Canadian Association
of Petroleum Producers

Migration of Methane into Groundwater from Leaking Production Wells near Lloydminster

Report for Phase 2 (1995)

March 1996
CAPP Pub. #1996-0003

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ACKNOWLEDGMENTS

B. Schreiner and M. Millard (SRC) conducted geological logging of the test holes at the new research sites; the cuttings were examined and interpreted by M. Millard. The gas and inorganic concentration analyses were conducted by the SRC Analytical Laboratory. Existing soil gas data were provided by Saskatchewan Energy and Mines and Husky Oil; further analyses for final site selection were conducted by Husky Oil.

TABLE OF CONTENTS

page

ACKNOWLEDGMENTS i
LIST OF FIGURES v
LIST OF TABLES vi
LIST OF APPENDICES vii

1.0 INTRODUCTION 1

2.0 BACKGROUND 2
2.1 Definition of the Study Area 2
2.2 Vertical Gas Migration 2
2.3 Regional Hydrogeology of the Lloydminster Area 9
2.3.1 Aquifers in the Judith River (Belly River) Formation 9
2.3.2 Aquifers in the Bearpaw Formation and Edmonton Group 10
2.3.3 Drift Aquifers 10
2.4 Review of 1994 Program Results 10

3.0 1995 DRILLING PROGRAM 11
3.1 Installation of Additional Monitoring Wells at the Lindbergh Site 12
3.2 Golden Lake (B10-32-48-23-W3, Petro Canada) 14
3.3 Lone Rock (07-20-47-26-W3, Carmanah) 14
3.4 Wildmere Site (13-14-47-05-W4, Koch Exploration) 17
3.5 Sedgewick Site (07-09-44-12-W4, Poco) 18
3.6 Swimming (10D-12-52-07-W4, Husky) 18

4.0 HYDRAULIC PROPERTIES OF AQUIFERS AT RESEARCH SITES 23
4.1 Swimming Site Pumping Test Results 24
4.2 Swimming Site Infiltrometer Testing Results 24
4.3 Lindbergh Site Pumping Test 25
4.4 Wildmere Site Slug Test Results 26

5.0 METHANE, ETHANE & OTHER ANALYSES FOR RESEARCH SITES, 1995 . 27
5.1 Sampling and Analytical Methods for Dissolved Species 27
5.2 Methane and Other Analyses for Marshall Site 28
5.3 Methane and Other Analyses for Lindbergh Site 33
5.4 Methane and Other Analyses for Wildmere Site 43
5.5 Methane and Other Analyses for Swimming Site 43

TABLE OF CONTENTS

page

6.0 MODELLING OF METHANE MIGRATION AT RESEARCH SITES 61
6.1 Background 61
6.2 Current Modelling Approach 62
6.3 Conceptual Model of Gas Phase Methane Migration 62
6.4 Empirical Studies of Gas Phase Migration - the Air Sparging Analogy 63
6.5 Relevant Mathematical Models for Simulation of Gas Phase Migration 63

7.0 METHANE IN WATER SUPPLY WELLS IN THE STUDY AREA 64
7.1 Historical Data on Presence of Gas in Supply Wells 65
7.2 1995 Survey of Methane in Water Supply Wells in Study Area 67
7.3 Methane in Groundwater in Other Oil and Gas Producing Areas 70

8.0 SUMMARY AND RECOMMENDATIONS 71
8.1 Recommendations 72

9.0 REFERENCES 73

LIST OF FIGURES

page

Figure 1. Lloydminster study area 3
Figure 2. Schematic cross section of near surface stratigraphy in the Lloydminster study area (generalized, not to scale) 5
Figure 3. Schematic of gas migration from a production well to adjacent soils and shallow aquifers 7
Figure 4. Plan of the Lindbergh Site and water levels measured on December 15, 1995 15
Figure 5. Plan of the Wildmere Site and water levels measured on September 26, 1995 19
Figure 6. Plan of the Swimming Site and water levels measured on December 14, 1995 21
Figure 7. Plan of the Marshall site with measured methane concentrations (mg/L) for samples collected on September 28 to 29, 1995 29
Figure 8. Plan of the Lindbergh site with measured methane concentrations (mg/L) for samples collected on November 14 to 17, 1995 35
Figure 9. Vertical profile of hydrochemistry at LND-95-6A, B and C 37
Figure 10. Vertical profile of hydrochemistry at LND-95-7A, B and C 39
Figure 11. Vertical profile of hydrochemistry at LND-95-8A, B and C 41
Figure 12. Plan of the Wildmere site with measured methane concentrations (mg/L) for samples collected on October 17 to 18, 1995 47
Figure 13. Plan of the Lindbergh site with measured methane concentrations (mg/L) for samples collected on November 22 (01A, 02 and 03) and December 14 to 15, 1995 (all other wells) 49
Figure 14. Vertical profile of hydrochemistry at MGN-95-4A, B and C 51
Figure 15. Vertical profile of hydrochemistry at MGN-95-5A, B and C 53
Figure 16. Vertical profile of hydrochemistry at MGN-95-6A, B and C 55
Figure 17. Vertical profile of hydrochemistry at MGN-95-7A, B and C 57

LIST OF TABLES

page

Table 1. Soil methane concentration data measured by soil probes at research sites, 1995 12
Table 2. Summary of installations at research sites, 1994-95 13
Table 3. Calculated hydraulic parameters for the aquifer at the Swimming site 24
Table 4. Calculated hydraulic parameters for the aquifer at the Swimming site 26
Table 5. Dissolved methane and ethane concentrations in groundwater at the Marshall site 31
Table 6. Major ions and other hydrochemical parameters in groundwater at the Marshall site 32
Table 7. Dissolved methane and ethane concentrations in groundwater at the Lindbergh site 34
Table 8. Major ions and other hydrochemical parameters in groundwater at the Lindbergh Site 44
Table 9. Dissolved methane and ethane concentrations in groundwater at the Wildmere site 45
Table 10. Major ions and other hydrochemical parameters in groundwater at the Wildmere Site 46
Table 11. Dissolved methane and ethane concentrations in groundwater at the Swimming site 59
Table 12. Major ions and other hydrochemical parameters in groundwater at the Swimming site 60
Table 13. Water wells in study area in which gas was noted to be present (Alberta Environmental Protection waterwell database) 66
Table 14. Survey of methane concentrations in water supply wells in the Saskatchewan portion of the study area 68

LIST OF APPENDICES

Appendix A. Completion Records for the Test Hole and Monitoring Wells at Lindbergh Site (1994-95)
Appendix B. Log of Test Hole at Golden Lake Site
Appendix C. Log of Test Hole at Lone Rock Site
Appendix D. Log of Test Hole and Completion Records for Monitoring Wells at Wildmere Site
Appendix E. Log of Test Hole at Sedgewick Site
Appendix F. Log of Test Hole and Completion Records for Monitoring Wells at Swimming Site
Appendix G. Pumping and Infiltrometer Tests at Swimming Site
Appendix H. Pumping Test at Lindbergh Site
Appendix I. Slug Test at Wildmere Site
Appendix J. Monitoring Well Water Level Data
Appendix K. Original Water Chemistry Data Sheets

1.0 INTRODUCTION

In 1995 the Saskatchewan Research Council continued an investigation of gas migration in groundwater in the Lloydminster area. This report documents the 1995 research program, which followed the initial (1994) program (Van Stempvoort and Jaworski, 1995; Schmitz, 1995).

The research project has the following objectives:

- to investigate the occurrence of methane in groundwater near leaking production wells in the Lloydminster study area,

- to determine whether the methane is derived from the leaking well or occurs naturally in the aquifer,

- to determine the concentration gradients and approximate flux rates of methane from leaking wells to shallow aquifers, and

- to predict the migration rate of methane in aquifers under various scenarios of time and physicochemical conditions (e.g., aquifer properties).

This project is funded by the Canadian Association of Petroleum Producers (CAPP), the Lloydminster Area Operators Gas Migration Team (LAOGMT), the Panel for Energy Research and Development (PERD) and the Saskatchewan Research Council (SRC). In 1995, the steering committee for this program included Ron Schmitz (Husky Oil, CAPP), Garry Lorenz (LAOGMT), Les Bernier (Saskatchewan Energy and Mines), David Blume (Provost Area Surface Rights), Tom Cook (Alberta Energy Utilities Board), Garry Ericson (Saskatchewan Energy and Mines), Margaret Klebek (Alberta Environmental Protection), Kennedy Kohlman (Koch Exploration), Brian Moneta (Elan Energy), Don Roberts (Alberta Energy Utilities Board), Scott Robinson (Saskatchewan Environment and Resources Management), Harold Seitz (Wascana Energy), Kurt Uhrich (Amoco) and Gary Webster (CAPP).

The 1995 program included five components as indicated in the following sections:

- expansion of monitoring at the Lindbergh site,
- selection of five new sites; installation of monitoring wells at two of these sites,
- investigation of dissolved methane and other hydrochemical species,
- development of modelling for simulation of methane migration in groundwater,
- survey of methane in 23 water supply wells in the Lloydminster area.

2.0 BACKGROUND

2.1 Definition of the Study Area

In this investigation, the Lloydminster study area (referred to subsequently as the "study area") refers to portions of Saskatchewan and Alberta as follows: Townships 36 through 63, Ranges 1 through 13, west of the 4th Meridian in Alberta; Townships 44 through 52, Ranges 17 through 28 and Townships 38 through 43, Ranges 24 through 28, west of the 3rd Meridian in Saskatchewan (Figure 1).

2.2 Vertical Gas Migration

Erno and Schmitz (1994) and others have documented leakage of natural gas (mainly methane) from oil and gas production well to soils in the Lloydminster area. The gas appears to be leaking from relatively deep geological units that have been intersected by the production wells: evidently the Cretaceous Mannville Group (production zones) and/or the Lea Park Formation (Rich et al., 1994, E. Jensen and K. Muelenbachs, personal comm., 1995; see Figure 2). The vertical pathways that transport methane from the deep sources to the soil horizons appear to be within the annuli of the production wells (Figure 3; cf. Chafin, 1994). Apparently there are permeable zones, referred to as "microannuli", within or adjacent to the cemented annuli, which allow upward migration of gas phase methane. This leaking gas apparently disperses readily along the ubiquitous networks of fractures and other pores in soil.

Along the vertical flow paths from deep formations to soil, methane may also migrate laterally into permeable sediments intersected by the production wells. Plumes of dissolved methane may spread by advection and dispersion into aquifers (Figure 3). In some cases, methane may also migrate laterally as a gas phase within these aquifers.

Studies conducted in the United States have documented the effects of large-scale invasion of natural gas from exploration holes or defective production wells to shallow aquifers and surface water bodies (Rose and Alexander, 1945; Preston, 1980; Kelly et al., 1985). In these cases, the gas apparently migrated along uncemented annuli, whereas the wells in the Lloydminster area generally have cement to surface. Kelly et al. (1985) examined changes in groundwater chemistry following a massive influx of gas from a "blow-out". The concentrations of reduced species (Fe, Mn and sulfide) increased, while concentrations of oxidized species (dissolved oxygen, nitrate and sulfate) decreased due to oxidation of the methane, which is consistent with the results from this program to date.

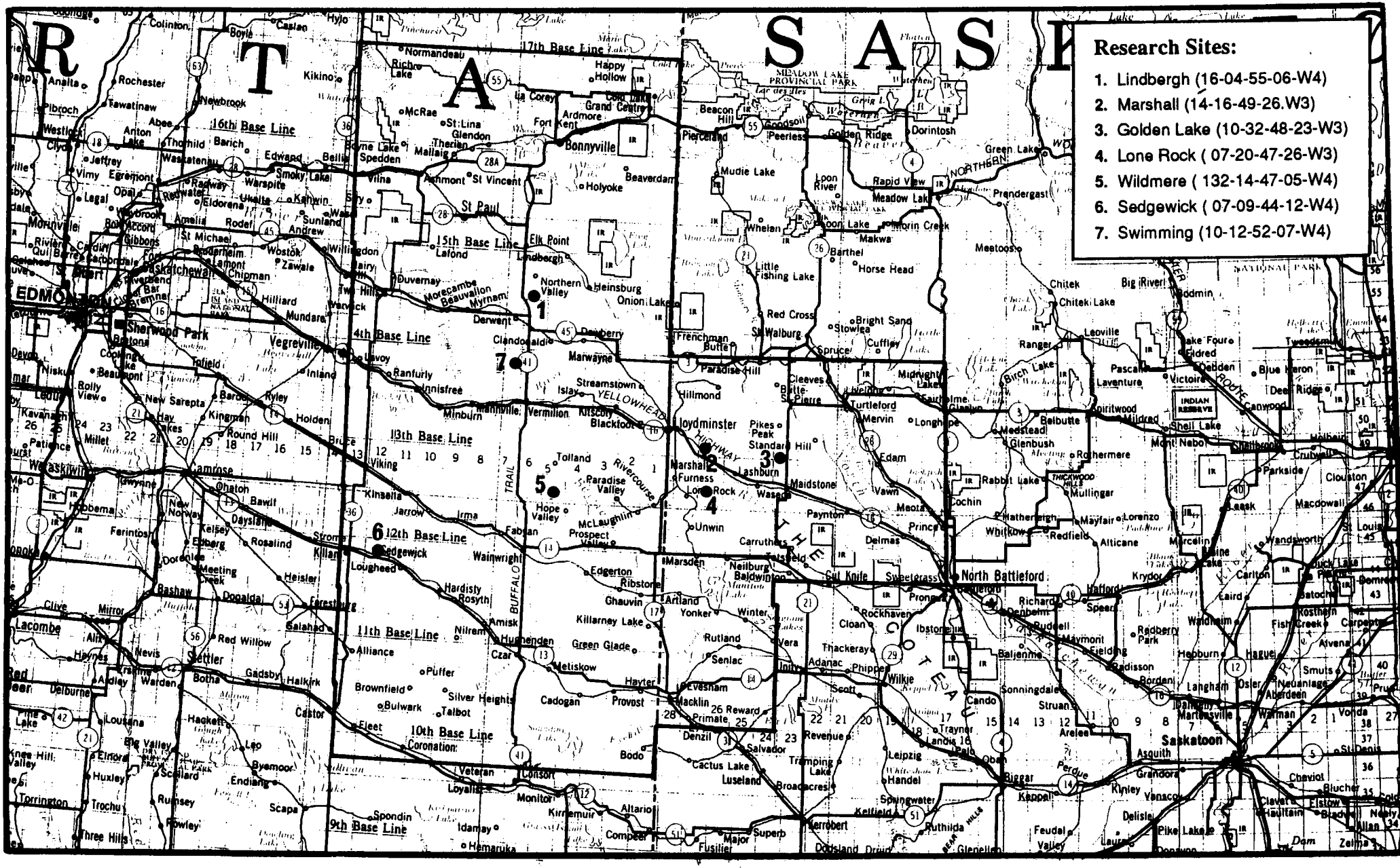


Figure 1. Lloydminster Study Area.

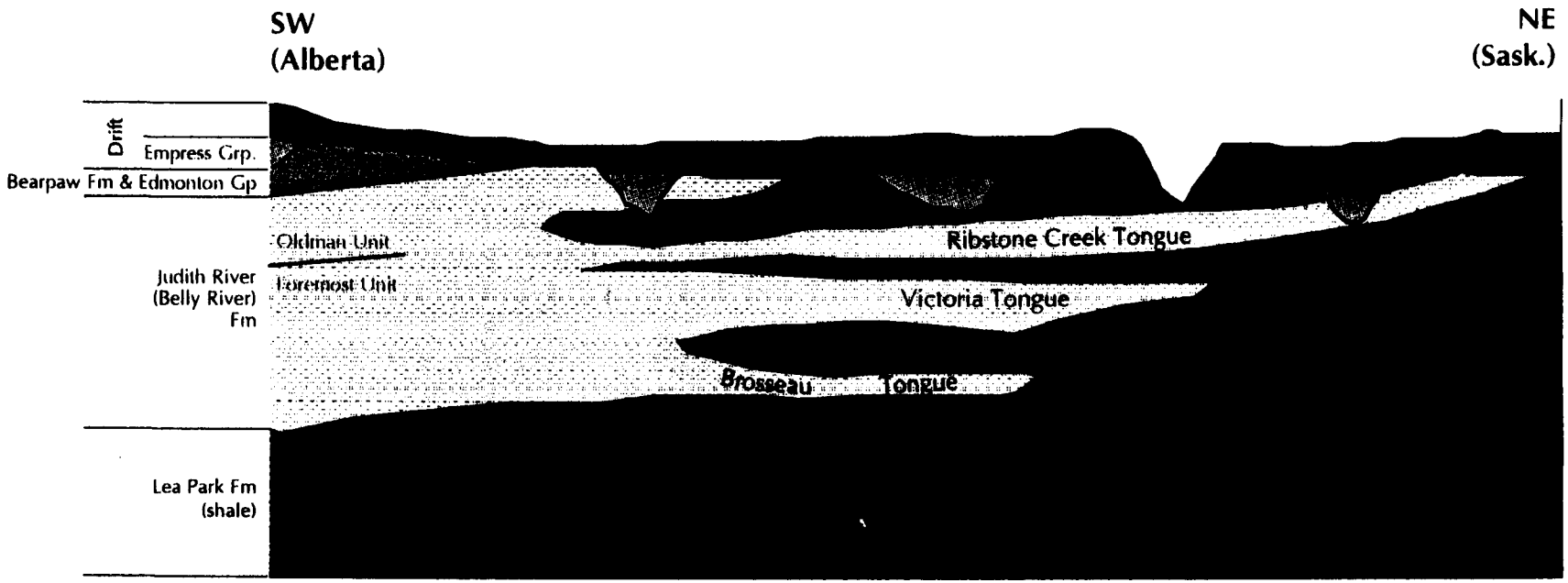


Figure 2 Schematic cross-section of near-surface geology of the Lloydminster Study Area (not to scale). Note that Judith River Fm. tongues may be discontinuous or difficult to correlate laterally (McLean, 1971).

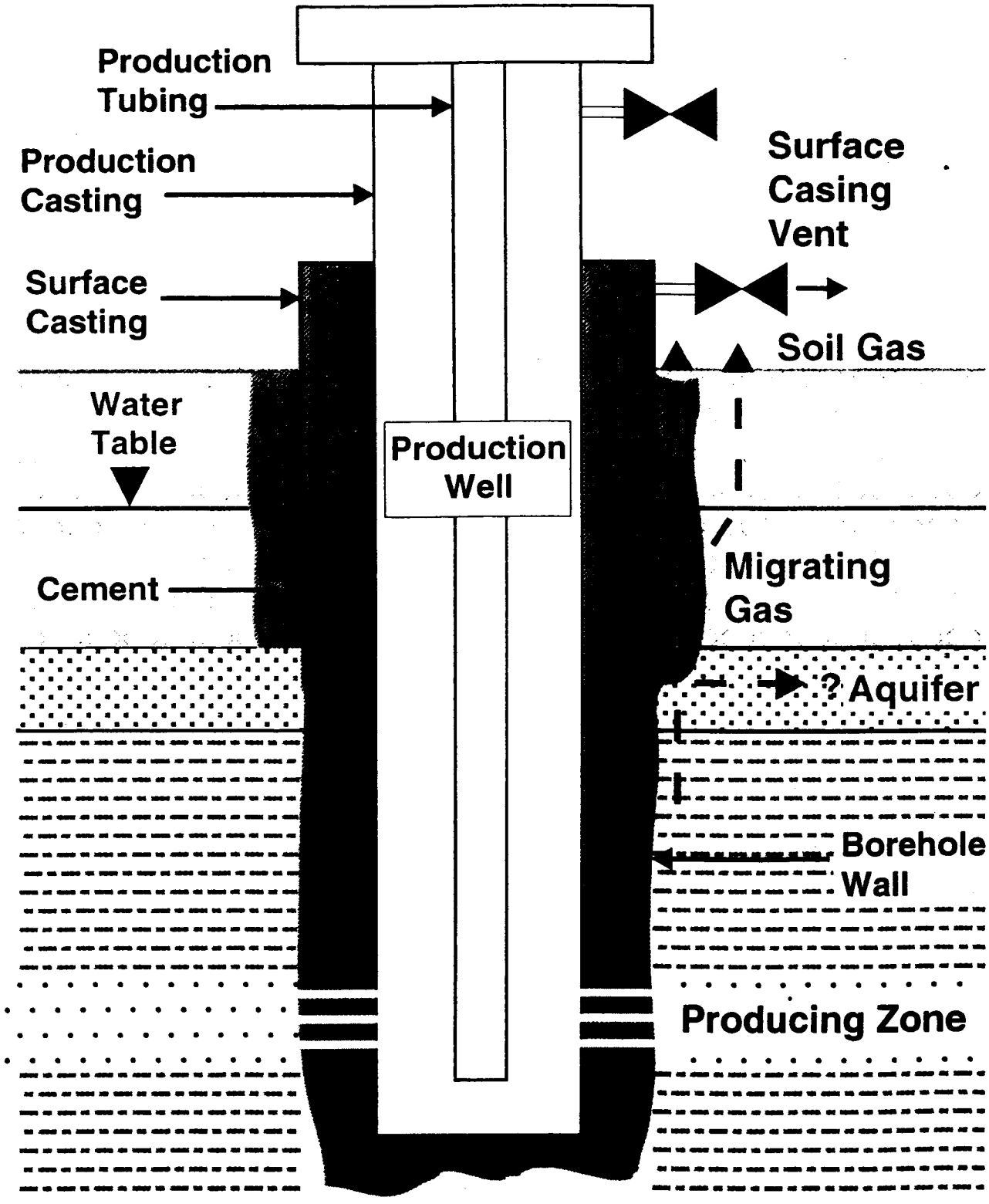


Figure 3 Schematic of gas migration, modified after Schmitz et al (1994).

2.3 Regional Hydrogeology of the Lloydminster Area

Overviews of the hydrogeology and/or surficial geology of portions of the study area have been given by Hackbarth (1975), Currie and Zacharko (1976), Pasloske (1985), Tokarsky (1985, 1987), Andrashek and Fenton (1989), Millard (1990) and Ozoray et al. (1994). Throughout the area, drift sediments, dominated by till, overlie Cretaceous "bedrock" sediments. The bedrock sediments outcrop in some low areas including river valleys. Regionally the shallow bedrock units dip to the southwest. Figure 2 gives a summary of the stratigraphic relationships of geologic units in this area.

2.3.1 Aquifers in the Judith River (Belly River) Formation

Throughout much of the area, sand and/or sandstone beds of the Cretaceous Judith River Fm. (as defined by McLean, 1971) are the deepest aquifers present. Most reports and maps published in Alberta refer to this unit as the Belly River Fm. Due to preglacial and/or glacial erosion, the Judith River Fm. is absent in the north and northeast portions of the Lloydminster Area.

The Judith River Fm. is composed of interbedded sand, silt and clay units. Cemented sand and silt beds are often reported as sandstone or siltstone. Other, less dominant lithologies include "ironstone" concretionary horizons and coal or carbonaceous beds. Individual units have "marked" lateral variations and are generally discontinuous, reflecting a complex array of deltaic depositional environments (McLean, 1971).

In the eastern portion of the study area, members of the Judith River Fm. intertongue with the uppermost portion of the Lea Park Fm., which is a marine clay ("shale", see Figure 2). According to McLean (1971), the regional stratigraphic correlation of Judith River Fm. tongues is sometimes problematic. The original descriptions of outcrops of these members (tongues) have referred specifically to "sandstone" units (see McLean, 1971). Later authors have referred to subsurface data, including e-logs, and have included finer grained lithologies in the defined tongues (e.g., interbedded silts and clays). The Ribstone Creek member is present along the erosional margin of the Judith River Fm. in Saskatchewan (Millard, 1990). In the central portion of the study area there are several members below the Ribstone Creek, including the "Victoria" and "Brosseau" tongues, as defined by Tokarsky (1987) and Ozoray et al. (1994), which pinch out easterly.

In the western and southwestern portions of the study area, individual tongues have not been identified. In this area the Judith River (Belly River) Fm. has been subdivided into a lower Foremost unit and an upper Oldman unit (e.g., McLean, 1971; Tokarsky, 1987; Ozoray et al., 1994).

2.3.2 Aquifers in the Bearpaw Formation and Edmonton Group (Horseshoe Canyon Fm.)

These Cretaceous strata, which include sand aquifer units, occur above the Judith River Formation in the extreme southwestern corner of the study area (Hackbarth, 1975; Tokarsky, 1987). There are no research sites for the gas migration program in this subarea.

2.3.3 Drift Aquifers

"Drift" includes all sediments above bedrock (Figure 2). Drift aquifers occur intermittently, and their lateral continuity is often unpredictable, even on a local (< 100 m) scale. Locally, Empress Group sands and gravels occur directly above the eroded upper bedrock surface (Figure 2), typically as buried preglacial or glacio-fluvial channel deposits. Some of these aquifers have potential for high rates of groundwater production (e.g., Battleford Valley aquifer - Hackbarth, 1975; Rex and Lloydminster Valley "basal" aquifers - Pasloske, 1985). Intertill and surficial sand and/or gravel aquifers are also present in the drift of the study area (e.g., Millard, 1990). Millard (1990) inferred that some relatively thick intertill aquifers extend over tens of square km.

2.4 Review of 1994 Program Results

The initial (1994) gas migration in groundwater program has been reported by Van Stempvoort and Jaworski (1995). Monitoring wells were completed at the Lindbergh and Marshall sites (Figure 1), in shallow aquifers close to gas "leakers" (in these cases, inactive oil production wells). At the Lindbergh site, the Judith River Fm. is missing due to erosion. Five monitoring wells are completed at ~30 m below ground surface (BGS) in an Empress Gp. channel sand and gravel deposit. This unit is at the base of the groundwater protection zone as defined by Alberta Environmental Protection. At the Marshall site, five monitoring wells are completed at ~20 m BGS in a sandstone unit in the Ribstone Creek tongue (Figure 2), which is the basal aquifer for this area.

A "closed" sampling system was designed in order to collect groundwater samples without degassing of methane. Samples were collected from each monitoring well and analysed for dissolved methane and other hydrochemical parameters. Elevated methane concentrations were observed in the vicinity of the production wells at each site. An analytical model, PATCH3D, was used for preliminary modelling of methane plume migration (see Section 6.1).

3.0 1995 DRILLING PROGRAM

Nine additional monitoring wells were completed at the Lindbergh research site as described in Section 3.1.

In consultation with the Steering Committee, additional research sites were chosen in the vicinity of Lloydminster. In all, five research sites (3 to 7 on Figure 1) with high soil gas concentrations adjacent to the wellhead (Table 1) were investigated in 1995, as described in Sections 3.2 to 3.6.

The selections of the new sites were based on existing information on leaking wells (surface casing vents, soils), production well completion data, test hole and water well records, groundwater and geology maps, and (re)sampling for soil gas concentrations in the vicinity of each wellhead. During the selection process, some cases were noted where production wells had leakage of gas at relatively high rates, but were located in areas where there were no clearly identifiable aquifers present, based on existing data.

The five sites that were chosen give a representative cross section of the problem of gas migration in terms of geology, depth to aquifer BGS and other factors, as described below. In most cases, relatively shallow aquifers (< 50 m BGS) were targeted for monitoring. Information provided by Alberta Environmental Protection had indicated that, in the Alberta portion of the study area, less than 7% of the water wells are completed at depths > 100 m BGS.

Drilling indicated that the targeted aquifers were not always present. On the basis of the information obtained during the site selection process and the drilling program, there are production wells in the Lloydminster area that do not intersect aquifers. Such wells have no potential to release methane directly to groundwater supplies.

Table 1. Soil methane concentration data measured by soil probes at research sites, 1995.

Some concentrations were reported relative to the lower explosive limit (LEL), which is 10% methane.

Site	Date	conc. at wellhead	conc. at 1 m	conc. at 3 m	conc. at 5 m	measured by
Golden Lake	May 25, 1995	28%	16%	20%	0%	D. William Husky Oil
Lone Rock	May 25, 1995	28%	15%	0.5%		D. William Husky Oil
Wildmere	June 5, 1995	1.3%	1.2%	2.1%	1.2%	D. William Husky Oil
Sedgewick	June 5, 1995	15%	12%	4.5%		D. William Husky Oil
Swimming*	Aug. 12, 1995	5.5% to 15%	7.5% to 16%			J. Metherell Husky Oil

*data collected after excavation to 2.4 m

The installations at all research sites in 1994-95 are summarized in Table 2.

3.1 Installation of Additional Monitoring Wells at the Lindbergh Site

Van Stempvoort and Jaworski (1995) had recommended completing one remote monitoring well, ~200 m from the production well at this site, in order to establish the hydraulic gradient before placing additional wells closer to the production well. After further consideration of the probable costs and benefits to the program, a remote monitoring well was not completed. Over the period November 3 to 6, 1995, three "nests" of monitoring wells were completed within 10 m of the production well (Appendix A). Each nest included three monitoring wells completed in a single borehole, at ~0.3, 2 and 4 m below the upper aquifer surface. These nests were installed to determine whether vertical variations in methane concentrations and other hydrochemical parameters are significant (see Appendix A).

Two of the monitoring well nests were completed approximately up-dip of the production well, with reference to the upper aquifer surface, as inferred by existing borehole data. The "up-dip" wells were included to test whether gas phase migration along the upper surface of the aquifer in this direction would be detectable as increased dissolved methane concentrations in the groundwater.

Table 2. Summary of installations at research sites, 1994-95.

Research Site	Location	Company	# of Testholes/ Monitoring Wells	Year Drilled/ Installed	Aquifer	Arrangement of Monitoring Network
Marshall (Aberfeldy)	C14-16-49-26-W3	Husky	1/5	1994	Judith R. Fm. at 20 m	5 individual wells
Lindbergh	16-04-55-06-W4	Amoco/Elan	1/5 0/9	1994 1995	Empress Gp. at 30 m	5 individual wells, 3 nests of 3 wells/borehole
Golden Lake	B10-32-48-23-W3	Petro Canada	1/0	1995	no significant aquifer	test hole grouted off
Lone Rock	07-20-47-26-W3	Carmanah	1/0	1995	no significant aquifer	test hole grouted off
Wildmere	13-14-47-05-W4	Koch	1/5	1995	Empress Gp. at 70 m	5 individual wells
Sedgewick	07-09-44-12-W4	Poco	1/0	1995	no aquifers at target depth	test hole grouted off
Swimming	10-12-52-07-W4	Husky	1/15	1995	Judith R. Fm. at 10 m	3 individual wells, 4 nests of 3 wells/borehole

The other nest was placed down-gradient with respect to the inferred direction of groundwater flow (Van Stempvoort and Jaworski, 1995), despite the uncertainty of this vector. The water level data collected in 1995 (Figure 4) were similar to 1994 data, and again indicated a very low hydraulic gradient. Again the uncertainties of the data were similar to the differences between water levels measured in the wells, so that the groundwater flow direction(s) could not be determined with confidence.

Wells were purged, first with compressed air by the drilling rig and later with a Grundfos Rediflo submersible pump at 14 to 27 L/min for ~60 min.

3.2 Golden Lake (B10-32-48-23-W3, Petro Canada)

This production well site is ~10 km north of Maidstone, Saskatchewan. Based on water well records, oil exploration e-logs in the vicinity, the Ribstone Creek tongue of the Judith River Fm. was inferred to be present at ~20 to 40 m BGS as a suitable shallow aquifer for monitoring. However, test-drilling on June 12 indicated that erosion has removed at least most of the Ribstone Creek tongue at this site (see test hole log for GLD-95-01: Appendix B). Bedrock was encountered at a depth of 46 m BGS, corresponding to an elevation of ~565 m asl. The bedrock lithologies between 46 m and 61 m (bottom of test hole) varied from silty clay to clay. The test drilling indicated two thin (~0.3 and 1 m) intertill sands, but the lateral extent of these units is unknown. This test hole was sealed with bentonite grout and abandoned.

3.3 Lone Rock (07-20-47-26-W3, Carmanah)

This production well site is ~15 km southwest of Lashburn, Saskatchewan. An e-log for another oil well in the same Section (01-20-47-26-W3) suggested the presence of a significant Empress Group aquifer at this site (Millard, 1990). Test drilling on the well lease to a depth of 55 m (~561 m asl) conducted on June 13, 1995 (LNR-95-01) indicated that Empress Group sediments are absent and that no significant aquifer is present at this site (Appendix C). The bedrock surface was encountered at 23 m BGS (593 m asl). The Ribstone Creek interval encountered at ~23 to 40 m BGS is composed mainly of clayey silt, with a thin (~0.5 m) siltstone or concretion horizon at ~26 m BGS. On the basis of evaluation of the cuttings and the e-log, this siltstone horizon does not represent a significant aquifer. Data compiled by Millard

N - S fenceline

Lindbergh Site (16-04-55-06-W4)

Scale 1:500

0 25 50

metres

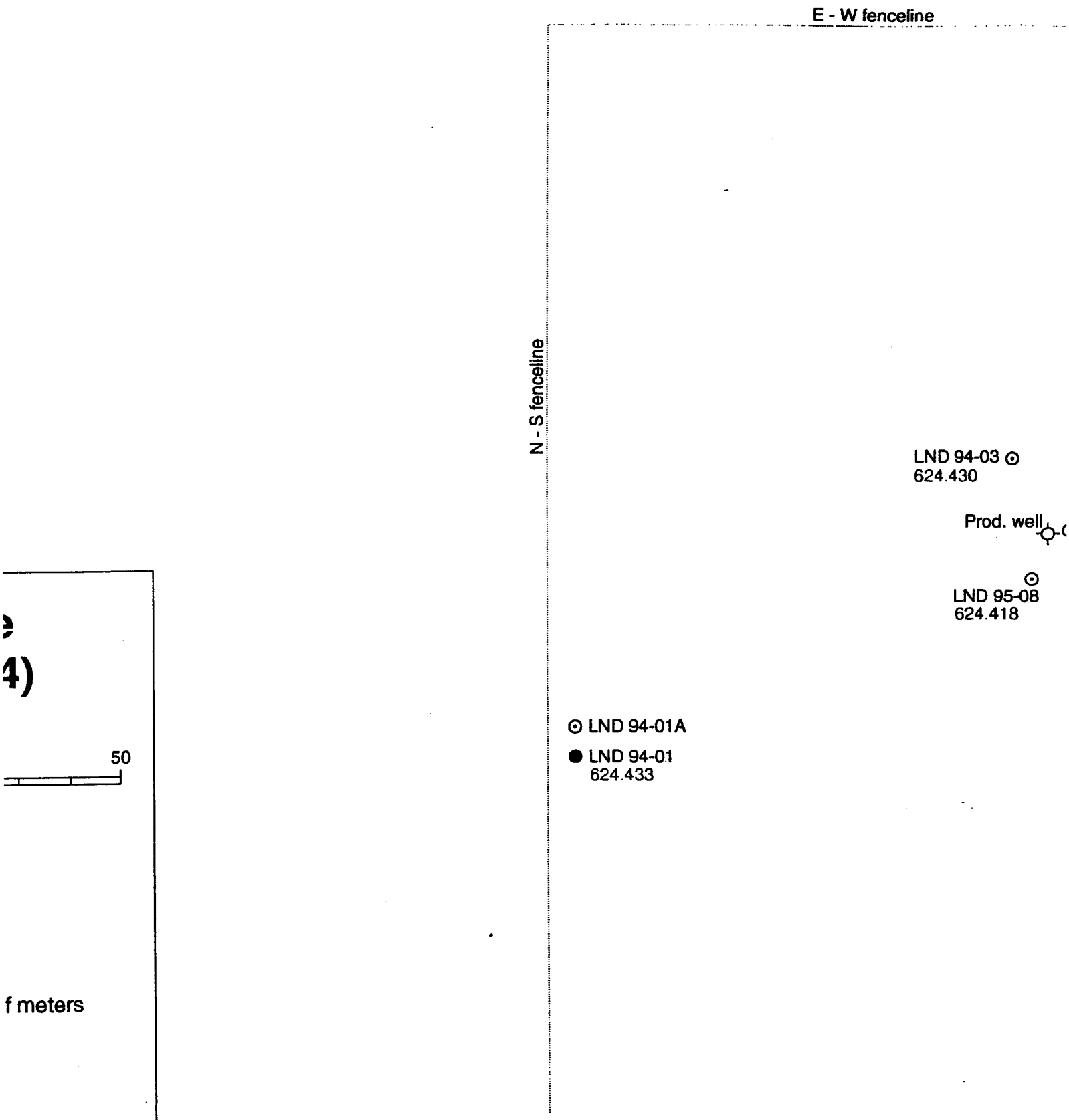
⊙ Monitoring well

Production well

● Testhole

Note: Data at monitoring wells are in units of meters above sea level (accuracy ~±0.005m).

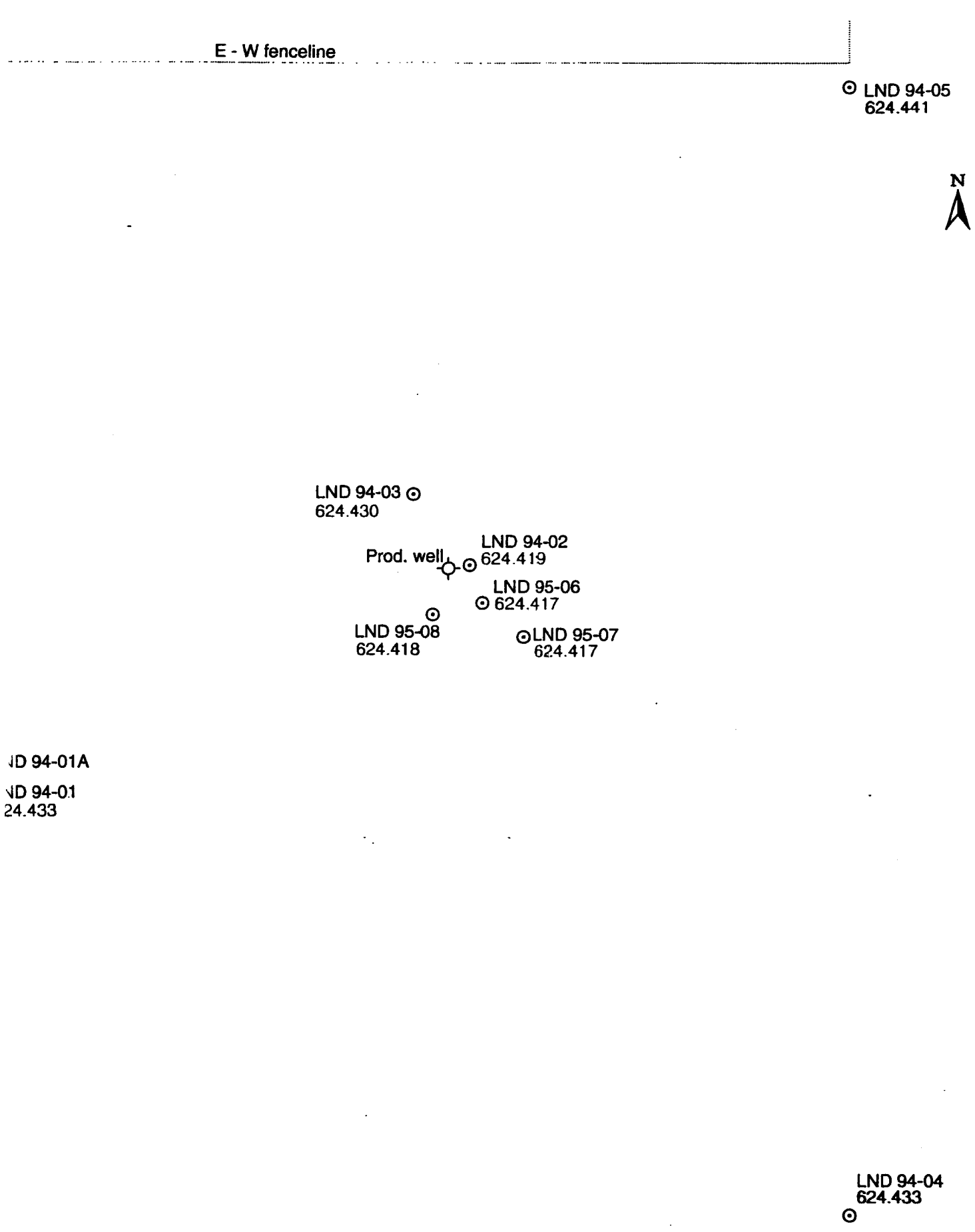
Figure 4: Plan of the Lindbergh site and water levels measured on Dec. 15, 1995.



4)

f meters

water levels


E - W fenceline
LND 94-05
624.441
N
LND 94-03
624.430
LND 94-02
624.419
Prod. well
LND 95-06
624.417
LND 95-08
624.418
LND 95-07
624.417
ND 94-01A
ND 94-01
24.433
LND 94-04
624.433

(St. Walburg map and report) suggest that the Ribstone Creek tongue is partially eroded at this site. The LNR-95-01 test hole was grouted with a bentonite slurry and abandoned.

3.4 Wildmere Site (13-14-47-05-W4, Koch Exploration)

This site is ~25 km northeast of Wainwright, Alta., near the Battle River Valley. The Victoria tongue of the Judith River Fm. was inferred to be present at ~50 to 100 m BGS, based on regional hydrogeological mapping by Ozoray et al. (1994), and examination of water well records and exploration e-logs for this vicinity (provided by Alberta Environmental Protection).

The production well at this site was completed in November, 1983. The total depth of drilling was ~670 m. The surface casing (244.5 mm) was set to a depth of 179.6 m BGS, and cemented with Class "A" + 3% $CaCl_2$. The 177.9 mm production casing was installed to a depth of 662.6 m BGS, and perforated from 638.6 to 643.6 m BGS. Production started in 1983 and has continued through 1995.

For this research program, test drilling adjacent to the production well on June 14 to 15 (WDM-95-01) indicated the presence of several intertill aquifers, a coarse sand and gravel Empress Gp. deposit at ~56 to 77 m, with a silt horizon at 66 to 70 m BGS (Appendix D). Very fine silty sand and silt units (Victoria tongue) were encountered between 82 and 98 m BGS. The suitability of the latter as aquifer zones is apparently marginal. Test drilling was terminated at 116 m BGS.

On the basis of field inspection of the drill cutting samples (1.5 m intervals) and an e-log of the test hole, it was decided to complete a monitoring well in the lower Empress Gp. sand and gravel unit, below the silt horizon. After well completion, the static water level was ~70 m BGS, similar to farm wells in the area (records provided by AEP). This deep level indicates that the Empress Gp. aquifer probably discharges into the Battle River Valley. The difference in ground elevation between the research well and the base of the Battle River Valley is ~75 m.

Four additional monitoring wells were completed in the same Empress Gp. aquifer between ~2 to 100 m from the production well on June 26 to 28 (WDM-95-02, WDM-95-03) and August 28 to 31 (WDM-95-04, WDM-95-05) (Figure 5, Appendix D).

The five wells were developed during several field excursions in August and September. A drilling rig was used to remove the drilling mud remaining within the well casing by displacement with fresh water, which was injected into the screen interval of each well at pressures in excess of 300 psi. Grundfos Redi-flo pumps were used to purge the wells at ~10 L/min for up to several hours. One of these pumps became stuck in well WDM-95-03 on September 21, and it has not yet been retrieved.

Water level data indicate that groundwater flow in this aquifer is to the northwest (Figure 5).

3.5 Sedgewick Site (07-09-44-12-W4, Poco)

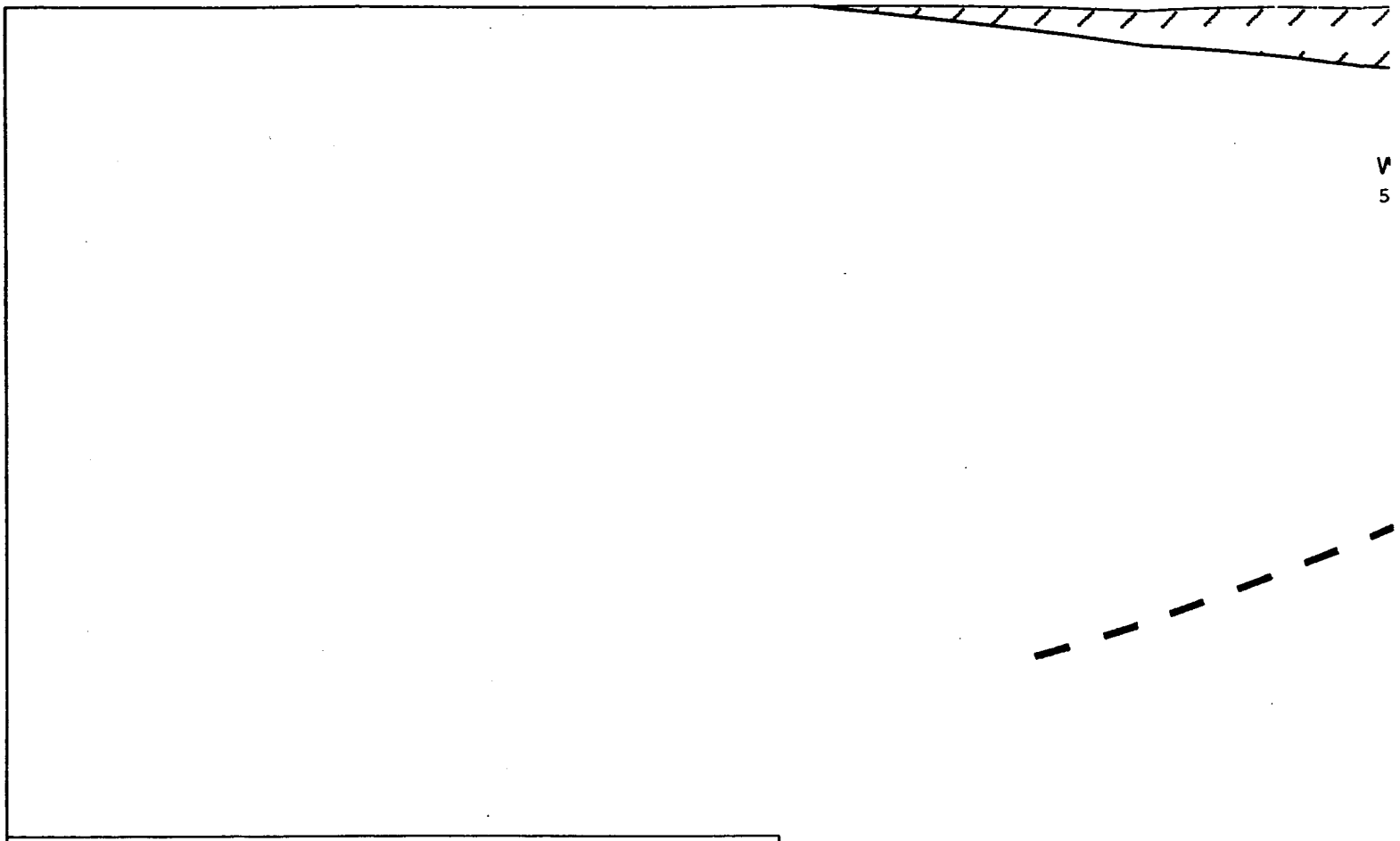
At this site, located a few km east of Sedgewick, Alberta, high gas concentrations were measured in soil adjacent to the wellhead. On the basis of examination of the e-log for this production well, there appeared to be a basal Judith River (Foremost unit) sand or silt unit at a depth of ~210 to 230 m BGS. This depth is below the base of the surface casing (182 m BGS). This zone was targeted as a potential aquifer for investigation of gas migration. A test hole was drilled on June 15 and 19 (SDG-95-01, Appendix E), indicating several significant aquifers:

- a sand unit at bedrock surface (6 to 17 m BGS), interpreted as Empress Group or Judith River Fm.,
- two thinner sands in the Judith River Fm. at ~35 to 36.5 and 38 to 40 m below ground.
- The original target zone (210 to 230 m BGS) consisted of concretionary horizons.

This test hole was filled with bentonite grout and abandoned. Based largely on the negative results of this test hole, and on subsequent discussions with the Steering Committee, it was decided that for the final site selection, it would be best to target a site where existing water well data, including lithologic descriptions, were available for the aquifer zone(s) of interest. It was decided to target the lowermost Judith River tongue (Victoria or Brosseau) in the Alberta portion of the Lloydminster area.

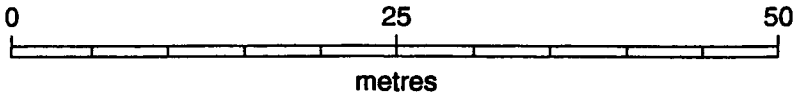
3.6 Swimming (10D-12-52-07-W4, Husky)

A site ~14 km north of Vermilion, Alberta (10D-12-52-07-W4) was chosen on the basis of high soil gas concentrations (Table 1) and inferred presence of the Victoria tongue, including



Wildmere Site
(NE 13-14-47-05-W4)

Scale 1:500



- ⊙ Monitoring well
- ⊕ Production well
- ● Testhole/monitoring well

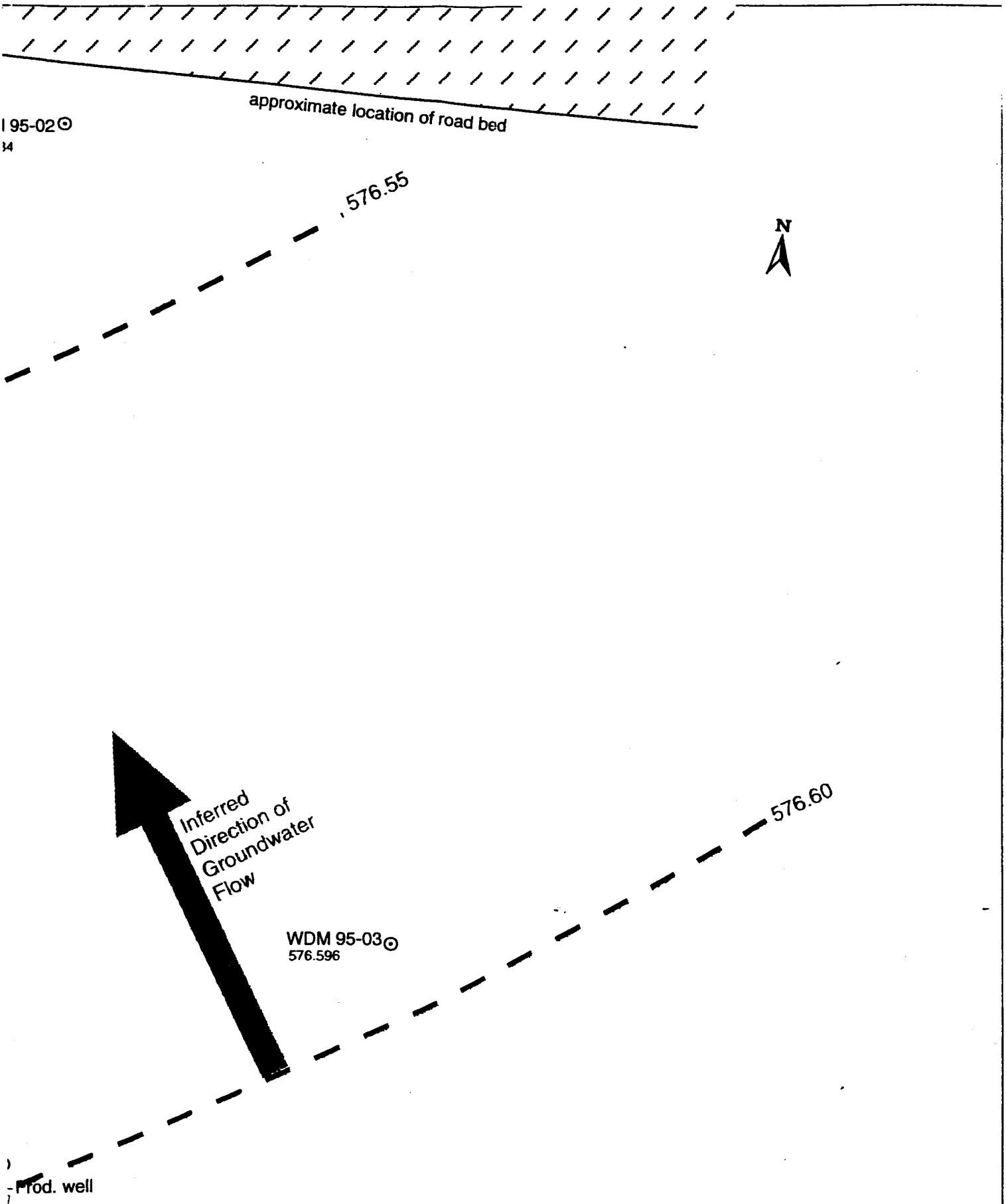
WDM 95-05
576.578 ⊙

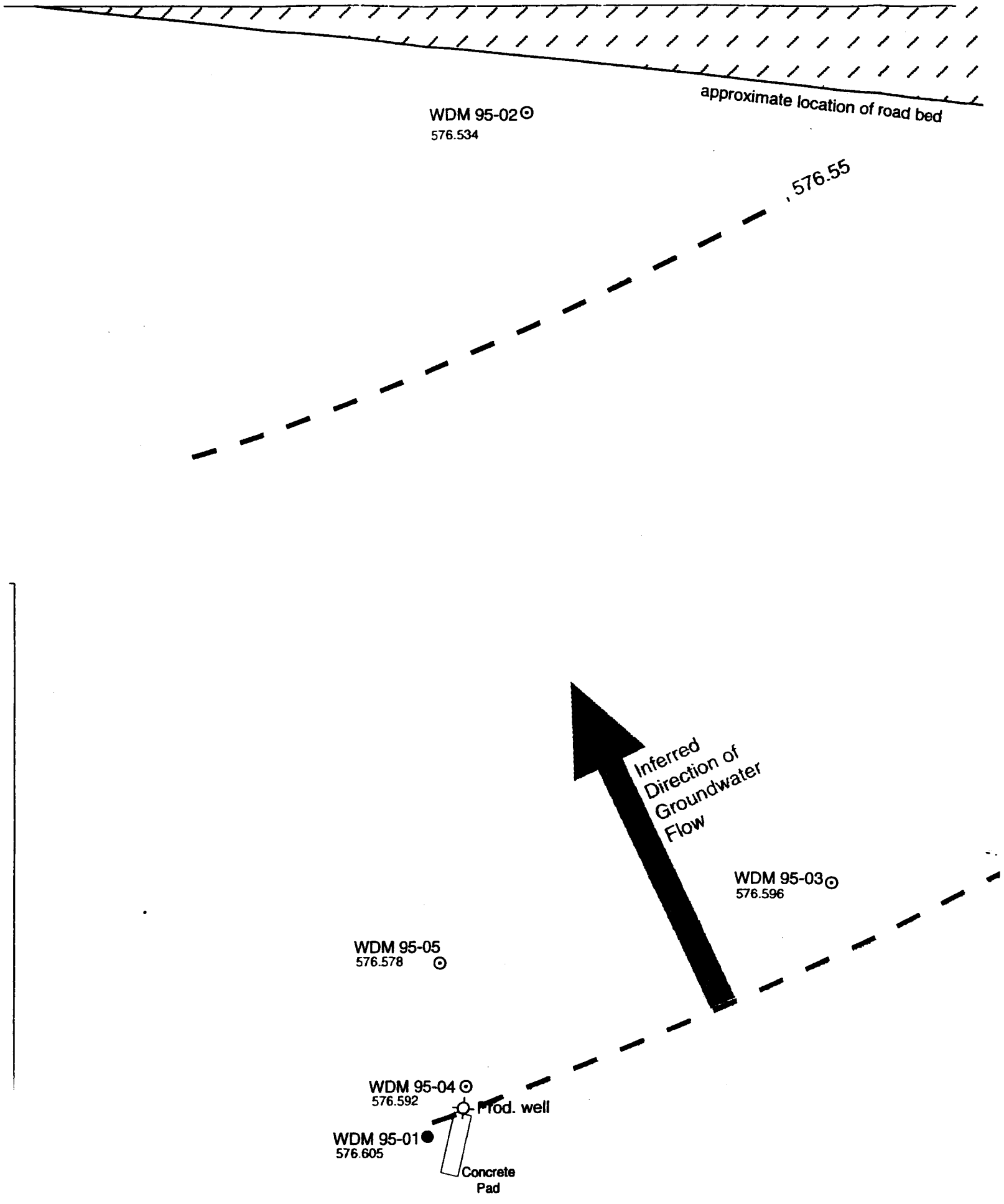
Note: Contours and data at monitoring wells in units of metres above sea level.

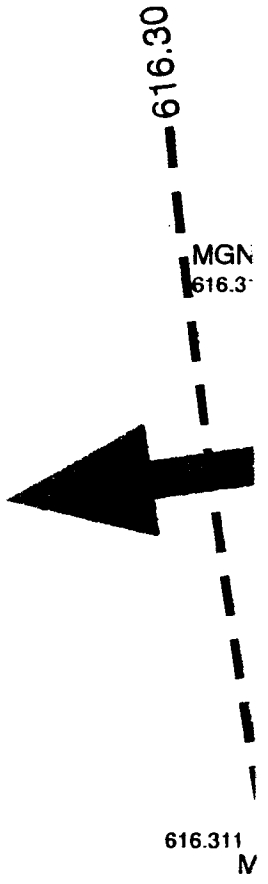
WDM 95-0
576.592

WDM 95-01 ●
576.605

Figure 5 : Plan of the Wildmere site and water levels measured on September 26, 1995.


approximate location of road bed
95-02
576.55
N
Inferred
Direction of
Groundwater
Flow
576.60
WDM 95-03
576.596
Prod. well
Concrete
Pad


approximate location of road bed
WDM 95-02
576.534
576.55
Inferred
Direction of
Groundwater
Flow
WDM 95-03
576.596
WDM 95-05
576.578
WDM 95-04
576.592
Prod. well
WDM 95-01
576.605
Concrete
Pad



Swimming Site
(NE 1/4 LSD 10-12-52-07-W4)

Scale 1:500

0 25 50

metres

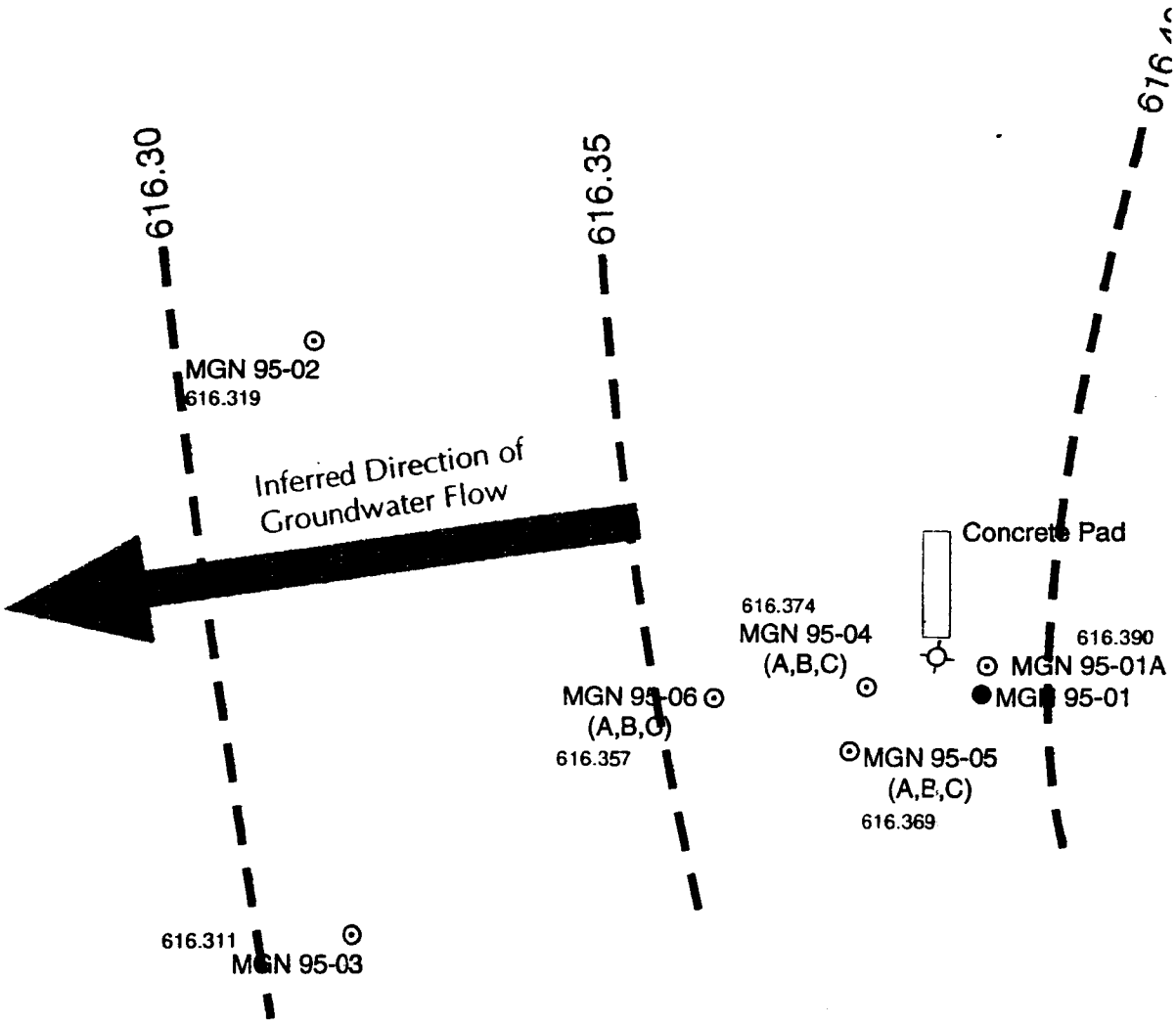
⊙ Monitoring well

⊹ Production well

● Testhole

Note: Contours and data at monitoring wells are in units of metres above sea level.

Figure 6: Plan of the Swimming site and water levels measured on December 14,1995.

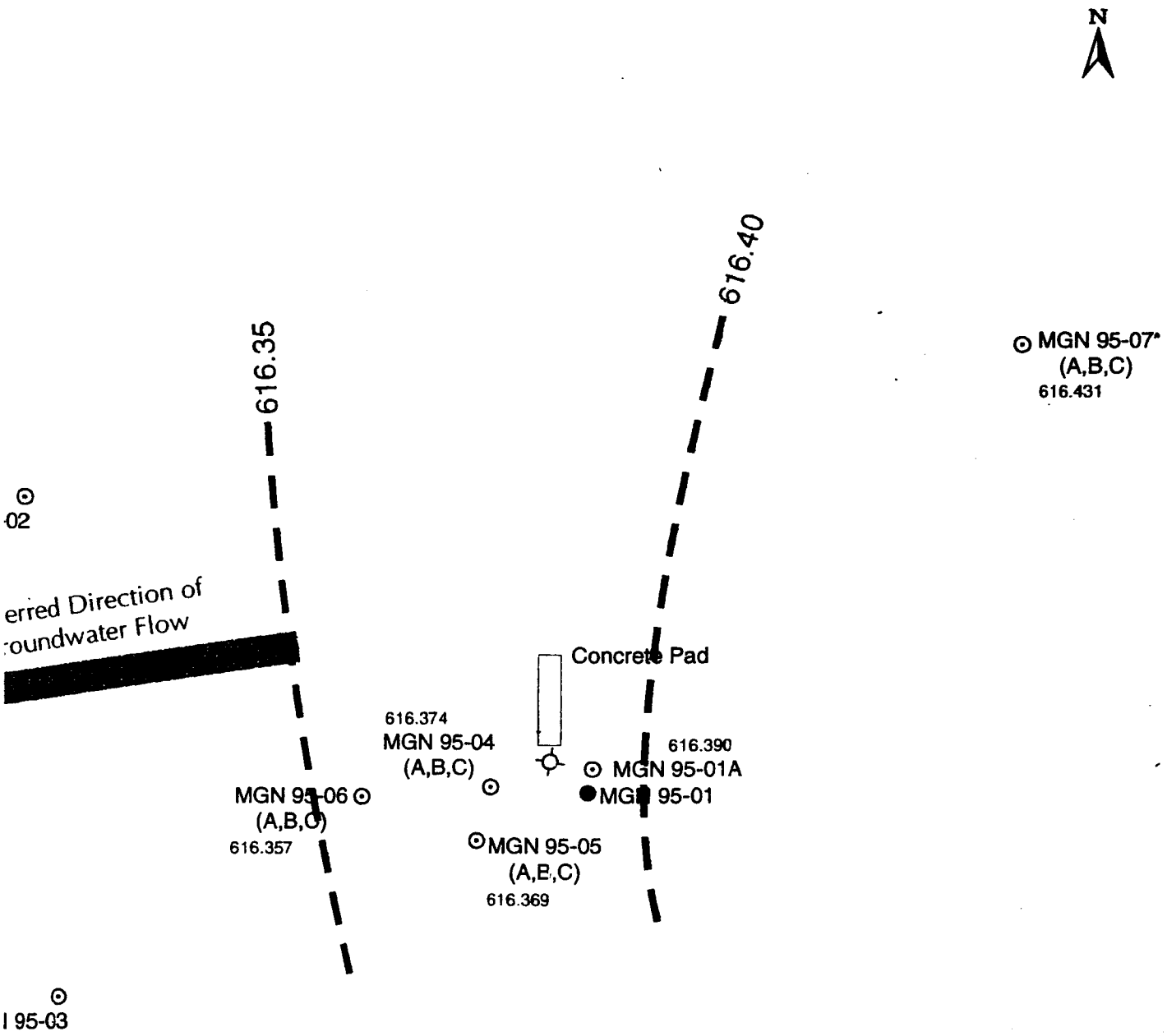

616.30
616.35
MGN 95-02
616.319
Inferred Direction of
Groundwater Flow
Concrete Pad
616.374
MGN 95-04
(A,B,C)
616.390
MGN 95-01A
MGN 95-01
MGN 95-06
(A,B,C)
616.357
MGN 95-05
(A,B,C)
616.369
616.311
MGN 95-03

W4)

50

ts

ls


N
616.35
616.40
MGN 95-07*
(A,B,C)
616.431
02
erred Direction of
roundwater Flow
Concrete Pad
616.374
MGN 95-04
(A,B,C)
616.390
MGN 95-01A
MGN 95-01
MGN 95-06
(A,B,C)
616.357
MGN 95-05
(A,B,C)
616.369
I 95-03

suitable sand(stone) aquifer zone(s), as indicated by hydrogeologic maps, cross sections and water well records obtained from Alberta Environmental Protection.

The oil well at this site was completed in November 1979. The surface casing (273 mm) was set in a 381 mm dia. borehole to a depth of 89 m BGS. The 178 mm production casing was installed to a depth of 652.4 m BGS. Four production zones were perforated at depths between 605 and 530 m BGS between July of 1980 and June of 1982. Production started in 1980 and ended in June 1988.

A test hole was drilled on August 23, 1995, adjacent to the production well to depth of ~91 m BGS (MGN-95-01, Appendix F). A Victoria tongue sand unit was encountered from 7.3 to 13.4 m BGS. This aquifer is semi-confined by weathered till and 3 m of intertill sand (1.2 to 4.2 m BGS). The test hole was grouted with bentonite slurry.

Three wells were completed in the Victoria tongue unit on August 24, 1995 (MGN-95-01A, -02 and -03; Appendix F). The wells were purged by a Grundfos Redi-flo pump at 15/L min for ~120 min. The water level data for these wells indicated flow to the southwest (Figure 6). Initial methane data indicated slightly elevated concentrations at MGN-95-03, approximately down flow of the production well (see Section 5.5).

Four additional nests of wells were completed on November 23 to 24, 1995: MGN-95-4, 5, 6 and 7 (Figure 6, Appendix F). Each nest included 3 wells installed in the same bedrock aquifer, completed near its base (A), middle (B) and top (C) (Appendix F). Within a day of completion, these wells were air-lifted for several minutes to remove drilling fluid and then purged with centrifugal pumps (GSW model 560580) at ~14 L/min for up to 125 min.

4.0 HYDRAULIC PROPERTIES OF AQUIFERS AT RESEARCH SITES

In 1995, the hydraulic properties of the aquifers being monitored at the Lindbergh and Swimming research sites were investigated by pumping tests. An infiltrometer test was also conducted at the Swimming site to obtain information on the hydraulic conductivity of the soil profile. A slug test provided an estimate of the hydraulic conductivity of the aquifer at the Wildmere site.

The data from a 1994 pumping test conducted at the Marshall site pumping test data have been reported by Van Stempvoort and Jaworski (1995) and are not discussed further here.

4.1 Swimming Site Pumping Test Results

At the time of the pumping test (October 19, 1995), only 3 of 15 monitoring wells had been installed at this site. The water elevations in all three wells were recorded using vented transducers (DRUCK model PTX 160/D-0241) and dataloggers. A Grundfos 5-cm diameter submersible pump was set ~5 m below the water table in well MGN-95-01A. The pumping test commenced at 9:58 am on October 19, 1995, and a constant pumping rate of 14 L/min was maintained for 189 minutes; the recovery was observed for 180 minutes.

The pumping test data from observation wells MGN-95-02 and MGN-95-03 provided information concerning the hydraulic conductivity, storativity, and semi-confined nature of the aquifer at this site. The calculations shown on Table 3 were based on the Theis method, using the AQTESOLV program (Geraghty and Miller, Inc., 1991) . Plots of the curve matches are given in Appendix G.

Table 3. Calculated hydraulic parameters for the aquifer at the Swimming site.

Well Transducer Data	Distance to Pump Well	Transmissivity		Conductivity (cm/s)	Storativity
		m^2/min	m^2/day		
MGN-95-01A-R	leakage from check valve, data not valid				
MGN-95-02-P	50.85	0.009913	14.23	0.0027	0.00037
MGN-95-03-P	46.74	0.01736	25	0.0047	0.00058

P = pumping R = recovery

The variations in transmissivity inferred on Table 3 may be caused by differences in saturated aquifer thickness between these wells, or differences in hydraulic conductivity. Hydraulic conductivity was estimated using a constant saturated thickness of 6.1 m.

4.2 Swimming Site Infiltrometer Testing Results

Three infiltrometer tests were run at the Swimming site ~20 m from well MGN-95-01A in the direction of well MGN-95-02. This area was on the grassed edge of the lease. The first test, at a depth of 50 cm did not produce any measurable infiltration, possibly because of frost or sidewall smearing during hole preparation. The second test at a depth of 100 cm indicated a saturated hydraulic conductivity of 1.7×10^{-4} cm/s, which is consistent with the silty and clayey

sand in the soil profile. A clean sandy layer at 90 to 95 cm depth may have skewed the result. The third test was at a depth of 50 cm. The saturated hydraulic conductivity was found to be 4.1 x 10^{-4} cm/s.

The semi-confined nature of the aquifer being monitored at this site is likely more dependent on hydraulic properties of subsoil till (to depth of ~7 m BGS) than of the soil horizons in which the infiltrometer test was performed.

4.3 Lindbergh Site Pumping Test

A total of seven observation wells were utilized during the pumping test at the Lindbergh site. In three of the observation wells, and the pumping well, the water elevation data were recorded using transducers and data loggers (as described in 4.1) In the remaining four wells water level data were obtained manually using an e-tape (electric water level indicator).

A Grundfos 5-cm diameter submersible pump was set ~7.5 m below the water table in well LND-94-02. The pumping test commenced at 11:30 am on November 21, 1995. A constant pumping rate of 20 L/min was maintained for 200 minutes; the recovery was observed for 120 minutes.

The transmissivities and storativities were calculated by matching the Theis curve in AQTESOLV. The hydraulic conductivity was then found by assuming an average aquifer thickness of 20 m throughout the area, based on the 1994 test hole log (LND-94-01). The calculated values are listed in Table 4.

Table 4. Calculated hydraulic parameters for the aquifer at the Swimming site.

Well	Distance from Pumping Well (m)	Transmissivity		Conductivity (cm/s)	Storativity
		m^2/min	m^2/day		
e-tape data					
LND-94-01A-R	52.5	0.1264	182	0.0105	0.00024
LND-94-03-P	9.04	0.06532	94		0.00044
-R		0.07886	113	0.0065	0.00027
LND-94-04-P	74.0	0.08127	117	0.0068	0.00016
-R		0.08197	118	0.0068	0.00016
LND-94-05-P	60.5	0.06852	99	0.0057	0.0001
-R		0.07216	104	0.006	0.00009
transducer data					
LND-94-02-R	0.0	0.000892	1.28	0.0005	n/a
LND-95-07-P	8.84	0.05632	81	0.0047	0.0015
-R		0.07274	105	0.0061	0.0005
LND-95-08-P	6.07	0.06296	91	0.0053	0.0002
-R		0.08055	116	0.0067	0.0004

P = pumping R = recovery
Additional transducer data was collected in wells LND-95-06A and -06C, but are not reported here.

The mean of calculated hydraulic conductivity is 6.0 x 10^{-3} cm/s, typical of a clean sand (Freeze and Cherry, 1979, p.29). This is very similar to the single estimate of 7.1 x 10^{-3} cm/s, based on 1994 pump test data (Van Stempvoort and Jaworski, 1995).

4.4 Wildmere Site Slug Test Results

A 1.62 L PVC slug was placed in monitoring well MGN-95-02 at the Wildmere site on October 18, 1995, above a pressure transducer (as described in 4.1). The water level data collected within a few seconds of 1) withdrawal, and 2) subsequent replacement of the slug, were analysed using the Bouwer and Rice Method in AQTESOLV. These analyses suggest that the hydraulic conductivity of the aquifer is 2.0 to 2.3 x 10^{-2} cm/s. This range is consistent with the typical values for well sorted sand and gravel.

5.0 METHANE, ETHANE & OTHER ANALYSES FOR RESEARCH SITES, 1995

5.1 Sampling and Analytical Methods for Dissolved Species

Water samples were collected from all monitoring wells and analysed for the following components: concentrations of dissolved methane and ethane, major ions, pH, Eh, Fe, Mn, and $NO_3 + NO_2$. The methane and ethane data are essential for modelling the fluxes of these gases from leaking wells into shallow aquifers. The redox species concentrations give a general indication of the potential for bio-oxidation of methane within the aquifers.

Improvements were made to methane (and ethane) sampling and extraction techniques, based on the methods and experience of the 1994 program (Van Stempvoort and Jaworski, 1995). Instead of using an in-line sampler above-ground in a back-pressured system, as in 1994, a modified system was designed for down-hole placement of samplers. The in-line samplers used in this system were very similar to the stainless steel and Teflon® samplers used in 1994, but narrower in construction so that they could be lowered down the monitoring wells. At the Marshall and Wildmere sites, groundwater was sampled with a bladder pump, but in the 1995 system the pump was located above rather than below the sampler. At the Lindbergh and Swimming sites, where water levels were relatively high, the samplers were placed downhole below peristaltic pumps. The low pumping rates during purging (~10 L) and sampling for methane (~100 to 200 mL/min) were chosen to maximize lateral flow from the formations to the samplers (Kearl et al., 1994), with negligible contamination from the overlying stagnant water column. Thus, inflatable packers were not used, as in 1994, to isolate the well screen interval. The above described modified sampling system was used for sampling all monitoring wells in 1995, and at the Lindbergh site and Swimming sites for up to two or three occasions.

For laboratory extraction of dissolved methane from the samplers, a modified system was tested and implemented. A small glass headspace vessel was designed (~20 mL), with a vacuum-tight fitting for attaching a sampler. For evolving methane into the evacuated headspace, each sample was agitated in an ultrasonic water bath at room temperature. The headspace was adjusted to 1 atm pressure with He injected from a gas reservoir through a septum. A subsample was then collected with a microsyringe via the same septum for injection into the gas chromatograph.

As anticipated, the above proposed changes in extraction procedures reduced the time required for each analysis, and eliminated the problem of some incomplete sample transfers, as occurred in 1994 (Van Stempvoort and Jaworski, 1995).

For analyses of methane, excepting those near the detection limit (at least one result of 0.003 mg/L or less, where detection limit = 0.001 mg/L), duplicates generally deviated by less

than 25%, and the mean deviation was 17.3%. Because these are sequential duplicates, it is unclear if the deviations of results, in excess of the instrumental precision of gas chromatography (+/- 5 to 10%), reflect real variations in the groundwater sampled, rather than errors due to sampling, storage and extraction procedures.

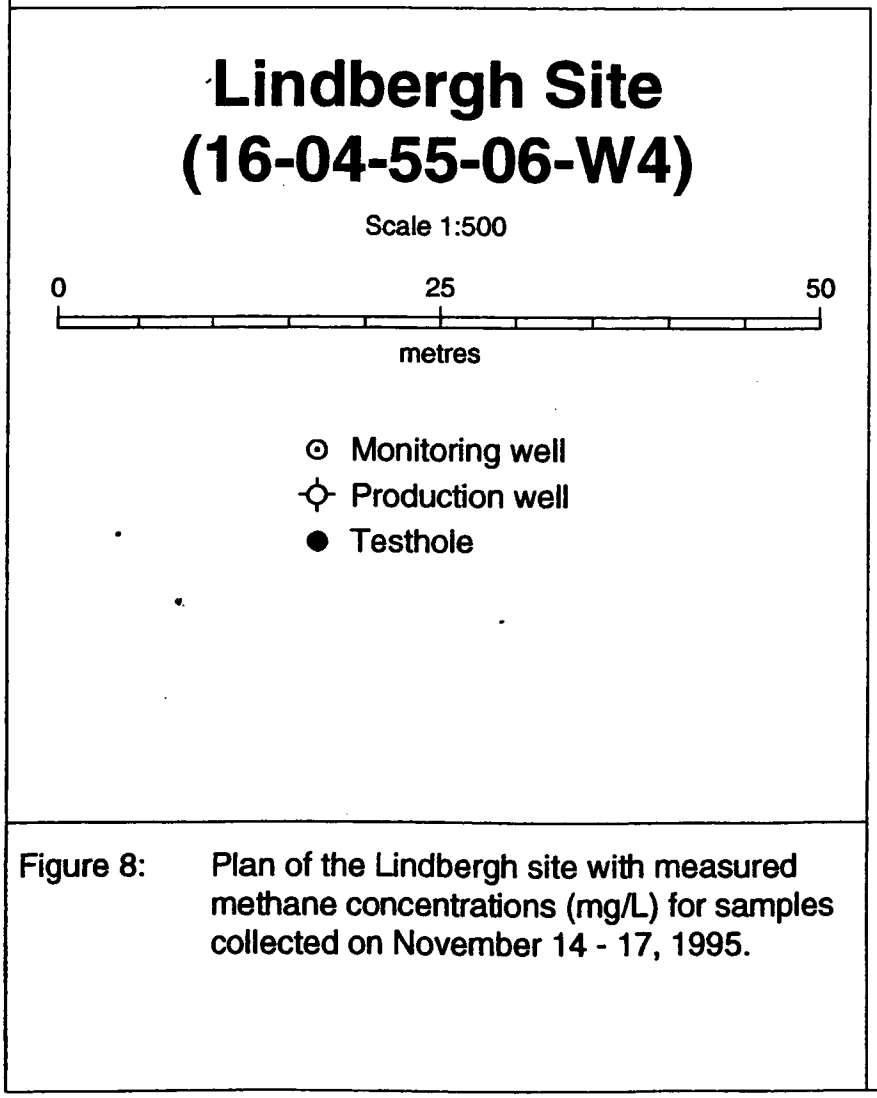
For samples that had detectable ethane > 0.002 mg/L (11 cases), the average deviation of duplicate analyses was 19.4%, which is similar to the results for methane.

Duplicate methane samples were collected once each from the Marshall and Wildmere sites in 1995. Methane was determined on two occasions for some of the wells at the Lindbergh and Swimming sites, because these sites have been selected for more detailed investigation.

5.2 Methane and Other Analyses for Marshall Site

As a group, the methane concentrations measured in the five monitoring wells at this site were low (< 0.1 mg/L) and similar to those determined in 1994 (Figure 7, Table 5). However, for individual wells, there were significant differences between 1994 and 1995 data. In 1994, the methane concentrations in MAR-94-01 and MAR-94-04 were the highest for this site, but they declined to lowest values at this site in 1995. The concentration measured for MAR-94-01 declined by nearly 2 orders in magnitude from 0.16 to 0.003 mg/L. The concentration in MAR-94-04 declined from 0.055 mg/L to non detectable (< 0.001 mg/L). In contrast, the level in monitoring well MAR-94-03 increased from the lowest values in 1994 for this site (0.002 to 0.004 mg/L) to the highest value in 1995 (0.06 mg/L). These results undermine the preliminary modelling of methane concentrations at this site by Van Stempvoort and Jaworski (1995), based on the spatial variations of 1994 data. The deviations between the concentrations measured in each of MAR-94-01, -03 and -04 in 1994 and 1995 are > 90%, much larger than the deviations for duplicate analyses conducted in 1995 (typically < 25%; see Section 5.1). This contrast indicates that the measured changes in methane concentrations in these wells from 1994 and 1995 are significant.

Other hydrochemical data collected from the monitoring wells at the Marshall site in 1995 were similar to equivalent 1994 data (Table 6). As in 1994, sulfate concentrations were lowest in MAR-94-01 and MAR-94-02, which are nearest to the production well. As discussed by Van Stempvoort and Jaworski (1995), this pattern suggests that sulfate reduction may occur during biodegradation of methane at this site.



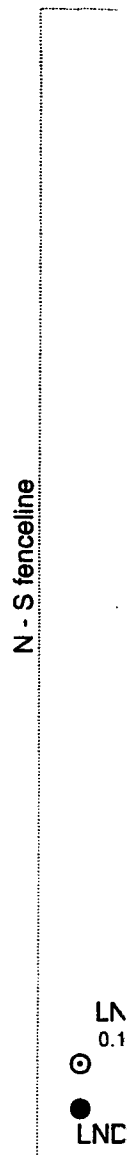
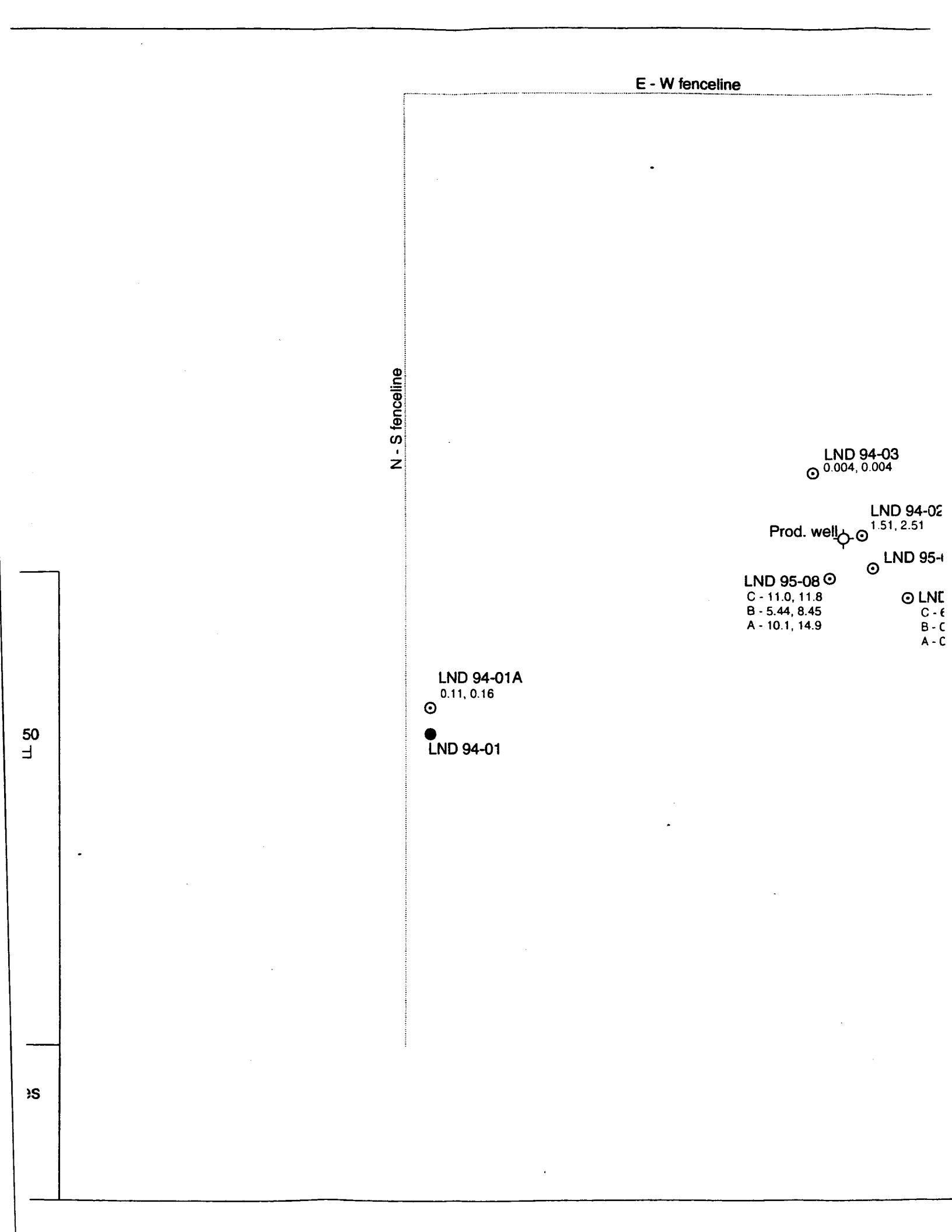


Figure 8: Plan of the Lindbergh site with measured methane concentrations (mg/L) for samples collected on November 14 - 17, 1995.


E - W fenceline
N - S fenceline
LND 94-03
0.004, 0.004
LND 94-02
1.51, 2.51
Prod. well
LND 95-
LND 95-08
C - 11.0, 11.8
B - 5.44, 8.45
A - 10.1, 14.9
LND
C -
B - C
A - C
LND 94-01A
0.11, 0.16
LND 94-01
50
TT
S

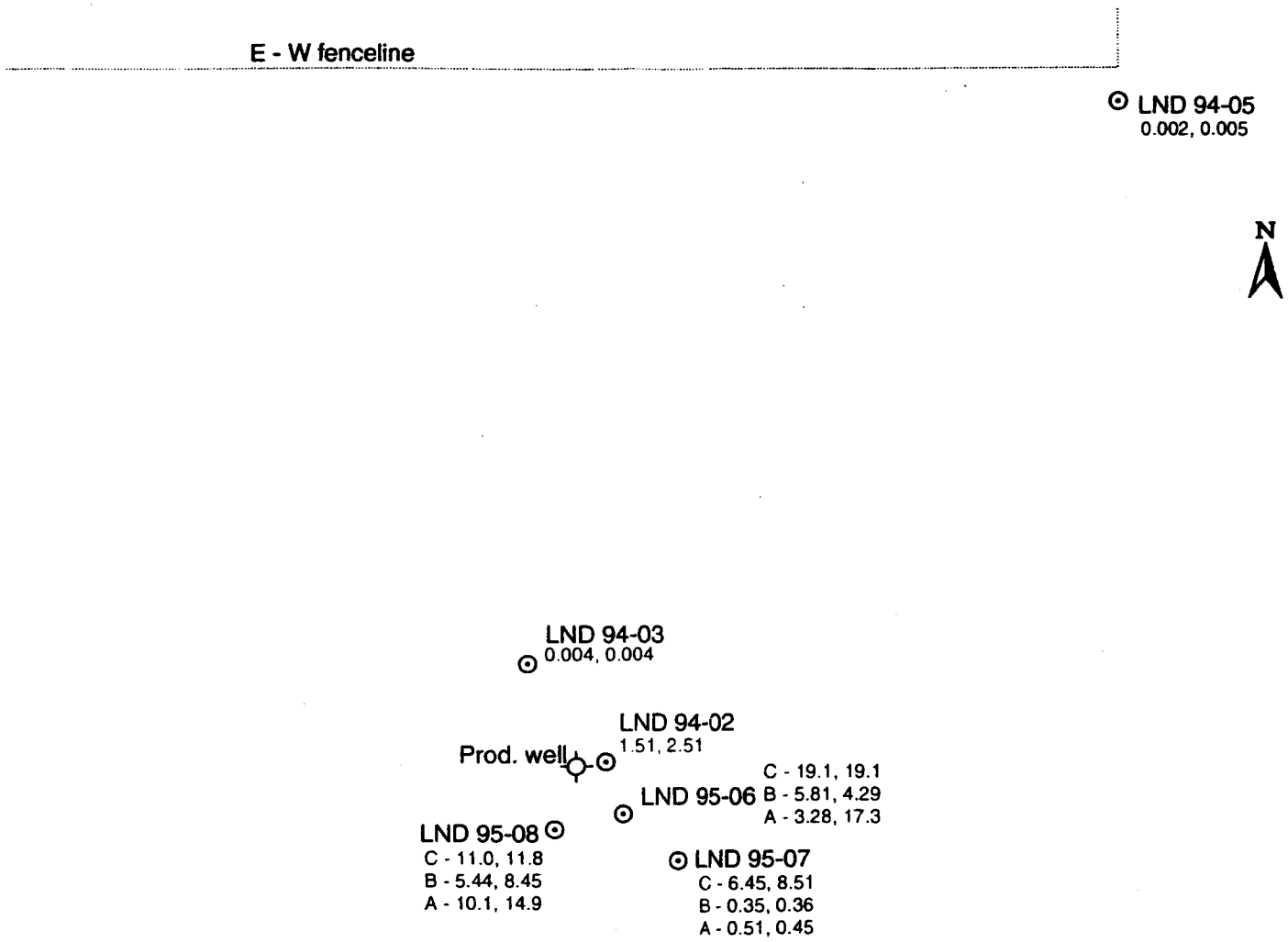

E - W fenceline
LND 94-05
0.002, 0.005
N
LND 94-03
0.004, 0.004
LND 94-02
1.51, 2.51
Prod. well
C - 19.1, 19.1
LND 95-06
B - 5.81, 4.29
A - 3.28, 17.3
LND 95-08
C - 11.0, 11.8
B - 5.44, 8.45
A - 10.1, 14.9
LND 95-07
C - 6.45, 8.51
B - 0.35, 0.36
A - 0.51, 0.45
LND 94-04
0.002, 0.003

Table 5. Dissolved methane and ethane concentrations in groundwater at the Marshall site.

Monitoring Well	Sample Date	Methane (mg/L)	Ethane (mg/L)
Marshall (Aberfeldy) Site			
MAR-94-01	May 30/94	0.16	ND
	May 30/94	0.044	ND
	Oct 19/94	(0.003**)	ND
	Sept 28/95	0.003	ND
MAR-94-02	May 30/94	0.025	ND
	May 30/94	0.012	ND
	May 30/94	0.039	ND
	Oct 19/94	0.022	ND
	Sept 28/95	0.011	ND
	Sept 28/95	0.007	ND
MAR-94-03	May 30/94	0.002	ND
	May 30/94	0.004	ND
	Oct 17/94	0.003	ND
	Sept 29/95	0.06	ND
MAR-94-04	Sept 30/94	(0.001**)	ND
	Sept 30/94	0.055*	
	Oct 17/94	0.027	ND
	Sept 29/95	<0.001	ND
MAR-94-05	Sept 30/94	0.003	ND
	Sept 30/94	0.0063*	
	Oct 17/94	0.015	ND
	Sept 29/95	0.003	ND
	Sept 29/95	0.004	ND

*analysed at the National Hydrology Research Institute, all other analyses at the Saskatchewan Research Council,
**assumed erroneous results because of observed incomplete sample transfers during extractions.
ND = not detectable

Table 6. Major ions and other hydrochemical parameters in groundwater at the Marshall site.

Monitoring Well	Date Sampled YYMMDD	pH field	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO3 (mg/L)	SO4 (mg/L)	Cl (mg/L)	Fe (mg/L)	Mn (mg/L)	NO3 + NO2 (mg/L)	field Eh mV	Sum of Ions (mg/L)
MAR-94-01	940530	7.28	125	45	139	7.3	514	338	5			<0.01		1173.3
	941019		128	50	59	5.5	535	213	2	1.4	0.16	<0.01		994.06
	951004	7.79	155	52	47	5.4	543	221	3	1.7	0.082	<0.01	-53.6	1028.18
MAR-94-02	940530	7.18	140	50	43	5.8	520	199	2			<0.01		959.8
	941019		144	51	40	6	622	208	2	1.3	0.27	0.01		1074.58
	951004	8.01	149	48	44	5.2	540	195	2	1.9	0.11	0.01	-70.5	985.22
MAR-94-03	940530	6.98	201	76	67	6.7	614	423	3			<0.01		1390.7
	941017		208	75	59	6	622	430	3	2.7	0.22	<0.01		1405.92
	950929	7.18	205	79	66	6.6	633	479	3	2.8	0.13	<0.01	-137.5	1474.53
MAR-94-04	940930	7.01	171	62	50	6.2	579	289	4			<0.01		1161.2
	941017		166	62	59	7.3	579	277	3	0.46	0.67	<0.01		1154.43
	950929	7.11	169	64	45	5.8	580	280	3	2	0.19	<0.01	-68	1148.99
MAR-94-05	940930	7.17	170	63	54	6	567	317	4			<0.01		1181
	941019		166	62	62	7.2	568	301	3	0.87	0.36	<0.01		1170.43
	950929	7.09	168	63	50	5.9	571	288	3	2.2	0.12	<0.01	-53.3	1151.22

The concentrations of sulfate in the groundwater at this site are 3 to 5 orders in magnitude higher than the dissolved methane concentrations. If the spatial variations in sulfate concentrations are directly or indirectly related to bacterial oxidation of methane as in Equation 1 (cf. Van Stempvoort and Jaworski, 1995), then most of the methane that was once present in the groundwater has been oxidized, and the amounts measured in the monitoring wells in 1994 to 95 are only a minute residual fractions.

$$SO_4^{2-} + CH_4 \text{ -------> } HS^- + HCO_3^- + H_2O \qquad \text{Equation 1}$$

Since the minimum and maximum sulfate concentrations in the monitoring wells at Marshall vary by ~280 mg/L, it is possible on the basis of Equation 1 that ~50 mg/L of methane is missing from the groundwater due to oxidation. In contrast, although the observed changes in the measured concentrations of methane over time in the wells (> 0.2 mg/L) are large relative to the concentration values, they correspond to very small changes in sulfate concentrations (> 1.2 mg/L, using Equation 1), relative to the measured concentrations of sulfate.

5.3 Methane and Other Analyses for Lindbergh Site

The 1995 hydrochemical data for the Lindbergh site included repeat analyses for the five monitoring wells installed in 1994 (Van Stempvoort and Jaworski, 1995). The 1995 methane concentrations were similar to the 1994 data (Figure 8, Table 7). Methane continued to be relatively high in LND-94-02 in 1995 (1.5 to 6 mg/L), but had generally declined over the period June 1994 to November 1995.

The new monitoring wells were installed in three nests to determine vertical gradients in hydrochemistry near the production well (see Section 3.1). The wells in these nests are completed within the upper 5 m of a thick (~20 m) sand and gravel channel.

The November 1995 data from these nests indicated highest levels of methane at any research site to date, as well as significant ethane concentrations (Figures 8 to 11, Table 7). In nest LND-95-06 (wells A, B and C), which is inferred to be 5 m up-dip of the production well, the concentrations (mg/L) were highest at the top of the aquifer (19.1), and lowest at the bottom well (3.3) excepting an anomalous duplicate analysis (17.3) (Figure 9). Nest LND-95-07(A, B, C), which is 10 m up-dip from the production well (Figure 8), had lower methane concentrations.

Table 7. Dissolved methane and ethane concentrations in groundwater at the Lindbergh site.

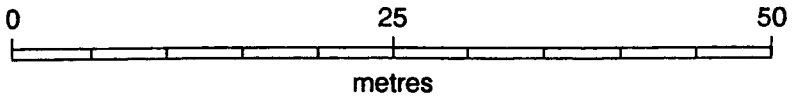
Monitoring Well	Sample Date	Methane (mg/L)	Ethane (mg/L)	Monitoring Well	Sample Date	Methane (mg/L)	Ethane (mg/L)
LND-94-01A	June 1/94	0.062	ND	LND-94-05	Oct. 6/94	0.003	ND
	June 1/94	0.063	ND		Oct. 6/94	0.025*	
	Oct. 18/94	0.02	ND		Oct. 18/94	(0.003**)	ND
	Sept 27/95	0.076	ND		Sept 27/95	0.006	ND
	Sept 27/95	0.013	ND		Nov 15/95	0.002	ND
	Nov 15/95	0.0106	ND		Nov 15/95	0.005	ND
	Nov 15/95	0.0162	ND				
				LND-95-06A	Nov 17/95	3.278	0.017
					Nov 17/95	17.25	0.01
LND-94-02	June 1/94	8.56	0.043				
	June 1/94	13.9	0.068				
	June 1/94	12.2	0.06	LND-95-06B	Nov 17/95	5.814	0.041
	Oct. 18/94	2.1	0.009		Nov 17/95	4.285	0.027
	Oct. 18/94	6.22*					
	Sept 27/95	5.98	0.017				
	Sept 27/95	3.77	0.01	LND-95-06C	Nov 17/95	19.083	0.077
	Nov 14/95	2.512	0.012		Nov 17/95	19.052	0.08
	Nov 14/95	1.508	0.006				
				LND-95-07A	Nov 17/95	0.505	0.003
					Nov 17/95	0.448	0.001
LND-94-03	June 1/94	0.02	ND				
	June 1/94	0.012	ND	LND-95-07B	Nov 17/95	0.359	0.002
	Oct. 18/94	0.014	ND		Nov 17/95	0.352	0.002
	Sept 27/95	0.013	ND				
	Sept 27/95	0.023	ND				
	Nov 14/95	0.004	ND	LND-95-07C	Nov 17/95	6.445	0.013
	Nov 14/95	0.004	ND		Nov 17/95	8.507	0.026
				LND-95-08A	Nov 17/95	10.09	0.045
					Nov 17/95	14.903	0.074
LND-94-04	Oct. 6/94	(< 0.001**)	ND				
	Oct. 18/94	0.03	ND				
	Sept 27/95	0.005	ND	LND-95-08B	Nov 17/95	8.445	0.036
	Nov 15/95	0.002	ND		Nov 17/95	5.438	0.021
	Nov 15/95	0.003	ND				
				LND-95-08C	Nov 17/95	10.953	0.025
					Nov 17/95	11.776	0.028

*analysed at the National Hydrology Research Institute, all other analyses at the Saskatchewan Research Council.
**assumed erroneous results because of observed incomplete sample transfers during extractions.
ND = not detectable

⊙ MAR 94-04
<0.001

Marshall Site
(NW1/4 LSD 14-16-49-26 W3)

Scale 1:500

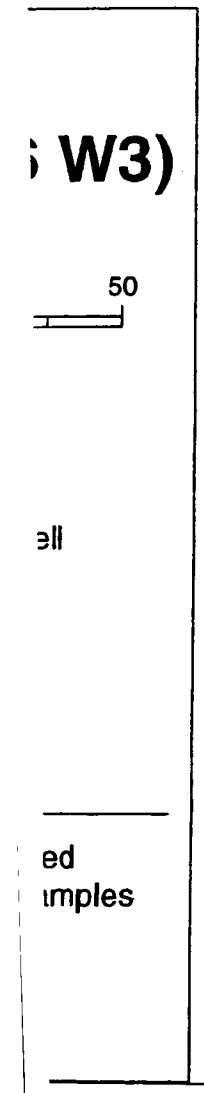


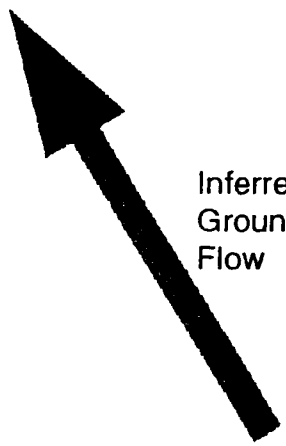
⊙ Monitoring well
⊹ Production well
● Testhole and monitoring well

Figure 7: Plan of the Marshall site with measured methane concentrations (mg/L) for samples collected on Sept. 28-29, 1995.

E -W fenceline

⊙MAR 94-04
<0.001





⊙MA
0.0(

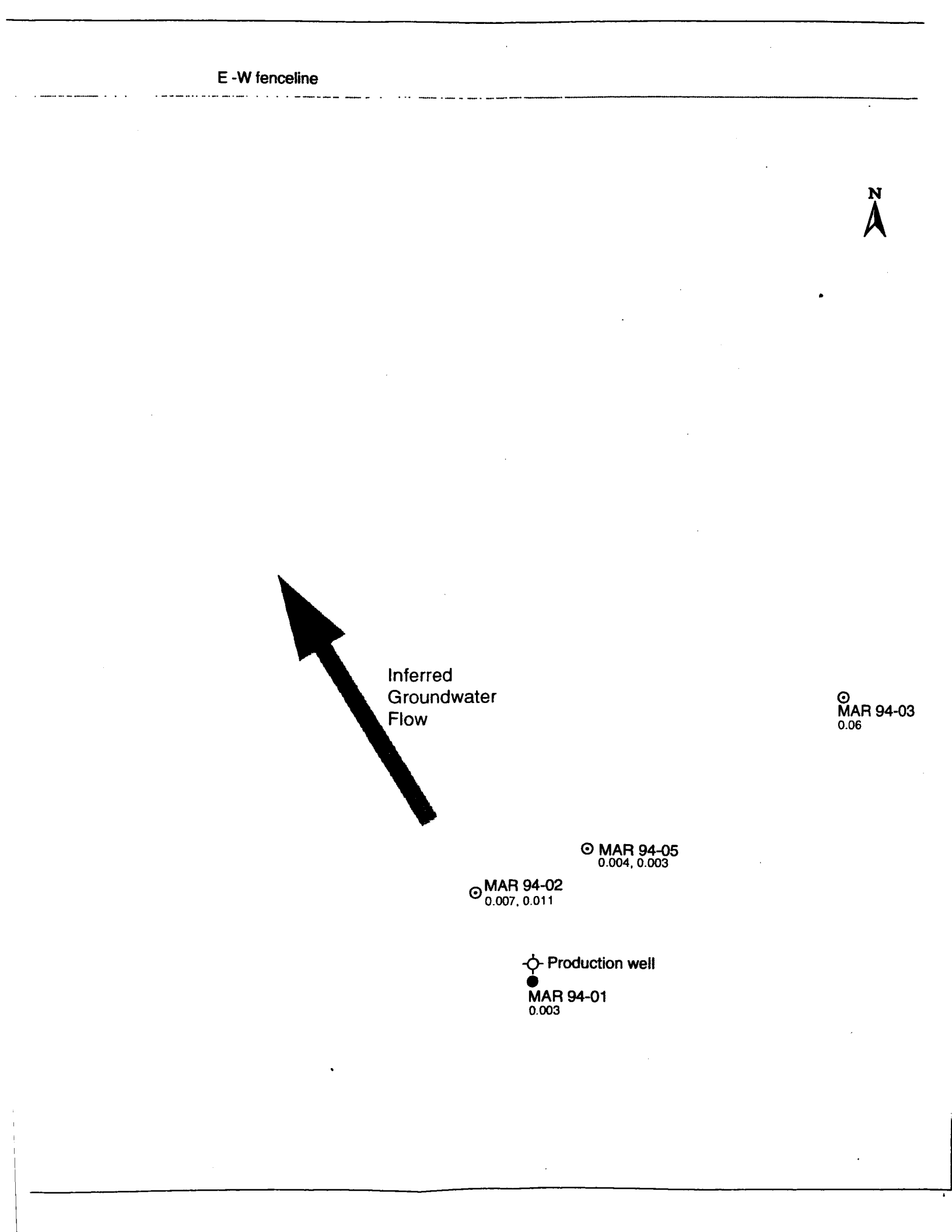

E -W fenceline
N
Inferred
Groundwater
Flow
MAR 94-03
0.06
MAR 94-05
0.004, 0.003
MAR 94-02
0.007, 0.011
Production well
MAR 94-01
0.003

Figure 9. Vertical profile of hydrochemistry at LND-95-06A, B and C.

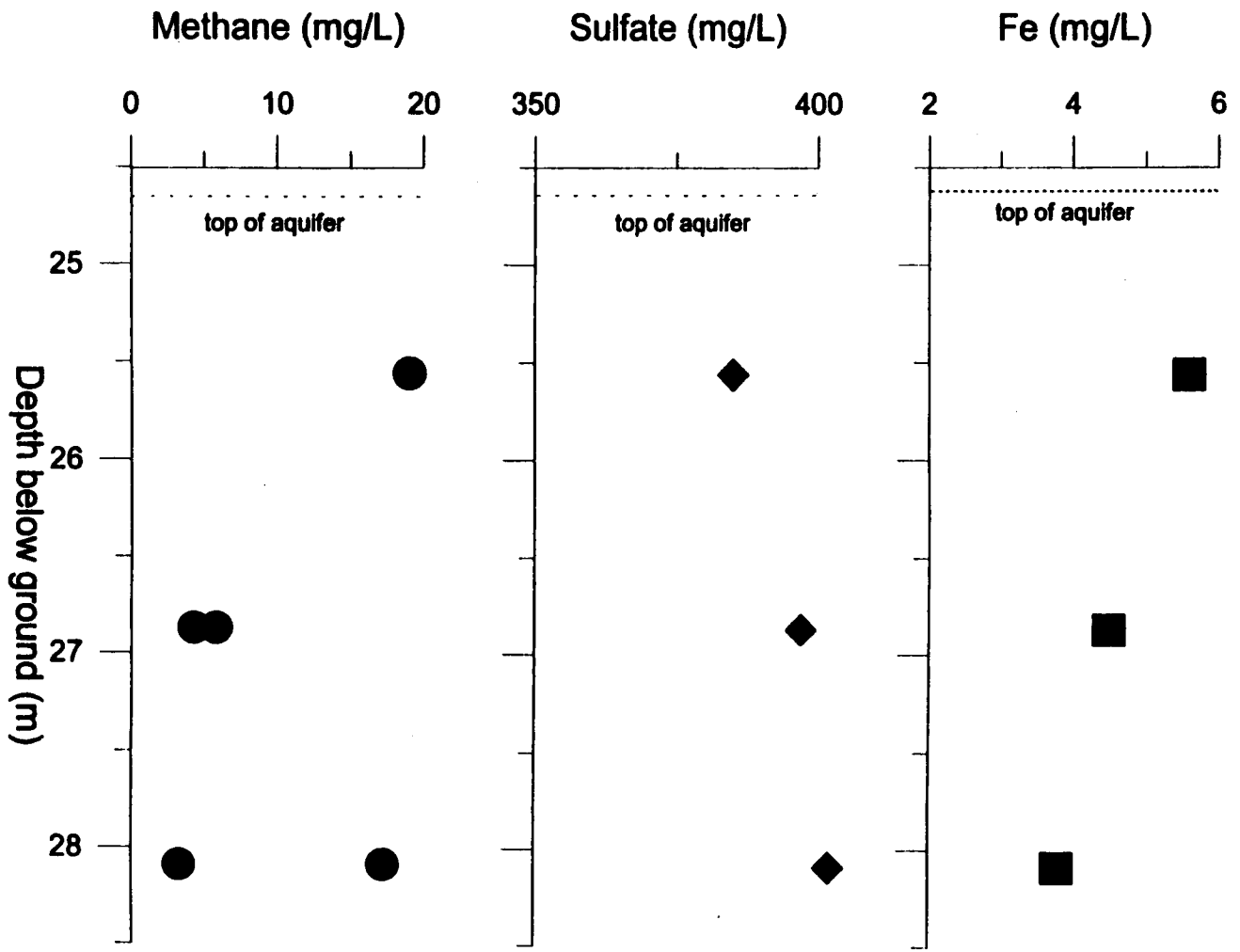


Figure 10. Vertical profile of hydrochemistry at LND-95-07A, B and C.

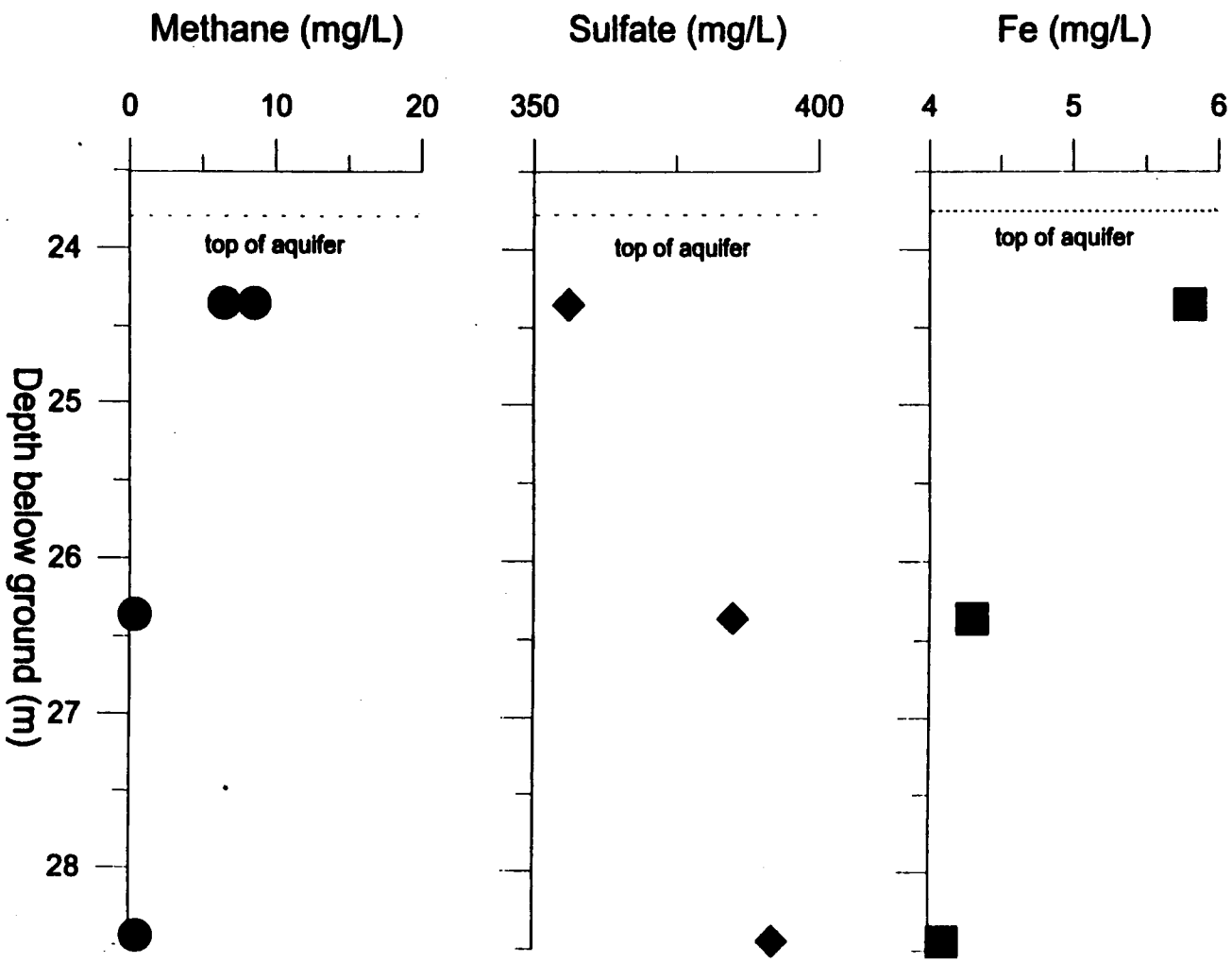
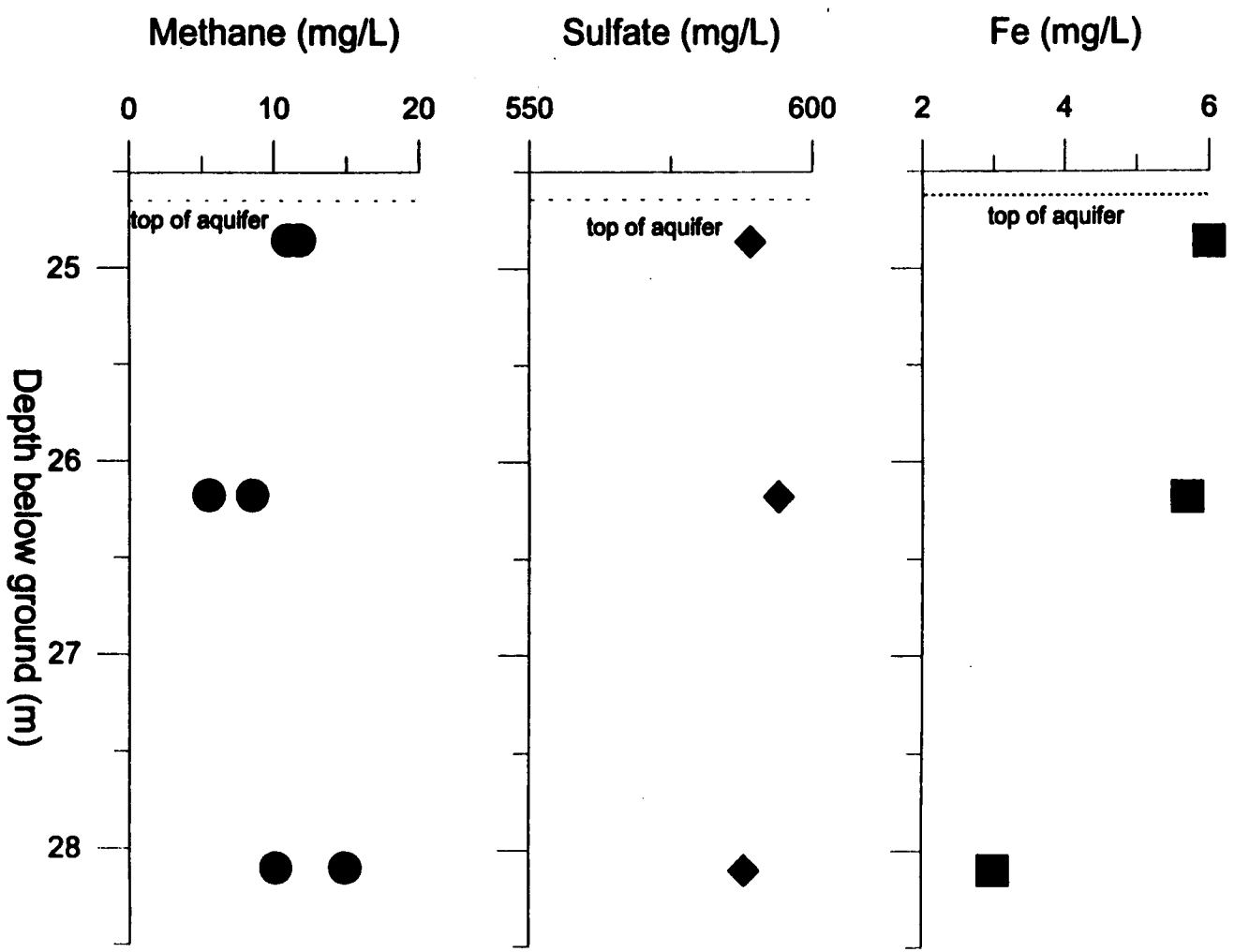


Figure 11. Vertical profile of hydrochemistry at LND-95-08A, B and C.



As for -06, the highest levels in LND-95-07 were at the top of the aquifer (6.4 to 8.5 mg/L) (Figure 10). Nest LND-95-08 (A, B, C) had highest methane levels (mg/L) at the bottom (10.1 to 14.9) and top (10.9 to 11.8) of the profile (Figure 11). This well is 5 m from the production well, possibly down-gradient with respect to groundwater flow (Figure 8).

The high methane levels detected near the top of the aquifer in all three nests, and the vertical gradients observed in nests LND-95-06 and -07 (Figure 9) are consistent with a gas phase source of dissolved methane, that has migrated along the upper surface of the aquifer (see Section 6.3). The lateral extent of gas phase methane migration at this site is presently unknown.

For other hydrochemical parameters re-sampled at the Lindbergh site in 1995, the data (Table 8) were similar to 1994 data. For all three new monitoring well nests, the sulfate concentration declined and the dissolved Fe increased towards the top of the aquifer (Figures 9 to 11). These data are consistent with Fe and sulfate reduction being focussed at the top of the aquifer, adjacent to a gas phase methane source. The 1995 data provide good evidence that biodegradation of methane occurs at this site, involving both sulfate and iron reduction.

5.4 Methane and Other Analyses for Wildmere Site

Methane samples were collected from four monitoring wells at the Wildmere site on October 17 to 18, 1995 (Table 9, Figure 12). Well WDM-95-03 could not be sampled because of a sampling pump was jammed in its screen (see Section 3.4). The analyses indicated relatively low methane concentrations (0.012 to 0.068 mg/L). A trace of ethane was detected in WDM-95-01 (0.003 to 0.006 mg/L). Other hydrochemical data collected in August and October (Table 10) indicated that sulfate concentrations were relatively low in the two wells that were close to and down gradient of the production well (WDM-95-04, -05), with respect to groundwater flow (Figure 12). As for the other research sites, this suggests that sulfate reduction is related to biodegradation of the leaking methane.

5.5 Methane and Other Analyses for Swimming Site

Methane samples were collected from the original three monitoring wells on two occasions, and from the four additional nests of three wells each on one occasion. Overall the analyses indicated low concentrations; the large majority were < 0.1 mg/L (Table 11, Figure 13).

Table 8. Major ions and other hydrochemical parameters in groundwater at the Lindbergh site.

Monitoring Well	Date Sampled YYMMDD	pH field	Ca (mg/L)	Mg (mg/L)	Na mg/L	K (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Fe (mg/L)	Mn (mg/L)	NO_3 + NO_2 (mg/L)	field Eh mV	Sum of Ions (mg/L)
LND-94-01A	940601	6.66	155	56	123	6	554	390	19			<0.01		1303
	941018		156	60	132	6.3	569	396	20	2.8	0.87	<0.01		1342.97
	950927	7.14	159	60	140	5.6	578	402	20	2.3	0.4	<0.01	-114.9	1367.3
LND-94-02	940601	7.02	158	58	123	5.8	562	382	19			<0.01		1307.8
	941018		158	56	106	4.9	581	375	20	5.4	2.1	0.01		1308.41
	950927	7.59	158	58	116	5.5	603	368	20	7.1	1.6	<0.01	-188.5	1337.2
LND-94-03	940601	6.95	143	59	131	5.4	574	390	19			<0.01		1321.4
	941018		150	62	111	6.4	590	389	19	4.2	1.5	0.01		1333.11
	950927	7.06	168	62	118	5.5	604	392	20	3.7	0.86	<0.01	-72.2	1374.06
LND-94-04	941006	6.9	155	61	100	6.6	574	384	18	0.79	0.62	<0.01		1300.01
	941018		152	61	101	7	574	378	18	1.7	0.82	0.01		1293.53
***	950927	6.71	168	58	110	6.1	581	378	18	5.7	0.66	<0.01	-116.7	1325.46
LND-94-05	941006	6.99	144	58	90	4.8	546	343	18	0.73	0.32	<0.01		1204.85
	941018		150	59	90	5	550	347	18	0.76	0.35	<0.01		1220.11
***	950927	6.7	153	62	101	5.3	592	372	19	2	0.51	<0.01	-78.3	1306.81
LND-95-06A	951116		150	62	120	5.6	593	402	20	3.8	0.26	0.08		1356.74
LND-95-06B	951116		150	62	120	5.4	595	397	20	4.5	0.26	0.07		1354.23
LND-95-06C	951116		140	64	120	5.2	595	385	20	5.6	0.26	0.03		1335.09
LND-95-07A	951115		150	62	120	5.5	601	392	20	4.1	0.28	0.02		1354.9
LND-95-07B	951115		150	62	120	5.5	600	385	20	4.3	0.27	0.02		1347.09
LND-95-07C	951116		140	63	110	5.2	601	356	19	5.8	0.3	<0.01		1300.3
LND-95-08A	951115		160	61	120	5.2	588	403	20	3	0.26	0.02		1360.48
LND-95-08B	951115		140	63	120	5.3	594	375	21	5.7	0.29	0.02		1324.31
LND-95-08C	951116		140	63	120	5.3	589	375	22	6	0.28	0.02		1320.6

***these samples may have inadvertently been mixed up.

Analyses for MGN-95-01A changed dramatically between September 28 and November 22, increasing from 0.002 to 2.6 mg/L (means of duplicate analyses). This increase in methane concentration was probably caused by the purging of more than 5000 L from this well during hydraulic testing on October 18 to 19, which may have drawn contaminated water from near the production well, located 3.4 m from this monitoring well.

Table 9. Dissolved methane and ethane concentrations in groundwater at the Wildmere site.

Monitoring Well	Sample Date	methane mg/L	ethane mg/L
WDM-95-01	Oct 17/95	0.06	0.006
	Oct 17/95	0.046	0.003
WDM-95-02	Oct 18/95	0.016	ND
	Oct 18/95	0.031	ND
WDM-95-03	no analyses due to pump stuck in well screen		
WDM-95-04	Oct 17/95	0.054	ND
	Oct 17/95	0.068	ND
WDM-95-05	Oct 18/95	0.013	ND
	Oct 18/95	0.012	ND

ND = not detectable. Detection limit is 0.001 mg/L

For samples collected on December 15 from nests MGN-95-04, -05 and -07, the methane concentrations increased from bottom to top of the aquifer (Figures 14, 15, 17). For nest MGN-95-06, the methane concentrations were low, but slightly higher in the deepest well than the other two (Figure 16). As a group, the samples taken from all wells at this site indicate relatively low concentrations of sulfate down gradient of the production well, and near the top of the aquifer (Figures 13 to 17, Table 12).

As for the Lindbergh site, collectively the methane and sulfate data are consistent with gas phase migration of methane, focused along the top of the aquifer (cf. Section 6.3), combined with biodegradation of the methane that involves sulfate as a terminal electron-acceptor.

Table 10. Major ions and other hydrochemical parameters in groundwater at the Wildmere site.

Monitoring Well	Date Sampled YYMMDD	pH field	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Fe (mg/L)	Mn (mg/L)	$NO_3 + NO_2$ (mg/L)	field Eh mV	Sum of Ions (mg/L)
WDM-95-01	950822	7.31	46	21	200	4.1	564	168	5	2.1	0.14	<0.01	-166.5	1010.34
WDM-95-02	951004	8.49	47	20	203	3.8	600	155	3	1.5	0.071	0.03	-99.9	1033.401
WDM-95-03	could not sample due to pump jammed in well screen													
WDM-95-04	951003	7.12	52	21	167	3.8	565	122	3	1.7	0.089	<0.01	-92.9	935.589
WDM-95-05	951003	7.09	52	20	167	3.8	569	128	3	1.6	0.092	<0.01	-111.7	944.492

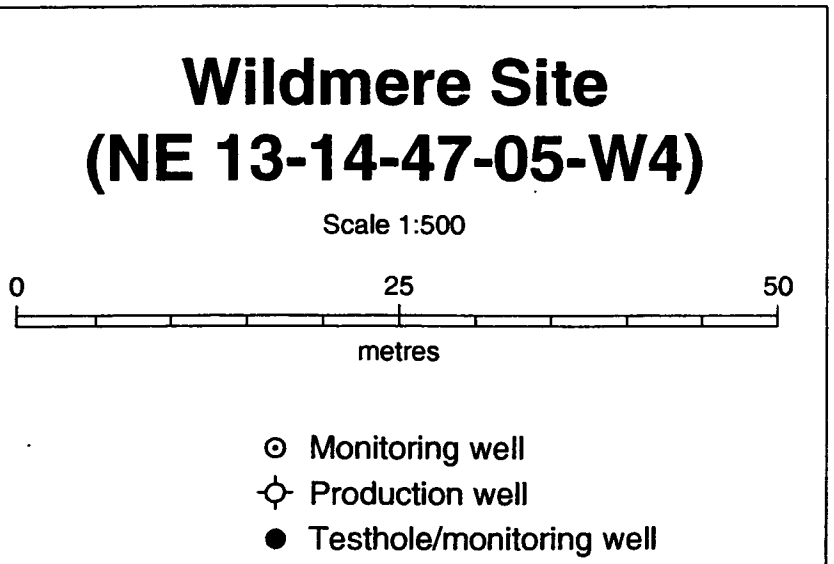
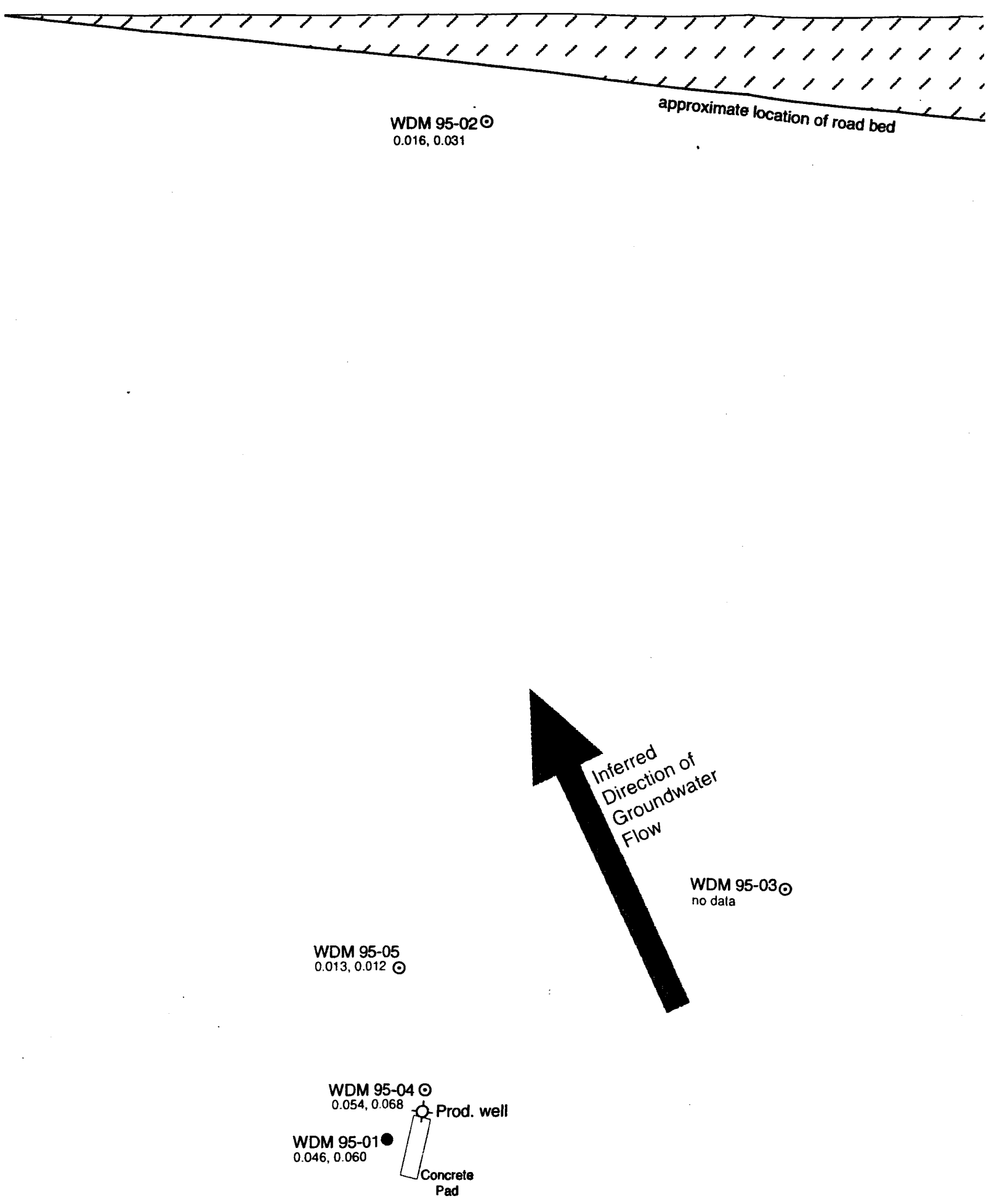
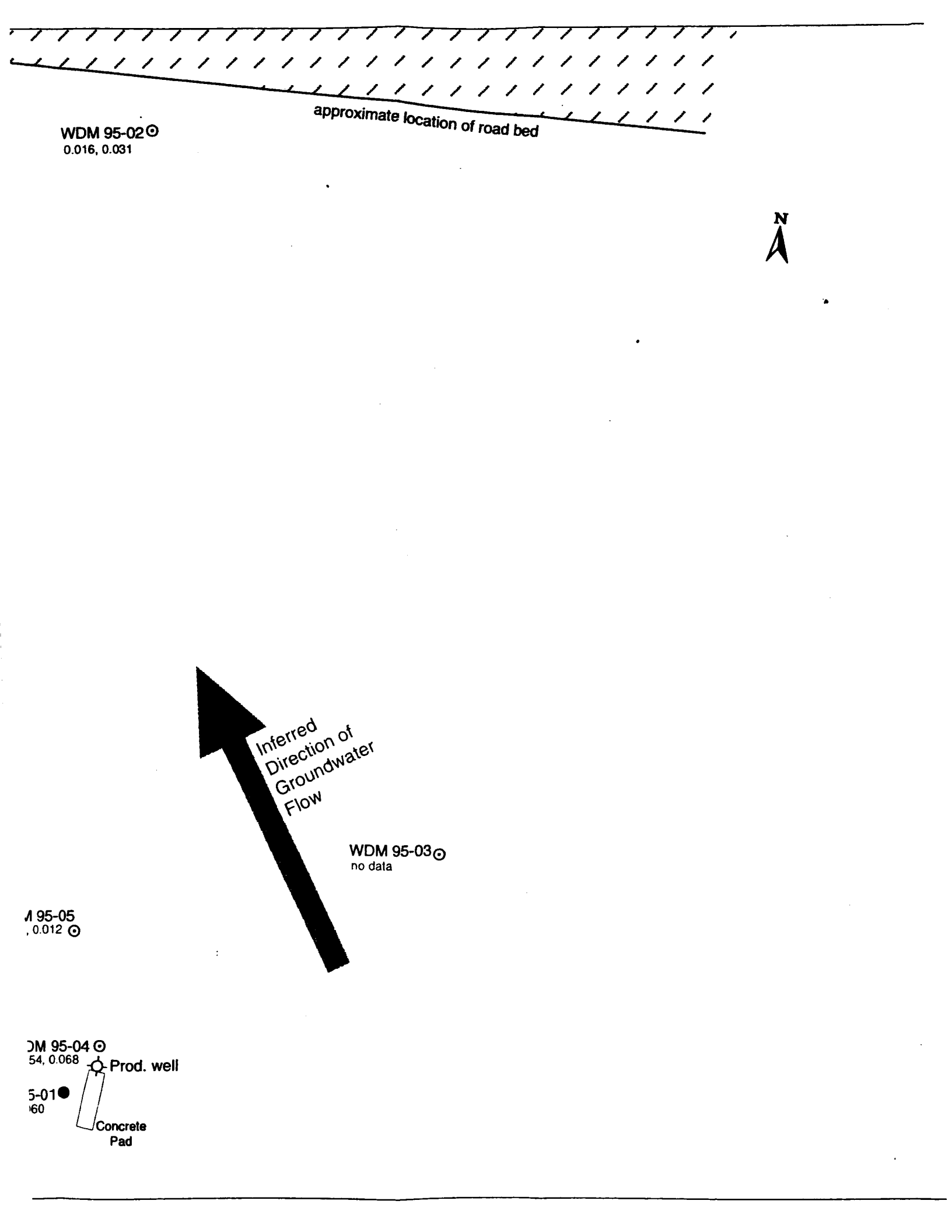


Figure 12 : Plan of the Wildmere site with measured methane concentrations (mg/L) for samples collected on Oct. 17-18, 1995.


approximate location of road bed
WDM 95-02
0.016, 0.031
Inferred
Direction of
Groundwater
Flow
WDM 95-03
no data
WDM 95-05
0.013, 0.012
WDM 95-04
0.054, 0.068
Prod. well
WDM 95-01
0.046, 0.060
Concrete
Pad


approximate location of road bed
WDM 95-02
0.016, 0.031
N
Inferred
Direction of
Groundwater
Flow
WDM 95-03
no data
95-05
, 0.012
DM 95-04
54, 0.068
Prod. well
5-01
60
Concrete
Pad

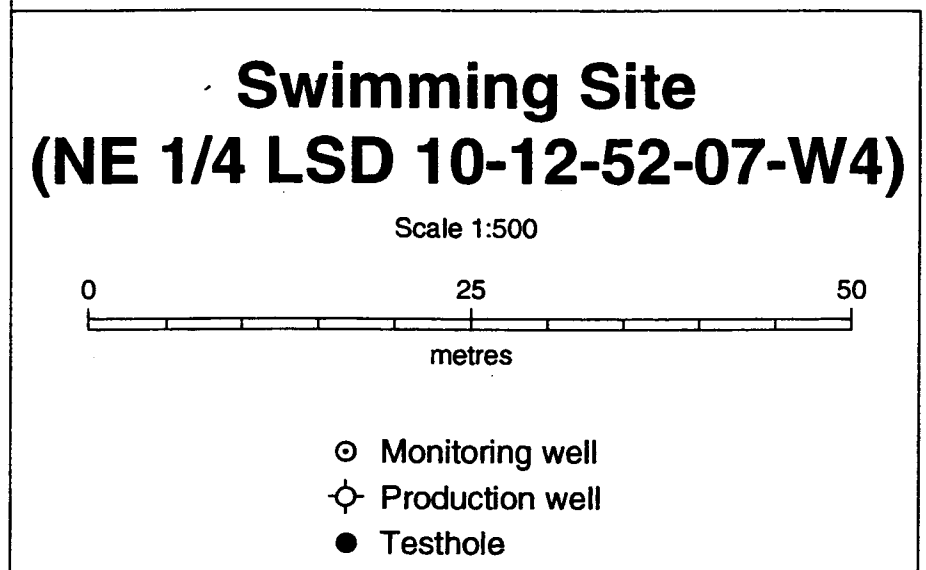
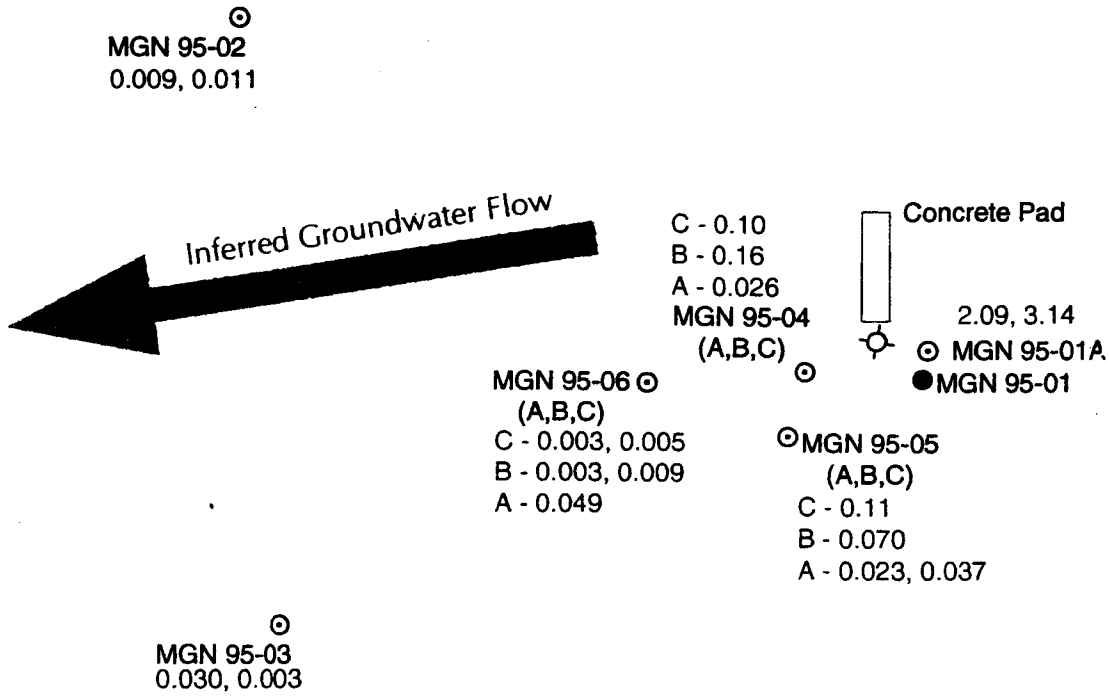


Figure 13: Plan of the Swimming site with measured methane concentrations (mg/L) for samples collected on Nov. 22 (01A, 02, 03) and Dec.14-15, 1995 (all other wells).

MGN 95-0
0.009, 0.01

Infe

MGN 9
0.030, (


MGN 95-02
0.009, 0.011
Inferred Groundwater Flow
C - 0.10
B - 0.16
A - 0.026
MGN 95-04
(A,B,C)
Concrete Pad
2.09, 3.14
MGN 95-01A
MGN 95-01
MGN 95-06
(A,B,C)
C - 0.003, 0.005
B - 0.003, 0.009
A - 0.049
MGN 95-05
(A,B,C)
C - 0.11
B - 0.070
A - 0.023, 0.037
MGN 95-03
0.030, 0.003

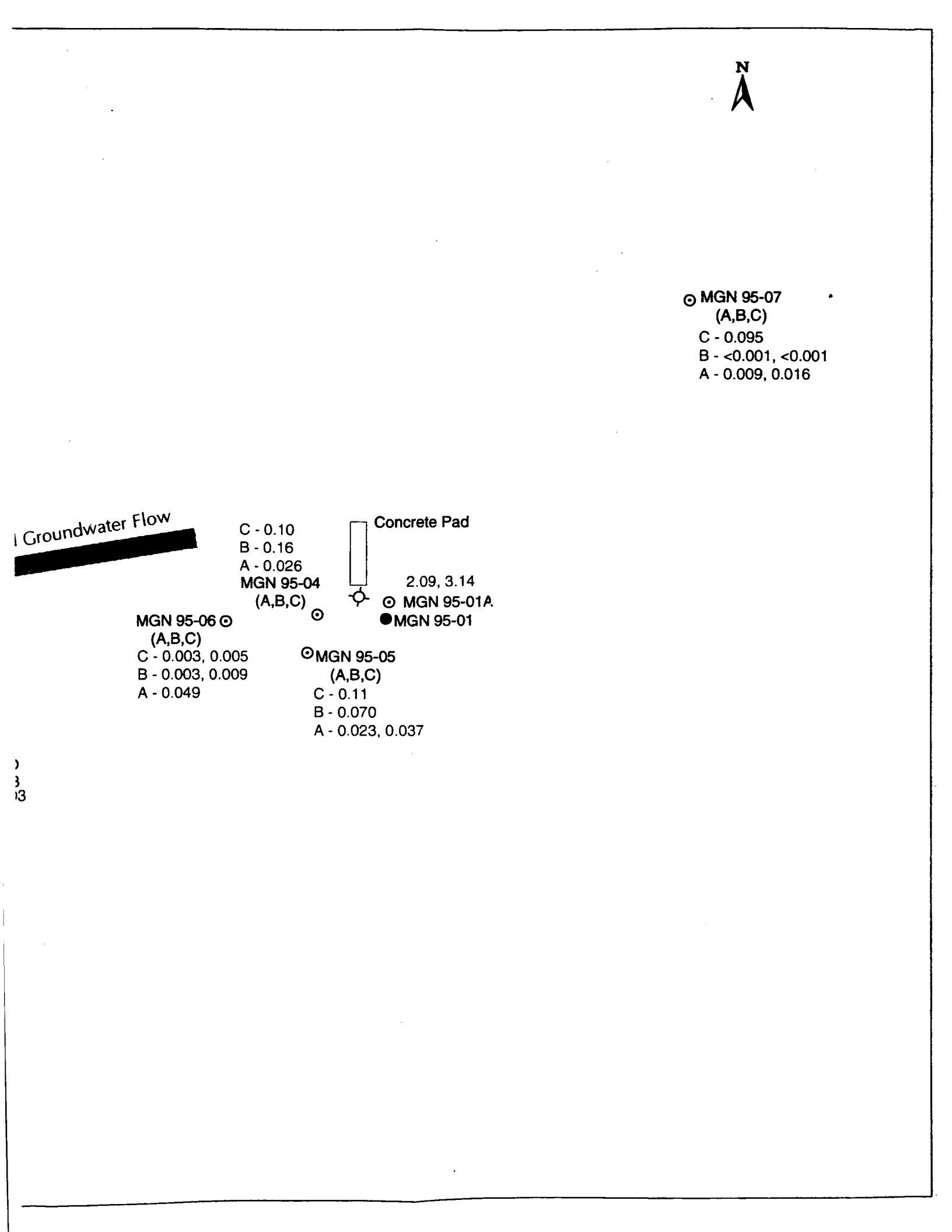

N
MGN 95-07
(A,B,C)
C - 0.095
B - <0.001, <0.001
A - 0.009, 0.016
Groundwater Flow
C - 0.10
B - 0.16
A - 0.026
MGN 95-04
(A,B,C)
Concrete Pad
2.09, 3.14
MGN 95-01A
MGN 95-01
MGN 95-06
(A,B,C)
C - 0.003, 0.005
B - 0.003, 0.009
A - 0.049
MGN 95-05
(A,B,C)
C - 0.11
B - 0.070
A - 0.023, 0.037

Figure 14. Vertical profile of hydrochemistry at MGN-95-04A, B and C.

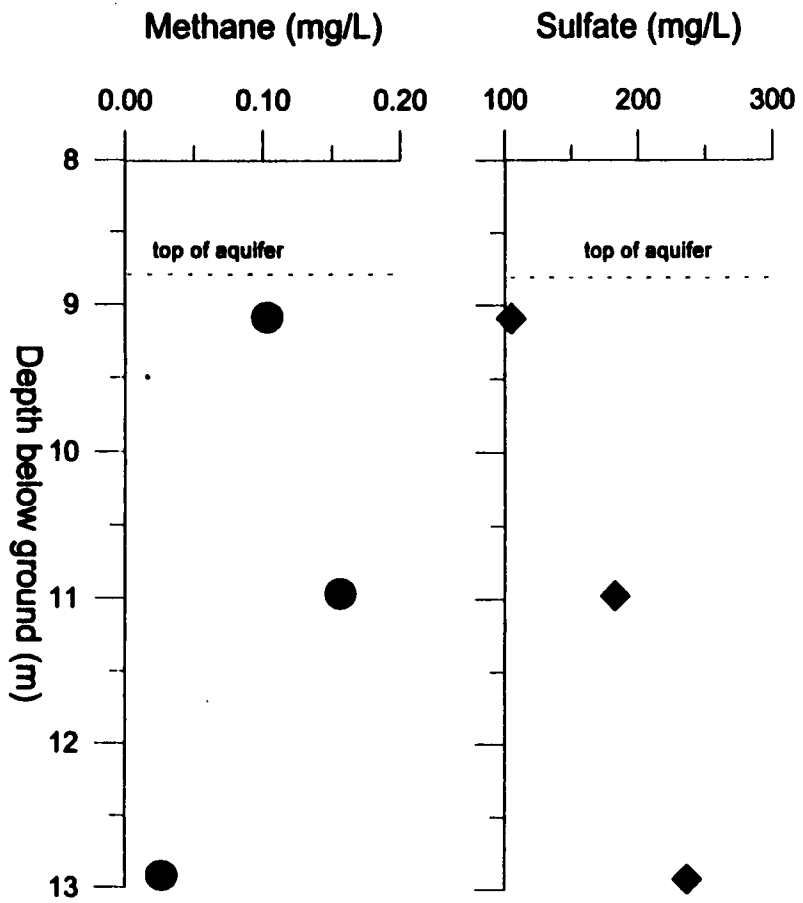


Figure 15. Vertical profile of hydrochemistry at MGN-95-05A, B and C.

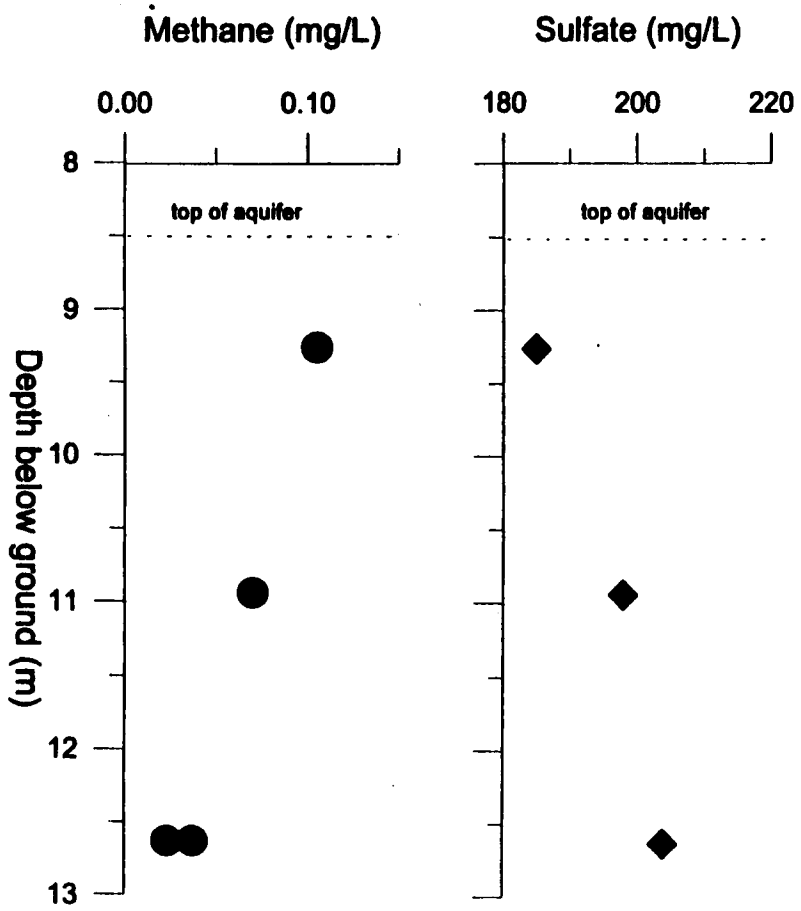


Figure 16. Vertical profile of hydrochemistry at MGN-95-06A, B and C.

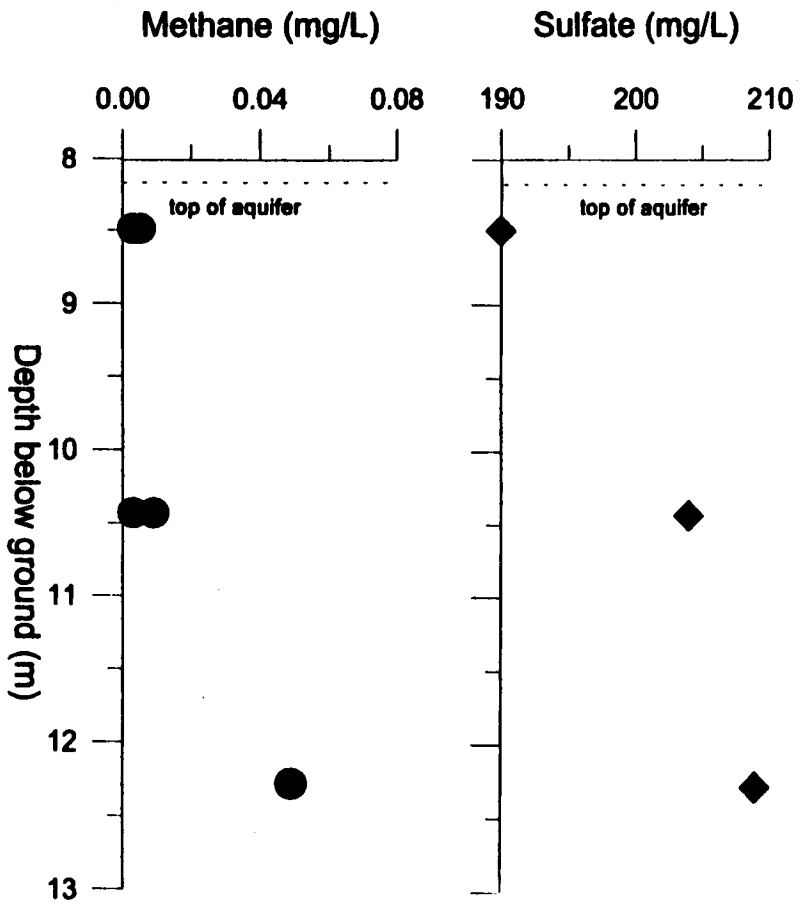


Figure 17. Vertical profile of hydrochemistry at MGN-95-07A, B and C.

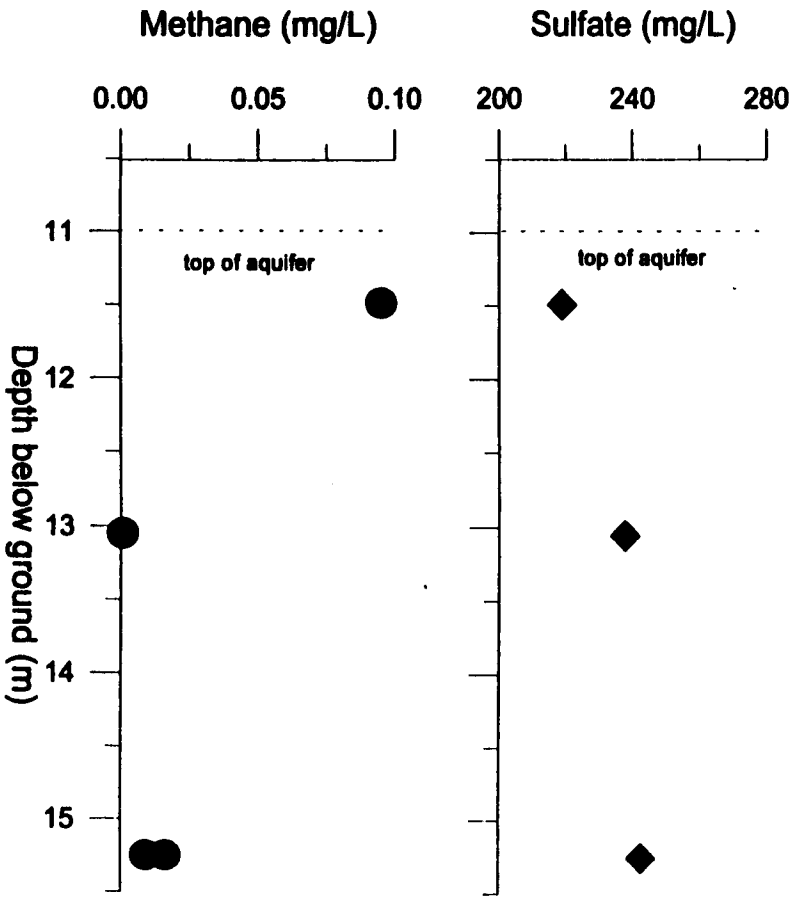


Table 11. Dissolved methane and ethane concentrations in groundwater at the Swimming site.

Monitoring Well	Sample Date	Methane (mg/L)	Ethane (mg/L)	Monitoring Well	Sample Date	Methane (mg/L)
MGN-95-01A	Sept. 28/95	0.003	ND	MGN-95-04A	Dec. 15/95	0.026
	Sept. 28/95	0.001	ND			
	Oct. 16/95	0.001	ND			
	Oct. 16/95	< 0.001	ND	MGN-95-04B	Dec. 15/95	0.156
	Nov. 22/95	2.09	0.005			
	Nov. 22/95	3.14	0.006			
				MGN-95-04C	Dec. 15/95	0.103
MGN-95-02	Sept. 28/95	0.002	ND			
	Sept. 28/95	0.001	ND			
	Oct. 16/95	0.001	ND	MGN-95-05A	Dec. 15/95	0.037
	Oct. 16/95	0.002	ND		Dec. 15/95	0.023
	Nov. 22/95	0.009	ND			
	Nov. 22/95	0.011	ND	MGN-95-05B	Dec. 15/95	0.07
MGN-95-03	Oct. 16/95	0.002	ND			
	Oct. 16/95	0.027	ND	MGN-95-05C	Dec. 15/95	0.105
	Nov. 22/95	0.03	ND			
	Nov. 22/95	0.003	ND			
				MGN-95-06A	Dec. 14/95	0.049
				MGN-95-06B	Dec. 15/95	0.003
					Dec. 15/95	0.009
				MGN-95-06C	Dec. 14/95	0.003
					Dec. 14/95	0.005
				MGN-95-07A	Dec. 14/95	0.016
					Dec. 14/95	0.009
				MGN-95-07B	Dec. 14/95	< 0.001
					Dec. 14/95	< 0.001
				MGN-95-07C	Dec. 15/95	0.095

ND = not detectable. Detection limit is 0.001 mg/L for methane and 0.003 mg/L for ethane.

Table 12. Major ions and other hydrochemical parameters in groundwater at the Swimming site.

Monitoring Well	Date Sampled YYMMDD	pH field	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Fe (mg/L)	Mn (mg/L)	$NO_3 + NO_2$ (mg/L)	field Eh mV	Sum of Ions (mg/L)
MGN-95-01	950920	6.89	127	50	50	9.8	526	183	2	2.4	0.26	0.29	-85.9	950.75
MGN-95-02	950920	6.99	119	52	43	7.8	519	164	2	0.71	0.53	<0.01	-11.4	908.04
MGN-95-03	950920	6.85	141	56	48	9.8	538	218	4	2.2	0.38	<0.01	-85.6	1017.38
MGN-95-04A	951124		134	57	61	12	601	237	2	2.9	0.62	0.01		1107.53
MGN-95-04B	951124		120	50	43	11	532	183	2	2.2	0.54	<0.01		943.74
MGN-95-04C	951124		91	38	37	8.8	445	105	4	1.2	0.43	0.02		730.45
MGN-95-05A	951124		124	52	55	11	556	204	2	2.4	0.32	<0.01		1006.72
MGN-95-05B	951124		118	50	53	11	544	198	2	2.5	0.31	<0.01		978.81
MGN-95-05C	951124		117	48	53	11	532	185	2	2.4	0.3	0.003		950.703
MGN-95-06A	951124		122	52	60	12	569	209	2	2.4	0.29	<0.01		1028.69
MGN-95-06B	951124		120	51	58	11	554	204	2	2.4	0.28	0.02		1002.7
MGN-95-06C	951124		118	49	55	11	540	190	2	2.3	0.28	0.02		967.6
MGN-95-07A	951124		133	57	67	11	593	243	2	2.9	0.27	0.04		1109.21
MGN-95-07B	951124		131	57	64	11	588	238	2	2.5	0.25	0.02		1093.77
MGN-95-07C	951125		127	56	57	11	572	219	2					1044

6.0 MODELLING OF METHANE MIGRATION AT RESEARCH SITES

The purpose of modelling in this research program is to obtain a more comprehensive understanding of the impacts of gas (methane) leaking from petroleum well sites on the shallow groundwater environment. Modelling will be used to estimate 1) quantities of methane leaking from the well into an aquifer as a gas phase, 2) transfer of methane from gas to dissolved phase, 3) transport of methane as a dissolved phase, 4) microbial degradation and sorption of dissolved methane, and 5) the effective areas impacted by dissolved methane plumes. Given suitable calibration to field data, this information will be used to assess the risks that methane leaking from production wells into water supplies will produce explosion hazards.

6.1 Background

Van Stempvoort and Jaworski (1995) conducted preliminary modelling of the migration of methane in groundwater at the Lindbergh and Marshall sites. This was based on the methane concentration data collected in 1994, using the analytical model PATCH3D (Sudicky et al., 1988). The PATCH3D model was deemed to be suitable for approximating the migration of a dissolved methane plume derived from a gas phase in/at the annulus of each production well. For each scenario, the methane source was considered to be a vertically oriented, 2D rectangular area, equal in diameter to the annulus of the well and extending completely through the aquifer. The dissolved source concentration was assumed to be equal to saturation of methane in the groundwater. Groundwater velocity was based on water levels and pumping test results. Dispersion parameters were initially based on literature values, and were altered to fit the Marshall site concentration data. Sorption and biodegradation of dissolved methane were also simulated.

For the Marshall site, the PATCH3D output Scenario M4 gave a relatively good match to measured (1994) dissolved gas concentrations down gradient from the source. However, PATCH3D was unable to predict relatively high concentrations measured in samples from wells located up gradient or cross-gradient (with respect to groundwater flow) at both the Marshall and Lindbergh sites.

In the 1995 program, strong vertical gradients of methane concentrations were observed in monitoring well nests at both the Lindbergh and Swimming sites (see Sections 5.3 and 5.5). These data indicate that lateral gas phase migration is probably important, focussed along the tops

of the aquifers. The PATCH3D model cannot be used to model lateral gas phase migration, nor is it suitable for modelling the migration of dissolved phase methane from horizontally oriented sources located along the upper surface of aquifers. Thus, the PATCH3D model is not suitable for ongoing modelling in this research program.

6.2 Current Modelling Approach

A revised modelling approach is being developed for this research program, which will include the following components:

- development and revision of conceptual models of methane migration,
- review of empirical data and laboratory studies (e.g., air sparging studies),
- application of suitable mathematical models to research sites,
- checking of model(s) with further field data.

It is anticipated that two research sites will be used for detailed modelling - the Lindbergh and Swimming sites. The choice of these sites was based on the following criteria:

- elevated dissolved methane levels in groundwater,
- isolation from other petroleum wells,
- presence of a shallow aquifer allowing a relatively inexpensive field program.

6.3 Conceptual Model of Gas Phase Methane Migration

At the present time, effort is being focussed on gas phase flow modelling.

In order for gas migration to occur at a production well, there has to be 1) a gas phase source in the subsurface, occurring at an elevated pressure, and 2) a vertical migration pathway. The buoyant gas phase must have a pressure sufficient to overcome the confining pressure of groundwater (Chafin, 1994, p. 49) and the capillary forces in the pores along the migration pathway. The minimum gas pressure required for the gas phase to migrate through water is referred to as the displacement, imbibition or bubbling pressure.

At a production well, the primary gas migration pathways are thought to consist of vertically aligned pores in or along the cemented annuli. Some of these pores may have been created by gas contamination during setting (Jocksch, 1993). Others may be fractures in geologic units near the well annuli that formed during drilling. The pores must have sufficient permeability

to allow significant vertical fluxes of buoyant gas phase methane from the source to soil or shallow ground waters.

In addition to primary upward migration of methane along the annuli of petroleum wells, bubbles or channels of gas phase methane may move outward into geologic units adjacent to the annuli. The extent of lateral movement will depend largely on the permeabilities of the geologic units. Lateral migration may occur in confined aquifers, which have greater permeabilities than adjacent aquitards. Due to the buoyant nature of the gas phase, it will tend to migrate horizontally as channels along the tops of aquifers, just below confining aquitards (Marley et al., 1992).

6.4 Empirical Studies of Gas Phase Migration - the Air Sparging Analogy

Air sparging is an appropriate analogy to gas-phase migration of methane from production wells into aquifers. Air sparging is a technology in which pressurized air is injected through a well (below the water table) and displaces water in the pores of an aquifer. This technology is now widely used for "in-situ" remediation of contaminated groundwater (e.g., Marley et al., 1992; Brown, 1994; Lundegard and LaBreque, 1995). The implementation of air sparging is based largely on empirical testing (Marley et al., 1992).

Using glass beads in thin Plexiglas tanks, Ji et al. (1993) simulated the development of air channels in an aquifer during air sparging. The visualizations illustrated by Ji et al. indicate that air flow occurred in "discrete, stable channels". In unconfined, uniform-sized bead media, the buoyant air tended to form parabolic or bell-shaped plumes of channels that spread out upwards. In heterogeneous, media, which were made of layers of different sized beads, air channels tended to form horizontal plumes just below the less permeable layers (smaller sized beads), as predicted by the conceptual model for confined aquifers (Section 6.3).

6.5 Relevant Mathematical Models for Simulation of Gas Phase Migration

Depending on the software used, it is possible that the mathematical modelling of methane migration will be done as a multi-stage process; first, simulation of the migration of gas phase methane, then transfer from gas phase to aqueous (dissolved) phase, and finally, transport as dissolved methane in groundwater, combined with sorption and biodegradation. Alternatively, a single model may be used, as described below.

To simulate air flow during sparging, Marley et al. (1992) developed a model called SPARG1. This model focusses on air flow, and assumes that flow of water is negligible.

TETRAD (Vinsome, V10.4 Users Manual, 1994; Vinsome and Shook, 1993; Shook, 1995) is a 3-dimensional, multi-phase (water/gas/oil) numerical model which accounts for partitioning of contaminants between all phases, transport, sorption and decay. This model calculates the pressure-dependent compressibility of liquids and gas phases. A modified version of TETRAD has been used to simulate the flow of air into an initially water-saturated aquifer during sparging (Lundegard and Anderson, 1993), and similar applications are ongoing (Arnold, 1995). The TETRAD model appears to be a promising tool for future application in the methane migration program.

A number of other complex numerical models have been designed to simulate multi-phase fluid flow and contaminant transport in aquifers (e.g., MOTRANS, Kaluarachchi and Parker, 1990; FEMWATER, G.T. Yeh et al., 1992). MOTRANS is a finite-element, 2-dimensional model developed to simulate the flow of water, dense or light nonaqueous phase liquid (NAPL) and/or gas (air), and partitioning of up to five chemical components between these phases. This model simulates the volatilization and flow of oil derived gases in the vadose zone. For conventional simulations, it ignores the flow of gas below the water table in order to improve run-time performance.

FEMWATER is a finite element model that, in conjunction with LEWASTE is capable of being used to model LNAPL and DNAPL flow (Yeh et al., 1992). The FEMWATER model is gaining acceptance for groundwater flow modelling. Unfortunately, this model does not yet consider the flow of a compressible gas below the watertable.

Further review of relevant mathematical models is ongoing.

7.0 METHANE IN WATER SUPPLY WELLS IN THE STUDY AREA

To provide a context for the data collected at the research sites, the following information was obtained:

- historical data on presence of "gas" in water supply wells in the study area,
- a survey of methane concentrations in 23 supply wells in the study area,
- published data on dissolved methane in supply wells in other gas and oil producing areas.

7.1 Historical Data on Presence of Gas in Supply Wells

Alberta Environmental Protection (AEP) has provided a summary of their records of water wells in the study area that indicated that "gas" was present. Of ~24,000 water well records, presence of gas was reported for 58 wells (Table 13). These records do not provide chemical analyses of the gas.

Fifteen of the AEP records of gas in wells were observations made during the Federal water well survey of 1935-36. Gas was reported for two other wells prior to oil and gas exploration and development in the area: in 1949 and 1953 (Table 13). Generally, the early AEP records (1935-53) indicated presence of gas in wells completed at depths > 40 m BGS. Although the gas was not identified, these records suggest that methane was present in some aquifers in the study area prior to oil and gas exploration.

Of the 41 later AEP records that report presence of gas (1960-95), most were observations made by drillers' at the time the wells were installed. These wells tended to be relatively deep (mean completion depth of 123 m BGS, range of 51 to 238 m BGS) compared to the average well in the region (< 50 m BGS based on AEP records).

A study by the Prairie Farm Rehabilitation Administration (1993) indicated occurrence of dissolved methane in eight monitoring wells completed in Judith (Belly) River Fm aquifers in the Special areas in Alberta. Methane was the dominant dissolved gas observed, but absolute concentrations were not determined. The source of the methane (intrinsic vs. oil & gas activities) was unknown. This area investigated by the PFRA overlaps with and includes the southernmost portion of the Lloydminster study area.

Currently there is no provincial database that provides historical information on the presence of gas in water wells for the Saskatchewan portion of the study area. Unlike the AEP records, the equivalent water well database provided by the Saskatchewan Water Corporation contains no information on the occurrence of gases in wells.

Table 13. Water wells in study area in which gas was noted to be present (Alberta Environmental Protection waterwell database).

Q or LSD	Sec	T	R	W4	Well Owner	Depth (m)	Year Reported
Reported between 1935 and 1953							
NE	32	41	2		Feero	117.3	1935
SW	4	42	2		McMann	114.3	1935
NW	6	42	7		S. McLaughlin	19.8	1935
SW	3	43	4		S.V. Snyder	3.0	1935
SW	11	44	3		A. Cooper	97.5	1935
12	3	48	12		F. Ploc	45.4	1935
8	35	49	1			6.1	1935
14	36	49	1			38.7	1935
1	3	50	1		Blackwell	50.6	1935
15	23	50	1		K. Parr	34.1	1935
SE	34	50	2			28.3	1935
15	34	52	4		Hodgson	47.2	1935
4	36	52	4		R. Seville	102.4	1935
SE	4	53	4		G. Brett	71.9	1935
NE	16	45	11		G.F. Albrecht	115.8	1936
SW	14	50	2		Plater	63.4	1949
4	7	45	12		Seman Engin.	54.9	1953
Reported between 1960 and 1995							
NE	29	36	5		Provo Gas Prod.	237.7	1960
NE	31	37	9		G. Hewitt	42.7	1960
NW	28	41	13		D. Bownes	73.2	1979
	34	37	8		S. Twa	160.0	1988
NW	23	37	13		R. Holloway	142.0	1964*
SW	15	50	2		W. Ulan	87.8	1964*
SE	24	36	12		H. Plenhert	132.6	1965*
SW	22	37	13		H. Wideman	189.0	1965*
14	20	46	2		J. W. Gordon	106.7	1966*
NW	30	43	9		Mon-Max Services	67.1	1967*
SW	4	39	13		D. Coppack	106.7	1968*
NE	32	36	12		S. Mereski	82.3	1969*
9	25	42	10		Hardisty Storage	125.3	1969*
SE	14	36	12		A. McRae	118.9	1970*
NW	4	57	3		North School (Frog L. IR)	56.4	1970*
SE	19	43	2		R. Morrison	71.9	1971*
NE	3	40	5		H. Tennant	167.6	1972*
11	25	50	5		Water Res.	51.8	1972*
	19	36	11		D.&E. Dennis	173.7	1973*
NE	8	48	11		J. Veenstra	106.7	1973*
SE	36	36	12		A. Bye	137.2	1974*
NW	20	40	8		L. Crone	192.0	1974*
SW	9	39	8		R. Gilbertson	152.4	1975*
SE	18	51	2		General Crude Oil	91.4	1975*
SE	6	36	3		R. Worobo	184.1	1976*
NW	8	36	6		K. Gilmer	160.3	1976*
NE	22	36	12		C. Plehnert	137.2	1976*
SE	28	37	8		J. Ekrol	177.4	1977*
SW	36	41	9		B. Cullen	169.5	1977*
SW	16	38	13		A. Engel	117.7	1978*
NW	11	59	9		A. Severin	68.3	1978*
NW	25	36	2		J. Scheck	142.0	1979*
10	28	60	3		World Wide Energy	109.7	1982*
SW	6	41	12		P. Spady	125.6	1986*
NW	26	50	2		L. Gnyra	109.7	1989*
NW	2	53	12		E. Horon	103.6	1989*
NE	19	53	7		Jacula Farms	85.3	1990*
4	21	38	1		Pan Cdn.	218.8	1992*
8	33	42	11		C. Davidson	65.5	1994*
NE	17	42	13		B. Kuefler	76.2	1994*
SW	33	52	2		M. Hames	97.5	1995*

*reported by driller at time of well installation

7.2 1995 Survey of Methane in Water Supply Wells in Study Area

Samples were also collected from 23 domestic water supply wells in the Saskatchewan portion of the Lloydminster study area and analyzed for methane concentrations (Table 14). These methane data are not directly comparable to the research site data (Section 2.3), due to differences in the collection methods. However, this supply well survey provides useful data on dissolved methane in groundwater as used in the region (cf. Chafin, 1994).

Analyses of major ions, Fe, Mn, and nitrate for samples from the same wells were conducted to indicate any correlation of dissolved methane and other hydrochemical parameters. The supply wells to be sampled were selected by members of the steering committee. Each well supply system chosen had:

- a lithologic log,
- an e-log,
- a well completion record (depth, screen interval),
- well casing < 30 cm (12") diameter,
- a submersible pump,
- an outdoor hydrant or tap for sampling of untreated water (i.e., no chlorine).

A single sample was taken from each well, using the supply pump. The stainless steel samplers that were used at the research sites (Section 5.1) were also used in this survey. These samplers were connected with 1.64 cm dia. vinyl (PVC reinforced) tubing to the well hydrant or tap, similar to the in-line, down-flow configuration used by Van Stempvoort and Jaworski (1995). A length of 0.82 cm dia. stainless steel tubing was attached to the down-flow end of each sampler to restrict the flow and produce back-pressure, in order to prevent formation of gas bubbles in the system. Each system was purged for 10 to 20 min prior to sampling.

Methane was detected in most of the supply wells (20 of 23 wells, see Table 14). The concentrations were generally low: all but three were < 0.05 mg/L. The two highest concentrations measured were slightly above 1 mg/L. In these two cases, there may be a risk of an explosion, if the water supplies pass through poorly ventilated air spaces (Harder et al., 1965).

Overall, there is no significant correlation between the methane concentrations and the completion depths of the supply wells, or methane and other hydrochemical parameters as shown in Table 14 (Pearson product moment correlation, 0.05 level of significance). However, it appears that methane concentrations are strongly dependent on geographic locations and aquifer

Table 14. Survey of methane concentrations in water supply wells in the Saskatchewan portion of the study area.

LOCATION					——Completion——													
Q	Sec	T	R W3	Well Owner	Depth (m)	Year Drilled	Aquifer Unit	Methane (mg/L)	Na	Ca	Mg	K	HCO	SO_4	Cl	NO_2 +NO_3	Fe	Mn	untreated water sampling point
Aberfeldy																			
NE	13	49	26	J. Phipps	29.6	1978	drift	0.002	278	120	49	6.5	599	578	17	< 0.01	2.0	0.12	remote hydrant
SW	15	49	26	G. Pierce	20.7	1981	Judith R.	0.005	402	87	46	5.8	631	692	34	1.2	0.31	0.04	wellhead hydrant
NE	18	49	26	M. Napper	27.4	1986	intertill	0.002	351	124	42	5.7	612	658	48	0.04	1.1	0.5	wellhead hydrant
NW	23	49	26	T. McDougall	40.2	1984	Judith R.	0.001	367	121	59	7.8	715	725	13	0.02	4.4	0.09	house tap
SE	28	49	26	S. Rollheiser	23.5	1987	Judith R.	0.008	226	190	84	8.8	692	718	8	0.02	1.4	0.03	remote hydrant
Golden Lake																			
SE	8	47	23	H. Tuplin	23.5	1976	intertill	0.002	158	268	97	8.7	598	932	23	< 0.01	4.2	1.1	wellhead hydrant
NW	30	47	23	R. Stevenson	55.5	1986	Judith R.	0.469	470	111	64	8.7	709	815	127	0.01	7.1	0.14	house tap
SE	35	47	23	C. Ballan	30.8	1994	Judith R.	0.015	747	37	18	6.8	494	1130	158	0.17	0.19	0.01	quonset tap
Lone Rock																			
SE	30	47	26	P. Mihalich	22.6	1993	Judith R.	0.01	365	91	43	8.0	601	643	29	0.06	1.2	0.05	wellhead hydrant
SW	10	47	27	G. Lamb	65.5	1986	Judith R.	0.007	620	37	18	5.5	619	928	15	0.06	0.32	0	wellhead hydrant
SW	15	47	27	J. Lamb	36.0	1976	Judith R.	1.308	609	30	15	4.1	633	885	14	0.05	1.3	0.02	house tap
SE	17	47	27	D. Graham	39.0	1984	Judith R.	1.071	441	67	36	6.6	694	668	9	0.16	0.72	0	wellhead hydrant
SW	30	47	27	J.W. Anderson	49.7	1987	Judith R.	0.006	210	132	66	7.1	698	480	7	0.08	2.0	0.01	wellhead hydrant
SE	33	47	27	M. Martin	68.9	1987	Judith R.	0.003	330	14	7.1	2.9	592	261	7	0.03	0.17	0	remote hydrant
Neilburg																			
SE	2	45	25	G. Hall	108.2	1977	Judith R.	0.032	900	18	6	5.7	464	1280	220	0.04	0.34	0.02	remote hydrant
SE	23	45	25	N. Hallet	118.9	1976	Judith R.	0.044	508	213	104	12.0	483	1440	124	< 0.01	5.6	0.11	wellhead hydrant
SW	8	45	26	N. Koch	27.4	1988	intertill	0.003	83	240	124	7.5	671	738	11	0.03	3.0	0.98	wellhead hydrant
SE	25	45	26	L. Watson	124.7	1980	Judith R.	0.006	898	86	31	6.9	468	1650	145	0.71	0.17	0.09	remote hydrant, leaking
NW	30	45	26	G. McGladdrey	26.2	1988	intertill	0.003	170	389	189	8.2	543	1520	26	< 0.01	2.8	1.3	wellhead hydrant
Celtic, Tangleflags																			
SE	23	51	25	L. Bright	20.4	1985	intertill	< 0.001	163	91	36	4.2	517	232	44	1.0	0.15	0.08	wellhead pressure tank
NE	5	51	23	K. Jarret	29.3	1977	Empress	< 0.001	107	119	48	7.8	465	294	28	0.89	0	0	remote hydrant
SE	34	52	22	L. Hoffman	29.9	1984	intertill	0.001	206	168	62	6.3	688	532	20	0.02	2.0	0.62	wellhead hydrant
SW	27	53	22	S. Schneider	43.9	1992	intertill	< 0.001	50	183	65	6.2	595	338	2	0.01	1.7	1.4	wellhead hydrant

Table 14) have very low concentrations, at or less than the detection limit of 0.001 mg/L. The range in concentrations (mg/L) of methane for all wells completed in Judith River sands is 0.001 to 1.3, and the mean is 0.21. In, contrast, the concentrations in wells completed in drift aquifers range from non-detectable to 0.003, and their mean is < 0.002.

The relationship between methane concentrations in water supply wells and presence of gas-leaking oil exploration and production holes (active, inactive, decommissioned) is unknown.

7.3 Methane in Groundwater in Other Oil and Gas Producing Areas

Dyck and Dunn (1986) found methane (and helium) anomalies associated with oil and gas fields in southwestern Saskatchewan. In their 1976 survey of 939 domestic wells and springs, they found that methane concentrations tended to be highest in areas where exploration drill hole density increased, and also had a weak positive correlation with depth of sampling. They suggested that the anomalies could be due to either leakage of methane from the exploration drillholes into aquifers tapped by the domestic wells, or due to "natural" migration from the oil and gas fields along faults and fracture zones. Overall, they found that 88% of the samples had methane concentrations below detection (< 0.014 mg/L), 95% were < 0.3 mg/L, and the maximum concentration was 94.5 mg/L.

Chafin et al. (1993) and Chafin (1994) documented a 1990-91 survey of 203 water supply wells and 2 springs in the Animas River Valley of Colorado and New Mexico. Gas has been produced from various formations in this area for decades. Recent expansion of the development of a coal-bed gas field in this area has led to public concern about "the possibility of increasing concentrations of natural gas in domestic water supplies". The survey indicated that the methane concentrations were below the reporting limit of 0.005 mg/L in 66% of the cases. Twelve precent of the sites had methane concentrations of 1 mg/L or more. The mean concentration was 1.3 mg/L, and the maximum was 39 mg/L. Wells completed in bedrock tended to have higher methane concentrations than those completed in surficial alluvium. Presence of methane was often associated with presence of H_2S. A concurrent survey of soil gas concentrations was conducted, at the groundwater collection sites and adjacent to 352 gas wells in the area. The carbon isotopic composition of methane in a few of the groundwater samples was analysed and compared to data for gas from production wells, cathodic-protection wells and soil adjacent to gas wells in the area. Chafin (1994) concluded that most "shallow" gas in the area is probably

derived from deep, thermogenic sources. Chafin did not find evidence for substantial vertical migration of methane by natural processes, including diffusion and fracture transport. He stated that the soil gas data "indicate that gas-well annuli are more important than natural fractures for the upward migration of gas". Chafin concluded that "manmade migration pathways probably introduced most near-surface gas to the study area".

8.0 SUMMARY AND RECOMMENDATIONS

Five new research sites with leaking production wells were investigated in the 1995 program. At two of these sites (Wildmere, Swimming), monitoring wells were installed in aquifers, at depths of ~70 and 10 m BGS respectively. At one site (Sedgewick), there were no aquifers in a deep zone targeted for monitoring (210 to 230 m BGS). At the other two new sites (Golden Lake, Lone Rock) there are no significant aquifers.

The Lindbergh (1994) and Swimming sites were selected for detailed investigations. Additional nests of monitoring wells were installed at both sites in 1995 to provide vertical profiles of the aquifer hydrochemistries. Pumping tests conducted at these two sites provide important information on hydraulic properties that can be used in future modelling.

Samples were collected from all available monitoring wells and analysed for methane concentrations and other selected hydrochemical parameters. Elevated concentrations of methane were detected in the aquifers at each site. The levels were typically highest within several m of the production wells. The highest concentrations (1995; mg/L) at the research sites were: 0.06 at Marshall, 0.068 at Wildmere, 3.1 at Swimming and 19.1 at Lindbergh.

In the well nests at the Swimming and Lindbergh sites, the levels of methane generally increased towards the top of the aquifer. These vertical gradients indicate that lateral gas phase migration of methane may be occurring along the top of the aquifers.

Gradients of sulfate concentrations at all four sites indicate that sulfate reduction is probably linked to biodegradation of methane in the aquifers.

An analytical model, PATCH3D , had been used for preliminary simulation of 1994 methane data. On the basis of the 1995 findings, this model is not suitable for the ongoing research program. A revised modeling approach is being developed that will take into account lateral gas phase migration. The focus during 1995 was examination of the gas phase migration process.

A survey was conducted of dissolved methane concentrations in 23 supply wells in the Saskatchewan portion of the study area. The methane concentrations were generally low (< 0.05 mg/L); two were slightly higher than 1 mg/L which is the minimum explosion hazard level (Harder et al., 1965). The concentrations appear to be strongly related to geographic locations and completion zones of the wells. Samples from the Judith River sands (mean = 0.21 mg/L) tended to be higher than from drift aquifers (mean < 0.002 mg/L). More study is required to establish the reasons for these higher concentrations.

8.1 Recommendations

1. It will be valuable to continue monitoring the methane concentrations in the monitoring wells at four research sites through 1997, with a focus on the Lindbergh and Swimming sites. These two sites have relatively large monitoring well networks (14 or 15 wells each), including vertical "nests" of wells. The networks may have to be expanded in the future, depending on further analytical results and modeling of the methane plumes at these sites. It is anticipated that members of the steering committee for this study will have the opportunity to review any specific proposals for expansion of the monitoring networks.

2. The development of quantitative models of methane migration should continue, in conjunction with an ongoing monitoring program. The modeling should focus on the Lindbergh and Swimming sites. Part of this modeling will be conducted as a graduate thesis project (M. Rieser, Masters student, U. of Montana).

3. The survey of dissolved methane in water supply wells in the Lloydminster study area (and selected other hydrochemical parameters) should be expanded. At least 50 to 100 additional analyses should be conducted to provide a database that will contain statistically significant information on the geographic and stratigraphic distribution of dissolved methane in groundwater in the study area. It will also be useful to review the protocol for sampling from these supply wells.

4. Selected analyses of the isotopic compositions of dissolved methane and sulfate should be conducted (research sites, supply wells). These data will provide additional information on the source and fate (e.g., biodegradation) of methane, and the significance of microbial reduction of sulfate.

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APPENDIX A.

Completion Records for the Test Hole and Monitoring Wells at Lindbergh Site (1994-95)

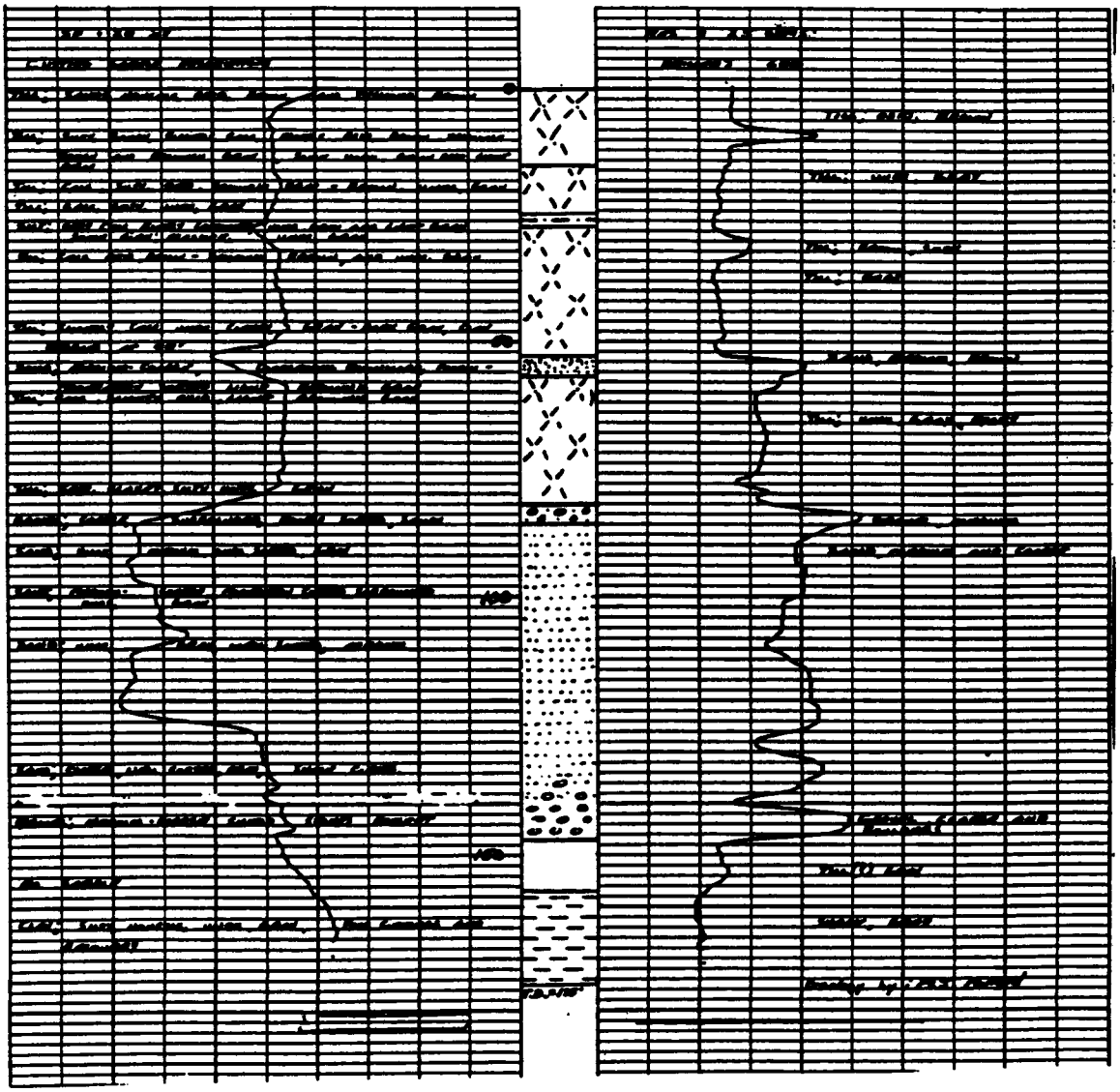
LND 94-01
16-4-55-6-W4

BOREHOLE NO. LND 94-01
LAND LOCATION 16-4-55-6-W4
UTM COORD. _____
GRD. ELEV. _____ DEPTH 175 ft
DATE DRILLED MAY 3, 1994
COND. WATER 350 uS/cm @ 25°C
COND. MUD 800 uS/cm @ 25°C
SPECIFIC GRAVITY MUD _____
SUPERVISOR M.J.MILLARD
ASS'T SUPERVISOR D.VAN STEMPVOORT
LOGGED BY G. MCALLISTER
INSTRUMENT _____
PROBE ELECTRIC _____
PROBE GAMMA _____
PROBE CALIPER _____
DATE LOGGED MAY 3, 1994
TIME OF LOGGING 5:30 PM TO 5:45 PM
DRILL OPERATOR G.MCALLISTER
CONTRACTOR MCALLISTER DRILLING LTD.
REMARKS POOR SAMPLE RECOVERY BEYOND 150' DUE TO ROCK BIT.HOLE PLUGGED AT 168'
PIEZ SETIN NEW HOLE -3M North(LND94-01A)

NTS 73E/10
PROJECT METHANE MIGRATION
CUTTING SAMPLE INTERVAL 5 FT
CORE SAMPLE INTERVAL _____
FROM _____
CASING DEPTH _____
CASING WALL THICKNESS _____
WATER OR MUD LEVEL _____
ABANDONMENT GROUTED TO SURFACE
BIT SIZE 6 1/4" INTERVAL 0-175'
BIT SIZE _____ INTERVAL _____
BIT SIZE _____ INTERVAL _____
TYPE OF DRILL RIG FAILING 1250

	DEPTH	SCALE	SPEED
SP	175	20	
RES.	175	25	
GAMMA			
CAL.			

GAMMA TIME CONSTANT (T.C.) _____SEC.
GEOLOGY BY M.J. MILLARD

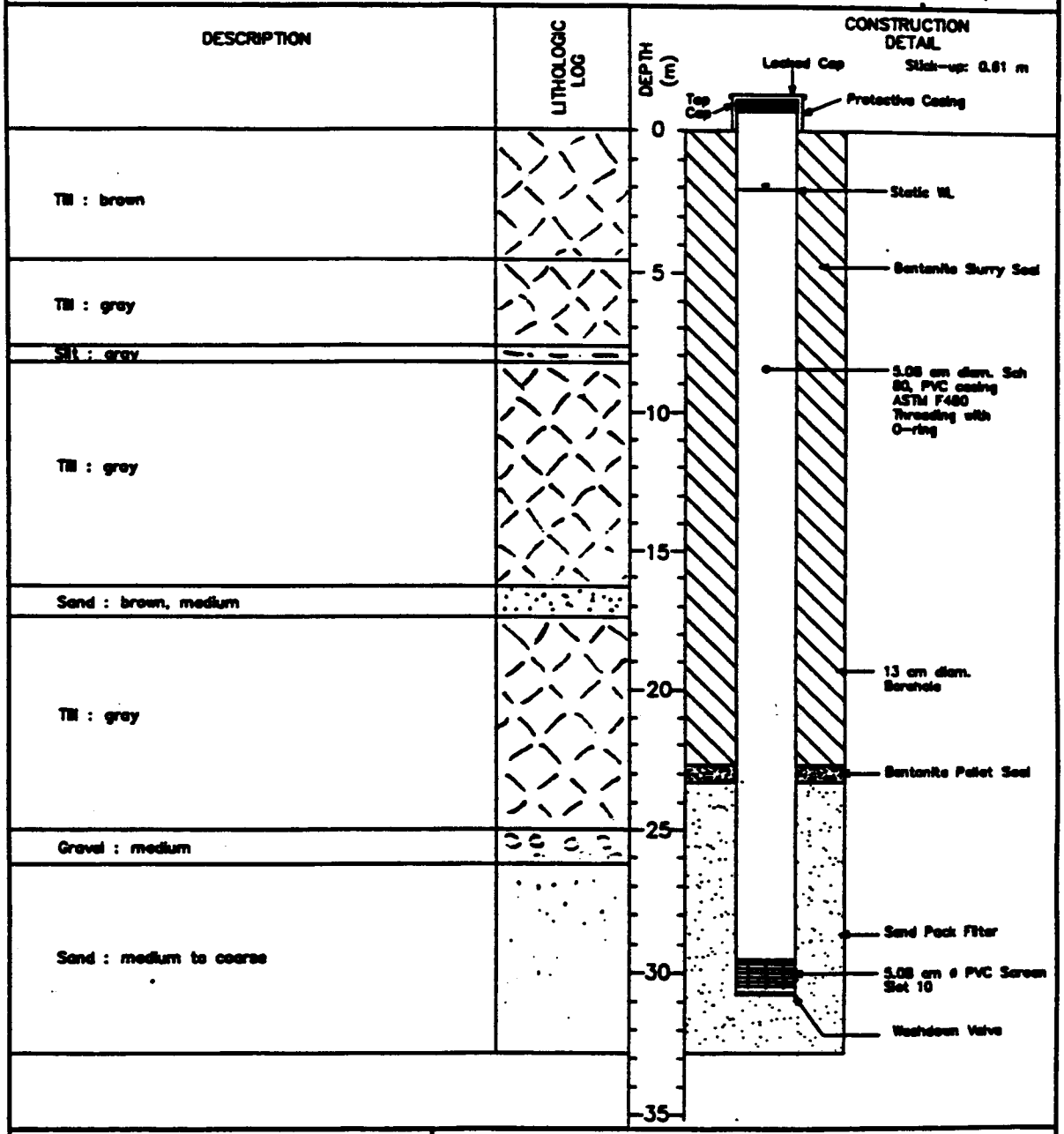


Monitoring Well Lnd-94-01A

PROJECT: Methane Migration
DRILL RIG: Rotary
DRILLING CO.: McAllister Water Wells Ltd.
ELEV. SOURCE: Ref. to Amoco Production Well

DATE: May 5, 1994
TOTAL DEPTH: 32.80
SURF. ELEV.: 626.43 masl
TOC. ELEV.: 627.041 masl

LOCATION: NE16-04-55-06-W4
UTM: 12/511700E/5953100N
DRILLER: G. McAllister
LOGGED BY: Dale Van Stempvoort*



Saskatchewan Research Council

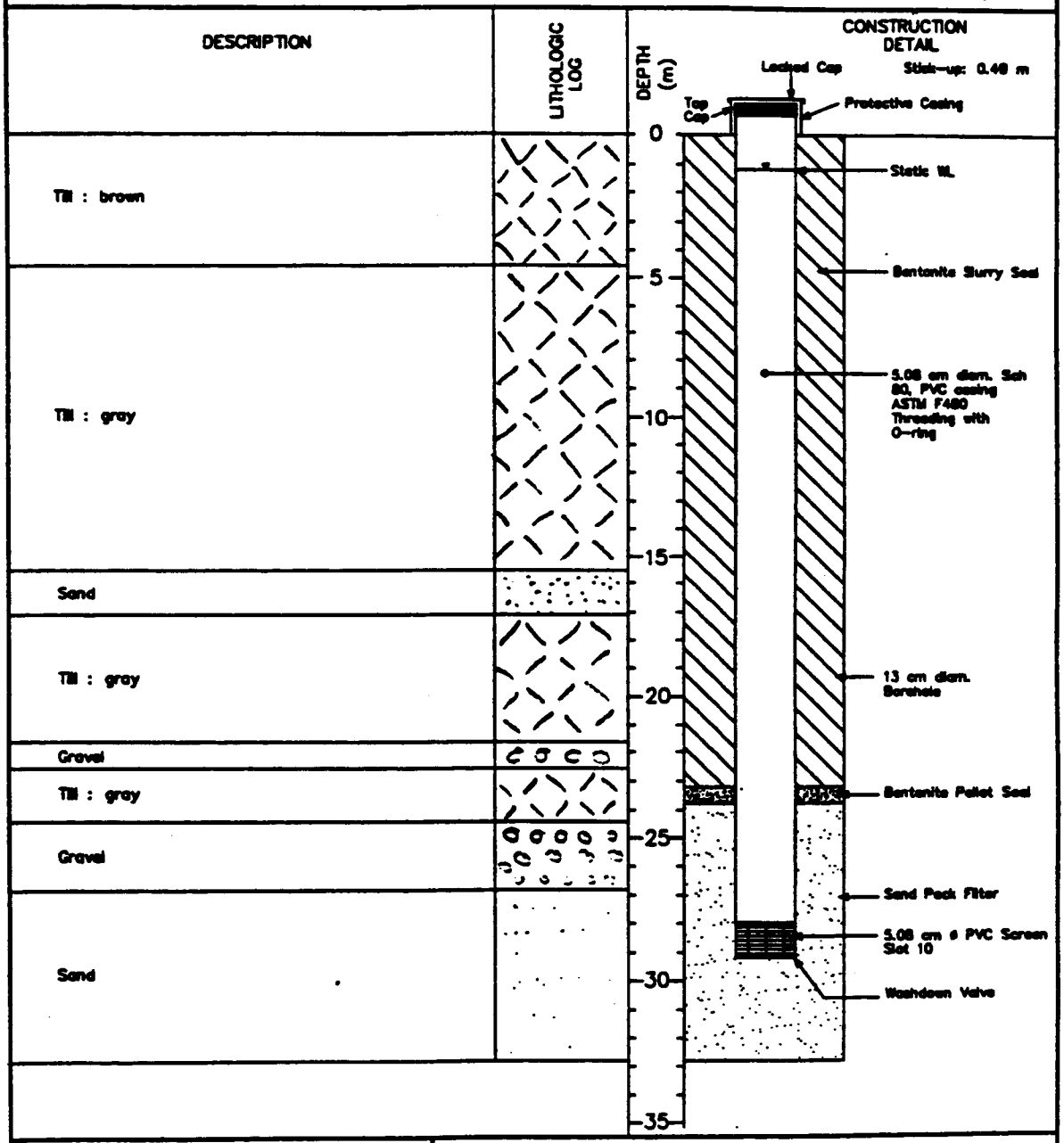
* Log based on detailed geologic description of testhole cuttings by Mac Millard, driller's log, and E-log.

Monitoring Well Lnd–94–02

PROJECT: Methane Migration
DRILL RIG: Rotary
DRILLING CO.: McAllister Water Wells Ltd.
ELEV. SOURCE: Ref. to Amoco Production Well

DATE: May 5, 1994
TOTAL DEPTH: 29.20
SURF. ELEV: 625.60 masl
TOC. ELEV. : 626.090 masl

LOCATION: NE16–04–55–06–W4
UTM: 12/511700E/5953100N
DRILLER: G. McAllister
LOGGED BY: Dale Van Stempvoort*



Saskatchewan Research Council

* Log based on detailed geologic description of testhole cuttings by Mac Millard, driller's log, and E-log.

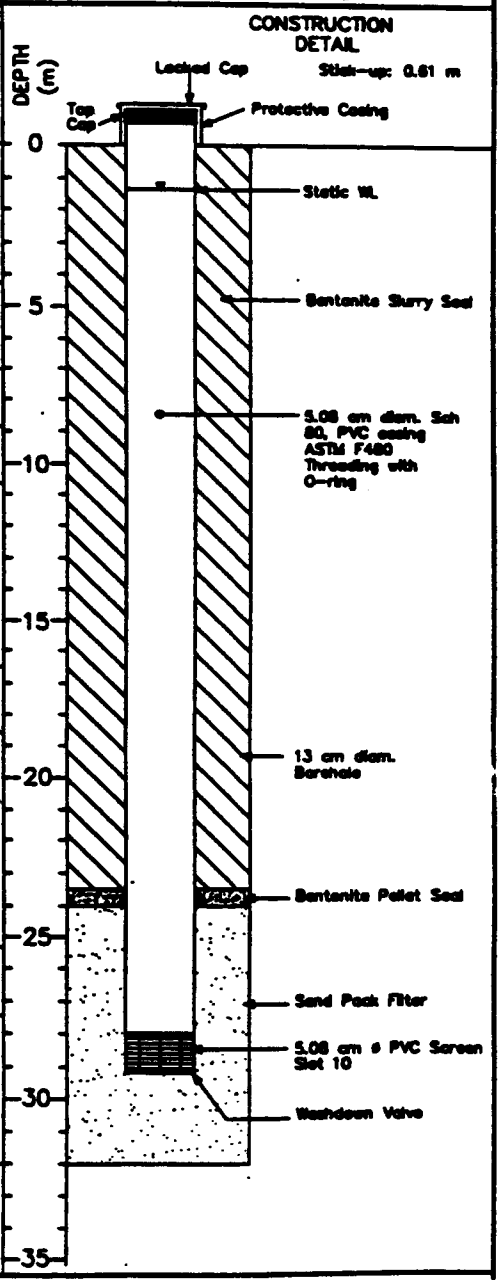
Monitoring Well Lnd–94–03

PROJECT: Methane Migration
DRILL RIG: Rotary
DRILLING CO.: McAllister Water Wells Ltd.
ELEV. SOURCE: Ref. to Amoco Production Well

DATE: May 6, 1994
TOTAL DEPTH: 29.20
SURF. ELEV: 625.66 masl
TOC. ELEV. : 626.269 masl

LOCATION: NE16–04–55–06–W4
UTM: 12/511700E/5953100N
DRILLER: G. McAllister
LOGGED BY: Dale Van Stempvoort*

DESCRIPTION	LITHOLOGIC LOG
Till : brown	
Till : gray	
Sand	
Till : gray	
Sand and gravel	
Till : gray	
Gravel	
Sand	



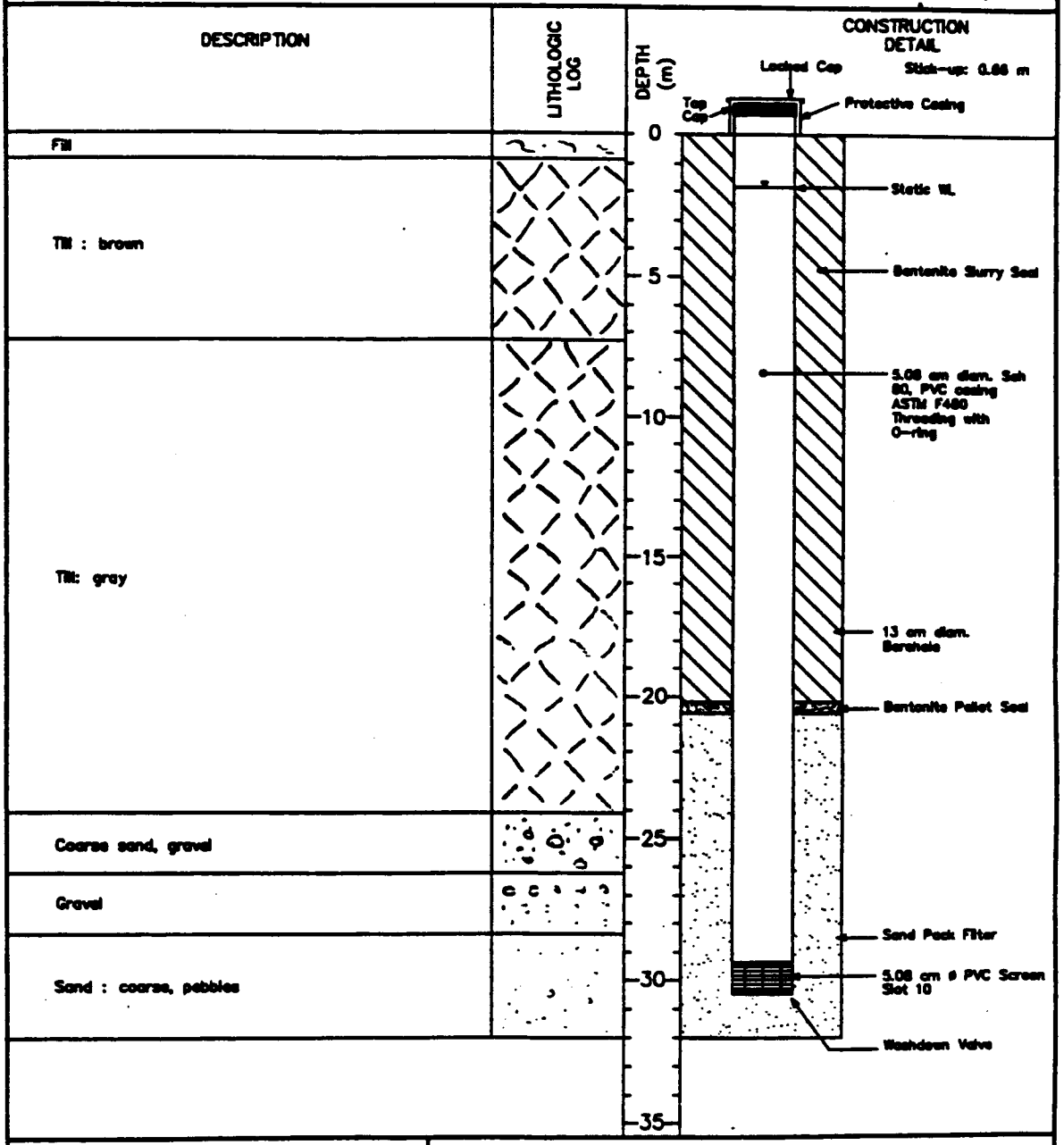
Saskatchewan Research Council

* Log based on detailed geologic description of testhole cuttings by Mac Millard, driller's log, and E–log.

Monitoring Well Lnd-94-04

PROJECT: Methane Migration
DRILL RIG: Rotary
DRILLING CO.: McAllister Water Wells Ltd.
ELEV. SOURCE: Ref. to Amoco Production Well

DATE: September 28, 1994 LOCATION: NE16-04-55-06-W4
TOTAL DEPTH: 32.00 m UTM:12/511700E/5953100N
SURF. ELEV: 626.18 masl DRILLER: T. Koppel
TOC. ELEV.: 626.843 masl LOGGED BY: Dale Van Stempvoort*



Saskatchewan Research Council

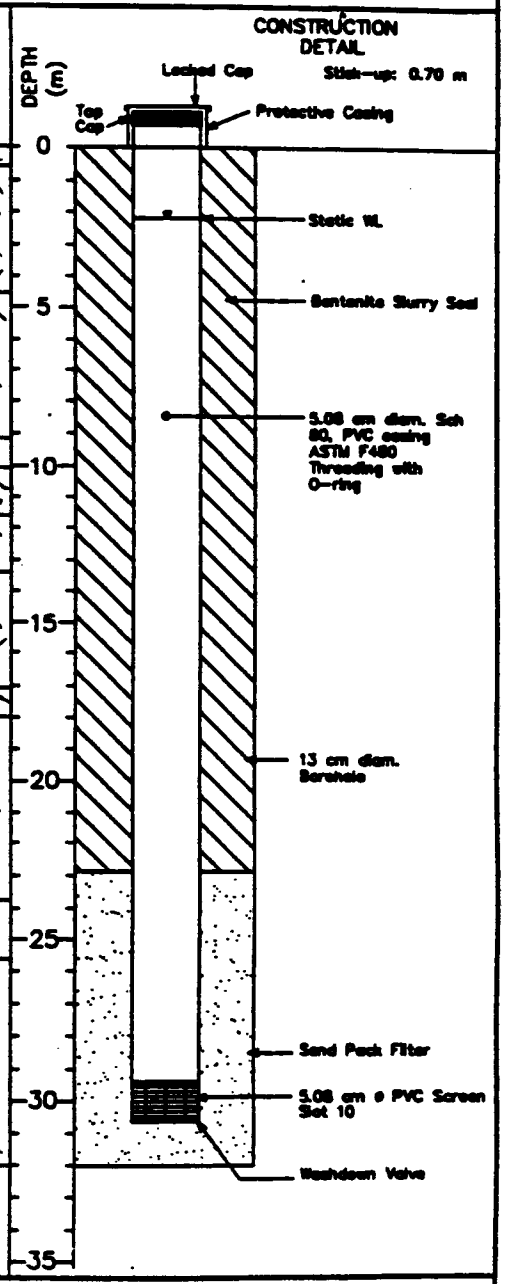
* Log based on detailed geologic description of testhole cuttings by Mac Millard, driller's log, and E-log.

Monitoring Well Lnd–94–05

PROJECT: Methane Migration
DRILL RIG: Rotary
DRILLING CO.: McAllister Water Wells Ltd.
ELEV. SOURCE: Ref. to Amoco Production Well

DATE: September 29, 1994 LOCATION: NE16–04–55–06–W4
TOTAL DEPTH: 32.00 m UTM: 12/511700E/5953100N
SURF. ELEV: 626.46 masl DRILLER: T. Koppel
TOC. ELEV.: 627.157 masl LOGGED BY: Dale Van Stempvoort*

DESCRIPTION	LITHOLOGIC LOG
Fill	
Till : brown	
Till : gray	
Sand : medium	
Till : gray	
Sand : medium, gray	
Till: gray	
Till: gray	
Sand and gravel	
Till or clay : gray	
Sand : coarse, some gravel	



Saskatchewan Research Council

* Log based on detailed geologic description of testhole cuttings by Mac Millard, driller's log, and E-log.

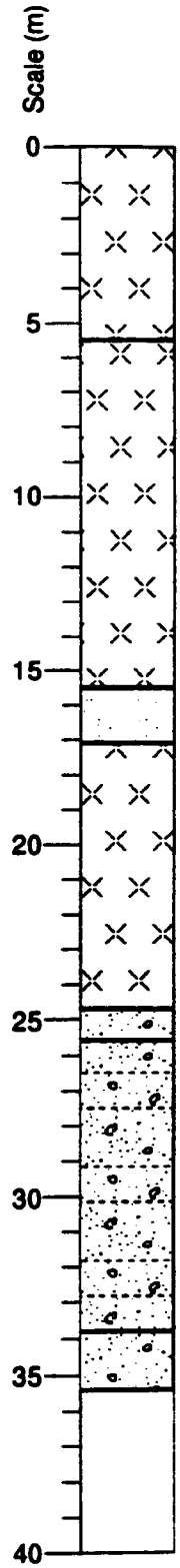
LND 95-06 (A, B, C)

Project: Methane Migration
Date Drilled - Date Completed: 95/11/03
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Wells supervised by: Dale Van Stempvoort

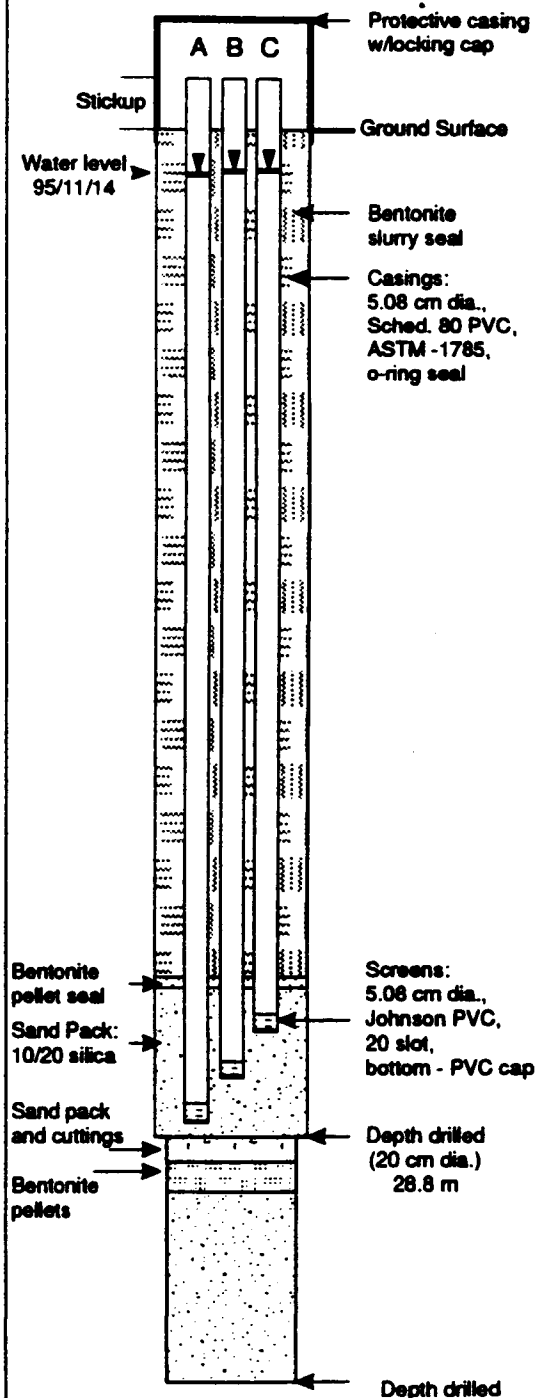
Location: NE16-04-55-06 W4
Surface Elevation: 625.63
Top of Casing: A - 626.228, B - 626.216, C - 626.225
Total Depth: 35.7

Interval	Description
0-5.5	Brown till
5.5-15.5	Gray till
15.5-17.1	Medium sand
17.1-24.7	Gray till
24.7-25.6	Sand and gravel
25.6-33.8	Sand, gravel, with silt and clay?
33.8-35.4	Sand and gravel

Geology based on driller's log and testhole by M. Millard (LND-94-01)



Monitoring Well Diagram



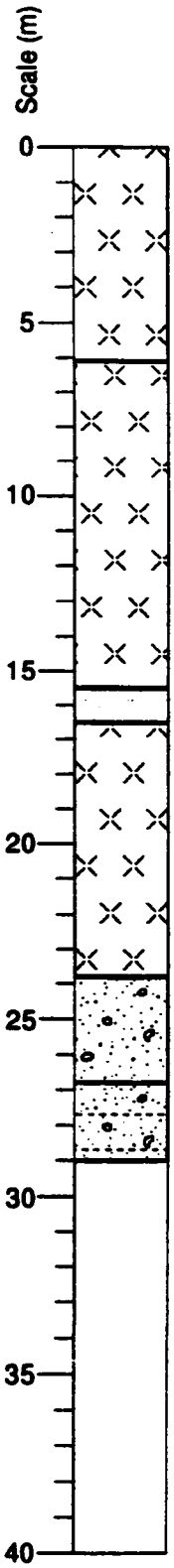
LND 95-07 (A, B, C)

Project: Methane Migration
Date Drilled - Date Completed: 95/11/04
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Wells supervised by: Dale Van Stempvoort

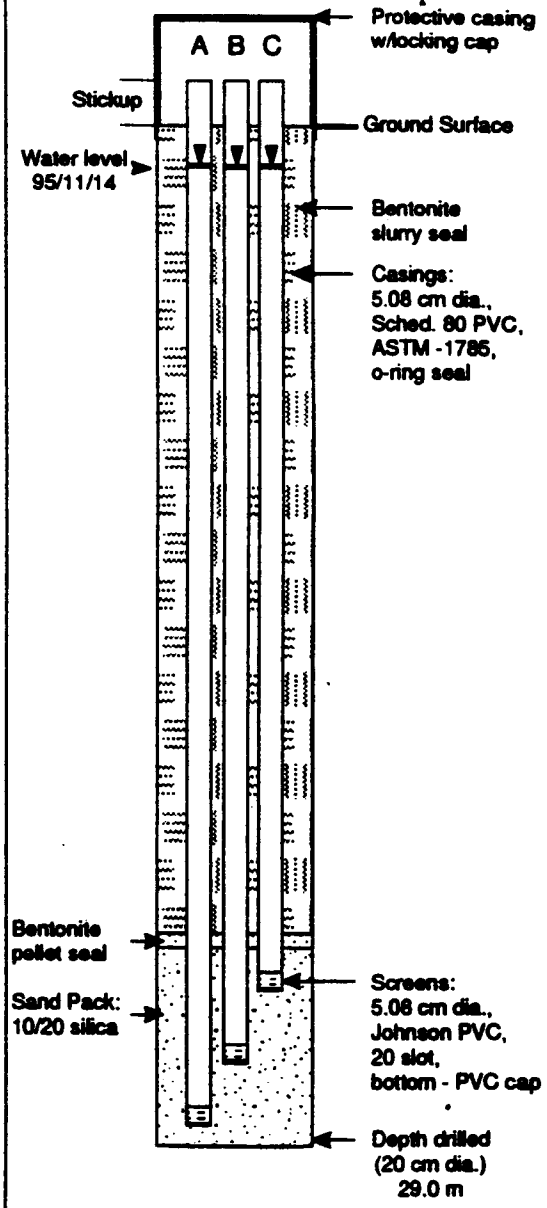
Location: NE16-04-55-06 W4
Surface Elevation: 625.56
Top of Casing: A - 626.164, B - 626.164, C - 626.167
Total Depth: 29 m

Interval	Description
0-6.1	Brown till
6.1-15.5	Gray till
15.5-16.5	Gray sand
16.5-23.8	Gray till
23.8-26.8	Sand and gravel
26.8-29.0	Sand & gravel, silt layers?

Geology based on driller's log and testhole log by M. Millard (LND-94-01)



Monitoring Well Diagram



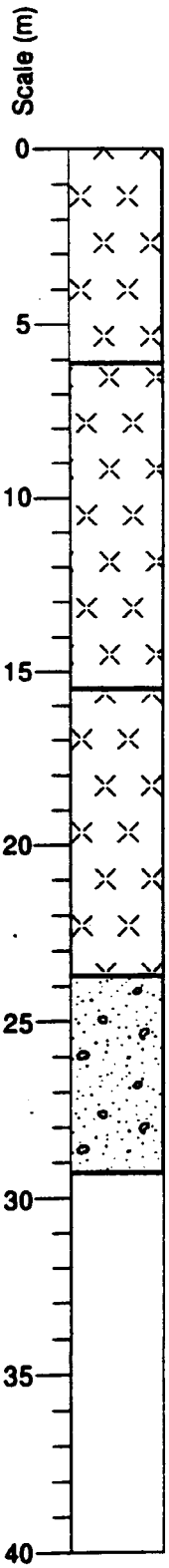
LND 95-08 (A, B, C)

Project: Methane Migration
Date Drilled - Date Completed: 95/11/06
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Wells supervised by: Dale Van Stempvoort

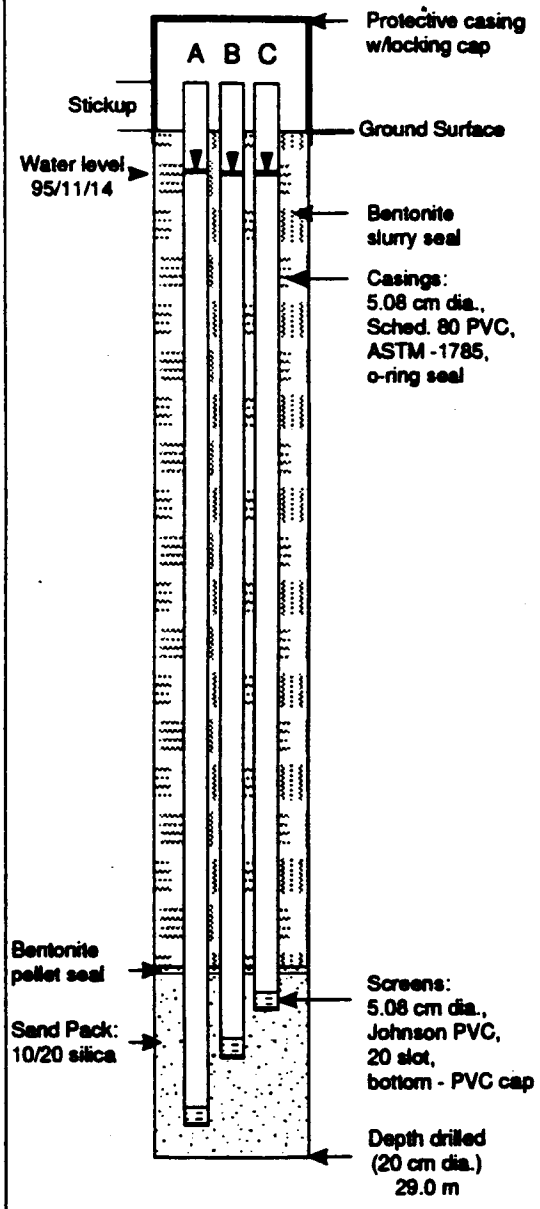
Location: NE16-04-55-06 W4
Surface Elevation: 625.61
Top of Casing: A - 626.218, B - 626.199, C - 626.193
Total Depth: 29.3 m

Interval	Description
0-6.1	Brown till
6.1-15.5	Gray till
15.5-23.7	Gray till, sandy
23.7-29.3	Sand and gravel

Geology based on driller's log and testhole log by M. Millard (LND-94-01)



Monitoring Well Diagram



APPENDIX B.

Log of Test Hole at Golden Lake Site

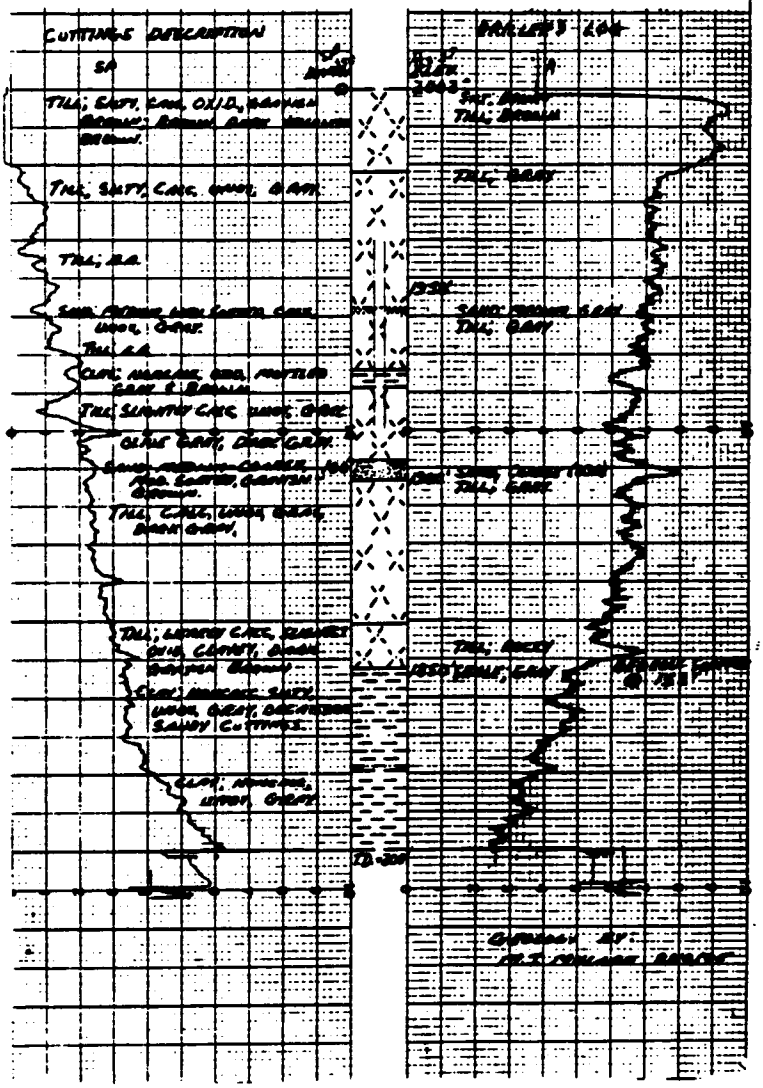
GLD-95-01
CAPPS MAIDSTONE
10-32-48-23-W3

BOREHOLE NO. GLD-95-01
LAND LOCATION 10-32-48-23-W3
UTM COORD.
GRD. ELEV. 2001' (610.5M) DEPTH 200 Ft
DATE DRILLED JUNE 12 1995
COND. WATER ____ mmhos/cm @ 25°C
COND. MUD ____ mmhos/cm @ 25°C
SPECIFIC GRAVITY MUD
SUPERVISOR R.T. SCHREINER
ASS'T SUPERVISOR
LOGGED BY G. MCALLISTER
INSTRUMENT TEXAS INSTRUMENT KLP
PROBE ELECTRIC
PROBE GAMMA
PROBE CALIPER
DATE LOGGED JUNE 12/95
TIME OF LOGGING 1300 HRS
DRILL OPERATOR G.MCALLISTER
CONTRACTOR MCALLISTER WATERWELLS LTD
REMARKS

NTS 73F
PROJECT CAPP METHANE MIGRATION
CUTTING SAMPLE INTERVAL 5 FT
CORE SAMPLE INTERVAL
FROM
CASING DEPTH
CASING WALL THICKNESS
WATER OR MUD LEVEL
ABANDONMENT BENTONITE GROUT
BIT SIZE 5 1/8" INTERVAL
BIT SIZE INTERVAL
BIT SIZE INTERVAL
TYPE OF DRILL RIG

	DEPTH	SCALE	SPEED
SP	200	250	
RES	200	25	
GAMMA			
CAL			

GAMMA TIME CONSTANT (T.C.) ____ SEC.
GEOLOGY BY M.J.MILLARD



APPENDIX C.

Log of Test Hole at Lone Rock Site

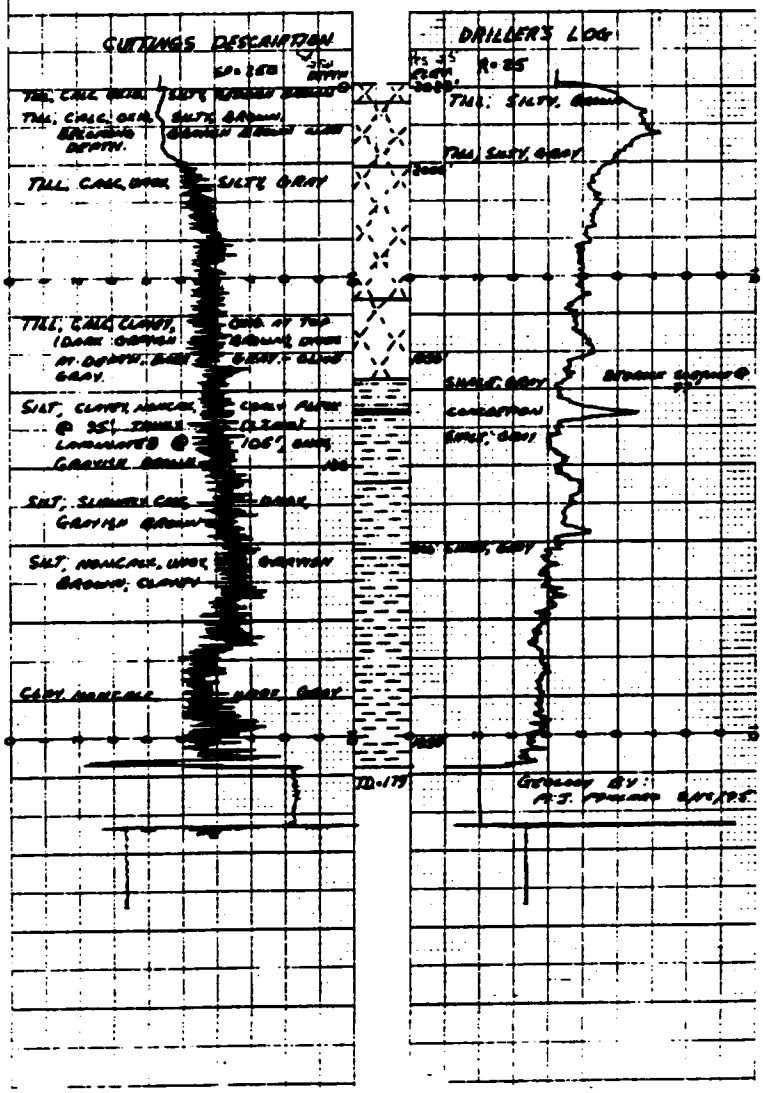
LNR-95-01
CAPPS CARMANAH
7-20-47-26-W3

BOREHOLE NO.	LNR-95-01	NTS	73F
LAND LOCATION	7-20-47-26-W3	PROJECT	CAPP METHANE MIGRATION
UTH COORD.		CUTTING SAMPLE INTERVAL	5 FT
GRD. ELEV.	2021' (616.6M) DEPTH 179 ft	CORE SAMPLE INTERVAL	
DATE DRILLED	JUNE 13, 1995	FROM	
COND. WATER	umhos/cm @ 25°C	CASING DEPTH	
COND. MUD	umhos/cm @ 25°C	CASING WALL THICKNESS	
SPECIFIC GRAVITY MUD		WATER OR MUD LEVEL	
SUPERVISOR	B.T.SCHREINER	ABANDONMENT	BENTONITE GROUT
ASS'T SUPERVISOR		BIT SIZE 5 1/8"	INTERVAL
LOGGED BY	G. MCALLISTER	BIT SIZE	INTERVAL
INSTRUMENT	TEXAS INSTRUMENT KLP	BIT SIZE	INTERVAL
PROBE ELECTRIC		TYPE OF DRILL RIG	
PROBE GAMMA			
PROBE CALIPER			
DATE LOGGED	JUNE 13/95		
TIME OF LOGGING	1230 HRS		
DRILL OPERATOR	G.MCALLISTER		
CONTRACTOR	MCALLISTER WATERWELLS LTD		
REMARKS			

	DEPTH	SCALE	SPEED
SP	179	250	
RES.	179	25	
GAMMA			
CAL.			

GAMMA TIME CONSTANT (T.C.) _____ SEC.

GEOLOGY BY M.J.MILLARD



APPENDIX D.

Log of Test Hole and Completion Records for Monitoring Wells at Wildmere Site

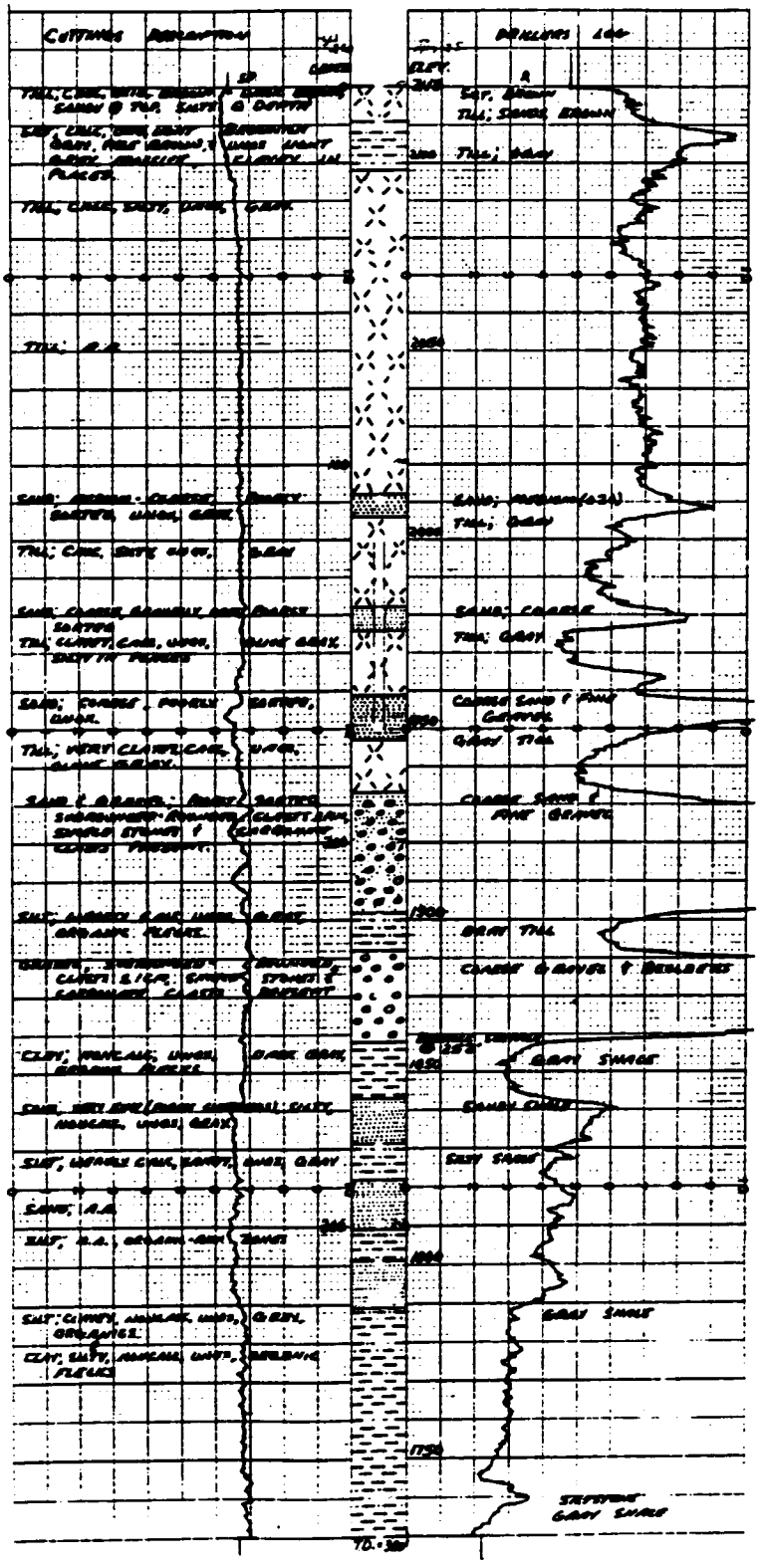
WDM-95-01
CAPPS KOCH
7-14-47- 5-W4

BOREHOLE NO. WDM-95-01
LAND LOCATION 7-14-47- 5-W4
UTM COORD.
GRD. ELEV. 2118' (645.5M) DEPTH 180 ft
DATE DRILLED JUNE 14, 1995
COND. WATER umhos/cm @ 25°C
COND. MUD umhos/cm @ 25°C
SPECIFIC GRAVITY MUD
SUPERVISOR B.T. SCHREINER
ASS'T SUPERVISOR
LOGGED BY G. MCALLISTER
INSTRUMENT TEXAS INSTRUMENT ELP
PROBE ELECTRIC
PROBE GAMMA
PROBE CALIPER
DATE LOGGED JUNE 14/95
TIME OF LOGGING 2000-2030 MBS
DRILL OPERATOR G.MCALLISTER
CONTRACTOR MCALLISTER WATERWELLS LTD
REMARKS PIEZOMETER SET @ 211'.

NTS 73E
PROJECT CAPP METHANE MIGRATION
CUTTING SAMPLE INTERVAL 5 FT
CORE SAMPLE INTERVAL
FROM
CASING DEPTH
CASING WALL THICKNESS
WATER OR MUD LEVEL
ABANDONMENT BENTONITE GROUT
BIT SIZE 5 1/8" INTERVAL
BIT SIZE INTERVAL
BIT SIZE INTERVAL
TYPE OF DRILL RIG

	DEPTH	SCALE	SPEED
SP	180	250	
RES.	180	25	
GAMMA			
CAL.			

GAMMA TIME CONSTANT (T.C.) SEC.
GEOLOGY BY M.J.HILLARD



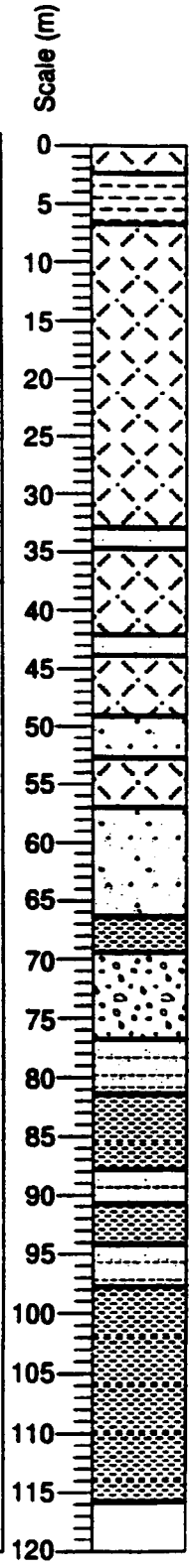
WDM 95-01

Project: Methane migration
Date Drilled - Date Completed: 95/06/15
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Testholes/Wells by: B. Schreiner & E. Jaworski

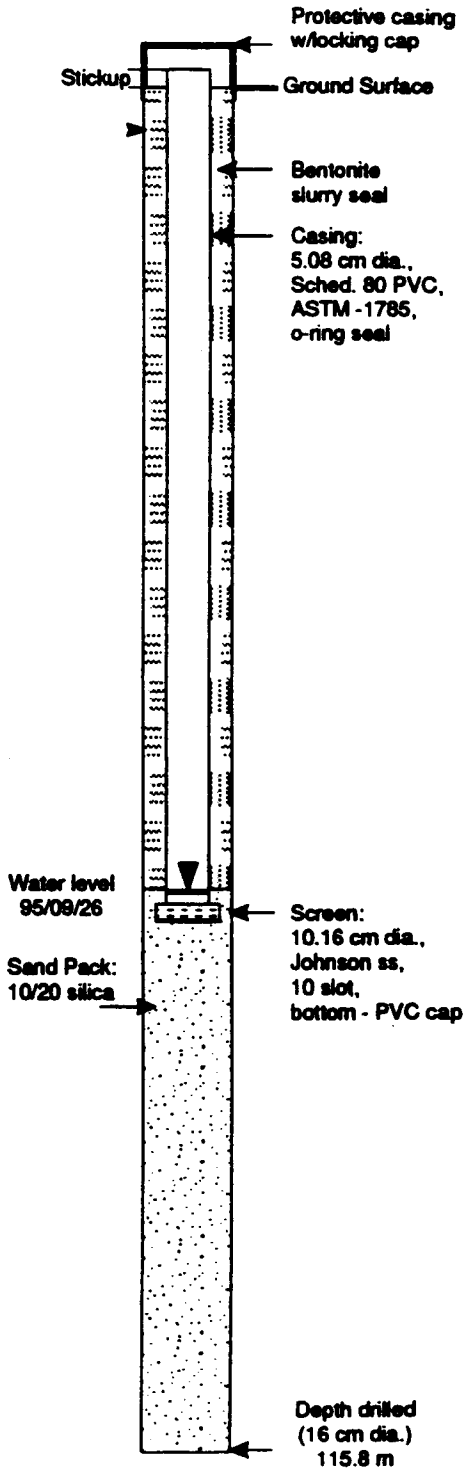
Location: NE 13-14-47-05 W3
Surface Elevation: 645.47 masl
Top of Casing: 646.118 masl
Total Depth: 115.8 m

Interval	Description
0-2.7	Brown till, silty, sandy
2.7-6.7	Silt
6.7-32.9	Gray till, silty
32.9-34.7	Gray sand, medium - coarse
34.7-42.1	Gray till, silty
42.1-43.9	Gray sand
43.9-49.1	Gray till, clayey
49.1-52.7	Coarse sand, gravel
52.7-57.0	Gray till, clayey
57.0-66.4	Sand and gravel
66.4-69.5	Gray silt
69.5-76.8	Gravel
76.8-81.4	Very fine, silty sand
81.4-87.8	Gray silt
87.8-91.7	Silty sand
91.7-94.2	Gray silt
94.2-97.8	Silty sand
97.8-115.8	Silt and clay

Geology based on testhole log by M. Millard



Monitoring Well Diagram



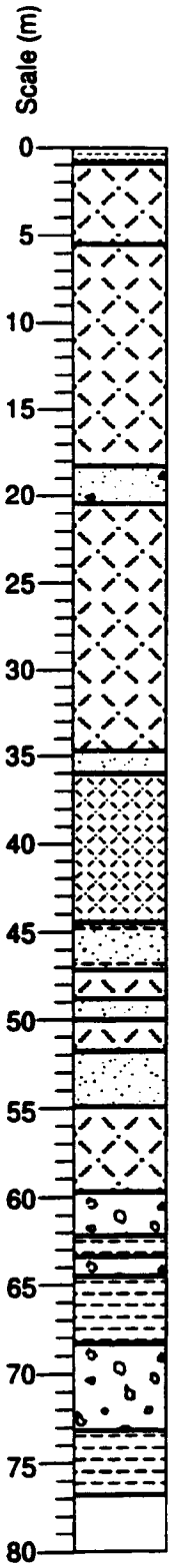
WDM 95-02

Project: Methane migration
Date Drilled - Date Completed: 95/06/27
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Well supervised by: Dale Van Stempvoort

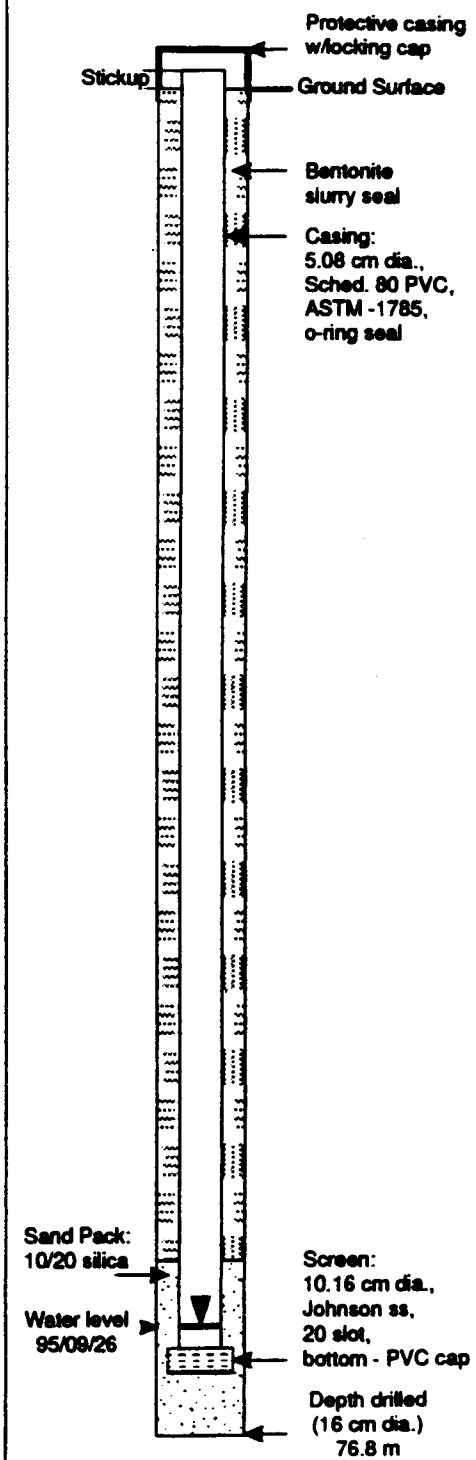
Location: NE 13-14-47-05 W4
Surface Elevation: 647.13 masl
Top of Casing: 647.773 masl
Total Depth: 76.8 m

Interval	Description
0-.9	Brown silt
.9-5.5	Brown till
5.5-18.3	Gray till
18.3-20.4	Sand & gravel
20.4-34.7	Gray till
34.7-36.0	Coarse sand
36.0-44.5	Gray till
44.5-47.2	Interbedded sand, till
47.2-48.8	Till
48.8-50.0	Sand
50.0-51.8	Till
51.8-54.9	Coarse sand
54.9-59.7	Gray till
59.7-62.2	Gravel
62.2-63.4	Silt
63.4-64.5	Gravel
64.5-68.3	Silt
68.3-73.2	Gravel
73.2-76.8	Gray silt

Geology based on driller's log and testhole by M. Millard (WDM-95-01)



Monitoring Well Diagram



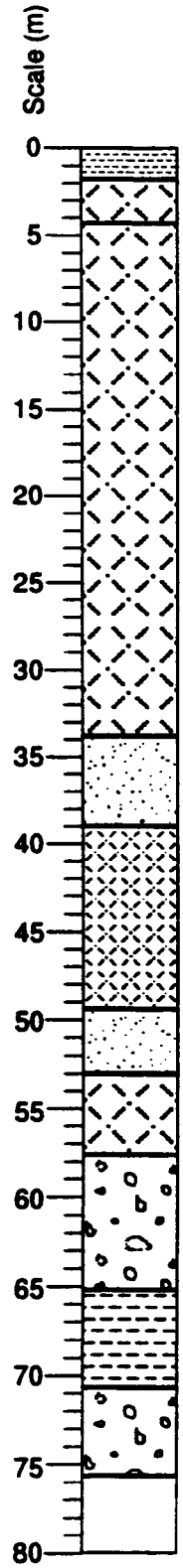
WDM 95-03

Project: Methane migration
Date Drilled - Date Completed: 95/06/28
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Well supervised by: Dale Van Stempvoort

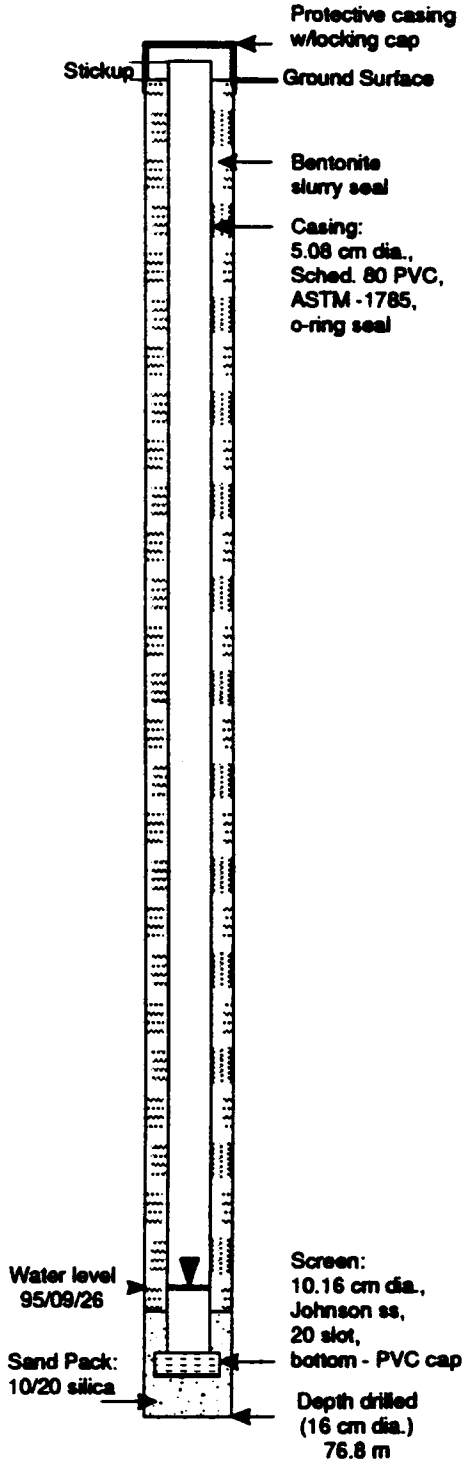
Location: NE 13-14-47-05 W4
Surface Elevation: 645.07 masl
Top of Casing: 645.536 masl
Total Depth: 75.6 m

Interval	Description
0-1.8	Brown silt
1.8-4.3	Brown till
4.3-33.8	Gray till
33.8-39.0	Sand
39.0-49.4	Gray till, thin interbedded sands
49.4-53.0	Coarse sand
53.0-57.6	Gray till
57.6-65.2	Gravel
65.2-70.7	Gray silt
70.7-75.6	Gravel

Geology based on driller's log and testhole log by M. Millard (WDM-95-01)



Monitoring Well Diagram



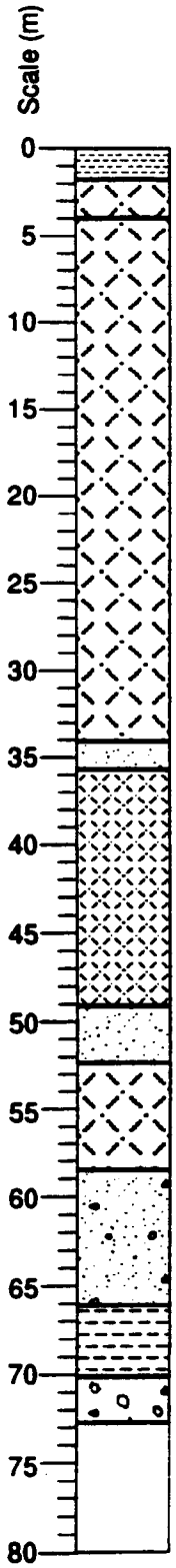
WDM 95-04

Project: Methane migration
Date Drilled - Date Completed: 95/08/29
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Well supervised by: Dale Van Stempvoort

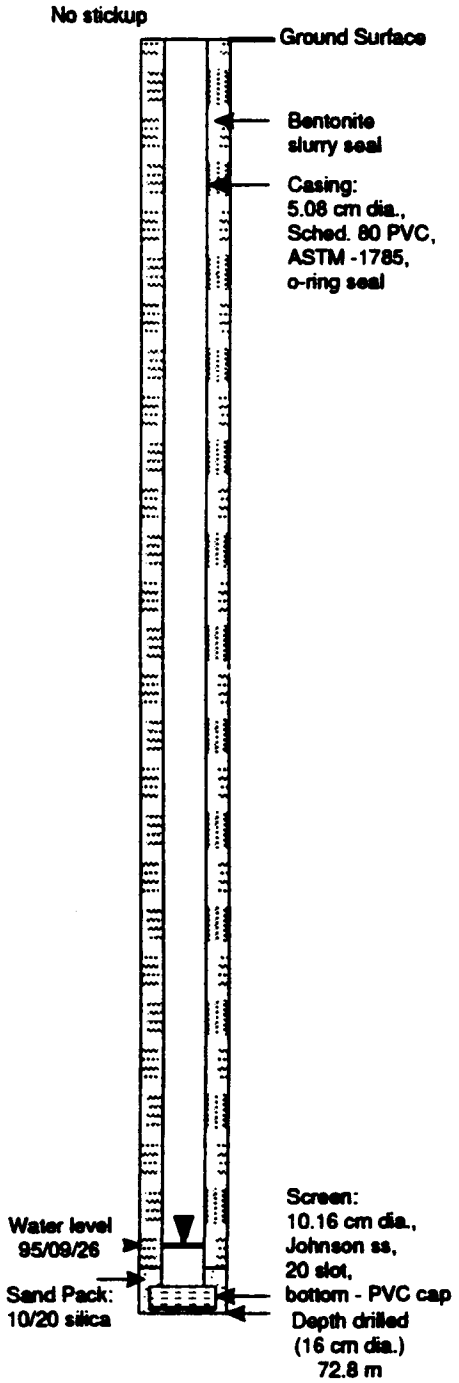
Location: NE 13-14-47-05 W4
Surface Elevation: 645.50 masl
Top of Casing: 645.490 masl
Total Depth: 72.8 m

Interval	Description
0-1.8	Brown silt
1.8-4.0	Brown till
4.0-34.1	Gray till
34.1-35.7	Medium sand
35.7-49.1	Gray till
49.1-52.4	Coarse sand
52.4-58.5	Gray till
58.5-66.1	Coarse sand and gravel
66.1-70.1	Gray silt
70.1-72.8	Gravel

Geology based on driller's log and testhole log by M. Millard (WDM-95-01)



Monitoring Well Diagram



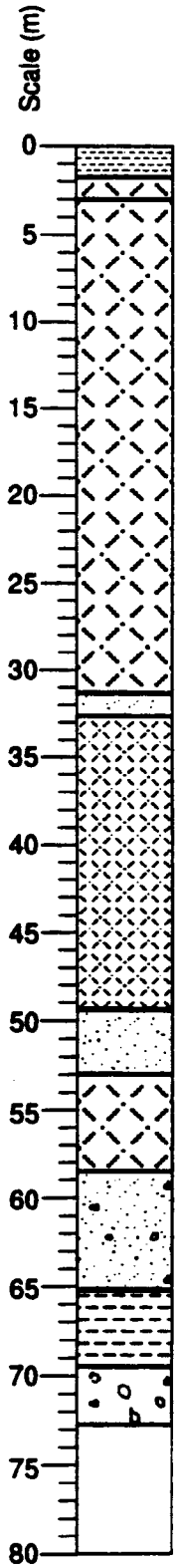
WDM 95-05

Project: Methane migration
Date Drilled - Date Completed: 95/08/31
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Well supervised by: Dale Van Stempvoort

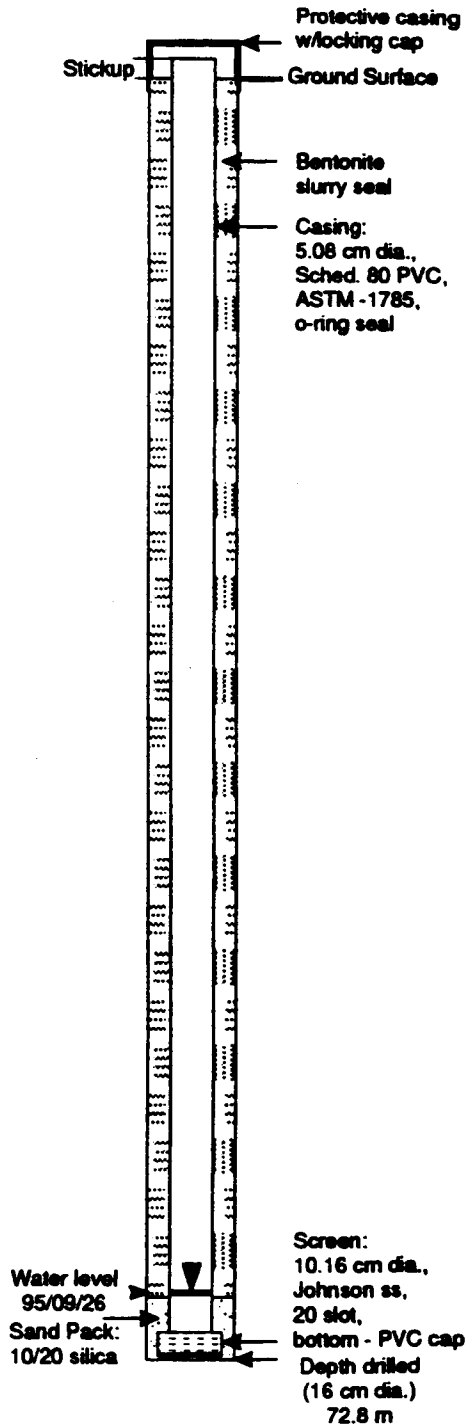
Location: NE 13-14-47-05 W4
Surface Elevation: 645.48 masl
Top of Casing: 646.060 masl
Total Depth: 72.8 m

Interval	Description
0-1.8	Brown silt
1.8-3.0	Brown till
3.0-31.4	Gray till
31.4-32.6	Medium sand
32.6-49.4	Gray till
49.4-53.0	Coarse sand
53.0-58.5	Gray till
58.5-65.2	Sand and gravel
65.2-69.5	Gray silt
69.5-72.8	Gravel

Geology based on driller's log and testhole log by M. Millard (WDM-95-01)

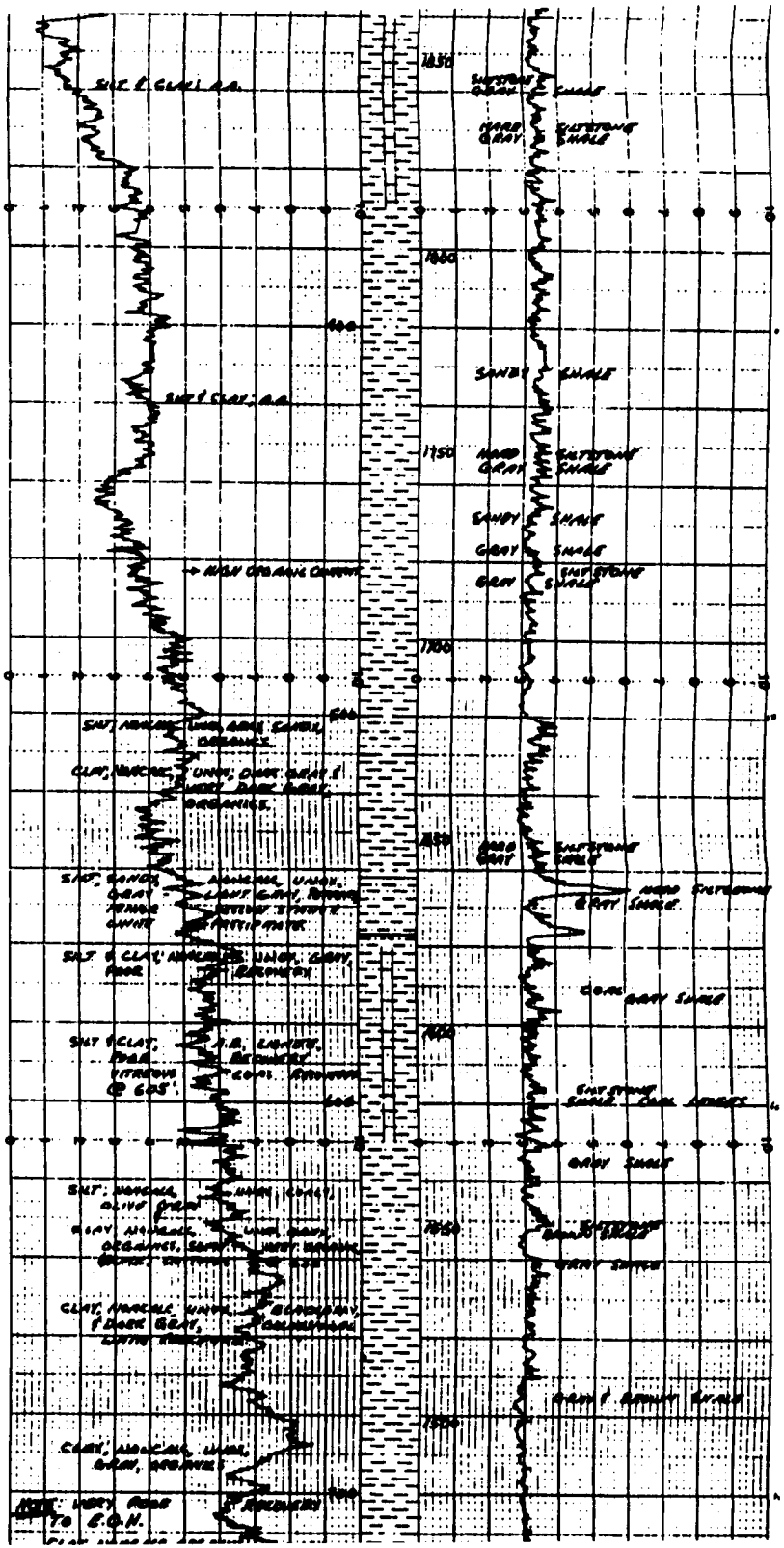


Monitoring Well Diagram



APPENDIX E.

Log of Test Hole at Sedgewick Site

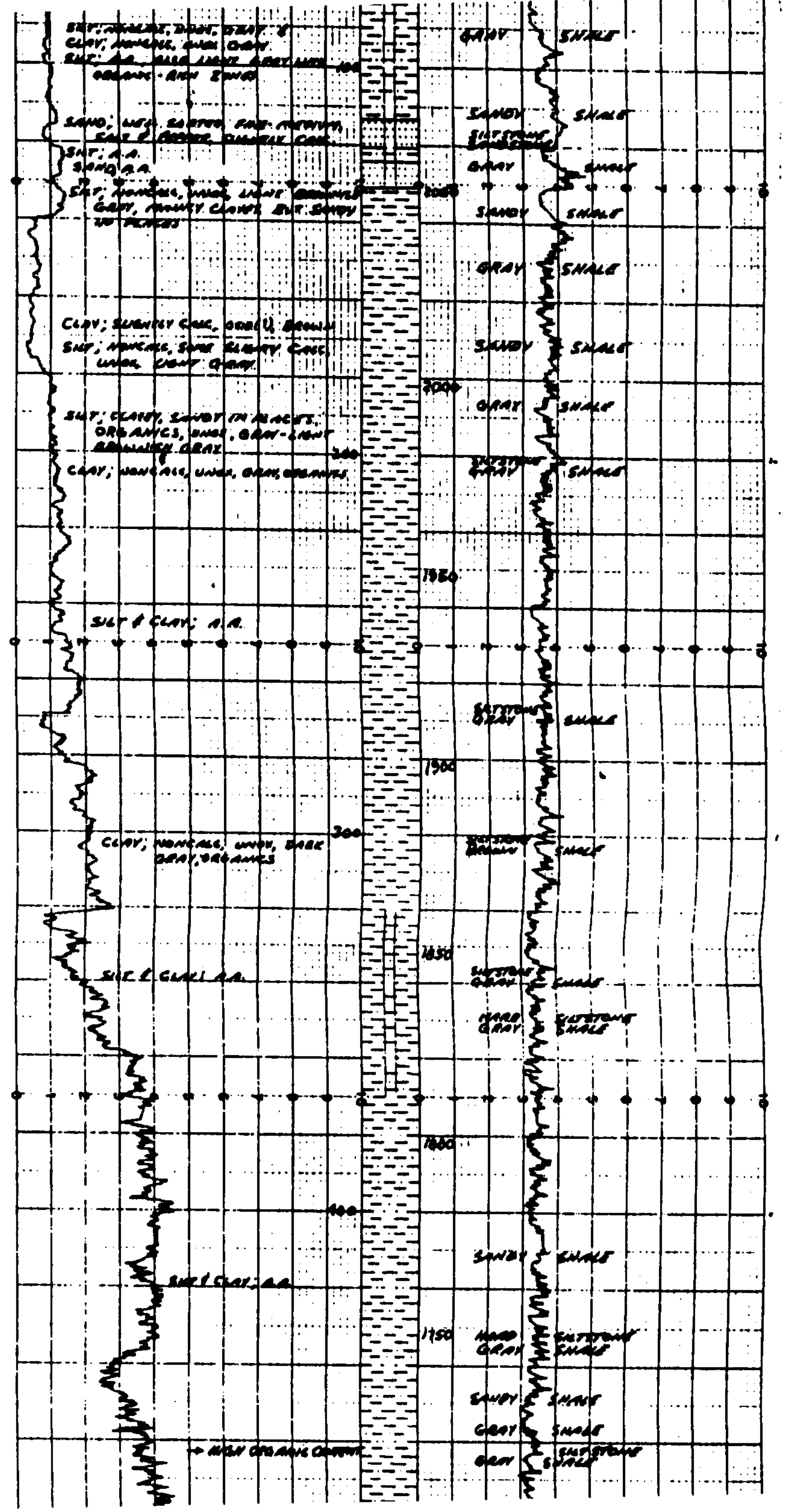


BOREHOLE NO. SDG-95-01
LAND LOCATION 7- 9-44-12-W4
UTM COORD.
GRD. ELEV. 2182' (665M) DEPTH 740 ft
DATE DRILLED JUNE 19, 1995
COND. WATER 400 umhos/cm @ 25°C
COND. MUD 250 umhos/cm @ 25°C
SPECIFIC GRAVITY MUD
SUPERVISOR B.T.SCHREINER
ASS'T SUPERVISOR
LOGGED BY T. KOPPEL
INSTRUMENT TEXAS INSTRUMENT KLP
PROBE ELECTRIC
PROBE GAMMA
PROBE CALIPER
DATE LOGGED JUNE 19/95
TIME OF LOGGING 1500 HRS
DRILL OPERATOR G.MCALLISTER/T.KOPPEL
CONTRACTOR MCALLISTER WATERWELLS LTD
REMARKS

NTS 73E
PROJECT CAPP METHANE MIGRATION
CUTTING SAMPLE INTERVAL 5 FT
CORE SAMPLE INTERVAL
FROM
CASING DEPTH
CASING WALL THICKNESS
WATER OR MUD LEVEL
ABANDONMENT BENTONITE GROUT
BIT SIZE 5 1/8" INTERVAL
BIT SIZE INTERVAL
BIT SIZE INTERVAL
TYPE OF DRILL RIG

	DEPTH	SCALE	SPEED
SP	740	100	
RES.	740	100	
GAMMA			
CAL.			

GAMMA TIME CONSTANT (T.C.) ____ SEC.
GEOLOGY BY M.J.MILLARD



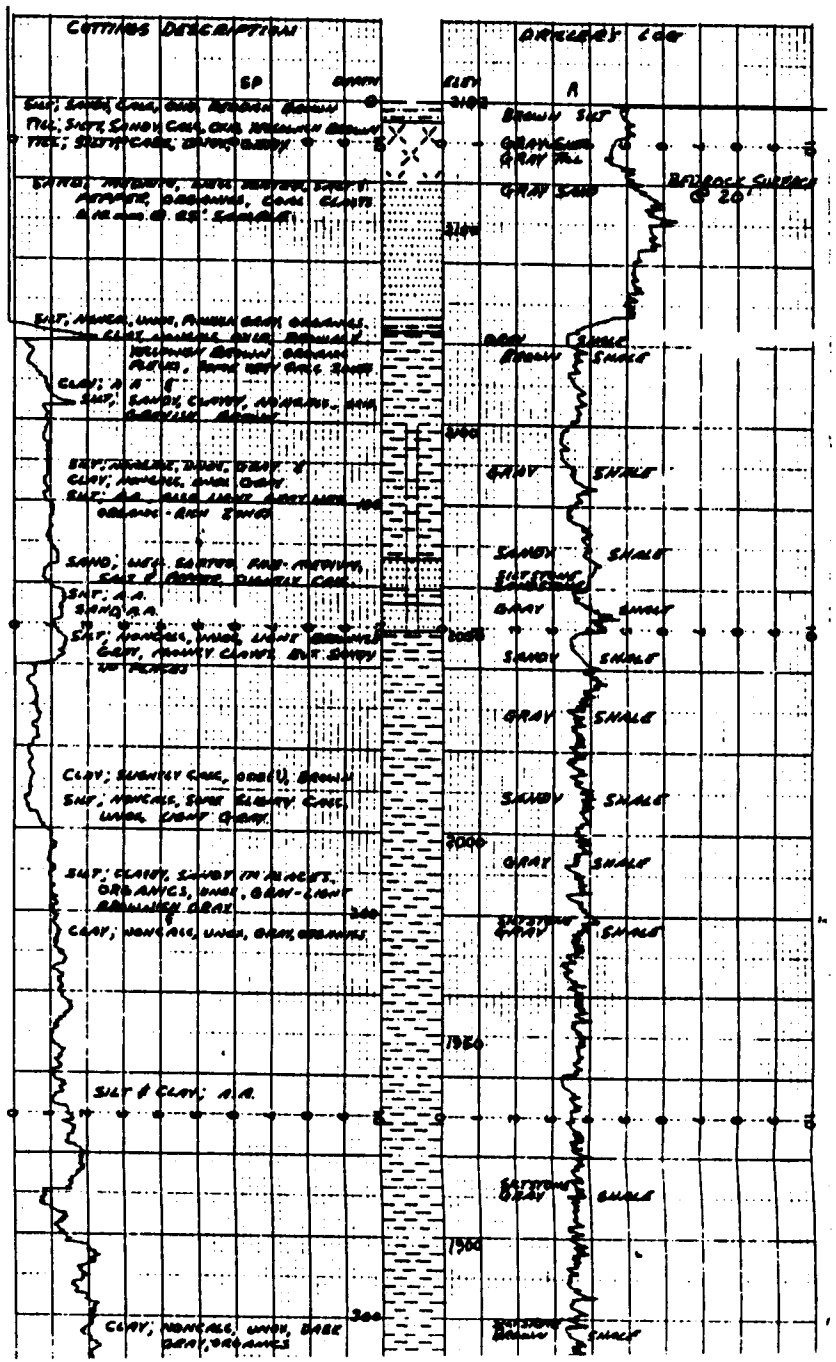
SDG-95-01
CAPPS SEDGEWICK

BOREHOLE NO.	SDG-95-01	NTS	73E
LAND LOCATION	7- 9-44-12-W4	PROJECT	CAPP METHANE MIGRATION
UTM COORD.		CUTTING SAMPLE INTERVAL	5 FT
GRD. ELEV.	2182' (665M) DEPTH 740 ft	CORE SAMPLE INTERVAL	
DATE DRILLED	JUNE 19, 1995	FROM	
COND. WATER	400 umhos/cm @ 25°C	CASING DEPTH	
COND. MUD	250 umhos/cm @ 25°C	CASING WALL THICKNESS	
SPECIFIC GRAVITY MUD		WATER OR MUD LEVEL	
SUPERVISOR	B.T.SCHREINER	ABANDONMENT	BENTONITE GROUT
ASS'T SUPERVISOR		BIT SIZE	5 1/8" INTERVAL
LOGGED BY	T. KOPPEL	BIT SIZE	INTERVAL
INSTRUMENT	TEXAS INSTRUMENT KLP	BIT SIZE	INTERVAL
PROBE ELECTRIC		TYPE OF DRILL RIG	
PROBE GAMMA			
PROBE CALIPER			
DATE LOGGED	JUNE 19/95		
TIME OF LOGGING	1500 HRS		
DRILL OPERATOR	G.MCALLISTER/T.KOPPEL		
CONTRACTOR	MCALLISTER WATERWELLS LTD		
REMARKS			

	DEPTH	SCALE	SPEED
SP	740	100	
RES.	740	100	
GAMMA			
CAL.			

GAMMA TIME CONSTANT (T.C.) _____ SEC.

GEOLOGY BY M.J.MILLARD



APPENDIX F.

Log of Test Hole and Completion Records for Monitoring Wells at Swimming Site

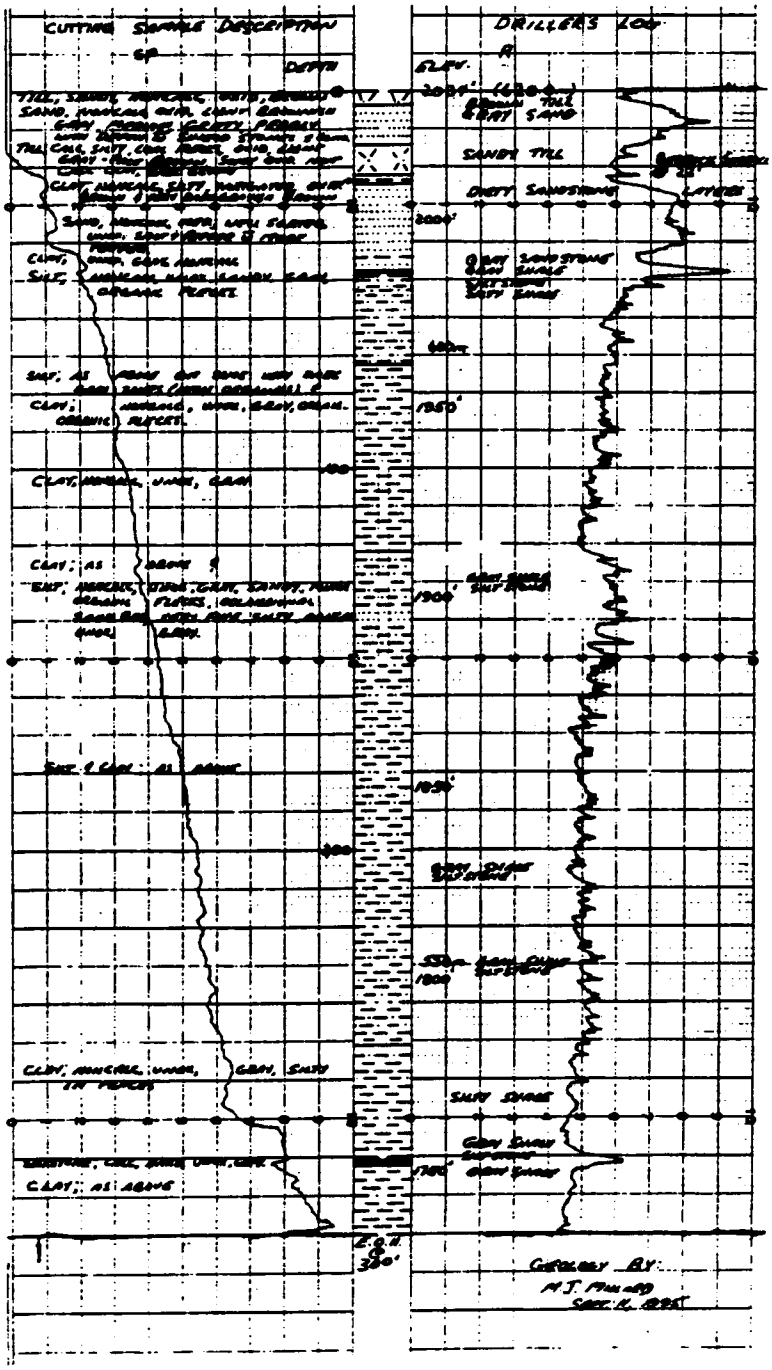
MGN-95-01
10-12-52-7-W4

BOREHOLE NO. MGN-95-01
LAND LOCATION 10-12-52-07-W4
UTM COORD. 12/506650m/5925200m
GRD. ELEV. 2034' (620M) DEPTH 300 ft
DATE DRILLED AUG. 24, 1995
COND. WATER 475 umhos/cm @ 25°C
COND. MUD 700 umhos/cm @ 25°C
SPECIFIC GRAVITY MUD
SUPERVISOR M.J. MILLARD
ASS'T SUPERVISOR
LOGGED BY G. MCALLISTER
INSTRUMENT TEXAS INSTRUMENT KLP
PROBE ELECTRIC
PROBE GAMMA
PROBE CALIPER
DATE LOGGED AUG. 24/95
TIME OF LOGGING 1700-1710 HRS
DRILL OPERATOR T.KAPPEL
CONTRACTOR MCALLISTER WATERWELLS LTD
REMARKS TESTHOLE ABANDONDED. PIEZO. SET AT 40' IN NEW HOLE.

NTS 73E/7
PROJECT CAPP METHANE MIGRATION
CUTTING SAMPLE INTERVAL 5 FT
CORE SAMPLE INTERVAL
FROM
CASING DEPTH
CASING WALL THICKNESS
WATER OR MUD LEVEL
ABANDONMENT BENSEAL
BIT SIZE 5 1/8" INTERVAL
BIT SIZE INTERVAL
BIT SIZE INTERVAL
TYPE OF DRILL RIG

	DEPTH	SCALE	SPEED
SP	100	20	
RES	100	50	
GAMMA			
CAL			

GAMMA TIME CONSTANT (T.C.) SEC.
GEOLOGY BY M.J. MILLARD



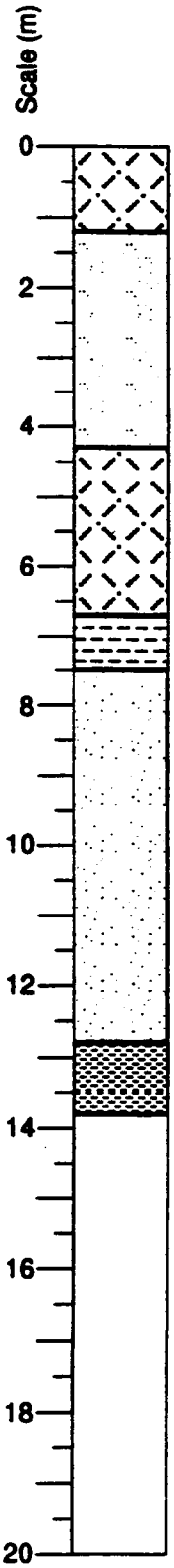
MGN 95-01A

Project: Methane Migration
Date Drilled - Date Completed: 95/08/25
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Well supervised by: E. Jaworski

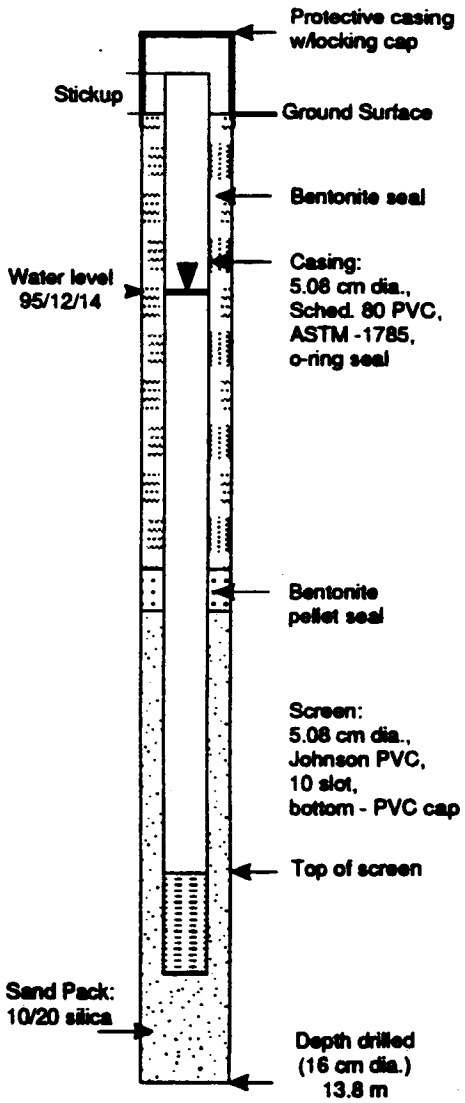
Location: NE 10-12-52-07 W4
Surface Elevation: 618.90 masl
Top of Casing: 619.400 m
Total Depth: 13.8 m

Interval	Description
0-1.2	Brown till, sandy
1.2-4.3	Medium sand
4.3-6.7	Till, gray/brown
6.7-7.5	Brown clay, silty
7.5-12.8	Medium sand
12.8-13.8	Silt, clay

Geology based on testhole log (MGN-95-01)



Monitoring Well Diagram



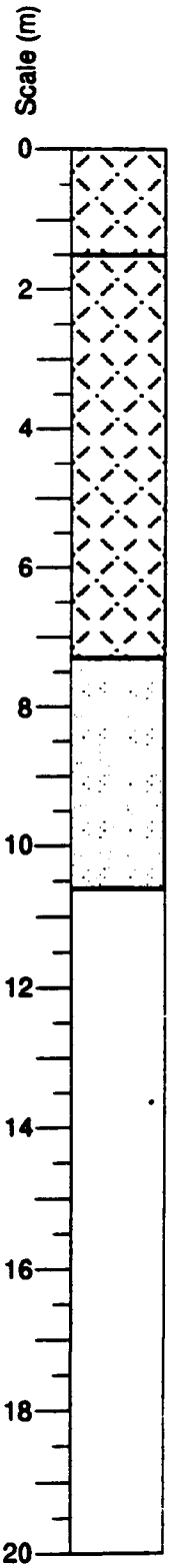
MGN 95-02

Project: Methane Migration
Date Drilled - Date Completed: 95/08/25
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Well supervised by: E. Jaworski

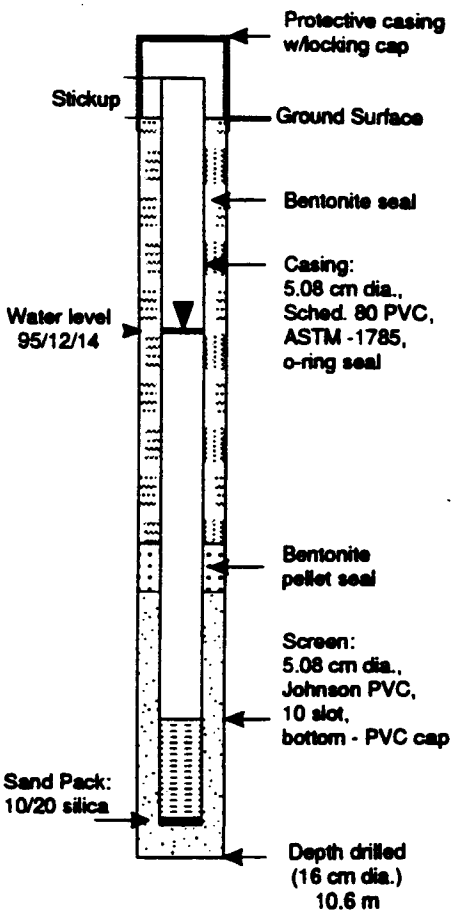
Location: NE 10-12-52-07 W4
Surface Elevation: 619.36 masl
Top of Casing: 619.898 m
Total Depth: 10.6 m

Interval	Description
0-1.5	Brown till, sandy
1.5-7.3	Til, gray/brown, possibly silty clay near base
7.3-10.7	Gray sand

Geology by Dale Van Stempvoort based on driller's log and testhole log by M. Millard (MGN-95-01)



Monitoring Well Diagram



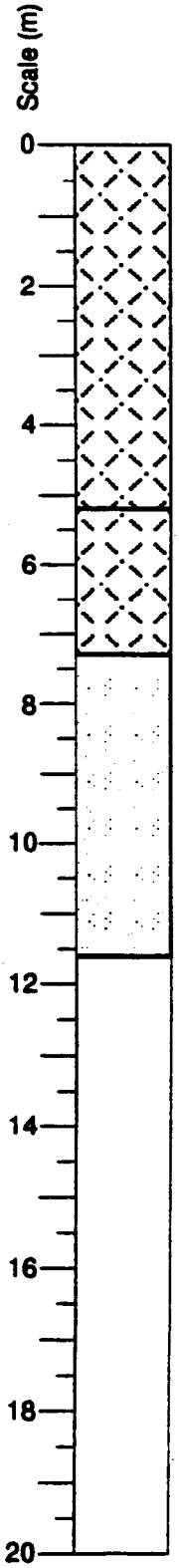
MGN 95-03

Project: Methane Migration
Date Drilled - Date Completed: 95/08/25
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Well supervised by: E. Jaworski

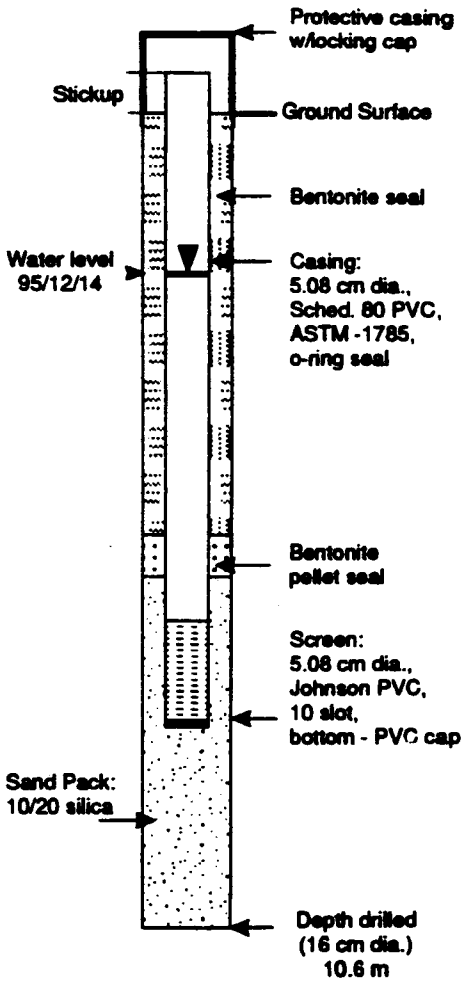
Location: NE 10-12-52-07 W4
Surface Elevation: 618.70 masl
Top of Casing: 619.095 m
Total Depth: 11.6 m

Interval	Description
0-5.2	Brown till, sandy
5.2-7.3	Gray till possibly silty clay near base
7.3-11.6	Gray sand

Geology based on driller's log and testhole log by M. Millard (MGN-95-01)



Monitoring Well Diagram



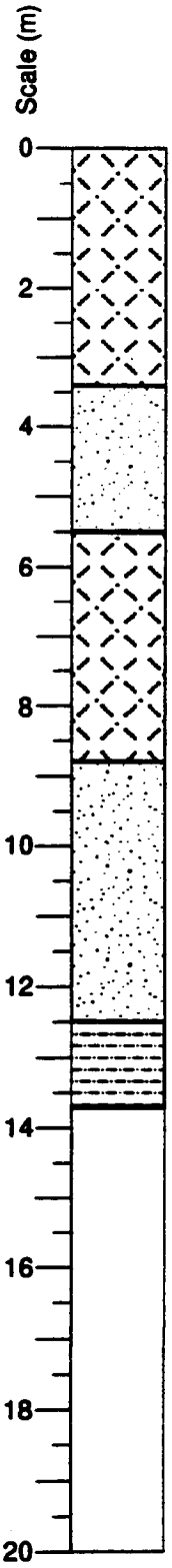
MGN 95-04 (A,B,C)

Project: Methane Migration
Date Drilled - Date Completed: 95/11/23
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Wells supervised by: Dale Van Stempvoort

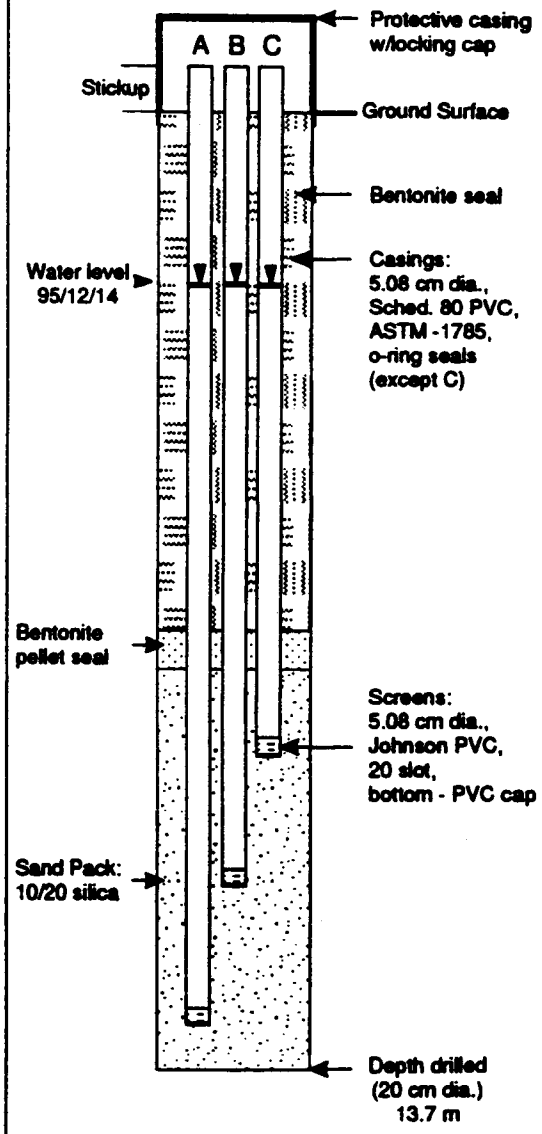
Location: NE 10-12-52-07 W4
Surface Elevation: 618.83 masl
Top of Casing: A-619.484, B-619.520, C-619.494 masl
Total Depth: 13.7 m

Interval	Description
0-3.4	Brown till
3.4-5.5	Brown sand
5.5-8.8	Gray till underlain by silty clay
8.8-12.5	Gray sand
12.5-13.7	Gray silt and clay

Geology based on driller's log and testhole log by M. Millard (MGN-95-01)



Monitoring Well Diagram



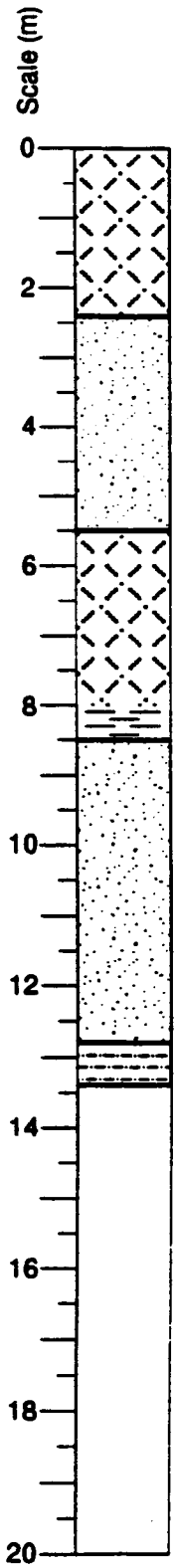
MGN 95-05 (A,B,C)

Project: Methane Migration
Date Drilled - Date Completed: 95/11/23
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Wells supervised by: Dale Van Stempvoort

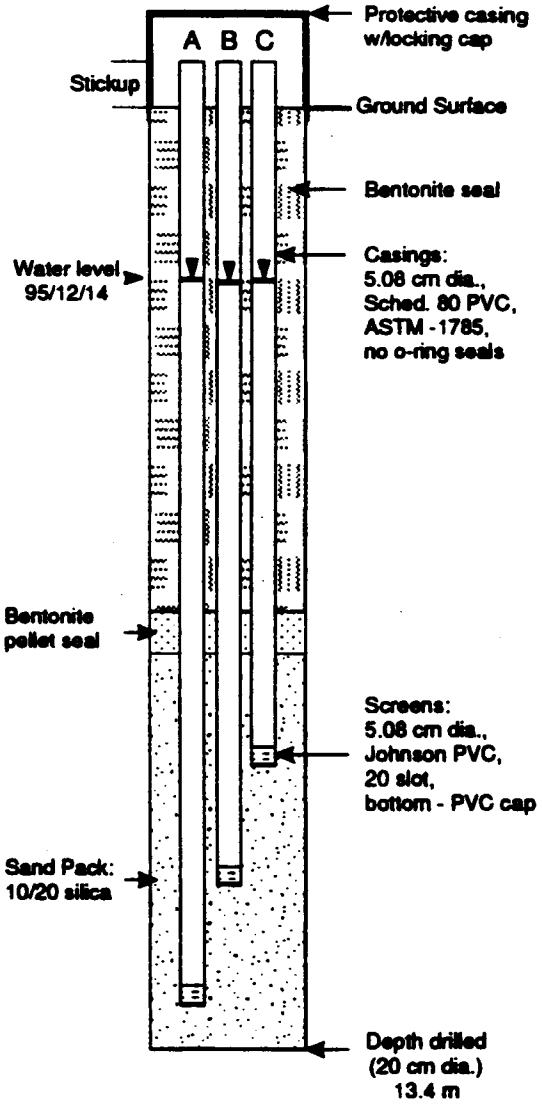
Location: NE 10-12-52-07 W4
Surface Elevation: 618.80 masl
Top of Casing: A-619.432, B-619.435, C-619.446 masl
Total Depth: 13.4 m

Interval	Description
0-2.4	Brown till
2.4-5.5	Brown sand
5.5-8.5	Gray till underlain by silty clay
8.5-12.8	Gray sand
12.8-13.4	Gray silt and clay

Geology based on driller's log and testhole log by M. Millard (MGN-95-01)



Monitoring Well Diagram



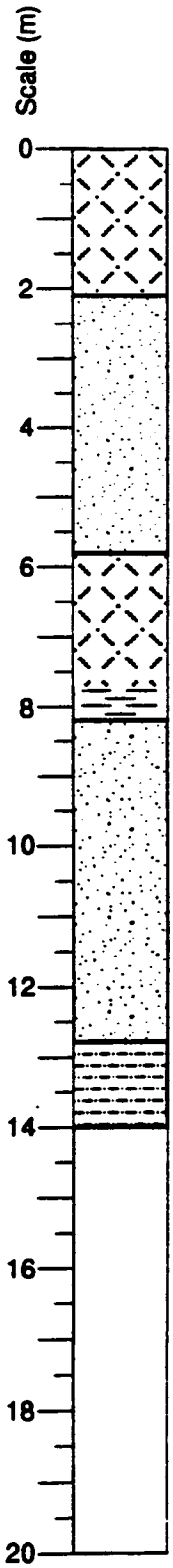
MGN 95-06 (A,B,C)

Project: Methane Migration
Date Drilled - Date Completed: 95/11/24
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Wells supervised by: Dale Van Stempvoort

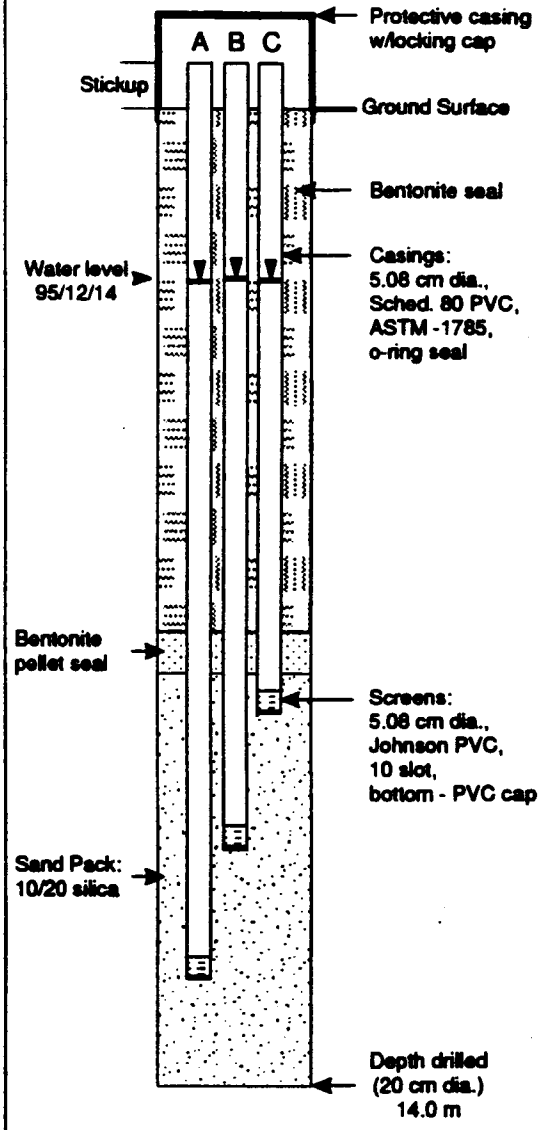
Location: NE 10-12-52-07 W4
Surface Elevation: 618.79 masl
Top of Casing: A-619.430, B-619.386, C-619.408 masl
Total Depth: 14.0 m

Interval	Description
0-2.1	Brown till
2.1-5.8	Brown sand
5.8-8.2	Gray till, silty clay (basal)
8.2-12.8	Gray sand
12.8-14.0	Silt and clay

Geology based on driller's log and testhole log by M. Millard (MGN-95-01)



Monitoring Well Diagram



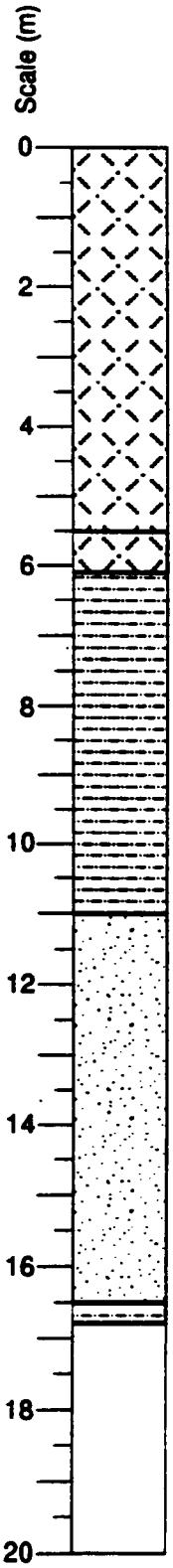
MGN 95-07 (A,B,C)

Project: Methane Migration
Date Drilled - Date Completed: 95/11/24
Drilling Method: Rotary
Drilling Company: McAllister Water Wells Ltd.
Comp. of Wells supervised by: Dale Van Stempvoort

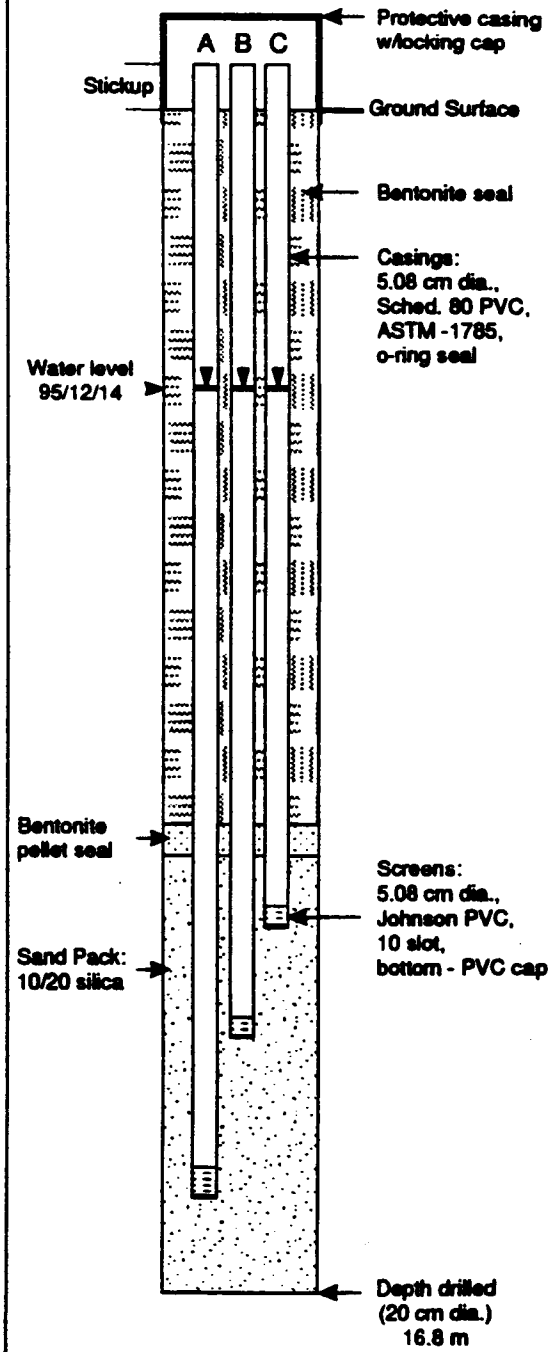
Location: NE 10-12-52-07 W4
Surface Elevation: 620.41 masl
Top of Casing: A-621.050, B-621.034, C-621.028 masl
Total Depth: 16.8 m

Interval	Description
0-5.5	Brown till
5.5-6.1	Gray till
6.1-11.0	Silty clay
11.0-16.5	Gray sand
16.5-16.8	Gray silt and clay

Geology based on driller's log and testhole log by M. Millard (MGN-95-01)

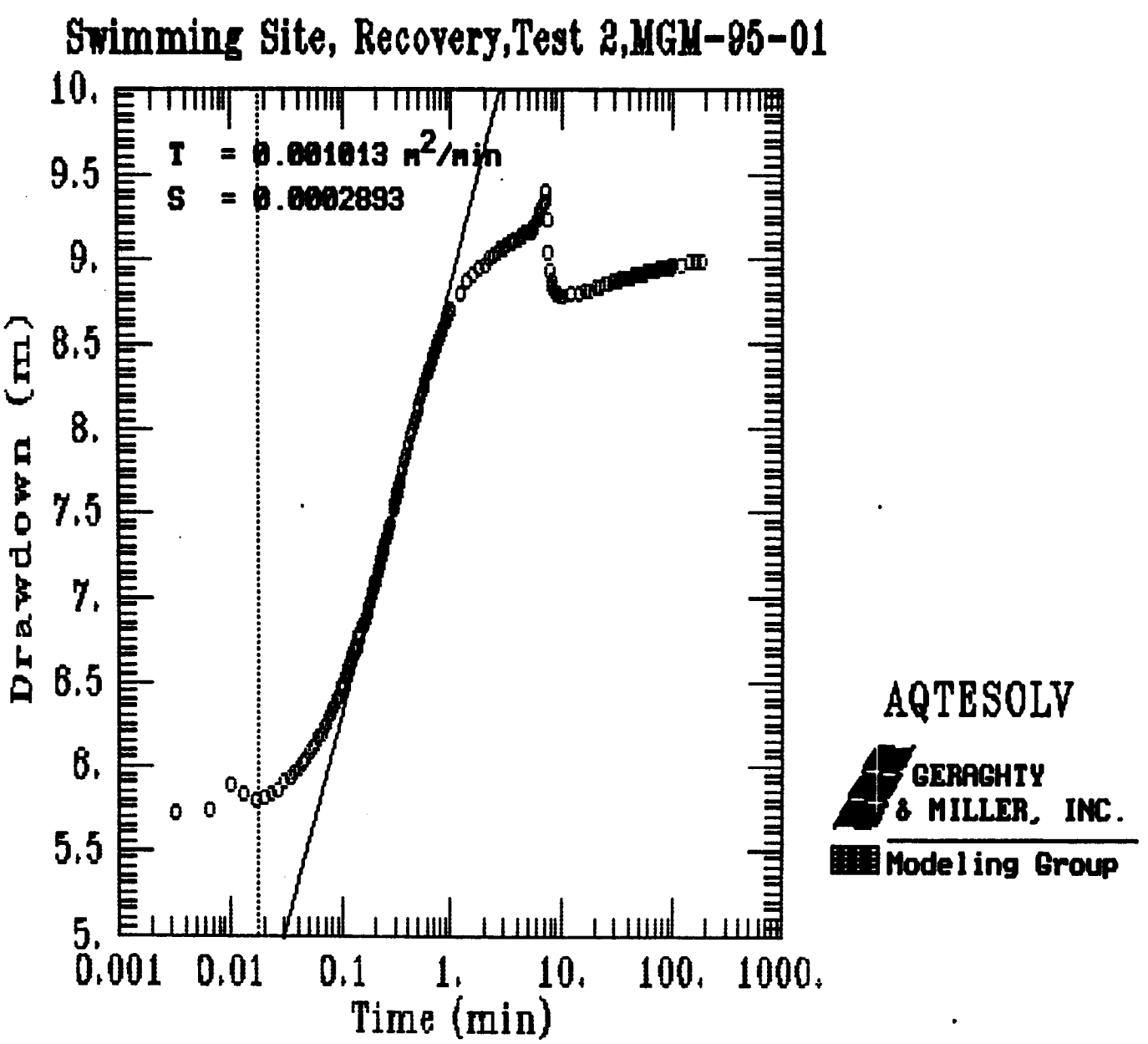


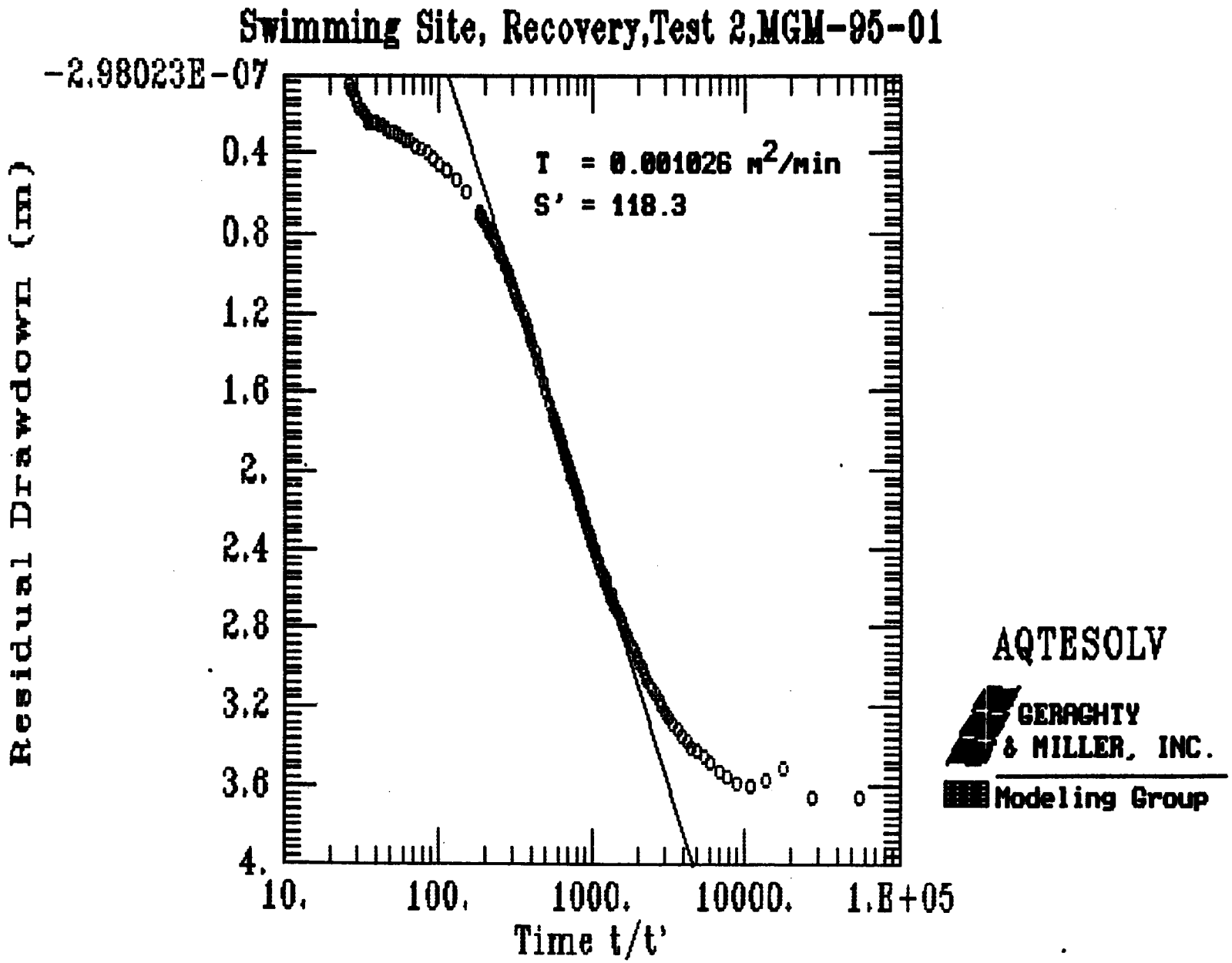
Monitoring Well Diagram

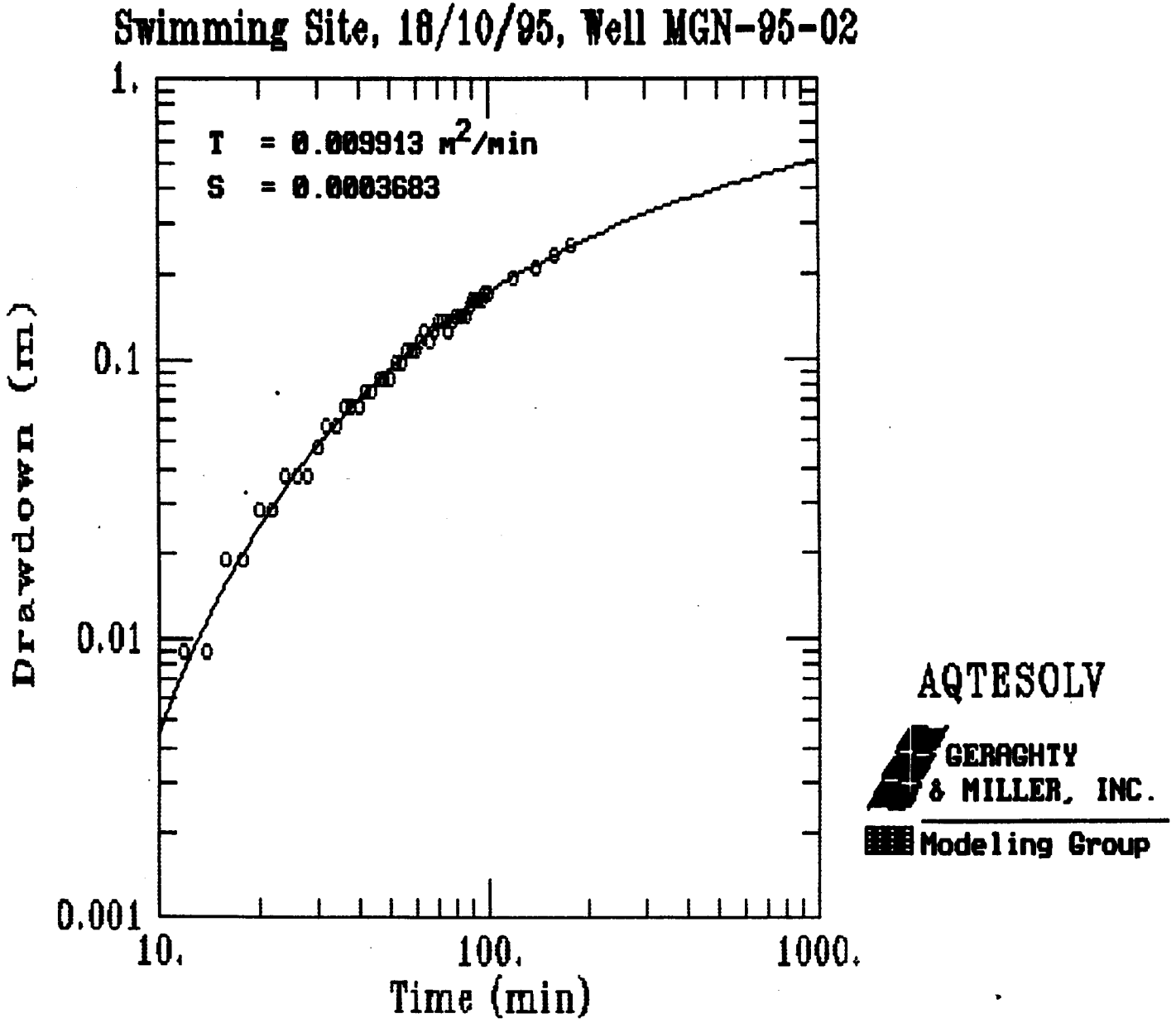


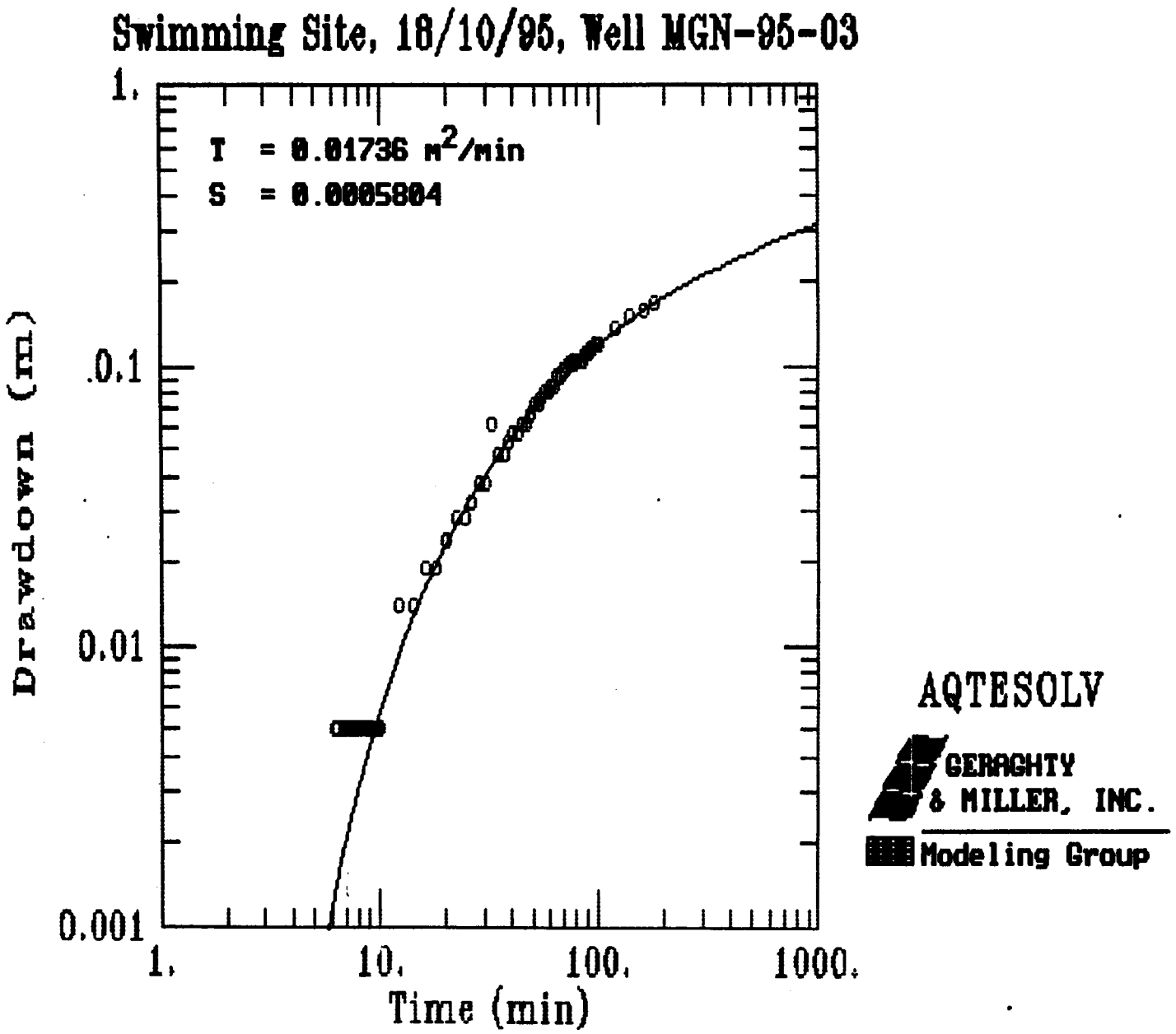
APPENDIX G.

Pumping and Infiltrometer Tests at Swimming Site


Swimming Site, Recovery,Test 2,MGM-95-01
T = 0.001013 m²/min
S = 0.0002893
Drawdown (m)
10.
9.5
9.
8.5
8.
7.5
7.
6.5
6.
5.5
5.
0.001
0.01
0.1
1.
10.
100.
1000.
Time (min)
AQTESOLV
GERAGHTY & MILLER, INC.
Modeling Group


Swimming Site, Recovery,Test 2,MGM-95-01
-2.98023E-07
0.4
0.8
1.2
1.6
2.
2.4
2.8
3.2
3.6
4.
Residual Drawdown (m)
T = 0.001026 m²/min
S' = 118.3
10.
100.
1000.
10000.
1.E+05
Time t/t'
AQTESOLV
GERAGHTY & MILLER, INC.
Modeling Group


Swimming Site, 18/10/95, Well MGN-95-02
T = 0.009913 m²/min
S = 0.0003683
Drawdown (m)
1.
0.1
0.01
0.001
10.
100.
1000.
Time (min)
AQTESOLV
GERAGHTY & MILLER, INC.
Modeling Group


Swimming Site, 18/10/95, Well MGN-95-03
T = 0.01736 m²/min
S = 0.0005804
Drawdown (m)
1.
0.1
0.01
0.001
1.
10.
100.
1000.
Time (min)
AQTESOLV
GERAGHTY & MILLER, INC.
Modeling Group

test 2

GP FIELD DATA SHEET — **SECTION 2: STANDARDIZED PROCEDURE FOR PERMEAMETER READINGS AND CALCULATIONS**

Date 21/10/93 Investigator Mike Rieser

F rvoir Constants: (See label on Permeamter)

Combined Reservoirs	X		cm²
Inner Reservoir	Y	2.18	cm²

CHECK RESERVOIR USED: [ ] Combined Reservoirs X [X] Inner Reservoir Y

Depth of Well Hole 100 cm

Note: In standardized procedure the radius of the well hole is always 3.0 cm

1st Set of Readings with height of water in well (H_1) set at 5 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_1, (CM/MIN)
1	0.30	—	51.0	—	—
2	1.00	0.5	51.0	0	0
3	3:00	2	54.0	0	0
4	5:00	2	54.7	3.7	1.85
5	7:00	2	59.2	4.5	2.25
6	9:00	2	63.7	4.5	2.25
7	11:00	2	67.5	3.8	1.9
8	13:00	2	73.1	5.6	2.8
9	14:00	1	75.4	2.3	2.3
		ref.11			
10					

2nd Set of Readings with height of water in well (H_2) set at 10 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_2, (CM/MIN)
1	0	—	3.6	—	—
2	2:00	2	10.9	7.3	3.65
3	4:00	2	17.9	7.0	3.5
4	6:00	2	25.4	7.5	3.75
5	8:00	2	33.2	7.8	3.9
6	10:00	2	41.6	8.4	4.2
7	12:00	2	50.3	8.7	4.35
8	14:00	2	59.1	8.8	4.4
9	16:00	2	68.1	9.0	4.5
10	17:30	1.5	74.8	6.7	4.47

CALCULATIONS

R, the steady state rate of flow, is achieved when R is the same in three consecutive time intervals.

For the 1st Set of Readings $\bar{R}_1$ = (2.228 (R_1)) / 60 = 0.0371 cm/sec

For the 2nd Set of Readings $\bar{R}_2$ = (4.085 (R_2)) / 60 = 0.0681 cm/sec

K_{fs} (FIELD SATURATED HYDRAULIC CONDUCTIVITY) = [(.0041)(2.18 RESERVOIR CONSTANT)(0.0681 R_2 - STEADY STATE RATE OF FLOW)] - [(.0054)(2.18 RESERVOIR CONSTANT)(0.0371 R_1 - STEADY STATE RATE OF FLOW)] = 1.7×10^{-4} cm/sec

ϕ_m (MATRIC FLUX POTENTIAL) = [(.0572)(2.18 RESERVOIR CONSTANT)(0.0371 R_1 STEADY STATE RATE OF FLOW)] - [(.0237)(2.18 RESERVOIR CONSTANT)(0.0681 R_2 STEADY STATE RATE OF FLOW)] = 1.1×10^{-3} cm²/sec

α (ALPHA PARAMETER) = (1.7×10^{-4} / K_{fs}) / (1.1×10^{-3} / ϕ_m) = 0.155 cm^{-1}

$\Delta\theta$ (DELTA THETA) = (_____ θ_s, FIELD SATURATED WATER CONTENT OF SOIL, IN CM/CM) − (_____ θ_i, AMBIENT WATER CONTENT OF SOIL, IN CM/CM) = _____ cm^3/cm^3

ESTIMATED	[ ]	CHECK ONE
MEASURED	[ ]	

Sorptivity = $\sqrt{2(\_\_\_\_\_)(\_\_\_\_\_)}$ = _____ cm $sec^{-1/2}$

($\Delta\theta$ / ϕ_m)

Test 3

GP FIELD DATA SHEET — **SECTION 2: STANDARDIZED PROCEDURE FOR PERMEAMETER READINGS AND CALCULATIONS**

Date 21/10/95 Investigator Mike Riesep

Reservoir Constants: (See label on Permeamter)

Combined Reservoirs X		cm²
Inner Reservoir Y	2.18	cm²

☐ CHECK RESERVOIR USED ☒

Depth of Well Hole 50 cm

Note: In standardized procedure the radius of the well hole is always 3.0 cm

1st Set of Readings with height of water in well (H_1) set at 5 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_1, (CM/MIN)
1	1:00	—	49.3	—	—
2	3:00	2	54.1	4.8	2.4
3	5:00	2	58.0	3.9	1.95
4	7:00	2	61.1	3.1	1.55
5	9:00	2	64.9	3.8	1.9
6	11:00	2	67.9	3.0	1.5
7	13:00	2	71.6	3.7	1.85

2nd Set of Readings with height of water in well (H_2) set at 10 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_2, (CM/MIN)
1	0	—	11.0	—	—
2	2:00	2	23.0	12.0	6.0
3	4:00	2	34.0	11.0	5.5
4	6:00	2	44.0	10.0	5.0
5	8:00	2	53.5	9.5	4.75
6	10:00	2	63.3	9.8	4.9
7	12:00	2	73.1	9.8	4.9

CALCULATIONS

$\bar{R}$, the steady state rate of flow, is achieved when R is the same in three consecutive time intervals.

For the 1st Set of Readings $\bar{R}_1 = (\underbrace{1.8107}_{R_1})/60 = 0.0302$ cm/sec

For the 2nd Set of Readings $\bar{R}_2 = (\underbrace{5.1143}_{R_2})/60 = 0.0852$ cm/sec

K_{fs} (FIELD SATURATED HYDRAULIC CONDUCTIVITY) $= [(.0041)(\underbrace{2.18}_{\text{RESERVOIR CONSTANT}})(\underbrace{0.0852}_{\bar{R}_2\text{-STEADY STATE RATE OF FLOW}})] - [(.0054)(\underbrace{2.18}_{\text{RESERVOIR CONSTANT}})(\underbrace{0.0302}_{\bar{R}_1\text{-STEADY STATE RATE OF FLOW}})] = 4.1\times10^{-4}$ cm/sec

ϕ_m (MATRIC FLUX POTENTIAL) $= [(.0572)(\underbrace{2.18}_{\text{RESERVOIR CONSTANT}})(\underbrace{0.0302}_{\bar{R}_1\text{ STEADY STATE RATE OF FLOW}})] - [(.0237)(\underbrace{2.18}_{\text{RESERVOIR CONSTANT}})(\underbrace{0.0852}_{\bar{R}_2\text{ STEADY STATE RATE OF FLOW}})] = -6.36\times10^{-4}$ cm²/sec

α (ALPHA PARAMETER) $= (\underbrace{4.1\times10^{-4}}_{K_{fs}}) / (\underbrace{-6.36\times10^{-4}}_{\phi_m}) = -0.64$ cm⁻¹

$\Delta\theta$ (TA) $= (\underbrace{\_\_\_\_\_}_{\theta_{fs}\text{, FIELD SATURATED WATER CONTENT OF SOIL, IN CM/CM}}) - (\underbrace{\_\_\_\_\_}_{\theta_i\text{, AMBIENT WATER CONTENT OF SOIL, IN CM/CM}}) = \_\_\_\_\_$ cm³/cm³

ESTIMATED	☐	CHECK ONE
MEASURED	☐	

S (SORPTIVITY) $= \sqrt{2(\underbrace{\_\_\_\_\_}_{\Delta\theta})(\underbrace{\_\_\_\_\_}_{\phi_m})} = \_\_\_\_\_$ cm sec$^{-1/2}$

Test 1, 21/10/95, Test Depth 50 cm

5 cm head		10 cm head	
Time	Level	Time	Level
0			3.5
1	0.6		
2			3.5
3	0.7		
4			3.5
5	0.7		
6			3.5
7	0.7		
8			3.5
9	0.7		
16			3.5

Test 2, 21/10/95, Test Depth 100 cm

5 cm head				Regression Output:		10 cm head				Regression Output:	
Time	Level					Time	Level				
0.5	51	Constant			43.78017	0	3.6	Constant			1.930897
1	51	Std Err of Y Est			0.512827	2	10.9	Std Err of Y Est			1.173573
3	51	R Squared			0.997381	4	17.9	R Squared			0.997949
5	54.7	No. of Observations			7	6	25.4	No. of Observations			10
7	59.2	Degrees of Freedom			5	8	33.2	Degrees of Freedom			8
9	63.7					10	41.6				
11	67.5	X Coefficient(s)		2.2260453		12	50.3	X Coefficient(s)		4.064616	
13	73.1	Std Err of Coef.		0.0510643		14	59.1	Std Err of Coef.		0.06548	
14	75.4					16	68.1				
						17.5	74.8				

Test 3, 21/10/95, Test Depth 50 cm

5 cm head				Regression Output:		10 cm head				Regression Output:	
Time	Level					Time	Level				
1	49.3	Constant			46.31071	0	11	Constant			12.44286
3	54.1	Std Err of Y Est			0.543271	2	23	Std Err of Y Est			0.976875
5	58	R Squared			0.995997	4	34	R Squared			0.998374
7	61.1	No. of Observations			7	6	44	No. of Observations			7
9	64.9	Degrees of Freedom			5	8	53.5	Degrees of Freedom			5
11	67.9					10	63.3				
13	71.6	X Coefficient(s)		1.8107143		12	73.1	X Coefficient(s)		5.114286	
		Std Err of Coef.		0.0513342				Std Err of Coef.		0.092306	

APPENDIX H.

Pumping Test at Lindbergh Site

AQUIFER TEST DATA

Owner Amoco Address 16-04-55-06-W4 County Prov. State A.

Date 21/11/95 Company performing test SRC / Montana Tech Measured by Mike Resor Ed Jaworski

LND-94-D:A Distance from pumping well 52.5 m Type of test Constant Rate Pumping Test No. 1

Measuring equipment e-tape, SPOHR-GmbH

Time Data
Pump on: Date ____ Time ____ (t)
Pump off: Date ____ Time ____ (t')
Duration of aquifer test:
Pumping ____ Recovery ____

Water Level Data
Static water level ____
Measuring point ____
Elevation of measuring point ____

Discharge Data
How Q measured ____
Depth of pump/air line ____
Previous pumping? Yes ____ No ____
Duration ____ End ____

Comments on factors affecting test data

Date	Clock time (min)	Time since pump started t	Time since pump stopped t'	t/t'		Water level measurement (TOC m)	Correction or Conversion	Water level	Water level change s or s'		Discharge measurement	Rate		
	0					2.623	*							
	112					2.687								
	132					2.689								
	152					2.694								
	172					2.697								
	192					2.699								
Recovery														
	11	1				2.679								
	9	18				2.673								
	25	25				2.669								
	32					2.666								
	44					2.661								
	61					2.657								
	82					2.653								
	103					2.652								
	124					2.648								

*- Assumed value from earlier pre-pumping measurement

AQUIFER TEST DATA

Owner Amoco Address 16-04-55-06-W4 County _____ Prov. State AB

D 21/11/95 Company performing test SRC / Montana Tech Measured by Mike Rieser / Ed Jaworski

We...o. LND-94-03 Distance from pumping well ~~3.95m~~ 9.04 m Type of test Constant Rate Pumping Test No. 1

Measuring equipment e-tape, SPOHR-GmbH

Time Data
Pump on: Date _____ Time _____ (t)
Pump off: Date _____ Time _____ (t')
Duration of aquifer test:
Pumping _____ Recovery _____

Water Level Data
Static water level _____
Measuring point _____
Elevation of measuring point _____

Discharge Data
How Q measured Pail & timer
Depth of pump/air line _____
Previous pumping? Yes ___ No ___
Duration _____ End _____

Date	Clock time	Time since pump started t	Time since pump stopped t'	t/t'		TOC m Water level measurement	Correction or Conversion	Water level	Water level change s or s'		Discharge measurement	Rate		Comments on factors affecting test data
	11:29	0				1.856	*							* - Assumed value from earlier pre-pumping measurement
		2				1.910								
		4				1.929								
		6				—						20 l/min		
		8				1.945								
		10				1.947								
		12				1.950								
		14				1.952								
		16				1.953								
		18				1.960								
		20				1.962								
		22				1.964								
		24				1.967								
		26				1.968								
		28				1.970								
		30				1.971								
		35				1.977								
		40				1.980								
		45				1.983								
		50				1.985								
		55				1.989								
		60				1.991								
		70				1.994								
		80				1.999								
		90				—								
		100				2.002					200 l/ 58s			
		110				2.004								
		120				2.003								
		130				2.								

AQUIFER TEST DATA

Owner Amoco Address 16-04-55-06-W4 County Provost AB

Date 21/11/95 Company performing test SAC/Mountain Tech Measured by Mike Rieser / Ed Jarowski

No. LND-94-03 Distance from pumping well 9.04 m Type of test Constant Rate Pumping Test No. 1

Measuring equipment e-tape, SPOHR-GmbH

Time Data
Pump on: Date ____ Time ____ (t)
Pump off: Date ____ Time ____ (t')
Duration of aquifer test:
Pumping ____ Recovery ____

Water Level Data
Static water level ____
Measuring point ____
Elevation of measuring point ____

Discharge Data
How Q measured ____
Depth of pump/air line ____
Previous pumping? Yes ____ No ____
Duration ____ End ____

Comments on factors affecting test data

Date	Clock time	Time since pump started t	Time since pump stopped t'	t/t'		Water level measurement	Correction or Conversion (TOC)	Water level	Water level change s or s'		Discharge measurement	Rate		
		140					2.011							
		150					2.013							
		160					2.016							
		170					2.016							
		180					2.019							
		192					2.019							
		198					2.019							
			Recovery											
		1					1.980							
		2					1.963							
		3					1.9[illegible]							
		[illegible]					1.94[illegible]							
		5					1.943							
		[illegible]					1.930							
		[illegible]					1.937							
		[illegible]					1.934							
		7					1.932							
		10					1.926							
		17					1.919							
		22.5					1.912							
		30.5					1.904							
		37					1.903							
		42					1.901							
		50					1.899							
		60					1.890							
		67					1.893							
		81					1.891							
		[illegible]					1.[illegible]							
		101					1.897							

AQUIFER TEST DATA

Owner Amoco Address 16-04-55-06-W4 County _____ State _____

Date 21/11/95 Company performing test SRC / Montana Tech Measured by Mike Riesor Ed Jarowski

Well No. [illegible] Distance from pumping well 9.04m Type of test Constant Rate Pumping Test No. 1

Measuring equipment e-tape, SPOHR - GmbH

Time Data	Water Level Data	Discharge Data	Comments on factors affecting test data
Pump on: Date ____ Time ____ (t)	Static water level ____	How Q measured ____	
Pump off: Date ____ Time ____ (t')	Measuring point ____	Depth of pump/air line ____	
Duration of aquifer test:	Elevation of measuring point ____	Previous pumping? Yes ____ No ____	
Pumping ____ Recovery ____		Duration ____ End ____	

Date	Clock time (MIN)	Time since pump started t	Time since pump stopped t'	t/t'		Water level measurement (TOC m)	Correction or Conversion	Water level	Water level change s or s'		Discharge measurement	Rate		
109						1.886								
122						1.883								
131						1.883								

AQUIFER TEST DATA

Owner Amoco Address 16-04-55-06-W4 County Aou, State AB

Date 21/11/95 Company performing test SAC / Montana Tech Measured by Mike Riesor Ed Jarowski

J. LND-94-24 Distance from pumping well 74m Type of test Constant Rate Pumping Test No. 1

Measuring equipment e-tape, SPOHA-GmbH

Time Data
Pump on: Date ____ Time ____ (t)
Pump off: Date ____ Time ____ (t')
Duration of aquifer test:
Pumping ____ Recovery ____

Water Level Data
Static water level ____
Measuring point ____
Elevation of measuring point ____

Discharge Data
How Q measured ____
Depth of pump/air line ____
Previous pumping? Yes ____ No ____
Duration ____ End ____

Comments on factors affecting test data

Date	Clock time	Time since pump started t	Time since pump stopped t'	t/t'		TOC m Water level measurement	Correction or Conversion	Water level	Water level change s or s'		Discharge measurement	Rate		
	min													
	0					2.425	*							
	115					2.500								
	134					2.503								
	154					2.508								
	174					2.510								
	195					2.513								
	Recovery													
	13.5	1				2.490								
	20	20				2.493								
	27	27				2.477								
	35					2.473								
	46					2.468								
	64					2.462								
	84					2.457								
	105					2.453								
	126					2.450								

*- Assumed value from earlier pre-pumping measurement

AQUIFER TEST DATA

Owner Amoco Address 16-04-55-06-W4 County Prov. State AB

Date 21/11/95 Company performing test SRC / Montana Tech Measured by Mike Rieser Ed Jarowski

Well No. LND-94-05 Distance from pumping well 60.5 m Type of test Constant Rate Pumping Test No. 1

Measuring equipment e-tape, SPOHR-GmbH

Time Data	Water Level Data	Discharge Data	Comments on factors affecting test data
Pump on: Date ____ Time ____ (t)	Static water level ____	How Q measured ____	
Pump off: Date ____ Time ____ (t')	Measuring point ____	Depth of pump/air line ____	
Duration of aquifer test:	Elevation of measuring point ____	Previous pumping? Yes ____ No ____	
Pumping ____ Recovery ____		Duration ____ End ____	

Date	Clock time	Time since pump started t	Time since pump stopped t'	t/t'		TOC m Water level measurement	Correction or Conversion	Water level	Water level change s or s'		Discharge measurement	Rate		
	0					2.734	*							
	117					2.840								
	136					2.843								
	156					2.848								
	176					2.850								
	196					2.853								
	Remarky													
	15.5	15.5				2.808								
	22	22				2.802								
	29					2.793								
	37					2.726								
	48					2.782								
	66					2.774								
	86					2.7[illegible]								
	107					2.765								
	129					2.762								

*- Assumed value from earlier pre-pumping measurement

AQUIFER TEST DATA

Owner Amoco Address 16-04-55-06-W4 County _____ State _____

Date 21/11/95 Company performing test SRC / Montana Tech Measured by Mike Rieser Ed Imonski

No. IND-95-06 AC Distance from pumping well 3.95m Type of test Constant Rate Pumping Test No. 1

Measuring equipment e-tape, SDOHR-GmbH

Time Data
Pump on: Date _____ Time _____ (t)
Pump off: Date _____ Time _____ (t')
Duration of aquifer test:
Pumping _____ Recovery _____

Water Level Data
Static water level _____
Measuring point _____
Elevation of measuring point _____

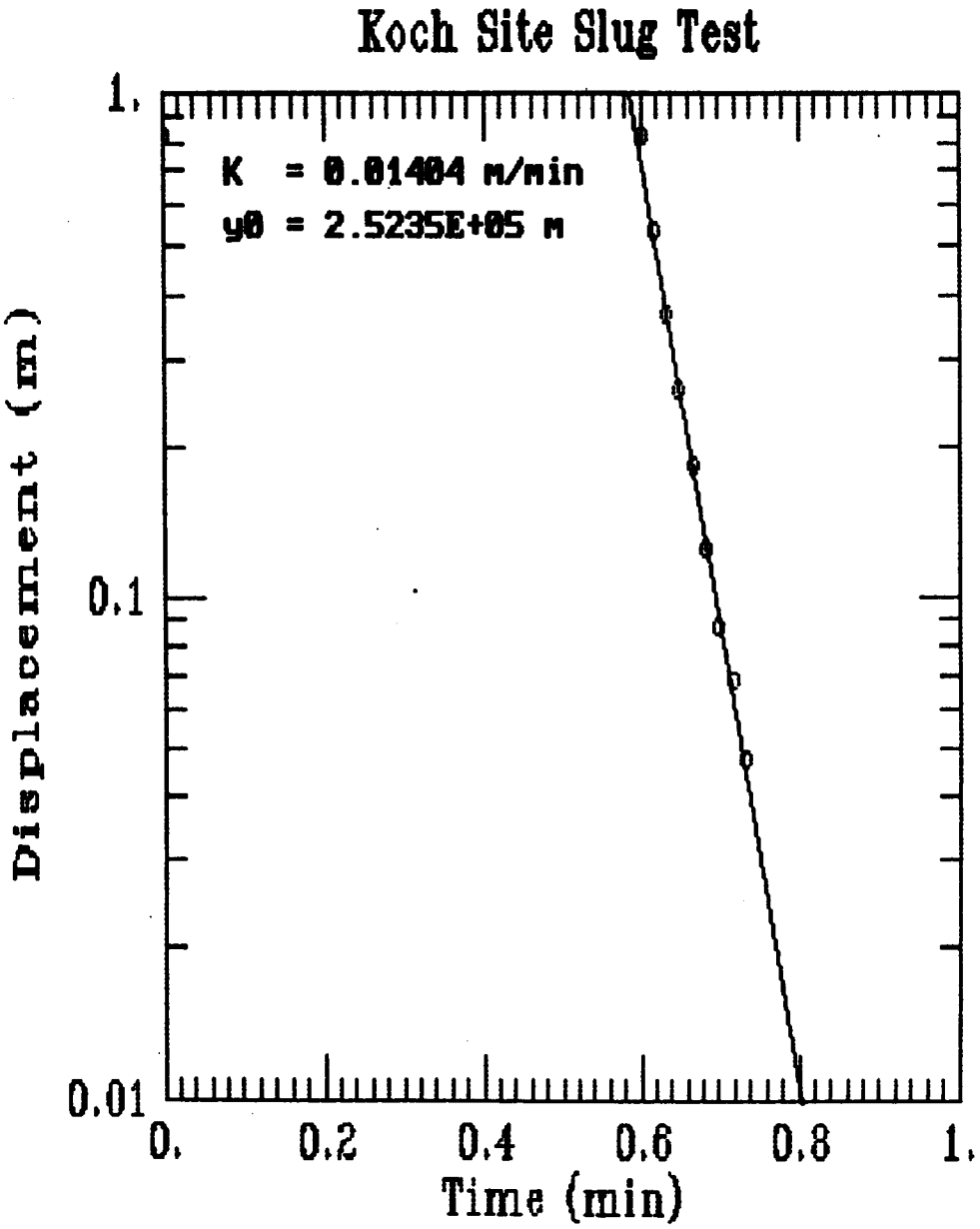
Discharge Data
How Q measured _____
Depth of pump/air line _____
Previous pumping? Yes ___ No ___
Duration _____ End _____

Comments on factors affecting test data

	Date	Clock time (Min)	Time since pump started t	Time since pump stopped t'	t/t'		Water level measurement (TOC m)	Correction or Conversion	Water level	Water level change s or s'		Discharge measurement	Rate		
A															
A			36				1.972								
C			36.5				1.977								
A			81				1.994								
C			81.5				1.999								
A			129.5				2.009								
C			129				2.010								
A			181				2.013								
			181.5				2.020								

APPENDIX I.

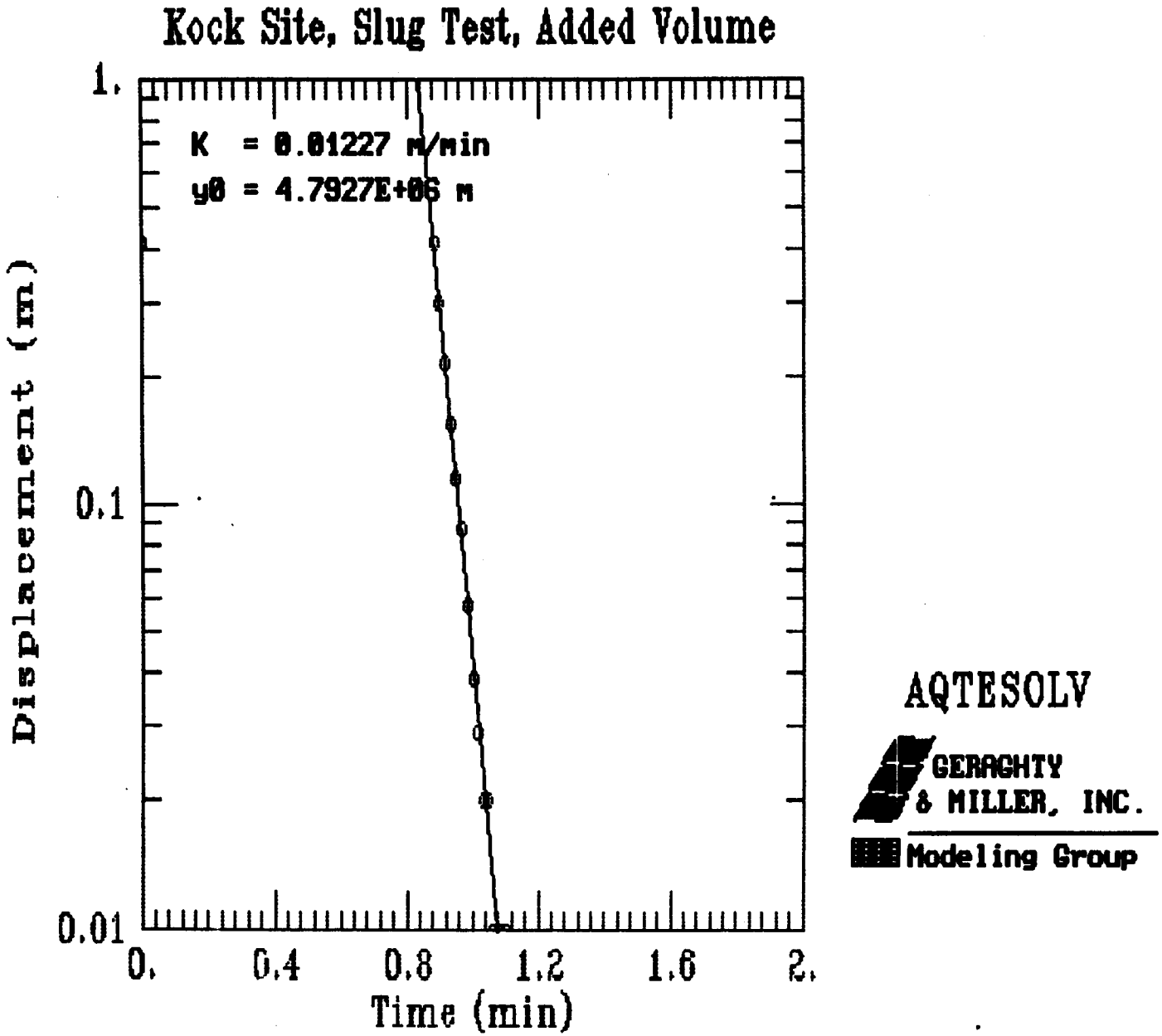
Slug Test at Wildmere Site



AQTESOLV

GERAGHTY & MILLER, INC.

Modeling Group


Kock Site, Slug Test, Added Volume
K = 0.01227 m/min
y0 = 4.7927E+06 m
Displacement (m)
1.
0.1
0.01
0.
0.4
0.8
1.2
1.6
2.
Time (min)
AQTESOLV
GERAGHTY
& MILLER, INC.
Modeling Group

APPENDIX J.

Monitoring Well Water Level Data

Table J.1. Water level data for the monitoring wells at the Marshall site collected in 1994 and 1995.

	Date	Time	Ground Elevation (m asl)	TOC Elevation (m asl)	Stick -up	Water Level below TOC	Water Level (m asl)
MAR-94-01	Jun 21/94		606.60	607.280	0.68	8.561	598.719
	Sep 26/94					8.528	598.752
	Oct 5/94					8.513	598.767
	Oct 17/94					8.510	598.770
	Sep 28/95	14:16				8.668	598.612
MAR-94-02	Jun 21/94			607.969	0.72	9.272	598.697
	Sep 26/94					9.240	598.729
	Oct 5/94					9.223	598.746
	Oct 17/94					9.222	598.747
	Sep 28/95	14:17				9.380	598.589
MAR-94-03	Jun 21/94			607.182	0.68	8.489	598.693
	Sep 26/94					8.454	598.728
	Oct 5/94					8.437	598.745
	Oct 17/94					8.433	598.749
	Sep 28/95	14:20				8.733	598.449
MAR-94-04	Oct 5/94			608.143	0.68	9.658	598.485
	Oct 17/94					9.665	598.478
	Sep 28/95	14:25				9.821	598.322
MAR-94-05	Oct 5/94			607.330	0.73	8.580	598.750
	Oct 17/94					8.578	598.752
	Sep 28/95	14:22				8.588	598.742

Table J.2. Water level data for the monitoring wells at the Lindbergh site collected in 1994 and 1995.

	Date	Time	Ground Elevation (m asl)	TOC Elevation (m asl)	Stick -up	Water Level below TOC	Water Level (m asl)
LND-94-01A	Jun 21/94		625.60	627.041	0.61	2.713	624.328
	Sep 26/94			627.041		2.759	624.282
	Oct 18/94			627.041		2.726	624.315
	Sep 27/95	8:20		627.041		2.568	624.473
	Nov 14/95	15:43		627.041		2.598	624.443
	Dec 15/95	7:36		627.041		2.608	624.433
LND-94-02	Jun 21/94			626.090	0.49	1.766	624.324
	Sep 26/94			626.090		1.804	624.286
	Oct 18/94			626.090		1.773	624.317
	Sep 27/95	8:23		626.090		1.617	624.473
	Nov 14/95	15:34		626.090		1.657	624.433
	Dec 15/95	7:50		626.090		1.671	624.419
LND-94-03	Jun 21/94			626.269	0.61	1.948	624.321
	Sep 26/94			626.269		1.989	624.280
	Oct 18/94			626.269		1.959	624.310
	Sep 27/95	8:33		626.269		1.798	624.471
	Nov 14/95	15:32		626.269		1.833	624.436
	Dec 15/95	7:49		626.269		1.839	624.430
LND-94-04	Oct 18/94			626.843	0.66	2.528	624.315
	Sep 27/95	8:29		626.843		2.368	624.475
	Nov 14/95	15:46		626.843		2.399	624.444
	Dec 15/95	8:17		626.843		2.410	624.433
LND-94-05	Oct 18/94			627.157	0.7	2.837	624.320
	Sep 27/95	8:32		627.157		2.678	624.479
	Nov 14/95	15:49		627.157		2.708	624.449
	Dec 15/95	8:19		627.157		2.716	624.441
LND-95-06A	Nov 14/95	15:33		626.228	0.6	1.797	624.431
	Dec 15/95	7:52		626.228		1.809	624.419
LND-95-06B	Nov 14/95	15:34		626.216		1.784	624.432
	Dec 15/95	7:53		626.216		1.800	624.416
LND-95-06C	Nov 14/95	15:35		626.225		1.793	624.432
	Dec 15/95	7:55		626.225		1.808	624.417
LND-95-07A	Nov 14/95	15:35		626.164	0.64	1.734	624.430
	Dec 15/95	7:58		626.164		1.747	624.417
LND-95-07B	Nov 14/95	15:36		626.164		1.734	624.430
	Dec 15/95	7:59		626.164		1.747	624.417
LND-95-07C	Nov 14/95	15:36		626.167		1.735	624.432
	Dec 15/95	8:00		626.167		1.747	624.420
LND-95-08A	Nov 14/95	15:38		626.218	0.61	1.776	624.442
	Dec 15/95	8:02		626.218		1.801	624.417
LND-95-08B	Nov 14/95	15:40		626.199		1.768	624.431
	Dec 15/95	8:02		626.199		1.781	624.418
LND-95-08C	Nov 14/95	15:40		626.193		1.759	624.434
	Dec 15/95	8:03		626.193		1.775	624.418

Table J.3. Water level data for the monitoring wells at the Wildmere site collected in 1995.

	Date	Time	Ground Elevation (m asl)	TOC Elevation (m asl)	Stick -up	Water Level below TOC	Water Level (m asl)
WDM-95-01	8/29/95	9:35	645.50	646.118	0.65	69.300	576.818
	8/30/95	9:46		646.118		69.385	576.733
	9/26/95	8:13		646.118		69.513	576.605
	10/3/95	16:07		646.118		69.228	576.890
	10/16/95	18:57		646.118		69.392	576.726
	10/17/95	8:33		646.118		69.349	576.769
WDM-95-02	8/29/95	9:47	647.13	647.773	0.64	71.030	576.743
	8/30/95	9:34		647.773		71.098	576.675
	9/26/95	8:18		647.773		71.239	576.534
	10/3/95	17:56		647.773		70.962	576.811
	10/16/95	19:06		647.773		71.097	576.676
	10/17/95	8:42		647.773		71.074	576.699
WDM-95-03	8/29/95	9:40	645.07	645.536	0.47	68.728	576.808
	8/30/95	9:41		645.536		68.808	576.728
	9/26/95	8:03		645.536		68.940	576.596
WDM-95-04	9/26/95	8:09	645.50	645.490	-0.01	68.898	576.592
	10/2/95	19:02		645.490		68.677	576.813
	10/16/95	18:55		645.490		68.750	576.740
	10/17/95	8:36		645.490		68.727	576.763
WDM-95-05	9/26/95	8:07		646.060	0.58	69.482	576.578
	10/3/95	11:25		646.060		69.187	576.873
	10/16/95	18:59		646.060		69.318	576.742
	10/17/95	8:38		646.060		69.297	576.763

Table J.4. Water level data for the monitoring wells at the Swimming site collected in 1995.

	Date	Time	Ground Elevation (m asl)	TOC Elevation (m asl)	Stick -up	Water Level below TOC	Water Level (m asl)
MGN-95-01	8/29/95	12:40	618.90	619.400	0.5	2.882	616.518
	9/20/95	14:14		619.400		2.949	616.451
	10/16/95	13:16		619.400		2.954	616.446
	11/22/95	9:16		619.400		2.998	616.402
	12/14/95	12:54		619.400		3.010	616.390
MGN-95-02	8/29/95	12:42	619.36	619.898	0.54	3.435	616.463
	9/20/95	14:15		619.898		3.517	616.381
	10/16/95	13:18		619.898		3.523	616.375
	11/22/95	9:21		619.898		3.566	616.332
	12/14/95	13:07		619.898		3.579	616.319
MGN-95-03	8/29/95	12:44	618.61	619.095	0.49	2.652	616.443
	9/20/95	14:13		619.095		2.722	616.373
	10/16/95	13:19		619.095		2.728	616.367
	11/22/95	9:23		619.095		2.772	616.323
	12/14/95	13:05		619.095		2.784	616.311
MGN-95-04A	12/14/95	12:55		619.484	0.65	3.114	616.370
MGN-95-04B	12/14/95	12:56		619.520		3.145	616.375
MGN-95-04C	12/14/95	12:57		619.494		3.120	616.374
MGN-95-05A	12/14/95	12:59		619.432	0.63	3.063	616.369
MGN-95-05B	12/14/95	13:00		619.435		3.068	616.367
MGN-95-05C	12/14/95	13:00		619.446		3.073	616.373
MGN-95-06A	12/14/95	13:01		619.430	0.64	3.074	616.356
MGN-95-06B	12/14/95	13:02		619.386		3.029	616.357
MGN-95-06C	12/14/95	13:03		619.408		3.051	616.357
MGN-95-07A	12/14/95	12:46		621.050	0.64	4.618	616.432
MGN-95-07B	12/14/95	12:48		621.034		4.603	616.431
MGN-95-07C	12/14/95	12:49		621.028		4.597	616.431

APPENDIX K.

Original Water Chemistry Data Sheets

SRC Group: 95-3392

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC
15 Innovation Blvd.
Saskatoon, Saskatchewan S7N 2X8
Attn: Dale Van Stempvoort, R1220-24

16-Oct-95 12:56

Date Samples Received: 02-Oct-95 Client P.O.:

SAMPLE	CLIENT DESCRIPTION	
15754	WDM-95-01 AUG 22/95 @15:50	*WATER*
15755	MGN-95-01 SEP 20/95 @19:20	*WATER*
15756	MGN-95-02 SEP 20/95 @16:20	*WATER*

ANALYTE	UNITS	15754	15755	15756
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, color.	mg/L	46	127	119
Cl, color.	mg/L	5	2	2
HCO3, acid titr	mg/L	564	526	519
K, flame	mg/L	4.1	9.8	7.8
Mg, color.	mg/L	21	50	52
Na, flame	mg/L	200	50	43
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	168	183	164
Sum of Ions	mg/L	1010	949	907
Tot. Alkalinity	mg/L	462	431	425
Tot. Hardness	mg/L	201	522	511
NUTRIENTS				
N, NO2+NO3	mg/L	<0.01	0.29	<0.01
PO4, ortho as P	mg/L	0.06	0.30	0.03
TRACE METALS				
Fe, ICP-AES	mg/L	2.1	2.4	0.71
Mn, ICP-AES	mg/L	0.14	0.26	0.53
PHYSICAL PROPERTIES				
Sp. Conduct.	uS/cm	1120	1040	1030
pH of water	pH units	7.63	7.15	7.26

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 16-Oct-95 12:56

SAMPLE	CLIENT DESCRIPTION	
15757	MGW-95-03 SEP 20/95 @18:45	*WATER*
15758	MAR-94-03 SEP 29/95 @13:35	*WATER*
15759	MAR-94-04 SEP 29/95 @14:30	*WATER*

ANALYTE	UNITS	15757	15758	15759
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, color.	mg/L	141	205	169
Cl, color.	mg/L	4	3	3
HCO3, acid titr	mg/L	538	633	580
K, flame	mg/L	9.8	6.6	5.8
Mg, color.	mg/L	56	79	64
Na, flame	mg/L	48	66	45
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	218	479	280
Sum of Ions	mg/L	1010	1470	1150
Tot. Alkalinity	mg/L	441	519	475
Tot. Hardness	mg/L	582	836	685
NUTRIENTS				
N, NO2+NO3	mg/L	<0.01	<0.01	<0.01
PO4, ortho as P	mg/L	0.06	0.08	0.07
TRACE METALS				
Fe, ICP-AES	mg/L	2.2	2.8	2.0
Mn, ICP-AES	mg/L	0.38	0.13	0.19
PHYSICAL PROPERTIES				
Sp. Conduct.	uS/cm	1150	1640	1260
pH of water	pH units	7.17	7.27	7.30

SRC Group: 95-3392

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 16-Oct-95 12:56

SAMPLE	CLIENT DESCRIPTION	
15760	MAR-94-05 SEP 29/95 @15:45	*WATER*
15761	LND-94-01A SEP 27/95 @17:30	*WATER*
15762	LND-94-02 SEP 27/95 @16:45	*WATER*

ANALYTE	UNITS	15760	15761	15762
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, color.	mg/L	168	159	158
Cl, color.	mg/L	3	20	20
HCO3, acid titr	mg/L	571	578	603
K, flame	mg/L	5.9	5.6	5.5
Mg, color.	mg/L	63	60	58
Na, flame	mg/L	50	140	116
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	288	402	368
Sum of Ions	mg/L	1150	1360	1330
Tot. Alkalinity	mg/L	468	474	494
Tot. Hardness	mg/L	678	643	633
NUTRIENTS				
N, NO2+NO3	mg/L	<0.01	<0.01	<0.01
PO4, ortho as P	mg/L	0.11	0.06	0.05
TRACE METALS				
Fe, ICP-AES	mg/L	2.2	2.3	7.1
Mn, ICP-AES	mg/L	0.12	0.40	1.6
PHYSICAL PROPERTIES				
Sp. Conduct.	uS/cm	1280	1550	1540
pH of water	pH units	7.27	7.35	7.32

SRC Group: 95-3392

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 16-Oct-95 12:56

SAMPLE	CLIENT DESCRIPTION	
15763	LND-94-03 SEP 27/95 @15:35	*WATER*
15764	LND-94-04 SEP 27/95 @18:50	*WATER*
15765	LND-94-05 SEP 27/95 @18:10	*WATER*

ANALYTE	UNITS	15763	15764	15765
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, color.	mg/L	168	168	153
Cl, color.	mg/L	20	18	19
HCO3, acid titr	mg/L	604	581	592
K, flame	mg/L	5.5	6.1	5.3
Mg, color.	mg/L	62	58	62
Na, flame	mg/L	118	110	101
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	392	378	372
Sum of Ions	mg/L	1370	1320	1300
Tot. Alkalinity	mg/L	495	476	485
Tot. Hardness	mg/L	674	657	636
NUTRIENTS				
N, NO2+NO3	mg/L	<0.01	<0.01	<0.01
PO4, ortho as P	mg/L	0.07	0.11	0.07
TRACE METALS				
Fe, ICP-AES	mg/L	3.7	5.7	2.0
Mn, ICP-AES	mg/L	0.86	0.66	0.51
PHYSICAL PROPERTIES				
Sp. Conduct.	uS/cm	1520	1470	1480
pH of water	pH units	7.27	7.23	7.35

SRC Group: 95-3461

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC
15 Innovation Blvd.
Saskatoon, Saskatchewan S7N 2X8
Attn: Dale Van Stempvoort, R1220-27

22-Oct-95 11:40

Date Samples Received: 05-Oct-95 Client P.O.:

SAMPLE	CLIENT DESCRIPTION	
16104	WDM 95-04 OCT 3/95 @11:00	*WATER*
16105	WDM 95-05 OCT 3/95 @18:15	*WATER*
16106	WDM 95-02 OCT 4/95 @12:50	*WATER*

ANALYTE	UNITS	16104	16105	16106
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, color.	mg/L	52	52	47
Cl, color.	mg/L	3	3	3
HCO3, acid titr	mg/L	565	569	600
K, flame	mg/L	3.8	3.8	3.8
Mg, color.	mg/L	21	20	20
Na, flame	mg/L	167	167	203
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	122	128	155
Sum of Ions	mg/L	934	943	1030
Tot. Alkalinity	mg/L	463	466	492
Tot. Hardness	mg/L	216	212	199
NUTRIENTS				
N, NO2+NO3	mg/L	<0.01	<0.01	0.03
PO4, ortho as P	mg/L	0.08	0.08	0.11
TRACE METALS				
Fe, ICP-AES	mg/L	1.7	1.6	1.5
Mn, ICP-AES	mg/L	0.089	0.092	0.071
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	1080	1050	1140
pH of water	pH units	7.69	7.57	7.56

SRC Group: 95-3461

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 22-Oct-95 11:41

SAMPLE	CLIENT DESCRIPTION	
16107	MAR 94-01 OCT 4/95 @16:40	*WATER*
16108	MAR 94-02 OCT 4/95 @17:20	*WATER*

ANALYTE	UNITS	16107	16108
MAJOR CONSTITUENTS			
CO3, acid titr.	mg/L	<1	<1
Ca, color.	mg/L	155	149
Cl, color.	mg/L	3	2
HCO3, acid titr	mg/L	543	540
K, flame	mg/L	5.4	5.2
Mg, color.	mg/L	52	48
Na, flame	mg/L	47	44
OH	mg/L	<1	<1
SO4, turb.	mg/L	221	195
Sum of Ions	mg/L	1030	983
Tot. Alkalinity	mg/L	445	443
Tot. Hardness	mg/L	600	569
NUTRIENTS			
N, NO2+NO3	mg/L	<0.01	0.01
PO4, ortho as P	mg/L	0.14	0.11
TRACE METALS			
Fe, ICP-AES	mg/L	1.7	1.9
Mn, ICP-AES	mg/L	0.082	0.11
PHYSICAL PROPERTIES			
Specific Conductivity	uS/cm	1110	1070
pH of water	pH units	7.23	7.27

SRC Group: 95-4085

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC
15 Innovation Blvd.
Saskatoon, Saskatchewan S7N 2X8
Attn: Dale Van Stempvoort, R1220-24

05-Dec-95 14:03

Date Samples Received: 27-Nov-95 Client P.O.:

SAMPLE	CLIENT DESCRIPTION	
19127	MGN 95-04A NOV 24/95 @10:20	*WATER*
19128	MGN 95-04B NOV 24/95 @11:20	*WATER*
19129	MGN 95-04C NOV 24/95 @12:25	*WATER*

ANALYTE	UNITS	19127	19128	19129
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	134	120	91
Cl, color.	mg/L	2	2	4
HCO3, acid titr	mg/L	601	532	445
K, ICP-SEQ	mg/L	12	11	8.8
Mg, ICP-SEQ	mg/L	57	50	38
Na, ICP-SEQ	mg/L	61	43	37
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	237	183	105
NUTRIENTS				
N, NO2+NO3	mg/L	0.01	<0.01	0.02
TRACE METALS				
Fe, ICP-AES	mg/L	2.9	2.2	1.2
Mn, ICP-AES	mg/L	0.62	0.54	0.43
PHYSICAL PROPERTIES				
pH of water	pH units	7.04	7.11	7.27

SRC Group: 95-4085

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 05-Dec-95 14:03

SAMPLE	CLIENT DESCRIPTION	
19130	MGN 95-05A NOV 24/95 @11:35	*WATER*
19131	MGN 95-05B NOV 24/95 @13:25	*WATER*
19132	MGN 95-05C NOV 24/95 @14:50	*WATER*

ANALYTE	UNITS	19130	19131	19132
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	124	118	117
Cl, color.	mg/L	2	2	2
HCO3, acid titr	mg/L	556	544	532
K, ICP-SEQ	mg/L	11	11	11
Mg, ICP-SEQ	mg/L	52	50	48
Na, ICP-SEQ	mg/L	55	53	53
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	204	198	185
NUTRIENTS				
N, NO2+NO3	mg/L	<0.01	<0.01	0.03
TRACE METALS				
Fe, ICP-AES	mg/L	2.4	2.5	2.4
Mn, ICP-AES	mg/L	0.32	0.31	0.30
PHYSICAL PROPERTIES				
pH of water	pH units	7.07	7.08	7.1

SRC Group: 95-4085

SASKATCHEWAN RESEARCH COUNCIL ANALYTICAL SERVICES

Resources Sector, SRC 05-Dec-95 14:04

SAMPLE	CLIENT DESCRIPTION	
19133	MGN 95-06A NOV 24/95 @17:15	*WATER*
19134	MGN 95-06B NOV 24/95 @18:25	*WATER*
19135	MGN 95-06C NOV 24/95 @19:25	*WATER*

ANALYTE	UNITS	19133	19134	19135
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	122	120	118
Cl, color.	mg/L	2	2	2
HCO3, acid titr	mg/L	569	554	540
K, ICP-SEQ	mg/L	12	11	11
Mg, ICP-SEQ	mg/L	52	51	49
Na, ICP-SEQ	mg/L	60	58	55
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	209	204	190
NUTRIENTS				
N, NO2+NO3	mg/L	<0.01	0.02	0.02
TRACE METALS				
Fe, ICP-AES	mg/L	2.4	2.4	2.3
Mn, ICP-AES	mg/L	0.29	0.28	0.28
PHYSICAL PROPERTIES				
pH of water	pH units	7.10	7.19	7.18

SRC Group: 95-4085

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 05-Dec-95 14:04

SAMPLE	CLIENT DESCRIPTION	
19136	MGN 95-07A NOV 24/95 @21:00	*WATER*
19137	MGN 95-07B NOV 24/95 @23:00	*WATER*

ANALYTE	UNITS	19136	19137
MAJOR CONSTITUENTS			
CO3, acid titr.	mg/L	<1	<1
Ca, ICP-SEQ	mg/L	133	131
Cl, color.	mg/L	2	2
HCO3, acid titr	mg/L	593	588
K, ICP-SEQ	mg/L	11	11
Mg, ICP-SEQ	mg/L	57	57
Na, ICP-SEQ	mg/L	67	64
OH	mg/L	<1	<1
SO4, turb.	mg/L	243	238
NUTRIENTS			
N, NO2+NO3	mg/L	0.04	0.02
TRACE METALS			
Fe, ICP-AES	mg/L	2.9	2.5
Mn, ICP-AES	mg/L	0.27	0.25
PHYSICAL PROPERTIES			
pH of water	pH units	7.15	7.16

SRC Group: 95-4085

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 05-Dec-95 14:04

SAMPLE	CLIENT DESCRIPTION
19138	MGN 95-07C NOV 25/95 @01:20 *WATER*

ANALYTE	UNITS	19138
MAJOR CONSTITUENTS		
CO3, acid titr.	mg/L	<1
Ca, ICP-SEQ	mg/L	127
Cl, color.	mg/L	2
HCO3, acid titr	mg/L	572
K, ICP-SEQ	mg/L	11
Mg, ICP-SEQ	mg/L	56
Na, ICP-SEQ	mg/L	57
OH	mg/L	<1
SO4, turb.	mg/L	219
PHYSICAL PROPERTIES		
pH of water	pH units	7.10

SRC Group: 95-4009

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC
15 Innovation Blvd.
Saskatoon, Saskatchewan S7N 2X8
Attn: H. Maathius, R1220-24

04-Dec-95 14:59

Date Samples Received: 20-Nov-95 Client P.O.:

SAMPLE	CLIENT DESCRIPTION	
18796	LND-95-06A NOV 16/95 @10:45	*WATER*
18797	LND-95-06B NOV 16/95 @13:00	*WATER*
18798	LND-95-06C NOV 16/95 @15:10	*WATER*

ANALYTE	UNITS	18796	18797	18798
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	150	150	140
Cl, color.	mg/L	20	20	20
HCO3, acid titr	mg/L	593	595	595
K, ICP-SEQ	mg/L	5.6	5.4	5.2
Mg, ICP-SEQ	mg/L	62	62	64
Na, ICP-SEQ	mg/L	120	120	120
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	402	397	385
Sum of Ions	mg/L	1350	1350	1330
Tot. Alkalinity	mg/L	486	488	488
Tot. Hardness	mg/L	629	629	612
NUTRIENTS				
N, NO2+NO3	mg/L	0.08	0.07	0.03
PO4, ortho as P	mg/L	0.09	0.10	0.14
TRACE METALS				
Fe, ICP-AES	mg/L	3.8	4.5	5.6
Mn, ICP-AES	mg/L	0.26	0.26	0.26
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	1530	1530	1540
pH of water	pH units	7.32	7.34	7.53

SRC Group: 95-4009

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 04-Dec-95 14:59

SAMPLE	CLIENT DESCRIPTION	
18799	LND-95-07A NOV 15/95 @16:15	*WATER*
18800	LND-95-07B NOV 15/95 @18:30	*WATER*
18801	LND-95-07C NOV 16/95 @13:15	*WATER*

ANALYTE	UNITS	18799	18800	18801
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	150	150	140
Cl, color.	mg/L	20	20	19
HCO3, acid titr	mg/L	601	600	601
K, ICP-SEQ	mg/L	5.5	5.2	5.2
Mg, ICP-SEQ	mg/L	62	62	63
Na, ICP-SEQ	mg/L	120	120	110
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	392	385	356
Sum of Ions	mg/L	1350	1340	1290
Tot. Alkalinity	mg/L	493	492	493
Tot. Hardness	mg/L	629	629	608
NUTRIENTS				
N, NO2+NO3	mg/L	0.02	0.02	<0.01
PO4, ortho as P	mg/L	0.09	0.10	0.12
TRACE METALS				
Fe, ICP-AES	mg/L	4.1	4.3	5.8
Mn, ICP-AES	mg/L	0.28	0.27	0.30
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	1540	1520	1490
pH of water	pH units	7.33	7.35	7.46

SRC Group: 95-4009

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 04-Dec-95 14:59

SAMPLE	CLIENT DESCRIPTION	
18802	LND-95-08A NOV 15/95 @16:35	*WATER*
18803	LND-95-08B NOV 15/95 @18:45	*WATER*
18804	LND-95-08C NOV 16/95 @11:00	*WATER*

ANALYTE	UNITS	18802	18803	18804
MAJOR CONSTITUENTS				
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	160	140	140
Cl, color.	mg/L	20	21	22
HCO3, acid titr	mg/L	588	594	589
K, ICP-SEQ	mg/L	5.2	5.3	5.3
Mg, ICP-SEQ	mg/L	61	63	63
Na, ICP-SEQ	mg/L	120	120	120
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	403	375	375
Sum of Ions	mg/L	1360	1320	1310
Tot. Alkalinity	mg/L	482	487	483
Tot. Hardness	mg/L	650	608	608
NUTRIENTS				
N, NO2+NO3	mg/L	0.02	0.02	0.02
PO4, ortho as P	mg/L	0.07	0.14	0.15
TRACE METALS				
Fe, ICP-AES	mg/L	3.0	5.7	6.0
Mn, ICP-AES	mg/L	0.26	0.29	0.28
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	1540	1560	1550
pH of water	pH units	7.36	7.40	7.43

SRC Group: 96-137

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC
15 Innovation Blvd.
Saskatoon, Saskatchewan S7N 2X8
Attn: Dale Van Stempvoort, R1220-24

24-Jan-96 13:29

Date Samples Received: 12-Jan-96 Client P.O.:

SAMPLE	CLIENT DESCRIPTION
722	NORMAN HALLET JAN 11/96 @14:10 *WATER*
723	GEORGE HALL JAN 11/96 @11:45 *WATER*
724	LLOYD WATSON JAN 11/96 @12:45 *WATER*

ANALYTE	UNITS	722	723	724
MAJOR CONSTITUENTS				
Alkalinity, P	mg/L	<1	<1	<1
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	213	18	86
Cl, color.	mg/L	124	220	145
HCO3, acid titr	mg/L	483	464	468
K, ICP-SEQ	mg/L	12	5.7	6.9
Mg, ICP-SEQ	mg/L	104	6.0	31
Na, ICP-SEQ	mg/L	508	900	898
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	1440	1280	1650
Sum of Ions	mg/L	2890	2900	3290
Tot. Alkalinity	mg/L	396	380	384
Tot. Hardness	mg/L	959	70	342
NUTRIENTS				
N, NO2+NO3	mg/L	<0.01	0.04	0.71
TRACE METALS				
Fe, ICP-AES	mg/L	5.6	0.34	0.17
Mn, ICP-AES	mg/L	0.11	0.017	0.088
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	3380	3830	4090
pH of water	pH units	7.36	8.25	7.59

SRC Group: 96-137

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 24-Jan-96 13:29

SAMPLE	CLIENT DESCRIPTION
725	GLEN MCGLADDREY JAN 11/96 @09:40 *WATER*
726	JAMES LAMB JAN 10/96 @18:00 *WATER*
727	GERALD LAMB JAN 10/96 @13:30 *WATER*

ANALYTE	UNITS	725	726	727
MAJOR CONSTITUENTS				
Alkalinity, P	mg/L	<1	<1	<1
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	389	30	37
Cl, color.	mg/L	26	14	15
HCO3, acid titr	mg/L	543	633	619
K, ICP-SEQ	mg/L	8.2	4.1	5.5
Mg, ICP-SEQ	mg/L	189	15	18
Na, ICP-SEQ	mg/L	170	609	620
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	1520	885	928
Sum of Ions	mg/L	2850	2190	2240
Tot. Alkalinity	mg/L	445	519	507
Tot. Hardness	mg/L	1750	136	166
NUTRIENTS				
N, NO2+NO3	mg/L	<0.01	0.05	0.06
TRACE METALS				
Fe, ICP-AES	mg/L	2.8	1.3	0.32
Mn, ICP-AES	mg/L	1.3	0.019	0.003
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	3070	2670	2730
pH of water	pH units	7.19	8.03	8.00

SRC Group: 96-137

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 24-Jan-96 13:29

SAMPLE	CLIENT DESCRIPTION
728	J.W. ANDERSON JAN 10/96 @15:45 *WATER*
729	PAUL MICBALID JAN 10/96 @17:00 *WATER*
730	NORBERT KOCH JAN 11/96 @10:45 *WATER*

ANALYTE	UNITS	728	729	730
MAJOR CONSTITUENTS				
Alkalinity, P	mg/L	<1	<1	<1
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	132	91	240
Cl, color.	mg/L	7	29	11
HCO3, acid titr	mg/L	698	601	671
K, ICP-SEQ	mg/L	7.1	8.0	7.5
Mg, ICP-SEQ	mg/L	66	43	124
Na, ICP-SEQ	mg/L	210	365	83
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	480	648	738
Sum of Ions	mg/L	1600	1790	1870
Tot. Alkalinity	mg/L	572	493	550
Tot. Hardness	mg/L	601	404	1110
NUTRIENTS				
N, NO2+NO3	mg/L	0.08	0.06	0.03
TRACE METALS				
Fe, ICP-AES	mg/L	2.0	1.2	3.0
Mn, ICP-AES	mg/L	0.013	0.054	0.98
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	1800	2190	2110
pH of water	pH units	7.43	7.63	7.37

SRC Group: 96-137

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 24-Jan-96 13:29

SAMPLE	CLIENT DESCRIPTION
731	MURRAY MARTIN JAN 10/96 @12:20 *WATER*
732	DON GRAHAM JAN 10/96 @14:50 *WATER*
733	GUY PIERCE JAN 10/96 @11:05 *WATER*

ANALYTE	UNITS	731	732	733
MAJOR CONSTITUENTS				
Alkalinity, P	mg/L	<1	<1	<1
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	14	67	87
Cl, color.	mg/L	7	9	34
HCO3, acid titr	mg/L	592	694	631
K, ICP-SEQ	mg/L	2.9	6.6	5.8
Mg, ICP-SEQ	mg/L	7.1	36	46
Na, ICP-SEQ	mg/L	330	441	402
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	261	668	692
Sum of Ions	mg/L	1210	1920	1900
Tot. Alkalinity	mg/L	485	569	517
Tot. Hardness	mg/L	64	315	406
NUTRIENTS				
N, NO2+NO3	mg/L	0.03	0.16	1.2
TRACE METALS				
Fe, ICP-AES	mg/L	0.17	0.72	0.31
Mn, ICP-AES	mg/L	0.008	0.005	0.037
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	1470	2170	2180
pH of water	pH units	8.07	7.64	7.79

SRC Group: 96-137

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 24-Jan-96 13:29

SAMPLE	CLIENT DESCRIPTION
734	MAURICE NAPPER JAN 10/96 @18:00 *WATER*
735	LEO HOFFMAN JAN 10/96 @10:40 *WATER*
736	LARRY BRIGHT JAN 10/96 @15:05 *WATER*

ANALYTE	UNITS	734	735	736
MAJOR CONSTITUENTS				
Alkalinity, P	mg/L	<1	<1	<1
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	124	168	91
Cl, color.	mg/L	48	20	44
HCO3, acid titr	mg/L	612	688	517
K, ICP-SEQ	mg/L	5.7	6.3	4.2
Mg, ICP-SEQ	mg/L	42	62	36
Na, ICP-SEQ	mg/L	351	206	163
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	658	532	232
Sum of Ions	mg/L	1840	1680	1090
Tot. Alkalinity	mg/L	502	564	424
Tot. Hardness	mg/L	482	674	375
NUTRIENTS				
N, NO2+NO3	mg/L	0.04	0.02	1.0
TRACE METALS				
Fe, ICP-AES	mg/L	1.1	2.0	0.15
Mn, ICP-AES	mg/L	0.50	0.62	0.081
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	2120	1840	1240
pH of water	pH units	7.42	7.32	7.54

SRC Group: 96-137

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 24-Jan-96 13:29

SAMPLE	CLIENT DESCRIPTION
737	SAM ROLLHEISER JAN 10/96 @17:10 *WATER*
738	JOHN PHIPPS JAN 11/96 @09:10 *WATER*
739	KEVIN JARRETT NE05-51-23-W3 JAN 10/96 @13:40 *WATER*

ANALYTE	UNITS	737	738	739
MAJOR CONSTITUENTS				
Alkalinity, P	mg/L	<1	<1	<1
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	190	120	119
Cl, color.	mg/L	8	17	28
HCO3, acid titr	mg/L	692	599	465
K, ICP-SEQ	mg/L	8.8	6.5	7.8
Mg, ICP-SEQ	mg/L	84	49	48
Na, ICP-SEQ	mg/L	226	278	107
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	718	578	294
Sum of Ions	mg/L	1930	1650	1070
Tot. Alkalinity	mg/L	567	491	381
Tot. Hardness	mg/L	819	501	494
NUTRIENTS				
N, NO2+NO3	mg/L	0.02	<0.01	0.89
TRACE METALS				
Fe, ICP-AES	mg/L	1.4	2.0	0.008
Mn, ICP-AES	mg/L	0.028	0.12	0.002
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	2100	1850	1220
pH of water	pH units	7.27	7.48	7.32

SRC Group: 96-137

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 24-Jan-96 13:29

SAMPLE	CLIENT DESCRIPTION
740	SYLVESTER SCHNEIDER JAN 10/96 @11:40 *WATER*
741	CAL BALLAN JAN 11/96 @13:00 *WATER*
742	TIM MCDOUGALL JAN 11/96 @09:45 *WATER*

ANALYTE	UNITS	740	741	742
MAJOR CONSTITUENTS				
Alkalinity, P	mg/L	<1	<1	<1
CO3, acid titr.	mg/L	<1	<1	<1
Ca, ICP-SEQ	mg/L	183	37	121
Cl, color.	mg/L	2	158	13
HCO3, acid titr	mg/L	595	494	715
K, ICP-SEQ	mg/L	6.2	6.8	7.8
Mg, ICP-SEQ	mg/L	65	18	59
Na, ICP-SEQ	mg/L	50	747	367
OH	mg/L	<1	<1	<1
SO4, turb.	mg/L	338	1130	725
Sum of Ions	mg/L	1240	2590	2010
Tot. Alkalinity	mg/L	488	405	586
Tot. Hardness	mg/L	724	166	544
NUTRIENTS				
N, NO2+NO3	mg/L	0.01	0.17	0.02
TRACE METALS				
Fe, ICP-AES	mg/L	1.7	0.19	4.4
Mn, ICP-AES	mg/L	1.4	0.010	0.092
PHYSICAL PROPERTIES				
Specific Conductivity	uS/cm	1340	3390	2300
pH of water	pH units	7.33	7.99	7.43

SRC Group: 96-137

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

Resources Sector, SRC 24-Jan-96 13:30

SAMPLE	CLIENT DESCRIPTION	
743	BOB STEVENSON JAN 11/96 @12:20	*WATER*
744	HAROLD TUPLIN JAN 11/96 @11:25	*WATER*

ANALYTE	UNITS	743	744
MAJOR CONSTITUENTS			
Alkalinity, P	mg/L	<1	<1
CO3, acid titr.	mg/L	<1	<1
Ca, ICP-SEQ	mg/L	111	268
Cl, color.	mg/L	127	23
HCO3, acid titr	mg/L	709	598
K, ICP-SEQ	mg/L	8.7	8.7
Mg, ICP-SEQ	mg/L	64	97
Na, ICP-SEQ	mg/L	470	158
OH	mg/L	<1	<1
SO4, turb.	mg/L	815	932
Sum of Ions	mg/L	2300	2080
Tot. Alkalinity	mg/L	581	490
Tot. Hardness	mg/L	540	1070
NUTRIENTS			
N, NO2+NO3	mg/L	0.01	<0.01
TRACE METALS			
Fe, ICP-AES	mg/L	7.1	4.2
Mn, ICP-AES	mg/L	0.14	1.1
PHYSICAL PROPERTIES			
Specific Conductivity	uS/cm	2780	2320
pH of water	pH units	7.70	7.24

SRC Group: 96-137

SASKATCHEWAN RESEARCH COUNCIL
ANALYTICAL SERVICES

15 Innovation Blvd.
Saskatoon, Saskatchewan S7N 2X8
(306) 933-6932

(Summary of charges: not an invoice)

Resources Sector, SRC 24-Jan-96 13:36 Page 1
15 Innovation Blvd.
Saskatoon, Saskatchewan S7N 2X8
Attn: Dale Van Stempvoort, R1220-24

Date Samples Received: 12-Jan-96 Client P.O.:

SRC Sample Numbers: 722 to 744

722 NORMAN HALLET JAN 11/96 @14:10 *WATER*
723 GEORGE HALL JAN 11/96 @11:45 *WATER*
724 LLOYD WATSON JAN 11/96 @12:45 *WATER*
725 GLEN MCGLADDREY JAN 11/96 @09:40 *WATER*
726 JAMES LAMB JAN 10/96 @18:00 *WATER*
727 GERALD LAMB JAN 10/96 @13:30 *WATER*
728 J.W. ANDERSON JAN 10/96 @15:45 *WATER*
729 PAUL MICBALID JAN 10/96 @17:00 *WATER*
730 NORBERT KOCH JAN 11/96 @10:45 *WATER*
731 MURRAY MARTIN JAN 10/96 @12:20 *WATER*
732 DON GRAHAM JAN 10/96 @14:50 *WATER*
733 GUY PIERCE JAN 10/96 @11:05 *WATER*
734 MAURICE NAPPER JAN 10/96 @18:00 *WATER*
735 LEO HOFFMAN JAN 10/96 @10:40 *WATER*
736 LARRY BRIGHT JAN 10/96 @15:05 *WATER*
737 SAM ROLLHEISER JAN 10/96 @17:10 *WATER*
738 JOHN PHIPPS JAN 11/96 @09:10 *WATER*
739 KEVIN JARRETT NE05-51-23-W3 JAN 10/96 @13:40 *WATER*
740 SYLVESTER SCHNEIDER JAN 10/96 @11:40 *WATER*
741 CAL BALLAN JAN 11/96 @13:00 *WATER*
742 TIM MCDOUGALL JAN 11/96 @09:45 *WATER*
743 BOB STEVENSON JAN 11/96 @12:20 *WATER*
744 HAROLD TUPLIN JAN 11/96 @11:25 *WATER*

No. of Detn's	Analyte Description	Unit Charge	No. of Detn's	Analyte Description	Unit Charge
23	Alkalinity, P	0.00	23	CO3, acid titr.	0.00
23	Ca, ICP-SEQ	8.25	23	Cl, color.	10.00
23	HCO3, acid titr	8.25	23	K, ICP-SEQ	8.25
23	Mg, ICP-SEQ	8.25	23	Na, ICP-SEQ	8.25
23	OH	0.00	23	SO4, turb.	11.00
23	Sum of Ions	0.00	23	Tot. Alkalinity	0.00
23	Tot. Hardness	0.00	23	N, NO2+NO3	11.00

...2

Post-it® Fax Note 7671	Date Oct 10	# of pages ▶ 1
To Dale VanStempvoort	From Fred Buschau	
Co./Dept.	Co.	
Phone #	Phone # 5231	
Fax # 5493	Fax #	

Saskatchewan
Research Council

ANALYTICAL SERVICES LABORATORY

15 Innovation Blvd Saskatoon, Saskatchewan Canada S7N 2X8 Phone (306) 933-6932 Fax (306) 933-7922

Resources Sector, SRC

Attention: D. Van Stempvoort

Date: October 6, 1995.

Ground water samples.

Sample ID	Water (g)	CH4 ug/ml	C2H2 ug/ml
LND-94-01A@16:00 SEPT 27/95	19.64	0.076	-
LND-94-02@12:05 SEPT 27/95	22.81	3.767	0.010
LND-94-02@12:05 SEPT 27/95	23.36	5.978	0.017
LND-94-03@13:45 SEPT 27 /95	22.32	0.013	-
LND-94-03@13:45 SEPT 27/95	21.96	0.023	-
LND-94-04@13:05 SEPT 27/95	22.83	0.005	-
LND-94-05@14:35 SEPT 27/95	21.36	0.006	-
LND-94-1A@11:15 SEPT 27/95	23.37	0.013	-
MAR-94-01@19:05 SEPT 28/95	23.89	0.003	-
MAR-94-03@11:25 SEPT 29/95	23.89	0.060	-
MAR-94-04@12:30 SEPT 29/95	23.18	<0.001	-
MAR-94-05@10:35 SEPT 29/95	22.26	0.004	-
MAR-94-05@10:35 SEPT 29/95	24.00	0.003	-
MAR-95-02@18:40 SEPT 28/95	23.49	0.007	-
MAR-95-02@18:40 SEPT 28/95	23.47	0.011	-
MGN-95-01@9:50 SEPT 28/95	23.03	0.003	-
MGN-95-01@9:50 SEPT 28/95	23.26	0.001	-
MGN-95-02@10:35 SEPT 28/95	23.37	0.002	-
MGN-95-02@10:35 SEPT 28/95	22.66	0.001	-
MGN-95-03@11:05 SEPT 28/95	1.07	0.026	-
MGN-95-03@11:05 SEPT 28/95	0.51	0.056	-

detection limit <0.001ug/mL

Check valve problem

Fred Buschau, B.Sc.
Analyst

Post-it® Fax Note 7671	Date Oct 24/95	# of pages ▶ 1
To Dale VanStempvoort	From Fred Buschau	
Co./Dept.	Co.	
Phone #	Phone #	
Fax # 5403	Fax #	

Saskatchewan Research Council

ANALYTICAL SERVICES LABORATORY

15 Innovation Blvd Saskatoon Saskatchewan Canada S7N 2X8 Phone (306) 933-6932 Fax (306) 933-7922

Resources Sector, SRC

Attention: D. Van Stempvoort

Date: October 24, 1995.

Ground water samples.

	Sample ID	Water (g)	CH4 ug/ml	C2H6 ug/ml
	MGN-95-01 @14:50 Oct. 16/95.	22.88	0.001	<0.003
	MGN-95-01 @14:50 Oct. 16/95.	22.67	<0.001	<0.003
	MGN-95-02 @15.25 Oct. 16/95.	23.19	0.001	<0.003
	MGN-95-02 @15:25 Oct. 16/95.	22.43	0.002	<0.003
*	MGN-95-03 @16:00 Oct 16/95.	22.77	0.002	<0.003
*	MGN-95-03 @16:00 Oct. 16/95.	23.09	0.027	<0.003
	WDM-95-01 @12:50 Oct. 17/95.	23.54	0.060	0.006
	WDM-95-01 @15:00 Oct. 17/95.	23.48	0.046	0.003
	WDM-95-02 @12:30 Oct. 18/95.	22.58	0.018	<0.003
	WDM-95-02 @14:35 Oct. 18/95.	23.67	0.031	<0.003
	WDM-95-04 @16:30 Oct. 17/95.	22.20	0.054	<0.003
	WDM-95-04 @16:30 Oct. 17/95.	23.61	0.068	<0.003
	WDM-95-05 @17:00 Oct. 18/95.	22.98	0.013	<0.003
	WDM-95-05 @17:00 Oct. 18/95.	23.50	0.012	<0.003

*** see attached**

Duplicate samples of MGN-95-03 @16:00 Oct. 16/95 seem to show that the sample is either non homogeneous or some other problem. From the chromatograms to follow you can see the ratios of CO, CH4 and CO2 peaks are completely different between duplicates.

CH4 detection limit <0.001ug/mL

C2H6 detection limit <0.003ug/mL

Fred Buschau, B.Sc.

Analyst

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ANALYTICAL SERVICES LABORATORY

15 Innovation Blvd. Saskatoon, Saskatchewan Canada S7N 2X8 Phone (306) 933-6932 Fax (306) 933-7922

Resources Sector, SRC

Attention: D. Van Stempvoort

Date: November 23, 1995.

Ground water samples.

Sample ID	Water (g)	CH4 ug/ml	C2H6 ug/ml	C2H6/CH4 x100 (%)	CO ug/ml	CO2 ug/ml
LND-95-6A Nov. 17, 95	23.29	3.278	0.017	0.522	<0.001	9.037
LND-95-6A Nov. 17, 95	22.57	17.250	0.010	0.061	<0.001	2.151
LND-95-6B Nov. 17, 95	23.65	5.814	0.041	0.708	0.003	14.810
LND-95-6B Nov. 17, 95	23.48	4.285	0.027	0.637	<0.001	5.791
LND-95-6C Nov. 17, 95	23.07	19.083	0.077	0.406	<0.001	17.191
LND-95-6C Nov. 17, 95	23.07	19.052	0.080	0.419	0.002	11.901
LND-95-7A Nov. 17, 95	22.00	0.505	0.003	0.518	0.003	4.796
LND-95-7A Nov. 17, 95	23.51	0.448	0.001	0.122	<0.001	7.224
LND-95-7B Nov. 17, 95	23.79	0.359	0.002	0.449	<0.001	5.482
LND-95-7B Nov. 17, 95	23.02	0.352	0.002	0.473	<0.001	6.812
LND-95-7C Nov. 17, 95	22.13	6.445	0.013	0.194	<0.001	5.193
LND-95-7C Nov. 17, 95	22.06	8.507	0.026	0.301	<0.001	9.014
LND-95-8A Nov. 17, 95	24.13	10.090	0.045	0.450	<0.001	15.186
LND-95-8A Nov. 17, 95	24.01	14.903	0.074	0.497	<0.001	18.664
LND-95-8B Nov. 17, 95	22.74	8.445	0.036	0.427	<0.001	8.189
LND-95-8B Nov. 17, 95	23.32	5.438	0.021	0.395	<0.001	8.637
LND-95-8C Nov. 17, 95	23.24	10.953	0.025	0.230	<0.001	12.301
LND-95-8C Nov. 17, 95	23.02	11.776	0.028	0.236	0.003	12.317

CH4 detection limit <0.001ug/mL

C2H6 detection limit <0.003ug/mL

CO detection limit <0.001ug/ml

ed Buschau, B.Sc.

Analyst

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Resources Sector, SRC

Attention: D. Van Stempvoort

Date: November 23, 1995.

Ground water samples.

Sample ID	Water (g)	CH4 ug/ml	C2H6 ug/ml	C2H6/CH4 x100 (%)	CO ug/ml	CO2 ug/ml
LND-94-02 @17:35 Nov. 14/95	23.51	2.512	0.012	0.472	<0.001	10.225
LND-94-02 @17:35 Nov. 14/95	22.96	1.508	0.006	0.373	<0.001	6.408
LND-94-03 @18:15 Nov. 14/95	23.28	0.004	<0.003	-	<0.001	6.640
LND-94-03 @18:15 Nov. 14/95	24.06	0.004	<0.003	-	<0.001	5.890
LND-94-04 @9:50 Nov. 15/95	23.67	0.003	<0.003	-	<0.001	7.506
LND-94-04 @9:50 Nov. 15/95	23.76	0.002	<0.003	-	<0.001	5.149
LND-94-05 @11:40 Nov. 15/95	21.97	0.002	<0.003	-	<0.001	2.140
LND-94-05 @11:40 Nov. 15/95	23.62	0.005	<0.003	-	<0.001	9.908
LND-94-1A @13:35 Nov. 15/95	22.31	0.106	<0.003	-	<0.001	7.069
LND-94-1A @13:35 Nov. 15/95	21.59	0.162	<0.003	-	<0.001	6.372

CH4 detection limit <0.001ug/mL

C2H6 detection limit <0.003ug/mL

CO detection limit <0.001ug/ml

d Buschau, B.Sc.

alyst

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Resources Sector, SRC

Attention: D. Van Stempvoort

Date: November 29, 1995.

Ground water samples.

Sample ID	Water (g)	CH4 ug/ml	C2H6 ug/ml	C2H6/CH4 x100 (%)	CO ug/ml	CO2 ug/ml
MGN-95-01 @11:15 Nov. 22/95	24.30	2.085	0.005	0.226	0.004	3.789
MGN-95-01 @11:15 Nov. 22/95	23.61	3.140	0.006	0.206	0.004	6.170
MGN-95-02 @13:10 Nov. 22/95	24.16	0.009	<0.003	-	0.003	1.226
MGN-95-02 @13:10 Nov. 22/95	23.29	0.011	<0.003	-	0.002	1.171
MGN-95-03 @17:10 Nov. 22/95	23.75	0.030	<0.003	-	0.005	7.004
MGN-95-03 @17:10 Nov. 22/95	23.81	0.003	<0.003	-	0.002	4.427

CH4 detection limit <0.001ug/mL

C2H6 detection limit <0.003ug/mL

CO detection limit <0.001ug/ml

)d Buschau, B.Sc.

Analyst

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Resources Sector, SRC

Attention: D. Van Stempvoort

Date: January 4, 1996.

Ground water samples.

Sample ID	Water (g)	CH4 ug/ml
MGN-95-04A @17:40 Dec. 15/95	24.06	0.026
MGN-95-04B @18:15 Dec. 15/95	23.77	0.156
MGN-95-04C @19:55 Dec. 15/95	22.77	0.103
MGN-95-05A @13:40 Dec. 15/95	22.25	0.037
MGN-95-05A @13:40 Dec. 15/95	23.52	0.023
MGN-95-05B @15:00 Dec. 15/95	22.21	0.070
MGN-95-05C @16:15 Dec. 15/95	23.42	0.105
MGN-95-06A @15:55 Dec. 14/95	23.05	0.049
MGN-95-06B @12:45 Dec. 15/95	26.16	0.003
MGN-95-06B @12:45 Dec. 15/95	23.73	0.009
MGN-95-06C @14:03 Dec. 14-95	22.67	0.003
MGN-95-06C @14:03 Dec. 14/95	22.69	0.005
MGN-95-07A @16:10 Dec. 14/95	22.64	0.016
MGN-95-07A @16:10 Dec. 14/95	23.57	0.009
MGN-95-07B @17:25 Dec. 14/95	22.25	<0.001
MGN-95-07B @17:25 Dec. 14/95	23.76	<0.001
MGN-95-07C @12:05 Dec. 15/95	21.97	0.095

Fred Buschau, B.Sc.
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15 Innovation Blvd Saskatoon, Saskatchewan Canada S7N 2X8 Phone: (306) 933-5932 Fax: (306) 933-7922

Resources Sector, SRC

Attention: D. Van Stempvoort

Date: January 16, 1996.

Ground water samples.

Sample ID	Water (g)	CH4 ug/ml
Anderson, J.W. @15:45 Jan. 10\96	24.11	0.006
Bright, Larry @15:05 Jan. 10\96	24.13	<0.001
Graham, Don @14:50 Jan. 10\96	24.64	1.071
Hoffman, Leo @10:40 Jan. 10\96	25.31	0.001
Jarrett, Kevin NE-5-51-23-w3 @13:40 Jan. 10\96	24.20	<0.001
Lamb, Gerald @13:30 Jan. 10\96	24.31	0.007
Lamb, James @18:00 Jan. 10\96	24.53	1.308
Martin, Murray @12:20 Jan. 10\96	24.50	0.003
Mihalich, Paul @17:00 Jan. 10\96	25.17	0.010
Napper, Maurice @18:00 Jan. 10\96	24.51	0.002
Pierce, Guy @11:05 Jan. 10\96	24.04	0.005
Sam Roll Ueiser @17:10 Jan. 10\96	23.85	0.008
Schneider, Sylvester @11:40 Jan. 10\96	24.36	<0.001

Detection Limit CH4 <0.001ug/ml

Detection Limit C2H6 <0.003ug/ml

Detection Limit CO <0.001ug/ml

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Resources Sector, SRC

Attention: D. Van Stempvoort

Date: January 16, 1996.

Ground water samples.

Sample ID	Water (g)	CH4 ug/ml
Ballan, Cal @13:00 Jan. 11\96	24.23	0.015
Hall, George @11:45 Jan. 11\96	23.86	0.032
Hallet, Norman @14:10 Jan. 11\96	24.38	0.044
Koch, Norberk @11:45 Jan. 11\96	24.60	0.003
McDougall, Tim @9:45 Jan. 11\96	24.40	0.001
McGladdrey, Glen @9:40 Jan. 11\96	24.05	0.003
Phipps, John @9:10 Jan. 11\96	24.16	0.002
Stevenson, Bob @12:20 Jan. 11\96	24.33	0.469
Tuplin, Harold @11:25 Jan. 11\96	24.19	0.002
Watson, Floyd @12:45 Jan. 11\96	23.83	0.006

Detection Limit CH4 <0.001ug/ml

Detection Limit C2H6 <0.003ug/ml

Detection Limit CO <0.001ug/ml

Fred Buschau, B.Sc.
Analyst