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and Labrador
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Government
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Environment Canada
Inland Waters Directorate
Dartmouth, Nova Scotia
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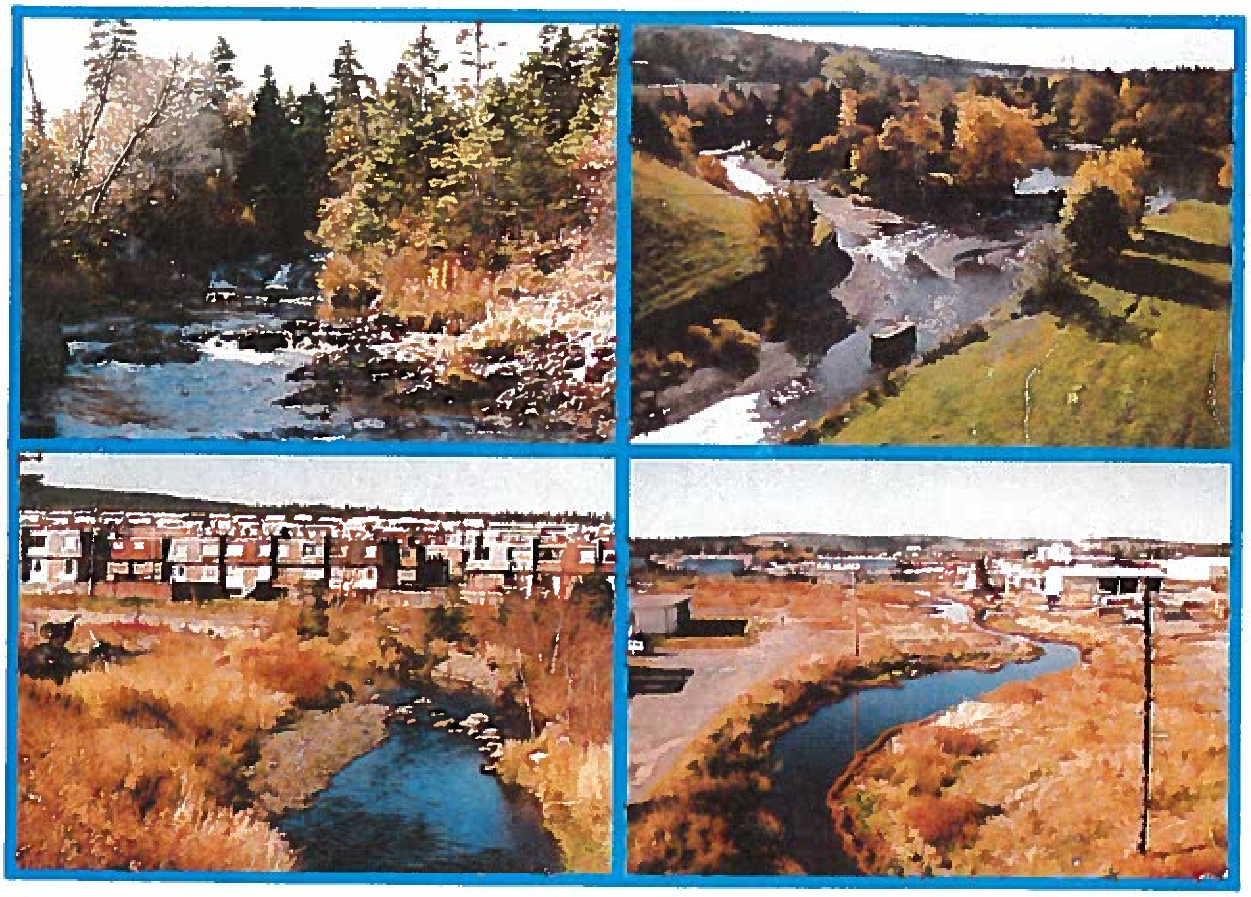
INSTALLATION AND TESTING OF THE MONITORING WELL NETWORK



Urban Hydrology Study of the Waterford River Basin

TECHNICAL REPORT No.

UHS-WRB 1.7

WATERFORD RIVER BASIN URBAN HYDROLOGY STUDY

INSTALLATION AND TESTING
OF
THE MONITORING WELL NETWORK

By

J.W. Robinson

Groundwater Resources Manager

WATER RESOURCES DIVISION REPORT UHS - WRB 1.7

GROUNDWATER BRANCH

DEPARTMENT OF ENVIRONMENT

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1.0 INTRODUCTION

The Waterford River Basin covers an area of about 61 km^2 and is situated immediately west-southwest of the City of St. John's, Newfoundland, (Figure 1.1). In addition to its proximity to this major urban centre, the established communities of Mount Pearl and Kilbride and the developing community of Newtown are located within the basin area. Each of these centres applies development pressure on the land within the catchment. It was for this reason that a joint Federal-Provincial study of urban hydrology was conducted in this basin. The Waterford River Basin Urban Hydrology Study was started in 1980 by the Canada and Newfoundland Departments of Environment to determine the effects of urban development on the water resources of the study area. Only the basin area above the Waterford Bridge Road bridge was included in this study. As an integral part of the study, a monitoring well network was established to allow groundwater sampling on a long-term basis for the determination of subsurface water quality. These wells also helped to characterize the geology, the groundwater flow systems and the hydraulic character of the bedrock and overburden formations.

The purpose of this report is to present the results of the work that was done to achieve the objectives of the groundwater study. This work involved four stages, the last two of which were concurrent. These included planning, installation, hydraulic testing and water quality testing. Each of these stages is described in detail in the following sections. The contents of this report will be useful to consulting firms as a technical aid for the planning, implementation and reporting of various hydrogeologic investigations in which they may become involved.

2.0 PLANNING THE MONITORING WELL NETWORK

2.1 Objectives

The main objective of the groundwater component of the aforementioned study was to determine the impact of urbanization on groundwater

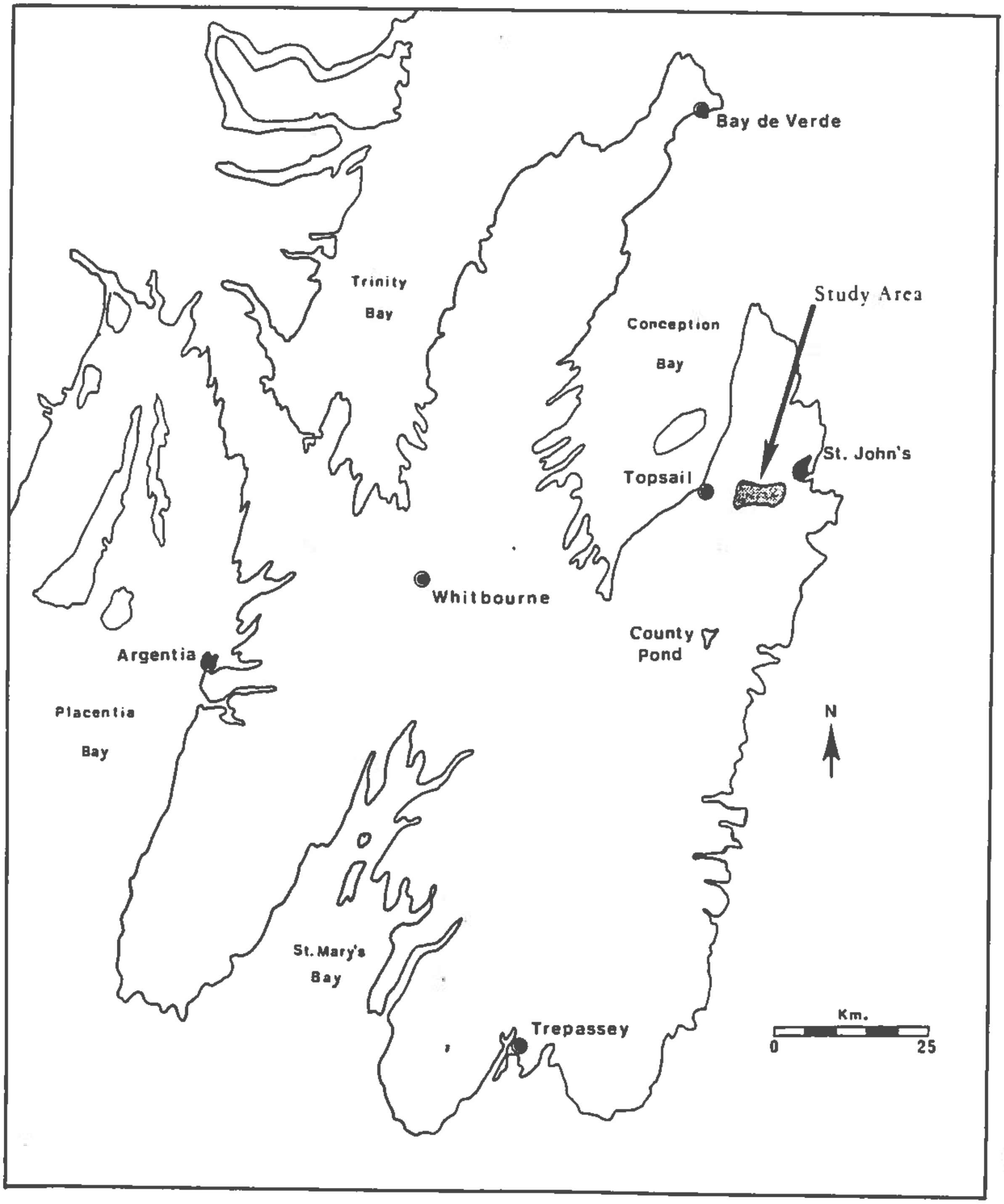


Figure 1.1. Location of the Waterford River Basin (after Batterson, 1984)

in terms of both quantity and quality. Due to lack of data on existing wells in the basin it was subsequently decided that the major emphasis of the study would be upon water quality. The drilling program was, therefore, designed for the installation of monitoring wells and not for the assessment of groundwater resources. To be sure, as much information as possible was obtained from the appropriate testing of each well but the site was chosen for determining water quality not the hydraulic properties of the aquifers.

The purpose of the monitoring well network was to provide sampling stations from which representative groundwater samples could be obtained. The network was designed to reflect the effects of the major land use categories found in the study area. In order to determine the impact that a particular land use has on the groundwater quality, water samples had to be obtained both upstream and downstream of the selected land uses. Placement of the monitoring wells at suitable locations required specific information on land use classification and the orientation of groundwater flow. These two aspects are discussed in the following parts of this section.

2.2 Land Use in the Waterford River Basin

Land use activity in the Waterford River Basin ranges widely from wilderness to light industrial. In addition, many small pockets of a particular activity are scattered throughout the basin. The topography of the basin is characterized by a well defined relief and as such, the quality of artesian groundwater reflects the effects of a relatively large land area. The shallow groundwater reflects only the effects of activity which is near by. This is due to the flow systems that exist in such areas, (See Figure 2.1). In order, therefore, to locate the monitoring wells so that the effects of land use would be reflected, in both shallow and artesian groundwater, it was necessary to classify relatively large areas of the basin in terms of the general land use

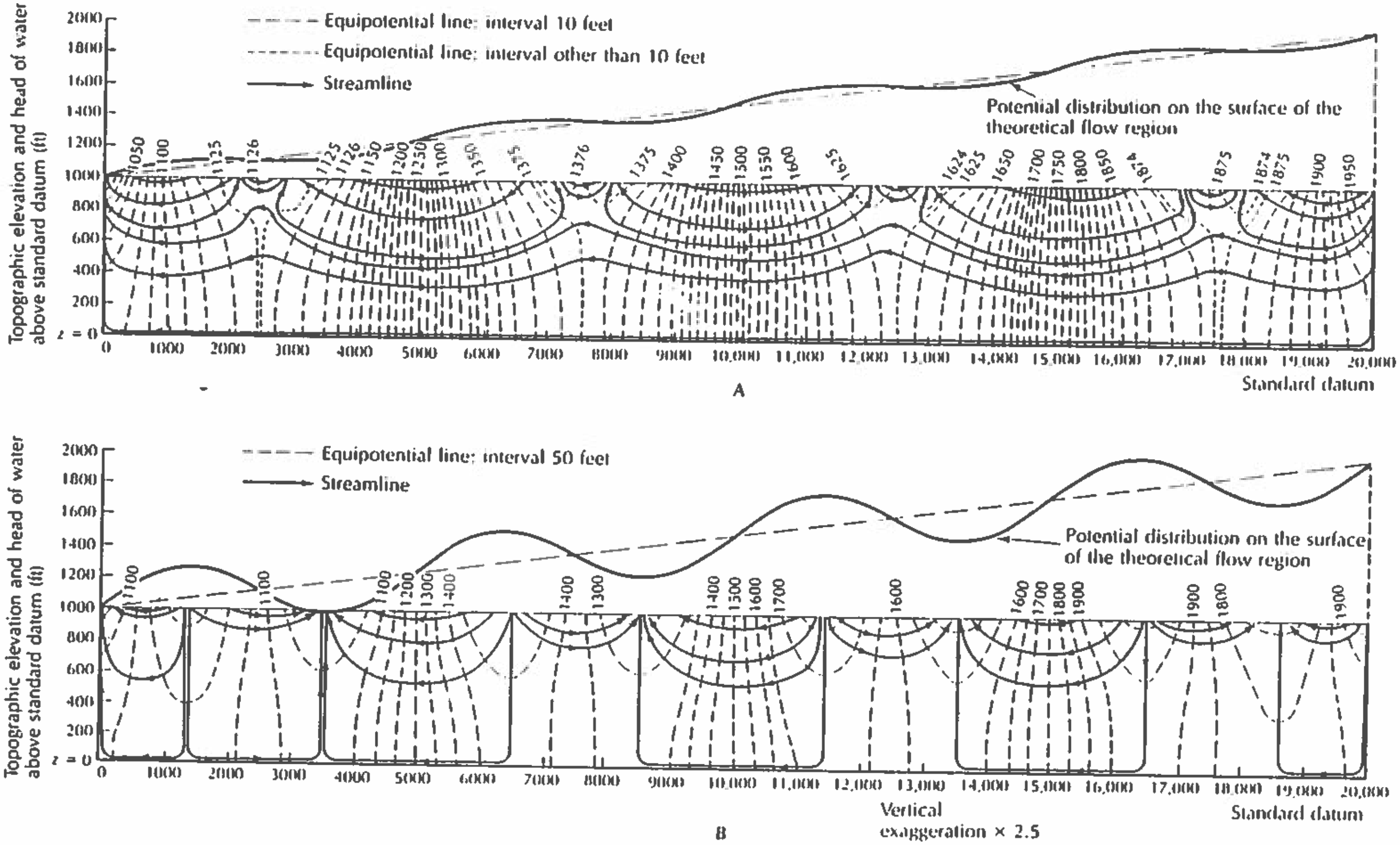


Figure 2.1: The amplitude of the undulations of the water table controls the depth of local flow systems. For shallow basins, this can determine whether both local and regional flow systems will develop (Part A), or, with deeper undulations, only local flow systems will form (Part B). After. J.A. Toth, (1963).

activity. For this purpose the classification set out in the original study plan for the Waterford River Basin Urban Hydrology Study was used. (See Figure 2.2 in back pocket). These were based on 1976 aerial photographs.

The approximate areas under the various land use categories are tabulated in **Table 2.1**. The classification reflects the most common land use found in the particular area. Because of budget constraints and its small size it was decided to exclude the recreational land use from this study. In order to accomplish the objective of the monitoring well network it was desirable to determine the water quality both upstream and downstream of the activity area.

TABLE 2.1

Land Use

Land Use Category	Area km^2
Forest	27.66
Agriculture	3.88
Urban & Suburban	12.43
Recreation	0.81
Other (ponds, bogs, barren river channels, gravel pits, etc.	6.53
TOTAL:	51.31

2.3 Groundwater Flow Systems

The most important aspect of the groundwater flow system, for the placement of effective monitoring wells, is the direction of flow. This depends on the hydraulic gradient and the directional permeability of the water bearing zone. The hydraulic gradient is determined by measuring the elevation of the water table or piezometric surface. The directional permeability is much more difficult to determine. It requires a minimum of 3 observation wells and a controlled pumping test using a fourth well

(Papadopoulos 1965). It can reasonably be assumed that the overburden material is isotropic, that is, its permeability is equal in all directions. This assumption is based on the fact that most of the overburden consists of glacial till (Batterson, 1984) which is relatively homogeneons. The bedrock aquifer, in contrast, is generally not isotropic. The rock types underlying the basin are siltstone, mudstone and shale (King 1984) which typically have very low primary permeability. Flow is thus confined to the fracture planes which have a preferred orientation.

There was not enough outcrop in the central portions of the basin to determine the orientation of fracture sets. In addition, it was not possible to use the techniques developed by Papadopoulos prior to the installation of monitoring wells. In any case, it is doubtful that such work would have been useful owing to the complexity of bedrock structure in the area (King 1984). It had to be assumed, therefore, that for the purposes of groundwater flow, the rock was isotropic and thus the directions of flow would be governed by hydraulic gradient as discussed above.

To determine the hydraulic gradient, an extensive survey of all wells in the Waterford River Basin was conducted. About 400 domestic wells were investigated primarily for the purpose of measuring the water level elevation, and in addition, to catalogue the well location and present use. The survey was completed in a two week period to minimize the effects of seasonal water table fluctuations. About 10% of the total number of wells were artesian drilled wells. The rest were shallow dug wells. None of the artesian wells was accessible for water level measurement and, therefore, the assumption that the piezometric level was represented by the water table, could not be confirmed. It was supported, however, during the aquifer testing. Pumping the deeper wells did cause some drawdown in the shallow wells, demonstrating some degree of hydraulic connection. In addition, the static water levels in adjacent shallow and deep wells were very close to the same elevation and both responded in a similar manner to rainfall events.

Using the above assumptions, the direction of groundwater flow in the basin was determined from a contour map of the water table. This was derived from water level measurements taken from the shallow well survey, spot elevation of pond levels and stream elevations as shown on topographic maps. The water table contours are shown in **Figure 2.3** (in back pocket). In isotropic materials, groundwater flow is perpendicular to these equipotential lines. The monitoring wells were positioned upstream and downstream of the major land use areas according to this flow configuration. These locations are also shown in **Figure 2.3.** Sites A and B were positioned to monitor industrial land use. Sites C, D, and F were located to reflect urban land use. Site E was situated to indicate the effects of agricultural activity and Site G was chosen to represent the undeveloped or background water quality.

3.0 INSTALLATION OF MONITORING WELLS

3.1 Introduction

The installation procedures for monitoring wells are more specific than for water supply wells. The need to ensure that water from deep zones does not mix with that of shallow zones is one concern. The need to identify the depth and yield of each water bearing zone and the geology of the intervals that comprise it are another concern. Operational details, drilling additives, and lubricants, that are used, must be known because of their possible effects on water quality. Site specific information on possible well bore contamination is required. In addition to these concerns, the emphasis for monitoring well construction is not the quantity of water obtained but rather the quality. Whereas a water supply well may obtain water from any zone to meet the requirements, the monitoring well ideally obtains water from one zone and is not concerned with the quantity, provided it is sufficient for sampling purposes. For these reasons detailed specifications were set out for the work to be done. These specifications are listed in **Appendix A.** Adherence to these requirements and the integrity of the borehole log were ensured by having a hydrogeologist on site during all operations.

On February 3, 1981 the drilling contractor began the construction of the groundwater monitoring wells. Drilling was done with an air hammer rotary drilling rig. At each of the seven sites the drilling contractor constructed two wells; one to sample the water table aquifer, and one to sample the artesian aquifer. Site A was an exception to this rule, as a suitable abandoned water table well was available for our use. The geologic logs and construction details for each well are shown in **Appendix B.**

3.2 Well Construction Methods

3.2.1 Artesian wells - general

Overburden depths in the basin are generally thin ranging from about 1.5 to 6.0 m below groundwater surface. In addition, there is a general lack of extensive confining layers. . It was required, therefore, that all artesian wells be constructed in the bedrock. In the absence of shallow water bearing zones in the bedrock the casing was set a minimum of 0.6 m below the overburden/bedrock contact. Where these zones were anticipated to be significant (ie., beside stream channels) more casing was installed.

Drilling commenced using a 20 cm air hammer bit. Cutting samples of overburden and bedrock were collected at 1.5 m intervals. These were labeled, logged and stored for future reference. The depth in the overburden at which saturated materials were encountered was noted. When drilling had proceeded into the bedrock to a sufficient depth to satisfy the criteria mentioned above, the hole was cleaned out as well as possible and the drill tools were removed. Approximately 1 kg of bentonite pellets was immediately poured into the hole and the appropriate length of 15.25 cm diameter casing, with drive shoe, was driven through the bentonite to the bottom of the hole and on into the bedrock as far as possible. In all cases, drive shoe penetration into the rock, beyond the bottom of the 20 cm hole, was minimal, however, the depth to which the casing was set in the bedrock and the placement of dry bentonite pellets around the drive shoe, ensured virtual isolation from the overburden aquifer. The annular space was then backfilled with overburden materials and drill cuttings.

Once the casing was set, drilling proceeded into the bedrock inside the casing using a 15.25 cm air hammer bit. Drill cutting samples were collected at 1.5 m intervals, and at significant water bearing zones. Drilling proceeded until a water bearing zone was encountered. Once penetrated, the zone was developed briefly and its yield measured. If the zone was considered adequate for sampling purposes the well was advanced 3 - 4.5 m past the zone and developed for about 30 min. and again the yield was measured. During this development the flow of rock cutting oil, which is normally injected with the compressed air, was stopped, to avoid any residual in the well. When the water was relatively clean the drill tools were removed and a well seal installed. Covering this assembly a steel cap was locked over the top of the casing. A typical deep well is shown in **Figure 3.1.**

3.2.2 Water table wells - general

Monitoring of a local water table aquifer has shown that the fluctuation of the water level ranges from 1.2 m in recharge areas to 0.7 m in discharge areas. (Nfld. Department of Environment Interim Report, 1982). The shallow wells were thus constructed to a minimum depth of 1.2 m below the water table. This depth was determined for each site during the drilling of the artesian well which in most cases was located less than 15 m away.

The open hole was drilled using a 20 cm air hammer bit. Drilling continued to the appropriate depth as outlined above. When soil caving occurred, the hole was extended a few extra feet to provide room for such caved materials. At this point the hole was cleaned out and the drill tools removed from the hole. The shallow well assemblage was then lowered into the hole and enough silica sand was emplaced around the

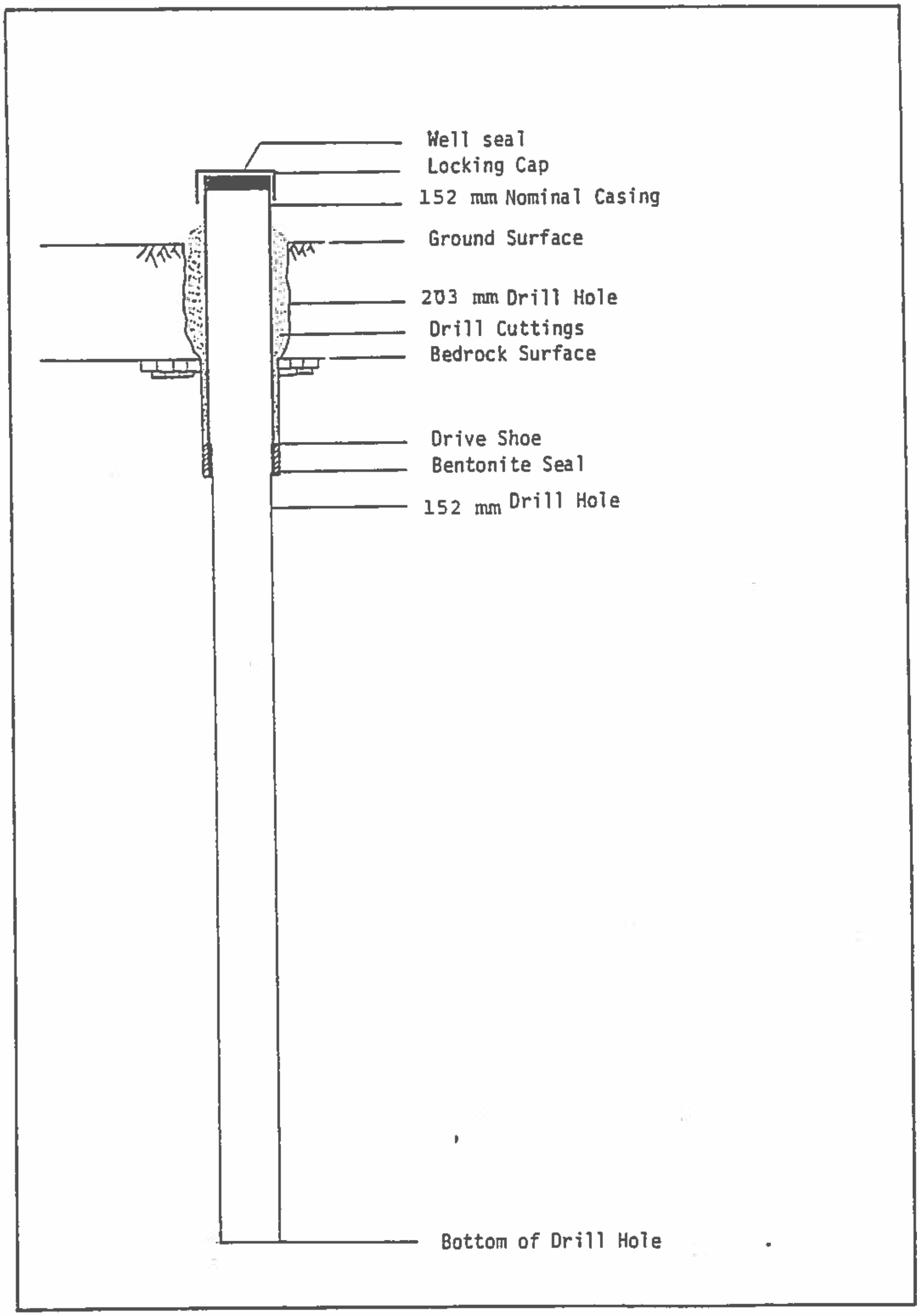


Figure 3.1. Typical artesian well construction details

slotted section at the bottom, to fill the annular space to a depth of about 1.5 m above the bottom of the hole. The well assembly consists of the appropriate length of 15.25 cm diameter PVC plastic pipe with a plastic cap at the bottom. The bottom metre length of the pipe was slotted.

The top of the silica sand was sealed with about 10 cm of drill cuttings and on top of this approximately 4.5 kg of bentonite pellets were emplaced. The remaining, open, annular space was filled with drill cuttings. A piece of 15.25 cm steel casing was forced down over the plastic pipe to a level below the ground surface and concrete was used to stabilize the resulting arrangement and seal the top of the hole. A conventional well seal was installed and a locking steel cap used to secure the well. A typical shallow well is shown in **Figure 3.2.**

3.3 Site Specific Drilling Activity

Due to site conditions some deviations from the general construction methods were employed. Drilling activity on each site is described in the following site by site accounts. The construction details and drill hole logs for each well are contained in **Appendix B.** For convenience, the construction details for each well are listed in **Table 3.1.**

3.3.1 Site A - industrial

Drilling at Site A began on February 5, 1981. **Figure 3.3** is a detailed map of this site showing the locations of well drilling operations. The first well, # 1518, was begun as an artesian well. Because of its close proximity to the Waterford River it was designed with 12.2 m of casing to seal off anticipated shallow water bearing zones in the rock. Much difficulty was encountered because of the loose bouldery till that overlies the bedrock in this area. Abundant water in this formation caused it to cave into the well bore. When the casing was driven into this material the bottom became bent and the well was abandoned and the casing left in the hole.

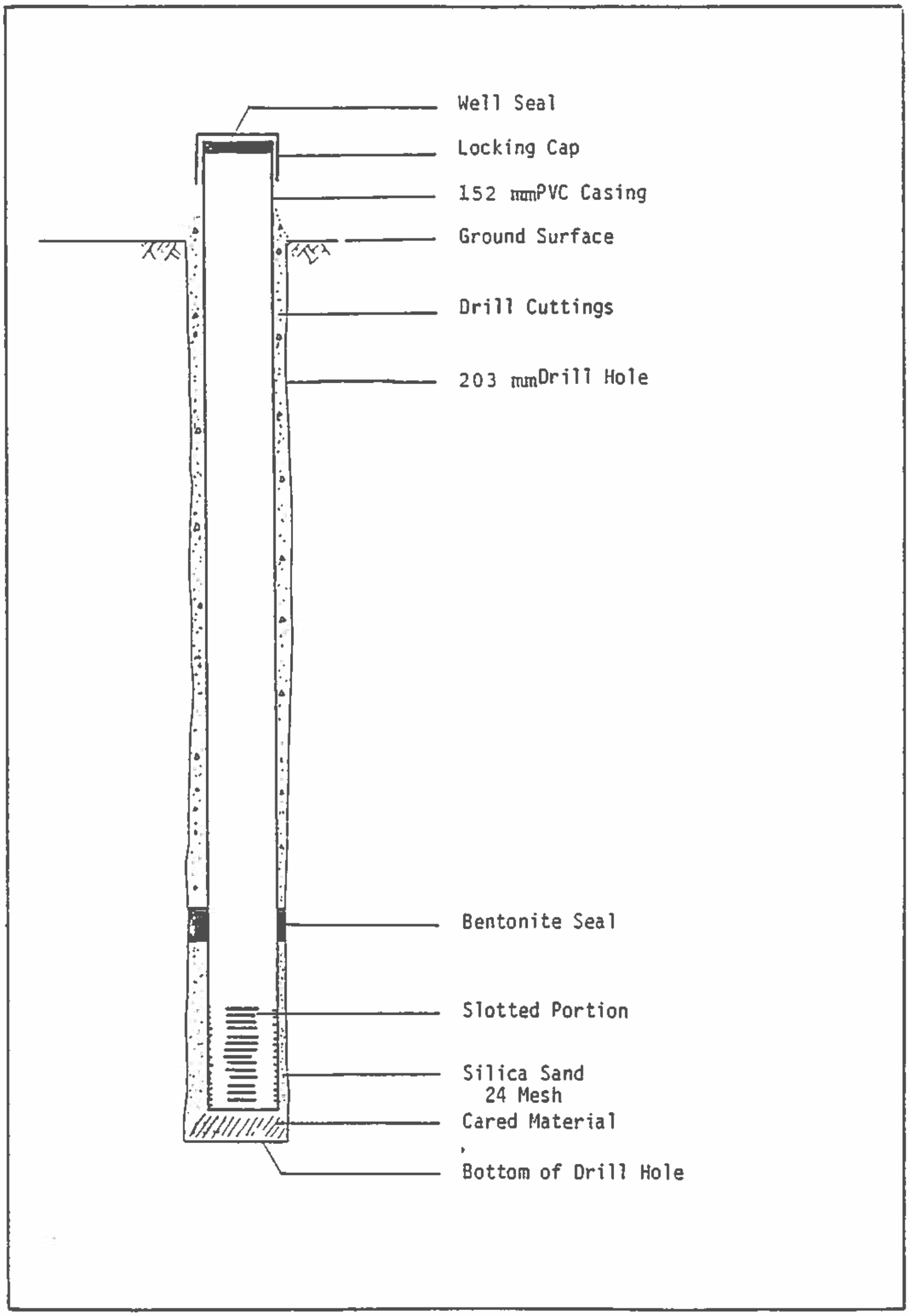
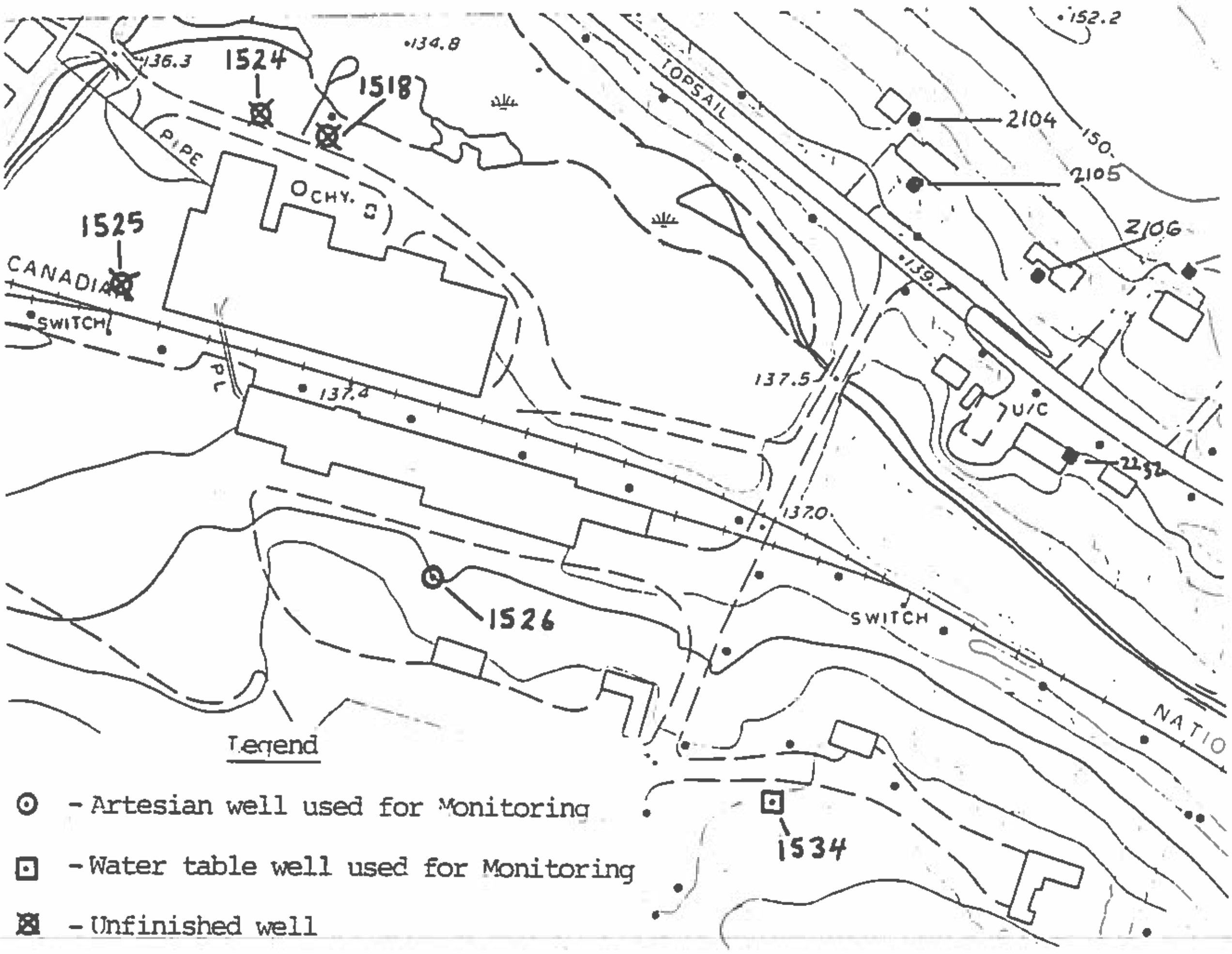


Figure 3.2. Typical water table well construction details



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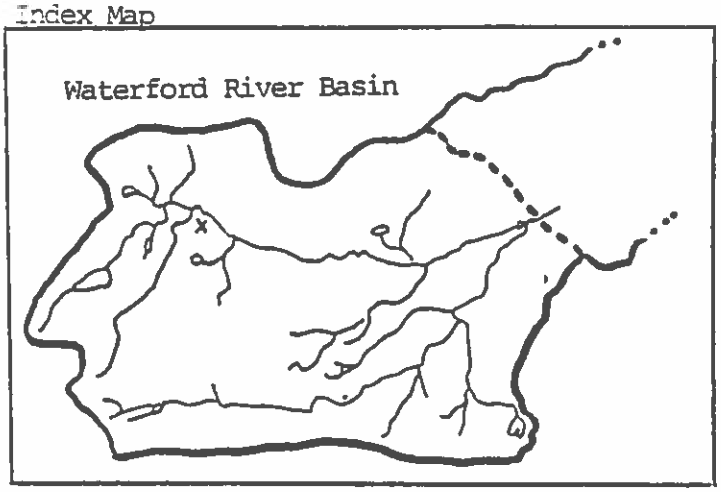


Figure 3.3. Monitoring wells at Site A.

TABLE 3.1

Construction Details For All Monitoring Wells

Site	Well No.	Type	Location (easting) (northing) 22T	Elev. GL m	Total Depth m	Casing Depth BGL (m)	Slotted Interval (m)	Depth to Water Bearing Zones (m)	Final Air Lift Yield (LPM)	Static Water Level Elev. ASL
A	1526	Deep	362100 5265350	139.4	24.7	4.9	N A	19.2	24	138.473
	1534	Shallow		143.3	5.3	2.0	N A			141.679
B	1529	Deep	361650 5264900	153.8	31.1	4.9	N A	23.5 24.4	1	150.089
	1530	Shallow		153.7	4.5	4.5	3.1 - 4.3	4.0		150.621
C	1527	Deep	364600 5264150	117.9	62.5	6.2	N A	29.6 32.6	20.0	114.716
	1528	Shallow		117.9	3.1	3.1	2.1 - 3.0	2.4	9	115.022
D	1531	Deep	364700 5262950	128.5	18.9	5.1	N A	16.2	12	126.232
	1532	Shallow		128.4	3.4	3.4	2.4 - 3.4	3.0		126.029
E	1522	Deep	365900 5263900	107.0	25.0	11.5	N A	14.3	30	102.453
	1535	Shallow		106.8	6.0	4.5	3.6 - 4.6			102.638
F	1521	Deep	362900 5264750	131.8	55.5	12.9	N A	53.9	25	Flowing
	1520	Shallow		130.3	13.7	8.6	N A	13.7		127.086
G	1519	Deep	361700 5262700	229.7	61.6	6.1	N A	54.9	1	227.039
	1533	Shallow		230.0	5.2	5.2	N A	3.7	9	227.194

BGL = Below Ground Level
LPM = Liters Per Minute

BMP = Below Measuring Point
NA = Not Applicable

A second attempt in the same vicinity was begun on March 11, 1981. In this well (#1524,) 20 cm casing was used to seal off the bouldery till formation so that the 15.25 cm casing could be installed. This attempt also ended in failure as it was not possible to stabilize the formation at the bottom of the 20 cm casing or to advance this casing to the bedrock. The hole was backfilled and the casing removed.

The third well was begun on March 12, 1981 at some distance from the original site of Well # 1518. In an attempt to find bedrock at a shallower depth, Well # 1525 was drilled further south. The same conditions prevailed, however, and this hole was also abandoned and backfilled. A final Well # 1526 was begun on March 12, 1981. This well encountered favourable conditions and was finished the same day. No shallow well was drilled at site A because of an existing abandoned dug well to which access was obtained.

3.3.2 Site B - industrial

Drilling at Site B began on March 17, 1981. **Figure 3.4** is a detailed map showing the location of the wells drilled at this site. Well # 1529 was the first to be drilled. Favourable drilling conditions were encountered in the overburden till, as only a trace of water was found just above the bedrock at about 3.6 m.

The bedrock had been penetrated about 1.5 m when the rig broke down. Repairs to the rig took 5 days in which time the hole filled up with water to 2.4 m below ground level. Problems arose when drilling recommenced. The coarse bouldery till, softened and disturbed by the prevous drilling, kept caving into the hole. Loosening of the overburden formations resulted in a greatly increased flow of water into the hole. The addition of a polymer drilling compound to the slurry into the hole stabilized the sidewalls sufficiently to set the 15.25 cm casing in the bedrock and the well was completed without any further problems.

On March 23, 1981 the installation of Shallow Well # 1530 commenced. Much difficulty was encountered drilling the 20 cm hole in the overburden. This was due to the loosening of these materials during the construction of Well # 1529 which was about 3 m away. Water flowing into the hole caused the side walls to cave. This time they could not be stabilized with the polymer drilling additive. In order to install the shallow well assembly a piece of 20 cm casing was driven through the caved material into the bedrock. The shallow well assembly was installed inside this 20 cm casing. As shown in **Appendix B**, the assembly was modified slightly by the addition of a 0.6 m blank riser to the bottom of the slotted casing. This was attached to raise the slotted portion of

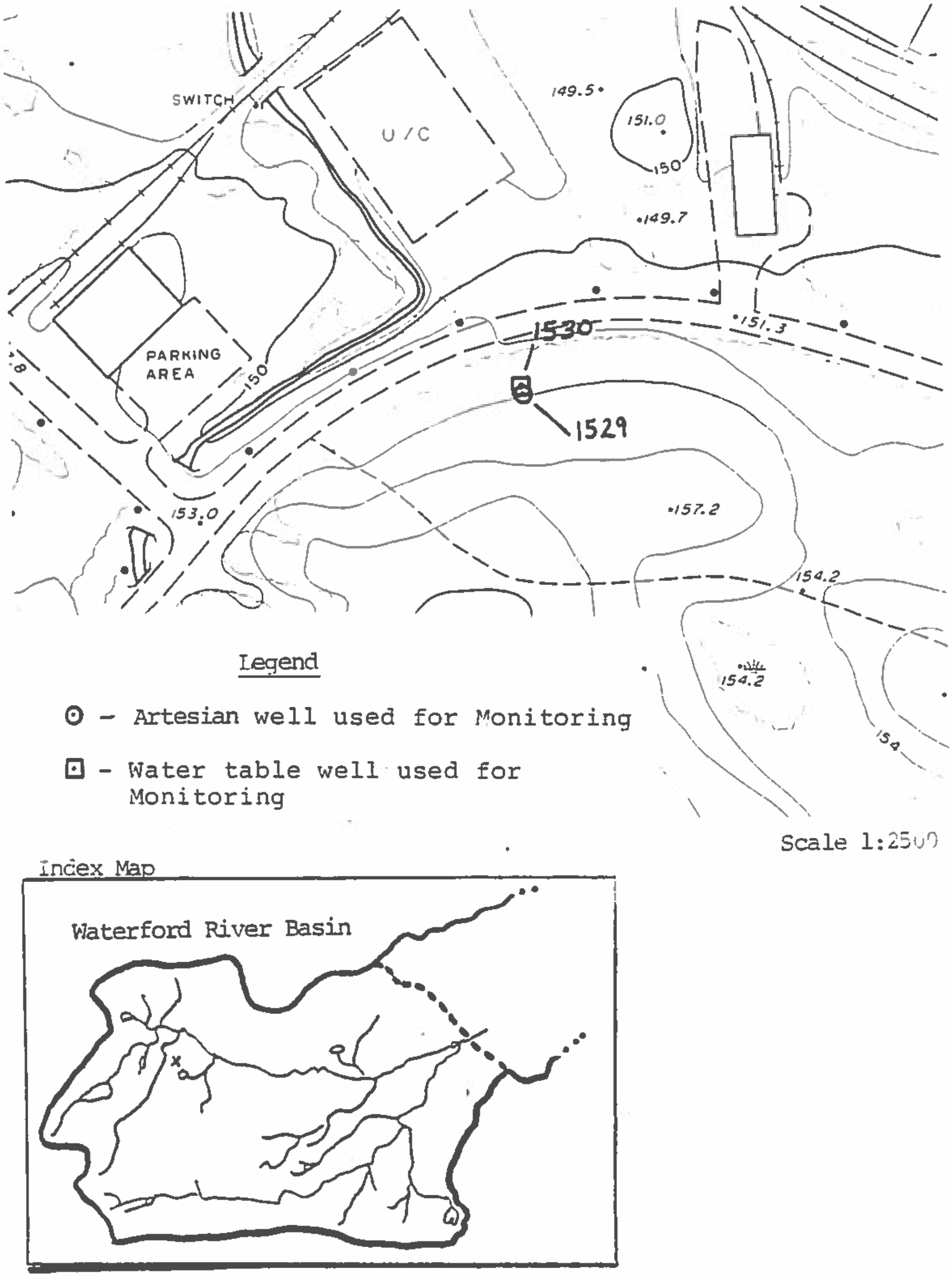


Figure 3.4. Monitoring wells at Site B.

the casing above the mud slurry which could not be removed from the bottom of the well.

Silica sand was emplaced inside the 20 cm casing and on top of this the bentonite seal was installed. This was done in anticipation of the removal of the 20 cm casing in which case the sidewalls of the hole would cave in around the already installed well pack and seal. It was not possible, however, to remove this casing and therefore the annular space between it and the side wall was sealed with bentonite and backfilled to the surface. Both wells were sealed with conventional well seals and secured with locking steel caps.

3.3.3 Site C - urban developed

Drilling at Site C began on March 13, 1981 and finished the same day. **Figure 3.5** shows the location of the wells drilled at this site. Well # 1527 was drilled, first, as the artesian well. Some difficulty was encountered below 2.4 m as abundant water caused caving of the coarse glacial till in the side walls of the borehole. Bentonite clay in powdered form was added to the slurry in the hole and this succeeded in stabilizing the formation. The 17.8 cm casing was set and the well was finished without further difficulty.

Construction of the shallow well (#1528) was also met with an excessive water condition in the overburden till. In order not to seal off the contributing zones no bentonite was used during drilling to stabilize the side walls. Consequently this hole was not as clear of drill cuttings as was desired. It was necessary to push the shallow well assembly the last 3 m. After the well pack was emplaced and sealed, and the annular space backfilled, the drill stem was lowered into the well and the screened area blown out to remove as much debris as possible from the well base.

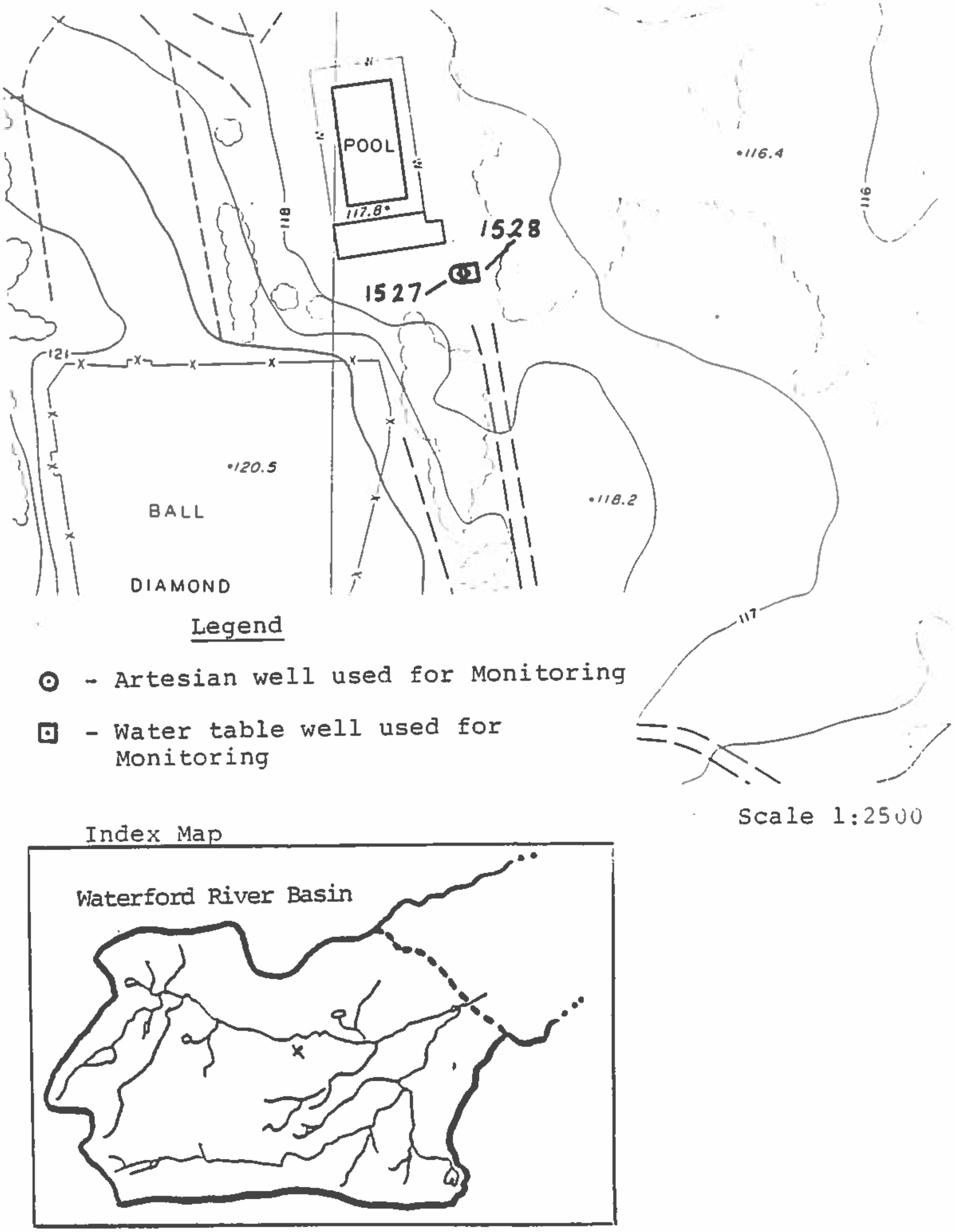


Figure 3.5. Monitoring wells at Site C.

3.3.4 Site D - urban developing

Drilling at Site D commenced on March 24, 1981 and finished on March 25, 1981. Figure 3.6 shows the location of the wells drilled. Again, the saturated bouldery till caved into the borehole. In both wells the sidewalls were stabilized by adding a polymer drilling additive to the slurry in the bottom of the hole. In this hole it was possible to set the 15.25 cm steel casing about 1.5 m into the bedrock.

In order to provide a relatively clean hole for the installation of the shallow well assembly, drilling was continued to 4.9 m. Thus a 1.5 m allowance, below the bottom of the well, was made for caved material.

3.3.5 Site E - agricultural

Drilling at Site E commenced on March 9, 1981 and was completed on March 11, 1981. Figure 3.7 shows the locations of the wells drilled. Well # 1522 was drilled to a depth of 8.2 m on March 9, 1981. At this depth, drilling was suspended because of an oil seal leak in the drilling head. On March 10, 1981 after repairs had been completed on the rig the hole was redrilled. Drilling conditions, which had been quite favourable when the hole was first drilled, became difficult because of water which had seeped into the hole overnight. Much time was spent cleaning out the hole and drilling onto 11.9 m which was about 9.3 m below the top of the bedrock. After the casing was installed no further problem was encountered.

Construction of Well # 1523 began on March 11, 1981 and finished on the same day. It had been noted during the drilling of Well # 1522 that saturated conditions existed at about 2.4 m depth and therefore the well assembly was emplaced 3.7 m below ground in the usual manner. This proved to be too high as the well remained dry. A replacement Well # 1535 was drilled on July 22, 1981 and the shallow well assembly was emplaced between 3.6 and 4.6 m. This well proved to be below the water table.

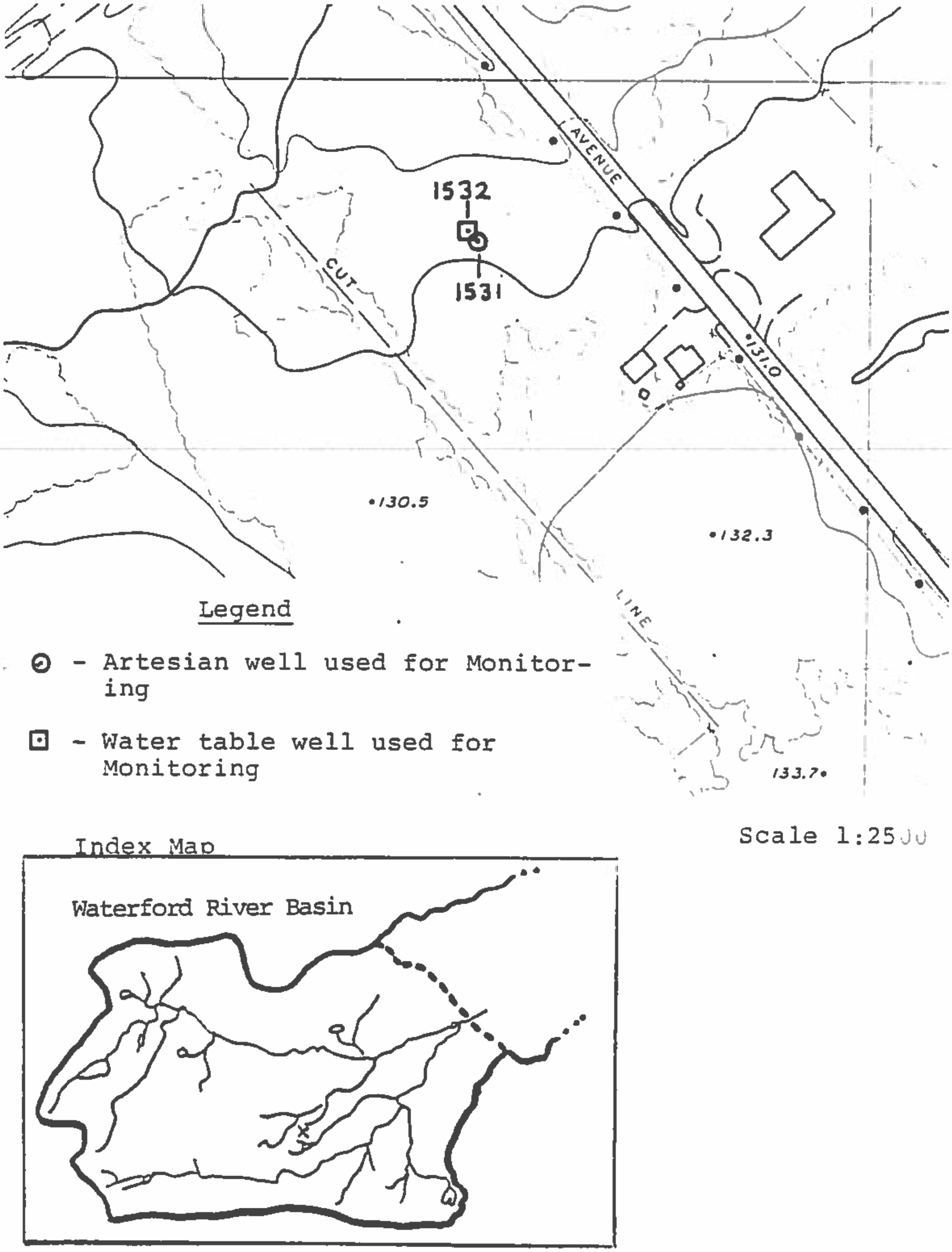


Figure 3.6. Monitoring wells at Site D.

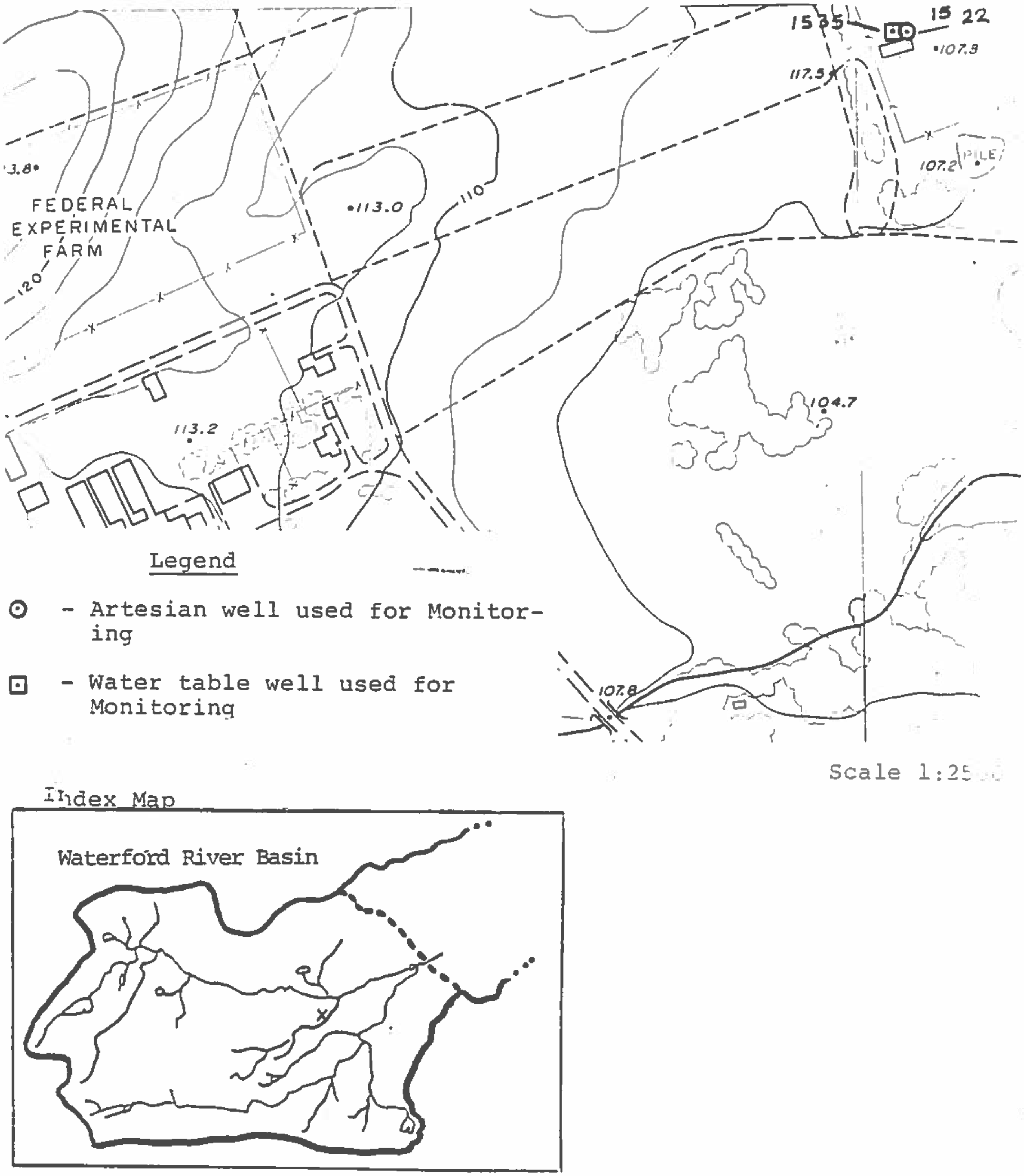


Figure 3.7. Monitoring wells at Site E.

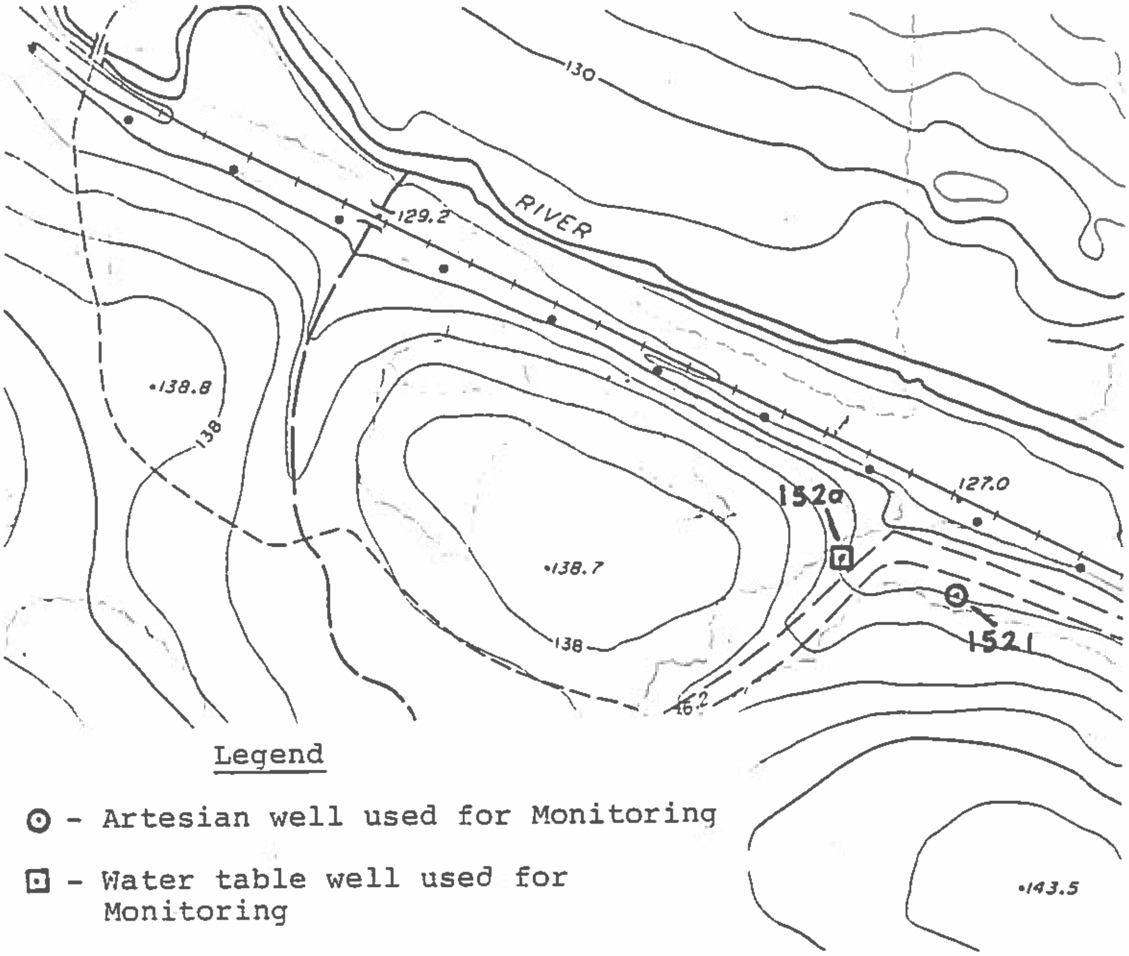
3.3.6 Site F - developing

Drilling began at Site F on February 12, 1981 and was completed on March 9, 1981. Figure 3.8 shows the location of each well at this site. Well # 1520 was begun as an artesian monitoring well. At 1.8 m, in loose bouldery fill the water table was encountered and thereafter it was not possible to get good cutting samples. Drilling characteristics were thus relied upon for identification of the bedrock. These proved misleading. Bedrock was reported by the driller at 2.4 m. Drilling continued using the 20 cm bit to 4.6 m and the casing was installed to that depth. Further drilling revealed that the material was not bedrock but rather uniform fill. At 6.0 m two successive hydraulic breakdowns resulted in about 22 L of hydraulic fluid being spilled down the hole. After repairs, drilling continued on February 19, 1981 and bedrock was again reported, this time at 7 m. Once more the amount of water in the formation prevented the removal of drill cuttings from the hole and thus samples were not representative. Drilling continued to 9.1 m and the casing was driven to about 3.5 m which was as far as it would go.

When drilling resumed, it soon became apparent that the material thought to be bedrock was really hard basal till. Since the casing could not be driven to the bedrock to seal off the upper water bearing zones it was decided to abandon this well as an artesian well and to use it for a water table well instead. Drilling continued to 14.0 m.

In order to seal off the upper soil zones which had been contaminated with hydraulic fluid, 1 m^3 of cement grout was displaced to a depth of 6.7 m down the casing using a 15.2 cm wooden plug. The grout was thus forced up the outside of the casing until it appeared in the annulus of the drill hole. The grout was allowed to set for 17 days and on March 9, 1981 it was drilled out to a depth of 14.0 m.

On February 20, 1981, drilling commenced on Well # 1521, the artesian well for site F. In order to avoid the water problems associ-



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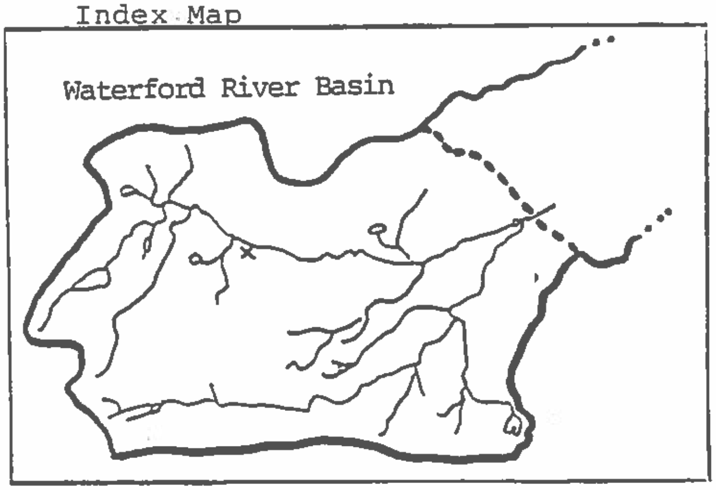


Figure 3.8. Monitoring wells at Site F.

ated with the drilling at this site, a 30.5 cm bit was used to allow for the installation of 2.4 m of 20 cm diameter casing. Drilling continued inside the 20 cm casing, using an 20 cm bit, to a depth of 12.8 m. 15.24 cm casing was installed to 12.8 m which was 4.9 m into the bedrock. Drilling continued to a depth of 36.9 m at which point the drilling rig broke down. At 51.8 m another breakdown occurred after which the hole was finished at 55.5 m.

3.3.7 Site G - control site

Drilling operations began at site G on February 9, 1981. Figure 3.9 shows the location of the two wells drilled at this site. Well # 1519 was the first well to be constructed. Drilling conditions proved to be favourable and no problems were encountered in installing the casing to a depth of 6.1 m which was 2.2 m into the bedrock. The hole was drilled without problem to 61.6 m.

The shallow well at this site (#1533) was more of a problem. Construction began on March 25, 1981. Water was encountered in the surficial bouldery till and thus caving of the open hole became a problem. After several attempts to install the shallow well assembly it became apparent that because of caving it would be impossible to sand pack the slotted portion. (One attempt resulted in a plugged well which had to be drilled out.) Since the upper few metres of bedrock appeared to be fractured it was decided to emplace an open ended 15.25 cm plastic pipe in the bedrock.

The drill hole was extended to 6.7 m which was 2.0 m below the surface of the bedrock to allow for caved material. The 15.2 cm PVC pipe was lowered to 5.2 m and then silica sand and bentonite pellets were backfilled around it. Drill cuttings filled the remainder of the annular space to the surface. When cleaned out for about 1.5 hrs. the well yielded about 9.1 L/min.

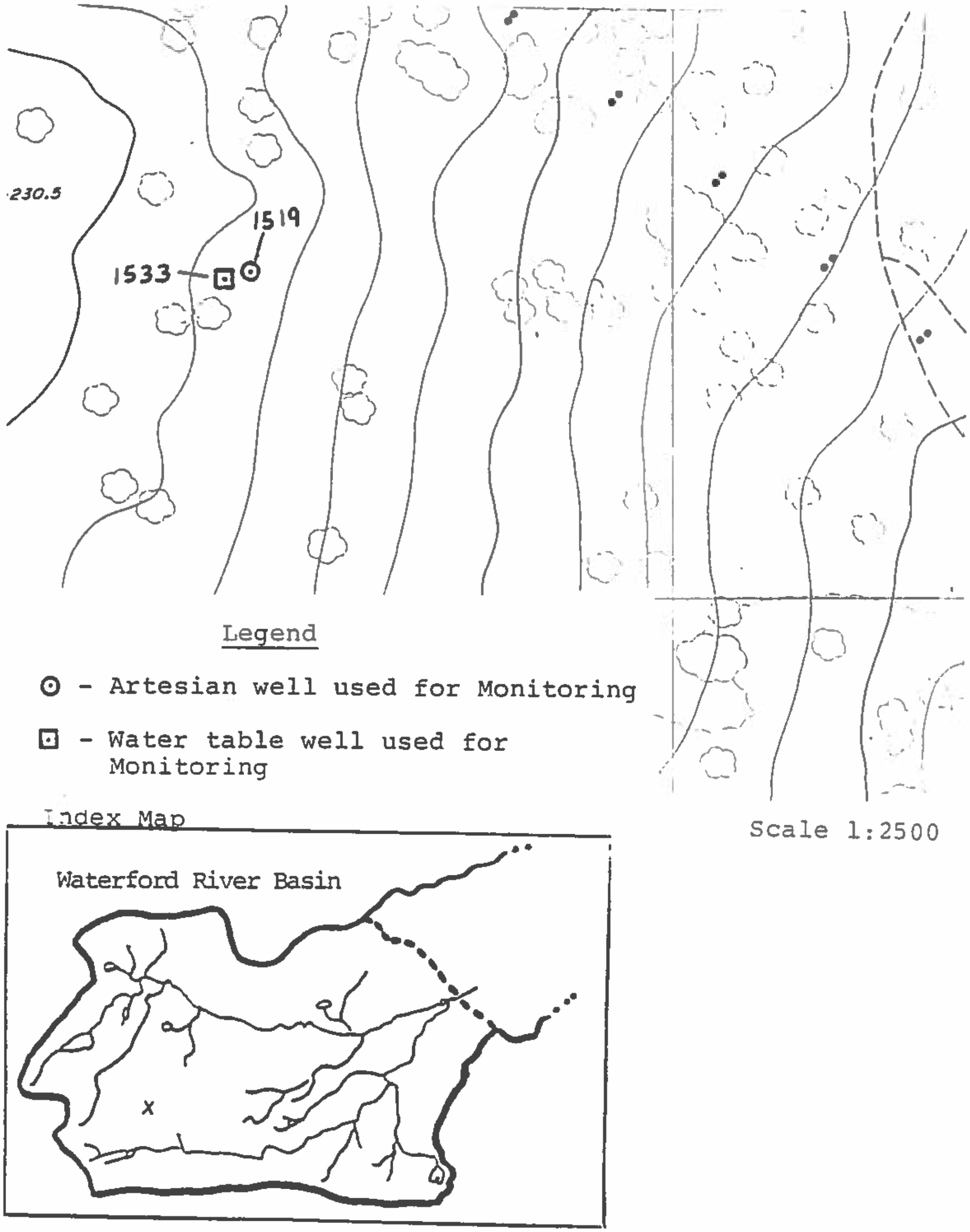


Figure 3.9. Monitoring wells at Site G.

3.3.8 Existing monitoring wells - site H

Two existing wells were chosen in the Kilbride area of the Waterford River Basin to monitor the water level on a continuous basis. The site is shown in Figure 3.10. Well #1026 was an existing artesian well which had been abandoned by the owner. A Leopold and Stevens model F68 chart recorder was installed on this well on July 1, 1981. Well #1028 was an existing water table well which had been abandoned by the owner. The same type of water level recorder was installed on this well on June 13, 1981.

4.0 HYDRAULIC TESTING OF WELLS

4.1 Introduction

In keeping with the major purpose of the Waterford River Urban Hydrology Study the monitoring wells were tested to determine the hydraulic characteristics of the aquifer in which they were constructed. Testing of the artesian aquifer was limited to the use of one well at each site. The hydraulic connection between the shallow and deeper aquifers was not sufficient to allow the shallow well to be used as an observation well. Consequently only the transmissivity and specific capacity could be determined. Testing of the overburden aquifer was limited by the yield of the shallow wells. In all cases the low yield prevented the use of the conventional pumping test. In these wells the hydraulic conductivity was determined by use of the slug test.

The purpose of hydraulic testing was to determine the relative ease with which a potential contaminant could be transported in the groundwater system. This information was considered to be necessary for the interpretation of the eventual water quality testing that is described in Section 5.0. If the effects of urbanization were to be evaluated realistically, some understanding of the transport capabilities was required. In addition to this specific need, a general appreciation of the potential groundwater yield of the basin was required to determine

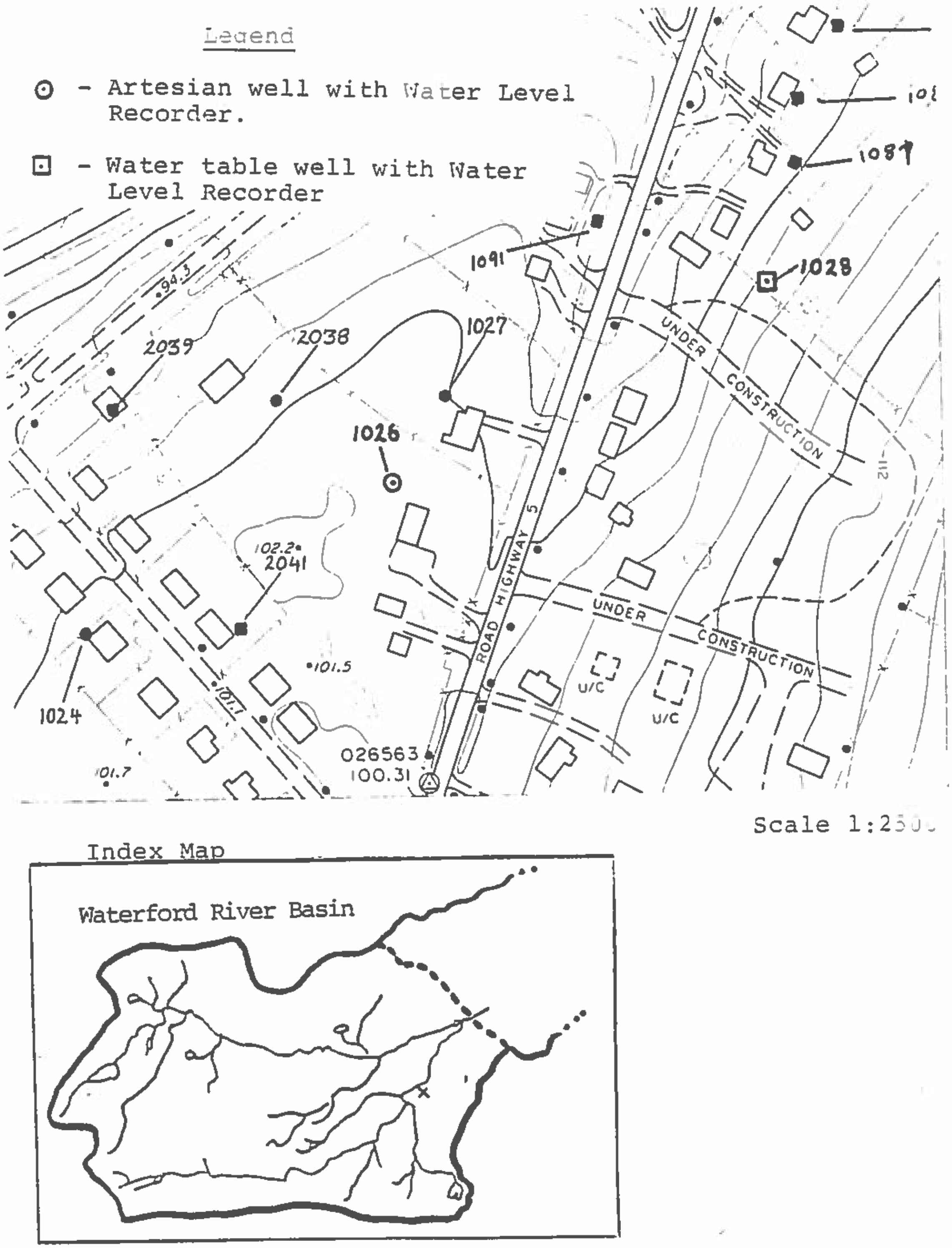


Figure 3.10. Monitoring wells at Site H.

the importance of groundwater as a source of water supply. The limited drilling and testing program described in this report could not fully accomplish these objectives for an area as large and diverse as the Waterford River Basin. Notwithstanding, the program was implemented to progress as far as was possible toward the achievement of these objectives.

4.2 Testing Artesian Wells

4.2.1 Step tests

4.2.1.1 Introduction

A step test was conducted on each of the artesian monitoring wells according to the method of Jacob (1947). Typically, each well was pumped at several different rates, or steps. Pumping continued at each step for a specified period of time and then was increased to the next value without allowing recovery. This was repeated for the chosen number of tests.

The purpose of these tests was to estimate the relationship between drawdown and pumping rate for each well. This relationship is unique for each well and is defined by the following equation (Rorabough 1953):

$$s = B\,Q + C\,Q^N \qquad (4.1)$$

where s = drawdown in the pumped well
B = formation loss coefficient at time t
C = well loss coefficient
Q = discharge
N = a turbulence exponent

It was essential that the response of each well to various pumping rates be known in order to estimate the well efficiency and to choose the optimal rate of pumping for the longer term aquifer test.

4.2.1.2 Methodology

The procedure followed for each of the step tests was similar in all cases. The approximate yield of the well had been estimated by the driller during construction. (See **Table 3.1**). Using this value as a guide, a number of pumping rates were chosen below and above this value so that the optimum yield could be determined. From Equation (4.1) it is evident that there are two components of well loss. One is linear and corresponds to laminar flow. The other is non-linear and corresponds to turbulent flow. For most of the wells, at least two, very low-volume rates were chosen in an attempt to establish the linear portion of Equation (4.1). Higher rates, having the potential to cause turbulent flow in the fractured reservoir were chosen to exhibit the non-linear portion. **Table 4.1** lists the pumping rates and other pertinent conditions under which these tests were conducted.

Controlling the flow rate, especially for such low values as are listed in **Table 4.1**, was a major concern. The results of step tests are extrapolated in time to estimate the drawdown that might be expected at other rates and for longer times. Accurate and constant flow control is thus essential. This was achieved using the constant head tank depicted in **Figure 4.1**. Water was pumped from the well into this tank. When the discharge valve was closed the water simply recirculated to the well through the overflow pipe inside the tank. This pipe also maintained a constant level in the tank. No water was lost from the system except the amount that was required to fill the tank. For wells that recovered slowly this loss was eliminated by pre-filling the tank from another source. During the test, water was discharged through the discharge line. The discharge valve was fully open during the test and the flow was controlled by the height of the open discharge line relative to the constant head of water in the tank. There are three major advantages of this method over the more traditional valve controlled method.

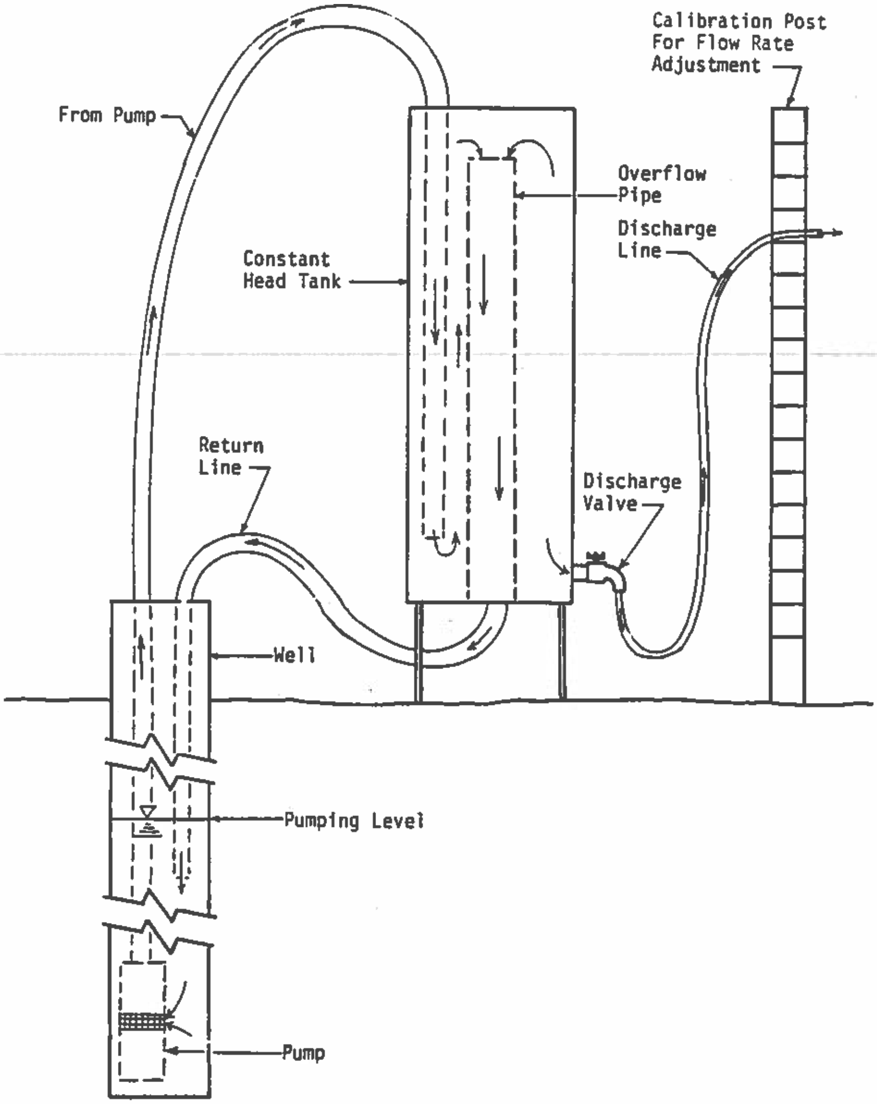


Figure 4.1 Constant head tank.

TABLE 4.1

Pumping Test Conditions

WELL #1526 SITE A

STEP	1	2	3	4	5
PUMPING RATE (L/min)	0.5	1.0	8.2	9.5	25.7
DRAWDOWN AT END OF STEP (m)	0.05	0.07	1.29	1.53	8.52

WELL #1529 SITE B

STEP	1	2	3	4	5
PUMPING RATE (L/min)	0.7	1.1	1.6	2.3	6.0
DRAWDOWN AT END OF STEP (m)	5.07	5.70	7.02	9.41	17.32

WELL #1527 SITE C

STEP	1	2	3	4
PUMPING RATE (L/min)	0.5	1.0	7.2	19.5
DRAWDOWN AT END OF STEP (m)	0.69	1.13	6.58	23.96

WELL #1531 SITE D

STEP	1	2	3	4	5
PUMPING RATE (L/min)	0.3	1.2	5.4	7.2	15.5
DRAWDOWN AT END OF STEP (m)	0.27	1.07	3.95	6.56	13.08

WELL #1522 SITE E

STEP	1	2	3	4	5
PUMPING RATE (L/min)	0.4	1.0	3.2	9.5	43.7
DRAWDOWN AT END OF STEP (m)	0.12	0.27	0.75	1.78	8.55

WELL #1521 SITE F

STEP	1	2	3	4	5
PUMPING RATE (L/min)	0.8	1.7	4.1	20.8	30.0
DRAWDOWN AT END OF STEP (m)	0.59	1.32	3.69	17.52	29.23

The first advantage is that prior to testing, the system can be brought to equilibrium with the pump running and the water circulating. Start-up can be instantaneous. This feature is becoming more important with the increasing use of electronic data loggers and pressure transducers.

The second advantage is the ability to accurately pre-calibrate the discharge by the height of the discharge line on the calibration post at specific flow rates. This can be done prior to the test start up and without any effect on the well if the water discharged during calibration is returned to the well. Thus very fast and accurate changes can be made during step tests and longer term tests can be started at exactly the correct rate.

The third advantage is the consistent control that such a system offers throughout the duration of the test. Variation in pump performance due to portable power sources and the dropping water level are completely damped out by the tank. Thus there is no need to constantly check the discharge rate or adjust the valve during the first portion of the test. As long as the pump is of sufficient size to exceed the discharge at the final drawdown no adjustment is required.

Once the discharge line was calibrated for the chosen flow rates and the system was at equilibrium, the step test commenced. The lowest rate was used first. Each step was 30 minutes in length. Throughout all the steps the water level in the pumping well was measured at the following intervals:

every minute	for the first	10 minutes
every 2 minutes	for the next	10 minutes
every 5 minutes	for the remaining	10 minutes

An electrical depth gauge was used for this purpose. These measurements are presented in **Appendix C** for all wells tested.

4.2.1.3 Discussion of results

One of the more useful results of a step test is the well signature or characteristic plot as described by Mackie (1982). This is simply a linear plot of specific drawdown (s/Q) versus discharge (Q) where s is drawdown at the end of each step. This type of plot provides the basis for a preliminary understanding of the near well flow regime. **Table 4.2** presents the values of Q, s and s/Q for each well at the end of each 30 minute step. These values are plotted in **Figure 4.2**. In general these plots are concave upwards in curvature. It is generally accepted that this type of response is due to the occurrence of a turbulence exponent (N) higher than 2.0. An alternate solution may be the existence of a

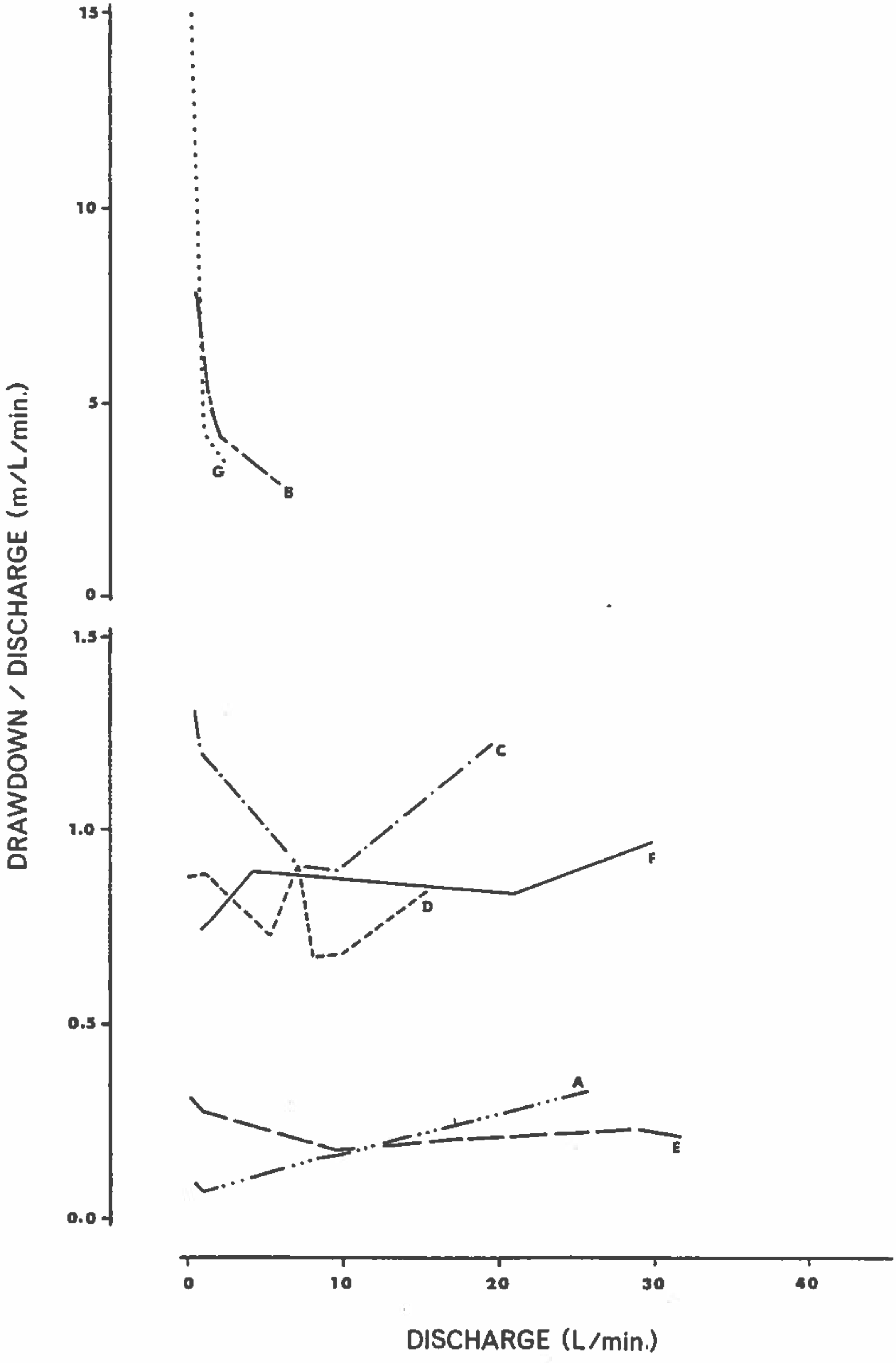


Figure 4.2: Plot of drawdown/discharge versus discharge for all deep drilled wells.

radially increasing turbulence coefficient (C) due to variable fracture geometry, permeability, and fracture roughness. While the former may be correct the alternative would have support in the fact that the water bearing fracture zone in many of the wells showed infilling by calcite which could produce a very irregular fracture geometry.

In theory, if one uses the results of at least 3 step tests then the solution to Equation (4.1) can be obtained. There are at least two methods of solving this equation. Rorabaugh (1953) introduced a graphical method of solution. Labadie et al., (1975) used a computer program based on regressional theory to solve the same equation. In this study a modified version of the Helweg program (Helweg, 1983) was used to obtain values of the well loss coefficients. No meaningful values could be determined however because of the irregularity of the measured values.

The most useful application of the step test results was based on a plot of drawdown versus the log of time. Figures 4.3 - 4.9 show these plots. In most cases the later portion of the plot line for each step indicated a linear relationship between drawdown and the log of time. These lines were extended in time to estimate the drawdown that would occur if pumping continued. The pumping rates for the long term aquifer tests were determined in this way. Depending upon the geology of the site, this value is often a conservative one, since "flattening" of the curve due to vertical leakage can occur in the later stages of the test. Fractured reservoirs, however, just as often, portray the opposite response due to poor connectivity of the fractures and a limited size of the aquifer. Both of these characteristics were demonstrated during the aquifer tests. The long term pumping rates determined from these steps are listed in Table 4.2. There is no entry for Site G in this table because the optimum flow rate from G was too small to conduct a long term test on the well.

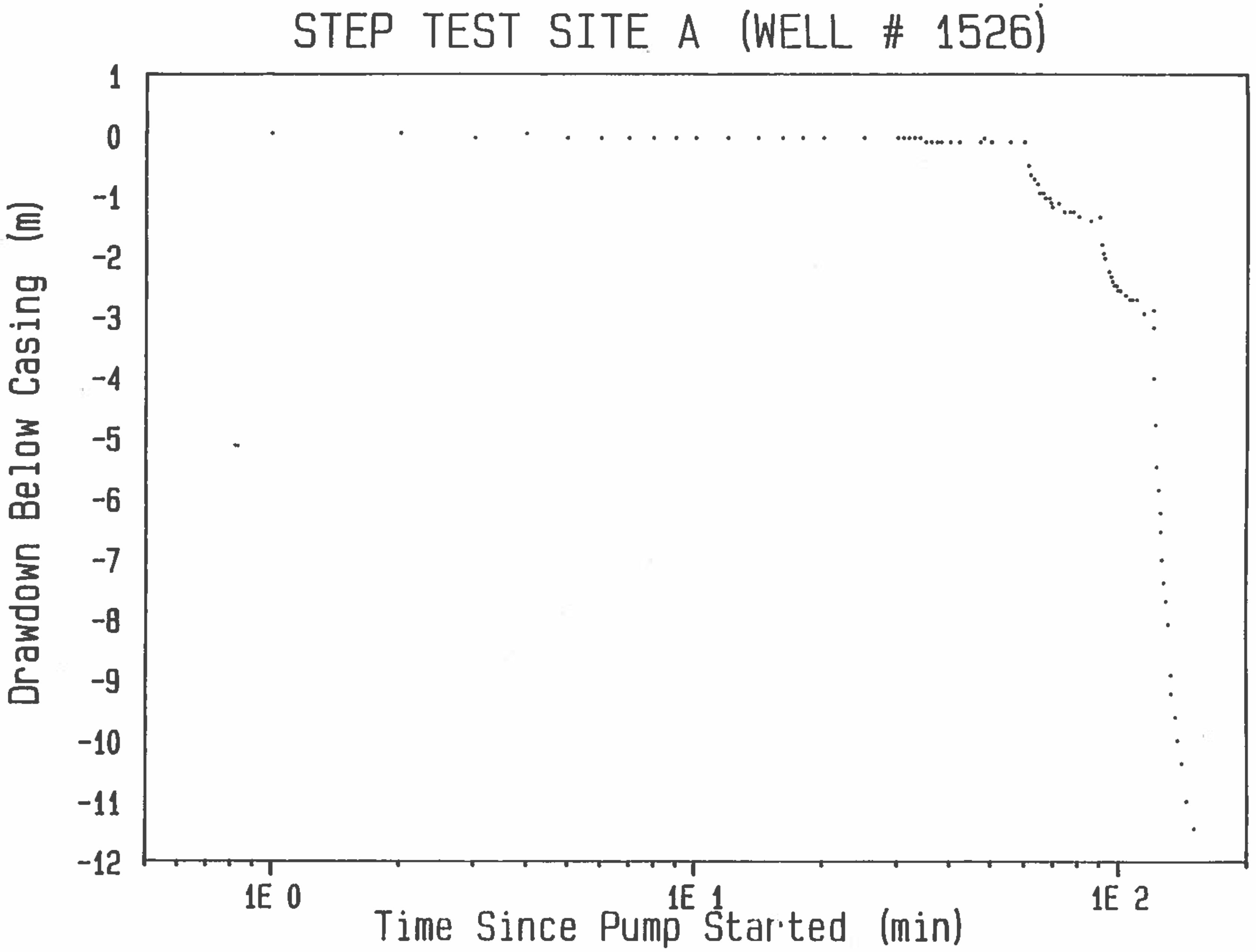
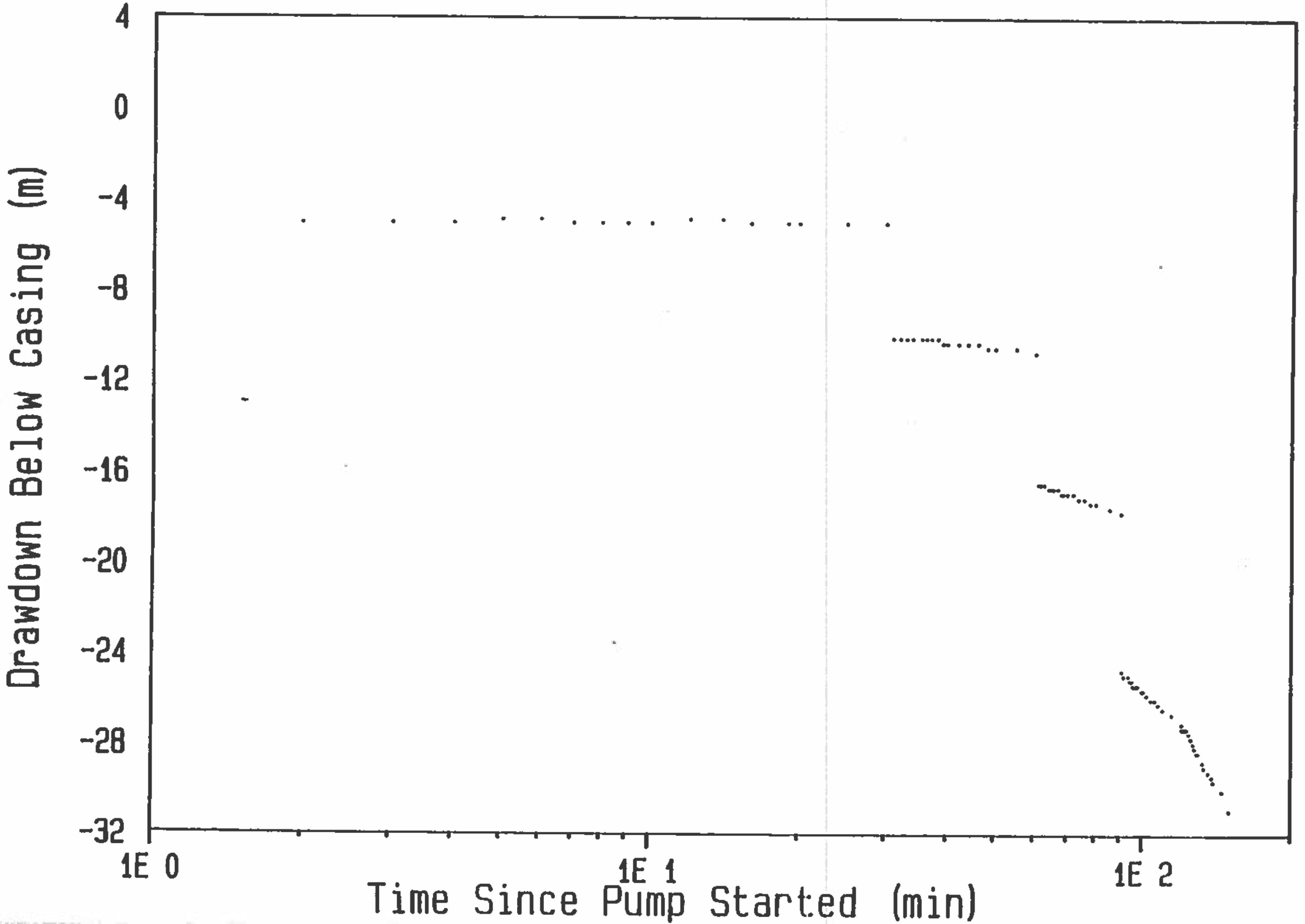


Figure 4.3: Plot of drawdown versus log time for step test on well #1526, Site A.

STEP TEST SITE B (WELL # 1529)



STEP TEST SITE C (WELL # 1527)

Figure 4.4: Plot of drawdown versus log time for step test on well #1529, Site B.

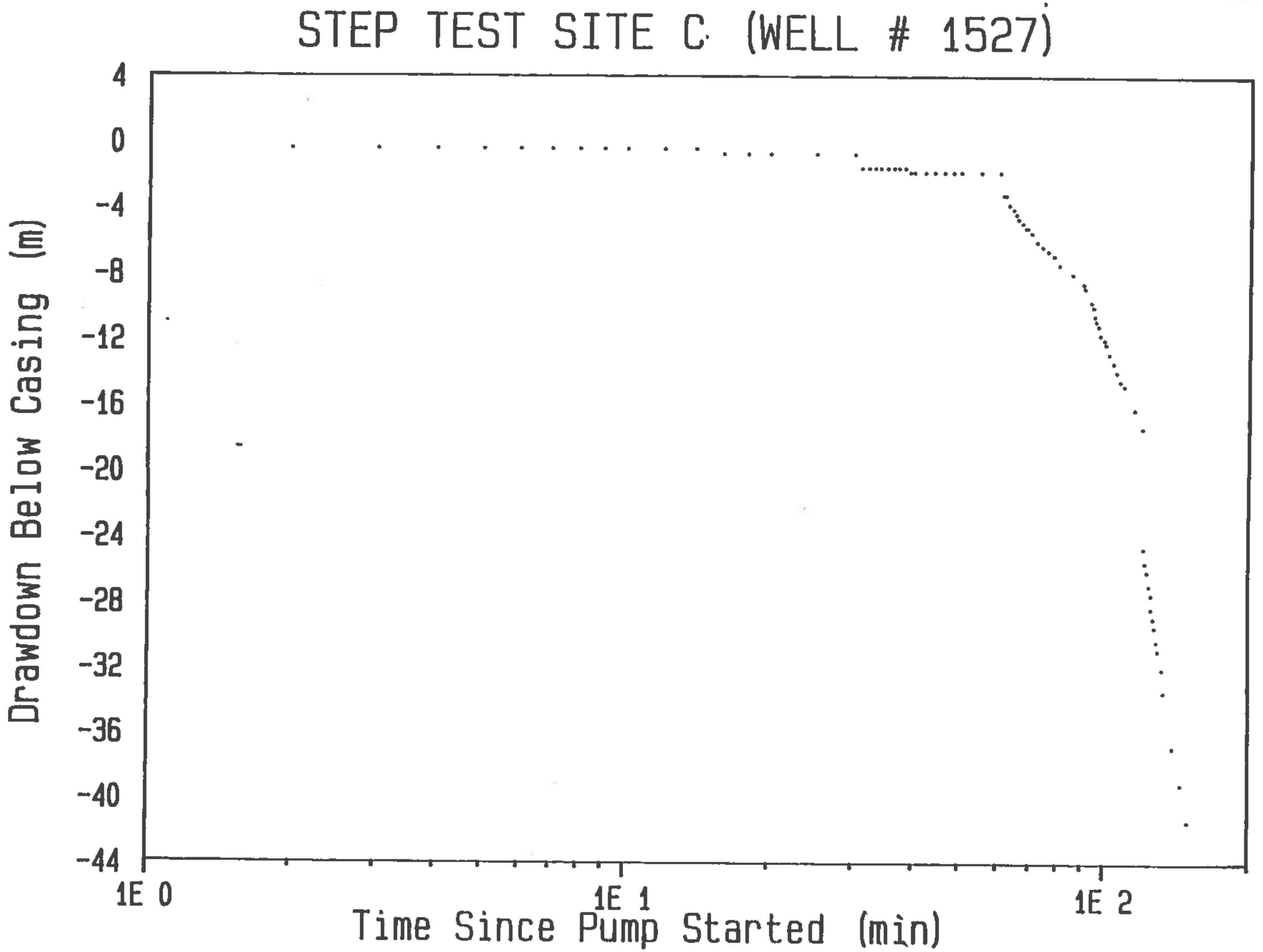


Figure 4.5: Plot of drawdown versus log time for step test on well #1527, Site C.

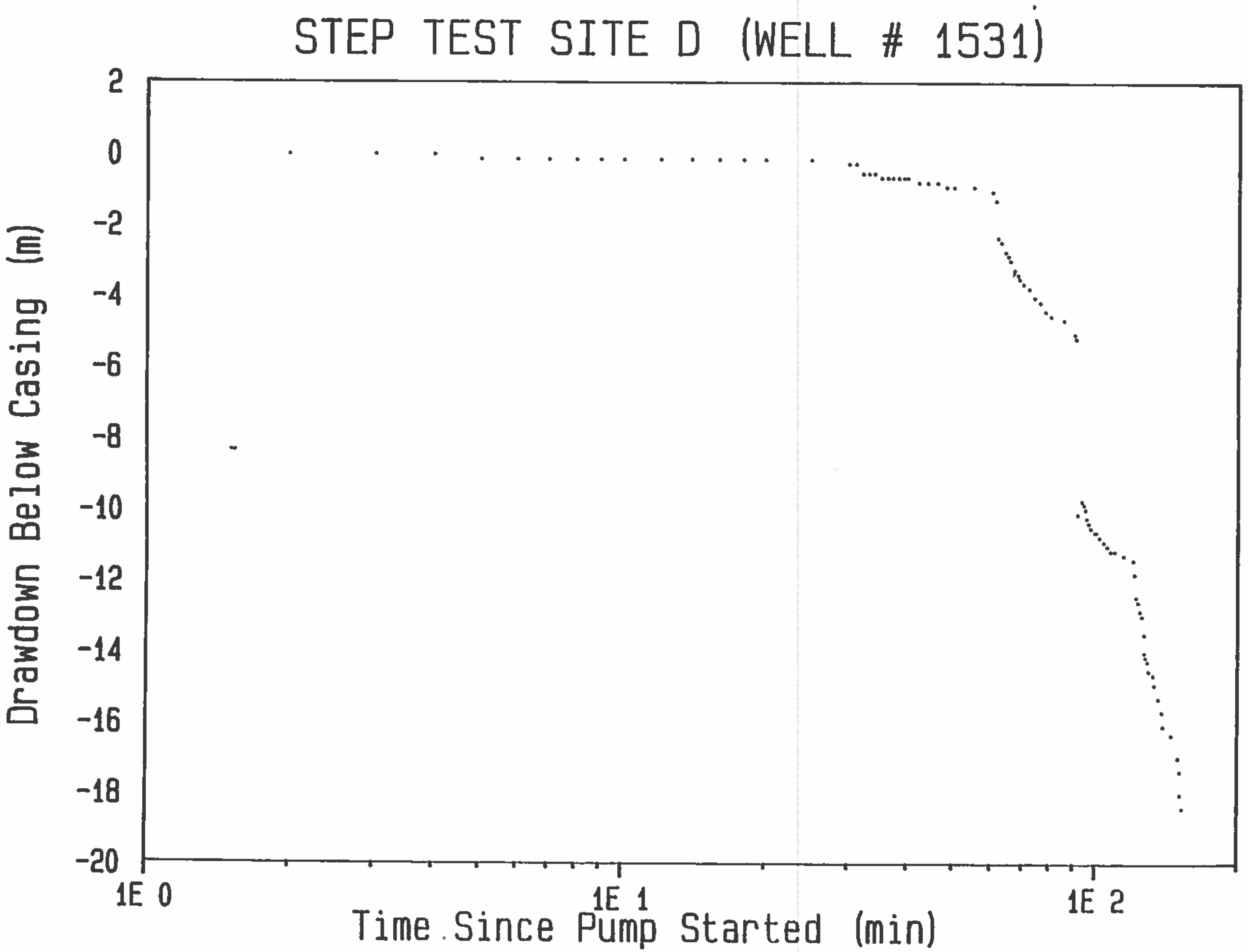


Figure 4.6: Plot of drawdown versus log time for step test on well #1531, Site D.

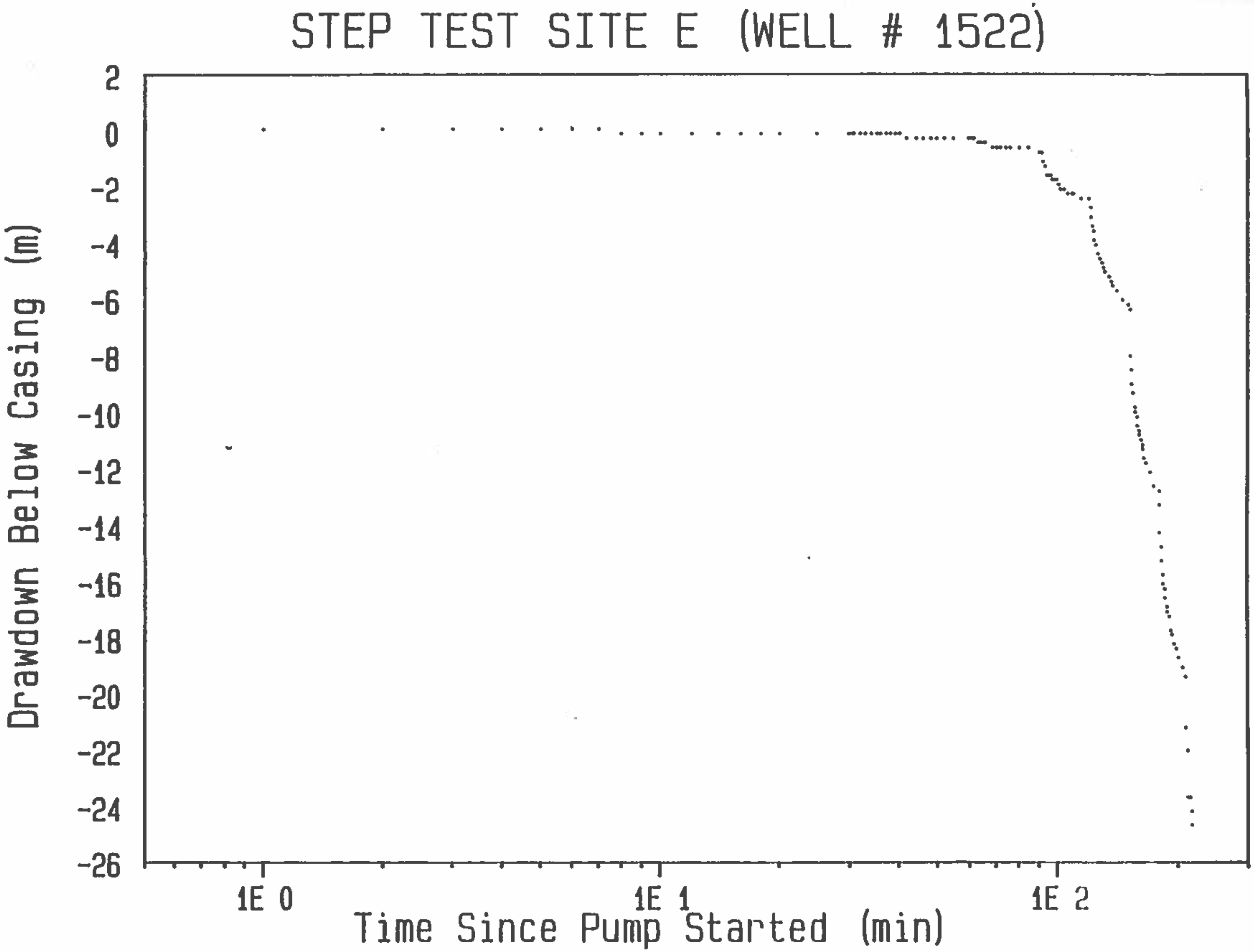


Figure 4.7: Plot of drawdown versus log time for step test on well #1522, Site E.

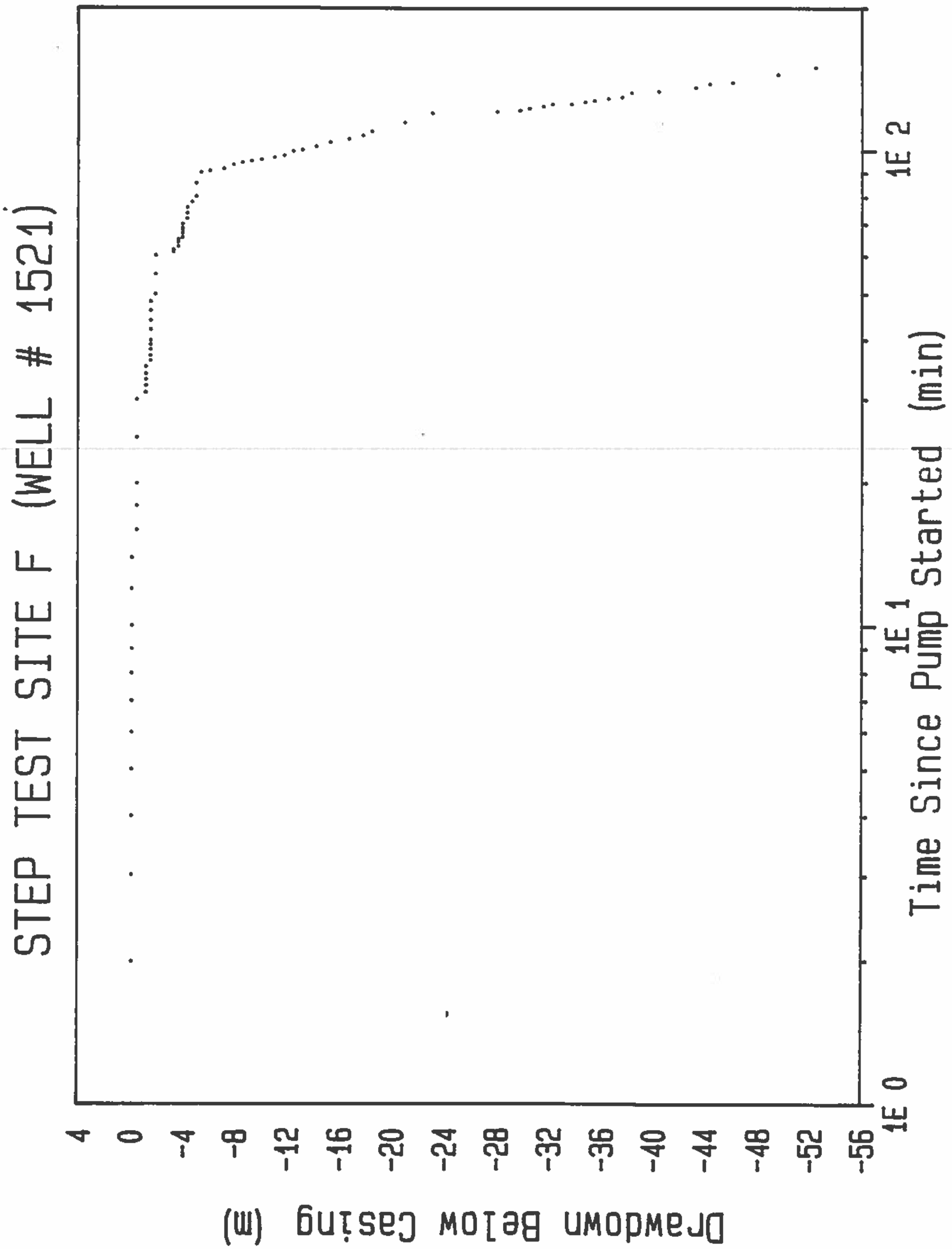


Figure 4.8: Plot of drawdown versus log time for step test on well #1521, Site F

STEP TEST SITE G (WELL # 1519)

Time Since Pump Started (min)

Figure 4.8: Plot of drawdown versus log time for step test on well #1524, Site F.

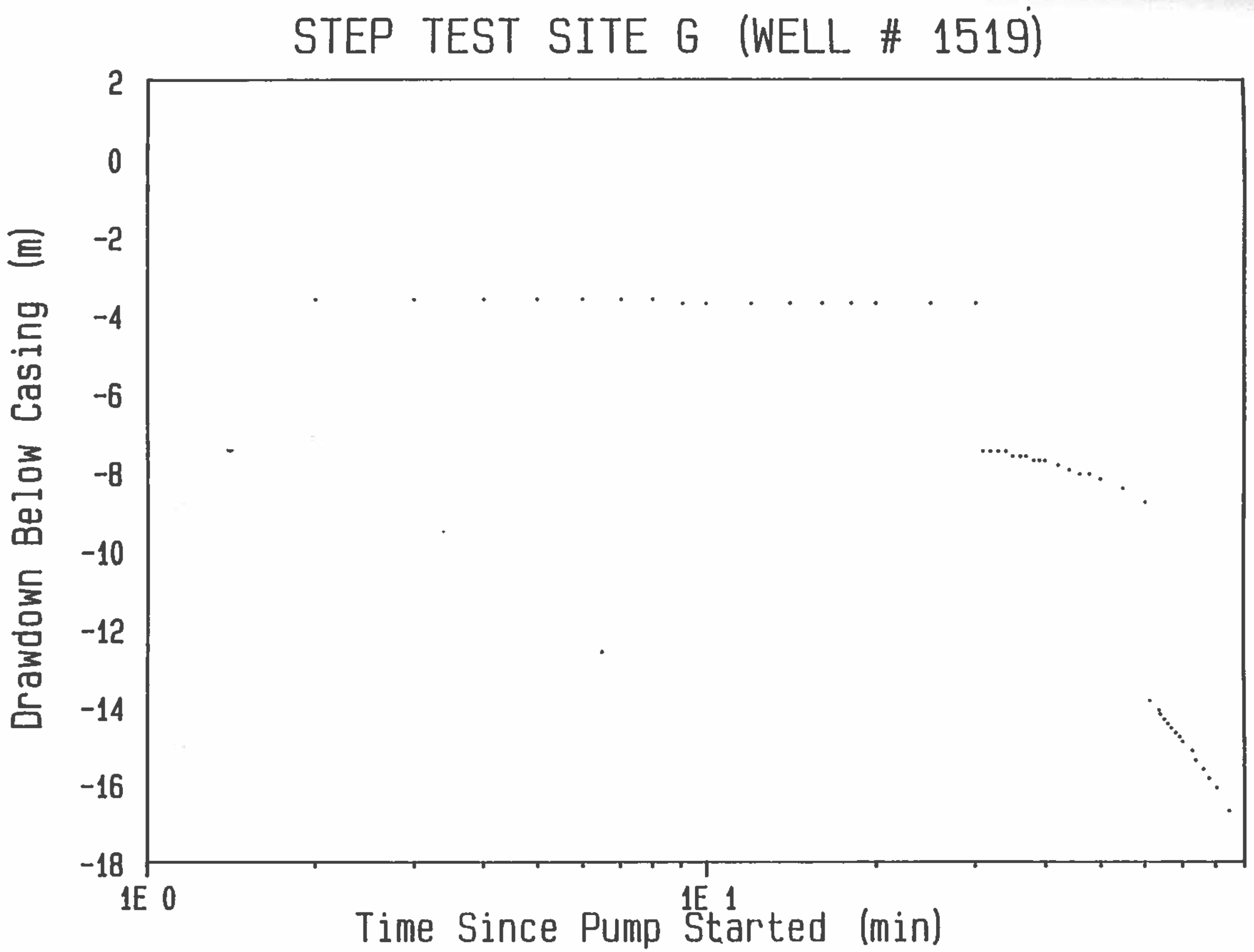


Figure 4.9: Plot of drawdown versus.log time for step test on well #1519, Site G.

TABLE 4.2

Long Term Pumping Rates Determined From Step Test

Well #	Well Site	Pumping Rate for 24 Hour Test L/min
1526	A	9.5
1529	B	3.0
1527	C	10.2
1531	D	8.2
1522	E	9.3
1521	F	20.9

4.2.2 Aquifer tests

4.2.2.1 Introduction

A long term pumping test was performed on each of the wells listed in **Table 4.2.** These tests were performed to determine the transmissivity of the fracture zone and if possible, some estimate of its areal extent. Unlike a step test, which is of short duration, an aquifer test is much longer usually 24-72 hours. The reason for this difference is that a step test measures the hydraulic characteristics of the well bore and the material immediately around it. In contrast, the aquifer test, measures the hydraulic characteristics of the aquifer. It can be appreciated that this determination will be more representative of the aquifer if a larger volume of aquifer is influenced by the test. This is the reason why it is so important to determine the optimum pumping rate for this test. The objective should be to choose the largest rate possible without exceeding the available drawdown. In this way the largest portion of the aquifer will be influenced.

The other purpose of the long term test was to determine the degree of hydraulic connection between the overburden well and the bedrock well. During all aquifer tests the nearby shallow well was monitored for this purpose.

4.2.2.2 Methodology

Each of the aquifer tests was conducted in a similar manner. Normally the required duration of aquifer testing in bedrock wells is considered to be 72 hours. The major reason for this longer time is primarily the more unpredictable nature of a fractured reservoir, as compared to porous media. A limited areal extent may result in dewatering of the aquifer. This may not be evident in 24 hours. Since the wells in question were not designed as water supply wells it was decided because of financial and time constraints to limit the aquifer testing to about 24 hours. Although the long term "safe yield" could not be reliably established from such a short test, this evaluation was only of secondary importance and the hydraulic characteristics of the aquifer could be determined from the shorter test.

Although each test was only 24 hours or less in duration there was the possibility that some natural fluctuation of the water level would occur during the test period. In order to compensate for this fluctuation, a continuous water level recorder was set up on Well # 1526 at site A and Well # 1522 at Site E. These wells were chosen to represent the two extremes in overburden thickness for the study area. Site A is thinly covered with glacial till and Site E is thickly covered with a similar material. The hydrographs for these wells are shown in Figures **4.10** and **4.11**. The response of each well to rainfall is markedly different. The water level at Site A responds quickly and drastically to rainfall while the response at Site E is subdued.

The recorders at these sites operated throughout the testing period except for the time when these wells themselves were being tested. The water level records obtained from these sites were used to adjust the results of the pumping tests. Site conditions dictated which hydrograph to apply.

Prior to the commencement of pumping it was determined that the

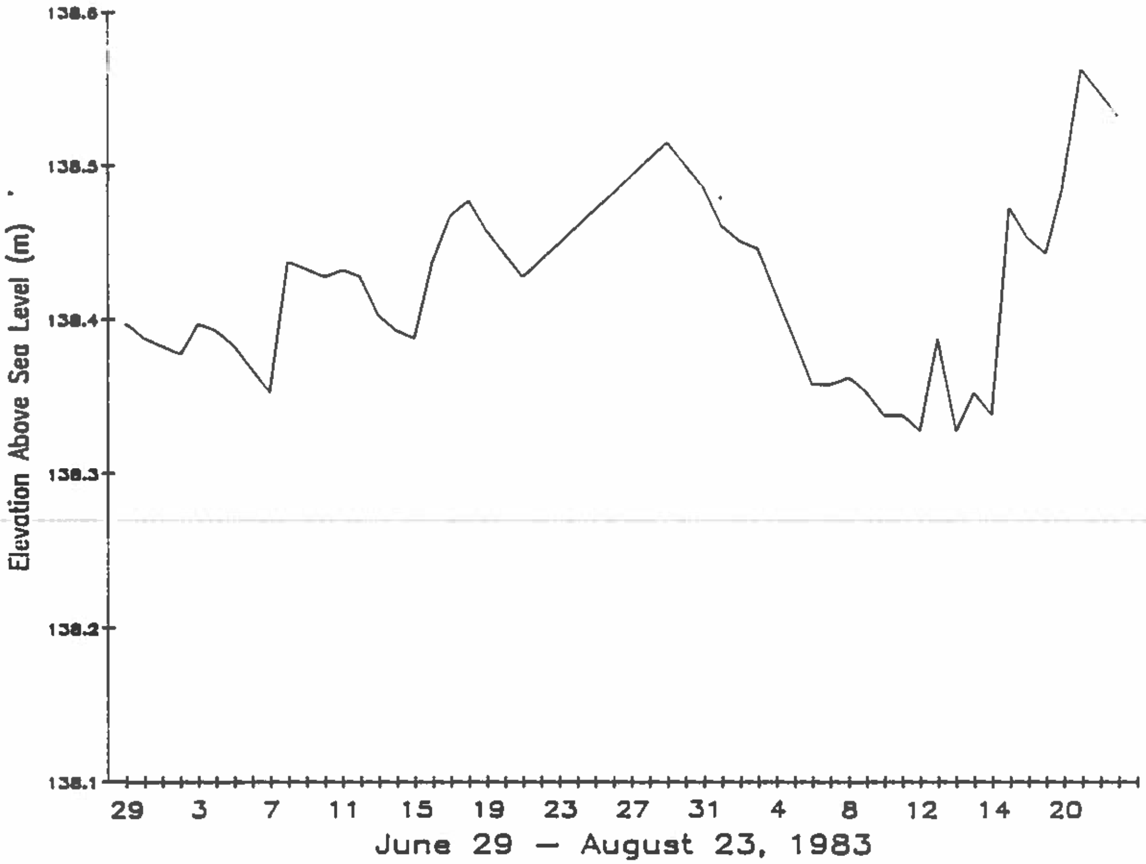


Figure 4.10. Hydrograph, Site A (Well # 1526).

water level in the well was the static water level. Static water levels were then obtained from the pumping well and in most cases the shallow monitoring well nearby. The constant head tank flow control system was calibrated for the chosen flow rate and pumping began. Water level measurements were obtained from the pumping well at approximately the following intervals:

every minute from 1 to 10 minutes
every 2 minutes from 10 to 20 minutes
every 5 minutes from 20 to 50 minutes
every 10 minutes from 50 to 90 minutes
every 15 minutes from 90 to 180 minutes
every 30 minutes from 180 to 300 minutes
every 60 minutes from 300 to 1440 minutes

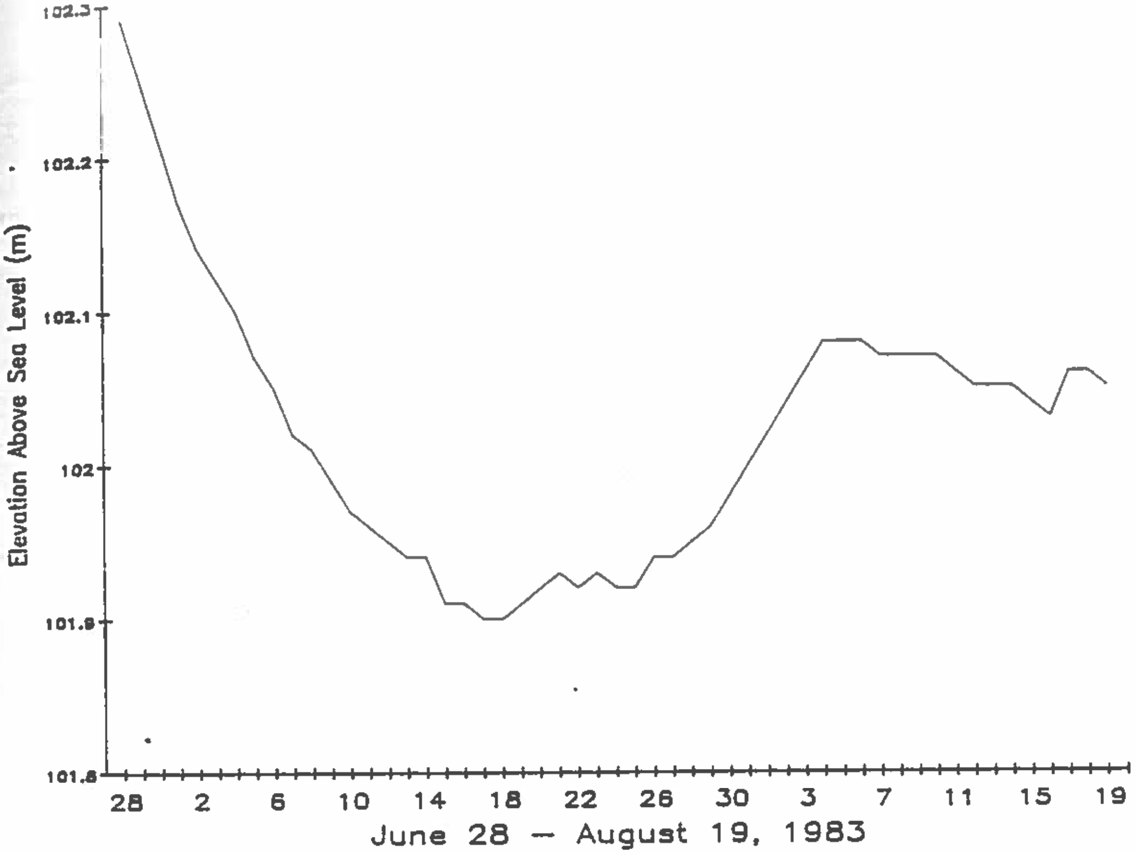


Figure 4.11. Hydrograph, Site E (Well # 1522)

The water level in the shallow well was measured hourly. At the end of the aquifer test, recovery measurements were recorded. This normally continued until about 80% recovery had been achieved.

For all measurements an electric depth gauge was utilized. The values thus obtained were expressed as drawdown (that is static level - the pumping level). These values were adjusted according to the natural fluctuation indicated by the appropriate hydrograph. Residual drawdown was calculated from the recovery measurements and the extended time drawdown curve. Adjusted values of drawdown, and residual drawdown are listed in **Appendix D.**

4.2.2.3 Discussion of results

The aquifer tests were analyzed using the Jacob modification of the Theis solution to transient radial flow. This method is outlined in many Hydrogeology textbooks. To apply the method, the drawdown and residual drawdown were plotted on similog graph paper. These plots are shown in Figures 4.12 - 4.17. In this method the transmissivity is calculated using the following equations.

$$T = \frac{2.3\ Q}{4v\ \ h} \qquad (4.2)$$

where T = transmissivity
Q = discharge
h = change in water level per log cycle

The calculated value of T, for each well, is summarized in Table 4.3.

TABLE 4.3
Results of Aquifer Testing

Well #	Site	Transmissivity m^2/day
1526	A	4.8
1529	B	3.0×10^{-2}
1527	C	1.7
1531	D	3.3×10^{-2}
1522	E	1.7
1521	F	2.4×10^{-2}

An examination of the drawdown plots shows that in all cases except at Sites A and B, a positive boundary condition was encountered. This is indicated by the gradual flattening of the curve in the latter stages of the test. The physical explanation of this is that the aquifer is receiving recharge from some source as the cone of depression extends further and further away from the well. The most likely source of recharge is the overburden, which is much thicker at the other sites than

AQUIFER TEST SITE A (WELL # 1526)

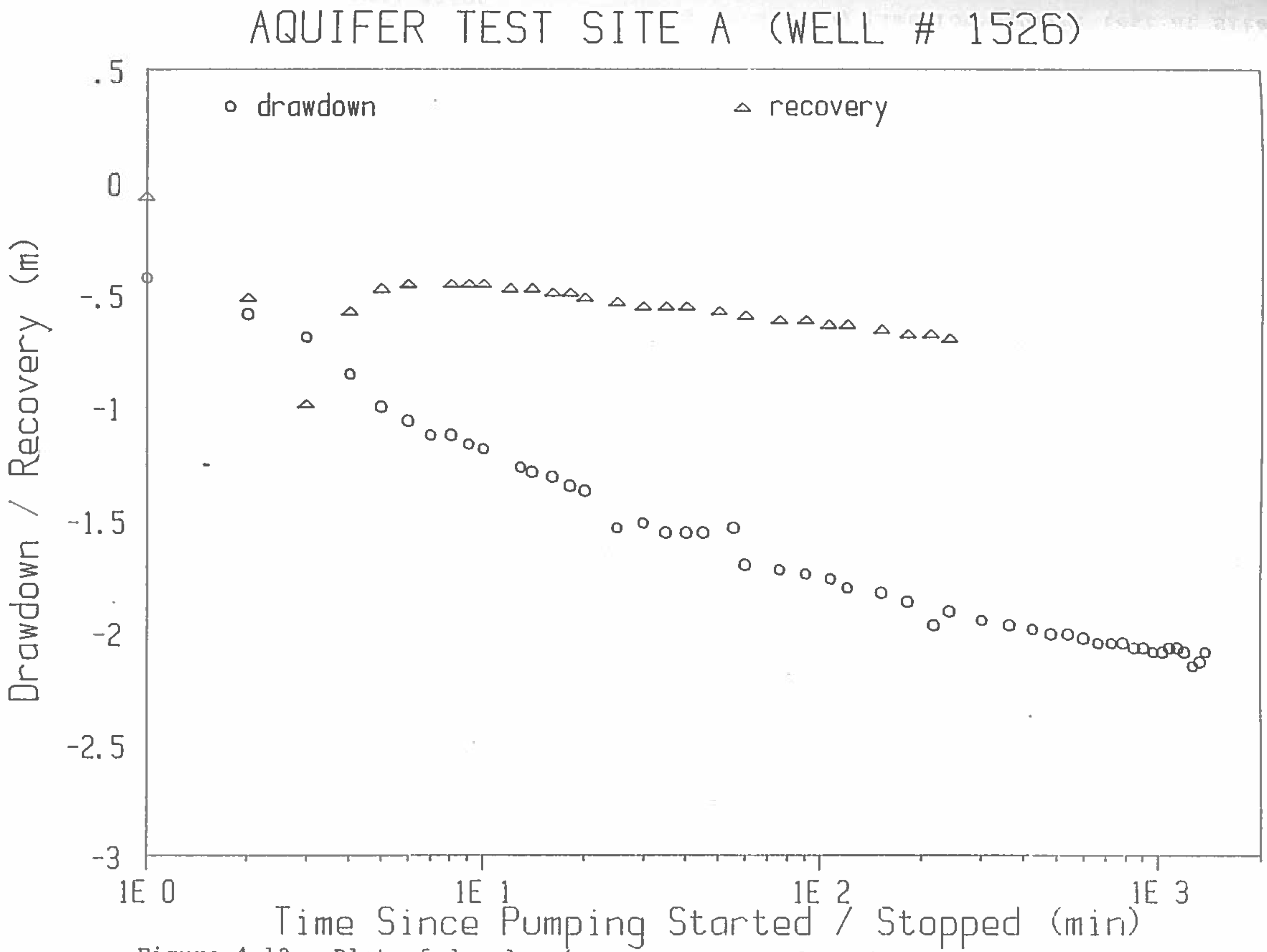


Figure 4.12: Plot of drawdown/recovery versus log time for aquifer test at Site A well #1526.

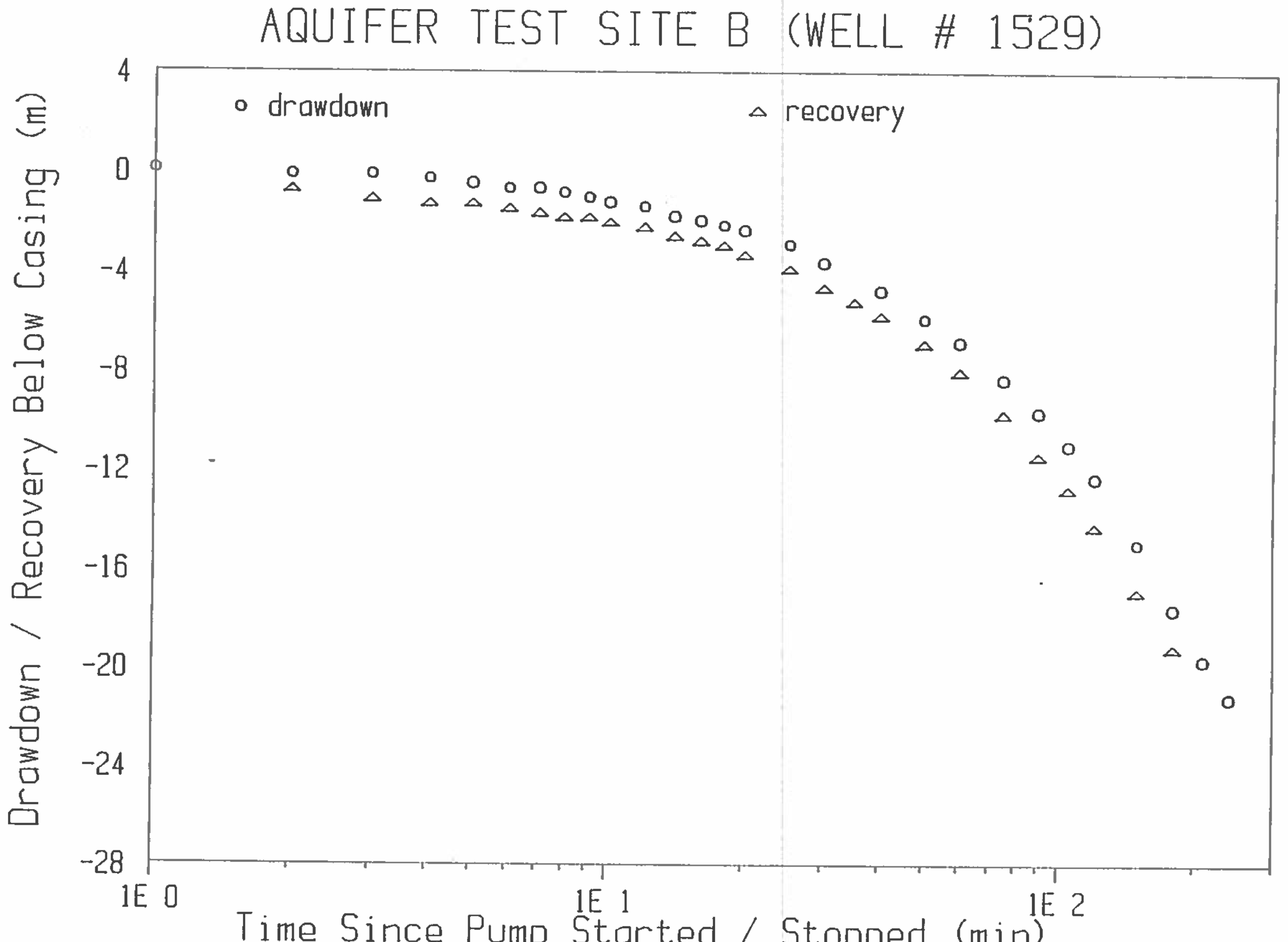


Figure 4.13: Plot of drawdown/recovery versus log time for aquifer test at Site B

AQUIFER TEST SITE C (WELL # 1527)

Figure 4.13: Plot of drawdown/recovery versus log time for aquifer test at Site B well #1529.

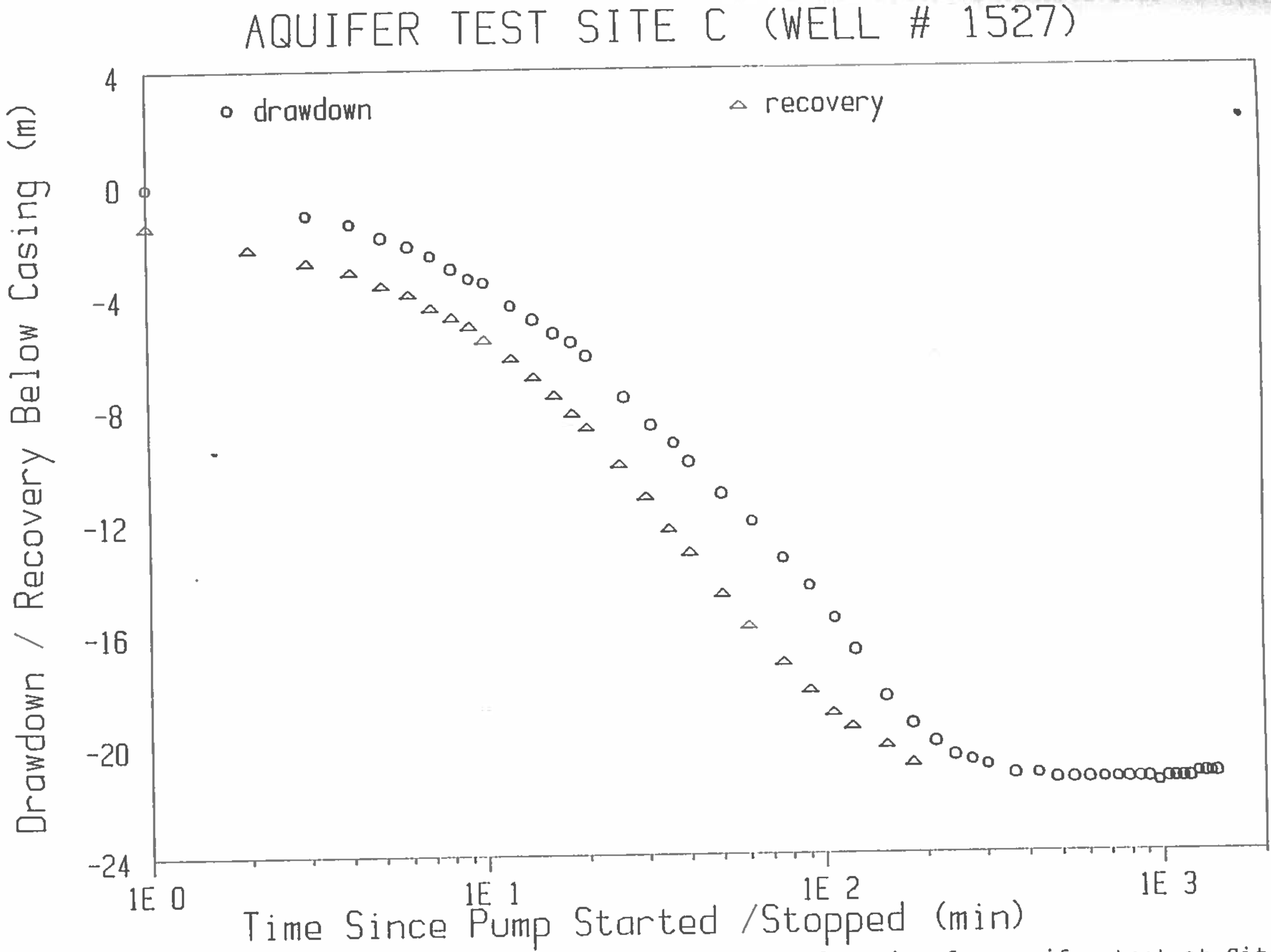


Figure 4.14: Plot of drawdown/recovery versus log time for aquifer test at Site C well #1527.

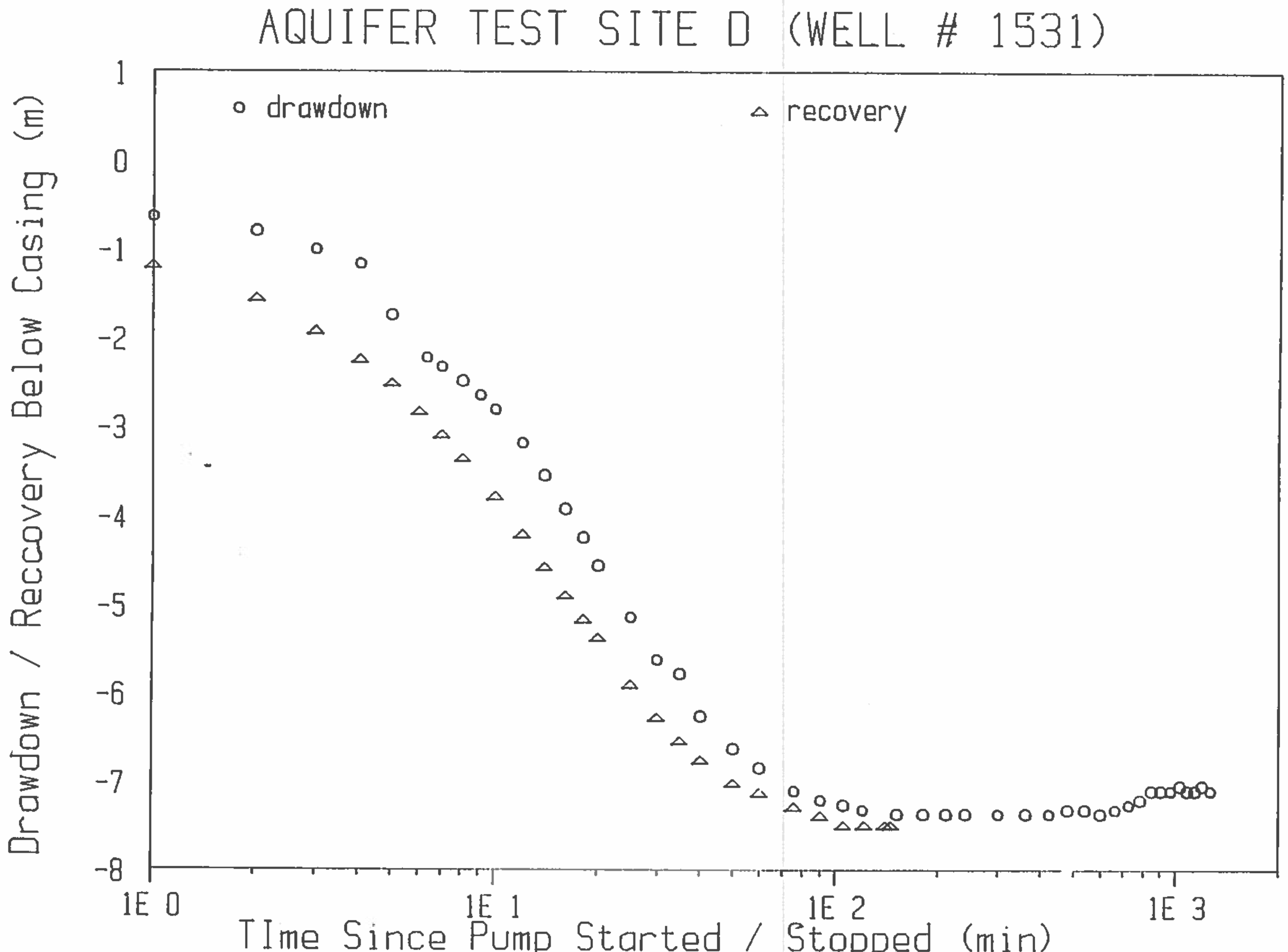


Figure 4.15: Plot of drawdown/recovery versus log time for aquifer test at Site D

AQUIFER TEST SITE E (WELL # 1522)

Figure 4.15: Plot of drawdown/recovery versus log time for aquifer test at Site D

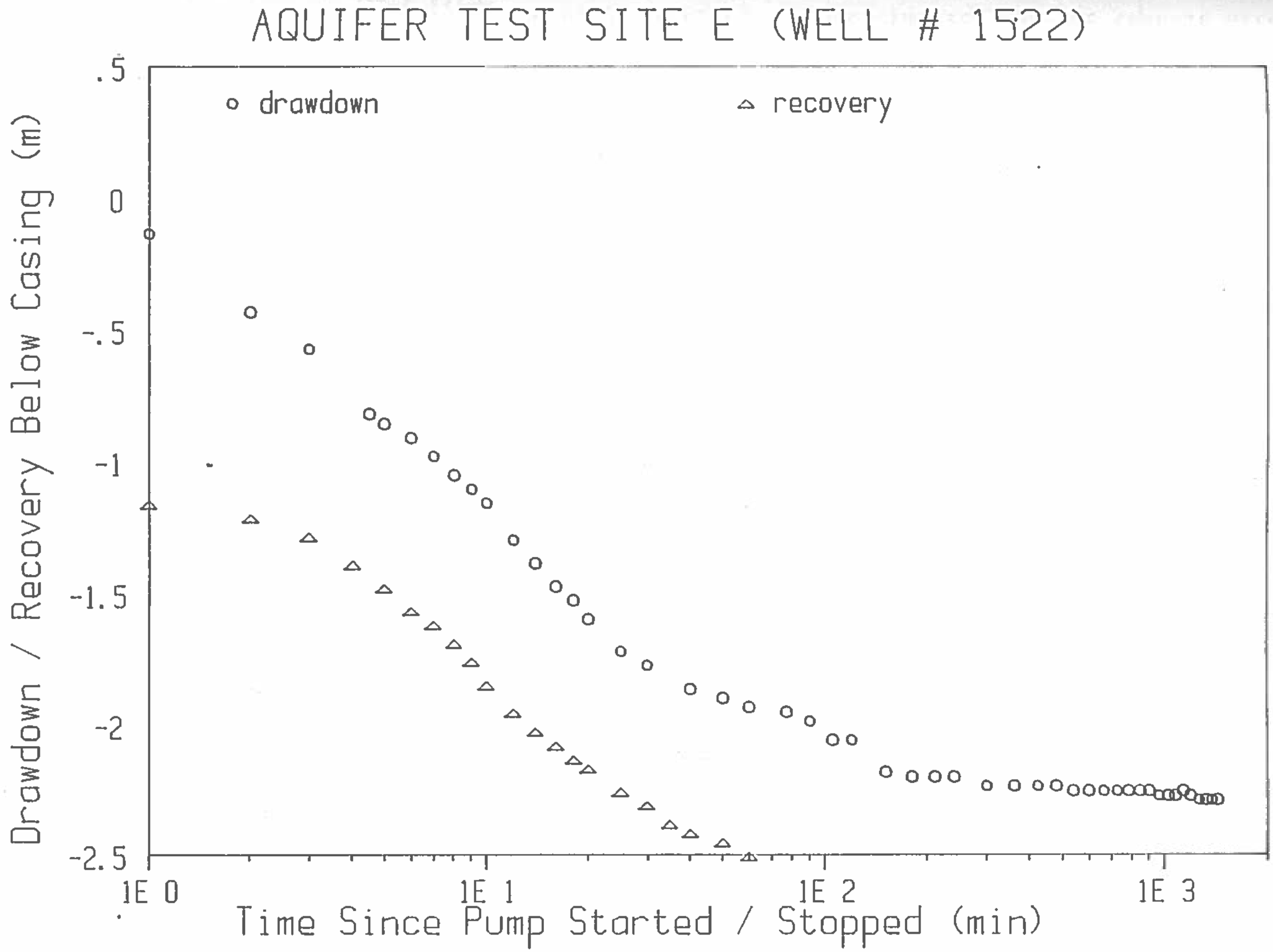


Figure 4.16: Plot of drawdown/recovery versus log time for aquifer test at Site E well #1522.

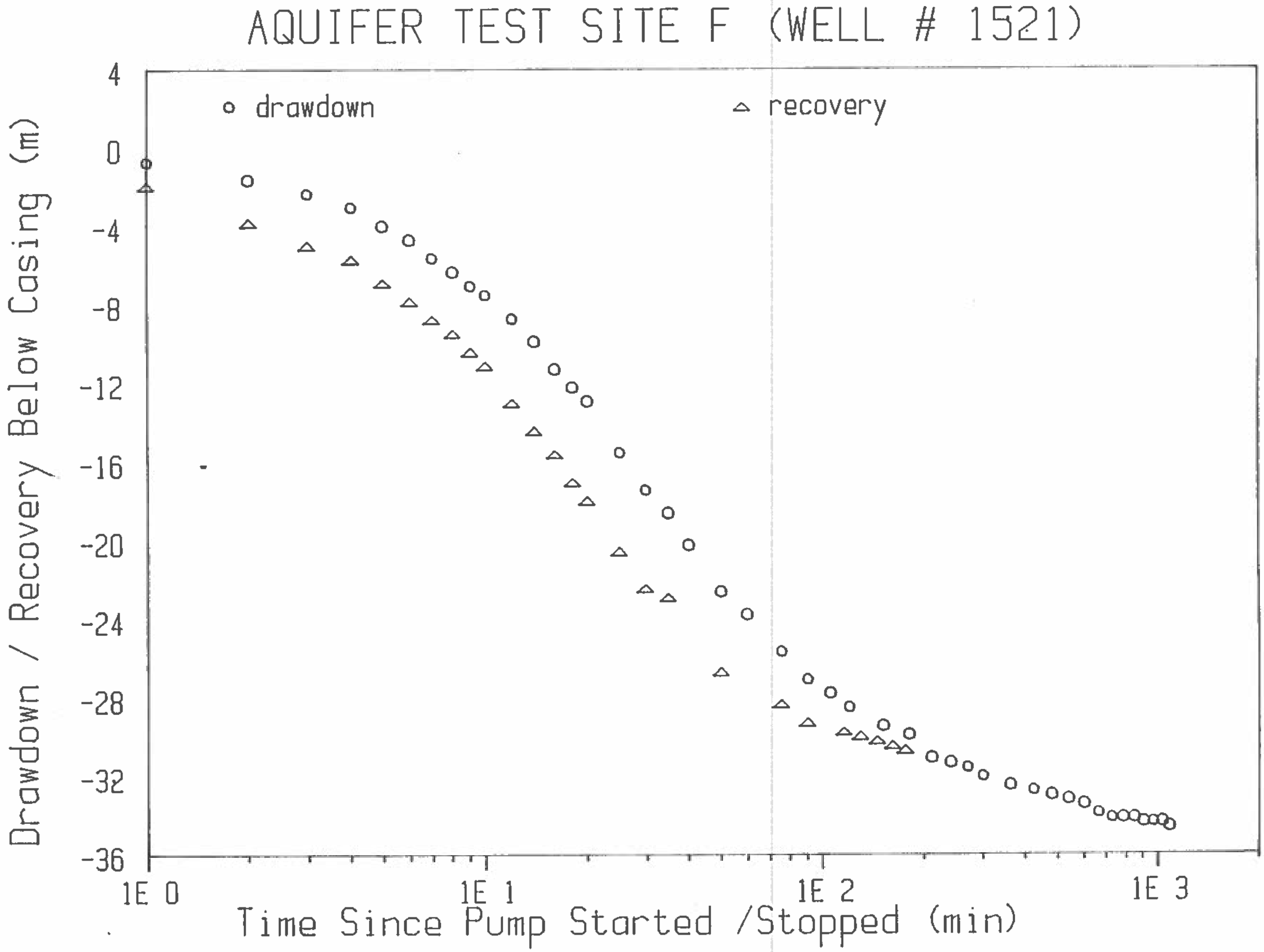


Figure 4.17: Plot of drawdown/recovery versus log time for aquifer test at Site F well #1521.

it is at Sites A and B. This fact is not so apparent from the well logs in Appendix B as these are, of course, point sources of information. Batterson (1984) shows the area, in general, surrounding Sites A and B, to be till veneer while the other sites have thicker cover.

It is not surprising then that the aquifer test at Site A shows, in general, a continuous downward trend in the pumping level. This indicates no recharge boundary. The results at Site B are even more limiting. The slope of the curve becomes increasingly steep indicating a negative boundary condition. The rock at this site was particularly dense and massive. The fracture zone evidently had little areal extent.

4.3 Testing Water Table Wells

4.3.3 Slug tests

4.3.1.1 Introduction

Adequate pumping tests could not be performed on the shallow wells due to the low yield characteristics of the overburden materials. In order to obtain some information on the hydraulic characteristics of these materials a slug test was used. The method of Hvorslev (1951) was employed (See Freeze and Cherry (1979) for a summary of this method). The method is based on the recovery of the water level in a point piezometer after the sudden removal of a known volume of water.

In preparation for the test a weighted 1 litre plastic sample bottle (the slug) was submerged in the well to be tested, and left for about 24 hours or until equilibrium conditions were reached. To facilitate the early time recovery measurements an electronic data logger and pressure transducer were used. Once the static level was determined, the slug was removed from the well and the recovery of the water level was recorded according to the following schedule.

every .2 seconds from 1 to 2 seconds
every second from 2 to 20 seconds
every 5 seconds from 20 seconds to 2 minutes
every 30 seconds from 2 minutes to 10 minutes

every 2 minutes from 10 minutes to 102 minutes
every 10 minutes from 102 minutes to 1002 minutes

The level of water in the well at time zero was calculated by subtracting the height of water column (equivalent to the volume of the slug) from the static level. Recovery of the well was taken relative to this value.

4.3.1.2 Discussion of results

The Hvorslev slug test was used to determine the hydraulic conductivity of the soil in which the shallow wells were constructed. The following equation was used.

$$K = \frac{r^2 \ln (L/R)}{2\ L\ T_o} \qquad (4.3)$$

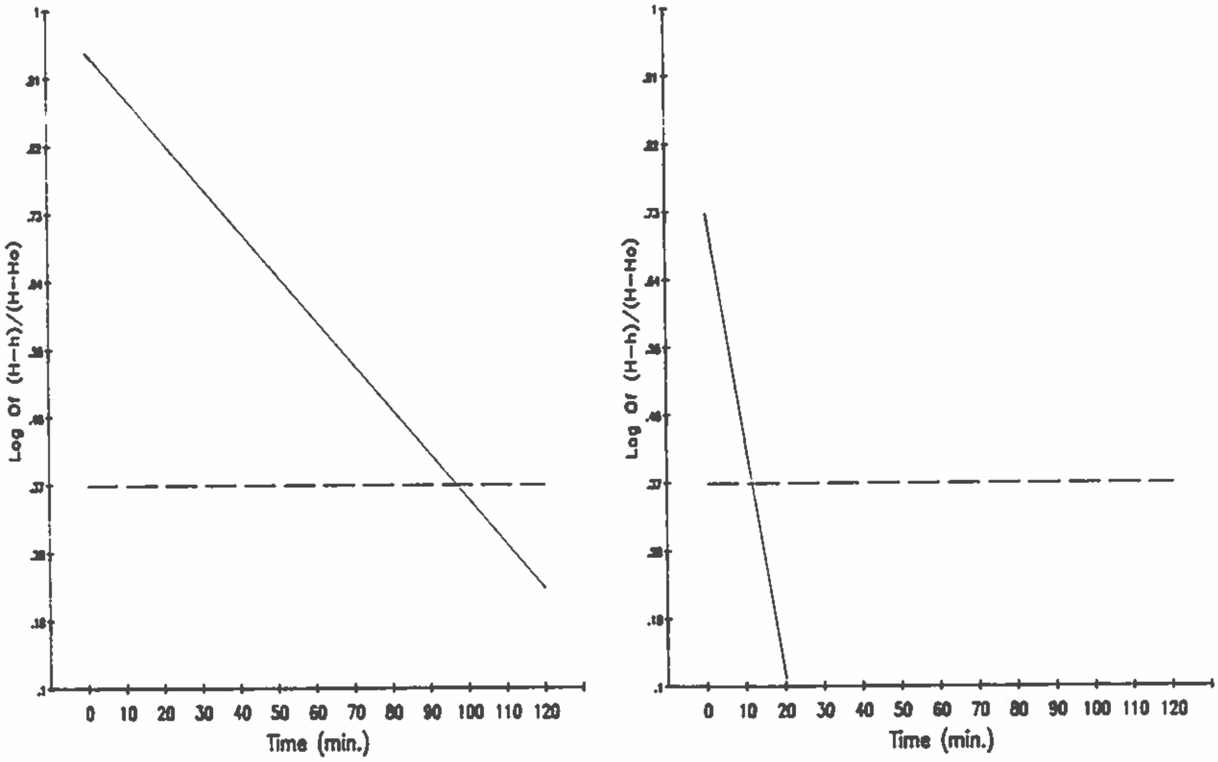
where K = hydraulic conductivity,
r = the radius of the piezometer tube,
L = the length of the perforated section of the piezometer,
R = the radius of the disturbed soil (usually taken as the borehole radius) and
T_o = the time that would be required for the complete equalization of the head difference if the original rate of inflow was maintained.

T_o is determined as follows:

$$\frac{H - h}{H - H_o} = e^{-t/T_o} \qquad (4.4)$$

where H = the height of water above some datum (ie., the bottom of the hole) under static conditions
h = the height of water at time t,
t = the time for the water to reach a height h, and
H_o = the height of water at time t = 0.

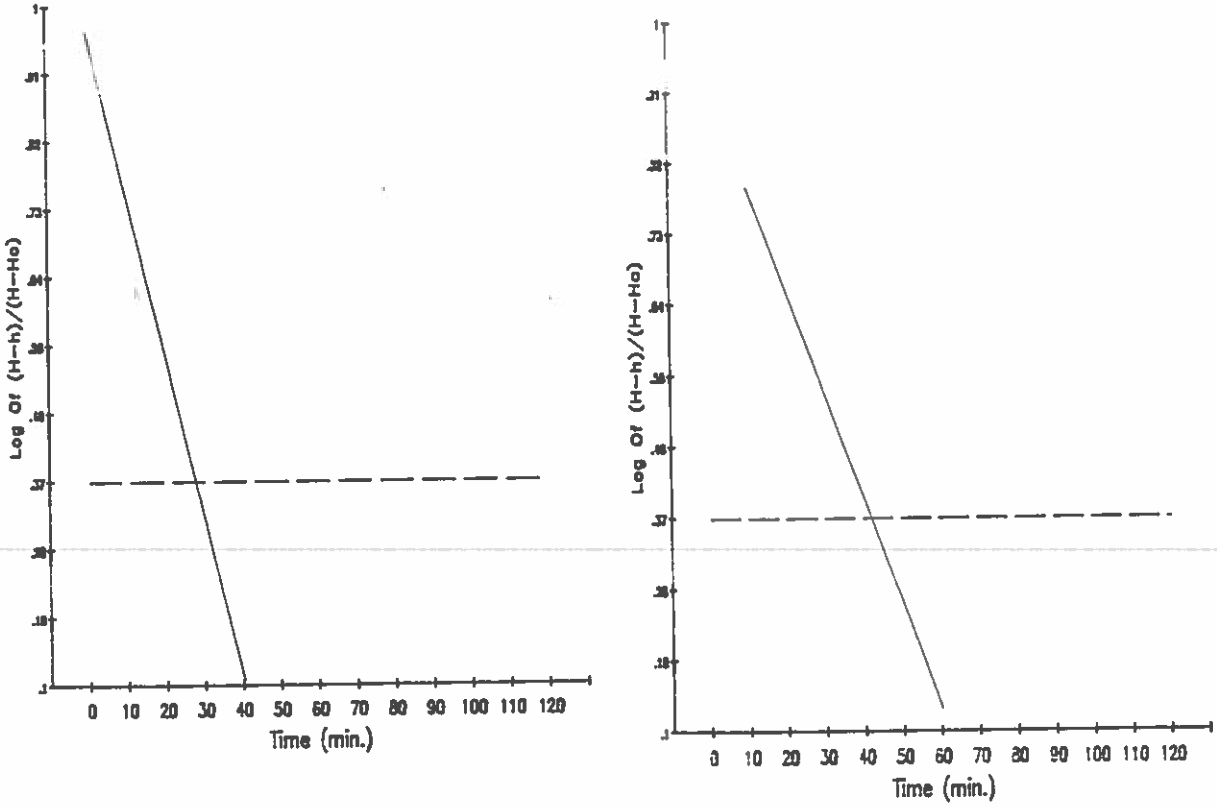
When $(H\text{-}h)/H\text{-}H_o) = 0.37$ then $\ln (H\text{-}h/H\text{-}Ho) = -1$ and Equation (4.4) reduces to $-1 = -t/T_o$ or $T_o = t$. It follows that to determine T_o, a plot of log $(H-h)/(H-H_0)$ versus t is made and the value of t at log $(H-h)/(H-H_0) = 0.37$ is equated with T_0. The recovery measurements are listed in **Appendix E.** The plots of $(H-h)/H-H_0)$ versus t are shown in **Figure 4.18.** The values of hydraulic conductivity for the 4 wells tested are tabulated in **Table 4.4.**



a

b

Figure 4.18. Plots of $(H-h)/H-H_0)$ versus t for a) Site B, b) Site D



a

b

Figure 4.19. Plots of $(H-h)/H-H_0)$ versus t for a) Site E and b) Site G

TABLE 4.4

Hydraulic Conductivity of Overburden Determined by Slug Test

Well#	Site	Hydraulic Conductivity cm/sec.
1530	B	1.31 x 10-4
1532	D	3.81 x 10-3
1535	E	1.62 x 10-4
1533	G	2.27 x 10-4

These values, although quite consistent, may be slightly large. As mentioned in Section 3, an air hammer rotary drilling rig, in most cases, will disturb a larger diameter than the drill bit size. From Equation

(4.4) it is evident that when R is increased K decreases. This decrease however, could not be expected to be more than one order of magnitude.

5.0 WATER QUALITY MONITORING

5.1 Introduction

The purpose of the water quality testing program was to determine the degree to which the various existing and proposed land use activities influence the underlying groundwater. In order to accomplish this purpose, the natural water quality had to be known. It was assumed, at the outset, that natural conditions at each site were no longer represented by the groundwater resident there. It was also assumed that the geology at each site would be reflected in the water quality. Within these limitations Site G was taken to represent the natural water quality and the other sites were taken as representing various stages and categories of development.

This section describes the4lechemical and physical water quality parameters that were chosen to differentiate between the natural and developed parts of the basin as described above. In addition, the sampling methods used to extract water samples that reliably reflected the resident groundwater are discussed.

5.2 Water Quality Criteria

In order to assess water quality effects of various land use activities on groundwater, the appropriate physical and chemical parameters were chosen for analyses. The particular effects of these activities are as follows:

1. Developing areas are characterized by physical changes in land surfaces. These include subsoil exposure, major soil disturbances, vegetation removal, excavation and exposure of bedrock, and wetland drainage. Subsoil exposure and soil

disturbance upset the natural equilibrium that exists in most soil profiles. Soluble minerals that have leached down from overlying layers and precipitated in the underlying zones are exposed to the weathering processes anew. They invariably redissolve and move down further perhaps entering the groundwater regime. Other minerals that have been deposited because of the chemical environment change quickly on exposure to oxygen and reenter the solute load of percolating recharge water. These effects are often represented by elevated levels of calcium, magnesium, alkalinity, specific conductance, pH, turbidity, hardness, iron and manganese. Vegetation removal can increase nitrification rates within the cutover portion. This produces high levels of nitrate and ammonia and other dissolved cations which infiltrate the soil layers. Excavation and exposure of bedrock units can result in the production of the equivalent of acid mine drainage. This is particularly likely in sandstone, shale and slate which are common in the Waterford River Basin. It is caused by the oxidation of sulphide minerals. Elevated levels of sulphate may result. When this is hydrolyzed, sulphuric acid is produced which lowers pH and may further leach otherwise insoluble minerals such as iron, manganese and some heavy metals such as zinc, copper, and lead. Wetland drainage may cause an influx of highly colored and acidic water into the saturated zone. High levels of manganese, organic acids, and lower pH can result.

2. Industrial and developed areas are characterized by a multitude of contaminants. A number of dissolved cations, metals and nutrients are recharged into the saturated zone. Byproducts of development such as deicing salts, dust control agents, bird and animal wastes, lawn fertilizers, oil wastes, septic tank effluents and detergents all add their load of solutes to the groundwater. Higher levels of TDS, BOD'S,

phosphorous, metals, sodium, and chloride, may be the result of such activity.

3. Agricultural practices cause nutrient enrichment of percolating groundwater. Levels of phosphorous, and nitrate can be elevated. Animal dropping causes higher pH, ammonium, bacteria and turbidity levels.

Table 5.1 lists the physical and chemical parameters that were used to monitor the effects of urbanization as outlined above.

TABLE 5.1

Physical and Chemical Parameters Used.

Calcium
Magnesium
Sodium
Potassium
Chloride
Sulphate
Total dissolved Solids (TDS)
Turbidity
Colour
Dissolved Oxygen
Temperature
Iron
Manganese

Bacteria
Total Nitrogen
Nitrate & Nitrite
Ammonia
Total Phosphorous
Ortho Phosphorous
Total Organic Carbon
Copper
Lead
Specific Conductance
Zinc
Alkalinity

5.3 Sampling Methods

The sampling frequency required to detect changes in water quality was determined by the velocity of subsurface flow. Groundwater typically moves very slowly through porous media or fractured materials. This is evident from the values of hydraulic conductivity determined in Section 4.3. Using a hydraulic gradient of 0.12, for instance, as indicated in **Figure 2.3**, in the vicinity of Site E, and the value of the hydraulic conductivity for the overburden at Site E, as listed in Table 4.4, the Darcy velocity is calculated as follows:

$$\text{velocity} = KI = 1.62 \times 10^{-4} \times 0.12 = 1.94 \times 10^{-5} \text{ cm/sec}$$

where

I = hydraulic gradient.

The instantaneous velocity is calculated by dividing this value by the porosity of the media. In the case of till, the porosity value is about 50%. It follows then that the flow velocity is about 0.03 m/day. This means that seasonally, the movement is about 4 m. It is evident then that yearly sampling would be adequate to detect changes in water quality. To determine seasonal fluctuation, however, a quarterly sampling schedule was maintained.

Different methods of obtaining representative water samples were used in the course of the study. The initial plans was to pump both shallow and deep wells until the water was clear and then to obtain samples. This proved to be very time consuming and samples exceeded the acceptable limit of turbidity for reliable chemical analysis. This method was used until February 1982. To reduce the time needed for sampling and the turbidity of the water obtained, a peristaltic pump was subsequently used to sample only from the perforated zone in the shallow wells and the fracture zone in the artesian wells. The shallow wells with the exception of the one at site F were pumped until two well volumes were discharged. A sample was then taken. With both types of wells, enough water was pumped to purge the tubing and then a sample was taken with the intake set at the water bearing zone. It was presumed that the water in the deep wells at the fracture zone was constantly being refreshed from the aquifer and it was deep enough to be unaffected by the free surface in the well. Sampling by this method continued until May 1982.

In order to speed up the sampling process still further a Kemmerer sampling tube was used beginning in May 1982. The model used had no metallic parts and it was used in the deep wells and the shallow well at Site F only. The tube was lowered into the well to the water bearing zone and then closed, thus obtaining a water sample at that depth.

A further change was incorporated into the sampling method used for the shallow wells in October 1982. Most of these wells did not supply water at a rate that was sufficient to pump out two well volumes. In addition the wells often required an overnight recovery period. It was evident, that sampling in this way was little different than sampling directly without purging the well. The method was, therefore, changed and the sample was taken from the unpurged well using the peristaltic pump. This modification further reduced the sampling time and yielded a less turbid sample.

The last modification of the sampling method was implemented on October 1982. Turbidity had been an intermittent problem, especially in the shallow wells. To ensure a consistently clean sample, the water was filtered within hours of the sampling time using a 2 to 40 micron filter.

The final sampling procedure that was followed is listed below:

1. The static water level was measured.
2. The specific conductance and temperature were measured at the water bearing zone.
3. The peristaltic pump inlet or Kemmerer tube was lowered to the water bearing zone.
4. The sample bottles were rinsed 3 times with well water.
5. The sample was filtered using .2 to 40 micron filter.
6. The sample used for metal analysis was preserved with 1 mL of HNO_3.

Chemical analyses were performed by the Water Quality Laboratory of Environment Canada in Moncton New Brunswick. Physical analyses were conducted by the Environmental Protection Service in St. John's.

Some testing was carried out to determine the validity of the changes that were made in the sampling procedures as discussed above. During the aquifer testing in August 1983, duplicate samples were taken using the Kemmerer tube sampler as well as the submersible pump at various times of pumping. The samples to be compared are shown in **Table 5.2.** The analyses for the samples listed in this Table are tabulated in Appendix F. The Kemmerer sample was taken before any pumping was done. The pump samples were taken from the discharge at the times shown.

It is evident from these analyses that the various sampling methods have little effect on the value of most parameters. As expected the parameter that was influenced the most was turbidity however, this was not consistently reduced by length of pumping. At Sites B, E, F and G the pumped samples showed slightly increased turbidity while at sites C and D the turbidity was decreased in the pumped samples. The slight differences in chemistry from one method to another are attributed to turbidity. Only at Site D were the differences more pronounced but significant only with respect to calcium, magnesium, sodium, chloride and sulphate. It is not immediately evident as to why these differences occur but possible causes are as follows:

1. proximity of the well to a stream draining a subdivision,
2. man made disturbance through proximity of a playground,
3. well may be less developed.

It is noted that this well in general has a relatively large range of variability in concentration values and therefore the same could be expected from the samples under discussion.

The limited effect of surface exposure in the artesian wells was further demonstrated by depth profiles of dissolved oxygen, pH, temperature, oxidation-reduction potential and conductivity. These parameters were measured using an in-situ measuring probe. The measurements were obtained at one metre intervals in Wells #1526 and #1522 at Sites E and G respectively. These profiles are shown in Figures 5.1 and 5.2. The values of the parameters measured at depth, appear to be consistent with the expected chemical characteristics of groundwater at these sites. At Site E for instance the aquifer is more permeable than at Site G, thus the value of dissolved oxygen would be relatively high below the casing with a gradual decline in value with depth. At Site G where the rock has a low permeability a very low concentration of dissolved oxygen would characterize the resident groundwater. The profiles reflect this. It appears in fact that there is very little effect, at depth, of surface exposure in the well. It can be concluded that for deep wells at least, the Kemmerer sampling method is an adequate method of obtaining representative groundwater samples.

TABLE 5.2

Multiple Samples Taken To Test Sampling Methods

Well #	Site	Kemmerer Sample	Pumping Test Sample
1529	B	August 8, 1983	14 hr. (August 9, 1983)
1527	C	August 10, 1983	14 hr. (August 11, 1983)
1531	D	August 15, 1983	14 hr. (August 17, 1983)
1522	E	August 1, 1983	0 hr. (August 2, 1983)
			12 hr. (August 2, 1983)
			24 hr. (August 3, 1983)
1521	F	August 17, 1983	0 hr. (August 18, 1983)
			12 hr. (August 19, 1983)
			24 hr. (August 19, 1983)
1519	G	August 8, 1983	1.5 hr. (August 9, 1983)

6.0 CONCLUSIONS AND RECOMMENDATIONS

A total of 13 monitoring wells were constructed for the purpose of determining the effects of urbanization on the quality of groundwater in the Waterford River Basin. The location of each site was determined from the direction of groundwater flow from the various representative land use zones. Sites A and B were positioned to monitor industrial land

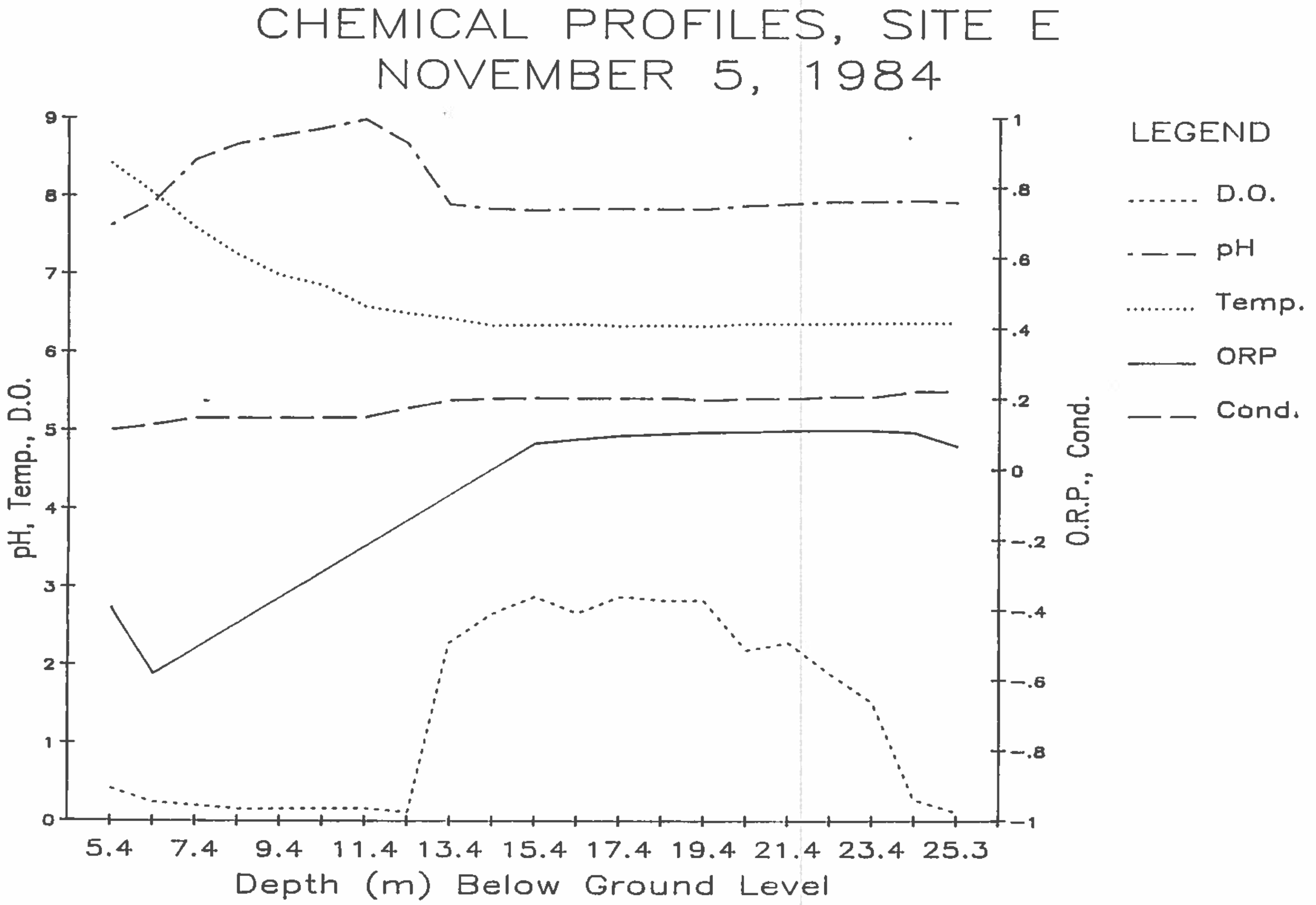


Figure 5.1: Chemical Profile of deep well #1522 at Site E, November 5, 1984.

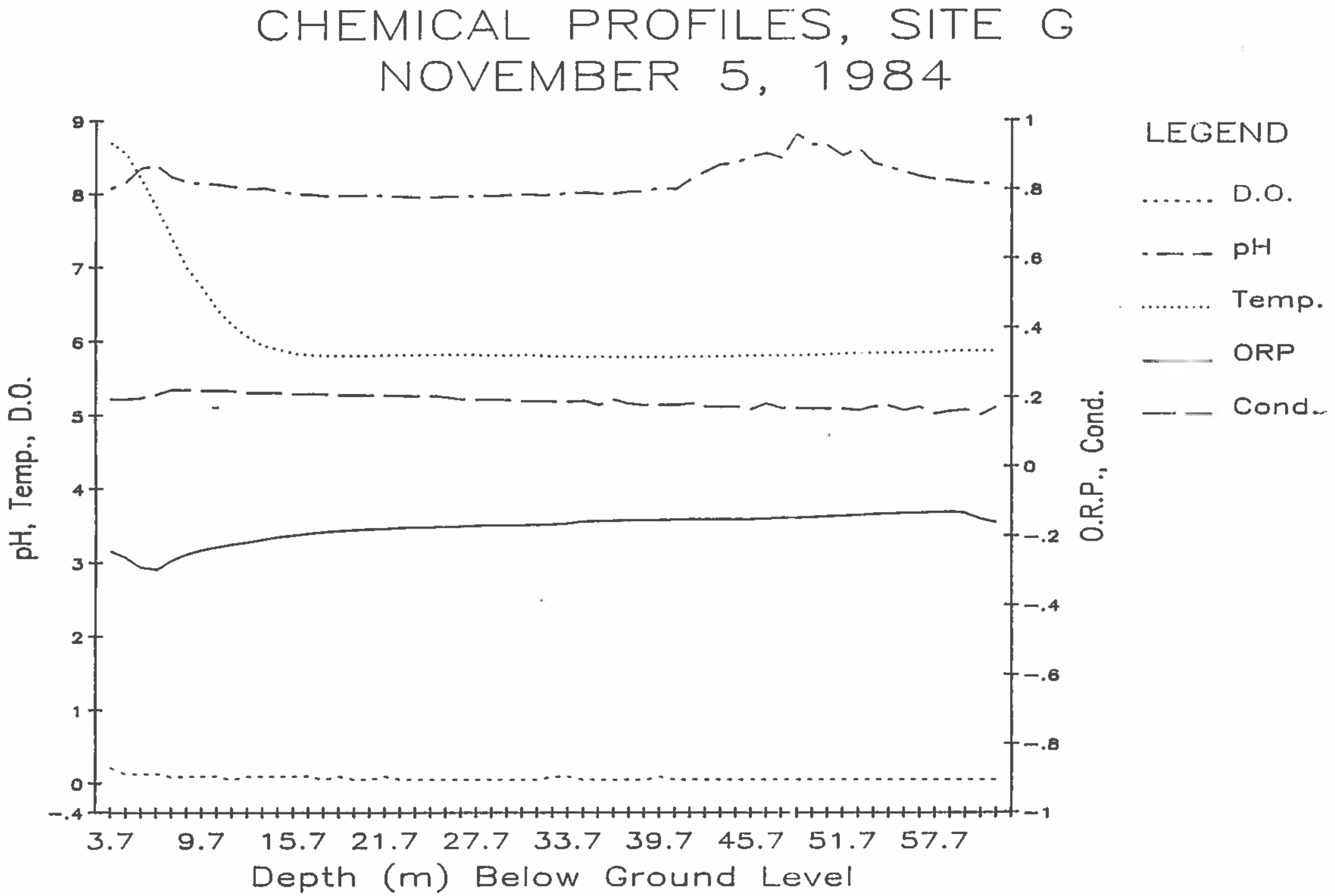


Figure 5.2: Chemical profile of deep well #1519 at Site G, November 5, 1984.

use zones. Sites A and B were positioned to monitor industrial land use. Sites C, D, and F were located to reflect urban land use. Site E was situated to indicate the effects of agricultural activity and Site G was chosen to represent the undeveloped or background water quality. The method used to determine the location for each of these wells is considered to be adequate for this study because of the relatively large areas that were to be monitored. If these areas were smaller then more sophisticated methods of testing, of the aquifer materials, would have been necessary. With regard to water quality, the use of Site G as the groundwater quality control site must be done with some degree of caution. This is because each of the sites differ with respect to the geologic conditions. One would expect the natural chemical quality, of groundwater, at each site to differ from Site G. This is not anticipated to be a very significant problem, however, since the rock types, though different, do not tend to be large contributors to the chemical load at any site.

At each of the seven sites, one well was used to sample the water table aquifer, and one to sample the artesian aquifer. Geologic conditions required that all artesian wells be constructed in the bedrock. The water table wells were constructed in the overburden materials. In general, the method of drilling that was used to install each of these wells is considered to be adequate for this type of study One exception is Well # 1520, the shallow well at Site F. At this site the greater depth of overburden required the use of a casing hammer so that the casing could be advanced as drilling proceeded. In addition, the grouting and redrilling of the well to avoid the effects of the hydraulic oil that was spilled into the well bore were not sufficient for this purpose. The well should have been abandoned and redrilled.

The purpose of hydraulic testing was to determine the relative ease with which a potential contaminant could be transported in the groundwater system. This information was considered to be necessary for the interpretation of the water quality testing that was to follow. If the effects of urbanization were to be evaluated realistically, some understanding of the transport capabilities of the aquifer was required. In addition to this specific need, a general appreciation of the potential groundwater yield of the basin was required to determine the importance of groundwater as a source of water supply. The limited drilling and testing program described in this report could not fully accomplish these objectives for an area as large and diverse as the Waterford River Basin. Notwithstanding, the program was implemented to progress as far as was possible toward the achievement of these objectives.

For the deep wells step tests were conducted to determine the formation loss coefficient, the well loss coefficient and the turbulence exponent. No meaningful values could be determined however because of the irregularity of the measured values. This information was not critical to the objectives of the study and therefore the use of more sophisticated equipment was not considered. The most useful application of the step test results was based on a plot of drawdown versus the log of time. In most cases the later portion of the plot line for each step indicated a linear relationship between drawdown and the log of time. These lines were extended in time to estimate the drawdown that would occur if pumping continued. The pumping rates for the long term aquifer tests were determined in this way.

The aquifer tests that were performed on each deep well were analyzed using the Jacob modification of the Theis solution to transient radial flow. In this method the transmissivity is calculated from the plot of drawdown versus the log of time. These plots also revealed that in all cases except at Sites A and B, a positive boundary condition was encountered. This is indicated by the gradual flattening of the curve in the latter stages of the test. The physical explanation of this is that the aquifer is receiving recharge from some source as the cone of depression extends further and further away from the well. The most likely source of recharge is the overburden, which is much thicker at the other sites than it is at Sites A and B. At Site A no recharge appears to be taking place. At Site B a negative boundary condition was encountered. The rock at this site was particularly dense and massive. The fracture zone evidently had little areal extent.

The Hvorslev slug test was used to determine the hydraulic conductivity of the soil in which the shallow wells were constructed. The values that were calculated using this method, although quite consistent, may be slightly large. The reason for this possible error is the diameter of disturbed formation which was assumed in the calculation. This may be larger when using an air hammer rotary drilling rig.

From the hydraulic conductivity values that were determined it is evident that yearly sampling would be adequate to detect changes in water quality. To determine seasonal quality fluctuations, however, a quarterly sampling schedule would be required. This schedule should be maintained until these are determined then an annual sampling will be sufficient to detect any water quality changes that may occur.

It is evident from the comparison of sampling methods that these have little effect on the value of most parameters. As expected the parameter that was influenced the most was turbidity however, the effect of any one method on this parameter was not consistent. Exposure of the water column to aor at the surface appeared to have little water quality effect in the artesian wells. This was demonstrated by depth profiles of dissolved oxygen, pH, temperature, oxidation-reduction potential and conductivity. It can be concluded that for deep wells, the Kemmerer sampling method is an adequate method of obtaining representative groundwater samples if the sample is obtained at the same depth as the contributing fracture.

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APPENDIX A
SPECIFICATIONS FOR WELL DRILLING AND SAMPLING

Department of Environment
Government of Newfoundland and Labrador

SPECIFICATIONS FOR WELL DRILLING AND SAMPLING

DATE: December 9, 1980

INDEX

SECTION I SUMMARY OF THE WORK

1. Location

The well drilling is to be carried out in the Waterford River Basin.

2. QUALIFICATION

The contractor must be a well driller in Newfoundland and be active and experienced in water well drilling.

3. SCOPE OF WORK

Furnish all labour, material, transportation, tool supplies, plant, equipment and supervision necessary for:

1. The drilling of 6-inch diameter wells at not less than six locations to the depth as decided by the Hydrogeologist
2. The supply and installation of well casing and other materials.
3. The development of the well by air lift pumping.
4. Capping the well with a conventional well seal.

4. TEMPORARY SERVICES

The Contractor is responsible for the supply of temporary services, such as light, heat, power, water and sanitary facilities which he may deem necessary for the performance of the work. Approval of the Hydrogeologist must be obtained before installing such temporary services.

5. ACCESS TO THE SITE

Access for the Contractor's drilling and pumping equipment will be provided by the Department at no cost to the Contractor.

6. PROTECTION OF SITE

1. The Contractor shall remove from the site all cuttings, drillings, debris and unused material and shall, on completion of his work, restore all areas disturbed by work under this contract as nearly as possible to conditions which existed at the time work was commenced.

...../2

2. Water pumped away from the well during the construction and development of the well shall be conducted to a place where it will be possible to dispose of the water without damage to property or creating a nuisance.

7. STANDARD SPECIFICATIONS

Work is to be performed in accordance with the American Water Works Association Standard for Deep Wells (latest revision). These specifications are intended to supplement or modify the AWWA Standard to fit the needs or expected conditions.

8. SAFETY

Adequate safety equipment shall be used by crews on the job site. The Contractor shall provide protection against accidents for workman or other persons, and shall ensure that all provisions of the Workmans Compensation Act within the Province are complied with.

SECTION II WELL DRILLING

1. DRILLING PROCEDURE

1. The Contractor must be prepared to drill through formations of clay, silt, sand, gravel, shale, sandstone, quartzite, limestone and boulders.

2. The Contractor must carry the necessary equipment and materials, including drilling fluid additives, to cope with caving hole and lost circulation conditions. The Contractor must be prepared to seal off or control holes that encounter artesian flow.

3. The Contractor must be prepared to drill a hole of sufficient size to accommodate a 6-inch hole nominal diameter casing. The completed well must be sufficiently plumb to allow at any depth the installation and proper operation of a turbine pump assembly 4-inch nominal diameter.

4. The Contractor shall collect samples at 5-foot intervals where major changes in lithology occur, and at water bearing zones, keep an accurate record of the top and bottom of each stratum penetrated and shall submit daily report describing the nature of the material encountered, the depth drilled, length of casing set and such other pertinent data of which he is requested to make a record by the Hydrogeologist.

...../3

5. The Contractor shall complete the well in the first suitable water bearing formation and shall report to the Hydrogeologist wherever water is struck and the quantity of water obtained at each water bearing zone. The Contractor shall carry out all testing necessary as determined by the Hydrogeologist. The Hydrogeologist will decide at each point whether testing is to be carried out, and after testing, if the well is to be deepened or abandoned. If testing is not ordered at a lesser depth, and in any event the maximum depth will be about 200 feet. The decision of the Hydrogeologist in these respects shall be final.

6. Casing either equipped with a drive shoe or cement grouted in place shall be installed into the bedrock; the minimum length of casing, measured from the ground surface, shall be 20 feet.

7. The Contractor shall furnish all necessary pumps, surge plunger, bailers, jetting tools or other needed equipment and shall develop each water bearing formation by such approved methods as shall be necessary to give the maximum yield of water per foot of drawdown and extract from the material so that when the well is pumped at its maximum rate, the water obtained from the well will be sand free and clear. This development procedure also applies when well screens are to be installed.

8. Where it is necessary to use a well screen for stabilizing a water bearing formation, the Contractor shall obtain a suitably sized representative sample of the material and submit it to a recognized and competent authority so that the correct length and slot opening size of the well screen can be determined. The well screen shall be stainless steel with continuous slots and shall be installed by standard approved methods, in casing that has been grouted to the top of the water bearing formation and the full length of the screen shall be exposed to the water bearing forcation.

9. A well not complying with the above specification will not be acceptable.

SECTION III OTHER ITEMS

1. CAPPING AND GRADING AROUND WELL

1. On completion of the well, the casing shall be cut off one foot above ground, and a sanitary well seal of approved design installed.

...../4

2. Grading and compacting around the well casing shall be such that surface drainage is away from the well.

2. ABANDONED HOLE

If the well fails to conform to the agreed upon standard contract specifications and the contractor is unable to meet the requirements (at his expense) it shall be considered an abandoned hole, and the contractor shall immediately start a new well at a nearby location designated by the Hydrogeologist. The well shall be sealed in accordance with procedures developed by the province in which the work is undertaken.

SECTION IV METHOD OF PAYMENT

Drillers may quote on the following Items.

1. Mobilization, Demobilization and Cleanup - Transporting all drilling equipment, casing, etc. and personnel to and from the well site, including setting up and dismantling the drilling equipment, and cleanup. Mobilization and demobilization is a lump sum fixed price.
2. Drilling - Drilling operations are per foot length. Payment shall be made for the actual depth drilled at the unit price per foot.
3. Casing - Payment for the supply and installation of casing shall be made for the actual length of casing required at the unit price per foot. It will be measured from one foot above ground to the bottom of the casing.
4. Drive Shoe - Payment for the supply of this item shall be made on a lump sum basis.
5. Removing Casing - Payment shall be made on an hourly rate for pulling casing and moving the equipment on the site in the event of the well being abandoned owing to a dry hole. In this event, no charge shall be made for the casing.
6. Well Development - Payment shall be made at an hourly rate for surging the borehole and for air lift testing the well.
7. Capping Well - Capping the well shall be paid for at the lump sum fixed price.

...../5

8. Standby Time - Is defined as the time during normal working hours up to a maximum of 8 hours in any one day, that the Contractor is directed by the Hydrogeologist to cease drilling operations for other than well capacity tests, non-compliance with the requirements of the contract, or termination of the drilling of the well. Payment will be made at an hourly rate.

SECTION V **APPENDIX "A"**

UNIT PRICE SCHEDULE

Where quantities are mentioned below for unit price items, these are estimated quantities only and may be increased or decreased in accordance with the requirements of the work. All payments for these items shall be based upon the actual quantities of materials supplied and work performed as certified by the Hydrogeologist.

BIDDERS PLEASE NOTE: All information to be inserted below shall be typewritten.

Item	Class of Labour Plant or Material (Description of Work)	Unit of Measurement	Estimated Quantity	Price Per Unit	Amount

TOTAL items to inclusive above $

APPENDIX B
GEOLOGIC LOGS AND WELL CONSTRUCTION DETAILS

LOG OF BOREHOLE

BOREHOLE 1526 Site A
PAGE ___ OF ___

LOC. or COORDS. 22T E 362100 N 5265350	DRILLER Waltsons Drilling Co. Ltd. Doyles, Newfoundland.	START DATE 81-03-12 / FINISH DATE 81-03-12
GROUND ELEV. 139.4 m	RIG C.P. T650	START TIME 12:30 P.M. / FINISH TIME 5:15 P.M.
TOTAL DEPTH 24.69 m	BIT(S) Air Hammer 20 cm	GEOPHYS. LOG ___YES ___NO
BOREHOLE DIAM. 150 mm	FLUID Air	HOW LEFT Sample Well

DEPTH	PENE. RATE	CIRC.		AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
		RET.	LOSS				
0 m							
							6" casing set @ 4.80 m
5 m.					Black Shale		Soft
	0.30			T**			
10 m							
				T			Minor Calcite
15 m	0.34			T	Mudstone		Layered
20 m				1.75 24			
25 m							End of Hole - Developed For 45 min.

* Pene. Rate = m/min.
**T = Trace

LOG OF BOREHOLE

BOREHOLE 1529 Site B
PAGE 1 OF 1

LOC. or COORDS. 22T E 361650 . N 5264900	DRILLER Waltsons Drilling Co. Ltd. Dovles, Newfoundland	START / FINISH
GROUND ELEV. 153.8 m	RIG C.P. T650	DATE 81-03-17 / 81-03-17
TOTAL DEPTH 31.09 m	BIT(S) Air Hammer 20 cm	TIME 8:00 A.M. / 12:15 P.M.
BOREHOLE DIAM. 150 mm	FLUID Air	GEOPHYS. LOG ___ YES X NO HOW LEFT Sample Well

DEPTH	PENE. RATE	CIRC. RET	CIRC. LOSS	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0 m					Topsoil		Brown
					Till		Grey, Silty, Sandy, Stoney
							6" casing set @ 4.9 m c/w Bentonite
				T**			
5 m					Siltstone		Grey Green Conchoidal Fracture
10 m							
				T			Minor Mudstone
15 m	0.11*						Minor Greywacke
20 m							
	0.16			T 1.0			Developed for 15 min.
25 m							
	0.15						Interlayered Green & Purple
30 m							End of Hole - Developed for 1 3/4 hr. Q = 1.25 L/min
35 m							

*Pene. Rate = m/min.

** T = Trace

LOG OF BOREHOLE

BOREHOLE 1527 Site C
PAGE ___ OF ___

LOC. or COORDS. 22T
E 364600 N 5264150
GROUND ELEV. 117.9
TOTAL DEPTH 36.73 m
BOREHOLE DIAM. 150 mm

DRILLER Waltsons Drilling Co. Ltd.
Doyles, Newfoundland
RIG C.P. T650
BIT(S) Air Hammer 20 cm
FLUID Air

	START	FINISH
DATE	81-03-13	81-03-31
TIME	6:30 A.M.	2:30 P.M.

GEOPHYS. LOG ___ YES ___ NO
HOW LEFT Sample Well

DEPTH	PENE. RATE	CIRC. RET.	CIRC. LOSS	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0 m					Fill		Brown Silt, Sand, Clay, Pebbles
				T*	Till		Grey Imported 6" casing set @ 6.27 m
					Till		Glacial
				9			
5 m							
					Black Shale		
							Minor Calcite Veins
	0.30*						
10 m							
				T			
15 m	0.28						Minor Calcite
							Minor Calcite
20 m	0.23						
				T			Minor Pyrite, Soft, Broken
25 m							
	0.15						
				2.2			
30 m							
	0.30			T			Soft Zones
				T			
35 m							
							End of Hole - Developed For 30 min Q = 20 L/min
40 m							

* Pene. Rate = m/min.
** T = Trace

LOG OF BOREHOLE

BOREHOLE 1531 Site D
PAGE 1 OF 1

LOC. or COORDS. 22T E 364700 N 5262950	DRILLER Waltsons Drilling Co. Ltd. Doyles, Newfoundland	
GROUND ELEV. 129.5 m	RIG C.P. T650	DATE START 81-03-24 FINISH 81-03-25
TOTAL DEPTH 18.90 m	BIT(S) Air Hammer 20 cm	TIME START 4:00 P.M. FINISH 10:00 A.M.
BOREHOLE DIAM. 150 mm	FLUID Air	GEOPHYS. LOG ___ YES ___ NO
		HOW LEFT Sample Well

DEPTH	PENE. RATE	CIRC.	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0 m				Fill/Topsoil		
				Till		Grey Sandy Silt
			T**	Rock		Broken
			T			
5 m.				Black Shale		6" casing set @ 5.11 m
10 m	0.18*		T			
			T	Black Shale & Mudstone		Interlayered
15 m			T			
			12.0			
						End of Hole - Developed For 30 min. Q = 12 L/min
20 m						

*Pene. Rate = m/min.
** T = Trace

BOREHOLE 1522 Site E

PAGE ____ OF ____

LOG OF BOREHOLE

LOC. or COORDS. 22T
E 365900 N 5263900
GROUND ELEV. 107.0 m
TOTAL DEPTH 25.00 m
BOREHOLE DIAM. 150 mm

DRILLER
Waltsons Drilling Co. Ltd.
Doyles, Newfoundland
RIG C.P. T650
BIT(S) Air Hammer 20 cm
FLUID Air

	START	FINISH
DATE	81-03-09	81-03-10
TIME	4:15 P.M.	7:30 P.M.

GEOPHYS. LOG ____YES ____NO
HOW LEFT Sample
Well

DEPTH	PENE. RATE	CIRC RET LOST	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0 m				Topsoil		
				Till		Brown Sandy - Silt Stoney (Ablation)
			T*			
5 m						
						Grey Stoney (Basal)
				Black Shale		Minor Calcite Seams
10 m						6" casing set at 11.48 m c/w Drive Shoe & 10 lb of Bentonite
			16.0			Water Turned Red @ 13.4 m
			8.0			Water Turned Grey @ 14.6 m
15 m	↑		6.0			
20 m	HARD					
						Calcite Seams Frequent
25 m	↓					End of Hole Q = 30 L/min

*T = Trace

LOG OF BOREHOLE

BOREHOLE 1521 Site F
PAGE ____ OF ____

LOC. or COORDS. 22T
E 362900 N 5264750
GROUND ELEV. 131.8 m
TOTAL DEPTH 55.47 m
BOREHOLE DIAM. 150 mm

DRILLER
Waltsons Drilling Co. Ltd.
Doyles, Newfoundland
RIG C.P. T 650
BIT(S) Air Hammer 20 cm
FLUID Air

	START	FINISH
DATE	81-02-20	81-03-09
TIME	4:00 P.M.	

GEOPHYS. LOG ____YES ____NO
HOW LEFT Sample
Well

DEPTH	PENE. RATE	CIRC. RET	CIRC. LOST	AIRLIFT Q (l/pm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0 m				∇ ☆☆T	Peat/Till		Till - Borwn Sandy Silt Grey Sandy Silt-Very Few Stones
				T			Boulders @ 1.8 m More Boulders @ 2.4 m Set 8" casing @ 2.29 m
				T			
10 m					Black Shale		Massive, No Apparent Cleavage Set 6" casing @ 12.8 m
							Fractured
	☆ 0.23				Shale or Siltsone Siltsone		Grey Grey-Black Grey
20 m							Dark Grey Rods Dropped 6"
	0.20				Greywacke Mudstone		Grey
				T			
	0.18				Sandstone/ Mudstone		Interlayered
30 m				T			Soft Rock
40 m							
	0.15			T			
50 m				T			
				15.0			End of Hole - Developed For 45 min. Q = 25 L/min
60 m							

☆Pen. Rate = m/min.
☆☆ T = Trace

LOG OF BOREHOLE

BOREHOLE 1519 Site G

PAGE 1 OF 1

LOC. or COORDS. 22T
E 361700 N 5262700
GROUND ELEV. 229.7 m
TOTAL DEPTH 61.56 m
BOREHOLE DIAM. 150 mm

DRILLER
Waltsons Drilling Co Ltd.
Doyles, Newfoundland.
RIG CP T650
BIT(S) Air Hammer 20 cm
FLUID Air

	START	FINISH
DATE	81/02/09	81/02/10
TIME	11:00 AM	10:30 AM

GEOPHYS. LOG ___ YES ___ NO
HOW LEFT Sample
Well

DEPTH	PENE. RATE	CIRC RET/LOSS	AIRLIFT Q (gpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0 m				Till		Bouldery
			T**	Siltstone		Grey - Green 6" Casing Set @ 6.1 m c/w Drive Shoe
				Sandstone		Grey - Green
10 m	0.17*			Siltstone		
				Sandstone		
				Siltstone		
	0.28			Greywacke		
				Siltstone		
20 m						
	0.18			Sandstone		Grey - Black
				Siltstone		Green
30 m	0.16					
				Mudstone		Interbeded, Brown
	0.13			Siltstone		Green
40 m				Greywacke To Siltstone		Black - Grey Green
	0.15					
	0.14			Greywacke		Green
50 m						
	0.10		0.25	Mudstone		Brown
				Greywacke		
60 m				Siltstone		End of Hole
70 m						

*Pene. Rate - m/min
**T = Trace

LOG OF BOREHOLE

BOREHOLE 1530 Site B

PAGE ____ OF ____

LOC. or COORDS. 22T
E 361650 N 5264900
GROUND ELEV. 153.7 m
TOTAL DEPTH 14.74m
BOREHOLE DIAM. 150 mm

DRILLER
Waltsons Drilling Co. Ltd.
Dovles. Newfoundland
RIG CP T 650
BIT(S) Air Hammer 20cm
FLUID Air

	START	FINISH
DATE	81-03-23	81-03-24
TIME	3:00 PM	10:00 AM

GEOPHYS. LOG ____ YES ____ NO
HOW LEFT Sample
Well

DEPTH	PENE. RATE	CIRC. RETN / LOSS	AIRLIFT Q (l pm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0m				Till		Gray, Silty Sandy,
1m						
2m			▽			
3m						
4m				Shale		Grey - Green
						End of hole
5m						

LOG OF BOREHOLE

BOREHOLE 1528 Site C

PAGE ____ OF ____

LOC. or COORDS. 22T

E 364600 N 5264150

GROUND ELEV. 117.9 m

TOTAL DEPTH 3.05 m

BOREHOLE DIAM. 150 mm

DRILLER

Waltsons Drilling Co. Ltd.

Doyles, Newfoundland

RIG C.P. T 650

BIT(S) Air Hammer 20 cm

FLUID Air

	START	FINISH
DATE	81-03-31	81-03-31
TIME	3:00 PM	4:00 PM

GEOPHYS. LOG ____ YES ____ NO

HOW LEFT Sample Well

DEPTH	PENE. RATE	CIRC RET	CIRC LOSS	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0m					Fill		
1m							
					Till		Imported
2m							
							Glacial
3m							End of Hole Q = 9 L/min
4m							

LOG OF BOREHOLE

BOREHOLE 1532 Site D
PAGE ____ OF ____

LOC. or COORDS. 22T
E 364700 N 5262950
GROUND ELEV. 128.4 m
TOTAL DEPTH 4.88m
BOREHOLE DIAM. 150 mm

DRILLER
Waltsons Drilling Co. Ltd.
Doyles, Newfoundland
RIG C.P. T 650
BIT(S) Air Hammer 20cm
FLUID Air

	START	FINISH
DATE	81-03-25	81-03-25
TIME	10:30 AM	1:00 PM

GEOPHYS. LOG ____ YES ____ NO
HOW LEFT Sample
Well

DEPTH	PENE. RATE	CIRC. RETURN LOSS	AIRLIFT Q (l/pm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0m						
				Till		Glacial
1m						
2m						
3m						
				Black Shale		
4m						
						End of Hole
5m						

LOG OF BOREHOLE

BOREHOLE 1535 Site E

PAGE ____ OF ____

LOC. or COORDS. 22T
E 365900 N 5263900

GROUND ELEV. 106.8 m

TOTAL DEPTH 6.10m

BOREHOLE DIAM. 102 mm

DRILLER
P. Sullivan & Son's Ltd.
Paradise, Newfoundland

RIG Speedstar SS 15

BIT(S) Air Hammer 20cm

FLUID Air

	START	FINISH
DATE	81-07-22	81-07-22
TIME		

GEOPHYS. LOG ____ YES ____ NO

HOW LEFT Sample
Well

DEPTH	PENE. RATE	CIRC RETN	CIRC LOSS	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0m					Topsoil		
					Till		Loose, Bouldery
1m							
2m							
3m							
4m							
							Basal - Hard & Bouldery
5m							
6m							End of Hole
7m							
8m							

LOG OF BOREHOLE

BOREHOLE 1520 Site F
PAGE ___ OF ___

LOC. or COORDS. 22T
E 362900 N 5264750
GROUND ELEV. 130.3 m
TOTAL DEPTH 14.02m
BOREHOLE DIAM. 150 mm

DRILLER Waltsons Drilling Co. Ltd.
Doyles, Newfoundland
RIG C.P. T 650
BIT(S) Air Hammer 20cm
FLUID Air

	START	FINISH
DATE	81-02-12	81-02-20
TIME	7:30 AM	1:00 PM

GEOPHYS. LOG ___ YES ___ NO
HOW LEFT Sample Well

DEPTH	PENE RATE	CIRC. RET.	CIRC. LOSS	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0m					Fill		
				T*			Bouldery
2m							
							Very Bouldery & Very Loose
4m							
6m							
					Till		
8m							
10m							
12m							
				9			
14m							End of Hole

* T=Trace

LOG OF BOREHOLE

BOREHOLE 1533 Site G
PAGE ___ OF ___

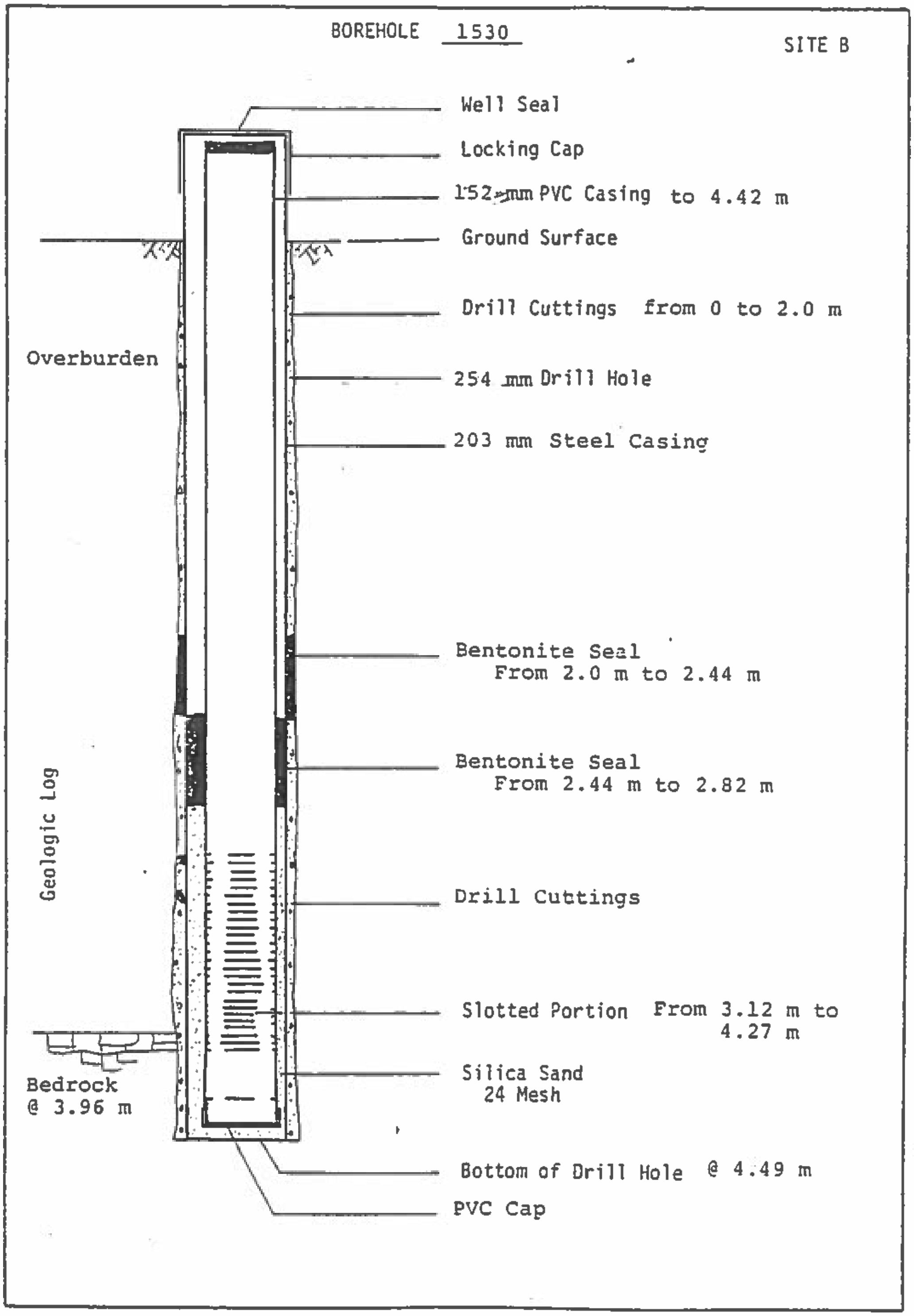
LOC. or COORDS. 22T
E 361700 N 5262700
GROUND ELEV. 230.0 m
TOTAL DEPTH 6.71m
BOREHOLE DIAM. 150 mm

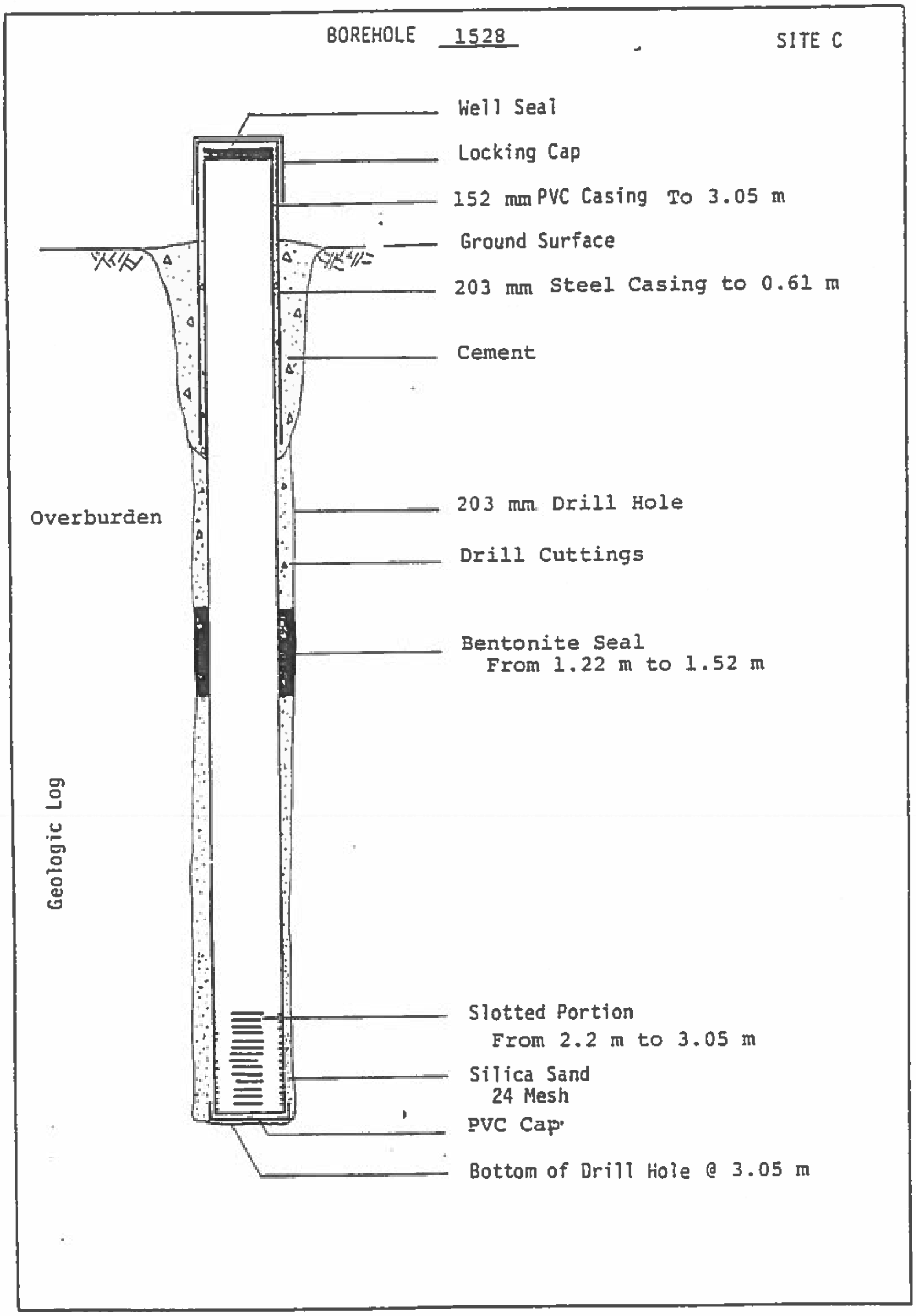
DRILLER
Waltsons Drilling Co. Ltd.
Doyles, Newfoundland
RIG CP T 650
BIT(S) Air Hammer 20cm
FLUID Air

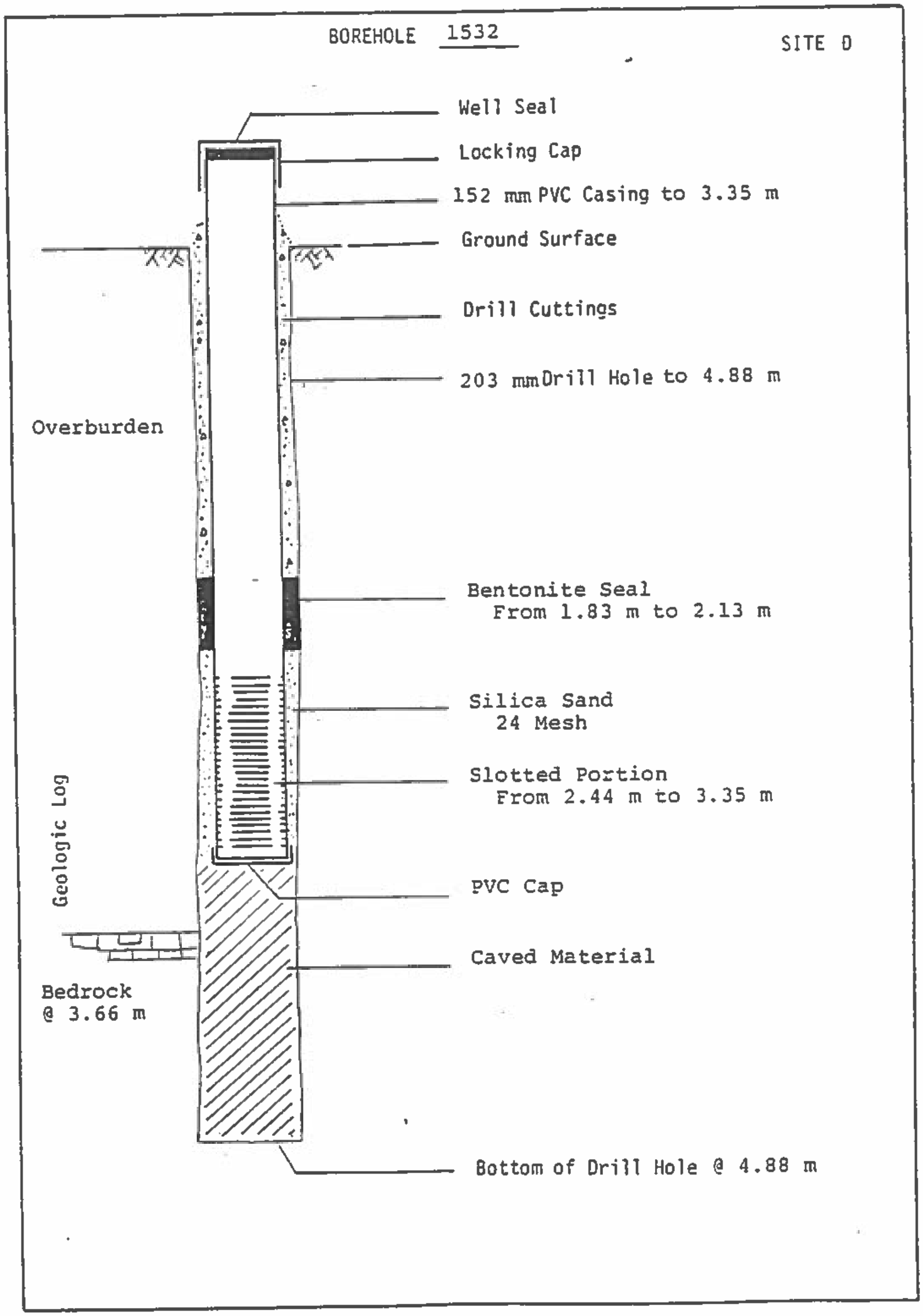
	START	FINISH
DATE	81-03-25	
TIME		

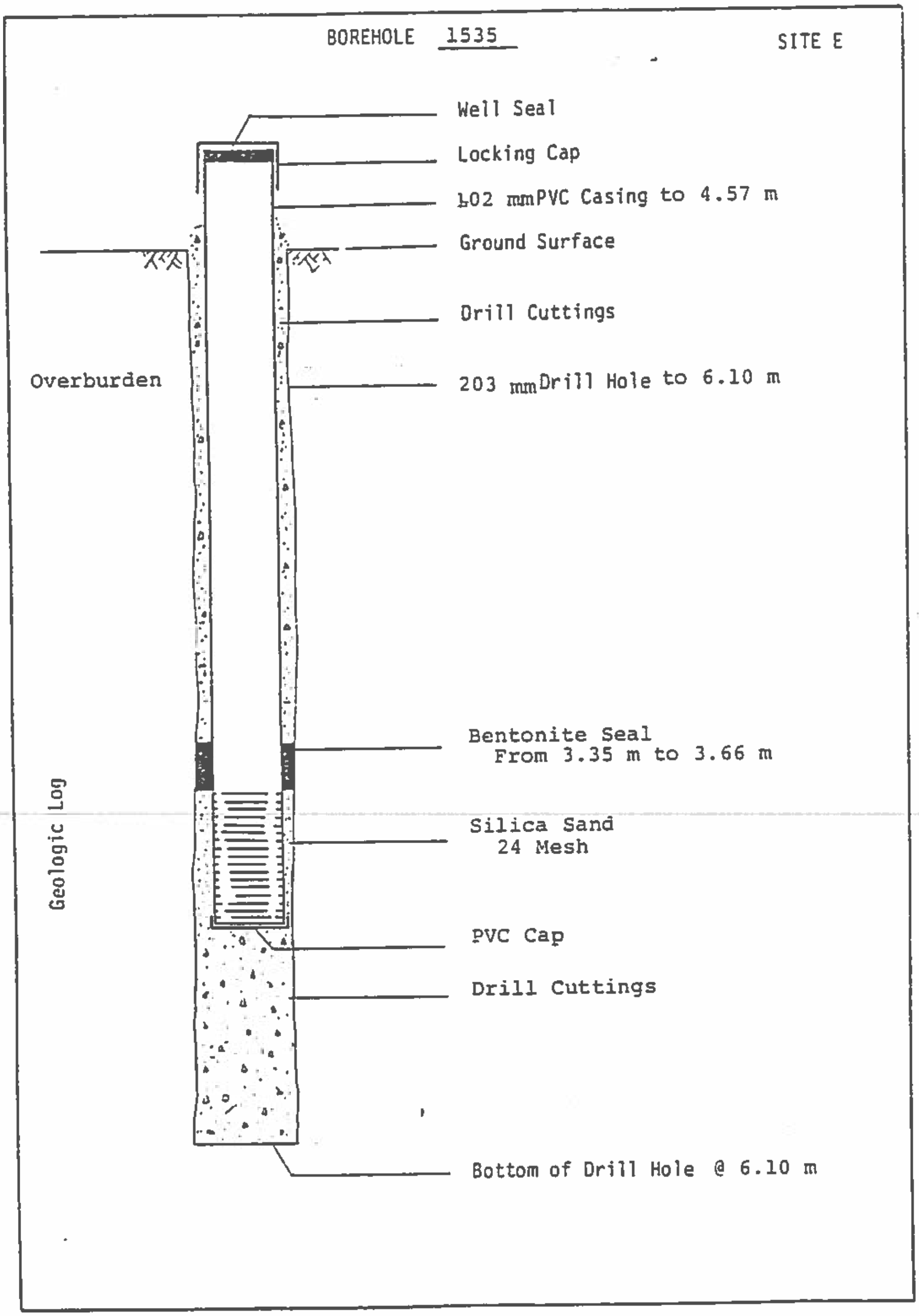
GEOPHYS. LOG ___ YES ___ NO
HOW LEFT Sample
Well

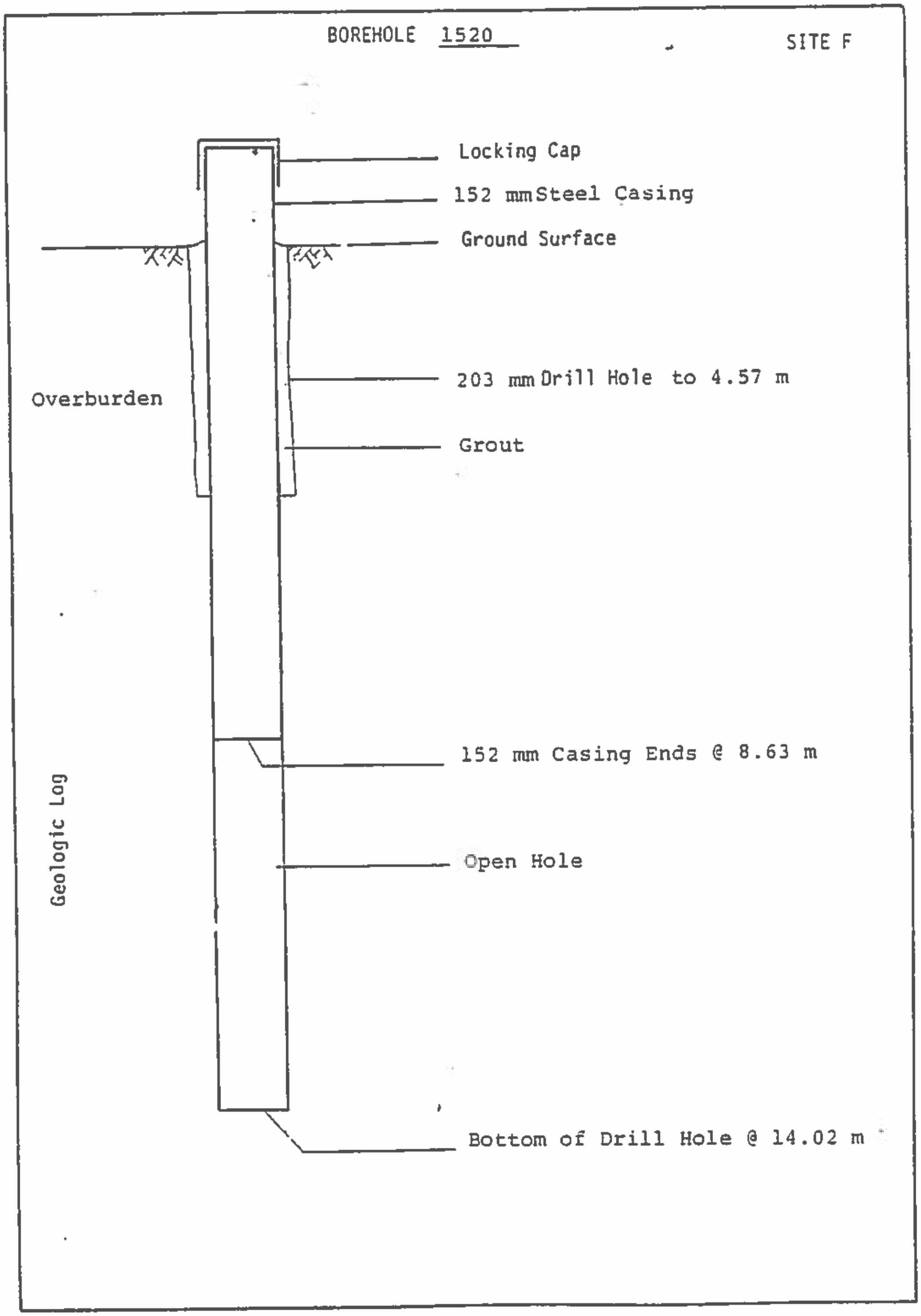
DEPTH	PENE. RATE	CIRC. RET.	CIRC. LOSS	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0m							
					Till		Bouldery
1m							
2m							
3m							
4m					Siltstone		Grey-Green
5m							
6m							
							End of Hole - Developed For 1½ hrs. Q = 9 L/min
7m							

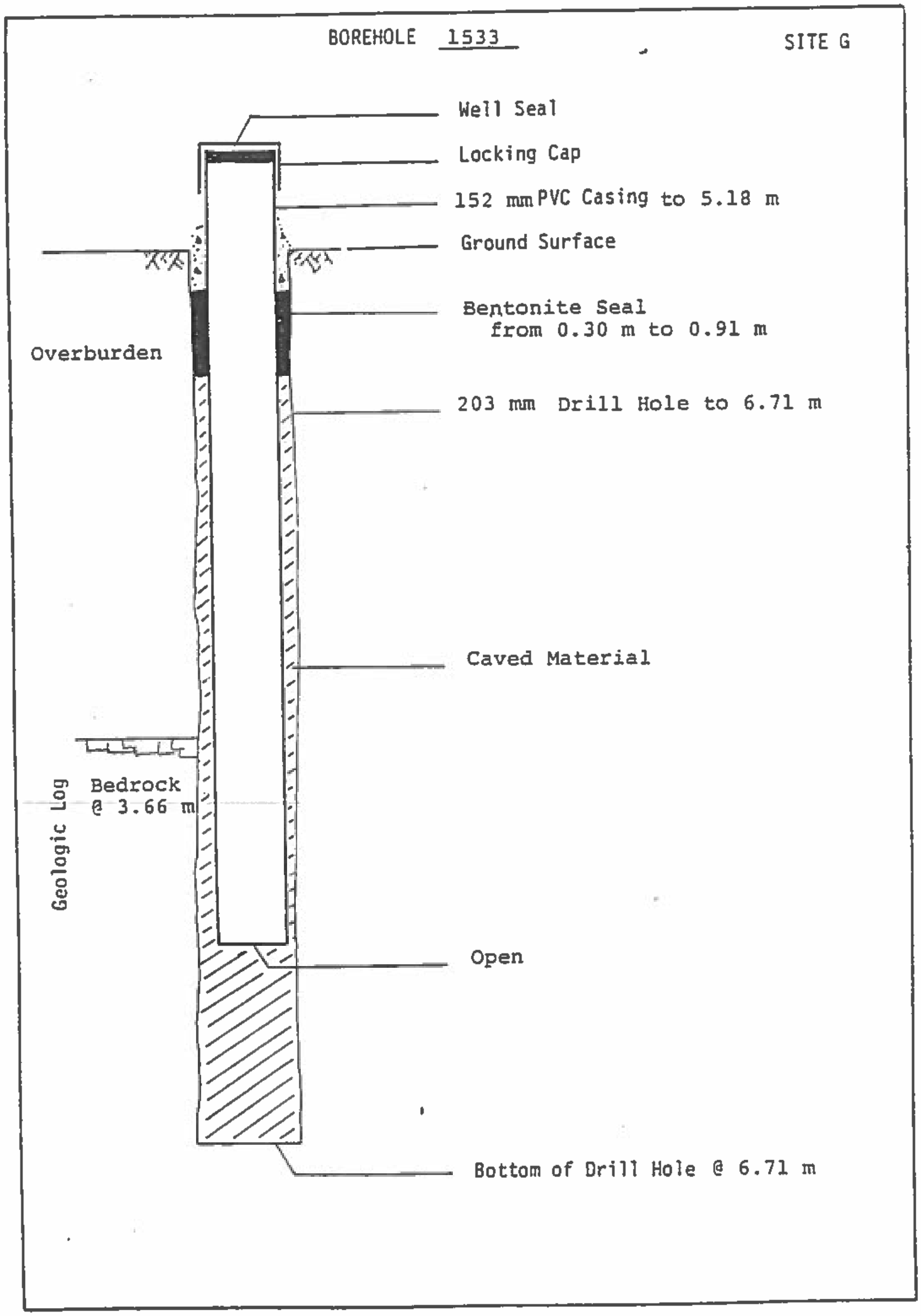

BOREHOLE 1530
SITE B
Well Seal
Locking Cap
152 mm PVC Casing to 4.42 m
Ground Surface
Drill Cuttings from 0 to 2.0 m
Overburden
254 mm Drill Hole
203 mm Steel Casing
Bentonite Seal
From 2.0 m to 2.44 m
Bentonite Seal
From 2.44 m to 2.82 m
Geologic Log
Drill Cuttings
Slotted Portion From 3.12 m to 4.27 m
Silica Sand
24 Mesh
Bedrock
@ 3.96 m
Bottom of Drill Hole @ 4.49 m
PVC Cap


BOREHOLE 1528
SITE C
Well Seal
Locking Cap
152 mm PVC Casing To 3.05 m
Ground Surface
203 mm Steel Casing to 0.61 m
Cement
Overburden
203 mm Drill Hole
Drill Cuttings
Bentonite Seal From 1.22 m to 1.52 m
Geologic Log
Slotted Portion From 2.2 m to 3.05 m
Silica Sand 24 Mesh
PVC Cap
Bottom of Drill Hole @ 3.05 m


BOREHOLE 1532
SITE D
Well Seal
Locking Cap
152 mm PVC Casing to 3.35 m
Ground Surface
Drill Cuttings
203 mm Drill Hole to 4.88 m
Overburden
Bentonite Seal
From 1.83 m to 2.13 m
Silica Sand
24 Mesh
Slotted Portion
From 2.44 m to 3.35 m
Geologic Log
PVC Cap
Caved Material
Bedrock
@ 3.66 m
Bottom of Drill Hole @ 4.88 m


BOREHOLE 1535
SITE E
Well Seal
Locking Cap
102 mmPVC Casing to 4.57 m
Ground Surface
Drill Cuttings
Overburden
203 mmDrill Hole to 6.10 m
Bentonite Seal
From 3.35 m to 3.66 m
Geologic Log
Silica Sand
24 Mesh
PVC Cap
Drill Cuttings
Bottom of Drill Hole @ 6.10 m


BOREHOLE 1520
SITE F
Locking Cap
152 mm Steel Casing
Ground Surface
Overburden
203 mm Drill Hole to 4.57 m
Grout
152 mm Casing Ends @ 8.63 m
Geologic Log
Open Hole
Bottom of Drill Hole @ 14.02 m


BOREHOLE 1533
SITE G
Well Seal
Locking Cap
152 mm PVC Casing to 5.18 m
Ground Surface
Bentonite Seal from 0.30 m to 0.91 m
Overburden
203 mm Drill Hole to 6.71 m
Caved Material
Bedrock @ 3.66 m
Geologic Log
Open
Bottom of Drill Hole @ 6.71 m

APPENDIX C
STEP TEST RESULTS

STEP TEST SITE A (WELL # 1526)

Time Since Pump Started (min)	Drawdown Below Casing (m)
.5	0
1	0
2	.015
3	.035
4	.025
5	.035
6	.035
7	.035
8	.045
9	.045
10	.045
12	.045
14	.045
16	.045
18	.045
20	.043
25	.045
30	.045
31	.075
32	.101
33	.104
34	.105
35	.109
36	.111
37	.115
38	.118
40	.118
42	.118
47	.117
48	.105
50	.118
55	.117
60	.117
60.05	.176
61	.526
62	.697
63	.775
64	.863
65	.958
66	1.015
67	1.032
68	1.06
69	1.127
70	1.207
72	1.165
74	1.257
76	1.277
78	1.287
80	1.362
85	1.422
90	1.402
91	1.82
92	1.992
93	2.097
94	2.27
95	2.4
96	2.464
97	2.524
98	2.537
99	2.565
100	2.59
103	2.667
104	2.683
106	2.715
108	2.751
110	2.777
115	2.942
120	2.927
120.5	3.201
121	4.026
122	4.798
123	5.504
124	5.899
125	6.289
126	6.588
127	7.053
128	7.377
129	7.733
130	8.093
133	8.96
134	9.253
136	9.638
138	10.011
140	10.367
145	10.971
150	11.453

STEP TEST SITE B (WELL # 1529)

Time Since Pump Started (min)	Drawdown Below Casing (m)
1	5.012
2	5.006
3	5.004
4	5.002
5	4.999
6	4.999
7	5.002
8	5.007
9	5.007
10	5.005
12	4.994
14	4.991
16	5.001
19	5.022
20	5.025
25	5.051
30	5.069
31	10.167
32	10.179
33	10.199
34	10.221
35.5	10.241
36.25	10.253
37	10.273
38	10.29
39	10.309
40	10.321
42	10.366
44	10.414
46	10.471
48	10.51
50	10.56
55	10.671
60	10.776
61	16.548
62	16.58
63	16.611
64	16.673
65	16.703
66	16.767
67	16.818
68	16.864
69	16.905
70	16.961
72	17.058
74	17.148
76	17.233
78	17.321
80	17.403
85	17.6
90	17.793
91	24.873
92	24.969
93	25.077
94	25.164
95	25.26
96	25.367
97	25.429
98	25.53
99	25.621
100	25.695
102	25.871
104	26.03
106	26.175
108	26.37
110	26.527
115	26.787
120	27.204
120.5	27.236
121	27.236
122	27.316
123	27.43
124	27.551
125	27.685
126	27.821
127	27.969
128	28.096
129	28.316
130	28.449
132	28.729
134	28.972
136	29.241
138	29.476
140	29.677
145	30.178
150	30.845

STEP TEST SITE C (WELL # 1527)

Time Since Pump Started (min)	Drawdown Below Casing (m)
1	.428
2	.471
3	.476
4	.505
5	.519
6	.531
7	.539
8	.555
9	.578
10	.588
12	.599
14	.658
16	.685
18	.701
20	.736
25	.758
30	.791
31	1.583
32	1.597
33	1.636
34	1.645
35	1.666
36	1.697
37	1.719
38	1.749
39	1.792
40	1.802
42	1.817
44	1.838
46	1.889
48	1.909
50	1.928
55	1.942
60	2.022
61	3.393
62	3.439
63	3.813
64	4.181
65	4.387
66	4.686
67	4.986
68	5.242
69	5.439
70	5.656
72	6.118
74	6.457
76	6.762
78	7.123
80	7.586
85	8.203
90	8.706
91	8.882
93	9.732
94	10.171
95	10.612
96	11.014
97	11.349
98	11.734
99	12.056
100	12.359
102	13.062
104	13.583
106	14.036
108	14.499
110	14.917
116	16.356
120	17.333
121	24.779
122	25.56
123	26.24
124	26.962
125	27.721
126	28.362
127	28.958
128	29.6
129	30.471
130	30.973
132	32.177
134	33.445
140	36.894
145	39.144
150	41.389

STEP TEST SITE D (WELL # 1531)

Time Since Pump Started (min)	Drawdown Below Casing (m)
1	.1
2	.117
3	.125
4	.133
5	.141
6	.153
7	.16
8	.161
9	.172
10	.179
12	.181
14	.192
16	.209
18	.218
20	.231
25	.237
30	.268
31	.273
32	.581
33	.603
34	.623
35	.654
36	.677
37	.706
38	.736
39	.753
40	.777
42	.8
44	.84
46	.876
48	.919
50	.975
55	1.003
60	1.084
61	1.338
62	2.433
63	2.549
64	2.74
65	2.925
66	3.105
67	3.288
68	3.423
69	3.559
70	3.696
72	3.807
74	4.028
76	4.225
78	4.418
80	4.589
85	4.73
90	5.082
91	5.285
92	10.105
93	9.726
94	9.940
95	10.089
96	10.23
97	10.38
98	10.491
99	10.619
100	10.722
102	10.791
104	10.957
106	11.069
108	11.181
110	11.259
115	11.312
120	11.397
121	11.845
122	12.479
123	12.645
124	12.861
125	13.041
126.3	13.572
127	14.088
128	14.165
129	14.355
130	14.511
132	14.673
134	15.01
136	15.38
138	15.765
140	16.08
145	16.388
150	16.995
151	17.475
152	18.088
153	18.509

STEP TEST SITE E (WELL # 1522)

Time Since Pump Started (min)	Drawdown Below Casing (m)
.5	.004
1	.008
2	.02
3	.03
4	.039
5	.047
6	.051
7	.056
8	.062
9	.06
10	.076
12	.085
14	.088
16	.097
18	.103
20	.105
25	.114
30	.122
30.5	.132
31	.137
32	.152
33	.165
34	.172
35	.188
36	.195
37	.198
38	.208
39	.215
40	.222
42	.226
44	.23
46	.243
48	.25
50	.253
52	.265
55	.267
60	.274
60.5	.305
61	.34
62	.382
63	.423
64	.461
65	.496
66	.537
69	.583
70	.573
72	.645
74	.665
76	.666
80	.692
85	.711
90	.746
91	.877
92	1.185
93	1.323
94.5	1.571
95	1.607
96	1.666
97	1.724
98	1.791
99	1.844
100	1.911
102	2.041
104	2.141
106	2.215
108	2.276
110	2.338
115	2.462
120	2.524
120.5	2.71
121	3.031
122	3.365
123	3.668
124	3.94
125	4.169
126	4.351
127	4.516
128	4.659
129	4.781
130	4.918
132	5.099
134	5.309
136	5.462
138	5.598
140	5.727
145	6.006
150	6.171
150.5	6.252
151	6.419
152	8.034
153	8.563
154	9.046
155	9.399
156	9.88
157	10.033
158	10.21

159	10.491
160	10.733
161	10.773
162	11.081
163	11.221
164	11.376
166	11.642
168	11.889
170	12.111
175	12.63
180	12.84
180.5	13.266
181	14.245
182	14.81
183	15.31
184	15.725
185	16.14
186	16.34
187	16.606
188	16.935
189	17.125
190	17.335
192	17.706
194	18.005
196	18.28
198	18.487
200	18.816
205	19.148
210	19.44
211	21.166
212	21.98
213	23.626
214	23.736
215	23.67
216	24.166
217	24.616

STEP TEST SITE F (WELL # 1521)

Time Since Pump Started (min)	Drawdown Below Casing (m)
1	.064
2	.085
3	.106
4	.131
5	.155
6	.165
7	.189
8	.204
9	.229
10	.24
12	.278
14	.305
16	.525
18	.535
20	.539
25	.545
30	.594
31	1.206
32	1.228
33	1.254
34	1.285
35	1.319
36	1.516
37	1.526
38	1.536
39	1.568
40	1.572
42	1.599
44	1.706
46	1.776
48	1.799
50	1.825
55	1.884
60	1.916
61	3.468
62	3.557
63	3.625
64	3.709
65	3.931
66	4.001
67	4.07
68	4.131
69	4.178
70	4.246
72	4.354
74	4.461
76	4.551
78	4.666
80	5.037
85	5.241
90	5.601
91	6.204
92	7.218
93	7.927
94	8.679
95	9.517
96	10.286
97	11.35
98	11.947
99	12.634
100	13.186
102	14.357
104	15.54
106	16.8
108	17.867
110	18.51
115	21.13
120	23.123
121	28.018
122	29.763
123	30.457
124	31.524
125	32.508
126	33.618
127	34.675
128	35.524
129	36.526
130	37.672
132	38.519
134	40.418
136	43.201
138	44.498
140	46.062
145	49.573
150	52.353

STEP TEST SITE G (WELL # 1519)

Time Since Pump Started (min)	Drawdown Below Casing (m)
1	3.685
2	3.684
3	3.688
4	3.692
5	3.693
6	3.694
7	3.701
8	3.703
9	3.708
10	3.708
12	3.714
14	3.723
16	3.729
18	3.732
20	3.734
25	3.736
30	3.741
31	7.493
32	7.516
33	7.552
34	7.585
35	7.618
36	7.649
37	7.688
38	7.724
39	7.76
40	7.803
42	7.896
44	7.978
46	8.079
48	8.164
50	8.267
55	8.512
60	8.775
61	13.893
63.5	14.158
64	14.208
65	14.309
66	14.437
67	14.547
68	14.67
69	14.778
70	14.909
172.5	15.207
74	15.372
76	15.61
78	15.848
80	16.12
85	16.688
90	17.235

APPENDIX D
AQUIFER TEST RESULTS

AQUIFER TEST SITE A (WELL # 1526)

Time Since Pumping Started / Stopped (min)	Drawdow Below Casing (m)
	Drawdown
1	.418
2	.59
3	.695
4	.868
5	.998
6	1.062
7	1.122
8	1.135
9	1.163
10	1.188
13	1.265
14	1.282
16	1.314
18	1.35
20	1.376
25	1.541
30	1.526
35	1.55
40	1.555
45	1.553
55	1.537
60	1.697
75	1.715
90	1.74
106	1.773
120	1.799
150	1.828
180	1.869
215	1.976
240	1.909
300	1.947
360	1.962
420	1.988
480	2.006
540	2.008
600	2.029
660	2.044
720	2.051
780	2.063
840	2.065
900	2.067
960	2.089
1020	2.099
1080	2.069
1140	2.081
1200	2.093
1260	2.161
1320	2.142
1380	2.103
	Recovery
1	.05
2	.51
3	.98
4	.57
5	.46
6	.44
6	.44
8	.44
9	.44
10	.45
12	.46
14	.47
16	.48
18	.48
20	.5
25	.52
30	.54
35	.55
40	.55
50	.57
60	.59
75	.61
90	.62
105	.63
120	.64
150	.66
180	.67
210	.68
240	.69

AQUIFER TEST SITE B (WELL # 1529)

Time Since Pump Started / Stopped (min)	Drawdown Below Casing (m)
	Drawdown
1	.032
2	.112
3	.226
4	.347
5	.481
6	.617
7	.765
8	.892
9	1.112
10	1.245
12	1.525
14	1.768
16	2.037
18	2.272
20	2.473
25	2.974
30	3.641
40	4.792
50	5.9301
60	6.8853
75	8.5147
90	9.831
105	11.1303
120	12.4547
150	15.0523
180	17.553
210	19.7747
240	21.1802
	Recovery
2	.71
3	1.01
4	1.18
5	1.32
6	1.44
7	1.65
8	1.75
9	1.85
10	1.97
12	2.26
14	2.51
16	2.79
18	3.04
20	3.32
25	3.94
30	4.59
35	5.16
40	5.81
50	6.99
60	8.13
75	9.82
90	11.37
105	12.81
120	14.2
150	16.8
180	19.2

AQUIFER TEST SITE C (WELL # 1527)

Time Since Pumping Started / Stopped (min)	Drawdown Below Casing (m)
	Drawdown
1	.176
3	1.026
4	1.465
5	1.906
6	2.308
7	2.643
8	3.028
9	3.35
10	3.653
12	4.356
14	4.877
16	5.33
18	5.793
20	6.211
26	7.66
31	8.627
36	9.406999
40	10.03
50	11.169
61	12.107
75	13.436
90	14.459
106	15.571
122	16.786
150	18.412
180	19.406
210	20.0392
240	20.4803
270	20.7035
300	20.9367
360	21.175
420	21.2163
480	21.3227
540	21.376
600	21.4173
660	21.4187
720	21.42
780	21.4203
840	21.4317
900	21.438
960	21.4483
1020	21.3737
1080	21.357
1140	21.3203
1200	21.2847
1260	21.215
1320	21.1763
1380	21.1837
1440	21.176
	Recovery
1	1.435
2	2.19
3	2.68
4	3.1
5	3.533
6	3.945
7	4.358
8	4.749
9	5.125
10	5.506
12	6.218
14	6.9
16	7.532
18	8.134
20	8.713
25	10.069
30	11.211
35	12.25
40	13.162
50	14.664
60	15.834
75	17.137
90	18.096
105	18.816
120	19.328
150	20.116
180	20.627

AQUIFER TEST SITE D (WELL # 1531)

Time Since Pump Started / Stopped (min)	Drawdown Below Casing (m)
	Drawdown
1	.634
2	.8
3	1.016
4	1.196
5	1.727
6.3	2.243
7	2.32
8	2.509
9	2.6649
10	2.8267
12	3.1635
14	3.5332
16	3.918
18	4.2327
20	4.5405
25	5.1469
30	5.6262
35	5.8016
40	6.27
50	6.604
60	6.8155
75	7.0766
90	7.1857
105	7.252
120	7.303
150	7.354
180	7.374
210	7.384
240	7.38
300	7.372
360	7.364
420	7.353
480	7.337
540	7.322
600	7.342
660	7.335
720	7.276
780	7.19
840	7.123
900	7.112
960	7.082
1020	7.066
1080	7.092
1140	7.086
1200	7.036
1260	7.076
	Recovery
1	1.168
2	1.561
3	1.886
4	2.208
5	2.519
6	2.787
7	3.059
8	3.339
10	3.787
12	4.19
14	4.536
16	4.899
18	5.133
20	5.378
25	5.886
30	6.252
35	6.52
40	6.719
50	6.972
60	7.112
75	7.233
90	7.352
105	7.469
121	7.451
139	7.459
146	7.463

AQUIFER TEST SITE E (WELL # 1522)

Time Since Pumping Started / Stopped (min)	Drawdown Below Casing (m)
	Drawdown
1	.131
2	.439
3	.577
4.5	.825
5	.861
6	.92
7	.978
8	1.045
9	1.098
10	1.165
12	1.295
14	1.395
16	1.469
18	1.53
20	1.592
25	1.716
30	1.778
40	1.864
50	1.898
60	1.93
77	1.96
90	1.98
105	2.064
120	2.065
150	2.1761
180	2.1914
210	2.1966
240	2.2018
300	2.2273
360	2.2377
420	2.2352
480	2.2376
540	2.251
600	2.2476
660	2.247
720	2.2585
780	2.2599
840	2.2594
900	2.2608
960	2.2663
1020	2.2667
1080	2.2652
1140	2.2607
1200	2.2681
1260	2.2796
1320	2.285
1380	2.2855
1440	2.2859
	Recovery
1	1.15
2	1.21
3	1.29
4	1.39
5	1.48
6	1.57
7	1.62
8	1.69
9	1.75
10	1.84
12	1.96
14	2.03
16	2.07
18	2.13
20	2.17
25	2.25
30	2.3
35	2.37
40	2.41
50	2.44
60	2.5
75	2.53
90	2.59
105	2.62
120	2.65
150	2.83
180	2.86

AQUIFER TEST SITE F (WELL # 1521)

Time Since Pump Started /Stopped (min)	Drawdown Below Casing (m)
	Drawdown
1	.603
2	1.617
3	2.326
4	3.078
5	3.916
6	4.685
7	5.749
8	6.346
9	7.033
10	7.585
12	8.755
14	9.939
16	11.199
18	12.266
20	12.909
25	15.529
30	17.522
35	18.616
40	20.191
50	22.522
60	23.87
75	25.73
90	27.004
105	27.775
120	28.48
150	29.333
180	29.967
210	31.121
240	31.23
270	31.631
300	31.896
360	32.406
420	32.746
480	33.047
540	33.287
600	33.527
660	33.767
720	34.008
780	34.048
840	34.178
900	34.288
960	34.358
1020	34.399
1080	34.499
	Recovery
1	1.79
2	3.74
3	4.89
4	5.72
5	6.79
6	7.71
7	8.67
8	9.34
9	10.26
10	11.17
12	13.02
14	14.38
16	15.64
18	16.84
20	17.95
25	20.37
30	22.29
35	22.92
50	26.62
75	28.13
90	29.09
115	29.57
130	29.98
145	30.23
160	30.42
175	30.64

APPENDIX E
SLUGTEST RESULTS

Site B
Shallow well # 1530

Time (sec)	Level Below Static (m)
0.0	0.00
0.2	0.00
0.4	0.00
0.6	0.00
0.8	0.00
1.0	0.01
1.2	0.04
1.4	0.06
1.6	0.06
1.8	0.06
2.0	0.06
3.0	0.07
4.0	0.07
5.0	0.07
6.0	0.07
7.0	0.07
8.0	0.07
9.0	0.07
10.0	0.07
11.0	0.07
12.0	0.07
13.0	0.07
14.0	0.07
15.0	0.07
16.0	0.07
17.0	0.07
18.0	0.08
19.0	0.08
20.0	0.08
25.0	0.08
30.0	0.08
35.0	0.08
40.0	0.08
45.0	0.09
50.0	0.09
55.0	0.09
60.0	0.09
65.0	0.10
70.0	0.10
75.0	0.11
80.0	0.10
85.0	0.10
90.0	0.10
95.0	0.10
100.0	0.10
105.0	0.10
110.0	0.10
115.0	0.10
120.0	0.10
150.0	0.10
180.0	0.10
210.0	0.10
240.0	0.10
270.0	0.10
300.0	0.10
330.0	0.10
360.0	0.10
390.0	0.09
420.0	0.09
450.0	0.09
480.0	0.09
510.0	0.09
540.0	0.09
570.0	0.09
600.0	0.09
720.0	0.08
840.0	0.08
960.0	0.08
1080.0	0.07
1200.0	0.07
1320.0	0.07
1440.0	0.07
1560.0	0.07
1680.0	0.07
1800.0	0.06
1920.0	0.06
2040.0	0.06
2160.0	0.06
2280.0	0.06
2400.0	0.06
2520.0	0.06
2640.0	0.05
2760.0	0.05
2880.0	0.05
3000.0	0.05
3120.0	0.05
3240.0	0.05
3360.0	0.05
3480.0	0.05
3600.0	0.05
3720.0	0.05
3840.0	0.05
3960.0	0.05
4080.0	0.05
4200.0	0.05
4320.0	0.05
4440.0	0.05
4560.0	0.05
4680.0	0.05
4800.0	0.04
4920.0	0.04
5040.0	0.04
5160.0	0.03
5280.0	0.03
5400.0	0.02
5520.0	0.02
5640.0	0.01

Site E
Shallow well # 1535

Time (sec)	Level Below Static (m)
0.0	0.00
0.2	0.00
0.4	0.00
0.6	0.00
0.8	0.00
1.0	0.00
1.2	0.00
1.4	0.00
1.6	0.00
1.8	0.00
2.0	0.00
3.0	0.00
4.0	0.00
5.0	0.00
6.0	0.00
7.0	0.00
8.0	0.00
9.0	0.03
10.0	0.10
11.0	0.13
12.0	0.13
13.0	0.13
14.0	0.13
15.0	0.13
16.0	0.13
17.0	0.13
18.0	0.12
19.0	0.12
20.0	0.12
25.0	0.12
30.0	0.11
35.0	0.11
40.0	0.11
45.0	0.11
50.0	0.11
55.0	0.11
60.0	0.10
65.0	0.10
70.0	0.10
75.0	0.10
80.0	0.10
85.0	0.10
90.0	0.10
95.0	0.10
100.0	0.10
105.0	0.10
110.0	0.10
115.0	0.09
120.0	0.09
150.0	0.09
180.0	0.09
210.0	0.08
240.0	0.08
270.0	0.07
300.0	0.07
330.0	0.07
360.0	0.07
390.0	0.06
420.0	0.06
450.0	0.06
480.0	0.06
510.0	0.06
540.0	0.06
570.0	0.06
600.0	0.05
720.0	0.05
840.0	0.04
960.0	0.04
1080.0	0.03
1200.0	0.03
1320.0	0.02
1440.0	0.02
1560.0	0.02
1680.0	0.01
1800.0	0.01
1920.0	0.01
2040.0	0.01
2160.0	0.01
2280.0	0.00
2400.0	0.00
2520.0	0.00
2640.0	0.00
2760.0	0.00
2880.0	0.00
3000.0	0.00
3120.0	0.00
3240.0	0.00
3360.0	0.00
3480.0	0.00
3600.0	0.00
3720.0	0.00
3840.0	0.00
3960.0	0.00
4080.0	0.00
4200.0	0.00
4320.0	0.00
4440.0	0.00
4560.0	0.00
4680.0	0.00
4800.0	0.00
4920.0	0.00
5040.0	0.00
5160.0	0.00
5280.0	0.00
5400.0	0.00
5520.0	0.00
5640.0	0.00

Site D
Shallow well # 1532

Time (sec)	Level Below Static (m)
0.0	0.00
0.2	0.00
0.4	0.00
0.6	0.00
0.8	0.00
1.0	0.00
1.2	0.00
1.4	0.14
1.6	0.57
1.8	0.86
2.0	0.86
3.0	0.86
4.0	0.86
5.0	0.86
6.0	0.86
7.0	0.86
8.0	0.86
9.0	0.86
10.0	0.86
11.0	0.86
12.0	0.86
13.0	0.86
14.0	0.86
15.0	0.86
16.0	0.86
17.0	0.86
18.0	0.86
19.0	0.86
20.0	0.71
25.0	0.71
30.0	0.71
35.0	0.71
40.0	0.71
45.0	0.71
50.0	0.71
55.0	0.71
60.0	0.71
65.0	0.71
70.0	0.71
75.0	0.71
80.0	0.71
85.0	0.71
90.0	0.71
95.0	0.71
100.0	0.71
105.0	0.71
110.0	0.71
115.0	0.71
120.0	0.71
150.0	0.57
180.0	0.57
210.0	0.57
240.0	0.57
270.0	0.43
300.0	0.43
330.0	0.43
360.0	0.43
390.0	0.43
420.0	0.29
450.0	0.29
480.0	0.29
510.0	0.29
540.0	0.29
570.0	0.29
600.0	0.29
720.0	0.29
840.0	0.14
960.0	0.14
1080.0	0.14
1200.0	0.14
1320.0	0.14
1440.0	0.14
1560.0	0.14
1680.0	0.14
1800.0	0.14
1920.0	0.14
2040.0	0.14
2160.0	0.14
2280.0	0.14
2400.0	0.14
2520.0	0.14
2640.0	0.14
2760.0	0.14
2880.0	0.14
3000.0	0.14
3120.0	0.14
3240.0	0.14
3360.0	0.14
3480.0	0.14
3600.0	0.14
3720.0	0.14
3840.0	0.14
3960.0	0.14
4080.0	0.14
4200.0	0.14

Site G
Shallow well # 1533

Time (sec)	Level Below Static (m)
0.0	0.00
0.2	0.00
0.4	0.00
0.6	0.00
0.8	0.00
1.0	0.00
1.2	0.00
1.4	0.00
1.6	0.00
1.8	0.00
2.0	0.00
3.0	0.06
4.0	0.06
5.0	0.06
6.0	0.06
7.0	0.06
8.0	0.07
9.0	0.07
10.0	0.07
11.0	0.07
12.0	0.07
13.0	0.07
14.0	0.07
15.0	0.07
16.0	0.07
17.0	0.07
18.0	0.07
19.0	0.08
20.0	0.08
25.0	0.08
30.0	0.08
35.0	0.08
40.0	0.08
45.0	0.08
50.0	0.08
55.0	0.08
60.0	0.08
65.0	0.08
70.0	0.08
75.0	0.08
80.0	0.09
85.0	0.09
90.0	0.09
95.0	0.09
100.0	0.09
105.0	0.09
110.0	0.09
115.0	0.09
120.0	0.09
150.0	0.09
180.0	0.09
210.0	0.09
240.0	0.09
270.0	0.09
300.0	0.09
330.0	0.09
360.0	0.09
390.0	0.08
420.0	0.08
450.0	0.08
480.0	0.08
510.0	0.08
540.0	0.08
570.0	0.08
600.0	0.07
720.0	0.07
840.0	0.06
960.0	0.06
1080.0	0.06
1200.0	0.05
1320.0	0.05
1440.0	0.05
1560.0	0.05
1680.0	0.04
1800.0	0.04
1920.0	0.04
2040.0	0.04
2160.0	0.04
2280.0	0.04
2400.0	0.03
2520.0	0.03
2640.0	0.02
2760.0	0.02
2880.0	0.02
3000.0	0.01
3120.0	0.01
3240.0	0.01
3360.0	0.01
3480.0	0.01
3600.0	0.01
3720.0	0.01
3840.0	0.01
3960.0	0.01
4080.0	0.01
4200.0	0.01

APPENDIX F
ANALYTICAL RESULTS FOR SAMPLING METHODS TESTING

Well # 1529 Site B

Parameter	Values For Each Sampling Method Kemmerer (Aug 8/83)	 14 hours (Aug 9/8)
Apparent Colour (Rel. Units)	5.0	
Calcium (mg/L)	33.0	31.0
Alkalinity Total (mg/L)	84.3	80.2
Iron Extractable (mg/L)	.06	2.4
Specific Conductance (uSi/cm)	180	
Temperature (Deg.C)	25.0	25.0
pH	7.8	6.7
Magnesium (mg/L)	1.7	1.7
Potassium (mg/L)	0.4	0.4
Sodium (mg/L)	9.5	9.2
Chloride (mg/L)	9.7	11.1
Silica (mg/L)	8.7	8.4
Sulphate (mg/L)	7.5	6.9
Residue (mg/L)	151	36.0
Nitrogen (mg/L)	0.03	0.04
Nitrogen (mg/L)	0.01	0.05
Carbon Organic (mg/L)	1.0	1.0
Carbon Inorganic (mg/L)	22	23.0
Copper Extractable (mg/L)	0.002	0.013
Turbidity (mg/L)	3.0	32.0
Lead Extractable (mg/L)	0.008	0.008
Manganese extractable (mg/L)	0.01	0.06
Zinc Extractable (mg/L)	.01	0.23
Phosphorous Total (mg/L)	0.02	0.041
Phosphorous Inorganic (mg/L)	0.001	0.001

Well # 1527 Site C

Parameter	Values For Each Sampling Method Kemmerer (Aug 10/83)	 14 Hours (Aug11/83)
Apparent Colour (Rel. Units)	5.0	5.0
Calcium (mg/L)	60.0	50.0
Alkalinity Total (mg/L)	76.5	74.5
Iron Extractable (mg/L)	0.06	0.008
Specific Conductance (uSi/cm)	418.0	
Temperature (Deg.Cd:)	25.0	25.0
pH	7.8	6.6
Magnesium (mg/L)	7.3	6.6
Potassium (mg/L)	1.0	0.8
Sodium (mg/L)	17.2	11.9
Chloride (mg/L)	91.0	60.0
Silica Practice (mg/L)	7.1	12.0
Sulphate (mg/L)	18.9	17.8
Residue (mg/L)	308.0	10.0
Nitrogen (mg/L	0.01	0.02
Nitrogen (mg/L)	0.01	0.01
Carbon Organic (mg/L)	1.0	1.0
Carbon Inorganic (mg/L)	22.0	17.0
Copper Extractable (mg/L)	0.002	0.002
Turbidity (mg/L)	3.0	0.1
Lead Extractable (mg/L)	0.014	0.002
Manganese Extractable (mg/L)	0.14	0.03
Zinc Extractable (mg/L)	0.03	0.04
Phosphorous Total (mg/L)	0.006	0.002
Phosphorous Inorganic (mg/L)	0.001	0.001

Well # 1531 Site D

Parameter	Values For Each Sampling Method Kemmerer (Aug 15/83)	 14 Hours (Aug17/83)
Apparent Colour (Rel. Units)	5.0	5.0
Calcium (mg/L)	110.0	75.0
Alkalinity Total (mg/L)	90.8	94.4
Iron Extractable (mg/L)	0.15	0.033
Specific Conductance (uSi/cm)	666.0	510.0
Temperature (Deg.Cd:)	25.0	25.0
pH	8.0	7.4
Magnesium (mg/L)	10.0	7.0
Potassium (mg/L)	1.0	0.8
Sodium (mg/L)	20.1	17.6
Chloride (mg/L)	200.0	105.0
Silica Practice (mg/L)	8.7	11.0
Sulphate (mg/L)	12.8	16.0
Residue (mg/L)	695.0	336.0
Nitrogen (mg/L	0.32	0.64
Nitrogen (mg/L)	0.35	0.59
Carbon Organic (mg/L)	1.0	1.0
Copper Extractable (mg/L)	0.002	0.002
Turbidity (mg/L)	2.0	1.0
Lead Extractable (mg/L)	0.006	0.002
Manganese Extractable (mg/L)	0.7	0.01
Zinc Extractable (mg/L)	0.02	0.08
Phosphorous Total (mg/L)	0.001	0.007
Phosphorous Inorganic (mg/L)	0.001	0.001

Well # 1522 Site E

Parameter	Values For Each Sampling Method			
	Kemmerer (Aug 1)	12 hrs (Aug2)	0 (Aug 2)	24 (Aug 3)
Apparent Colour (Rel. Units)	5.0	5.0	5.0	5.0
Calcium (mg/L)	32.0	34.0	33.0	34.0
Alkalinity Total (mg/L)	64.7	67.2	66.7	67.3
IRon Extractable (mg/L)	0.017	0.12	0.033	0.07
Specific Conductance (uSi/cm)	230.0		220.0	193.0
Temperature (Deg.Cd:)	25.0	25.0	25.0	25.0
pH	8.0	6.5	8.0	7.8
Magnesium (mg/L)	2.4	2.5	2.5	2.5
Potassium (mg/L)	0.6	0.6	0.6	0.6
Sodium (mg/L)	8.3	8.2	8.3	8.3
Chloride (mg/L)	10.1	10.6	10.3	11.0
Silica Practice (mg/L)	7.7	9.2	9.0	9.2
Sulphate (mg/L)	17.2	17.2	16.9	17.8
Residue (mg/L)	222.0	10.0	201.0	124
Nitrogen (mg/L	3.0	3.0	2.9	3.1
Nitrogen (mg/L)	2.7	3.0	2.8	3.0
Carbon Organic (mg/L)	1.0	1.0	1.0	1.2
Carbon Inorganic (mg/L)	14.0			
Copper Extractable (mg/L)	0.002	0.002	0.002	0.002
Turbidity (mg/L)	1.0	0.5	2.0	2.0
Lead Extractable (mg/L)	0.016	0.002	0.007	0.002
Manganese Extractable (mg/L)	0.05	0.01	0.02	0.01
Zinc Extractable (mg/L)	0.01	0.04	0.07	0.04
Phosphorous Total (mg/L)	0.004	0.005	0.001	0.003
Phosphorous Inorganic (mg/L)	0.001	0.001	0.001	0.001

Well # 1521 Site F

Parameter	Values For Each Sampling Method			
	Kemmerer (Aug17)	0 hrs (Aug18)	12 (Aug19)	24 (Aug19)
Apparent Colour (Rel. Units)	5.0	5.0	5.0	5.0
Calcium (mg/L)		46.0	46.0	53.0
Alkalinity Total (mg/L)		58.5	57.9	56.4
IRon Extractable (mg/L)	0.06	0.04	0.07	0.60
Specific Conductance (uSi/cm)	311.0	320.0	370.0	440.0
Temperature (Deg.Cd:)		25.0	25.0	25.0
pH	8.2	8.1	8.2	8.1
Magnesium (mg/L)		3.2	3.5	3.6
Potassium (mg/L)		1.0	1.1	1.1
Sodium (mg/L)		30.0	34.0	38.0
Chloride (mg/L)		8.6	9.3	8.9
Silica Practice (mg/L)		9.0	9.0	8.9
Sulphate (mg/L)		129.0	144.0	168.0
Residue (mg/L)	180.0	255.0	282.0	307.0
Nitrogen (mg/L		0.06	0.01	0.02
Nitrogen (mg/L)		0.06	0.01	0.01
Carbon Organic (mg/L)		1.0	1.0	1.7
Carbon Inorganic (mg/L)		15.0	15.0	
Copper Extractable (mg/L)	0.002	0.002	0.002	0.002
Turbidity (mg/L)	1.0	1.0	2.0	3.0
Lead Extractable (mg/L)	0.005	0.002	0.002	0.002
Manganese Extractable (mg/L)	0.02	0.02	0.02	0.03
Zinc Extractable (mg/L)	0.01	0.02	0.03	0 03
Phosphorous Total (mg/L)	0.007	0.007	0.002	0.012
Phosphorous Inorganic (mg/L)	0.003	0.001	0.001	0.001

Well # 1519 Site G

Parameter	Values For Each Sampling Method	
	Kemmerer	1.5
	(Aug 8/83)	(Aug 9/8)
Apparent Colour (Rel. Units)	5.0	5.0
Calcium (mg/L)	32.0	31.0
Alkalinity Total (mg/L)	93.0	88.1
IRon Extractable (mg/L)	0.07	0.08
Specific Conductance (uSi/cm)	192.0	178
Temperature (Deg.Cd:)	25.0	25.0
pH	8.2	8.2
Magnesium (mg/L)	2.4	2.3
Potassium (mg/L)	0.8	0.6
Sodium (mg/L)	11.4	10.9
Chloride (mg/L)	7.6	7.2
Silica Practice (mg/L)	9.4	8.7
Sulphate (mg/L)	6.9	6.8
Residue (mg/L)	104.0	104.0
Nitrogen (mg/L	0.02	0.01
Nitrogen (mg/L)	0.01	0.01
Carbon Organic (mg/L)	1.0	1.0
Carbon Inorganic (mg/L)		26.0
Copper Extractable (mg/L)	0.002	0.002
Turbidity (mg/L)	3.0	3.0
Lead Extractable (mg/L)	0.004	0.003
Manganese Extractable (mg/L)	0.04	0.04
Zinc Extractable (mg/L)	0.01	0.03
Phosphorous Total (mg/L)	0.003	0.004
Phosphorous Inorganic (mg/L)	0.001	0.001