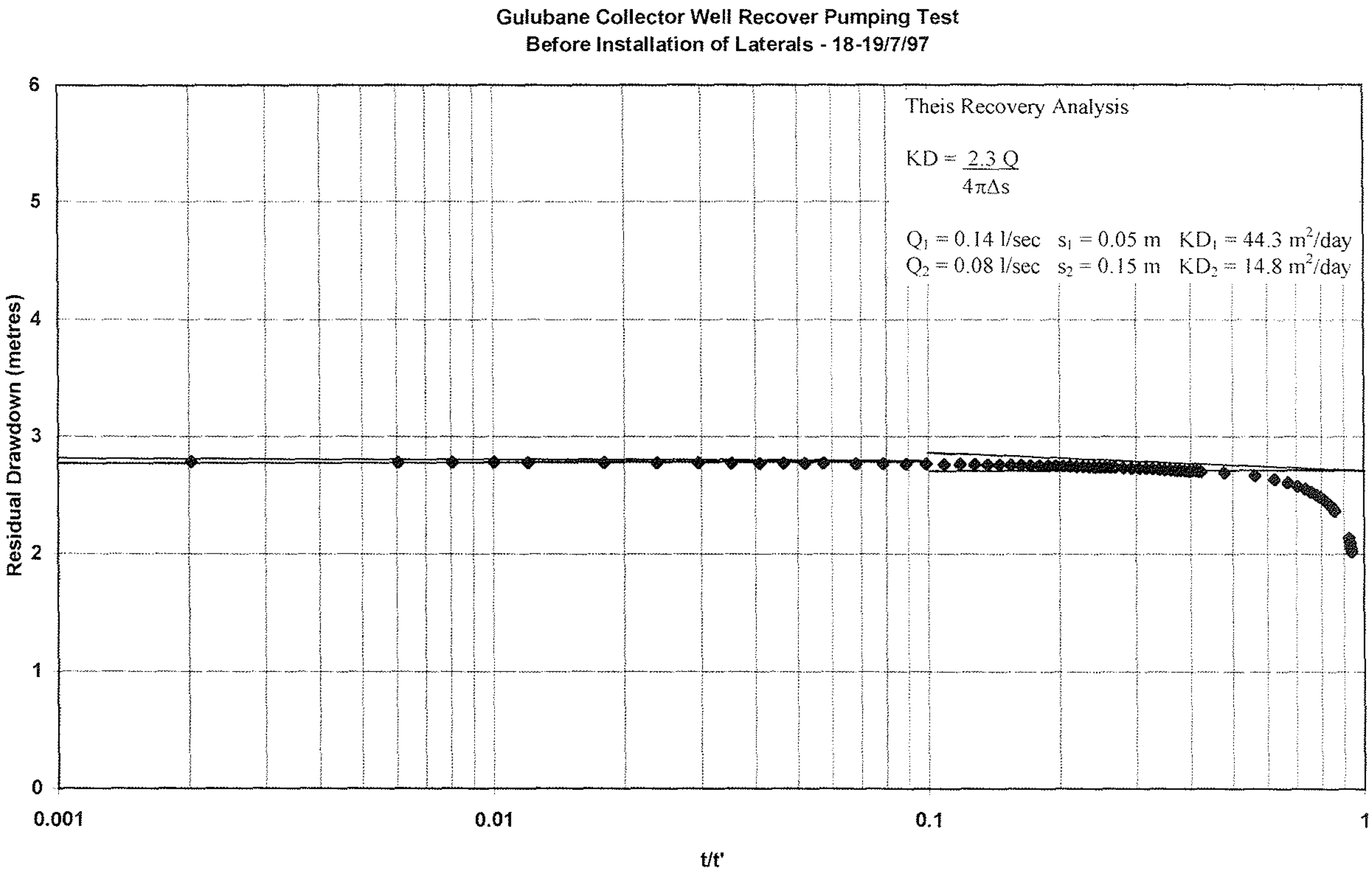
Gulubane Collector Well Drawdown Pumping Test
Before Installation of Laterals - 18/7/97
10
1
0.1
0.01
Drawdown (metres)
0.1
1
10
100
Time (mins)

Gulubane Collector Well - Pre-installation of Laterals
Drawdown and Inflow Data - 18/7/97



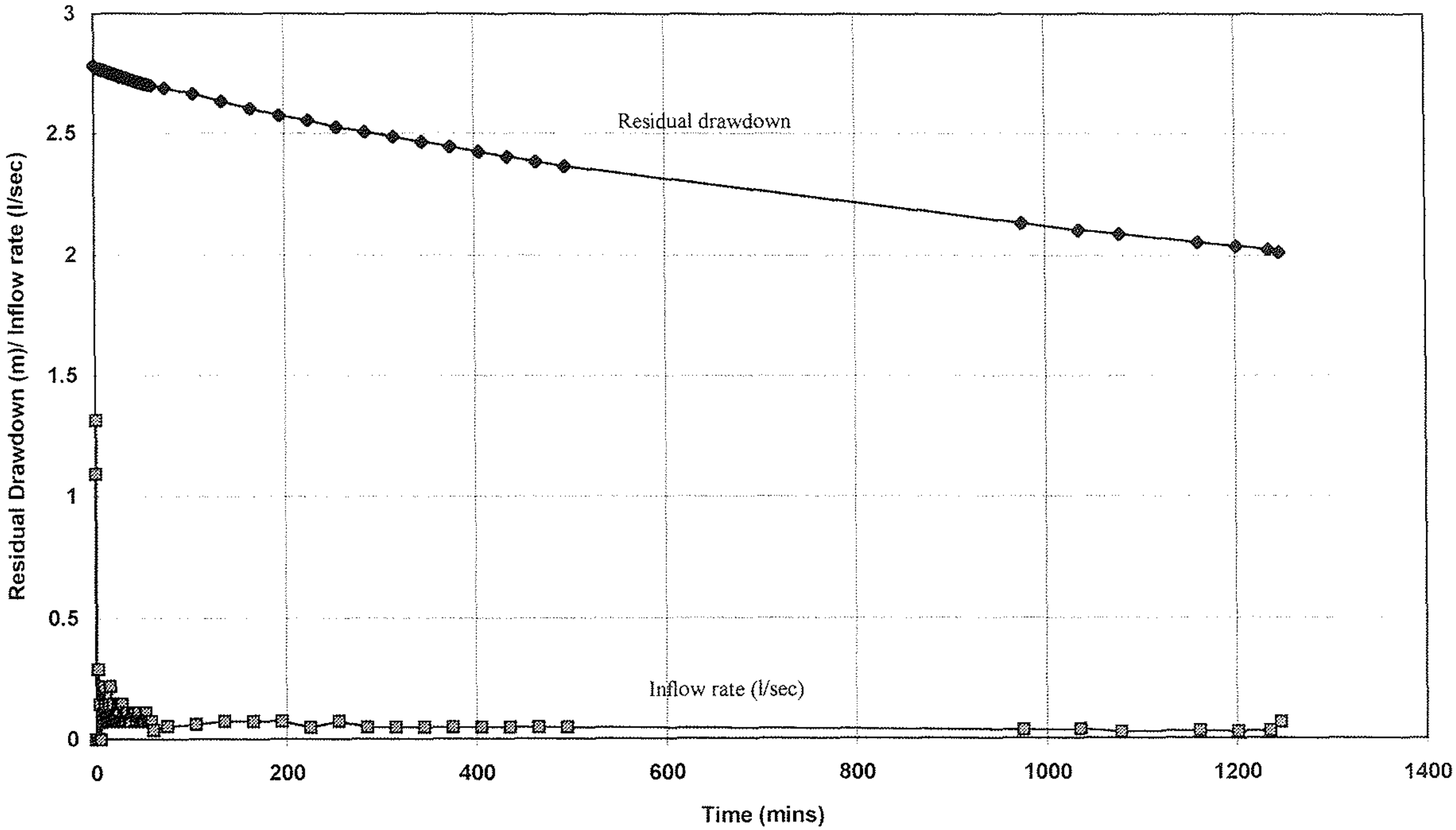
Start of recovery						
Time mins	Time since start mins	t/t'	PWL metres	Residual Drawdown metres	Volume of water in we m3	rate of inflow
0	82	0	9.49	2.785	0	
0.166667	82.16667	0.002028	9.49	2.785	0	0
0.5	82.5	0.006061	9.485	2.78	0.021831	1.091567
0.667	82.667	0.008069	9.485	2.78	0.021831	0
0.833	82.833	0.010056	9.482	2.777	0.03493	1.315141
1	83	0.012048	9.482	2.777	0.03493	0
1.5	83.5	0.017964	9.482	2.777	0.03493	0
2	84	0.02381	9.48	2.775	0.043663	0.291085
2.5	84.5	0.029586	9.48	2.775	0.043663	0
3	85	0.035294	9.478	2.773	0.052395	0.291085
3.5	85.5	0.040936	9.477	2.772	0.056761	0.145542
4	86	0.046512	9.477	2.772	0.056761	0
4.5	86.5	0.052023	9.477	2.772	0.056761	0
5	87	0.057471	9.477	2.772	0.056761	0
6	88	0.068182	9.474	2.769	0.06986	0.218313
7	89	0.078652	9.473	2.768	0.074227	0.072771
8	90	0.088889	9.47	2.765	0.087325	0.218313
9	91	0.098901	9.468	2.763	0.096058	0.145542
10	92	0.108696	9.467	2.762	0.100424	0.072771
11	93	0.11828	9.466	2.761	0.10479	0.072771
12	94	0.12766	9.465	2.76	0.109157	0.072771
13	95	0.136842	9.463	2.758	0.117889	0.145542
14	96	0.145833	9.462	2.757	0.122256	0.072771
15	97	0.154639	9.459	2.754	0.135354	0.218313
16	98	0.163265	9.458	2.753	0.139721	0.072771
17	99	0.171717	9.456	2.751	0.148453	0.145542
18	100	0.18	9.455	2.75	0.152819	0.072771
19	101	0.188119	9.454	2.749	0.157186	0.072771
20	102	0.196078	9.453	2.748	0.161552	0.072771
21	103	0.203883	9.452	2.747	0.165918	0.072771
22	104	0.211538	9.451	2.746	0.170284	0.072771
23	105	0.219048	9.449	2.744	0.179017	0.145542
24	106	0.226415	9.447	2.742	0.18775	0.145542
25	107	0.233645	9.446	2.741	0.192116	0.072771
26	108	0.240741	9.445	2.74	0.196482	0.072771
27	109	0.247706	9.443	2.738	0.205215	0.145542
28	110	0.254545	9.442	2.737	0.209581	0.072771
29	111	0.261261	9.441	2.736	0.213947	0.072771
30	112	0.267857	9.44	2.735	0.218313	0.072771
32	114	0.280702	9.437	2.732	0.231412	0.109157
34	116	0.293103	9.435	2.73	0.240145	0.072771
36	118	0.305085	9.433	2.728	0.248877	0.072771
38	120	0.316667	9.43	2.725	0.261976	0.109157
40	122	0.327869	9.427	2.722	0.275075	0.109157
42	124	0.33871	9.425	2.72	0.283807	0.072771
44	126	0.349206	9.422	2.717	0.296906	0.109157
46	128	0.359375	9.42	2.715	0.305639	0.072771
48	130	0.369231	9.418	2.713	0.314371	0.072771
50	132	0.378788	9.416	2.711	0.323104	0.072771
52	134	0.38806	9.413	2.708	0.336203	0.109157

54	136	0.397059	9.411	2.706	0.344935	0.072771
56	138	0.405797	9.409	2.704	0.353668	0.072771
58	140	0.414286	9.407	2.702	0.3624	0.072771
60	142	0.422535	9.406	2.701	0.366767	0.036386
75	157	0.477707	9.395	2.69	0.414795	0.053365
105	187	0.561497	9.37	2.665	0.523952	0.060643
135	217	0.62212	9.34	2.635	0.65494	0.072771
165	247	0.668016	9.31	2.605	0.785928	0.072771
195	277	0.703971	9.28	2.575	0.916916	0.072771
225	307	0.732899	9.26	2.555	1.004242	0.048514
255	337	0.756677	9.23	2.525	1.13523	0.072771
285	367	0.776567	9.21	2.505	1.222555	0.048514
315	397	0.793451	9.19	2.485	1.30988	0.048514
345	427	0.807963	9.17	2.465	1.397206	0.048514
375	457	0.820569	9.15	2.445	1.484531	0.048514
405	487	0.831622	9.13	2.425	1.571856	0.048514
435	517	0.841393	9.11	2.405	1.659182	0.048514
465	547	0.850091	9.09	2.385	1.746507	0.048514
495	577	0.857886	9.07	2.365	1.833833	0.048514
975	1057	0.922422	8.84	2.135	2.838074	0.03487
1035	1117	0.926589	8.81	2.105	2.969062	0.036386
1078	1160	0.92931	8.795	2.09	3.034556	0.025385
1161	1243	0.934031	8.76	2.055	3.187376	0.030687
1201	1283	0.936087	8.745	2.04	3.25287	0.027289
1235	1317	0.937737	8.73	2.025	3.318364	0.032105
1246	1328	0.938253	8.72	2.015	3.362026	0.066156
		Average inflow rate l/sec =			0.044971	



Gulubane Collector Well Recover Pumping Test
Before Installation of Laterals - 18-19/7/97
Theis Recovery Analysis
KD = 2.3 Q / 4πΔs
Q1 = 0.14 l/sec s1 = 0.05 m KD1 = 44.3 m2/day
Q2 = 0.08 l/sec s2 = 0.15 m KD2 = 14.8 m2/day
Residual Drawdown (metres)
0
1
2
3
4
5
6
0.001
0.01
0.1
1
t/t'

Gulubane Collector Well - Pre-installation of Laterals
Recovery and Inflow Data - 18-19/7/97



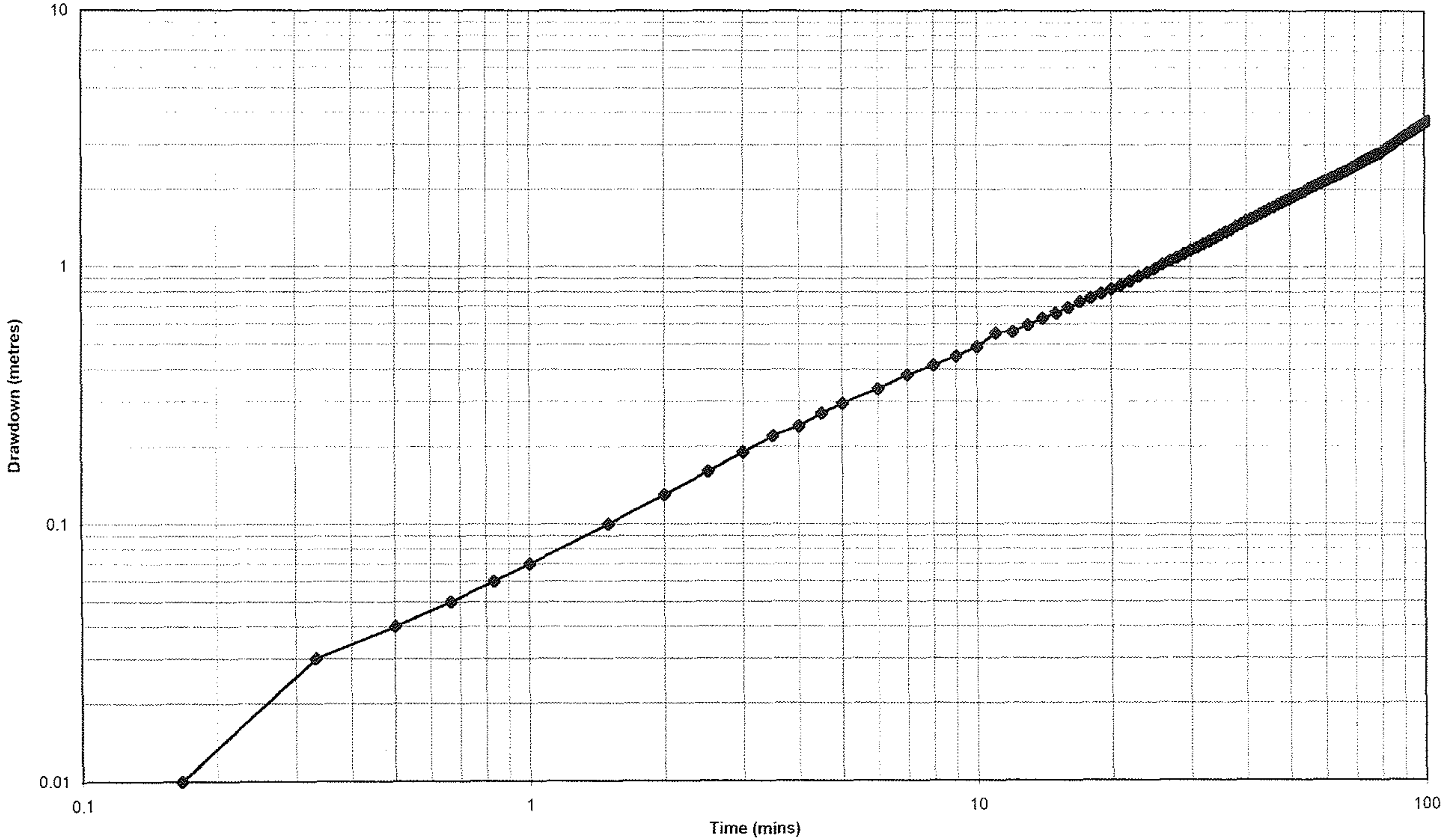
Pumping test 27/07/97
Gulubane Collector Well
After installation of laterals
Rest water leve 6.11 mbtoc
Well depth 10.08 mbtoc
Top of casing 0.4 magl
Start of test

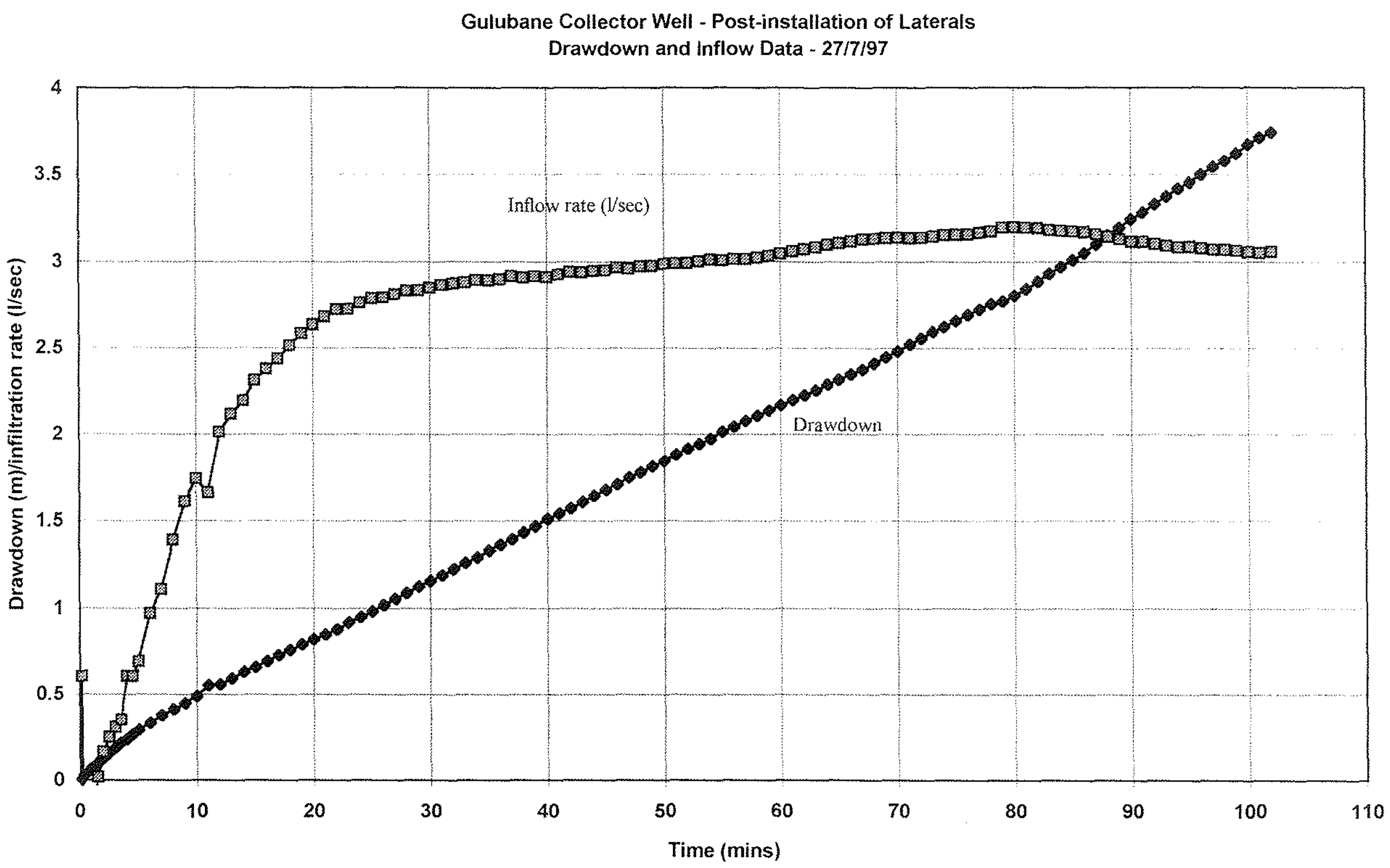
Time mins	PWL metres	Drawdown metres	Pumping Rate l/sec	Vol of well emptied m3	Cum vol emptied m3	Volume pumped m3	Cum vol pumped m3	inflow rate m3	inflow rate l/sec
0	6.11	0	5.882353						
0.167	6.125	0.015	5.882353	0.065494	0.06549	0.05882	0.05882	-0.007	-0.67
0.333	6.14	0.03	5.882353	0.065494	0.13099	0.05882	0.11765	-0.013	-0.67
0.5	6.15	0.04	5.882353	0.043663	0.17465	0.05882	0.17647	0.002	0.061
0.667	6.16	0.05	5.882353	0.043663	0.21831	0.05894	0.23541	0.017	0.427
0.833	6.17	0.06	5.882353	0.043663	0.26198	0.05859	0.294	0.032	0.641
1	6.18	0.07	5.882353	0.043663	0.30564	0.05894	0.35294	0.047	0.788
1.5	6.21	0.1	5.882353	0.130988	0.43663	0.17647	0.52941	0.093	1.031
2	6.24	0.13	5.882353	0.130988	0.56761	0.17647	0.70588	0.138	1.152
2.5	6.27	0.16	5.882353	0.130988	0.6986	0.17647	0.88235	0.184	1.225
3	6.3	0.19	5.882353	0.130988	0.82959	0.17647	1.05882	0.229	1.274
3.5	6.33	0.22	5.882353	0.130988	0.96058	0.17647	1.23529	0.275	1.308
4	6.35	0.24	5.882353	0.087325	1.0479	0.17647	1.41176	0.364	1.516
4.5	6.38	0.27	5.882353	0.130988	1.17889	0.17647	1.58824	0.409	1.516
5	6.405	0.295	5.882353	0.109157	1.28805	0.17647	1.76471	0.477	1.589
6	6.445	0.335	5.882353	0.174651	1.4627	0.35294	2.11765	0.655	1.819
7	6.49	0.38	5.882353	0.196482	1.65918	0.35294	2.47059	0.811	1.932
8	6.525	0.415	6.451613	0.152819	1.812	0.3871	2.85769	1.046	2.179
9	6.56	0.45	6.451613	0.152819	1.96482	0.3871	3.24478	1.28	2.37
10	6.6	0.49	6.451613	0.174651	2.13947	0.3871	3.63188	1.492	2.487
11	6.664	0.554	6.451613	0.279441	2.41891	0.3871	4.01898	1.6	2.424
12	6.67	0.56	6.451613	0.026198	2.44511	0.3871	4.40607	1.961	2.724
13	6.705	0.595	6.451613	0.152819	2.59793	0.3871	4.79317	2.195	2.814
14	6.742	0.632	6.451613	0.161552	2.75948	0.3871	5.18027	2.421	2.882
15	6.77	0.66	6.451613	0.122256	2.88174	0.3871	5.56736	2.686	2.984
16	6.805	0.695	6.451613	0.152819	3.03456	0.3871	5.95446	2.92	3.042
17	6.84	0.73	6.451613	0.152819	3.18738	0.3871	6.34156	3.154	3.092
18	6.87	0.76	6.451613	0.130988	3.31836	0.3871	6.72865	3.41	3.158
19	6.9	0.79	6.451613	0.130988	3.44935	0.3871	7.11575	3.666	3.216
20	6.93	0.82	6.25	0.130988	3.58034	0.375	7.49075	3.91	3.259
21	6.96	0.85	6.25	0.130988	3.71133	0.375	7.86575	4.154	3.297
22	6.99	0.88	6.25	0.130988	3.84232	0.375	8.24075	4.398	3.332
23	7.03	0.92	6.25	0.174651	4.01697	0.375	8.61575	4.599	3.332
24	7.06	0.95	6.25	0.130988	4.14795	0.375	8.99075	4.843	3.363
25	7.092	0.982	6.25	0.139721	4.28768	0.375	9.36575	5.078	3.385
26	7.13	1.02	6.25	0.165918	4.45359	0.375	9.74075	5.287	3.389
27	7.164	1.054	6.25	0.148453	4.60205	0.375	10.1157	5.514	3.404
28	7.197	1.087	6.25	0.144087	4.74613	0.375	10.4907	5.745	3.419
29	7.235	1.125	6.25	0.165918	4.91205	0.375	10.8657	5.954	3.422
30	7.268	1.158	6.25	0.144087	5.05614	0.375	11.2407	6.185	3.436
31	7.3	1.19	6.17284	0.139721	5.19586	0.37037	11.6111	6.415	3.449
32	7.335	1.225	6.17284	0.152819	5.34868	0.37037	11.9815	6.633	3.455
33	7.37	1.26	6.17284	0.152819	5.5015	0.37037	12.3519	6.85	3.46
34	7.402	1.292	6.17284	0.139721	5.64122	0.37037	12.7222	7.081	3.471

35	7.44	1.33	6.17284	0.165918	5.80714	0.37037	13.0926	7.285	3.469
36	7.475	1.365	6.17284	0.152819	5.95996	0.37037	13.463	7.503	3.474
37	7.505	1.395	6.17284	0.130988	6.09094	0.37037	13.8333	7.742	3.488
38	7.545	1.435	6.17284	0.174651	6.26559	0.37037	14.2037	7.938	3.482
39	7.58	1.47	6.25	0.152819	6.41841	0.375	14.5787	8.16	3.487
40	7.62	1.51	6.25	0.174651	6.59306	0.375	14.9537	8.361	3.484
41	7.652	1.542	6.25	0.139721	6.73279	0.375	15.3287	8.596	3.494
42	7.682	1.572	6.25	0.130988	6.86377	0.375	15.7037	8.84	3.508
43	7.72	1.61	6.25	0.165918	7.02969	0.375	16.0787	9.049	3.507
44	7.755	1.645	6.25	0.152819	7.18251	0.375	16.4537	9.271	3.512
45	7.79	1.68	6.25	0.152819	7.33533	0.375	16.8287	9.493	3.516
46	7.82	1.71	6.25	0.130988	7.46632	0.375	17.2037	9.737	3.528
47	7.86	1.75	6.25	0.174651	7.64097	0.375	17.5787	9.938	3.524
48	7.89	1.78	6.25	0.130988	7.77196	0.375	17.9537	10.18	3.535
49	7.925	1.815	6.25	0.152819	7.92478	0.375	18.3287	10.4	3.539
50	7.955	1.845	6.17284	0.130988	8.05576	0.37037	18.6991	10.64	3.548
51	7.99	1.88	6.17284	0.152819	8.20858	0.37037	19.0695	10.86	3.549
52	8.025	1.915	6.17284	0.152819	8.3614	0.37037	19.4398	11.08	3.551
53	8.055	1.945	6.17284	0.130988	8.49239	0.37037	19.8102	11.32	3.559
54	8.085	1.975	6.17284	0.130988	8.62338	0.37037	20.1806	11.56	3.567
55	8.125	2.015	6.17284	0.174651	8.79803	0.37037	20.5509	11.75	3.561
56	8.155	2.045	6.17284	0.130988	8.92902	0.37037	20.9213	11.99	3.569
57	8.19	2.08	6.17284	0.152819	9.08184	0.37037	21.2917	12.21	3.57
58	8.22	2.11	6.17284	0.130988	9.21283	0.37037	21.662	12.45	3.577
59	8.25	2.14	6.17284	0.130988	9.34381	0.37037	22.0324	12.69	3.584
60	8.28	2.17	6.451613	0.130988	9.4748	0.3871	22.4195	12.94	3.596
61	8.31	2.2	6.451613	0.130988	9.60579	0.3871	22.8066	13.2	3.607
62	8.34	2.23	6.451613	0.130988	9.73678	0.3871	23.1937	13.46	3.617
63	8.37	2.26	6.451613	0.130988	9.86777	0.3871	23.5808	13.71	3.628
64	8.4	2.29	6.451613	0.130988	9.99875	0.3871	23.9679	13.97	3.638
65	8.43	2.32	6.451613	0.130988	10.1297	0.3871	24.355	14.23	3.648
66	8.46	2.35	6.451613	0.130988	10.2607	0.3871	24.7421	14.48	3.657
67	8.49	2.38	6.451613	0.130988	10.3917	0.3871	25.1292	14.74	3.666
68	8.525	2.415	6.451613	0.152819	10.5445	0.3871	25.5163	14.97	3.67
69	8.56	2.45	6.451613	0.152819	10.6974	0.3871	25.9034	15.21	3.673
70	8.595	2.485	6.451613	0.152819	10.8502	0.3871	26.2905	15.44	3.676
71	8.635	2.525	6.451613	0.174651	11.0248	0.3871	26.6776	15.65	3.674
72	8.67	2.56	6.451613	0.152819	11.1776	0.3871	27.0647	15.89	3.678
73	8.705	2.595	6.451613	0.152819	11.3305	0.3871	27.4518	16.12	3.681
74	8.735	2.625	6.451613	0.130988	11.4615	0.3871	27.8389	16.38	3.689
75	8.77	2.66	6.451613	0.152819	11.6143	0.3871	28.226	16.61	3.691
76	8.805	2.695	6.451613	0.152819	11.7671	0.3871	28.6131	16.85	3.694
77	8.835	2.725	6.451613	0.130988	11.8981	0.3871	29.0002	17.1	3.702
78	8.865	2.755	6.451613	0.130988	12.0291	0.3871	29.3873	17.36	3.709
79	8.882	2.772	6.451613	0.074227	12.1033	0.3871	29.7744	17.67	3.728
80	8.915	2.805	6.369427	0.144087	12.2474	0.38217	30.1565	17.91	3.731
81	8.955	2.845	6.369427	0.174651	12.422	0.38217	30.5387	18.12	3.728
82	8.995	2.885	6.369427	0.174651	12.5967	0.38217	30.9208	18.32	3.724
83	9.04	2.93	6.369427	0.196482	12.7932	0.38217	31.303	18.51	3.717
84	9.08	2.97	6.369427	0.174651	12.9678	0.38217	31.6852	18.72	3.714
85	9.12	3.01	6.369427	0.174651	13.1425	0.38217	32.0673	18.92	3.711
86	9.16	3.05	6.369427	0.174651	13.3171	0.38217	32.4495	19.13	3.708
87	9.21	3.1	6.369427	0.218313	13.5354	0.38217	32.8317	19.3	3.697
88	9.26	3.15	6.21118	0.218313	13.7537	0.37267	33.2043	19.45	3.684

89	9.305	3.195	6.21118	0.196482	13.9502	0.37267	33.577	19.63	3.675
90	9.355	3.245	6.21118	0.218313	14.1685	0.37267	33.9497	19.78	3.663
91	9.392	3.282	6.21118	0.161552	14.3301	0.37267	34.3224	19.99	3.662
92	9.44	3.33	6.21118	0.209581	14.5397	0.37267	34.695	20.16	3.651
93	9.485	3.375	6.21118	0.196482	14.7362	0.37267	35.0677	20.33	3.644
94	9.53	3.42	6.21118	0.196482	14.9326	0.37267	35.4404	20.51	3.636
95	9.565	3.455	6.25	0.152819	15.0855	0.375	35.8154	20.73	3.637
96	9.61	3.5	6.25	0.196482	15.2819	0.375	36.1904	20.91	3.63
97	9.655	3.545	6.25	0.196482	15.4784	0.375	36.5654	21.09	3.623
98	9.69	3.58	6.25	0.152819	15.6312	0.375	36.9404	21.31	3.624
99	9.732	3.622	6.25	0.183383	15.8146	0.375	37.3154	21.5	3.62
100	9.78	3.67	6.25	0.209581	16.0242	0.375	37.6904	21.67	3.611
101	9.82	3.71	6.25	0.174651	16.1989	0.375	38.0654	21.87	3.608
102	9.85	3.74	6.25	0.130988	16.3298	0.375	38.4404	22.11	3.613
103	9.85	3.74	4.25						
			Average inflow rate (l/sec) =				3.61283		

Gulubane Collector Well Drawdown Pumping Test
After Installation of Laterals - 27/7/97





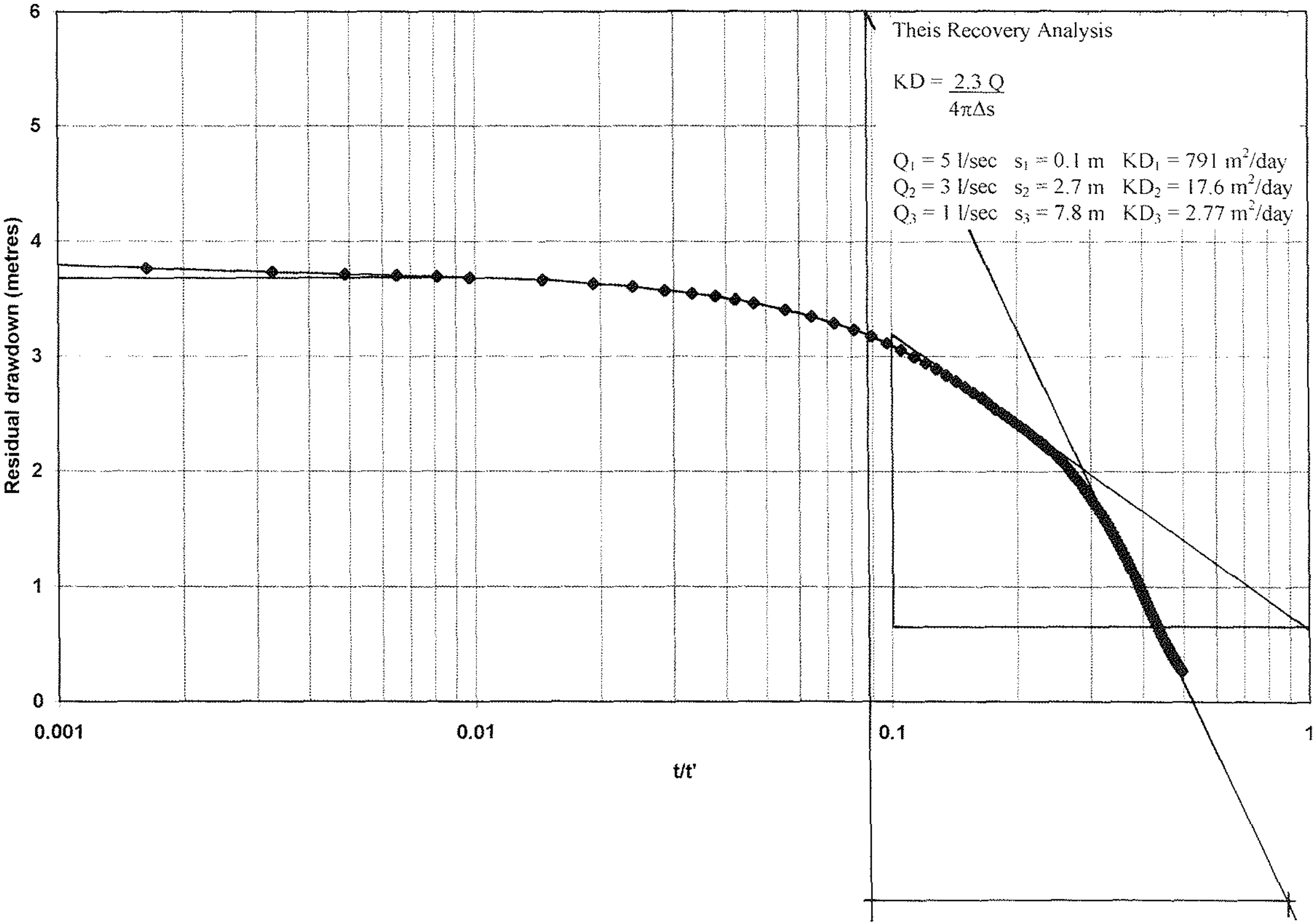
Gulubane Collector Well - Post-installation of Laterals
Drawdown and Inflow Data - 27/7/97
Inflow rate (l/sec)
Drawdown
Drawdown (m)/infiltration rate (l/sec)
Time (mins)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
10
20
30
40
50
60
70
80
90
100
110

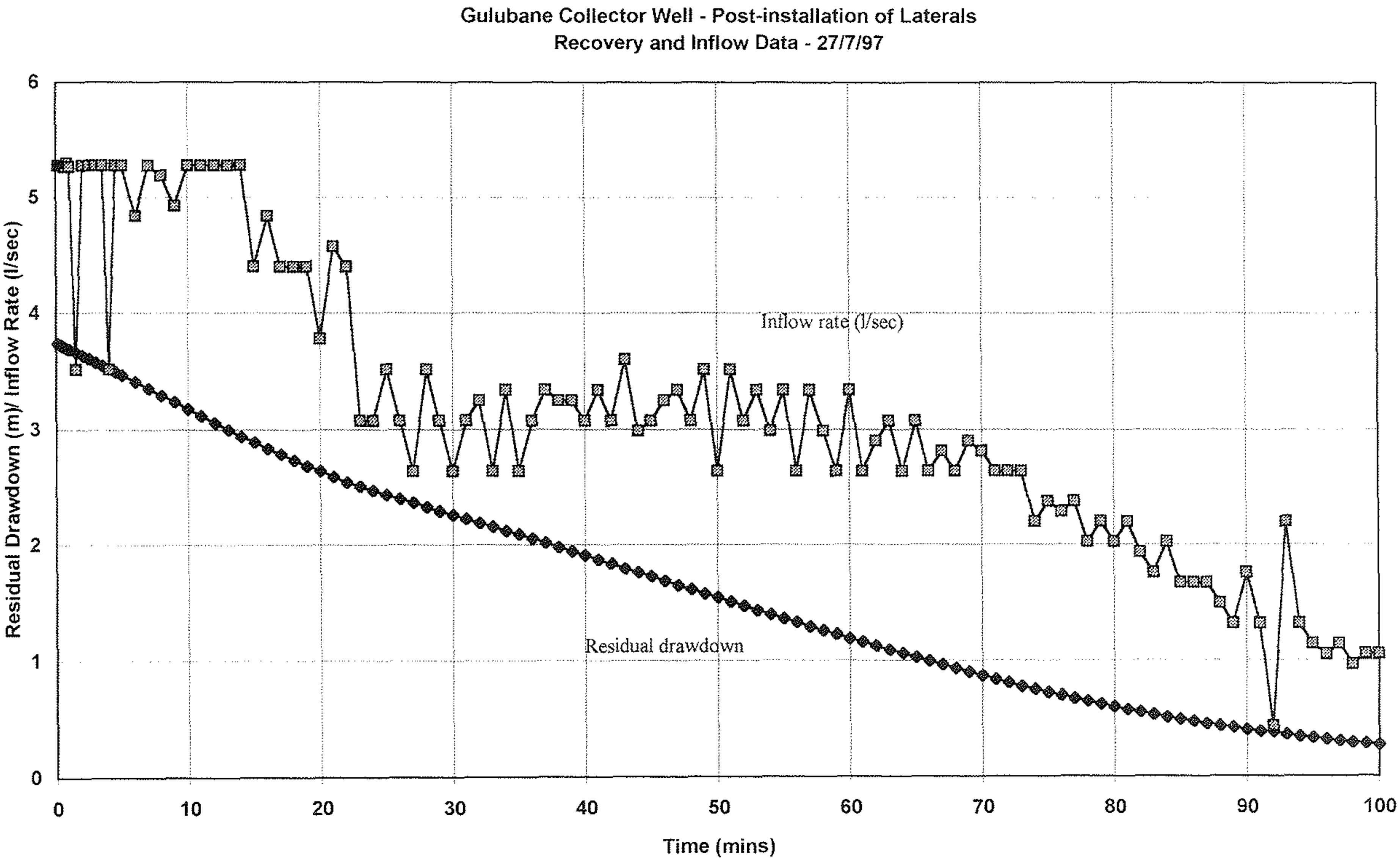
Time at start of recovery			14:45				
Time since recovery started mins	Time since pumping started mins	t/t'	PWL metres	Residual drawdown metres	Vol well filled m3	cum vol well filled m3	inflow rate l/sec
0	102	0	9.86	3.75			
0.166667	102.16667	0.001631	9.85	3.74	0.043663	0.043663	4.366268
0.33333	102.33333	0.003257	9.84	3.73	0.043663	0.087325	4.366355
0.5	102.5	0.004878	9.83	3.72	0.043663	0.130988	4.366181
0.667	102.667	0.006497	9.82	3.71	0.043663	0.174651	4.357553
0.833	102.833	0.008101	9.81	3.7	0.043663	0.218313	4.383803
1	103	0.009709	9.8	3.69	0.043663	0.261976	4.357553
1.5	103.5	0.014493	9.78	3.67	0.087325	0.349301	2.910845
2	104	0.019231	9.75	3.64	0.130988	0.480289	4.366268
2.5	104.5	0.023923	9.72	3.61	0.130988	0.611278	4.366268
3	105	0.028571	9.69	3.58	0.130988	0.742266	4.366268
3.5	105.5	0.033175	9.66	3.55	0.130988	0.873254	4.366268
4	106	0.037736	9.64	3.53	0.087325	0.960579	2.910845
4.5	106.5	0.042254	9.61	3.5	0.130988	1.091567	4.366268
5	107	0.046729	9.58	3.47	0.130988	1.222555	4.366268
6	108	0.055556	9.525	3.415	0.240145	1.4627	4.002412
7	109	0.06422	9.465	3.355	0.261976	1.724676	4.366268
8	110	0.072727	9.406	3.296	0.25761	1.982286	4.293497
9	111	0.081081	9.35	3.24	0.244511	2.226797	4.075183
10	112	0.089286	9.29	3.18	0.261976	2.488773	4.366268
11	113	0.097345	9.23	3.12	0.261976	2.750749	4.366268
12	114	0.105263	9.17	3.06	0.261976	3.012725	4.366268
13	115	0.113043	9.11	3	0.261976	3.274701	4.366268
14	116	0.12069	9.05	2.94	0.261976	3.536677	4.366268
15	117	0.128205	9	2.89	0.218313	3.75499	3.638557
16	118	0.135593	8.945	2.835	0.240145	3.995135	4.002412
17	119	0.142857	8.895	2.785	0.218313	4.213449	3.638557
18	120	0.15	8.845	2.735	0.218313	4.431762	3.638557
19	121	0.157025	8.795	2.685	0.218313	4.650075	3.638557
20	122	0.163934	8.752	2.642	0.18775	4.837825	3.129159
21	123	0.170732	8.7	2.59	0.227046	5.064871	3.784099
22	124	0.177419	8.65	2.54	0.218313	5.283184	3.638557
23	125	0.184	8.615	2.505	0.152819	5.436004	2.54699
24	126	0.190476	8.58	2.47	0.152819	5.588823	2.54699
25	127	0.19685	8.54	2.43	0.174651	5.763474	2.910845
26	128	0.203125	8.505	2.395	0.152819	5.916293	2.54699
27	129	0.209302	8.475	2.365	0.130988	6.047281	2.183134
28	130	0.215385	8.435	2.325	0.174651	6.221932	2.910845
29	131	0.221374	8.4	2.29	0.152819	6.374751	2.54699
30	132	0.227273	8.37	2.26	0.130988	6.505739	2.183134
31	133	0.233083	8.335	2.225	0.152819	6.658559	2.54699
32	134	0.238806	8.298	2.188	0.161552	6.820111	2.692532
33	135	0.244444	8.268	2.158	0.130988	6.951099	2.183134
34	136	0.25	8.23	2.12	0.165918	7.117017	2.765303
35	137	0.255474	8.2	2.09	0.130988	7.248005	2.183134
36	138	0.26087	8.165	2.055	0.152819	7.400824	2.54699
37	139	0.266187	8.127	2.017	0.165918	7.566742	2.765303
38	140	0.271429	8.09	1.98	0.161552	7.728294	2.692532
39	141	0.276596	8.053	1.943	0.161552	7.889846	2.692532

40	142	0.28169	8.018	1.908	0.152819	8.042666	2.54699
41	143	0.286713	7.98	1.87	0.165918	8.208584	2.765303
42	144	0.291667	7.945	1.835	0.152819	8.361403	2.54699
43	145	0.296552	7.904	1.794	0.179017	8.54042	2.983616
44	146	0.30137	7.87	1.76	0.148453	8.688873	2.474219
45	147	0.306122	7.835	1.725	0.152819	8.841693	2.54699
46	148	0.310811	7.798	1.688	0.161552	9.003245	2.692532
47	149	0.315436	7.76	1.65	0.165918	9.169163	2.765303
48	150	0.32	7.725	1.615	0.152819	9.321982	2.54699
49	151	0.324503	7.685	1.575	0.174651	9.496633	2.910845
50	152	0.328947	7.655	1.545	0.130988	9.627621	2.183134
51	153	0.333333	7.615	1.505	0.174651	9.802272	2.910845
52	154	0.337662	7.58	1.47	0.152819	9.955091	2.54699
53	155	0.341935	7.542	1.432	0.165918	10.12101	2.765303
54	156	0.346154	7.508	1.398	0.148453	10.26946	2.474219
55	157	0.350318	7.47	1.36	0.165918	10.43538	2.765303
56	158	0.35443	7.44	1.33	0.130988	10.56637	2.183134
57	159	0.358491	7.402	1.292	0.165918	10.73229	2.765303
58	160	0.3625	7.368	1.258	0.148453	10.88074	2.474219
59	161	0.36646	7.338	1.228	0.130988	11.01173	2.183134
60	162	0.37037	7.3	1.19	0.165918	11.17765	2.765303
61	163	0.374233	7.27	1.16	0.130988	11.30863	2.183134
62	164	0.378049	7.237	1.127	0.144087	11.45272	2.401447
63	165	0.381818	7.202	1.092	0.152819	11.60554	2.54699
64	166	0.385542	7.172	1.062	0.130988	11.73653	2.183134
65	167	0.389222	7.137	1.027	0.152819	11.88935	2.54699
66	168	0.392857	7.107	0.997	0.130988	12.02034	2.183134
67	169	0.39645	7.075	0.965	0.139721	12.16006	2.328676
68	170	0.4	7.045	0.935	0.130988	12.29104	2.183134
69	171	0.403509	7.012	0.902	0.144087	12.43513	2.401447
70	172	0.406977	6.98	0.87	0.139721	12.57485	2.328676
71	173	0.410405	6.95	0.84	0.130988	12.70584	2.183134
72	174	0.413793	6.92	0.81	0.130988	12.83683	2.183134
73	175	0.417143	6.89	0.78	0.130988	12.96782	2.183134
74	176	0.420455	6.865	0.755	0.109157	13.07697	1.819278
75	177	0.423729	6.838	0.728	0.117889	13.19486	1.964821
76	178	0.426966	6.812	0.702	0.113523	13.30838	1.892049
77	179	0.430168	6.785	0.675	0.117889	13.42627	1.964821
78	180	0.433333	6.762	0.652	0.100424	13.5267	1.673736
79	181	0.436464	6.737	0.627	0.109157	13.63585	1.819278
80	182	0.43956	6.714	0.604	0.100424	13.73628	1.673736
81	183	0.442623	6.689	0.579	0.109157	13.84544	1.819278
82	184	0.445652	6.667	0.557	0.096058	13.94149	1.600965
83	185	0.448649	6.647	0.537	0.087325	14.02882	1.455423
84	186	0.451613	6.624	0.514	0.100424	14.12924	1.673736
85	187	0.454545	6.605	0.495	0.082959	14.2122	1.382652
86	188	0.457447	6.586	0.476	0.082959	14.29516	1.382652
87	189	0.460317	6.567	0.457	0.082959	14.37812	1.382652
88	190	0.463158	6.55	0.44	0.074227	14.45235	1.237109
89	191	0.465969	6.535	0.425	0.065494	14.51784	1.091567
90	192	0.46875	6.515	0.405	0.087325	14.60517	1.455423
91	193	0.471503	6.5	0.39	0.065494	14.67066	1.091567
92	194	0.474227	6.495	0.385	0.021831	14.69249	0.363856
93	195	0.476923	6.47	0.36	0.109157	14.80165	1.819278

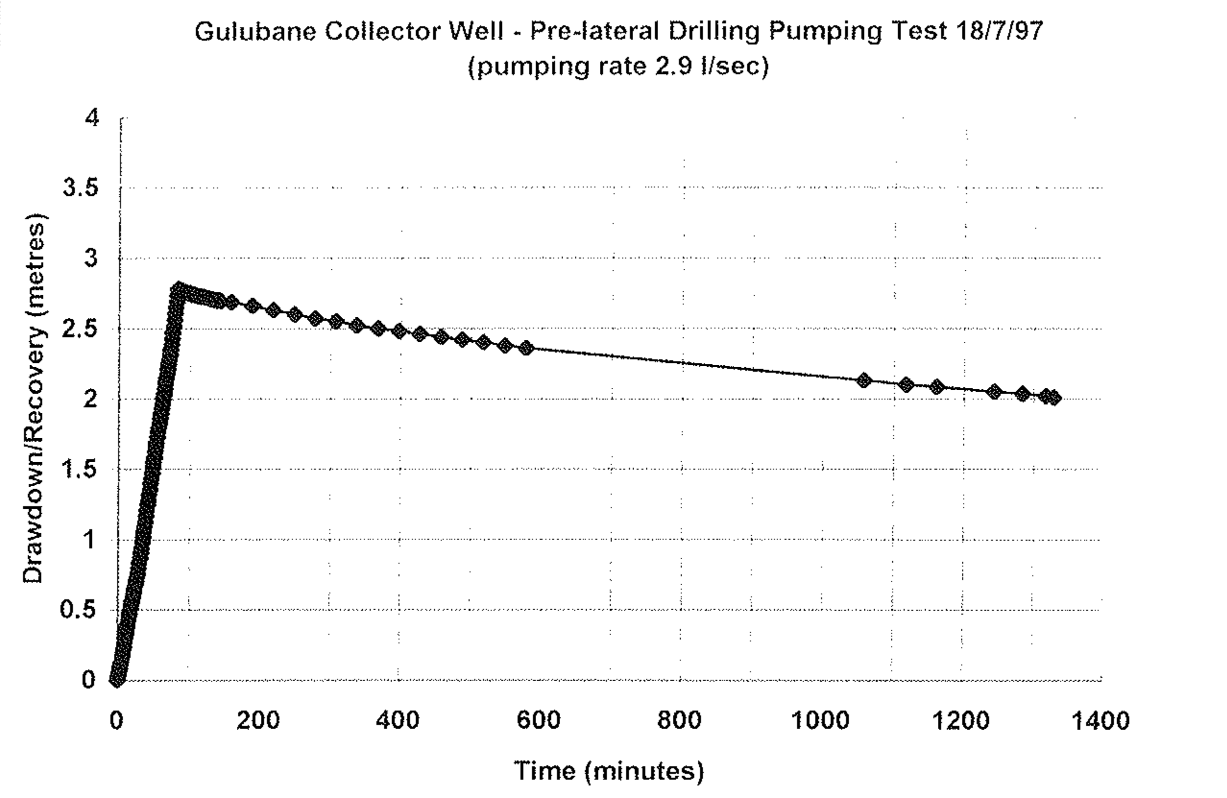
94	196	0.479592	6.455	0.345	0.065494	14.86714	1.091567
95	197	0.482234	6.442	0.332	0.056761	14.9239	0.946025
96	198	0.484848	6.43	0.32	0.052395	14.9763	0.873254
97	199	0.487437	6.417	0.307	0.056761	15.03306	0.946025
98	200	0.49	6.406	0.296	0.048029	15.08109	0.800482
99	201	0.492537	6.394	0.284	0.052395	15.13348	0.873254
100	202	0.49505	6.382	0.272	0.052395	15.18588	0.873254
			Average inflow rate (l/sec) =			2.53098	

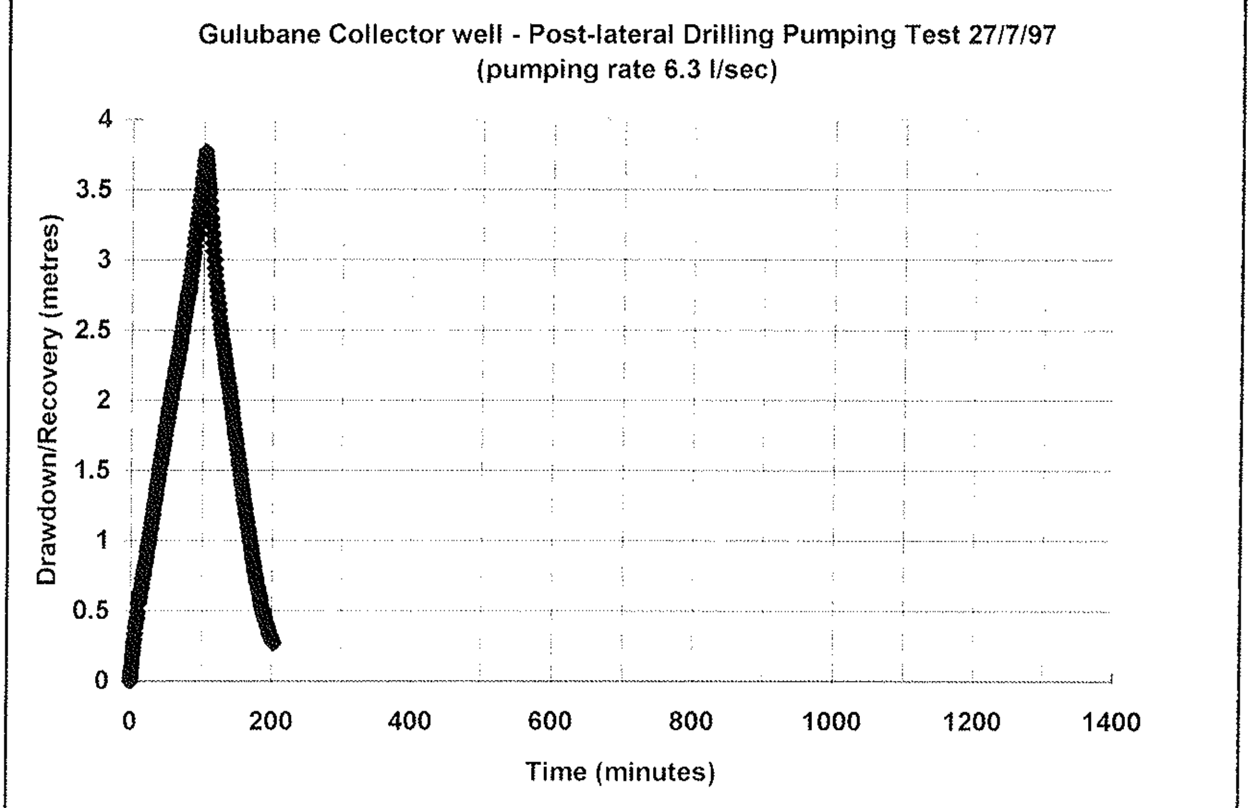
Gulubane Collector Well Recovery Pumping Test
After Installation of Laterals - 27/7/97





Gulubane Collector Well - Post-installation of Laterals
Recovery and Inflow Data - 27/7/97
Residual Drawdown (m)/ Inflow Rate (l/sec)
Inflow rate (l/sec)
Residual drawdown
Time (mins)
0
1
2
3
4
5
6
10
20
30
40
50
60
70
80
90
100


Gulubane Collector Well - Pre-lateral Drilling Pumping Test 18/7/97
(pumping rate 2.9 l/sec)
Drawdown/Recovery (metres)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1000
1200
1400
Time (minutes)


Gulubane Collector well - Post-lateral Drilling Pumping Test 27/7/97
(pumping rate 6.3 l/sec)
Drawdown/Recovery (metres)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1000
1200
1400
Time (minutes)

Pumping test 28/07/97

Matshelagabedi Collector Well

Before installation of laterals

Rest water level 2.87 mbtoc

Well depth 8.73 mbtoc

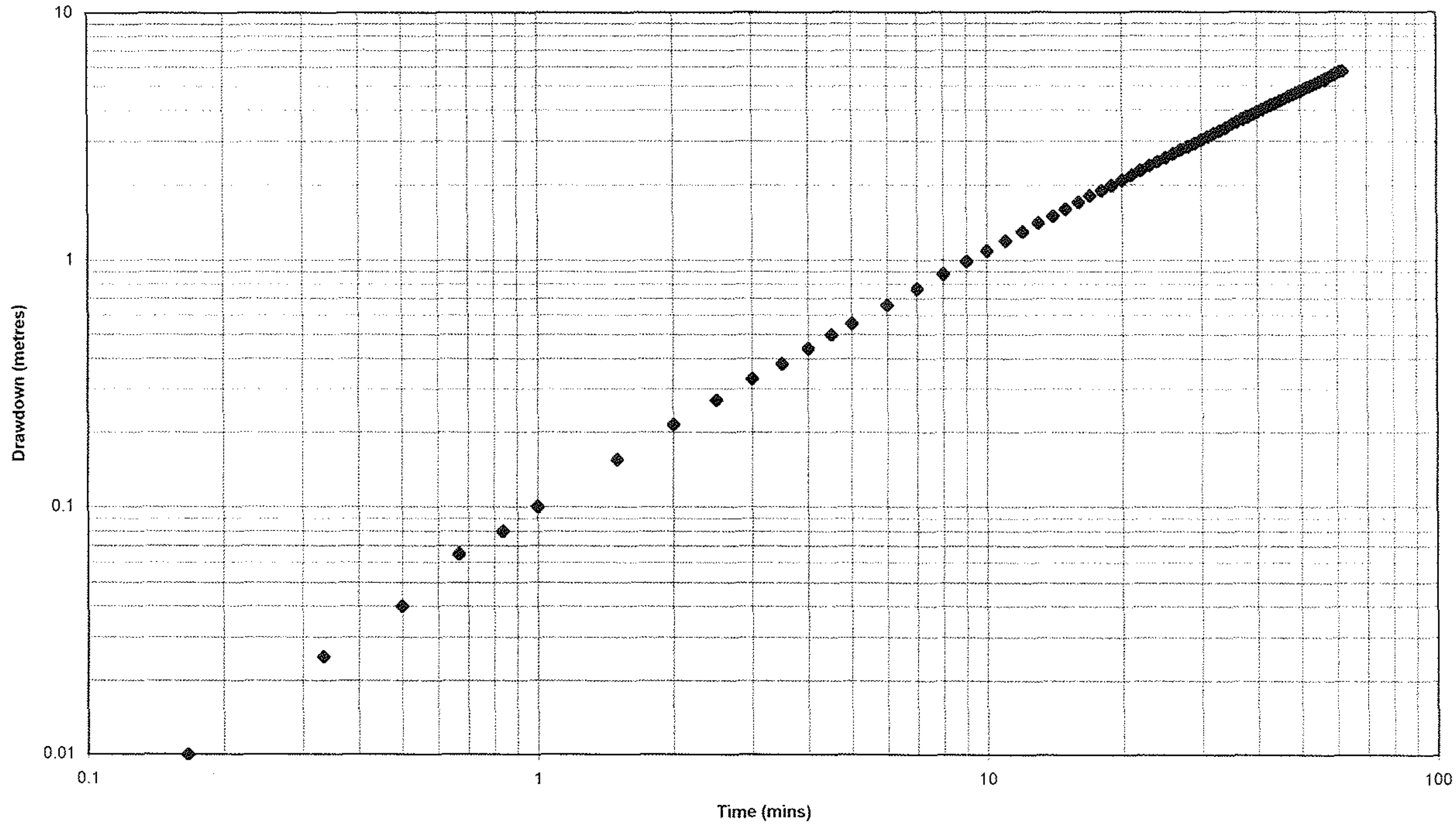
Top of casing 0.422 magl

Start of test

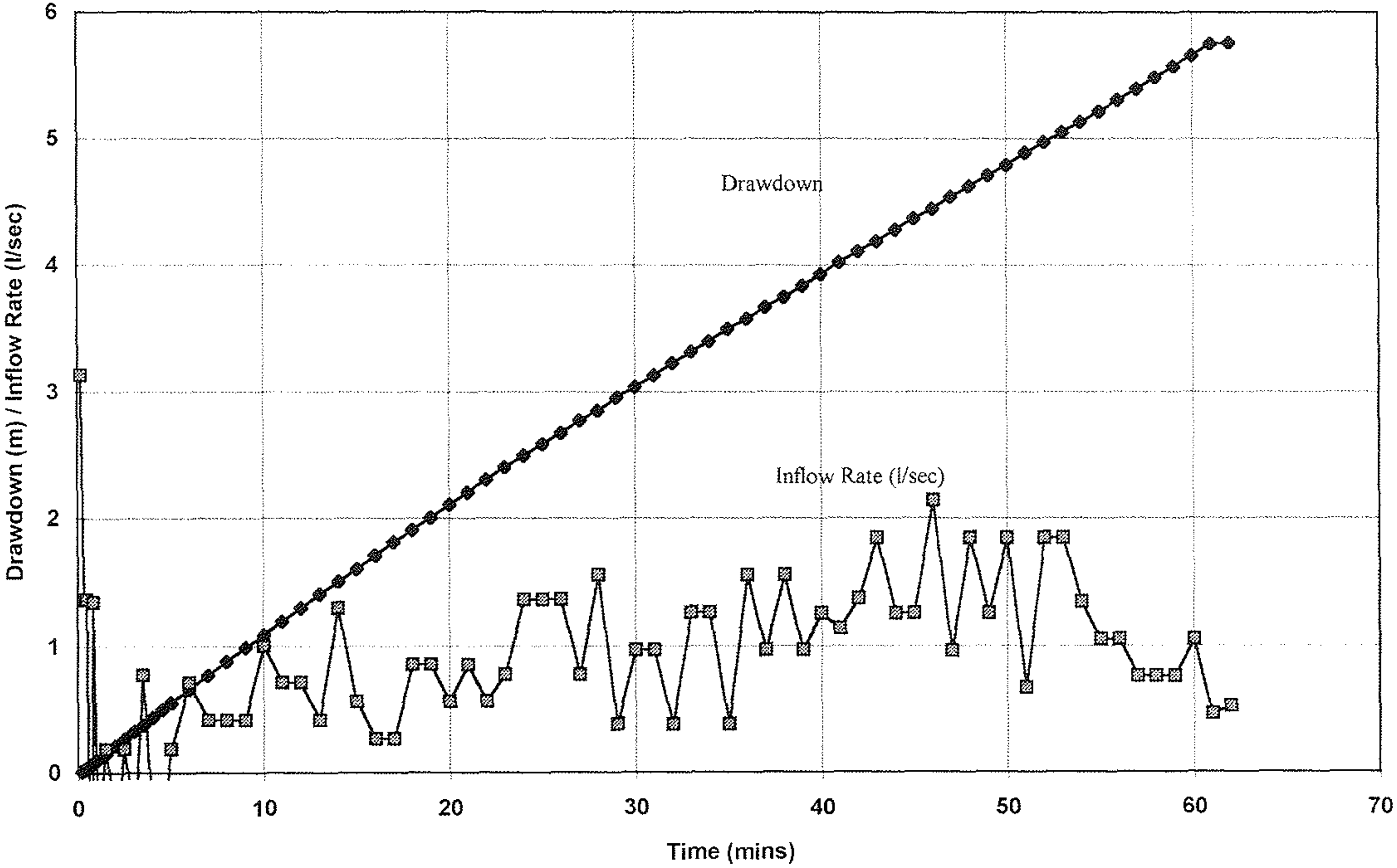
Time mins	PWL metres	Drawdown metres	Pumping rate l/sec	Vol of well emptied m3	Cum vol emptied m3	Volume pumped m3	Cum vol pumped m3	inflow m3	inflow rate l/sec
0	2.87	0	6.66667						
0.16667	2.88	0.01	6.66667	0.035338	0.03534	0.06667	0.06667	0.0313	3.132817
0.33333	2.895	0.025	6.66667	0.053008	0.08835	0.06667	0.13333	0.0137	1.365892
0.5	2.91	0.04	6.66667	0.053008	0.14135	0.06667	0.2	0.0137	1.365892
0.667	2.935	0.065	6.66667	0.088346	0.2297	0.0668	0.2668	-0.0215	-2.15032
0.833	2.95	0.08	6.66667	0.053008	0.28271	0.0664	0.3332	0.0134	1.344603
1	2.97	0.1	6.66667	0.070677	0.35339	0.0668	0.4	-0.0039	-0.38693
1.5	3.025	0.155	6.66667	0.194362	0.54775	0.2	0.6	0.0056	0.187942
2	3.085	0.215	6.66667	0.212031	0.75978	0.2	0.8	-0.012	-0.40103
2.5	3.14	0.27	6.66667	0.194362	0.95414	0.2	1	0.0056	0.187942
3	3.2	0.33	6.66667	0.212031	1.16617	0.2	1.2	-0.012	-0.40103
3.5	3.25	0.38	6.66667	0.176692	1.34286	0.2	1.4	0.0233	0.776917
4	3.31	0.44	6.66667	0.212031	1.55489	0.2	1.6	-0.012	-0.40103
4.5	3.37	0.5	6.66667	0.212031	1.76693	0.2	1.8	-0.012	-0.40103
5	3.425	0.555	6.66667	0.194362	1.96129	0.2	2	0.0056	0.187942
6	3.53	0.66	6.89655	0.371054	2.33234	0.41379	2.41379	0.0427	0.712314
7	3.64	0.77	6.89655	0.388724	2.72106	0.41379	2.82759	0.0251	0.417827
8	3.75	0.88	6.89655	0.388724	3.10979	0.41379	3.24138	0.0251	0.417827
9	3.86	0.99	6.89655	0.388724	3.49851	0.41379	3.65517	0.0251	0.417827
10	3.96	1.09	6.89655	0.353385	3.8519	0.41379	4.06897	0.0604	1.006802
11	4.065	1.195	6.89655	0.371054	4.22295	0.41379	4.48276	0.0427	0.712314
12	4.17	1.3	6.89655	0.371054	4.59401	0.41379	4.89655	0.0427	0.712314
13	4.28	1.41	6.89655	0.388724	4.98273	0.41379	5.31034	0.0251	0.417827
14	4.375	1.505	6.89655	0.335716	5.31844	0.41379	5.72414	0.0781	1.301289
15	4.475	1.605	6.45161	0.353385	5.67183	0.3871	6.11123	0.0337	0.561863
16	4.58	1.71	6.45161	0.371054	6.04288	0.3871	6.49833	0.016	0.267375
17	4.685	1.815	6.45161	0.371054	6.41394	0.3871	6.88543	0.016	0.267375
18	4.78	1.91	6.45161	0.335716	6.74965	0.3871	7.27253	0.0514	0.85635
19	4.875	2.005	6.45161	0.335716	7.08537	0.3871	7.65962	0.0514	0.85635
20	4.975	2.105	6.45161	0.353385	7.43875	0.3871	8.04672	0.0337	0.561863
21	5.07	2.2	6.45161	0.335716	7.77447	0.3871	8.43382	0.0514	0.85635
22	5.17	2.3	6.45161	0.353385	8.12786	0.3871	8.82091	0.0337	0.561863
23	5.27	2.4	6.66667	0.353385	8.48124	0.4	9.22091	0.0466	0.776917
24	5.36	2.49	6.66667	0.318047	8.79929	0.4	9.62091	0.082	1.365892
25	5.45	2.58	6.66667	0.318047	9.11733	0.4	10.0209	0.082	1.365892
26	5.54	2.67	6.66667	0.318047	9.43538	0.4	10.4209	0.082	1.365892
27	5.64	2.77	6.66667	0.353385	9.78876	0.4	10.8209	0.0466	0.776917
28	5.72	2.85	6.26959	0.282708	10.0715	0.37618	11.1971	0.0935	1.557792
29	5.82	2.95	6.26959	0.353385	10.4249	0.37618	11.5733	0.0228	0.379842
30	5.91	3.04	6.26959	0.318047	10.7429	0.37618	11.9494	0.0581	0.968817
31	6	3.13	6.26959	0.318047	11.061	0.37618	12.3256	0.0581	0.968817
32	6.1	3.23	6.26959	0.353385	11.4143	0.37618	12.7018	0.0228	0.379842
33	6.185	3.315	6.26959	0.300377	11.7147	0.37618	13.078	0.0758	1.263305
34	6.27	3.4	6.26959	0.300377	12.0151	0.37618	13.4541	0.0758	1.263305

35	6.37	3.5	6.26959	0.353385	12.3685	0.37618	13.8303	0.0228	0.379842
36	6.45	3.58	6.26959	0.282708	12.6512	0.37618	14.2065	0.0935	1.557792
37	6.54	3.67	6.26959	0.318047	12.9692	0.37618	14.5827	0.0581	0.968817
38	6.62	3.75	6.26959	0.282708	13.2519	0.37618	14.9588	0.0935	1.557792
39	6.71	3.84	6.26959	0.318047	13.57	0.37618	15.335	0.0581	0.968817
40	6.8	3.93	6.55738	0.318047	13.888	0.39344	15.7285	0.0754	1.256602
41	6.892	4.022	6.55738	0.325114	14.2131	0.39344	16.1219	0.0683	1.138807
42	6.98	4.11	6.55738	0.310979	14.5241	0.39344	16.5153	0.0825	1.374397
43	7.06	4.19	6.55738	0.282708	14.8068	0.39344	16.9088	0.1107	1.845577
44	7.15	4.28	6.55738	0.318047	15.1249	0.39344	17.3022	0.0754	1.256602
45	7.24	4.37	6.55738	0.318047	15.4429	0.39344	17.6957	0.0754	1.256602
46	7.315	4.445	6.55738	0.265039	15.708	0.39344	18.0891	0.1284	2.140065
47	7.41	4.54	6.55738	0.335716	16.0437	0.39344	18.4826	0.0577	0.962115
48	7.49	4.62	6.55738	0.282708	16.3264	0.39344	18.876	0.1107	1.845577
49	7.58	4.71	6.55738	0.318047	16.6444	0.39344	19.2694	0.0754	1.256602
50	7.66	4.79	6.55738	0.282708	16.9271	0.39344	19.6629	0.1107	1.845577
51	7.76	4.89	6.55738	0.353385	17.2805	0.39344	20.0563	0.0401	0.667627
52	7.84	4.97	6.55738	0.282708	17.5632	0.39344	20.4498	0.1107	1.845577
53	7.92	5.05	6.55738	0.282708	17.8459	0.39344	20.8432	0.1107	1.845577
54	8	5.13	6.06061	0.282708	18.1287	0.36364	21.2069	0.0809	1.348806
55	8.085	5.215	6.06061	0.300377	18.429	0.36364	21.5705	0.0633	1.054319
56	8.17	5.3	6.06061	0.300377	18.7294	0.36364	21.9341	0.0633	1.054319
57	8.26	5.39	6.06061	0.318047	19.0475	0.36364	22.2978	0.0456	0.759831
58	8.35	5.48	6.06061	0.318047	19.3655	0.36364	22.6614	0.0456	0.759831
59	8.44	5.57	6.06061	0.318047	19.6835	0.36364	23.025	0.0456	0.759831
60	8.525	5.655	6.06061	0.300377	19.9839	0.36364	23.3887	0.0633	1.054319
61	8.62	5.75	6.06061	0.335716	20.3196	0.36364	23.7523	0.0279	0.465344
62	8.63	5.76	1.11111	0.035339	20.355	0.06667	23.819	0.0313	0.522136
			Average rate of inflow (l/sec) =				0.93118		

Matshelagabedi Drawdown pumping test before drilling of laterals 28/7/97



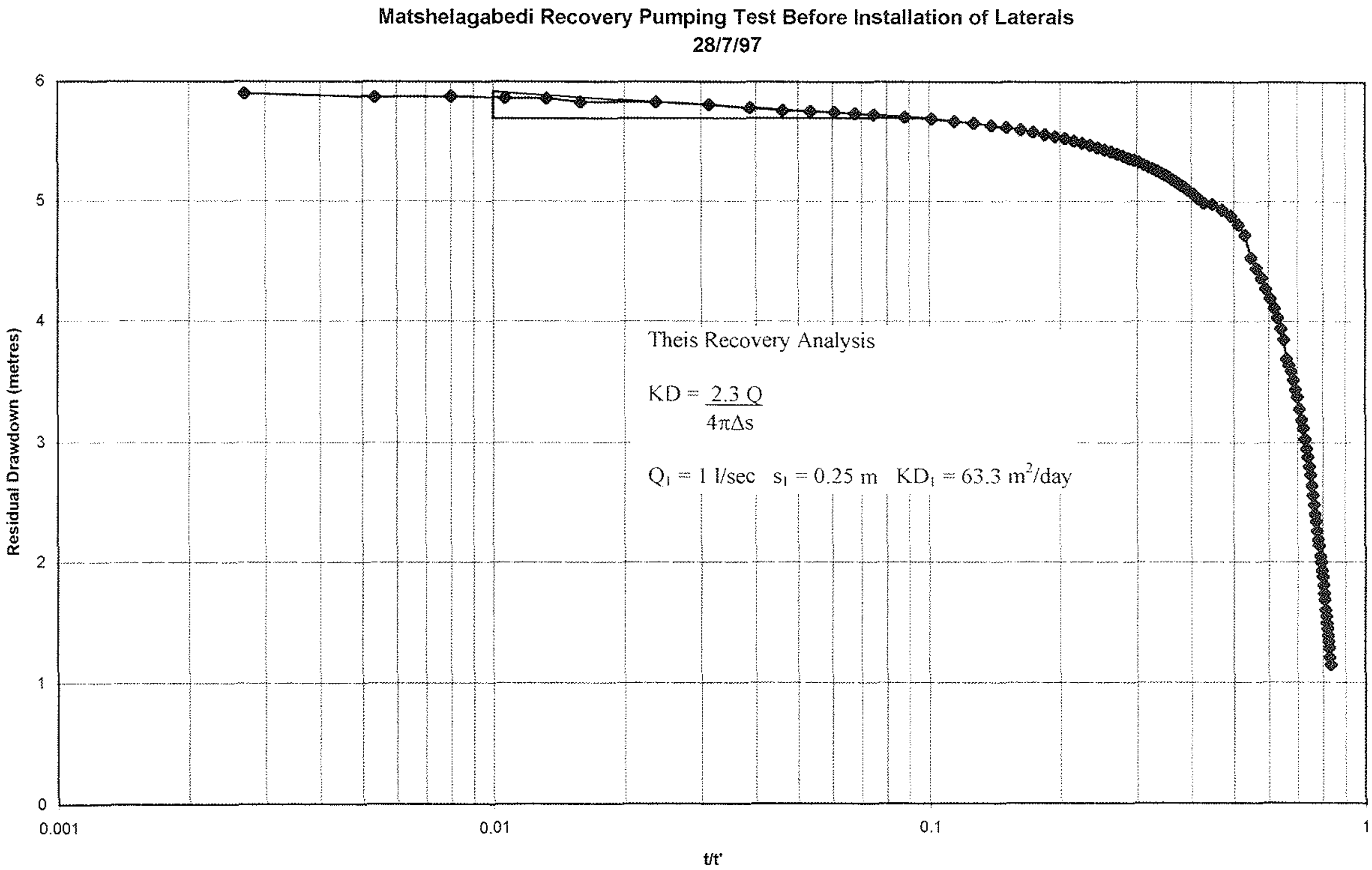
Matshelagabedi Collector Well - Pre-installation of Laterals
Drawdown and Inflow Data - 28/7/97



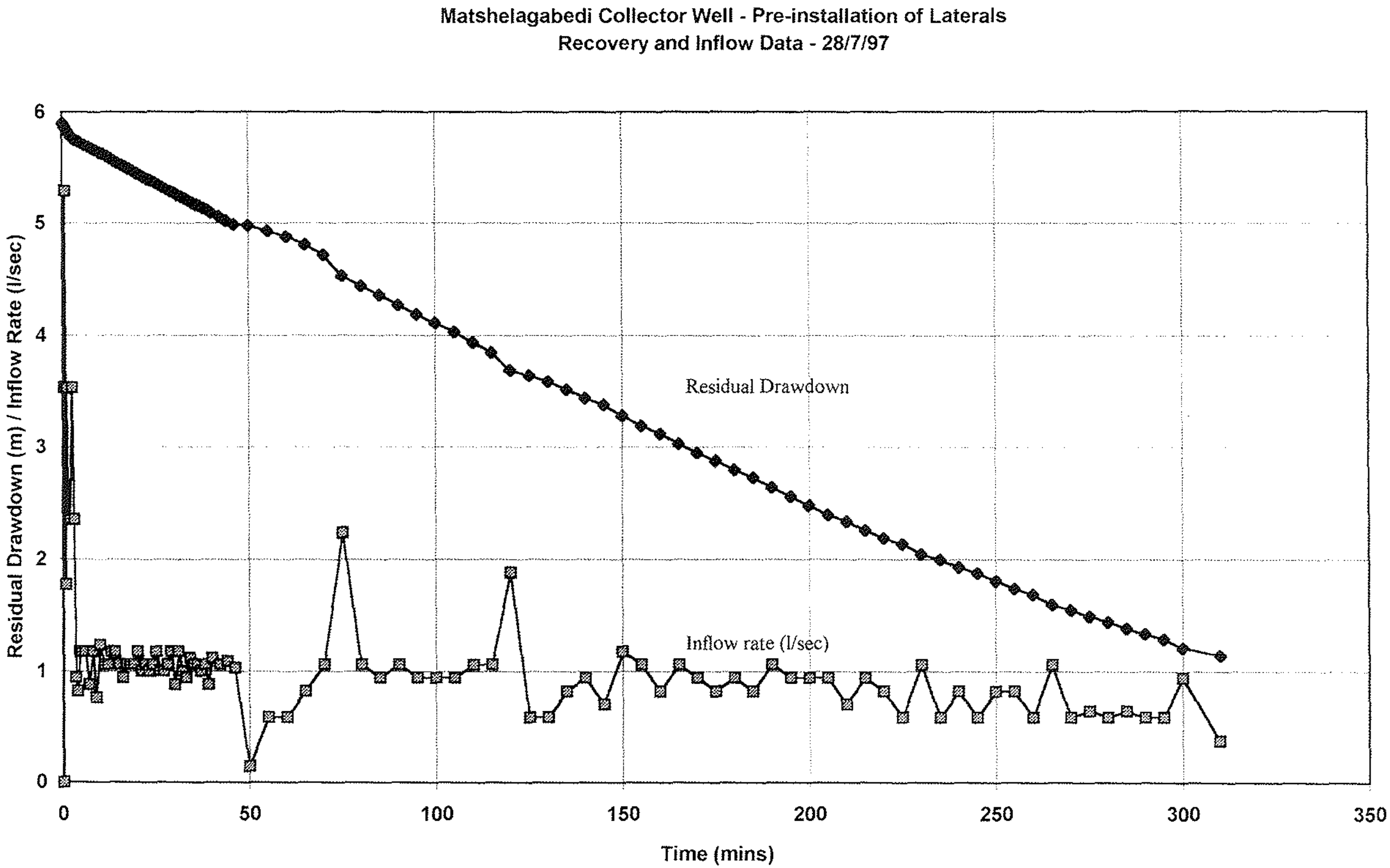
Start of recovery							
Time mins	Time since start mins	t/t'	PWL metres	Residual drawdown metres	Vol well filled m3	cum vol well filled m3	inflow rate l/sec
0	62	0	8.77	5.9			
0.16667	62.167	0.002681	8.77	5.9	0	0	0
0.33333	62.333	0.005348	8.76	5.89	0.03534	0.03534	3.53392
0.5	62.5	0.008	8.75	5.88	0.03534	0.07068	3.53378
0.667	62.667	0.010644	8.735	5.865	0.05301	0.12368	5.29019
0.833	62.833	0.013257	8.73	5.86	0.01767	0.14135	1.77402
1	63	0.015873	8.72	5.85	0.03534	0.17669	3.5268
1.5	63.5	0.023622	8.7	5.83	0.07068	0.24737	2.3559
2	64	0.03125	8.68	5.81	0.07068	0.31805	2.3559
2.5	64.5	0.03876	8.65	5.78	0.10602	0.42406	3.53385
3	65	0.046154	8.63	5.76	0.07068	0.49474	2.3559
3.5	65.5	0.053435	8.622	5.752	0.02827	0.52301	0.94236
4	66	0.060606	8.615	5.745	0.02474	0.54775	0.82456
4.5	66.5	0.067669	8.605	5.735	0.03534	0.58309	1.17795
5	67	0.074627	8.595	5.725	0.03534	0.61842	1.17795
6	68	0.088235	8.575	5.705	0.07068	0.6891	1.17795
7	69	0.101449	8.56	5.69	0.05301	0.74211	0.88346
8	70	0.114286	8.54	5.67	0.07068	0.81279	1.17795
9	71	0.126761	8.527	5.657	0.04594	0.85873	0.76567
10	72	0.138889	8.506	5.636	0.07421	0.93294	1.23685
11	73	0.150685	8.488	5.618	0.06361	0.99655	1.06016
12	74	0.162162	8.47	5.6	0.06361	1.06016	1.06015
13	75	0.173333	8.45	5.58	0.07068	1.13083	1.17795
14	76	0.184211	8.43	5.56	0.07068	1.20151	1.17795
15	77	0.194805	8.412	5.542	0.06361	1.26512	1.06015
16	78	0.205128	8.396	5.526	0.05654	1.32166	0.94236
17	79	0.21519	8.378	5.508	0.06361	1.38527	1.06016
18	80	0.225	8.36	5.49	0.06361	1.44888	1.06016
19	81	0.234568	8.342	5.472	0.06361	1.51249	1.06015
20	82	0.243902	8.322	5.452	0.07068	1.58316	1.17795
21	83	0.253012	8.305	5.435	0.06008	1.64324	1.00126
22	84	0.261905	8.287	5.417	0.06361	1.70685	1.06015
23	85	0.270588	8.27	5.4	0.06008	1.76693	1.00126
24	86	0.27907	8.252	5.382	0.06361	1.83053	1.06015
25	87	0.287356	8.232	5.362	0.07068	1.90121	1.17795
26	88	0.295455	8.215	5.345	0.06008	1.96129	1.00126
27	89	0.303371	8.198	5.328	0.06008	2.02136	1.00126
28	90	0.311111	8.18	5.31	0.06361	2.08497	1.06016
29	91	0.318681	8.16	5.29	0.07068	2.15565	1.17795
30	92	0.326087	8.145	5.275	0.05301	2.20866	0.88346
31	93	0.333333	8.125	5.255	0.07068	2.27933	1.17795
32	94	0.340426	8.108	5.238	0.06008	2.33941	1.00126
33	95	0.347368	8.092	5.222	0.05654	2.39595	0.94236
34	96	0.354167	8.073	5.203	0.06714	2.46309	1.11905
35	97	0.360825	8.055	5.185	0.06361	2.5267	1.06016
36	98	0.367347	8.037	5.167	0.06361	2.59031	1.06015
37	99	0.373737	8.02	5.15	0.06008	2.65039	1.00126
38	100	0.38	8.002	5.132	0.06361	2.714	1.06015
39	101	0.386139	7.987	5.117	0.05301	2.767	0.88346
40	102	0.392157	7.968	5.098	0.06714	2.83415	1.11905

42	104	0.403846	7.932	5.062	0.12722	2.96137	1.06015
44	106	0.415094	7.895	5.025	0.13075	3.09212	1.0896
46	108	0.425926	7.86	4.99	0.12368	3.2158	1.03071
50	112	0.446429	7.85	4.98	0.03534	3.25114	0.14724
55	117	0.470085	7.8	4.93	0.17669	3.42783	0.58897
60	122	0.491803	7.75	4.88	0.17669	3.60453	0.58897
65	127	0.511811	7.68	4.81	0.24737	3.8519	0.82457
70	132	0.530303	7.59	4.72	0.31805	4.16994	1.06016
75	137	0.547445	7.4	4.53	0.67143	4.84137	2.2381
80	142	0.56338	7.31	4.44	0.31805	5.15942	1.06016
85	147	0.578231	7.23	4.36	0.28271	5.44213	0.94236
90	152	0.592105	7.14	4.27	0.31805	5.76018	1.06016
95	157	0.605096	7.06	4.19	0.28271	6.04288	0.94236
100	162	0.617284	6.98	4.11	0.28271	6.32559	0.94236
105	167	0.628743	6.9	4.03	0.28271	6.6083	0.94236
110	172	0.639535	6.81	3.94	0.31805	6.92635	1.06016
115	177	0.649718	6.72	3.85	0.31805	7.24439	1.06016
120	182	0.659341	6.56	3.69	0.56542	7.80981	1.88472
125	187	0.668449	6.51	3.64	0.17669	7.9865	0.58897
130	192	0.677083	6.46	3.59	0.17669	8.16319	0.58897
135	197	0.685279	6.39	3.52	0.24737	8.41056	0.82457
140	202	0.693069	6.31	3.44	0.28271	8.69327	0.94236
145	207	0.700483	6.25	3.38	0.21203	8.9053	0.70677
150	212	0.707547	6.15	3.28	0.35338	9.25869	1.17795
155	217	0.714286	6.06	3.19	0.31805	9.57673	1.06016
160	222	0.720721	5.99	3.12	0.24737	9.8241	0.82456
165	227	0.726872	5.9	3.03	0.31805	10.1421	1.06016
170	232	0.732759	5.82	2.95	0.28271	10.4249	0.94236
175	237	0.738397	5.75	2.88	0.24737	10.6722	0.82457
180	242	0.743802	5.67	2.8	0.28271	10.9549	0.94236
185	247	0.748988	5.6	2.73	0.24737	11.2023	0.82457
190	252	0.753968	5.51	2.64	0.31805	11.5204	1.06016
195	257	0.758755	5.43	2.56	0.28271	11.8031	0.94236
200	262	0.763359	5.35	2.48	0.28271	12.0858	0.94236
205	267	0.76779	5.27	2.4	0.28271	12.3685	0.94236
210	272	0.772059	5.21	2.34	0.21203	12.5805	0.70677
215	277	0.776173	5.13	2.26	0.28271	12.8632	0.94236
220	282	0.780142	5.06	2.19	0.24737	13.1106	0.82457
225	287	0.783972	5.01	2.14	0.17669	13.2873	0.58897
230	292	0.787671	4.92	2.05	0.31805	13.6053	1.06016
235	297	0.791246	4.87	2	0.17669	13.782	0.58897
240	302	0.794702	4.8	1.93	0.24737	14.0294	0.82457
245	307	0.798046	4.75	1.88	0.17669	14.2061	0.58897
250	312	0.801282	4.68	1.81	0.24737	14.4534	0.82457
255	317	0.804416	4.61	1.74	0.24737	14.7008	0.82456
260	322	0.807453	4.56	1.69	0.17669	14.8775	0.58898
265	327	0.810398	4.47	1.6	0.31805	15.1956	1.06016
270	332	0.813253	4.42	1.55	0.17669	15.3722	0.58897
275	337	0.816024	4.365	1.495	0.19436	15.5666	0.64787
280	342	0.818713	4.315	1.445	0.17669	15.7433	0.58897
285	347	0.821326	4.26	1.39	0.19436	15.9377	0.64787
290	352	0.823864	4.21	1.34	0.17669	16.1144	0.58897
295	357	0.826331	4.16	1.29	0.17669	16.291	0.58897
300	362	0.828729	4.08	1.21	0.28271	16.5738	0.94236

310	372	0.833333	4.016	1.146	0.22617	16.7999	0.37694
		Average rate of inflow (l/sec) =				0.90322	



Matshelagabedi Recovery Pumping Test Before Installation of Laterals
28/7/97
Residual Drawdown (metres)
0
1
2
3
4
5
6
0.001
0.01
0.1
1
t/t'
Theis Recovery Analysis
KD = 2.3 Q / 4πΔs
Q1 = 1 l/sec s1 = 0.25 m KD1 = 63.3 m2/day



Matshelagabedi Collector Well - Pre-installation of Laterals
Recovery and Inflow Data - 28/7/97
Residual Drawdown (m) / Inflow Rate (l/sec)
6
5
4
3
2
1
0
Residual Drawdown
Inflow rate (l/sec)
0
50
100
150
200
250
300
350
Time (mins)

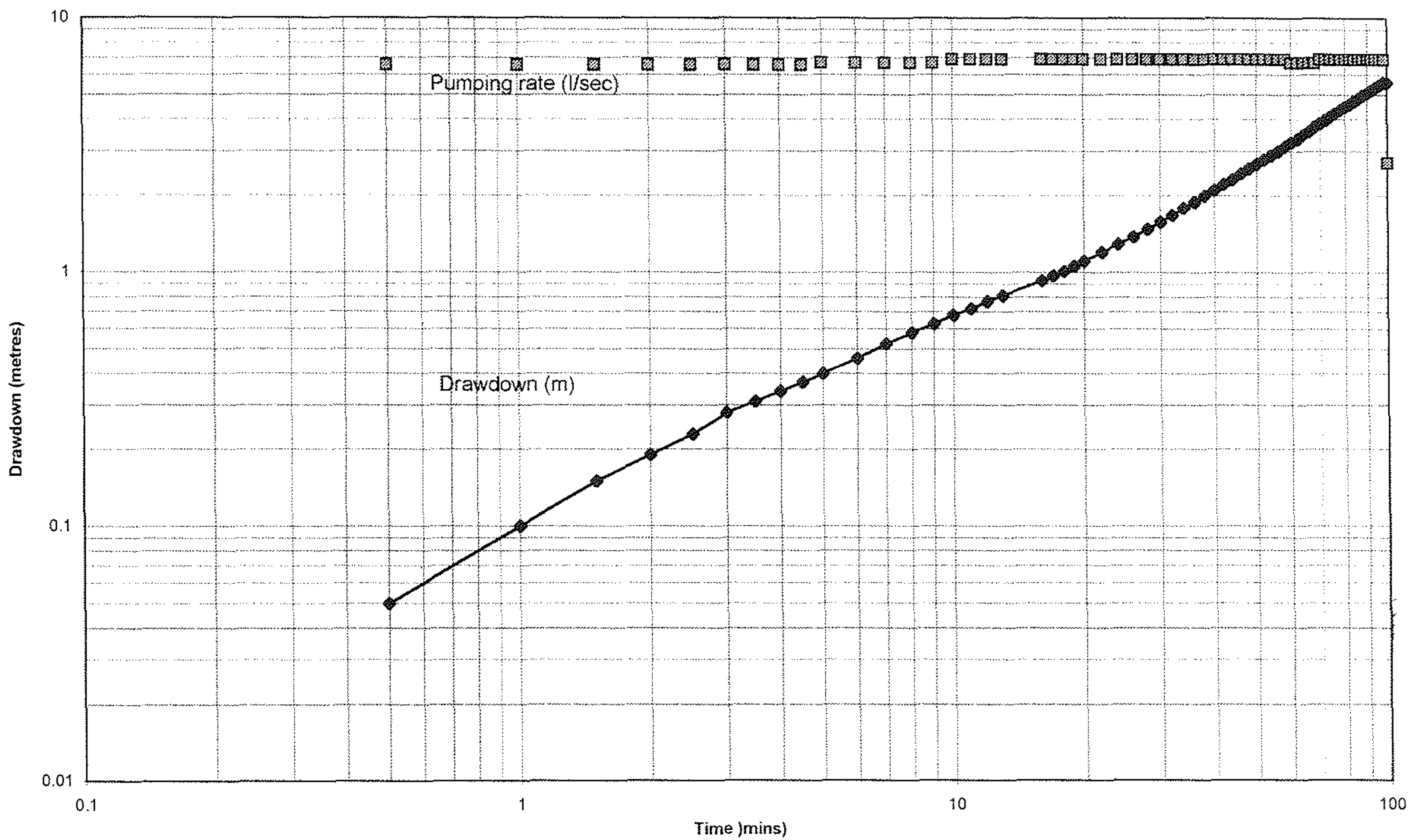
Pumping test 03/08/97
Matshelagabedi Collector Well
After installation of laterals

Rest water level	2.9	mbtoc
Well depth	8.73	mbtoc
Top of casing	0.422	magl

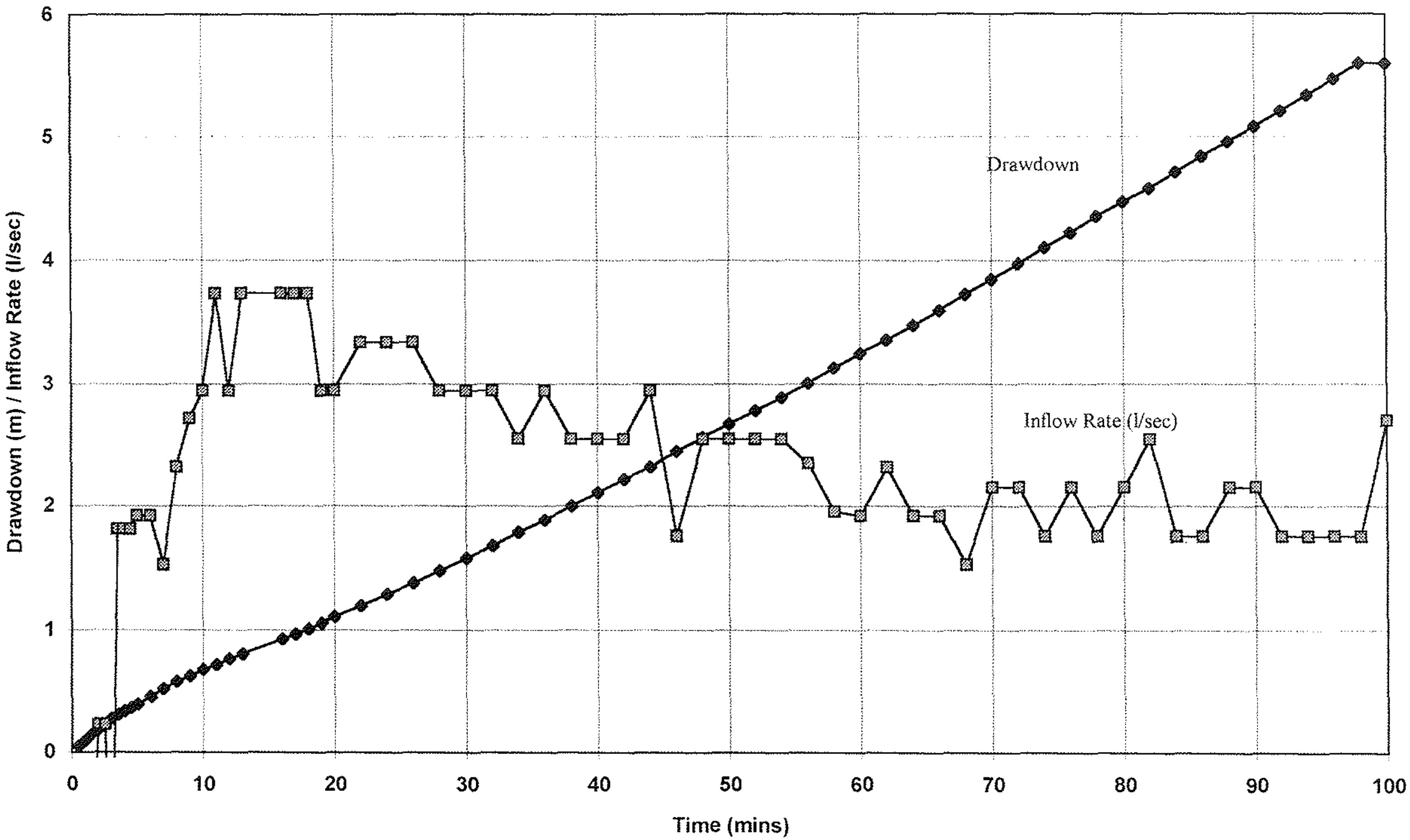
Time mins	PWL metres	Drawdown metres	Pumping rate l/sec	Vol of well emptied m3	Cum vol emptied m3	Volume pumped m3	Cum vol pumped m3	Inflow rate m3	Inflow rate l/sec
0	2.9	0	6.55738						
0.5	2.95	0.05	6.55738	0.176693	0.1767	0.1967	0.1967	0.02	0.668
1	3	0.1	6.55738	0.176692	0.3534	0.1967	0.3934	0.02	0.668
1.5	3.05	0.15	6.55738	0.176692	0.5301	0.1967	0.5902	0.02	0.668
2	3.09	0.19	6.55738	0.141354	0.6714	0.1967	0.7869	0.055	1.846
2.5	3.13	0.23	6.55738	0.141354	0.8128	0.1967	0.9836	0.055	1.846
3	3.18	0.28	6.55738	0.176693	0.9895	0.1967	1.1803	0.02	0.668
3.5	3.21	0.31	6.55738	0.106015	1.0955	0.1967	1.377	0.091	3.024
4	3.24	0.34	6.55738	0.106016	1.2015	0.1967	1.5738	0.091	3.024
4.5	3.27	0.37	6.55738	0.106015	1.3075	0.1967	1.7705	0.091	3.024
5	3.3	0.4	6.66667	0.106015	1.4135	0.2	1.9705	0.094	3.133
6	3.36	0.46	6.66667	0.212031	1.6256	0.4	2.3705	0.188	3.133
7	3.425	0.525	6.66667	0.2297	1.8553	0.4	2.7705	0.17	2.838
8	3.48	0.58	6.66667	0.194362	2.0496	0.4	3.1705	0.206	3.427
9	3.53	0.63	6.66667	0.176692	2.2263	0.4	3.5705	0.223	3.722
10	3.58	0.68	6.89655	0.176693	2.403	0.4138	3.9843	0.237	3.952
11	3.62	0.72	6.89655	0.141354	2.5444	0.4138	4.3981	0.272	4.541
12	3.67	0.77	6.89655	0.176692	2.7211	0.4138	4.8119	0.237	3.952
13	3.71	0.81	6.89655	0.141354	2.8624	0.4138	5.2257	0.272	4.541
16	3.83	0.93	6.89655	0.424062	3.2865	1.2414	6.467	0.817	4.541
17	3.87	0.97	6.89655	0.141354	3.4278	0.4138	6.8808	0.272	4.541
18	3.91	1.01	6.89655	0.141354	3.5692	0.4138	7.2946	0.272	4.541
19	3.96	1.06	6.89655	0.176692	3.7459	0.4138	7.7084	0.237	3.952
20	4.01	1.11	6.89655	0.176692	3.9226	0.4138	8.1222	0.237	3.952
22	4.1	1.2	6.89655	0.318047	4.2406	0.8276	8.9498	0.51	4.246
24	4.19	1.29	6.89655	0.318047	4.5587	0.8276	9.7774	0.51	4.246
26	4.28	1.38	6.89655	0.318047	4.8767	0.8276	10.605	0.51	4.246
28	4.38	1.48	6.89655	0.353385	5.2301	0.8276	11.433	0.474	3.952
30	4.48	1.58	6.89655	0.353385	5.5835	0.8276	12.26	0.474	3.952
32	4.58	1.68	6.89655	0.353385	5.9369	0.8276	13.088	0.474	3.952
34	4.69	1.79	6.89655	0.388724	6.3256	0.8276	13.915	0.439	3.657
36	4.79	1.89	6.89655	0.353385	6.679	0.8276	14.743	0.474	3.952
38	4.9	2	6.89655	0.388724	7.0677	0.8276	15.57	0.439	3.657
40	5.01	2.11	6.89655	0.388723	7.4564	0.8276	16.398	0.439	3.657
42	5.12	2.22	6.89655	0.388724	7.8451	0.8276	17.226	0.439	3.657
44	5.22	2.32	6.89655	0.353385	8.1985	0.8276	18.053	0.474	3.952
46	5.35	2.45	6.89655	0.459401	8.6579	0.8276	18.881	0.368	3.068
48	5.46	2.56	6.89655	0.388724	9.0467	0.8276	19.708	0.439	3.657
50	5.57	2.67	6.89655	0.388724	9.4354	0.8276	20.536	0.439	3.657
52	5.68	2.78	6.89655	0.388723	9.8241	0.8276	21.364	0.439	3.657
54	5.79	2.89	6.89655	0.388724	10.213	0.8276	22.191	0.439	3.657
56	5.905	3.005	6.89655	0.406393	10.619	0.8276	23.019	0.421	3.51
58	6.03	3.13	6.89655	0.441731	11.061	0.8276	23.846	0.386	3.215
60	6.15	3.25	6.66667	0.424062	11.485	0.8	24.646	0.376	3.133

62	6.26	3.36	6.66667	0.388723	11.874	0.8	25.446	0.411	3.427
64	6.38	3.48	6.66667	0.424062	12.298	0.8	26.246	0.376	3.133
66	6.5	3.6	6.66667	0.424062	12.722	0.8	27.046	0.376	3.133
68	6.63	3.73	6.66667	0.459401	13.181	0.8	27.846	0.341	2.838
70	6.75	3.85	6.89655	0.424062	13.605	0.8276	28.674	0.404	3.363
72	6.87	3.97	6.89655	0.424062	14.029	0.8276	29.502	0.404	3.363
74	7	4.1	6.89655	0.459401	14.489	0.8276	30.329	0.368	3.068
76	7.12	4.22	6.89655	0.424062	14.913	0.8276	31.157	0.404	3.363
78	7.25	4.35	6.89655	0.459401	15.372	0.8276	31.984	0.368	3.068
80	7.37	4.47	6.89655	0.424062	15.796	0.8276	32.812	0.404	3.363
82	7.48	4.58	6.89655	0.388724	16.185	0.8276	33.639	0.439	3.657
84	7.61	4.71	6.89655	0.459401	16.644	0.8276	34.467	0.368	3.068
86	7.74	4.84	6.89655	0.459401	17.104	0.8276	35.295	0.368	3.068
88	7.86	4.96	6.89655	0.424062	17.528	0.8276	36.122	0.404	3.363
90	7.98	5.08	6.89655	0.424062	17.952	0.8276	36.95	0.404	3.363
92	8.11	5.21	6.89655	0.4594	18.411	0.8276	37.777	0.368	3.068
94	8.24	5.34	6.89655	0.459401	18.871	0.8276	38.605	0.368	3.068
96	8.37	5.47	6.89655	0.4594	19.33	0.8276	39.433	0.368	3.068
98	8.5	5.6	6.89655	0.459401	19.79	0.8276	40.26	0.368	3.068
100	8.5	5.6	2.7027	0	19.79	0.3243	40.584	0.324	2.703
			Average rate of inflow (l/sec) =			3.4658			

Matshelagabedi Collector Well - Drawdown pumping test after drilling of laterals - 3/8/97



Matshelagabedi Collector Well - Post-installation of Laterals Drawdown and Inflow Rate Data - 3/8/97

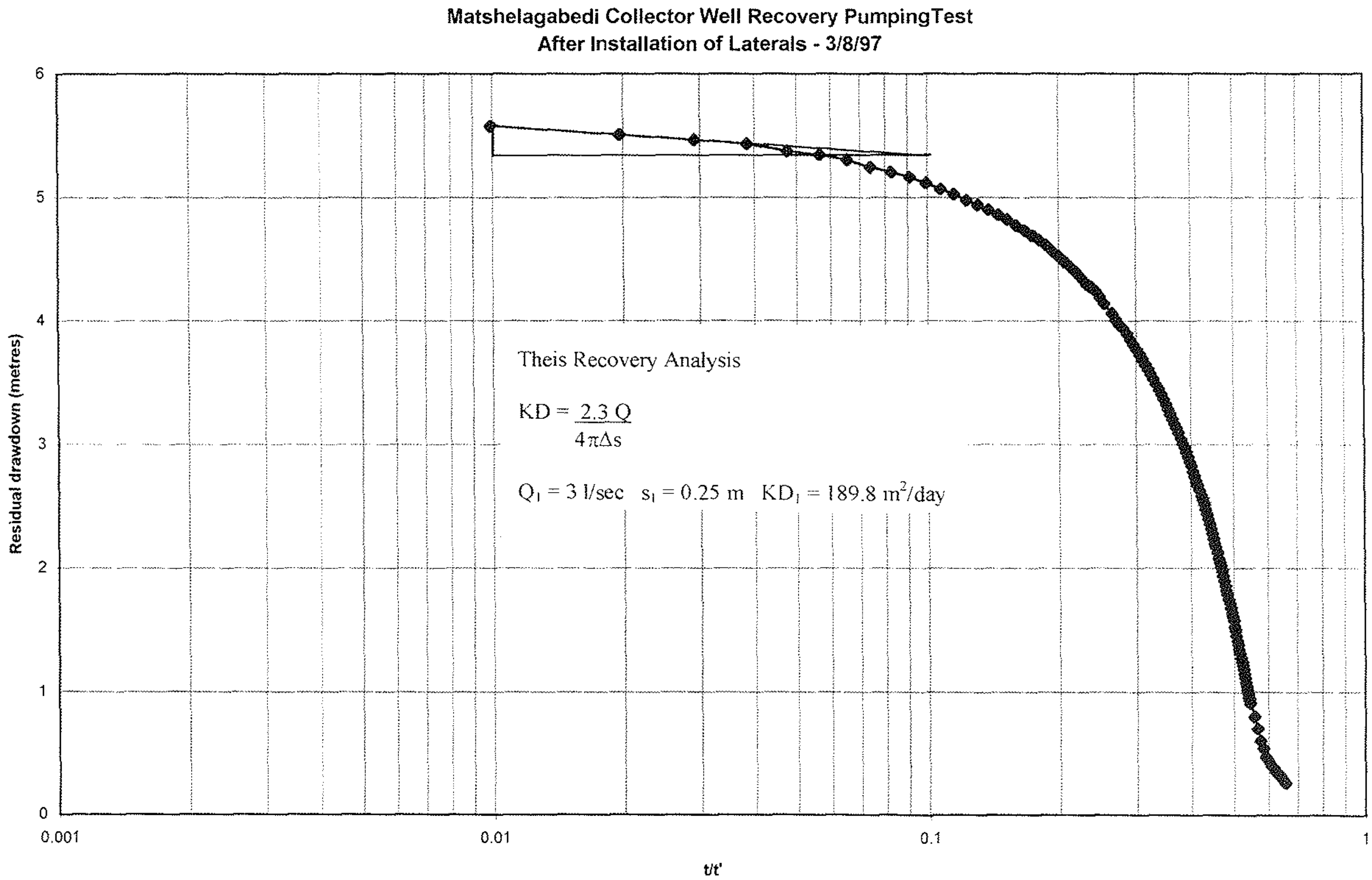


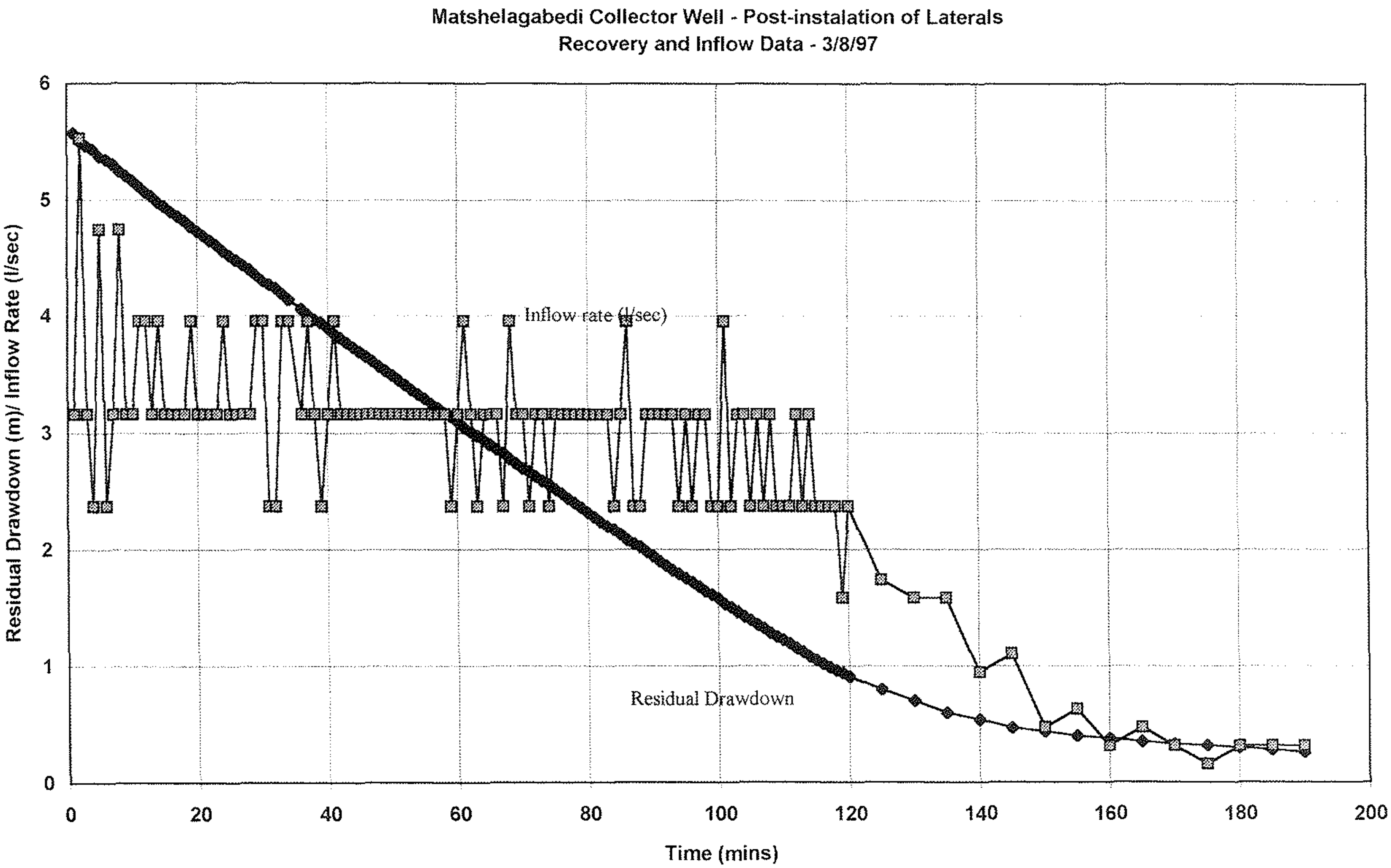
Recovery Test

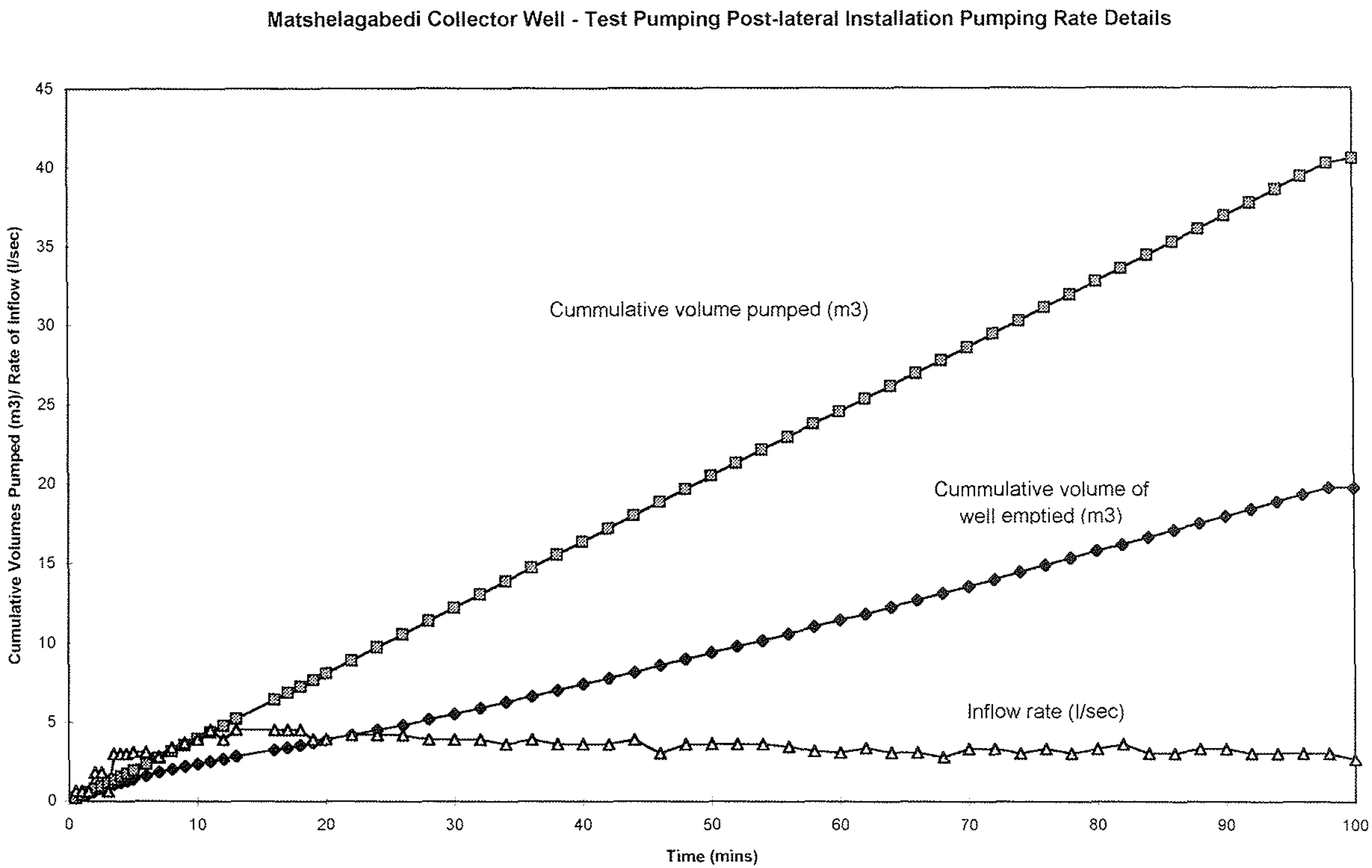
Time since recovery started (t) mins	Time since pumping started (t') mins	t/t'	PWL metres	Residual drawdown metres	Vol well filled m3	cum vol well filled m3	inflow rate l/sec
0	100		8.52	5.62			
1	101	0.01	8.48	5.58	0.1414	0.14135	2.3559
2	102	0.02	8.41	5.51	0.2474	0.38872	4.1228
3	103	0.029	8.37	5.47	0.1414	0.53008	2.3559
4	104	0.038	8.34	5.44	0.106	0.63609	1.7669
5	105	0.048	8.28	5.38	0.212	0.84812	3.5339
6	106	0.057	8.25	5.35	0.106	0.95414	1.7669
7	107	0.065	8.21	5.31	0.1414	1.09549	2.3559
8	108	0.074	8.15	5.25	0.212	1.30752	3.5339
9	109	0.083	8.11	5.21	0.1414	1.44888	2.3559
10	110	0.091	8.07	5.17	0.1414	1.59023	2.3559
11	111	0.099	8.02	5.12	0.1767	1.76693	2.9449
12	112	0.107	7.97	5.07	0.1767	1.94362	2.9449
13	113	0.115	7.93	5.03	0.1414	2.08497	2.3559
14	114	0.123	7.88	4.98	0.1767	2.26166	2.9449
15	115	0.13	7.84	4.94	0.1414	2.40302	2.3559
16	116	0.138	7.8	4.9	0.1414	2.54437	2.3559
17	117	0.145	7.76	4.86	0.1414	2.68573	2.3559
18	118	0.153	7.72	4.82	0.1414	2.82708	2.3559
19	119	0.16	7.67	4.77	0.1767	3.00377	2.9449
20	120	0.167	7.63	4.73	0.1414	3.14513	2.3559
21	121	0.174	7.59	4.69	0.1414	3.28648	2.3559
22	122	0.18	7.55	4.65	0.1414	3.42783	2.3559
23	123	0.187	7.51	4.61	0.1414	3.56919	2.3559
24	124	0.194	7.46	4.56	0.1767	3.74588	2.9449
25	125	0.2	7.42	4.52	0.1414	3.88724	2.3559
26	126	0.206	7.38	4.48	0.1414	4.02859	2.3559
27	127	0.213	7.34	4.44	0.1414	4.16994	2.3559
28	128	0.219	7.3	4.4	0.1414	4.3113	2.3559
29	129	0.225	7.25	4.35	0.1767	4.48799	2.9449
30	130	0.231	7.2	4.3	0.1767	4.66468	2.9449
31	131	0.237	7.17	4.27	0.106	4.7707	1.7669
32	132	0.242	7.14	4.24	0.106	4.87671	1.7669
33	133	0.248	7.09	4.19	0.1767	5.05341	2.9449
34	134	0.254	7.04	4.14	0.1767	5.2301	2.9449
36	136	0.265	6.96	4.06	0.2827	5.51281	2.3559
37	137	0.27	6.91	4.01	0.1767	5.6895	2.9449
38	138	0.275	6.87	3.97	0.1414	5.83085	2.3559
39	139	0.281	6.84	3.94	0.106	5.93687	1.7669
40	140	0.286	6.8	3.9	0.1414	6.07822	2.3559
41	141	0.291	6.75	3.85	0.1767	6.25491	2.9449
42	142	0.296	6.71	3.81	0.1414	6.39627	2.3559
43	143	0.301	6.67	3.77	0.1414	6.53762	2.3559
44	144	0.306	6.63	3.73	0.1414	6.67898	2.3559
45	145	0.31	6.59	3.69	0.1414	6.82033	2.3559
46	146	0.315	6.55	3.65	0.1414	6.96168	2.3559
47	147	0.32	6.51	3.61	0.1414	7.10304	2.3559
48	148	0.324	6.47	3.57	0.1414	7.24439	2.3559

49	149	0.329	6.43	3.53	0.1414	7.38575	2.3559
50	150	0.333	6.39	3.49	0.1414	7.5271	2.3559
51	151	0.338	6.35	3.45	0.1414	7.66845	2.3559
52	152	0.342	6.31	3.41	0.1414	7.80981	2.3559
53	153	0.346	6.27	3.37	0.1414	7.95116	2.3559
54	154	0.351	6.23	3.33	0.1414	8.09252	2.3559
55	155	0.355	6.19	3.29	0.1414	8.23387	2.3559
56	156	0.359	6.15	3.25	0.1414	8.37522	2.3559
57	157	0.363	6.11	3.21	0.1414	8.51658	2.3559
58	158	0.367	6.07	3.17	0.1414	8.65793	2.3559
59	159	0.371	6.04	3.14	0.106	8.76395	1.7669
60	160	0.375	6	3.1	0.1414	8.9053	2.3559
61	161	0.379	5.95	3.05	0.1767	9.08199	2.9449
62	162	0.383	5.91	3.01	0.1414	9.22335	2.3559
63	163	0.387	5.88	2.98	0.106	9.32936	1.7669
64	164	0.39	5.84	2.94	0.1414	9.47072	2.3559
65	165	0.394	5.8	2.9	0.1414	9.61207	2.3559
66	166	0.398	5.76	2.86	0.1414	9.75343	2.3559
67	167	0.401	5.73	2.83	0.106	9.85944	1.7669
68	168	0.405	5.68	2.78	0.1767	10.0361	2.9449
69	169	0.408	5.64	2.74	0.1414	10.1775	2.3559
70	170	0.412	5.6	2.7	0.1414	10.3188	2.3559
71	171	0.415	5.57	2.67	0.106	10.4249	1.7669
72	172	0.419	5.53	2.63	0.1414	10.5662	2.3559
73	173	0.422	5.49	2.59	0.1414	10.7076	2.3559
74	174	0.425	5.46	2.56	0.106	10.8136	1.7669
75	175	0.429	5.42	2.52	0.1414	10.9549	2.3559
76	176	0.432	5.38	2.48	0.1414	11.0963	2.3559
77	177	0.435	5.34	2.44	0.1414	11.2376	2.3559
78	178	0.438	5.3	2.4	0.1414	11.379	2.3559
79	179	0.441	5.26	2.36	0.1414	11.5204	2.3559
80	180	0.444	5.22	2.32	0.1414	11.6617	2.3559
81	181	0.448	5.18	2.28	0.1414	11.8031	2.3559
82	182	0.451	5.14	2.24	0.1414	11.9444	2.3559
83	183	0.454	5.1	2.2	0.1414	12.0858	2.3559
84	184	0.457	5.07	2.17	0.106	12.1918	1.7669
85	185	0.459	5.03	2.13	0.1414	12.3331	2.3559
86	186	0.462	4.98	2.08	0.1767	12.5098	2.9449
87	187	0.465	4.95	2.05	0.106	12.6158	1.7669
88	188	0.468	4.92	2.02	0.106	12.7219	1.7669
89	189	0.471	4.88	1.98	0.1414	12.8632	2.3559
90	190	0.474	4.84	1.94	0.1414	13.0046	2.3559
91	191	0.476	4.8	1.9	0.1414	13.1459	2.3559
92	192	0.479	4.76	1.86	0.1414	13.2873	2.3559
93	193	0.482	4.72	1.82	0.1414	13.4286	2.3559
94	194	0.485	4.69	1.79	0.106	13.5346	1.7669
95	195	0.487	4.65	1.75	0.1414	13.676	2.3559
96	196	0.49	4.62	1.72	0.106	13.782	1.7669
97	197	0.492	4.58	1.68	0.1414	13.9234	2.3559
98	198	0.495	4.54	1.64	0.1414	14.0647	2.3559
99	199	0.497	4.51	1.61	0.106	14.1707	1.7669
100	200	0.5	4.48	1.58	0.106	14.2768	1.7669
101	201	0.502	4.43	1.53	0.1767	14.4534	2.9449
102	202	0.505	4.4	1.5	0.106	14.5595	1.7669

103	203	0.507	4.36	1.46	0.1414	14.7008	2.3559
104	204	0.51	4.32	1.42	0.1414	14.8422	2.3559
105	205	0.512	4.29	1.39	0.106	14.9482	1.7669
106	206	0.515	4.25	1.35	0.1414	15.0895	2.3559
107	207	0.517	4.22	1.32	0.106	15.1956	1.7669
108	208	0.519	4.18	1.28	0.1414	15.3369	2.3559
109	209	0.522	4.15	1.25	0.106	15.4429	1.7669
110	210	0.524	4.12	1.22	0.106	15.5489	1.7669
111	211	0.526	4.09	1.19	0.106	15.655	1.7669
112	212	0.528	4.05	1.15	0.1414	15.7963	2.3559
113	213	0.531	4.02	1.12	0.106	15.9023	1.7669
114	214	0.533	3.98	1.08	0.1414	16.0437	2.3559
115	215	0.535	3.95	1.05	0.106	16.1497	1.7669
116	216	0.537	3.92	1.02	0.106	16.2557	1.7669
117	217	0.539	3.89	0.99	0.106	16.3617	1.7669
118	218	0.541	3.86	0.96	0.106	16.4677	1.7669
119	219	0.543	3.84	0.94	0.0707	16.5384	1.178
120	220	0.545	3.81	0.91	0.106	16.6444	1.7669
125	225	0.556	3.7	0.8	0.3887	17.0332	1.2957
130	230	0.565	3.6	0.7	0.3534	17.3865	1.178
135	235	0.574	3.5	0.6	0.3534	17.7399	1.178
140	240	0.583	3.44	0.54	0.212	17.952	0.7068
145	245	0.592	3.37	0.47	0.2474	18.1993	0.8246
150	250	0.6	3.34	0.44	0.106	18.3053	0.3534
155	255	0.608	3.3	0.4	0.1414	18.4467	0.4712
160	260	0.615	3.28	0.38	0.0707	18.5174	0.2356
165	265	0.623	3.25	0.35	0.106	18.6234	0.3534
170	270	0.63	3.23	0.33	0.0707	18.6941	0.2356
175	275	0.636	3.22	0.32	0.0353	18.7294	0.1178
180	280	0.643	3.2	0.3	0.0707	18.8001	0.2356
185	285	0.649	3.18	0.28	0.0707	18.8708	0.2356
190	290	0.655	3.16	0.26	0.0707	18.9414	0.2356
		Average rate of inflow (l/sec)			1.6615		


Matshelagabedi Collector Well Recovery PumpingTest
After Installation of Laterals - 3/8/97
Residual drawdown (metres)
6
5
4
3
2
1
0
0.001
0.01
0.1
1
t/t'
Theis Recovery Analysis
KD = 2.3 Q / 4πΔs
Q1 = 3 l/sec   s1 = 0.25 m   KD1 = 189.8 m2/day


Matshelagabedi Collector Well - Post-instalation of Laterals
Recovery and Inflow Data - 3/8/97
Residual Drawdown (m)/ Inflow Rate (l/sec)
Time (mins)
Inflow rate (l/sec)
Residual Drawdown
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
160
180
200



Matshelagabedi Collector Well - Test Pumping Post-lateral Installation Pumping Rate Details
Cumulative Volumes Pumped (m3)/ Rate of Inflow (l/sec)
Time (mins)
Cummulative volume pumped (m3)
Cummulative volume of well emptied (m3)
Inflow rate (l/sec)
0
5
10
15
20
25
30
35
40
45
0
10
20
30
40
50
60
70
80
90
100

Pumping test			18/08/97						
Tobane 1 Collector Well									
After installation of laterals									
Rest water level			4.8	mbtoc					
Well depth			8.2	mbtoc					
Top of casing				magl					
Start of test									
Time mins	PWL metres	Drawdown metres	Pumping rate l/sec	Vol of well emptied m3	Cum vol emptied m3	Volume pumped m3	Cum vol pumped m3	Inflow rate m3	Inflow rate l/sec
0	4.8	0	6.66667						
0.5	4.86	0.06	6.66667	0.207319	0.2073	0.2	0.2	-0.007	-0.244
1	4.91	0.11	6.66667	0.172766	0.3801	0.2	0.4	0.027	0.908
1.5	4.97	0.17	6.66667	0.207319	0.5874	0.2	0.6	-0.007	-0.244
2	5.02	0.22	6.66667	0.172766	0.7602	0.2	0.8	0.027	0.908
2.5	5.08	0.28	6.66667	0.207319	0.9675	0.2	1	-0.007	-0.244
3	5.14	0.34	6.66667	0.207319	1.1748	0.2	1.2	-0.007	-0.244
3.5	5.19	0.39	6.66667	0.172766	1.3476	0.2	1.4	0.027	0.908
4	5.25	0.45	6.66667	0.207319	1.5549	0.2	1.6	-0.007	-0.244
4.5	5.29	0.49	6.66667	0.138213	1.6931	0.2	1.8	0.062	2.06
5	5.34	0.54	6.66667	0.172766	1.8659	0.2	2	0.027	0.908
5.5	5.39	0.59	6.66667	0.172766	2.0386	0.2	2.2	0.027	0.908
6	5.45	0.65	6.66667	0.207319	2.246	0.2	2.4	-0.007	-0.244
6.5	5.5	0.7	6.66667	0.172766	2.4187	0.2	2.6	0.027	0.908
7	5.55	0.75	6.66667	0.172766	2.5915	0.2	2.8	0.027	0.908
7.5	5.6	0.8	6.66667	0.172766	2.7643	0.2	3	0.027	0.908
8	5.65	0.85	6.66667	0.172766	2.937	0.2	3.2	0.027	0.908
9	5.75	0.95	6.66667	0.345532	3.2826	0.4	3.6	0.054	0.908
10	5.85	1.05	6.66667	0.345532	3.6281	0.4	4	0.054	0.908
11	5.95	1.15	6.66667	0.345532	3.9736	0.4	4.4	0.054	0.908
12	6.05	1.25	6.66667	0.345532	4.3192	0.4	4.8	0.054	0.908
13	6.14	1.34	6.66667	0.310979	4.6301	0.4	5.2	0.089	1.484
14	6.23	1.43	6.66667	0.310979	4.9411	0.4	5.6	0.089	1.484
15	6.32	1.52	6.66667	0.310979	5.2521	0.4	6	0.089	1.484
16	6.41	1.61	6.66667	0.310979	5.5631	0.4	6.4	0.089	1.484
17	6.51	1.71	6.66667	0.345532	5.9086	0.4	6.8	0.054	0.908
18	6.61	1.81	6.66667	0.345532	6.2541	0.4	7.2	0.054	0.908
19	6.71	1.91	6.66667	0.345532	6.5997	0.4	7.6	0.054	0.908
20	6.81	2.01	6.66667	0.345532	6.9452	0.4	8	0.054	0.908
21	6.91	2.11	6.66667	0.345532	7.2907	0.4	8.4	0.054	0.908
22	7	2.2	6.66667	0.310979	7.6017	0.4	8.8	0.089	1.484
23	7.1	2.3	6.66667	0.345532	7.9472	0.4	9.2	0.054	0.908
25	7.28	2.48	6.66667	0.621958	8.5692	0.8	10	0.178	1.484
27	7.48	2.68	6.66667	0.691064	9.2603	0.8	10.8	0.109	0.908
29	7.69	2.89	6.66667	0.725617	9.9859	0.8	11.6	0.074	0.62
31	7.88	3.08	6.66667	0.656511	10.642	0.8	12.4	0.143	1.196
31.6	7.935	3.135	6.66667	0.190043	10.832	0.24	12.64	0.05	1.388
Rate of inflow		0.9852217	l/sec after dewatering pumping with air						
Average inflow rate (l/sec) =			0.94495		Apparent well diameter (m) =			1.1	

Start of recovery		Tobane 1 Collector Well		18/08/97

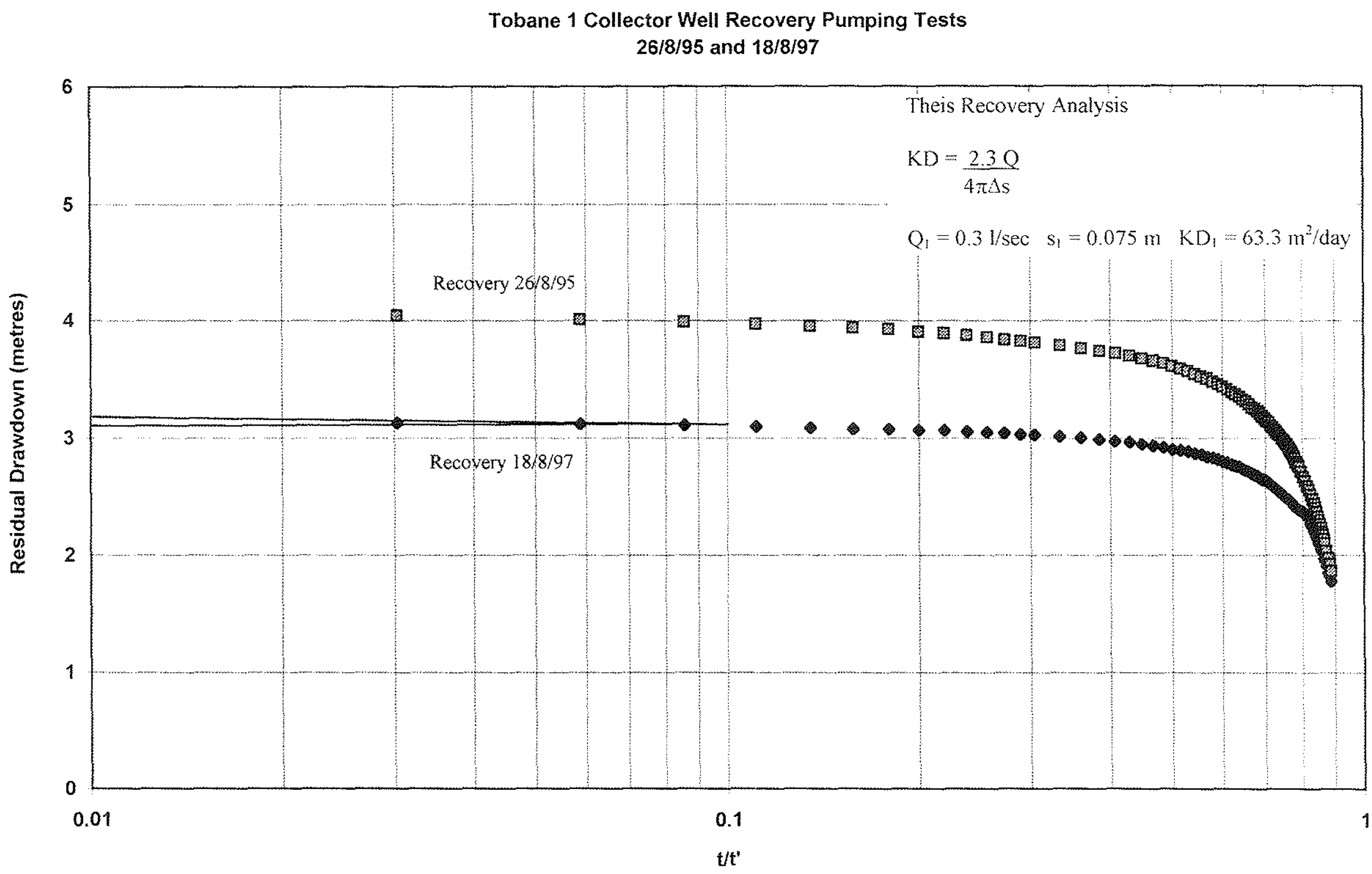
Time since recovery started mins (t)	Time since pumping started mins (t')	t/t'	PWL metres	Residual drawdown metres	Vol well filled m3	Cum vol well filled m3	Inflow rate l/sec
0	32	0	7.935	3.135			
1	33	0.030303	7.93	3.13	0.017277	0.017277	0.287943
2	34	0.058824	7.92	3.12	0.034553	0.05183	0.575887
3	35	0.085714	7.91	3.11	0.034553	0.086383	0.575887
4	36	0.111111	7.9	3.1	0.034553	0.120936	0.575887
5	37	0.135135	7.89	3.09	0.034553	0.155489	0.575887
6	38	0.157895	7.88	3.08	0.034553	0.190043	0.575887
7	39	0.179487	7.875	3.075	0.017277	0.207319	0.287943
8	40	0.2	7.87	3.07	0.017277	0.224596	0.287943
9	41	0.219512	7.865	3.065	0.017277	0.241872	0.287943
10	42	0.238095	7.857	3.057	0.027643	0.269515	0.460709
11	43	0.255814	7.85	3.05	0.024187	0.293702	0.403121
12	44	0.272727	7.845	3.045	0.017277	0.310979	0.287943
13	45	0.288889	7.835	3.035	0.034553	0.345532	0.575887
14	46	0.304348	7.83	3.03	0.017277	0.362809	0.287943
15	47	0.319149	7.82	3.02	0.034553	0.397362	0.575887
16	48	0.333333	7.815	3.015	0.017277	0.414638	0.287943
17	49	0.346939	7.81	3.01	0.017277	0.431915	0.287943
18	50	0.36	7.805	3.005	0.017277	0.449192	0.287943
19	51	0.372549	7.8	3	0.017277	0.466468	0.287943
20	52	0.384615	7.79	2.99	0.034553	0.501021	0.575887
21	53	0.396226	7.78	2.98	0.034553	0.535575	0.575887
22	54	0.407407	7.775	2.975	0.017277	0.552851	0.287943
23	55	0.418182	7.77	2.97	0.017277	0.570128	0.287943
24	56	0.428571	7.765	2.965	0.017277	0.587404	0.287943
25	57	0.438596	7.76	2.96	0.017277	0.604681	0.287943
26	58	0.448276	7.75	2.95	0.034553	0.639234	0.575887
27	59	0.457627	7.74	2.94	0.034553	0.673787	0.575887
28	60	0.466667	7.735	2.935	0.017277	0.691064	0.287943
29	61	0.47541	7.73	2.93	0.017277	0.708341	0.287943
30	62	0.483871	7.72	2.92	0.034553	0.742894	0.575887
31	63	0.492063	7.71	2.91	0.034553	0.777447	0.575887
32	64	0.5	7.705	2.905	0.017277	0.794724	0.287943
33	65	0.507692	7.7	2.9	0.017277	0.812	0.287943
34	66	0.515152	7.695	2.895	0.017277	0.829277	0.287943
35	67	0.522388	7.69	2.89	0.017277	0.846553	0.287943
36	68	0.529412	7.685	2.885	0.017277	0.86383	0.287943
37	69	0.536232	7.675	2.875	0.034553	0.898383	0.575887
38	70	0.542857	7.67	2.87	0.017277	0.91566	0.287943
39	71	0.549296	7.665	2.865	0.017277	0.932936	0.287943
40	72	0.555556	7.66	2.86	0.017277	0.950213	0.287943
41	73	0.561644	7.65	2.85	0.034553	0.984766	0.575887
42	74	0.567568	7.64	2.84	0.034553	1.019319	0.575887
43	75	0.573333	7.635	2.835	0.017277	1.036596	0.287943
44	76	0.578947	7.63	2.83	0.017277	1.053873	0.287943
45	77	0.584416	7.62	2.82	0.034553	1.088426	0.575887
46	78	0.589744	7.615	2.815	0.017277	1.105702	0.287943
47	79	0.594937	7.61	2.81	0.017277	1.122979	0.287943

48	80	0.6	7.6	2.8	0.034553	1.157532	0.575887
49	81	0.604938	7.595	2.795	0.017277	1.174809	0.287943
50	82	0.609756	7.59	2.79	0.017277	1.192085	0.287943
51	83	0.614458	7.58	2.78	0.034553	1.226639	0.575887
52	84	0.619048	7.575	2.775	0.017277	1.243915	0.287943
53	85	0.623529	7.57	2.77	0.017277	1.261192	0.287943
54	86	0.627907	7.565	2.765	0.017277	1.278468	0.287943
55	87	0.632184	7.56	2.76	0.017277	1.295745	0.287943
56	88	0.636364	7.555	2.755	0.017277	1.313022	0.287943
57	89	0.640449	7.55	2.75	0.017277	1.330298	0.287943
58	90	0.644444	7.54	2.74	0.034553	1.364851	0.575887
59	91	0.648352	7.53	2.73	0.034553	1.399405	0.575887
60	92	0.652174	7.525	2.725	0.017277	1.416681	0.287943
61	93	0.655914	7.52	2.72	0.017277	1.433958	0.287943
62	94	0.659574	7.515	2.715	0.017277	1.451234	0.287943
63	95	0.663158	7.51	2.71	0.017277	1.468511	0.287943
64	96	0.666667	7.5	2.7	0.034553	1.503064	0.575887
65	97	0.670103	7.495	2.695	0.017277	1.520341	0.287943
66	98	0.673469	7.49	2.69	0.017277	1.537617	0.287943
67	99	0.676768	7.485	2.685	0.017277	1.554894	0.287943
68	100	0.68	7.48	2.68	0.017277	1.572171	0.287943
69	101	0.683168	7.47	2.67	0.034553	1.606724	0.575887
70	102	0.686275	7.465	2.665	0.017277	1.624	0.287943
71	103	0.68932	7.46	2.66	0.017277	1.641277	0.287943
72	104	0.692308	7.45	2.65	0.034553	1.67583	0.575887
73	105	0.695238	7.445	2.645	0.017277	1.693107	0.287943
74	106	0.698113	7.44	2.64	0.017277	1.710383	0.287943
75	107	0.700935	7.435	2.635	0.017277	1.72766	0.287943
76	108	0.703704	7.43	2.63	0.017277	1.744937	0.287943
77	109	0.706422	7.425	2.625	0.017277	1.762213	0.287943
78	110	0.709091	7.42	2.62	0.017277	1.77949	0.287943
79	111	0.711712	7.41	2.61	0.034553	1.814043	0.575887
80	112	0.714286	7.405	2.605	0.017277	1.83132	0.287943
81	113	0.716814	7.395	2.595	0.034553	1.865873	0.575887
82	114	0.719298	7.39	2.59	0.017277	1.883149	0.287943
83	115	0.721739	7.38	2.58	0.034553	1.917703	0.575887
84	116	0.724138	7.375	2.575	0.017277	1.934979	0.287943
85	117	0.726496	7.37	2.57	0.017277	1.952256	0.287943
86	118	0.728814	7.365	2.565	0.017277	1.969532	0.287943
87	119	0.731092	7.36	2.56	0.017277	1.986809	0.287943
88	120	0.733333	7.35	2.55	0.034553	2.021362	0.575887
89	121	0.735537	7.345	2.545	0.017277	2.038639	0.287943
90	122	0.737705	7.34	2.54	0.017277	2.055915	0.287943
91	123	0.739837	7.335	2.535	0.017277	2.073192	0.287943
92	124	0.741935	7.33	2.53	0.017277	2.090469	0.287943
93	125	0.744	7.325	2.525	0.017277	2.107745	0.287943
94	126	0.746032	7.32	2.52	0.017277	2.125022	0.287943
95	127	0.748031	7.31	2.51	0.034553	2.159575	0.575887
96	128	0.75	7.301	2.501	0.031098	2.190673	0.518298
97	129	0.751938	7.3	2.5	0.003455	2.194128	0.057589
98	130	0.753846	7.295	2.495	0.017277	2.211405	0.287943
99	131	0.755725	7.29	2.49	0.017277	2.228681	0.287943
100	132	0.757576	7.285	2.485	0.017277	2.245958	0.287943
101	133	0.759398	7.28	2.48	0.017277	2.263235	0.287943

102	134	0.761194	7.275	2.475	0.017277	2.280511	0.287943
103	135	0.762963	7.27	2.47	0.017277	2.297788	0.287943
104	136	0.764706	7.265	2.465	0.017277	2.315064	0.287943
105	137	0.766423	7.26	2.46	0.017277	2.332341	0.287943
106	138	0.768116	7.255	2.455	0.017277	2.349618	0.287943
107	139	0.769784	7.25	2.45	0.017277	2.366894	0.287943
108	140	0.771429	7.245	2.445	0.017277	2.384171	0.287943
109	141	0.77305	7.24	2.44	0.017277	2.401447	0.287943
110	142	0.774648	7.235	2.435	0.017277	2.418724	0.287943
112	144	0.777778	7.225	2.425	0.034553	2.453277	0.287943
113	145	0.77931	7.22	2.42	0.017277	2.470554	0.287943
114	146	0.780822	7.215	2.415	0.017277	2.48783	0.287943
115	147	0.782313	7.21	2.41	0.017277	2.505107	0.287943
116	148	0.783784	7.205	2.405	0.017277	2.522384	0.287943
117	149	0.785235	7.2	2.4	0.017277	2.53966	0.287943
118	150	0.786667	7.195	2.395	0.017277	2.556937	0.287943
119	151	0.788079	7.19	2.39	0.017277	2.574213	0.287943
120	152	0.789474	7.185	2.385	0.017277	2.59149	0.287943
125	157	0.796178	7.165	2.365	0.069106	2.660596	0.230355
130	162	0.802469	7.145	2.345	0.069106	2.729703	0.230355
135	167	0.808383	7.125	2.325	0.069106	2.798809	0.230355
140	172	0.813953	7.105	2.305	0.069106	2.867916	0.230355
145	177	0.819209	7.085	2.285	0.069106	2.937022	0.230355
150	182	0.824176	7.065	2.265	0.069106	3.006128	0.230355
155	187	0.828877	7.04	2.24	0.086383	3.092511	0.287943
160	192	0.833333	7.015	2.215	0.086383	3.178894	0.287943
165	197	0.837563	6.99	2.19	0.086383	3.265277	0.287943
170	202	0.841584	6.965	2.165	0.086383	3.35166	0.287943
175	207	0.845411	6.94	2.14	0.086383	3.438043	0.287943
180	212	0.849057	6.91	2.11	0.10366	3.541703	0.345532
185	217	0.852535	6.89	2.09	0.069106	3.610809	0.230355
190	222	0.855856	6.86	2.06	0.10366	3.714469	0.345532
195	227	0.859031	6.835	2.035	0.086383	3.800852	0.287943
200	232	0.862069	6.81	2.01	0.086383	3.887235	0.287943
205	237	0.864979	6.78	1.98	0.10366	3.990895	0.345532
210	242	0.867769	6.755	1.955	0.086383	4.077278	0.287943
215	247	0.870445	6.74	1.94	0.05183	4.129107	0.172766
220	252	0.873016	6.71	1.91	0.10366	4.232767	0.345532
225	257	0.875486	6.68	1.88	0.10366	4.336427	0.345532
230	262	0.877863	6.65	1.85	0.10366	4.440086	0.345532
235	267	0.88015	6.64	1.84	0.034553	4.474639	0.115177
240	272	0.882353	6.62	1.82	0.069106	4.543746	0.230355
245	277	0.884477	6.6	1.8	0.069106	4.612852	0.230355
250	282	0.886525	6.58	1.78	0.069106	4.681959	0.230355

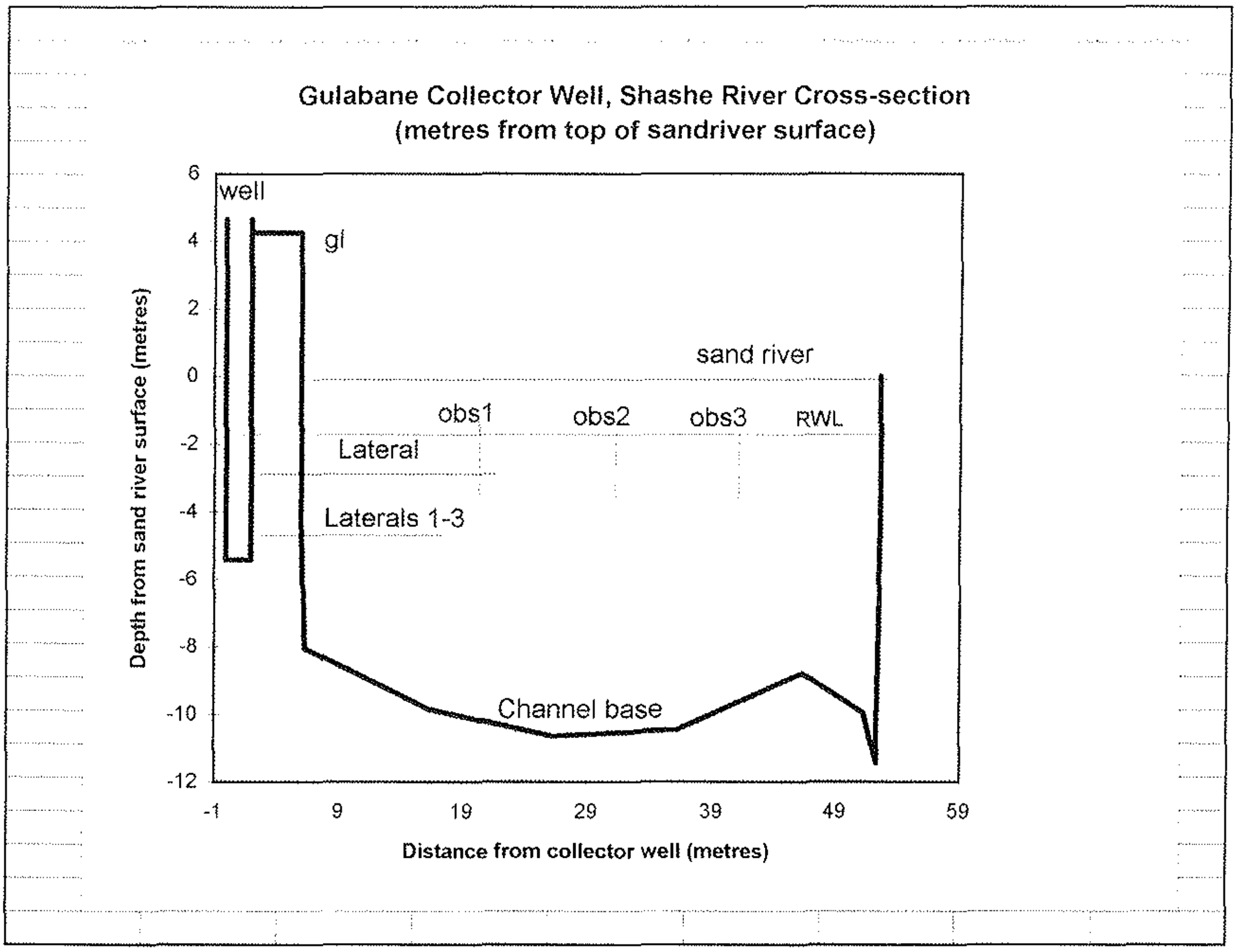
Average rate of inflow (l/sec) = 0.312131

Apparent well diameter (m) = 1.1



Tobane 1 Collector Well Recovery Pumping Tests
26/8/95 and 18/8/97
Theis Recovery Analysis
KD = 2.3 Q / 4πΔs
Q1 = 0.3 l/sec s1 = 0.075 m KD1 = 63.3 m²/day
Recovery 26/8/95
Recovery 18/8/97
Residual Drawdown (metres)
0
1
2
3
4
5
6
0.01
0.1
1
t/t'

APPENDIX E: SEDIMENT GRAIN SIZE ANALYSES


Gulabane Collector Well, Shashe River Cross-section
(metres from top of sandriver surface)
well
gl
sand river
obs1
obs2
obs3
RWL
Lateral
Laterals 1-3
Channel base
Depth from sand river surface (metres)
6
4
2
0
-2
-4
-6
-8
-10
-12
-1
9
19
29
39
49
59
Distance from collector well (metres)

	Grain size analyses							
	Sample No	Gul1	Gul2	Gul3	Gul4	Gul5	Gul6	Gul7
	Distance	10	10	20	20	20	30	30
phi	Depth	1	2	1	2	3	1	2
scale	Sieve size	weight gm	weight gm	weight gm	weight gm	weight gm	weight gm	weight gm
pan	0.71	115.9	75.5	78.5	53.5	141.15	60.13	114.5
0.25	0.85	19.1	24.5	15.8	11.7	30.6	16.15	27.3
0	1	19.7	29	15.7	14.6	30.26	15.9	27
-0.25	1.18	17.5	32.8	15	19.5	28.26	15.25	27
-0.5	1.4	22.5	47.3	17.4	46.3	33.75	16.15	35
-0.75	1.7	4.3	10.7	5	12.7	3.3	4.4	7.85
-1	2	9	22.8	8.5	38.9	12.5	8.15	66.85
-1.25	2.3	16.9	59.2	12.7	129.6	40.6	14	42.5
		224.9	301.8	168.6	326.8	320.42	150.13	348

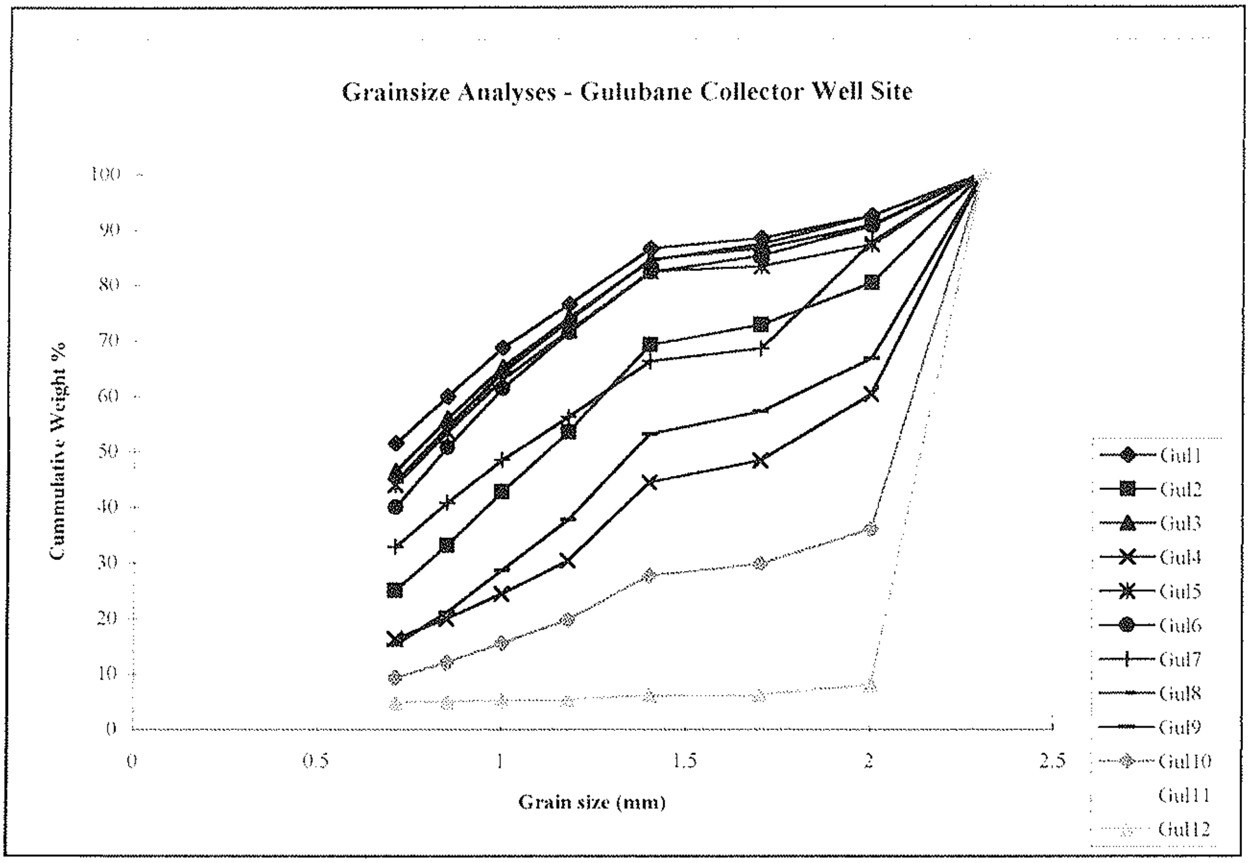
	Sample No	Gul1	Gul2	Gul3	Gul4	Gul5	Gul6	Gul7
	Distance	10	10	20	20	20	30	30
	Depth	1	2	1	2	3	1	2
phi scale	Sieve size	% weight	% weight	% weight	% weight	% weight	% weight	% weight
0.5	0.71	51.53402	25.01657	46.55991	16.37087	44.05156	40.05195	32.9023
0.25	0.85	8.492663	8.117959	9.371293	3.580171	9.549966	10.75734	7.844828
0	1	8.759449	9.609013	9.311981	4.467564	9.443855	10.59082	7.758621
-0.25	1.18	7.781236	10.86812	8.896797	5.966952	8.819674	10.15786	7.758621
-0.5	1.4	10.00445	15.67263	10.32028	14.16769	10.53305	10.75734	10.05747
-0.75	1.7	1.911961	3.545394	2.965599	3.886169	1.029898	2.930793	2.255747
-1	2	4.001779	7.554672	5.041518	11.9033	3.90113	5.428629	19.20977
-1.25	2.3	7.514451	19.61564	7.532622	39.65728	12.67087	9.325251	12.21264
	sum	100	100	100	100	100	100	100

	Sample No	Gul1	Gul2	Gul3	Gul4	Gul5	Gul6	Gul7
	Distance	10	10	20	20	20	30	30
	Depth	1	2	1	2	3	1	2
		cummulativ	cummulativ	cummulativ	cummulativ	cummulativ	cummulativ	cummulativ
phi scale	Sieve size	% weight	% weight	% weight	% weight	% weight	% weight	% weight
		Gul1	Gul2	Gul3	Gul4	Gul5	Gul6	Gul7
0.5	0.71	51.53402	25.01657	46.55991	16.37087	44.05156	40.05195	32.9023
0.25	0.85	60.02668	33.13453	55.9312	19.95104	53.60152	50.8093	40.74713
0	1	68.78613	42.74354	65.24318	24.4186	63.04538	61.40012	48.50575
-0.25	1.18	76.56736	53.61166	74.13998	30.38556	71.86505	71.55798	56.26437
-0.5	1.4	86.57181	69.28429	84.46026	44.55324	82.3981	82.31533	66.32184
-0.75	1.7	88.48377	72.82969	87.42586	48.43941	83.428	85.24612	68.57759
-1	2	92.48555	80.38436	92.46738	60.34272	87.32913	90.67475	87.78736
-1.25	2.3	100	100	100	100	100	100	100

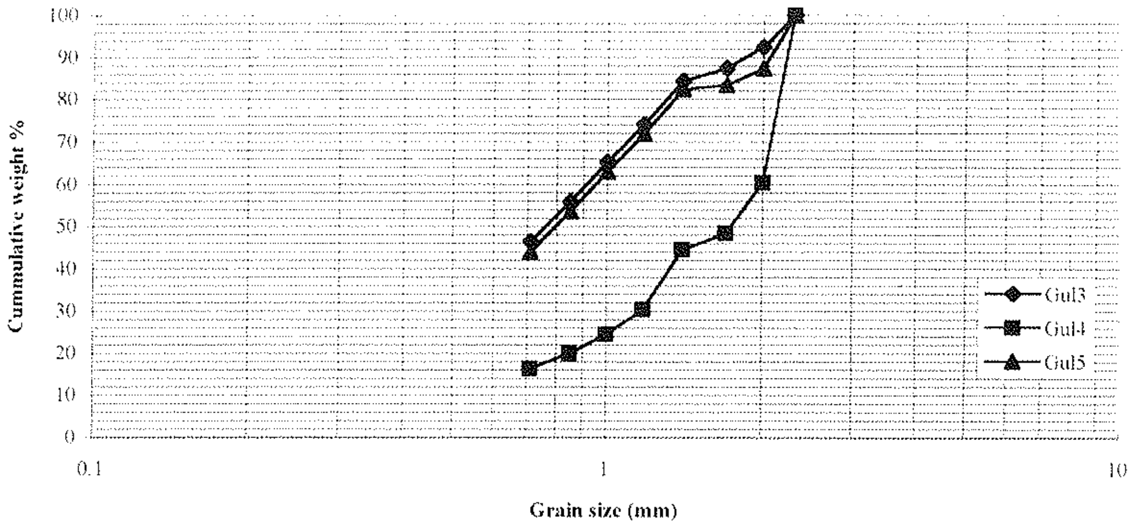
		Gul8	Gul9	Gul10	Gul11	Gul12
	Distance	30	30	30	2	2
phi	Depth	3	4	5	1	2
scale	Sieve size	weight gm	weight gm	weight gm	weight gm	weight gm
pan	0.71	128.7	46.8	33.4	82	12.9
0.25	0.85	28.4	17.8	9.73	12.4	0.5
0	1	28.35	23.2	12.1	12.8	0.8
-0.25	1.18	27.2	27.7	15	10	0.3
-0.5	1.4	31.25	47.2	28.2	10.3	2.2
-0.75	1.7	5.9	12.3	7.55	1.8	0.1
-1	2	12	29.35	22.65	2.3	4.8
-1.25	2.3	26.5	101.7	227.2	1.2	245.4
		288.3	306.05	355.83	132.8	267

		Gul8	Gul9	Gul10	Gul11	Gul12
	Distance	30	30	30	2	2
	Depth	3	4	5	1	2
phi scale	Sieve size	% weight	% weight	% weight	% weight	% weight
0.5	0.71	44.641	15.29162	9.386505	61.74699	4.831461
0.25	0.85	9.85085	5.816043	2.734452	9.337349	0.187266
0	1	9.833507	7.580461	3.4005	9.638554	0.299625
-0.25	1.18	9.434617	9.050809	4.215496	7.53012	0.11236
-0.5	1.4	10.8394	15.42232	7.925133	7.756024	0.82397
-0.75	1.7	2.046479	4.018951	2.1218	1.355422	0.037453
-1	2	4.162331	9.589936	6.365399	1.731928	1.797753
-1.25	2.3	9.191814	33.22986	63.85072	0.903614	91.91011
	sum	100	100	100	100	100

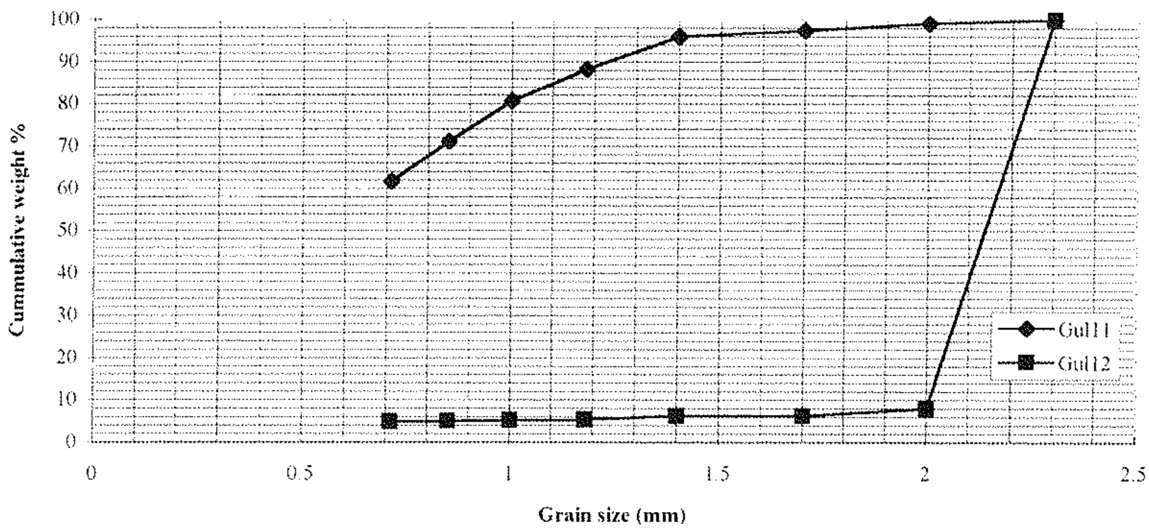
		Gul8	Gul9	Gul10	Gul11	Gul12
	Distance	30	30	30	2	2
	Depth	3	4	5	1	2
e		cummulativ	cummulativ	cummulativ	cummulativ	cummulati
phi scale	Sieve size	% weight	% weight	% weight	% weight	% weight
		Gul8	Gul9	Gul10	Gul11	Gul12
0.5	0.71	44.641	15.29162	9.386505	61.74699	4.831461
0.25	0.85	54.49185	21.10766	12.12096	71.08434	5.018727
0	1	64.32536	28.68812	15.52146	80.72289	5.318352
-0.25	1.18	73.75997	37.73893	19.73695	88.25301	5.430712
-0.5	1.4	84.59938	53.16125	27.66209	96.00904	6.254682
-0.75	1.7	86.64586	57.1802	29.78389	97.36446	6.292135
-1	2	90.80819	66.77014	36.14928	99.09639	8.089888
-1.25	2.3	100	100	100	100	100

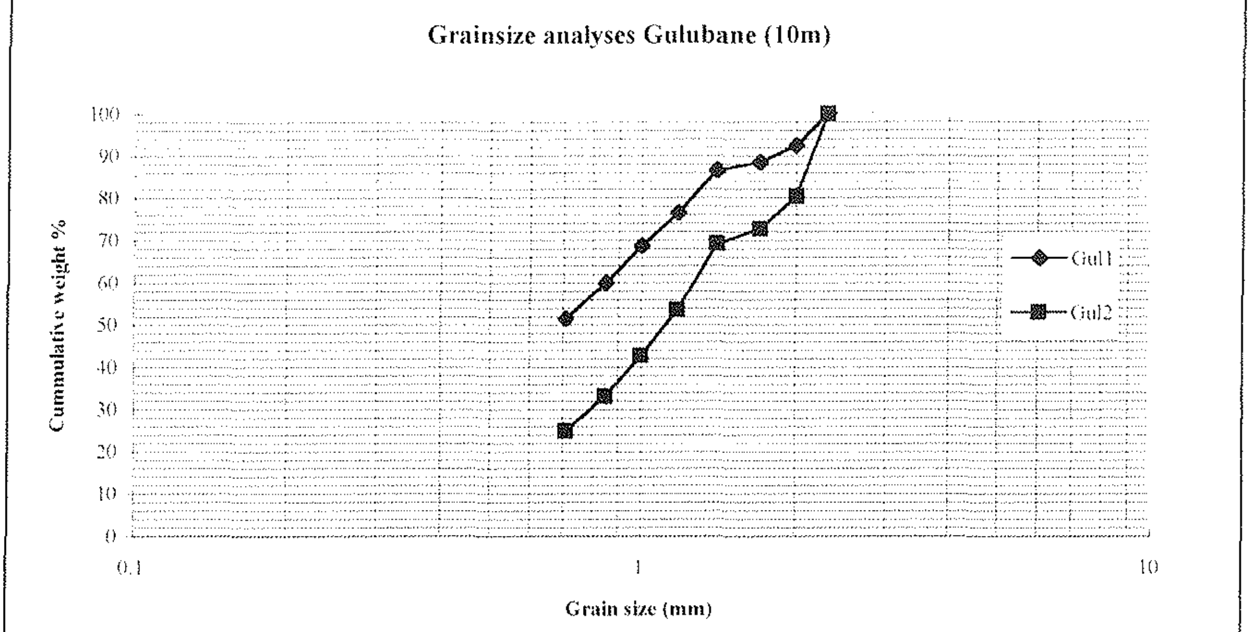

Grainsize Analyses - Gulubane Collector Well Site
Cummulative Weight %
100
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
Grain size (mm)
Gul1
Gul2
Gul3
Gul4
Gul5
Gul6
Gul7
Gul8
Gul9
Gul10
Gul11
Gul12

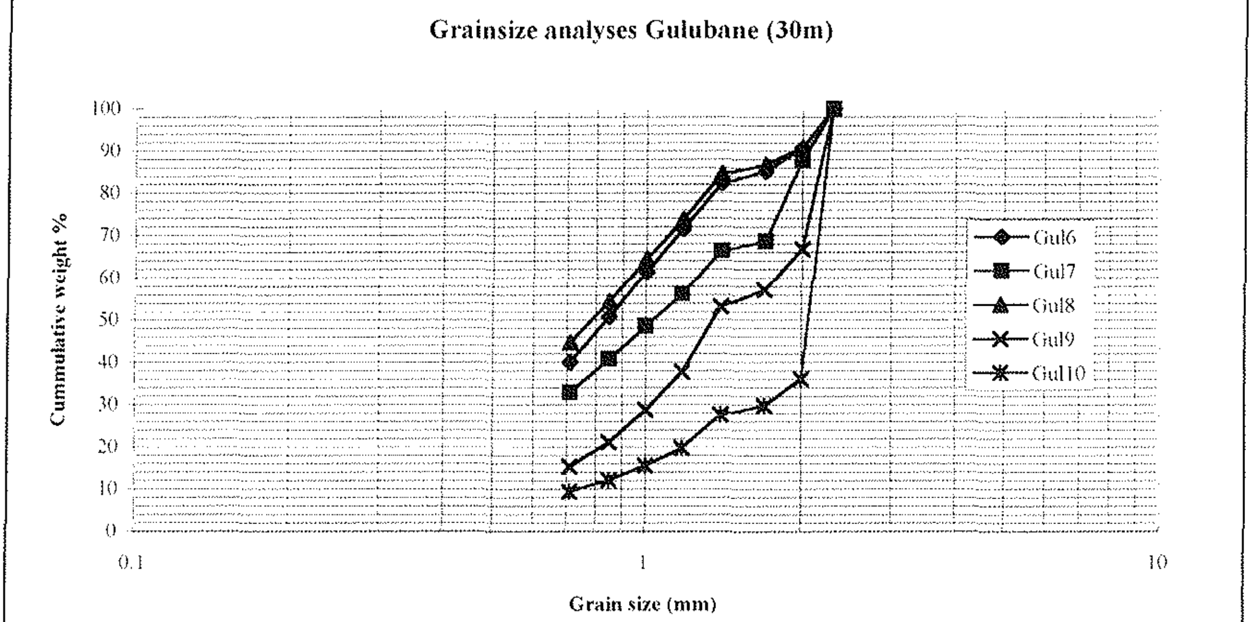
Grainsize analyses Gulubane (20m)



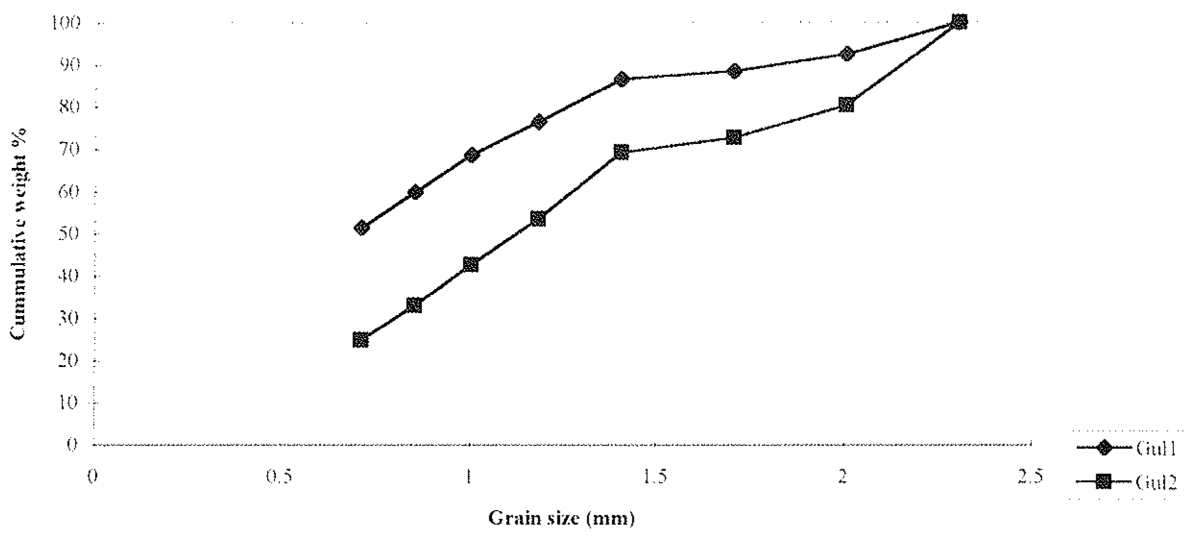
Grainsize analyses Gulubane (2m)



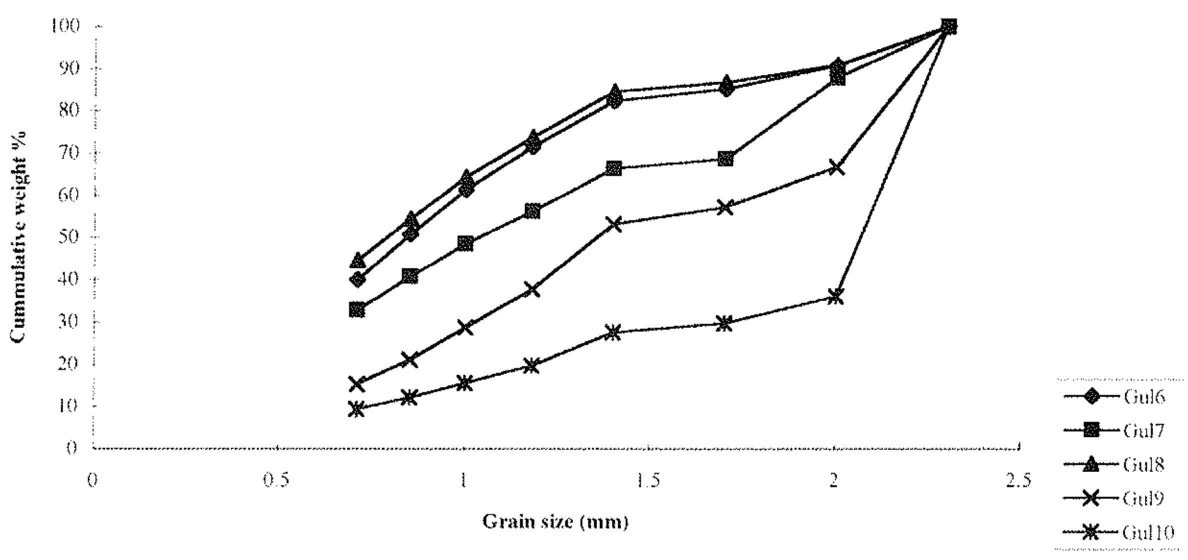

Grainsize analyses Gulubane (10m)
Cummulative weight %
0
10
20
30
40
50
60
70
80
90
100
0.1
1
10
Grain size (mm)
Gul1
Gul2

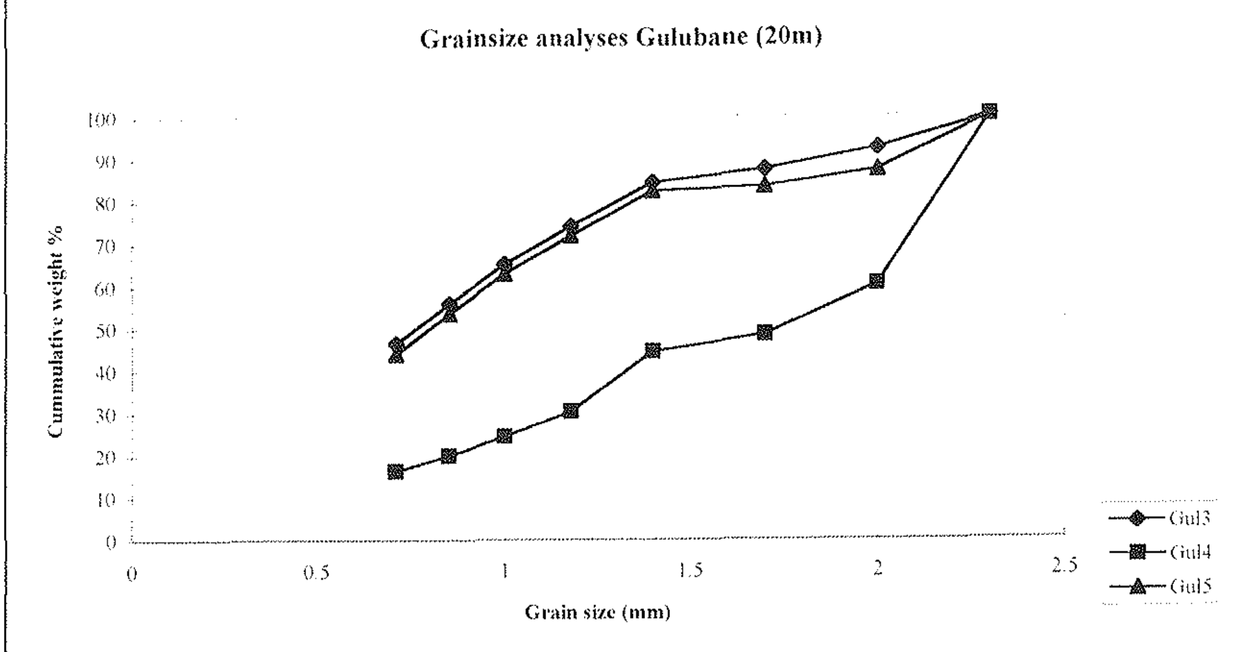

Grainsize analyses Gulubane (30m)
Cummulative weight %
0
10
20
30
40
50
60
70
80
90
100
0.1
1
10
Grain size (mm)
Gul6
Gul7
Gul8
Gul9
Gul10

Grainsize analyses Gulubane (10m)

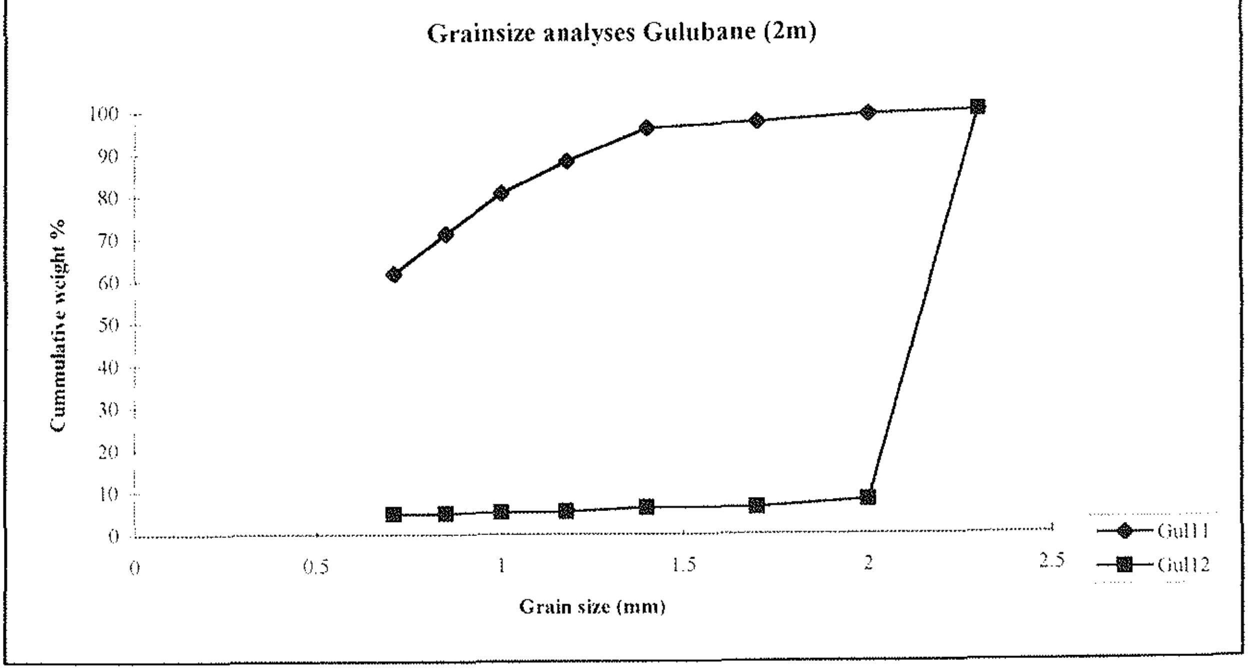


Grainsize analyses Gulubane (30m)



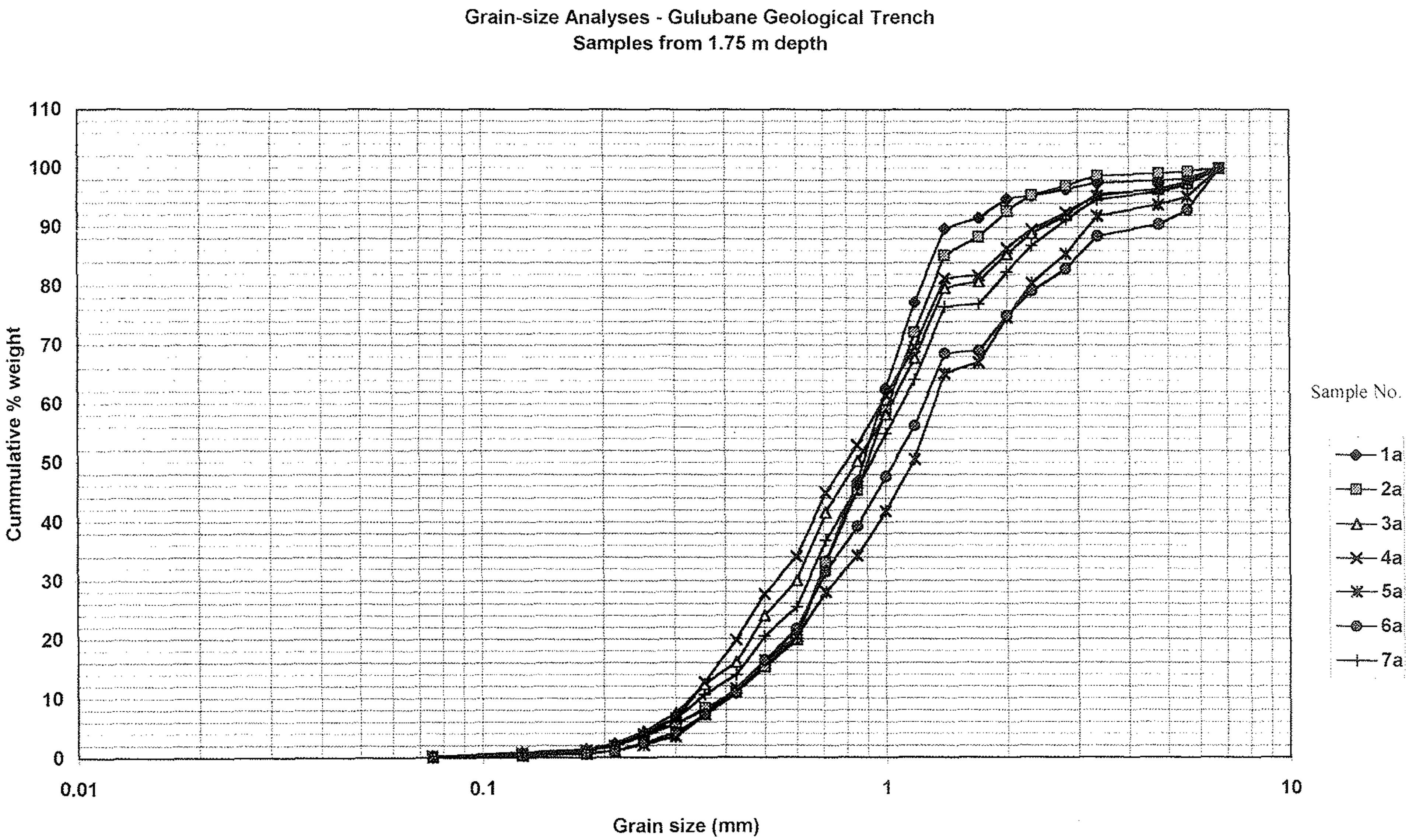


Grainsize analyses Gulubane (20m)
Cummulative weight %
100
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
Grain size (mm)
Gul3
Gul4
Gul5

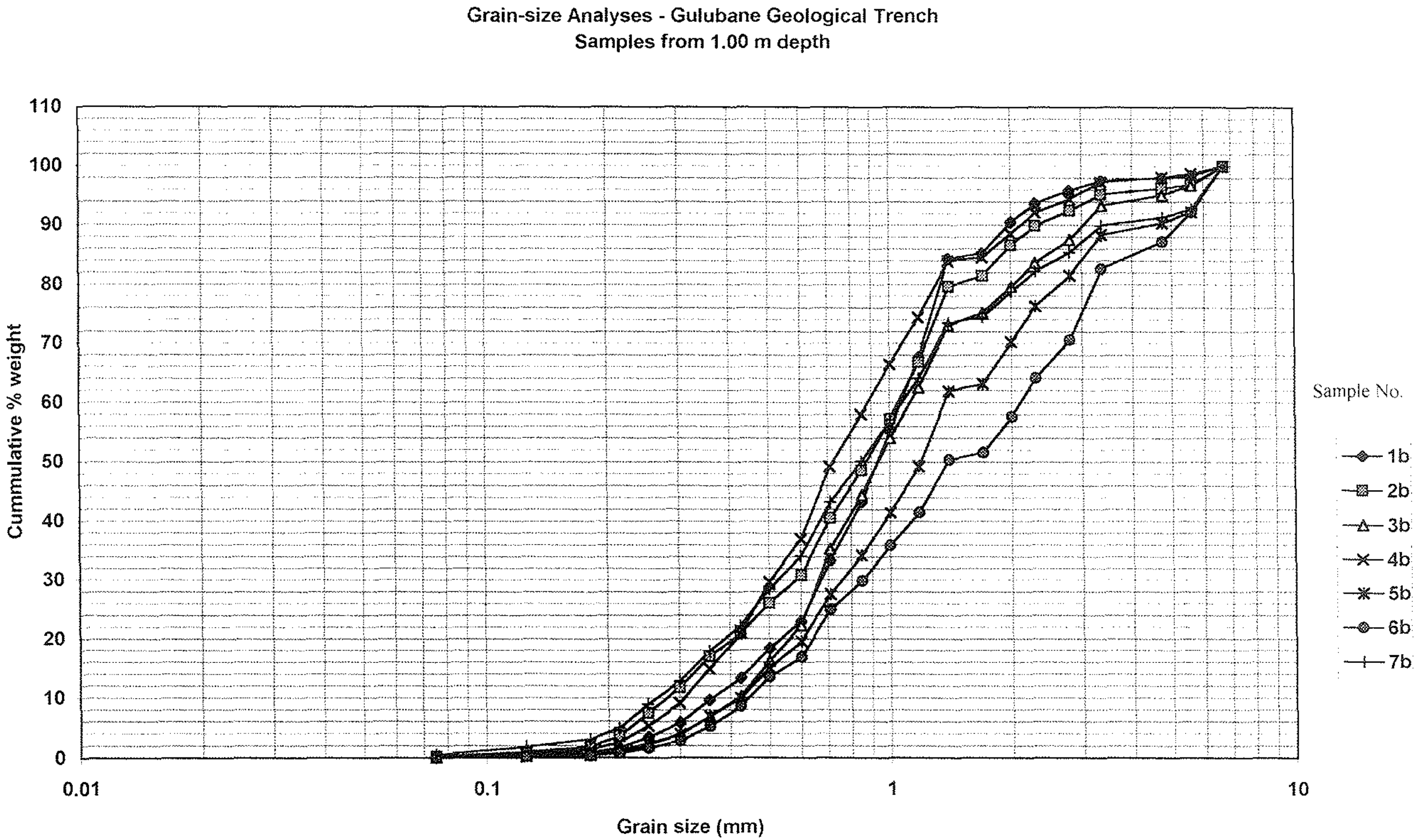


Grainsize analyses Gulubane (2m)
Cummulative weight %
100
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
Grain size (mm)
Gul11
Gul12

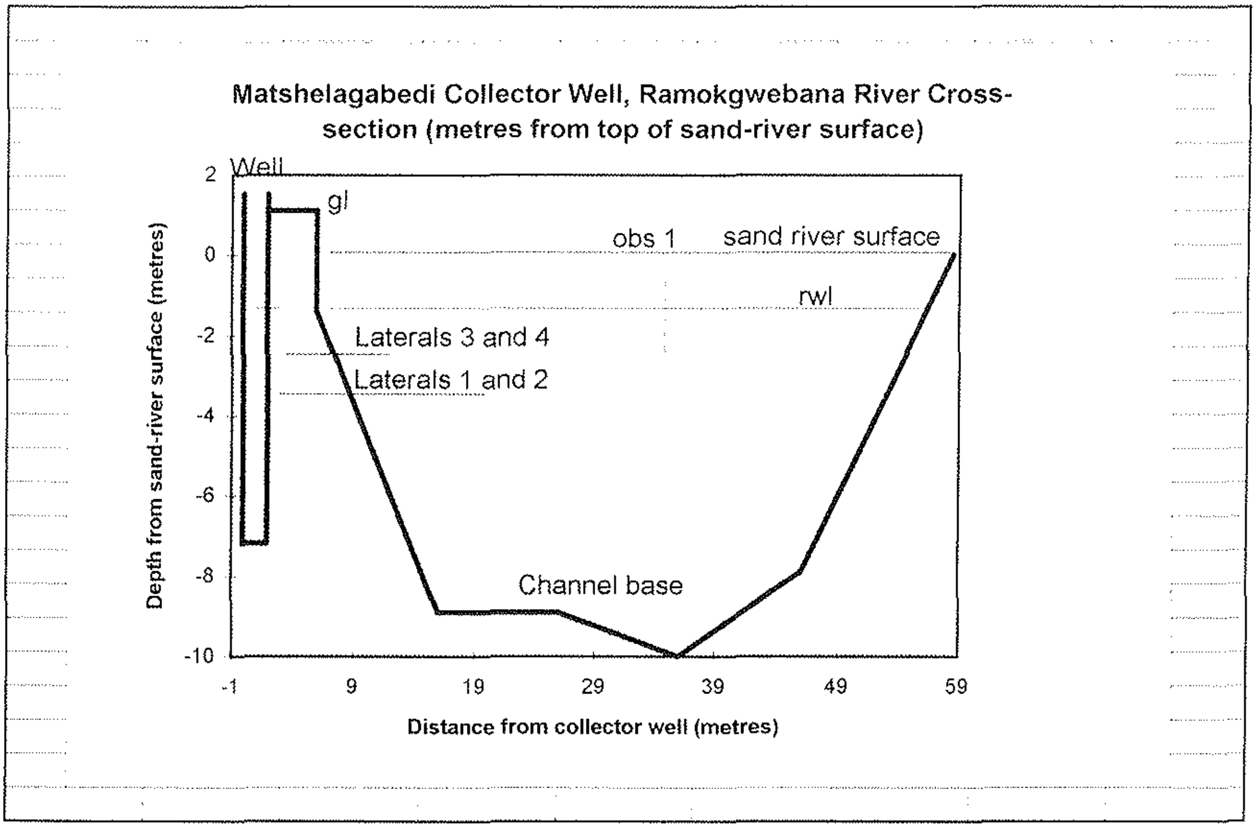
	Grain size analyses			Gulubane site geological trench				
	Sample No	1a	2a	3a	4a	5a	6a	7a
	Distance	2	5	10	15	20	25	30
phi	Depth	1.75	1.75	1.75	1.75	1.75	1.75	1.75
scale	Sieve size mm	weight gm	weight gm	weight gm	weight gm	weight gm	weight gm	weight gm
	0.075	2.2	2	3.3	2.88	1.48	1.28	4.06
3	0.125	5.86	6.48	8.38	6.88	4.36	2.88	9.7
2.5	0.18	5.96	6.86	7.14	6.54	4.6	3.2	8.72
2.25	0.212	10.18	12.1	11.88	10.6	7.8	6.28	15.58
2	0.25	17.4	24.72	27.7	26.92	15.04	16.28	31.86
1.75	0.3	18.32	28.26	41.5	36.9	21.4	22.1	41.38
1.5	0.355	26.28	39.14	64.9	84.5	58.98	38.58	68.84
1.25	0.425	31.36	39.84	49.58	99.88	67.7	44.88	55.24
1	0.5	47.26	59.54	106	107.44	74.64	69.76	112.38
0.75	0.6	54.28	66.02	79.92	89.26	61.7	66.34	83.08
0.5	0.71	134.28	189.8	154.74	150.46	119.22	123.08	193.92
0.25	0.85	142.62	175.64	116.2	109.98	98.2	96.44	151.16
0	1	169.32	193.82	105.92	117.4	117.54	105.28	154.62
-0.25	1.18	154.26	190.72	128.48	114.36	136.78	107.86	156.2
-0.5	1.4	132.9	187.72	159.26	161.4	227.42	154.88	210.72
-0.75	1.7	18.68	44.46	14	6.9	30.46	5.74	7.56
-1	2	34.52	62.8	61.98	63.9	118.34	73.94	92.38
-1.25	2.3	4.9	38.36	46.6	43.44	91.54	53.68	75.3
-1.5	2.8	11.86	23.4	41.78	39.98	77.62	46.88	75.4
-1.75	3.35	12.04	24.08	46.64	38.86	99.38	68.7	57.06
-2.2	4.75	4.12	5.16	11.36	15.82	29.26	25.28	21.66
-2.4	5.6	3.5	5.08	13.92	16.92	21.72	31.4	21.3
-2.7	6.7	18.6	7.9	34	32.04	75	87.7	46.84
		1060.7	1433.9	1335.18	1383.26	1560.18	1252.44	1694.96
phi sca	Sieve size mm	% weight	% weight	% weight	% weight	% weight	% weight	% weight
	0.075	0.20741	0.13948	0.247158	0.208204	0.094861	0.102204	0.239534
3	0.125	0.552465	0.451914	0.627631	0.497376	0.279455	0.229958	0.572285
2.5	0.18	0.561893	0.478416	0.534759	0.472796	0.294838	0.255509	0.514466
2.25	0.212	0.959744	0.843852	0.889768	0.766306	0.499942	0.501437	0.919196
2	0.25	1.640426	1.72397	2.074627	1.946127	0.963991	1.299904	1.87969
1.75	0.3	1.727161	1.970849	3.108195	2.667611	1.371637	1.764612	2.441356
1.5	0.355	2.477609	2.729619	4.860768	6.108758	3.780333	3.080485	4.061453
1.25	0.425	2.956538	2.778436	3.713357	7.220624	4.339243	3.58352	3.259074
1	0.5	4.455548	4.152312	7.939004	7.767159	4.784063	5.570105	6.630245
0.75	0.6	5.117375	4.604226	5.98571	6.452872	3.954672	5.29703	4.901591
0.5	0.71	12.65956	13.23663	11.58945	10.8772	7.641426	9.827531	11.44098
0.25	0.85	13.44584	12.24911	8.702946	7.950783	6.294146	7.700415	8.918205
0	1	15.96304	13.51698	7.933013	8.487197	7.533746	8.40626	9.122339
-0.25	1.18	14.54323	13.30079	9.622673	8.267426	8.766937	8.612264	9.215557
-0.5	1.4	12.52946	13.09157	11.92798	11.66809	14.57652	12.36666	12.43215
-0.75	1.7	1.761101	3.100635	1.048548	0.498822	1.952339	0.45832	0.446028
-1	2	3.254455	4.379664	4.642071	4.619522	7.585022	5.903865	5.450276
-1.25	2.3	0.461959	2.675221	3.490166	3.140407	5.867272	4.286171	4.442583
-1.5	2.8	1.11813	1.631913	3.129166	2.890274	4.975067	3.743213	4.448483
-1.75	3.35	1.135099	1.679336	3.493162	2.809306	6.369778	5.485468	3.366451
-2.2	4.75	0.388423	0.359858	0.850822	1.143675	1.875425	2.018524	1.277906
-2.4	5.6	0.329971	0.354279	1.042556	1.223197	1.392147	2.507186	1.256667
-2.7	6.7	1.753559	0.550945	2.546473	2.316267	4.807138	7.002555	2.763487
	sum	100	100	100	100	100	100.0032	100


Grain-size Analyses - Gulubane Geological Trench
Samples from 1.75 m depth
Cummulative % weight
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
Grain size (mm)
Sample No.
1a
2a
3a
4a
5a
6a
7a

		1b	2b	3b	4b	5b	6b	7b
		2	5	10	15	20	25	30
		1	1	1	1	1	1	1
scale	Sieve size	weight gm	weight gm	weight gm	weight gm	weight gm	weight gm	weight gm
	0.075	2.32	2.02	1.34	1.5	0.58	0.72	5.94
3	0.125	4.64	7.62	3.46	5.28	1.98	1.64	15.08
2.5	0.18	4.42	8.02	3.84	5.68	2.44	1.92	14.76
2.25	0.212	9.32	16.32	6.4	11.34	4.94	3.84	20.54
2	0.25	23.32	37.8	13.52	26.1	11.54	10.22	46.24
1.75	0.3	31.04	41.32	19.22	35.98	17.04	12.36	45.48
1.5	0.355	48.84	51.12	35.3	55.16	29.16	26.72	58.24
1.25	0.425	48.12	37.72	42.16	55.7	31.14	37.34	50.44
1	0.5	63.92	49.58	70.88	82.88	49.66	53.54	72.3
0.75	0.6	59.78	45.9	73.84	69.32	44.12	36.72	64.74
0.5	0.71	133.54	93.58	157.46	114.6	79.12	88.38	105.06
0.25	0.85	128.16	77.86	110.8	83.42	65.12	54.1	79.12
0	1	153.94	83.12	115.8	79.56	71.32	65.92	80.58
-0.25	1.18	158.96	92.5	103.38	74.16	76.24	61.86	80.6
-0.5	1.4	214.68	123.5	127.12	90.64	124.36	96.74	108.64
-0.75	1.7	11.46	17.32	25.04	5.7	12.44	13	11.44
-1	2	68.52	50.28	54.72	37.76	69.46	66.36	49.16
-1.25	2.3	40.68	31.12	48.64	32.54	59.46	70.9	39.42
-1.5	2.8	26.94	25.52	46.62	21.92	51.6	70.34	37.16
-1.75	3.35	22.02	25.48	70.08	27.08	67.28	131.84	52.94
-2.2	4.75	5.9	10.34	21.78	7.88	19.8	51.16	16.38
-2.4	5.6	5.2	5.82	19.66	5.96	18.4	53.9	14.9
-2.7	6.7	20.6	30.5	39.68	11.66	76.06	85.2	84.42
		1286.32	964.36	1210.74	941.82	983.26	1094.72	1153.58
phi scale	Sieve size	% weight	% weight	% weight	% weight	% weight	% weight	% weight
	0.075	0.180359	0.209465	0.110676	0.159266	0.058987	0.06577	0.514919
3	0.125	0.360719	0.790161	0.285776	0.560617	0.201371	0.14981	1.307235
2.5	0.18	0.343616	0.83164	0.317161	0.603088	0.248154	0.175387	1.279495
2.25	0.212	0.724548	1.692314	0.528602	1.204052	0.50241	0.350775	1.780544
2	0.25	1.812924	3.919698	1.116672	2.77123	1.173647	0.933572	4.008391
1.75	0.3	2.413085	4.284707	1.587459	3.820263	1.733011	1.129056	3.942509
1.5	0.355	3.796878	5.300925	2.915572	5.856745	2.965645	2.440807	5.048631
1.25	0.425	3.740904	3.911402	3.482168	5.914081	3.167016	3.410918	4.372475
1	0.5	4.969215	5.141234	5.854271	8.799983	5.050546	4.890748	6.267446
0.75	0.6	4.647366	4.759633	6.09875	7.360217	4.487114	3.354282	5.612095
0.5	0.71	10.38155	9.703845	13.00527	12.16793	8.046702	8.073297	9.107301
0.25	0.85	9.963306	8.073748	9.151428	8.857319	6.622867	4.941903	6.858649
0	1	11.96747	8.619188	9.564399	8.447474	7.253422	6.021631	6.985211
-0.25	1.18	12.35773	9.591854	8.53858	7.874116	7.753799	5.65076	6.986945
-0.5	1.4	16.68947	12.80642	10.49936	9.62392	12.64772	8.836963	9.417639
-0.75	1.7	0.890914	1.79601	2.068157	0.605211	1.265179	1.187518	0.991695
-1	2	5.326824	5.213821	4.51955	4.009259	7.064256	6.061824	4.261516
-1.25	2.3	3.16251	3.227011	4.017378	3.455013	6.047231	6.476542	3.417188
-1.5	2.8	2.094347	2.646315	3.850538	2.327409	5.247849	6.425387	3.221276
-1.75	3.35	1.71186	2.642167	5.788196	2.875284	6.842544	12.04326	4.589192
-2.2	4.75	0.458673	1.072214	1.7989	0.836678	2.013709	4.673341	1.419928
-2.4	5.6	0.404254	0.603509	1.6238	0.632817	1.871326	4.923633	1.291631
-2.7	6.7	1.601468	3.162719	3.277335	1.238028	7.735492	7.782812	7.318088
	sum	100	100	100	100	100	100	100



Grain-size Analyses - Gulubane Geological Trench
Samples from 1.00 m depth
Cummulative % weight
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
Grain size (mm)
Sample No.
1b
2b
3b
4b
5b
6b
7b


Matshelagabedi Collector Well, Ramokgwebana River Cross-section (metres from top of sand-river surface)
Well
gl
obs 1
sand river surface
rwl
Laterals 3 and 4
Laterals 1 and 2
Channel base
Depth from sand-river surface (metres)
2
0
-2
-4
-6
-8
-10
-1
9
19
29
39
49
59
Distance from collector well (metres)

	Grain size analyses							
	Sample No	Mat1	Mat2	Mat3	Mat4	Mat5	Mat6	Mat7
	Distance	2	2	10	10	20	20	20
phi	Depth	1	2	1	2	1	2	3
scale	Sieve size	weight gm	weight gm	weight gm	weight gm	weight gm	weight gm	weight gm
pan	0.71	133.2	88	78.9	7.12	75.1	87.2	71.1
0.25	0.85	18.9	33.4	9.4	20.1	11.9	28.6	20
0	1	15.9	45.8	11.5	23.1	13.6	31.7	23
-0.25	1.18	14.2	49.8	9.3	26.4	13.3	34.4	26.3
-0.5	1.4	3.3	55.3	11.3	39.4	17.6	44	39.3
-0.75	1.7	2.4	18.6	2.4	10.9	3.3	9.6	10.8
-1	2	3.9	14.2	4.1	20.6	6.9	16.9	20.5
-1.25	2.3	4.3	33.1	6.1	70.2	15.1	31.1	70.1
		196.1	338.2	133	217.82	156.8	283.5	281.1

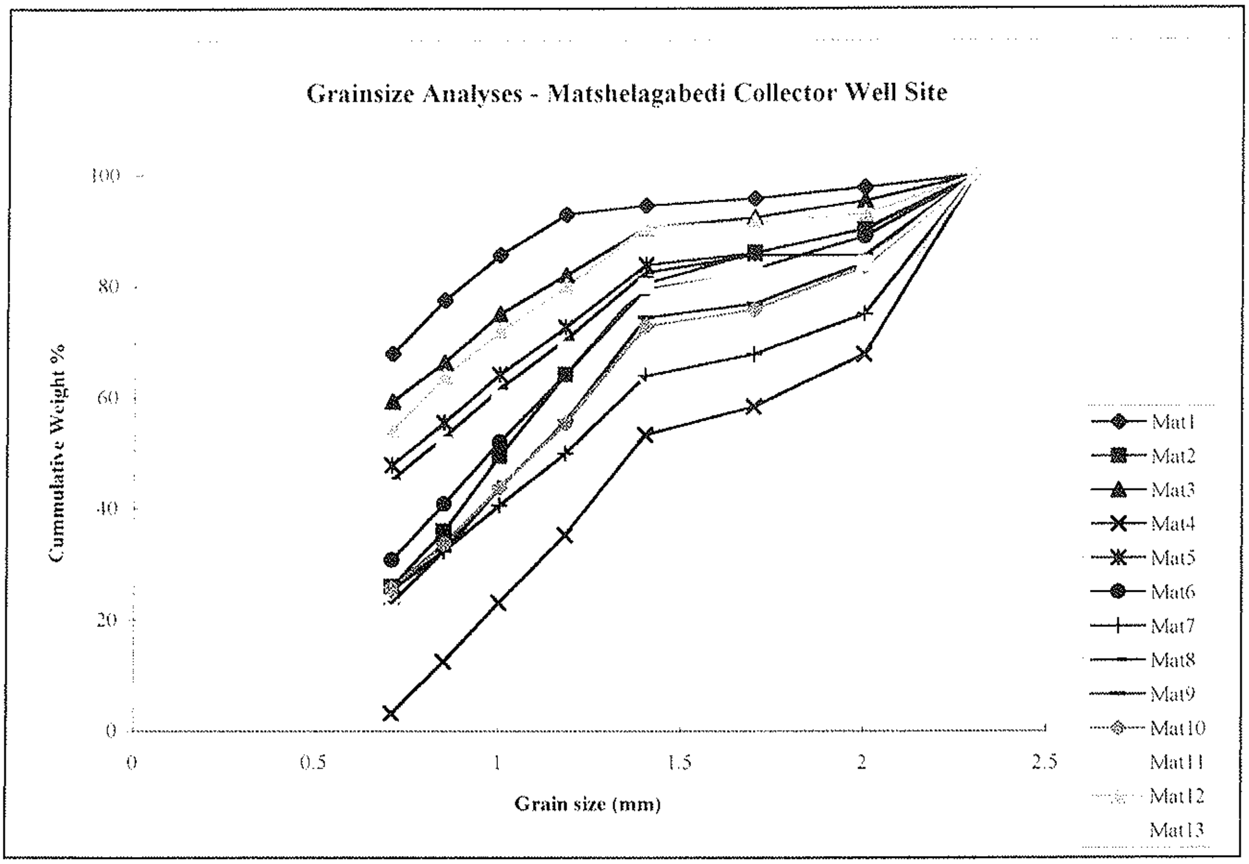
	Sample No	Mat1	Mat2	Mat3	Mat4	Mat5	Mat6	Mat7
	Distance	2	2	10	10	20	20	20
	Depth	1	2	1	2	1	2	3
phi scale	Sieve size	% weight	% weight	% weight	% weight	% weight	% weight	% weight
0.5	0.71	67.92453	26.02011	59.32331	3.268754	47.89541	30.75838	25.29349
0.25	0.85	9.63794	9.875813	7.067669	9.227803	7.589286	10.08818	7.114906
0	1	8.108108	13.54228	8.646617	10.60509	8.673469	11.18166	8.182142
-0.25	1.18	7.241203	14.72501	6.992481	12.1201	8.482143	12.13404	9.356101
-0.5	1.4	1.682815	16.35127	8.496241	18.08833	11.22449	15.52028	13.98079
-0.75	1.7	1.223865	5.499704	1.804511	5.004132	2.104592	3.386243	3.842049
-1	2	1.988781	4.198699	3.082707	9.45735	4.40051	5.961199	7.292778
-1.25	2.3	2.192759	9.787108	4.586466	32.22845	9.630102	10.97002	24.93774
	sum	100	100	100	100	100	100	100

	Sample No	Mat1	Mat2	Mat3	Mat4	Mat5	Mat6	Mat7
	Distance	2	2	10	10	20	20	20
	Depth	1	2	1	2	1	2	3
		cummulativ	cummulativ	cummulativ	cummulativ	cummulativ	cummulativ	cummulativ
phi scale	Sieve size	% weight	% weight	% weight	% weight	% weight	% weight	% weight
		Mat1	Mat2	Mat3	Mat4	Mat5	Mat6	Mat7
0.5	0.71	67.92453	26.02011	59.32331	3.268754	47.89541	30.75838	25.29349
0.25	0.85	77.56247	35.89592	66.39098	12.49656	55.48469	40.84656	32.4084
0	1	85.67058	49.4382	75.03759	23.10164	64.15816	52.02822	40.59054
-0.25	1.18	92.91178	64.16322	82.03008	35.22174	72.64031	64.16226	49.94664
-0.5	1.4	94.59459	80.51449	90.52632	53.31007	83.8648	79.68254	63.92743
-0.75	1.7	95.81846	86.01419	92.33083	58.3142	85.96939	83.06878	67.76948
-1	2	97.80724	90.21289	95.41353	67.77155	90.3699	89.02998	75.06226
-1.25	2.3	100	100	100	100	100	100	100

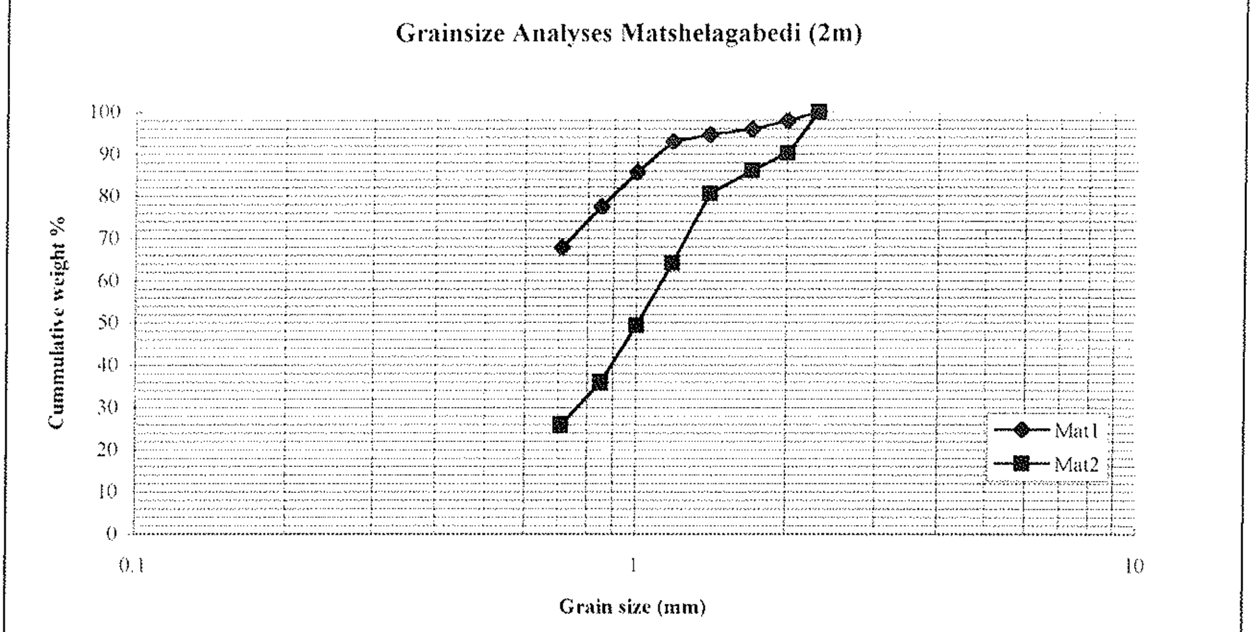
	Sample No	Mat8	Mat9	Mat10	Mat11	Mat12	Mat13
	Distance	30	30	30	40	40	40
phi	Depth	1	2	3	1	2	3
scale	Sieve size	weight gm	weight gm	weight gm	weight gm	weight gm	weight gm
pan	0.71	81.1	65.9	74.3	99.4	156.5	61.7
0.25	0.85	13.7	26.8	23.3	17.6	27.8	19.5
0	1	15.7	32.4	29.4	19	23.8	22.6
-0.25	1.18	15.9	34.5	33.5	19.9	23	25.3
-0.5	1.4	21.5	53.1	50.5	25.6	30.8	43.9
-0.75	1.7	5.6	7.2	8.5	6.7	2.8	7.45
-1	2	0.01	21	22.4	2.75	4.2	21
-1.25	2.3	25.8	45	47.6	35.9	20	76.1
		179.31	285.9	289.5	226.85	288.9	277.55

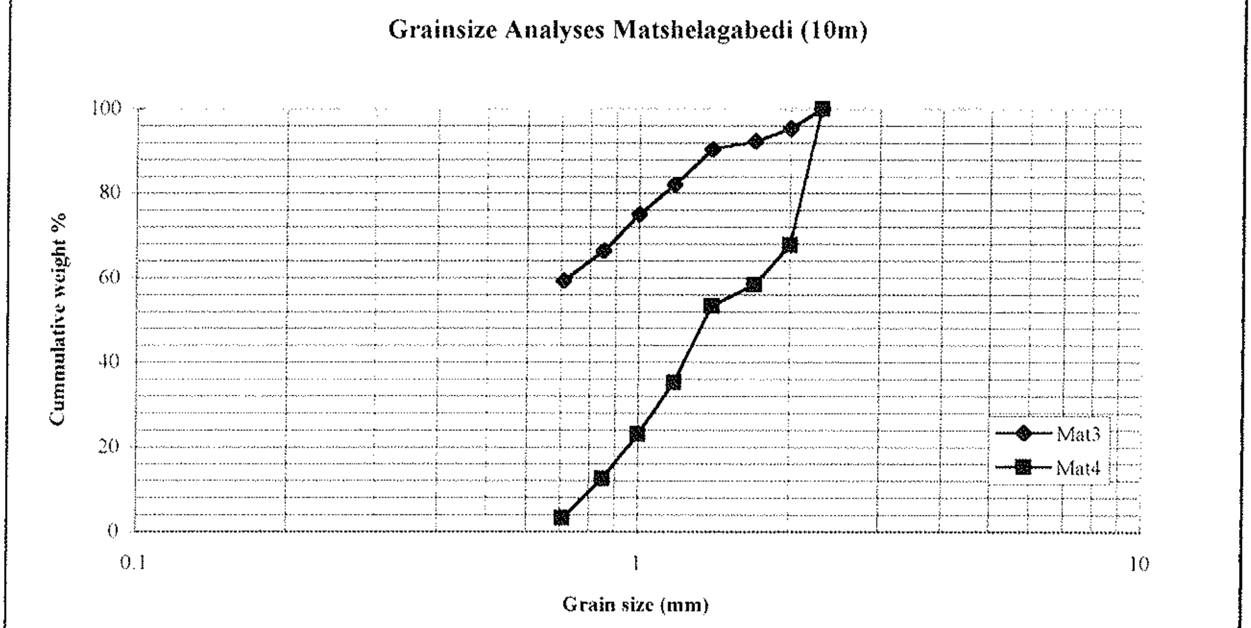
	Sample No	Mat8	Mat9	Mat10	Mat11	Mat12	Mat13
	Distance	30	30	30	40	40	40
	Depth	1	2	3	1	2	3
phi scale	Sieve size	% weight	% weight	% weight	% weight	% weight	% weight
0.5	0.71	45.22893	23.05002	25.66494	43.8175	54.17099	22.23023
0.25	0.85	7.640399	9.373907	8.048359	7.758431	9.622707	7.025761
0	1	8.755786	11.33263	10.15544	8.375579	8.238145	8.142677
-0.25	1.18	8.867325	12.06716	11.57168	8.772317	7.961232	9.115475
-0.5	1.4	11.99041	18.57293	17.44387	11.28499	10.66113	15.81697
-0.75	1.7	3.123083	2.518363	2.936097	2.953493	0.969193	2.684201
-1	2	0.005577	7.345226	7.737478	1.212255	1.45379	7.566204
-1.25	2.3	14.38849	15.73977	16.44214	15.82544	6.922811	27.41848
	sum	100	100	100	100	100	100

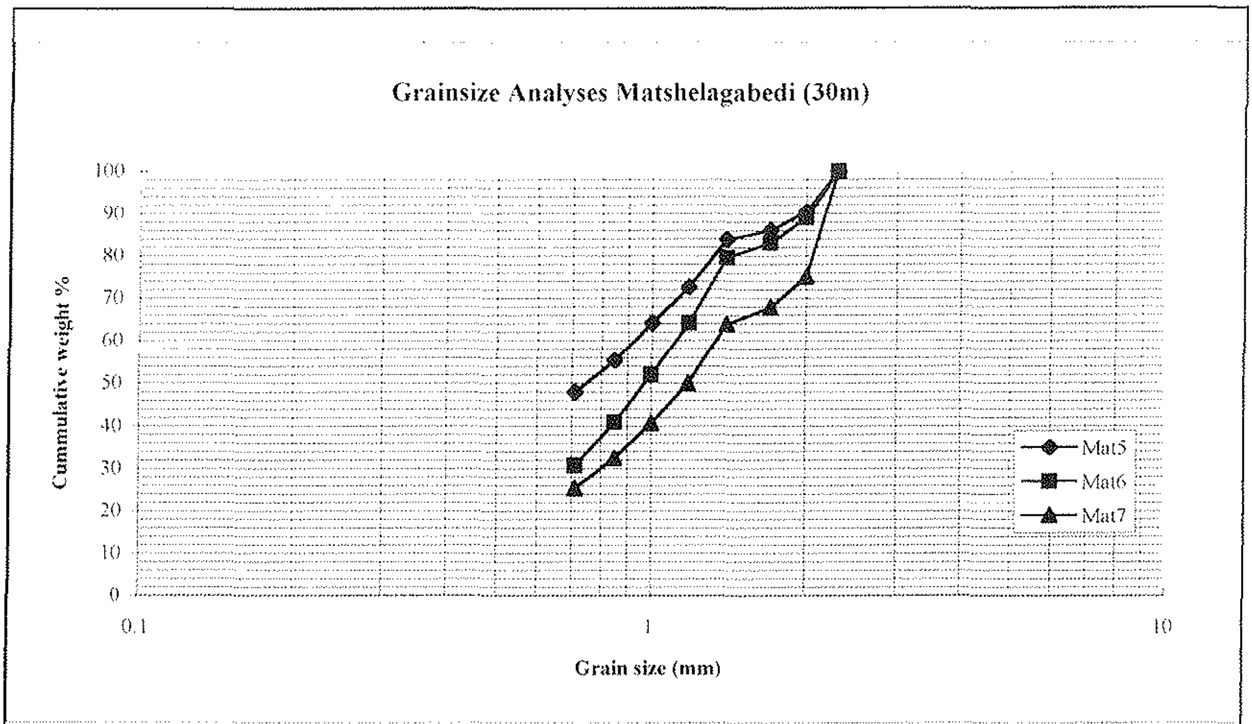
	Sample No	Mat8	Mat9	Mat10	Mat11	Mat12	Mat13
	Distance	30	30	30	40	40	40
	Depth	1	2	3	1	2	3
e		cummulativ	cummulativ	cummulativ	cummulativ	cummulativ	cummulative
phi scale	Sieve size	% weight	% weight	% weight	% weight	% weight	% weight
		Mat8	Mat9	Mat10	Mat11	Mat12	Mat13
0.5	0.71	45.22893	23.05002	25.66494	43.8175	54.17099	22.23023
0.25	0.85	52.86933	32.42392	33.7133	51.57593	63.7937	29.25599
0	1	61.62512	43.75656	43.86874	59.95151	72.03184	37.39867
-0.25	1.18	70.49244	55.82371	55.44041	68.72383	79.99308	46.51414
-0.5	1.4	82.48285	74.39664	72.88428	80.00882	90.65421	62.33111
-0.75	1.7	85.60593	76.91501	75.82038	82.96231	91.6234	65.01531
-1	2	85.61151	84.26023	83.55786	84.17456	93.07719	72.58152
-1.25	2.3	100	100	100	100	100	100

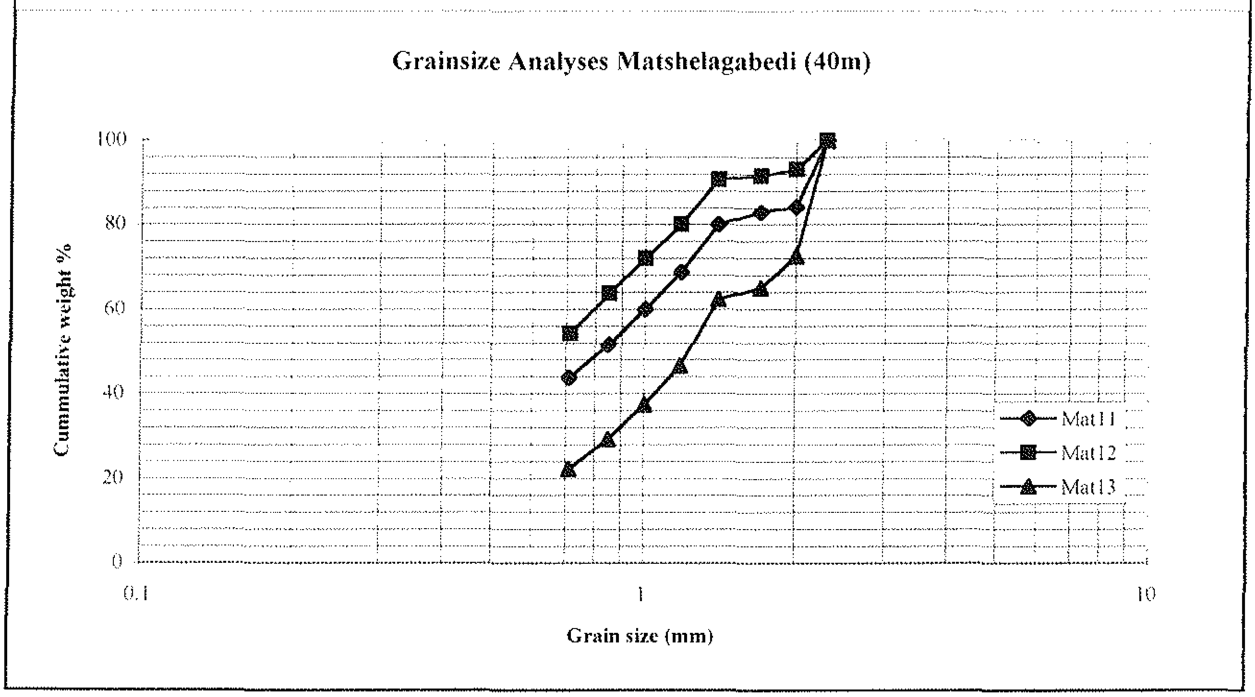


Grainsize Analyses - Matshelagabedi Collector Well Site
Cummulative Weight %
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
Grain size (mm)
Mat1
Mat2
Mat3
Mat4
Mat5
Mat6
Mat7
Mat8
Mat9
Mat10
Mat11
Mat12
Mat13


Grainsize Analyses Matshelagabedi (2m)
Cummulative weight %
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
Grain size (mm)
Mat1
Mat2


Grainsize Analyses Matshelagabedi (10m)
Cummulative weight %
100
80
60
40
20
0
0.1
1
10
Grain size (mm)
Mat3
Mat4


Grainsize Analyses Matshelagabedi (30m)
Cummulative weight %
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
Grain size (mm)
Mat5
Mat6
Mat7

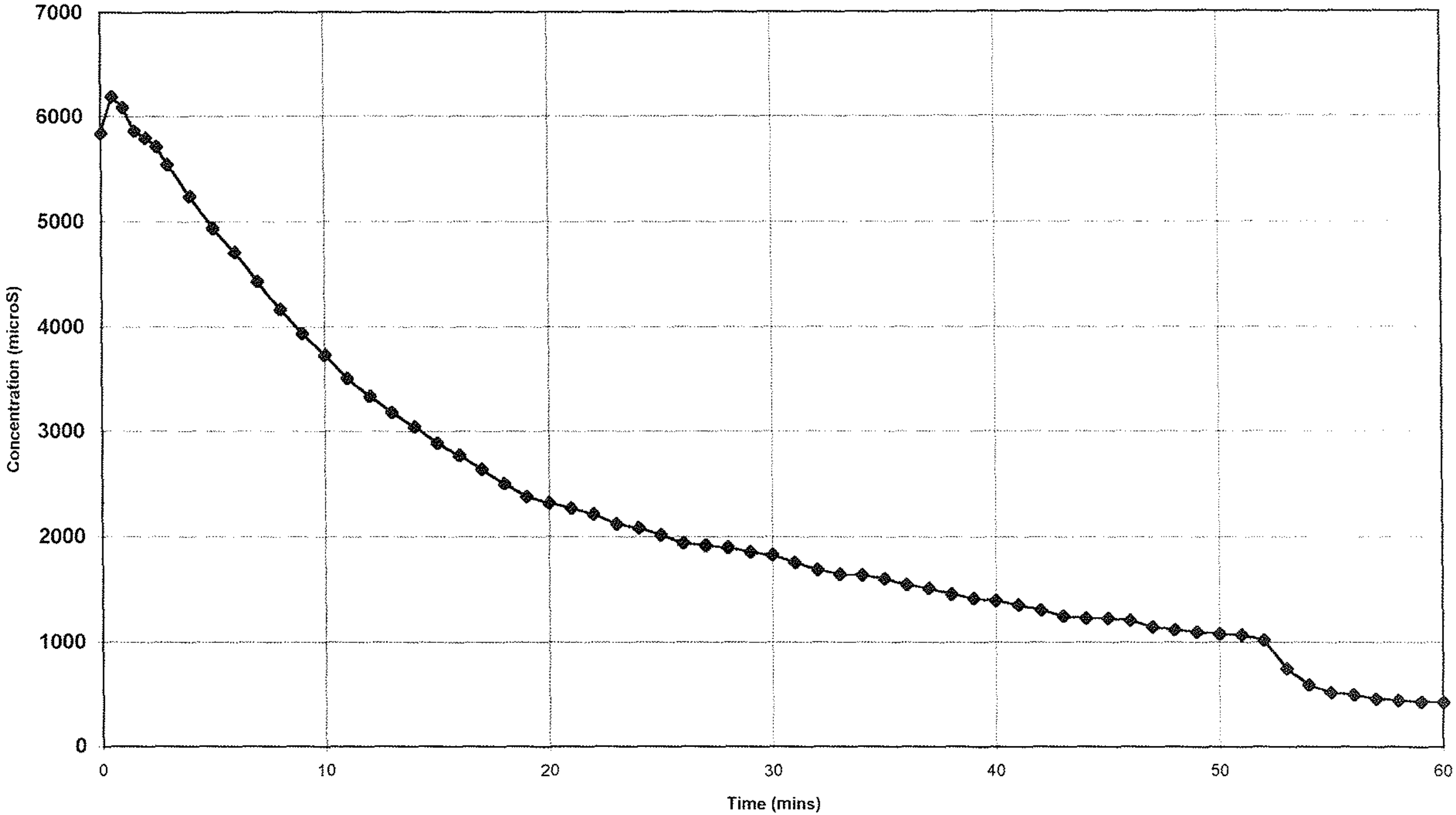

Grainsize Analyses Matshelagabedi (40m)
Cummulative weight %
100
80
60
40
20
0
0.1
1
10
Grain size (mm)
Mat11
Mat12
Mat13

APPENDIX F: SALT DILUTION FLOW TEST RESULTS AND CONDUCTANCE PROFILES

Location	Gulubane Collector Well		19/07/97			
Trench obs bh 1						
darcy velocity from point dilution method						
enter values in consistant units below						
rw	l	b	t1	log10(c1-c0)	t2	log10(c2-c0)
0.038	1.83	1.83	0.027777778	3.146	0.034722222	3.0334238
darcy v=			graph slope=			
1.112782766			16.2109728			
			calculating alpha			
			kpack/kaquif		rpack/raquif	
			1		2	
			alpha=	alpha used		
			2	2		
n.b.DISCHARGE DOWN-RIVER=V*XSECTION. Also,alpha coeff used in a8 is from e14						
X-section area =		63	m2	stream gradient =		0.0075
Discharge =	70.10531428	m3/day	Permeabilty	=	148.3710355	m/day
	0.8114041	l/sec	Transmissivity	=	271.518995	m2/day
Initial conductivity			160			
Time	Conductivity					
mins	microS					
0	6000		5840			
0.5	6350		6190			
1	6250		6090			
1.5	6025		5865			
2	5950		5790			
2.5	5870		5710			
3	5700		5540			
4	5400		5240			
5	5100		4940			
6	4870		4710			
7	4600		4440			
8	4330		4170			
9	4100		3940			
10	3890		3730			
11	3670		3510			
12	3490		3330			
13	3340		3180			
14	3200		3040			
15	3050		2890			
16	2930		2770			
17	2800		2640			
18	2660		2500			
19	2540		2380			
20	2480		2320			
21	2430		2270			
22	2370		2210			
23	2280		2120			
24	2240		2080			
25	2180		2020			
26	2100		1940			

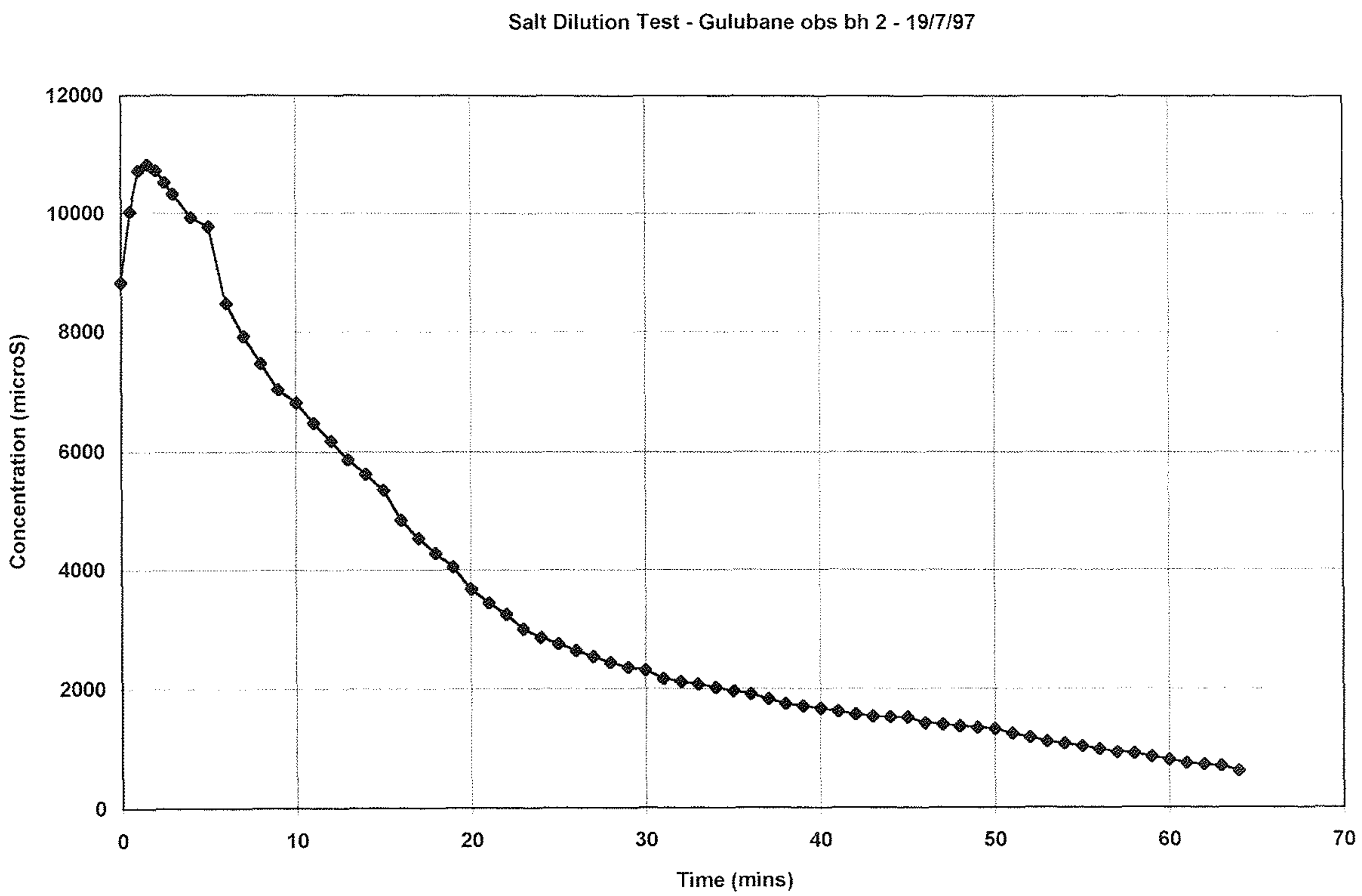
27	2080		1920			
28	2060		1900			
29	2020		1860			
30	1990		1830			
31	1920		1760			
32	1850		1690			
33	1810		1650			
34	1800		1640			
35	1770		1610			
36	1710		1550			
37	1680		1520			
38	1620		1460			
39	1580		1420			
40	1560		1400			
41	1520		1360			
42	1470		1310			
43	1410		1250			
44	1390		1230			
45	1390		1230			
46	1370		1210			
47	1310		1150			
48	1280		1120			
49	1260		1100			
50	1240		1080			
51	1230		1070			
52	1180		1020			
53	910		750			
54	750		590			
55	682		522			
56	658		498			
57	620		460			
58	605		445			
59	592		432			
60	585		425			

Salt Dilution Test - Gulubane obs bh 1 - 19/7/97



Location	Gulubane Collector Well						
Trench obs bh 2		Date of test		19/07/97			
darcy velocity from point dilution method							
enter values in consistant units below							
rw	l	b	t1	log10(c1-c0)	t2	log10(c2-c0)	
0.038	2.22	2.22	0.027777778	3.2227	0.041666667	2.9085	
darcy v=			graph slope=				
1.552887489			22.6224				
			calculating alpha				
			kpack/kaquif		rpack/raquif		
			1		2		
			alpha=	alpha used			
			2	2			
n.b.DISCHARGE DOWN-RIVER=V*XSECTION. Also,alpha coeff used in a8 is from e14							
X-section area =		42.25	m2	stream gradient =			0.0075
Discharge =	65.60949643	m3/day	Permeabilty =		207.0516653	m/day	
	0.759369172	l/sec	Transmissivity =		459.6546969	m2/day	
Initial conductivity				170			
Time	Conductivity						
mins	microS						
0	9000			8830			
0.5	10200			10030			
1	10900			10730			
1.5	11000			10830			
2	10900			10730			
2.5	10700			10530			
3	10500			10330			
4	10100			9930			
5	9950			9780			
6	8650			8480			
7	8100			7930			
8	7650			7480			
9	7220			7050			
10	7000			6830			
11	6650			6480			
12	6350			6180			
13	6030			5860			
14	5790			5620			
15	5520			5350			
16	5010			4840			
17	4700			4530			
18	4450			4280			
19	4220			4050			
20	3850			3680			
21	3610			3440			
22	3420			3250			
23	3170			3000			
24	3030			2860			
25	2920			2750			
26	2810			2640			

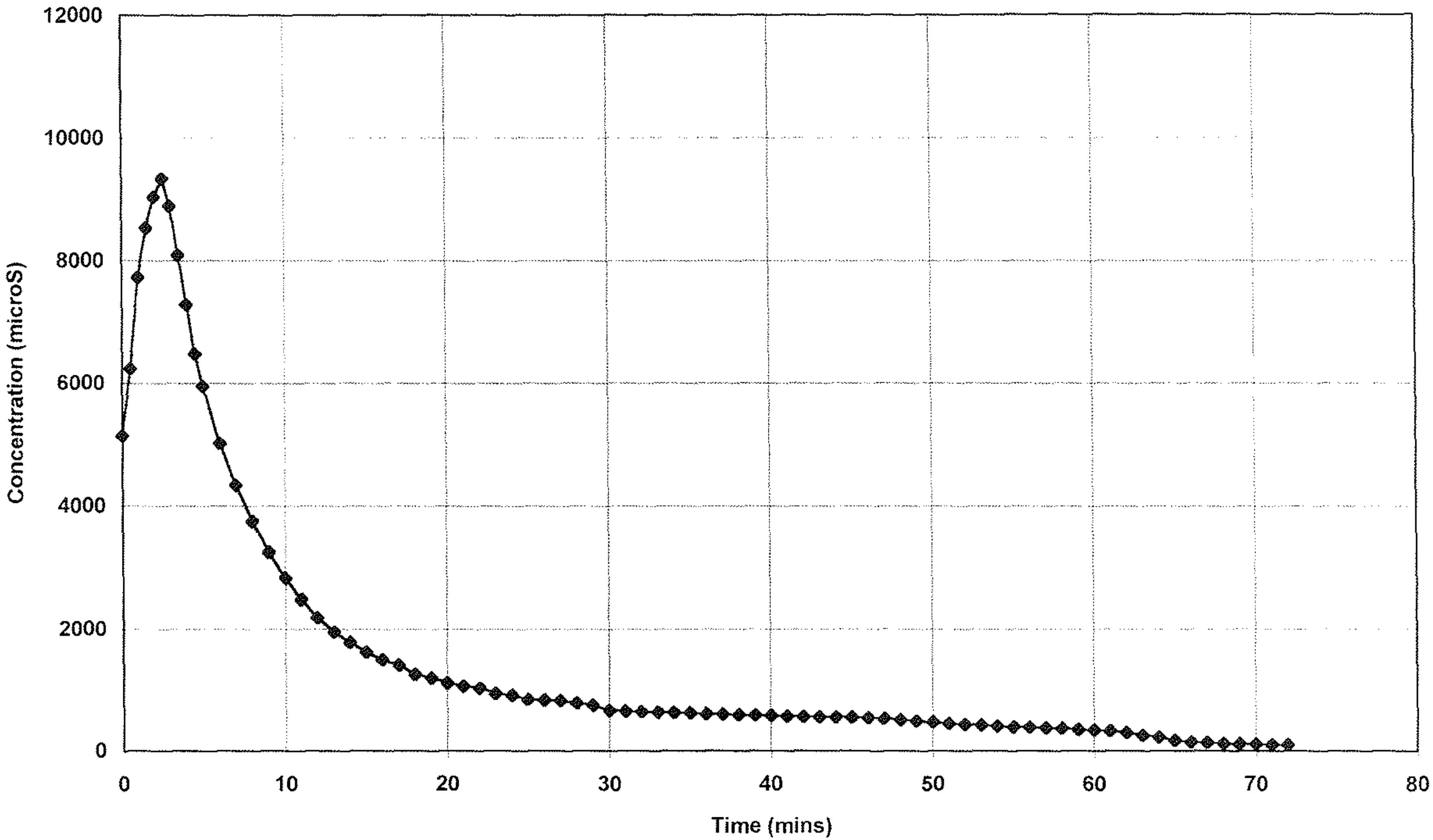
27	2710	2540
28	2610	2440
29	2530	2360
30	2480	2310
31	2340	2170
32	2290	2120
33	2250	2080
34	2190	2020
35	2130	1960
36	2080	1910
37	2000	1830
38	1920	1750
39	1880	1710
40	1840	1670
41	1790	1620
42	1740	1570
43	1710	1540
44	1700	1530
45	1690	1520
46	1600	1430
47	1570	1400
48	1540	1370
49	1520	1350
50	1500	1330
51	1420	1250
52	1360	1190
53	1290	1120
54	1250	1080
55	1210	1040
56	1160	990
57	1110	940
58	1090	920
59	1030	860
60	980	810
61	925	755
62	902	732
63	876	706
64	790	620


Salt Dilution Test - Gulubane obs bh 2 - 19/7/97
Concentration (microS)
12000
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
Time (mins)

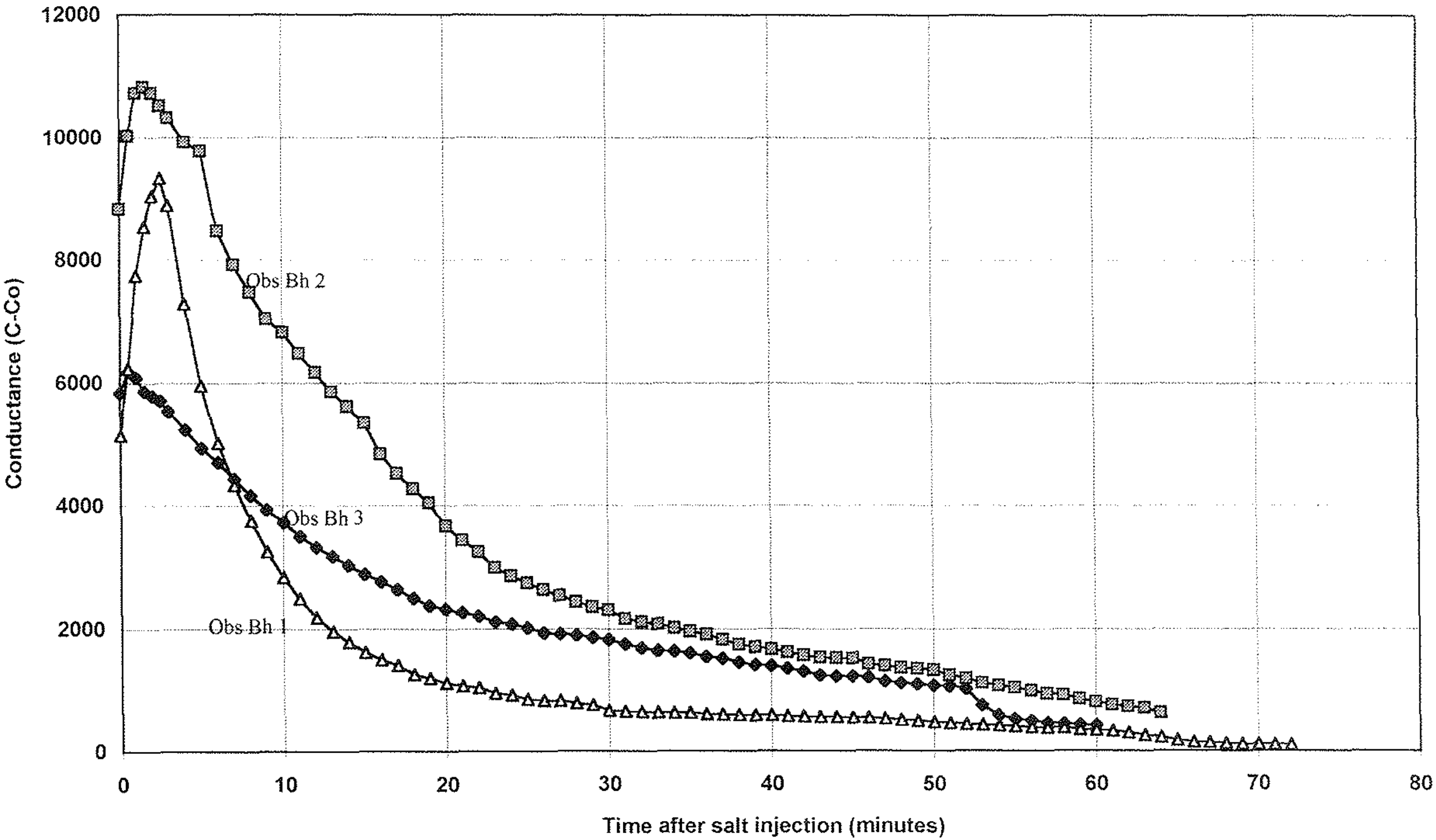
Location	Gulubane Collector Well					
Trench obs bh 3		Date of test	19/07/97			
darcy velocity from point dilution method						
enter values in consistant units below						
rw	l	b	t1	log10(c1-c0)	t2	log10(c2-c0)
0.038	2.21	2.21	0.027777778	2.7686	0.041666667	2.544
darcy v=			graph slope=			
1.11005261			16.1712			
			calculating alpha			
			kpack/kaquif		rpack/raquif	
			1		2	
			alpha=	alpha used		
			2	2		
n.b.DISCHARGE DOWN-RIVER=V*XSECTION. Also,alpha coeff used in a8 is from e14						
X-section area =		63	m2	stream gradient =		0.0075
Discharge =	69.93331444	m3/day	Permeabilty	=	148.0070147	m/day
	0.809413362	l/sec	Transmissivity	=	518.0245514	m2/day
Initial conductivity			160			
Time	Conductivity					
mins	microS					
0	5300		5140			
0.5	6400		6240			
1	7900		7740			
1.5	8700		8540			
2	9200		9040			
2.5	9500		9340			
3	9050		8890			
3.5	8250		8090			
4	7450		7290			
4.5	6650		6490			
5	6120		5960			
6	5180		5020			
7	4500		4340			
8	3920		3760			
9	3420		3260			
10	3000		2840			
11	2650		2490			
12	2350		2190			
13	2120		1960			
14	1950		1790			
15	1780		1620			
16	1660		1500			
17	1570		1410			
18	1420		1260			
19	1360		1200			
20	1280		1120			
21	1230		1070			
22	1200		1040			
23	1110		950			
24	1080		920			

25	1010		850			
26	999		839			
27	990		830			
28	947		787			
29	918		758			
30	828		668			
31	813		653			
32	808		648			
33	799		639			
34	790		630			
35	789		629			
36	769		609			
37	763		603			
38	758		598			
39	751		591			
40	747		587			
41	733		573			
42	724		564			
43	720		560			
44	719		559			
45	715		555			
46	708		548			
47	694		534			
48	672		512			
49	655		495			
50	635		475			
51	618		458			
52	602		442			
53	589		429			
54	576		416			
55	562		402			
56	551		391			
57	543		383			
58	539		379			
59	517		357			
60	510		350			
61	491		331			
62	463		303			
63	425		265			
64	385		225			
65	339		179			
66	310		150			
67	302		142			
68	290		130			
69	281		121			
70	271		111			
71	268		108			
72	265		105			

Salt Dilution Test - Gulubane obs bh 3 - 19/7/97



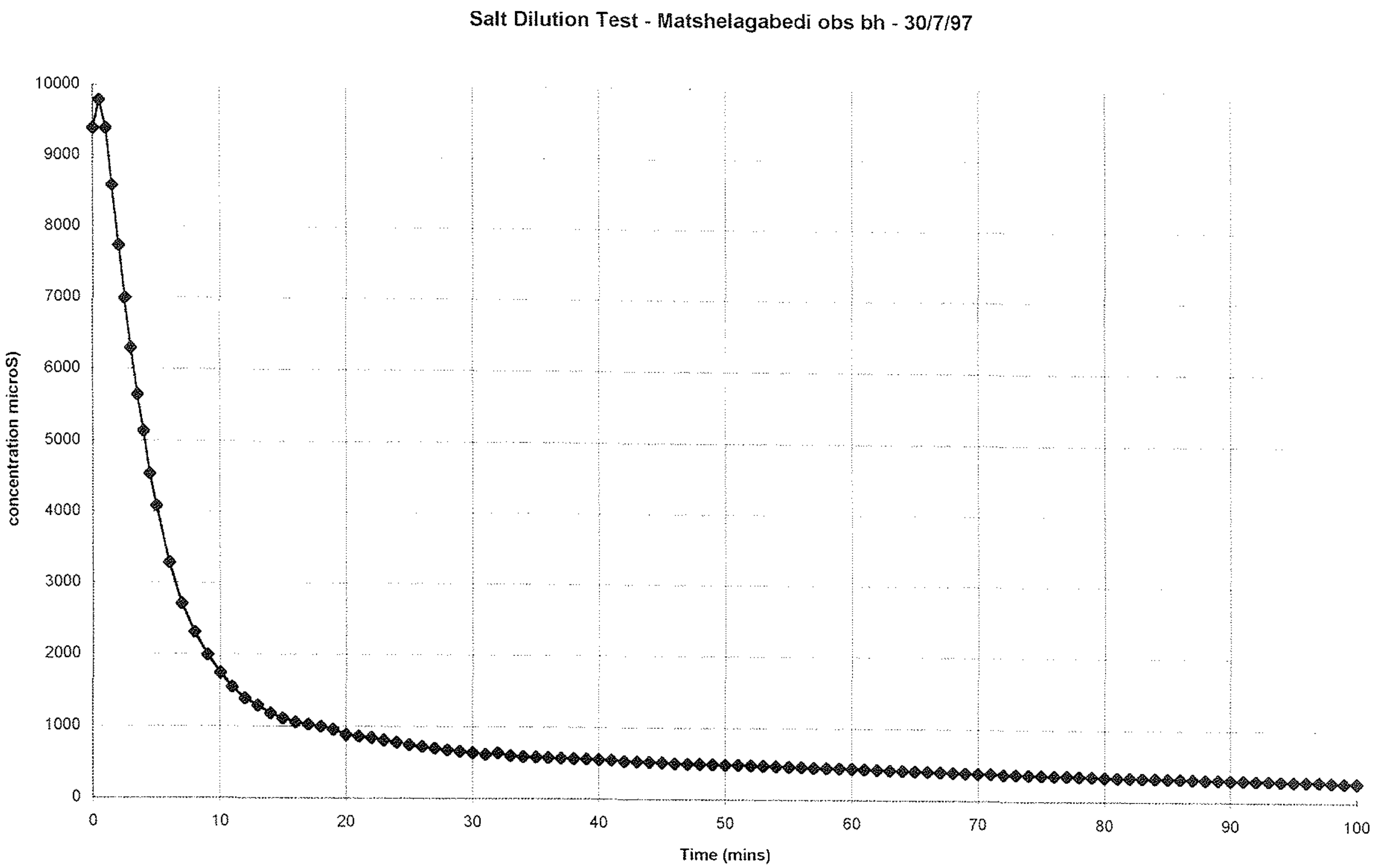
Gulubane Collector Well Salt Dilution Flow Tests at Observation Boreholes 1, 2 and 3.



Location	Matshelagabedi Collector Well					
Obs Bh		Date of test	30/07/97			
darcy velocity from point dilution method						
enter values in consistant units below						
rw	l	b	t1	log10(c1-c0)	t2	log10(c2-c0)
0.038	1	1	0.034722222	2.692	0.05555556	2.5378
darcy v=			graph slope=			
0.508073946			7.4016			
			calculating alpha			
			kpack/kaquif		rpack/raquif	
			1		2	
			alpha=	alpha used		
			2	2		
n.b.DISCHARGE DOWN-RIVER=V*XSECTION. Also,alpha coeff used in a8 is from e14						
X-section area =		269.5	m2	stream gradient =		0.0025
Discharge =	136.92593	m3/day	Permeabilty	=	203.229578	m/day
	1.5847908	l/sec	Transmissivity	=	203.229578	m2/day
Initial conductivity			110			
Time	Conductivity					
mins	microS					
0	9500		9390			
0.5	9900		9790			
1	9500		9390			
1.5	8700		8590			
2	7850		7740			
2.5	7100		6990			
3	6400		6290			
3.5	5750		5640			
4	5250		5140			
4.5	4650		4540			
5	4200		4090			
6	3400		3290			
7	2820		2710			
8	2420		2310			
9	2100		1990			
10	1850		1740			
11	1650		1540			
12	1500		1390			
13	1400		1290			
14	1290		1180			
15	1220		1110			
16	1170		1060			
17	1140		1030			
18	1110		1000			
19	1070		960			
20	1000		890			
21	975		865			
22	958		848			
23	920		810			
24	890		780			

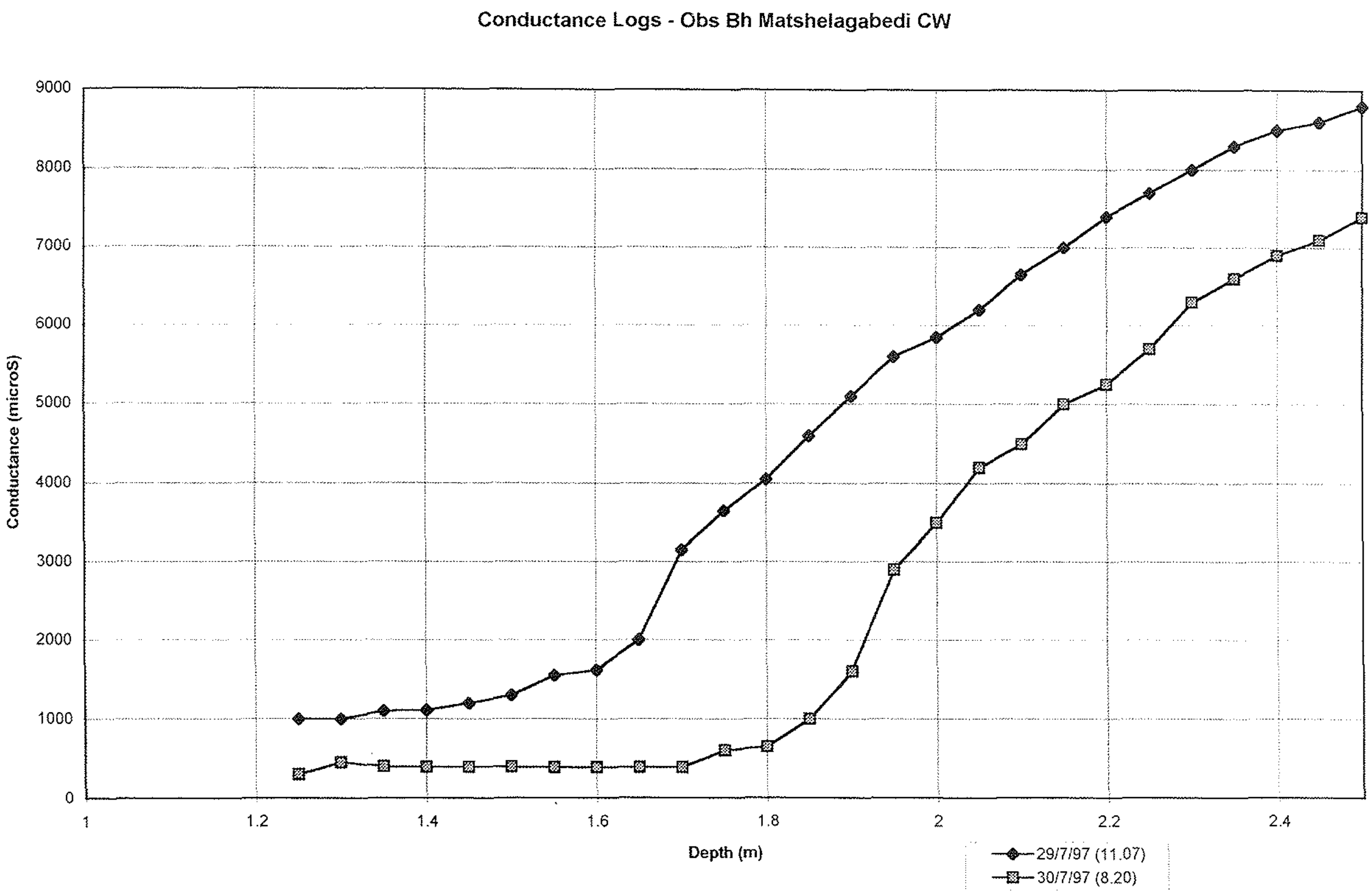
25	860	750
26	835	725
27	810	700
28	789	679
29	770	660
30	750	640
31	730	620
32	755	645
33	710	600
34	700	590
35	692	582
36	688	578
37	683	573
38	677	567
39	669	559
40	662	552
41	657	547
42	650	540
43	644	534
44	638	528
45	629	519
46	620	510
47	615	505
48	611	501
49	608	498
50	602	492
51	598	488
52	592	482
53	587	477
54	583	473
55	579	469
56	573	463
57	568	458
58	562	452
59	558	448
60	553	443
61	549	439
62	543	433
63	538	428
64	532	422
65	527	417
66	521	411
67	515	405
68	509	399
69	502	392
70	498	388
71	494	384
72	490	380
73	487	377
74	481	371
75	476	366
76	473	363
77	470	360
78	465	355

79	460	350
80	455	345
81	451	341
82	448	338
83	444	334
84	441	331
85	439	329
86	435	325
87	431	321
88	427	317
89	423	313
90	420	310
91	418	308
92	415	305
93	411	301
94	407	297
95	403	293
96	402	292
97	401	291
98	391	281
99	386	276
100	384	274



Salt Dilution Test - Matshelagabedi obs bh - 30/7/97
concentration microS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Time (mins)

Conductivity Profiles - Matshelagabedi Obs Bh		
Depth metres	Conductance 29/7/97 (11.07)	Conductance 30/7/97 (8.20)
1.25	1000	300
1.3	1000	450
1.35	1100	400
1.4	1110	395
1.45	1200	395
1.5	1300	395
1.55	1550	390
1.6	1620	390
1.65	2000	390
1.7	3150	390
1.75	3650	600
1.8	4050	650
1.85	4600	1000
1.9	5100	1600
1.95	5600	2900
2	5850	3500
2.05	6200	4200
2.1	6650	4500
2.15	7000	5000
2.2	7400	5250
2.25	7700	5700
2.3	8000	6300
2.35	8300	6600
2.4	8500	6900
2.45	8600	7100
2.5	8800	7400


Conductance Logs - Obs Bh Matshelagabedi CW
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Conductance (microS)
1
1.2
1.4
1.6
1.8
2
2.2
2.4
Depth (m)
29/7/97 (11.07)
30/7/97 (8.20)