Delineation of Hydrogeological Units in the Lower Dungeness River Basin, Clallam County, Washington

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 95-4008

Prepared in cooperation with
CLALLAM COUNTY DEPARTMENT
OF COMMUNITY DEVELOPMENT

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Tacoma, Washington
1996

U.S. DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06308	liter per second

degree Fahrenheit (^oF) $^oC = 5/9 \times (^oF-32)$ degree Celsius

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ABSTRACT

Increased stress on the ground-water and surface-water systems due to increased population and changes in land use in the lower Dungeness River Basin area of Clallam County, Washington, has caused concern about ground-water and surface-water availability and water-quality degradation. Thus, a series of hydrogeologic sections was constructed in an attempt to delineate sources of ground water.

Five hydrogeologic sections were completed that delineate three aquifer units and two semiconfining to confining units, contained within the unconsolidated Quaternary deposits. The general thicknesses, as interpreted from the sections, of the water-table, upper confined, and lower confined aquifer units are about 120, 80, and 100 feet, respectively. Thicknesses of the upper and lower semiconfining to confining units are about 50 and 80 feet, respectively. Specific capacities per foot of open interval for the three aquifer units ranged from 0.0007 to more than 75 gallons per minute per foot of drawdown. The potential for additional deeper aquifer units exists in the northern and northeastern parts of the study area where the unconsolidated deposits are thickest.

The bedrock is not a significant source of water, although in the southern and southwestern parts of the study area, where the unconsolidated deposits are thin, bedrock may be the only source of ground water.

INTRODUCTION

Some of the oldest developed areas in western Washington are in Clallam County, but in the mid 1960's land use in the county began shifting from agriculture to residential, resulting in population increases beginning in the 1970's and continuing into the 1990's. The demand for more water because of these changes has led to stresses in the ground-water and surface-water systems. In order to better manage the ground-water resources of the lower Dungeness River Basin of Clallam County, county health and planning officials would like a better understanding of the aquifers currently being utilized in that area.

Purpose and Scope

To provide county planners with information needed to effect ground-water quality protection and to guide further growth in the lower Dungeness River Basin, the U.S. Geological Survey completed a study to verify, refine, and expand the knowledge of the extent, thickness, and lithologic characteristics of that area's aquifers. The study was completed in cooperation with the Clallam County Department of Community Development.

A ground-water investigation of the lower Dungeness River Basin in the late 1970's (Drost, 1983) resulted in a series of maps depicting unit tops, thickness of units, and one hydrogeologic section oriented north-south that depicts the number and stratigraphic locations of aquifers tapped by wells at that time. Since that time, many new wells have been drilled in the area. Some of the new wells have been drilled to greater depths than was common in the late 1970's, and some new wells are located in geographic areas that were largely undeveloped at the time of the earlier study. This report presents the five hydrogeologic sections constructed from selected wells from the earlier study and newer wells inventoried specifically for this study to refine and expand our previous understanding of the thickness and extent of the aquifers in the lower Dungeness River Basin.

Description of the Study Area

The lower Dungeness River Basin study area covers approximately 125 mi^2 on the north-central coast of the Olympic Peninsula in Washington. The study area is bounded on the north by the Strait of Juan de Fuca, on the east by Sequim Bay, on the west near Bagley Creek, and on the south by Lost and Round Mountains and Burnt Hill, which are part of the foothills of the Olympic Mountains. Land-surface altitudes in the study area range from near sea level in the north and east to more than 2,500 feet in the southeast.

The study area has a temperate marine climate with warm, dry summers and cool, wet winters; the mean annual temperature is 49^{o}F. The coolest month of the year is January, with an average temperature of 38^{o}F, and the warmest month of the year is July, with an average temperature of 60^{o}F (Phillips, 1972).

About 75 percent of the precipitation in the area occurs during the winter months of October to March. Although the seasonal distribution of precipitation is similar throughout the area, annual precipitation totals vary due to the altitude of the land surface and the orographic influence of the nearby Olympic Mountains. Precipitation data are not available for the higher altitudes, but at the Sequim weather station the average annual precipitation is 16.32 inches (1917-91; H. H. Bauer, U.S. Geological Survey, written commun., 1994).

The area is transected by several creeks whose headwaters originate within the study area boundaries and by the Dungeness River whose headwaters originate in the Olympic Mountains south of the study area. The predominant use of water in the area is for irrigation; almost all irrigation water is diverted from the Dungeness River. The second greatest use is for public supply (Drost, 1983 and 1986).

Well-Numbering System

Wells in Washington are assigned numbers that identify their location in a township, range, and section. Well number 30N/04W-16D01 indicates, successively, the township (T. 30 N.) and range (R. 04 W.) north and west of the Willamette base line meridian. The first number following the hyphen indicates the section (16) within the township, and the letter following the section number gives the 40-acre subdivision of the section, as shown below (fig. 1). The number (01) following the letter is the sequence number of the well within the 40-acre subdivision.

Acknowledgments

The assistance and cooperation provided by Ann Soule, Clallam County Department of Community Development, and by Welden Clark, member of the Advisory Committee for the Groundwater Protection Project, for access and use of their well data base, is gratefully acknowledged. Steven Gray, Clallam County Department of Community Development, supplied a copy of the surficial geology of Clallam County in a digital format. A special acknowledgment is given to Melanie Cable of the Jamestown S'Klallam Tribe for doing the well inventory. Appreciation is also expressed to the many well owners and to well drillers who supplied information and well records.

METHODS OF INVESTIGATION

This study began with the compilation of existing well information from the data bases of the U.S. Geological Survey and the Clallam County Department of Community Development. Beginning in January 1994, more than 3,000 well records were reviewed; from these records, the wells were selected to be field inventoried. The field inventory process included locating the well in the field; determining the latitude, longitude, and approximate land-surface altitude of the well; compiling, analyzing, and interpreting the information incorporated on the driller's report of the well construction and lithology; then entering the information into a computerized data base.

Well selection was based on geographic location, the availability of a lithologic log, and well depth. From the 101 wells inventoried, 75 wells were selected and used, along with 23 previously inventoried wells, to construct five hydrogeologic sections trending north-south and

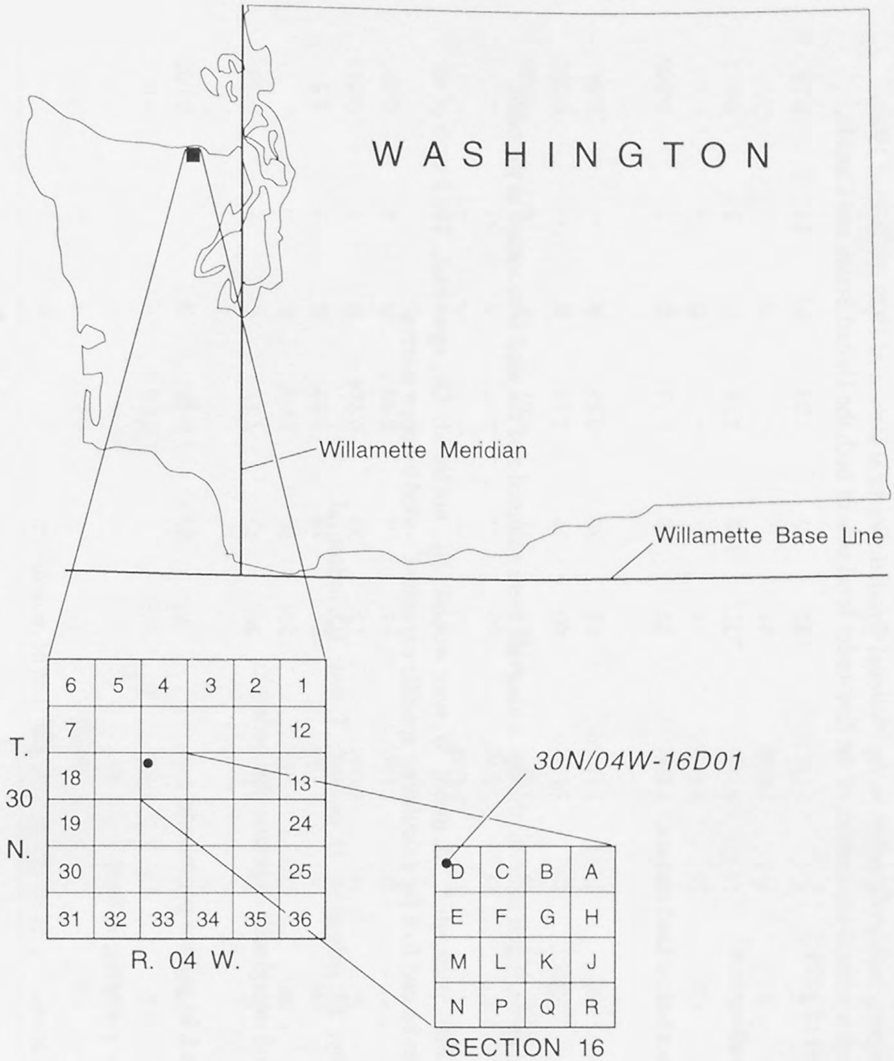

Figure 1.--Well-numbering system used in Washington.

east-west. The sections were used to identify and correlate the continuity of permeable and semiconfining to confining hydrogeologic units present in the study area. Starting at land surface and moving downward through the unconsolidated Quaternary deposits, each hydrogeologic unit (either permeable or semiconfining to confining) was extrapolated laterally to the extent available data would allow. Generally, the thinner the hydrogeologic unit the less certain is its correlation. As illustrated in the hydrogeologic sections, the trend of the surface topography is commonly reflected in the altitude variations of the uppermost units. Thicknesses of the units reported in the text are based on interpretations of the sections.

The locations of the wells and sections are shown on the map. A list of the lithologic logs used to construct the sections and the specific capacities calculated from data supplied by the driller are provided in table 1. The specific-capacity tests generally consist of short-term bailer tests performed by the driller. Information from a map of unconsolidated thickness was used in determining the depth to bedrock for the five sections (Jones, 1996).

Table 1.--*Records of wells used in sections*

EXPLANATION

Land surface datum	Feet above sea level. In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) --a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level of 1929."
Depth of hole	Depth drilled, in feet below land surface.
Depth of well	Depth of completed well, in feet below land surface.
Top of first open interval	Feet below land surface.
Length of open interval	In feet. For wells with more than one open interval, the open intervals were summed and the total is recorded in the table.
Type of open interval	OH, open hole; S, screened; PRF, perforated; M, mesh; W, wire wound; NL, not listed; OE, open end. The length of an open-end interval is assumed to be one foot for calculating specific capacity divided by open interval.
Use of water	D, domestic; PB, public supply; IR, irrigation; U, unused; T, test; ID, industrial.
Aquifer unit number and type	Unc, unconsolidated glacial and interglacial deposits; Br, bedrock.
Yield	Rate at which well was pumped, in gallons per minute.
Drawdown	Lowering of water level due to pumping, in feet.
Specific capacity	The yield divided by the drawdown, in gallons per minute per foot of drawdown.
Type of test	B, bail test; A, air test; P, pump test.
Test duration	In hours.
--	No data.

Table 1.--*Records of wells used in sections--Continued*

Well number	Land surface datum	Depth of hole	Depth of well	Top of first open interval	Length of open interval	Type of open interval	Use of water	Aquifer unit number and type	Yield	Draw-down	Specific capacity	Type of test	Test duration	Specific capacity per foot of open interval
29N/03W-05D01	720	188	188	140	48	OH	D	1Unc/Br	--	--	--	B	1	--
29N/03W-05E01	850	112	112	60	26	OH	D	1 Unc/Br	3	107	0.028	B	--	0.001
29N/04W-03C03	890	446	446	42	404	OH	PB	Br	--	--	--	--	--	--
30N/03W-06M12	130	151	151	145	5	S	D	1 Unc	30	1	30.00	B	--	6.0
30N/03W-06N01	105	165	138	85	47	PRF	D	1Unc	9	80	0.11	B	--	0.002
30N/03W-07C02	100	210	207	202	5	S	D	3 Unc	50	45	1.11	B	1.5	0.22
30N/03W-07D01	102	--	130	--	--	NL	D	1 Unc	20	10	2.00	B	--	--
30N/03W-07M02	95	193	193	193	1	OE	D	3 Unc	25	10	2.50	B	7	2.5
30N/03W-07N07	110	98	98	93	5	S	D	1 Unc	15	70	0.214	B	1	0.043
30N/03W-07Q03	120	116	116	111	5	S	D	1 Unc	14	28	0.50	B	4	0.10
30N/03W-08R02	110	201	201	191	10	S	D	3 Unc	30	--	--	A	2	--
30N/03W-08R03	110	241	239	229	10	S	D	3 Unc	20	--	--	A	>1	--
30N/03W-09R01	100	591	591	548	31	S	IR	5 Unc	195	241	0.81	P	6.25	0.026
30N/03W-15G01	20	574	574	523	46	PRF	D	5 Unc	40	12	3.33	B	--	0.072
30N/03W-16B03	110	113	113	113	1	OE	D	1 Unc	15	28	0.54	B	--	0.54
30N/03W-16C06	115	240	240	234	5	S	D	3 Unc	20	60	0.33	B	2	0.066
30N/03W-17A01	125	157	157	157	1	OE	D	3 Unc	25	--	--	B	--	--
30N/03W-17F02	110	340	340	279	41	S	U	5 Unc	375	145	2.59	P	3	0.063
30N/03W-18A03	115	96	96	91	5	S	D	1 Unc	45	--	--	B	--	--
30N/03W-18G03	135	355	336	279	25	W	T	5 Unc	182	35	5.20	P	14	0.21
30N/03W-18N03	170	134	133	128	5	S	D	1 Unc	25	--	--	A	>1	--
30N/03W-19M02	240	165	165	104	9	PRF	D	1 Unc	30	4	7.50	B	6	0.83
30N/03W-19P01	250	207	207	202	5	PRF	D	3 Unc	20	70	0.29	B	--	0.058
30N/03W-30D01	300	172	172	169	3	M	D	3 Unc	20	65	0.31	B	--	0.10
30N/03W-30D05	290	185	185	180	5	S	PB	3 Unc	50	18	2.78	P	3.25	0.56

Table 1.--*Records of wells used in sections--Continued*

Well number	Land surface datum	Depth of hole	Depth of well	Top of first open interval	Length of open interval	Type of open interval	Use of water	Aquifer unit number and type	Yield	Draw-down	Specific capacity	Type of test	Test duration	Specific capacity per foot of open interval
30N/03W-30K01	400	199	199	35	164	OH	D	Br	4	190	0.02	B	2.5	0.0001
30N/03W-31N01	640	224	200	61	139	OH	D	Br	1	--	--	A	1	--
30N/03W-31R01	662	171	171	171	1	OE	D	3 Unc	8	46	0.17	B	--	0.17
30N/03W-32D04	500	270	270	--	--	NL	U	Br	Dry hole	--	--	--	--	--
30N/03W-32E01	550	118	118	107	11	S	D	1 Unc	80	25	3.20	P	4	0.29
30N/03W-32N01	710	162	139	134	5	S	D	1 Unc	5	--	--	A	1.5	--
30N/03W-32Q01	660	201	201	--	--	NL	D	3 Unc	--	--	--	--	--	--
30N/03W-32R01	644	185	185	135	45	PRF	IR	3 Unc	385	5.5	70.00	P	4	1.6
30N/03W-33N01	640	101	100	76	10	S	D	1 Unc	70	8.25	8.48	P	3	0.85
30N/03W-33N02	620	404	404	50	354	PRF	D	Br	40	186	0.22	B	4	0.0006
30N/03W-35M03	75	460	460	55	405	PRF, OH	D	1 Unc/Br	60	6	10.00	B	2	0.025
30N/04W-01J03	120	141	141	136	5	S	D	1 Unc	20	--	--	B	1.5	--
30N/04W-03H07	80	228	228	223	5	S	U	3 Unc	50	60	0.83	B	1	0.17
30N/04W-03P01	120	188	188	185	3	S	D	3 Unc	8	--	--	B	--	--
30N/04W-03Q01	108	265	249	234	15	S	PB	3 Unc	40	20	2.00	P	--	0.13
30N/04W-07N01	167	284	281	266	15	S	D	3 Unc	8	20	0.40	B	2	0.027
30N/04W-07Q01	180	111	111	111	1	OE	D	1 Unc	10	13	0.77	B	1	0.77
30N/04W-07R02	175	608	468	428	20	S	U	5 Unc	106	111	0.95	P	6.7	0.048
30N/04W-08Q01	170	105	105	95	10	S	D	1 Unc	45	--	--	B	2	--
30N/04W-10C01	110	67	60	56	4	S	D	1 Unc	25	33	0.76	B	--	0.19
30N/04W-10Q02	135	82	82	76	5	S	D	1 Unc	65	12	5.42	B	2	1.1
30N/04W-12R03	120	140	138	133	5	S	D	1 Unc	20	40	0.50	B	--	0.10
30N/04W-13R09	180	89	89	89	1	OE	D	1 Unc	40	--	--	B	--	--
30N/04W-14B01	135	140	140	136	--	S	U	1 Unc	7	--	--	A	2	--
30N/04W-15J02	170	145	144	139	5	S	D	3 Unc	60	30	2.00	B	--	0.40

Table 1.--*Records of wells used in sections--Continued*

Well number	Land surface datum	Depth of hole	Depth of well	Top of first open interval	Length of open interval	Type of open interval	Use of water	Aquifer unit number and type	Yield	Draw-down	Specific capacity	Type of test	Test duration	Specific capacity per foot of open interval
30N/04W-15J03	165	101	101	91	10	S	ID	1 Unc	50	--	--	A	1	--
30N/04W-15R02	170	177	177	159	18	S	PB	3 Unc	120	--	--	A	2	--
30N/04W-16C01	145	80	80	--	--	NL	U	1 Unc	--	--	--	--	--	--
30N/04W-16D01	150	230	230	220	10	S	D	3 Unc	40	35	1.14	B	2	0.11
30N/04W-17D01	200	146	146	--	--	NL	D	1 Unc	--	--	--	--	--	--
30N/04W-20J02	360	220	220	180	40	PRF	U	Br	2.5	--	--	A	1.5	--
30N/04W-20J04	340	125	118	35	83	PRF, OH	D	1 Unc/Br	4	5	0.80	B	30	0.010
30N/04W-20M03	430	165	165	65	100	OH	D	Br	0.5	20	0.03	B	--	0.0003
30N/04W-21K04	365	340	340	340	12	PRF	D	5 Unc	20	6	3.33	B	1	0.28
30N/04W-21L01	326	326	326	321	5	S	D	5 Unc	15	20	0.75	B	5.5	0.15
30N/04W-21L02	365	384	327	322	5	S	D	5 Unc	5	37	0.14	B	6	0.028
30N/04W-21M01	360	210	210	50	160	PRF	D	1 Unc/Br	2	195	0.01	B	--	0.00006
30N/04W-22H01	215	163	163	158	5	S	D	3 Unc	50	46.5	1.08	P	8.5	0.22
30N/04W-22H02	230	298	298	160	12	PRF	PB	3/5 Unc	30	10	3.00	B	2	0.25
30N/04W-22N02	370	416	409	409	1	OE	U	5 Unc	2.75	152	0.02	B	4	0.020
30N/04W-22P01	320	270	270	--	--	PRF	U	1 Unc	2	--	--	B	--	--
30N/04W-24B05	200	95	95	92	3	S	D	1 Unc	30	35	0.86	B	--	0.29
30N/04W-24H04	230	111	111	98	9	PRF	PB	1 Unc	60	--	--	B	1	--
30N/04W-24R01	282	276	276	272	4	M	D	3 Unc	30	60	0.50	B	--	0.12
30N/04W-27A03	320	201	201	201	1	OE	U	1 Unc	12	--	--	B	--	--
30N/04W-27L02	520	152	150	145	5	S	D	1 Unc	6	42	0.14	B	2	0.029
30N/04W-30A01	470	130	90	50	40	PRF	D	1 Unc	3.5	50	0.07	B	--	0.002
30N/04W-34C01	570	110	110	50	40	PRF	D	1 Unc	7	--	--	B	2	--
30N/04W-34E01	645	321	303	--	--	NL	D	Br	Dry hole	--	--	--	--	--
30N/04W-35Q01	420	118	118	118	1	OE	D	1 Unc	24	10	2.40	B	1	2.40

Table 1.--*Records of wells used in sections--Continued*

Well number	Land surface datum	Depth of hole	Depth of well	Top of first open interval	Length of open interval	Type of open interval	Use of water	Aquifer unit number and type	Yield	Draw-down	Specific capacity	Type of test	Test duration	Specific capacity per foot of open interval
30N/04W-35Q02	435	181	181	171	10	S	D	1 Unc	26	--	--	A	2	--
30N/04W-36J02	570	395	395	--	--	NL	U	Br	Dry hole	--	--	--	--	--
30N/04W-36Q01	720	220	220	65	155	OH	D	Br	8	186	0.04	B	1	0.0003
30N/05W-09N01	255	265	261	261	1	OE	D	1 Unc	10	22	0.45	B	2	0.46
30N/05W-10N01	330	361	190	110	76	PRF	D	1 Unc	2.5	44	0.06	P	3	0.0007
30N/05W-11L01	300	251	251	251	1	OE	D	1 Unc	7	8	0.88	B	3	0.88
30N/05W-25A01	615	214	214	209	5	S	PB	1 Unc	10	3	3.33	B	2	0.67
30N/05W-25B02	600	223	221	221	1	OE	D	1 Unc	10	5	2.00	B	1	2.0
30N/05W-25D02	610	154	154	149	5	S	D	1 Unc	5	60	0.08	B	1.5	0.017
30N/05W-26E01	775	250	249	244	5	S	D	1 Unc	15	0	>15	B	2	>3.0
30N/05W-26K01	690	261	261	--	--	NL	U	Unc	Dry hole	--	--	--	--	--
31N/03W-30N02	5	236	235	230	5	S	D	3 Unc	36	27	1.33	B	1	0.27
31N/03W-31L01	19	95	88	88	1	OE	D	1 Unc	75	0	>75	B	1	>75.
31N/04W-34E01	100	108	108	108	1	OE	D	1 Unc	15	7	2.14	B	--	2.1
31N/04W-34G01	125	542	542	--	--	NL	U	3 Unc	--	--	--	--	--	--
31N/04W-34H02	100	122	122	117	5	S	D	1 Unc	10	12	0.83	B	3	0.17
31N/04W-34H03	120	146	146	146	1	OE	D	1 Unc	18	18	1.00	B	--	1.0
31N/04W-35E03	98	279	278	273	5	S	D	3 Unc	20	--	--	A	1	--
31N/04W-35F01	105	134	132	132	1	OE	D	1 Unc	25	7	3.57	B	1.5	3.6
31N/04W-35H01	100	618	616	552	26	S	U	5 Unc	650	69.3	9.38	P	7.5	0.36
31N/04W-35N02	145	416	415	405	10	S	D	5 Unc	7	246	0.03	B	2.5	0.003
31N/04W-36B06	15	97	96	96	1	OE	D	1 Unc	60	--	--	A	1	--
31N/04W-36E03	80	131	130	130	1	OE	D	1 Unc	35	--	--	A	1.5	--

[1] All wells have been field inventoried.

HYDROGEOLOGIC UNITS

An understanding of the lithologic and hydrologic characteristics of the hydrogeologic units that underlie the study area is important to determining the occurrence and availability of ground water there. Approximately 95 percent of the geologic units exposed at the surface consist of unconsolidated glacial and interglacial deposits of Quaternary age (Othberg and Palmer, 1980a, b, and c). The remaining 5 percent is consolidated rocks of Tertiary age.

The consolidated rocks, herein called bedrock, consist of sedimentary and volcanic rocks. The sedimentary rocks consist of marine sandstone, siltstone, mudstone, and conglomerate of the Twin River Group, Aldwell Formation, and Blue Mountain Unit (Tabor and Cady, 1978), and the volcanic rocks are submarine basalt flows and breccias of the Crescent Formation of Tertiary age. Bedrock is exposed in the foothills along the southern and southwestern parts of the study area, and in the valleys along Canyon, McDonald, and Siebert Creeks. Because wells completed in the bedrock yield relatively small quantities of water, the bedrock is considered the base of the ground-water system within the study area. The bedrock usually is overlain by the unconsolidated Quaternary deposits.

The total thickness of the unconsolidated Quaternary deposits ranges from a veneer in areas of bedrock outcrop to more than 2,400 feet. Configuration of the bedrock surface, as shown on sections A-A'-E-E', is based on data from a report by M. A. Jones (in press). The deposits are thinnest in the southern part of the study area (section C2-C2') and thickest in the northeastern part (section B2-B2'). In the western part of the study area, where the altitude of bedrock is high (sections B1-B1' and C1-C1'), incised streams have locally exposed areas of bedrock in their valleys (Othberg and Palmer, 1980a). The bedrock highs shown in sections B1-B1' and C1-C1' may extend farther to the east. An alternate interpretation of well log 30N/04W-22H02 in section D-D' may indicate a higher bedrock altitude, which would extend the bedrock high eastward, but more information is needed to confirm this. The unconsolidated Quaternary deposits increase in thickness to the north and east, as shown in sections B2-B2', D-D', and E-E'. In some areas (parts of sections A-A', B2-B2', and D-D'), however, there is not enough information to extrapolate the thickness of the unconsolidated deposits reliably.

The unconsolidated Quaternary deposits constitute the principal hydrogeologic units in the study area. The lateral extent of those units generally is delineated by the extent of the Vashon Drift deposits from the last glaciation and the younger alluvial deposits (Othberg and Palmer, 1980a, b, and c).

The principal hydrogeologic units consist of 3 aquifer units and 2 semiconfining to confining units, based on the hydraulic properties of 64 of the 98 wells selected for construction of the sections. The aquifer units are the water-table aquifer (unit 1), the upper confined aquifer (unit 3), and the lower confined aquifer (unit 5). The semiconfining to confining units are the upper and lower semiconfining to confining units 2 and 4. The aquifer units consist mostly of coarse-grained sand and gravel deposits of both glacial (advance and recessional outwash deposits) and interglacial (proglacial and coarse-grained fluvial deposits) origin. The semiconfining to confining units consist mostly of fine-grained silt and clay of both glacial (till and glaciomarine) and interglacial (lacustrine and fine-grained fluvial) deposits.

The hydrogeologic units identified in this report do not necessarily correspond to geologic time-stratigraphic deposits identified in previous reports (Noble, 1960, and Sweet-Edwards/EMCON, Inc., 1991). In some parts of the study area, fine-grained glacial deposits directly overlie or underlie fine-grained interglacial deposits and differentiating between them is difficult. Thus, these fine-grained deposits are grouped into a single semiconfining to confining unit. Similarly, where coarse-grained glacial and interglacial deposits are vertically adjacent, they also are grouped into a single aquifer unit.

The water-table aquifer deposits (unit 1) as described by Drost (1983) extend throughout the study area and include at least seven geologic deposits identified by Othberg and Palmer (1980a, b, and c): alluvium, older alluvium, Everson glaciomarine drift, Everson sand, Vashon recessional ice-contact and outwash deposits, Vashon till, and Vashon advance outwash. Because of the complex and discontinuous nature of the surficial deposits and the minimal amount of data available to construct the sections, the water-table aquifer was not separated into individual coarse-grained and fine-grained deposits, and thus contains both coarse- and fine-grained deposits. Where the coarse-grained deposits are extensive and saturated, they form a productive aquifer unit; where the coarse-grained units are thin, they are less productive and in places non-productive. The thickness of the water-table aquifer ranges from about 10 to 360 feet and is generally about 120 feet. On the basis of data from 28 wells finished in unit 1 only (table 1), the specific capacity of the water-table aquifer per foot of open interval ranges from 0.0007 to more than 75 gallons per minute per foot of drawdown, with a median value of 0.60.

The upper semiconfining to confining unit (unit 2) underlies the water-table aquifer. This unit is generally thought to correspond to the pre-Vashon fine-grained, interglacial and proglacial silt and clay deposits. Locally this unit contains some thin, discontinuous lenses of peat and water-bearing sand. This unit is exposed in the study area along coastal bluffs and in incised valleys (Othberg and Palmer, 1980a, b, and c). The thickness of this unit, where present, ranges from 5 to more than 175 feet and is generally about 80 feet (sections A-A' through E-E').

The upper confined aquifer (unit 3) underlies the semiconfining to confining unit and is generally thought to correspond to pre-Vashon outwash deposits. It is composed of sand, sand-and-gravel lenses, and some thin lenses of silt and clay. The upper confined aquifer is present in only part of the study area; it is generally assumed to be continuous in the northern and northeastern parts where the unconsolidated deposits are thickest. In some areas it may have been removed by erosion; in other areas it has a low permeability and therefore was combined with one of the semiconfining to confining units (sections C1-C1' and D-D'). In the southern and southwestern parts of the study area, where bedrock is at shallow depths, the unit may not be present at all (parts of sections B1-B1', C1-C1', C2-C2', D-D', and E-E') or it is present as small discontinuous lenses (section C2-C2'). The thickness of unit 3, where present, ranges from about 5 to 105 feet and is generally about 50 feet (sections A-A' through E-E'). On the basis of data from 16 wells finished in unit 3 only (table 1), the specific capacity of this aquifer per foot of open interval ranges from 0.027 to 2.5 gallons per minute per foot of drawdown with a median value of 0.17.

The lower semiconfining to confining unit (unit 4) generally underlies unit 3. It is composed largely of till and interbedded clay, silt, and fine-grained sand, but locally contains thin lenses of water-bearing sand. This unit is not exposed in the study area and few wells penetrate it, but its extent is assumed to be similar to that of unit 3. The thickness of unit 4 ranges from 5 to 190 feet and is generally about 100 feet (sections A-A', B1-B1', B2-B2', C1-C1', D-D', and E-E').

The lower confined aquifer (unit 5) underlies the lower semiconfining to confining unit and is generally composed of sand with thin lenses of sand and gravel, silt, and clay. Little is known about this unit because few wells are completed in it. Therefore, the unit is assumed to be continuous in the northern and northeastern parts of the study area where the unconsolidated deposits are thick and absent in the southern and southwestern parts of the study area where the unconsolidated deposits are thin. The thickness of the lower confined unit ranges from 10 to 180 feet and is generally about 80 feet (sections A-A', B1-B1', B2-B2', C1-C1', D-D', and E-E'). Based on data from 11 wells completed in unit 5 only (table 1), the specific capacity of this aquifer per foot of open interval ranges from 0.003 to 0.36 gallons per minute per foot of drawdown with a median value of about 0.063.

The unconsolidated deposits that underlie unit 5 are referred to in this report as undifferentiated glacial and non-glacial Quaternary deposits. Because available data are too sparse to adequately identify and correlate the individual units, the extent, thickness, and yield of any potential water-bearing units in this sequence of undifferentiated deposits are largely unknown.

POSSIBLE FURTHER STUDY

The objective of this study was to verify, refine, and expand the knowledge of the extent, thickness, and lithologic characteristics of hydrogeologic units in the study area. This was done with the completion of five hydrogeologic sections that used only the information from the 98 wells described earlier. To further extend the understanding of the ground-water system in the study area, additional wells could be field inventoried and seismic data collected to extend the sections presented in this report and to update and extend the top and thickness maps prepared by Drost (1983). The wells inventoried would include both deep and shallow wells. Data from the deep wells and seismic surveys would help define the water-bearing units at depth and the location of bedrock. Data from the shallow wells would help define the extent of the various subunits that make up unit 1. The information collected from seismic surveys and from additional drilled wells could be used to refine the knowledge of the bedrock surface, especially in areas where it appears to drop off abruptly to the east (sections B1-B1' and C1-C1').

Water levels and water-quality data could be collected and used to construct water-level maps for each aquifer unit, and to describe general water quality in the units. In addition, specific-capacity data for each aquifer unit could be extended beyond what is presented in this report.

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