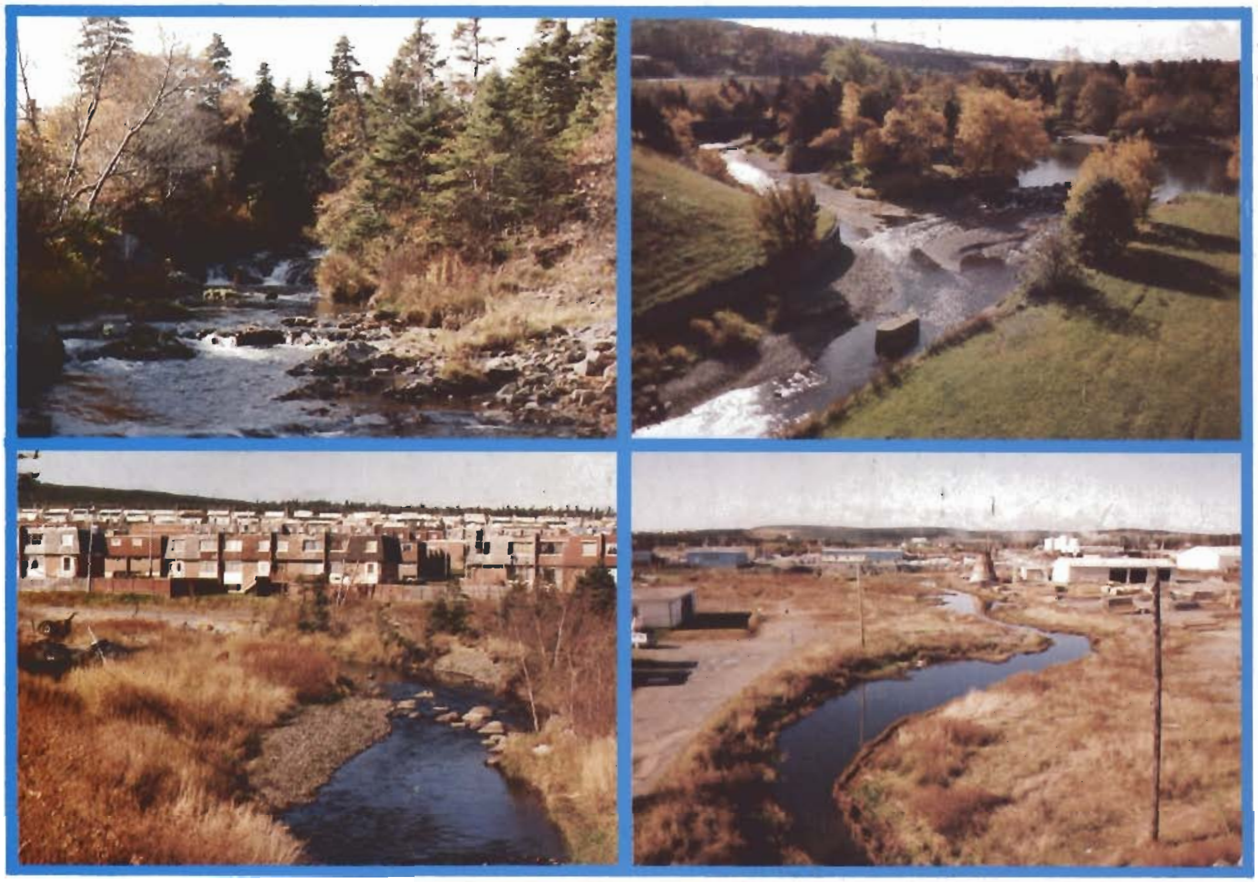
Government of Newfoundland and Labrador
Department of Environment
Water Resources Division
St. John's, Newfoundland

Government of Canada
Environment Canada
Inland Waters Directorate
Dartmouth, Nova Scotia
National Water Research Institute
Burlington, Ontario

GROUNDWATER IN THE WATERFORD RIVER BASIN



Urban Hydrology Study of the Waterford River Basin

TECHNICAL REPORT No.

UHS-WRB 1.6

GROUNDWATER

IN THE

WATERFORD RIVER BASIN

BY

THE GROUNDWATER SUB-COMMITTEE

J.W. ROBINSON J.E. GIBB

NEWFOUNDLAND ENVIRONMENT

ENVIRONMENT CANADA

St. John's, NEWFOUNDLAND

AUGUST 1985

LETTER OF TRANSMITTAL

Groundwater Branch
Water Resources Division
Department of Environment
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Dr. Wasi Ullah, Chairman
Technical Committee
Waterford River Basin Urban Hydrology Study
Water Resources Division
Department of Environment
Box 4750, St. John's, Newfoundland
A1C 5T7

Dear Dr. Ullah;

I am pleased to enclose a copy of the final report of the Groundwater Sub-Committee entitled "Groundwater in the Waterford River Basin". This report is our contribution to the Waterford River Basin Urban Hydrology Study.

Yours truly,

J.W. Robinson, M.Sc.
Chairman of the
Groundwater Sub-Committee

Members

J.W. Robinson, Newfoundland Department of Environment (Chairman)
J. Gibb, Environment Canada

ABSTRACT

Groundwater is the major portion of water that is retained in any watershed. As part of the overall study of the effects of urbanization on the water resources of the Waterford River Basin, the bedrock and surficial geology of the basin were described and five land use activities were determined. Seven well sites were chosen to monitor the impact of these land uses on the quality of groundwater. At each site a deep well and a shallow water table well was constructed. One of the sites was located in the undeveloped natural area of the basin and was used as a control site for the study. In each of these wells the water level was measured monthly and a quarterly water sample was obtained for analyses. An additional site was chosen within the basin, at which the water level was monitored continuously in both a shallow and a deep well. During the five years of the study, no effects could be clearly attributed to the various land uses activities, with the exception of road salt stockpiling and application. Further monitoring is recommended for another five years.

RÉSUMÉ

Les eaux souterraines constituent le plus grand volume d'eau échappant au partage des eaux. Une étude globale des effets de l'urbanisation sur les eaux du Bassin de Waterford River comporte une description géologique des strates tant inférieures que supérieures du Bassin, et cinq activitiés d'exploitation du terrain y sont définies. Sept localisations de nappes d'eau ont été choisies pour étudier l'impact de ces exploitations du sol sur la qualité des eaux souterraines. A chacune d'elles, on a construit deux puits; l'un de grande, et l'autre de faible profondeur. L'un de ces enplacements a été choisi dans la région naturelle non exploitée du Bassin et a été utilisé comme piont de référence pour cette étude. Dans chacun de ces puits, le niveau d'eau a été mesuré mensuellement et un échantillon trimestriel a été prélevé aux fins d'analyses. A un autre endroit du Bassin, on a enregistré le niveau d'eau de façon contunue dans un puit profond et un autre, peu profond. Au cours des cinq ans couverts par cette étude, aucun effet n'a pu être clairement attribué à ces divenses activités d'exploitation du sol à l'exception de l'épandage et du stockage de sel destiné aux routes. On recommande de poursuivre ces travaux de recherche au cours d'une autre période de cinq ans.

PREFACE

The Waterford River Basin Urban Hydrology Study, developed as a co-operative effort between the Governments of Canada and the Province of Newfoundland, was proposed by the Newfoundland Department of Environment in response to watershed management problems that had resulted from urbanization of the Waterford River Basin. Among such problems, the negative effects of urbanization on both water quality and quantity were found to be so serious that the Newfoundland Department of Environment identified the Waterford River Basin as a high priority area.

The five-year study began in 1980 and most tasks were completed in March, 1985. Primary objectives of the study were to develop environmentally acceptable criteria for urban development in Newfoundland and to utilize the study results directly in the urban planning process in the Province. The specific objectives of the study, as outlined in the report "Waterford River Basin - Urban Hydrology Study Plan", were as follows:

1. To examine the processes leading to changes in the hydrologic regime of the Waterford River watershed. This should include evaluation and monitoring of major hydrologic changes caused by urbanization, the study of precipitation-runoff processes, and the study of various forms of pollution originating in the urban areas of the watershed.

2. To provide a hierarchy of mathematical models describing hydrologic processes in the watershed. Such models should deal with both water quantity and quality, and should be capable of simulating the impact of urbanization on the water resources in the studies basin.

3. To recommend solutions to specific water management problems in the studies basin and to develop guidelines for implementation of similar solutions elsewhere in Newfoundland. Furthermore, planning and management criteria should be developed for those aspects of the urban development which relate to the environmental protection of the affected water sources.

The complexity of the study called for a comprehensive approach which included hydrometric surveys, hydrological modelling, groundwater studies, biological surveys, water quality assessment, investigations of flooding, and land use and socio-economic analyses.

The study was administered by a Steering Committee appointed by the governments of Newfoundland and Canada. To implement the study plan, a Technical Committee consisting of two representatives of each government was established. Subsequently the Technical Committee appointed sub-committees and working groups to prepare and carry out work plans for the various components of the study. The report that follows deals with one such component - groundwater.

ACKNOWLEDGEMENTS

Many people have contributed to this work and the authors take this opportunity to mention a few. Mr. Dave Hansen and Mr. Ken Rollings were responsible for the routine water sampling and water level monitoring. Mr. Bob Lethbridge assisted in all phases of the field work and provided most of the plots and figures that are found in the text. Many hard-working student assistants contributed many hours to the field work. Among them were Mr. Spencer Vatcher, Mr. Bob Groves, Mr. Greg Dawe and Mr. Peter Alston. Much of the data manipulation was accomplished by computer, directed by Mr. Peter Downey. All of the chemical analyses were done by the Water Analysis Laboratory of Environment Canada in Moncton, New Brunswick under the direction of Dr. Tom Pollock. In addition to these participants, much encouragement and guidance was derived from numerous discussions with Dr. Wasi Ullah and Mr. Terry Hennigar, without whose initial drive it is questionable whether the study would have been done at all. Finally, for their dedication and perseverance, we thank Miss Sherie Dalton and Mrs. Louise Evans who typed the manuscript.

The study was jointly funded by the Governments of Canada and Newfoundland through their respective Environment Departments. The authors wish to express their gratitude to all the individuals who helped in any way to bring this report to fruition, and their appreciation to the funding bodies for the opportunity to conduct such a project.

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CHAPTER ONE

INTRODUCTION

1.1 Purpose And Scope Of The Study

The Waterford River Basin Urban Hydrology Study was initiated to investigate the way in which urbanization modifies the hydrologic character of a watershed. The objective was to determine this impact in terms of the quantity and quality of both surface water and groundwater. Although this type of study had been undertaken in other parts of Canada and had shown the effects to be substantial, no study of this kind had been done in the Province of Newfoundland. From a national perspective its absence was significant. This was due to the conditions that are indigenous to Newfoundland and that were at variance to those of the rest of Canada. The results of other studies then, could not be applied directly to this province, nor were they intended to be. In order to provide some of the tools that other provinces enjoyed in this regard, the Provincial Department of Environment and the Federal Department of Environment jointly undertook the aforesaid study in the Waterford River Basin near St. John's, Newfoundland (see **Figure 1.1**). This basin was chosen because of the ongoing development that was taking place and because of evidence that many of the deleterious effects of such change were apparent in the Basin.

The present study concerns the groundwater component of the water cycle and the processes affecting the hydrologic cycle of the basin. As the major component of this cycle, the movement and storage of subsurface waters and the quality of this resource were of major concern. It is well known that the impact of urbanization on groundwater is potentially as varied as that for surface water. This stems from the fact that groundwater receives recharge from surface water sources via infiltration from precipitation or natural and man made impoundments. In addition, groundwater forms a major part of streamflow during low flow periods and a significant part in higher flow periods. A physical change in the groundwater regime is therefore not isolated to this resource. Eventually it is transmitted to other parts of the hydrologic cycle although the effects may be reduced.

In the Waterford River Basin at present, there are about 400 domestic wells of which about 70 are abandoned because of the availability of an alternate supply. Of these 400 wells about 10% are drilled artesian wells, the other 90% are dug, water table wells. The remaining households in the basin are supplied with water from the Bay Bulls Big Pond water supply system operated by the City of St. John's. Groundwater is therefore not a major source of water for the basin. It does however provide an adequate and valuable interim supply for those residences that are outside the major planned developments such as New Town and Mount Pearl. It is anticipated that groundwater will remain the only water supply for these areas until they are incorporated into the more organized developments. This is typical of many small watersheds in Newfoundland, therefore a study of this nature should be applicable to all of these areas and increase our knowledge of groundwater's occurrence, in the Waterford Basin, and

4. To investigate the physical and chemical processes that lead to changes in the groundwater.

Despite the large number of wells in the basin, virtually no information was available concerning their construction or yield characteristics. In addition, for the most part, they were concentrated in one developed area. Because of this, most of the resources that were available to accomplish the objectives listed above were expended for the construction of monitoring wells. It became obvious very early in the study that the emphasis would have to be placed on the water quality effects of urban development. Thus the objectives were made subservient to this requirement. This imposed a severe limitation on the attainment of objectives 1 and 4. The definition of major aquifers could only be accomplished insofar as information was available from wells drilled for the purpose of monitoring the various land use activities in the basin. The determination of the groundwater component of the hydrologic budget was limited to an annual estimate of baseflow for the years 1974-1983. In addition, no independent study of physical and chemical processes that operate in the basin was possible.

For the purposes of this study, land use in the basin was divided up into five categories. These were: 1) forested or natural areas, 2) agricultural areas, 3) urban or sub-urban areas, 4) recreational areas and 5) other areas such as ponds, bogs, barrens, river channels, gravel pits, etc. A monitoring well system was constructed to determine the bridge. The watershed characteristics below this point are not addressed in this study. The selection of the upper portion of the basin for study was logical because of the hydrometric station located at the bridge and the availability of a number of years of streamflow data from this station. In addition, the area of the basin downstream of the gauging station is almost completely developed and in a number of places the drainage system has been modified. For example, some of the smaller tributaries have been replaced by storm sewers. A further complication involves several unidentified cross-connections of sanitary and storm sewers and domestic sewage discharge points which would create problems in the interpretation of results. In order to avoid these problems this part of the basin was excluded from the study area.

1.3 Previous Investigations And Reports

The study area has been the subject of three technical reports that relate to groundwater. Batterson (1984) reported on the surficial geology of the basin and gave many observational comments concerning the water bearing characteristics of the overburden formations. Included in his report are maps of approximate overburden thickness and materials. King (1984) provided an up-to-date summary of the bedrock geology of the area and its immediate surroundings. The major structural features of the area are also discussed in this study and both structure and geology are shown on a map included with the report. Robinson (1986) provided a complete review of the planning, installation, hydraulic testing and water quality testing of the monitoring well network. Included in this

CHAPTER TWO

GEOGRAPHY

2.1 Physiography

The Waterford River basin, as shown in **Figure 2.1**, drains an area of approximately 61 km^2 and is located within, and extends south west of, the City of St. John's, Newfoundland. Rising from Bremigens Pond at an elevation of about 168 m above sea level, the main channel of the Waterford River flows north-easterly over a distance of about 14.2 km to discharge into salt water in St. John's Harbour. The mouth is located at coordinates 47^{o} 33' 18" N and 52^{o} 42' 46" w (Topographic map reference 1N/10 East). The major tributary, South Brook, originates from a swamp area in the upper reaches of the south central part of the basin. Other smaller tributaries drain into either the main channel or South Brook and some have intermittent flow.

The principal geomorphological features of the basin are listed in **Table 2.1.** Significant relief features are generally confined to the perimeter. Kenmount Hill in the north dominates a relatively smooth ridge of till-cloaked highland. It forms the highest point in the basin at 236 m above sea level. The east boundary contains the more ragged South Side Hills, the highest of which is Turtle Hill at 206 m above sea level. Over much of the rest of the basin a lack of significant relief is typified by gently rolling hills with slopes of 2-5%.

Regionally, the basin is almost wholly situated within the north-south trending highland area that flanks the western part of the Avalon Peninsula.

Table 2.1

Principal Geomorphological Features of the Waterford River Basin

Total Drainage Area	61	km^2
(area under study)	51	km^2
Mean Width	4	km
Axial Length	14	km
Basin Perimeter	40	km
Maximum Relief	259	m
Channel Slope	36.3	m/km
Length (Waterford River)	14.2	km
Length (South Brook)	10.3	km
Length (Tributaries)	33.8	km
Drainage Density	0.9	km/km^2

2.2 Climate

The climate of the Avalon Peninsula is somewhat more temperate than the remainder of the Island, due to its proximity to the sea. The mean annual temperature is 5.0 degrees C, the average yearly precipitation is 1594.7 mm and the estimated average annual evaporation is 381.0 mm. The distribution of precipitation is fairly uniform throughout the year, except in June and July which receive relatively less rainfall. The Canada Department of Agriculture Research Station in Mount Pearl has a meteorological observatory for monitoring routine weather elements including radiation. This station is within the study area. Historical weather data are also available from the Weather Station at Torbay Airport. The precipitation normals for 1951-1980 (rainfall and snowfall)

2.3 Land Use

The existing land uses in the area, based on 1976 aerial photographs, are shown in **Figure 2.1.** The approximate size of the areas under the various land use catagories are given in **Table 2.3.**

Table 2.3

Land Use (based on 1976 aerial photographs)

Land Use	Area (km^2)	Percentage of total
Forest	27.66	53.91
Agriculture	3.88	7.56
Urban & suburban	12.43	24.22
Recreation	0.81	1.58
Other*	6.53	12.73
Totals	51.31	100.00

*(ponds,bogs,barrens, river channels,gravel pits etc)

Urban expansion has taken place in the Waterford River Basin at the expense of forested areas. These areas, however, still make up over 50% of the total area as of 1976. No future economic contribution is foreseen from these areas as the soil conditions and climate are unfavorable to regeneration and growth. No forest management plans are operating in the area to significantly improve this outlook.

A relatively small percentage of land is exploited for agriculture. Many small farms operate in the area, as well as the Canada and Newfoundland Agricultural Research Station. Vegetable and dairy farming are the

CHAPTER THREE

GEOLOGY

3.1 Bedrock Geology

3.1.1 Description and distribution

The geology of the Waterford River Basin has been reported by King (1984) from which the following is summarized. The study area is within the Avalon Zone of the Appalachian Orogeny. This zone is characterized by thick sequences of late Precambrian volcanic and sedimentary rocks, overlain in some localities by Paleozoic sediments with fossils characteristic of the Atlantic realm. The study area itself consists of late Precambrian, clastic, sedimentary rocks that have been folded into broad anticlinoria and synclinoria.

The distribution of geology is shown in **Figure 3.1.** The oldest rocks exposed in the Basin are represented by the Drook and Mistaken Point Formations. These are part of the Conception Group. The Drook Formation is the thickest unit in the study area (100 m) and underlies the western and northern parts of it. It consists of yellowish green, siliceous silty sandstone and bedded cryptocrystalline cherts. An abundance of tuff and other volcanic detritus found in the Drook Formation, as well as in the whole of the Conception Group, suggests sedimentation contemporaneous with volcanism. The formation is gradational upward. The lower facies is exposed along the Paddy's Pond Anticline and in the Donovans, Wishingwell Road and Kenmount Hill areas. It consists of medium-to-thick bedded,dark green, siliceous, silty sandstone alterna and minor shale. Overlying this facies is a distinctive unit of streaky white and red, siliceous sandstone. These rocks are exposed from Bremigens Pond around the Paddy's Pond and Cochrane Pond Anticlines, to the Ruth Avenue Overpass along the Harbour Arterial Road. The sandstones are arkosic and coarsely laminated with wisps of red mudstone, and thin lenses of argillite and tuff fragments. The uppermost facies is an easily recognised volcanic unit and can be traced around the plunging folds between Bremigens Pond and the Trans-Canada Highway/Harbour Arterial Road junction to the Ruth Avenue Overpass. It consists of a fining upward sequence of graded, siliceous sandstones and interbedded, siliceous siltstones and tuffs. The top 10 m is mainly capped by alternating, yellowish green tuff and reddish purple, sandy, tufaceous siltstone.

The Mistaken Point Formation is approximately 400 m thick and lies conformably upon the Drook Formation. It consists of interbedded greenish grey and reddish purple, tufaceous siltstones, shales and sandstones. It is exposed in Donovans Industrial Park and in the low-lying area between the Ruth Avenue Extension and the ridge between Brazil and Bremigens Ponds. Although these argillaceous beds have a massive appearance, finely spaced, parallel laminations are recognizable. They are softer than the similar, but more cherty, rock of the Drook Formation. In the northeast part of the Basin, exposures of red and green argillaceous rocks are intermittent between Blackmarsh Road and Canada Drive due to the till blanket that occurs here. It is assumed that the Mistaken Point Formation subcrops beneath much of this area.

strip in the eastern portion of the study area. It consists of alternating lamina and very thin beds of siltstone and sandstone set in dark shale. The greater sand content differentiates this unit from the one below.

The most recent bedrock in the basin is represented by the Signal Hill Group. This group consists of alluvial facies and is subdivided into three distinct formations. Only the lower two are found exposed in the study area. These, are in ascending order, the Gibbett Hill and Quidi Vidi Formations. The Gibbett Hill Formation is found on the eastern border of the study area and consists of medium to thick beds of grey sandstone. This is a gradational change from the shales of the Renews Head Formation. Upwards through the unit, further grading occurs to a coarse grained, grey sandstone of massive appearance. Closer examination reveals laminations and small scale sedimentary structures. These rocks are arkosic in composition with 20-35% quartz, 20-30% plagioclase feldspar, <15% orthoclase feldspar, <15% rock fragment, and <15% groundmass. Secondary growths of quartz have reduced the permeability of the rock substantially.

Only a small area of the Quidi Vidi Formation is located in the study area. It is composed of medium to thick beds of red and grey arkosic sandstone with interbeds of siltstone, mudstone, breccia and conglomerate. In the Basin, only the red sandstones are exposed in the extreme south-eastern part.

along the Waterford River between Donovans and Branscombe's Pond are separated abruptly from these deformed Drook strata by the Donovans-Blackmarsh Fault. A later phase of folding has warped this fault, as well as tight folds in the shales, around the Anticlinorium and possibly produced the steeply dipping, north-northwest trending, platy cleavage in the Fermeuse Formation in the Newtown area.

The South Brook Anticlinorium extends from downtown St. John's along part of South Brook to the Goulds. It consists of a north-north-east trending 500 to 1000 m wide zone of tightly folded, faulted and disrupted strata of the Fermeuse Formation. It is a result of intense compression of incompetent shales between relatively competent sandstone within the Kenmount Hill Anticlinorium and Blackhead Syncline.

The Kenmount Road Fault trends northeast on the northern border of the study area. It is a narrow fault zone (100 m wide). Numerous faults, dipping steeply, northwest, are exposed along its length. Movement has been down-dip. The Newtown Fault apparently originates as a bedding plane fault near the Trans-Canada Highway. It is an assumed strike-slip rupture and the apparent cause of the change in axis orientation of the Cochrane Pond Anticline.

Numerous joint sets and fracture zones are evident in virtually all rock units present in the map area. Joint systems are especially well developed in the thick bedded sandstones and conglomerate of the Signal Hill Group. Joints are rhombohedral and probably developed perpendicular rather than any significant erosional activity. The till smoothed the surface relief by filling the depressions. Till thicknesses are therefore variable, ranging from 0 to 6 m. The distribution of terrain units that exist in the study area is shown in **Figure 3.2.** A more detailed map is included in the report by Batterson (1984). Areas of bedrock overlain by a thin (0.2 m) veneer of overburden or vegetation comprise approximately 15% of the study area and are designated as Rc. This unit is generally confined to the highland areas, particularly in the southwestern, northern and eastern parts. Other minor areas occur along the margins of South Brook and the Waterford River in their lower reaches.

About 60% of the field area is covered by a veneer (average 3 m) of till (Tv). This till covers the gently sloping areas in the western half of the basin between areas of Rc to the north and south. There is some variability within this terrain unit, notably in a dissected till veneer along incised sections of South Brook and the Waterford River, in gullied sections of the uplands at the headwaters of South Brook, and in a terraced till veneer along the South Side Hills east of Petty Harbour road. A similar, but single, terrace is also present around Kenmount Hill and near the Clearview Drive-In in Paradise.

Toward the eastern half of the basin, the Tv unit merges into Tvh, a hummocky till veneer. The major difference between the two units is the presence of an irregular till surface on the latter, which in some places has indistinct lineations. The poor development of these lineations, however, excludes a drumlinoid characterization, and the term "hummocky" is preferred. Till thicknesses are similar to those in the Tv unit. The Tvh unit pinches out toward the east, where bedrock control becomes dominant again, and to the northeast, where constriction of the valley is evident.

The remaining 5-10% of the basin is largely composed of organic terrain (O). This occurs along the low areas at the headwaters of South Brook and the Waterford River, at isolated localities along their courses, and in depressions over the entire basin. The material underlying the organic terrain varies. Sections east of Donovans Industrial Park are underlain by till; other areas are underlain by bedrock. The depth of the organic terrain is also variable, ranging from less than 1 m to thicknesses of over 4 m reported in the Goulds area. These areas presumably represent preexisting ponds which have been infilled by plant succession.

A small area (about 2%) of the basin is covered by recent alluvial deposits (A). The largest area occurs immediately north of Mount Pearl along the Waterford River. Upstream, patchy alluvium occurs along the river banks, but a well-defined flood plain has not developed. Downstream, incision of the valley has occurred which restricts the development of alluvial deposits. A small area of alluvium is located at the entrance to Bremigens Pond; this may be a glaciofluvial deposit related to the deglaciation of the last ice sheet.

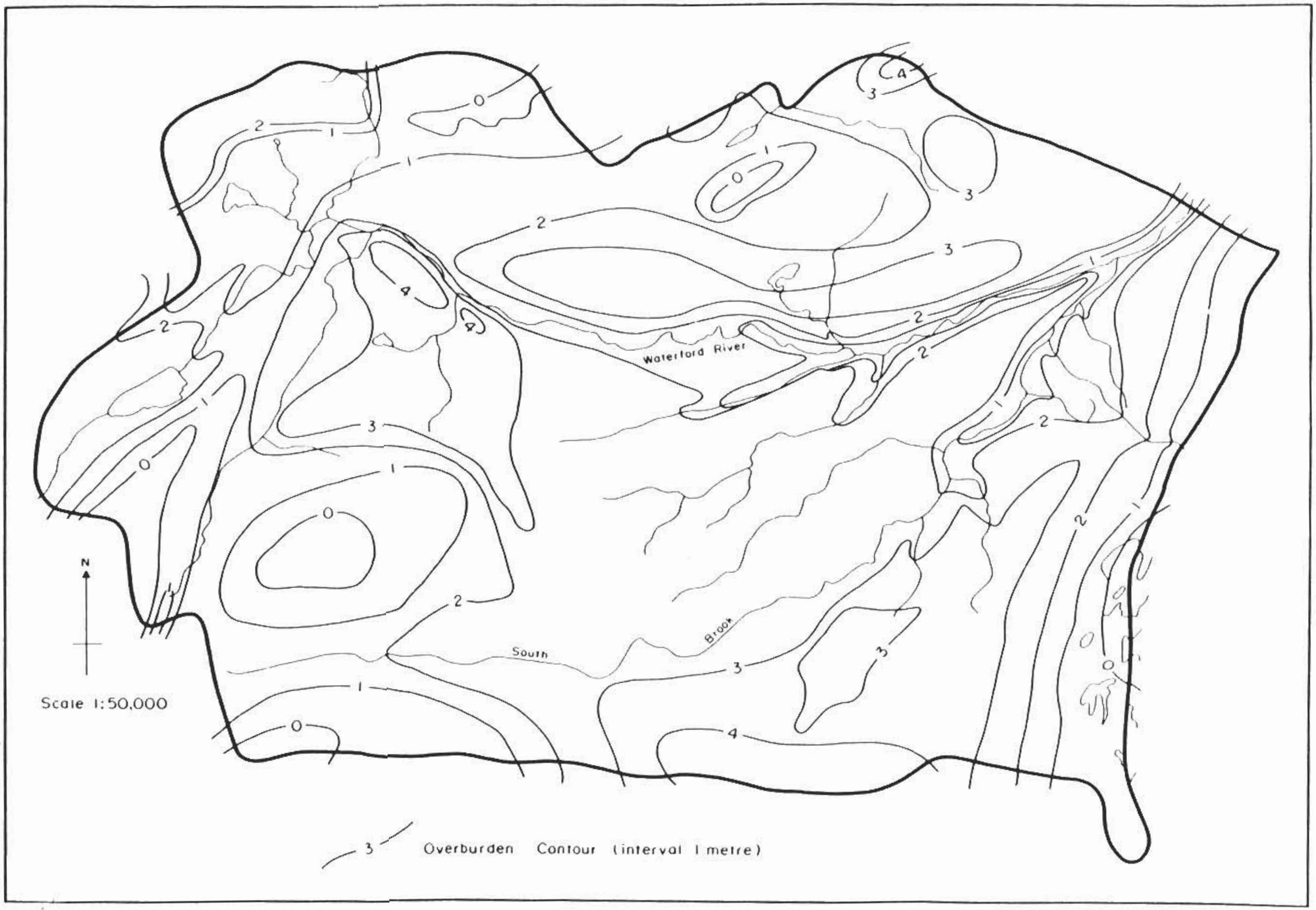


Figure 3.3 Generalized overburden thicknesses within the Waterford River Basin (After Batterson, 1984)

of the basin and on the South Side Hills. Elsewhere this facies is poorly developed, nonexistent or obscured by soil development and unrecognizable. This unit is a poorly-sorted, clast-supported till. Any matrix present is coarse to medium sand with an average of 3.7% silt and clay. Clasts are subangular and lack striations. This description is consistent with that of a supraglacial till, an interpretation further supported by the existence of fine sand lenses, up to 20 cm long and 5 cm wide, developed by meltwater activity during deglaciation.

The supraglacial unit always overlies a subglacial till and is generally better sorted, less compacted and has fewer fines than the underlying unit. The average thickness of the supraglacial unit is 50 cm, but it reaches thicknesses of 150 cm east of Donovans Industrial Park. The supraglacial tills are thickest in the west-central part of the basin and thinnest toward the basin margins. Despite being transported farther than the subglacial unit, all clasts are from sources within the map area, which suggests that transport distances may be 2 km or less.

Where a supraglacial till is not exposed in the basin, a third unit is often present. This deposit is a compacted, poorly sorted till with higher silt-clay content and lower clast content than the underlying lodgement till unit. Silt-clay content averages 18.1%. This unit has no obvious structure or fabric.

The low clast content relative to the underlying lodgement till,

CHAPTER FOUR

MONITORING WELL NETWORK

4.1 Location Of Monitoring Wells

Due to the limitations discussed in Section 1.1 and the lack of information from existing wells, it was decided that the major emphasis of the study would be upon water quality. The practical outcome of this decision was that the initial drilling program was designed for the installation of monitoring wells and not for the delineation 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 permanent sampling stations from which representative groundwater samples could be obtained. The network was designed to reflect the effects of each of the major land use categories found in the study area. In order to determine the impact that a particular land use had on the groundwater quality, water samples had to be obtained both upstream and downstream of the activity in question. In order to locate the wells so that the desired effects could be monitored, the direction of groundwater flow in the basin was determined from the available information. It was assumed that the rock was isotropic and thus the directions of flow would be governed by hydraulic gradient alone. To determine the hydraulic gradient, an extensive survey of all wells in the Waterford River Basin was conducted extensive confining layers within the overburden required 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 (i.e., beside stream channels) more casing was installed.

Drilling commenced using an 20 cm air hammer bit. When drilling had proceeded into the bedrock to a sufficient depth to satisfy the aforementioned criteria, the hole was cleaned out as well as possible and the drill tools were removed. Approximately 1 kg of bentonite pellets were immediately poured into the hole and the appropriate length of 15 cm 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 emplacement of dry bentonite pellets around the drive shoe ensured virtual isolation from the overburden aquifer. The annular space was then back filled with overburden materials and drill cuttings.

Once the casing was set, drilling proceeded into the bedrock inside the casing using a 15 cm air hammer bit. Drill cutting samples were collected at 1.5 m intervals, and at significant water bearing zones. Drilling proceeded until a fracture 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 to

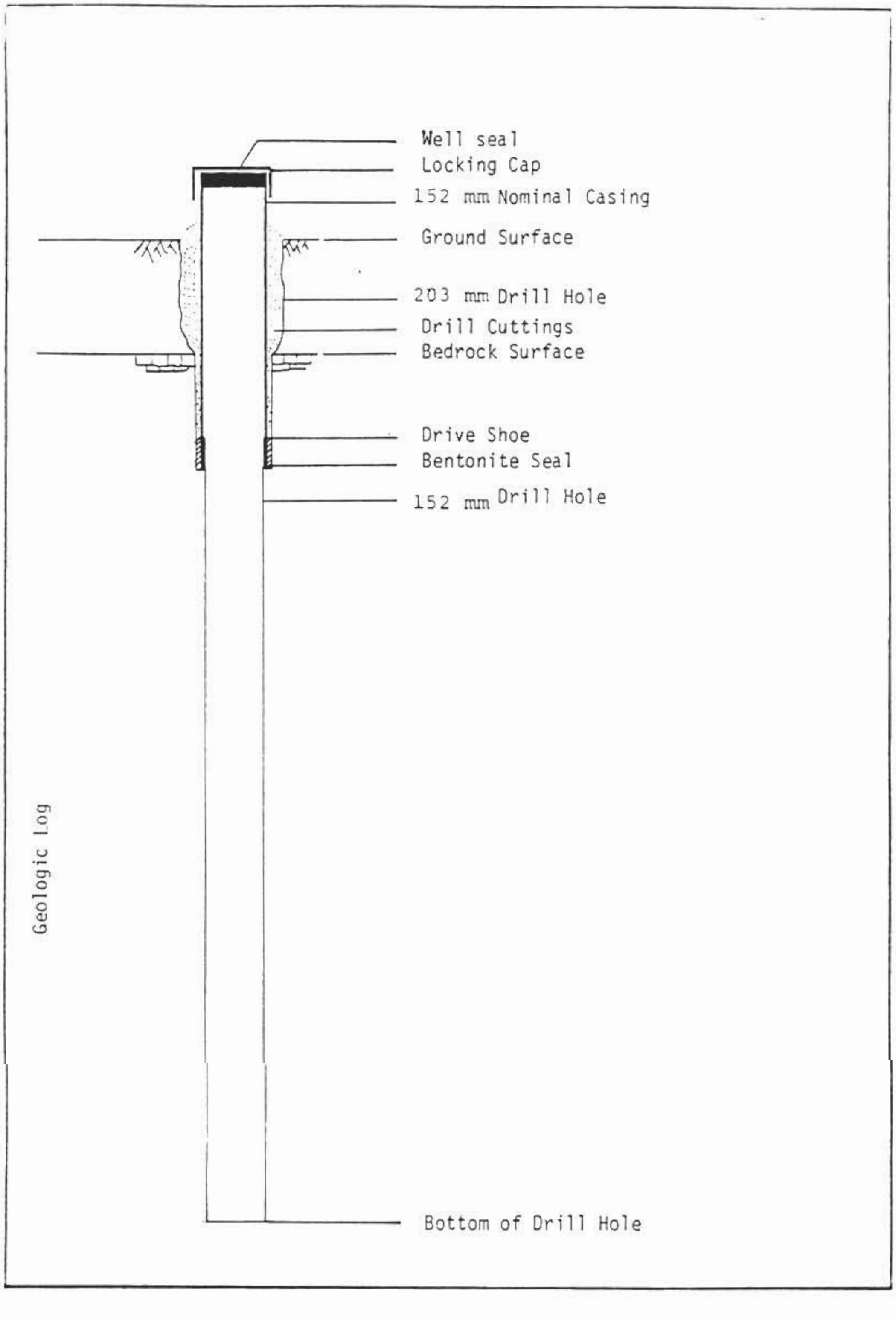


Figure 4.2 Typical artesian well construction details.

Table 4.1

Construction Details for 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	4.8	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			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			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			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			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			227.194

BGL = Below Ground Level
LPM = Liters Per Minute

BMP = Below Measuring Point
NA = Not Applicable

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

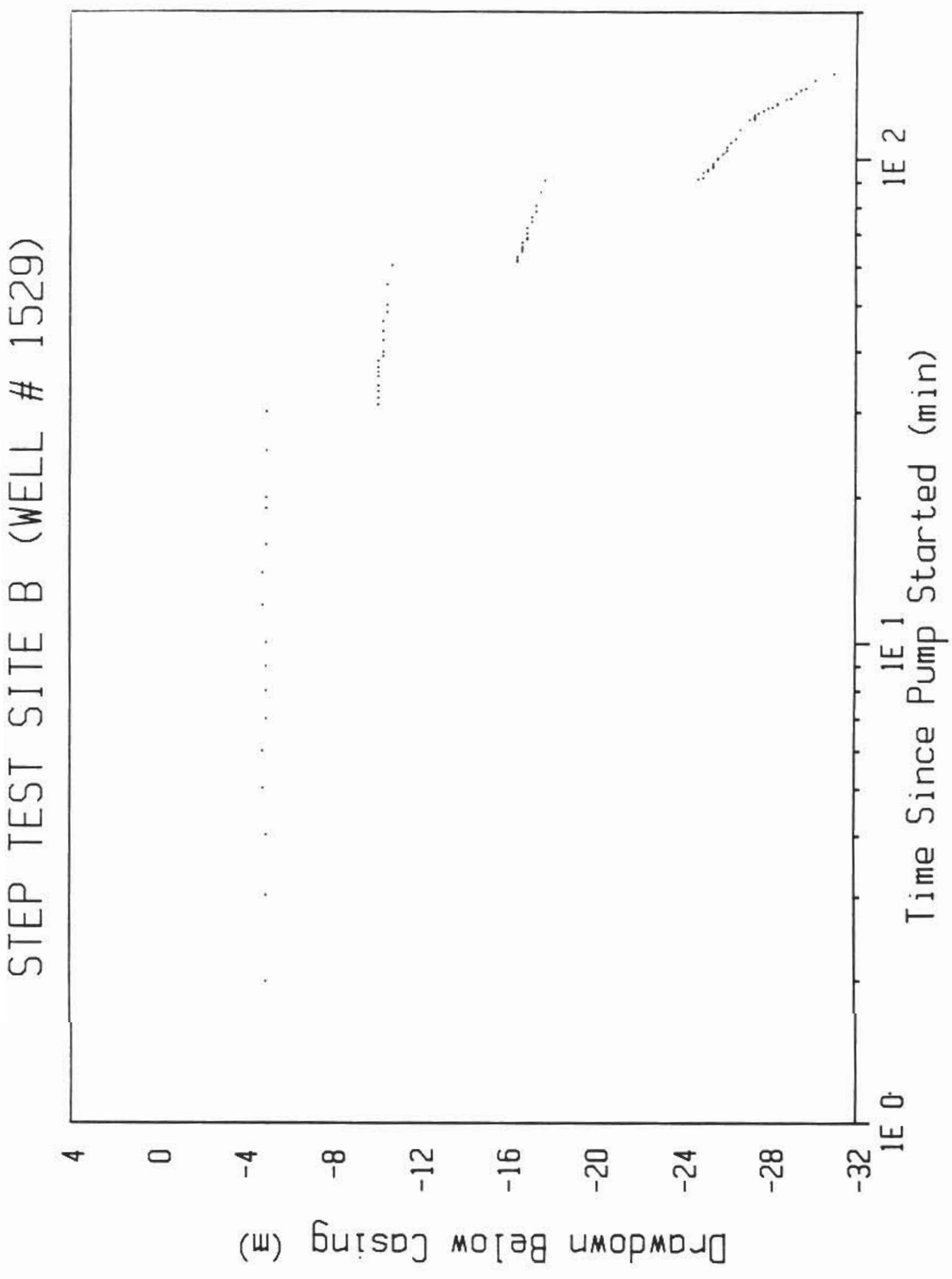


Figure 4.4 Typical Dradown Plot for Step Tests

Each of the aquifer tests was conducted for 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. Of primary importance was the hydraulic character of the aquifer which could be determined from the shorter test.

Water level measurements obtained during pumping were adjusted for natural fluctuation using the hydrographs of two wells that were monitored continuously for this purpose. The aquifer tests were analyzed using the Jacob modification of the Thesis solution to transient radial flow. A typical plot of drawdown versus the log of time used in this determination is shown in **Figure 4.4.** The value of transmissivity determined in this way for each well is given in **Table 4.3.** In all cases except at sites A and B, a positive boundary condition was encountered during the test. This indicates that the aquifer was receiving recharge from some source as the cone of depression extended further and further away from the well. The most likely source of recharge is the overburden. At sites A and B the overburden is much thinner than at the other sites. This fact is not so apparent from the well logs in **Appendix A** as these are, of course, point sources of information. Reference to **Figure 3.3** shows the general area surrounding sites A and B as having thin till veneer, while the other sites have thicker cover.

Table 4.3

Results of Aquifer Testing

Well #	Site	Transmissivity (m^2/day) (x 10^{-2})
1526	A	480
1529	B	3.0
1527	C	170
1531	D	3.3
1522	E	170
1521	F	2.4

4.3.3 Slug tests

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 character 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 test is based on the recovery of the water level in a point piezometer after the sudden removal of a known volume of water. The values of hydraulic conductivity for the 4 wells tested are summarized in **Table 4.4.** These values, although quite consistent, may be slightly high due to the use of an air hammer rotary drilling rig, which in most cases disturbed a larger diameter than the nominal 8 inch drill bit.

In order to address each of these needs, a two-part water level monitoring program was followed for this study. To establish the response to precipitation events, two wells, one shallow and one deep, were monitored continuously at site H. To determine the seasonal fluctuations and the areal variation of fluctuation, each monitoring well at the other 7 sites was monitored on a monthly basis. The yearly hydrographs of the wells at site H are shown in **Appendix B.** Also included in this Appendix are the hydrographs of the other wells as measured for the duration of the study.

CHAPTER FIVE

HYDROGEOLOGY

5.1 Introduction

The Waterford River Basin, as discussed in chapter 3, is underlain by a series of argillaceous, volcanoclastic, bedrock units. These in turn are overlain by a thin discontinuous veneer of surficial materials that have a glacial origin. In general, the primary permeability of both of these types of formations is low. The bedrock is well cemented and the glacial till is characteristically overconsolidated, thus the porosity of each is reduced. It is difficult to differentiate the hydrogeologic characteristics of an area under these conditions. The difficulty arises from the fact that variations of small magnitude require much more information to distinguish than those of a larger magnitude. A further complication is the existence of secondary permeability due to joints, fracture zones and shear zones. It is not enough to examine only the matrix, of bedrock or overburden materials, as even those with seemingly dense, massive textures can have high values of permeability if sufficiently fractured or jointed. The till units of the study area are apparently unfractured (Batterson 1984). The clastic sedimentary rocks in the study area are reportedly highly fractured especially in the cores of folds (King 1984). In fact, since these rocks have very low matrix permeability, approaching that of most metamorphic and granitic rocks, it can be assumed that, at least in the near surface environment, fractures are the primary conduits for groundwater movement. Since fractures do not depend entirely on lithology, it is essential that categorize the various groups for groundwater potential. This work has been used in conjunction with the results of the monitoring well testing, described in Chapter Four, to distinguish similar catagories for the Waterford River Basin. For the overburden materials, use has been made of the grain size analyses reported by Batterson (1984), conducted at 51 sites across the basin. These data, in addition to the in-situ hydraulic conductivity tests reported in Chapter 4, have been used in the report to categorize the overburden material of the basin as similarly as possible to that of the bedrock.

5.2 Hydrostratigraphic Units

5.2.1 Bedrock

As discussed above, groundwater flow in the bedrock materials of the study area is primarily through fractures, at least in the near surface environment. Fractures from a hydrogeological perspective include three main features: joints, fracture zones and shear zones. These are illustrated in **Figure 5.1.** According to Gale et al., (1985) joints are discontinuous within their own planes, but when the ratio of joint length to joint spacing is equal to or greater than 1.0 they generally form continuous networks for flow. In rock masses such as those found on the Avalon Peninsula, the hydraulic characteristics are predominantly a result of the interconnection of the different joint sets. In clastic sedimentary rocks, bedding planes, if open, form conduits similar to joints. Fracture zones are defined as zones of closely-spaced and highly-interconnected discrete fractures that are or in regularly jointed rock? The well log data available for the Avalon Peninsula in general did not allow such differentiation. Neither could the data obtained from the monitoring wells provide any additional insight as each well was apparently located in regularly-jointed rock; hence the hydrostratigraphic units have been determined on the basis of assumed rock-mass hydrogeologic characteristics.

Using all existing well logs, it was possible to assign 608 wells to various specific bedrock groups. **Table 5.1** summarizes the hydrogeologic characteristics of the three bedrock groups represented in the study area. The values in this table were obtained from Gale (1985), with the additional information from the monitoring wells included.

Table 5.1

Distribution of Hydrogeologic Characteristics for Bedrock Groups

Bedrock Group	Rock Type	No. of Wells	Well Yield* Mean	Well Yield* Range	Pump Tests	T#
Signal Hill	brc, cgl, sdst, sldt sh, tf	18	43.0	1.1-273.0	0	-
St. Johns	sdst, sh, sl	97	26.0	1.1-227.5	9	1.1
Conception	Siliceous sdst, sh, tf, til, volc slst	213	20.4	0.6-136.5	2	0.6

* yield in L/min   # transmissivity in m^2/day

br = breccia   sdst = sandstone   sh = shale
cgl = conglomerate   slst = siltstone   tf = tuff
volc = volcaniclastics   sl = slate   til = tillite

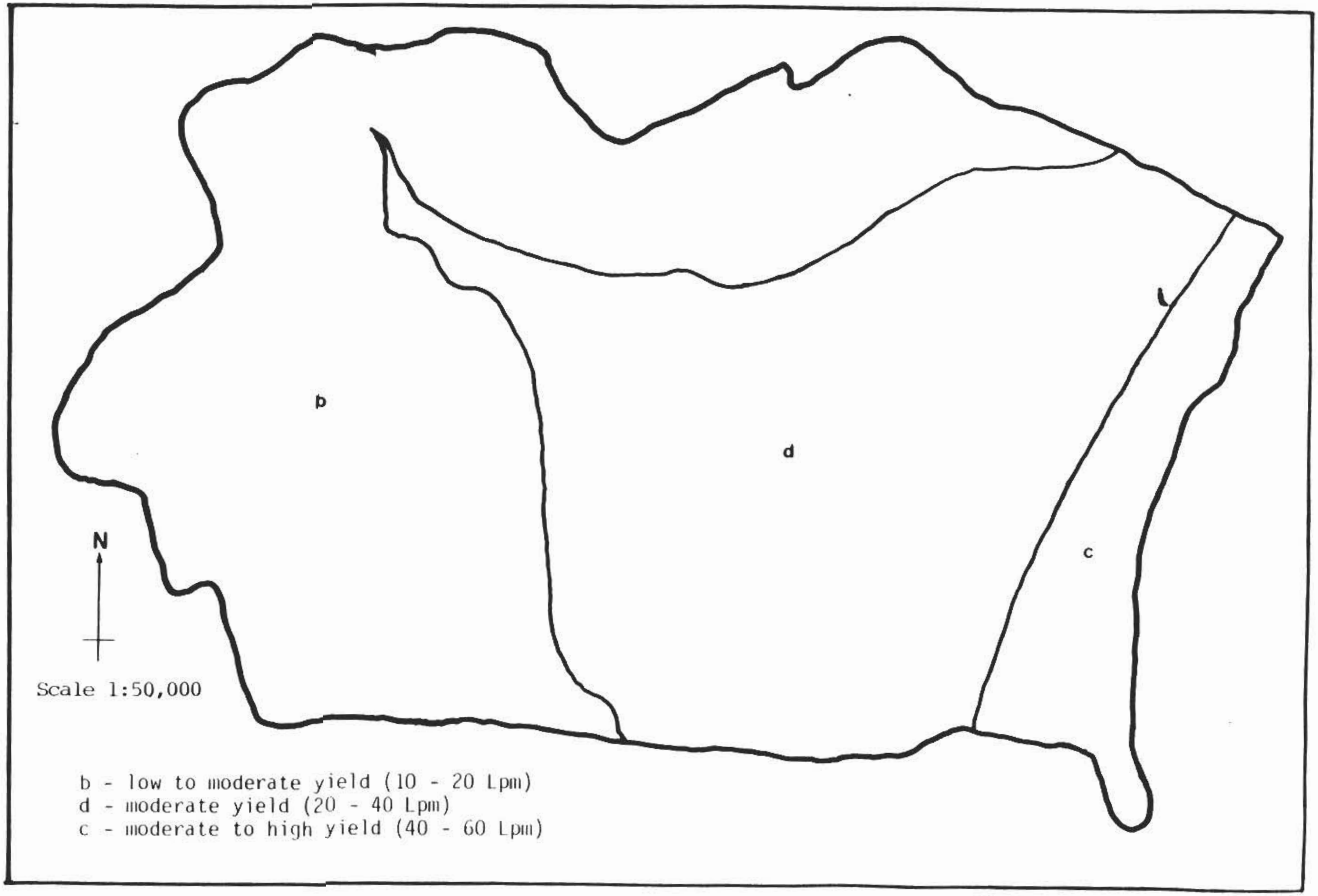


Figure 5.2 Bedrock hydrostratigraphic units.

Another function of the overburden materials is that of protection of the deeper groundwater. For this it is very well suited. Having a relatively high silt-clay content, it provides a filter and an exchange medium for waters percolating through it.

Because of its importance to domestic users and its role as a reservoir supplying the deeper systems, it is useful to distinguish the areal variability of the overburden with regard to groundwater movement. For his report on the surficial geology of the Waterford River Basin, Batterson (1984) conducted grain size analyses on 66 samples of overburden materials from 51 sites located across the study area. The hydraulic conductivity of unconsolidated materials depends on several parameters, in addition to grain size. However, in the absence of these other data the simple empirical relation of Hazen (Freeze and Cherry, 1979) was used to estimate the hydraulic conductivity of the samples mentioned above. Hazen permeability, as it is sometimes called, was calculated for each grain size analyses according to the following equation:

$$KH = d10^2 \qquad (5.1)$$

where KH is the Hazen permeability and d10 is the effective grain size.

The effective grain size is the grain size diameter in mm at which 10% by weight of the soil particles are finer and 90% are coarser. Although this method does not account for the shape of grains, packing or consolidation, it does yield values of hydraulic conductivity that are

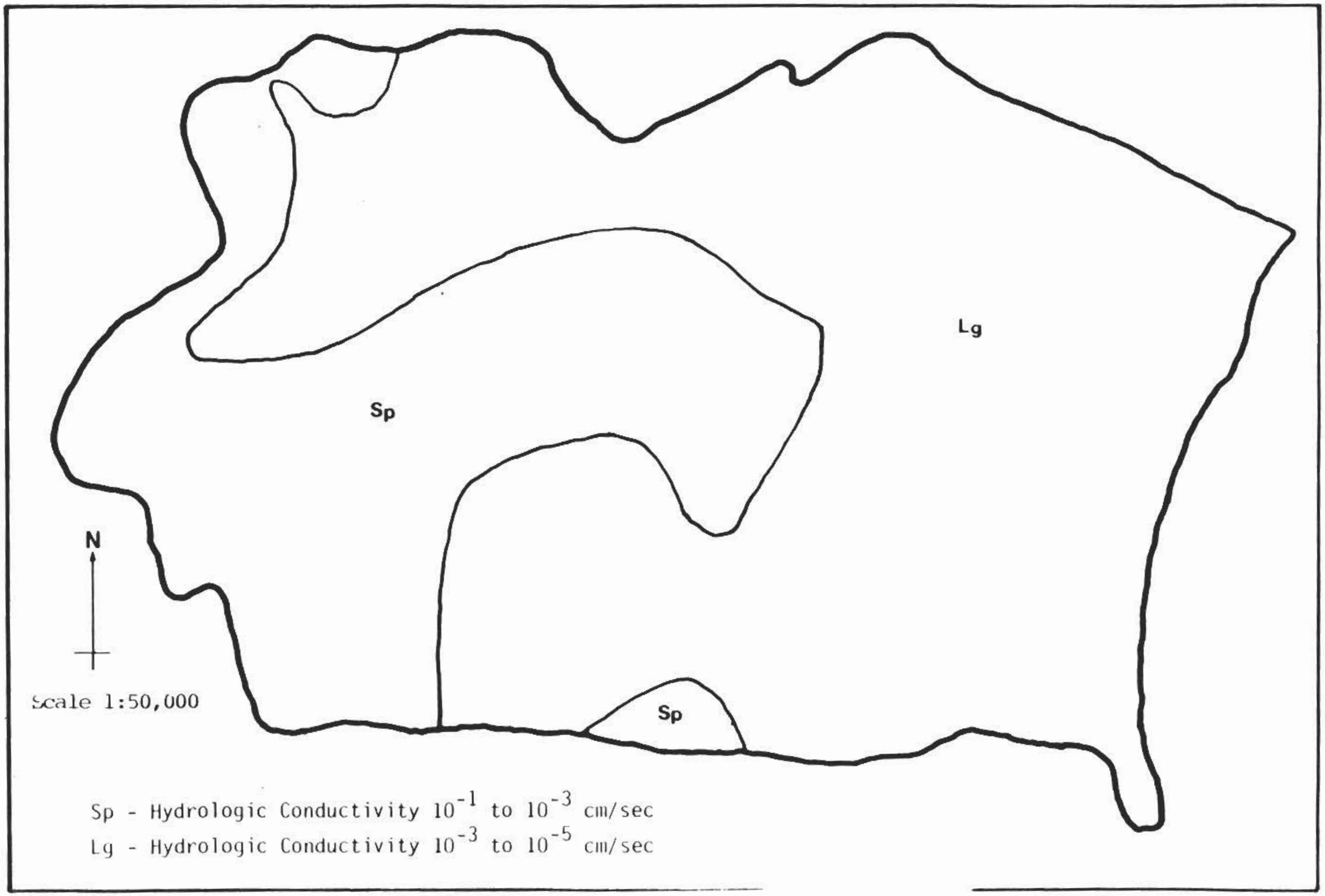


Figure 5.3 Overburden hydrostratigraphic units.

CHAPTER SIX

GROUNDWATER QUALITY

6.1 Parameters Used

In order to differentiate the water quality effects of various land use activities on groundwater, the appropriate physical and chemical parameters were chosen for analyses. The particular affects 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 wet land drainage. Subsoil exposure and soil disturbance upsets 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 oxidize quickly on exposure to the air and reenter the solute load of percolating recharge water. These affects 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

especially nitrate and ammonia. Animal droppings also can cause increased bacterial loading to groundwater and where the soils are thin or very permeable, increased turbidity.

Table 6.1 lists the physical and chemical parameters that were used to monitor the effects of urbanization as outlined above.

Table 6.1

Physical and Chemical Parameters Used.

Calcium	*Bacteria
Magnesium	Total Nitrogen
Sodium	Nitrate and Nitrite
Potassium	Ammonia
Chloride	Total Phosphorous
Sulphate	Orthophosphorous
Total Dissolved Solids	Total Organic Carbon
Turbidity	Copper
Colour	Lead
Dissolved Oxygen	Specific Conductance
Temperature	Zinc
Iron	Alkalinity
Manganese	

* total and faecal coliform

6.2 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 as indicated in **Figure 4.1** in the vicinity of site E and the value of hydraulic conductivity for the overburden at site E, (1.62×10^{-4} cm/sec) as listed in **Table 4.4**, the sampling tube was used beginning in May 1982. The model used had no metallic parts. It was used in all of the deep wells and in one shallow well at site F. The tube was lowered into the well until it was opposite the contributing fracture. It was then closed, thus obtaining a water sample at that depth. This method continues to be used on these wells.

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 volumes. In addition the wells often required an overnight recovery period. It was evident therefore, 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 also implemented in October 1982. Turbidity had been an intermittent problem, especially with 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. Duplicate sampling conducted on the deep wells using a Kemmerer tube and a submersible pump was sufficient to show that the various sampling methods had little effect on the value of most parameters (Robinson, 1986).

The limited effect of surface exposure to the top of the water

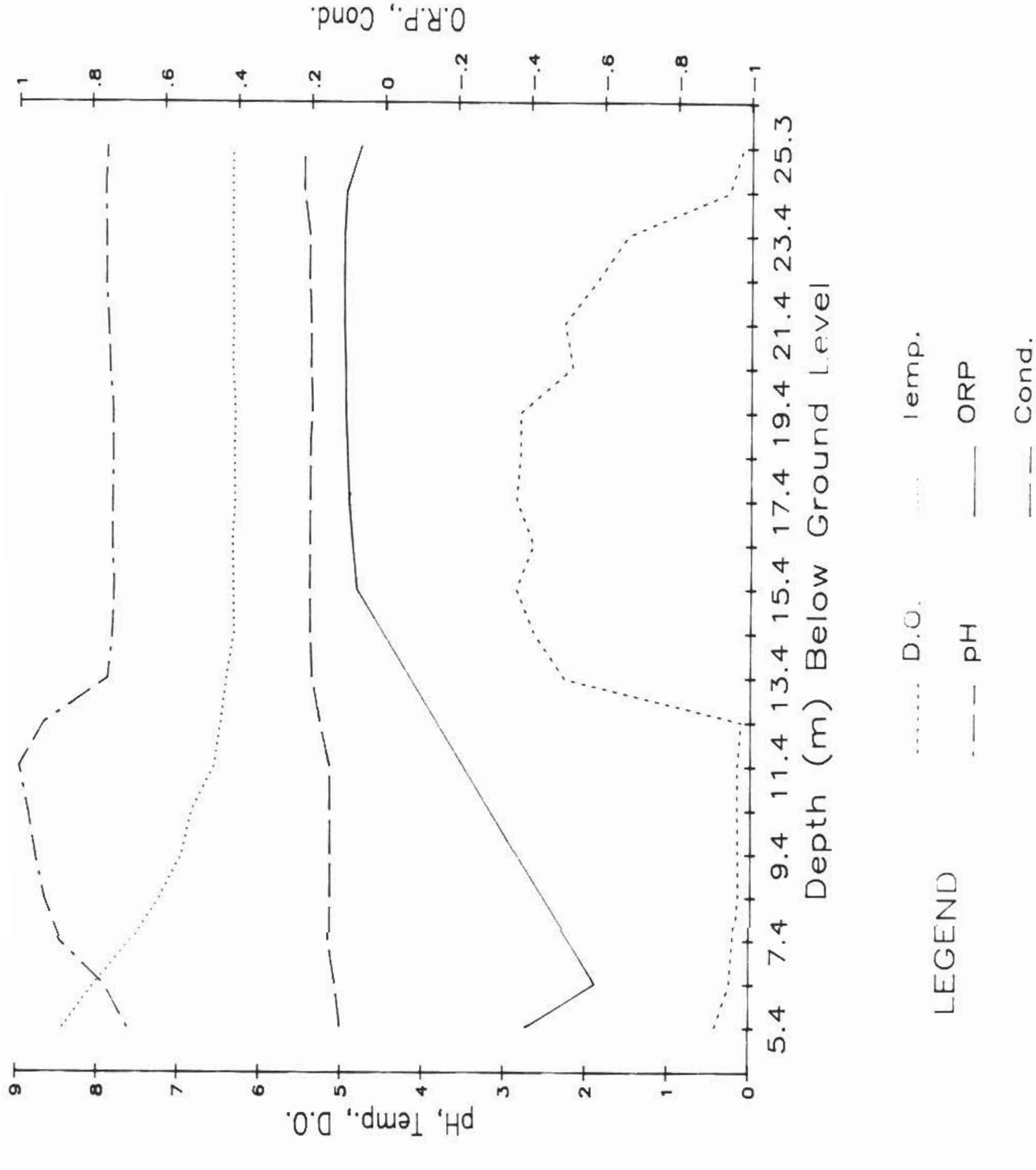


Figure 6.1 Chemical profiles at site E, November 5, 1984.

Chemical analyses were done by the Water Quality Branch, Inland Waters Directorate, Environment Canada, in Moncton, New Brunswick. Physical parameter analyses were conducted by the Environmental Protection Service, Environment Canada, in St. John's. The value of specific conductance versus time for all of the wells are in **Appendix** C. The change in water quality with time is also shown in the triliner plots for each well, located in **Appendix C.**

6.3 Characterization Of Groundwater Quality In The Basin

6.3.1 Geologic influences on groundwater quality

In general, geology influences the quality of groundwater by the mineralogical make-up of the earth media through which the groundwater is moving. The other major influence is the length of time the groundwater is in contact with the earth media. This is a function of the length of the flow system between the recharge and discharge area and the velocity of groundwater flow.

6.3.1.1 Bedrock hydrogeochemistry

The seven bedrock wells used in the study area are located in late Precambrian clastic sedimentary rocks. Wells designated B and G (**Figure 4.1**) are in the Conception Group, which generally consists of green-grey and red greywacke, siltstone shale, chert and minor tuff (Hsu, 1976.) This is generally reflected in the stratigraphic bore hole logs for wells B and G in **Appendix A.** The other five wells (A, C, D, E and F) are somewhat different chemical character. Although calcium is still the dominant cation, sodium exerts more of an influence. More noticeably, the sulphate and chloride influence significantly lessens the bicarbonate character of these waters (**Figures C-3 to C-6**). Wells C, D and F all tend to have higher TDS values than wells A, B and G (see specific conductance in **Figures C-8, C-11 and C-13**). Well E, is most similar to the first three, although higher sulphate tends to offset the bicarbonate content (**Figure C-5**). Well C shows some similarity to Well E although it is higher in TDS. Wells D and F display interesting trends. Well D displays water of a predominantly calcium chloride character, with chloride values in the 150 - 180 mg/L range, significantly higher than values of sodium (ranging from 25 to 30 mg/L). Well F, on the other hand, is a calcium, sodium sulphate water, with sulphate in the 90 to 115 mg/L range. The common feature of groundwaters in both bedrock units is the pH, which generally falls in the slightly alkaline range of 7 to 8.

The general dominance of the calcium cation in the water and the slightly alkaline pH is not difficult to explain in view of the reported calcite and dolomite mineralization. A possible source of increased sulphate in the Fermeuse Group is the reported pyrite mineralization. Drill cuttings revealed some signs of iron oxidation (King, 1984). The relatively high sulphate content in the water from well F is puzzling. Even less productive is speculation on a natural source of high calcium and chloride in waters at well D.

Total dissolved solids were up to twice as high, however (the well at site C is contaminated by de-icing salt). Shallow groundwater at site D is similar to site A, but with a slightly greater sulphate tendency in 1982 and chloride in 1983 and 1984 (**Figure C-18**). Specific conductance tends to be somewhat higher (**Figure C-25**). Site E closely resembles the background station (compare **Figures C-19 and C-21**), with a tendency towards a slightly higher calcium influence. Total dissolved solids are somewhat higher (**Figure C-26**).

6.3.2 Anthropogenic influences

As indicated in chapter 4, the monitoring well network was designed to reflect potential effects of the various major land use categories in the basin - industrial, urban, agricultural and, for background, undeveloped land. This cannot be considered an exhaustive treatment as available resources limited the number of wells installed. Unfortunately, for reasons described earlier, previously existing private wells were of little use in the study. In addition, and possibly of more significance, the period of monitoring has been relatively short, making it difficult to define trends.

The most obvious impact on groundwater quality from anthropogenic activities is that of road de-icing salt application. The shallow well at monitoring site C in Mount Pearl (**Figure 4.1**) shows high sodium and chloride, but with a notable decreasing trend since the removal of the depot in 1982 (note **Figure C-29**). Sodium chloride increased dramatically

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This study was limited to the determination of the impact of urbanization on the groundwater and to the importance of groundwater in the hydrologic cycle. For these purposes the geologic formations, both surficial and bedrock, were examined and described in detail. In addition the study area was examined, and the land within it was categorized, according to the general land use activity in each area. These preliminary surveys are considered to be adequate for the purposes of this study.

A monitoring well network, comprised of sixteen wells, was established for water level monitoring and obtaining water samples. The use of an air-rotary drilling rig for the installation of at least three of these wells, was considered to be inadequate because caving into the borehole, below the water table, could not be controlled and the sand filter in the shallow wells and the bentonite seal in both types of wells could not be installed properly. The site chosen for the control wells was considered to be appropriate for the purposes of this study. Although the deep well at this site was constructed in a rock formation that was different from most of the other monitoring wells, the short flow paths that characterize this watershed, minimize the effects of contact with the various earth materials.

1. In any future study of this nature more detailed information should be obtained regarding the structural attributes of the bedrock. Some of these features, such as fractures, control the flow direction of the groundwater, thus the accurate placement of monitoring wells may not possible without this type of consideration.

2. Water samples should be obtained on an annual basis for at another five years to determine if the period of study was of sufficient length for detecting the effects of urbanization in this watershed. For this purpose the analyses should be somewhat reduced to include only the major ions and a few selected mobile ions since the concentration of many of the ions was very small. Water samples should be obtained using a Kemmerer tube, at the contributing fracture, in the deep wells and a peristaltic pump in the shallow wells.

3. Water level measurements should be obtained on a monthly basis from all wells at sites A to G with the exception of site E. The monitoring wells at site H should be abandoned and the continuous recorders at this site should be set up at site E.

4. The deep well at site E should be incorporated into the Provincial Observation Well Network.

REFERENCES

Batterson, M.J., Surficial Geology of the Waterford River Basin, St. John's, Newfoundland, Urban Hydrology of the Waterford River Basin, Technical Report UHS-WRB 1.2 Newfoundland Department of Environment, Water Resources Division. pp 29, map inc. 1984.

Canadian Climate Normals 1951 - 1980, Temperature and Precipitation, Atlantic Provinces, Environment Canada, Atmospheric Environment Service

Deubert, K.H., Impact of Human Activities on the Quality of Groundwater and Surface Water in the Cape Cod Area, Massachusetts Univ., Amherst Water Resource Research Centre, Publication No. 42, (1974), 56 pp.

Eisen, C., Anderson, M.P., The Effects of Urbanization on Ground-Water Quality, A Case Study, Wisconsin Univ., Madison Dept. of Geology and Geophysics. Groundwater, Vol 17, No 5, p 456-462, September-October 1979.

Fetter, C.W., Applied Hydrogeology, C.E. Merrill Publishing Co., Columbus, Ohio, 488 pp., 1980.

Freeze, R.A., and Cherry, J.A.,Groundwater, Prentice-Hall, Inc., pp 604., 1979.

Gale, J.E., Francis, R.M., King, A.F., and Rogerson, R.J., Hydrogeology of the Avalon Peninsula Area, Water Resources Report 2-6, Groundwater Series, Newfoundland Department of the Environment, pp 142., 1984.

Hsu, E., Geology of the St. John's Peninsula, Report on activities 1975, Nfld. Dept. of Mines and Energy, Min. Dev. Div., pp 94-101, 1976.

Hvorslev, M.J., Time Log and Soil Permeability in Groundwater Observations, U.S. Army Corps. Engs. Waterways Exp. Sta. Bull. 36, Vicksburg, Miss., 1951.

Jacob, C.E., Drawdown Test to Determine Effective Radius of Artesian Wells, ASCE Trans. Vol. 112., 1947.

King, A., Geology of The Waterford River Basin. St. John's, Newfoundland, Urban Hydrology of the Waterford River Basin, Technical Report UHS-WRB 1.1, Newfoundland Department of Environment, Water Resources Division, pp 25, map inc., 1984.

APPENDIX A
BOREHOLE LOGS AND WELL CONSTRUCTION DETAILS

LOG OF BOREHOLE

BOREHOLE [illegible] Site A

PAGE ____ OF ____

LOC. or COORDS. 227 E [illegible] N [illegible] GROUND ELEV. 139.4 m TOTAL DEPTH 24.89 m BOREHOLE DIAM. 150 mm	DRILLER Waltsons Drilling Co. Ltd. Doyles, Newfoundland. RIG C.P. T650 BIT(S) Air Hammer 20 cm FLUID Air	DATE START 81-03-12 FINISH 81-03-12 TIME START 12:30 P.M. FINISH 6:15 P.M. GEOPHYS. LOG ___ YES ___ NO HOW LEFT Sample Well

DEPTH	PENE. RATE	CIRC. RET./LOSS	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0 m						
5 m				Black Shale		6" casing set @ 4.80 m Soft
10 m	0.33		T**			
15 m	0.34		T T	Mudstone		Minor Calcite 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 [illegible] Site C

PAGE ____ OF ____

LOC. or COORDS. [illegible]	DRILLER Waltsons Drilling Co. Ltd. Doyles, Newfoundland		START	FINISH
[illegible]		DATE 81-[illegible]	81-[illegible]
GROUND ELEV. [illegible]	RIG C.P. [illegible]650	TIME [illegible] A.M.	[illegible] P.M.
TOTAL DEPTH [illegible].73 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 RET/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
			8	Till		Glacial
5 m				Black Shale		
	0.30*					Minor Calcite Veins
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 1522 Site E

PAGE ____ OF ____

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. RETN. LOSS	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0 m				Topsoil		
			T*	Till		Brown Sandy - Silt Stoney (Ablation)
5 m						
						Grey Stoney (Basal)
				Black Shale		
10 m						Minor Calcite Seams
						6" casing set at 11.48 m c/w Drive Shoe & 10 lb of Bentonite
			16.0			Water Turned Red @ 13.4 m
15 m			6.0			Water Turned Grey @ 14.6 m
			6.0			
20 m	HARD					
						Calcite Seams Frequent
25 m						End of Hole Q = 30 L/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 RETURN	CIRC 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 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/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: 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. RET/LOSS	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0m				Topsoil		
1m				Till		Loose, Bouldery
2m						
3m						
4m						Basal - Hard & Bouldery
5m						
6m						End of Hole
7m						
8m						

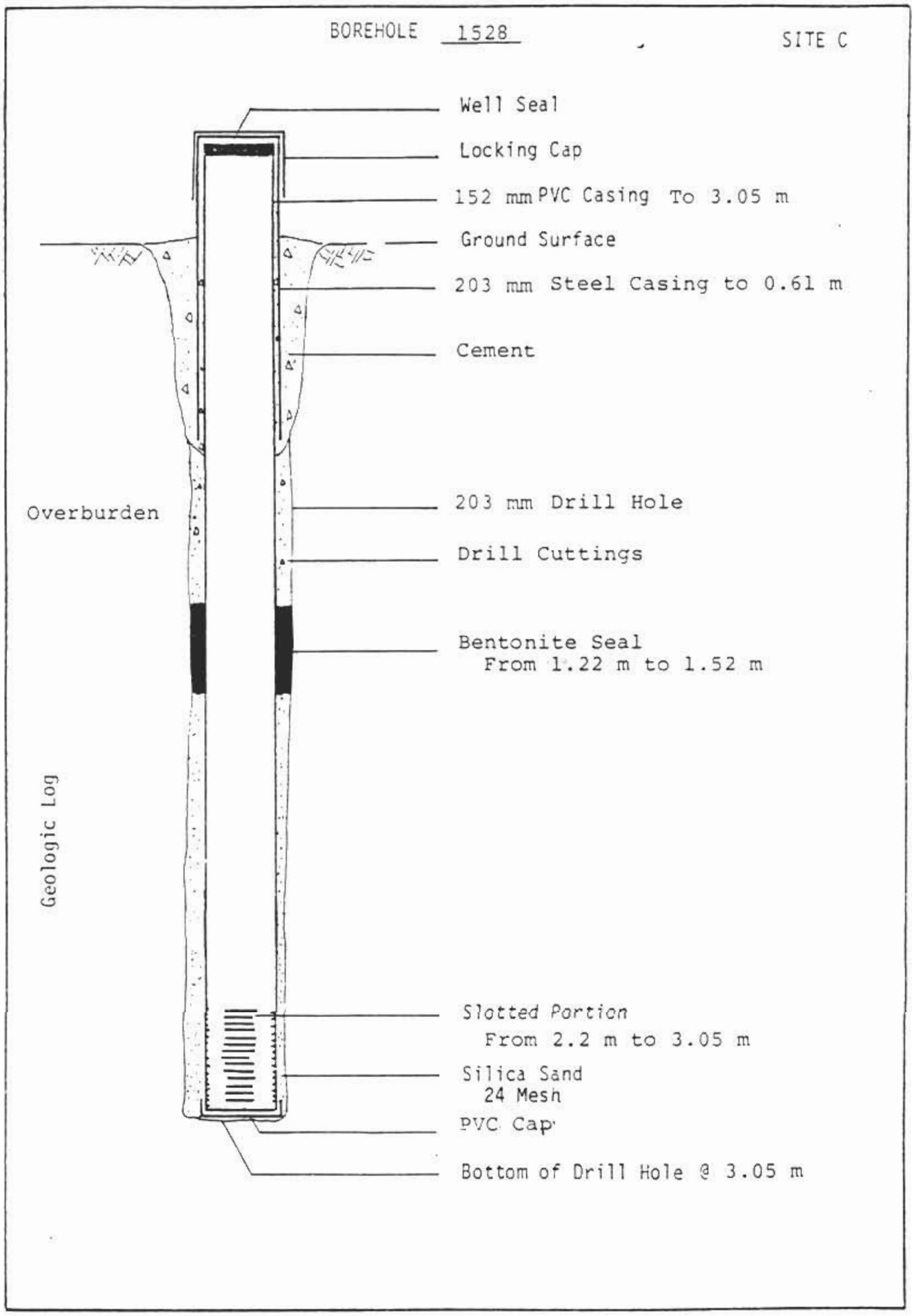
LOG OF BOREHOLE

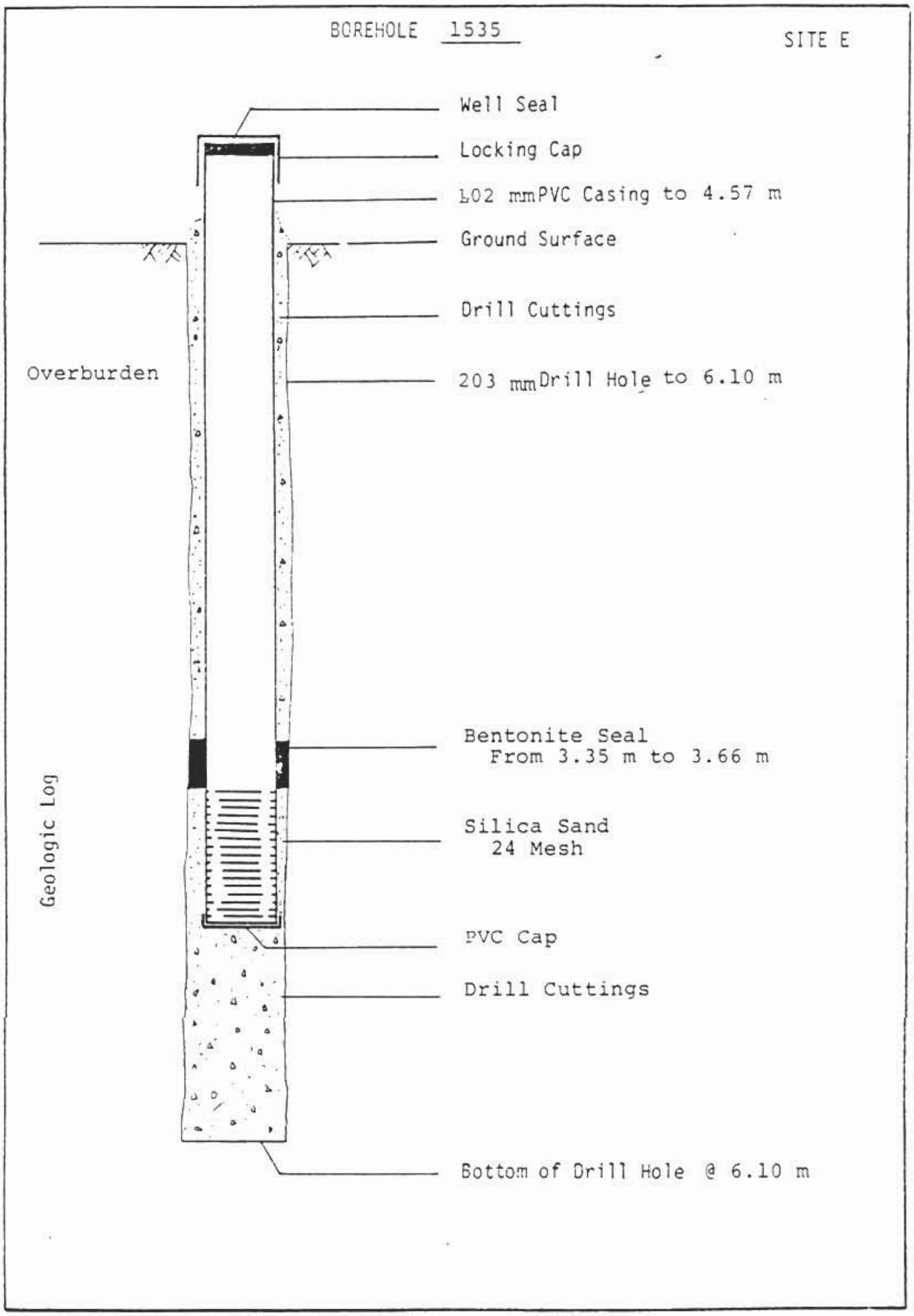
BOREHOLE 1533 Site G

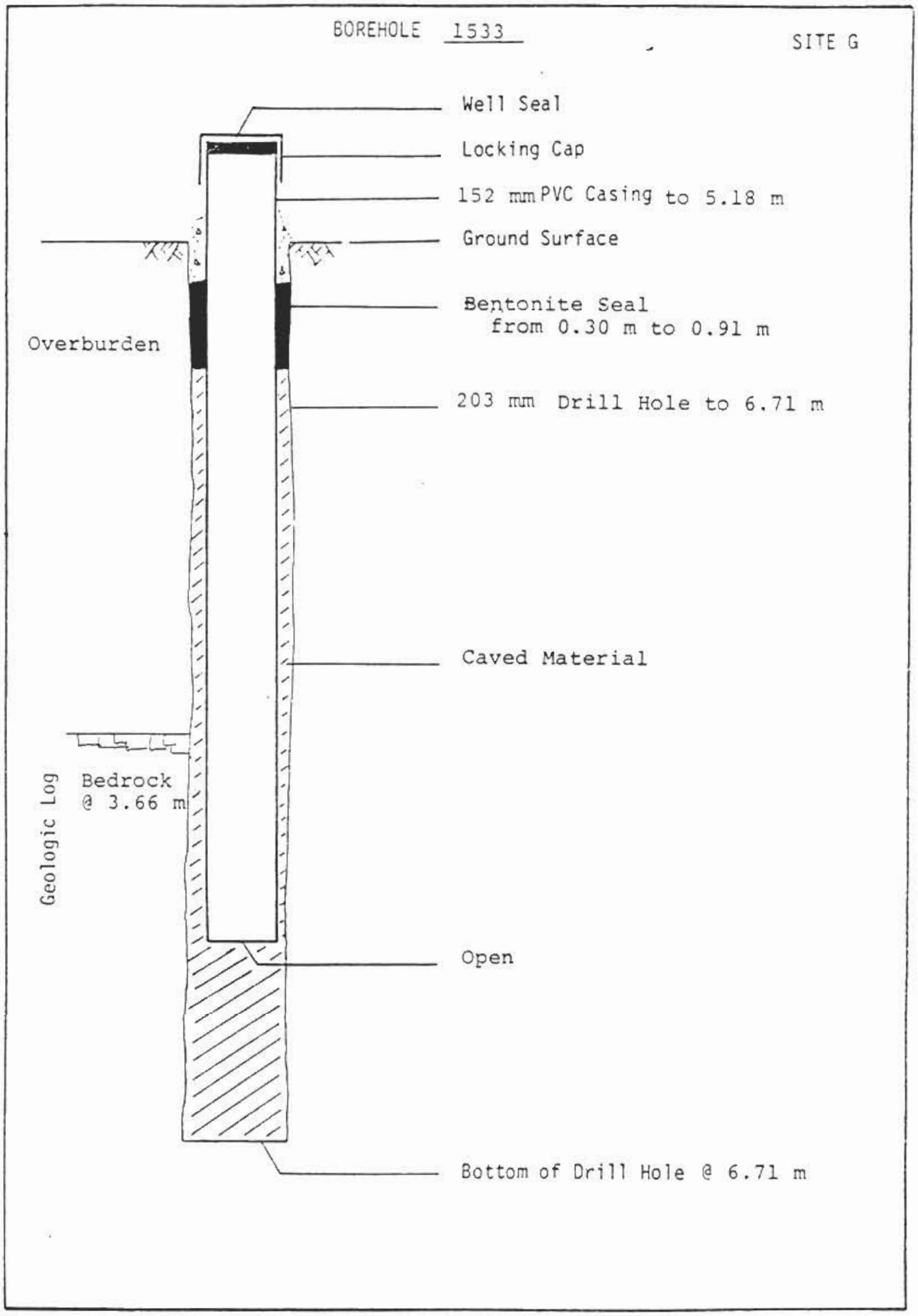
PAGE ___ OF ___

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

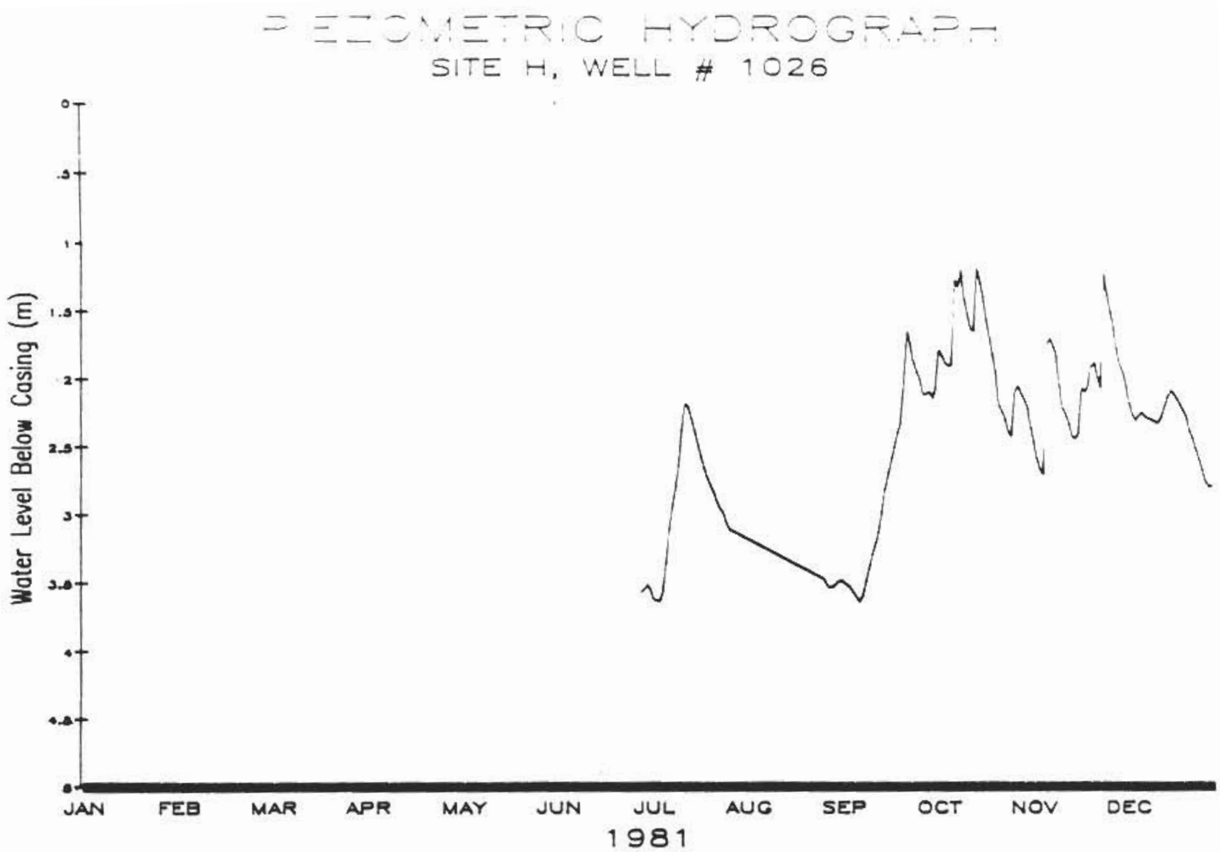
DEPTH	PENE. RATE	CIRC. RET/LOSS	AIRLIFT Q (lpm)	MATERIAL	SYMBOL	DESCRIPTION and COMMENTS
0m						
				Till		Bouldery
1m						
2m						
3m						
4m				Siltstone		Grey-Green
5m						
6m						
						End of Hole - Developed For 1½ hrs. Q = 9 L/min
7m						

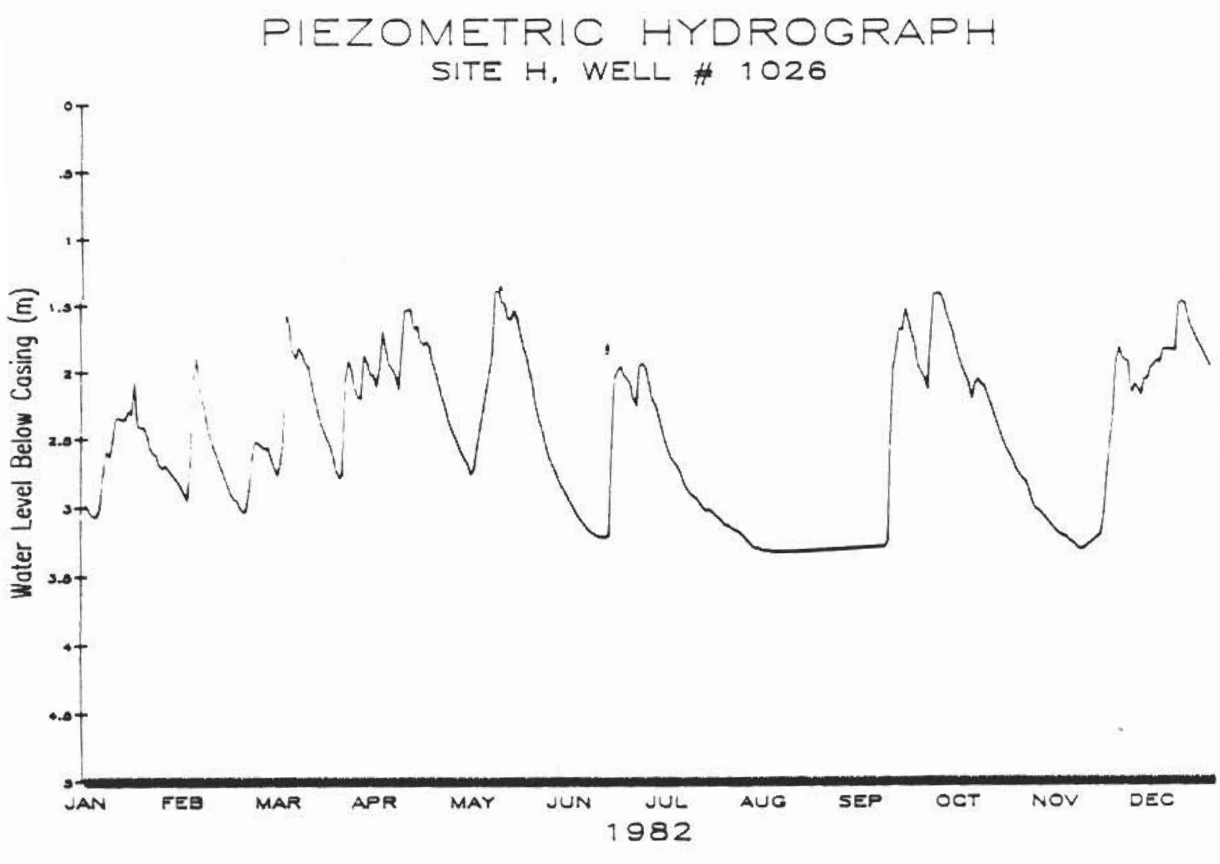

BOREHOLE 1528
SITE C
Well Seal
Locking Cap
152 mm PVC Casing To 3.05 m
Ground Surface
203 mm Steel Casing to 0.61 m
Cement
203 mm Drill Hole
Overburden
Drill Cuttings
Bentonite Seal
From 1.22 m to 1.52 m
Geologic Log
Slotted Portion
From 2.2 m to 3.05 m
Silica Sand
24 Mesh
PVC Cap
Bottom of Drill Hole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


BOREHOLE 1535
SITE E
Well Seal
Locking Cap
102 mm PVC Casing to 4.57 m
Ground Surface
Drill Cuttings
Overburden
203 mm Drill 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

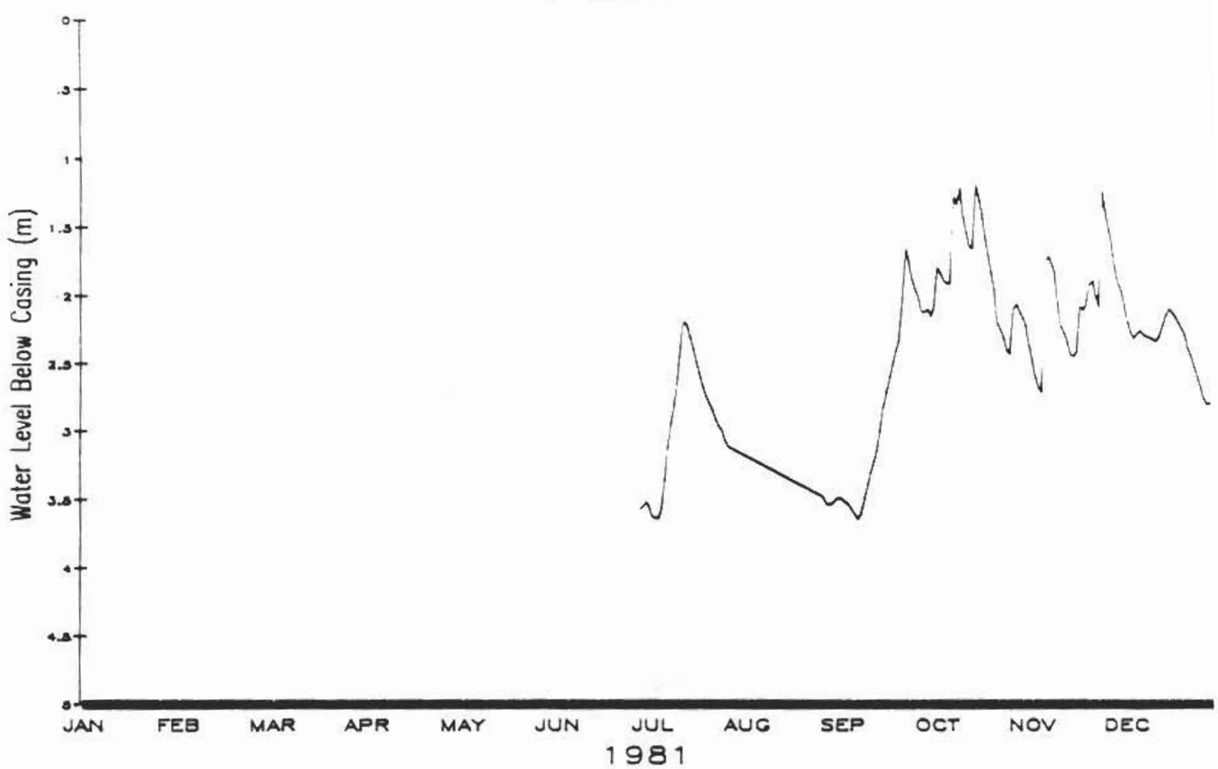

BOREHOLE 1533
SITE G
Well Seal
Locking Cap
152 mm PVC Casing to 5.18 m
Ground Surface
Bentonite Seal
from 0.30 m to 0.91 m
Overburden
203 mm Drill Hole to 6.71 m
Caved Material
Bedrock
@ 3.66 m
Geologic Log
Open
Bottom of Drill Hole @ 6.71 m

APPENDIX B
HYDROGRAPHS OF WELLS

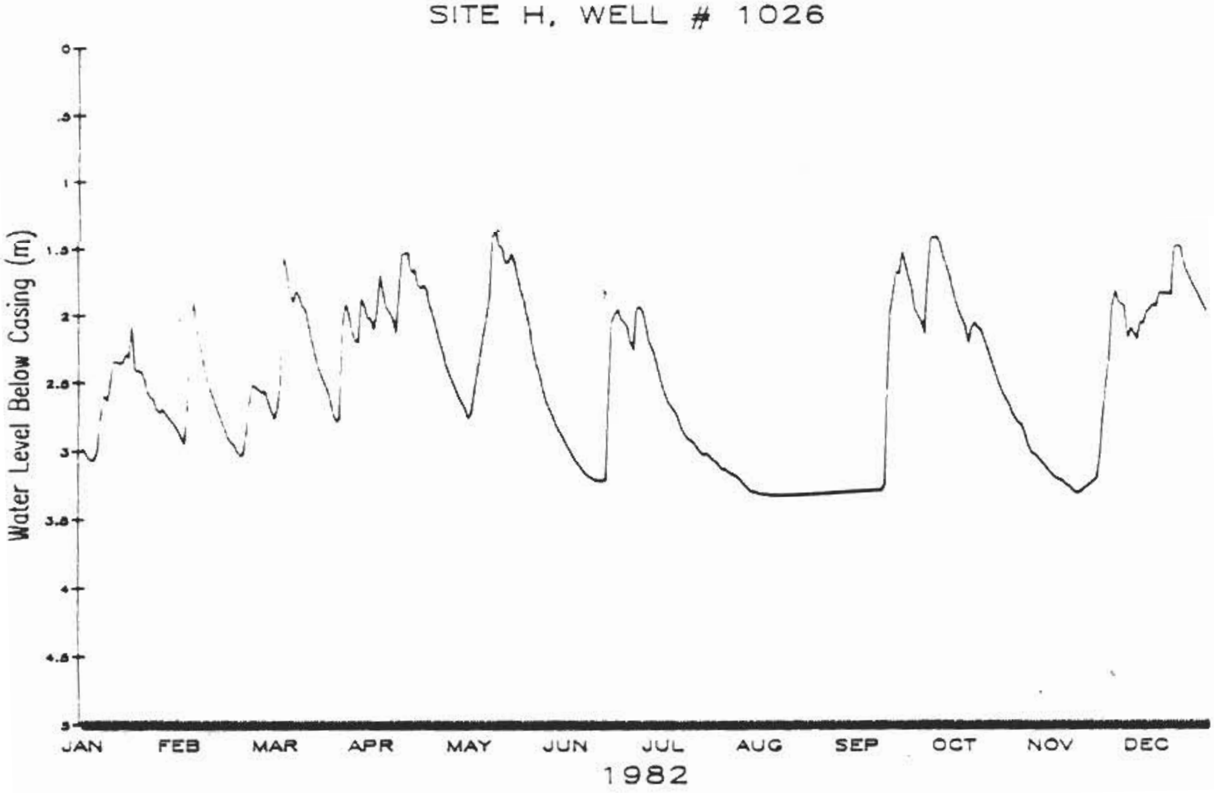

PIEZOMETRIC HYDROGRAPH
SITE H, WELL # 1026
Water Level Below Casing (m)
0
.5
1
1.5
2
2.5
3
3.5
4
4.5
5
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1981


PIEZOMETRIC HYDROGRAPH
SITE H, WELL # 1026
Water Level Below Casing (m)
0
.5
1
1.5
2
2.5
3
3.5
4
4.5
5
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

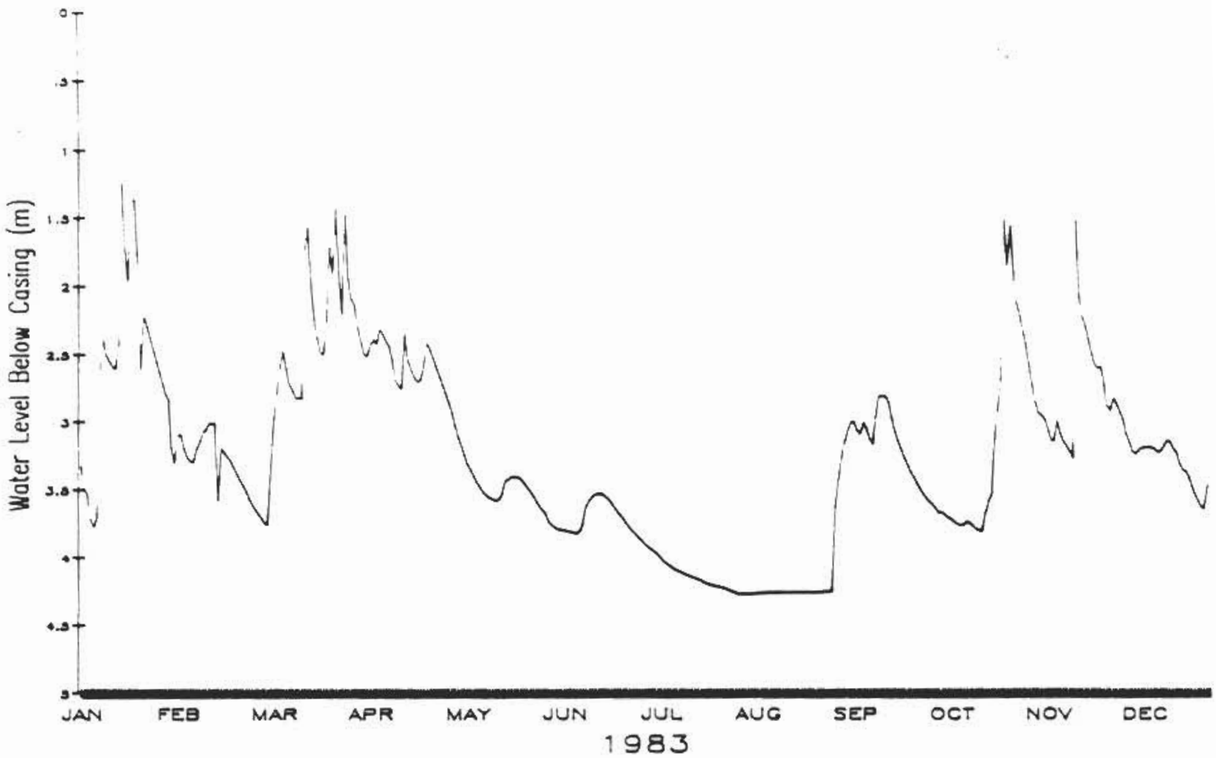
PIEZOMETRIC HYDROGRAPH
SITE H, WELL # 1026



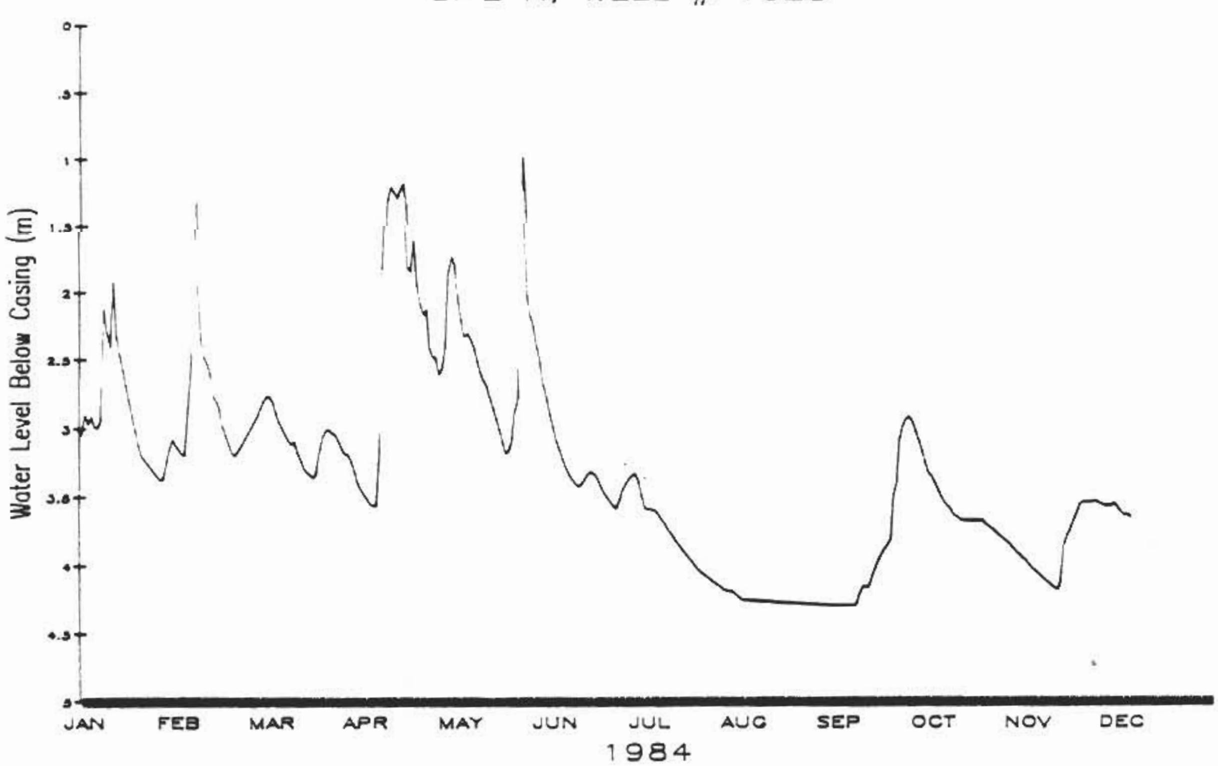
PIEZOMETRIC HYDROGRAPH
SITE H, WELL # 1026



WATER TABLE HYDROGRAPH
SITE H, WELL # 1028

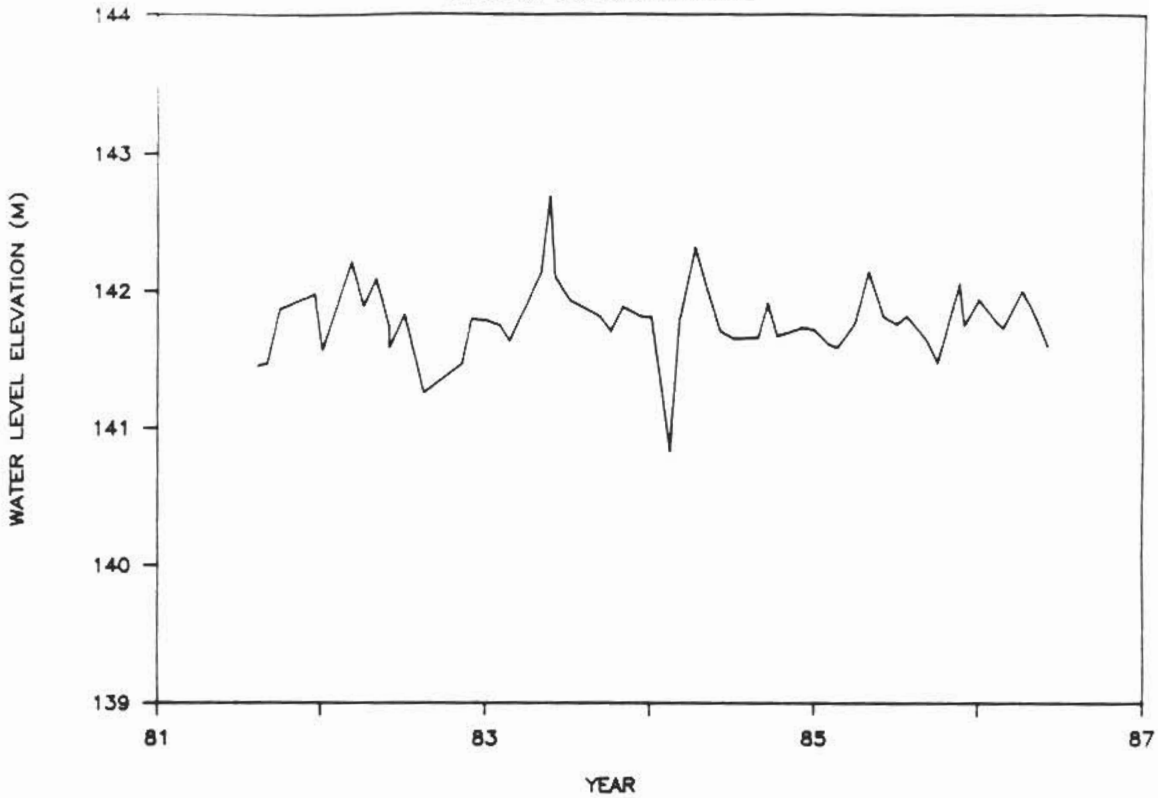


WATER TABLE HYDROGRAPH
SITE H, WELL # 1028



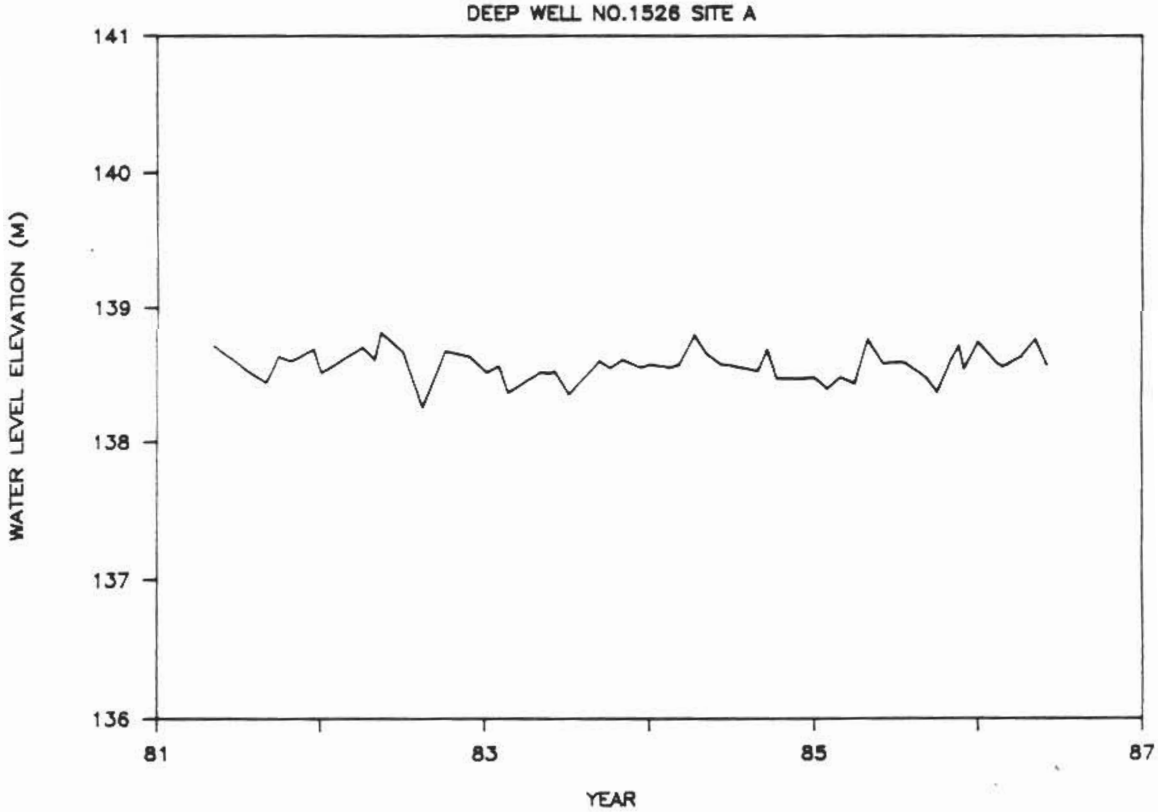
WATERFORD RIVER BASIN

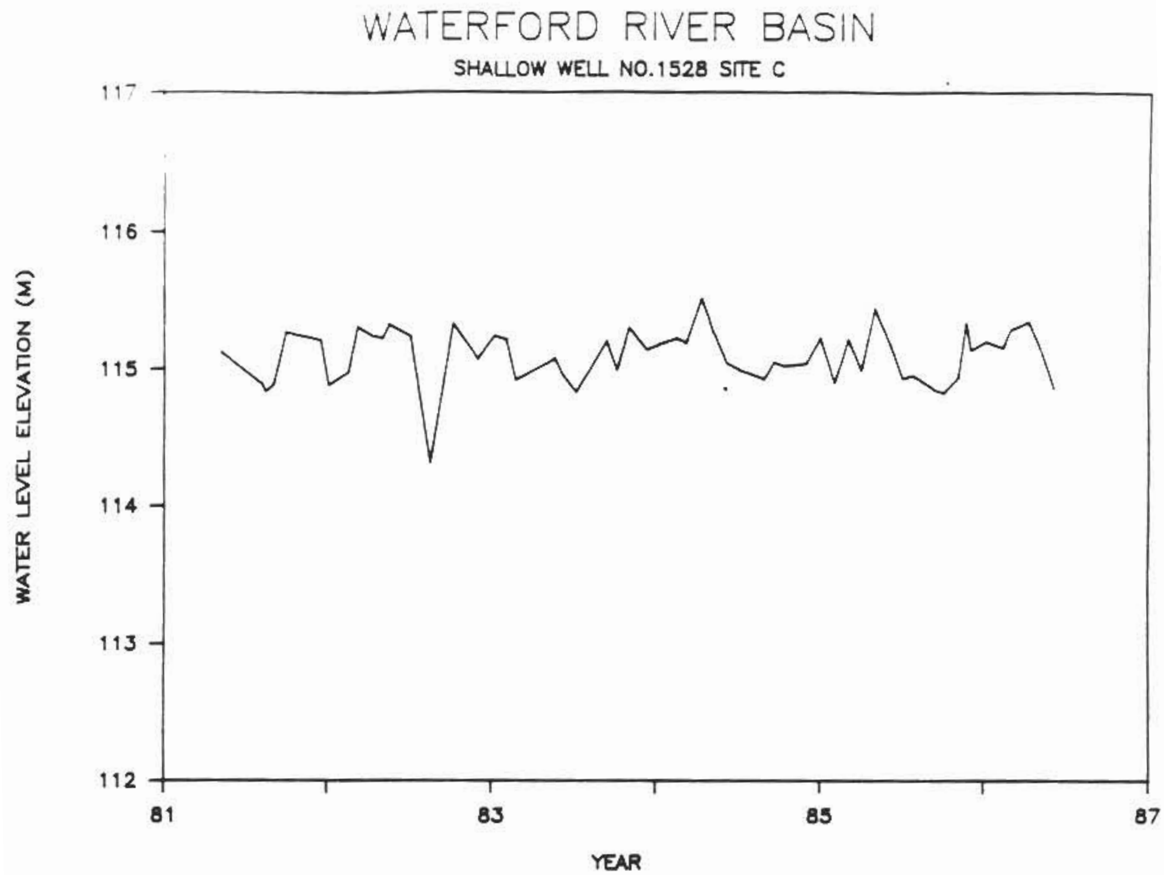
SHALLOW WELL NO.1534 SITE A

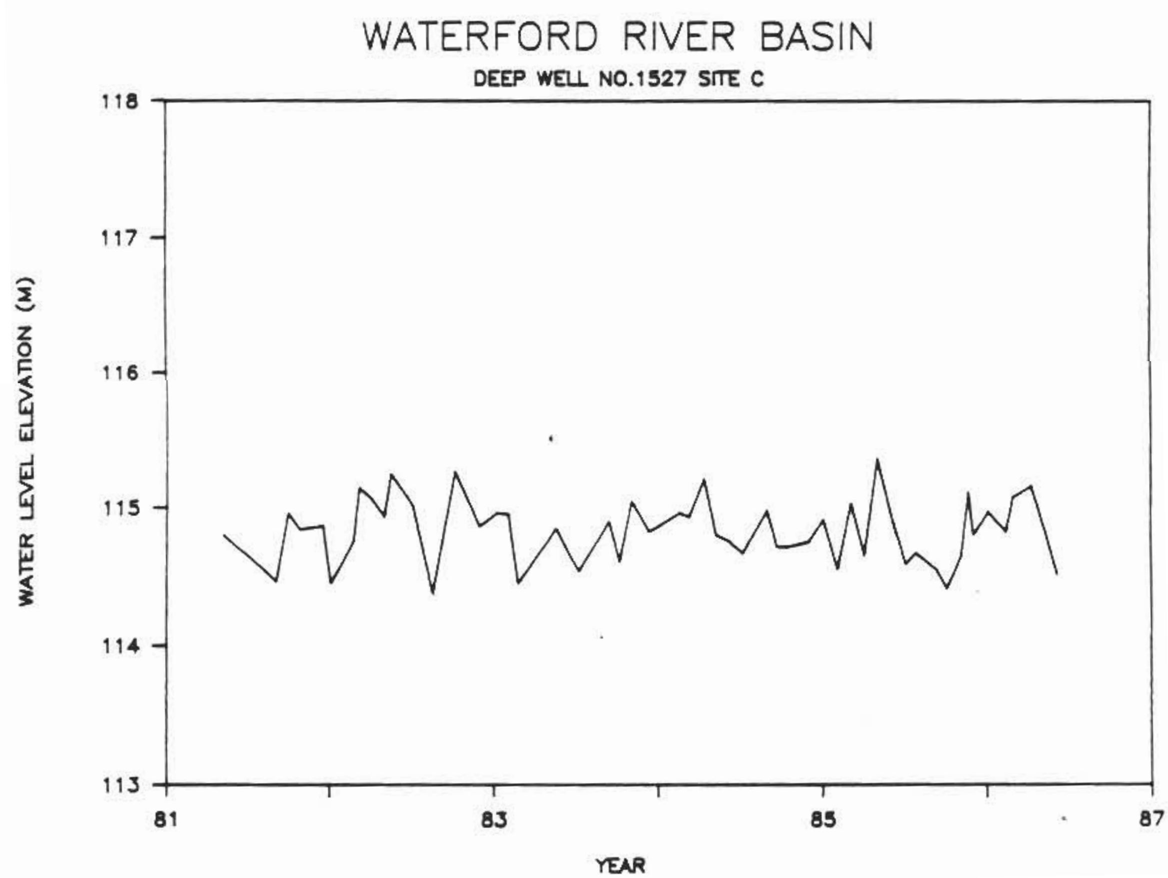


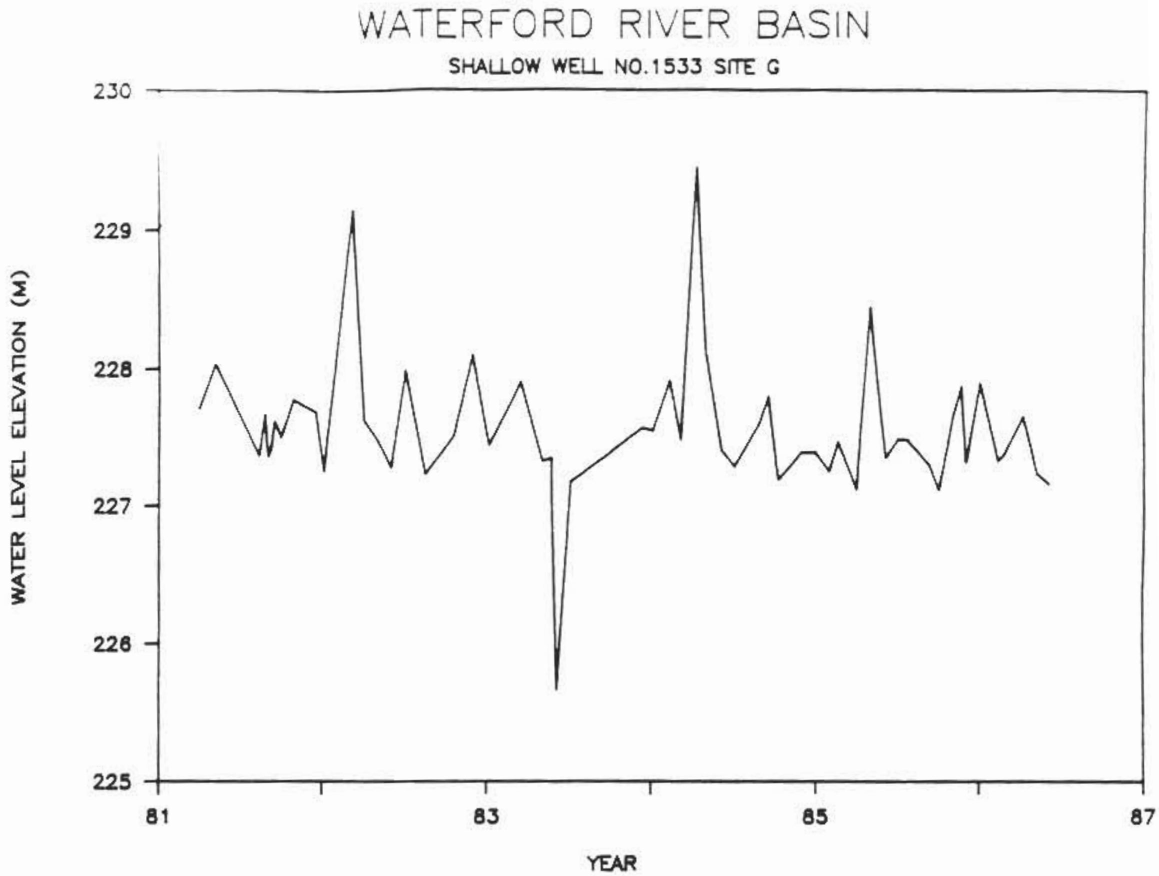
WATERFORD RIVER BASIN

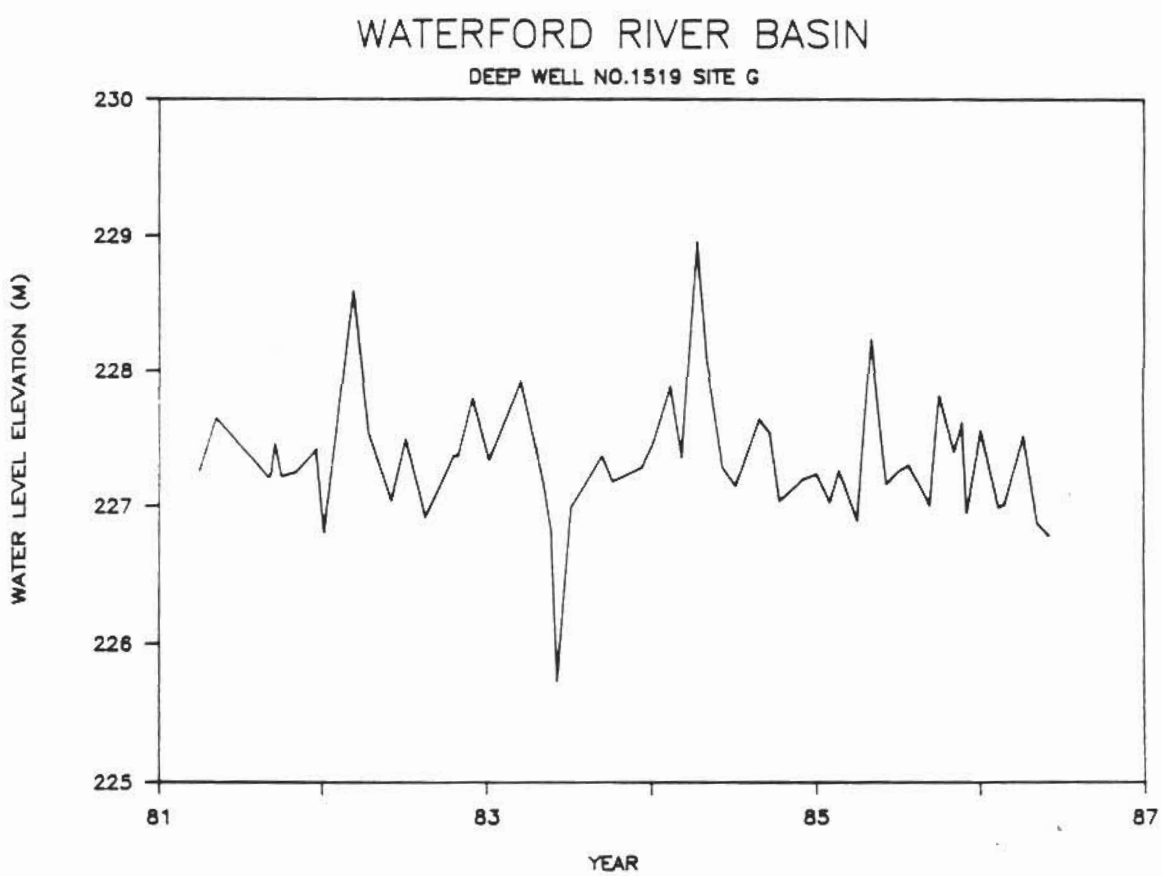
DEEP WELL NO.1526 SITE A



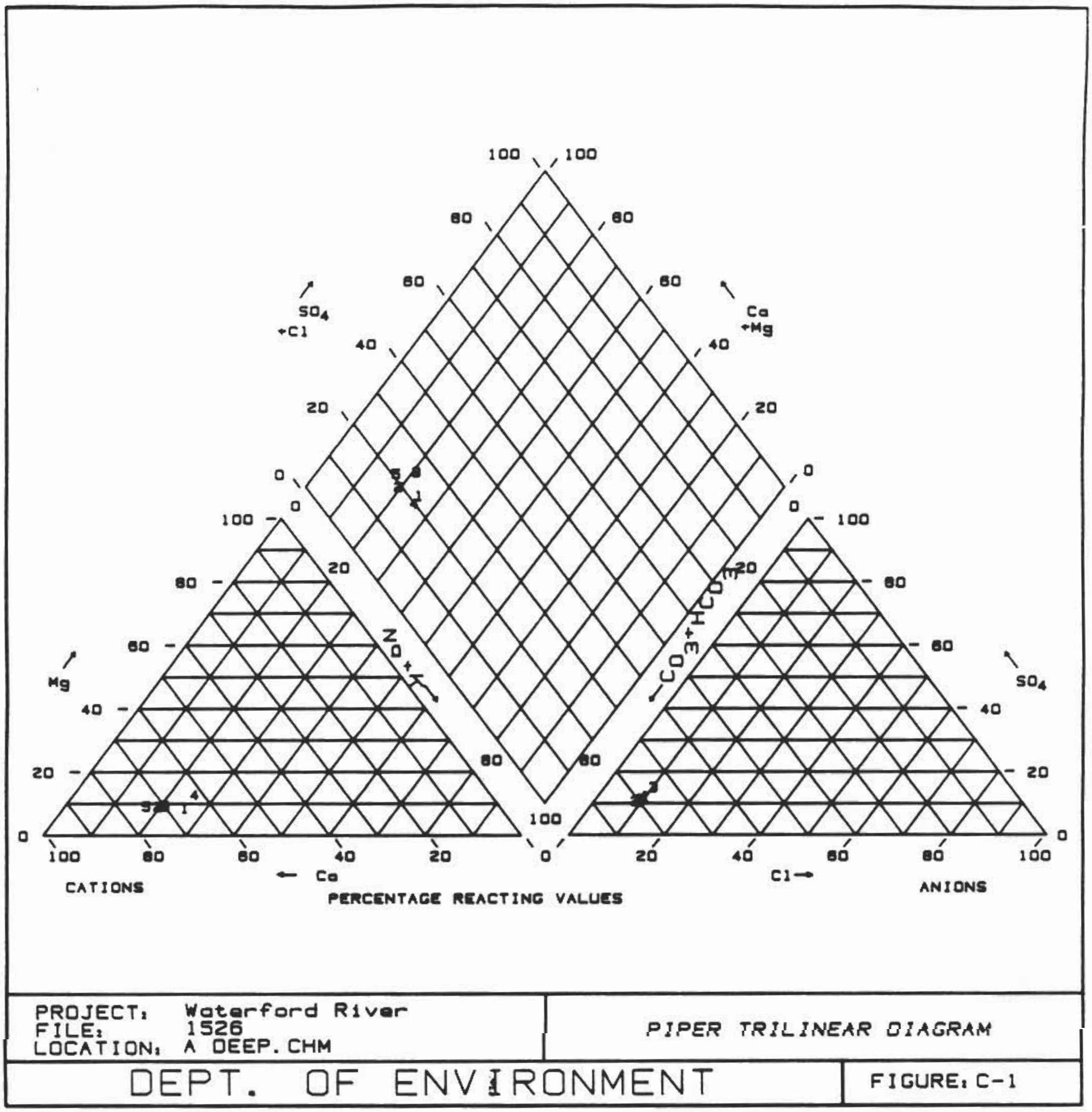

WATERFORD RIVER BASIN
SHALLOW WELL NO.1528 SITE C
WATER LEVEL ELEVATION (M)
117
116
115
114
113
112
81
83
85
87
YEAR


WATERFORD RIVER BASIN
DEEP WELL NO.1527 SITE C
WATER LEVEL ELEVATION (M)
118
117
116
115
114
113
81
83
85
87
YEAR


WATERFORD RIVER BASIN
SHALLOW WELL NO.1533 SITE G
WATER LEVEL ELEVATION (M)
230
229
228
227
226
225
81
83
85
87
YEAR


WATERFORD RIVER BASIN
DEEP WELL NO.1519 SITE G
WATER LEVEL ELEVATION (M)
230
229
228
227
226
225
81
83
85
87
YEAR

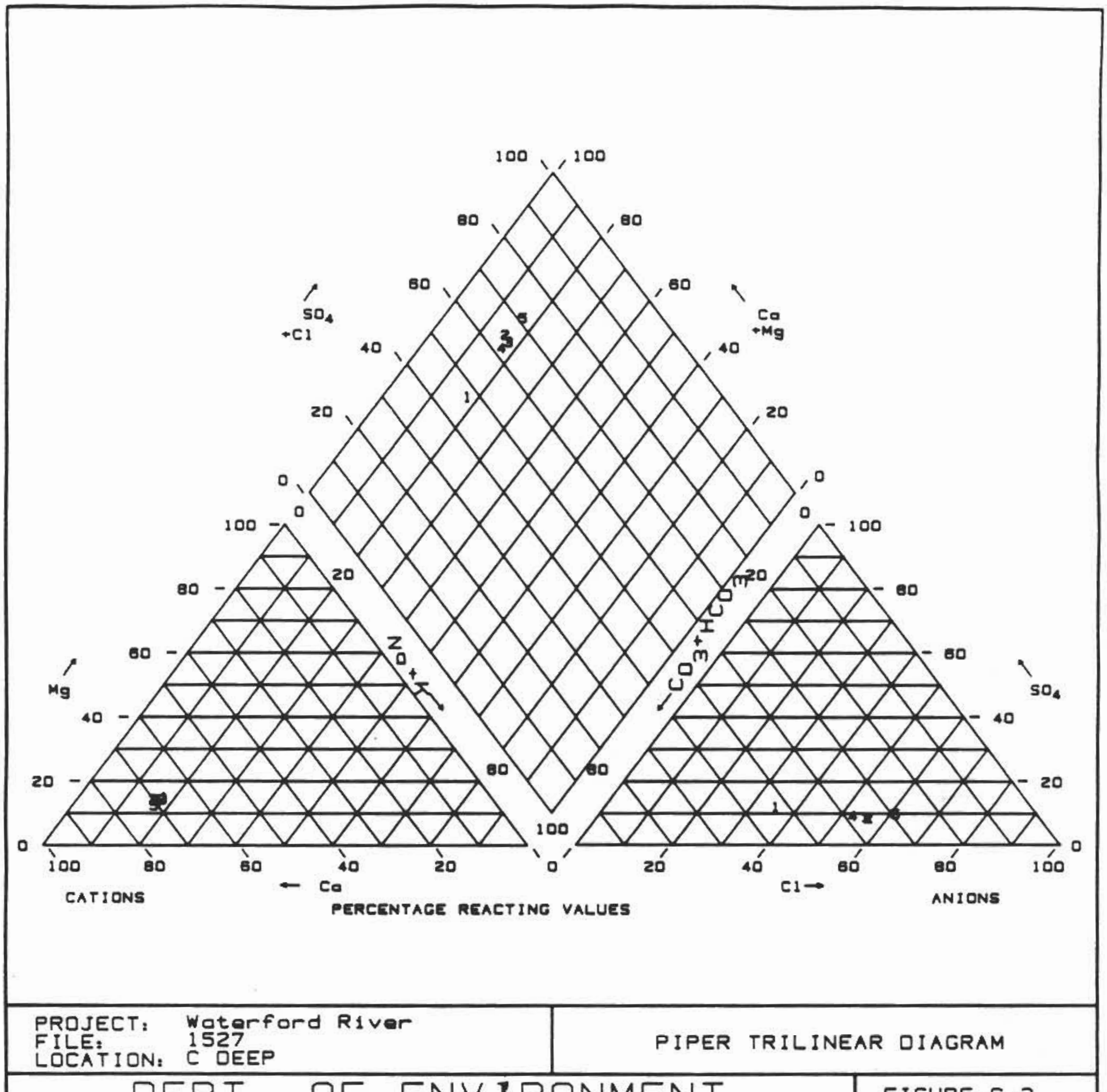
APPENDIX C
TRILINEAR AND LINE PLOTS OF CHEMICAL PARAMETERS



LEGEND

1 = 1981 2 = 1982
3 = 1983 4 = 1984
5 = 1985

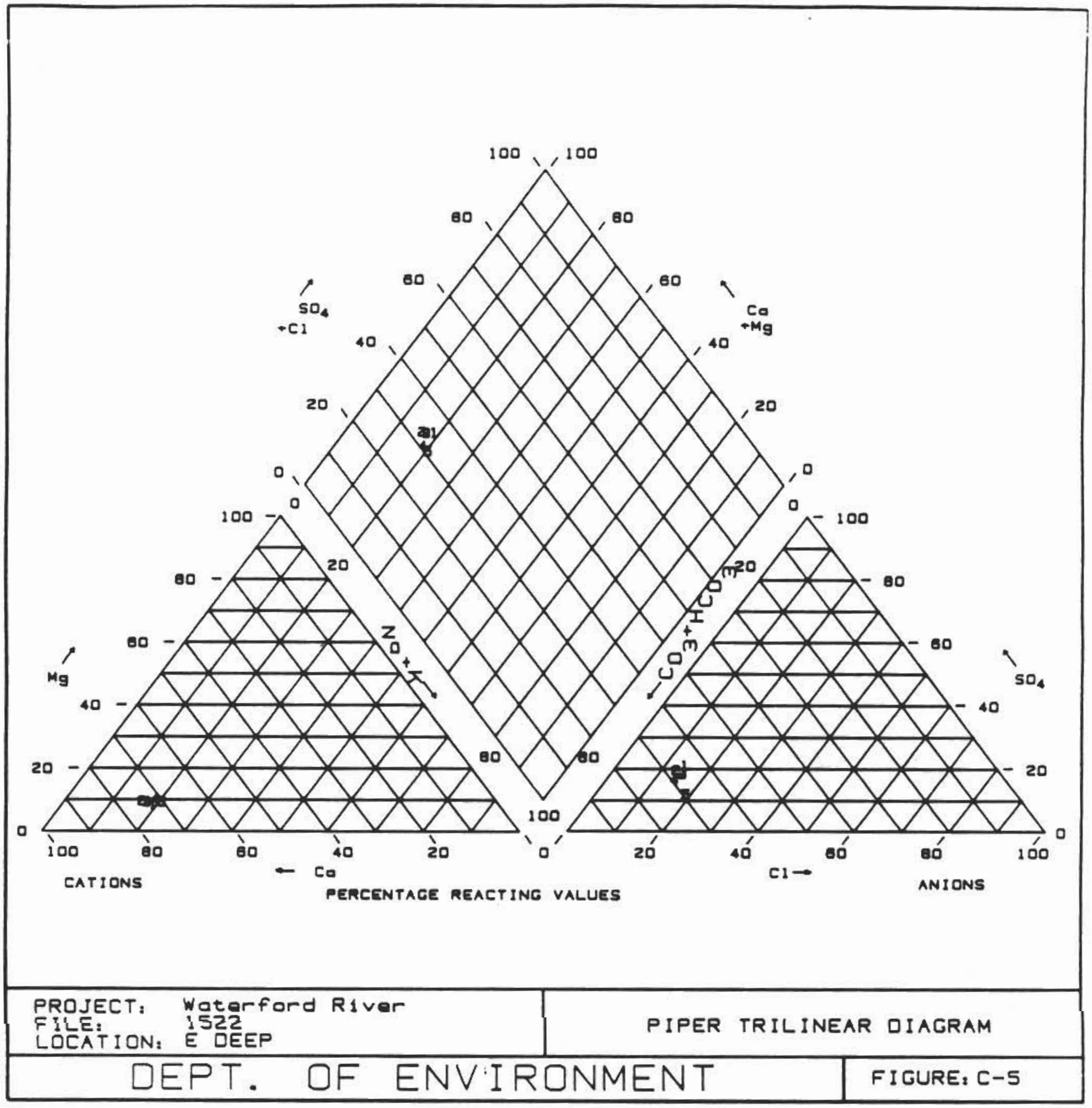
Figure C-1 Trilinear diagram of water chemistry at Site A, Well #1526



LEGEND

1 = 1981 2 = 1982
3 = 1983 4 = 1984
5 = 1985

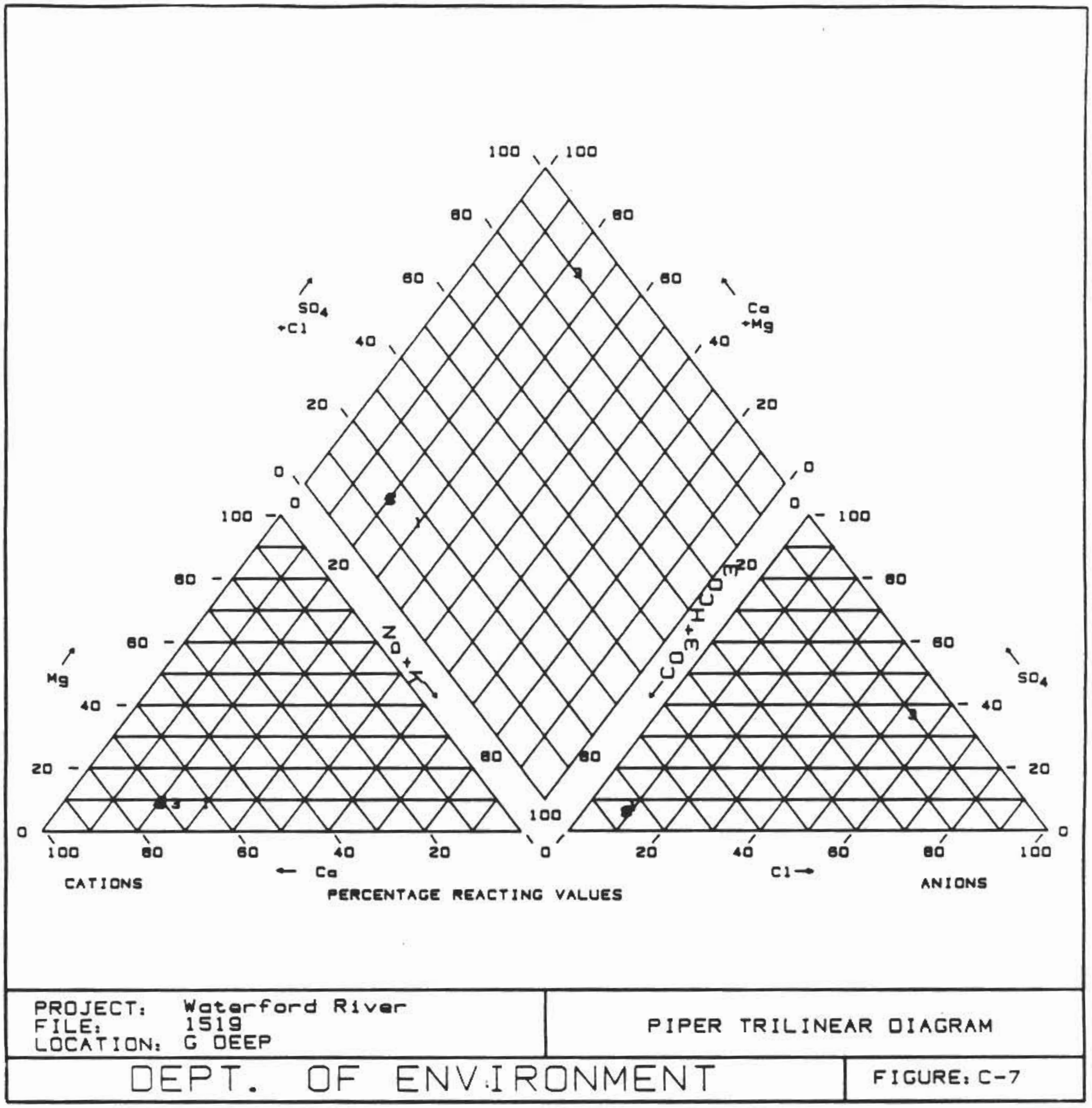
Figure C-3 Trilinear diagram of water chemistry at Site C, Well #1527



LEGEND

1 = 1981 2 = 1982
3 = 1983 4 = 1984
5 = 1985

Figure C-5 Trilinear diagram of water chemistry at Site E, Well #1522



LEGEND

1 = 1981 2 = 1982
3 = 1983 4 = 1984
5 = 1985

Figure C-7 Trilinear diagram of water chemistry at Site G, Well #1519

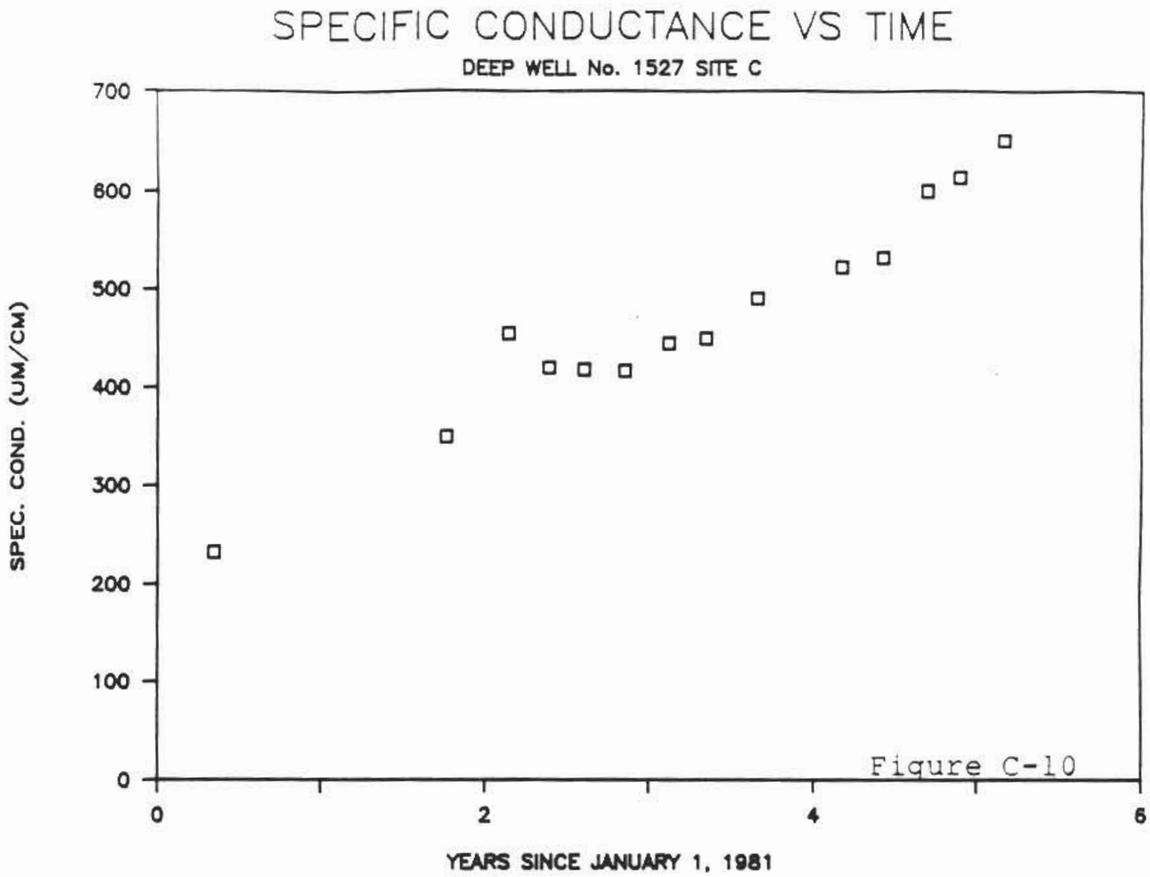


Figure C-10

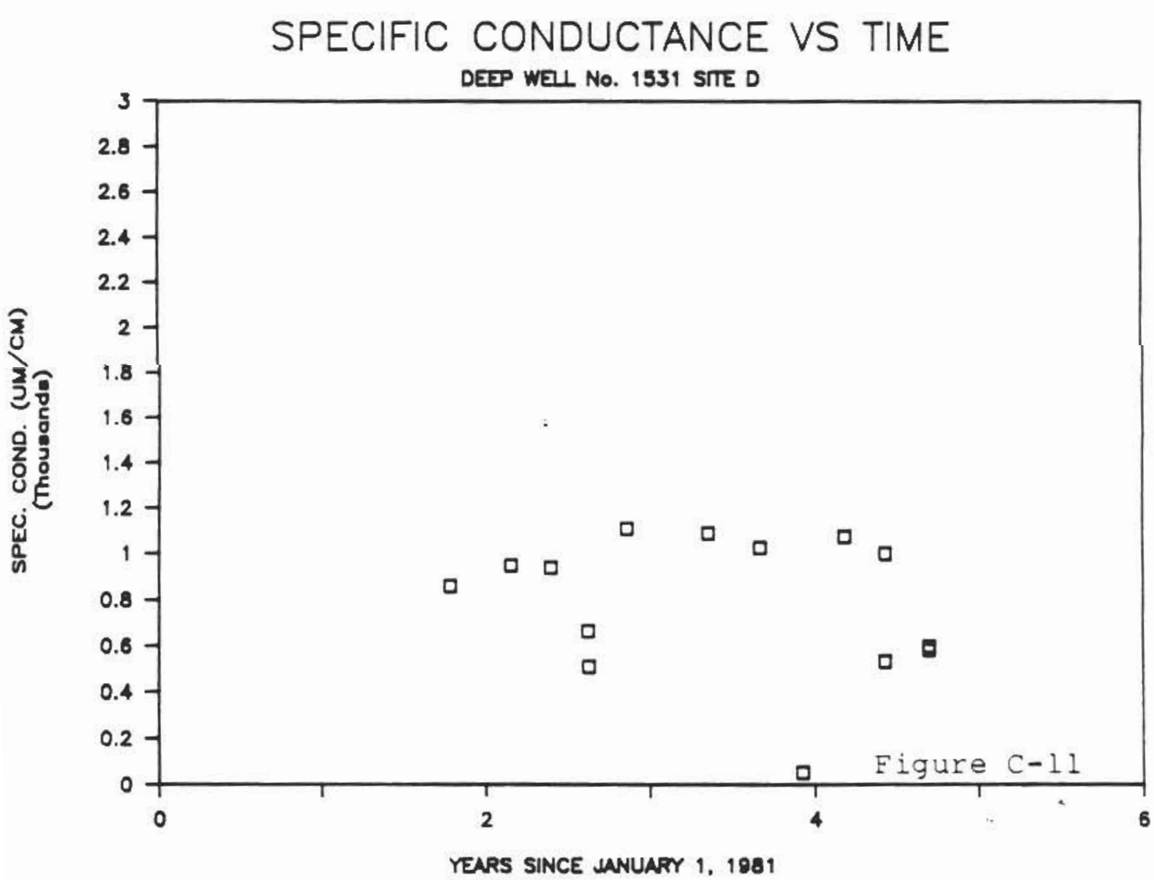


Figure C-11

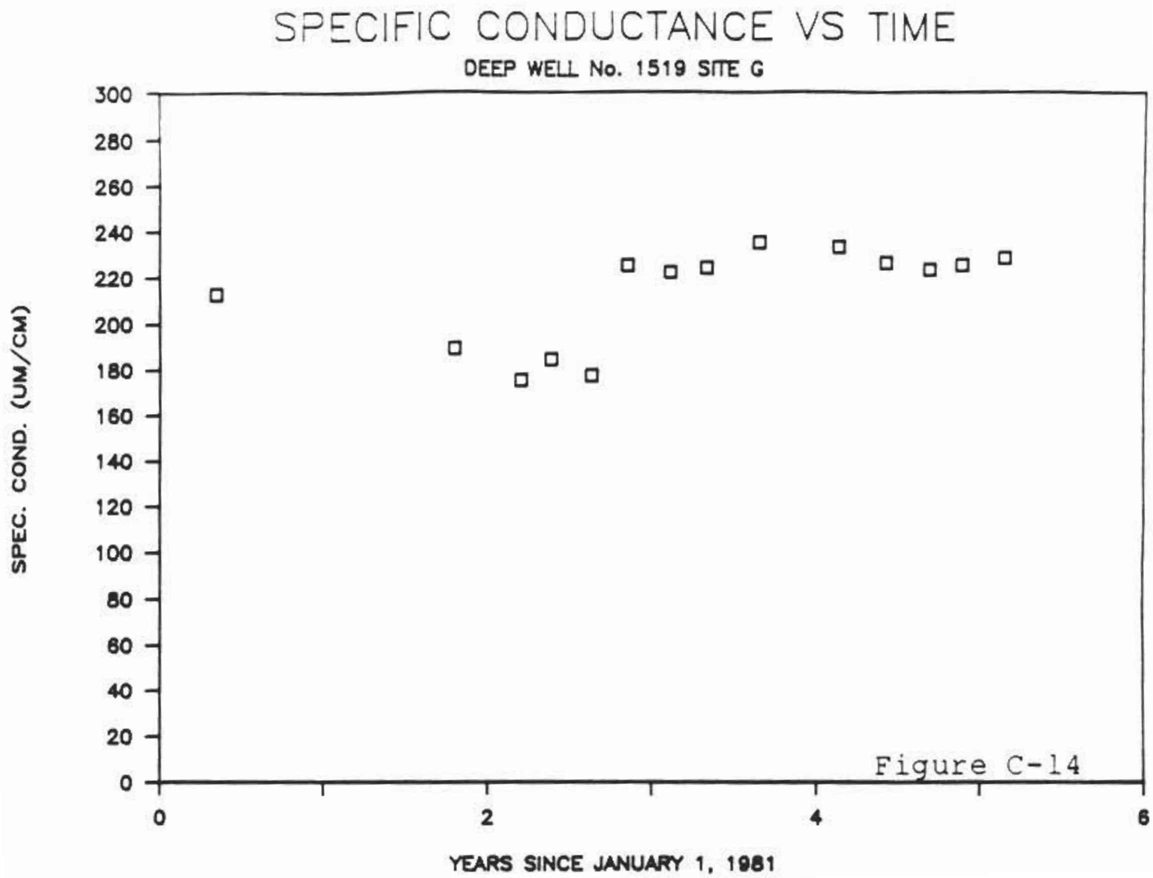
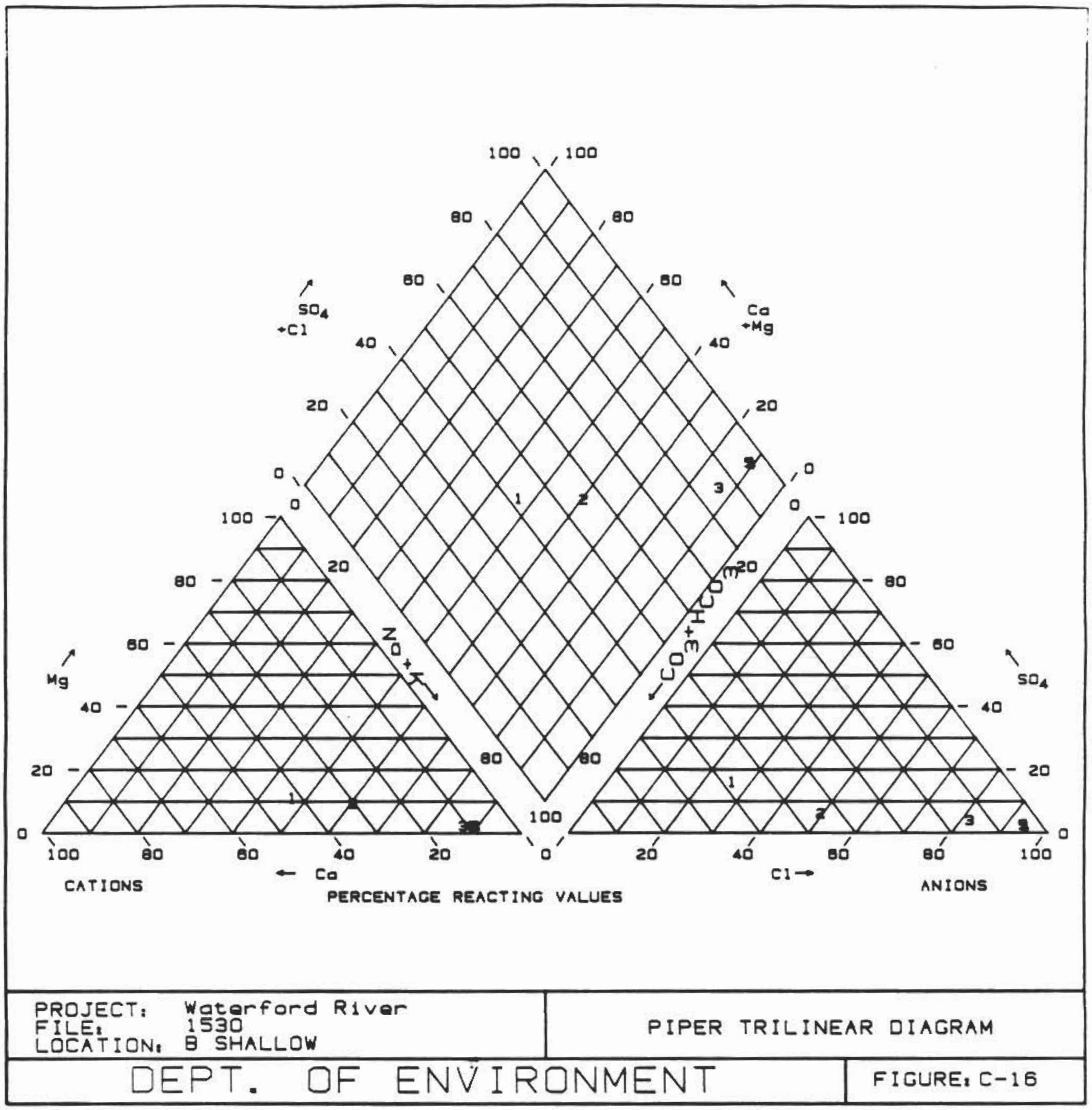

SPECIFIC CONDUCTANCE VS TIME
DEEP WELL No. 1519 SITE G
SPEC. COND. (UM/CM)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
2
4
6
YEARS SINCE JANUARY 1, 1981

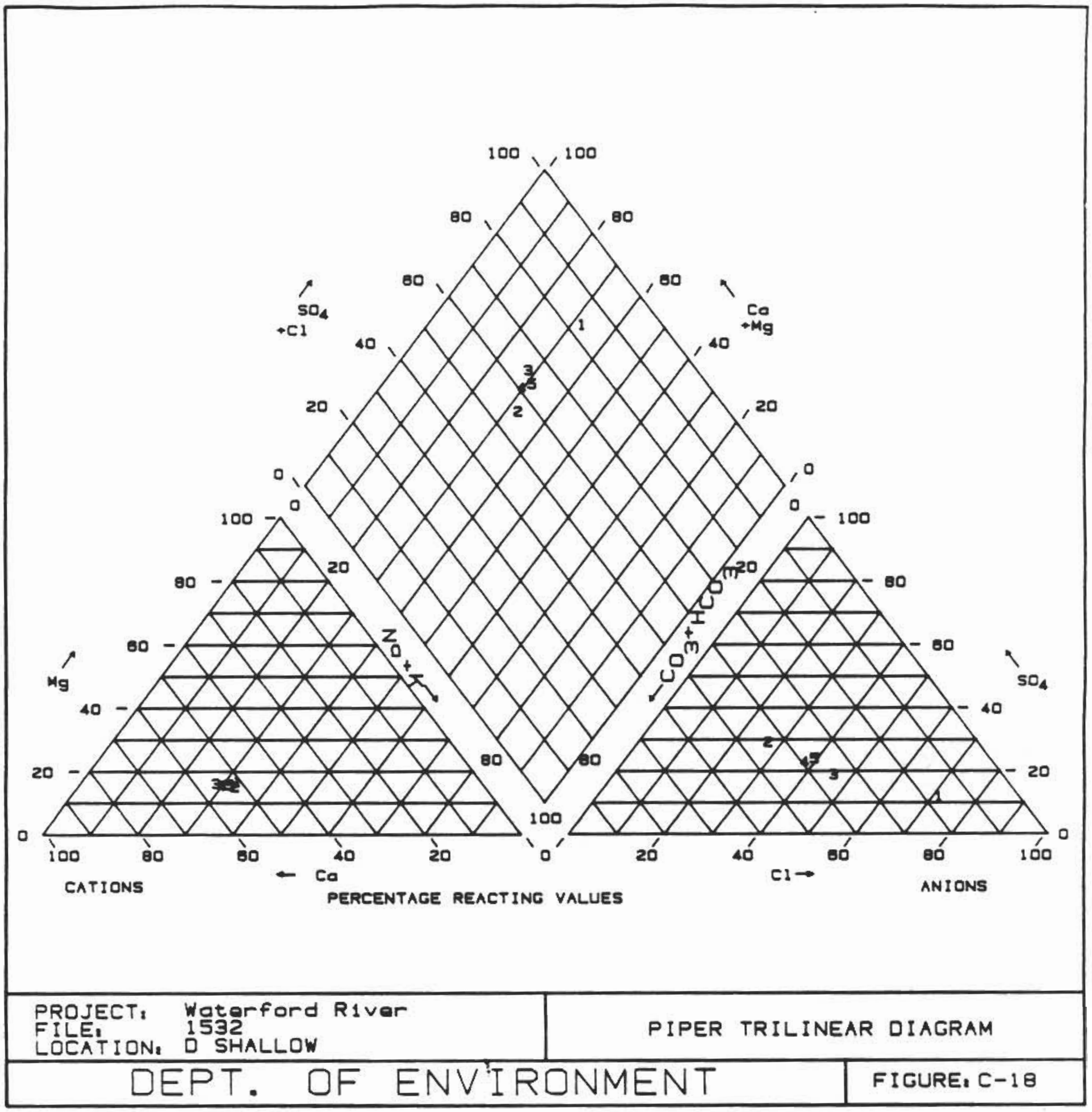
Figure C-14



LEGEND

1 = 1981 2 = 1982
3 = 1983 4 = 1984
5 = 1985

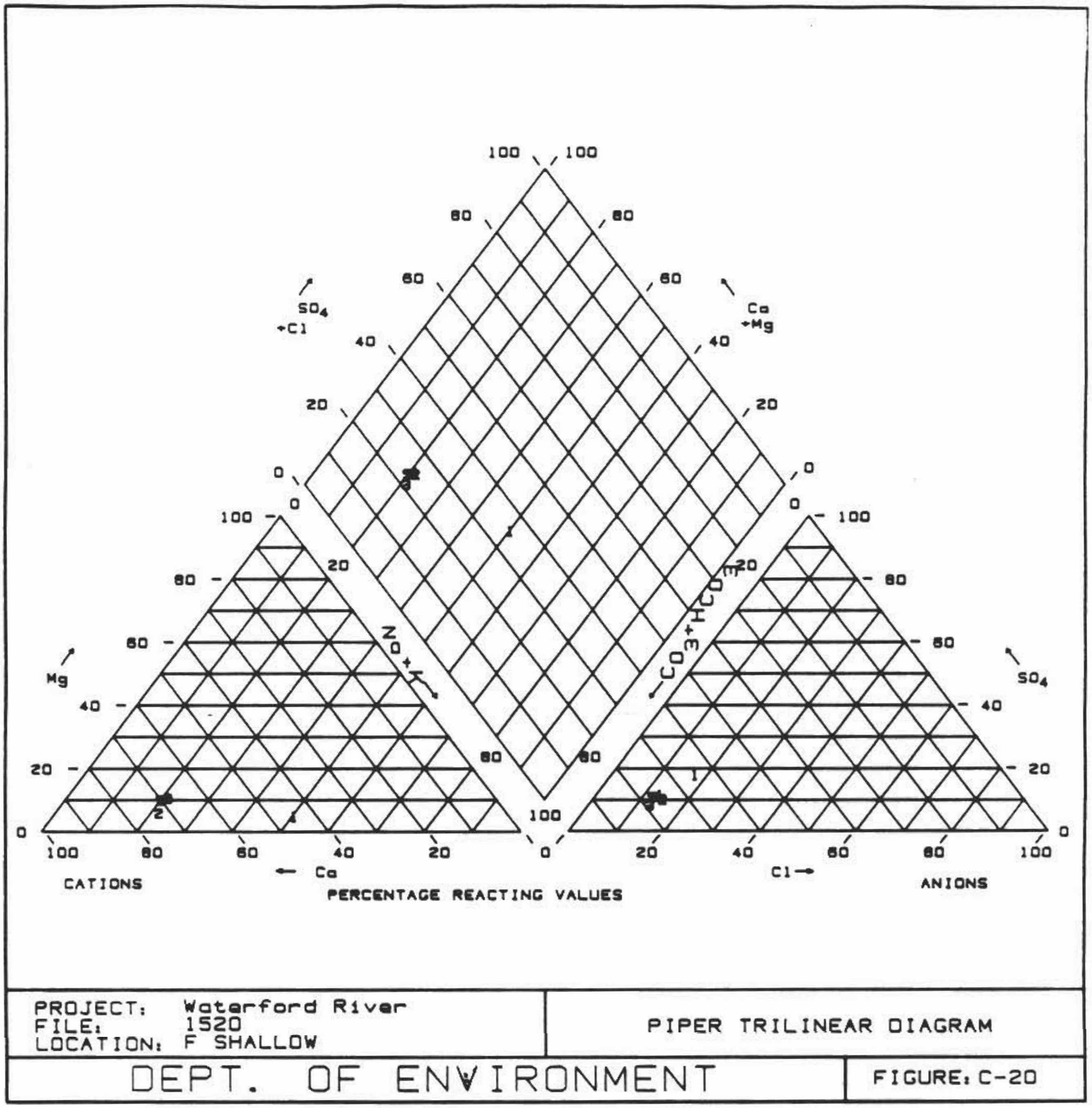
Figure C-16 Trilinear diagram of water chemistry at Site B, Well #1530



LEGEND

1 = 1981 2 = 1982
3 = 1983 4 = 1984
5 = 1985

Figure C-18 Trilinear diagram of water chemistry at Site D, Well #1532



LEGEND

1 = 1981 2 = 1982
3 = 1983 4 = 1984
5 = 1985

Figure C-20 Trilinear diagram of water chemistry at Site F, Well #1520

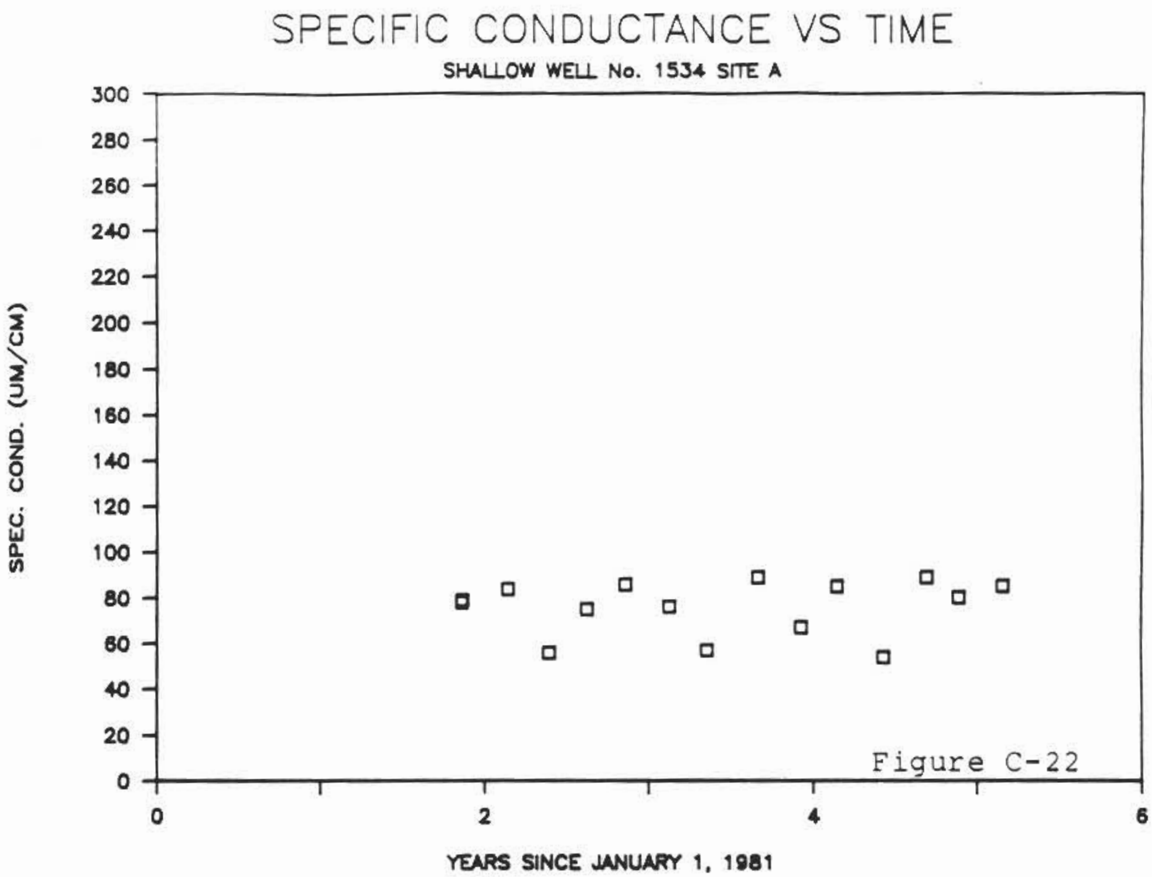


Figure C-22

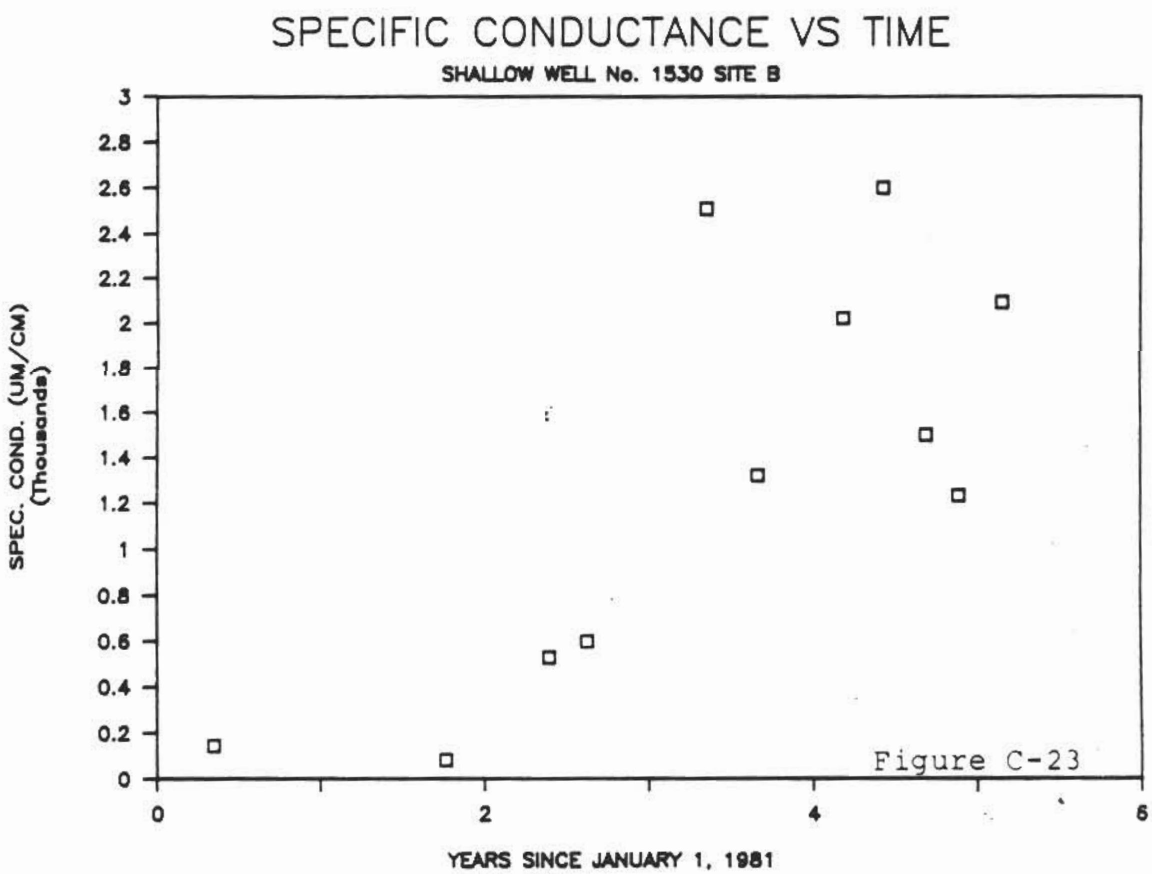


Figure C-23

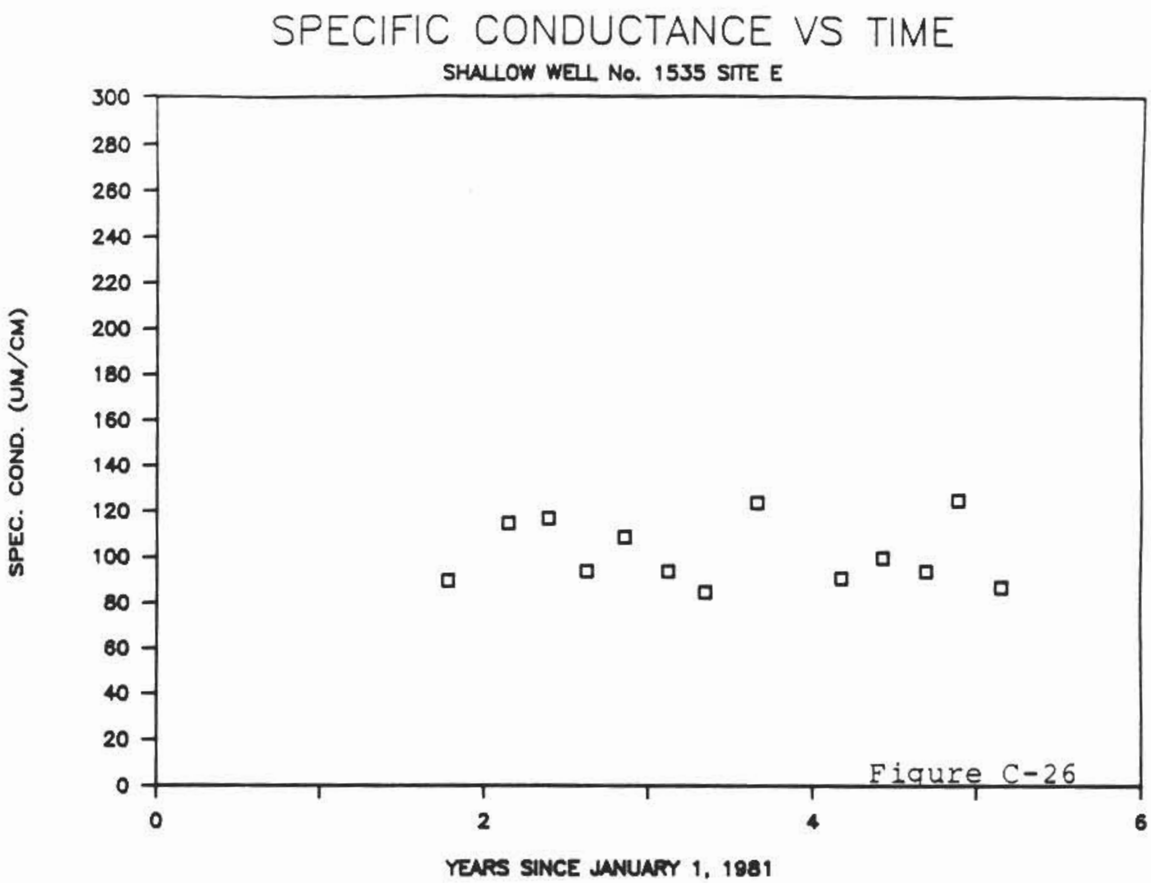


Figure C-26

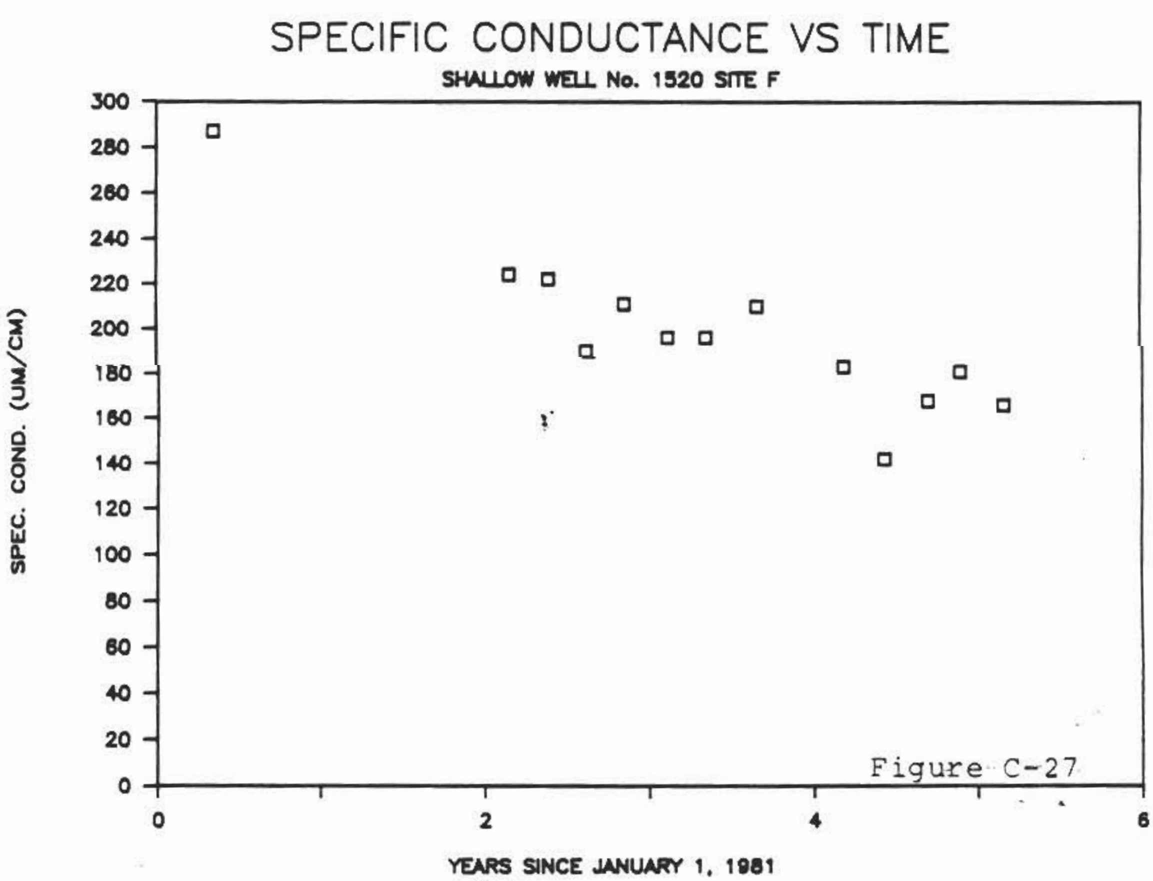


Figure C-27

SODIUM CONCENTRATION VS TIME

SHALLOW WELL No. 1533 SITE G

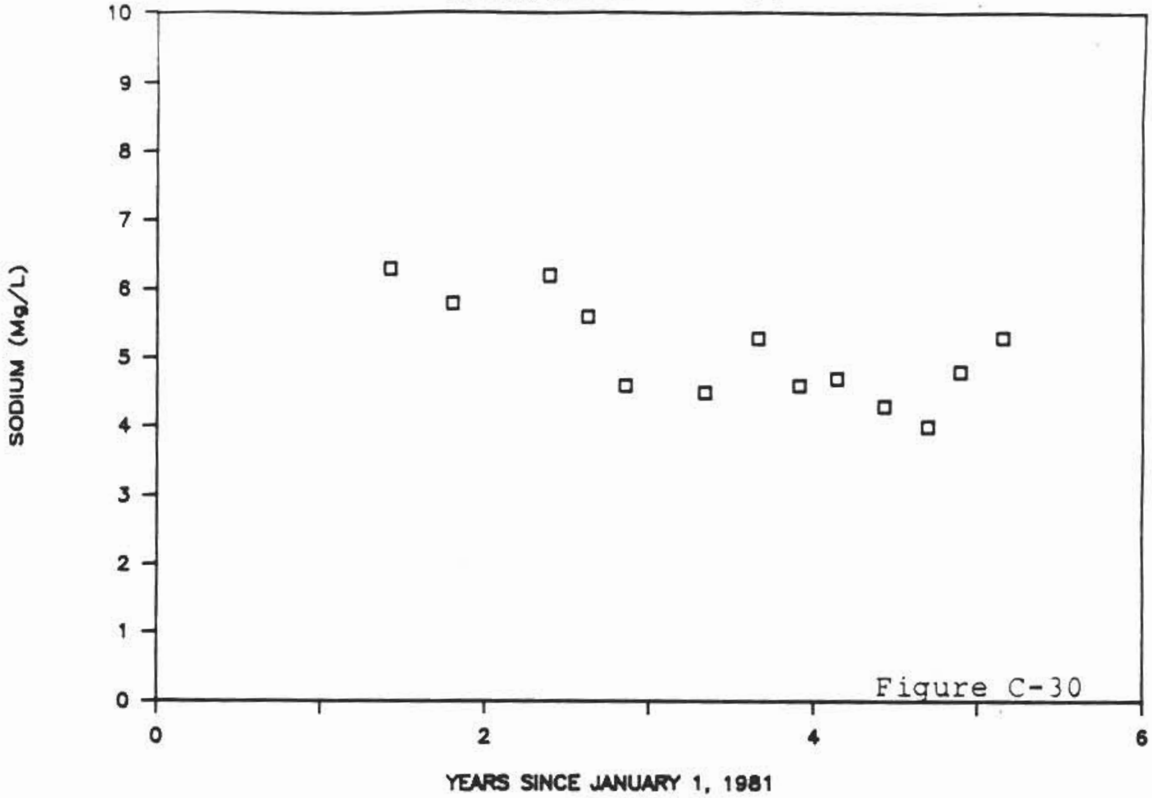


Figure C-30

CALCIUM CONCENTRATION VS TIME

SHALLOW WELL No. 1533 SITE G

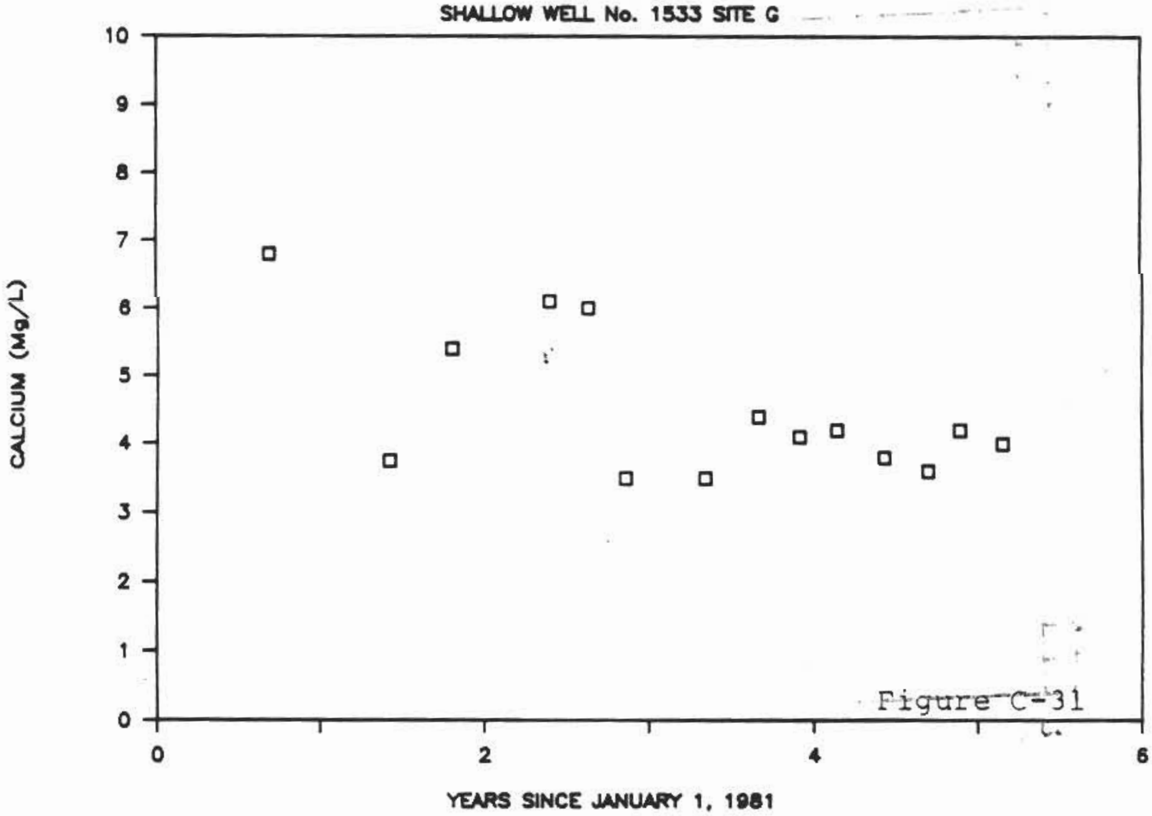


Figure C-31