HYDROGEOLOGICAL ASSESSMENT
and
WATER WELL EVALUATION

FOR THE
SALTSPRING ISLAND RESORT
281 ROBINSON ROAD
SALTSPRING ISLAND, BC

PREPARED FOR

SALTSPRING ISLAND VILLAGE RESORT LTD.
SUITE 200, 1687 WEST BROADWAY
VANCOUVER, B.C. V6J 1X2

SUBMITTED TO

THE CAPITAL REGIONAL DISTRICT
ENVIRONMENTAL HEALTH DEPARTMENT
WATER MANAGEMENT SECTION
#201 - 771 VERNON AVENUE
VICTORIA, BC V8X 5A7

PRESENTED BY

AQUATERRA CONSULTANTS LTD.
ABBOTSFORD, B.C.

FILE 9509

FEBRUARY 1996

TABLE OF CONTENTS

APPENDICES

1.0 Introduction

AquaTerra Consultants has completed a preliminary hydrogeological assessment and water well evaluation of Well #1 as part of the water supply for the proposed resort development on the north east shore of Bullock's Lake, near Ganges, on Saltspring Island, B.C. This study has focused on assessing the aquifer capabilities and well performance for development of a ground water supply for community use.

It is understood that the planned development includes 123 private resort cottages and a public lodge facility containing a restaurant and banquet facilities. The water supply is to be provided by drilled water wells which will be developed to serve the lodge and each individual unit.

This study, is to support an application for a construction permit of the above facilities, and was conducted over the period of November 1995 to January 1996. It has consisted of :

- Reviewing existing background information for the study area including maps of surficial geology and topography;
- Reviewing existing information and reports on ground water resources in the study area such as well logs, ground water reports, and chemical analyses;
- Reviewing a report on the hydrology on the of Bullock's Lake by the Ministry of Environment, Hydrology Section (1981);
- Reviewing a report of the Saltspring Island Water Allocation Plan by the Ministry of Environment, Regional water management (1993);
- Reviewing a report on the hydrogeology of Saltspring Island by the Ministry of Environment, Ground Water Section (1995);
- Several site visits by the author during which time various field studies such as monitoring water levels, observing pumping tests and obtaining water samples.
- Preparation of this document.

1.1 Scope

The work was carried out under the terms of the British Columbia Health Act, Safe Drinking Water Regulation, 1992. The requirements of the regulation to be met are:

2 (1) (a) A person must not commence or carry on construction of a waterworks system unless he obtains from a public health engineer a construction permit stating that work on the construction may be commenced,

2 (2) (b) The results of a water analysis for those water quality parameters that have been specified by a medical health officer for a water source.

5 (1) A water purveyor must provide potable water to all users served by the waterworks system.

where in this regulation

"*domestic purposes*" means the use of water for normal household requirements, including sanitation, human consumption and food preparation;

"*potable water*" means water which meets the requirements of the Schedule and is safe to drink and fit for domestic purposes without further treatment;

"*water purveyor*" means a person that offers or supplies, or holds itself out as being available to offer or supply, water for domestic purposes;

"*waterworks system*" means a system of water supply including its source, treatment, storage, transmission and distribution facilities, where water is furnished or offered for domestic purposes, but does not include a water supply serving only one single family residence.

A total of six wells exist on the property and were drilled by Albert Kaye & Sons Drilling Ltd. and by D.A. Smithson & Sons Water Well Drilling. The well test, under the supervision of AquaTerra Consultants Ltd., was carried out by Albert Kaye & Sons Drilling Ltd. during January, 1996. This period generally represents an average flow (recharge) condition for the year. The location of the wells for each lot are shown on the Site Plan. Chemical and bacteriological analysis were carried out by Norwest Labs. Ltd. of Langley B.C.

This report presents the field and laboratory test data, an evaluation of Well #1, and a hydrogeological summary.

2.0 Background

2.1 Location and Topography

Legal Description : Lots 1 to 5, Section 7, Range 3E, District 16, Portion North Saltspring Island, Cowichan District, Plan VIP 52850

Civic Description: 281 Robinson Road, Saltspring Island, B.C.

The study site is located northwest of Long Harbour on the northeast slopes of Bullock's Lake. It is bounded by Robinson Road to the north, Bullock's Lake to the south, forested slopes to the west and an agricultural farm to the east. Refer to Figure 1 site plan. The surrounding properties are generally agricultural, second growth timber, and rural residential. The site has been partially logged in the past and old logging trails remain present through various portions of the property.

Bullock's Lake is situated approximately two kilometres north of Ganges Harbour and is a low lying valley that drains towards Ganges Harbour. The lake is at a geodetic elevation of approximately 26m. The slopes of the study area rise another 35m above the lake with variable grades ranging between 16 and 35 percent.

The property is 14 ha (35 acres) in area and is triangular in shape, measuring about 250m at the apex and about 700m along the base, with approximately 450m of this as lake frontage.

3.0 Surface Water

Bullock's Lake and Bullock Creek, the stream that enters and leaves the lake, are the only significant surface water features in the vicinity of the proposed development. No stream flow and water volume information is available from the Ministry of Environment or the Water Survey of Canada. The drilled wells are about 200 metres upslope from the lake.

A recent remedial enhancement project funded in part by Ducks Unlimited, The Salmon Enhancement Society and Saltspring Island Village Resort has seen both the upper and lower sections of Bullock Creek cleaned out and deepened. This has resulted in an improved year round flow condition through the lake.

4.0 Bedrock and Structural Geology

The quaternary geology of the study area is comprised generally of metaplastic or low grade metamorphic sands and shales. These rocks were deposited under marine sedimentary conditions, and subjected to higher pressures from regional thrust fault tectonism, resulting in low grade metamorphism. Over time, the rock has been eroded by glaciofluvial activity and weathering. This has produced a capping of young stony soils overlying the parent material, the result of weathering of the subcrop and deposition by local fluvial transport events.

Bedrock exposures are noted in two places along the crest of the slope in the north portion of the property. The bedrock ranges in depth from surface to greater than 3 metres. The average depth from surface is between 1 and 2 metres in most places.

The exposures are sandstone of the Galiano Formation. The formation consists of thick bedded, medium to coarse grained sandstone and pebble conglomerate. The sandstone is classified as arkosic to lithic arenite and is up to 400m thick in places on Saltspring Island. Clasts are predominantly of argillite and sandstone, bedding is massive; and contacts are sharp and planar. The contact with the under lying Northumberland Formation is sharp (England 1990). Weathering of this material has produced a layer of unconsolidated material of variable thickness that covers the sandstone.

At the base of the slope, parallel to the strike of the lake shore, is a section of weathered Northumberland Formation silty shale. The material has been deeply weathered to an unconsolidated silt and clay. The Northumberland rests stratigraphically under the Galiano sandstone. Conformably overlying and mixed with the Northumberland silts are lacustrine silts from Bullock's Lake.

Saltspring Island has undergone complex structural deformation, predominantly thrust faulting and folding. Thrust sheets dip to the north-northeast and are stacked upon one another defining belts of rock between the major thrust faults that are oriented in a northwest - southeast lineation on the island. Smaller, minor thrusts are contained within the main thrust sheets, as are anticlinal and synclinal folding.

The property is north of the Ganges Fault that runs through the town of Ganges and is situated on the west limb of a syncline. Several north - south transecting faults are present on the island, the most prominent in the area being the one on the west side of St. Mary's Lake. A fault is indicated by work from Winsby, 1973 to cut through the subject property. The high degree of structural deformation in the brittle sandstone rock has allowed for the development of a fracture connected aquifer.

5.0 Hydrogeology

The Ground Water Section of the Ministry of Environment has 1535 water wells records for Saltspring Island up to the end of 1992 (Hodge, 1995). These records are generally up to date, however, since mandatory filing of drilling reports is not required by drillers in BC, there are undoubtedly other wells present for which data is unavailable.

The majority of the wells in the area are completed within a confined aquifer, and the static water levels are reported to range between 1m and 100m below the ground surface throughout the area. The occurrence and movement of ground water on Saltspring Island is controlled by local geology, availability of pores and fractures in the bedrock, recharge, and movement of water from recharge to discharge points. The variability in rock type significantly affects their ability to store and transmit water. Pathways can exist as intergranular pores in the sandstone, or as bedding planes, fractures, faults and joints.

Well record information suggests complex geologic and hydrologic conditions for several distinct aquifers on Saltspring Island. Reports on the aquifers found in the study area suggest a deep confined bedrock aquifer within the Galiano Formation sandstone. Bedrock exists as both outcrop and subcrop on the property. The rock is bedded, and joint sets and fractures are evident in outcrop. These structural features will exist at depth. The fracture zones act as storage reservoirs for water. The sandstone rock was formed under marine conditions and has the necessary hydraulic characteristics to supply water, but at limited rates. The fractures result in secondary porosity enhancing the hydraulic capability of the rock. This is the dominant control over water storage and movement in this type of rock.

Post emplacement structural changes can produce significant alterations in these rock masses, thereby enhancing their potential usefulness for water supply. The depth of the fractures can extend down hundreds of metres giving a significant storage factor.

Most of the recharge to the bedrock flow regime is the result of limited but direct infiltration of precipitation at the ground surface. The water percolates to the saturated zone and moves through shallow, local flow systems until discharge into surface water courses, springs or lakes occurs. Some of the ground water moves down into the deeper regional ground water flow system with in the bedrock.

Hydraulic relationships exist between the creeks, lake, springs and wetlands found in the study area. Surface water and ground water are two interdependent components that effect each other. A shallow perched water table exists within the unconsolidated surface soils over some of the site. This feature is directly related to and controlled by seasonal precipitation that falls above and on the property. The entire site is moderately sloped towards Bullock's Lake, affording a strong gradient for southwest ground water flow, towards the lake's edge.

6.0 Recharge to Ground Water Flow Systems

6.1 Shallow Surface Recharge

Ground water occurs locally as a seasonal perched water table at the base of the slope towards the lake. During the wet season (October to April) precipitation infiltrates down through the shallow, permeable surface sediments and flows along the less permeable, underlying, sandstone and shales. During the drier summer months (May to September) the perched water table disappears. This is a direct response to the limited precipitation falling within the catchment area. The height of this shallow water table is directly influenced by the upslope catchment area, the amount of precipitation that falls within that area, and the hydraulic conductivity of the shallow subsurface sediments.

6.2 Deep Bedrock Recharge

Recharge to the bedrock flow regime in the study area is related to infiltration of precipitation from the ground surface percolating through the shallow, unconsolidated overburden, downward into the deeper regional ground water flow system. The infiltration is controlled degree of precipitation, permeability of the overburden, and hydraulic characteristics of the bedrock. Aquifer storativity and bedrock fracture permeability are more limiting factors for ground water yield and recharge and not total precipitation (Hodge, 1995). The available annual recharge to bedrock consider by Hodge (1995) was considered to be 3 percent of total annual precipitation. Climatic data from the Ganges station for a 30 year record was recorded as a mean average of 1065 mm (42 inches). This would produce an annual available recharge to bedrock aquifer of 32 mm (1.25 inches). This was shown to be a reasonable amount when applied to bedrock aquifers on a regional scale.

7.0 Septic Disposal Fields

The outline of the approved septic disposal field location in relationship to the well locations is shown on Figure 1 site plan. All wells are located a minimum of 30m from the disposal field, as required by the Health Act. The location of the disposal fields will have no impact on the water quality of the well.

8.0 Existing Water Well Record Information

A total of 5 well logs were reviewed for the study area . The water well locations are across Robinson to the north and east, and are all private wells for domestic use. The water well logs are summarized below in the table below.

Local Water Wells

Well No.	Depth (m)	Lithology	Water Level	Yield
1	10	Sand and Gravel	unreported	unreported
2	46	Shale	unreported	9 gpm
3	38	Sandstone and Shale	unreported	1 gpm
4	99	Sandstone and Shale	unreported	5 gpm
5	76	Sandstone and Shale	unreported	2 gpm

The domestic wells are likely completed within the confined water table aquifer within 100m of the surface. All recorded wells are drilled and cased except for well #1 which is a shallow dug well obtaining water from the shallow surface aquifer. Recorded yields range between 5-40 L/sec.

9.0 Well Completion Details

Six wells have been drilled by air rotary methods on the property. Three wells were drilled by D.A. Smithson & Sons in 1987 and three additional wells were drilled in 1995 by Albert Kaye & Sons Drilling Ltd. The wells range in depth between 31 and 128m below the ground surface and are drilled in Galiano sandstone. Each well is cased with 150mm steel casing into the bedrock. The remainder of the hole is an open completion with no screen.

Each of the wells were air tested by the driller for an estimation of water flow The flows varied from 1 gpm to 90 gpm. A summary of the well information is shown in the table below. A location of the wells is shown in Figure 1 site plan.

Drilled Well Information Summary

Well No.	Lot Location	Surface Elevation	Well Depth	Static Level	Driller's Flow Rate
1	Lot 1	96 m	100 m	14 m	90 gpm
2	Lot 1	94 m	99 m	27 m	30 gpm
3	Lot 1	96 m	128 m	13 m	3 gpm
4	Lot 2	95 m	91 m	3.5 m	4 gpm
5	Lot 3	89 m	100.5 m	5.5 m	1 gpm
6	Lot 5	76 m	31 m	4.5 m	2 gpm

10.0 Pumping Test Data

An aquifer performance and well test was carried out on Well #1. The test consisted of pumping the well for a period of five days at varying rates of 10, 25 and 20 gpm, and measuring the recovery response for a five day period. The discharge rate was measures using repeated timed, volumetric measurements. Drawdown and recovery measurements were taken with an electric tape from the pumping well and three nearby observations wells. This monitoring aids in determining well influence.

A pumping test is one of the most useful means of determining hydraulic properties of water bearing geological units. All formulas for the analysis of pumping test data are based on certain sets of assumptions and generalizations with each solution's validity being under a restricted set of circumstances.

Ramey and Gringarten developed a method that takes the storage effects of the fractures into account for a well intersecting a non-plane vertical fracture in a homogeneous, isotropic, confined aquifer. The Ramey and Gringarten analyses for the Well #1 pumping test are included in Appendix B.

The following set of general assumptions and conditions are applied for the Ramey and Gringarten curve fitting method:

> The aquifer is confined and of infinite areal extent;
>
> The thickness of the aquifer is uniform over the area that will be influenced by the pump test;
>
> The well fully penetrates a single vertical fracture;
>
> Prior to pumping, the piezometric surface is horizontal over the area that will be influenced by the test;
>
> The flow towards the well is in an unsteady state:
>
> The well loses are negligible.

The aquifer type encountered on the property by all six wells is considered confined. There are two types of flow equations, those describing steady-state flow and those describing unsteady-state flow.

Steady-state flow occurs when there is an equilibrium attained between the discharge of the pumped well and the recharge of the aquifer by an outside source.

Unsteady-state flow occurs when the potentiometric surface changes with time, due to pumping. Well #1 exhibited unsteady-state flow conditions during the pump test.

In determining the most important hydraulic properties of confined aquifers, the following formation factors are used: Transmissivity and storage coefficient.

Transmissivity is the product of the average hydraulic conductivity and the thickness of the aquifer. The effective transmissivity, as used for fractured media, refers to the fractures principle axes of permeability. The storativity ratio is a parameter that controls the flow from the aquifer matrix blocks (the sandstone) into the fractures of a confined fractured aquifer of the double porosity type. Being a ratio, storativity is dimensionless. The storage constant is the ratio of change in volume of water in the well plus vertical fracture, and the corresponding drawdown (m^2).

The transmissivity of the confined fractured bedrock aquifer for Well #1 was determined as 26.02 m^2 /day. This high value is expected for fracture related aquifers and reflects the heterogeneity of the fracture width, length and orientation which in turn affects the other hydraulic parameters.

The storativity ratio of the fractures was determined to be 5.206. This high value reflects the heterogeneity of the fracture pattern in the subsurface and the amount of water available from the rock matrix.

The storage constant was determined to be 2.6 m^2. This also reflects the fracture's length, size and connectivity as being relatively large, which ultimately determines the supply of water available for use.

The results of the Ramey and Gringarten analysis are summarized below.

Well No.	Effective Transmissivity (m^2/day)	Fracture Storativity (dimensionless)	Storage Constant (m^2)	Percent Drawdown	Percent Recovery
Well #1	26.03	5.206	2.6	30 %	93 %

The test may be summarized as follows:

Well Depth 100m
Depth to water 14m
Water Column 86m

Duration of pumping 120 hours (5 days) with the following pumping rates:

0 - 48 hours @ 10 gpm for 14,400 gallons per day
48 - 96 hours @ 15 gpm for 21,600 gallons per day
96 - 120 hours @ 20 gpm for 28,800 gallons per day

Amount of drawdown: 26m or 30 percent of the water column
Total volume pumped: 100,800 gallons
Average daily flow rate: 20,160 gallons per day

Well #1 exhibited strong storage and recharge capability, however, the results indicate that storage tanks are needed. The volume for storage should exceed the average 48 hour demand. This could change over time depending on actual water usage rate, any additional wells drilled in the area from future developments, and the recharge conditions during the year.

The well should be fitted with a low-level, shutoff control to protect the submersible pump. Further, it is recommended that the delivery system be fitted with a flow control device such as a "Dole" valve. Flow should be restricted to 15 gpm as a maximum.

11.0 Water Quality Hydrochemistry

Two water sample were taken from Well #1 and submitted for laboratory analysis. The first sample was taken approximately 3 hours after pumping began, and the second water sample taken after the conclusion of testing. The dual sample analysis was to provide an indication of whether any marked change in electrical conductivity or total dissolved solids was evident as a result of increasing salinity. The results strongly indicated that this was not the case.

The chemistry of water from fractured bedrock is dependent upon composition of the recharge system feeding the aquifer. This is affected by the length of the flow path and the composition of the host material (Koenig, 1995). The water quality analysis reveals a natural water with a relatively short travel path, which would be expected for an island aquifer system.. The chemical constituents reveal a bicarbonate - calcium type water with a slightly basic pH. This is indicative that only a small degree of chemical transformation from the original meteoric composition has occurred during the travel to the well.

The waters pH is just slightly above normal, but well within the drinking water guidelines. This indicates the water is very slightly alkaline. The alkalinity is due to the presence of the bicarbonate (HCO_3) in the water. Again, the bicarbonate value is well within acceptable limits. The hardness of the water, determined by the amount of $CaCO_3$ present, indicates a soft water.

A copy of the water quality laboratory test results are included in Appendix A.

The analysis indicates that the water meets all of the water quality guidelines of the Canadian and B.C. Drinking Water Standards, 1982 and meets the microbiological standards of the Safe Drinking Water Regulation Schedule. **A certificate of potability for water from Well #1 is included at the end of this report.**

12.0 Conclusions

1. Well #1 is capable of producing a sustained yield of 15 gpm or 21,660 gallons per day (280 m^3/ day).

2. Water quality test results meet the Canadian and B.C. Drinking Water Standards, 1982 and meets the microbiological standards of the Safe Drinking Water Regulation Schedule of the Health Act.

3. A flow control device of 15 gpm for Well #1 is recommended. This is to protect the well and the aquifer from over pumping. This information should be passed on to the Building Inspection Department to ensure the owner is aware of this requirement.

4. The well should be fitted with a low-level, shutoff control to protect the submersible pump. The pump size should be determined by an engineer with suitable expertise in the area of waterworks systems and the pump should be set within 4 metres of the base the well to maximize well storage and available drawdown.

5. The storage tank capacity should exceed 48 hours of normal average demand for the development.

13.0 Closure

We trust the above is suitable for your immediate needs. Further information will be provided on the project as it becomes available. If you require further assistance or have any questions, please contact the undersigned.

Prepared by:

AquaTerra Consultants Ltd.

Ray Koenig, P.Geo.
Environmental Hydrogeologist

References

Driscoll, F.G. 1986. Groundwater and Wells. John Filtration Systems Inc., St.Paul, Minnesota. 1089p.

England, T.D.J. 1989. Lithostratigraphy of the Nanaimo Group, Georgia Basin, southwestern British Columbia. Current Research, Part E, Geological Survey of Canada Paper 89-1E. pp103-108.

England, T.D.J. 1990. Late Cretaceous to Paleogene evolution of the Georgia Basin, southwestern British Columbia. Unpublished Ph.D. thesis, Memorial University of Newfoundland, St.John's, Newfoundland. 481p.

Federal-Provincial Subcommittee on Drinking Water. 1989. Guidelines for Canadian Drinking Water Quality, Fourth Edition. Ministry of National Health and Welfare, Canada. 25p.

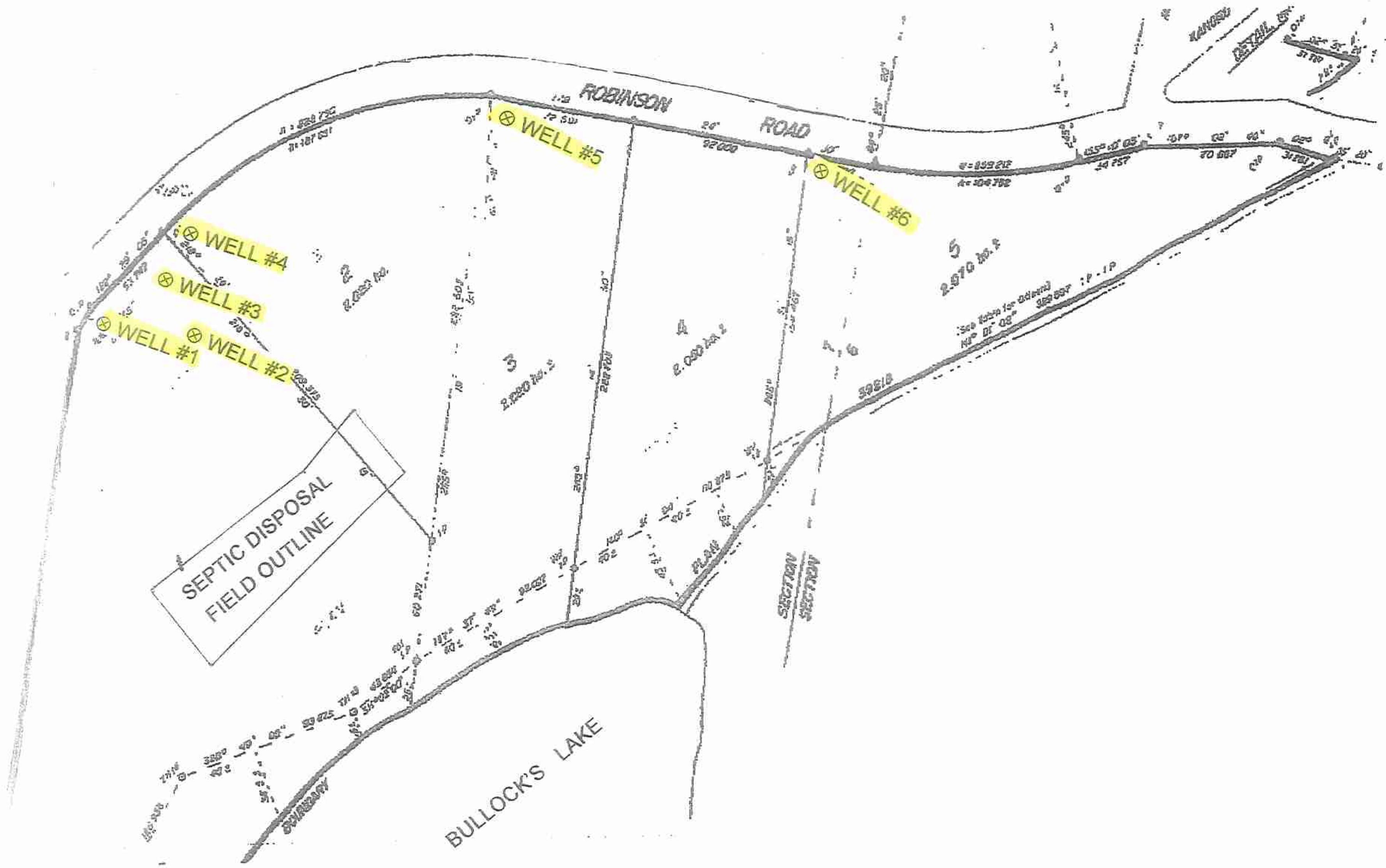
Hodge, W.S. 1995. Groundwater Conditions On Saltspring Island. Water Management Division, B.C. Environment. 74p.

Koenig, R.M. 1995. A Comparison of Water Quality between Aquifers in Glacial Deposits and Fracture Bedrock- Sumas Mountain, B.C. Mountain Hydrology - Peaks and Valleys in Research and Applications, Proceedings. Canadian Society for Hydrological Sciences, Canadian Water Resources Association, Cambridge, Ontario, Canada. pp 85-91.

Kruseman, G.P. and deRidder N.A. 1991. Analysis and Evaluation of Pumping Test Data. 2nd edition, ILRI Publication 47. Wageningen, The Netherlands. 377p.

Mustard, P.S. 1995. The Upper Cretaceous Nanaimo Group, Georgia Basin, Southwestern British Columbia. Geological Survey of Canada. Vancouver, B.C. 115p.

Winsby, J.A. 1973. Geology of the Upper Cretaceous Nanaimo Group, Saltspring Island, British Columbia. Unpublished BSc. thesis, University of British Columbia. Vancouver, B.C. 34p.



SALTSPRING ISLAND RESORT
WELL LOCATION SITE PLAN

FIGURE 1

AQUATERRA CONSULTANTS LTD.

one:
504) 530-4344
-800-889-1433
ax:
604)534-9996

NORWEST
LABS

203-20771 Langley Bypass
Langley, B.C. V3A 5E8

Work Order Number: 17067
Date Issued: 02/20/96

Certification Of Potability

Sample Id Saltspring Island Village Resort

Well Water @ 281 Robinson Road

Norwest Soil Research Inc. certifies that the above mentioned water sample number 17067-1 supplied by Aqua Terra Consultants Ltd. meets the chemical and bacteriological requirements specified by the 1993 Guidelines for Canadian Drinking Water Quality for the constituents tested.

Approved By

Randy Neumann, B.Sc.
Laboratory Manager

APPENDIX A

Phone:
(604) 530-4344
1-800-889-1433
Fax:
(604) 534-9996

NORWEST LABS

203-20771 Langley Bypass
Langley, B.C. V3A 5E8

W.O. (Lang.) : 17067
W.O. (Other) :
P.O. # :
Date Received : 02/19/96
Date Completed : 02/20/96

Client		Received From	
Name	: AQUA TERRA CONSULTANTS LTD.	Name	:
Address	: 3297 PONDEROSA ST.	Address	:
	: ABBOTSFORD, BC		:
	: V2T 5G2		:
Phone	: 850-3521	Phone	:
Fax	: 850-3542	Fax	:
Attention:	RAY KOENIG	Attention:	

WATER ANALYSIS REPORT

Lab #: 17067- 1
Sample ID: SALTSPRING ISLAND VILLAGE RESORT WELL WATER @ 281 ROBINSON ROAD

ANALYTICAL RESULTS			GUIDELINES FOR DRINKING WATER
pH	7.67		pH values between 6.5 & 8.5 considered acceptable
Electrical Conductivity	106	uS/cm	Values above 1000 uS/cm indicate excessive salt content
Total Dissolved Solids	77	mg/L	Objective level 500 mg/L; higher values indicate high salts
Total Suspended Solids	60	mg/L	Values above 250 mg/L indicate excessive levels of sediment
Ammonium-N	< 0.1	mg/L	No acceptable level set; values normally below 0.5 mg/L
Potassium	0.4	mg/L	No acceptable level set; values normally 0.5 to 10 mg/L
Calcium	8.10	mg/L	Objective below 75 mg/L; causes hardness
Magnesium	2.60	mg/L	Objective below 50 mg/L; causes hardness
Sodium	7.20	mg/L	Aesthetic limit 200 mg/L; below 20 mg/L for low sodium diets
Iron (Dissolved)	0.01	mg/L	>0.3 mg/L may cause staining; objective level <0.05 mg/L
Copper (Dissolved)	< 0.01	mg/L	Aesthetic limit 1.0 mg/L; objective below 0.01 mg/L
Zinc (Dissolved)	< 0.01	mg/L	Aesthetic limit 5.0 mg/L; objective below 1.0 mg/L
Manganese (Dissolved)	0.01	mg/L	Aesthetic limit 0.05 mg/L; objective below 0.01 mg/L
Phosphate-P	0.05	mg/L	No acceptable limit set
Sulphate	9.4	mg/L	Aesthetic limit 500 mg/L
Nitrate-N (+ Nitrite-N)	< 0.47	mg/L	Below 10 mg/L acceptable; objective level below 1.0 mg/L
Chloride	10.8	mg/L	Aesthetic limit 250 mg/L
Fluoride	0.05	mg/L	Values up to 1.2 mg/L desirable; under 1.5 mg/L acceptable
Boron	0.10	mg/L	Below 5.0 mg/L acceptable
Carbonate	< 1.0	mg/L	Presence indicates alkaline water
Bicarbonate	26.6	mg/L	High level indicates moderately alkaline water
Hardness (CaCO3 equiv)	31.0	mg/L	Soft waters are less than 75mg/L; hard waters are above 150 mg/l
Total coliforms	< 1	/100mL	Below 3/100 mL acceptable
Fecal coliforms	< 1	/100mL	Below 1/100 mL acceptable

APPROVED BY: Randy Neumann B.Sc.
Laboratory Manager

Results quoted as zero indicate concentrations below the following detection limits:

Less than 0.01 mg/l Fe, Cu, Zn, Mn, B
Less than 0.05 mg/l Na, Ca, Mg, K, PO4-P, NH4-N, NO3-N
Less than 0.10 mg/l Cl, Fl, SO4-S
Less than 1 mg/l TDS, TSS, carbonate & bicarbonate

Accredited By: CANADIAN ASSOCIATION OF ENVIRONMENTAL ANALYTICAL LABORATORIES
For specific tests registered with the Association

Phone:
(604) 530-4344
1-800-889-1433
Fax:
(604) 534-9996

NORWEST LABS

203-20771 Langley Bypass
Langley, B.C. V3A 5E8

W.O. (Lang.) : 16668
W.O. (Other) :
P.O. # :
Date Received : 01/08/96
Date Completed : 01/11/96

Client		Received From	
Name	: AQUA TERRA CONSULTANTS LTD.	Name	:
Address	: 3297 PONDEROSA ST.	Address	:
	: ABBOTSFORD, BC		:
	: V2T 5G2		:
Phone	: 850-3521	Phone	:
Fax	: 850-3542	Fax	:
Attention:	RAY KOENIG	Attention:	

WATER ANALYSIS REPORT

Lab #: 16668- 1
Sample ID: WELL WATER @ SALT SPRING ISLAND RESORT, ROBSON RD. WELL #1

ANALYTICAL RESULTS			GUIDELINES FOR DRINKING WATER
pH	7.11		pH values between 6.5 & 8.5 considered acceptable
Electrical Conductivity	231	uS/cm	Values above 1000 uS/cm indicate excessive salt content
Total Dissolved Solids	150	mg/L	Objective level 500 mg/L; higher values indicate high salts
Total Suspended Solids	1	mg/L	Values above 250 mg/L indicate excessive levels of sediment
Ammonium-N	< 0.1	mg/L	No acceptable level set; values normally below 0.5 mg/L
Potassium	0.5	mg/L	No acceptable level set; values normally 0.5 to 10 mg/L
Calcium	21.00	mg/L	Objective below 75 mg/L; causes hardness
Magnesium	5.70	mg/L	Objective below 50 mg/L; causes hardness
Sodium	19.00	mg/L	Aesthetic limit 200 mg/L; below 20 mg/L for low sodium diets
Iron (Dissolved)	0.05	mg/L	>0.3 mg/L may cause staining; objective level <0.05 mg/L
Copper (Dissolved)	0.01	mg/L	Aesthetic limit 1.0 mg/L; objective below 0.01 mg/L
Zinc (Dissolved)	0.06	mg/L	Aesthetic limit 5.0 mg/L; objective below 1.0 mg/L
Manganese (Dissolved)	0.19	mg/L	Aesthetic limit 0.05 mg/L; objective below 0.01 mg/L
Phosphate-P	< 1.00	mg/L	No acceptable limit set
Sulphate	6.8	mg/L	Aesthetic limit 500 mg/L
Nitrate-N (+ Nitrite-N)	0.47	mg/L	Below 10 mg/L acceptable; objective level below 1.0 mg/L
Chloride	12.0	mg/L	Aesthetic limit 250 mg/L
Fluoride	0.09	mg/L	Values up to 1.2 mg/L desirable; under 1.5 mg/L acceptable
Boron	0.26	mg/L	Below 5.0 mg/L acceptable
Carbonate	< 0.1	mg/L	Presence indicates alkaline water
Bicarbonate	105.0	mg/L	High level indicates moderately alkaline water
Hardness (CaCO3 equiv)	76.0	mg/L	Soft waters are less than 75mg/L; hard waters are above 150 mg/l

APPROVED BY: [signature]
Randy Neumann B.Sc.
Laboratory Manager

Results quoted as zero indicate concentrations below the following detection limits:
Less than 0.01 mg/l Fe, Cu, Zn, Mn, B
Less than 0.05 mg/l Na, Ca, Mg, K, PO4-P, NH4-N, NO3-N
Less than 0.10 mg/l Cl, Fl, SO4-S
Less than 1 mg/l TDS, TSS, carbonate & bicarbonate

Accredited By: CANADIAN ASSOCIATION OF ENVIRONMENTAL ANALYTICAL LABORATORIES
For specific tests registered with the Association

APPENDIX B

Ramey and Gringarten Pumping Test Analysis*

If a well intersects a single vertical fracture, the aquifer's unsteady drawdown response to pumping differs significantly from that predicted by the Theis solution. This well flow problem has long been the a subject of research in the petroleum industry, especially with the discovery that when an oil well is artificially fractured (hydraulic fracturing) its yield can be raised substantially. Various solution models have been proposed, but major steps forward were taken when the fracture was assumed to be a plane, vertical fracture of relatively short length and infinite hydraulic conductivity. This made it possible to analyze the system as an 'equivalent', anisotropic, homogeneous, porous medium, with a single fracture of high permeability intersected by the pumped well.

The concept underlying the analytical solutions is as follows: The aquifer is homogeneous, isotropic, and of large lateral extent, and is bounded above and below by impermeable beds. A single plane, vertical `fracture of relatively short length dissects the aquifer. The pumped well intersects the fracture midway. The fracture is assumed to have an infinite (or very large) hydraulic conductivity. This means that the drawdown in the fracture is uniform over its entire length at any instant in time (i.e. there is no hydraulic gradient inside the fracture). This uniform drawdown induces a flow from the aquifer into the fracture. At early pumping times, the flow is one dimensional (i.e. it is horizontal, parallel, and perpendicular to the fracture). All along the fracture, a uniform flux condition is assumed to exist (i.e. water from the aquifer enters the fracture at the same rate per unit area). As pumping continues, the flow pattern changes from parallel flow to pseudo-radial flow, regardless of the fracture's hydraulic conductivity. During this period, most of the well's discharge originates from areas farther removed from the fracture.

For a well intersecting a non-plane vertical fracture in a homogeneous, isotropic, confined aquifer, Ramey and Gringarten developed a method that takes the storage effects of the fracture into account. Their equation reads

$$S_w = \frac{Q}{4\pi T} \; F(u_{vf}, C'_{vf})$$

where

$$C'_{vf} = \frac{C_{vf}}{Sx_f^2}$$

$$Sx_f^2 = \frac{T\,t}{u_{vf}}$$

*Taken from an excerpt in Kruseman, G.P. and deRidder N.A. 1991. Analysis and Evaluation of Pumping Test Data.

C_{vf} = a storage constant = $\Delta V/s_w$ = ratio of change in volume of water in the well plus vertical fracture, and the corresponding drawdown (m^2).

In practice the apparent storage effect C_{vf}, is due to not only to the total volume of the well, but also the to the pore volume of the fracture.

C'_{vf} is the type curve value for a vertical fracture (0.5)

Sx_f^2 is the storage constant of the fracture (calculated)

$F(u_{vf}, C'_{vf})$ is the drawdown well function constant from the type curve match point (10)

u_{vf} is determined from the match point (10)

T is the transmissivity (calculated)

S_w is the drawdown determined from the match point (4m)

Q is the volume of water during pumping at a constant rate (130.9m^3)

t is the time determined from the match point (2 days)

A family of type curves $F(u_{vf}, C'_{vf})$ versus u_{vf} for different values of C'_{vf} for a vertical fracture, taking into account well-bore storage effects were plotted. Initially the curves follow a straight line of unit slope, indicating the period during which the storage effects prevail. This straight line gradually passes into another straight line with a slope of 0.5, representing the horizontal parallel-flow period. Finally, when using semi-log paper, a straight -line segment also appears, which corresponds to the period of pseudo-radial flow. The slope of this line is 1.15.

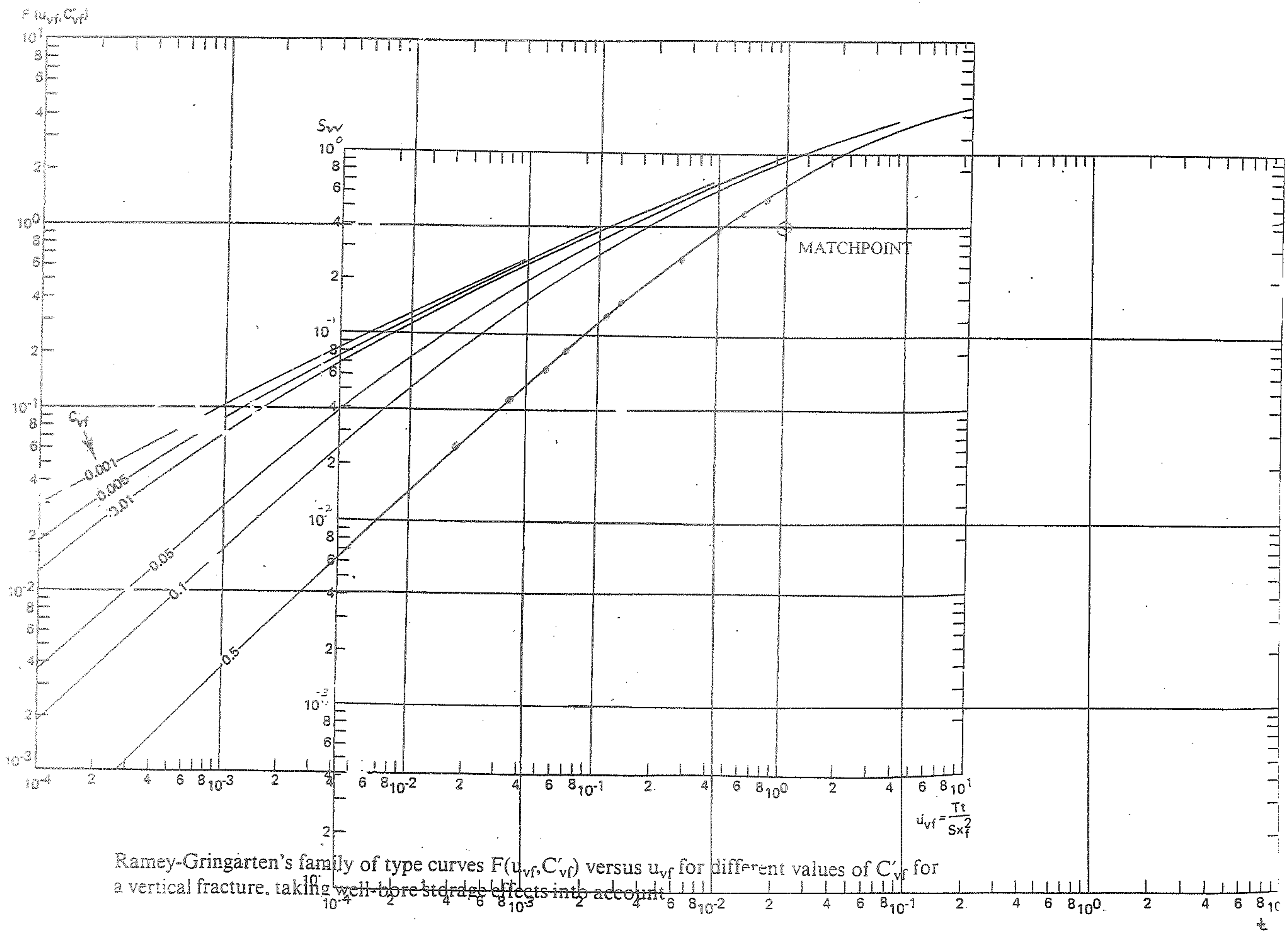
Plotting S_w versus t on semi log paper, the data curve is matched with one of the type curves. The value for C'_{vf} and the values for $F(u_{vf}, C'_{vf})$, u_{vf}, S_w ,and t are noted. The values are then substituted into the equations as follows.

Rearranging and substituting

$T = \frac{130.9\ m^3}{4\pi\ 4m}(10)$ **$T = 26.03\ m^2/day$**

$Sx_f^2 = \frac{26.3\ (2)}{10}$ **$Sx_f^2 = 5.206$**

$C_{vf} = 0.5\ (5.206\ m^2)$ **$C_{vf} = 2.6\ m^2$**



Ramey-Gringarten's family of type curves $F(u_{vf}, C'_{vf})$ versus u_{vf} for different values of C'_{vf} for a vertical fracture, taking well-bore storage effects into account