ANALYSIS OF AQUIFER TESTS IN TWO FRACTURED ROCK WELLS, HALIFAX AREA, NOVA SCOTIA

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ABSTRACT

Two drilled wells completed in fractured quartzite bedrock at sites in East Dartmouth and Waverley were tested to determine aquifer properties and well yields. Tests were conducted at different rates for various durations to determine aquifer response. The data was analyzed by a number of different analytical methods. The current short term test required by Canada Mortgage and Housing Corporation (CMHC) for mortgage purposes was also assessed for its applicability in determining aquifer properties and well yield.

The two wells showed a very different type of response. The East Dartmouth well behaved generally in the manner expected of an ideal confined aquifer. The Waverley well, with a single water-bearing fracture at very shallow depth, behaved in a non-ideal manner. Functionally, the Waverley drilled well was more similar to a shallow dug well completed in fractured bedrock.

The transmissivity values obtained from the analytical methods (excluding the slug tests) ranged from 0.5 to 0.7 m^2/d for the East Dartmouth well and are consistent with the performance of the well. Values for the Waverley well showed a much wider range, from 0.4 to 1.2 m^2/d. The wide range of results for the Waverley well illustrate the difficulty of determining aquifer properties under non-ideal, low yield, shallow single fracture conditions.

Short term (30-60 minute) well yields based on transmissivity and available drawdown ranged from 18.4 to 26.8 m^3/d for the East Dartmouth well, and from 13.72 to 47.72 m^3/d for the Waverley well. Rough estimates based on casing storage rather than traditional analytical methods gave comparable results.

The Waverley well gives a higher apparent transmissivity and yield under low rate pumping that does not result in fracture dewatering. In order to optimize yield from similar wells, it may be more appropriate to pump at a lower rate for a longer period of time. In practical terms, this would require additional storage capability in a home, which would in turn increase the cost of the water system.

The slug test method is a fast, simple and inexpensive method for determining aquifer properties compared to pumping methods. However, the transmissivities obtained were too high based on calculated yields, and reflected influence of areas that are very close to the well and of fractures with the highest hydraulic conductivity.

The CMHC test is not very useful in determining aquifer properties under non-ideal conditions. Estimates of well yield based on casing storage methods are probably just as applicable under conditions such as those that occur in the Waverley well.

Although the CMHC test is not really amenable to aquifer parameter determination under non-ideal conditions, it is useful as a practical tool to evaluate well response under possible usage conditions. Its test rate is also more typical of conventional submersible domestic pumps.

Recommendations for further work include consideration of cyclic and step drawdown methods, longer recovery periods, and assessment of other short term yield tests if a database were compiled. Longer term tests should consider use of the derivative method to identify the period during which radial flow can be assumed for traditional analytical methods such as Theis and Jacob.

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1.0 INTRODUCTION

1.1 Purpose and Scope

The purpose of this project is to consider the evaluation of aquifer properties and well yields from short term aquifer tests in fractured bedrock. The aquifer tests were conducted at various discharge rates and durations.

For the study, data were obtained from two wells, one located in East Dartmouth and one in Waverley (Fig. 1.1). The Dartmouth well site is located in an area of quartzite bedrock that is overlain by 21 m of glacial till. The Waverley well site is in an area of quartzite bedrock, which is at or near the surface. The two well sites represent fractured rock aquifers of the same lithologic type acting under different confining conditions.

The well sites in this study were selected on the basis of their availability for pump test analysis and also on the availability of previously acquired data.

1.2 Importance

In 1993, 55% of Nova Scotians depended on groundwater for domestic uses (www.ec.gc.ca/water/index.htm). It is estimated that the average Nova Scotian home requires a water supply in the order of 75 gallons per person per day (gpcd) (340 litres pcd) to sufficiently meet all household water requirements (NS Department of Environment and Labour (NSDEL), 2001). The daily water usage within a home may be concentrated into a period of one or two hours, often in different areas of the house at the same time. The water supply system must be able to meet this type of peak demand.

Nova Scotia regulations require that a driller perform a yield test upon the completion of well construction to estimate the well yield. A well that is constructed to supply water for domestic purposes (< 23 000 litres/day) for a single family unit must

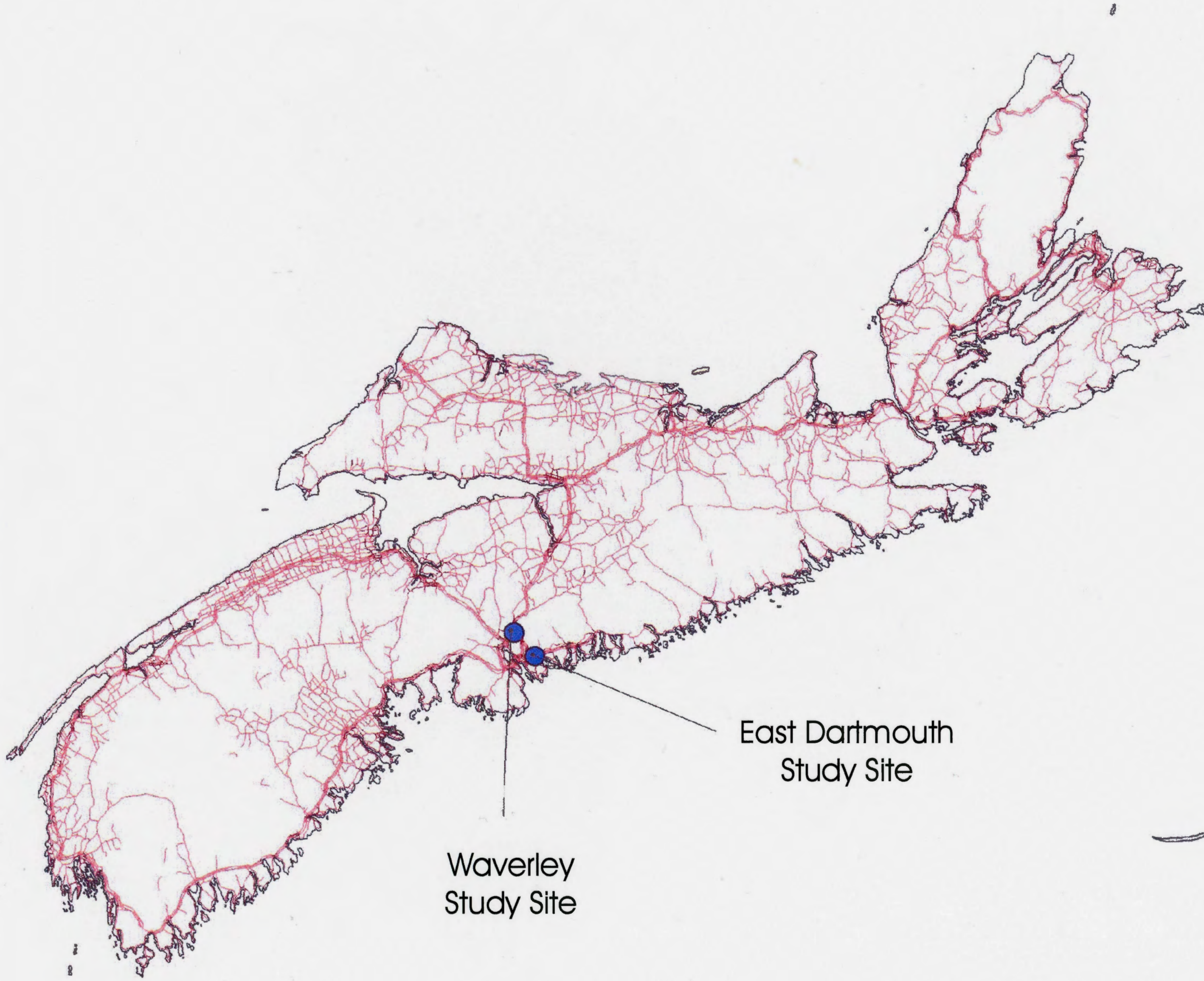

Figure 1.1: Map showing the general location of the study sites, East Dartmouth and Waverley, Nova Scotia, Canada.

have either a bail or air lift test for at least one hour duration, or a pump test that is no less than six hours in duration. A 24-hour pump test is required for domestic wells intended to produce more than 23 000 litres per day. However, non-domestic wells require a pump test no less than 72 hours in duration (NS Well Construction Regulations, 1995).

In order to approve a mortgage loan, the Canada Mortgage and Housing Corporation (CMHC) requires that a well must maintain 4.4 gallons per minute (gpm) (0.33 L/s) for one hour to be able to meet peak demands. In addition, the well must be able to reproduce this yield 24 hours later (NSDEL, 2001). However, many crystalline rock wells cannot maintain a pumping rate of 4.4 gpm for a one-hour duration. In Nova Scotia, where crystalline basement rocks underlie approximately two-thirds of the mainland, there are many low yielding bedrock wells. Where individual wells produce less than 4.4 gpm, CMHC suggests a minimum of 200 gal (900 L) of cold-water storage.

In typical practice, wells are pumped at 4 gpm for one hour, then recovery measurements are taken for one hour; wells are rarely retested 24 hours later. Where yields are less than 4 gpm, alternative pumping and/or storage scenarios may be more efficient to optimize well yields.

1.3 Organization of Thesis

Chapter Two outlines the geology and hydrogeologic setting of the two well sites. Chapter Three presents the data obtained for this study together with the theory for the analytical methods applied. Chapter Four presents the calculated aquifer parameters and well yields for the Waverley and Dartmouth well sites and discusses their implications. Chapter Five provides conclusions, recommendations, and suggestions for further work.

1.4 Terminology

The following is an explanation of a number of hydrogeologic terms as they are used in this thesis.

Aquifer: Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs (Fetter, 1994).

Aquifer, confined: An aquifer that is overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer (Fetter, 1994).

Aquifer, semiconfined: An aquifer confined by a low-permeability layer that permits water to slowly flow through it. During pumping of the aquifer, recharge to the aquifer can occur across the confining layer. Also known as a leaky artesian or leaky confined aquifer (Fetter, 1994).

Aquifer, unconfined: An aquifer in which there are no confining beds between the zone of saturation and the surface. There will be a water table in an unconfined aquifer. Water table aquifer is a synonym (Fetter, 1994).

Discharge: The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time (Fetter, 1994).

Drawdown (s): The difference between the static water level and the surface of the cone of depression or pumping water level at a particular location (usually at a well) (Driscoll, 1986).

Flow, steady-state: The flow that occurs when, at any point in the flow field, the magnitude of the specific discharge is constant with time and there is no change in head with time (Fetter, 1994).

Flow, unsteady-state: The flow that occurs when, at any point in the flow field, the magnitude of the specific discharge changes with time and the head changes with time. Also called transient flow or nonsteady flow (Fetter, 1994).

Head (total hydraulic): Energy contained in a water mass, sum of the elevation, pressure, and velocity heads at any given point in the aquifer (Driscoll, 1986).

Head loss: That part of the head energy which is lost because of friction as water flows (Driscoll, 1986).

Hydraulic conductivity (K): A coefficient of proportionality describing the rate at which water can move through a permeable medium. The density and kinematic viscosity of the water must be considered in determining the hydraulic conductivity (Fetter, 1994).

Hydraulic gradient: The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head (Fetter, 1994).

Pumping test: A test made by pumping a well for a period of time and observing the change in hydraulic head in the aquifer. A pumping test may be used to determine the capacity of the well and the hydraulic characteristics of the aquifer. Also called an aquifer test (Fetter, 1994).

Radial flow: The radial flow of water in an aquifer toward a vertically oriented well (Fetter, 1994).

Recovery: The rate at which the water level in a well rises after the pump has been shut off. It is the inverse of drawdown (Fetter, 1994).

Safe yield: The amount of naturally occurring groundwater that can be economically and legally withdrawn from an aquifer on a sustained basis without impairing the native groundwater quality or creating an undesirable effect such as environmental damage. It cannot exceed the increase in recharge or leakage from adjacent strata plus the reduction in discharge, which is due to the decline in head caused by pumping (Fetter, 1994).

Specific capacity (Q/s): An expression of the productivity of a well, obtained by dividing the rate of discharge of water form a well by the drawdown of the water level in the well. Specific capacity should be described on the basis of the number of hours of pumping prior to the time the drawdown measurement is made. It will usually decrease with time as the drawdown increases (Fetter, 1994).

Static Water Level (SWL): The level of water in a well that is not being affected by withdrawal of groundwater (Driscoll, 1986).

Storativity (S): The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to the specific yield. Also called the storage coefficient (Fetter, 1994).

Transmissivity (T): The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media (Fetter, 1994).

2.0 STUDY AREA

The East Dartmouth well site is located slightly east of the Dartmouth City limits in the vicinity of 4948770N and 461100E (NAD27 datum; Fig. 1.1). Access is possible from the Halifax city center by Highway Route 111 exiting on to Highway 7. The East Dartmouth study area is covered by the National Topographic System (NTS) 1:50 000 map sheet 11D11 and by the NTS 1:10 000 map sheets YNV9XO, YNPLXQ, YNU9YB, and YNOLZ6 of NS Department of Natural Resources (NSDNR). The Waverley well site lies roughly 10 km north-northeast of Halifax and is located in the vicinity of 4958750N and 451180E (NAD27 datum; Fig. 1.1). It is covered by the southeastern most portion of the NTS 1:50 000 map sheet 11D13 and by the NTS 1:10 000 map sheet YMZYOW (NSDNR). Access to the Waverley study area is most conveniently by Highway Route 102, exiting at Cobequid Road.

2.1 Topography

The study sites are located in the physiographic region known as the Southern Upland of Nova Scotia, an erosional plain characterized by slate, greywacke and granite bedrocks (Fig. 2.1; Roland, 1982). The upland slopes gently to the southeast (Driscoll, 1986) with a maximum altitude of approximately 275 metres (Roland, 1982).

The regional topography of the East Dartmouth study area is generally flat to rolling (Fig. 2.2). The rolling topography is the result of numerous northwest – southeast oriented drumlins deposited during the last (Wisconsinan) glaciation. The major lakes and rivers in the study area are also aligned in a northwest – southeast direction and drain to the southeast into the Cole Harbour drainage basin (Fig. 2.2).

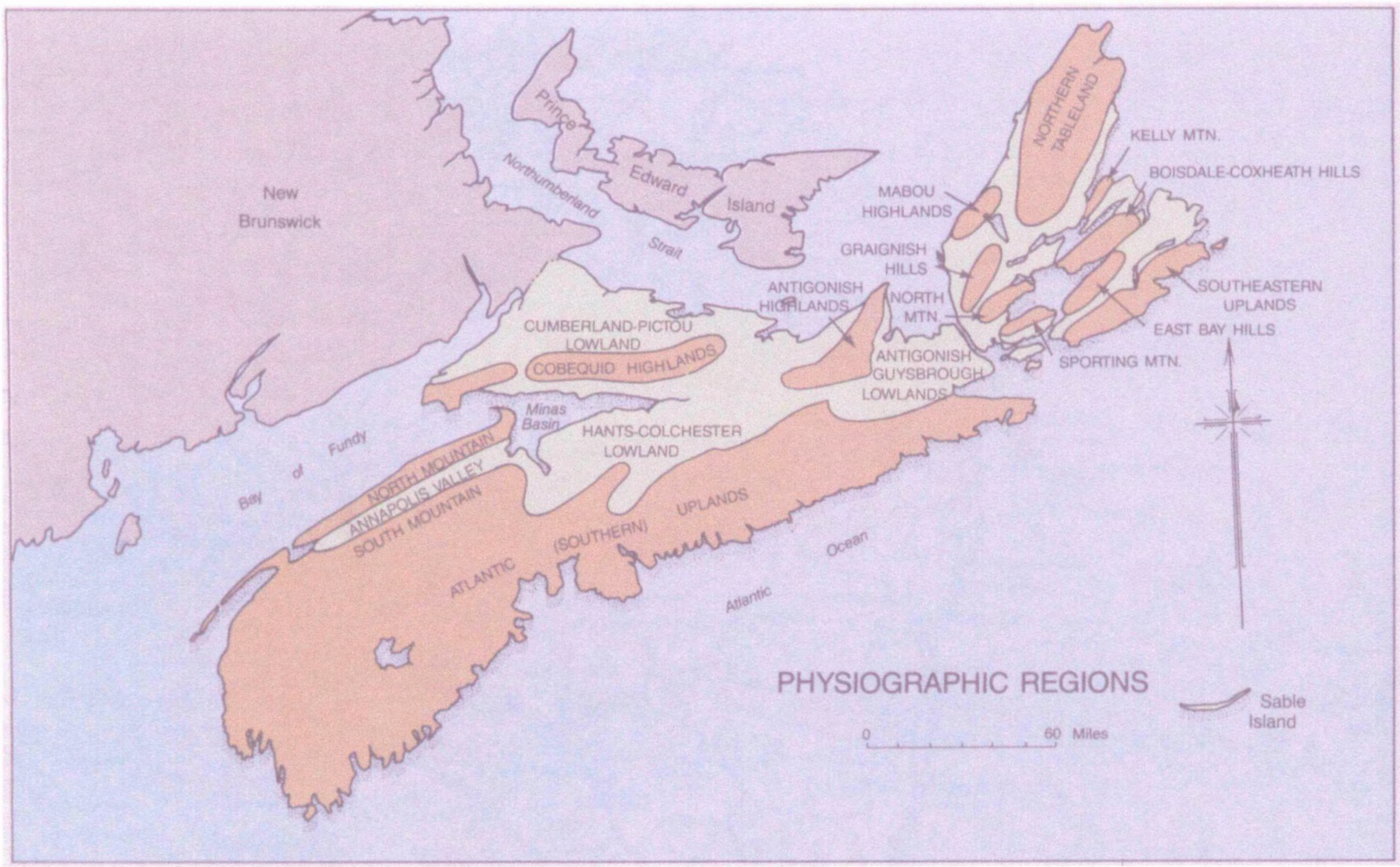

Figure 2.1: Physiographic regions of Nova Scotia (after Stea et al., 1992).

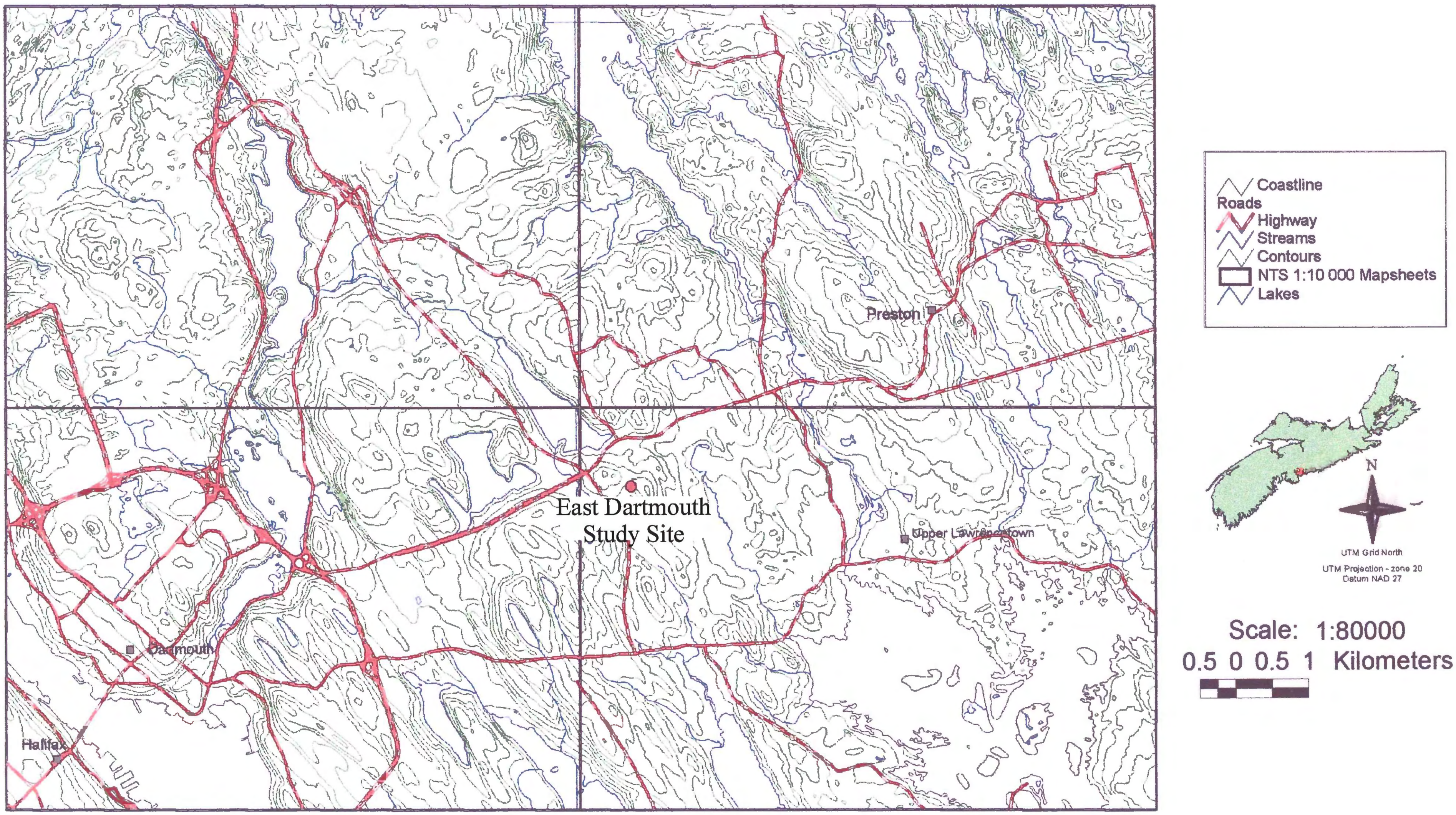

Figure 2.2: Topography of the East Dartmouth study area.

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Locally, the East Dartmouth well site is situated on a small saddle plateau between two topographic highs. The plateau forms a small drainage divide, separating areas to the north that drain into Loon Lake and areas to the south that drain either into Cranberry Lake to the southwest or into Bissett Lake to the southeast. The elevation of the East Dartmouth well site is approximately 90 m above sea level.

The lithology of the underlying bedrock is the primary control on topography in the Waverley area (Stea and Fowler, 1981b). Regionally, the topography is flat to rolling (Fig. 2.3) with many surface boulders. North to northwest – south to southeast trending, elongate to oval drumlins produce the rolling topography in the study area. The topography becomes less variable in areas underlain by the more resistant quartzite bedrock of the Goldenville Formation (Fig 2.3 and Fig. 2.5).

The Waverley well site is situated at an elevation of approximately 35 m above sea level. It is located near the base of a topographic high to the east. The area drains southward into Powder Mill Lake.

2.2 Bedrock Geology

The East Dartmouth and Waverley study areas are underlain by metamorphosed sediments of the Meguma Group, a thick sequence of siliclastic rocks ranging in age from Late Cambrian or older to Early Ordovician (Schenk, 1995). The Meguma Group is divided into an underlying Goldenville Formation and an overlying Halifax Formation (Keppie, 2000a). The geological maps for the study areas are shown in Figures 2.4 and 2.5. The driller's well logs for the study sites are presented later in Tables 3.2 and 3.3 (page 25).

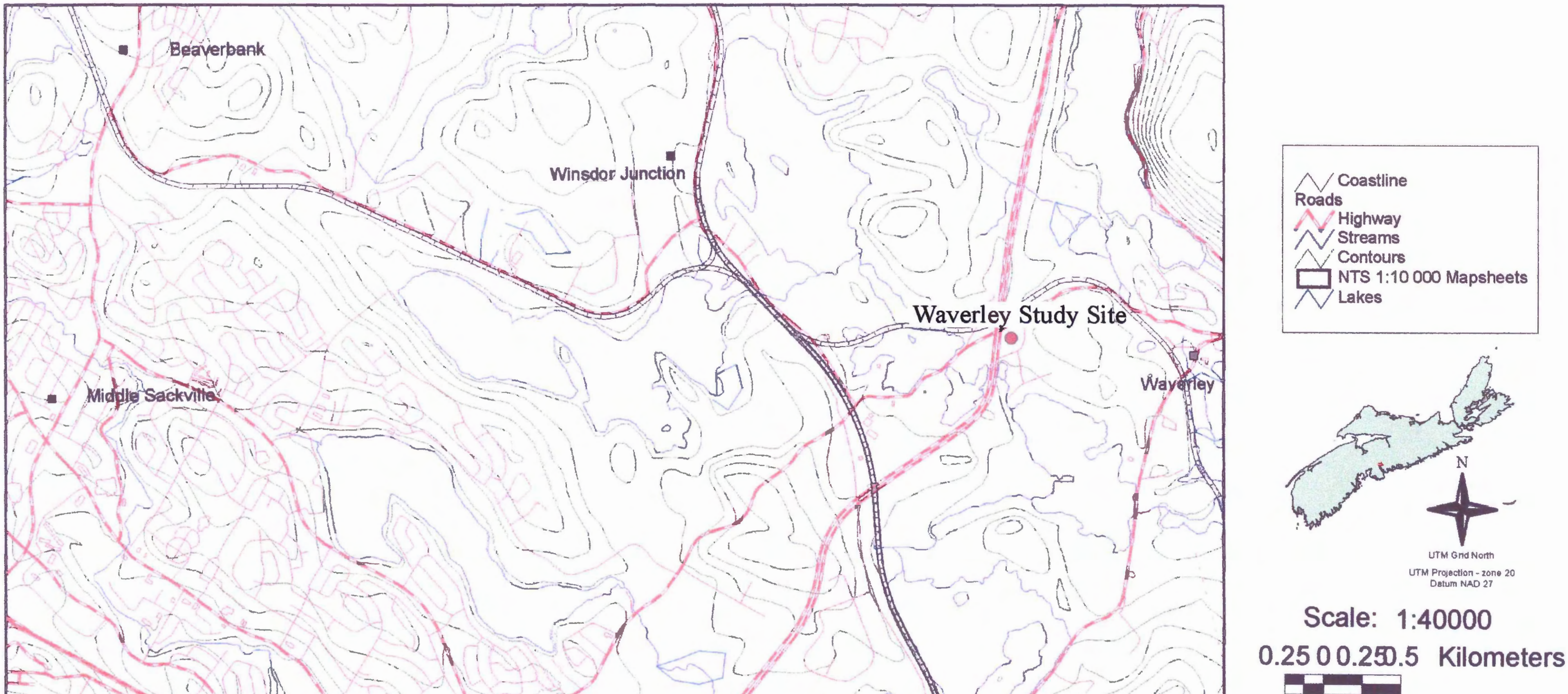

Figure 2.3: Topography of the Waverley study area.

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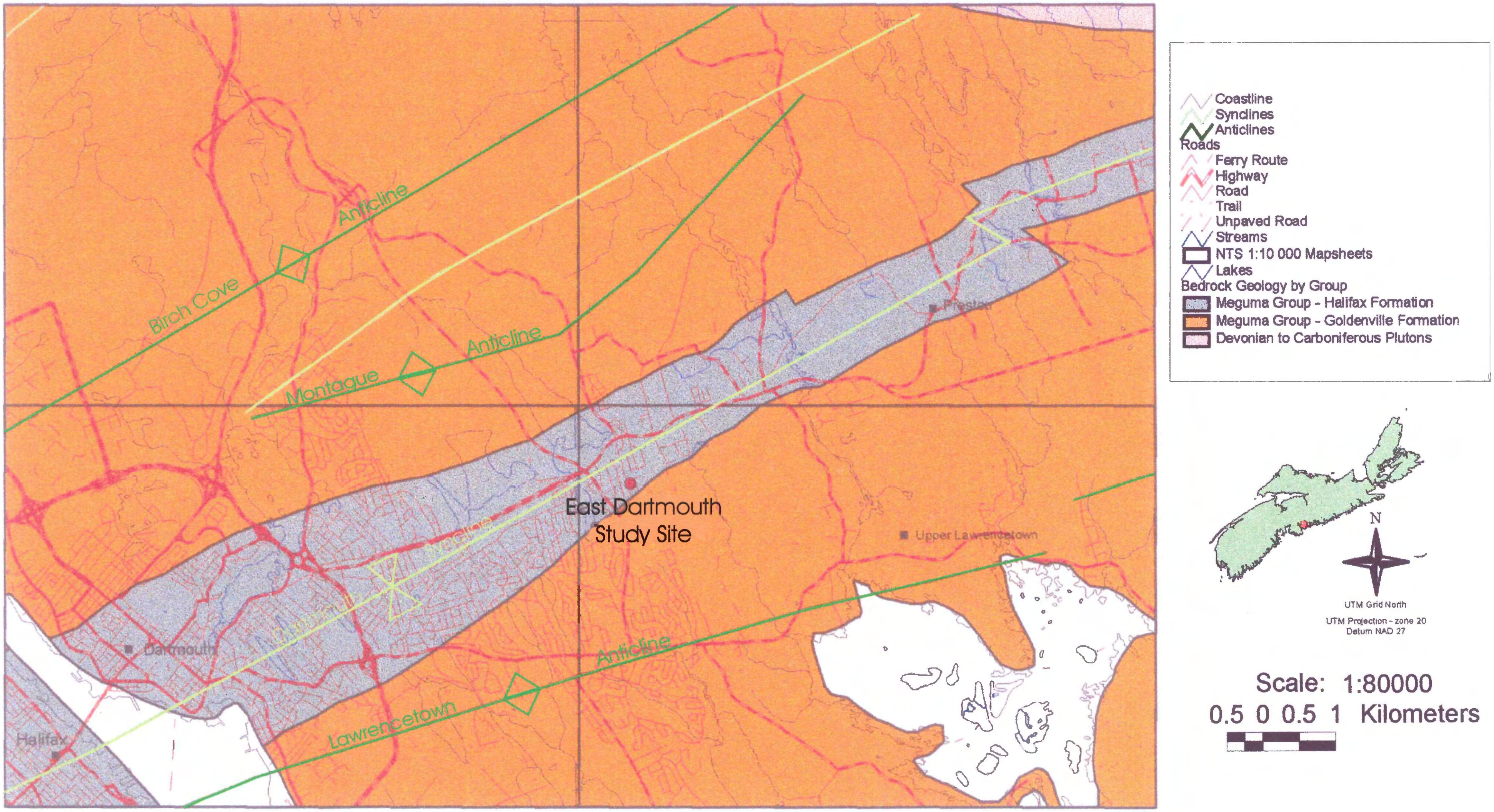

Figure 2.4: Bedrock geology of the East Dartmouth study area.

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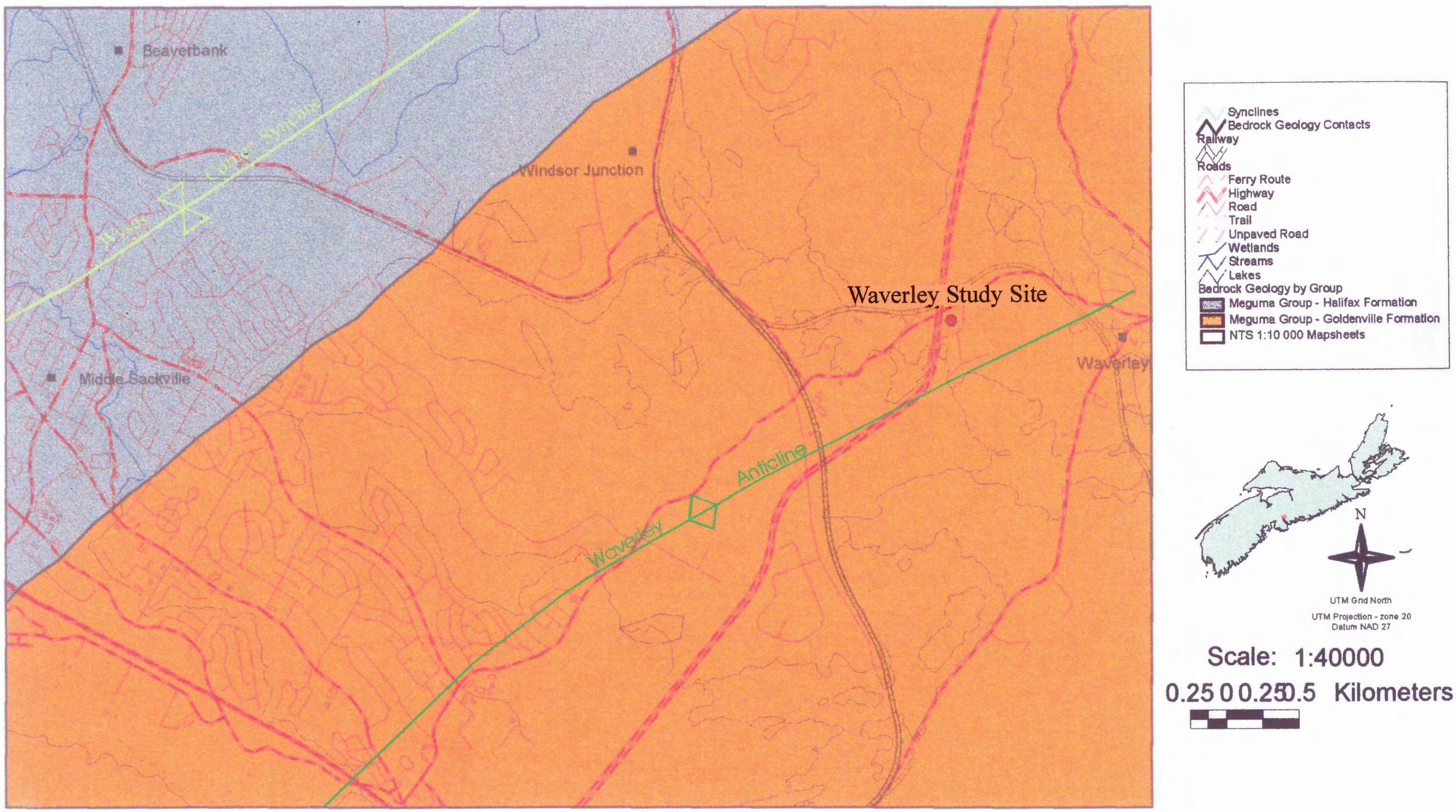

Figure 2.5: Bedrock geology of Waverley study area.

2.2.1 Goldenville Formation

The Goldenville Formation consists mainly of thickly-bedded, massive to locally laminated, quartzose to feldspathic metawacke with minor laminated siltstone and slate. Coarse pyrite is locally common in the quartzite layers. The quartzite ranges from green to grey-green or light to medium-grey in colour, depending on the amount of chlorite and biotite present (Taylor and Schiller, 1966).

The exact thickness of the Goldenville Formation is unknown since the formation has no known base. The maximum measured thickness of the Goldenville Formation is 6.7 km near Liverpool (Faribault, 1914).

Sedimentary and/or early diagenetic flakes of muscovite are dated at 476 ± 19 and 496 ± 20 Ma suggesting a Late Cambrian to Early Ordovician age for the Goldenville Formation. U-Pb concordant zircon and detrital titanite ages near the base and the top of the unit are 566 ± 8 and 552 ± 5 Ma, respectively (Keppie, 2000b). *Paleodictyon (Glenodictyum) cf. imperfectum* found in the upper portion of the Goldenville Formation also suggests an Ordovician age (Schenk, 1995).

2.2.2 Halifax Formation

The Halifax Formation is characterized by finely laminated grey to black slates with thin, interbedded, planar to cross-bedded siltstone and sandstone. The slates are generally sulphide-rich with a significant pyrite content. The pyrite occurs as coarse cubes and as fine to coarse mineralization along cleavage planes (Horne et al., 1998). Colour variation in the rocks of the Halifax Formation is primarily dependent on the presence or absence of chlorite and graphite (Taylor and Schiller, 1966).

The Halifax Formation has no known top over almost its entire exposure. The Formation is 11.8 km thick at the stratotype in the Halifax area (Schenk, 1995).

The upper portions of the formation contain Early Ordovician (Tremadocian) acritarchs and graptolites *Dictyonema flabelliforme* (Eichwald) and *Anisograptus sp.* (Schenk, 1995).

2.3 Metamorphism of the Meguma Group

The Meguma Group rocks exhibit both regional and contact metamorphism in the two study areas (Taylor and Schiller, 1966). The rocks have undergone low grade regional metamorphism to a greenschist facies, under low to medium pressure and high temperature conditions. The age of the regional metamorphism has been set at between 412 and 400 Ma (Reynolds and Muecke, 1978).

Contact metamorphism produced from the intrusion of granitic rocks has superimposed a hornblende-hornfels facies upon the regional greenschist facies rocks of the Meguma Group. The hornblende-hornfels facies suggest that the rocks experienced temperatures of 550-700 °C and water pressures between 1 000 and 3 000 bars (Taylor and Schiller, 1966).

2.4 Structure of the Meguma Group

2.4.1 Regional Structure

At least three generations of folds and faults affect sedimentary strata of the Meguma terrane (Fyson, 1966). The main folds are low plunging and upright with regular wavelengths at approximately 15 km apart. The folds describe an arc that trends northerly in the southwest to easterly in the eastern part of the terrane. It is thought that these first generation folds formed during the Middle Devonian Acadian Orogeny through maximum horizontal compression of the Meguma terrane which resulted in vertical extension. The stress direction then changed to east-west, forming a second generation of steeply plunging cross-folds in the Halifax Formation that trend north to northeast. This folding event continued both before and after the Late Devonian and Early Carboniferous granitic plutons intruded the Meguma strata. Kink-folds and kink-bands form a third generation of folds that trend northwest and plunge steeply to the southeast (Schenk, 1995). Fyson (1966) suggested that the third generation of folds appears to be younger than the granites. During the third folding event, northwest striking sinistral faults and northeast to eastward dextral faults also formed (Schenk, 1995).

2.4.2 Local Structure

The East Dartmouth well site is located in the slates of the Halifax Formation, near a contact with greywackes of the underlying Goldenville Formation (Fig. 2.4). According to the well driller's log (Table 3.2), the well intersects quartzite from 20 m (68 ft) to 53 m (175 ft) at the base of the well. The East Dartmouth well site is situated on the southern limb of the northeast – southwest trending Dartmouth Syncline, close to the axial trace (Faribault, 1908). There are no outcrops in the immediate vicinity, however the bedding in the surrounding area strikes southwest and is steeply dipping (75-80°) to the northwest. Cleavage in the area strikes parallel to the bedding and dips almost vertically. Two major northwest – southeast trending faults lie west of the study site (Keppie, 2000a).

The Waverley well site is situated within the quartzites of the Goldenville Formation on the northern limb of the southwest – northeast trending, southwest plunging Waverley Anticline (Fig. 2.5) (Horne et al., 1998; Faribault, 1909). Bedding strikes south-southwest and is moderately to steeply dipping (45-80°) to the northwest. Sub-vertical slaty cleavage parallels the axial surface of the Waverley Anticline.

There are two major joint sets, cross-strike joints and strike-parallel joints in the Waverley study area (Fig. 2.6). Cross-strike joints, otherwise known as ac joints, trend at high angles (~60° to ~90°) to the regional bedding strike. They trend north-northwest and are nearly vertical (80°) (Fig. 2.7). These joints form the principal joint set in the study area. The second joint set in the study area is strike-parallel, or bc joints which parallel the general strike of the bedding (i.e. regional fold hinges) (Fig. 2.7). Discordant quartz veins parallel the principal (north-northwest trending) joint set. Bedding parallel veins are also present close to the hinge zone of the Waverley Anticline (Horne et al., 1998).

2.5 Surficial Geology

Work by Stea et al. (1992) and Stea and Fowler (1981a; 1981b) has produced maps of the surficial units deposited in the East Dartmouth and Waverley study areas throughout the various phases of ice flow during the Wisconsinan (last) glaciation. The relevant portions of these maps are shown in Figures 2.8 and 2.9.

2.5.1 East Dartmouth Study Area

The predominant surficial cover in the East Dartmouth study area is referred to as "Silty Till Plain" on the map sheet by Stea et al. (1992) and "Lawrencetown Till" on the map sheet by Stea and Fowler (1981a). It is noted as having a matrix composed of 50 % sand, 30% silt, and 20% clay material (Stea and Fowler, 1981a), and is considered as having moderate drainage and stoniness (Stea et al., 1992). The till is described as a dark reddish-brown silty matrix till that is moderately compact, fissile and massive. Stea and Fowler (1981a) suggest that the clays within the till are dominated by kaolinite. The till is

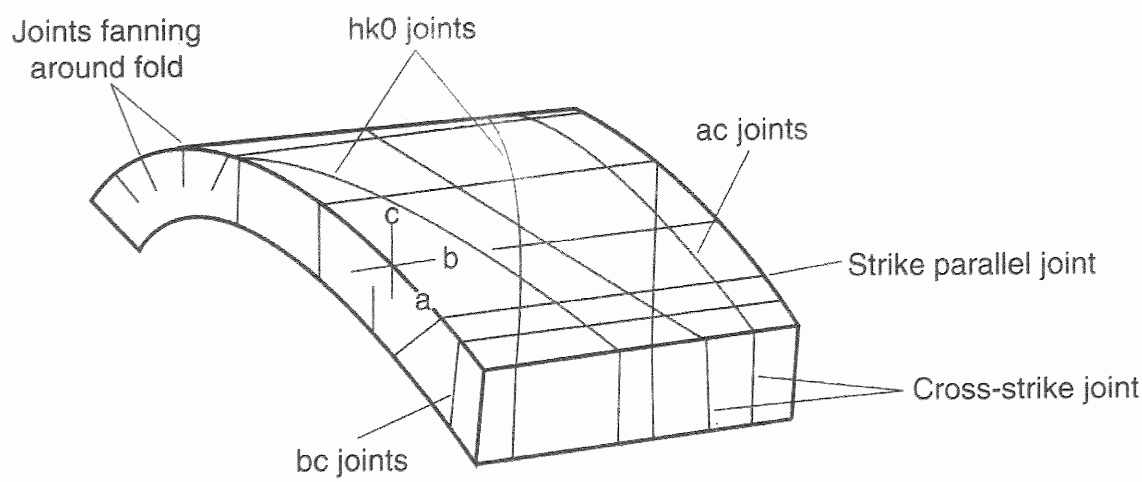

Figure 2.6: Idealized fold, showing arrangement of joint arrays with respect to fold symmetry axes (after van der Pluijm and Marshak, 1997).

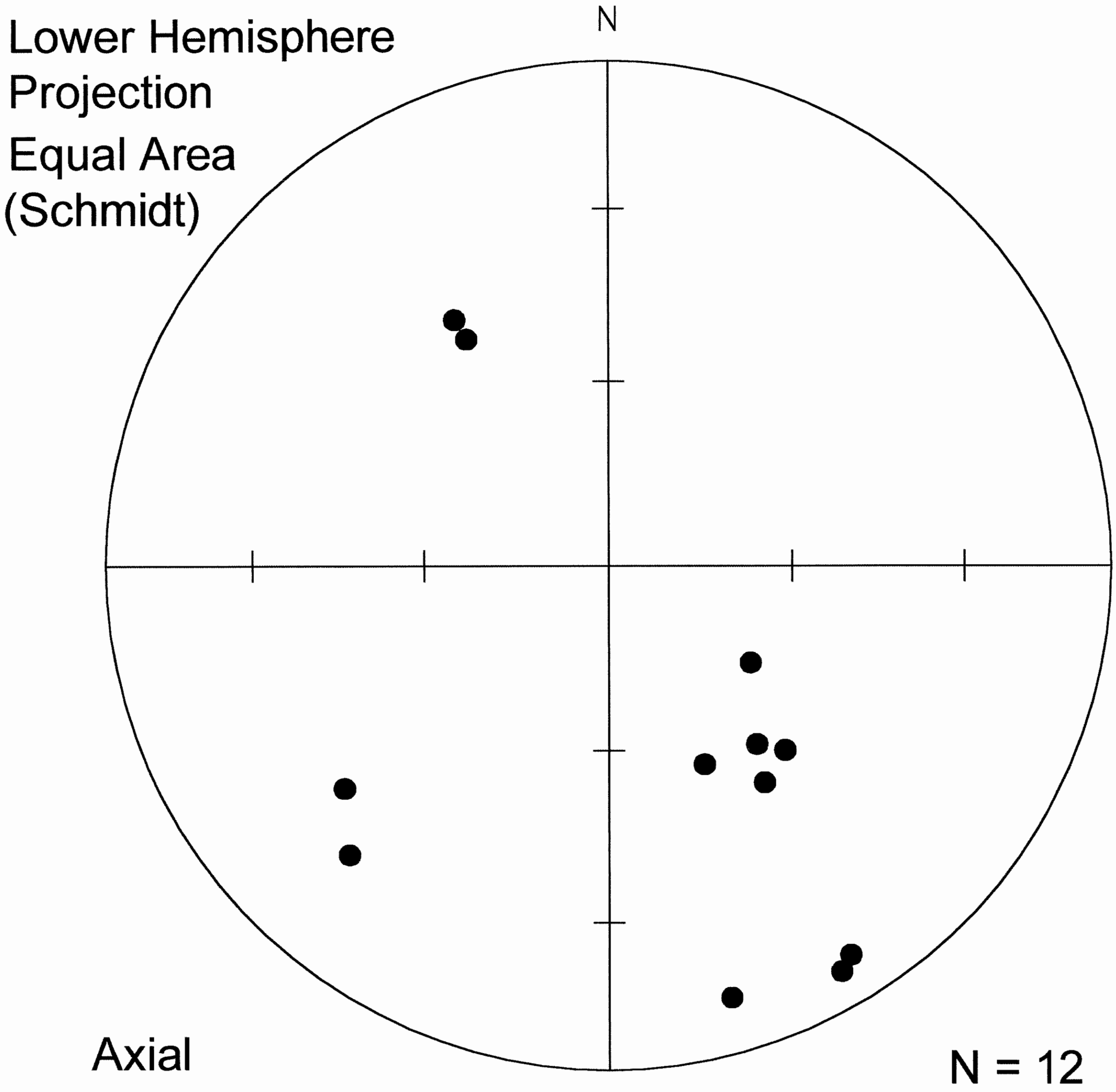

Figure: 2.7: Poles to joints, Waverley Study Area

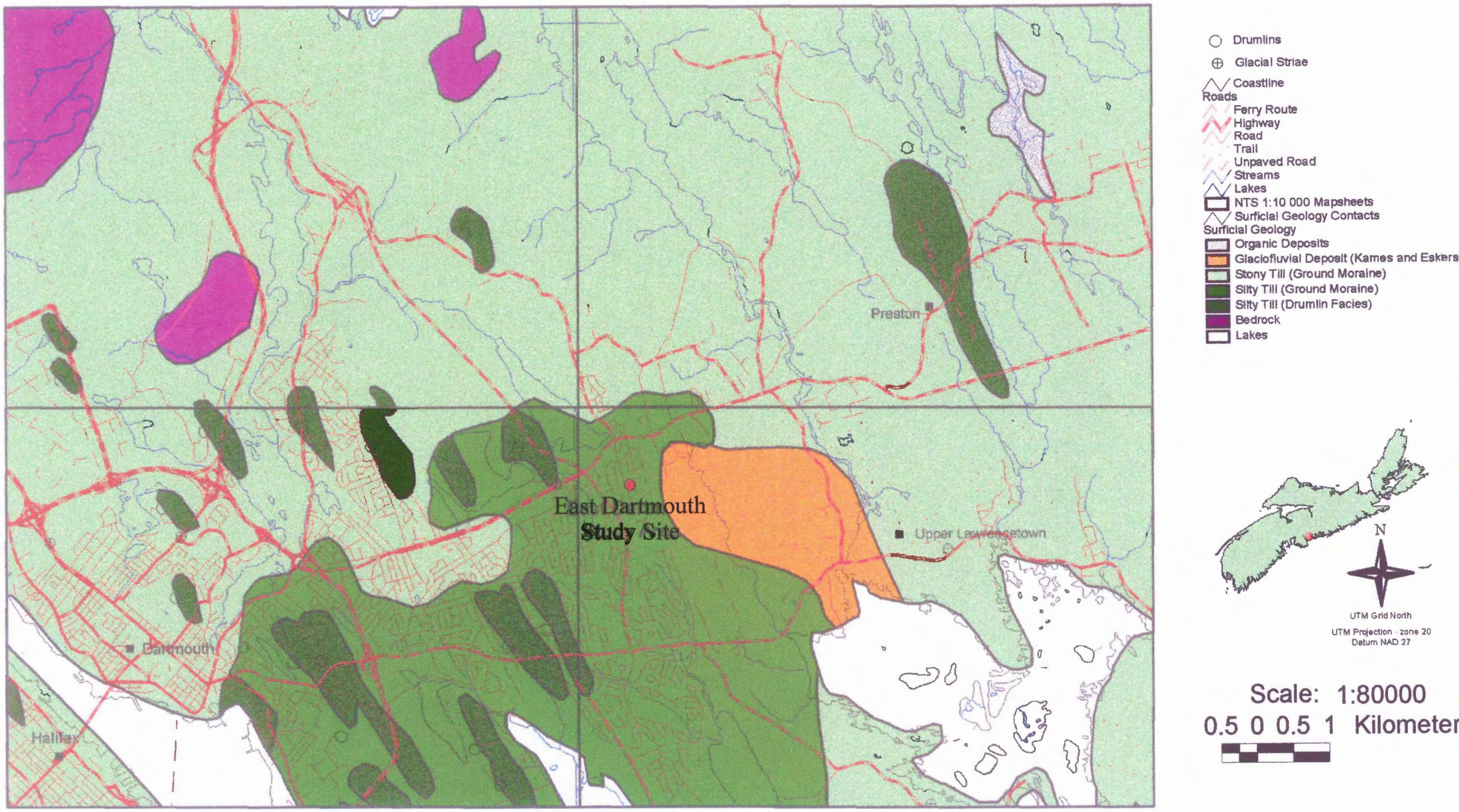

Figure 2.8: Surficial geology of the East Dartmouth study area.

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Figure 2.9: Surficial geology of the Waverley study area.

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matrix-supported and 2-20 m thick where it is ground moraine, but can reach thicknesses of 30 m where the landscape is covered by drumlins (Stea and Fowler, 1981a). According to the well driller's log, the local till thickness is 20 m for the East Dartmouth study area and consists mainly of clay material (Table 3.2, page 25). The Lawrencetown Till contains approximately 10-30% allochthonous clasts that were transported from a distance of 10-70 km. Stea et al. (1992) suggested that Carboniferous sediments from the Prince Edward Island region and material from the vast area of redbeds in northern Mainland Nova Scotia make up a significant portion of the till throughout the study area.

Kame fields and esker deposits overlie the silty till plain to the east of the well site and extend northward, intersecting the Cole Harbour basin (Fig. 2.8). The glaciofluvial deposits contain poorly to well bedded gravel, sand and silt, and diamicton layers that are described by Stea et al. (1992) as having rapid drainage and stoniness. The deposits contain horizontal to angular beds in which fractures and collapse features are common (Stea et al., 1992). The glaciofluvial deposits vary in thickness, but regional average is 4-6 m (Stea et al., 1992). The kame fields and esker deposits are considered to be the result of outwash from the margins of remnant ice caps during a final phase of Wisconsinan ice flow over Nova Scotia, and are restricted to low-lying areas (Stea et al., 1992).

2.5.2 Waverley Study Area

The surficial material in the Waverley study area is classified as a "Stony Till Plain" on the map sheet by Stea et al. (1992) and a "Quartzite Till" on the map sheet by Stea and Fowler (1981b). The till is described as a light bluish grey, clast-dominated till with a sandy matrix composed of 80% sand, 15% silt, and 5% clay. The clasts are angular, largely cobble sized, and have meta-greywacke, gneiss, and quartzite lithologies, suggesting mainly a local bedrock provenance (Stea and Fowler, 1981b). The thickness of the till plain can vary from 1-10 m, however, regionally it averages 3 m (Stea and Fowler, 1981b). The local till thickness at the Waverley study site is 5 m according to the well log (Table 3.3, page 25). The till is also noted by Stea et al. (1992) to have rapid drainage and a high water table.

3.0 DATA AND METHODS

3.1 Field Methods

3.1.1 Well Data

The wells at the East Dartmouth and Waverley sites are both drilled wells. The East Dartmouth well was drilled in 1970 using the air rotary drilling method and is located on private property in a residential area. The Waverley well was also drilled using the air rotary drilling method in 1999 for the purpose of a hydrogeology field school. The Waverley well site is located on private property near a commercial establishment. The East Dartmouth well supplies water for limited domestic use. The Waverley well is used only periodically for testing purposes. Both sites have central water available.

Both wells were developed by "blowing" or flushing with air and water for approximately one hour to clean the borehole and remove fines generated from drilling. Estimated yields by the driller were taken during this time.

Specific well data and lithologic logs are included below in Table 3.1, Table 3.2 and Table 3.3. The lithologic logs were constructed based on cuttings brought to the surface during drilling. Down-hole camera logs for the East Dartmouth and Waverley wells are given in Tables 3.4, 3.5 and 3.6.

Wells	East Dartmouth	Waverley
Driller	Nodland	H.J. Edwards
Year	1970	1999
Well Depth (feet)	175	200
Well Diameter (inches)	6	6
Casing Length (feet)	74	20
Static Water Level (feet)	6	50
Air Lift Yield (gpm)	4	0.5

Table 3.1: Well data from drillers' logs.
1 inch = 2.54 cm; 1 foot = 0.3048 m; 1 gallon/minute = 7.575 x 10^{-2} litres/second

Depth (ft)	Sample Description
0 – 68	Clay
68 – 175	Quartzite

Table 3.2: Lithologic log for the East Dartmouth well (from water well driller's report). 1 foot = 0.3048 m

Depth (ft)	Sample Description
0 – 11	Sand and gravel
11– 15	Gravel
15 – 33	Fractured grey quartzite with quartz stringers, slaty interbeds and iron staining
33 – 36	Same as 15 – 33, but no iron staining in fractures
36 – 54	Grey quartzite with minor interbedded slate, quartz filled fractures and iron staining in open fractures
54 – 60	Grey quartzite with some iron staining
60 – 66	Grey quartzite with minor slate interbeds
66 – 72	Grey quartzite, little iron staining, trace pyrite, fractured
72 – 75	Slate with minor quartzite, slight iron staining
75 – 101	Dark grey quartzite with quartz filled fractures
101 – 138	Dark grey quartzite with slate interbeds, quartz filled fractures, iron stained open fractures
138 – 145	Dark grey slate with quartz filled fractures
145 – 182	Dark grey quartzite with quartz filled fractures
182 – 185	Dark grey slate with minor quartzite, reddish-brown stain on open fractures
185 – 188	Grey quartzite with quartz filled fractures, reddish-brown stain on open fractures
188 – 191	Dark grey quartzite
191 – 194	Medium to dark grey slate
194 – 197	Slate with quartzite interbeds, quartz filled fractures
197 – 200	Grey quartzite with minor slate interbeds, quartz filled fractures

Table 3.3: Lithologic log for the Waverley well (logged by students during drilling). 1 foot = 0.3048 m

Depth (ft)	Borehole Description
4	Weld
47	Increased corrosion
83	Fracture
91	Possible fracture
105-109	Colour change
115	Possible fracture / and colour change
124 - 139	Water cloudier
139	Water clearing
145	Colour change
151	Banding
153	Possible fracture
166	Colour change
168	Colour change
172	Bottom (soft)

Table 3.4: Vertical down-hole camera log for the East Dartmouth well.
1 foot = 0.3048 m

Depth (ft)	Borehole Description
3-4	Weld
47	Corroded zone to approximately 47 feet
52	Water Level
83-84	Sub-horizontal fractures
89	Fracture or ledge
92	Vertical fracture
105	Colour change
107 – 108	Small fracture / ledge
109 – 116	Fractured zone
129	Small washout
137	Colour change
138	Fracture
145	Possible fracture
147 – 148	Colour change
153 – 156	Possible fracture
156	Colour change
157	Small vertical fractures
166	Possible fracture / colour change

Table 3.5: Side down-hole camera log for the East Dartmouth well.
1 foot = 0.3048 m

The camera logs for the East Dartmouth well show that the bedrock in the borehole contains a number of potential water-bearing fractures at some depth. However, the relative contributions of the fractures cannot be determined.

Depth (ft)	Borehole Description
20	Water flowing into the well from a shallow fracture system at the bottom of the casing
37	Quartz vein
48 – 49	Small fractures
58	Fracture
60	Small fracture
65	Quartz vein
67	Quatz vein
70	Fracture
78	Fracture
82	Sub-vertical fracture
85	Quartz vein
88	Quartz vein
89	Quartz vein
103	Steeply dipping vein
104	Steeply dipping vein with minor folding
105	Quarz vein
106	Quartz vein
108 – 109	Quartz vein
112 – 113	Vertical fracture
119	Lighter coloured quartzite
120	Quartz vein
127	Sub-horizontal in-filled fractures
145	Steeply dipping quartz vein
154 – 155	Very steeply dipping, sub-vertical quartz vein
156	Light gray quartzite
158	Moderately dipping quartz vein
167	Steeply dipping quartz vein
168 – 169	Small fractures
177 – 178	Steeply dipping, large quartz vein
189	Fracture
191	Sub-vertical quartz vein / pump location

Table 3.6: Vertical down-hole camera log for the Waverley well.
1 foot = 0.3048 m

The camera log for the Waverley well showed that water was flowing into the well at the base of the casing, representing water from a very shallow fracture system in the bedrock. Although drilling difficulties prevented the casing from being totally tight, the water quality indicates that the well is receiving shallow groundwater rather than surface water (H. Cross, personal communication). Bedrock in the borehole is consolidated throughout its entirety and contains minor fractures which do not contribute a significant amount of water to the well. Functionally this well is more similar to a dug well completed in bedrock than a drilled well.

3.1.2 Pump Data

A Goulds Pumps Model 5GS centrifugal variable speed 4 inch submersible pump was used for the pump tests conducted in this study (Fig. 3.1). A variable speed pump was used in order to adjust for the changes in discharge as the head in the well decreased without the use of a return line and/or use of excessive back pressure on the pump. Performance curves for the test pump are given in Appendix 1.

3.1.3 Field Measurements

Field measurements conducted during the pump tests include the static water level just before the test was started, time since the pump started, pumping rate, pumping water levels at various intervals during the pumping period, the time the pump stopped, and water level measurements after the pump stopped (recovery).

Water-level measurements

The depth to water was measured in this study using a Solinst Model 101 water level meter (Fig. 3.2). It is essentially a measuring tape that consists of an electrode (probe), two-wire cable, a light and a "beep" that sounds (indicating a closed circuit) when the

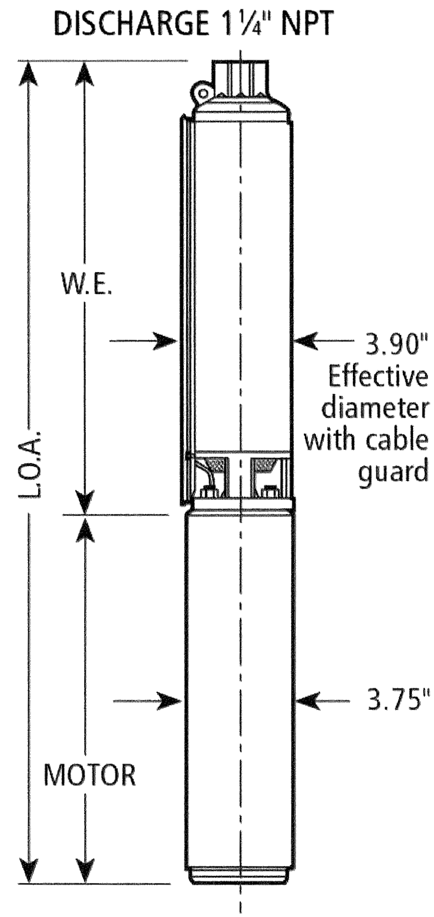


Figure 3.1: Goulds Pumps model 5GS centrifugal, variable speed 4" submersible pump used in the pump tests conducted in this study.

Figure 3.2: Solinst Model 101 water level meter used to obtain the water-level measurements in this study.

electrode touches the water (Fig. 3.2). The water level measurements are taken manually at predetermined time intervals. See Appendix 2 for the time intervals used for measuring drawdown in this study.

Discharge-rate measurements

The pumping rate or discharge rate was measured using a calibrated two-gallon bucket and stopwatch and an inline "Neptune" water meter.

The pumping rate was calculated using the calibrated bucket by observing the time (using a stopwatch) required to fill the two-gallon bucket, i.e. if it takes 30 seconds to fill a 2-gallon bucket, the discharge rate is 4 gallons per minute (gpm). This method is simple, accurate and reliable, and also provides an independent check on the water meter.

The dials on the water meter show the total volume discharged through the meter up to the time of observation. Subtracting two readings and dividing by the time between readings gives the pumping rate. The water meter stopped measuring during some of the pump tests conducted on the Waverley well, and therefore proved to be unreliable. Problems encountered with the meter included clogging with sediment and pumping rate (and thus water volume) too low for the meter to accurately record the discharge. Another disadvantage of the meter is the delay in obtaining values at the start of the test, when the pumping rate is being fine-tuned.

Conductivity and Temperature Measurements

The conductivity of the discharge water was measured using a Hanna HI 9033 multi-range conductivity meter. The temperature of the water was measured using an alcohol thermometer.

3.1.4 Types of Pump Tests Conducted

Four different types of pump tests were conducted on both the East Dartmouth and Waverley wells: step drawdown, constant rate, cyclic, and slug tests.

Step Drawdown

In a step drawdown test the well is pumped at a low constant-discharge rate for a specific length of time, usually from 30 to 120 minutes. The pumping rate is then increased to a higher constant-discharge rate and the well is pumped again. This process is repeated through at least three steps of equal duration. Ideally the drawdown tends toward stabilization prior to the end of each step.

For this study, the step drawdown test consisted of four steps, each of 30 minutes in duration in both the East Dartmouth and Waverley wells. Drawdown measurements were recorded in the pumped well during the test, and recovery measurements were taken after the pump was shut off at the conclusion of the test. Appendix 2 contains the raw data for the step tests.

Constant Discharge

During the pump test, the well is pumped at a constant discharge (constant rate) for a predetermined amount of time. Drawdown and recovery measurements were taken in the pumped well. For this study several constant rate tests of varying duration were conducted for both wells. Appendix 2 contains the field data for the constant rate tests.

Cyclic Test

In a cyclic test the well is pumped at a constant rate for three or more cycles of equal duration. Between each cycle the pump is shut off and the well is allowed to recover for a time equal to the pumping cycles. However, the duration of the last recovery cycle depends on the time it takes for a complete recovery (i.e. until the water level reaches the static water levels recorded before the commencement of the test). In this study, a cyclic pump test was conducted with three pumping cycles, each one hour in duration. Cyclic tests were performed on the wells in both study sites. Appendix 2 contains the field data for the cyclic tests.

Falling Head Slug Test

A slug test can be used to determine the hydraulic conductivity of the formation in the immediate vicinity of the well. In a falling head slug test the water level in the casing is caused to rise instantaneously above the initial head. The excess head decays as the water flows from the well into the formation. The fall of the water level is measured with respect to time (Fetter, 1994). Enough water must be added to raise the water level by about 10 to 50 cm (Kruseman and de Ridder, 1990). Four gallons of water was added to the wells at each study site to conduct the slug tests. Appendix 2 contains the field data for the slug tests.

Slug tests are typically used more in environmental monitoring wells than water wells. Since they are simple and inexpensive to carryout compared to pump tests, it was considered important to check how transmissivity estimates from slug tests compared to those from other methods.

3.2 Analytical Methods

Five different analytical procedures are used to determine the hydraulic parameters of the aquifers in this study. They are the Hantush-Bierschenk method for step drawdown tests, the Theis method, Jacob's method, Gringarten et al.'s method for constant discharge tests, and Hvorslev's method for slug test analysis. The derivative method is used to help define different flow regimes during an aquifer test and thus determine which methods may be most applicable. The safe yield and specific capacity of the wells are also calculated.

3.2.1 Hantush-Bierschenk's Method – Step Drawdown

A step drawdown test is a type of well-performance test conducted to determine the specific capacity of the well at various pumping rates, head losses, and the unique hydraulic characteristics of the well (Kruseman and de Ridder, 1990). Drawdown in a well is due to two components of head loss, aquifer and well losses (Fig. 3.3).

Aquifer losses are the head losses that occur in the aquifer where the flow is laminar. They are time-dependent and vary linearly with the well discharge. Well losses are of two types, linear and non-linear, as shown on Figure 3.3. Well losses can cause the drawdown inside the well to be much greater than that expected on theoretical grounds.

Linear well loss is caused by damage to the aquifer during drilling and completion of the well, i.e. head loss due to compaction of the aquifer material during drilling, head loss due to plugging of the aquifer with drilling mud, which reduces the permeability near the borehole; head loss in the gravel pack; and head loss in the screen section (Fig 3.3).

Non-linear well loss is friction loss that occurs inside the well screen and in the suction pipe (where flow is turbulent), and in the zone adjacent to the well (where flow is also turbulent) (Fig. 3.3).

The Hantush-Bierschenk method to analyze step drawdown tests can be applied if the following assumptions and conditions are satisfied (Kruseman and de Ridder, 1990):

1. The aquifer is confined, leaky or unconfined.
2. The aquifer is horizontal and of infinite horizontal extent.
3. The piezometric surface of the aquifer is horizontal prior to the start of pumping.

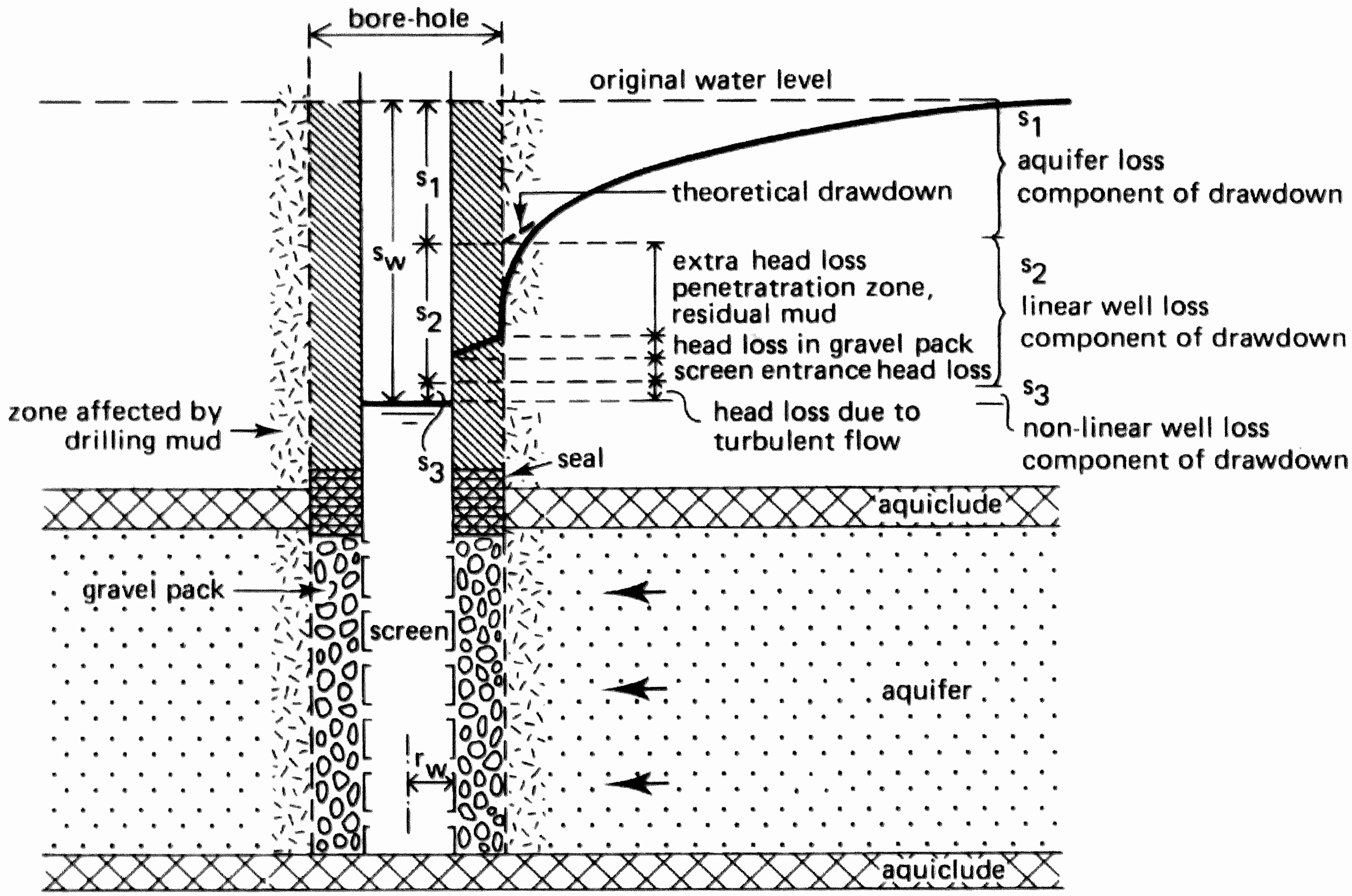


Figure 3.3: Various head losses in a pumped well (after Kruseman and de Ridder, 1990).

4. The piezometric surface of the aquifer is not changing with time prior to the start of pumping.
5. All changes in the position of the piezometric surface are due to the effect of the pumping well alone.
6. The aquifer is homogeneous and isotropic.
7. All flow is radial towards the well.
8. Groundwater flow is horizontal.
9. Darcy's law is valid (i.e. laminar flow exists throughout the well and aquifer).
10. Groundwater has a constant density and viscosity.
11. The pumping well is fully penetrating (i.e. it is screened over the entire thickness of the aquifer).
12. The pumping well has an infinitesimally small diameter (i.e. the storage in the well can be neglected) and is 100-percent efficient.
13. There is no source of recharge to the aquifer.
14. The aquifer is compressible and water is released instantaneously from the aquifer as the head is lowered.
15. The aquifer is pumped step-wise at increased discharged rates.
16. The flow to well is in unsteady state (i.e. the drawdown differences with time are not negligible, nor is the hydraulic gradient constant with time).
17. The non-linear well losses are appreciable and vary according to the square of the discharge.

The equation describing drawdown in a pumping well is (Kruseman and de Ridder, 1990):

$$s_w = BQ + CQ^n \tag{3.1}$$

where

s_w	= predicted drawdown in the well at time t (L)
Q	= rate of discharge or pumping rate (L^3/t)
B	= linear well loss coefficient (t/L^2)
C	= non-linear well loss coefficient (t^2/L^5)
n	= exponent, typically taken as 2.0

If aquifer loss is BQ, and well loss is CQ^2 then well efficiency could be determined from a step drawdown test by the equation $L_p = \frac{BQ}{BQ+CQ^2} \bullet 100$. However, the BQ term almost always includes a major portion of the well losses and the CQ^2 term occasionally includes some aquifer loss, thus L_p represents only the percentage of head loss attributable to laminar flow, rather than well efficiency (Driscoll, 1986). Even though the well efficiency cannot be accurately determined from a step drawdown test, the values of B and C can be used to predict drawdown in the well for any realistic discharge Q at a certain time t (B is time dependent). The relationship between drawdown and discharge can be used to choose an optimum pumping rate for the well.

Hantush (1964) expressed the drawdown $s_{w(n)}$ in a well during the n-th step of a drawdown test as

$$s_{w(n)} = \sum_{i=1}^{n} \Delta Q_i B(r_{ew,t-t_i}) + CQ_n^2 \tag{3.2}$$

where

$s_{w(n)}$ = total drawdown in the well during the n-th step at time t
r_{ew} = effective radius of the well
t_i = time at which the i-th step begins ($t_i = 0$)
Q_n = constant discharge during the n-th step
Q_i = constant discharge during the i-th step of that preceding the n-th step
ΔQ_i = Q_i-Q_{i-1} = discharge increment beginning at time t_i

The sum of increments of drawdown taken at a fixed interval of time from the beginning of each step (t-$t_i = \Delta t$) can be obtained from Equation 3.3

$$\sum_{i=1}^{n} \Delta s_{w(i)} = s_{w(n)} = B(r_{ew}, \Delta t)Q_n + CQ_n^2 \tag{3.3}$$

where

$\Delta s_{w(i)}$ = drawdown increment between the i-th step and that preceding it, taken at time $t_i + \Delta t$ from the beginning of the i-th step

On the semi-log plot of the drawdown data versus time, the drawdown differences ($\Delta s_{w(i)}$) for each step are determined by taking the difference between the observed drawdown at a fixed interval Δt, taken from the beginning of each step, and the corresponding drawdown on the extrapolated curve of the preceding step.

If each term in Equation 3.3 is divided by Q we have the following relationship

$$\frac{s_{w(n)}}{Q_n} = B(r_{ew}, \Delta t) + CQ_n \tag{3.4}$$

A plot of the specific drawdown values ($s_{w(n)}/Q_n$) against the corresponding values Q_n on arithmetic graph paper results in a straight line with a slope ($\Delta(s_{w(n)}/Q_n)/\Delta Q_n$) equal to C, and the y-intercept on the on the $s_{w(n)}/Q_n$ axis ($Q = 0$) equal to B.

A problem with the Hantush-Bierschenk's method is that the values of $\Delta s_{w(i)}$ depend on extrapolated data and are therefore subject to some error.

Hazel (1973; as cited by Clark, 1977) devised a graphical method of analysis of step drawdown tests in which the true drawdown-discharge rate curve for each step is reconstructed. The test data are plotted against the logarithm of time and then reconstructed or corrected to account for prior drawdown. This is a complex procedure that was not carried out directly by the author and is therefore not discussed further. A more detailed account of this method is given by Clark (1977).

An estimation of transmissivity can be made using the reconstructed step drawdown data by use of the Jacob method (discussed in Section 3.2.3), even when equilibrium for each step has not been reached (Clark, 1977). The equation to calculate transmissivity is written as

$$T = \frac{0.183}{\Delta s/Q} = \frac{0.183Q}{\Delta s} \tag{3.5}$$

where

T = aquifer transmissivity (ft^2/d or m^2/d)
Q = discharge rate from pumped well (ft^3/d or m^3/d)
Δs = incremental drawdown (ft or m)
0.183 = constant $2.3/4\pi$ (see Equation 3.15, page 44)

3.2.2 Theis Method – Radial Flow Model

Derivation of the Theis equation is based on the following assumptions:

1. The aquifer is confined top and bottom.
2. The aquifer is horizontal and of infinite horizontal extent.
3. The piezometric surface of the aquifer is horizontal prior to the start of pumping.
4. The piezometric surface of the aquifer is not changing with time prior to the start of pumping.
5. All changes in the position of the piezometric surface are due to the effect of the pumping well alone.
6. The aquifer is homogeneous and isotropic.
7. All flow is radial towards the well.
8. Groundwater flow is horizontal. Darcy's law is valid (i.e. laminar flow exists throughout the well and aquifer).
9. Groundwater has a constant density and viscosity. The pumping well is fully penetrating (i.e. it is screened over the entire thickness of the aquifer).
10. The pumping well has an infinitesimally small diameter (i.e. the storage in the well can be neglected) and is 100-percent efficient.
11. There is no source of recharge to the aquifer.
12. The aquifer is compressible and water is released instantaneously from the aquifer as the head is lowered. Discharge rate is constant.
13. The flow to well is in unsteady state (i.e. the drawdown differences with time are not negligible, nor is the hydraulic gradient constant with time) (Fig. 3.4; Fetter, 1994; Kruseman and de Ridder, 1990).

The Theis equation, which gives the drawdown at any time t and radial distance r, is written as

$$s = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-y}dy}{y} = \frac{Q}{4\pi T}W(u) \qquad (3.6)$$

where

s	= the drawdown (ft or m)
r	= is radial distance of the piezometer from the pumping well (ft or m)
Q	= the constant well discharge (ft^3/d or m^3/d)
T	= is aquifer transmissivity (ft^2/d or m^2/d)
u	$= \dfrac{r^2 S}{4Tt}$ (3.7)
S	= is aquifer storativity (dimensionless)
t	= the time since pumping started (days)
$W(u)$	= -0.5772 – ln u + u – $u^2/2.2! + u^3/3.3!$ - …)

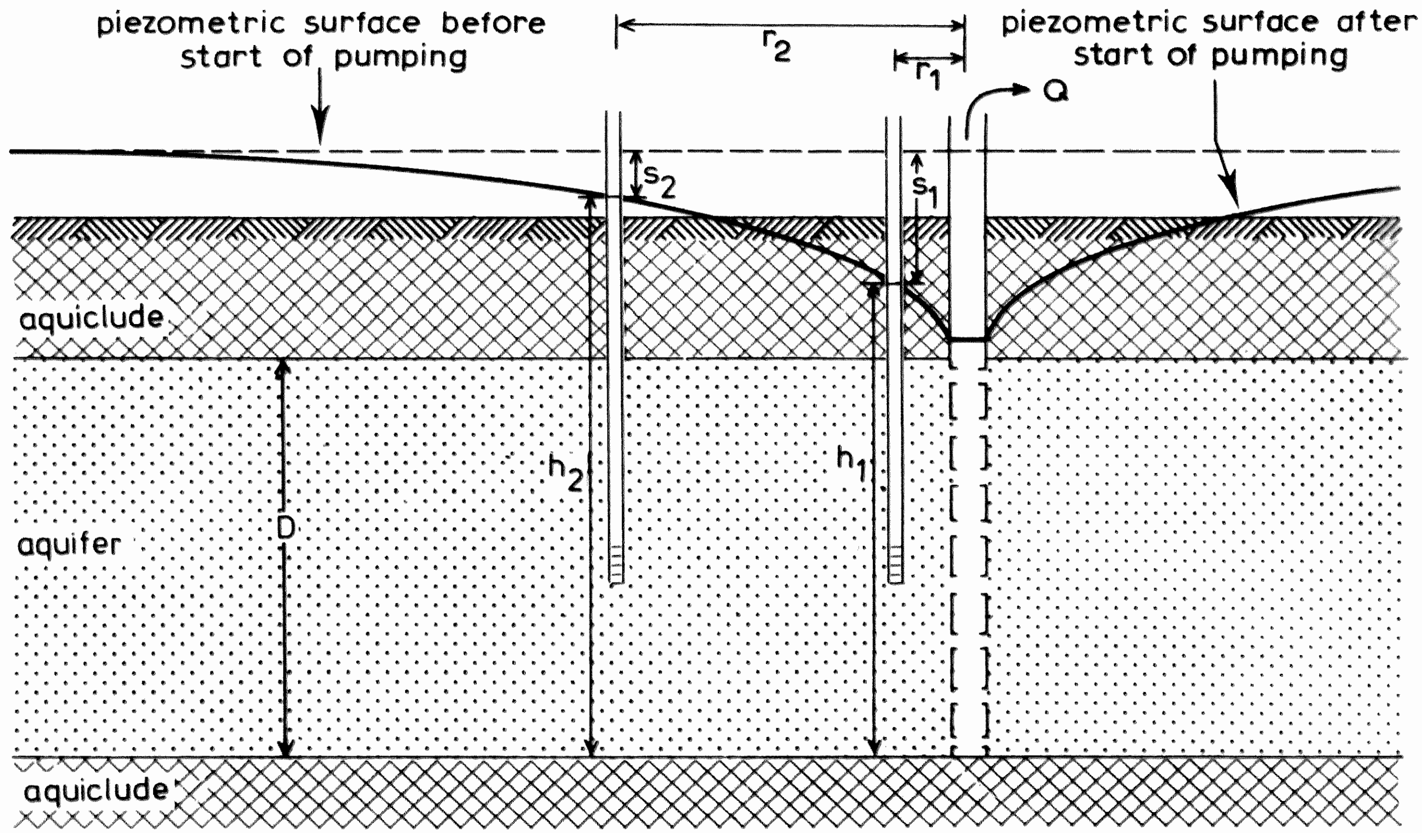


Figure 3.4: Cross-section of a pumped confined aquifer (after Kruseman and de Ridder, 1990).

The exponential integral $W(u)$ is referred to as the 'Theis well function', or 'well function of u'; it is also sometimes described by the symbol $-Ei(-u)$ (Kruseman and de Ridder, 1990). The values for $W(u)$ as u varies are given in Appendix 3.

Equation 3.6 can be written as

$$T = \frac{Q}{4\pi s} \times W(u) \tag{3.8}$$

and Equation 3.7 as

$$S = \frac{4Ttu}{r^2} \tag{3.9}$$

Once the values of T and S are known, it is possible to predict the effects of various pumping rates on drawdowns at various times and distances.

Theis developed the 'curve-fitting method' to calculate T and S using equations 3.6 and 3.7. Equation 3.6 can be written as

$$\log s = \log (Q/4\pi T) + \log (\mathrm{W}(u))$$

and Equation 3.6 as

$$\log (t) = \log (r^2 S/4T) + \log (1/u)$$

Since $Q/4\pi T$ and $4T/S$ are constant, the relation between log s and log t must be similar to the relation between *log* $W(u)$ and log $(1/u)$. If s is plotted against t (the pumping test data) and $W(u)$ against u (type curve) on the same log-log paper, the resulting curves will be the same shape, but horizontally and vertically offset by the constants $Q/4\pi T$ and $4T/S$. The Theis curve-fitting method involves matching the curve plotted from the pumping test data with the type curve. The coordinates of an arbitrary matching point are the related values of s, t, $(1/u)$, and $\mathrm{W}(u)$, which can be used in Equations 3.6 and 3.7 to calculate T and S. (Kruseman and de Ridder, 1990).

For this study, drawdown data was available only from the pumping well, which allows only the calculation of transmissivity (*T*). Storativity (*S*) cannot be accurately determined at the pumping well because of the difficulty in determining the effective radius of the well. Effective radius is the distance from the well axis at which measured drawdown equals theoretical drawdown from Equation 3.6. Drawdown data from at least one observation well is required to accurately determine *S*.

The value of *T* calculated from pumped well data tends to be more conservative than the values obtained from observation well data. However, as *u* becomes small ($<<1$), large changes in *u* correspond to relatively small changes in *W*(*u*), and there is less error in the value of *T* calculated from Equation 3.8. Since *T* and *S* are constants, Equation 3.9 shows that *u* is small when the ratio of r^2/t is small, for example when *r* is small and *t* is large.

3.2.3 Jacob's Method – Radial Flow Model

The Jacob method requires that the following conditions be met:

1. The assumptions listed for the Theis method are also met.
2. In addition, the value of u is small ($u << 1$), i.e. r is small and t is sufficiently large.

The Jacob method is a modification of the Theis nonequilibrium formula, Equation 3.5.

$$s = \frac{Q}{4\pi T}W(u) = \frac{Q}{4\pi T}(-0.5772 - \ln u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - ...)$$

The terms beyond ln *u* in the infinite series become small enough that they can be neglected when drawdown observations are made near the well (small *r*) and after a sufficiently long pumping time. So for small values of *u* ($u < 0.01$), the drawdown can be approximated by

$$s = \frac{Q}{4\pi T}(-0.5772 - \ln\frac{r^2 S}{4Tt}) \tag{3.10}$$

or

$$s = \frac{Q}{4\pi T}(-\ln(1.78) - \ln\frac{r^2 S}{4Tt}) \tag{3.11}$$

Using this equation, the drawdown can be calculated with an error less than 1% for a u smaller than 0.03, 2% for a u smaller than 0.05, 5% for a u smaller than 0.1, and less than 10% error for a u smaller than 0.15 (Kruseman and de Ridder, 1990). Combining the natural log terms in Equation 3.11 we obtain

$$s = \frac{Q}{4\pi T}\ln\frac{4Tt}{1.78r^2 S} \tag{3.12}$$

After converting to base 10 logs and simplifying, Equation 3.12 can be written as

$$s = \frac{2.30Q}{4\pi T}\log\frac{2.25Tt}{r^2 S} \tag{3.13}$$

Since T and S are constant, and Q is constant for a particular test, Equation 3.13 plots as a straight line on semilogarithmic paper (s versus log t) if the limiting condition of small u is met. If this line is extended until it intercepts the time-axis where there is zero drawdown, the interception point has the coordinates $s = 0$ and $t = t_0$. Substituting the values of s and t into Equation 3.13 gives

$$0 = \frac{2.30Q}{4\pi T}\log\frac{2.25Tt_0}{r^2 S}$$

Since $\frac{2.30Q}{4\pi T} \neq 0$, this requires that $\frac{2.25Tt_0}{r^2 S} = 1$ (log 1 = 0) so

$$S = \frac{2.25Tt_0}{r^2} \tag{3.14}$$

The slope of the line in Equation 3.13 is

$$\frac{\Delta s}{\log \Delta t} = \frac{2.30Q}{4\pi T}$$

If Δs is measured over one log cycle of time ($\log \Delta t = \log 10 = 1$) then

$$T = \frac{2.30Q}{4\pi \Delta s} \qquad (3.15)$$

where

T	= the transmissivity (ft^2/d or m^2/d)
Q	= the pumping rate (ft^3/d or m^3/d)
s	= the drawdown per log cycle of time (ft or m)
S	= storativity (dimensionless)
r	= the radial distance to the well (ft or m)
t_0	= the time, where the straight line intersects the drawdown axis (days)

3.2.4 Gringarten et al.'s Method – Vertical Fracture Flow Model

The drawdown response to pumping is significantly different from that predicted by the Theis solution (described above) if a single vertical fracture in the aquifer is intersected by the well. The intersected fracture is assumed to be a plane (a fracture with zero width, meaning fracture storage can be disregarded), vertical fracture of relatively short length and infinite hydraulic conductivity. This makes it possible to analyze the system as an 'equivalent', anisotropic, homogeneous, porous medium, with a single fracture of high permeability intersected by the pumping well (Kruseman and de Ridder, 1990).

At early pumping times, the flow of water from the aquifer into the fracture is one-dimensional, i.e. it is horizontal, parallel, and perpendicular to the fracture (Fig. 3.5B). All along the fracture, a uniform flux is assumed, i.e. water from the aquifer enters the fracture at the same rate per unit area. However, as pumping continues, the flow

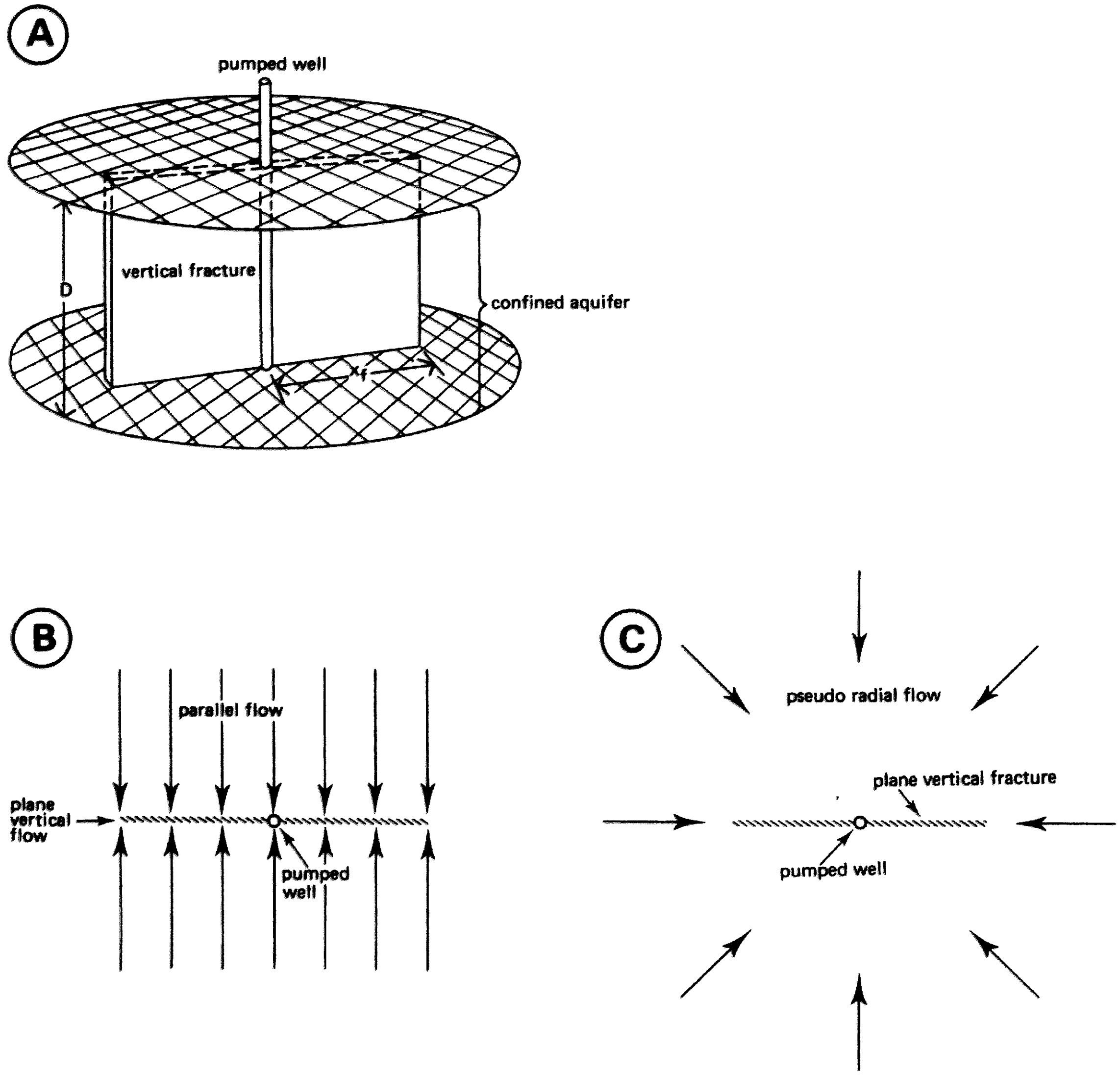


Figure 3.5: A well that intersects a single, vertical, plane fracture of finite length and infinite hydraulic conductivity (after Kruseman and de Ridder, 1990).
A: The well-fracture aquifer system
B: The parallel flow system at early pumping times
C: The pseudo-radial flow system at late pumping times

changes from parallel to pseudo-radial flow, regardless of the fracture's hydraulic conductivity (Fig. 3.5C). Most of the discharge of the well originates from areas farther removed from the fracture during this period. Uneconomic pumping times are often required to attain pseudo-radial flow (Kruseman and de Ridder, 1990).

The Gringarten et al. method for the pumping well is based on the following assumptions and conditions:

1. The aquifer is confined, homogeneous, isotropic, of large lateral extent, bounded above and below by impermeable beds.
2. A single plane, vertical fracture of relatively short length dissects the aquifer from top to bottom (i.e. the aquifer is fully penetrated by a single vertical fracture).
3. The fracture is a plane (i.e. storage in the fracture can be neglected, and is of infinite horizontal extent).
4. The pumped well intersects the fracture midway (the well is located on the axis of the fracture).
5. The fracture has an infinite (or very large) permeability, so drawdown in the fracture is uniform over its entire length at any instant of time (i.e. no hydraulic gradient in the fracture); this uniform drawdown induces flow into the fracture.
6. With a decline in head, water is instantaneously removed from storage in the aquifer.
7. Water from the aquifer enters the fracture at the same rate per unit area (i.e. a uniform flux exists along the fracture, or the fracture conductivity is high although not infinite.
8. The diameter of the well is very small (i.e. well bore storage can be neglected).
9. The well losses are negligible (Fig. 3.5A; Kruseman and de Ridder, 1990).

Gringarten and Ramey (1974) obtained the following general solution for the drawdown in a pumped well that intersects a single, plane, vertical fracture in an otherwise homogeneous, isotropic, confined aquifer (Fig. 3.5A)

$$s_w = \frac{Q}{4\pi T} F(u_{vf}) \tag{3.16}$$

where

$$u_{vf} = \frac{Tt}{Sx_f^2} \tag{3.17}$$

S = storativity of the aquifer (dimensionless)

T = transmissivity of the aquifer (m^2/d)
x_f = half length of the vertical fracture (m)

$$F(u_{vf}) = 2\sqrt{\pi u_{vf}}\, erf\left(\frac{1}{2\sqrt{u_{vf}}}\right) - Ei\left(-\frac{1}{4u_{vf}}\right) \tag{3.18}$$

and

$$-Ei(-x) = \int_0^x \frac{e^{-u}}{u} du = \text{ the exponential integral of x}$$

The values of the function $F(u_{vf})$ as u_{vf} varies are given in Appendix 4. Plotting $F(u_{vf})$ versus u_{vf} on log-log paper produces the type curve used in the Gringarten et al. curve-fitting method.

The drawdown in the well is governed by horizontal parallel flow from the aquifer into the fracture at early pumping times (Fig. 3.5B; Kruseman and de Ridder, 1990). The equation for drawdown at early pumping times is written as

$$s_w = \frac{Q}{4\pi T} F(u_{vf}) \tag{3.19}$$

where

$$F(u_{vf}) = 2\sqrt{\pi u_{vf}} \tag{3.20}$$

or

$$\log F(u_{vf}) = 0.5 \log(u_{vf}) + \text{constant}$$

and consequently

$$s_w = \frac{Q}{2\sqrt{\pi T S x_f^2}} \sqrt{t} \tag{3.21}$$

or

$$\log s_w = 0.5 \log(t) + \text{constant}$$

Equations 3.20 and 3.21 show the early-time parallel flow period is characterized by a straight line with a slope of 0.5 on a log-log plot of $F(u_{vf})$ versus u_{vf} (the type curve) and also on the corresponding data plot (s_w versus t). According to Gringarten and Ramey (1975) the parallel-flow period ends at approximately $u_{vf} = 1.6 \times 10^{-1}$. However, the parallel-flow period may last relatively long if the aquifer has a low transmissivity and the fracture is elongated.

Gringarten et al. (1975) suggests that the pseudo-radial-flow period starts at $u_{vf} = 2$. During this period, the drawdown in the well varies according to the Theis equation for radial flow in a pumped, homogeneous, isotropic, confined aquifer (Equation 3.6), plus a constant, and can be approximated by the following expression

$$s_w = \frac{2.30Q}{4\pi T}\log\frac{16.59Tt}{Sx_f^2}$$

The value of T and the product of Sx_f^2 are determined by matching the data curve with the type curve and selecting a match point. T is calculated by substituting the values of $F(u_{vf})$ and s_w (obtained from the match point) and the known value of Q into Equation 3.19. The calculated value of T and the values of u_{vf} and t (from match point) are substituted into Equation 3.17 to determine the product of Sx_f^2.

For $t \geq 2\frac{Sx_f^2}{T}$ (i.e. large values of pumping time), the data can be analyzed by constructing a semi-log plot of s_w versus t and determining the slope of the straight line (Δs_w). The aquifer transmissivity and Sx_f^2 are calculated from the equations

$$T = \frac{2.30Q}{4\pi\Delta s_w} \tag{3.22}$$

and

$$Sx_f^2 = 16.59Tt_o \tag{3.23}$$

There are several limitations of the Gringarten et al. curve-fitting method, including:

1. Drawdown data from at least two observation wells must be available to obtain separate values of x_f^2 and S.
2. Gringarten et al.'s method can only be applied to data from perfect wells (i.e. wells that have no well losses), which rarely exist. However, applying this method to late time drawdown data $\left(t \geq 2\frac{Sx_f^2}{T} \right)$ allows transmissivity to be calculated.
3. Gringarten et al.'s method is not applicable if the early-time drawdown data is affected by well-bore storage (a slope of 1 instead of 0.5), which indicates a large storage volume connected with the well, and corresponds to a fracture of large dimensions rather than the assumed plane fracture (Kruseman and de Ridder, 1990).

3.2.5 Hvorslev Method – Slug Test Analysis

The Hvorslev method for slug test analysis is based on the following assumptions and conditions (Cross, 2000):

1. The aquifer is bounded above and below by aquicludes.
2. All layers are horizontal and extend infinitely in the radial direction.
3. The initial piezometric surface (before injection) is horizontal and extends infinitely in the radial direction.
4. The aquifer is homogeneous and isotropic.
5. Darcy's law is valid (i.e. laminar flow exists throughout the well and aquifer).
6. The groundwater has a constant density and viscosity.
7. Groundwater flow is horizontal and is directed laterally away from the injection well.
8. A volume of water is injected instantaneously at time $t = 0$.
9. The injection well is considered to be a slot (line source) with infinitesimal width.
10. The aquifer is incompressible.
11. The influence of time lags / head losses due to stress adjustment or air or gas in soil or piezometer, or clogging of intake, etc. are negligible.

The water level in the well is measured prior to the time the slug is instantaneously poured into the well. The height to which the water level rises above the static water level immediately upon adding the slug into the well is H_o. The height of the water level above the static water level at some time, t, after the slug is added is H

(Fig.3.6). On a semilogarithmic graph of the head ratio (log (H/H_o)) versus time (t), the time-drawdown data should plot on a straight line (Fetter, 1994). Since $H/H_o = 1$ at $t = 0$ by definition of initial conditions, the best fit line to the data is shifted if necessary to intersect this point. The new line remains parallel to the original data plot. The theory behind this method is discussed in Hvorslev (1951), Dawson and Istok (1991), and Butler (1998).

The Hvorslev method allows for the analysis of various well and aquifer geometries. The two well geometries assumed to model the East Dartmouth and Waverley wells and surrounding aquifers are geometry F and G, respectively (Fig. 3.7). The basic time lag equation, which gives the aquifer horizontal hydraulic conductivity for a well point filter at an impervious boundary (Geometry F), is written as

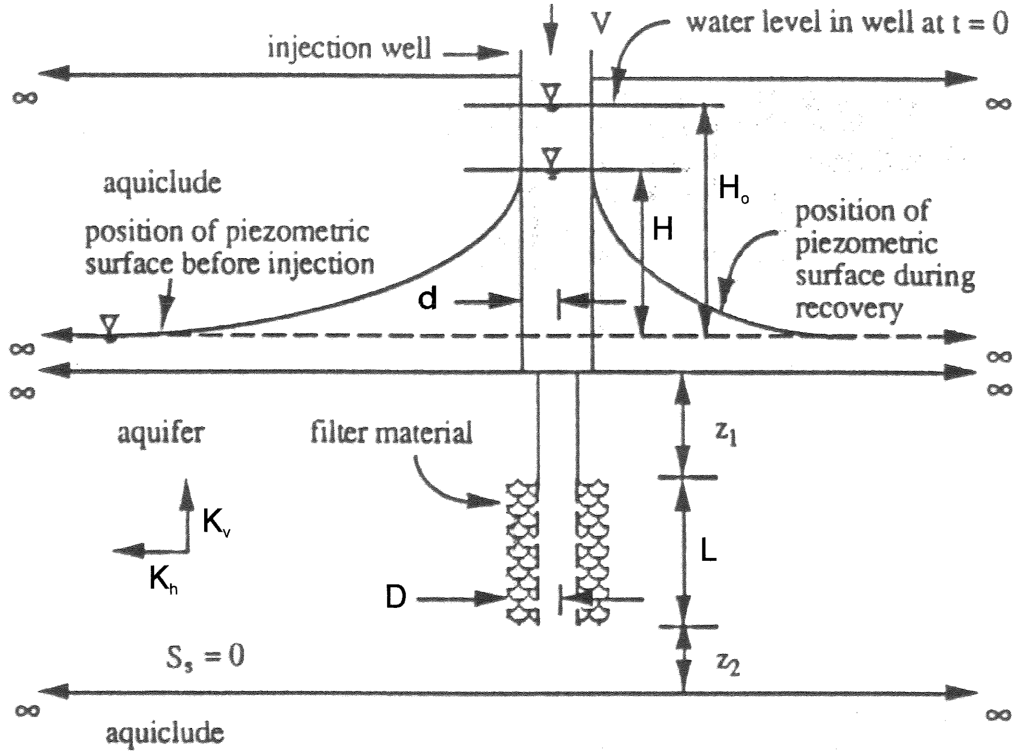
$$K_h = \frac{d^2 \ln\left[\frac{2mL}{D} + \sqrt{1 + \left(\frac{2mL}{D}\right)^2}\right]}{8LT} \tag{3.24}$$

or

$$K_h = \frac{d^2 \ln\left(\frac{4mL}{D}\right)}{8LT} \quad \text{for} \quad \frac{2mL}{D} > 4 \tag{3.25}$$

where

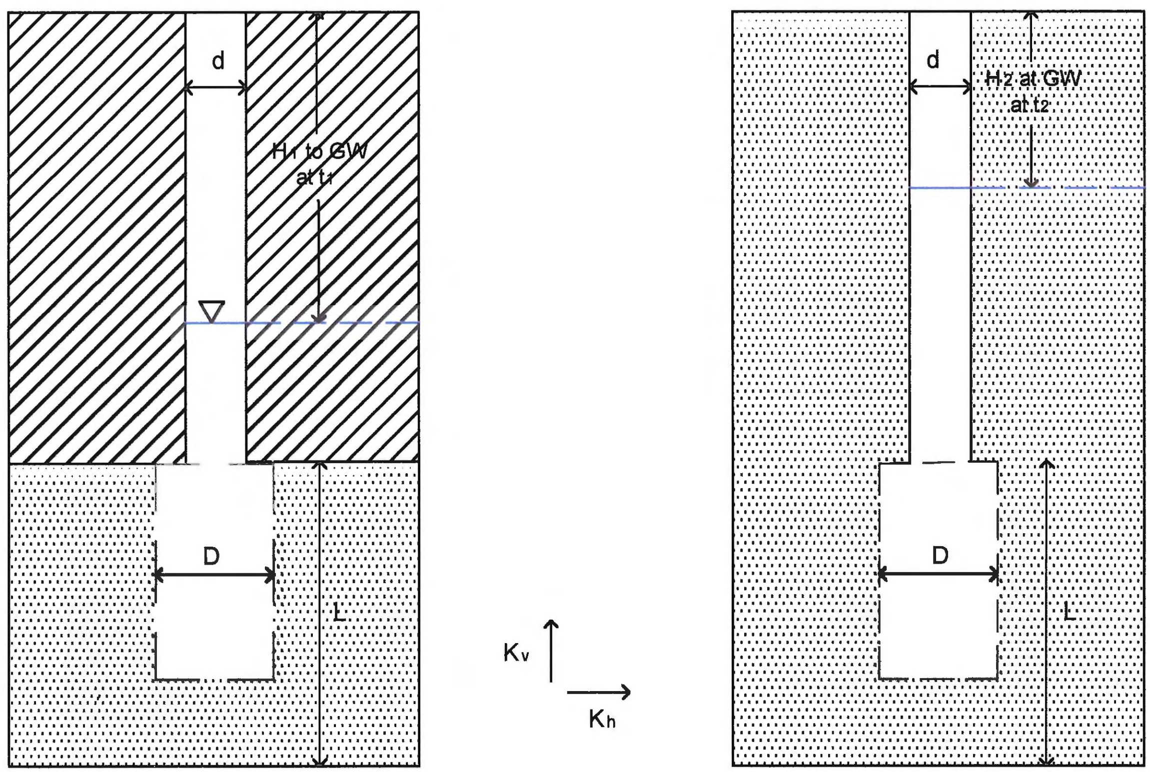
D	= intake diameter (ft, m, or cm)
d	= standpipe diameter (ft, m, or cm)
L	= intake length (ft, m, or cm)
H	= head above or below static water level (ft, m, or cm), at
t	= time (sec)
T	= basic time lag, i.e. the time it takes for the water level to rise or fall 37-percent of the initial change (sec)
K_h	= horizontal hydraulic conductivity (ft/sec, m/sec, or cm/sec)



Definition of Terms:

H_o	**= initial head change in the well casing due to an injection of volume V at time t = 0**
H	**= height of water in the well above the equilibrium level at time t > 0**
K_h	**= aquifer horizontal hydraulic conductivity**
K_v	**= aquifer vertical hydraulic conductivity**
L	**= length of screen, filter pack, or open hole over which water leaves or enters the well**
n	**= porosity of filter material or developed zone**
d	**= effective radius of the well casing over which the water level in the well changes** **= D if the water level is always above the well screen** $= \sqrt{d_i{}^2\!/_4 (1-n) + {}^{nd_o}\!/_4}$ **if the water level is falling within the screened length of the well and the hydraulic conductivity of the filter material or developed zone is much larger than the hydraulic conductivity of the aquifer**
D	**= effective radius of the well bore or open hole** **= borehole radius if the filter is much more permeable than the aquifer** **= screen radius if no filter is used or if the filter has a hydraulic conductivity similar to that of the aquifer**
d_i	**= inside radius of well screen**
d_o	**= outside radius of filter material or developed zone**
S_s	**= aquifer specific elastic storage**
V	**= volume of water injected into the well at time t = 0**
z_1	**= vertical distance from the top of the screen, filter pack, or open hole to the top of the aquifer**
z_2	**= vertical distance from the bottom of the screen, filter pack, or open hole to the bottom of the aquifer**

Figure 3.6: Well into which a volume, V, of water is suddenly injected for a slug test of a confined aquifer.



F

Well point filter at
impervious boundary

G

Well point filter in
uniform soil

Figure 3.7: Well geometries F and G assumed to model the East Dartmouth and Waverley wells and surrounding aquifers.

K_v = vertical hydraulic conductivity (ft/sec, m/sec, or cm/sec)
m = transformation ratio $m = \sqrt{K_h / K_v}$

For a well point filter in uniform soil (Geometry G), the hydraulic conductivity of the aquifer is described by

$$K_h = \frac{d^2 \ln\left[\frac{mL}{D} + \sqrt{1 + \left(\frac{mL}{D}\right)^2}\right]}{8LT} \tag{3.26}$$

or

$$K_h = \frac{d^2 \ln\left(\frac{2mL}{D}\right)}{8LT} \quad \text{for} \quad \frac{mL}{D} > 4 \tag{3.27}$$

where parameters are defined as for Equations 3.24 and 2.35 on page 50 previously. The aquifer transmissivity is estimated by substituting the calculated hydraulic conductivity into the following equation

$$T = Kb \tag{3.28}$$

where

T = aquifer transmissivity (ft^2/sec, m^2/sec, or cm^2/sec)
K = hydraulic conductivity (ft/sec, m/sec, or cm/sec)
b = saturated thickness of the aquifer, here assumed as open zone of the well (ft, m, or cm)
= well depth – casing length, if static water level is within casing
= well depth – static water level, if static water level is below the casing

3.2.6 Derivative Method

Derivative curves can be used as a diagnostic tool to identify the type of flow regime that is present. Allen (1999) suggests that there are several characteristic derivative curve responses (Fig. 3.8) that indicate the presence of well bore storage, hydrogeologic boundaries, and the type of flow regime present, i.e. linear or radial. The presence of well bore storage is indicated by a characteristic "hump" in the drawdown derivative plot (Fig. 3.8A). The "hump" increases in amplitude and duration as the associated well bore storage value increases. There is no drop (i.e. no "hump" produced) in the derivative before the commencement of infinite-acting radial flow if well bore storage is not present. Infinite-acting radial flow conditions are implied during testing when the change in drawdown at the point of observation increases in proportion to the logarithm of time. Infinite-acting radial flow is also indicated when the derivative curve becomes horizontal. If test data displays this derivative pattern, it can be analyzed using Jacob's straight-line method which requires radial flow. The presence of non-radial flow conditions caused by leakage, vertical flow, or boundaries is shown on the derivative plot by a deviation from the horizontal radial flow line region of the graph (Allen, 1999).

The derivative response is sensitive to small variations in the rate of drawdown change that occurs during testing, which would be less obvious with standard time-drawdown (head) analysis (Allen, 1999). However, the derivative method is affected by 'noisy' data due to its sensitivity.

The derivative curve used in this method is produced by a simple fixed end-point algorithm that can calculate the pressure derivative. The algorithm calculates the first derivative of the drawdown, with respect to the natural logarithm of the change of time,

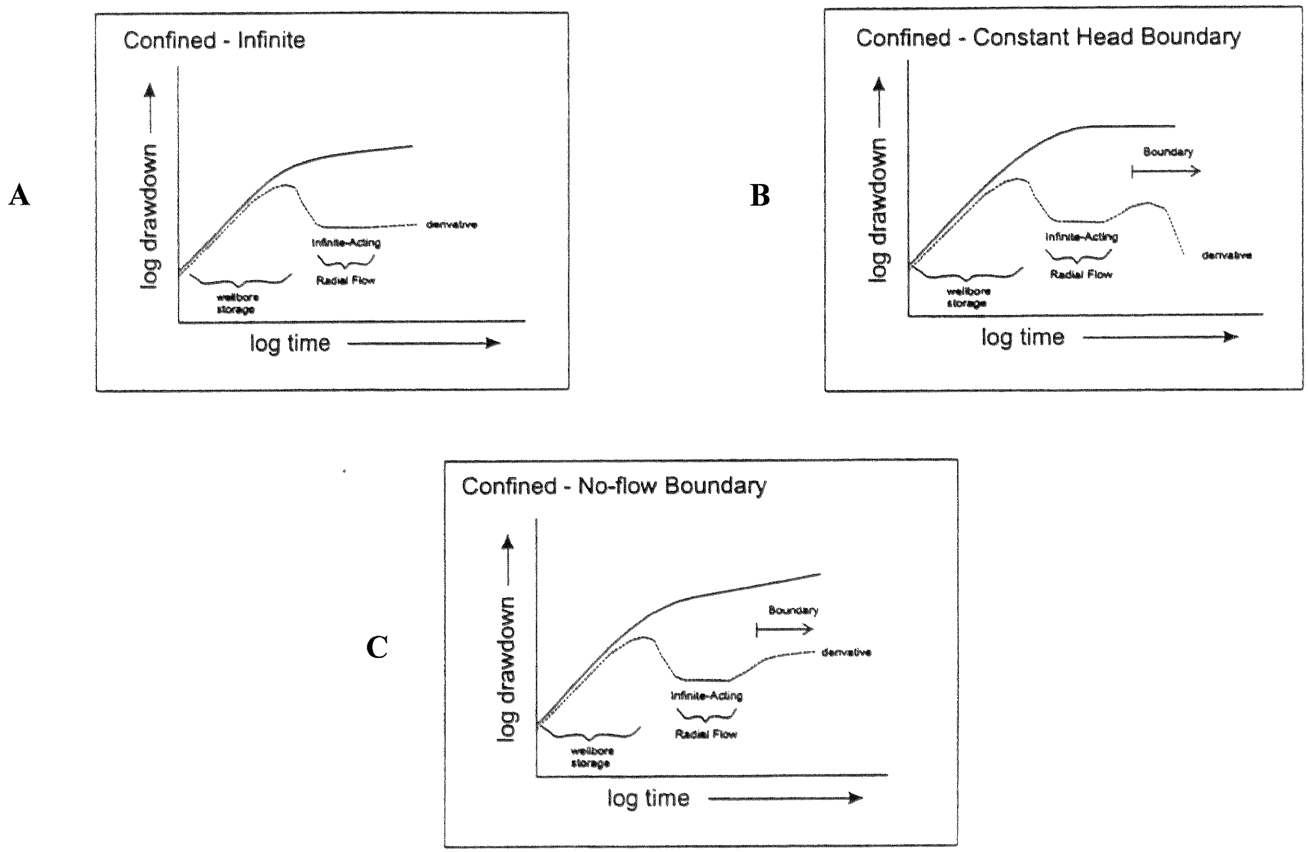


Figure 3.8: Characteristic log-log drawdown versus time and derivative plots for various hydrogeological boundary conditions in confined aquifers (after Allen, 1999).
A: The effect of well bore storage
B: The effect of a constant head boundary
C: The effect of a no-flow boundary

using the point immediately before and immediately after the point of interest, and averages the two values (Allen, 1999). The mathematical expression used to calculate the pressure derivative is written as

$$\left(\frac{dP}{dX}\right)_i = \left[\frac{(\Delta P_1/\Delta X_1)\Delta X_2 + (\Delta P_2/\Delta X_2)\Delta X_1}{\Delta X_1 + \Delta X_2}\right] \tag{3.29}$$

where

i	= the point(s) of interest
1	= point(s) before the point of interest
2	= point(s) after the point of interest
X	= natural logarithm of time, t
t	= time, which is a function of the test type (i.e. constant discharge or recovery) and the variable changes accordingly

Plotting dP/dX versus t on log-log paper produces the derivative curve used to analyze the data in this method. Although the theory of this method is beyond the scope of this thesis, the derivative method is a centered difference finite difference approach for unequally spaced points, based on Taylor series expansion around the point of interest. Compared to a 'normal' calculus derivative, which is accurate proportional to ΔX, the derivative method is more accurate, being proportional to $(\Delta X_1)(\Delta X_2)$.

3.2.7 Safe Yield

After a value of transmissivity has been calculated, an estimation of safe or sustainable yield can be made using the Jacob method. The equation for safe yield is written as

$$Q_s = \frac{TH}{0.183 \log t} \tag{3.30}$$

where

Q_s	= safe or sustainable yield at time t (ft^3/d or m^3/d)
T	= transmissivity (ft^2/d or m^2/d)
H	= available drawdown (ft or m)
$\log t$	= number of log cycles of time

The calculation of a 20-year safe yield or long term safe yield is common practice in Nova Scotia and the groundwater industry in general. From one minute to 20 years is approximately 10^7 minutes, or seven log cycles of time. The prediction of 20-year safe yield applies only to the well on which the test was conducted since transmissivity values are too variable and tend to have a log normal distribution (Cross, in prep.). The use of this method implies that the final straight-line section of the drawdown curve can be extrapolated from when the test ended over the remaining portion of the 20 years, which imparts a weakness to the method.

A safety factor of 0.7 to 0.8 is usually applied to Equation 3.30 to help account for the pump setting, seasonal and drought water levels, and future drop in the well efficiency during operation. The predicted safe yield is effectively reduced by 20-30%. The safety factor also reflects the fact that approximately 90-percent of the yield is obtained with roughly 70-percent of the available drawdown. With the safety factor incorporated, Equation 3.30 for 20 years becomes

$$Q_{20} = \frac{0.7TH}{1.281} \tag{3.31}$$

A common practice for short term yield is to substitute a shorter period of time for the drought period, especially if there is only seasonal usage of the well. The estimated long term yield should be at or below the discharge rate at which the well was pumped during the aquifer test. This takes into consideration that the response of the well may change at higher discharge rates, which is often the case for fractured rock aquifers.

A conservative estimate of the well yield can be calculated based on casing storage within the well. The equation, which gives the yield based on casing storage from drawdown data, is written as

$$Q = \frac{Total\ Pumped\ (m^3) - Storage\ Volume\ (m^3)}{Length\ of\ Test\ (\mathrm{min}\ utes)} \tag{3.32}$$

The conservative yield based on casing storage from the recovery data can be estimated using the following equation for a 0.152 m (6 inch) diameter well

$$Q = \frac{Recovery\ (after\ 1\ hr.) * factor}{60\ minutes} \tag{3.33}$$

factor = 18.0 L/m or 1.22 gal/ft

3.2.8 Specific Capacity

Specific capacity (Q/s) is an expression of the productivity of the well and is defined as the discharge rate divided by the drawdown in the pumping well, or yield per unit drawdown (Fetter, 1994). The specific capacity normalizes the yield for different drawdowns. Generally, the higher the value of specific capacity, the greater the yield of the well. Specific capacity is described on the basis of the number of hours of pumping prior to the time the drawdown measurement is made. Driscoll (1986) suggests that 24 hours should be used as a standard on longer tests. For shorter tests, such as those conducted in this study, the specific capacity is calculated after one hour since this is the maximum common duration for the tests.

Huntley et al. (1992) obtained the following best-fit regression line for a log-log plot of transmissivity and specific capacity data for wells completed in fractured crystalline rock aquifers

$$T = K(Q/s)^{1.18} \tag{3.34}$$

where

T = estimated transmissivity (m^2/d)
Q/s = specific capacity (m^2/d)
K = regression coefficient = 0.12 for the units above.

Equation 3.34 provides an estimate of transmissivity from the specific capacity of a well. It should be noted however, that the value of the regression coefficient is specific only for the units of transmissivity and specific capacity noted above. According to Huntley et al. (1992), it is unclear as to whether Equation 3.34 can be applied to all fractured crystalline rock aquifers or is limited to the population it initially tested.

The 90 % prediction interval about the best-fit line of Equation 3.34 spans slightly more than one order of magnitude of transmissivity. Thus, the actual transmissivity could possibly be approximately four times or one-quarter the estimated transmissivity ($\pm$ one-half order of magnitude) (Huntley et al., 1992). Therefore, these relations should only be used to obtain rough estimates of transmissivity when more complete aquifer test information is unavailable.

4.0 DISCUSSION OF RESULTS

4.1 East Dartmouth Well

4.1.1 Step Drawdown Test Results

The results of the step drawdown test for the East Dartmouth well are shown in Figures 4.1 and 4.2 and Tables 4.1 and 4.2. Specific drawdowns (s/Q), defined as the ratio of the incremental drawdown of a particular step to the pumping rate for that step (inverse of specific capacity), were calculated for the step test using the Hantush-Bierschenk method (Fig. 4.1). Table 4.1 shows the calculated specific drawdown for each step in the test for the East Dartmouth well. The specific drawdowns range from 0.34 to 0.46 d/m^2 and were calculated using a time step of 30 minutes for the incremental drawdowns (Fig. 4.1). Specific drawdown in the well is low at low pumping rates and gradually increases as the pumping rate increases (Fig. 4.2).

Step	Q (gpm)	Q (m^3/d)	Δs (m)	s (m)	s/Q (d/m^2)
1	1.09	7.13	2.40	2.40	0.34
2	2.35	15.38	3.58	5.98	0.39
3	2.95	19.31	2.40	8.38	0.43
4	4.01	26.25	3.80	12.18	0.46

Table 4.1: Summary of the drawdown (s) and specific drawdown (s/Q) for the East Dartmouth well calculated for each step interval. A plot of specific drawdown versus discharge rate is shown in Figure 4.2.

Analysis of the data using Equation 3.1 shows that the drawdown in the pumping well is

$$s_w = 0.29Q + 0.007Q^2$$

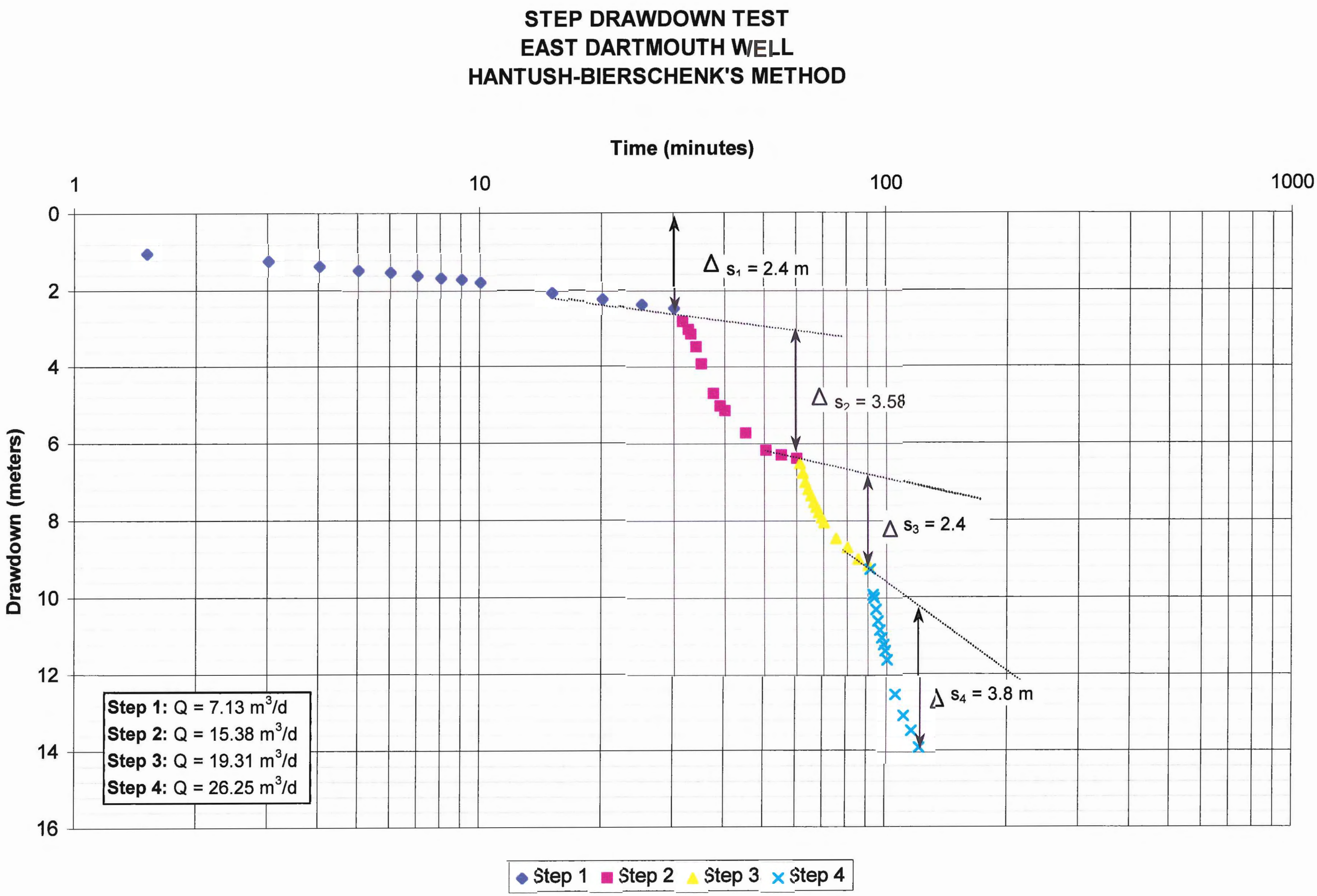


Figure 4.1: The drawdown curve for the step drawdown test conducted on the East Dartmouth well. The incremental drawdown for each step is calculated using the Hantush-Bierschenk method.

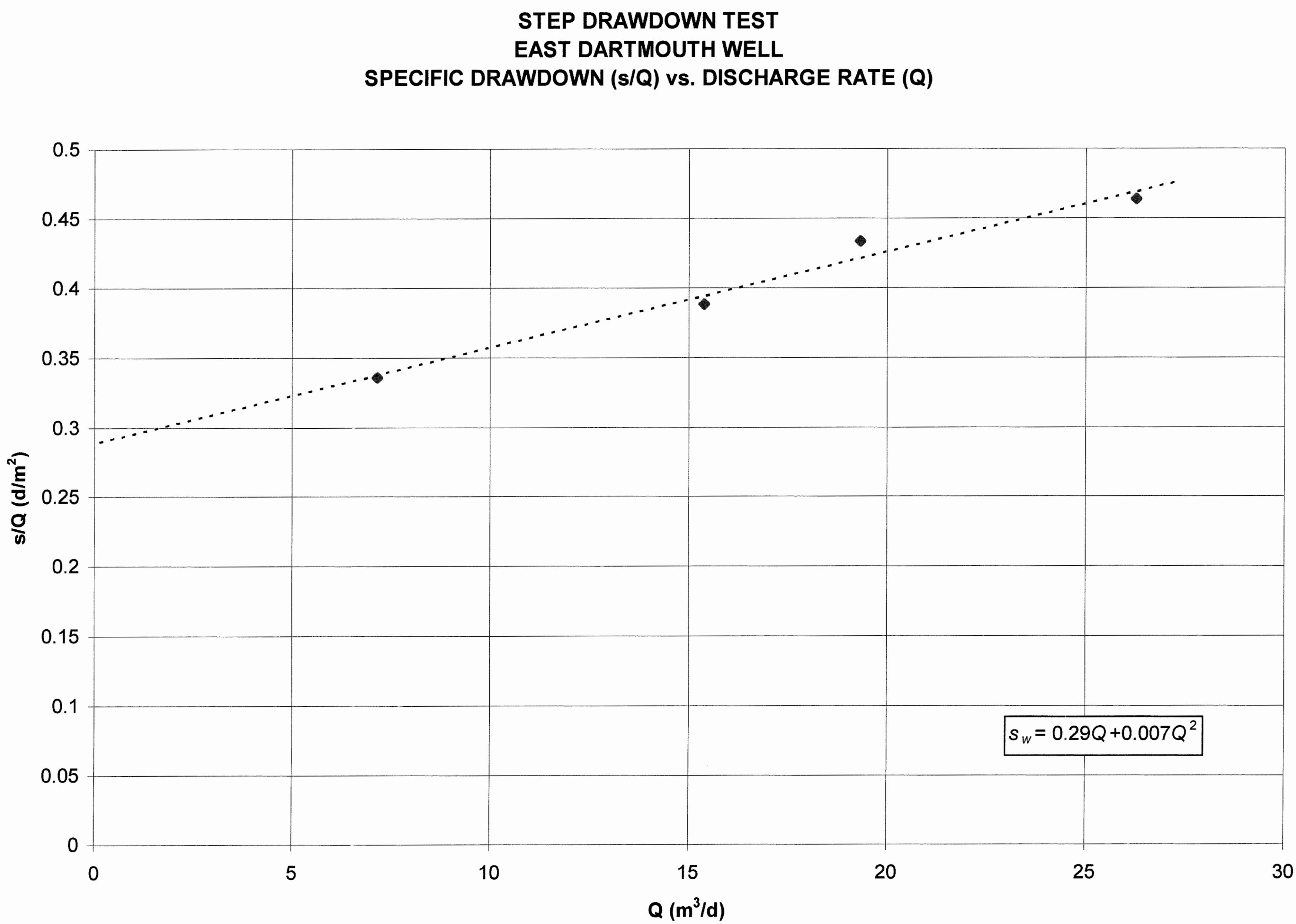


Figure 4.2: Plot of (s/Q) versus (Q) for each step interval of the step drawdown test. The y-intercept gives B = 0.29 d/m^2. The slope of the line gives the value of C = 0.007 d^2/m^5.

where

$$B \quad = 0.29 \text{ d/m}^2$$
$$C \quad = 0.007 \text{ d}^2\text{/m}^5$$

The above equation is used to predict drawdowns that would be obtained at different pumping rates in the East Dartmouth well. Table 4.2 is a summary of the results calculated from the five constant discharge tests (CR-1 to CR-5) conducted on the East Dartmouth well. The results show that the actual drawdown observed at 30 minutes for the constant discharge tests (CR-1 to CR-5) are similar to those predicted by the drawdown equation. Since B is dependent on the time step Δt (selected 30 min) and since none of the steps reached equilibrium, the fact that the predicted drawdown reflects the actual drawdown indicates that the results are consistent with the theory. Constant rate tests CR-1, CR-2, and CR-3 show actual values (at 30 min) that are less than predicted, with less than 10 percent difference. The actual drawdown values (at 30 min) for constant rate tests CR-4 and CR-5 are slightly greater than predicted, with a percent difference of 11 and 5.

Pump Test	Q (m^2/d)	BQ	CQ^2	s_w (predicted) m	s (actual-30 min) m	s (actual-60 min) m	% diff (30)	% diff (60)
CR - 1	24.22	7.02	4.12	11.14	10.76	13.20	3	16
CR - 2	12.44	3.61	1.08	4.69	4.60	5.86	2	20
CR - 3	39.47	11.44	10.91	22.35	20.56	23.62	8	5
CR - 4	12.57	3.64	1.11	4.75	5.31	6.14	11	23
CR - 5	30.57	8.86	6.54	15.40	16.13	19.97	5	23

Table 4.2: Summary of the predicted and actual drawdown results calculated using the discharge rates (Q) of the five constant discharge tests conducted on the East Dartmouth well. The drawdown equation used for the calculations is $s_w = 0.29Q + 0.007Q^2$.

The reconstructed step drawdown data are shown in Figure 4.3. Table 4.3 lists the transmissivity value and yields obtained from the reconstructed data. The calculated aquifer properties will be discussed in more detail in Section 4.1.6.

Pump Test	T (m^2/d)	Q_{20} (m^3/d)	Q_{1hr} (m^3/d)	Q_{30min} (m^3/d)
Step Test	0.69	5.75	23.66	26.82

Table 4.3: Summary of the aquifer properties calculated for the East Dartmouth well using reconstructed step drawdown test data. Q_{30min}, Q_{1hr} and Q_{20} are the estimated yields for 30 minutes, one hour and 20 years.

4.1.2 Constant Discharge Test Results

Five constant discharge tests of varying duration and discharge rate were preformed on the East Dartmouth well. Table 4.4 summarizes the test parameters and gives the abbreviated name of the pump test which will be used in the following discussion. All constant discharge test data for the East Dartmouth well were plotted on logarithmic and semi-logarithmic graphs.

4.1.2.1 Derivative Method

The results of the derivative method for constant discharge tests CR-1 to CR-5 for the East Dartmouth well are shown in Figures 4.4 to 4.8, respectively. The graphs of the first derivative of the drawdown plotted against the logarithm of time can be used to distinguish between the different types of flow regimes present during testing (Allen and Michel, 1998). At early time ($t < 5$ minutes), well-bore storage dominates in constant discharge tests CR-1 and CR-2 and is reflected in the sharp rise and fall in the derivative (Figs. 4.4 and 4.5). From five minutes to approximately seven minutes, the derivative increases, reflecting non-radial flow. From seven minutes to the completion of the test in

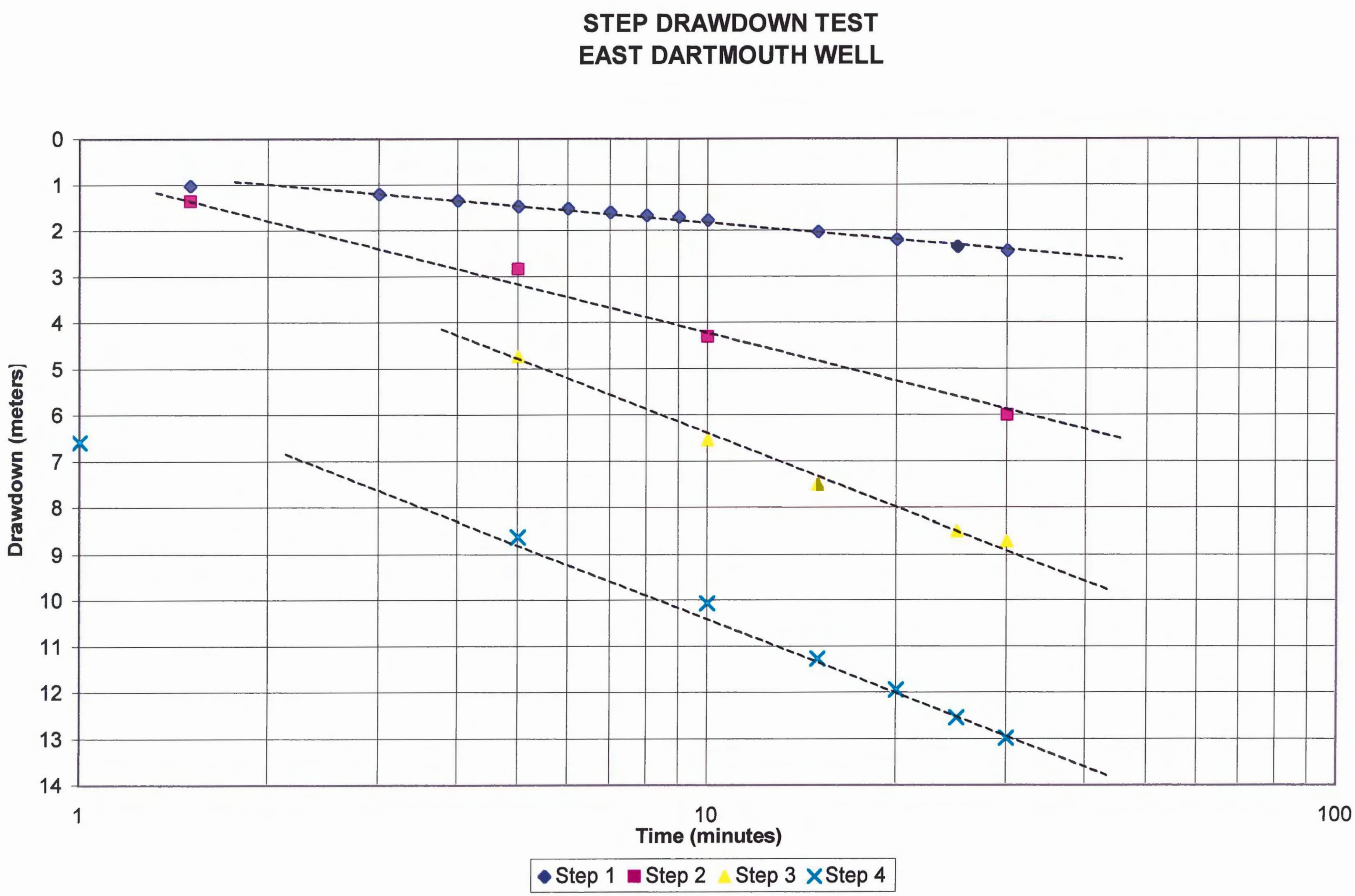


Figure 4.3: Reconstructed step drawdown data.

Pump Test	Length of Test (min)	Length of Test (days)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (gallons)	Total Pumped (m^3)	Total Pumped (litres)	Total Drawdown (ft)	Total Drawdown (m)
CR - 1	60.0	0.042	3.70	24.22	0.28	222.0	1.009	1009.0	43.30	13.20
CR - 2	360.0	0.250	1.90	12.44	0.14	685.0	3.112	3112.0	27.15	8.28
CR - 3	60.0	0.042	6.04	39.47	0.46	362.0	1.645	1645.0	77.50	23.62
CR - 4	720.0	0.500	1.92	12.57	0.14	1382.0	6.279	6279.0	29.13	8.88
CR - 5	240.0	0.167	4.68	30.57	0.35	1120.0	5.089	5089.0	87.02	26.52

Table 4.4: Summary of the constant discharge test parameters for the East Dartmouth well. Discharge rate (Q) is given in imperial gallons per minute (gpm), m^3/day and litres per second (L/s).

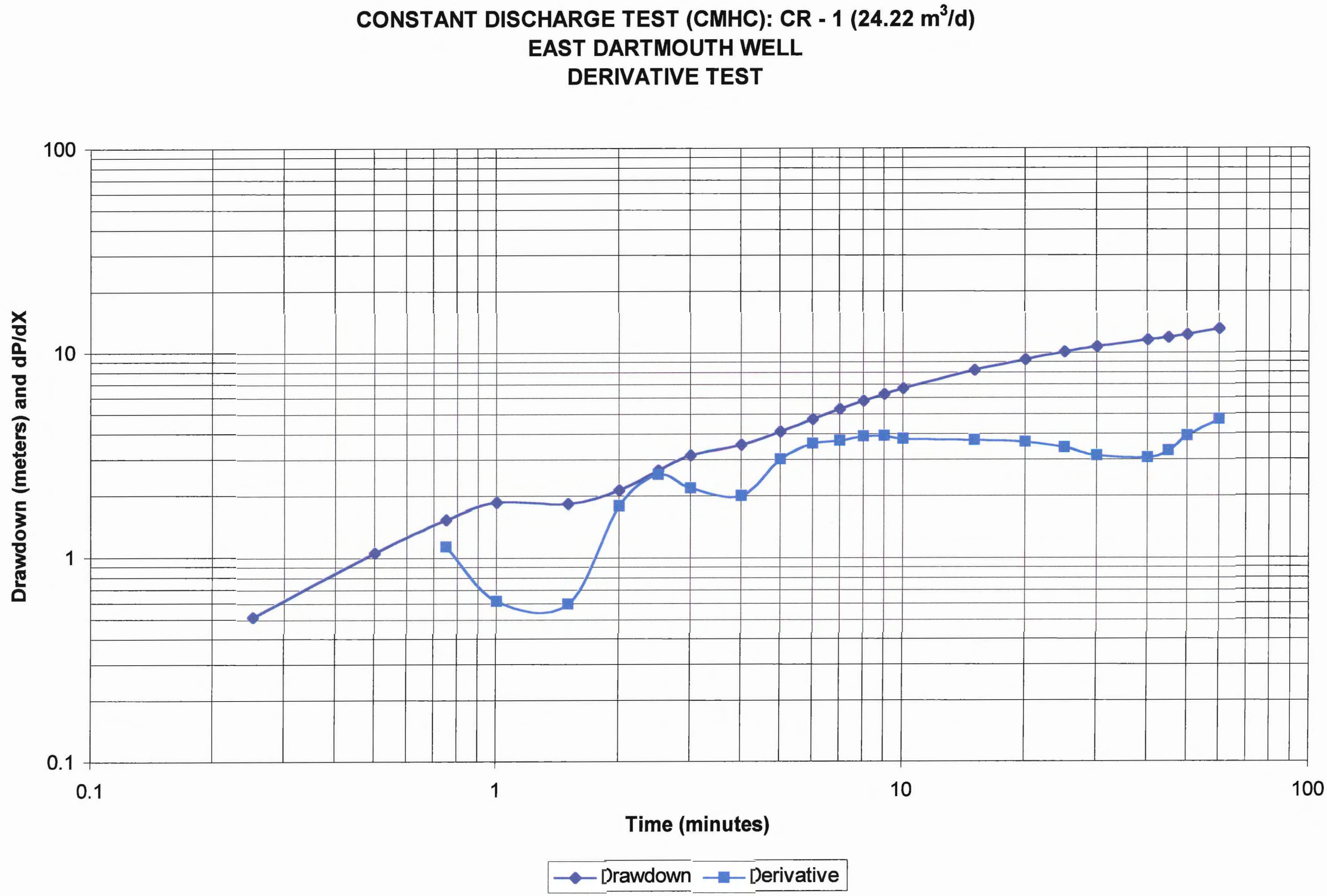


Figure 4.4: The first derivative of the drawdown plotted against the logarithm of time for test CR-1.

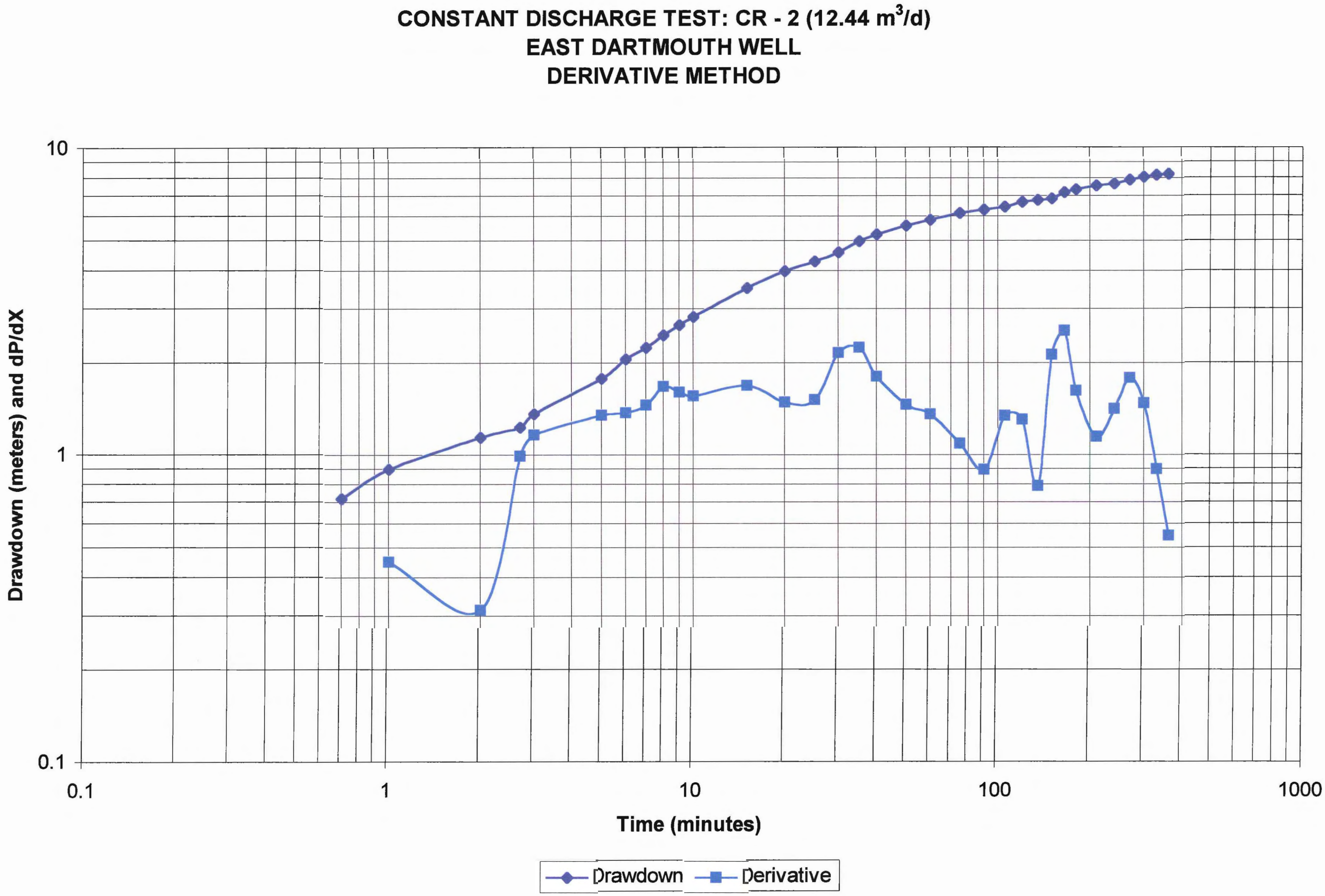


Figure 4.5: The first derivative of the drawdown plotted against the logaritm of time for test CR-2

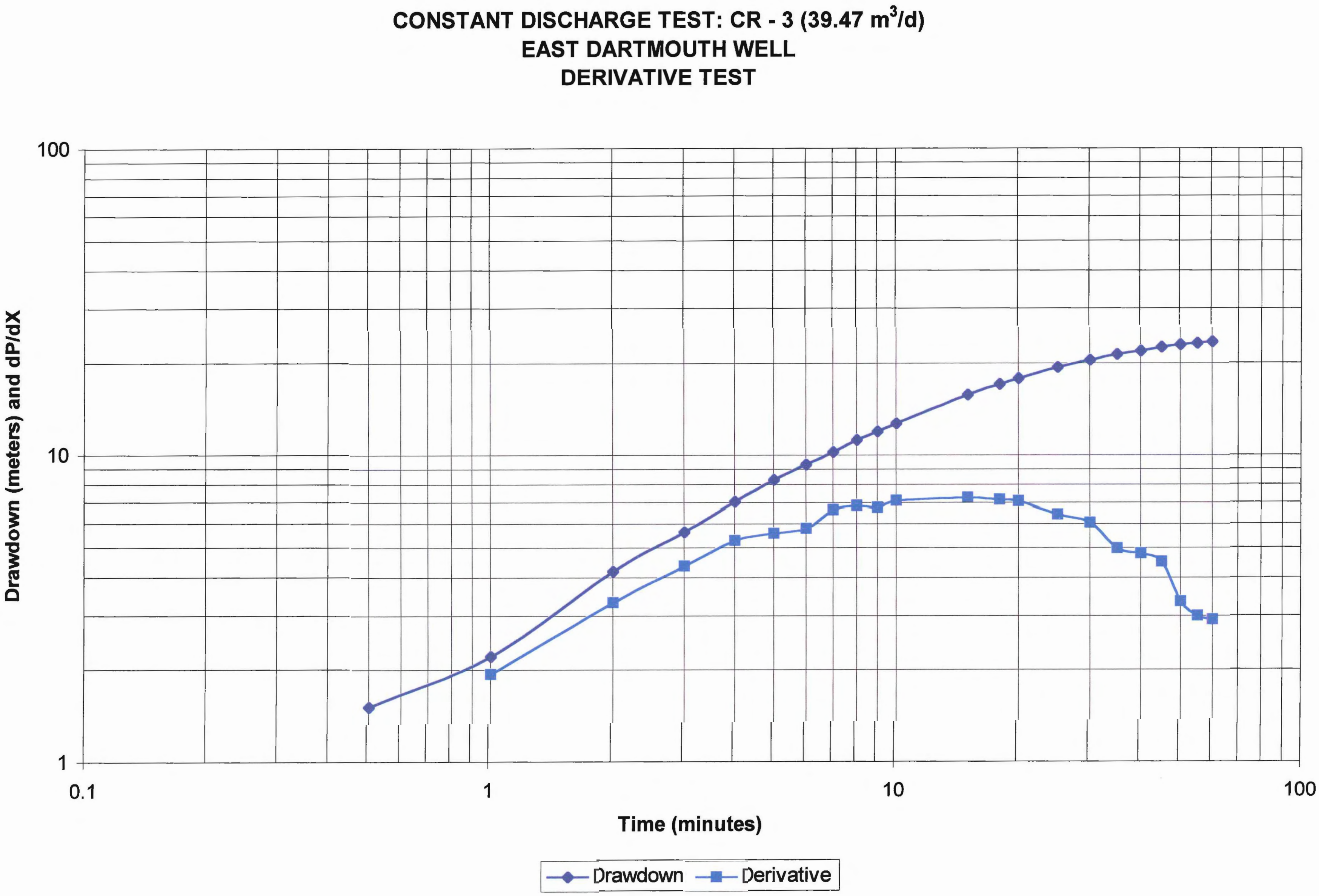


Figure 4.6: The first derivative of the drawdown plotted against the logarithm of time for test CR-3.

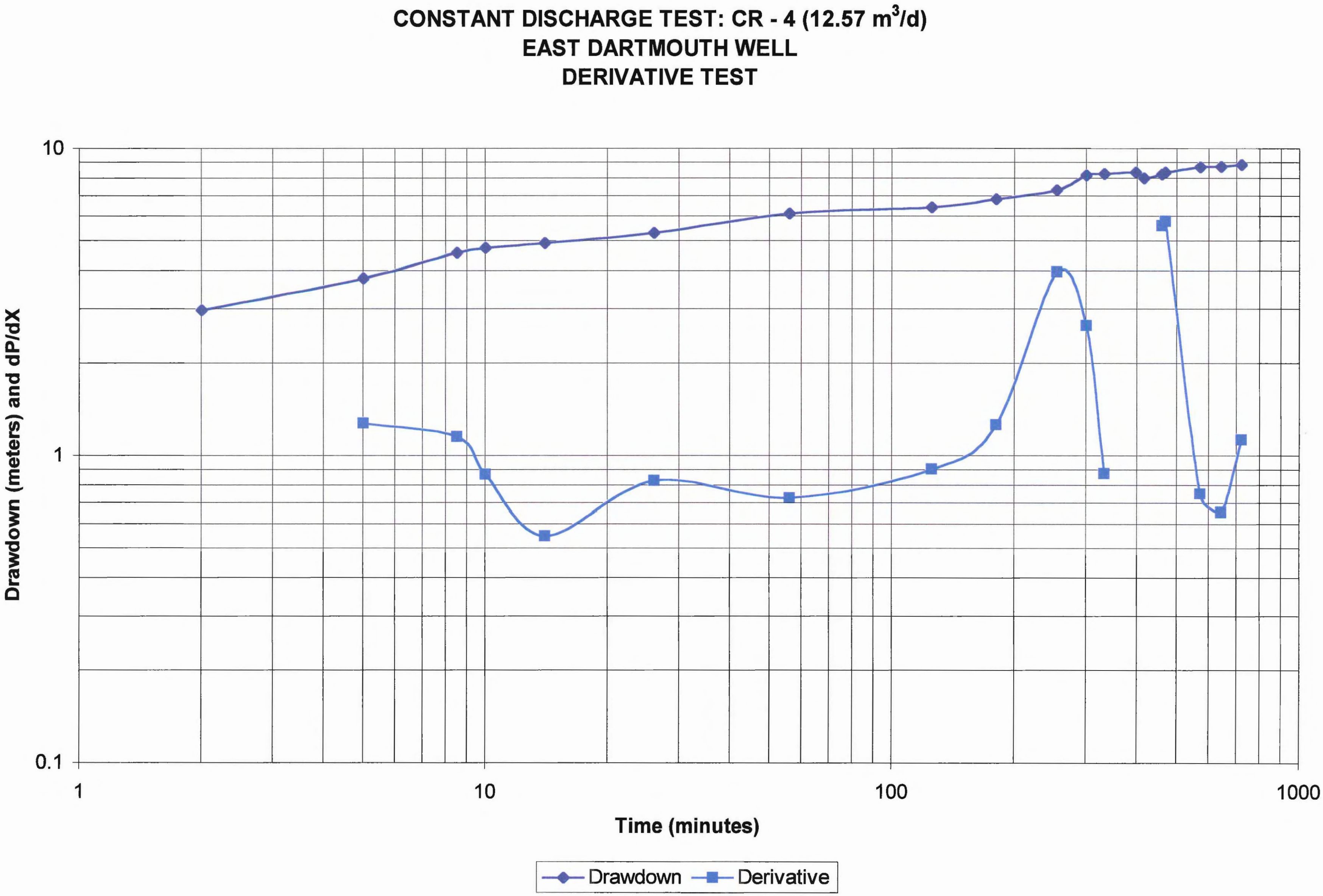


Figure 4.7: The first derivative of the drawdown plotted against the logarithm of time for test CR-4.

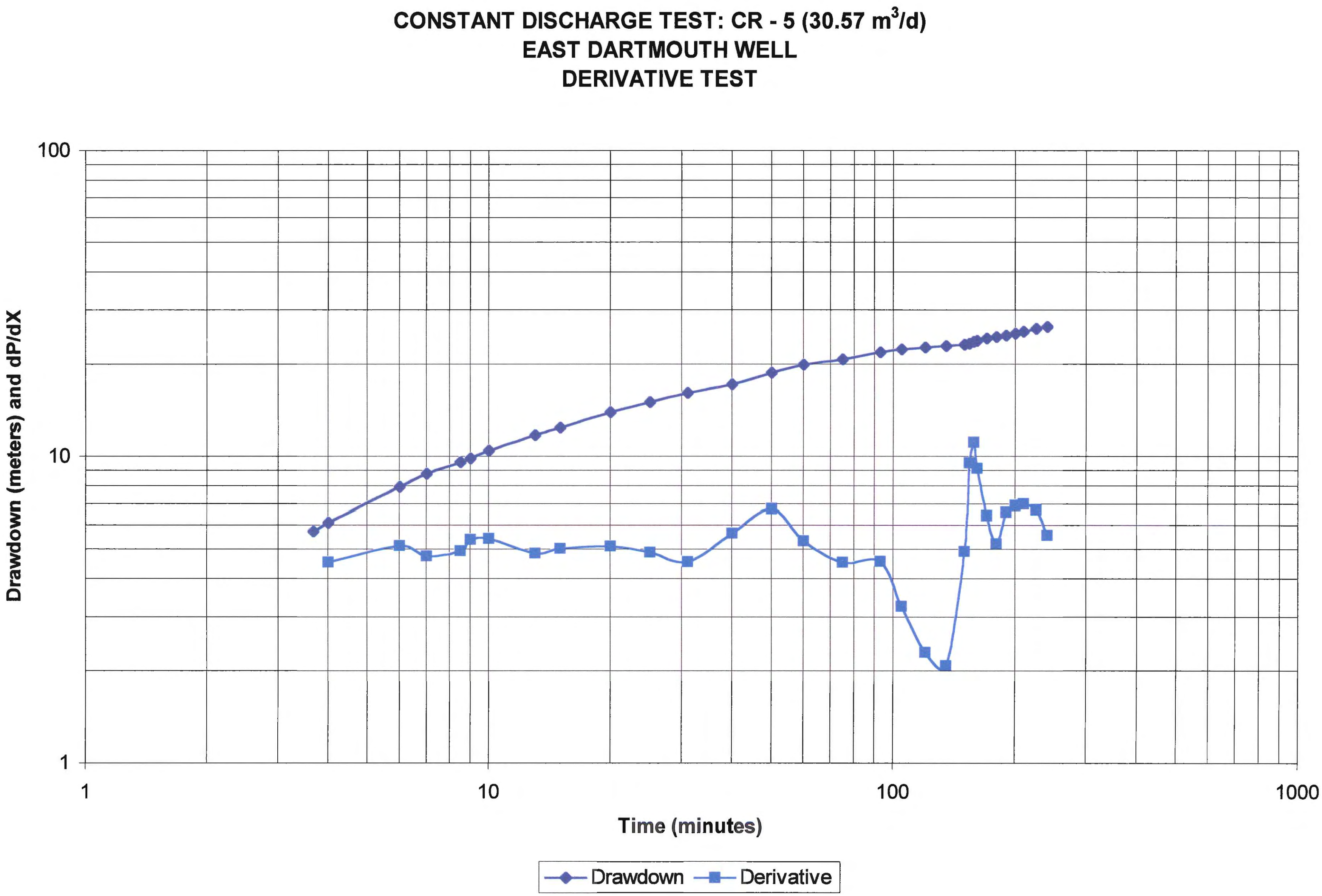


Figure 4.8: The first derivative of the drawdown plotted against the logarithm of time for test CR-5.

CR-1, and to 300 minutes in test CR-2, the derivative appears to level out, which is consistent with radial flow to the well. Constant discharge test CR-3 shows a slightly different response with a steady increase in the derivative of the drawdown at early pumping times ($t < 5$ minutes), consistent with non-radial flow and the absence of any well-bore storage effects (Fig. 4.6). At late time ($t > 20$ minutes), a recharge boundary is encountered as evidenced by the decrease in the derivative. The first derivative of the drawdown for constant discharge tests CR-4 and CR-5 (Figs. 4.7 and 4.8) indicates the presence of radial flow to the well throughout the majority of the tests.

4.1.2.2 Theis Method

Logarithmic graphs of the drawdown data are shown with the Theis curve fit and match point for the constant discharge tests CR-1 to CR-5 in Figures 4.9 to 4.13, respectively. The Theis method is only valid for radial flow conditions in the aquifer. Non-radial flow to the East Dartmouth well occurs during the brief period at early pumping times in which well-bore storage effects act and when boundary conditions are encountered at later pumping times. These conditions are most evident on the log-log plots for the constant discharge tests CR-1, CR-2 and CR-3, where a departure from the Theis curve is apparent (Figs. 4.9, 4.10 and 4.11). The transition to and from radial flow is difficult to identify on a log-log plot, so the derivative method was used to identify the period in which radial flow occurs (Figs. 4.4 to 4.8, previously). The time interval corresponding to radial flow in the well was used for the Theis curve fit in each constant discharge test analyzed.

The logarithmic graphs of the drawdown data for constant discharge tests CR-1 to CR-5 all model the Theis curve reasonably well. Very early drawdowns in the constant

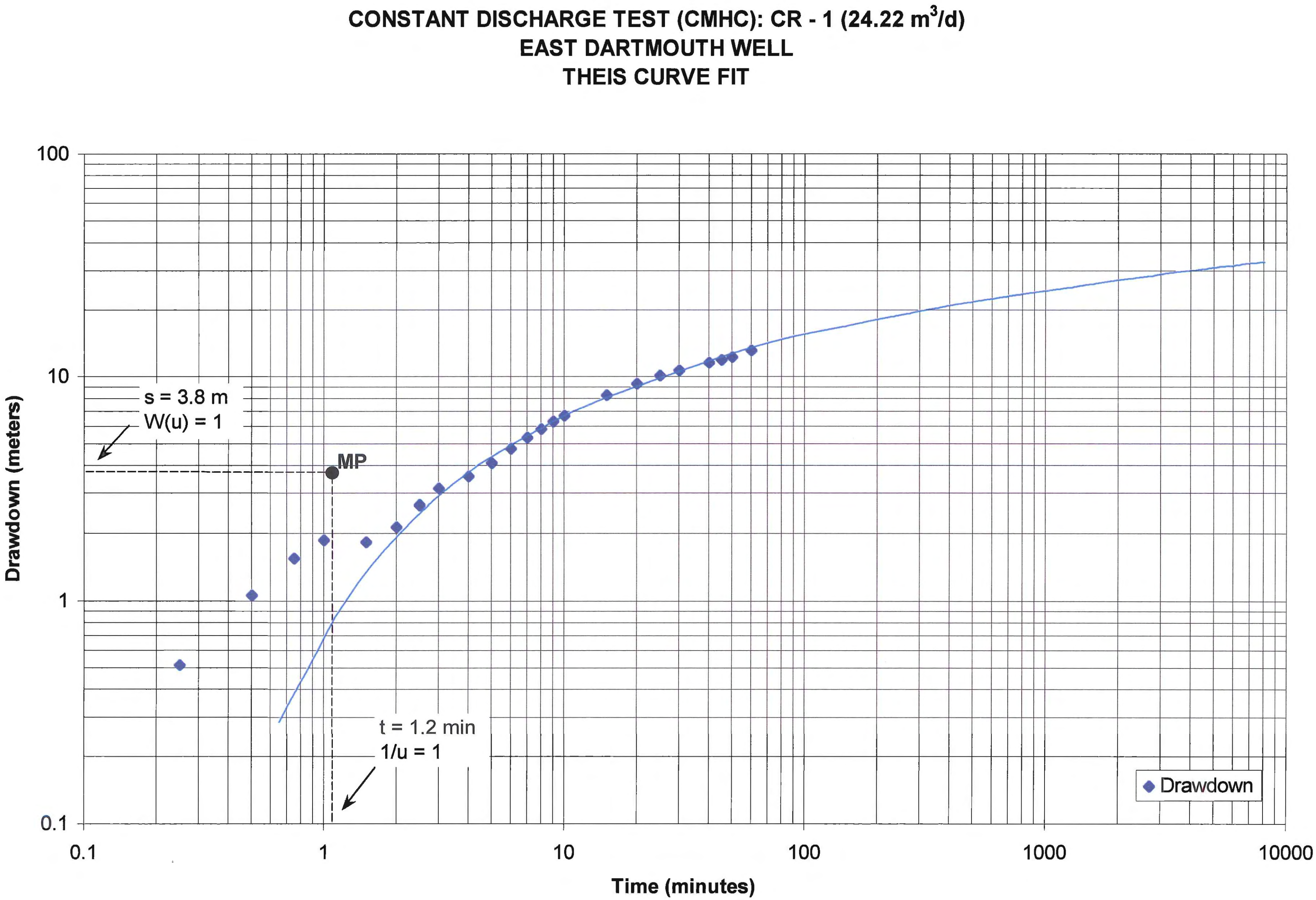


Figure 4.9: Logarithmic graph of the drawdown data showing the Theis curve fit and match point for test CR-1

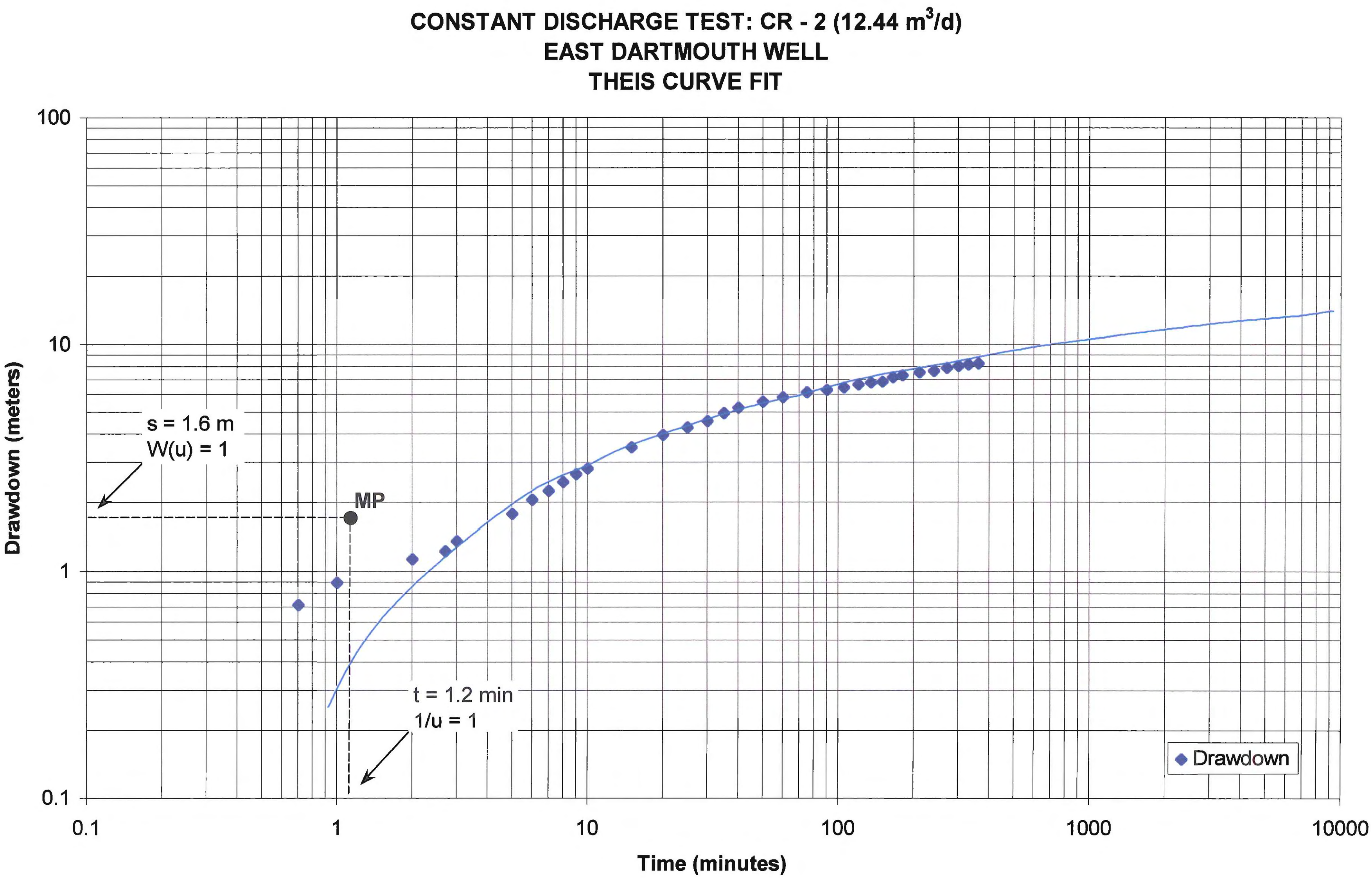


Figure 4.10: Logarithmic graph of the drawdown data showing the Theis curve fit and match point for test CR-2.

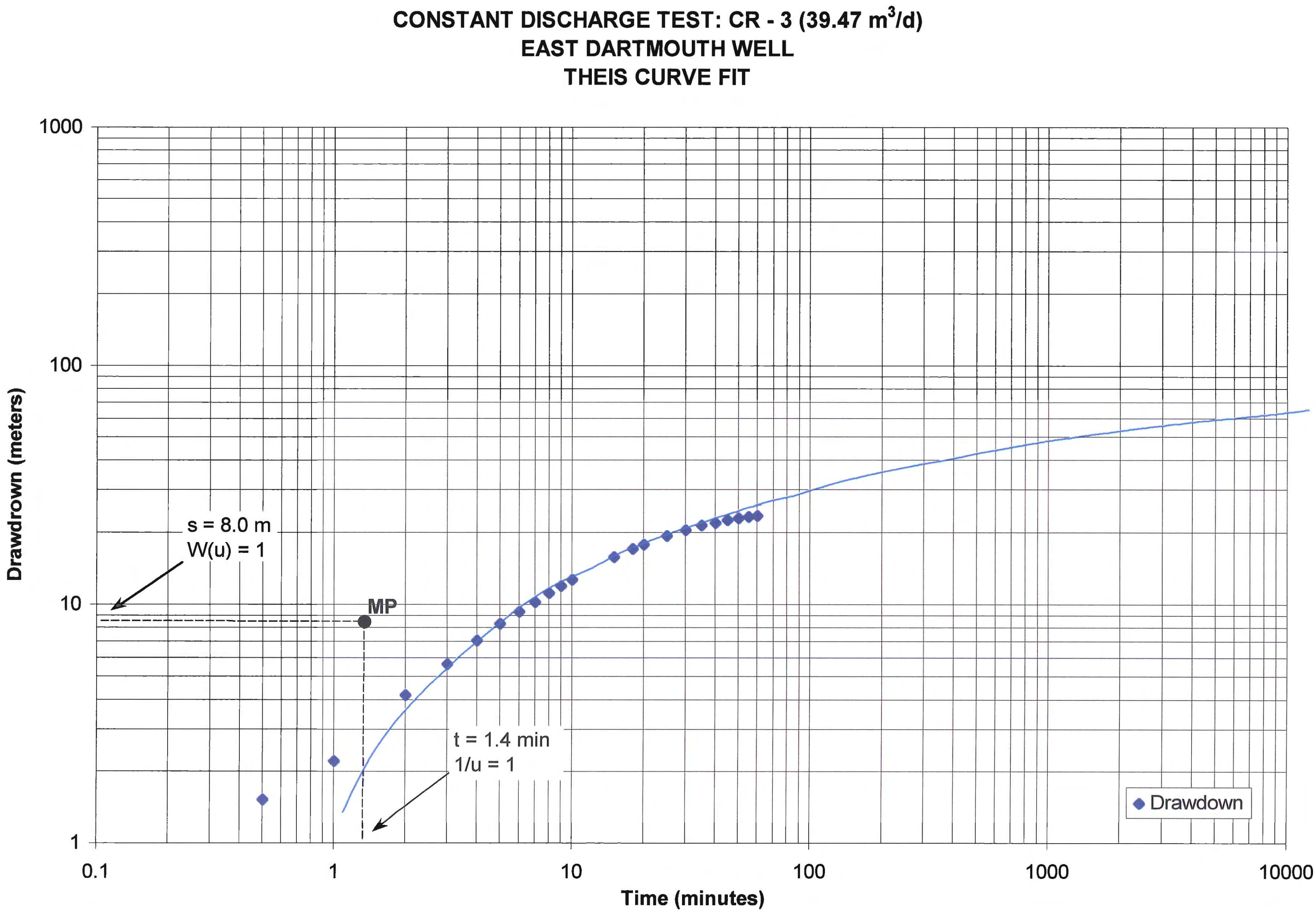


Figure 4.11: Logarithmic graph of the drawdown data showing the Theis curve fit and match point for test CR-3.

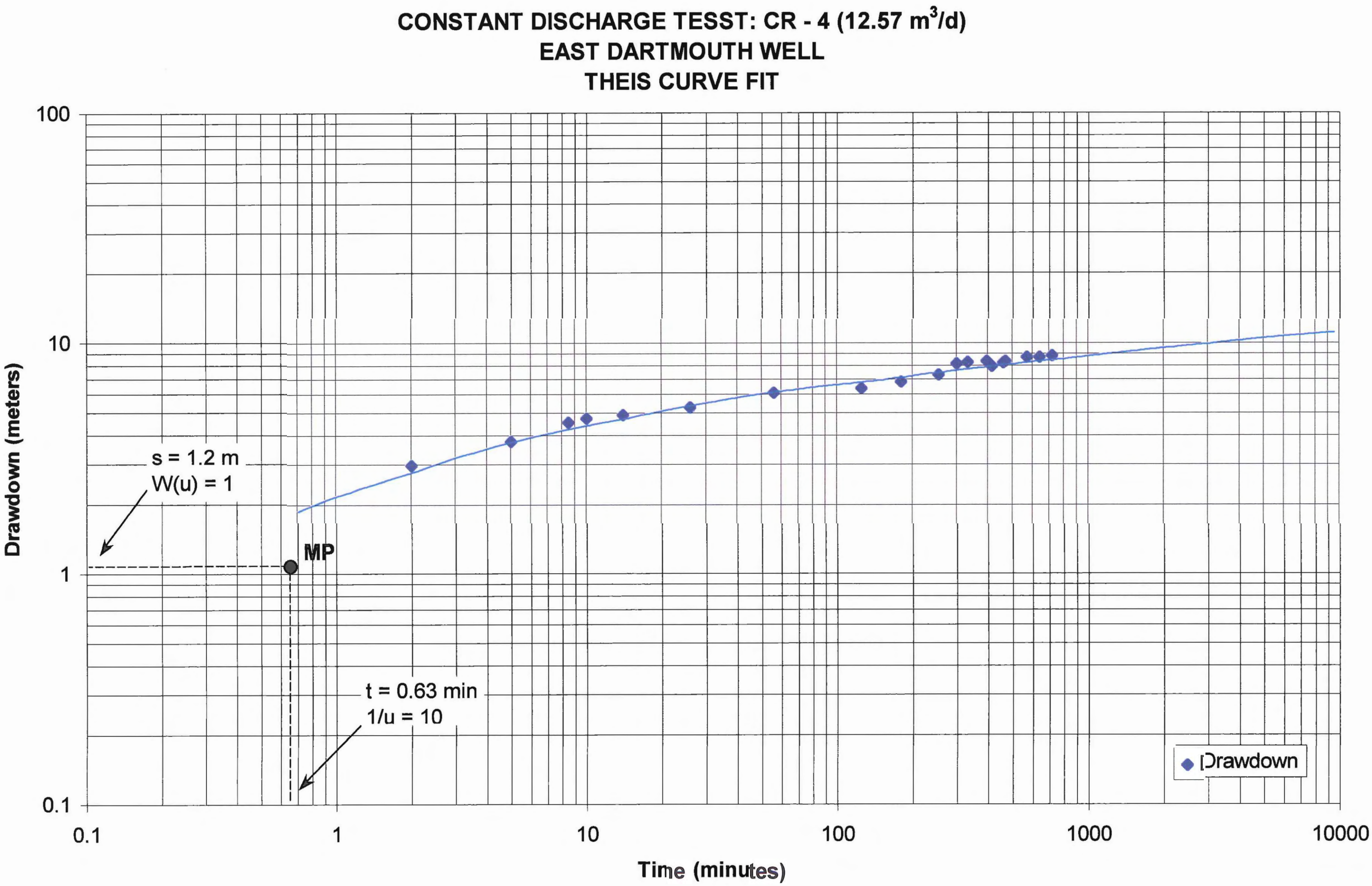


Figure 4.12: Logarithmic graph of the drawdown data showing the Theis curve fit and match point for test CR-4.

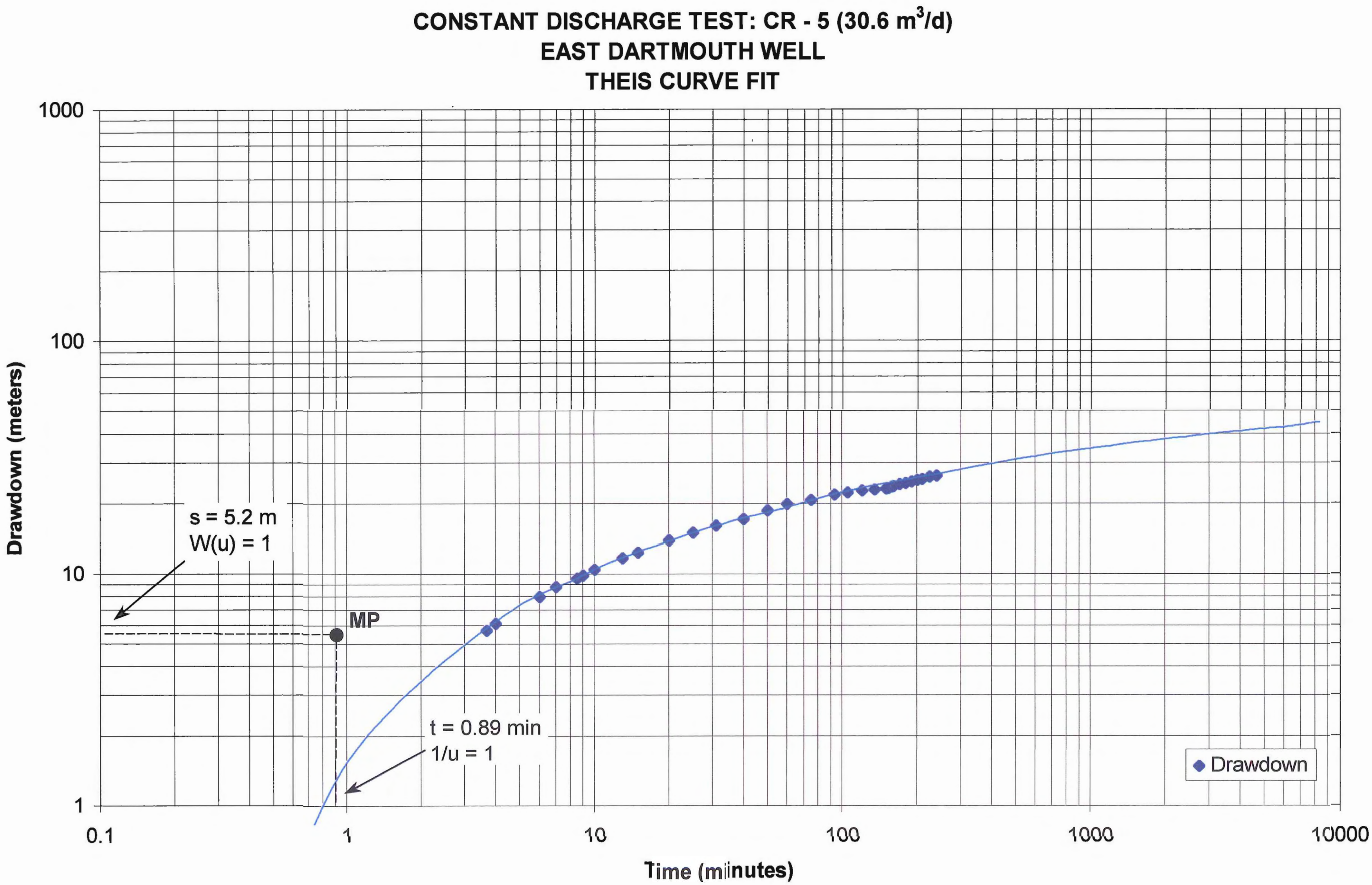


Figure 4.13: Logarithmic graph of the drawdown data showing the Theis curve fit and match point for test CR-5.

discharge tests CR-1, CR-2 and CR-3 (Figs. 4.9, 4.10 and 4.11) deviate slightly from the Theis curve, likely due to initial well-bore storage effects, since water is derived from the well-bore as well as from the aquifer. The Theis method assumes that the diameter of the well is negligible. The effects of well-bore storage are less evident in tests CR-4 and CR-5 (Figs. 4.12 and 4.13). The results of the derivative test concur.

Table 4.5 lists the transmissivity values calculated using the Theis method of analysis for the East Dartmouth well. Transmissivity values calculated using the Theis method range from 0.39 to 0.83 m^2/d. Geometric mean was used to calculate the averages for the aquifer properties calculated for each pump test in this study. This is because hydraulic properties such as hydraulic conductivity (K) and transmissivity (T) are usually log-normally distributed, so geomean gives a better value than arithmetic mean since it avoids the influence of extremes. A comparison of these values and those calculated using other methods is provided in Section 4.1.6.

Pump Test	Length of Test (hours)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (L)	T_{dd} (m^2/d)	Q_{20} (m^3/d)	Q_{1hr} (m^3/d)	Q_{30min} (m^3/d)
CR - 1	1	3.70	24.22	0.28	1008.7	0.51	4.22	17.39	19.71
CR - 2	6	1.90	12.44	0.14	3112.4	0.62	5.15	21.22	24.04
CR - 3	1	6.04	39.47	0.46	1644.8	0.39	3.27	13.46	15.26
CR - 4	12	1.92	12.57	0.14	6279.4	0.83	6.94	28.59	32.40
CR - 5	4	4.68	30.57	0.35	5088.9	0.47	3.90	16.04	18.18
					Geomean:	0.54	4.54	18.69	21.18

Table 4.5: Summary of the aquifer properties calculated using the Theis method of analysis for the East Dartmouth well. Discharge rate (Q) is given in imperial gallons per minute (gpm), m^3/day and litres per second (L/s). T_{dd} are the transmissivity values calculated using drawdown data. Q_{30min}, Q_{1hr} and Q_{20} are the estimated yields for 30 minutes, one hour and 20 years.

4.1.2.3 Jacob Method

Semi-logarithmic graphs of the drawdown and residual drawdown data are shown with the Jacob straight-line fit for the constant discharge tests CR-1 to CR-5 in Figures 4.14 to 4.18, respectively. Semi-logarithmic representation of the drawdown data enhances certain features not apparent on the log-log graphs. Most evident is the curvilinear portion of the graph at early pumping times resulting from well-bore storage effects. The storage effects are most evident at early times ($t < 5$ minutes) in constant discharge tests CR-1, CR-2 and to a lesser extent in CR-3 (Figs. 4.14, 4.15 and 4.16). At late pumping times, the semi-log graph of constant discharge test CR-3 shows a slight decline in the rate of change of drawdown with time, which suggests the presence of a recharge boundary. The semi-log plots for all of the constant discharge tests (CR-1 to CR-5) show the straight-line response of an ideal aquifer for the majority of the test, signifying radial flow to the well. Tests CR-1, CR-2 and CR-3 show the linear relationship following the period in which storage effects act (after five minutes). The shape of the curves for constant discharge tests CR-4 and CR-5 (Figs. 4.17 and 4.18) are essentially linear throughout the entirety of the test.

The semi-logarithmic graphs for the recovery data exhibit a slight "S" curve for the aquifer tests pumped at higher discharge rates. This can be seen in the constant discharge tests CR-1, CR-3, and CR-5 (Figs. 4.14, 4.16 and 4.18), which have discharge rates of 24.22 m^3/d, 39.47 m^3/d and 30.57 m^3/d respectively. Constant discharge tests CR-2 and CR-4 (Figs. 4.15 and 4.17) were pumped at lower discharge rates (12.44 m^3/d and 12.57 m^3/d) and the recovery data exhibits a more classical straight-line response.

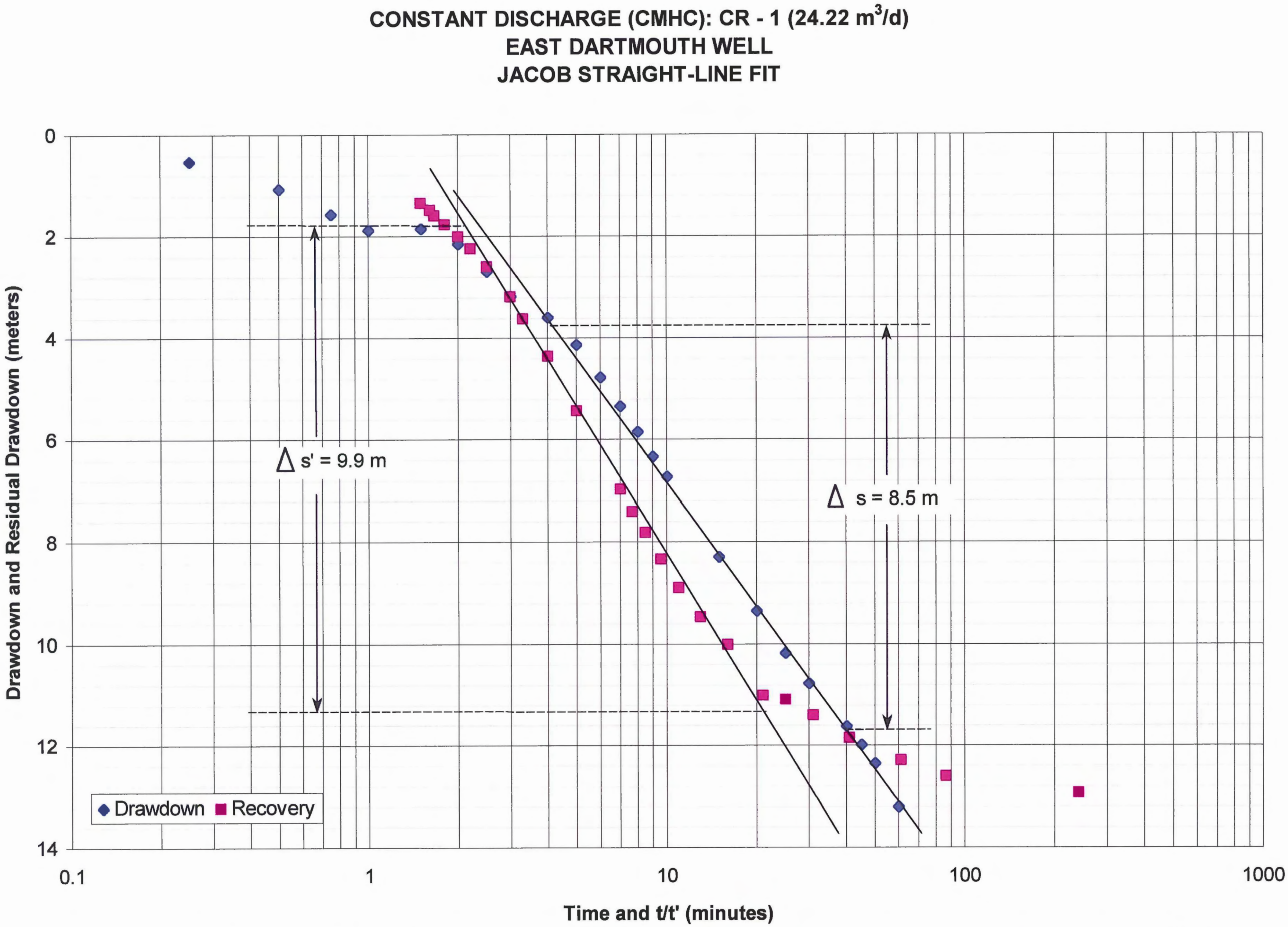


Figure 4.14: Semi-logarithmic graphs of the drawdown and recovery data with the Jacob straight-line best fit for test CR-1.

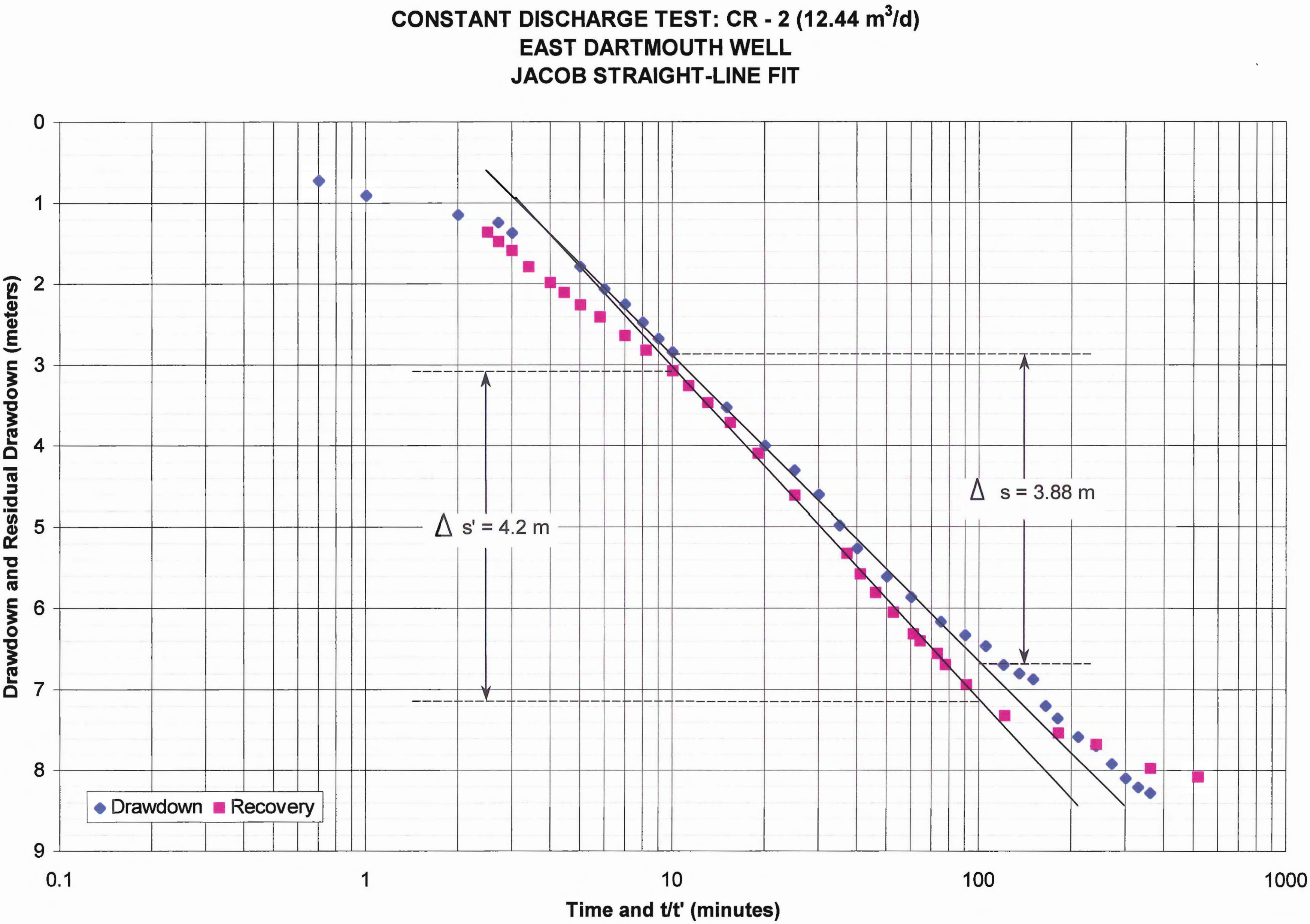


Figure 4.15: Semi-logarithmic graphs of the drawdown and recovery data with the Jacob straight-line best fit for test CR-2.

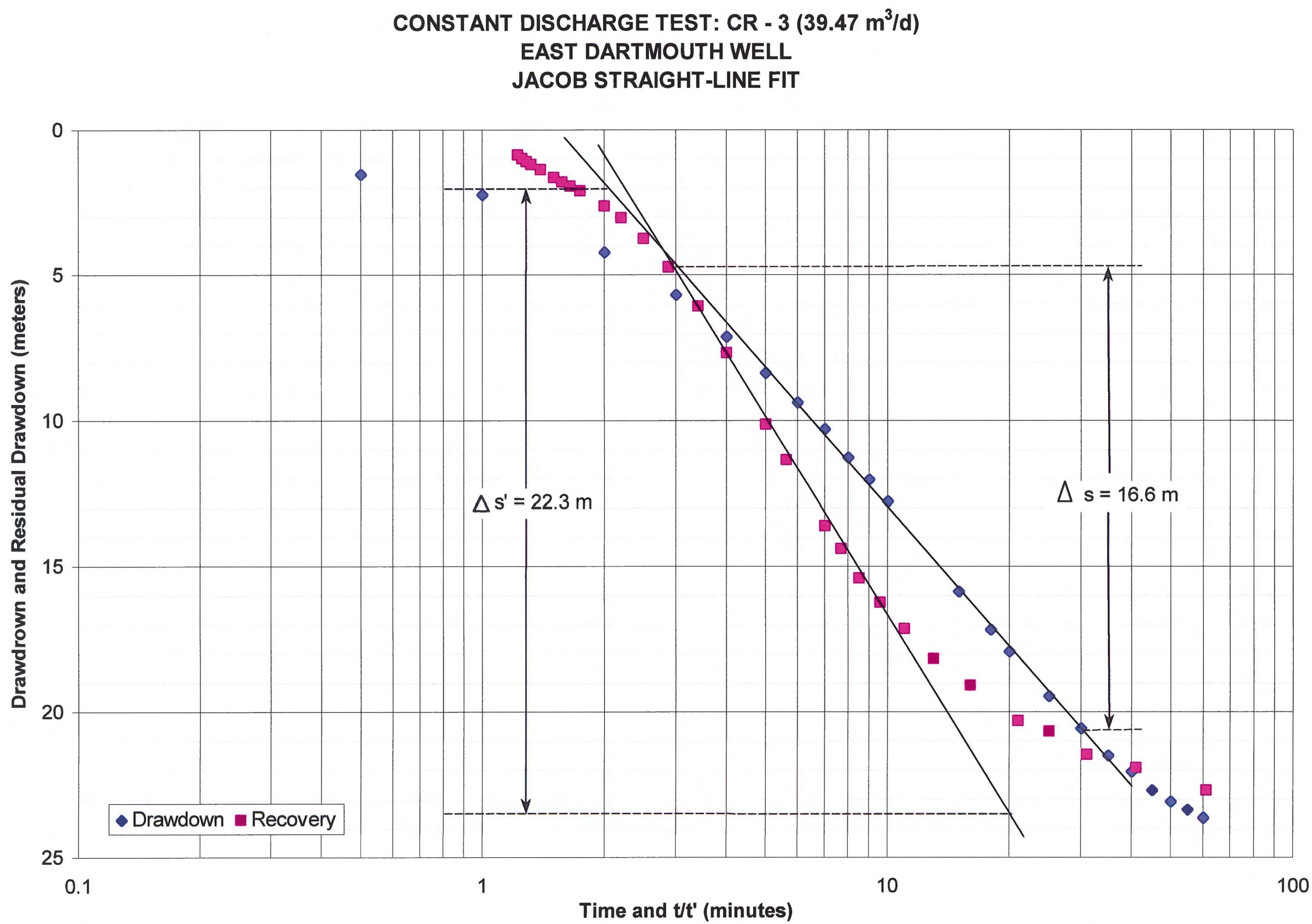


Figure 4.16: Semi-logarithmic graphs of the drawdown and recovery data with the Jacob straight-line best fit for test CR-3.

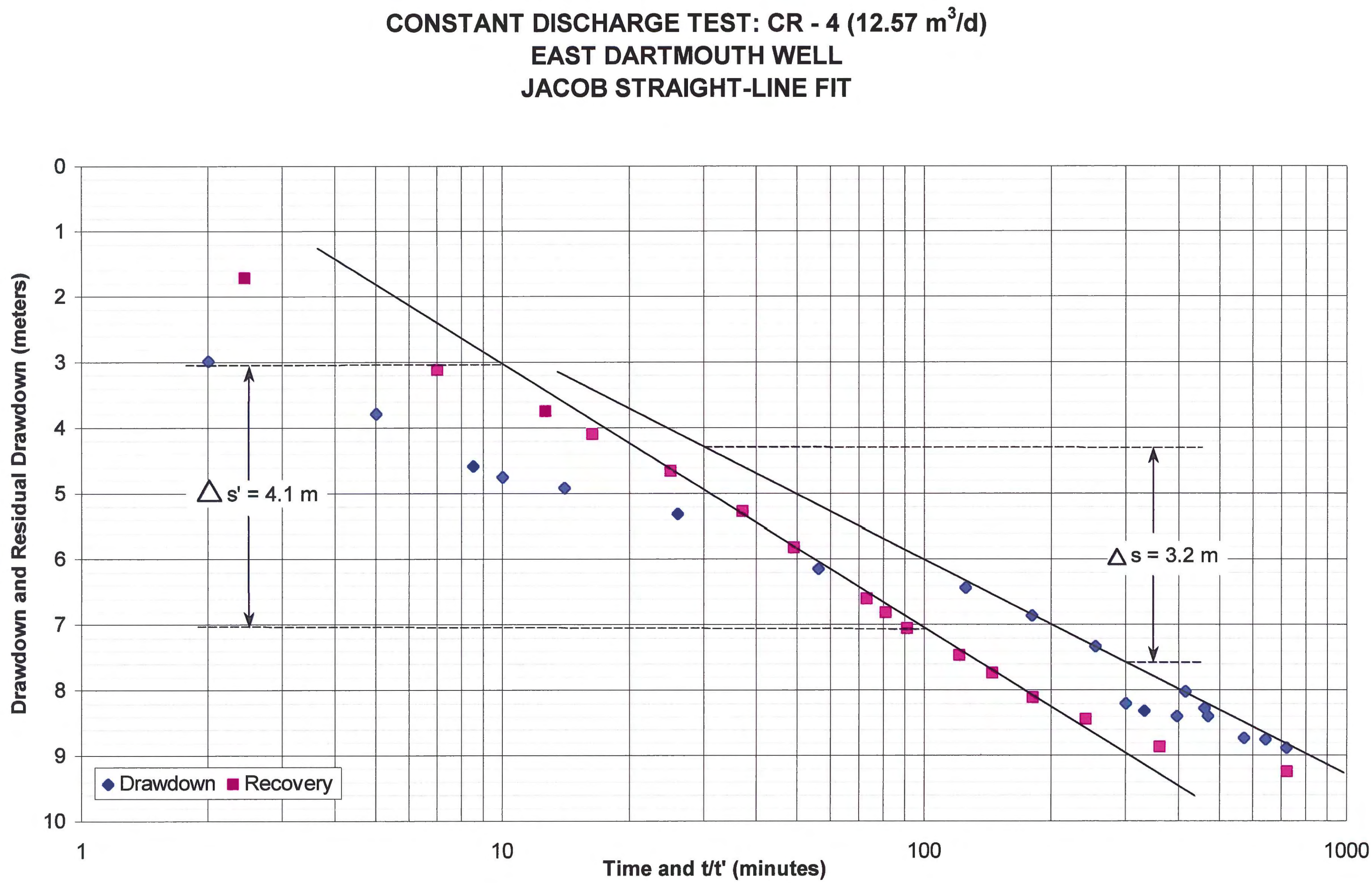


Figure 4.17: Semi-logarithmic graphs of the drawdown and recovery data with the Jacob straight-line best fit for test CR-4.

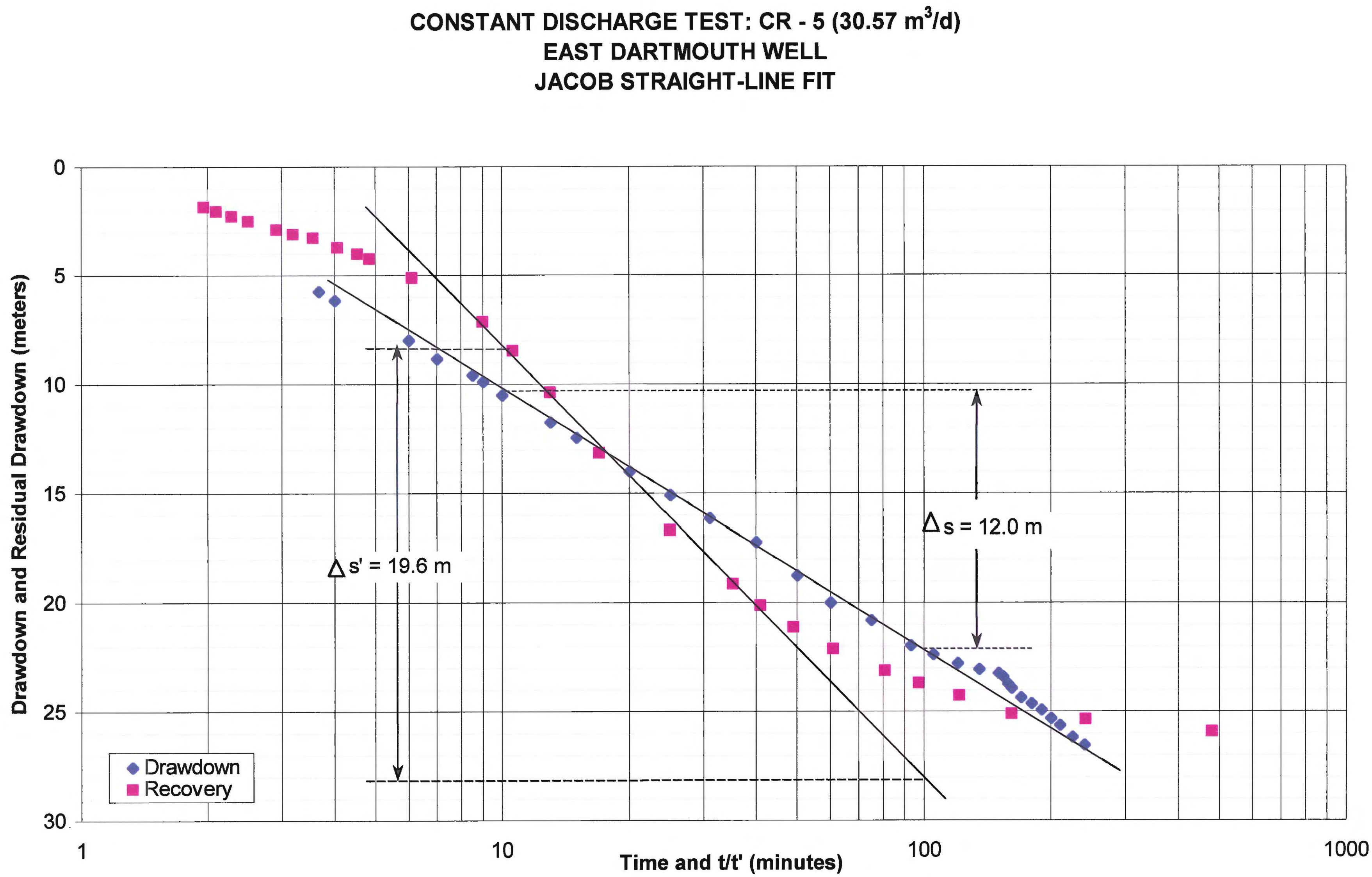


Figure 4.18: Semi-logarithmic graphs of the drawdown and recovery data with the Jacob straight-line best fit for test CR-5.

Well-bore storage and boundary effects are not accounted for in the Jacob method, so only the drawdown data that are considered representative of radial flow were used in the analysis and are shown by the placement of the best-fit straight-line in the semi-log graphs for the Jacob method (Figs. 4.14 to 4.18). In the analysis of the recovery data, the segment of the curve selected for most of the tests coincides with the same radial flow time segment used for the drawdown data (Figs. 4.14 to 4.18).

Table 4.6 lists the transmissivity values that were calculated using the Jacob method of analysis for both the drawdown and recovery data for the East Dartmouth well. Transmissivity values using the Jacob method range from 0.44 to 0.72 m^2/d when calculated using the drawdown data. The transmissivities calculated using the recovery data range from 0.29 to 0.56 m^2/d. The geometric mean of the drawdown and recovery data gives a range of transmissivities from 0.36 to 0.64 m^2/d. These values are discussed in greater detail in Section 4.1.6 and compared with values obtained from the other methods analyzed in this study.

4.1.2.4 Gringarten et al. Method

The characteristic drawdown curve for a pumping well which interests a single vertical planar fracture in an otherwise, homogeneous, isotropic, confined aquifer, has a straight-line portion with slope of 0.5 on a logarithmic plot during early pumping times, when the drawdown in the well is governed by horizontal, laminar flow in the aquifer (i.e. linear flow).

Logarithmic graphs of the drawdown data are shown with the Gringarten et al. curve fit and match point for the constant discharge tests CR-2, CR-4 and CR-5 in Figures 4.19, 4.20 and 4.21. Constant discharge tests that were one hour in duration (CR-

Pump Test	Length of Test (hours)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (L)	T_{dd} (m^2/d)	T_{rec} (m^2/d)	T_{gm} (m^2/d)	Q_{20} (m^3/d)	Q_{1hr} (m^3/d)	Q_{30min} (m^3/d)
CR - 1	1	3.70	24.22	0.28	1008.7	0.52	0.45	0.48	4.03	16.58	18.79
CR - 2	6	1.90	12.44	0.14	3112.4	0.59	0.54	0.56	4.70	19.34	21.92
CR - 3	1	6.04	39.47	0.46	1644.8	0.44	0.32	0.38	3.13	12.87	14.59
CR - 4	12	1.92	12.57	0.14	6279.4	0.72	0.56	0.64	5.29	21.77	24.68
CR - 5	4	4.68	30.57	0.35	5088.9	0.47	0.29	0.36	3.04	12.51	14.17
					Geomean:	0.54	0.42	0.47	3.94	16.22	18.39

Table 4.6: Summary of the aquifer properties calculated using the Jacob method of analysis for the East Dartmouth well. Discharge rate (Q) is given in imperial gallons per minute. T_{dd} refers to the transmissivity values calculated using the drawdown data. T_{rec} are the transmissivity values calculated using recovery data. T_{gm} is the geometric mean of the transmissivities calculated using the drawdown and recovery data for each constant discharge test. Q_{30min}, Q_{1hr} and Q_{20} are the estimated yields for 30 minutes, one hour and 20 years.

1 and CR-3) did not conform to Gringarten et al.'s model for fracture flow in the pumping well. The early time drawdown data for test CR-1 and to a lesser extent, test CR-3 displays a slope of one on a log-log plot (Figs. 4.9 and 4.11). According to Kruseman and de Ridder (1990), well-bore storage effects have influenced early time drawdown data that exhibit a slope of one (instead of 0.5). Such results usually indicate a large storage volume connected with the well, which corresponds to a fracture of large dimensions rather than the assumed planar fracture. Both the derivative method and qualitative analysis of the semi-logarithmic graphs also suggests that the early time data for CR-1 and CR-3 are influenced by storage effects in the well (Figs. 4.4, 4.6, 4.14 and 4.16). Gringarten et al.'s method cannot be applied if well-bore storage exists. It is also possible that the East Dartmouth well is not a "perfect well", i.e. a well that has no well losses, which also cannot be modeled by Gringarten et al.'s method for a single vertical fracture (Kruseman and de Ridder, 1990).

Constant discharge tests CR-2, CR-4 and CR-5 are longer in duration than tests CR-1 and CR-3 (6, 12 and 4 hours respectively) and contain early time drawdown data that fall on a line with a slope of 0.5, thus showing less deviation from the Gringarten et al. type curve (Figs. 4.19, 4.20 and 4.21). This implies that the longer tests show fewer effects from well-bore storage and well losses.

Table 4.7 lists the transmissivity values calculated using Gringarten et al.'s vertical fracture flow model for applicable tests. The transmissivity values range from 0.36 to 1.00 m^2/d for the East Dartmouth well. These values are discussed in greater detail in Section 4.1.6 and are compared with transmissivity values obtained using the other methods of analysis outlined in this study.

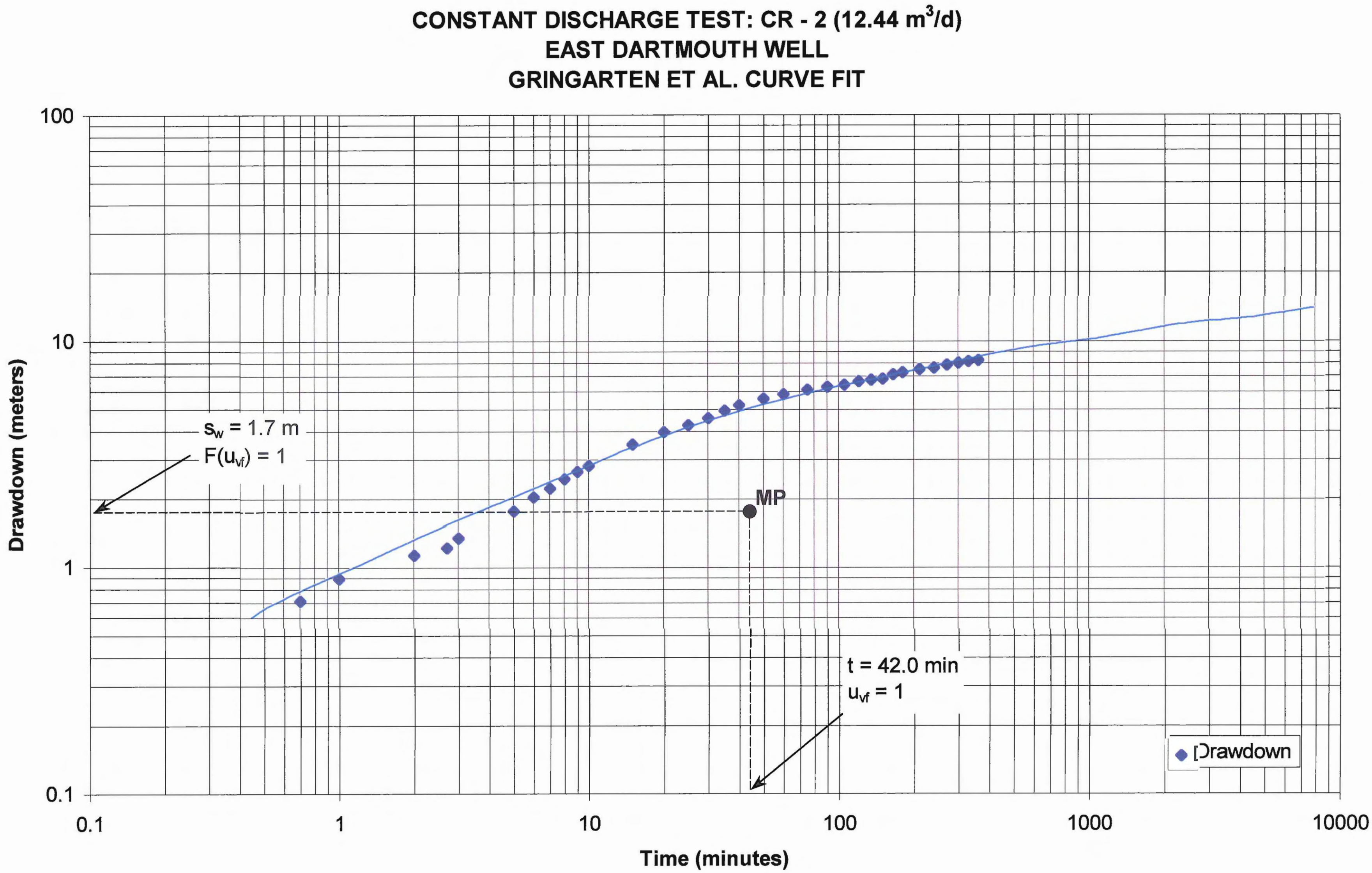


Figure 4.19: Logarithmic graph of the drawdown data showing the Gringarten et al. curve fit and match point for test CR-2

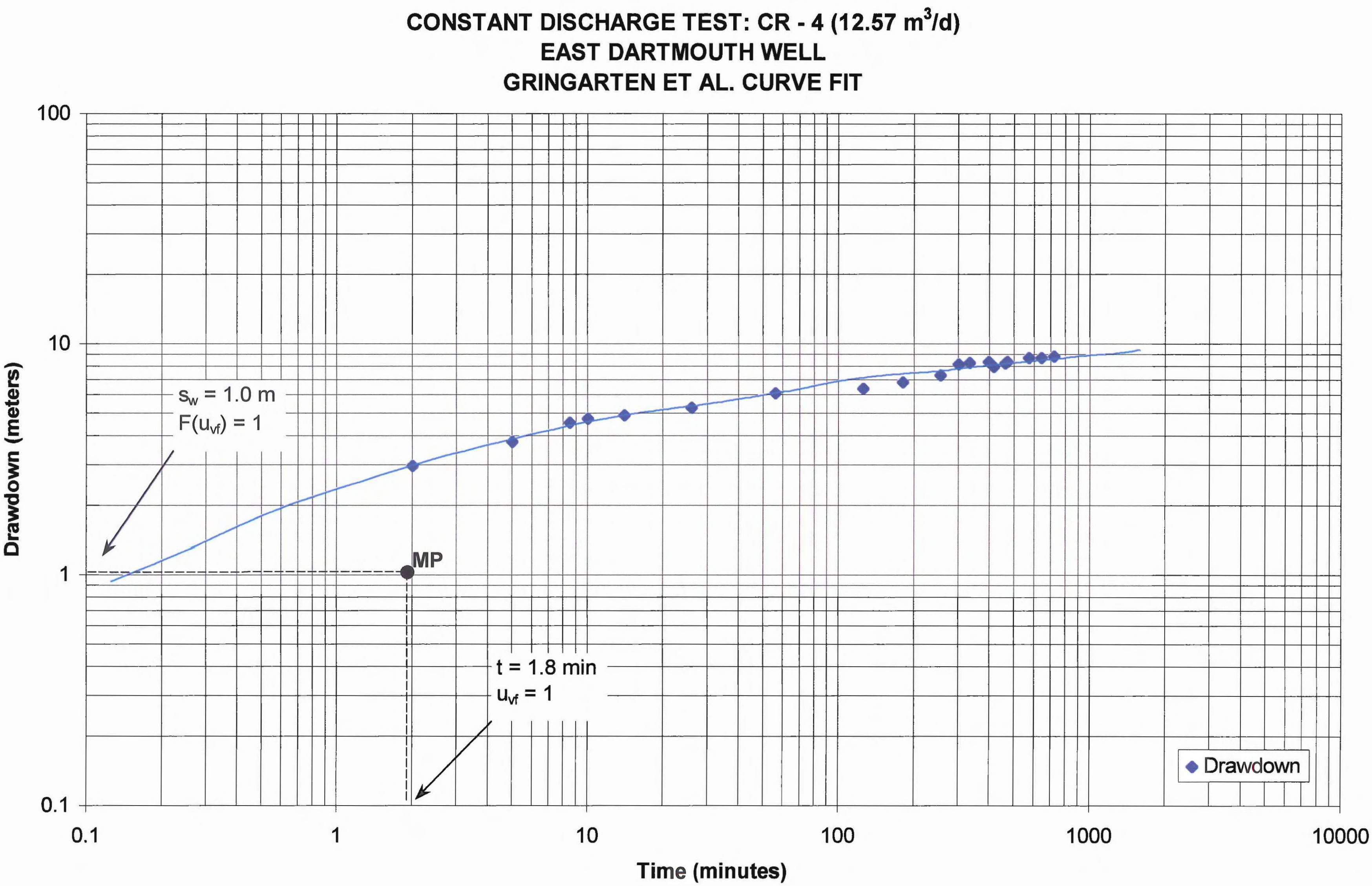


Figure 4.20: Logarithmic graph of the drawdown data showing the Gringarten et al. curve fit and match point for test CR-4.

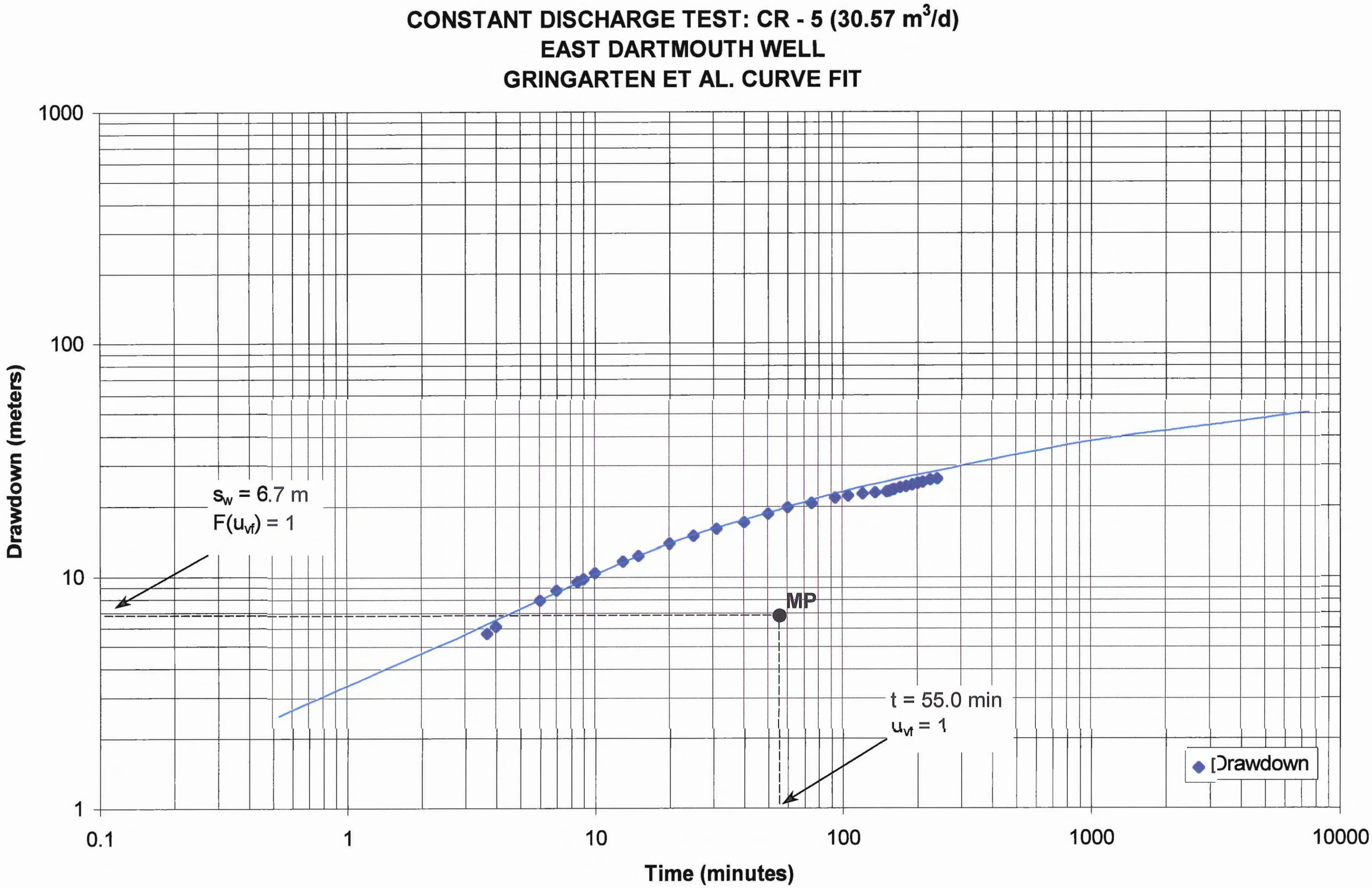


Figure 4.21: Logarithmic graph of the drawdown data showing the Gringarten et al. curve fit and match point for test CR-5.

Pump Test	Length of Test (hours)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (L)	T_{dd} (m^2/d)	Q_{20} (m^3/d)	Q_{1hr} (m^3/d)	Q_{30min} (m^3/d)
CR - 1	1	3.70	24.22	0.28	1008.7	X	X	X	X
CR - 2	6	1.90	12.44	0.14	3112.4	0.58	4.83	19.89	22.54
CR - 3	1	6.04	39.47	0.46	1644.8	X	X	X	X
CR - 4	12	1.92	12.57	0.14	6279.4	1.00	8.33	34.32	38.89
CR - 5	4	4.68	30.57	0.35	5088.9	0.36	3.02	12.45	14.11
					Geomean:	0.60	4.96	20.41	23.13

Table 4.7: Summary of the aquifer properties calculated using Gringarten et al.'s method for vertical fracture flow for the East Dartmouth well. Discharge rate (Q) is given in imperial gallons per minute (gpm), m^3/day and litres per second (L/s). T_{dd} are the transmissivity values calculated using drawdown data. Q_{30min}, Q_{1hr} and Q_{20} are the estimated yields for 30 minutes, one hour and 20 years. This method could not be applied to the one-hour tests, which are denoted by an **X**.

4.1.3 Cyclic Test Results

The drawdown and recovery curves for the cyclic test performed on the East Dartmouth well are shown in Figure 4.22. The curves indicate a slight net gain over the entire period of the test. This is evident in the progressively decreasing amount of total drawdown at the conclusion of each cycle with time. The total drawdown decreases from 13.96 m in cycle 1 to 12.44 m in cycle 2 and finally 11.90 m in cycle 3. The curves exhibit good recovery with nearly complete recovery within one hour in each of the three cycles. No water bearing fractures were dewatered throughout the cyclic test since the total drawdown for each cycle (13.96 m, 12.44 m and 11.90 m respectively) never exceeded the bottom of the well casing (22.6 m). The on-off nature of the cyclic test is expected to be closest to the response of the well to homeowner usage. Each cycle was pumped at approximately 26.0 m^3/d (4.0 gpm) resembling the pumping rate set for domestic water pumps. This suggests that the well can maintain the CMHC standard for repeated cycles and still experience a net gain.

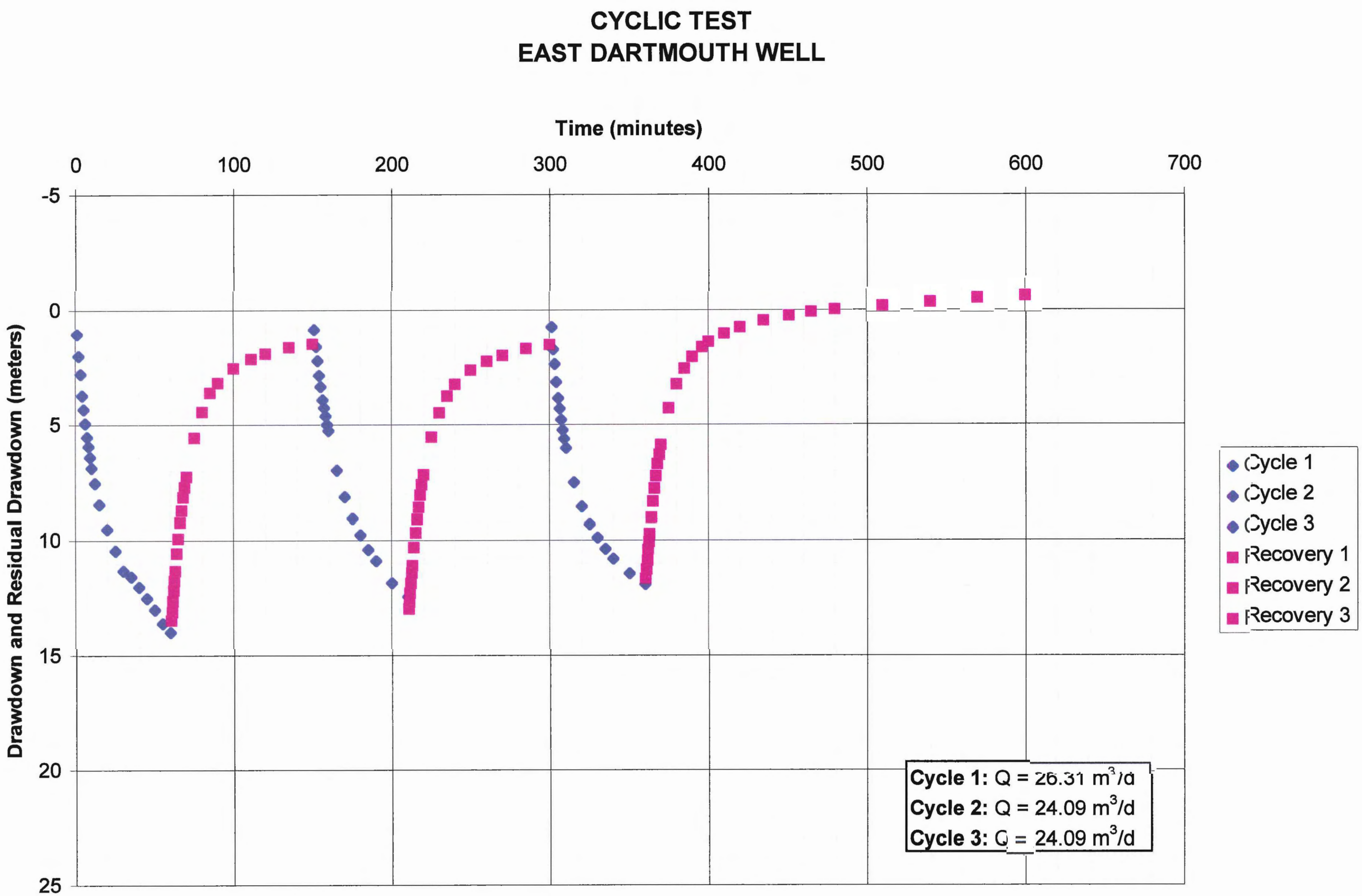


Figure 4.22: The drawdown and recovery curves for the cyclic test performed on the East Dartmouth well.

4.1.4 Slug Test Results

The plot of the falling head slug test data for the East Dartmouth well is shown in Figure 4.23. The horizontal hydraulic conductivity (K_h) was calculated for the slug test using the Hvorslev basic time lag method with F-type configuration (Equation 3.25 in Section 3.2.5).

The calculated aquifer transmissivity is 2.41 m^2/d as shown in Table 4.8. The transmissivity value obtained by the slug test is discussed in greater detail in Section 4.1.6 and is also compared with the transmissivity values attained using the other methods of analysis for the step drawdown and constant discharge pump tests discussed previously.

Pump Test	K_h (m/d)	b = open zone of well (m)	T (m^2/d)	Q_{20} (m^3/d)	Q_{1hr} (m^3/d)	Q_{30min} (m^3/d)
Slug Test	0.087	30.78	2.69	22.40	92.24	105.54

Table 4.8: Summary of the aquifer properties calculated for the East Dartmouth well using the Hvorslev method for slug test analysis. K_h is the horizontal hydraulic conductivity of the aquifer calculated using the Basic Time Lag equation. The value of the open zone of the well was used to calculate the transmissivity from the equation T=Kb. Q_{30min}, Q_{1hr} and Q_{20} are the estimated yields for 30 minutes, one hour and 20 years.

4.1.5 Specific Capacity

Specific capacity (Q/s) is an expression of the productivity of the well and is defined as the yield per unit drawdown. Specific capacities were calculated for each constant discharge test (CR-1 to CR-5) and the first cycle of the cyclic test (C1). The amount of drawdown in the well after one hour of pumping was used for the calculation since this is the duration of the shortest pump test conducted.

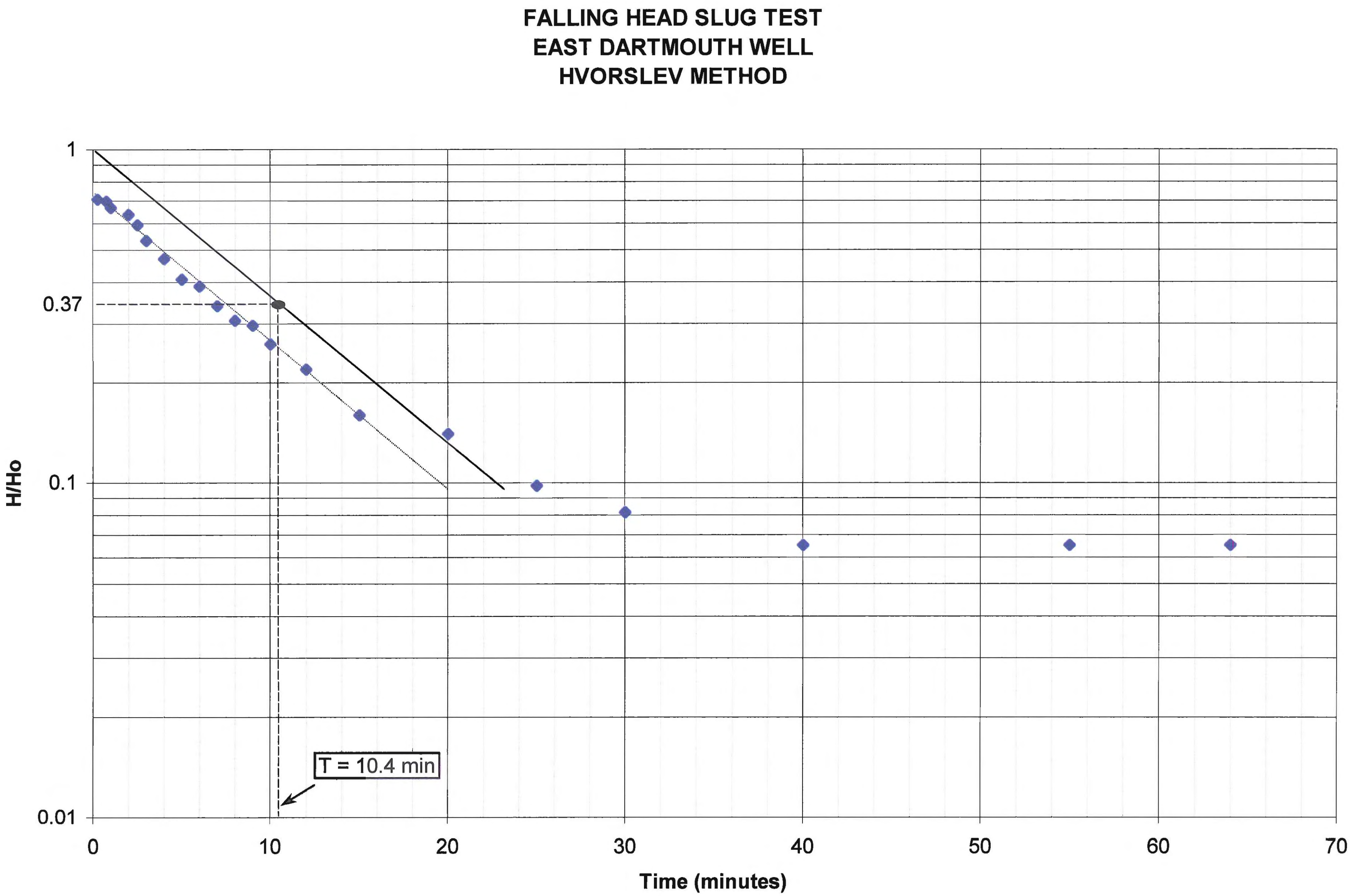


Figure 4.23: The semilogarithmic plot of H/Ho versus time for the falling head slug test conducted on the East Dartmouth well.

Table 4.9 shows that calculated specific capacities for the well range from 1.53 to 2.12 $m^3/d/m$, which are values representative of a low capacity well. Higher values of specific capacity are obtained from the longer term tests performed at lower discharge rates (CR-2 and CR-4), which suggest a greater yield for the well. The short term tests at pumped higher discharge rates give a lower specific capacity and therefore imply a lower yield. Figure 4.24 shows that as the discharge rate increases, the specific capacity gradually decreases. This relationship is the result of the increased drawdown in the well at higher discharge rates due to well losses.

Pump Test	Length of Test (hours)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (L)	s (after 1 hr) (m)	s (at end of pumping period) (m)	Q/s (after 1 hr) ($m^3/d/m$)
CR – 1	1	3.70	24.22	0.28	1008.7	13.98	13.20	1.73
CR – 2	6	1.90	12.44	0.14	3112.4	5.86	8.27	2.12
CR – 3	1	6.04	39.47	0.46	1644.8	23.62	23.62	1.67
CR – 4	12	1.92	12.57	0.14	6279.4	6.14	8.88	2.05
CR – 5	4	4.68	30.57	0.35	5088.9	19.97	26.50	1.53
Cyclic - C1	1	4.02	26.31	0.30	1095.0	13.96	13.96	1.88

Table 4.9: Specific capacities calculated using the amount of drawdown after one hour during the first cycle of the cyclic test and the constant discharge tests conducted on the East Dartmouth well. Discharge rate (Q) is given in imperial gallons per minute (gpm), m^3/day and litres per second (L/s).

Estimates of transmissivity from specific capacity data using Equation 3.34 (Huntley et al., 1992) range from 0.20 to 0.29 m^2/d (Table 4.10). The estimated values of transmissivity based on the specific capacity of the well are compared with the actual aquifer transmissivities obtained from the other methods analyzed in this study in Section 4.1.6.

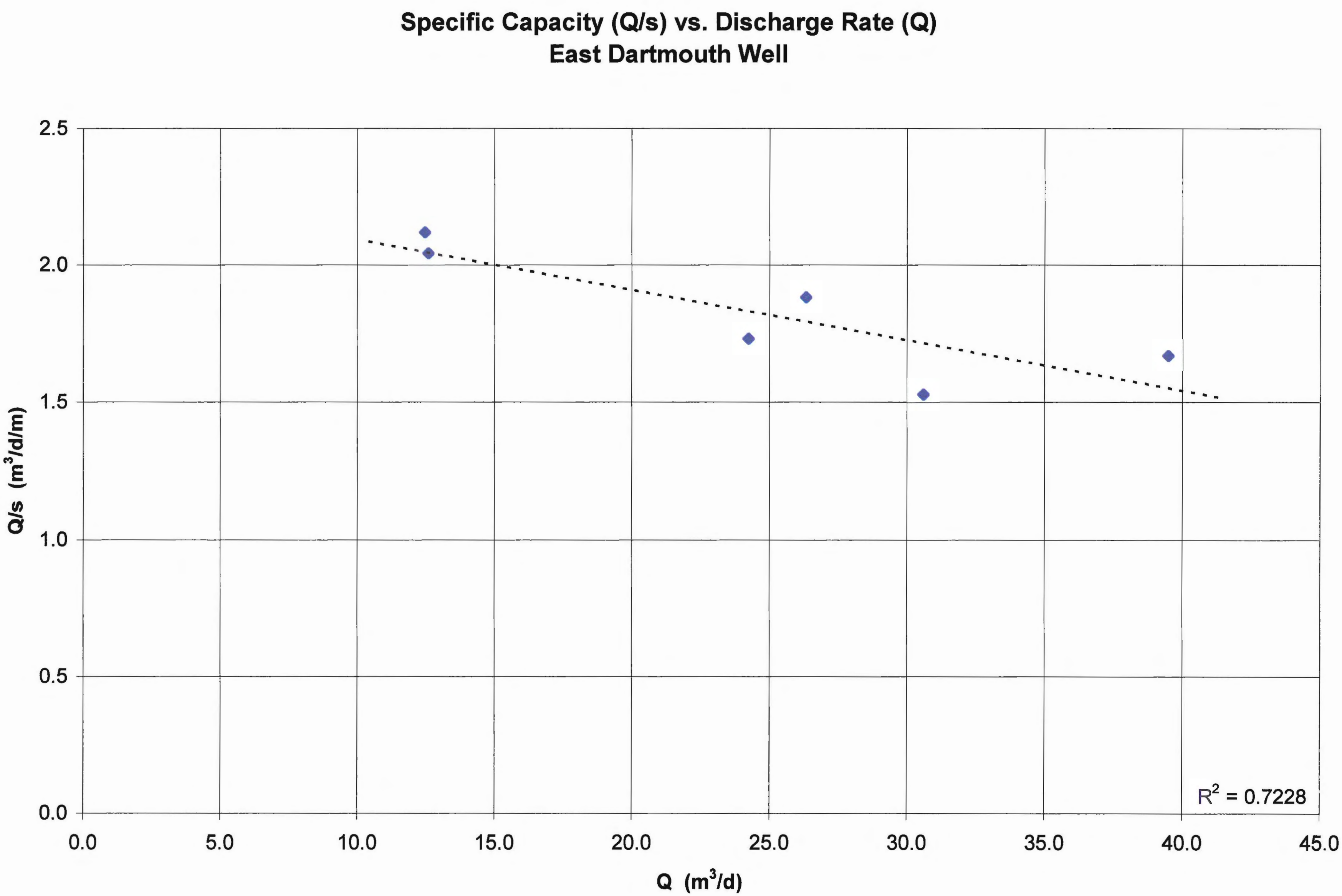


Figure 4.24: Specific capacity (Q/s) versus discharge rate (Q) for the East Dartmouth well.

Pump Test	Length of Test (hours)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (L)	Q/s (after 1 hr) (m^3/d/m)	T= $K(Q/s)^{1.18}$
CR – 1	1	3.70	24.22	0.28	1008.7	1.73	0.23
CR – 2	6	1.90	12.44	0.14	3112.4	2.12	0.29
CR – 3	1	6.04	39.47	0.46	1644.8	1.67	0.22
CR – 4	12	1.92	12.57	0.14	6279.4	2.05	0.28
CR – 5	4	4.68	30.57	0.35	5088.9	1.53	0.20
Cyclic – C1	1	4.02	26.31	0.30	1095.0	1.88	0.25
						Geomean:	0.24

Table 4.10: Summary of the estimated transmissivity values based on specific capacity data (Q/s) for the East Dartmouth well. The estimated transmissivity values are given in m^2/day. Discharge rate (Q) is given in imperial gallons per minute (gpm), m^3/day and litres per second (L/s).

4.1.6 Comparison of Calculated Transmissivities

Table 4.11 summaries the T values calculated in the previous sections by the analytical methods applied in this study. An available drawdown of 15.2 m (50 ft) was assumed for the East Dartmouth well to calculate long and short term safe yields.

- Theis versus Jacob

The transmissivities (T) calculated using the Theis and Jacob methods show very similar results for the East Dartmouth well. The geometric mean of the T_{dd} values calculated from Jacob is the same as the geometric mean of T values calculated using the Theis method (0.54 m^2/d) (Table 4.11). The similarity of the results obtained from the two methods is expected because the Jacob method is a special case of the Theis nonequilibrium formula (Equation 3.5). The fact that the data fits the Theis and Jacob models reasonably well suggests that even though fractured rock aquifers are not ideal, i.e. they do not meet all the assumptions required by the models, the models can still be applied to the East Dartmouth well.

Method of Analysis	T (m^2/d)	Q_{20} (gpm)	Q_{20} (m^3/d)	Q_{20} (L/s)	Q_{1hr} (gpm)	Q_{1hr} (m^3/d)	Q_{1hr} (L/s)	Q_{30min} (gpm)	Q_{30min} (m^3/d)	Q_{30min} (L/s)
Reconstructed Step Drawdown	0.69	0.88	5.75	0.07	3.62	23.66	0.27	4.10	26.82	0.31
Theis Method	0.54	0.69	4.54	0.05	2.86	18.69	0.22	3.24	21.18	0.24
Jacob Method Drawdown: Recovery: Geomean:	0.54 0.42 0.47	0.60	3.94	0.04	2.48	16.22	0.19	2.81	18.39	0.21
Gringarten et al. Method	0.60	0.76	4.96	0.06	3.12	20.41	0.24	3.54	23.13	0.27
Hvorslev Method – Slug Test	2.69	3.43	22.40	0.26	14.11	92.24	1.07	16.15	105.54	1.21
$T=K(Q/s)^{1.18}$	0.24	0.32	2.07	0.02	0.11	0.70	0.01	1.48	9.68	0.12

Table 4.11: Summary table showing the geometric means of the calculated transmissivities (T), long term (Q_{20}) and short term (Q_{1hr} and Q_{30min}) yields for each analytical method in this study for the East Dartmouth well.

- Theis versus Gringarten et al.

The geometric mean T calculated from the Gringarten et al. method is slightly less than the value calculated using the Theis method (Table 4.11). Through down-hole camera logging, it has been established that the East Dartmouth well contains numerous fractures, instead of a single, vertical plane fracture, and therefore does not meet all the assumptions required for this model. However, it is not known which fractures are the main water bearing fractures.

- Slug Test - Hvorslev method

The T value obtained from the slug test using the Hvorslev method of analysis is much higher than T values calculated from all other methods (Table 4.11). The slug test gives unreasonably high estimates of T because it is a very short term, localized test that is most likely reflecting the T of the major, most productive fracture(s) in the well, as opposed to the aquifer as a whole. Since pumps tests are longer in duration, they affect a larger area and therefore give T values that are more representative of the surrounding aquifer, which includes both fractures and matrix blocks.

- Reconstructed Step Drawdown

The T value calculated from the reconstructed step drawdown data are higher than the values calculated using the radial flow (Theis and Jacob) and fracture flow (Gringarten et al.) models (Table 4.11). This is most likely because the reconstructed data are based on 30 minute time steps, and each step was not pumped at rates greatly exceeding the capability of the well.

- Transmissivity Estimate Using Specific Capacity

The estimated T values based on specific capacity are lower (by a factor of 2) than the actual transmissivities obtained from pump test data (Table 4.11). This is because Equation 3.34 represents the best estimate of transmissivity, but the actual transmissivity could be approximately four times or one-quarter the estimated transmissivity (Huntley, 1992). If such is the case, the T estimates based on the specific capacity of the well fall within the range of the actual T values calculated from the pump test data (Table 4.11).

4.1.7 Comparison of Well Yields

The safe yields for the East Dartmouth well in Table 4.11 (page 98) were calculated using Equation 3.31, for periods of 20 years (7 log cycles), one-hour (~1.7 log cycles), and 30 minutes (~1.5 log cycles). The assumed available drawdown for the calculation was 15.2 m (50 ft). The calculated yield values are directly related to transmissivity for a particular time period since all other factors in Equation 3.31 are constant.

Based on calculations in Table 4.11, the best estimate of well yield for the East Dartmouth well is likely 4 to 5 m^3/d (0.6 to 0.8 gpm) for the long term, and 16 to 20 m^3/d (2.5 to 3.0 gpm) for the short term.

Since the average homeowner is not trained in the analytical methods, but can do simple volumetric calculations, yields were also estimated based on casing storage depletion and recovery for comparison purposes.

The estimated yields based on casing storage calculated from drawdown data range from 11.85 to 27.67 m^3/d (1.8 to 4.2 gpm) (Table 4.12) and are most comparable with the one-hour short term safe yields calculated for the East Dartmouth well (Table 4.11). If

Pump Test	Length of Test (min)	Length of Test (days)	Test Q (m^3/d)	Total Pumped (gallons)	Total Pumped (m^3)	Total Drawdown (ft)	Total Drawdown (m)	Storage Volume (gallons)	Storage Volume (m^3)	Estimated Yield		
										Q (gpm)	Q (m^3/d)	Q (L/s)
CR - 1	60	0.042	24.22	222	1.009	43.30	13.20	52.83	0.238	2.82	18.51	0.21
CR - 2	360	0.250	12.44	685	3.112	27.15	08.28	33.12	0.149	1.81	11.85	0.14
CR - 3	60	0.042	39.47	362	1.645	77.50	23.62	94.55	0.425	4.46	29.28	0.34
CR - 4	720	0.500	12.57	1382	6.279	29.13	8.88	35.54	0.160	1.87	12.24	0.14
CR - 5	240	0.167	30.57	1120	5.089	87.02	26.52	106.16	0.477	4.22	27.67	0.32
Cyclic - C1	60	0.042	26.31	241	1.095	45.80	13.96	55.88	0.251	3.09	20.25	0.23
Cyclic - C2	60	0.042	24.09	221	1.004	40.80	12.44	49.78	0.224	2.85	18.72	0.22
Cyclic - C3	60	0.042	24.09	221	1.004	39.05	11.90	47.64	0.214	2.89	18.96	0.29
									Geomean:	2.87	18.80	0.23

Table 4.12: Conservative yield based on casing storage from drawdown data for the East Dartmouth Well. Gallons per minute are given in imperial units.

Pump Test	Length of Test (hours)	Test Q (m^3/d)	Total Pumped (m^3)	Recovery (after 1 hr) (ft)	Recovery (after 1 hr) (m)	% Recovery of drawdown (in 1 hr)	Conservative Yield		
							Q (gpm)	Q (m^3/d)	Q (L/s)
CR - 1	1	24.22	1.009	36.75	11.20	85	0.75	4.89	0.06
CR - 2	6	12.44	3.112	18.50	5.64	68	0.38	2.46	0.03
CR - 3	1	39.47	1.645	68.92	21.01	89	1.40	9.17	0.11
CR - 4	12	12.57	6.279	16.85	5.14	58	0.34	2.24	0.02
CR - 5	4	30.57	5.089	73.15	22.30	84	1.49	9.74	0.11
Cyclic - C1	1	26.31	1.095	39.60	12.07	86	0.81	5.27	0.06
Cyclic - C2	1	24.09	1.004	34.35	10.47	84	0.70	4.57	0.05
Cyclic - C3	1	24.09	1.004	36.58	11.15	94	0.74	4.87	0.06
						Geomean:	0.73	4.80	0.05

Table 4.13: Conservative yield based on casing storage from recovery data for the East Dartmouth well. Gallons per minute are given in imperial units.

only the 60 minute tests in Table 4.12 are considered, the range is 18.51 to 29.28 m^3/d (2.8 to 4.4 gpm). The lower end of this range is comparable to the short term yield calculated from analytical methods.

Conservative yields based on casing storage calculated from recovery data range from 2.46 to 9.74 m^3/d (0.4 to 1.5 gpm) (Table 4.13) and are most similar to the 20-year long term safe yields given in Table 4.11. The lower values calculated from recovery data in Table 4.13 reflects the length of time required for full recovery. According to Huntley (1992), full recovery takes up to four times longer than the drawdown period. The results from this study are in agreement with this statement.

4.2 Waverley Well

4.2.1 Step Drawdown Test Results

The results of the step drawdown test are shown in Figures 4.25 and 4.26 and in Tables 4.14 and 4.15. The Hantush-Bierschenk method was used to calculate the specific drawdowns (s/Q) for the Waverley well and are listed in Table 4.14. The specific drawdowns range from 0.06 to 1.03 m^2/d and were calculated using a time step of 30 minutes for the incremental drawdowns (Fig. 4.25). Specific drawdown in the well is low at low discharge rates and increases rapidly as the pumping rate increases (Fig. 4.26).

Step	Q (gpm)	Q (m^3/d)	Δs (m)	s (m)	s/Q ($m^3/d/m$)
1	1.08	7.07	0.40	0.40	0.06
2	2.15	14.07	1.50	1.90	0.14
3	3.32	21.73	13.50	15.40	0.71
4	4.38	28.67	14.00	29.40	1.03

Table 4.14: Summary of the drawdown (s) and specific drawdown (s/Q) calculated for each step interval in the step drawdown test conducted on the Waverley well. A plot of specific drawdown versus discharge rate is shown in Figure 4.26.

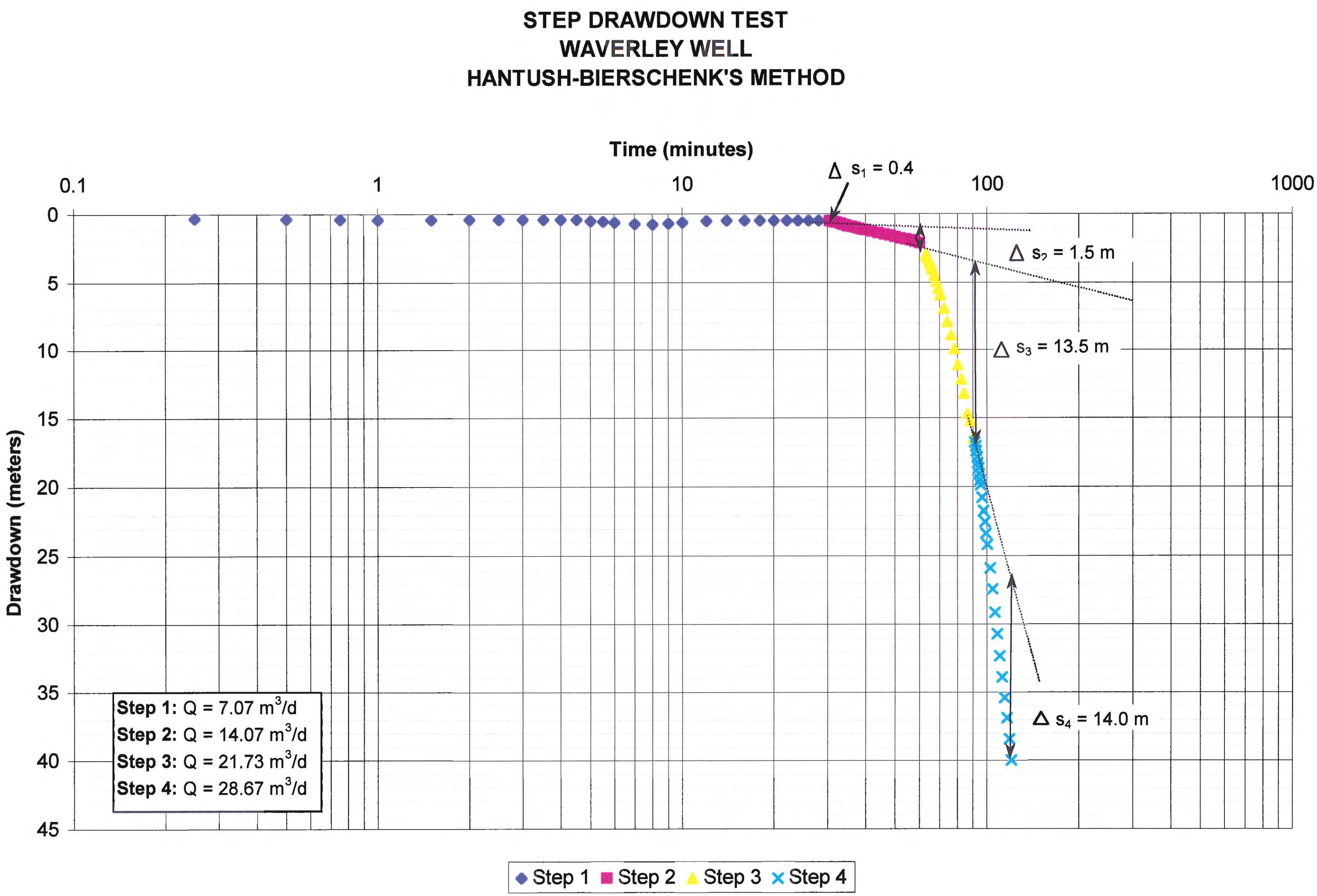


Figure 4.25: Drawdown curve for the step drawdown test conducted on the Waverley well. The incremental drawdown for each step is calculated using the Hantush-Bierschenk method.

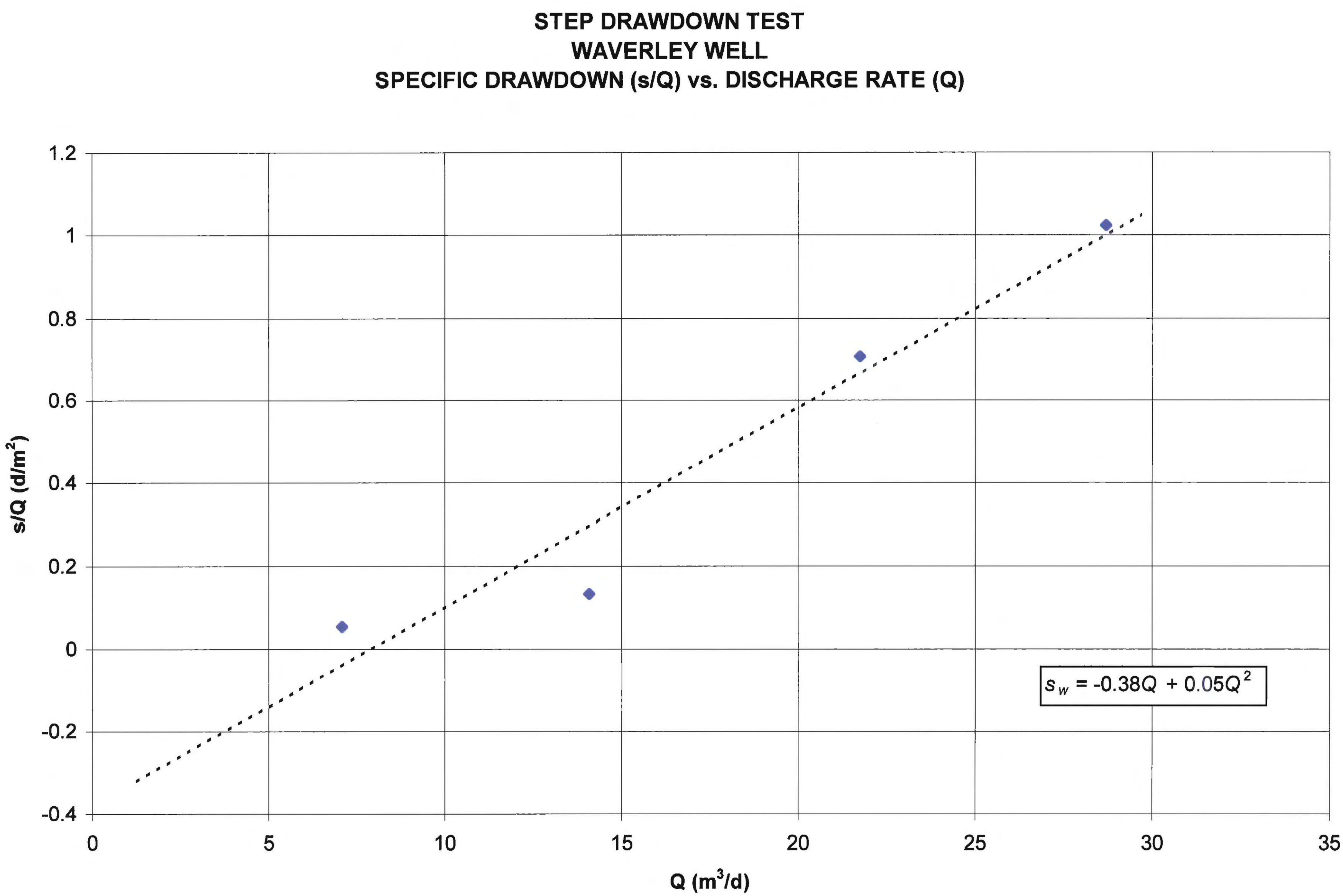


Figure 4.26: Plot of s/Q versus discharge rate (Q) for each interval of the step drawdown test. The y-intercept gives B= - 0.38 d/m^2. The slope of the line gives the value of C=0.048d^2/m^5.

Analysis of the step drawdown data using Equation 3.1 shows that the drawdown in the pumping well is described by the equation

$$s_w = -0.38Q + 0.05Q^2$$

where

B = - 0.38 d/m^2
C = 0.05 d^2/m^5

Since the value of B cannot equal a negative number, it is assumed to equal zero, thus altering the equation for the drawdown in the pumping well to be

$$s_w = 0.05Q^2$$

where

B = 0 d/m^2
C = 0.05Q d^2/m^5

Table 4.15 summarizes the predicted drawdowns for different pumping rates, using the two constant rate tests and the first cycle of the cyclic test (MR-1, MR-2 and C-1). The results show a large difference in the actual drawdown observed at 30 and 60 minutes compared to those predicted by the drawdown equation (a percent difference between 15-50 for actual drawdown values at 30 minutes and a percent difference between 35-45 for actual drawdown values at 60 minutes) (Table 4.15). Since the predicted drawdown does not reflect the actual drawdown observed in the well, the results are not consistent with the theory.

Pump Test	Q (m^2/d)	BQ	CQ^2	s (predicted) m	s (actual-30 min) m	s (actual-60 min) m	% diff (30)	% diff (60)
MR - 1	24.87	0	30.92	30.92	24.37	47.34	21	35
MR - 2	8.18	0	3.34	3.34	1.58	1.81	53	46
Cyclic - C1	16.365	0	13.39	13.39	11.43	20.20	15	34

Table 4.15: Summary of the predicted and actual drawdown results calculated using the discharge rates (Q) of the two constant discharge tests and the first cycle of the cyclic test preformed on the Waverley well. The drawdown equation used in the calculations is $s_w = 0.05Q^2$.

The reconstructed step drawdown data are shown in Figure 4.27. Table 4.16 lists the transmissivity value and yields obtained from the reconstructed data. The calculated aquifer properties will be discussed in more detail in Section 4.2.6.

Pump Test	T_{dd} (m^2/d)	Q_{20} (m^3/d)	Q_{1hr} (m^3/d)	Q_{30min} (m^3/d)
Step Test	0.40	3.33	13.72	15.55

Table 4.16: Summary of the aquifer properties calculated for the Waverley well using reconstructed step drawdown test data. Q_{30min}, Q_{1hr} and Q_{20} are the estimated yields for 30 minutes, one hour and 20 years determined using reconstructed step drawdown test data.

4.2.2 Constant Discharge Test Results

Two constant discharge tests of differing discharge rate and duration were performed on the Waverley well. Table 4.17 summarizes the test parameters and gives the abbreviated names for the two pump tests. All constant discharge data for the Waverley well were plotted on logarithmic and semi-logarithmic graphs. The results will be discussed in the following sections.

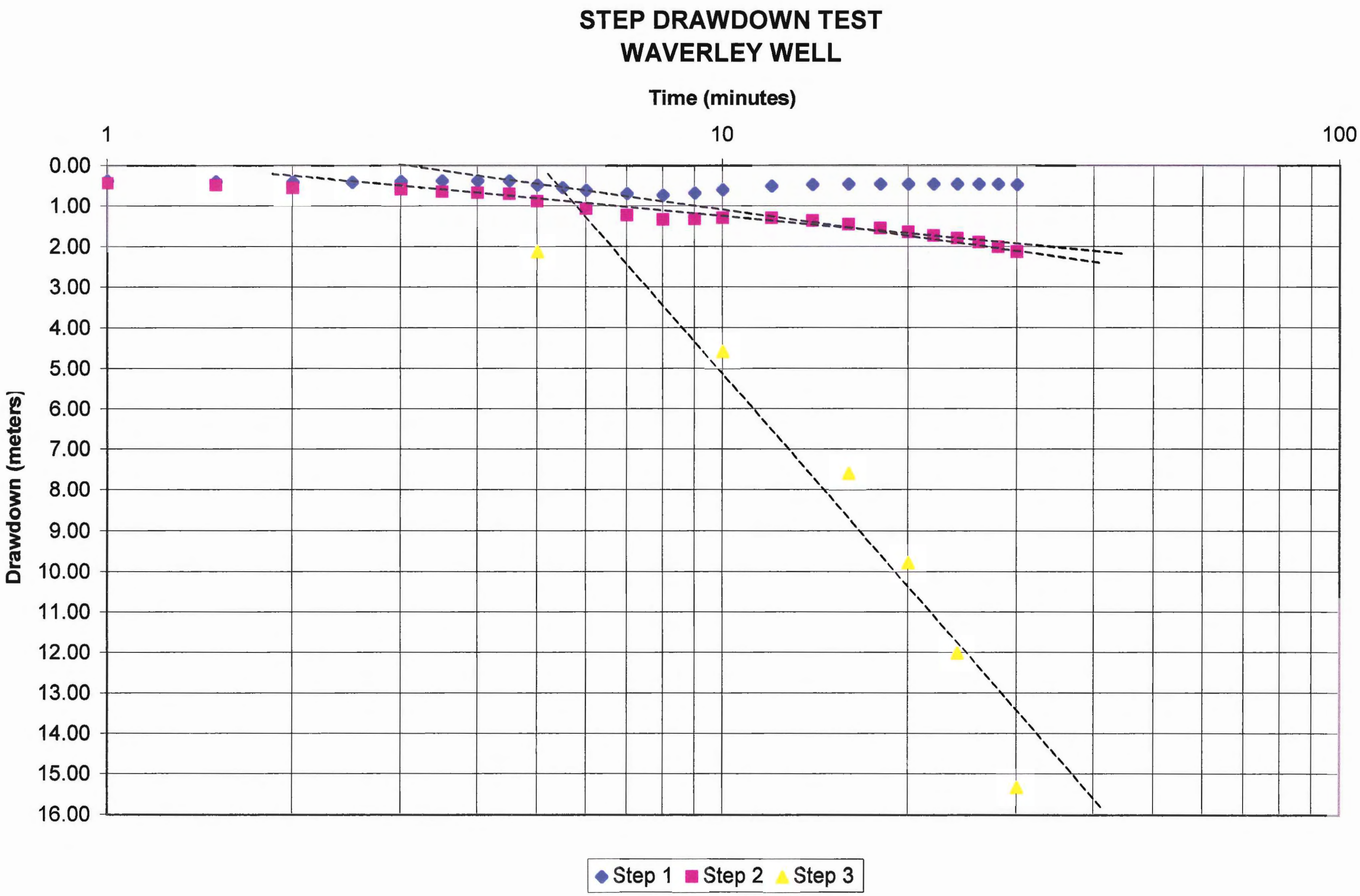


Figure 4.27: Reconstructed step drawdown data.

Pump Test	Length of Test (min)	Length of Test (days)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (gallons)	Total Pumped (m^3)	Total Pumped (litres)	Total Drawdown (ft)	Total Drawdown (m)
MR - 1	60	0.04	3.80	24.87	0.29	225.0	1.02	1022.0	155.32	47.34
MR - 2	360	0.25	1.25	8.18	0.09	450.0	2.04	2045.0	12.86	3.92

Table 4.17: Summary of the constant discharge test parameters for the Waverley well. Discharge rate (Q) is given in imperial gallons per minute (gpm), m^3/day and litres per second (L/s).

4.2.2.1 Derivative Method

The results of the derivative method for constant discharge tests MR-1 and MR-2 for the Waverly well are shown in Figures 4.28 and 4.29. The continuous increase in the derivative of the drawdown with time for constant discharge test MR-1 suggests the presence of non-radial flow to the well throughout the test (Fig. 4.28). This result is most likely due to dewatering of the major water producing fracture, promoting non-radial flow, and to the effects of well-bore storage.

Figure 4.29 shows a gradual increase in the derivative curve from three minutes to approximately six minutes, possibly reflecting non-radial flow to the well or the result of noisy data. From six minutes to 60 minutes, the derivative appears to level out (shows an average level but it is very noisy data), reflecting the presence of a radial flow regime. At late pumping times ($t > 60$ minutes), a possible recharge boundary is encountered, indicated by a decrease in the derivative. A rapid increase in the derivative prior to the encountered boundary suggests a second period of non-radial flow (Fig. 4.29).

The inconsistencies in the response of the derivative for the two constant discharge tests for the Waverley well are the result of the difference in discharge rates. Test MR-1 was pumped at a high discharge rate (24.87 m^3/d) for a short duration (one hour), rapidly dewatering the major producing fracture located shallow depth, resulting in non-radial flow regimes. In contrast, test MR-2 was pumped at a low discharge rate (8.18 m^3/d) for an extended time period (six hours), the total drawdown (3.92 m) not exceeding the well casing (6.09 m) and thus not dewatering the major water bearing fracture.

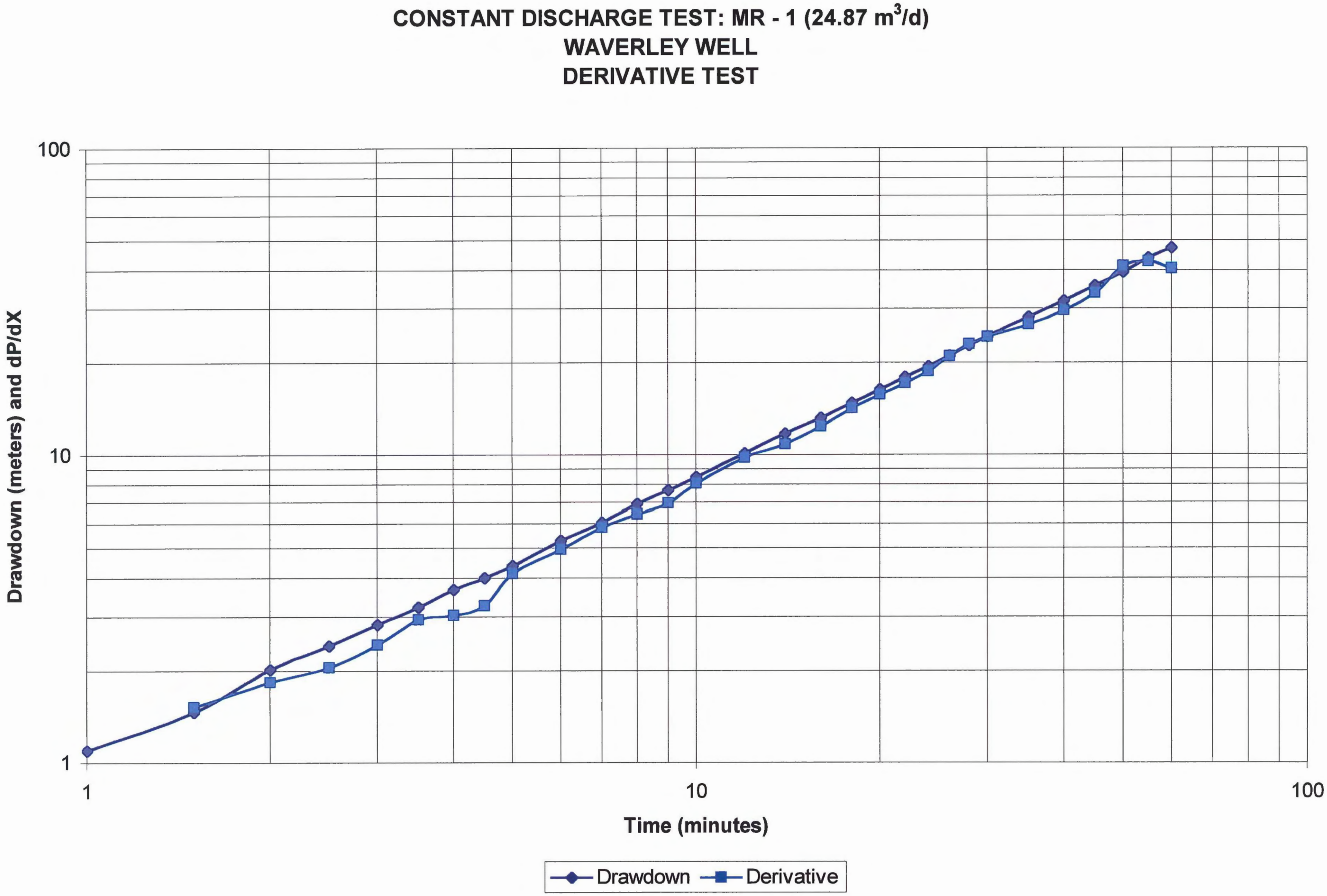


Figure 4.28: The first derivative of the drawdown plotted against the logarithm of time for test MR-1

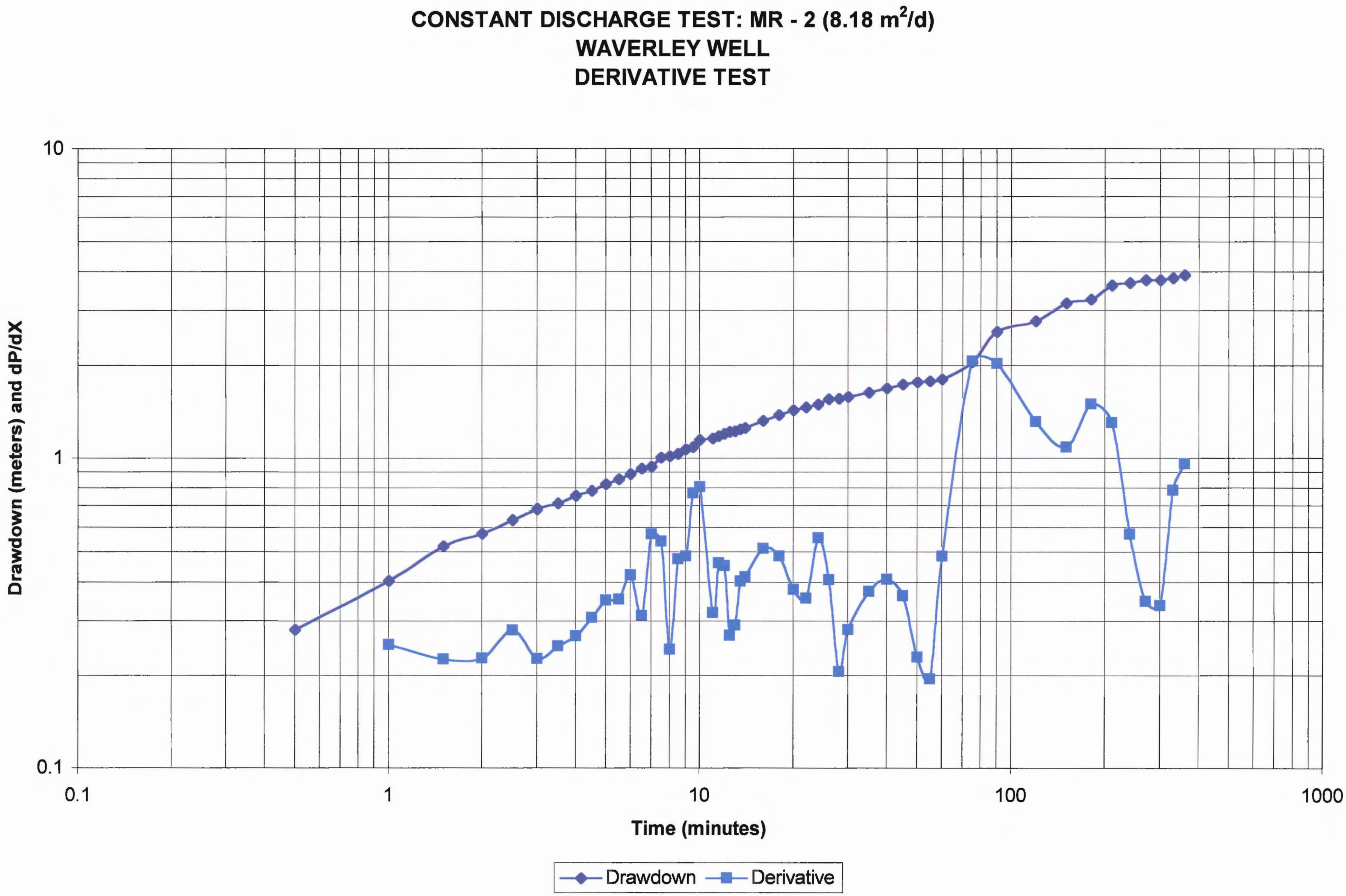


Figure 4.29: The first derivative of the drawdown plotted against the logarithm of time for test MR-2.

4.2.2.2 Theis Method

The CMHC constant discharge test MR-1 does not conform to the Theis model for radial flow and plots as a straight line of unit slope on a log-log plot of drawdown versus time (i.e. a 45 degree angle) (Fig. 4.30). This results in a drawdown curve that is less steep in relation to Theis and is the product of water removed from the well-bore (well-bore storage) as opposed to being removed from the aquifer. Since the Theis method assumes the pumping well has an infinitesimally small diameter (i.e. the storage in the well can be neglected) and is 100-percent efficient, the Theis method cannot be applied to the results of this test.

A logarithmic graph of the drawdown data for constant discharge test MR-2 is displayed with the Theis curve fit and match point in Figure 4.31. Test MR-2 shows less deviation from the Theis curve, resulting in a better fit. Test MR-2 was pumped at a much lower discharge rate than test MR-1 (8.18 m^3/d as opposed to 24.87 m^3/d) and experienced less total drawdown in the well. The total drawdown at the completion of test MR-2 (3.9 m) did not exceed the base of the casing (6.1 m) and therefore did not dewater the major water producing fracture in the well. This suggests that the water was derived from the aquifer, not solely from the well casing, allowing the Theis method to be applied to that portion of the test in which radial flow occurs. Early time drawdown data ($t < 5$ minutes) for the constant discharge test MR-2 plots on a straight line with a slope of one resulting in an apparent departure from the Theis curve, reflecting well-bore storage effects. At late time ($t > 80$ minutes), a possible barrier boundary is encountered as evidenced by the increase of the drawdown data with respect to the Theis curve (Fig.

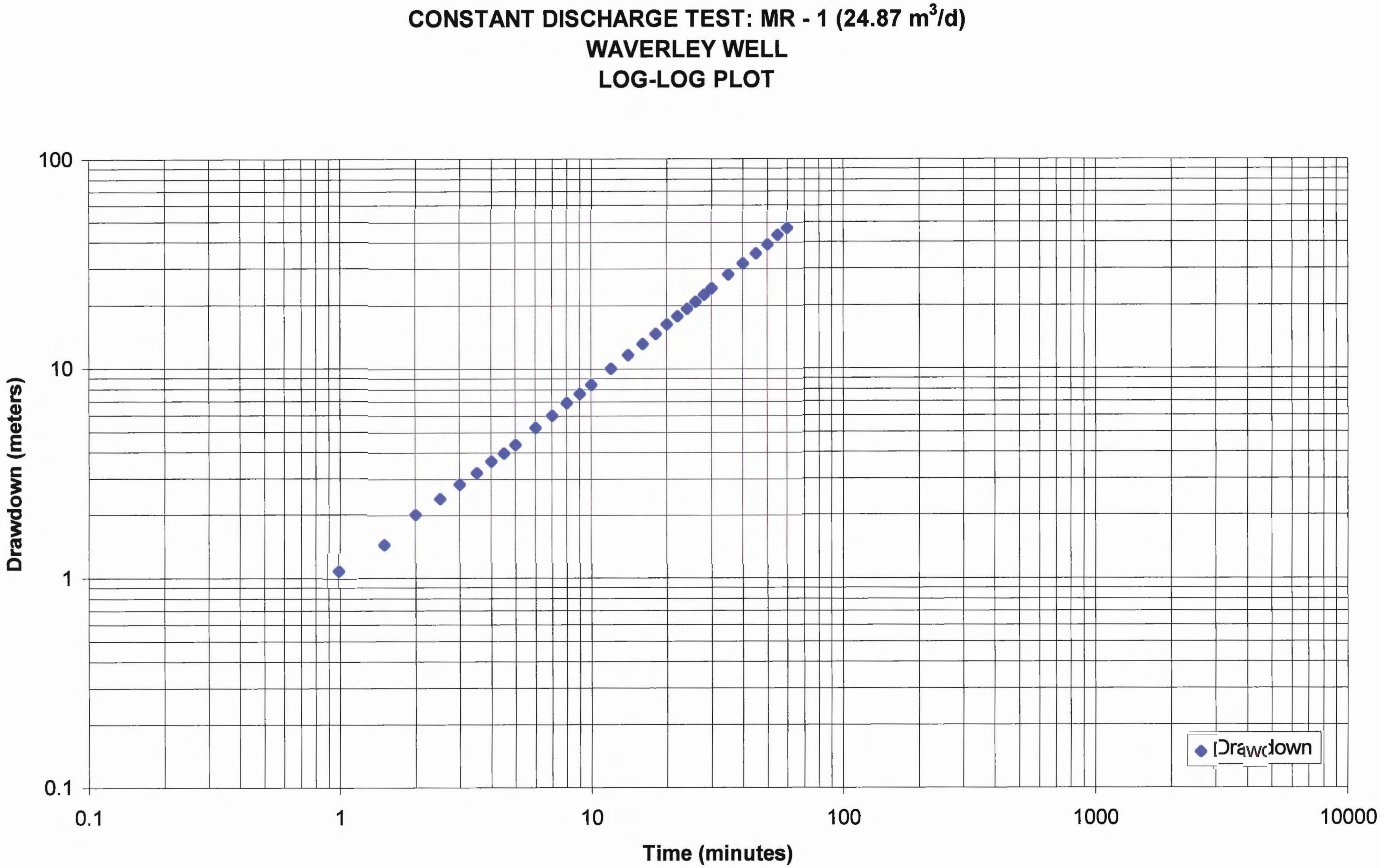


Figure 4.30: Logarithmic graph of the drawdown data for test MR-1

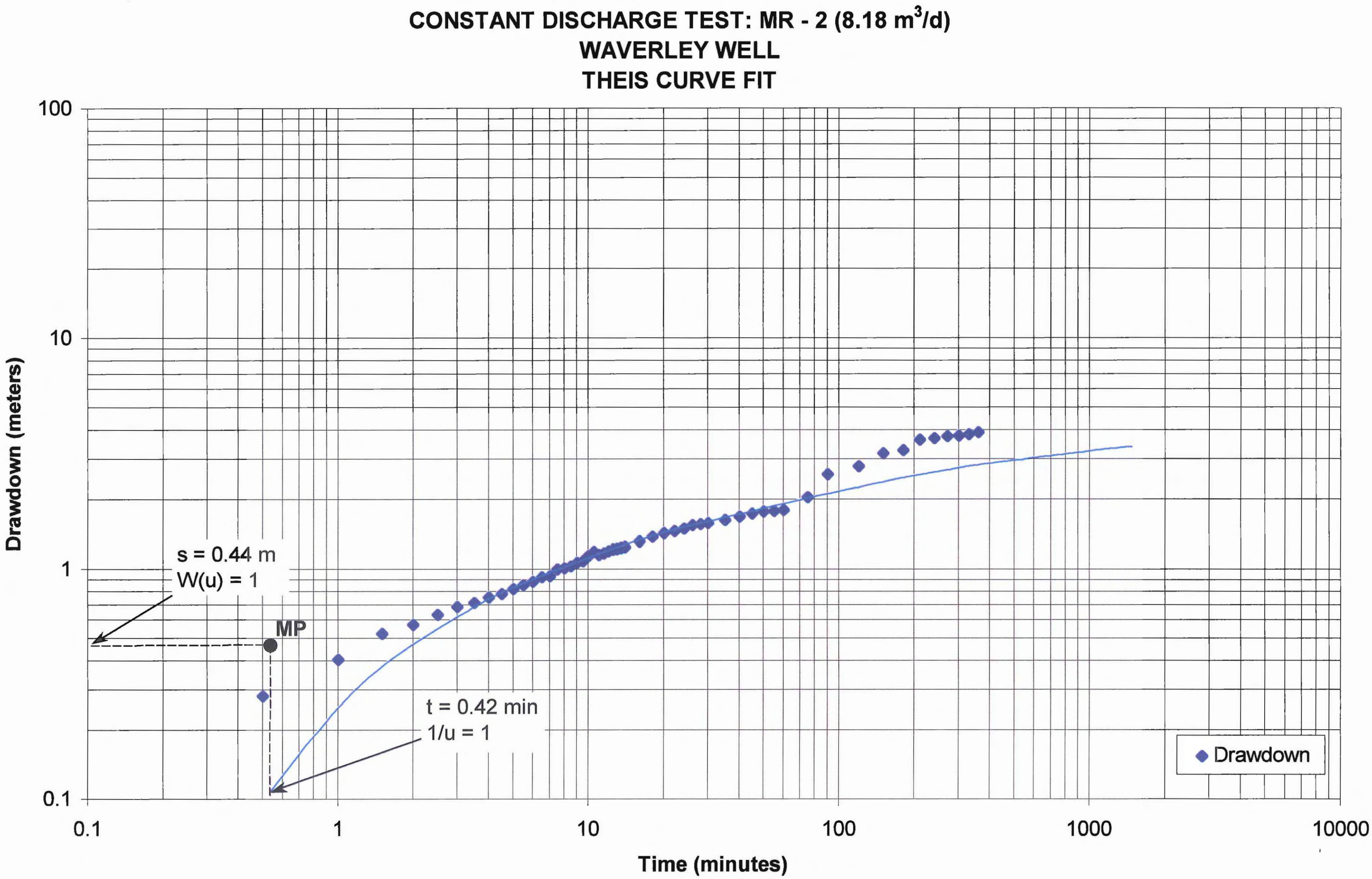


Figure 4.31: Logarithmic graph of the drawdown data showing the Theis curve fit and match point for test MR-2

4.31). Both storage effects and barrier conditions promote non-radial flow to the well, and are not valid conditions for the application of the Theis method. The time interval corresponding to radial flow in the well as determined by the derivative method was used for the Theis curve fit in test MR-2.

Table 4.18 lists the aquifer properties calculated using the Theis method of analysis. The calculated aquifer transmissivity is 1.23 m^2/d using the Theis method. A comparison of the value obtained from this method and the other methods employed in this study is provided in Section 4.2.6.

Pump Test	Length of Test (hours)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (L)	T_{dd} (m^2/d)	Q_{20} (m^3/d)	Q_{1hr} (m^3/d)	Q_{30min} (m^3/d)
MR – 1	1	3.80	24.87	0.29	1022.3	X	X	X	X
MR – 2	6	1.25	8.18	0.09	2044.7	1.23	10.23	42.11	47.72

Table 4.18: Summary of the aquifer properties calculated using Theis method of analysis for the Waverley well. Discharge rate (Q) is given in imperial gallons per minute (gpm), m^3/day and litres per second (L/s). T_{dd} are the transmissivity values calculated using drawdown data. Q_{30min}, Q_{1hr} and Q_{20} are the estimated yields for 30 minutes, one hour and 20 years. This method could not be applied to the one-hour test which is denoted by an **X**.

4.2.2.3 Jacob Method

Semilogarithmic plots of drawdown (s) and residual drawdown (s') data for the constant discharge tests MR-1 and MR-2 are given in Figures 4.32 and 4.33. The plot for CMHC test MR-1 shows a distinct curvature instead of the straight lines expected if the flow is radial (Fig. 4.32). The Jacob straight-line fit shown in Figure 4.32 for test MR-1 is not a justifiable fit. However, this is what is often incorrectly done in practice in analyzing short term CMHC tests, so an attempt at analyzing the data was made using this method. Since the Theis model was not applicable for the CMHC test (MR-1), the Jacob model is not technically valid either, since it is derived directly from Theis.

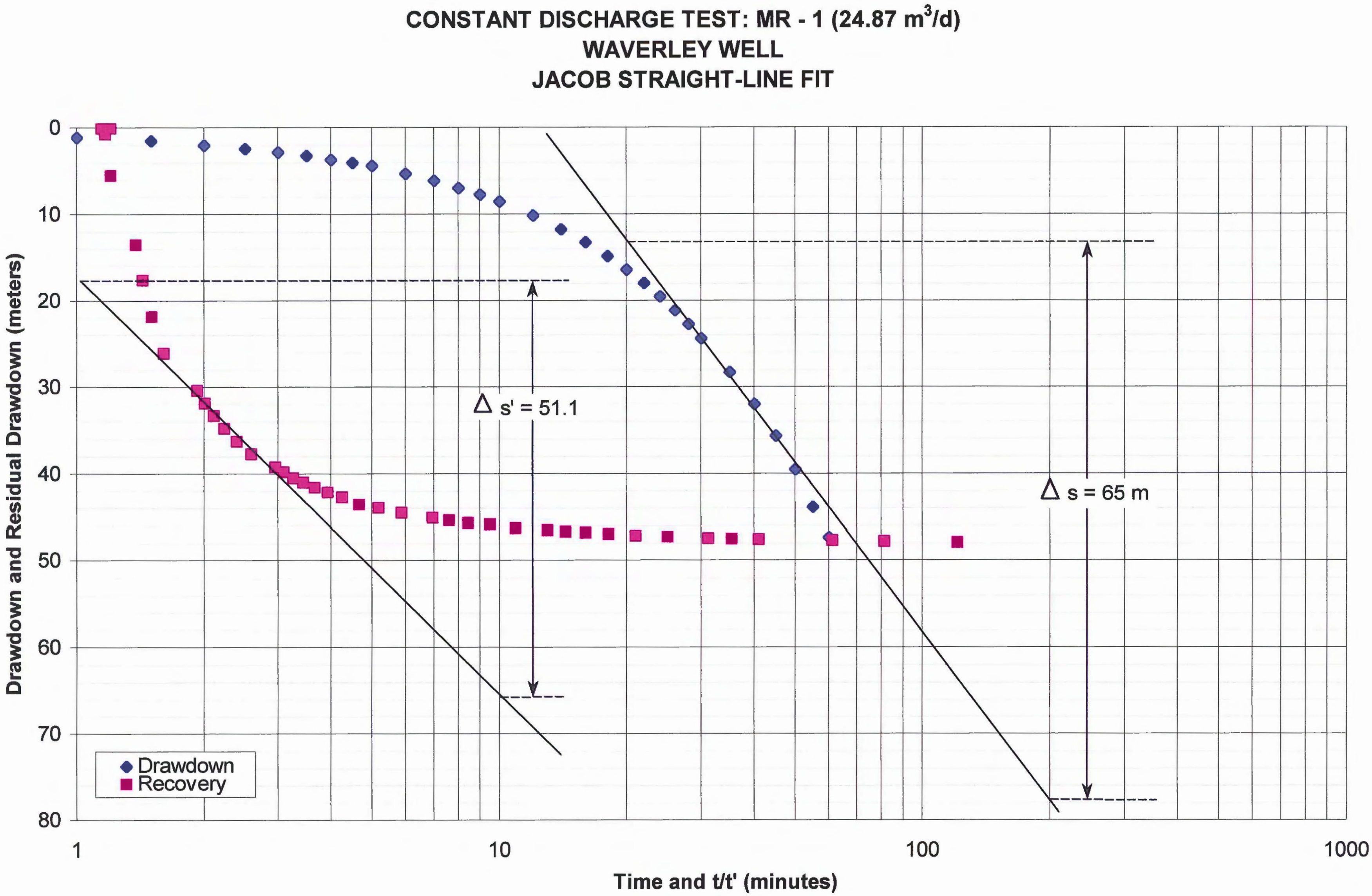


Figure 4.32: Semi-logarithmic graphs of the drawdown and recovery data with the Jacob straight-line best fit for test MR-1.

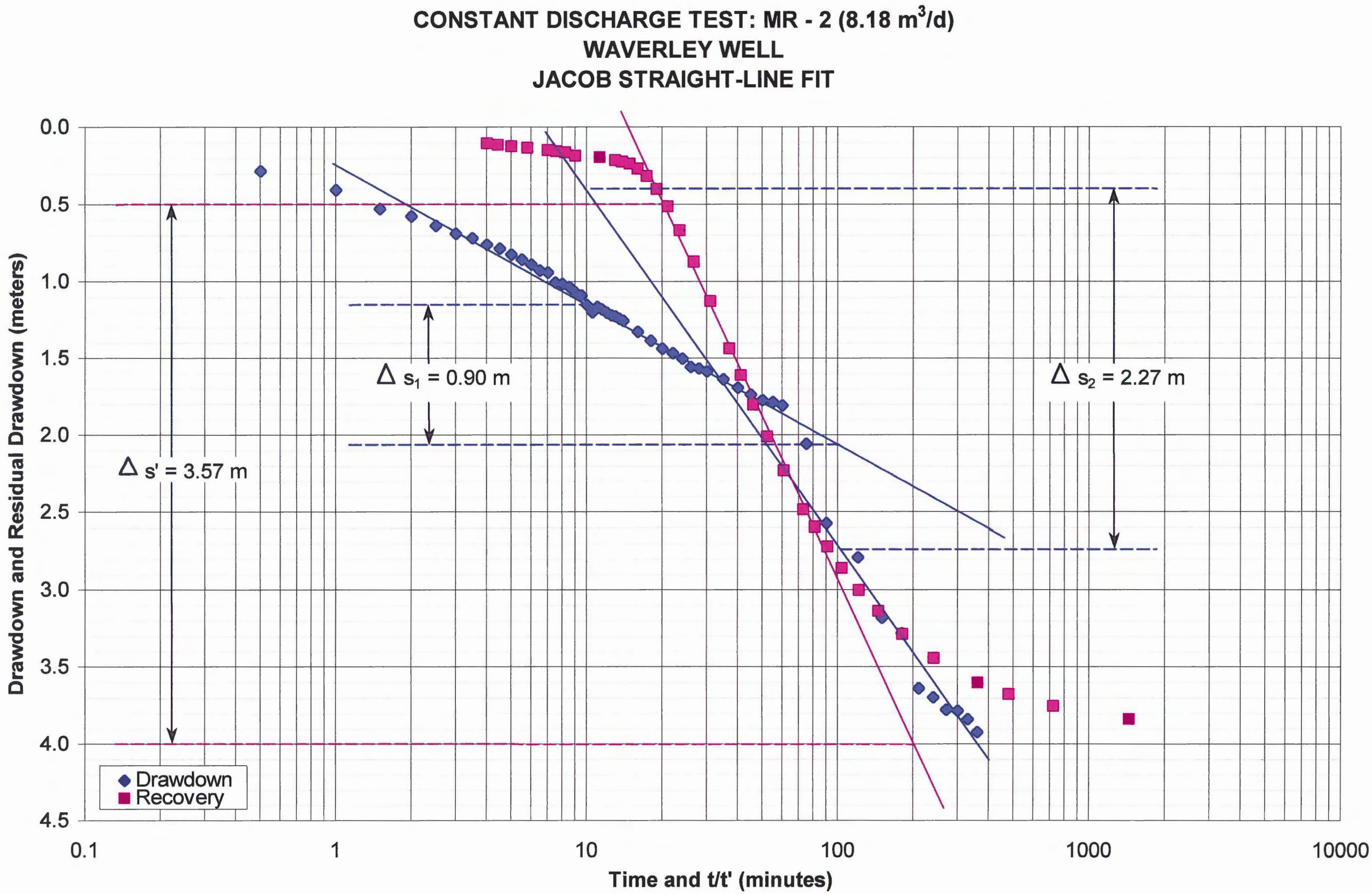


Figure 4.33: Semi-logarithmic graphs of the drawdown and recovery data with the Jacob straight-line best fit for test MR-2

The drawdown data for the constant discharge test MR-2 falls on two distinct slopes when plotted on a semi-log graph (Fig. 4.33). The first slope corresponds to radial flow to the well and may represent the transmissivity of the aquifer; once a barrier (no-flow) boundary is encountered at approximately 60 minutes, the slope steepens dramatically. In practical terms, Driscoll (1986) suggests that the transmissivity of the aquifer near the well in such cases is probably in between. The initial steepening of the field data curve (forming the second slope) corresponds to the intense fluctuations displayed by the derivative curve in Figure 4.29. The boundary effect is due to fracture dewatering, or limited aquifer effect.

The recovery curve for the CMHC test MR-1 is a mirror image of the drawdown data and represents limited aquifer and casing storage effects (Fig. 4.32). The best fit line has no real justification. The recovery data for constant discharge test MR-2 exhibits a distinct "S" curve in a semi-log plot (Fig 4.33), and has a straight line segment.

Table 4.19 lists the transmissivity values calculated using the Jacob method of analysis for the Waverley well. The geometric mean of the transmissivity values calculated using the drawdown and recovery data for both constant discharge tests (MR-1 and MR-2) is 0.18 m^2/d. However, the best estimate of transmissivity is most likely 0.42 m^2/d, calculated using the recovery data for test MR-2. This is because the placement of the best fit straight-lines for the other calculations are not justifiable, and therefore do not give representative values of the aquifer transmissivity. The aquifer properties calculated using the Jacob method are discussed in more detail in Section 4.2.6.

Pump Test	Length of Test (hours)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (L)	T_{dd} (m^2/d)	T_{rec} (m^2/d)	T_{gm} (m^2/d)	Q_{20} (m^3/d)	Q_{1hr} (m^3/d)	Q_{30min} (m^3/d)
MR - 1	1	3.80	24.87	0.29	1022.3	0.06	0.07	0.06	0.53	2.18	2.47
MR - 2	6	1.25	8.18	0.09	2044.7	0.66	0.42	0.53	4.41	18.17	20.60
					Geomean:	0.20	0.18	0.18	1.53	6.29	7.13

Table 4.19: Summary of the aquifer properties calculated using Jacob method of analysis for the Waverley well. Discharge rate (Q) is given in imperial gallons per minute (gpm), m^3/day and litres per second (L/s). T_{dd}, T_{rec} and T_{gm} are the transmissivity values calculated using drawdown data, recovery data and the geometric mean of the drawdown and recovery T values. Q_{30min}, Q_{1hr} and Q_{20} are the estimated yields for 30 minutes, one hour and 20 years.

NOTE: MR-1 data are only calculated to show the incorrect use of the Jacob Method. The MR-2 recovery data is considered the best estimate using this method.

4.2.2.4 Gringarten et al. Method

The logarithmic graph of the drawdown data shown with the Gringarten et al. curve fit and match point for the constant discharge test MR-2 is shown in Figure 4.34. The CMHC test MR-1 did not conform to Gringarten et al.'s model for flow in a vertical fracture. The drawdown data for the CMHC test MR-1 exhibits a slope of one on a log-log plot (Fig. 4.30), the product of well-bore storage, and is indicative of a large storage volume connected with the well, i.e. the water producing fracture is a fracture of large dimensions rather than a plane fracture that is assumed for the method and storage in the fracture cannot be neglected. Gringarten et al's method is not applicable under these conditions.

Constant discharge test MR-2 contains early time drawdown data that fall on a straight line with a slope of 0.5, which is characteristic of a well that pumps a single plane vertical fracture in a confined, homogeneous, and isotropic aquifer of low permeability (Kruseman and de Ridder, 1990). The field curve for test MR-2 (Fig. 4.34) steepens at late pumping times ($t > 60$ minutes), deviating upward from the theoretical curve of Gringarten et al., and suggests that the cone of depression encountered a barrier (no-flow) boundary. However, it is also possible that the increased drawdown in the well could be reflecting a slight increase in the pumping rate.

Table 4.20 shows that transmissivity calculated using Gringarten et al.'s method is 1.17 m^2/d. This value is discussed in greater detail in Section 4.2.6 and compared with transmissivity values obtained using the other methods of analysis outlined in this study.

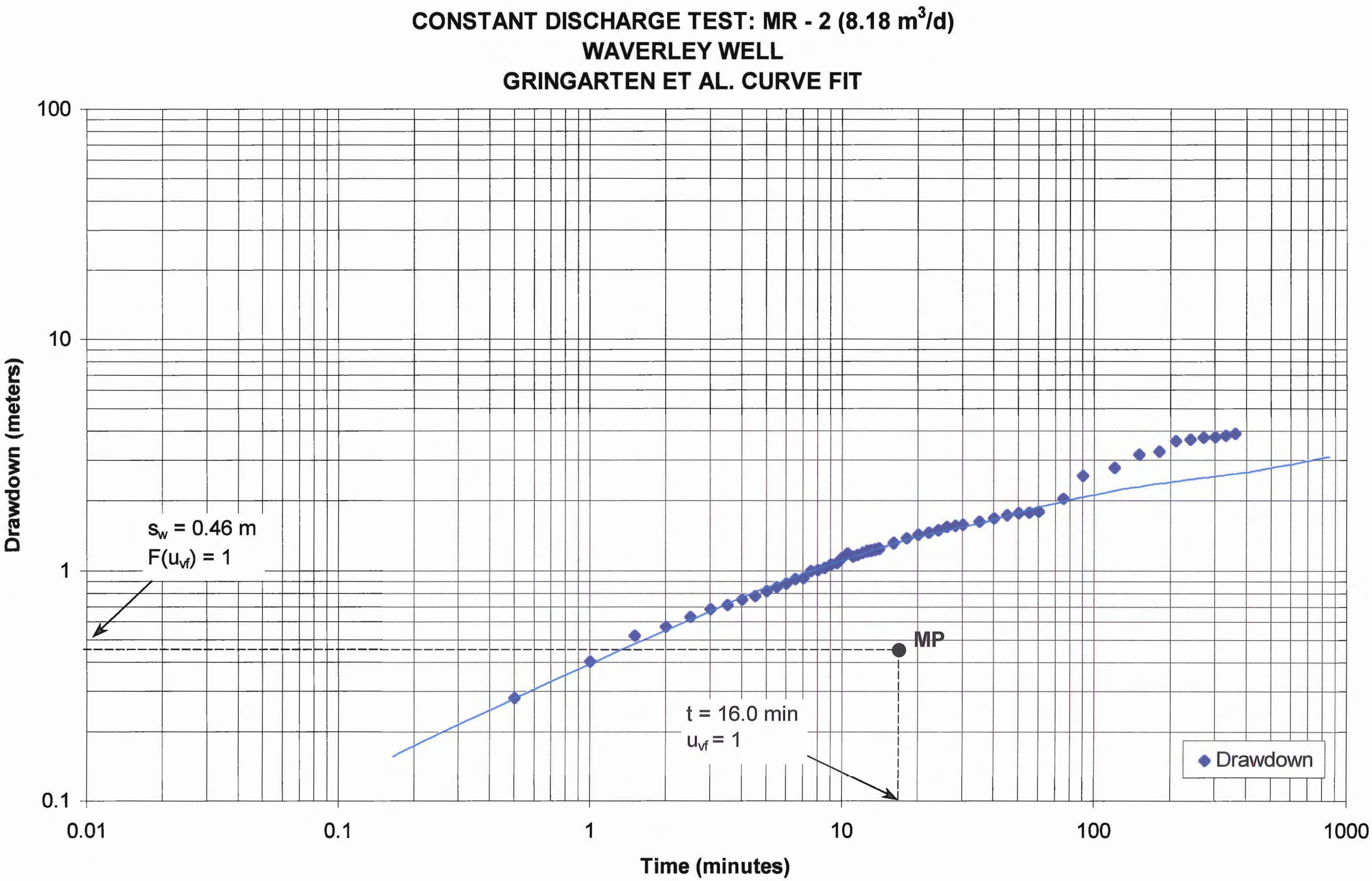


Figure 4.34: Logarithmic graph of the drawdown data with the Gringarten et al. curve fit for test MR-2.

Pump Test	Length of Test (hours)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (L)	T_{dd} (m^2/d)	Q_{20} (m^3/d)	Q_{1hr} (m^3/d)	Q_{30min} (m^3/d)
MR - 1	1	3.80	24.87	0.29	1022.3	X	X	X	X
MR - 2	6	1.25	8.18	0.09	2044.7	1.17	9.78	40.28	45.65

Table 4.20: Summary of the aquifer properties calculated using Gringarten et al.'s method for vertical fracture flow for the Waverley well. Discharge rate (Q) is given in imperial gallons per minute (gpm), m^3/day and litres per second (L/s). T_{dd} are the transmissivity values calculated using drawdown data. Q_{30min}, Q_{1hr} and Q_{20} are the estimated yields for 30 minutes, one hour and 20 years. This method could not be applied to the one-hour CMHC test (MR-1), which is denoted by an **X**.

4.2.3 Cyclic Test Results

The drawdown and recovery curves for the cyclic test performed on the Waverley well are shown in Figure 4.35. The curves show a slight increase in the total drawdown at the conclusion of each cycle, resulting in a net loss over the entire period of the test. The total drawdown increases from 20.19 m in cycle 1 to 20.71 m in cycle 2 and finally 22.36 m in cycle 3, at a discharge rate of 16.36 m^3/d for each cycle. The main water bearing fracture (located just below the casing) for the Waverley well was dewatered during each drawdown cycle since the total drawdown of each pumping cycle (20.19 m, 20.71 m and 22.36 m respectively) exceeded the bottom of the casing (6.10 m). The increase in drawdown would become more pronounced with increased discharge rates, suggesting that the Waverley well would not be able to maintain the CMHC standard for repeated pumping cycles without exceeding the total available drawdown (15.24 m) in the well. The curves show complete recovery between each drawdown cycle; however, the well still experiences an overall net loss in available water.

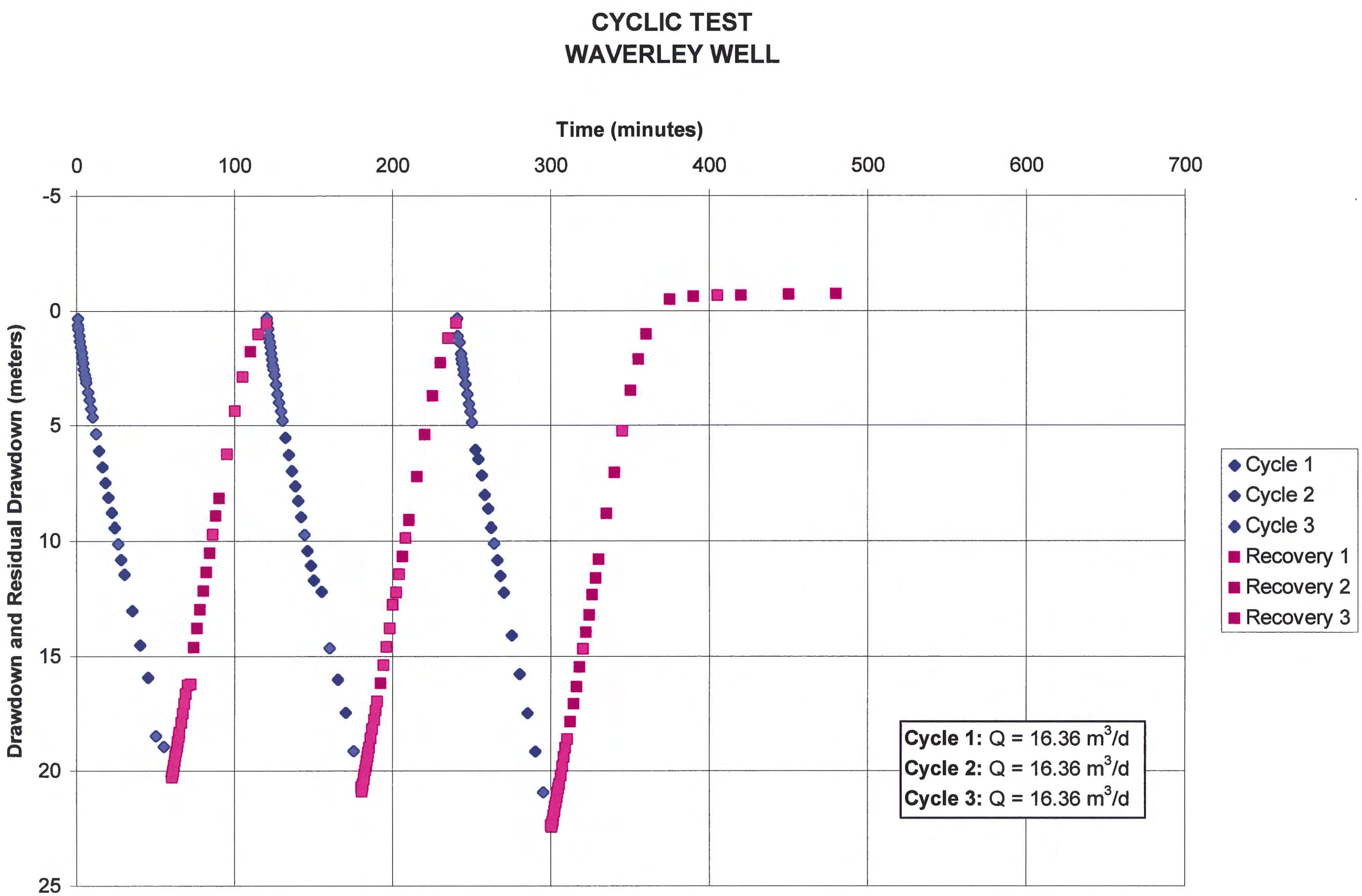


Figure 4.35: The drawdown and recovery curves for the cyclic test performed on the Waverley well.

4.2.4 Slug Test Results

The data plots from two falling head slug tests performed on the Waverley well are shown in Figures 4.36 and 4.37. The horizontal hydraulic conductivity (K_h) was calculated using the Hvorslev basic time lag method with G-type configuration (Equation 3.27 in Section 3.2.5).

The calculated aquifer transmissivity for slug test 1 is 17.25 m^2/d, and 17.35 m^2/d for slug test 2, as shown in Table 4.21. The transmissivity values obtained by the two slug tests will be discussed further in Section 4.2.6.

Pump Test	K_h (m/d)	b = open zone of well (m)	T (m^2/d)	Q_{20} (m^3/d)	Q_{1hr} (m^3/d)	Q_{30min} (m^3/d)
Slug Test 1	0.3145	54.86	17.25	143.68	591.63	670.52
Slug Test 2	0.3162	54.86	17.35	144.47	594.88	674.20
		Geomean:	17.30	144.08	593.26	672.36

Table 4.21: Summary of the aquifer properties calculated for the Waverley well using the Hvorslev method for slug test analysis. K_h is the horizontal hydraulic conductivity of the aquifer calculated using the Basic Time Lag equation. The value of the open zone of the well was used to calculate the transmissivity from the equation T=Kb. Q_{30min}, Q_{1hr} and Q_{20} are the estimated yields for 30 minutes, one hour and 20 years.

4.2.5 Specific Capacity

Specific capacities were calculated for each constant discharge test (MR-1 and MR-2) and the first cycle of the cyclic test (C1). The amount of drawdown in the well after one hour of pumping was used for the calculation since this is the duration of the shortest pump test conducted.

The specific capacities calculated for the Waverley well are shown in Table 4.22, and range from 0.53 to 0.81 $m^3/d/m$. The results indicate a very low yielding well. The constant discharge test MR-2 shows the highest specific capacity and thus gives the

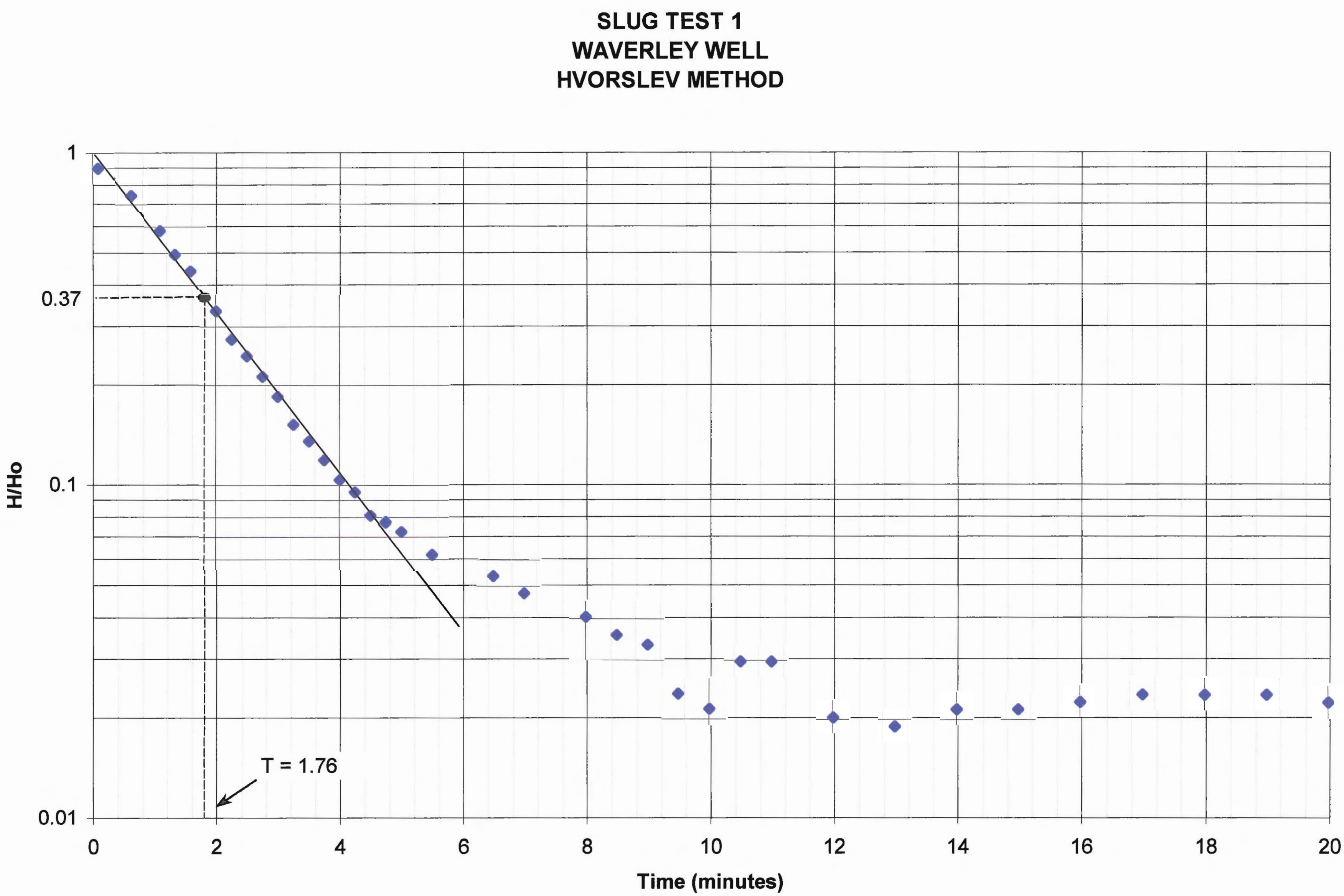


Figure 4.36: The semilogarithmic plot of H/Ho versus time for the falling head slug test 1 conducted on the Waverley well.

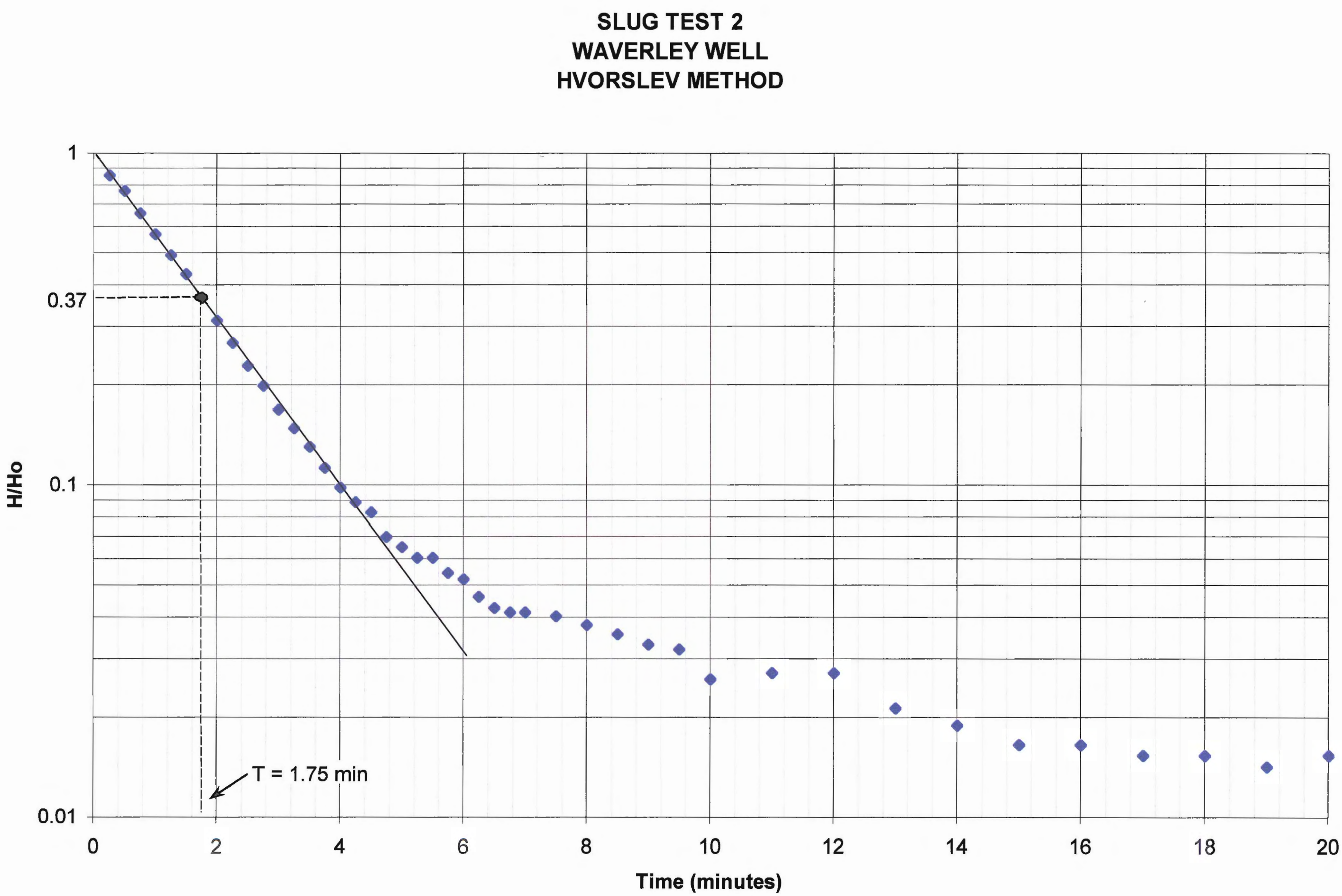


Figure 4.37: The semilogarithmic plot of H/Ho versus time for the falling head slug test 2 conducted on the Waverley well.

greatest yield. The short term (CMHC) and cyclic tests performed at higher discharge rates, give lower specific capacities, therefore suggesting lower well yields. Figure 4.38 shows the relationship between specific capacity and discharge rate for the Waverley well. As the discharge rate is increased, the specific capacity of the well rapidly decreases. This occurs because there is a greater drawdown in the well at higher discharge rates. The pronounced increase in drawdown with increased discharge rate is mainly the result of fracture dewatering within the well.

Pump Test	Length of Test (hours)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (L)	s (after 1 hr) (m)	s (at end of pumping period) (m)	Q/s (after 1 hr) ($m^3/d/m$)
MR - 1	1	3.80	24.87	0.29	1022.3	47.341	47.341	0.53
MR - 2	6	1.25	8.18	0.09	2044.7	1.805	3.010	4.53
Cyclic - C1	1	2.50	16.365	0.19	681.5	20.198	20.198	0.81

Table 4.22: Specific capacities calculated using the amount of drawdown after one hour during the first of the cyclic test and the constant discharge tests conducted on the Waverley well.

Estimates of transmissivity from specific capacity data using Equation 3.34 range from 0.06 to 0.71 m^2/d (Table 4.23). According to Huntley et al., 1992, the actual transmissivity could be four times or one-quarter the estimated value. The estimated values of transmissivity based on the specific capacity of the well are compared with the actual aquifer transmissivities obtained from the other methods analyzed in this study in Section 4.2.6.

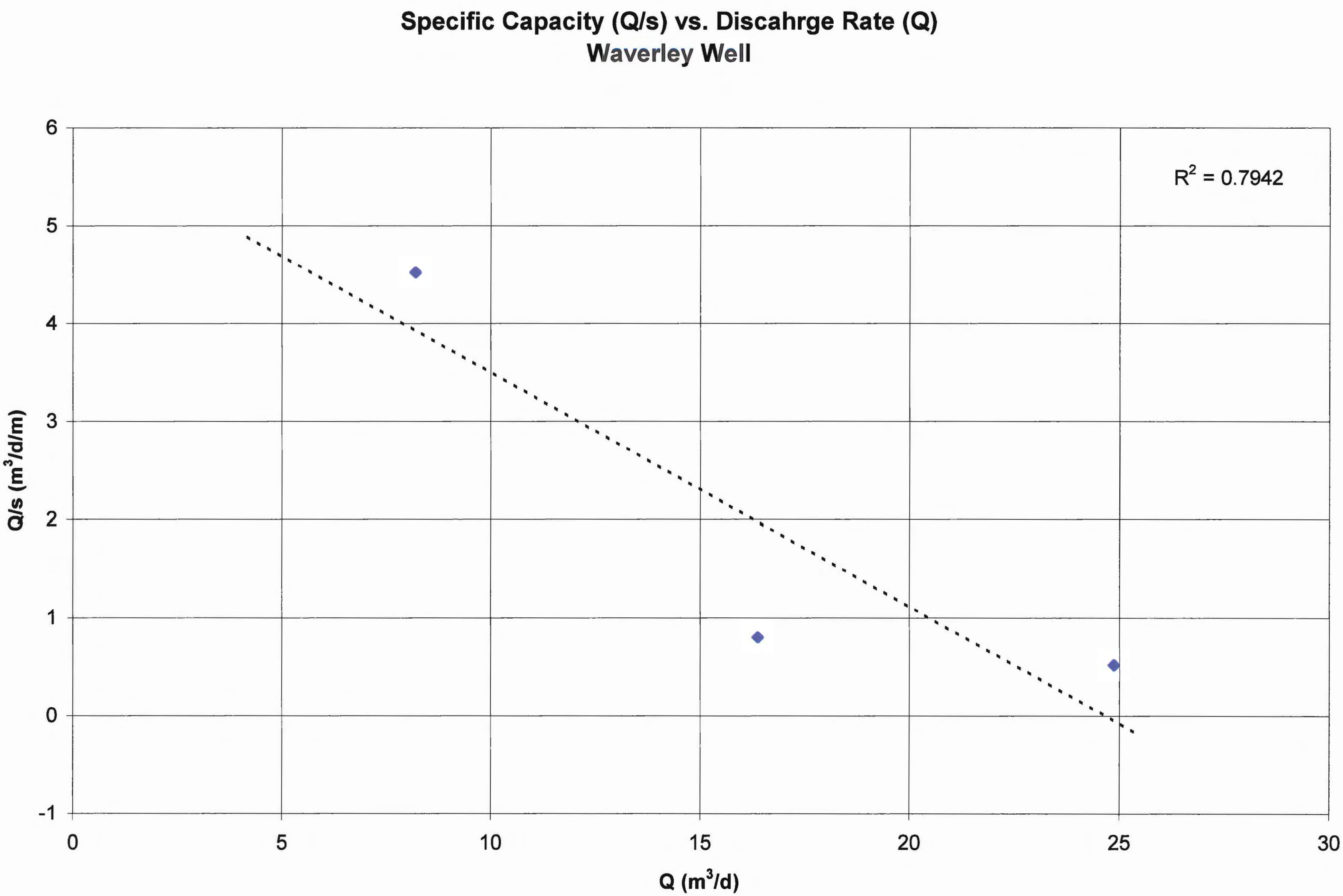


Figure 4.38: Specific capacity (Q/s) versus discharge rate (Q) for the Waverley well.

Pump Test	Length of Test (hours)	Q (gpm)	Q (m^3/d)	Q (L/s)	Total Pumped (L)	Q/s (after 1 hr) (m^3/d/m)	$T= K(Q/s)^{1.18}$
MR - 1	1	3.80	24.87	0.29	1022.3	0.53	0.06
MR - 2	6	1.25	8.18	0.09	2044.7	4.53	0.71
Cyclic - C1	1	2.50	16.365	0.19	681.5	0.81	0.09
						Geomean:	0.16

Table 4.23: Summary of the estimated transmissivity values based on specific capacity data (Q/s) for the Waverley well. The estimated transmissivity is given in m^2/day. Discharge rate (Q) is given in imperial gallons per minute (gpm), m^3/day and litres per second (L/s).

4.2.6 Comparison of Calculated Transmissivities

Table 4.24 summarizes the T values calculated in the previous sections by the analytical methods applied in this study. An available drawdown of 15.2 m (50 ft) was assumed for the Waverley well to calculate long and short term safe yields.

- Theis versus Jacob

The transmissivities (T) calculated using the Theis and Jacob methods show very different results for the Waverley well. Comparing the T estimates from the Theis and Jacob methods show that the T values calculated using Jacob (0.42 m^2/d) are much less than the T values obtained from Theis (1.23 m^2/d) (Table 4.24). Since the well is acting more like an unconfined to semi-confined aquifer, it shows drawdown and recovery responses that are not ideal. Therefore, the response of the well does not conform to the classic analytical methods (Theis and Jacob) commonly applied.

- Theis versus Gringarten et al.

The geometric mean T value calculated from the Gringarten et al. method is slightly less than the value calculated using the Theis method (Table 4.24). According to Allen (1999), the Theis method will generally overestimate T in a linear flow regime,

Method of Analysis	T (m^2/d)	Q_{20} (gpm)	Q_{20} (m^3/d)	Q_{20} (L/s)	Q_{1hr} (gpm)	Q_{1hr} (m^3/d)	Q_{1hr} (L/s)	Q_{30min} (gpm)	Q_{30min} (m^3/d)	Q_{30min} (L/s)
Reconstructed Step Drawdown	0.40	0.51	3.33	0.04	2.10	13.72	0.16	2.38	15.55	0.18
Theis Method	1.23	1.56	10.23	0.12	6.44	42.11	0.49	7.30	47.72	0.55
Jacob Method	0.42	0.27	1.75	0.02	1.10	7.22	0.08	1.25	8.18	0.09
Gringarten et al. Method	1.17	1.50	9.78	0.11	6.16	40.28	0.47	6.98	45.65	0.53
Hvorslev Method – Slug Test	15.67	19.97	130.54	1.51	82.24	537.51	6.22	93.20	609.18	7.05
$T = K(Q/s)^{1.18}$	0.16	0.16	1.03	0.01	0.65	4.23	0.05	0.73	4.79	0.05

Table 4.24: Summary table showing the geometric means of the calculated transmissivities (T), long term (Q_{20}) and short term (Q_{1hr} and Q_{30min}) yields for each analytical method in this study for the Waverley well. Available drawdown is assumed to be 15.2 m (50 ft).

because the drawdown in the aquifer is lower in the presence of a fracture. Through down-hole camera logging (Table 3.5, page 26), it is known that the Waverley well is supplied by a shallow fracture located at the base of the casing.

- Slug Test - Hvorslev method

The T value obtained from the slug test using the Hvorslev method of analysis are much higher than those calculated from the pump test data using the radial flow models (Theis and Jacob) or Gringarten et al.'s vertical fracture flow method. The slug test gives unreasonably high estimates of T because it is a very short term, localized test that is most likely reflecting the T of the major, most productive fracture in the well as opposed to the aquifer as a whole. Since pumps tests are longer in duration, they affect a larger area and therefore give T values that are more representative of the surrounding aquifer, which consists of both fractures and matrix blocks. Pump tests are also more likely to identify boundary conditions.

- Reconstructed Step Drawdown

The T value calculated from the reconstructed step drawdown data are slightly higher than the values calculated using Jacob, but lower than the values obtained using the Theis and Gringarten et al. methods (Table 4.24).

- Transmissivity Estimate Using Specific Capacity

The estimated T values based on specific capacity using Equation 3.34, are much lower than the actual transmissivities obtained from pump test data (Table 4.24). The actual T values are greater than four times the estimated transmissivity and therefore do not follow the predictions outlined in Huntley (1992).

4.2.7 Comparison of Well Yields

The safe yields for the Waverley well were calculated using Equation 3.31, for periods of 20 years (7 log cycles), one hour (~1.7 log cycles), and 30 minutes (~1.5 log cycles). The assumed available drawdown for the calculation was 15.2 m (50 ft) to provide a comparison with the East Dartmouth well. The calculated yield values are directly related to transmissivity for a particular time since all other factors in Equation 3.31 are constant.

Based on calculations in Table 4.24 and on well performance, the best estimate of well yield for the Waverley well is likely about 1.8 m^3/d (0.3 gpm) for the long term, and 7 to 8 m^3/d (1.0 to 1.2 gpm) for the short term. Even though the Gringarten et al. model was felt to fit the data, the calculated yield values were too high based on actual well performance, because of the occurrence of the main water bearing fracture at shallow depth.

Since the average homeowner is not trained in analytical methods, but can do simple volumetric calculations, yields were also estimated based on casing storage depletion and recovery for comparison purposes.

The estimated yields based on casing storage calculated from drawdown data range from 4.08 to 7.90 m^3/d (0.6 to 1.2 gpm) (Table 4.25) and are most similar to 20 year long term yields calculated for the Waverley well (Table 4.24). The drawdown yield estimates are greatest for the lower discharge rate tests (MR-2 and C1). The geomean value is consistent with the best short term estimate of 7 to 8 m^3/d (1.0 to 1.2 gpm) noted above from analytical methods.

Pump Test	Length of Test (min)	Length of Test (days)	Test Q (m^3/d)	Total Pumped (gallons)	Total Pumped (m^3)	Total Drawdown (ft)	Total Drawdown (m)	Storage Volume (gallons)	Storage Volume (m^3)	Estimated Yield		
										Q (gpm)	Q (m^3/d)	Q (L/s)
MR - 1	60	0.04	24.87	225	1.02	155.32	47.34	189.49	0.85	0.59	4.08	0.05
MR - 2	360	0.25	8.18	450	2.04	12.86	3.92	15.69	0.07	1.21	7.90	0.09
Cyclic - C1	60	0.04	16.36	150	0.68	66.27	20.20	80.84	0.36	1.15	7.64	0.09
Cyclic - C2	60	0.04	16.36	150	0.68	67.94	20.71	82.89	0.37	1.12	7.42	0.08
Cyclic - C3	60	0.04	16.36	150	0.68	73.04	22.26	89.11	0.40	1.01	6.75	0.08
									Geomean:	0.99	6.58	0.08

Table 4.25: Conservative yield based on casing storage from drawdown data for the Waverley well. Gallons per minute are given in imperial units.

Conservative yields based on casing storage calculated from recovery data range from 1.65 to 9.33 m^3/d (0.3 to 1.4 gpm) (Table 4.26) and are also most similar to the 20-year long term yields given in Table 4.24. The geomean estimate is consistent with the best short term estimate from the analytical methods.

4.3 Well Comparison

The East Dartmouth well behaves as if it is pumping from a confined aquifer, probably due to the thick cover (~20 m) of clay-rich glacial material overlying the bedrock. Since the well is acting more like a confined aquifer, it shows more ideal drawdown and recovery responses. Therefore, classic analytical methods such as the Theis method and Jacob method are applicable. The fractured zone in the East Dartmouth well consists of a number of fractures present at different depths in the open zone of the well. It is not known which fractures supply water to the well, and their relative contributions.

The Waverley well is acting more like a dug well in an unconfined to semi-confined aquifer due to the thin overburden (< 3 m) deposits in the vicinity of the well. The well is supplied by a single fracture located at a relatively shallow depth. This aquifer is limited, as shown by boundary effects, and thus the test data gives drawdown and recovery responses that are not ideal. Therefore, the well responses do not conform to the classic analytical methods, such as the Theis and Jacob's methods, which are commonly applied, though not necessarily correctly.

Pump Test	Length of Test (hours)	Test Q (m^3/d)	Total Pumped (m^3)	Recovery (after 1 hr) (ft)	Recovery (after 1 hr) (m)	% Recovery of drawdown (in 1 hr)	Conservative Yield		
							Q (gpm)	Q (m^3/d)	Q (L/s)
MR - 1	1	24.87	1.02	55.41	16.89	36	1.13	7.38	0.08
MR - 2	6	8.18	2.04	12.37	3.77	96	0.25	1.65	0.02
Cyclic - C1	1	16.36	0.68	64.53	19.67	97	1.31	8.59	0.10
Cyclic - C2	1	16.36	0.68	66.27	20.20	97	1.35	8.82	0.10
Cyclic - C3	1	16.36	0.68	70.12	21.37	96	1.43	9.33	0.11
						Geomean:	0.93	6.12	0.07

Table 4.26: Conservative yield based on casing storage from recovery data for the Waverley well. Gallons per minute are given in imperial units.

5.0 CONCLUSIONS

A number of conclusions can be made from this study.

1. The two fractured bedrock wells tested in this study are representative of the low yielding bedrock wells encountered in roughly two-thirds of mainland Nova Scotia. The test results showed a very different type of response in the two wells. The East Dartmouth well behaved generally in the manner expected of an ideal confined aquifer. The well has a number of potential water-bearing fractures at some depth (based on borehole camera logging), although their relative contributions are not known. The Waverley well behaved in a manner more reflective of a shallow limited aquifer with boundary conditions. The well is supplied by a single water-bearing fracture at very shallow depth (determined through borehole camera logging). Functionally, the Waverley well is more similar to a shallow dug well completed in fractured bedrock than a drilled well.

2. Qualitatively, the step drawdown test shows that the East Dartmouth well can maintain a pumping rate of approximately 15.4 m^3/day (2.3 gpm) without greatly exceeding the capabilities of the well. On the other hand, the Waverley well only stabilizes at low pumping rates, in the order of 7.1 m^3/day (1.1 gpm). Higher pumping rates overstress the well and promote fracture dewatering.

3. Transmissivity values for the East Dartmouth well obtained from the analytical methods (excluding the slug tests) range from 0.4 to 0.7 m^2/day. Since the data fits the Theis and Jacob models reasonably well, and the derivative method indicates the presence of radial flow, the best estimates of transmissivity are most likely provided by these models. The Gringarten et al. model for a single vertical fracture probably does not provide the most accurate estimate of aquifer properties, since the East Dartmouth well is likely supplied by more than one fracture.

4. Transmissivity values for the Waverley well exhibit a much wider range, from 0.4 to 1.2 m^2/day. The wider range is due to the wells non-ideal response under different pumping rates since at higher rates the single shallow fracture supplying the well was dewatered rapidly. Higher apparent transmissivity and yield are obtained under low pumping rates that do not result in fracture dewatering. Traditional methods of analysis, such as the Theis and Jacob models, are not applicable under these conditions. The Gringarten et al. model for a single vertical fracture gives reasonable estimates of transmissivity since the Waverley well is supplied predominately by a single fracture.

5. Transmissivity values calculated from an average specific capacity equation were much lower than those from the analytical methods, but were within the reported range of one quarter to four times the average. However, this range is too wide to be considered a useful estimate of transmissivity.

6. Short term (30-60 minute) well yields based on transmissivity and available drawdown ranged from 18.4 to 26.8 m^3/d for the East Dartmouth well. The long term yield (traditional 20 year safe yield) is about four to five times lower than the short term yield. The short term well yields calculated using the Jacob method give the closest estimate to the maintainable pumping rates indicated by the step drawdown test. Conservative yields based on casing storage calculated from drawdown data gave results comparable to the short term yields calculated from traditional analytical methods. Conservative yields based on casing storage calculated from recovery data are more comparable with the long term safe yields calculated from analytical methods.

7. Short term (30-60 minute) yields based on transmissivity and available drawdown ranged from 13.72 to 47.72 m^3/d for the Waverley well. The long term yield (traditional 20 year safe yield) is approximately five times lower than the short term yield. The

conservative yields based on casing storage calculated from drawdown data are greatest for the lower discharge rate tests and are most similar to the long term yield calculated from analytical methods. Conservative yields based on casing storage calculated from recovery data are also most similar to the long term safe yields from analytical methods. This indicates the need to be conservative when estimating yields from low yield wells.

8. The cyclic test shows that the East Dartmouth well experiences a slight net gain when pumped at the CMHC standard (26.3 m^3/day). Therefore, the well can maintain this level of pumping for repeated cycles and still experience a net gain. However, the Waverley well experiences a net loss when pumped at rates lower than the CMHC standard (16.36 m^3/day). The increase in drawdown would become more pronounced with increased discharge rates, suggesting that the well would not be able to maintain the CMHC standard for repeated pumping cycles without exceeding the total available drawdown.

9. The slug test method is a fast, simple and inexpensive method for determining aquifer properties compared to pumping methods. However, the results proved not to be applicable because the high aquifer transmissivities obtained are reflective of areas that are very close to the well and of fractures with the highest hydraulic conductivity.

10. The CMHC test is not very useful in determining aquifer properties under non-ideal conditions such as single fractures at shallow depth. Estimates of well yield based on volumetric casing storage methods are probably just as applicable under conditions such as those in the Waverley well.

6.0 RECOMMENDATIONS

The following are some recommendations from this study.

1. The wide range of results for the Waverley well illustrate the difficulty of determining aquifer properties under non-ideal, low yield, shallow single fracture conditions. Under these conditions, it appears that the casing storage method may be applicable to estimate short term yield.

2. In order to optimize yield from wells in which higher apparent transmissivity and yield are obtained under low pumping rates that limit fracture dewatering, it may be more appropriate to pump at a lower rate for a longer period of time. In practical terms, this would require additional storage capability in a home. Because of the cost of increasing storage, this option is rarely used on individual domestic wells, although it is a more viable option for non-domestic uses.

3. Although the CMHC test is not amenable to aquifer parameter determination under non-ideal conditions, it is still useful as a practical tool to evaluate well response under possible usage conditions. Its test rate is also more reflective of typical submersible domestic pumps (5 USgpm or 4 gpm).

4. In the present field practice of the CMHC test, better information could be obtained from low yield wells if recovery measurements were taken for more than one hour. Since recovery may take up to four times the pumping period, ideally four hours should be monitored. Because of the cost factor, at least two hours are recommended rather than the present practice of one hour.

5. Cyclic pumping at the CMHC rate with at least two cycles would be more useful than a single one hour test to determine net loss or gain of storage in the well. The on-off nature of a cyclic test is also most reflective of the response of the well to actual homeowner usage.

6. A two hour step drawdown test would provide better information on well response at different pumping rates and to check for fracture dewatering than the current one hour CMHC test.

7. It would be useful to establish a database of short term pump test data which could be reanalyzed using various methods such as derivative, Jacob, and casing storage; this would assess the validity of the results of this study over a larger population.

8. Use of simplified radial flow models in most test analyses, as is traditionally done now, can lead to a misinterpretation of the data, especially in the case where fracture dewatering occurs during the test. Other non-traditional methods should be considered in both short and long term aquifer test analysis. For example, the derivative method could be used to determine when traditional analytical methods based on radial flow equations are applicable. The single fracture analytical model could be considered if fracture data are available from drillers' logs and/or borehole camera logs. An unconfined analytical model could be considered where fractured bedrock is at or near the surface if significant fracture dewatering does not occur.

9. Where feasible, additional geological information should be obtained on test sites, such as air photo evaluation, local geology, and fracture mapping.

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http://www.ec.gc.ca/water/index/htm

APPENDIX 1

PERFORMANCE CURVES FOR THE GOULDS PUMP

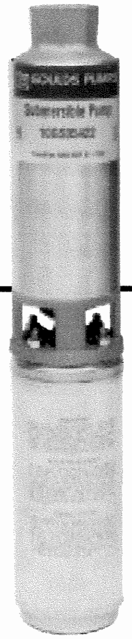
MODEL 5GS TEST PUMP

GOULDS PUMPS

60 Hz Standard Capacity 4" Submersible Pumps

MODEL GS

5GS, 7GS, 10GS, 13GS, 18GS, 25GS



SPECIFICATIONS

Model	Flow Range GPM	Horsepower Range	Best Eff. GPM	Discharge Connection	Minimum Well Size	Rotation①
5GS	1.2 – 7.5	½ – 2	5	1¼	4"	CCW
7GS	1.5 – 10	½ – 3	7	1¼	4"	CCW
10GS	3 – 16	½ – 5	10	1¼	4"	CCW
13GS	4 – 20	½ – 3	13	1¼	4"	CCW
18GS	6 – 28	¾ – 5	18	1¼	4"	CCW
25GS	8 – 33	1 – 5	25	1¼	4"	CCW

① Rotation is counterclockwise when observed from pump discharge end.

FEATURES

■ **Powered for Continuous Operation:** All ratings are within the working limits of the motor as recommended by the motor manufacturer. Pump can be operated continuously without damage to the motor.

■ **Field Serviceable:** Pump can be rebuilt in the field to like new condition with common tools and readily available spare parts. **NOTE: The Model GS has left hand casing threads.**

■ **Sand Resistant Construction:** Field proven over almost four decades, face clearance design and floating impellers for an extremely abrasion resistant configuration.

■ **Stainless Steel Metal Parts:** AISI types 302, 303 and 304 are corrosion resistant, non-toxic and non-leaching.

■ **FDA Compliant Non-Metallic Parts:** Impellers, diffusers and bearing spiders are constructed of a glass filled engineered composite. This material is corrosion resistant and non-toxic.

■ **Discharge Head:** High profile precision cast 303 stainless steel for superior strength and durability. Cast in loop for safety line.

■ **Motor Adapter:** Precision cast 303 stainless steel is extremely rigid for accurate alignment of liquid end to motor. Generous space for removal of motor mounting nuts with regular open-end wrench.

■ **Bowls:** Stainless steel for strength and abrasive resistance.

■ **Check Valve:** Built in check valve constructed of stainless steel and low compression, FDA compliant, BUNA rubber for excellent abrasive resistance and quiet, efficient operation.

■ **Stainless Steel Casing:** Polished stainless steel is attractive and durable in the most corrosive water.

■ **Hex Shaft Design:** Six sided shafts for positive impeller drive.

■ **Shaft Coupling:** Exposed for ease of field alignment to motor shaft and to check pump rotation.

■ **Urethane Upper and Middle Bearings:** Fluted design for free passage of abrasives and excellent resistance to sand damage.

■ **Franklin Electric Motor:**

- Corrosion resistant stainless steel construction through 2 HP, stainless steel casing with nickel plated gray iron end bells on motors over 2 HP.
- Built-in surge arrestor is provided on single phase motors through 5 HP.
- Stainless steel splined shaft.
- Hermetically sealed windings.
- Replaceable motor lead assembly.
- UL 778 recognized.
- NEMA mounting dimensions.
- Control box is required with 3 wire single phase units.
- Three phase units require a magnetic starter with three leg protection. Magnetic starter and heaters must be ordered separately.

■ **Agency Listings:** All complete pump/motor assemblies are UL778 and CSA listed and complies with ANSI/NSF std. 61. All 4" Franklin Electric Motors are UL778 recognized.

ORDER NUMBER CODE

5 GS 05 4 1 2 (R)

GPM at Best Efficiency — 5, 7, 10, 13, 18, 25

GS Pump Series

Horsepower Code
05 = ½
07 = ¾
10 = 1
15 = 1½
20 = 2
30 = 3
50 = 5

4 = 4" Franklin Motor

Phase
1 = 1 Phase 3 Wire
2 = 1 Phase 2 Wire
3 = 3 Phase 3 Wire

Voltage
1 = 115 V
2 = 230 V
3 = 380 V
4 = 460 V
7 = 575 V

Reduced Stage ½ HP Water End
("R" model replaces the ⅓ HP model.)

"GS" SERIES MATERIALS OF CONSTRUCTION

Part Name	Material
Discharge Head	AISI 303 SS
Check Valve Poppet	AISI 304 SS
Check Valve Seal	BUNA, FDA compliant
Check Valve Seat	AISI 304 SS
Check Valve Retaining Ring	AISI 302 SS
Bearing Spider – Upper	Glass Filled Engineered Composite
Bearing	Urethane, FDA compliant
Klipring	AISI 301 SS
Diffuser	Glass Filled Engineered Composite
Impeller	Glass Filled Engineered Composite
Bowl	AISI 304 SS
Intermediate Sleeve①	AISI 304 SS, Powder Metal
Intermediate Shaft Coupling②	AISI 304 SS, Powder Metal
Intermediate Bearing Spider①	Glass Filled Engineered Composite
Intermediate Bearing Spider②	AISI 303 SS
Bearing	Urethane, FDA compliant
Shim	AISI 304 SS
Spacer	AISI 304 SS, Powder Metal
Screws – Cable Guard	AISI 304 SS
Motor Adapter	AISI 303 SS
Casing	AISI 304 SS
Shaft	AISI 304 SS
Coupling	AISI 304 SS, Powder Metal
Cable Guard	AISI 304 SS
Suction Screen	AISI 304 SS

① Used on pumps over 24 stages.
② Used on models with 27 stages or larger.

AGENCY LISTINGS

Canadian Standards Association

Underwriters Laboratories

Classified ANSI/NSF 61-1992

Goulds Pumps is ISO 9001 Registered.

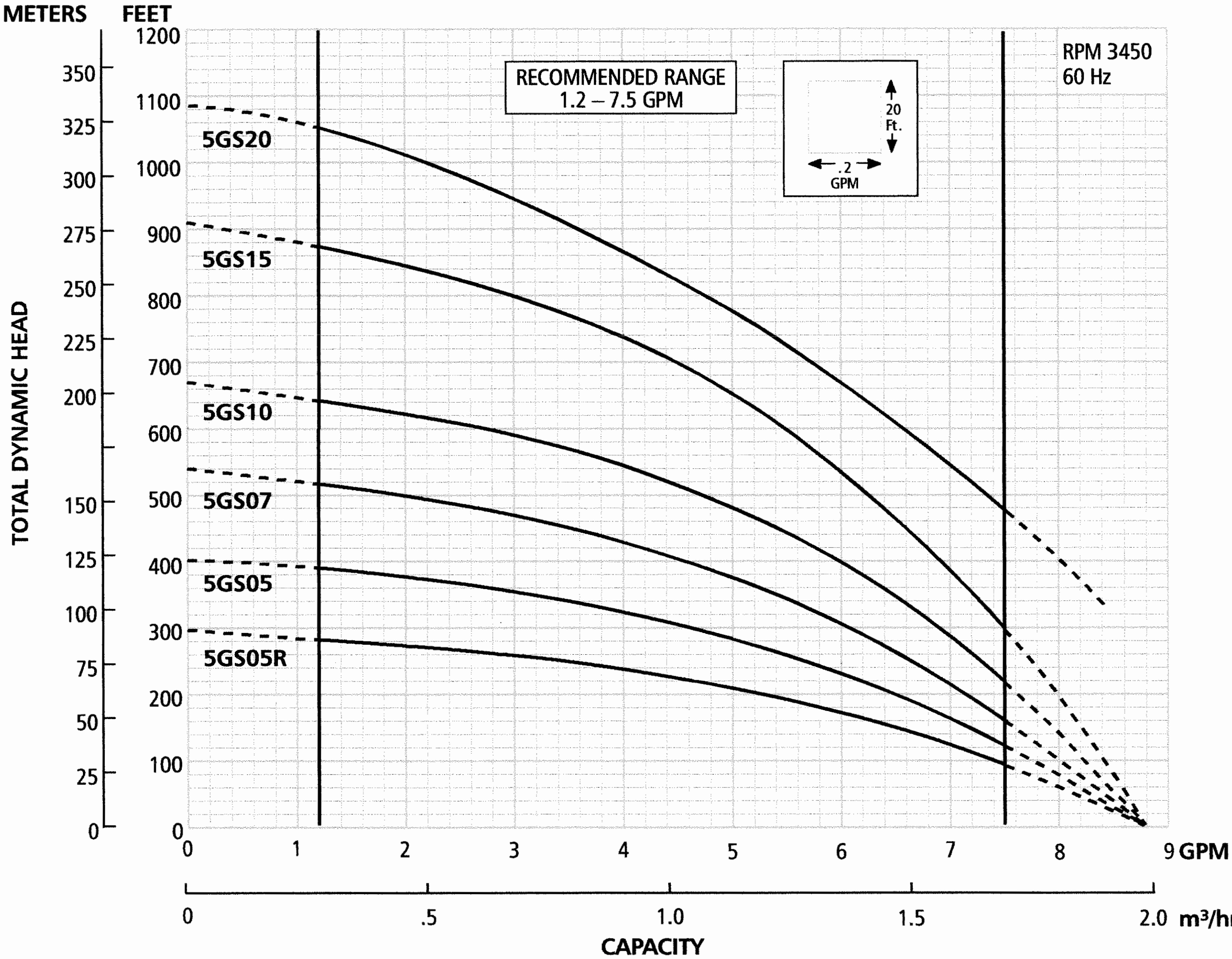
Goulds Pumps

ITT Industries

Appendix 1

Model 5GS

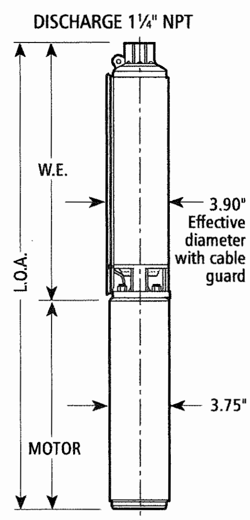
GOULDS PUMPS



DIMENSIONS AND WEIGHTS

Model	HP	Phase	Stages	Length (inches)			Weight (lbs.)		
				W.E.②	Motor	L.O.A.③	W.E.	Motor	Total
5GS05412R,22,11,21①	½R①	1	9	12.4	9.5	21.9	7	18	25
5GS05412,22,11,21	½	1	12	14.5	9.5	24.0	8	18	26
5GS07412,22	¾	1	15	16.5	10.7	27.2	9	20	29
5GS10412,22	1	1	20	20.0	11.8	31.8	11	23	34
5GS15412	1½	1	26	25.3	13.6	38.9	14	31	45
5GS15422	1½	1	26	25.3	15.1	40.4	14	23	42
5GS15432,34	1½	3	26	25.3	11.8	37.1	14	23	37
5GS20412	2	1	33	30.1	15.1	45.2	17	32	49
5GS20432,34	2	3	33	30.1	13.6	43.7	17	29	46

① Reduced stage ½ HP pump/water end for low head applications. This model replaces the ⅓ HP water end.
② W.E. = water end or pump without motor.
③ L.O.A. = length of assembly – complete pump – water end and motor.



SELECTION CHART

Horsepower Range ½ – 1½, Recommended Range 1.2 – 7.5 GPM, 60 Hz, 3450 RPM

Pump Model	HP	PSI	Depth to Water in Feet/Ratings in GPM (Gallons per Minute)																																
			20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	340	380	420	460	500	540	580	620	660	700	740	780	820	860	900	940	980	1020
5GS05R	½	0					7.5	7.2	6.8	6.3	5.8	5.2	4.7	3.8	2.9																				
		20			7.4	7.1	6.7	6.2	5.7	5.1	4.4	3.7	2.6																						
		30		7.3	6.9	6.6	6.0	5.6	5.0	4.3	3.4	2.3																							
		40	7.3	6.9	6.5	6.0	5.5	4.9	4.2	3.4	2.2																								
		50	6.9	6.5	5.9	5.4	4.9	4.1	3.2	2.0																									
		60	6.2	5.6	5.2	4.6	3.8	2.7	1.2																										
Shut-off PSI			120	112	103	94	86	77	68	60	51	42	34	25	16																				
5GS05	½	0							7.4	7.2	6.9	6.6	6.3	5.9	5.4	5.0	4.5	3.4																	
		20					7.4	7.2	6.9	6.5	6.1	5.7	5.3	4.9	4.4	3.8	3.2	1.3																	
		30			7.7	7.4	7.1	6.8	6.4	6.0	5.6	5.2	4.8	4.3	3.7	3.1	2.2																		
		40			7.4	7.1	6.7	6.4	6.0	5.6	5.2	4.7	4.2	3.6	3.0	2.2																			
		50	7.6	7.3	7.0	6.7	6.3	6.0	5.5	5.1	4.6	4.1	3.5	2.9	2.0																				
		60	7.0	6.7	6.5	6.2	5.8	5.4	5.0	4.6	4.0	3.4	2.6	1.2																					
Shut-off PSI			166	156	147	139	130	121	113	104	95	87	78	69	61	52	43	26																	
5GS07	¾	0									7.5	7.3	7.1	6.9	6.7	6.4	6.1	5.6	5.0	4.2	3.3	2.0													
		20							7.5	7.3	7.1	6.8	6.6	6.4	6.1	5.8	5.5	4.8	4.1	3.1	1.8														
		30					7.6	7.4	7.2	7.0	6.8	6.5	6.3	6.0	5.7	5.4	5.1	4.4	3.5	2.2															
		40				7.6	7.4	7.2	7.0	6.8	6.5	6.3	6.0	5.7	5.4	5.1	4.7	3.9	2.9	1.6															
		50			7.6	7.4	7.2	6.9	6.7	6.5	6.2	6.0	5.7	5.3	5.0	4.7	4.3	3.4	2.2																
		60	7.5	7.3	7.1	6.9	6.8	6.5	6.3	6.1	5.8	5.5	5.2	4.9	4.5	4.1	3.7	2.6	1.2																
Shut-off PSI			225	216	208	199	190	182	173	166	156	147	139	130	121	113	104	87	69	52	35	17													
5GS10	1	0											7.6	7.5	7.3	7.1	6.9	6.6	6.1	5.7	5.2	4.6	3.9	3.1	2.1										
		20										7.4	7.3	7.1	6.9	6.7	6.5	6.0	5.6	5.1	4.5	3.8	3.0	2.0											
		30									7.4	7.2	7.1	6.9	6.6	6.4	6.2	5.8	5.3	4.7	4.1	3.3	2.4												
		40								7.4	7.2	7.0	6.8	6.6	6.4	6.2	6.0	5.5	5.0	4.4	3.7	2.9	1.8												
		50						7.5	7.4	7.2	7.0	6.8	6.6	6.4	6.2	6.0	5.7	5.2	4.6	4.0	3.2	2.2													
		60				7.5	7.4	7.2	7.0	6.9	6.7	6.5	6.4	6.2	6.0	5.7	5.5	5.0	4.4	3.6	2.7	1.2													
Shut-off PSI						253	245	234	227	219	210	201	193	184	175	167	158	141	123	106	89	71	54	37	19										
5GS15	1½	0															7.5	7.2	7.0	6.8	6.5	6.3	6.0	5.6	5.3	4.9	4.5	4.0	3.3	2.4	1.6				
		20												7.5	7.5	7.3	7.2	7.0	6.7	6.4	6.2	6.0	5.6	5.3	4.8	4.4	3.9	3.2	2.4	1.2					
		30											7.5	7.4	7.3	7.2	7.1	6.8	6.6	6.3	6.0	5.7	5.4	5.0	4.6	4.0	3.5	2.8	1.8						
		40										7.5	7.4	7.3	7.2	7.1	6.9	6.7	6.4	6.1	5.8	5.5	5.2	4.7	4.3	3.7	3.2	2.2							
		50									7.5	7.4	7.3	7.2	7.1	6.9	6.8	6.5	6.3	6.0	5.6	5.3	4.9	4.6	4.0	3.4	2.5	1.5							
		60									7.5	7.4	7.2	7.1	7.0	6.9	6.6	6.4	6.1	5.7	5.4	5.1	4.7	4.2	3.6	2.9	2.0								
Shut-off PSI											316	307	299	290	281	273	276	247	229	212	195	177	160	143	126	108	91	74	56	39	22				
5GS20	2	0																			7.6	7.3	7	6.7	6.4	6.1	5.7	5.4	4.9	4.6	4.1	3.6	3.1	2.5	1.9
		20																		7.5	7.2	7	6.7	6.3	6	5.7	5.3	4.9	4.5	4	3.6	3	2.4	1.7	
		30																	7.6	7.4	7.1	6.8	6.5	6.1	5.8	5.5	5.1	4.7	4.2	3.8	3.3	2.7	2.1	1.2	
		40																	7.5	7.2	6.9	6.6	6.3	6	5.6	5.2	4.8	4.5	4	3.5	3	2.3	1.6		
		50																7.6	7.3	7	6.7	6.4	6.1	5.8	5.4	5	4.6	4.2	3.7	3.2	2.6	1.9			
		60																7.4	7.2	6.9	6.6	6.2	5.9	5.5	5.2	4.8	4.4	3.9	3.4	2.9	2.2	1.5			
Shut-off PSI																		322	305	288	270	253	236	219	201	184	167	149	132	115	97	80	63	45	28

Appendix 1

APPENDIX 2

PUMP TEST DATA FOR THE EAST DARTMOUTH

AND WAVERLEY WELLS

NOTE: Corrected depth to water (DTW) is relative to ground level.

PUMP TEST DATA

TEST TYPE: Step Drawdown, Step 1
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE:** 1

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
24-Jul-97	6:45	0	55.15	53.15	0	0		5587.1	
		1.5	58.50	56.50	3.35	1.02			
		3	59.10	57.10	3.95	1.20			
		4	59.55	57.55	4.40	1.34			
		5	59.95	57.95	4.80	1.46		5595.3	
		6	60.10	58.10	4.95	1.51			
		7	60.38	58.38	5.23	1.59			
		8	60.60	58.60	5.45	1.66			
		9	60.73	58.73	5.58	1.70			
	6:55	10	60.95	58.95	5.80	1.77	1.09	5600.1	
	7:00	15	61.80	59.80	6.65	2.03		5606.1	
		20	62.35	60.35	7.20	2.19		5610.0	
		25	62.85	60.85	7.70	2.35		5614.8	
	7:15	30	63.15	61.15	8.00	2.44		5619.8	

TEST TYPE: Step Drawdown, Step 2

PAGE: 2

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
24-Jul-97		0	63.15	61.15	8	2.44			
	7:16	1.5	64.30	62.30	9.15	2.79			
		2.5	65.00	63.00	9.85	3.00			
		3	65.42	63.42	10.27	3.13			
		4	66.52	64.52	11.37	3.47			
		5	68.00	66.00	12.85	3.92		5630.8	
		7.5	70.53	68.53	15.38	4.69			
		9	71.60	69.60	16.45	5.01			
	7:25	10	72.00	70.00	16.85	5.14	2.35	5644.6	
	7:30	15	73.90	71.90	18.75	5.72		5656.5	
	7:35	20.5	75.40	73.40	20.25	6.17		5669.5	
	7:40	25	75.80	73.80	20.65	6.29		5679.5	
	7:45	30	76.10	74.10	20.95	6.39		5690.3	

TEST TYPE: Step Drawdown, Step 3

PAGE: 3

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
24-Jul-97	7:46	0	76.10	74.10	20.95	6.39		5690.3	
		1	76.50	74.50	21.35	6.51			
		2	77.30	75.30	22.15	6.75			
		3	78.10	76.10	22.95	7.00			
		4	78.70	76.70	23.55	7.18			
		5	79.25	77.25	24.10	7.35		5705.2	
		6	79.80	77.80	24.65	7.51			
		7	80.15	78.15	25.00	7.62			
		8	80.61	78.61	25.46	7.76			
		9	81.05	79.05	25.90	7.89			
		10	81.48	79.48	26.33	8.03	2.95	5720.0	
		15	82.81	80.81	27.66	8.43		5735.0	
		20	83.60	81.60	28.45	8.67		5749.0	
		25	84.58	82.58	29.43	8.97		5764.0	
		30	85.10	83.10	29.95	9.13		5778.0	

TEST TYPE: Step Drawdown, Step 4

PAGE: 4

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
24-Jul-97		0	85.10	83.10	29.95	9.13			
		1	85.45	83.45	30.30	9.24			
		2.5	87.60	85.60	32.45	9.89			
		3	87.90	85.90	32.75	9.98			
		4	88.88	86.88	33.73	10.28			
		5	89.84	87.84	34.69	10.57		5798.7	
		6	90.62	88.62	35.47	10.81			
		7	91.30	89.30	36.15	11.02			
		8	91.86	89.86	36.71	11.19			
		9	92.40	90.40	37.25	11.35			
		10	93.18	91.18	38.03	11.59	4.01	5819.1	
	8:30	15	96.10	94.10	40.95	12.48		5839.5	
		20	97.90	95.90	42.75	13.03		5859.2	
		25	99.20	97.20	44.05	13.43		5878.4	
	8:45	30	100.60	98.60	45.45	13.85		5899.2	

PUMP TEST DATA

TEST TYPE: Step Drawdown, Recovery
PROJECT LOCATION: East Dartmouth

MEASURING POINT: 2 ft

PAGE: 1

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Recovery meters	Remarks
24-Jul-97		120	0	0	100.60	98.60	30.05	45.45	13.85	0	
		121	1	121.0	98.60	96.60	29.44	43.45	13.24	0.61	
		122	2	61.0	95.74	93.74	28.57	40.59	12.37	1.48	
		123	3	41.0	92.86	90.86	27.69	37.71	11.49	2.36	
		124	4	31.0	90.30	88.30	26.91	35.15	10.71	3.14	
		125	5	25.0	88.10	86.10	26.24	32.95	10.04	3.81	
		126	6	21.0	85.90	83.90	25.57	30.75	9.37	4.48	
		127	7	18.1	83.85	81.85	24.95	28.70	8.75	5.10	
		128	8	16.0	82.28	80.28	24.47	27.13	8.27	5.58	
		129	9	14.3	80.73	78.73	24.00	25.58	7.80	6.05	
	8:55	130	10	13.0	79.24	77.24	23.54	24.09	7.34	6.51	
	9:00	135	15	9.0	73.40	71.40	21.76	18.25	5.56	8.29	
		140	20	7.0	69.72	67.72	20.64	14.57	4.44	9.41	
		145	25	5.8	67.20	65.20	19.87	12.05	3.67	10.18	
	9:15	150	30	5.0	65.60	63.60	19.39	10.45	3.19	10.66	
	9:25	160	40	4.0	63.48	61.48	18.74	8.33	2.54	11.31	
	9:35	170	50	3.4	62.24	60.24	18.36	7.09	2.16	11.69	
	9:45	180	60	3.0	61.45	59.45	18.12	6.30	1.92	11.93	
	10:00	195	75	2.6	60.66	58.66	17.88	5.51	1.68	12.17	
	10:15	210	90	2.3	60.10	58.10	17.71	4.95	1.51	12.34	
	10:30	225	105	2.1	59.58	57.58	17.55	4.43	1.35	12.50	
	10:51	246	126	2.0	59.07	57.07	17.39	3.92	1.19	12.66	

PUMP TEST DATA

TEST TYPE: Constant Rate (CMHC) CR-1
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE:** 1

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
10-Jul-97	10:00	0	53.70	51.70	15.76	0	0		51.7	
		0.25	55.40	53.40	16.28	1.70	0.52			
		0.5	57.20	55.20	16.82	3.50	1.07			
		0.75	58.80	56.80	17.31	5.10	1.55			
		1	59.85	57.85	17.63	6.15	1.87			
		1.5	59.75	57.75	17.60	6.05	1.84			
		2	60.75	58.75	17.91	7.05	2.15			
		2.5	62.50	60.50	18.44	8.80	2.68			
		3	64.11	62.11	18.93	10.41	3.17			
		4	65.45	63.45	19.34	11.75	3.58			
		5	67.24	65.24	19.89	13.54	4.13		73.7	
		6	69.35	67.35	20.53	15.65	4.77			
		7	71.22	69.22	21.10	17.52	5.34			
		8	72.85	70.85	21.60	19.15	5.84			
		9	74.45	72.45	22.08	20.75	6.32			
		10	75.74	73.74	22.48	22.04	6.72	4.01	94.5	slightly cloudy
	10:15	15	80.90	78.90	24.05	27.20	8.29			
		20	84.36	82.36	25.10	30.66	9.35			
		25	87.05	85.05	25.92	33.35	10.17			
		30	89.00	87.00	26.52	35.30	10.76		159.5	
		40	91.80	89.80	27.37	38.10	11.61		185.0	
		45	93.00	91.00	27.74	39.30	11.98	3.57	190.0	
		50	94.22	92.22	28.11	40.52	12.35		195.2	clearing / H_2O meter quit
		60	97.00	95.00	28.96	43.30	13.20	3.75	210.0	H_2O cloudy but clearing

PUMP TEST DATA

TEST TYPE: Constant Rate (CMHC) CR-1, Recovery
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE:** 1

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Recovery meters	Remarks
10-Jul-97		60.00	0	0	97.00	95.00	28.96	43.30	13.20	0	
		60.15	0.25	240.60	96.10	94.10	29.29	42.40	12.92	0.27	
	11:03	60.60	0.7	86.57	95.02	93.02	28.96	41.32	12.59	0.60	
		60.90	1	60.90	94.00	92.00	28.65	40.30	12.28	0.91	
		61.40	1.5	40.93	92.55	90.55	28.21	38.85	11.84	1.36	
		61.90	2	30.95	91.10	89.10	27.77	37.40	11.40	1.80	
		62.40	2.5	24.96	90.08	88.08	27.46	36.38	11.09	2.11	
		62.90	3	20.97	89.80	87.80	27.37	36.10	11.00	2.19	
		63.90	4	15.98	86.51	84.51	26.37	32.81	10.00	3.20	
	11:07	64.90	5	12.98	84.75	82.75	25.83	31.05	9.46	3.73	
		65.90	6	10.98	82.87	80.87	25.26	29.17	8.89	4.31	
		66.90	7	9.56	81.05	79.05	24.70	27.35	8.34	4.86	
		67.90	8	8.49	79.32	77.32	24.18	25.62	7.81	5.39	
		68.90	9	7.66	78.00	76.00	23.77	24.30	7.41	5.79	
	11:12	69.90	10	6.99	76.55	74.55	23.33	22.85	6.96	6.23	
	11:17	74.90	15	4.99	71.50	69.50	21.79	17.80	5.43	7.77	
	11:22	79.90	20	4.00	68.00	66.00	20.73	14.30	4.36	8.84	
	11:28	85.90	26	3.30	65.55	63.55	19.98	11.85	3.61	9.59	
	11:32	89.90	30	3.00	64.15	62.15	19.55	10.45	3.19	10.01	
	11:42	99.90	40	2.50	62.20	60.20	18.96	8.50	2.59	10.61	
	11:52	109.90	50	2.20	61.05	59.05	18.61	7.35	2.24	10.96	
	12:02	119.90	60	2.00	60.25	58.25	18.36	6.55	2.00	11.20	
	12:17	134.90	75	1.80	59.48	57.48	18.13	5.78	1.76	11.44	
	12:32	149.90	90	1.67	58.91	56.91	17.96	5.21	1.59	11.61	
	12:40	157.90	98	1.61	58.55	56.55	17.85	4.85	1.48	11.72	
	13:02	179.90	120	1.50	58.10	56.10	17.71	4.40	1.34	11.86	

PUMP TEST DATA

TEST TYPE: Constant Rate CR-2

PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE: 1**

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
12-Jul-97	11:29	0	54.25	52.25	15.93	0	0		210.7	
		0.7	56.60	54.60	16.64	2.35	0.72			
		1	57.20	55.20	16.82	2.95	0.90	1.89		
		2	58.00	56.00	17.07	3.75	1.14	1.89		
		2.7	58.30	56.30	17.16	4.05	1.23			
		3	58.73	56.73	17.29	4.48	1.37			H_2O clear
		5	60.10	58.10	17.71	5.85	1.78			
		6	61.00	59.00	17.98	6.75	2.06			
		7	61.63	59.63	18.18	7.38	2.25			
		8	62.36	60.36	18.40	8.11	2.47			
		9	63.02	61.02	18.60	8.77	2.67	1.90		
		10	63.55	61.55	18.76	9.30	2.83		229.7	
	11:35	15	65.80	63.80	19.45	11.55	3.52	1.89	239.0	
		20	67.36	65.36	19.92	13.11	4.00			
	11:45	25	68.36	66.36	20.23	14.11	4.30		258.0	
	11:50	30	69.35	67.35	20.53	15.10	4.60		266.3	
		35	70.58	68.58	20.90	16.33	4.98			
	12:00	40	71.50	69.50	21.18	17.25	5.26		285.8	
	12:10	50	72.65	70.65	21.53	18.40	5.61	1.89	305.0	
	12:20	60	73.48	71.48	21.79	19.23	5.86		323.8	
	12:35	75	74.45	72.45	22.08	20.20	6.16		353.6	
	12:50	90	75.00	73.00	22.25	20.75	6.32		384.3	
	13:05	105	75.45	73.45	22.39	21.20	6.46		410.2	
	13:20	120	76.20	74.20	22.62	21.95	6.69		438.0	
	13:35	135	76.55	74.55	22.72	22.30	6.80		465.1	
	13:50	150	76.78	74.78	22.79	22.53	6.87		491.6	

TEST TYPE: Constant Rate CR-2 (continued)

PAGE: 2

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
12-Jul-97		165	77.86	75.86	23.12	23.61	7.20		520.6	
	14:20	180	78.35	76.35	23.27	24.10	7.35		551.5	
	14:50	210	79.10	77.10	23.50	24.85	7.57	1.89	607.0	
	15:20	240	79.48	77.48	23.62	25.23	7.69	1.89	666.2	
	15:50	270	80.20	78.20	23.84	25.95	7.91		722.0	
	16:20	300	80.80	78.80	24.02	26.55	8.09		779.4	
	16:50	330	81.18	79.18	24.13	26.93	8.21		837.0	
	17:20	360	81.40	79.40	24.20	27.15	8.28		895.5	

PUMP TEST DATA

TEST TYPE: Constant Rate CR-2, Recovery
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE:** 1

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawdown meters	Recovery meters	Remarks
12-Jul-97	17:20	360	0	0	81.40	79.40	27.15	8.28	0	
		360.8	0.8	451.00	80.75	78.75	26.50	8.08	0.20	
		361.8	1	361.80	80.40	78.40	26.15	7.97	0.30	
		362.3	1.5	241.53	79.42	77.42	25.17	7.67	0.60	
		362.8	2	181.40	78.95	76.95	24.70	7.53	0.75	
		363.8	3	121.27	78.25	76.25	24.00	7.32	0.96	
		364.8	4	91.20	77.00	75.00	22.75	6.93	1.34	
		365.2	4.7	77.70	76.20	74.20	21.95	6.69	1.58	
		365.8	5	73.16	75.75	73.75	21.50	6.55	1.72	
		366.2	5.7	64.25	75.25	73.25	21.00	6.40	1.87	
		366.8	6	61.13	74.95	72.95	20.70	6.31	1.97	
		367.8	7	52.54	74.08	72.08	19.83	6.04	2.23	
		368.8	8	46.10	73.30	71.30	19.05	5.81	2.47	
		369.8	9	41.09	72.55	70.55	18.30	5.58	2.70	
		370.8	10	37.08	71.72	69.72	17.47	5.32	2.95	
		375.8	15	25.05	69.38	67.38	15.13	4.61	3.66	
		380.8	20	19.04	67.68	65.68	13.43	4.09	4.18	
		385.8	25	15.43	66.43	64.43	12.18	3.71	4.56	
		390.8	30	13.03	65.62	63.62	11.37	3.47	4.81	
		395.8	35	11.31	64.92	62.92	10.67	3.25	5.02	
		400.8	40	10.02	64.33	62.33	10.08	3.07	5.20	
		410.8	50	8.22	63.50	61.50	9.25	2.82	5.46	
		420.8	60	7.01	62.90	60.90	8.65	2.64	5.64	
		435.8	75	5.81	62.15	60.15	7.90	2.41	5.87	
		450.8	90	5.01	61.66	59.66	7.41	2.26	6.02	
		465.8	105	4.44	61.15	59.15	6.90	2.10	6.17	
		480.8	120	4.01	60.76	58.76	6.51	1.98	6.29	
		510.8	150	3.41	60.12	58.12	5.87	1.79	6.49	
		540.8	180	3.00	59.47	57.47	5.22	1.59	6.68	
		570.8	210	2.72	59.10	57.10	4.85	1.48	6.80	
		600.8	240	2.50	58.70	56.70	4.45	1.36	6.92	

PUMP TEST DATA

TEST TYPE: Constant Rate CR-3
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE: 1**

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
15-Jul-97	11:00	0	54.80	52.80	16.09	0	0		1578.5	
		0.5	59.80	57.80	17.62	5.00	1.52			
		1	62.10	60.10	18.32	7.30	2.23			
		2	68.60	66.60	20.30	13.80	4.21			
		3	73.40	71.40	21.76	18.60	5.67			
		4	78.08	76.08	23.19	23.28	7.10			
		5	82.18	80.18	24.44	27.38	8.35		1628.2	
		6	85.50	83.50	25.45	30.70	9.36			
		7	88.52	86.52	26.37	33.72	10.28	7.5		
		8	91.70	89.70	27.34	36.90	11.25			
		9	94.25	92.25	28.12	39.45	12.02			
		10	96.68	94.68	28.86	41.88	12.77	6.0	1661.0	H_2O getting cloudy
		15	106.80	104.80	31.94	52.00	15.85	6.0	1691.2	
	11:28	18	111.08	109.08	33.25	56.28	17.15			
	11:30	20	113.56	111.56	34.00	58.76	17.91		1722.4	
		25	118.60	116.60	35.54	63.80	19.45		1752.0	
	11:40	30	122.25	120.25	36.65	67.45	20.56		1780.5	H_2O still cloudy
	11:45	35	125.30	123.30	37.58	70.50	21.49		1808.4	H_2O dirter
	11:50	40	127.10	125.10	38.13	72.30	22.04		1830.1	
	11:55	45	129.20	127.20	38.77	74.40	22.68		1861.9	
	12:00	50	130.48	128.48	39.16	75.68	23.07		1888.0	
	12:05	55	131.43	129.43	39.45	76.63	23.36		1913.7	
	12:10	60	132.30	130.30	39.72	77.50	23.62		1940.0	

PUMP TEST DATA

TEST TYPE: Constant Rate CR-3, Recovery
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE: 1**

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Recovery meters	Remarks
15-Jul-97		60	0	0.00	132.30	130.30	39.72	77.50	23.62	0.00	
		61	1	61.00	129.20	127.20	38.77	74.40	22.68	0.94	
		61.5	1.5	41.00	126.70	124.70	38.01	71.90	21.92	1.71	
		62	2	31.00	125.20	123.20	37.55	70.40	21.46	2.16	
		62.5	2.5	25.00	122.55	120.55	36.74	67.75	20.65	2.97	
		63	3	21.00	121.40	119.40	36.39	66.60	20.30	3.32	
		64	4	16.00	117.40	115.40	35.17	62.60	19.08	4.54	
		65	5	13.00	114.38	112.38	34.25	59.58	18.16	5.46	
		66	6	11.00	111.00	109.00	33.22	56.20	17.13	6.49	
		67	7	9.57	108.05	106.05	32.32	53.25	16.23	7.39	
		68	8	8.50	105.30	103.30	31.49	50.50	15.39	8.23	
		69	9	7.67	102.00	100.00	30.48	47.20	14.39	9.24	
	12:20	70	10	7.00	99.45	97.45	29.70	44.65	13.61	10.01	
		73	13	5.62	92.00	90.00	27.43	37.20	11.34	12.28	
		75	15	5.00	87.95	85.95	26.20	33.15	10.10	13.52	
		80	20	4.00	79.95	77.95	23.76	25.15	7.67	15.96	
		85	25	3.40	74.70	72.70	22.16	19.90	6.07	17.56	
	12:42	92	32	2.88	70.30	68.30	20.82	15.50	4.72	18.90	
	12:50	100	40	2.50	67.08	65.08	19.84	12.28	3.74	19.88	
	13:00	110	50	2.20	64.70	62.70	19.11	9.90	3.02	20.60	
	13:10	120	60	2.00	63.38	61.38	18.71	8.58	2.62	21.01	
	13:31	141	81	1.74	61.65	59.65	18.18	6.85	2.09	21.53	
	13:43	153	93	1.65	61.13	59.13	18.02	6.33	1.93	21.69	
	13:55	165	105	1.57	60.63	58.63	17.87	5.83	1.78	21.85	
	14:10	180	120	1.50	60.15	58.15	17.72	5.35	1.63	21.99	
	14:44	214	154	1.39	59.25	57.25	17.45	4.45	1.36	22.27	

TEST TYPE: Constant Rate CR-3, Recovery (continued)

PAGE: 2

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Recovery meters	Remarks
15-Jul-97	15:20	250	190	1.32	58.64	56.64	17.26	3.84	1.17	22.45	
	15:42	272	212	1.28	58.33	56.33	17.17	3.53	1.08	22.55	
	16:10	300	240	1.25	58.00	56.00	17.07	3.20	0.98	22.65	
		330	270	1.22	57.60	55.60	16.95	2.80	0.85	22.77	

PUMP TEST DATA

TEST TYPE: Constant Rate CR-4
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE: 1**

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
18-Jul-97	9:30	0	54.72	52.72	16.07	0	0		1940	H_2O cloudy at start
		2	64.50	62.50	19.05	9.78	2.98			
		5	67.13	65.13	19.85	12.41	3.78			
		8.5	69.75	67.75	20.65	15.03	4.58			
		10	70.30	68.30	20.82	15.58	4.75		1973.7	
		14	70.85	68.85	20.99	16.13	4.92		1981.7	
	9:56	26	72.13	70.13	21.38	17.41	5.31		2006.7	
	10:26	56	74.88	72.88	22.21	20.16	6.14		2064.3	
	11:35	125	75.82	73.82	22.50	21.10	6.43		2189.3	
	12:30	180	77.20	75.20	22.92	22.48	6.85		2286.2	
	13:44	254	78.75	76.75	23.39	24.03	7.32	1.88	2417.7	
	14:30	300	81.60	79.60	24.26	26.88	8.19		2510.8	
	15:02	332	81.97	79.97	24.37	27.25	8.31		2574.6	
	16:06	396	82.25	80.25	24.46	27.53	8.39	1.93	2703.8	
	16:25	415	81.00	79.00	24.08	26.28	8.01			
	17:10	460	81.85	79.85	24.34	27.13	8.27	1.91	2820.5	
	17:19	469	82.25	80.25	24.46	27.53	8.39			
	19:01	571	83.35	81.35	24.80	28.63	8.73	1.92	3037.9	
	20:12	642	83.42	81.42	24.82	28.70	8.75		3173.3	
	21:30	720	83.85	81.85	24.95	29.13	8.88		3321.9	

PUMP TEST DATA

TEST TYPE: Constant Rate CR-4, Recovery
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE:** 1

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Recovery meters	Remarks
18-Jul-97		720	0	0	83.85	81.85	24.95	29.13	8.88	0	
		721	1	721.0	82.65	80.65	24.58	30.33	9.24	-0.37	
		722	2	361.0	81.40	79.40	24.20	29.08	8.86	0.02	
		723	3	241.0	80.00	78.00	23.77	27.68	8.44	0.44	
		724	4	181.0	78.90	76.90	23.44	26.58	8.10	0.78	
		725	5	145.0	77.70	75.70	23.07	25.38	7.74	1.14	
		726	6	121.0	76.80	74.80	22.80	24.48	7.46	1.42	
		728	8	91.0	75.45	73.45	22.39	23.13	7.05	1.83	
		729	9	81.0	74.65	72.65	22.14	22.33	6.81	2.07	
		730	10	73.0	73.95	71.95	21.93	21.63	6.59	2.29	
		735	15	49.0	71.40	69.40	21.15	19.08	5.82	3.06	
		740	20	37.0	69.60	67.60	20.60	17.28	5.27	3.61	
	22:00	750	30	25.0	67.60	65.60	19.99	15.28	4.66	4.22	
	22:17	767	47	16.3	65.75	63.75	19.43	13.43	4.09	4.79	
	22:32	782	62	12.6	64.60	62.60	19.08	12.28	3.74	5.14	
	23:30	840	120	7.0	62.55	60.55	18.46	10.23	3.12	5.76	
	5:50	1220	500	2.4	57.95	55.95	17.05	5.63	1.72	7.16	

PUMP TEST DATA

TEST TYPE: Constant Rate CR-5
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE: 1**

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Depth to water meters	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
20-Jul-97	13:50	0	55.18	53.18	16.21	0	0		3322.1	
	13:53	3.67	74.00	72.00	21.95	18.82	5.74			
	13:54	4	75.30	73.30	22.34	20.12	6.13			
	13:56	6	81.35	79.35	24.19	26.17	7.98	6.0		
		7	84.10	82.10	25.02	28.92	8.81			
		8.5	86.60	84.60	25.79	31.42	9.58			H_2O clear
		9	87.60	85.60	26.09	32.42	9.88			
		10	89.55	87.55	26.69	34.37	10.48	6.85	3387.9	
		13	93.70	91.70	27.95	38.52	11.74			
	14:05	15	96.00	94.00	28.65	40.82	12.44		3417.3	
	14:10	20	101.05	99.05	30.19	45.87	13.98		3440.2	hear small trickle
	14:15	25	104.68	102.68	31.30	49.50	15.09		3464.9	
	14:20	31	108.10	106.10	32.34	52.92	16.13		3493.7	
	14:30	40	111.65	109.65	33.42	56.47	17.21		3535.6	
	14:40	50	116.70	114.70	34.96	61.52	18.75	5.2	3584.0	
	14:50	60	120.70	118.70	36.18	65.52	19.97		3632.6	
	15:05	75	123.40	121.40	37.00	68.22	20.79		3702.4	
	15:23	93	127.20	125.20	38.16	72.02	21.95		3786.8	
	15:35	105	128.50	126.50	38.56	73.32	22.35		3841.8	
	15:50	120	129.85	127.85	38.97	74.67	22.76		3910.1	
	16:05	135	130.75	128.75	39.24	75.57	23.03	4.85	3977.5	
	16:20	150	131.40	129.40	39.44	76.22	23.23		4044.3	
	16:24	154	131.90	129.90	39.59	76.72	23.38			cascading
	16:28	158	133.00	131.00	39.93	77.82	23.72		4083.5	cascading
	16:31	161	133.60	131.60	40.11	78.42	23.90			cascading
	16:40	170	135.00	133.00	40.54	79.82	24.33		4135.7	cascading

TEST TYPE: Constant Rate CR-5 (continued)

PAGE: 2

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Depth to water meters	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
20-Jul-97	16:50	180	135.92	133.92	40.82	80.74	24.61	4.62	4180.1	cascading
	17:00	190	136.92	134.92	41.12	81.74	24.91	4.62	4224.2	cascading
	17:10	200	138.18	136.18	41.51	83.00	25.30		4268.4	H_2O slightly cloudy
	17:20	210	139.20	137.20	41.82	84.02	25.61		4312.0	
	17:35	225	141.00	139.00	42.37	85.82	26.16		4377.6	
	17:50	240	142.20	140.20	42.73	87.02	26.52		4441.7	

PUMP TEST DATA

TEST TYPE: Constant Rate CR-5, Recovery
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE:** 1

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, feet	Corrected DTW, feet	Depth to water, meters	Drawdown feet	Drawdown meters	Recovery meters	Remarks
20-Jul-97	17:50	240.0	0	0	142.20	140.20	42.73	87.02	26.52	0	
		240.3	0.5	480.60	140.20	138.20	42.12	85.02	25.91	0.61	
		241.3	1	241.30	138.32	136.32	41.55	83.14	25.34	1.18	
		241.8	1.5	161.20	137.50	135.50	41.30	82.32	25.09	1.43	
		242.3	2	121.15	134.75	132.75	40.46	79.57	24.25	2.27	
		242.8	2.5	97.12	132.88	130.88	39.89	77.70	23.68	2.84	lost cascade
		242.3	3	80.77	131.03	129.03	39.33	75.85	23.12	3.40	
		243.3	4	60.83	127.73	125.73	38.32	72.55	22.11	4.41	
	17:55	244.3	5	48.86	124.40	122.40	37.31	69.22	21.10	5.43	
		245.3	6	40.88	121.15	119.15	36.32	65.97	20.11	6.42	
		246.3	7	35.19	117.90	115.90	35.33	62.72	19.12	7.41	
		249.3	10	24.93	109.90	107.90	32.89	54.72	16.68	9.85	
		254.3	15	16.95	98.30	96.30	29.35	43.12	13.14	13.38	
		259.3	20	12.97	89.20	87.20	26.58	34.02	10.37	16.15	
		264.3	25	10.57	82.95	80.95	24.67	27.77	8.46	18.06	
	18:20	269.3	30	8.98	78.60	76.60	23.35	23.42	7.14	19.39	
	18:35	274.3	45	6.10	72.00	70.00	21.34	16.82	5.13	21.40	
	18:50	289.3	60	4.82	69.05	67.05	20.44	13.87	4.23	22.30	
	18:55	294.3	65	4.53	68.35	66.35	20.22	13.17	4.01	22.51	
	19:05	304.3	75	4.06	67.35	65.35	19.92	12.17	3.71	22.81	
	19:20	319.3	90	3.55	65.85	63.85	19.46	10.67	3.25	23.27	
	19:35	334.3	105	3.18	65.30	63.30	19.29	10.12	3.08	23.44	
	19:50	349.3	120	2.91	64.56	62.56	19.07	9.38	2.86	23.66	
	20:24	383.3	154	2.49	63.30	61.30	18.68	8.12	2.47	24.05	
	20:50	409.3	180	2.27	62.58	60.58	18.46	7.40	2.26	24.27	
	21:20	439.3	210	2.09	61.80	59.80	18.23	6.62	2.02	24.51	
	21:50	469.3	240	1.96	61.17	59.17	18.04	5.99	1.83	24.70	

PUMP TEST DATA

TEST TYPE: Cyclic Test, Cycle 1
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE:** 1

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
13-Jul-97	12:45	0	55.10	53.10	0	0		895.8	
		1	58.48	56.48	3.38	1.03			
		2	61.60	59.60	6.50	1.98			
		3	64.20	62.20	9.10	2.77			
		4	67.24	65.24	12.14	3.70			
		5	69.20	67.20	14.10	4.30			
		6	71.24	69.24	16.14	4.92			
		7	73.20	71.20	18.10	5.52			
		8	74.51	72.51	19.41	5.92			
		9	76.03	74.03	20.93	6.38			
	12:55	10	77.58	75.58	22.48	6.85	4.35	939.3	
		12	79.72	77.72	24.62	7.50			
	13:00	15	82.72	80.72	27.62	8.42	4.30	960.0	
		20	86.23	84.23	31.13	9.49		980.1	
	13:10	25	89.28	87.28	34.18	10.42	4.00	1010.1	
	13:15	30	92.20	90.20	37.10	11.31		1020.0	
		35	93.00	91.00	37.90	11.55		1038.9	
	13:25	40	94.45	92.45	39.35	11.99		1058.0	
		45	96.06	94.06	40.96	12.48		1081.2	
	13:35	50	97.70	95.70	42.60	12.98		1097.2	
		55	99.65	97.65	44.55	13.58			
	13:45	60	100.90	98.90	45.80	13.96		1136.7	

PUMP TEST DATA

TEST TYPE: Cyclic Test, Recovery 1
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE:** 2

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawdown meters	Recovery	Remarks
13-Jul-97	13:45	60	0	0	100.9	98.9	45.8	13.96	0	
		60.5	0.5	121.0	99.25	97.25	44.15	13.46	0.50	
		61	1	61.0	98.00	96.00	42.90	13.08	0.88	
		61.5	1.5	41.0	96.50	94.50	41.40	12.62	1.34	
		62	2	31.0	94.98	92.98	39.88	12.16	1.80	
		62.5	2.5	25.0	93.62	91.62	38.52	11.74	2.22	
		63	3	21.0	92.24	90.24	37.14	11.32	2.64	
		64	4	16.0	89.75	87.75	34.65	10.56	3.40	
		65	5	13.0	87.61	85.61	32.51	9.91	4.05	
		66	6	11.0	85.33	83.33	30.23	9.21	4.75	
		67	7	9.6	83.63	81.63	28.53	8.70	5.26	
		68	8	8.5	81.80	79.80	26.70	8.14	5.82	
		69	9	7.7	80.35	78.35	25.25	7.70	6.26	
		70	10	7.0	78.92	76.92	23.82	7.26	6.70	
		75	15	5.0	73.32	71.32	18.22	5.55	8.41	
		80	20	4.0	69.62	67.62	14.52	4.43	9.53	
		85	25	3.4	66.92	64.92	11.82	3.60	10.36	
		90	30	3.0	65.52	63.52	10.42	3.18	10.78	
		100	40	2.5	63.42	61.42	8.32	2.54	11.42	
		111	51	2.2	62.06	60.06	6.96	2.12	11.84	
	14:45	120	60	2.0	61.29	59.29	6.19	1.89	12.07	
		135	75	1.8	60.40	58.40	5.30	1.62	12.34	
	15:15	150	90	1.7	59.90	57.90	4.80	1.46	12.50	

TEST TYPE: Cyclic Test, Cycle 2

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawndown meters	Q=discharge gpm	Water meter reading	Remarks
13-Jul-97	15:15	0	59.90	57.90	0	0		1136.8	
		1	62.60	60.60	2.70	0.82			
		2	65.07	63.07	5.17	1.58			
		3	67.09	65.09	7.19	2.19			
		4	69.16	67.16	9.26	2.82			
	15:20	5	70.78	68.78	10.88	3.32		1154.5	
		6	72.68	70.68	12.78	3.90			
		7	73.78	71.78	13.88	4.23			
		8	74.95	72.95	15.05	4.59			
		9	76.25	74.25	16.35	4.98			
	15:25	10	77.10	75.10	17.20	5.24	3.5	1171.8	
		15	82.73	80.73	22.83	6.96		1190.4	
	15:35	20	86.52	84.52	26.62	8.11	3.6	1209.4	
		25	89.55	87.55	29.65	9.04		1227.9	
	15:45	30	91.90	89.90	32.00	9.75		1246.7	
	15:50	35	93.93	91.93	34.03	10.37		1265.4	
	15:55	40	95.56	93.56	35.66	10.87		1283.7	
	16:05	50	98.70	96.70	38.80	11.83		1320.8	
	16:15	60	100.70	98.70	40.80	12.44		1357.7	

TEST TYPE: Cyclic Test, Recovery 2

PAGE: 4

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawdown meters	Recovery	Remarks
13-Jul-97	16:15	210.7	0.7	301.0	99.00	97.00	42.50	12.95	-0.52	
		211	1	211.0	98.00	96.00	41.50	12.65	-0.21	
		211.5	1.5	141.0	96.75	94.75	40.25	12.27	0.17	
		212	2	106.0	95.40	93.40	38.90	11.86	0.58	
		212.5	2.5	85.0	93.95	91.95	37.45	11.41	1.02	
		213	3	71.0	92.90	90.90	36.40	11.09	1.34	
		214	4	53.5	90.28	88.28	33.78	10.30	2.14	
		215	5	43.0	88.20	86.20	31.70	9.66	2.77	
		216	6	36.0	86.34	84.34	29.84	9.10	3.34	
		217	7	31.0	84.65	82.65	28.15	8.58	3.86	
		218	8	27.3	82.92	80.92	26.42	8.05	4.38	
		219	9	24.3	81.40	79.40	24.90	7.59	4.85	
		220	10	22.0	80.05	78.05	23.55	7.18	5.26	
		225	15	15.0	74.68	72.68	18.18	5.54	6.89	
		230	20	11.5	71.15	69.15	14.65	4.47	7.97	
		235	25	9.4	68.76	66.76	12.26	3.74	8.70	
		240	30	8.0	67.13	65.13	10.63	3.24	9.20	
		250	40	6.3	65.10	63.10	8.60	2.62	9.81	
		260	50	5.2	63.82	61.82	7.32	2.23	10.20	
	17:15	270	60	4.5	62.96	60.96	6.46	1.97	10.47	
		285	75	3.8	62.03	60.03	5.53	1.69	10.75	
	17:45	300	90	3.3	61.45	59.45	4.95	1.51	10.93	

TEST TYPE: Cyclic Test, Cycle 3

Date	Time	Elapsed time, min	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
13-Jul-97	17:45	0	61.45	59.45	0.00	0.00		1357.8	
		1	63.80	61.80	2.35	0.72			
		2	67.05	65.05	5.60	1.71			
		3	69.12	67.12	7.67	2.34			
		4	71.70	69.70	10.25	3.12			
		5	74.00	72.00	12.55	3.83			
		6	75.50	73.50	14.05	4.28			
		7	77.09	75.09	15.64	4.77			
		8	78.57	76.57	17.12	5.22		1391.0	
		9	79.83	77.83	18.38	5.60			
		10	81.13	79.13	19.68	6.00	3.9	1396.9	
	18:00	15	86.05	84.05	24.60	7.50		1416.1	
		20	89.45	87.45	28.00	8.53		1435.0	
		25	91.95	89.95	30.50	9.30		1453.4	
	18:15	30	93.84	91.84	32.39	9.87		1471.3	
		35	95.47	93.47	34.02	10.37		1489.5	
		40	96.85	94.85	35.40	10.79		1507.4	
		50	98.95	96.95	37.50	11.43		1542.6	
	18:45	60	100.50	98.50	39.05	11.90		1578.4	

TEST TYPE: Cyclic Test, Recovery 3

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Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, feet	Corrected DTW, feet	Drawdown feet	Drawdown meters	Recovery	Remarks
13-Jul-97	18:45	360.5	0.5	721.0	99.70	97.70	38.25	11.66	0.24	
		361	1	361.0	98.40	96.40	36.95	11.26	0.64	
		361.5	1.5	241.0	97.10	95.10	35.65	10.87	1.04	
		362	2	181.0	95.60	93.60	34.15	10.41	1.49	
		362.5	2.5	145.0	94.50	92.50	33.05	10.07	1.83	
		363	3	121.0	93.35	91.35	31.90	9.72	2.18	
		364	4	91.0	91.08	89.08	29.63	9.03	2.87	
		365	5	73.0	88.75	86.75	27.30	8.32	3.58	
		366	6	61.0	86.90	84.90	25.45	7.76	4.15	
		367	7	52.4	85.15	83.15	23.70	7.22	4.68	
		368	8	46.0	83.45	81.45	22.00	6.71	5.20	
		369	9	41.0	82.10	80.10	20.65	6.29	5.61	
		370	10	37.0	80.72	78.72	19.27	5.87	6.03	
		375	15	25.0	75.48	73.48	14.03	4.28	7.63	
		380	20	19.0	72.05	70.05	10.60	3.23	8.67	
		385	25	15.4	69.80	67.80	8.35	2.55	9.36	
		390	30	13.0	68.12	66.12	6.67	2.03	9.87	
		396	36	11.0	66.75	64.75	5.30	1.62	10.29	
		400	40	10.0	66.01	64.01	4.56	1.39	10.51	
		410	50	8.2	64.80	62.80	3.35	1.02	10.88	
	19:45	420	60	7.0	63.92	61.92	2.47	0.75	11.15	
		435	75	5.8	62.95	60.95	1.50	0.46	11.45	
	20:16	451	91	5.0	62.20	60.20	0.75	0.23	11.67	
		465	105	4.4	61.68	59.68	0.23	0.07	11.83	
		480	120	4.0	61.30	59.30	-0.15	-0.05	11.95	
		510	150	3.4	60.53	58.53	-0.92	-0.28	12.18	
	21:45	540	180	3.0	59.95	57.95	-1.50	-0.46	12.36	
		570	210	2.7	59.45	57.45	-2.00	-0.61	12.51	
	22:45	600	240	2.5	59.05	57.05	-2.40	-0.73	12.63	

PUMP TEST DATA

TEST TYPE: Slug Test
PROJECT LOCATION: East Dartmouth **MEASURING POINT:** 2 ft **PAGE: 1**

Date	Time	t (sec)	t (min)	Depth to water (feet)	Corrected DTW (feet)	Depth to water (meters)	H (feet)	H (meters)	H/Ho	Remarks
21-Jul-97	15:15	0-	0-	55.75	53.75	16.38	0	0	0	
	15:17	0+	0+	52.65	50.65	15.44	3.10	0.93	1	poured in ~ 4 gal H_2O
		15	0.25	52.70	50.70	15.45	3.05	0.66	0.71	
		45	0.75	53.58	51.58	15.72	2.17	0.65	0.70	
	15:18	60	1	53.61	51.61	15.73	2.14	0.62	0.67	
	15:19	120	2	53.70	51.70	15.76	2.05	0.59	0.64	
		150	2.5	53.80	51.80	15.79	1.95	0.55	0.60	
	15:20	180	3	53.93	51.93	15.83	1.82	0.50	0.53	
	15:21	240	4	54.12	52.12	15.89	1.63	0.44	0.47	
	15:22	300	5	54.31	52.31	15.94	1.44	0.38	0.41	
	15:23	360	6	54.50	52.50	16.00	1.25	0.36	0.39	
	15:24	420	7	54.56	52.56	16.02	1.19	0.32	0.34	
	15:25	480	8	54.71	52.71	16.07	1.04	0.29	0.31	
	15:26	540	9	54.81	52.81	16.10	0.94	0.28	0.30	
	15:27	600	10	54.84	52.84	16.11	0.91	0.24	0.26	
	15:29	720	12	54.95	52.95	16.14	0.80	0.20	0.22	
	15:32	900	15	55.08	53.08	16.18	0.67	0.15	0.16	
	15:37	1200	20	55.26	53.26	16.23	0.49	0.13	0.14	
	15:42	1500	25	55.32	53.32	16.25	0.43	0.09	0.10	
	15:47	1800	30	55.45	53.45	16.29	0.30	0.08	0.08	
	15:57	2400	40	55.50	53.50	16.31	0.25	0.06	0.07	
	16:12	3300	55	55.55	53.55	16.32	0.20	0.06	0.07	
	16:21	3840	64	55.55	53.55	16.32	0.20	0.06	0.07	
	16:32	4500	75	55.55	53.55	16.32	0.20	0	0	

PUMP TEST DATA

TEST TYPE: Step Drawdown, Step 1
PROJECT LOCATION: Waverley **MEASURING POINT:** 0.37 m **PAGE:** 1

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
16-Nov-00		0	1.750	1.380	0		274.7	
		0.25	2.030	1.660	0.280			
		0.5	2.060	1.690	0.310			
		0.75	2.110	1.740	0.360			
		1	2.120	1.750	0.370			
		1.5	2.138	1.768	0.388			
		2	2.148	1.778	0.398			
		2.5	2.140	1.770	0.390			
		3	2.130	1.760	0.380			
		3.5	2.120	1.750	0.370			
		4	2.118	1.748	0.368			
		4.5	2.118	1.748	0.368			
		5	2.230	1.860	0.480		279.0	
		5.5	2.285	1.915	0.535			
		6	2.352	1.982	0.602			
		7	2.440	2.070	0.690			
		8	2.478	2.108	0.728			
		9	2.422	2.052	0.672			
		10	2.350	1.980	0.600	1.08		
		12	2.250	1.880	0.500			
		14	2.210	1.840	0.460			
		16	2.200	1.830	0.450		meter stopped	
		18	2.200	1.830	0.450			
		20	2.200	1.830	0.450			
		22	2.200	1.830	0.450			
		24	2.200	1.830	0.450			
		26	2.205	1.835	0.455			
		28	2.205	1.835	0.455			
		30	2.210	1.840	0.460			

TEST TYPE: Step Drawdown, Step 2

PAGE: 2

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
16-Nov-00		30.5	2.250	1.880	0.500			
		31	2.275	1.905	0.525			
		31.5	2.302	1.932	0.552			
		32	2.347	1.977	0.597			
		33	2.415	2.045	0.665			
		33.5	2.486	2.116	0.736			
		34	2.510	2.140	0.760			
		34.5	2.545	2.175	0.795			
		35	2.610	2.240	0.860			
		36	2.678	2.308	0.928			
		37	2.745	2.375	0.995			
		38	2.810	2.440	1.060			
		39	2.855	2.485	1.105			
		40	2.908	2.538	1.158	2.15		
		42	3.003	2.633	1.253			
		44	3.115	2.745	1.365			
		46	3.211	2.841	1.461			
		48	3.298	2.928	1.548			
		50	3.400	3.030	1.650			
		52	3.490	3.120	1.740			
		54	3.560	3.190	1.810			
		56	3.640	3.270	1.890			
		58	3.757	3.387	2.007			
		60	3.870	3.500	2.120			

TEST TYPE: Step Drawdown, Step 3

PAGE: 3

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
16-Nov-00		63	4.645	4.275	2.895			
		63.5	4.813	4.443	3.063			
		64	4.980	4.610	3.230			
		64.5	5.160	4.790	3.410			
		65	5.347	4.977	3.597			
		65.5	5.570	5.200	3.820			
		66	5.745	5.375	3.995			
		67	6.185	5.815	4.435			
		68	6.655	6.285	4.905			
		69	7.17	6.800	5.420			
		70	7.658	7.288	5.908			
		72	8.670	8.300	6.920	3.32		
		74	9.635	9.265	7.885			
		76	10.612	10.242	8.862			
		78	11.642	11.272	9.892			
		80	12.825	12.455	11.075			
		82	13.880	13.510	12.130			
		84	14.935	14.565	13.185			
		86	16.400	16.030	14.650			
		88	16.920	16.550	15.170			
		90	18.200	17.830	16.450			

TEST TYPE: Step Drawdown, Step 4

PAGE: 4

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
16-Nov-00		91	18.452	18.082	16.702			
		91.5	18.740	18.370	16.990			
		92	19.101	18.731	17.351			
		92.5	19.540	19.170	17.790			
		93	19.968	19.598	18.218			
		93.5	20.365	19.995	18.615			
		94	20.792	20.422	19.042			
		94.5	21.230	20.860	19.480			
		95	21.602	21.232	19.852			
		96	22.505	22.135	20.755			
		97	23.450	23.080	21.700			
		98	24.210	23.840	22.460			
		99	25.072	24.702	23.322			
		100	25.860	25.490	24.110	4.38		
		102	27.595	27.225	25.845			
		104	29.120	28.750	27.370			
		106	30.848	30.478	29.098			
		108	32.400	32.030	30.650			
		110	34.050	33.680	32.300			
		112	35.595	35.225	33.845			
		114	37.125	36.755	35.375			
		116	38.580	38.210	36.830			
		118	40.140	39.770	38.390			
		120	41.680	41.310	39.930			

PUMP TEST DATA

TEST TYPE: Step Drawdown, Recovery
PROJECT LOCATION: Waverley **MEASURING POINT:** 0.37 m **PAGE:** 1

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Remarks
16-Nov-00		120.0	0	0	41.680	41.310	39.930	
		120.5	0.5	241.0	41.537	41.167	39.787	
		121.0	1	121.0	41.360	40.990	39.610	
		121.5	1.5	81.0	41.100	40.730	39.350	
		122.0	2	61.0	41.080	40.710	39.330	
		122.5	3	40.8	40.780	40.410	39.030	
		123.5	3.5	35.3	40.400	40.030	38.650	
		124.0	4	31.0	40.270	39.900	38.520	
		124.5	4.5	27.7	40.130	39.760	38.380	
		125.0	5	25.0	40.015	39.645	38.265	
		125.5	6	20.9	39.655	39.285	37.905	
		126.5	7	18.1	39.332	38.962	37.582	
		127.5	8	15.9	39.000	38.630	37.250	
		128.5	9	14.3	38.612	38.242	36.862	
		129.5	10	13.0	38.305	37.935	36.555	
		130.5	12	10.9	37.632	37.262	35.882	
		132.5	14	9.5	36.960	36.590	35.210	
		134.5	16	8.4	36.190	35.820	34.440	
		136.5	18	7.6	35.622	35.252	33.872	
		138.5	20	6.9	34.880	34.510	33.130	
		140.5	22	6.4	34.255	33.885	32.505	
		142.5	24	5.9	33.490	33.120	31.740	
		144.5	26	5.6	32.925	32.555	31.175	
		146.5	28	5.2	32.248	31.878	30.498	
		148.5	30	5.0	31.602	31.232	29.852	

TEST TYPE: Step Drawdown, Recovery (continued)

PAGE: 2

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Remarks
16-Nov-00		150.5	37	4.1	29.275	28.905	27.525	
		157.5	40	3.9	28.240	27.870	26.490	
		160.5	45	3.6	26.560	26.190	24.810	
		165.5	50	3.3	24.905	24.535	23.155	
		170.5	55	3.1	23.270	22.900	21.520	
		175.5	60	2.9	21.605	21.235	19.855	
		180.5	71	2.5	17.920	17.550	16.170	
		191.5	81	2.4	14.870	14.500	13.120	
		201.5	90	2.2	11.800	11.430	10.050	
		210.5	100	2.1	8.870	8.500	7.120	
		220.5	110	2.0	5.885	5.515	4.135	
		230.5	120	1.9	3.805	3.435	2.055	

PUMP TEST DATA

TEST TYPE: Constant Rate (CMHC) MR-1
PROJECT LOCATION: Waverley **MEASURING POINT:** 0.36m **PAGE: 1**

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water Meter Reading	Remarks
17-Nov-00	9:17	0	1.717	1.357	0		526.5	
		1	2.815	2.455	1.098			
		1.5	3.185	2.825	1.468			
		2	3.750	3.390	2.033			
		2.5	4.140	3.780	2.423			
		3	4.562	4.202	2.845			
		3.5	4.955	4.595	3.238			
		4	5.394	5.034	3.677			
		4.5	5.727	5.367	4.010			
		5	6.113	5.753	4.396			cascading
		6	7.025	6.665	5.308			
		7	7.785	7.425	6.068			
		8	8.673	8.313	6.956			
		9	9.412	9.052	7.695			
		10	10.213	9.853	8.496	4.00	566.6	
		12	11.842	11.482	10.125			
		14	13.462	13.102	11.745			
		16	14.946	14.586	13.229			
		18	16.535	16.175	14.818			
		20	18.102	17.742	16.385			
		22	19.673	19.313	17.956			
		24	21.223	20.863	19.506			
		26	22.801	22.441	21.084		625.7	
		28	24.448	24.088	22.731			
		30	26.088	25.728	24.371			
		35	29.995	29.635	28.278			

TEST TYPE: Constant Rate (CMHC) MR-1 (continued)

PAGE: 2

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water Meter Reading	Remarks
17-Nov-00	9:57	40	33.713	33.353	31.996			
		45	37.403	37.043	35.686			
		50	41.214	40.854	39.497			
	10:12	55	45.588	45.228	43.871		732.5	
	10:17	60	49.058	48.698	47.341		751.8	

PUMP TEST DATA

TEST TYPE: Constant Rate (CMHC) MR-1, Recovery
PROJECT LOCATION: Waverley **MEASURING POINT:** 0.36 m **PAGE: 1**

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Recovery meters	Remarks
17-Nov-00	10:17	60.00	0	0	49.058	48.698	47.341	0	
		60.50	0.5	121.000	49.610	49.250	47.893	-0.552	
		61.00	0.75	81.333	49.530	49.170	47.813	-0.472	
		61.25	1	61.250	49.400	49.040	47.683	-0.342	
		61.50	1.5	41.000	49.295	48.935	47.578	-0.237	
		62.00	1.75	35.429	49.237	48.877	47.520	-0.179	
		62.25	2	31.125	49.163	48.803	47.446	-0.105	
		62.50	2.5	25.000	49.011	48.651	47.294	0.047	
		63.00	3	21.000	48.880	48.520	47.163	0.178	
		63.50	3.5	18.143	48.716	48.356	46.999	0.342	
		64.00	4	16.000	48.560	48.200	46.843	0.498	
		64.50	4.5	14.333	48.430	48.070	46.713	0.628	
		65.00	5	13.000	48.270	47.910	46.553	0.788	
		65.50	6	10.917	48.007	47.647	46.290	1.051	
		66.50	7	9.500	47.575	47.215	45.858	1.483	
		67.50	8	8.438	47.403	47.043	45.686	1.655	
		68.50	9	7.611	47.080	46.720	45.363	1.978	
		69.50	10	6.950	46.815	46.455	45.098	2.243	
		70.50	12	5.875	46.224	45.864	44.507	2.834	
		72.50	14	5.179	45.658	45.298	43.941	3.400	
		74.50	16	4.656	45.306	44.946	43.589	3.752	
		76.50	18	4.250	44.431	44.071	42.714	4.627	
		78.50	20	3.925	43.872	43.512	42.155	5.186	
		80.50	22	3.659	43.283	42.923	41.566	5.775	
		82.50	24	3.438	42.718	42.358	41.001	6.340	

TEST TYPE: Constant Rate (CMHC) MR-1, Recovery (continued)

PAGE: 2

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Recovery meters	Remarks
17-Nov-00	10:17	84.50	26	3.250	42.216	41.856	40.499	6.842	
		86.50	28	3.089	41.536	41.176	39.819	7.522	
		88.50	30	2.950	40.954	40.594	39.237	8.104	
		90.50	35	2.586	39.448	39.088	37.731	9.610	
		95.50	40	2.388	37.985	37.625	36.268	11.073	
		100.50	45	2.233	36.519	36.159	34.802	12.539	
		105.50	50	2.110	35.043	34.683	33.326	14.015	
		110.50	55	2.009	33.594	33.234	31.877	15.464	
		115.50	60	1.925	32.168	31.808	30.451	16.890	
		120.50	75	1.607	27.842	27.482	26.125	21.216	
		135.50	90	1.506	23.554	23.194	21.837	25.504	
		150.50	105	1.433	19.338	18.978	17.621	29.720	
	12:17	165.50	120	1.379	15.222	14.862	13.505	33.836	
		180.50	150	1.203	7.226	6.866	5.509	41.832	
		210.50	180	1.169	2.440	2.080	0.723	46.618	
		240.50	210	1.145	1.803	1.443	0.086	47.255	
		270.50	225	1.202	1.790	1.430	0.073	47.268	

PUMP TEST DATA

TEST TYPE: Constant Rate MR-2
PROJECT LOCATION: Waverley **MEASURING POINT:** 0.33 m **PAGE:** 1

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water Meter Reading	Remarks
18-Nov-00	7:12	0	1.698	1.368	0		751.9	
		0.5	1.980	1.650	0.282			
		1	2.103	1.773	0.405			
		1.5	2.223	1.893	0.525			
		2	2.274	1.944	0.576			
		2.5	2.334	2.004	0.636			
		3	2.387	2.057	0.689			
		3.5	2.414	2.084	0.716			
		4	2.456	2.126	0.758			
		4.5	2.483	2.153	0.785			
		5	2.523	2.193	0.825			
		5.5	2.554	2.224	0.856			
		6	2.587	2.257	0.889			
		6.5	2.624	2.294	0.926			
		7	2.637	2.307	0.939			
		7.5	2.702	2.372	1.004			
		8	2.713	2.383	1.015			
		8.5	2.732	2.402	1.034			
		9	2.768	2.438	1.070			
		9.5	2.787	2.457	1.089			
		10	2.847	2.517	1.149	1.25		
		10.5	2.895	2.565	1.197			
		11	2.860	2.530	1.162			
		11.5	2.878	2.548	1.180			
		12	2.900	2.570	1.202			

TEST TYPE: Constant Rate MR-2 (continued)

PAGE: 2

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water Meter Reading	Remarks
18-Nov-00		12.5	2.916	2.586	1.218	1.25		
		13	2.922	2.592	1.224			
		13.5	2.938	2.608	1.240			
		14	2.952	2.622	1.254			
		16	3.023	2.693	1.325			
		18	3.082	2.752	1.384			
		20	3.132	2.802	1.434			
		22	3.160	2.830	1.462			
		24	3.196	2.866	1.498			
		26	3.251	2.921	1.553		625.7	
		28	3.262	2.932	1.564			
		30	3.280	2.950	1.582			
		35	3.331	3.001	1.633			
		40	3.386	3.056	1.688			
		45	3.434	3.104	1.736			
		50	3.468	3.138	1.770			
		55	3.482	3.152	1.784		732.5	
		60	3.503	3.173	1.805		751.8	
		75	3.751	3.421	2.053			
		90	4.271	3.941	2.573		859.8	
	9:15	120	4.485	4.155	2.787			
	9:44	150	4.877	4.547	3.179			
	10:14	180	4.976	4.646	3.278			
	10:44	210	5.332	5.002	3.634			
	11:14	240	5.390	5.060	3.692			
	11:44	270	5.472	5.142	3.774			
	12:14	300	5.476	5.146	3.778			

TEST TYPE: Constant Rate MR-2 (continued)

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Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water Meter Reading	Remarks
18-Nov-00	12:44	330	5.534	5.204	3.836	1.25		
	12:14	360	5.617	5.287	3.919			

PUMP TEST DATA

TEST TYPE: Constant Rate MR-2, Recovery
PROJECT LOCATION: Waverley **MEASURING POINT:** 0.33 m **PAGE: 1**

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Recovery meters	Remarks
18-Nov-00	12:14	360.00	0		5.617	5.287	3.919	0	
		360.25	0.25	1441.00	5.533	5.203	3.835	0.084	
		360.50	0.5	721.00	5.450	5.120	3.752	0.167	
		360.75	0.75	481.00	5.370	5.040	3.672	0.247	
		361.00	1	361.00	5.296	4.966	3.598	0.321	
		361.50	1.5	241.00	5.140	4.810	3.442	0.477	
		362.00	2	181.00	4.983	4.653	3.285	0.634	
		362.50	2.5	145.00	4.836	4.506	3.138	0.781	
		363.00	3	121.00	4.700	4.370	3.002	0.917	
		363.50	3.5	103.86	4.556	4.226	2.858	1.061	
		364.00	4	91.00	4.417	4.087	2.719	1.200	
		364.50	4.5	81.00	4.293	3.963	2.595	1.324	
		365.00	5	73.00	4.181	3.851	2.483	1.436	
		366.00	6	61.00	3.928	3.598	2.230	1.689	
		367.00	7	52.43	3.706	3.376	2.008	1.911	
		368.00	8	46.00	3.500	3.170	1.802	2.117	
		369.00	9	41.00	3.307	2.977	1.609	2.310	
		370.00	10	37.00	3.133	2.803	1.435	2.484	
		372.00	12	31.00	2.827	2.497	1.129	2.790	
		374.00	14	26.71	2.570	2.240	0.872	3.047	
		376.00	16	23.50	2.367	2.037	0.669	3.250	
		378.00	18	21.00	2.213	1.883	0.515	3.404	
		380.00	20	19.00	2.097	1.767	0.399	3.520	
		382.00	22	17.36	2.016	1.686	0.318	3.601	
		384.00	24	16.00	1.966	1.636	0.268	3.651	

TEST TYPE: Constant Rate MR-2, Recovery (continued)									**PAGE: 2**
Date	**Time**	**t**	**Elapsed time, min t'**	**t/t'**	**Depth to water, meters**	**Corrected DTW, meters**	**Drawdown meters**	**Recovery meters**	**Remarks**
18-Nov-00		386.00	26	14.85	1.935	1.605	0.237	3.682	
		388.00	28	13.86	1.921	1.591	0.223	3.696	
		390.00	30	13.00	1.912	1.582	0.214	3.705	
		395.00	35	11.29	1.891	1.561	0.193	3.726	
		405.00	45	9.00	1.881	1.551	0.183	3.736	
		410.00	50	8.20	1.861	1.531	0.163	3.756	
		415.00	55	7.55	1.852	1.522	0.154	3.765	
		420.00	60	7.00	1.845	1.515	0.147	3.772	
		435.00	75	5.80	1.830	1.500	0.132	3.787	
		450.00	90	5.00	1.821	1.491	0.123	3.796	
		465.00	105	4.43	1.810	1.480	0.112	3.807	
		480.00	120	4.00	1.800	1.470	0.102	3.817	

PUMP TEST DATA

TEST TYPE: Cyclic Test, Cycle 1
PROJECT LOCATION: Waverley **MEASURING POINT:** 0.33 m **PAGE: 1**

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
19-Nov-00		0	1.812	1.482	0			
	7:18	0.5	2.114	1.784	0.302			
		0.75	2.412	2.082	0.600			
		1	2.581	2.251	0.769			
		1.5	2.855	2.525	1.043			
		2	3.110	2.780	1.298			
		2.5	3.363	3.033	1.551			
		3	3.602	3.272	1.790			
		3.5	3.841	3.511	2.029			
		4	4.073	3.743	2.261			
		4.5	4.348	4.018	2.536			
		5	4.588	4.258	2.776			
		5.5	4.739	4.409	2.927			
		6	4.923	4.593	3.111			
		7	5.341	5.011	3.529			
		8	5.694	5.364	3.882			
		9	6.072	5.742	4.260			cascading
		10	6.424	6.094	4.612	2.5		
		12	7.144	6.814	5.332			
		14	7.902	7.572	6.090			
		16	8.597	8.267	6.785			
		18	9.273	8.943	7.461			
		20	9.916	9.586	8.104			
		22	10.571	10.241	8.759			
	7:42	24	11.214	10.884	9.402			

TEST TYPE: Cyclic Test, Cycle 1 (continued)								**PAGE: 2**
Date	**Time**	**Elapsed time, min**	**Depth to water, meters**	**Corrected DTW, meters**	**Drawdown meters**	**Q=discharge gpm**	**Water meter reading**	**Remarks**
19-Nov-00	7:44	26	11.920	11.590	10.108	2.5		
		28	12.591	12.261	10.779			
		30	13.246	12.916	11.434			
		35	14.806	14.476	12.994			
		40	16.303	15.973	14.491			
		45	17.706	17.376	15.894			
		50	20.251	19.921	18.439			
		55	20.727	20.397	18.915			
	8:18	60	22.010	21.680	20.198			

PUMP TEST DATA

TEST TYPE: Cyclic Test, Recovery 1
PROJECT LOCATION: Waverley **MEASURING POINT:** 0.33 m **PAGE: 3**

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Recovery meters	Remarks
19-Nov-00	8:18	60	0	0	22.010	21.680	20.198	0	
		60.25	0.25	241.00	21.940	21.610	20.268	-0.070	
		60.5	0.5	121.00	21.840	21.510	20.168	0.030	
		60.75	0.75	81.00	21.723	21.393	20.051	0.147	
		61	1	61.00	21.622	21.292	19.950	0.248	
		61.5	1.5	41.00	21.418	21.088	19.746	0.452	
		62	2	31.00	21.211	20.881	19.539	0.659	
		62.5	2.5	25.00	20.998	20.668	19.326	0.872	
		63	3	21.00	20.792	20.462	19.120	1.078	
	8:21	63.5	3.5	18.14	20.580	20.250	18.908	1.290	
		64	4	16.00	20.371	20.041	18.699	1.499	
		64.5	4.5	14.33	20.168	19.838	18.496	1.702	
		65	5	13.00	19.970	19.640	18.298	1.900	
		66	6	11.00	19.540	19.210	17.868	2.330	
		67	7	9.57	19.135	18.805	17.463	2.735	
		68	8	8.50	18.716	18.386	17.044	3.154	
		69	9	7.67	18.291	17.961	16.619	3.579	
		70	10	7.00	17.910	17.580	16.238	3.960	
		72	12	6.00	17.873	17.543	16.201	3.997	
		74	14	5.29	16.260	15.930	14.588	5.610	
		76	16	4.75	15.432	15.102	13.760	6.438	
		78	18	4.33	14.621	14.291	12.949	7.249	
		80	20	4.00	13.827	13.497	12.155	8.043	
		82	22	3.73	13.013	12.683	11.341	8.857	
	8:42	84	24	3.50	12.183	11.853	10.511	9.687	

TEST TYPE: Cyclic Test, Recovery 1 (continued)

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Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Recovery meters	Remarks
19-Nov-00	8:44	86	26	3.31	11.382	11.052	9.710	10.488	
		88	28	3.14	10.587	10.257	8.915	11.283	
		90	30	3.00	9.815	9.485	8.143	12.055	
		95	35	2.71	7.915	7.585	6.243	13.955	
		100	40	2.50	6.038	5.708	4.366	15.832	
		105	45	2.33	4.550	4.220	2.878	17.320	
		110	50	2.20	3.443	3.113	1.771	18.427	
		115	55	2.09	2.667	2.337	0.995	19.203	
	9:18	120	60	2.00	2.200	1.870	0.528	19.670	

TEST TYPE: Cyclic Test, Cycle 2

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
19-Nov-00	9:18	0	2.200	1.870	0			
		0.25	2.482	2.152	0.282			
		0.5	2.693	2.363	0.493			
		1	2.938	2.608	0.738			
		1.5	3.257	2.927	1.057			
		2	3.511	3.181	1.311			
		2.5	3.761	3.431	1.561			
		3	4.031	3.701	1.831			
		3.5	4.308	3.978	2.108			
		4	4.555	4.225	2.355			
		4.5	4.735	4.405	2.535			
		5	4.990	4.660	2.790			
		6	5.395	5.065	3.195	2.5		
		7	5.807	5.477	3.607			
		8	6.180	5.850	3.980			cascading
		9	6.570	6.240	4.370			
		10	6.958	6.628	4.758			
		12	7.718	7.388	5.518			
		14	8.457	8.127	6.257			
		16	9.168	8.838	6.968			
		18	9.807	9.477	7.607			
		20	10.447	10.117	8.247			
		22	11.156	10.826	8.956			
		24	11.905	11.575	9.705			
		26	12.600	12.270	10.400			
		28	13.236	12.906	11.036			
	9:48	30	13.875	13.545	11.675			

TEST TYPE: Cyclic Test, Cycle 2 (continued)

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
19-Nov-00	9:53	35	14.372	14.042	12.172	2.5		
		40	16.818	16.488	14.618			
		45	18.184	17.854	15.984			
		50	19.626	19.296	17.426			
		55	21.316	20.986	19.116			
	10:18	60	22.910	22.580	20.710			

TEST TYPE: Cyclic Test, Recovery 2

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Recovery meters	Remarks
19-Nov-00	10:18	180	0	0.000	22.910	22.580	20.710	0	
		180.25	0.25	721.000	23.090	22.760	20.890	-0.180	
		180.5	0.5	361.000	22.987	22.657	20.787	-0.077	
		180.75	0.75	241.000	22.875	22.545	20.675	0.035	
		181	1	181.000	22.771	22.441	20.571	0.139	
		181.5	1.5	121.000	22.562	22.232	20.362	0.348	
		182	2	91.000	22.366	22.036	20.166	0.544	
		182.5	2.5	73.000	22.163	21.833	19.963	0.747	
		183	3	61.000	21.973	21.643	19.773	0.937	
		183.5	3.5	52.429	21.762	21.432	19.562	1.148	
		184	4	46.000	21.567	21.237	19.367	1.343	
		184.5	4.5	41.000	21.367	21.037	19.167	1.543	
		185	5	37.000	21.166	20.836	18.966	1.744	
		186	6	31.000	20.760	20.430	18.560	2.150	
		187	7	26.714	20.348	20.018	18.148	2.562	
		188	8	23.500	19.954	19.624	17.754	2.956	
		189	9	21.000	19.550	19.220	17.350	3.360	
		190	10	19.000	19.143	18.813	16.943	3.767	
		192	12	16.000	18.352	18.022	16.152	4.558	
		194	14	13.857	17.568	17.238	15.368	5.342	
		196	16	12.250	16.765	16.435	14.565	6.145	
		198	18	11.000	15.970	15.640	13.770	6.940	
		200	20	10.000	14.940	14.610	12.740	7.970	
		202	22	9.182	14.409	14.079	12.209	8.501	
		204	24	8.500	13.625	13.295	11.425	9.285	
		206	26	7.923	12.855	12.525	10.655	10.055	
	10:46	208	28	7.429	12.045	11.715	9.845	10.865	

TEST TYPE: Cyclic Test, Recovery 2 (continued)

PAGE: 8

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Recovery meters	Remarks
19-Nov-00	10:48	210	30	7.000	11.285	10.955	9.085	11.625	
		215	35	6.143	9.423	9.093	7.223	13.487	
		220	40	5.500	7.581	7.251	5.381	15.329	
		225	45	5.000	5.905	5.575	3.705	17.005	
		230	50	4.600	4.457	4.127	2.257	18.453	
		235	55	4.273	3.370	3.040	1.170	19.540	
	11:18	240	60	4.000	2.711	2.381	0.511	20.199	

TEST TYPE: Cyclic Test, Cycle 3

PAGE: 9

Date	Time	Elapsed time, min	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Q=discharge gpm	Water meter reading	Remarks
19-Nov-00	11:18	0	2.711	2.381	0			
		0.5	3	2.670	0.289			
		0.75	3.78	3.450	1.069			
		2	4.056	3.726	1.345			
		3	4.561	4.231	1.850			
		3.5	4.796	4.466	2.085			
		4	4.992	4.662	2.281			
		4.5	5.237	4.907	2.526			
		5	5.473	5.143	2.762			
		6	5.878	5.548	3.167			
		7	6.325	5.995	3.614			cascading
		8	6.756	6.426	4.045			
		9	7.091	6.761	4.380			
		10	7.558	7.228	4.847	2.5		
		12	8.753	8.423	6.042			
		14	9.156	8.826	6.445			
		16	9.864	9.534	7.153			
		18	10.703	10.373	7.992			
		20	11.297	10.967	8.586			
		22	12.114	11.784	9.403			
		24	12.794	12.464	10.083			
		26	13.512	13.182	10.801			
		28	14.201	13.871	11.490			
		30	14.931	14.601	12.220			
		35	16.776	16.446	14.065			
		40	18.454	18.124	15.743			
	12:03	45	20.156	19.826	17.445			

TEST TYPE: Cyclic Test, Cycle 3 (continued)								**PAGE: 10**
Date	**Time**	**Elapsed time, min**	**Depth to water, meters**	**Corrected DTW, meters**	**Drawdown meters**	**Q=discharge gpm**	**Water meter reading**	**Remarks**
19-Nov-00	12:08	50	21.845	21.515	19.134	2.5		
		55	23.621	23.291	20.910			
	12:18	60	25.075	24.745	22.364			

TEST TYPE: Cyclic Test, Recovery 3

PAGE: 11

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Recovery meters	Remarks
19-Nov-00	12:18	300	0	0	25.075	24.745	22.364	0	
		300.25	0.25	1201.000	25.000	24.670	22.439	-0.075	
		300.5	0.5	601.000	24.911	24.581	22.350	0.014	
		300.75	0.75	401.000	24.800	24.470	22.239	0.125	
		301	1	301.000	24.705	24.375	22.144	0.220	
		301.5	1.5	201.000	24.491	24.161	21.930	0.434	
		302	2	151.000	24.321	23.991	21.760	0.604	
		302.5	2.5	121.000	24.115	23.785	21.554	0.810	
		303	3	101.000	23.952	23.622	21.391	0.973	
		303.5	3.5	86.714	23.684	23.354	21.123	1.241	
		304	4	76.000	23.492	23.162	20.931	1.433	
		304.5	4.5	67.667	23.302	22.972	20.741	1.623	
		305	5	61.000	23.121	22.791	20.560	1.804	
		306	6	51.000	22.751	22.421	20.190	2.174	
		307	7	43.857	22.356	22.026	19.795	2.569	
		308	8	38.500	21.953	21.623	19.392	2.972	
		309	9	34.333	21.541	21.211	18.980	3.384	
		310	10	31.000	21.148	20.818	18.587	3.777	
		312	12	26.000	20.382	20.052	17.821	4.543	
		314	14	22.429	19.601	19.271	17.040	5.324	
		316	16	19.750	18.868	18.538	16.307	6.057	
		318	18	17.667	18.017	17.687	15.456	6.908	
		320	20	16.000	17.211	16.881	14.650	7.714	
		322	22	14.636	16.487	16.157	13.926	8.438	
		324	24	13.500	15.756	15.426	13.195	9.169	
		326	26	12.538	14.876	14.546	12.315	10.049	
	12:46	328	28	11.714	14.156	13.826	11.595	10.769	

TEST TYPE: Cyclic Test, Recovery 3 (continued)

PAGE: 12

Date	Time	t	Elapsed time, min t'	t/t'	Depth to water, meters	Corrected DTW, meters	Drawdown meters	Recovery meters	Remarks
19-Nov-00	12:48	330	30	11.000	13.347	13.017	10.786	11.578	
		335	35	9.571	11.387	11.057	8.826	13.538	
		340	40	8.500	9.612	9.282	7.051	15.313	
		345	45	7.667	7.803	7.473	5.242	17.122	
		350	50	7.000	6.036	5.706	3.475	18.889	
		355	55	6.455	4.657	4.327	2.096	20.268	
	13:18	360	60	6.000	3.551	3.221	0.99	21.374	
		375	75	5.000	2.052	1.722	-0.509	22.873	
	13:48	390	90	4.333	1.914	1.584	-0.647	23.011	
		405	105	3.857	1.881	1.551	-0.68	23.044	
	14:18	420	120	3.500	1.877	1.547	-0.684	23.048	
		450	150	3.000	1.840	1.510	-0.721	23.085	
	15:18	480	180	2.667	1.825	1.495	-0.736	23.100	

PUMP TEST DATA

TEST TYPE: Slug Test 1
PROJECT LOCATION: Waverley   **MEASURING POINT:** 0.37 m   **PAGE:** 1

Date	Time	t (sec)	t (min)	Depth to water (meters)	Corrected DTW (meters)	H (meters)	H/Ho	Remarks
17-Nov-00		0-	0-	1.750	1.380	0	0	
		0+	0+	0.915	0.545	0.835	1	added ~ 4 gal H_2O
		4.98	0.083	0.996	0.626	0.754	0.903	
		37.02	0.617	1.125	0.755	0.625	0.749	
		64.98	1.083	1.261	0.891	0.489	0.586	
		79.98	1.333	1.335	0.965	0.415	0.497	
		94.98	1.583	1.380	1.010	0.370	0.443	
		120	2	1.470	1.100	0.280	0.335	
		135	2.25	1.520	1.150	0.230	0.275	
		150	2.5	1.545	1.175	0.205	0.246	
		165	2.75	1.572	1.202	0.178	0.213	
		180	3	1.595	1.225	0.155	0.186	
		195	3.25	1.622	1.252	0.128	0.153	
		210	3.5	1.636	1.266	0.114	0.137	
		225	3.75	1.650	1.280	0.100	0.120	
		240	4	1.663	1.293	0.087	0.104	
		255	4.25	1.670	1.300	0.080	0.096	
		270	4.5	1.682	1.312	0.068	0.081	
		285	4.75	1.685	1.315	0.065	0.078	
		300	5	1.689	1.319	0.061	0.073	
		330	5.5	1.698	1.328	0.052	0.062	
		390	6.5	1.705	1.335	0.045	0.054	
		420	7	1.710	1.340	0.040	0.048	
		480	8	1.716	1.346	0.034	0.041	
		510	8.5	1.720	1.350	0.030	0.036	

TEST TYPE: Slug Test 1 (continued)								**PAGE: 2**
Date	**Time**	**t** (sec)	**t** (min)	**Depth to water** (meters)	**Corrected DTW** (meters)	**H** (meters)	**H/Ho**	**Remarks**
17-Nov-00		540	9	1.722	1.352	0.028	0.034	
		570	9.5	1.730	1.360	0.020	0.024	
		600	10	1.732	1.362	0.018	0.022	
		630	10.5	1.725	1.355	0.025	0.030	
		660	11	1.725	1.355	0.025	0.030	
		720	12	1.733	1.363	0.017	0.020	
		780	13	1.734	1.364	0.016	0.019	
		840	14	1.732	1.362	0.018	0.022	
		900	15	1.732	1.362	0.018	0.022	
		960	16	1.731	1.361	0.019	0.023	
		1020	17	1.730	1.360	0.020	0.024	
		1080	18	1.730	1.360	0.020	0.024	
		1140	19	1.730	1.360	0.020	0.024	
		1200	20	1.731	1.361	0.019	0.023	

PUMP TEST DATA

TEST TYPE: Slug Test 2

PROJECT LOCATION: Waverley **MEASURING POINT:** 0.37 m **PAGE:** 1

Date	Time	t (sec)	t (min)	Depth to water (meters)	Corrected DTW (meters)	H (meters)	H/Ho	Remarks
17-Nov-00	14:33	0-	0-	1.725	1.355	0	0	
		0+	0+	0.883	0.513	0.842	1	added ~ 4 gal H_2O
		15	0.25	1.002	0.632	0.723	0.859	
		30	0.5	1.077	0.707	0.648	0.770	
		45	0.75	1.170	0.800	0.555	0.659	
		60	1	1.245	0.875	0.480	0.570	
		75	1.25	1.310	0.940	0.415	0.493	
		90	1.5	1.361	0.991	0.364	0.432	
		105	1.75	1.415	1.045	0.310	0.368	
		120	2	1.461	1.091	0.264	0.314	
		135	2.25	1.499	1.129	0.226	0.268	
		150	2.5	1.532	1.162	0.193	0.229	
		165	2.75	1.557	1.187	0.168	0.200	
		180	3	1.583	1.213	0.142	0.169	
		195	3.25	1.600	1.230	0.125	0.148	
		210	3.5	1.615	1.245	0.110	0.131	
		225	3.75	1.630	1.260	0.095	0.113	
		240	4	1.642	1.272	0.083	0.099	
		255	4.25	1.650	1.280	0.075	0.089	
		270	4.5	1.655	1.285	0.070	0.083	
		285	4.75	1.666	1.296	0.059	0.070	
		300	5	1.670	1.300	0.055	0.065	
		315	5.25	1.674	1.304	0.051	0.061	
		330	5.5	1.674	1.304	0.051	0.061	
	14:38	345	5.75	1.679	1.309	0.046	0.055	

TEST TYPE: Slug Test 2 (continued)

PAGE: 2

Date	Time	t (sec)	t (min)	Depth to water (meters)	Corrected DTW (meters)	H (meters)	H/Ho	Remarks
17-Nov-00	14:39	360	6	1.681	1.311	0.044	0.052	
		375	6.25	1.686	1.316	0.039	0.046	
		390	6.5	1.689	1.319	0.036	0.043	
		405	6.75	1.690	1.320	0.035	0.042	
		420	7	1.690	1.320	0.035	0.042	
		450	7.5	1.691	1.321	0.034	0.040	
		480	8	1.693	1.323	0.032	0.038	
		510	8.5	1.695	1.325	0.030	0.036	
		540	9	1.697	1.327	0.028	0.033	
		570	9.5	1.698	1.328	0.027	0.032	
		600	10	1.703	1.333	0.022	0.026	
		660	11	1.702	1.332	0.023	0.027	
		720	12	1.702	1.332	0.023	0.027	
		780	13	1.707	1.337	0.018	0.021	
		840	14	1.709	1.339	0.016	0.019	
		900	15	1.711	1.341	0.014	0.017	
		960	16	1.711	1.341	0.014	0.017	
		1020	17	1.712	1.342	0.013	0.015	
		1080	18	1.712	1.342	0.013	0.015	
		1140	19	1.713	1.343	0.012	0.014	
	14:53	1200	20	1.712	1.342	0.013	0.015	

APPENDIX 3

VAULES OF THE THEIS WELL FUNCTION W(u)

FOR VARIOUS VALUES OF (u)

Values of the Theis well function W(u) for various values of u.

u	W(u)	u	W(u)	u	W(u)	u	W(u)	u	W(u)	u	W(u)
1 X 10^{-15}	33.96	1 X 10^{-12}	27.05	1 X 10^{-9}	20.15	1 X 10^{-6}	13.24	1 X 10^{-3}	6.33	1 X 10^{-0}	0.219
2	33.27	2	26.36	2	19.45	2	12.55	2	5.64	2	0.049
3	32.86	3	25.96	3	19.05	3	12.14	3	5.23	3	0.013
4	32.58	4	25.67	4	18.76	4	11.85	4	4.95	4	0.0037
5	32.35	5	25.44	5	18.54	5	11.63	5	4.73	5	0.0014
6	32.17	6	25.26	6	18.35	6	11.45	6	4.54	6	0.0003601
7	32.02	7	25.11	7	18.2	7	11.29	7	4.39	7	0.00011
8	31.88	8	24.97	8	18.07	8	11.16	8	4.26	8	0.000037
9	31.76	9	24.86	9	17.95	9	11.04	9	4.14	9	0.000012
1 X 10^{-14}	31.66	1 X 10^{-11}	24.75	1 X 10^{-8}	17.84	1 X 10^{-5}	10.94	1 X 10^{-2}	4.04		
2	30.97	2	24.06	2	17.15	2	10.24	2	3.35		
3	30.56	3	23.65	3	16.74	3	9.84	3	2.96		
4	30.27	4	23.36	4	16.46	4	9.55	4	2.68		
5	30.05	5	23.14	5	16.23	5	9.33	5	2.47		
6	29.87	6	22.96	6	16.05	6	9.14	6	2.3		
7	29.71	7	22.81	7	15.9	7	8.99	7	2.15		
8	29.58	8	22.67	8	15.76	8	8.86	8	2.03		
9	29.46	9	22.55	9	15.65	9	8.74	9	1.92		
1 X 10^{-13}	29.36	1 X 10^{-10}	22.45	1 X 10^{-7}	15.54	1 X 10^{-4}	8.63	1 X 10^{-1}	1.823		
2	28.66	2	21.76	2	14.85	2	7.94	2	1.223		
3	28.26	3	21.35	3	14.44	3	7.53	3	0.906		
4	27.97	4	21.06	4	14.15	4	7.25	4	0.702		
5	27.75	5	20.84	5	13.93	5	7.02	5	0.56		
6	27.56	6	20.66	6	13.75	6	6.84	6	0.454		
7	27.41	7	20.5	7	13.6	7	6.69	7	0.374		
8	27.28	8	20.37	8	13.46	8	6.55	8	0.311		
9	27.16	9	20.25	9	13.34	9	6.44	9	0.26		

APPENDIX 4

VALUES OF THE FUCTION $F(u_{vf})$ FOR

DIFFERENT VALUES OF (u_{vf})

Values of the function $F(u_{vf})$ for different values of u_{vf} (after Gringarten, Ramey and Raghavan, 1975).

u_{vf}	$F(u_{vf})$	u_{vf}	$F(u_{vf})$
0.01	0.3544	10	5.1200
0.015	0.4342	15	5.5226
0.02	0.5014	20	5.8090
0.03	0.6140	30	6.2130
0.04	0.7090	40	6.5000
0.05	0.7926	50	6.7228
0.06	0.8680	60	6.9048
0.08	1.0010	80	7.1922
0.1	1.1170	100	7.4150
0.15	1.3580	150	7.8202
0.2	1.5510	200	8.1078
0.3	1.8520	300	8.5132
0.4	2.0830	400	8.8008
0.5	2.2100	500	9.0238
0.6	2.4290	600	9.2062
0.8	2.6850	800	9.4938
1	2.8890	1000	9.7168
1.5	3.2690	1500	10.1224
2	3.5430	2000	10.4100
3	3.9350	3000	10.8154
4	4.2160	4000	11.1032
5	4.4350	5000	11.3262
6	4.6150	6000	11.5086
8	4.8990	8000	11.7962