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Redmond-Bear Creek

Ground Water Management Program

Draft Hydrogeologic Characterization Report

Volume 1

Prepared for
Seattle-King County Health Department
Funded in Part by the
Washington State Department of Ecology

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Project 0121-003.07

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1 INTRODUCTION

1.1 Purpose and Scope

This report summarizes existing and new geologic, hydrogeologic, and ground water quality information for the Redmond-Bear Creek Ground Water Management Area (GWMA) in northern King County, Washington. The purpose of this report is to provide a framework for understanding the geologic and hydrogeologic conditions in the GWMA and to provide information necessary for short- and long-term water resource planning and protection. Information contained in this report was obtained from existing sources and through new data collection activities. Some of the data used in this report was collected by personnel who were not employees of EMCON Northwest. These included personnel of the Seattle-King County Health Department, City of Redmond, Union Hill, and Northeast Lake Sammamish water districts, and members of the Redmond Ground Water Advisory Committee.

The scope of work performed to prepare this report included the following tasks:

- existing data collection and analysis
- an electrical resistivity survey
- design and implementation of a ground water monitoring network
- water level monitoring
- well installation and testing
- water quality sampling and analysis
- stream flow gauging
- precipitation monitoring
- evaluation of data
- preparation of this report documenting findings and conclusions

All new data collection activities are discussed in Section 2 of this report. Section 3 describes the interpreted geologic conditions. Sections 4 and 5 include the hydrogeologic and ground water quality conditions respectively.

1.2 Study Area Description

The Redmond-Bear Creek GWMA is located in north-central King County approximately 20 miles northeast of Seattle, Washington. The GWMA covers approximately 50 square miles. It is bounded on the east by the Sammamish River and on the north by the Snohomish-King County line. The western boundary follows the topographic divide between the Bear Creek and Snohomish River valleys. The southern boundary coincides with the topographic divide between the Evans Creek Valley, the Sahalee Plateau, and Lake Sammamish (Figure 1-1). The Bear Creek Valley bisects the study area north to south, and the Evans Creek Valley bisects the southern tip east to west.

Elevations in the GWMA range from approximately 30 feet above mean sea level in downtown Redmond to just over 600 feet near the Redmond watershed. Surface elevations rise steadily as one proceeds north from the City of Redmond up the Bear Creek Valley gaining approximately 450 feet of elevation. The GWMA contains a number of lakes and streams. The primary streams include Cottage Creek, Daniels Creek, Seidel Creek, Bear Creek, and Evans Creek. The four largest lakes inside the GWMA boundary are Lake Leota, Cottage Lake, Welcome Lake, and Peterson Park.

Figure 2-1 Location of Electrical Resistivity Soundings

Figure 1-1 Redmond-Bear Creek Ground Water Management Area

D

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A

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Figure 2-3 Geophysical Section 2 - Woodinville-Duvall Road

D

R

A

F

T

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D

R

A

F

T

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Figure 2-6 Geophysical Section 5 - NE 208th

D R A F T

Figure 2-7 Location of New Test Wells

D

R

A

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Figure 2-12 Isohyetal Map (July 1990)

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Figure 2-13 Isohyetal Map (October 1990)

D R A F T

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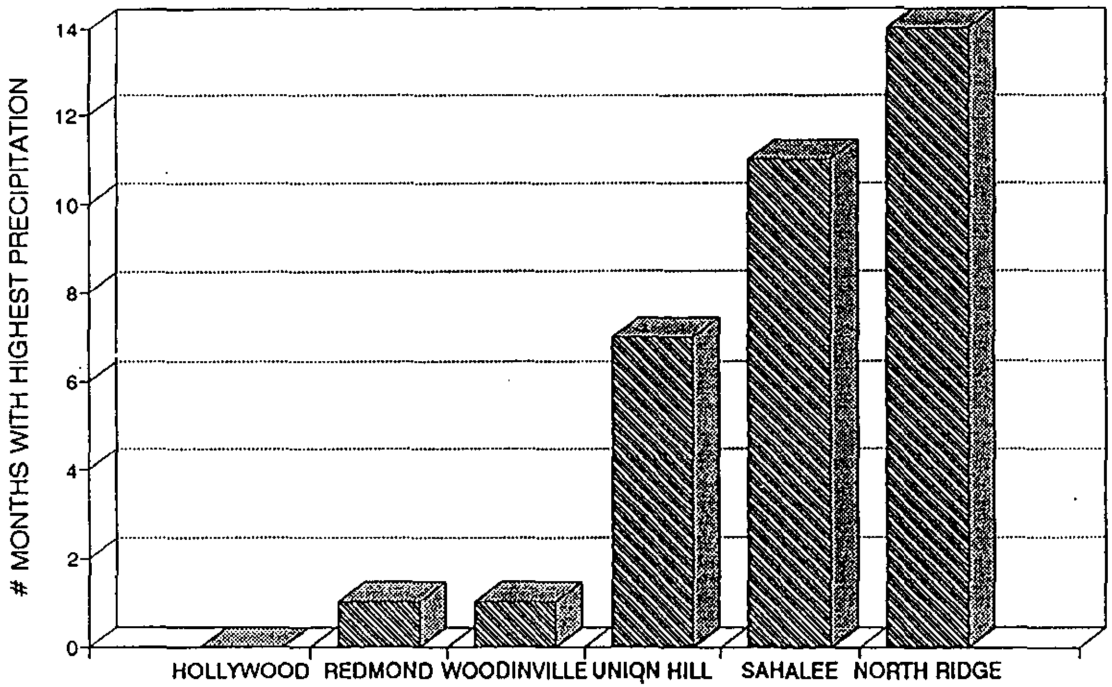

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Figure 2-14
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

FREQUENCY OF HIGHEST PRECIPITATION

Figure 2-15 Location of Stream Gauging Stations

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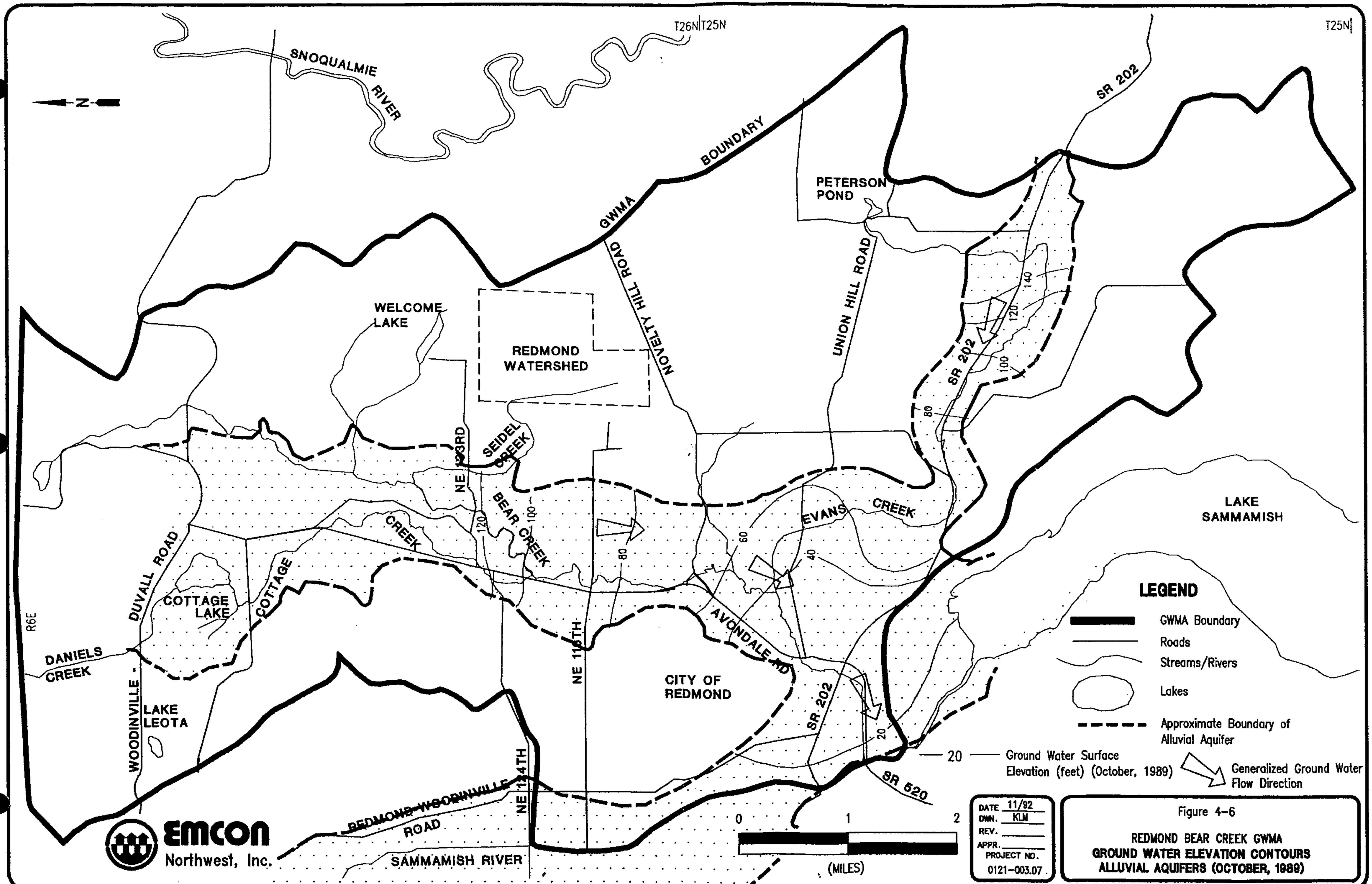

SNOQUALMIE RIVER
T26N T25N
T25N
N
GWMA BOUNDARY
SR 202
PETERSON POND
UNION HILL ROAD
NOVELTY HILL ROAD
WELCOME LAKE
REDMOND WATERSHED
SEIDEL CREEK
NE 133RD
BEAR CREEK
EVANS CREEK
LAKE SAMMAMISH
DUVALL ROAD
COTTAGE LAKE
COTTAGE CREEK
R6E
DANIELS CREEK
WOODINVILLE - DUVALL ROAD
LAKE LEOTA
NE 116TH
NE 124TH
CITY OF REDMOND
AVONDALE RD
SR 202
SR 520
REDMOND-WOODINVILLE ROAD
SAMMAMISH RIVER
140
120
100
80
60
40
20
LEGEND
GWMA Boundary
Roads
Streams/Rivers
Lakes
Approximate Boundary of Alluvial Aquifer
20 Ground Water Surface Elevation (feet) (October, 1989)
Generalized Ground Water Flow Direction
0 1 2
(MILES)
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PROJECT NO. 0121-003.07
Figure 4-6
REDMOND BEAR CREEK GWMA
GROUND WATER ELEVATION CONTOURS
ALLUVIAL AQUIFERS (OCTOBER, 1989)

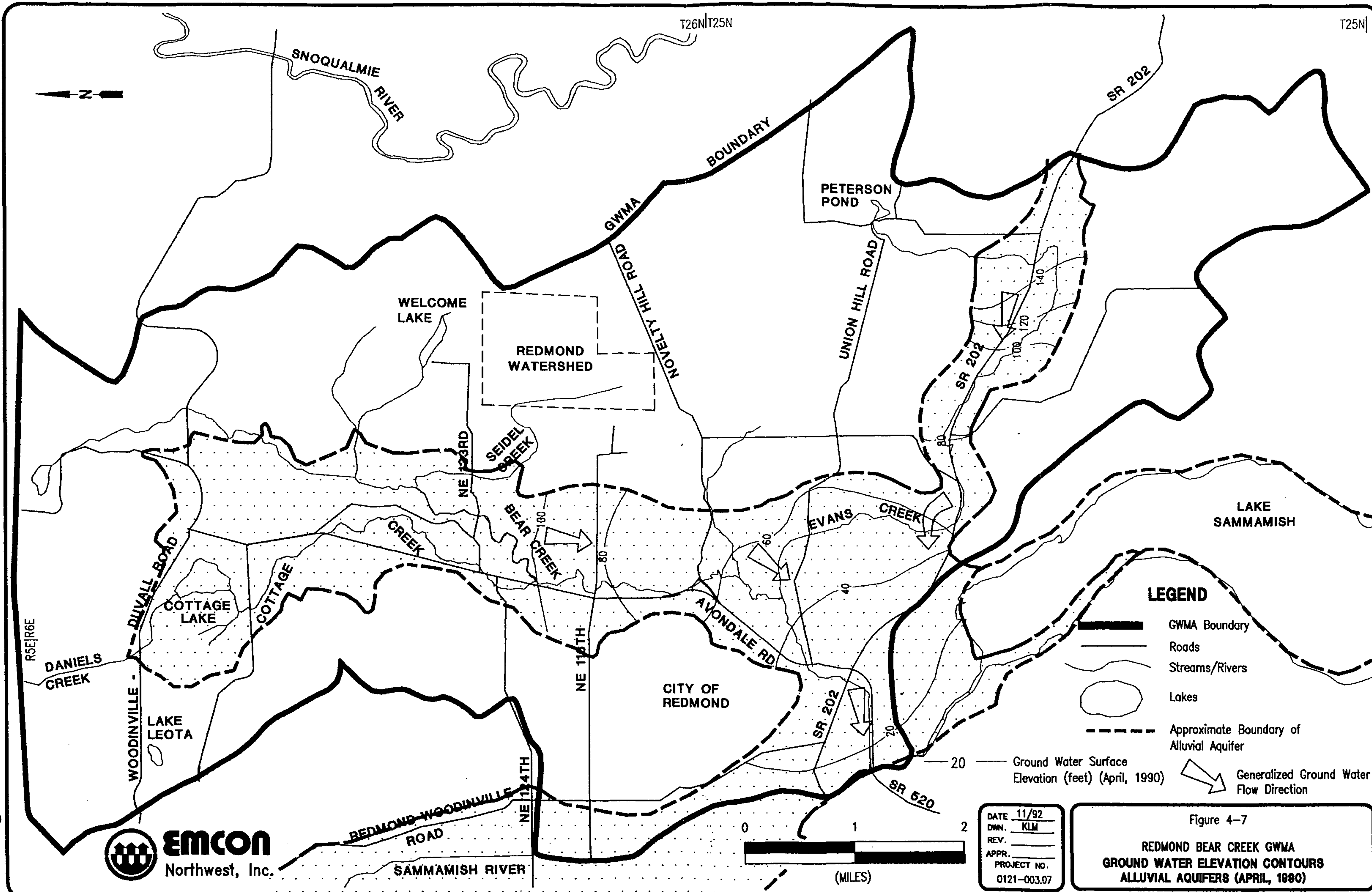

Figure 4-7

REDMOND BEAR CREEK GWMA
GROUND WATER ELEVATION CONTOURS
ALLUVIAL AQUIFERS (APRIL, 1990)

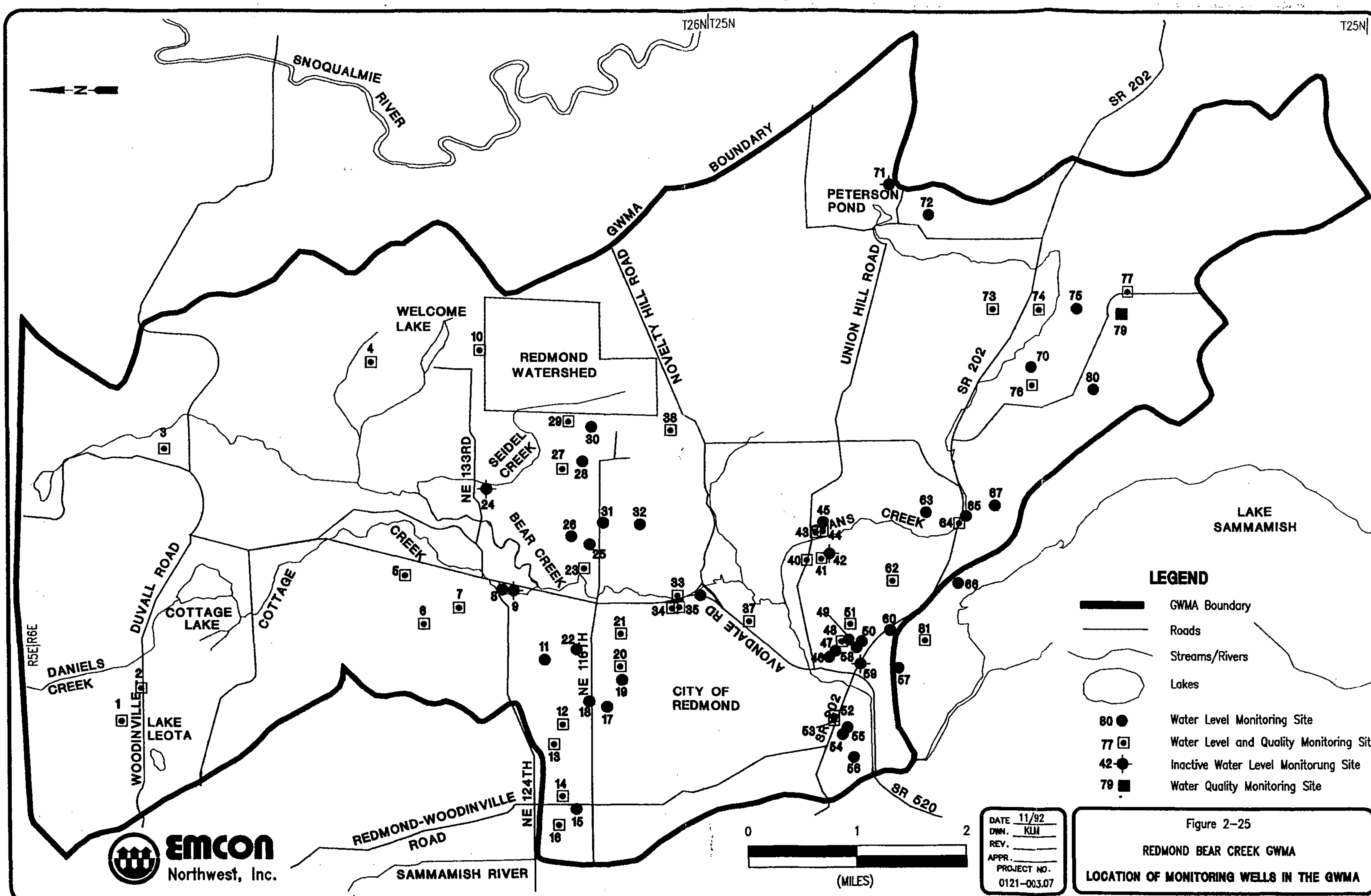

Figure 2–25

REDMOND BEAR CREEK GWMA

LOCATION OF MONITORING WELLS IN THE GWMA

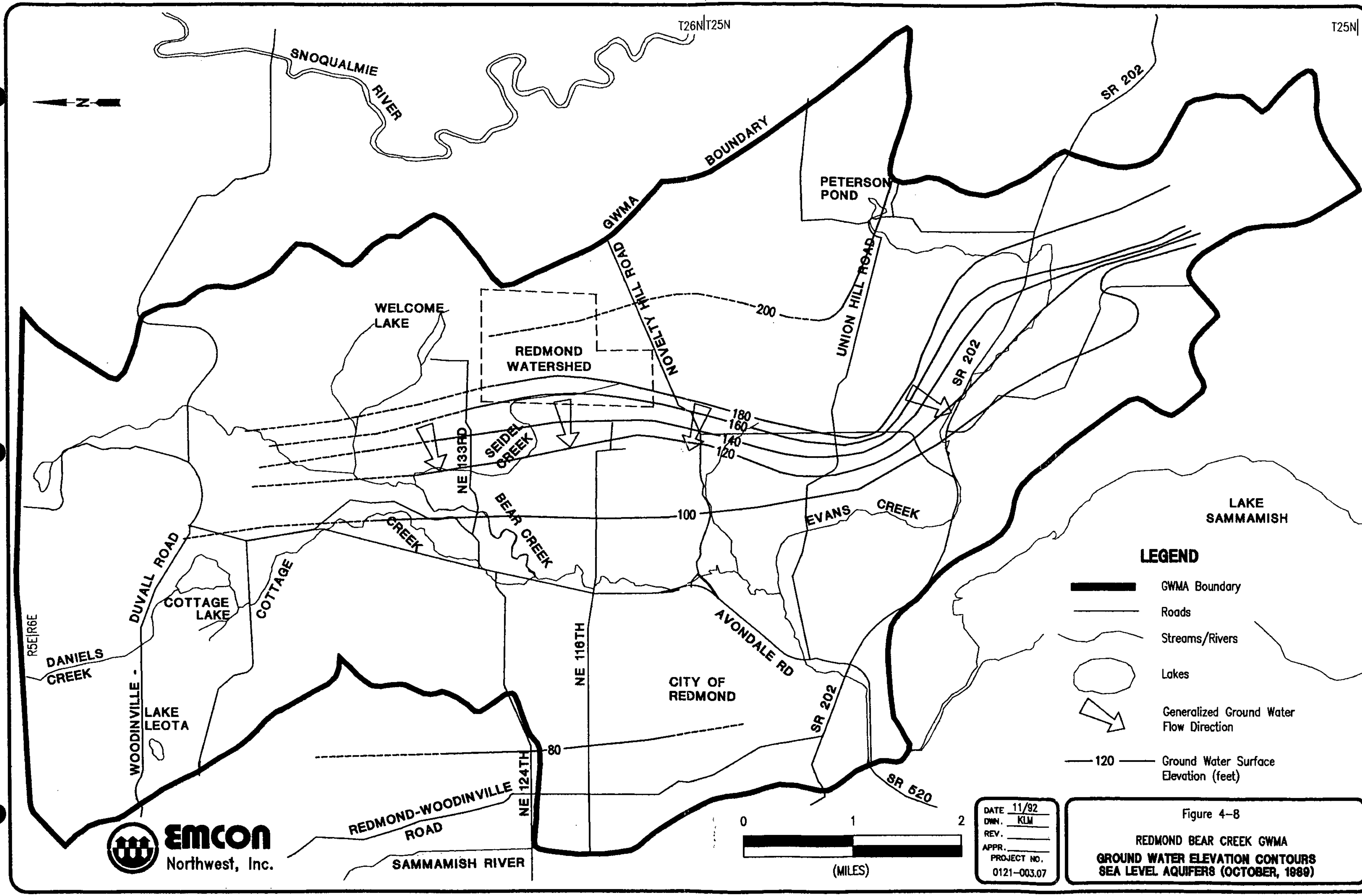

Figure 4-8
REDMOND BEAR CREEK GWMA
GROUND WATER ELEVATION CONTOURS
SEA LEVEL AQUIFERS (OCTOBER, 1989)

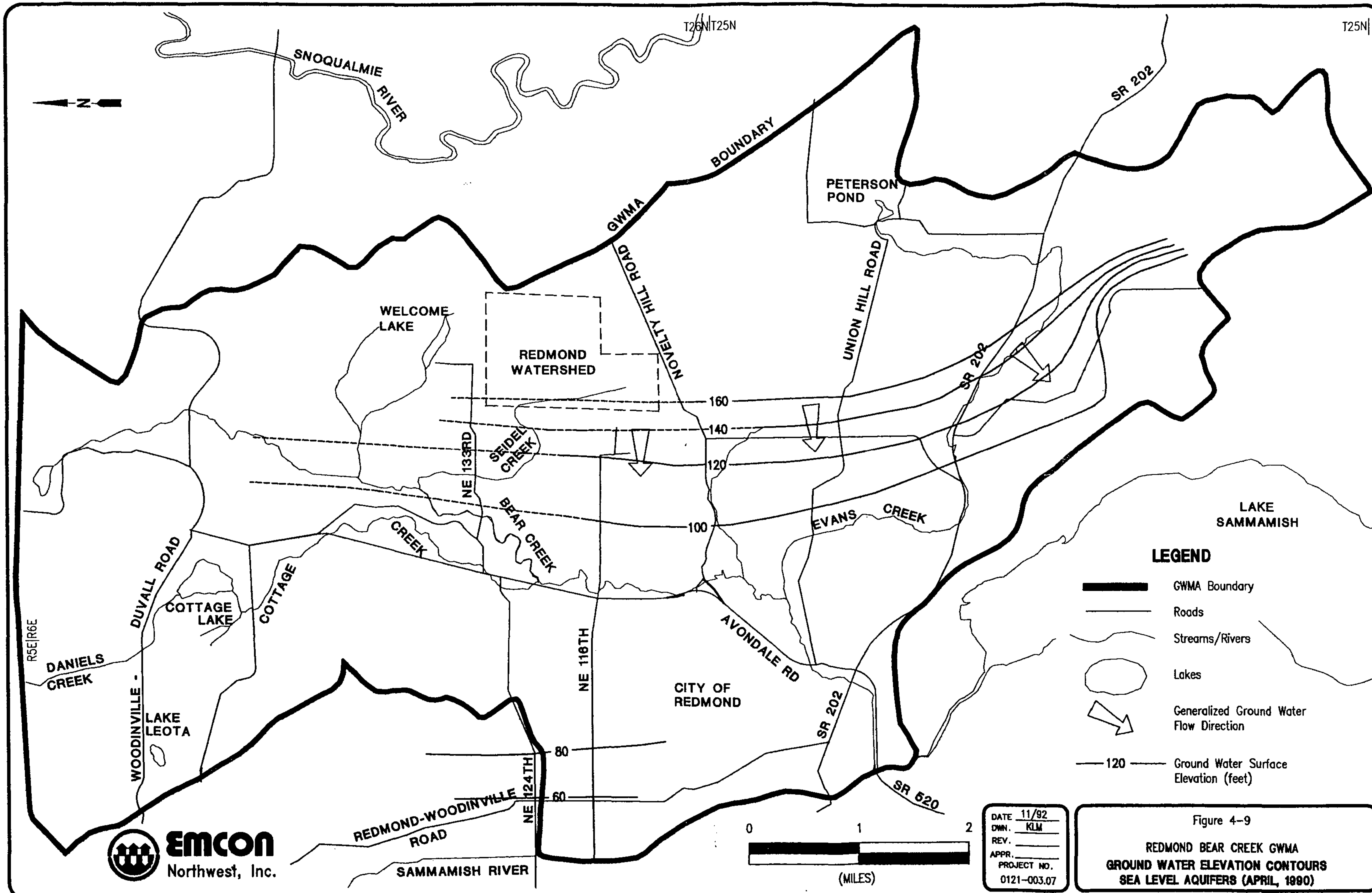

Figure 4-9

REDMOND BEAR CREEK GWMA
GROUND WATER ELEVATION CONTOURS
SEA LEVEL AQUIFERS (APRIL, 1990)

1=4000 11-13-92 0121\003\07C08

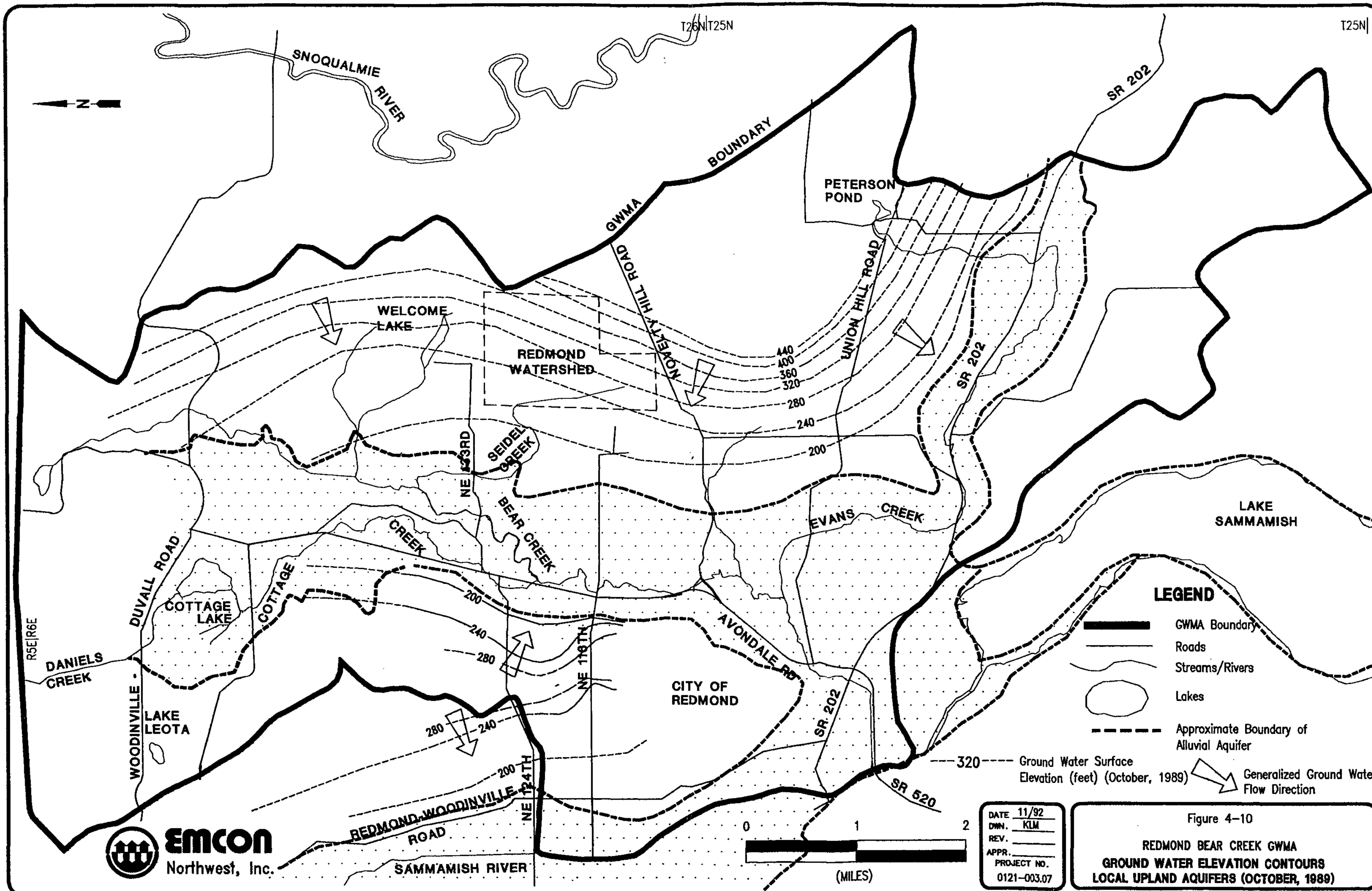

Figure 4-10

REDMOND BEAR CREEK GWMA
GROUND WATER ELEVATION CONTOURS
LOCAL UPLAND AQUIFERS (OCTOBER, 1989)

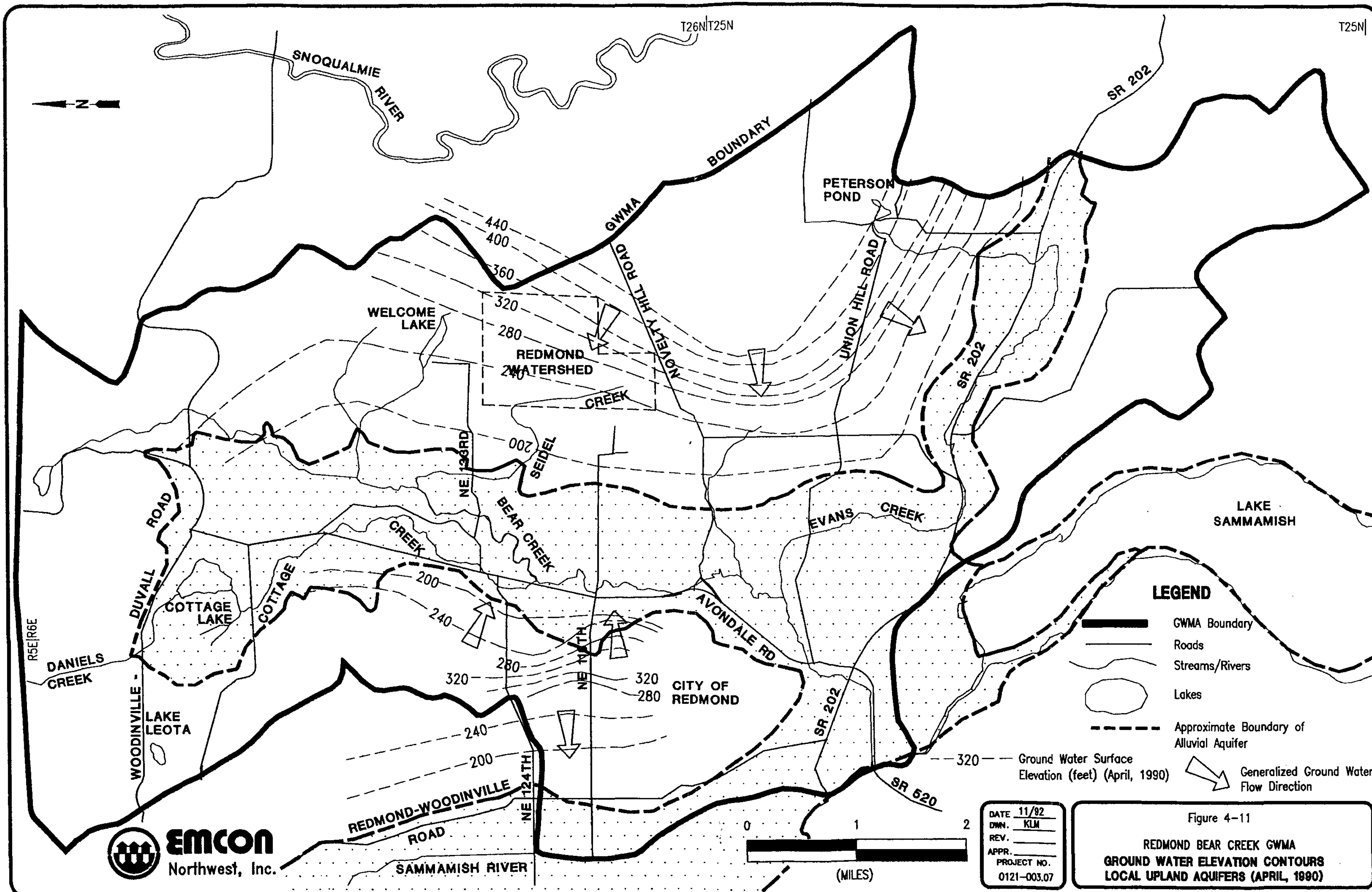

Figure 4-11

REDMOND BEAR CREEK GWMA
GROUND WATER ELEVATION CONTOURS
LOCAL UPLAND AQUIFERS (APRIL, 1990)

1=4000 11-17-92 0121\003\07C11

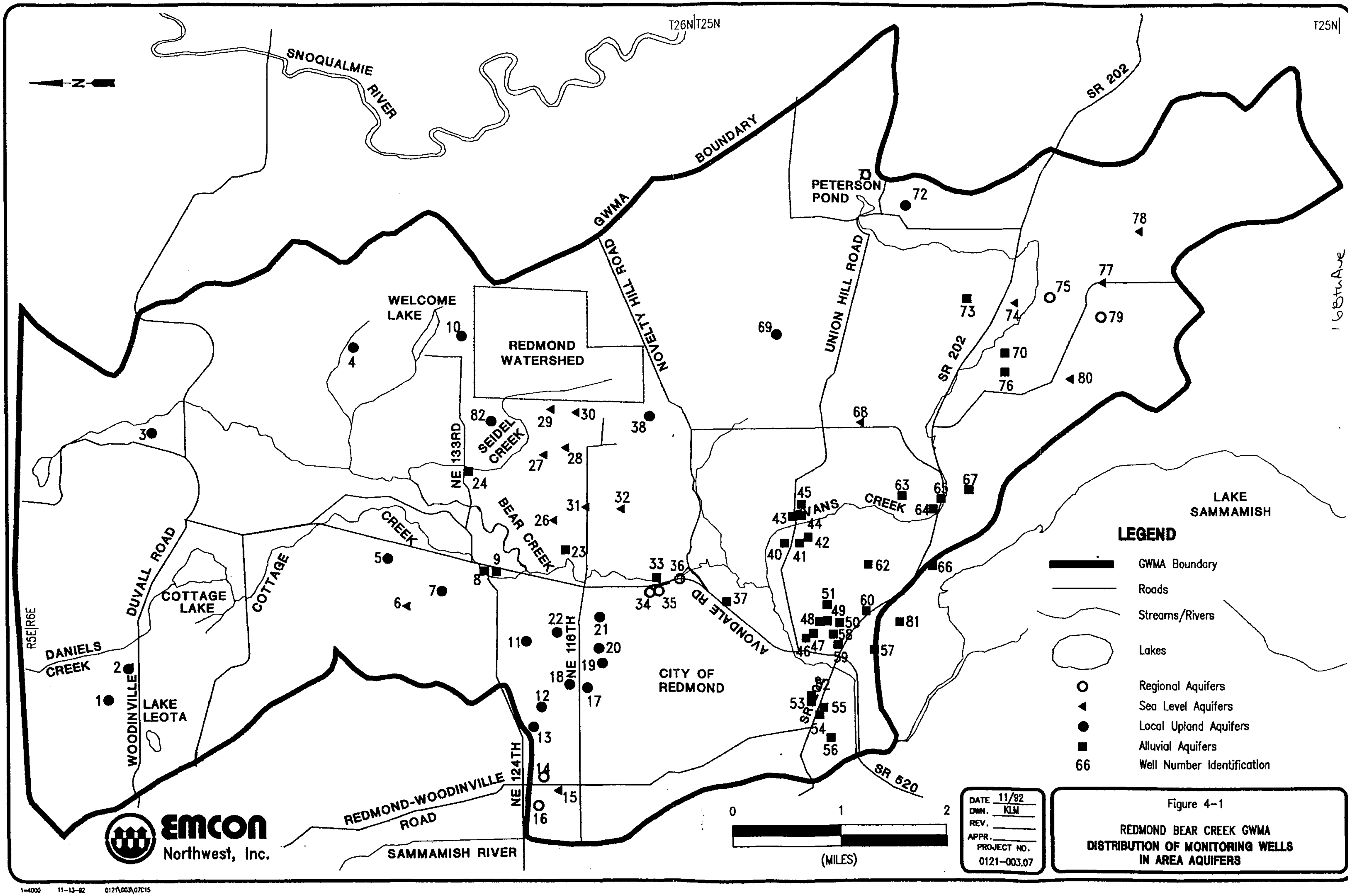

Figure 4-1

REDMOND BEAR CREEK GWMA
DISTRIBUTION OF MONITORING WELLS IN AREA AQUIFERS

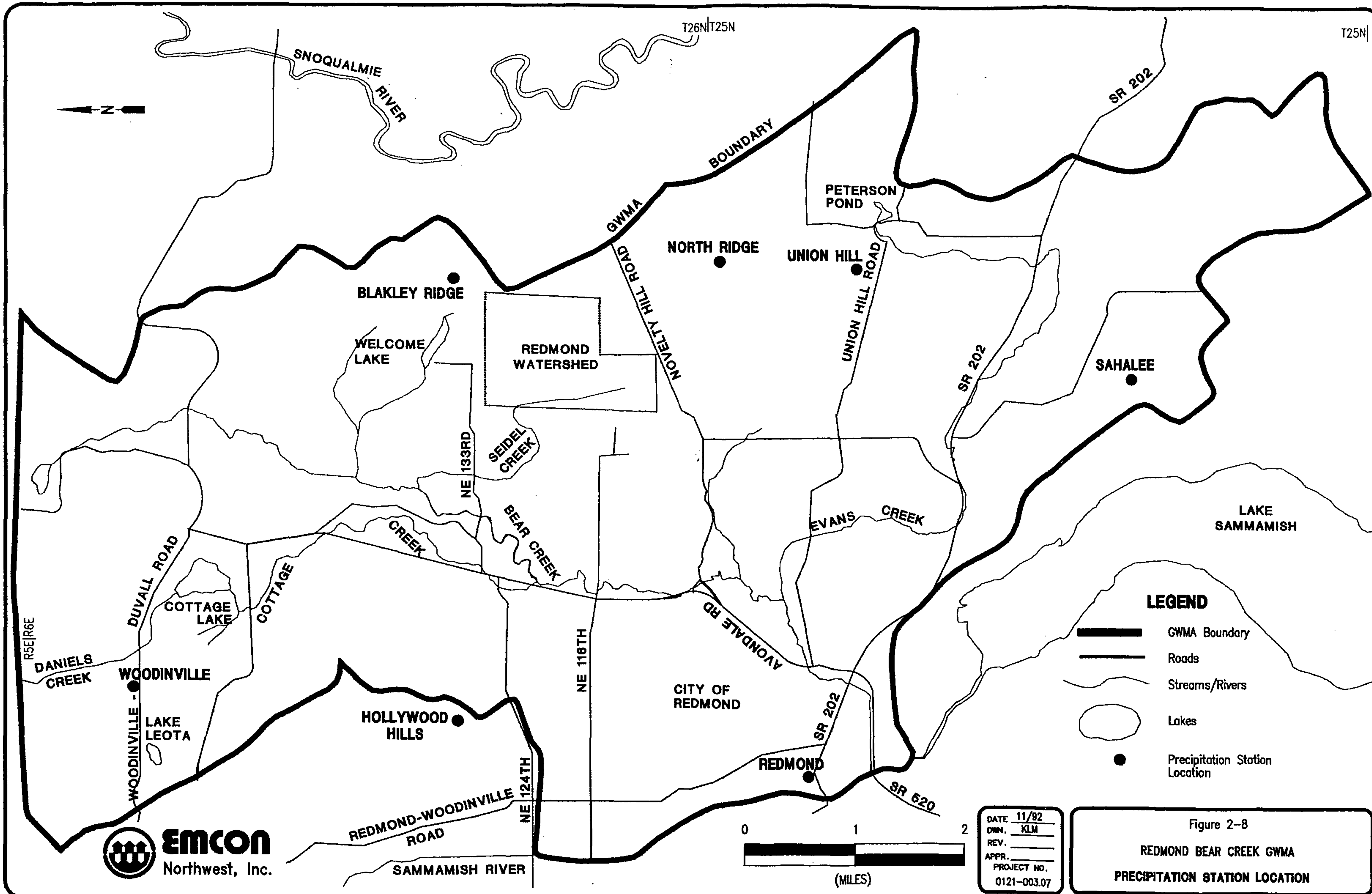

Figure 2-8

REDMOND BEAR CREEK GWMA

PRECIPITATION STATION LOCATION

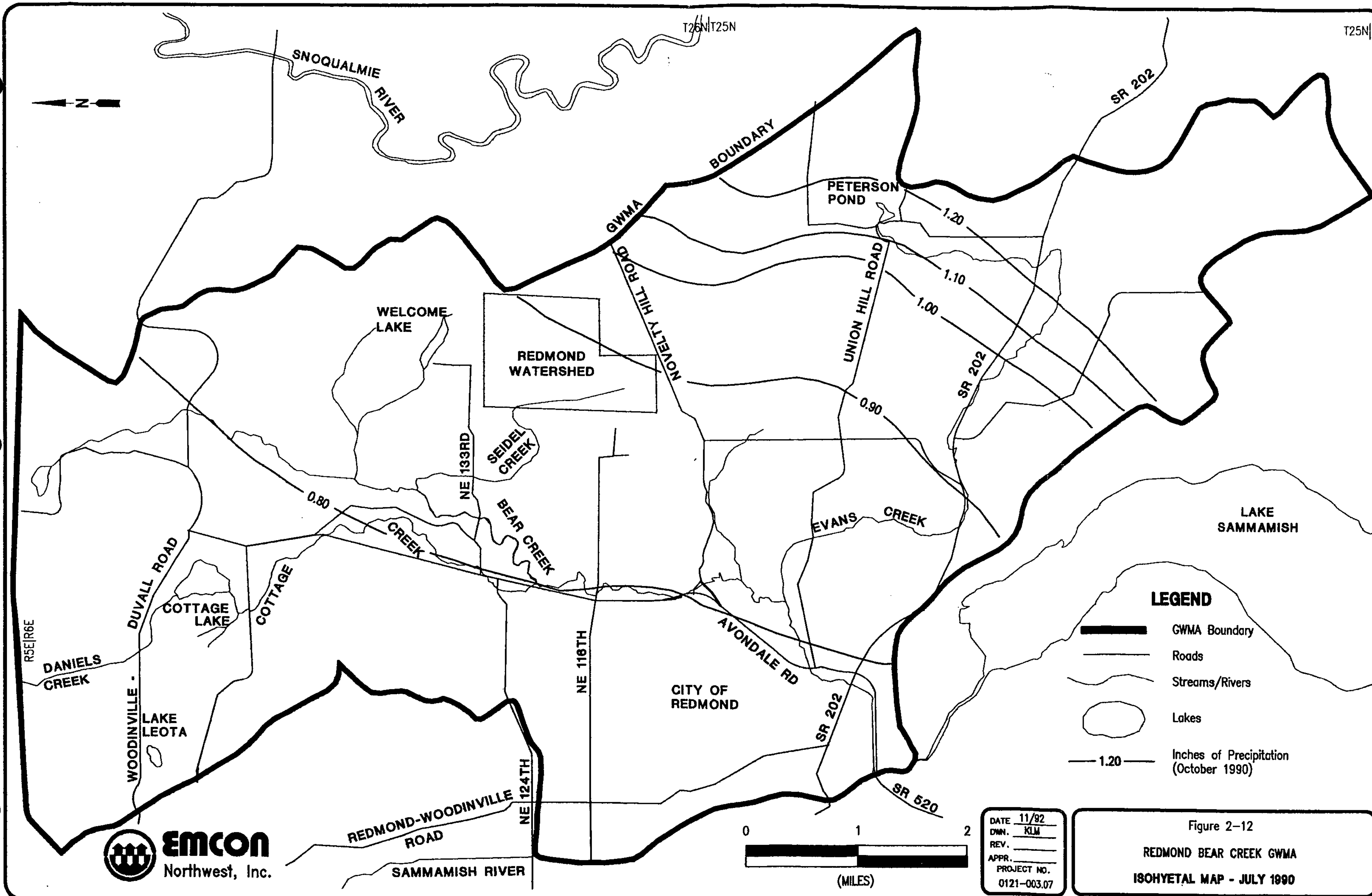

Figure 2-12

REDMOND BEAR CREEK GWMA

ISOHYETAL MAP - JULY 1990

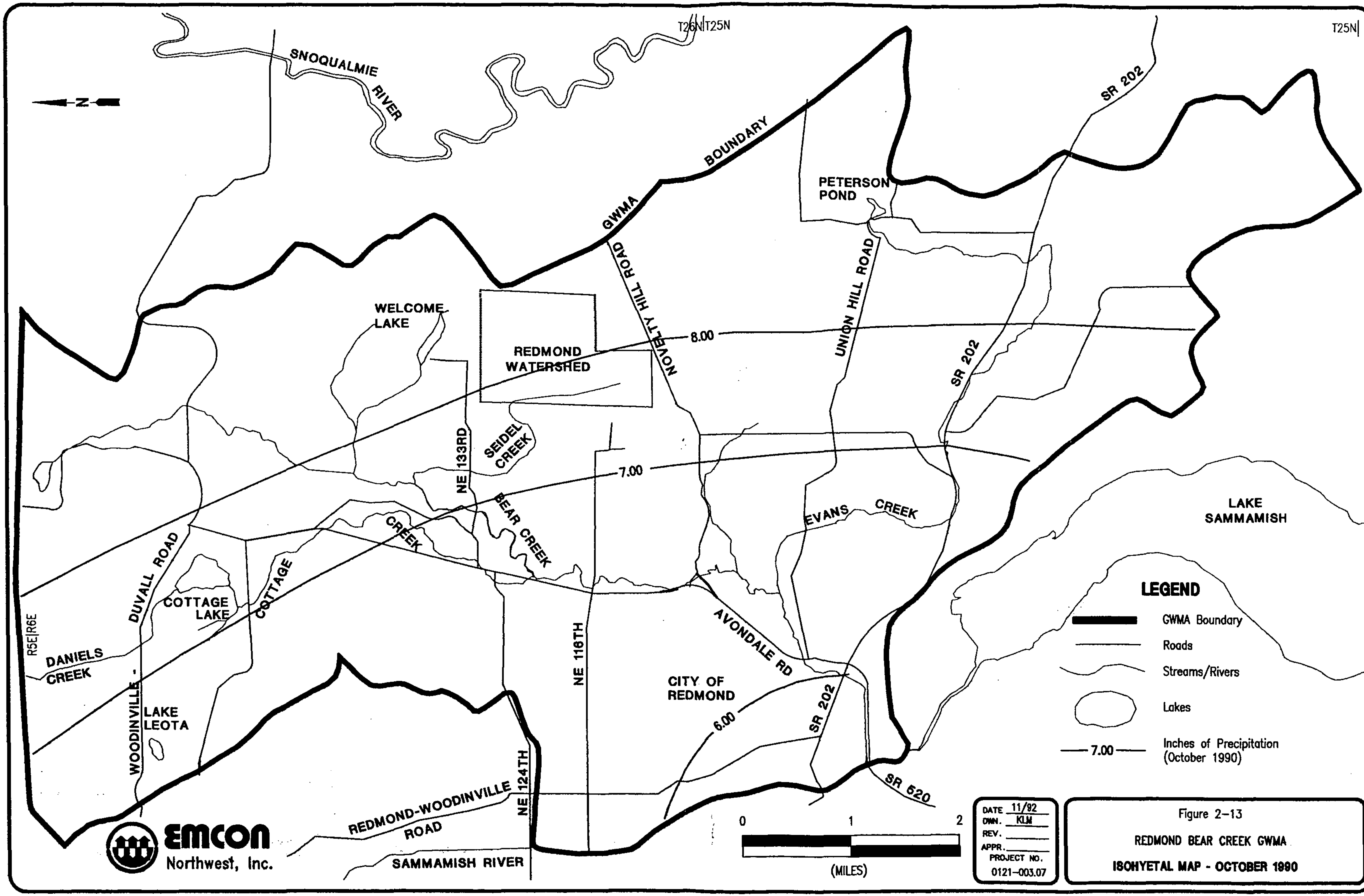

Figure 2-13
REDMOND BEAR CREEK GWMA
ISOHYETAL MAP - OCTOBER 1990

1=4000 11-13-92 0121\003\07C07

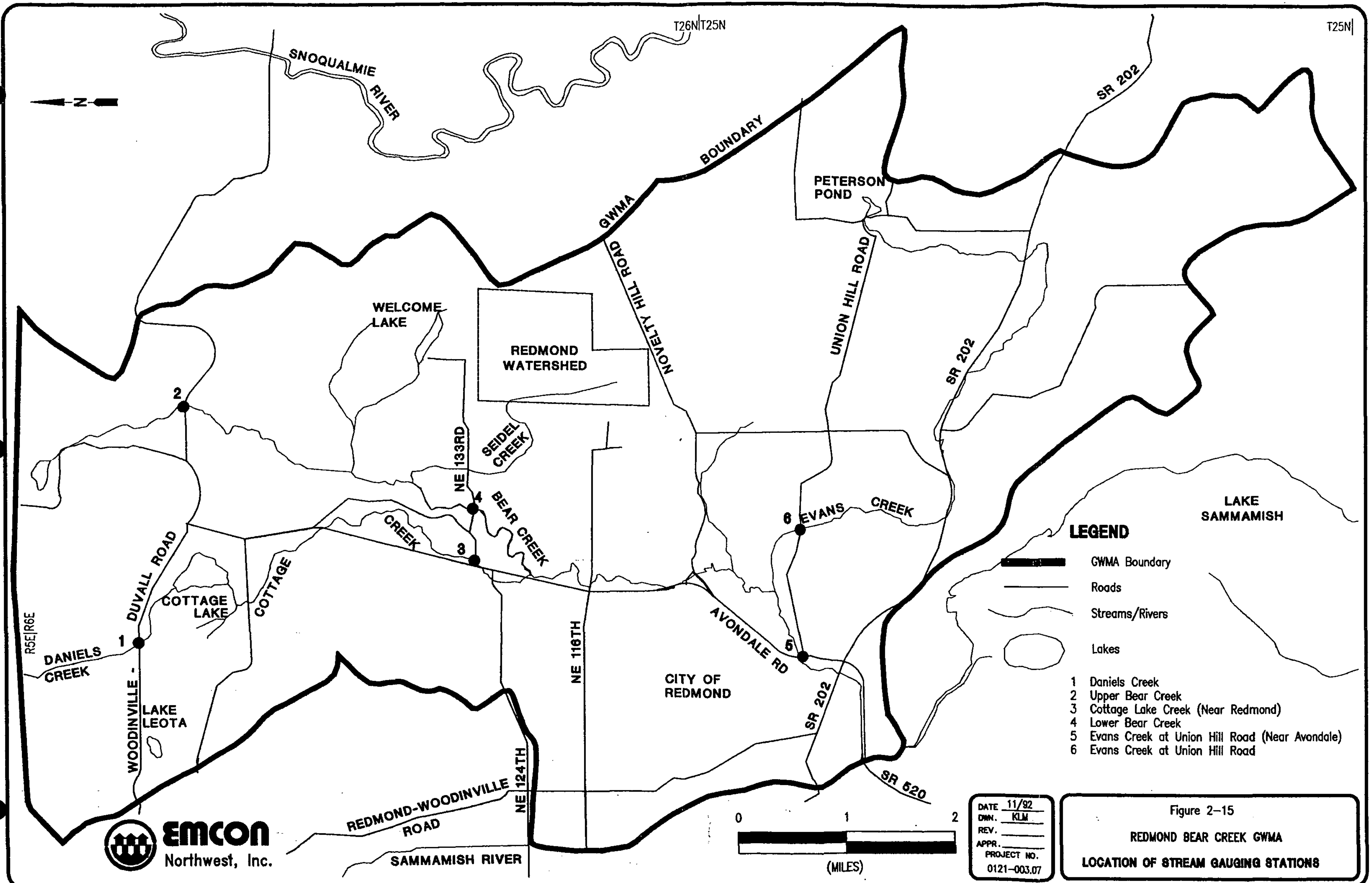

Figure 2-15

REDMOND BEAR CREEK GWMA

LOCATION OF STREAM GAUGING STATIONS

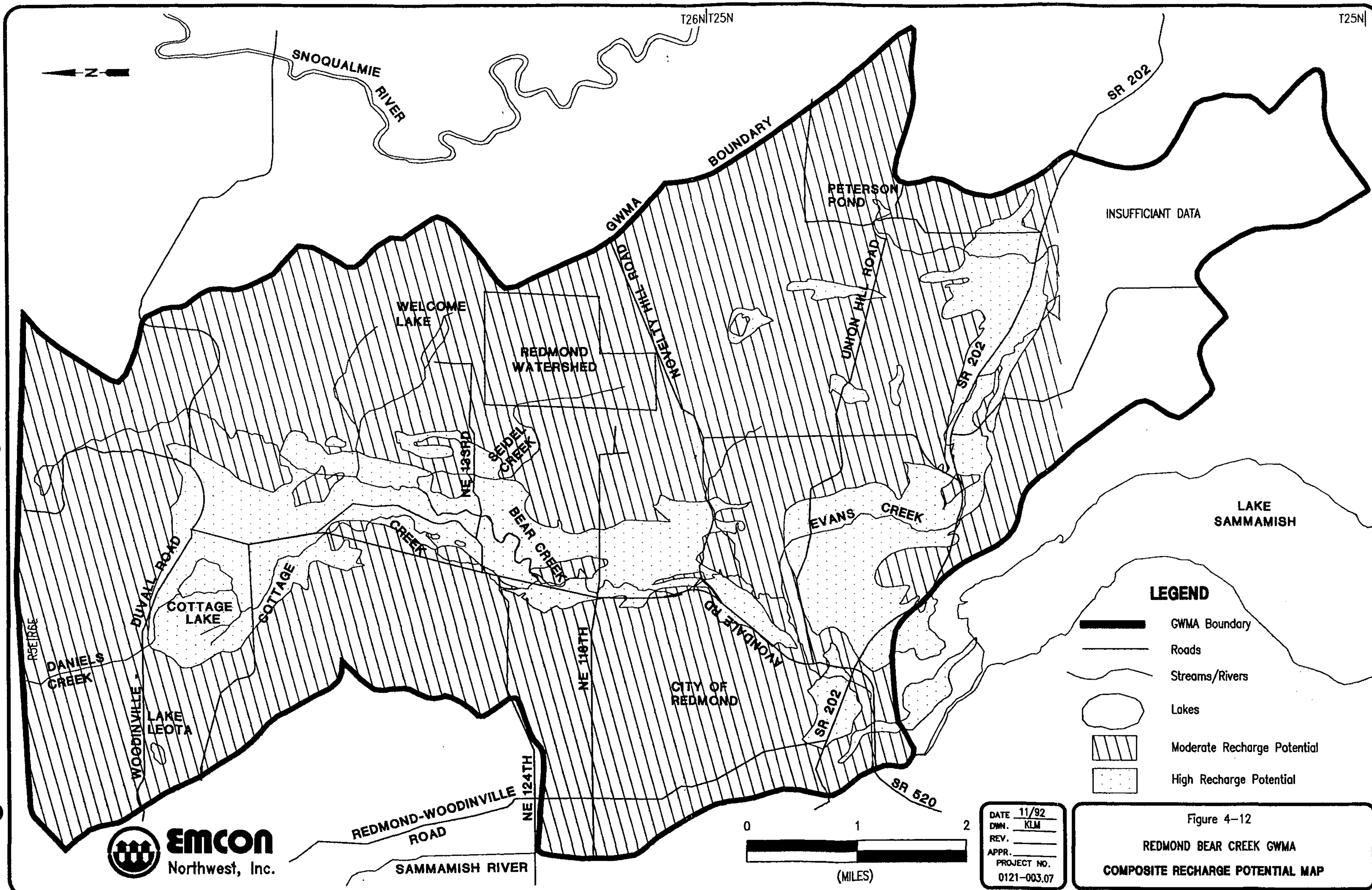

Figure 4–12

REDMOND BEAR CREEK GWMA

COMPOSITE RECHARGE POTENTIAL MAP

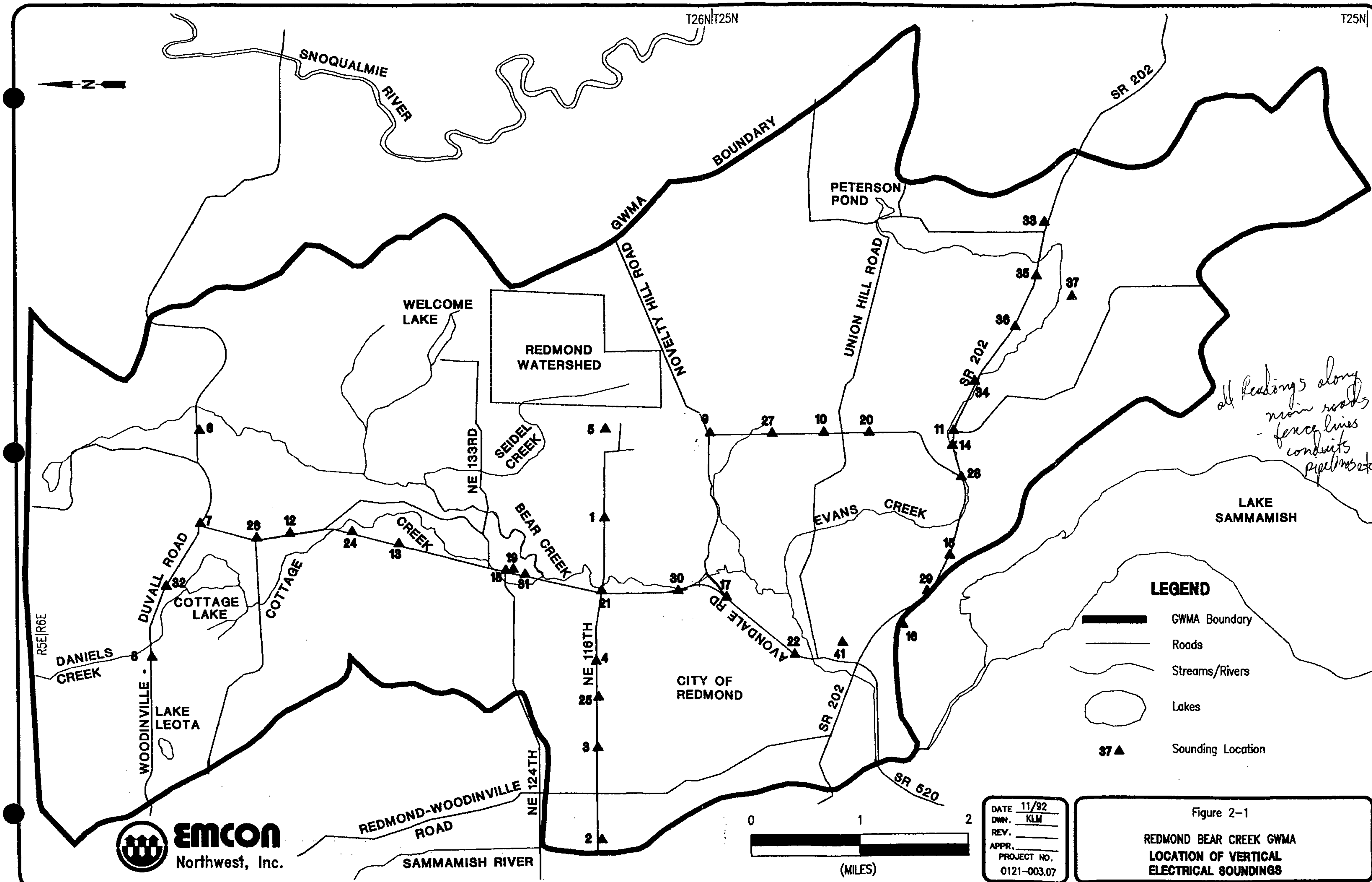

Figure 2-1

REDMOND BEAR CREEK GWMA
LOCATION OF VERTICAL ELECTRICAL SOUNDINGS

1-4000 11-13-92 0121\003\07C16

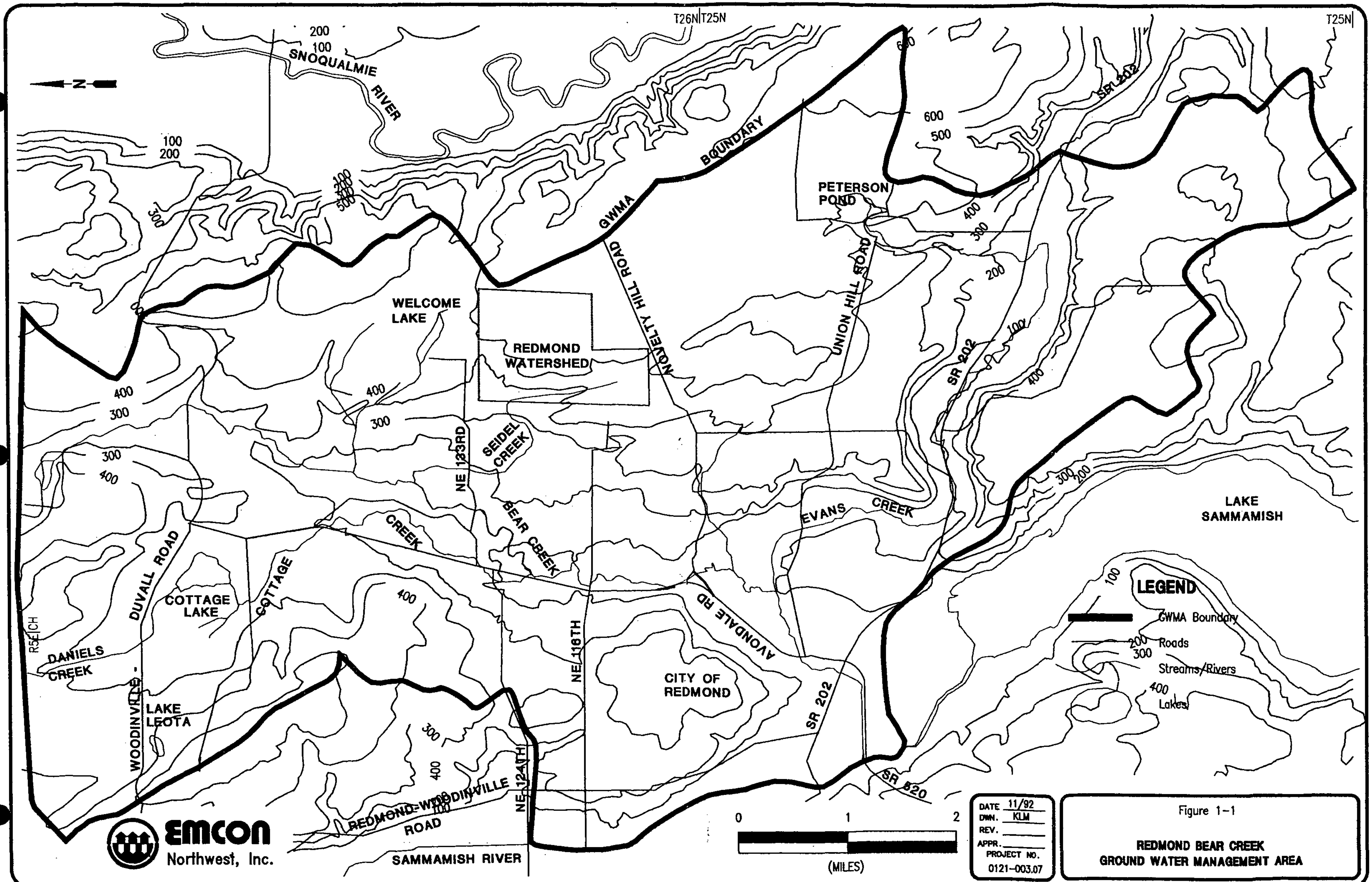

Figure 1-1

REDMOND BEAR CREEK GROUND WATER MANAGEMENT AREA

1-4000 11-17-92 0121\003\07C21

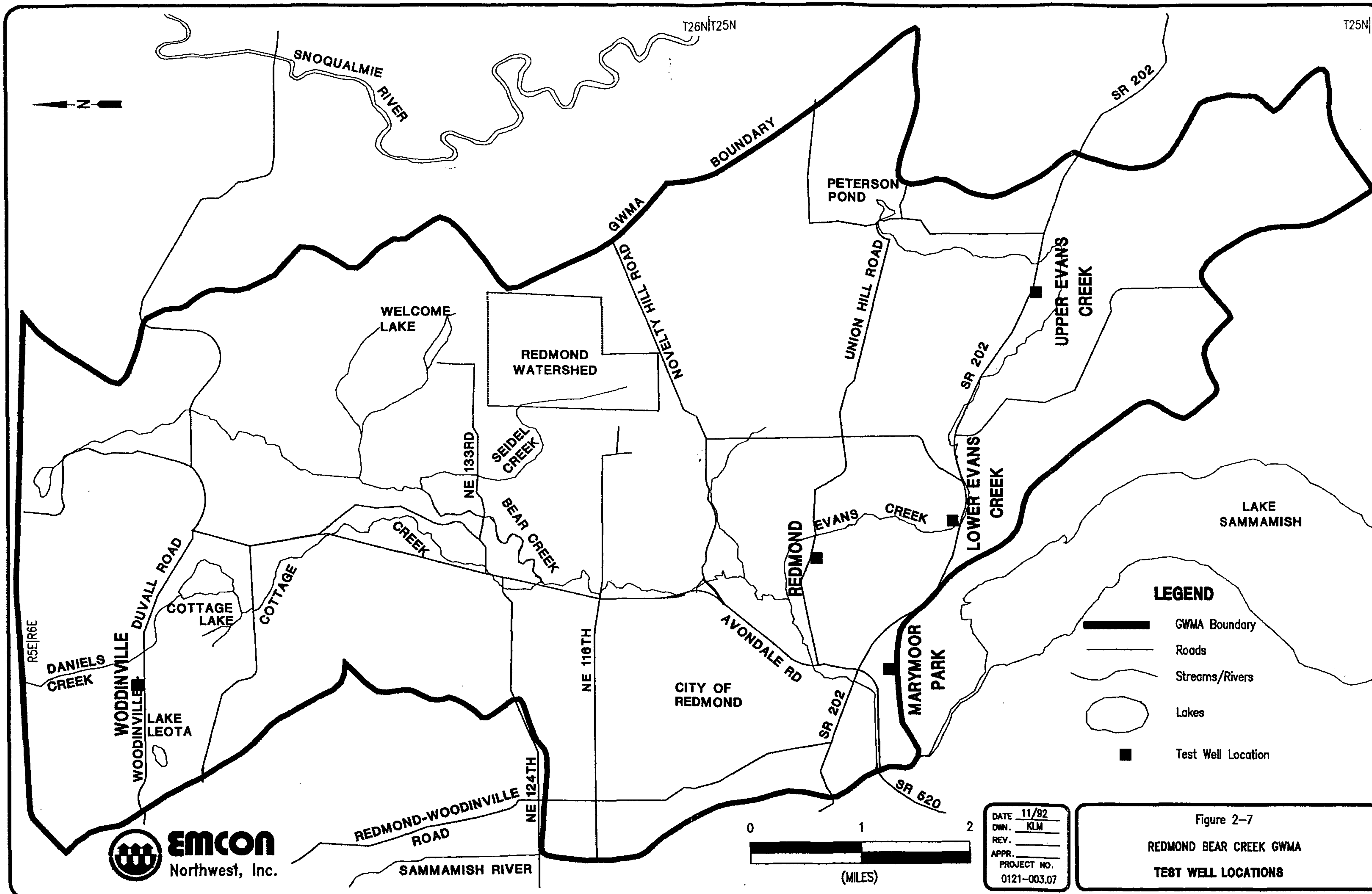

Figure 2-7
REDMOND BEAR CREEK GWMA
TEST WELL LOCATIONS

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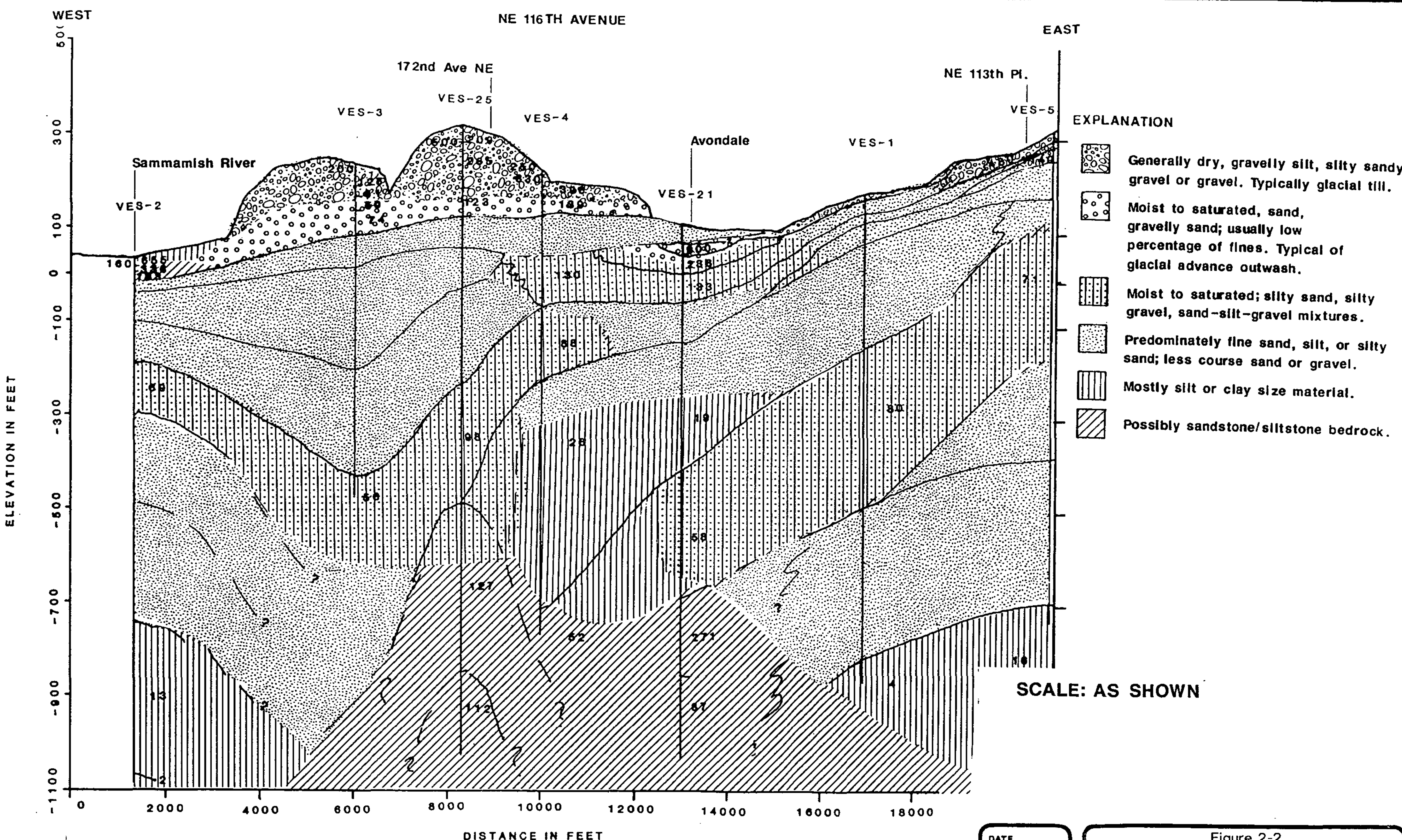

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Figure 2-2
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
ELECTRICAL RESISTIVITY STUDY
GEOLOGIC INTERPRETATION SECTION 1

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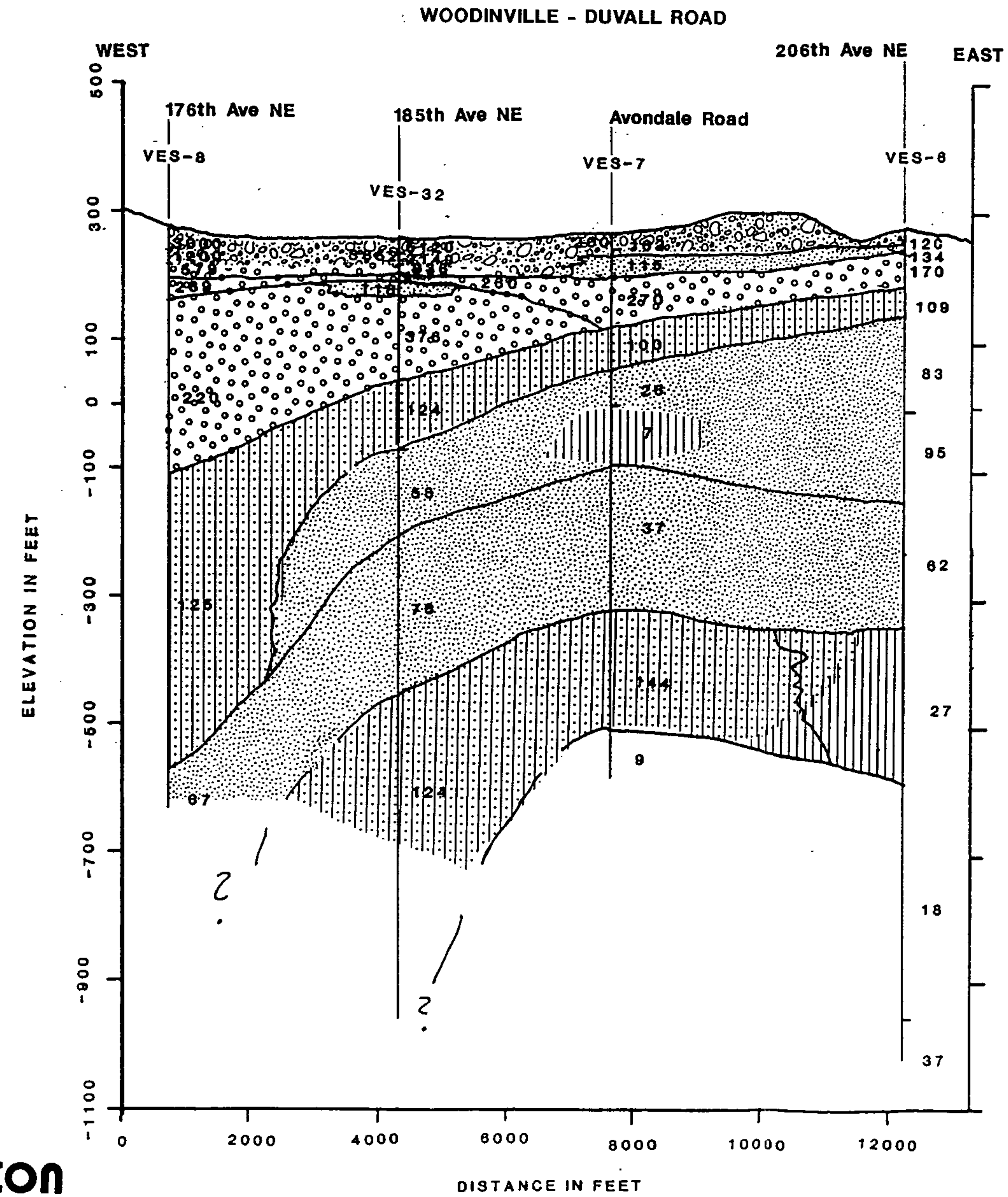

EXPLANATION

- Generally dry, gravelly silt, silty sandy gravel or gravel. Typically glacial till.
- Moist to saturated, sand, gravelly sand; usually low percentage of fines. Typical of glacial advance outwash.
- Moist to saturated; silty sand, silty gravel, sand-silt-gravel mixtures.
- Predominately fine sand, silt, or silty sand; less course sand or gravel.
- Mostly silt or clay size material.
- Possibly sandstone/siltstone bedrock.

SCALE: AS SHOWN

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Figure 2-3
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
ELECTRICAL RESISTIVITY STUDY
GEOLOGIC INTERPRETATION SECTION 2

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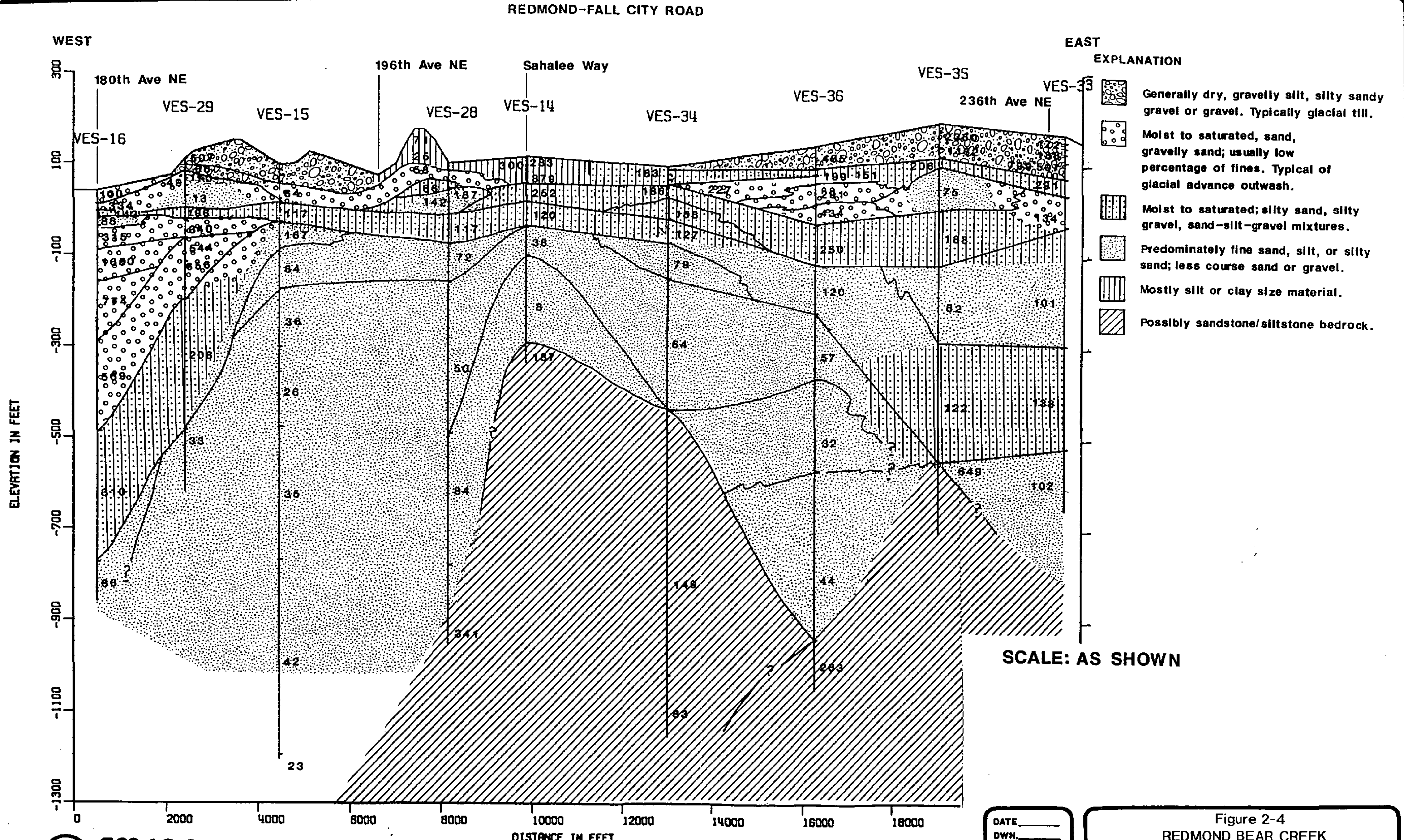

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Figure 2-4
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
ELECTRICAL RESISTIVITY STUDY
GEOLOGIC INTERPRETATION SECTION 3

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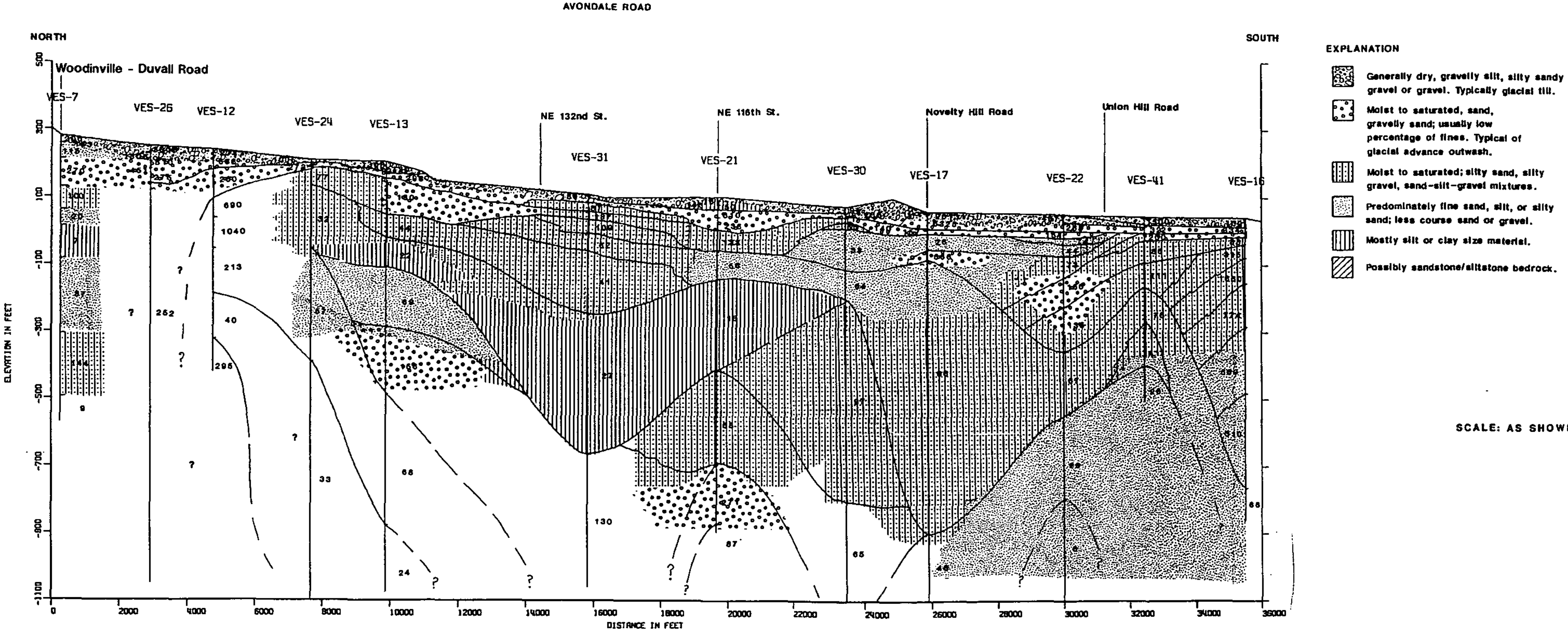

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Figure 2-5
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
ELECTRICAL RESISTIVITY STUDY
GEOLOGIC INTERPRETATION SECTION 4

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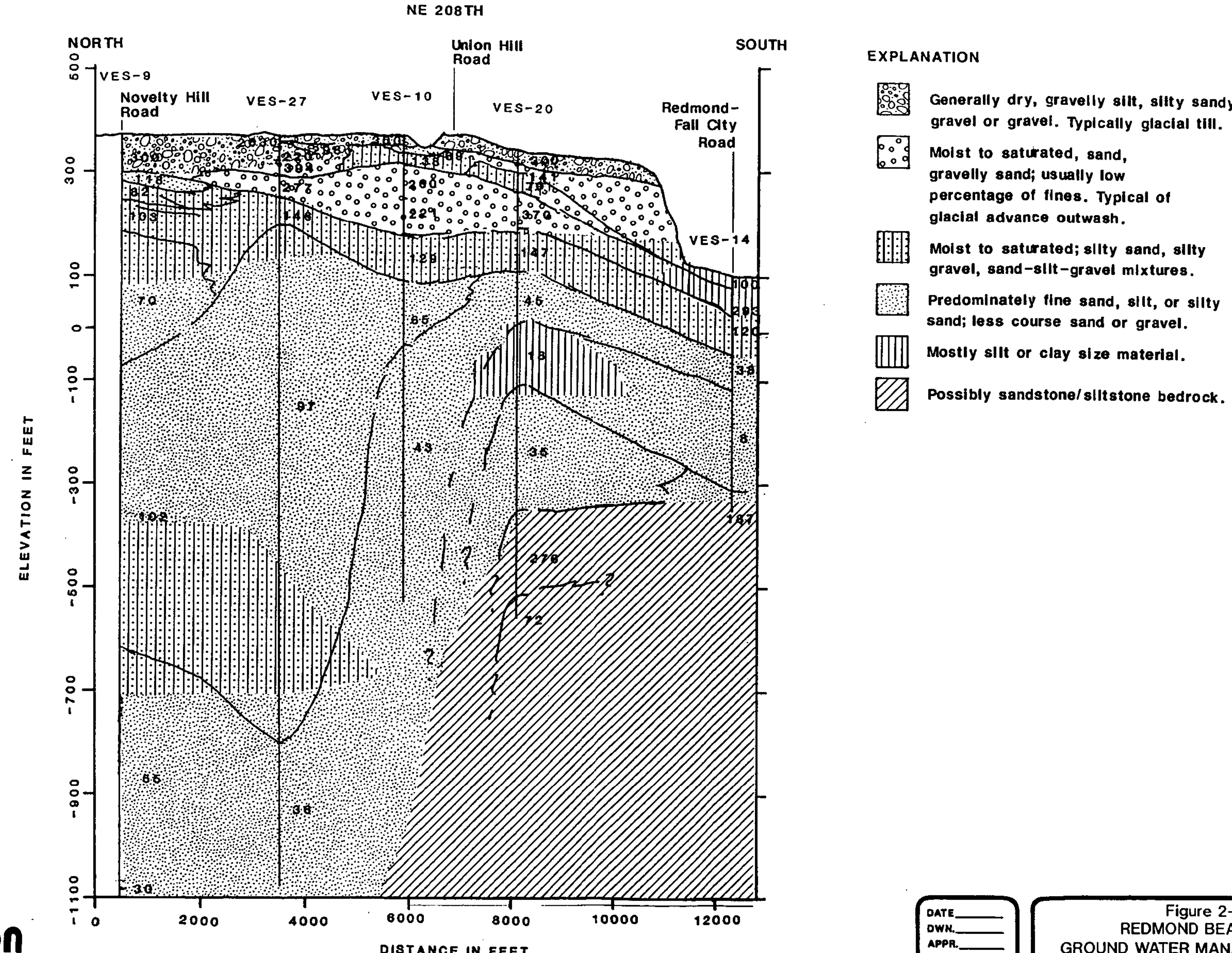

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Figure 2-6
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
ELECTRICAL RESISTIVITY STUDY
GEOLOGIC INTERPRETATION SECTION 5

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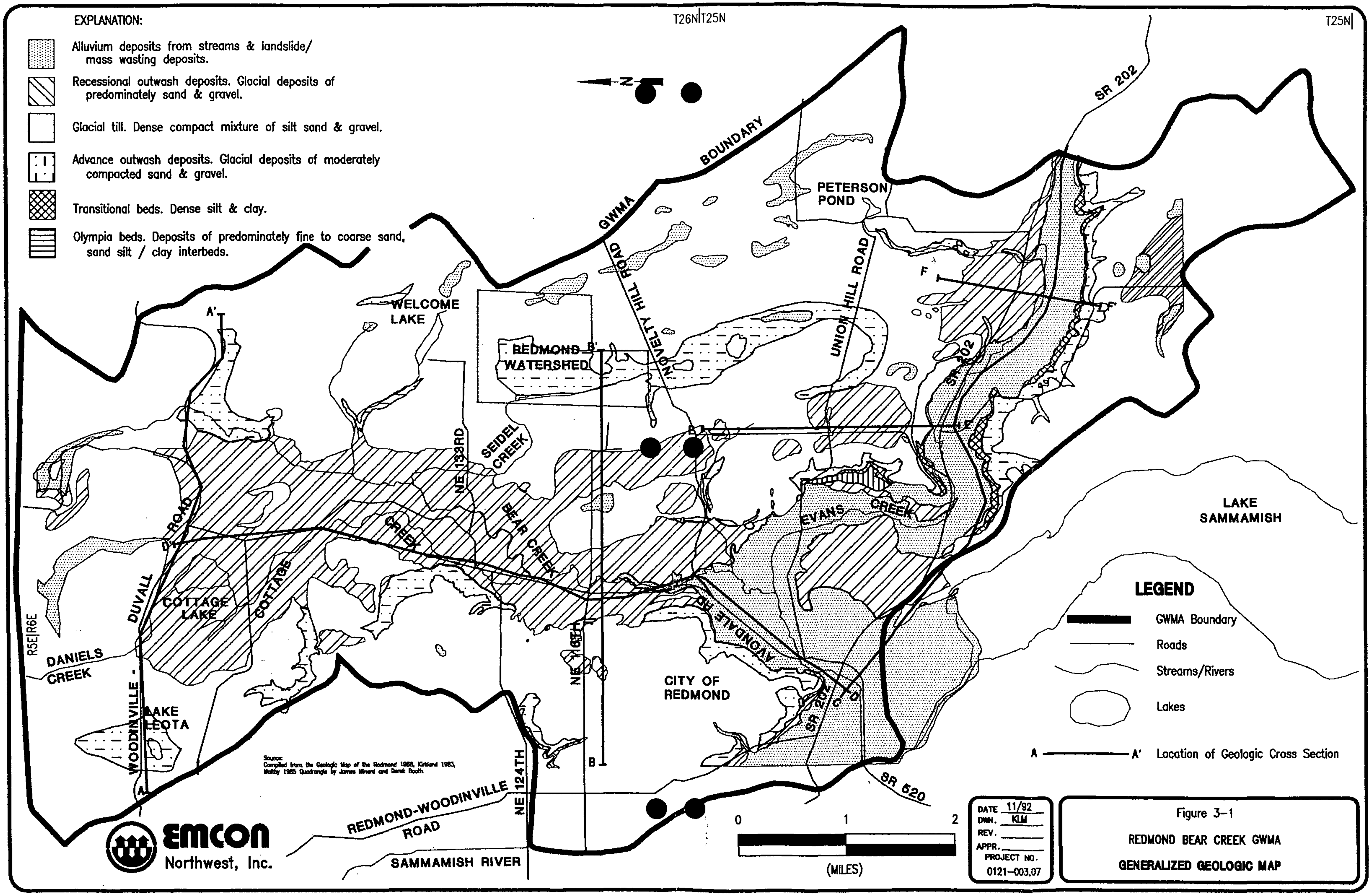
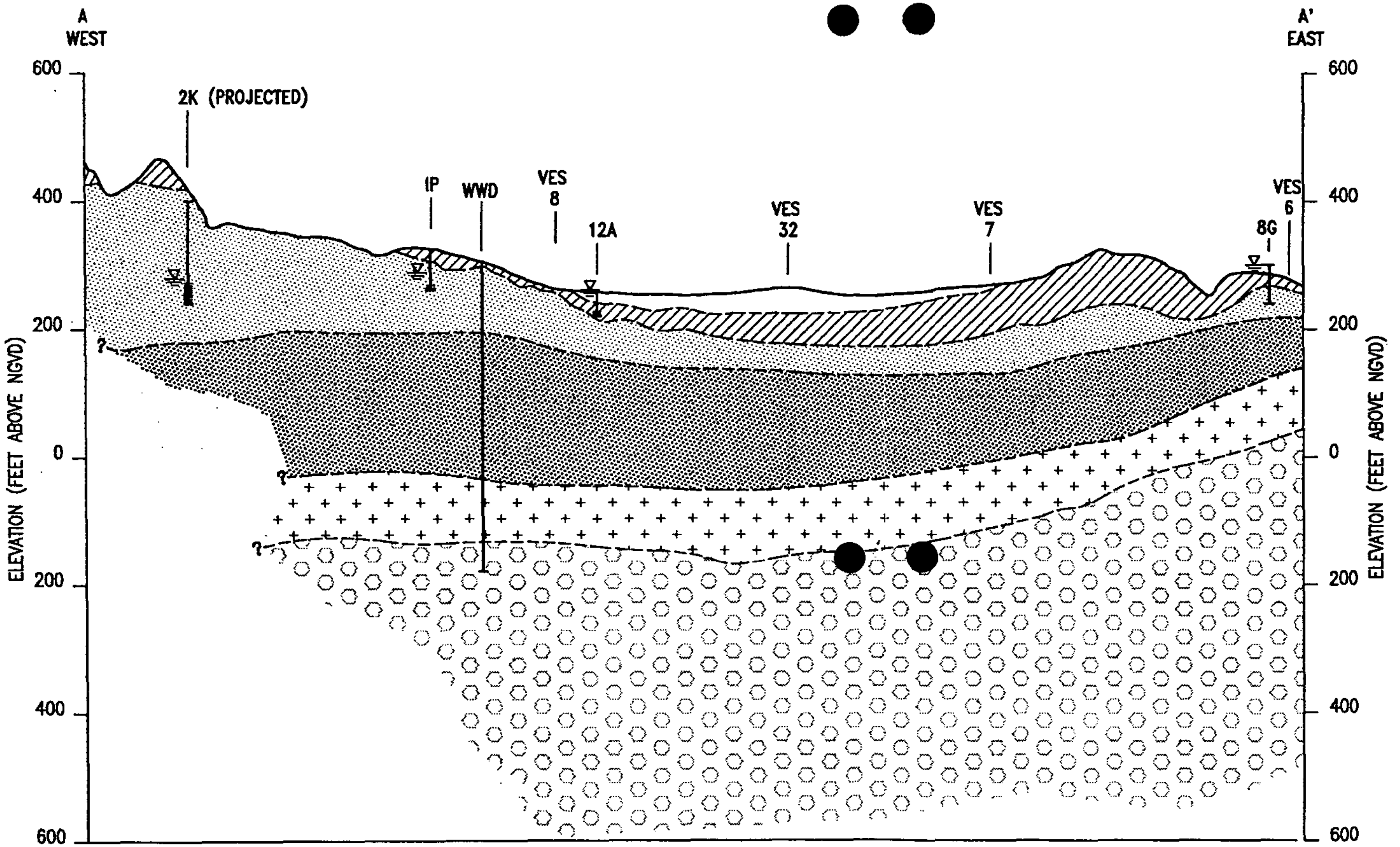


Figure 3-1
REDMOND BEAR CREEK GWMA
GENERALIZED GEOLOGIC MAP

1-4000 11-17-92 0121\003\07C19



LEGEND

- Alluvium
- Glacial-Fluvial Recessional Outwash
- Glacial Till
- Glacial Advance Outwash
- Transitional Beds
- Olympia Gravel
- Older Undifferentiated Deposits

Ves-29 Location of Resistivity Sounding
WWD Well Number
—?— — Inferred Geologic Contact

Scale:
Horizontal 1"=2,000'
Vertical 1"=200'
Note: Vertical Exaggeration 10X

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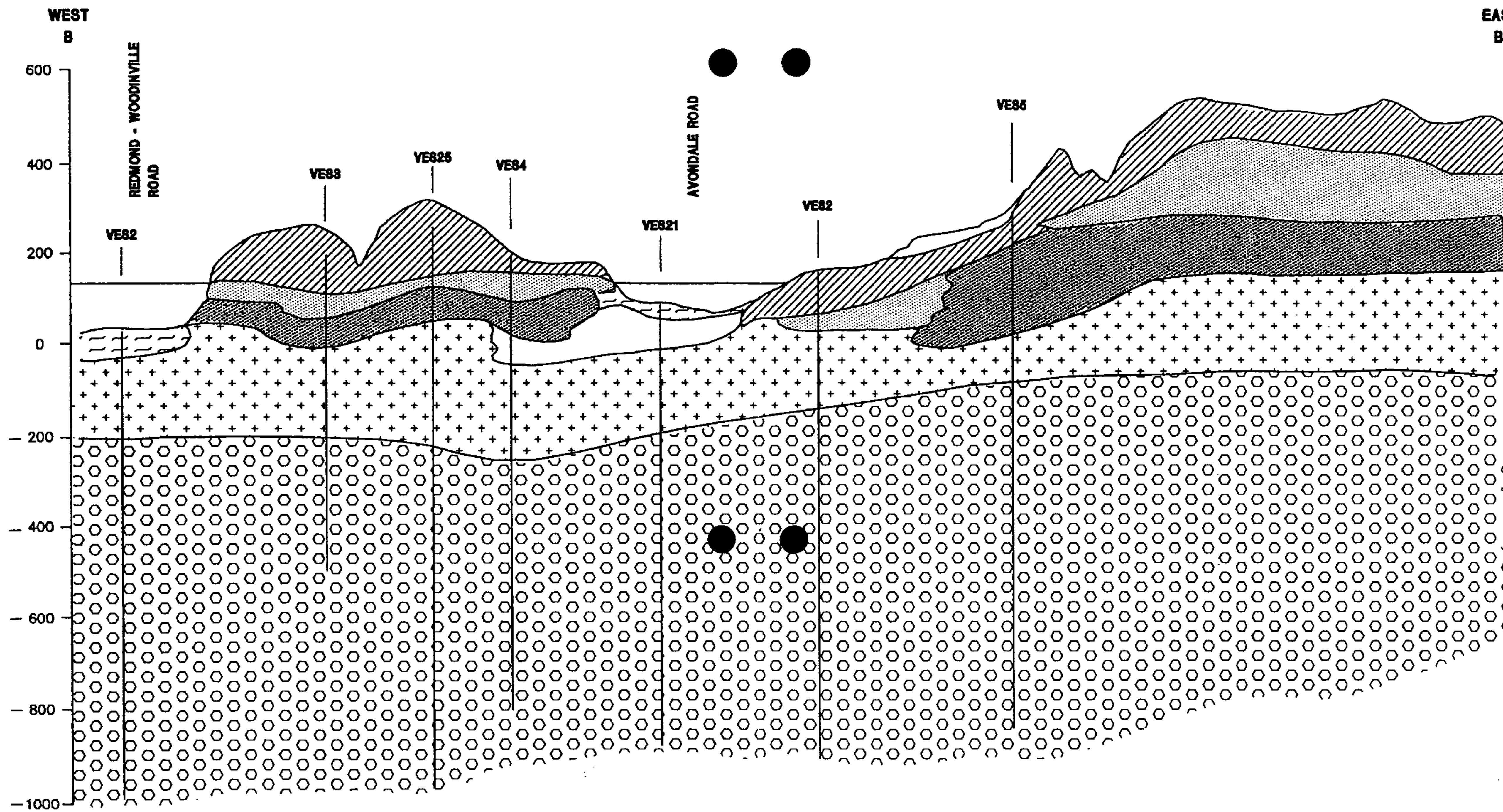
Figure 3-3

REDMOND BEAR CREEK GWMA

GEOLOGIC CROSS-SECTION A-A'

1= 1 11-16-92 D:\0121\003\03C12



LEGEND

Alluvium

Glacial-Fluvial Recessional Outwash

Glacial Till

Glacial Advance Outwash

Transitional Beds

Olympia Gravel

Older Undifferentiated Deposits

Ves-29 Location of Resistivity Sounding

WWD Well Number

—?— — Inferred Geologic Contact

Scale:
Horizontal 1"=160'
Vertical 1"=16'

Note: Vertical Exaggeration 10X

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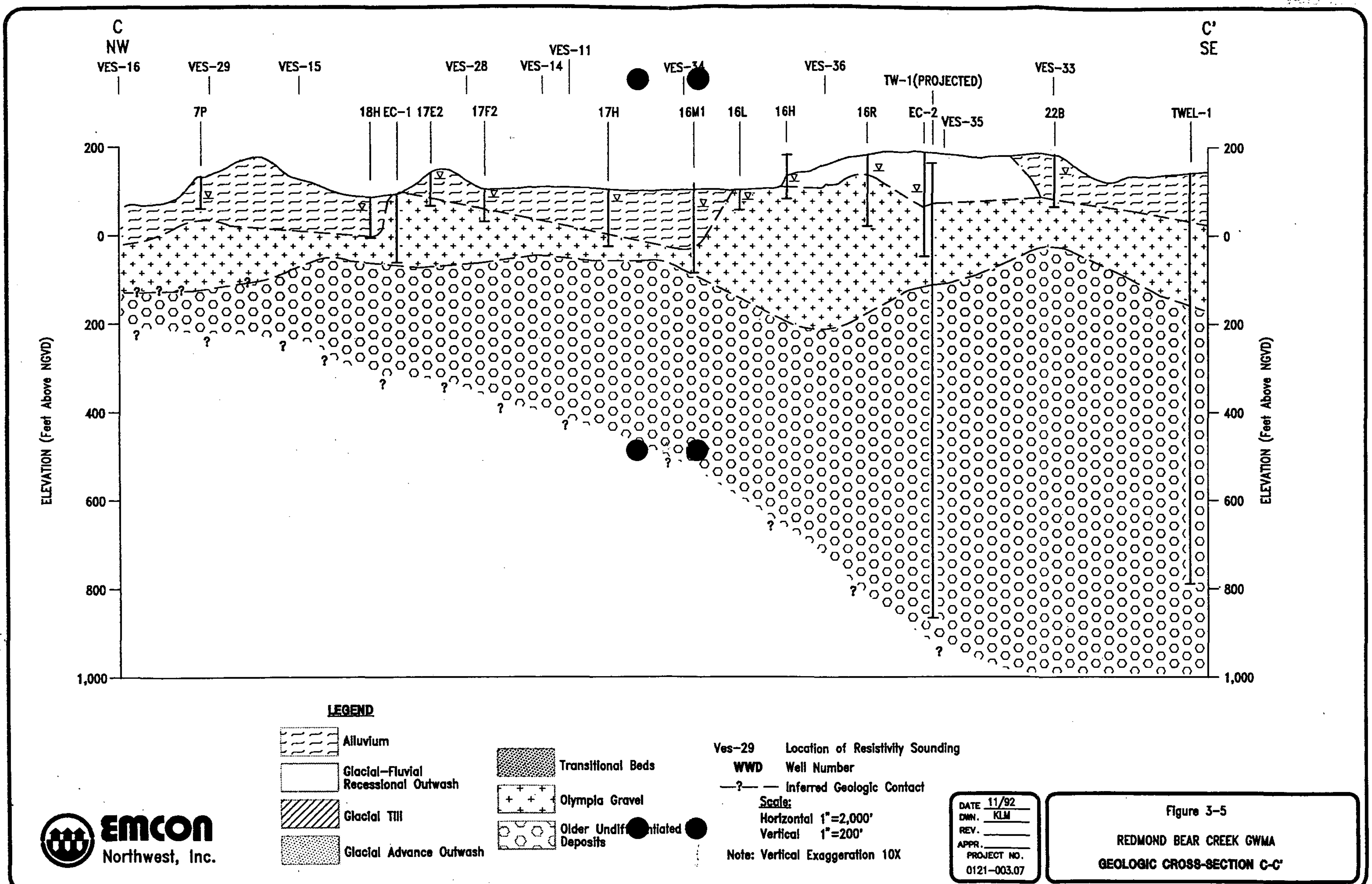
Figure 3-4

REDMOND BEAR CREEK GWMA

GEOLOGIC CROOS SECTION B - B'

1= 1 11-16-92 J:\DATA\DWG\0121\003\07C20



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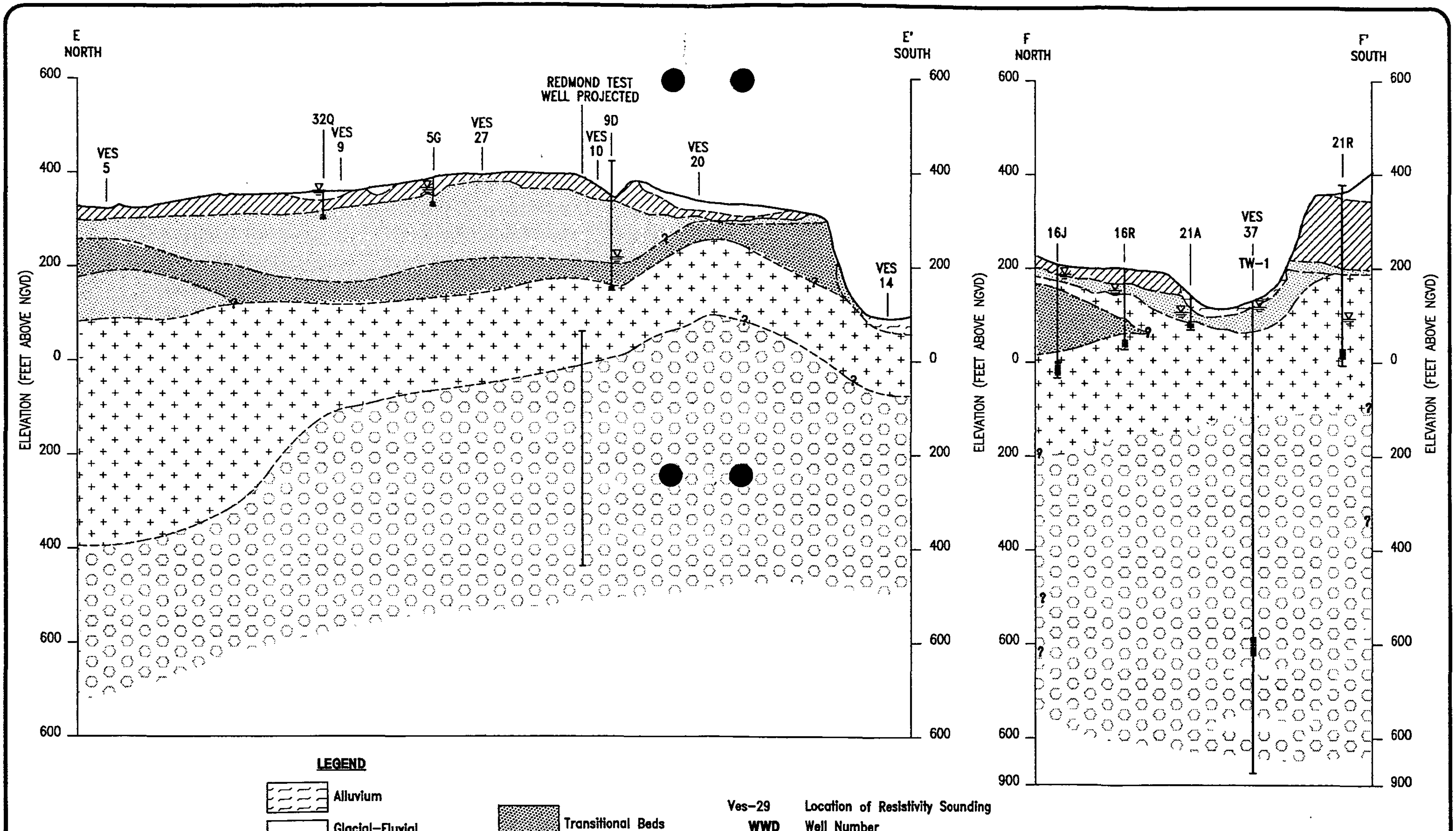
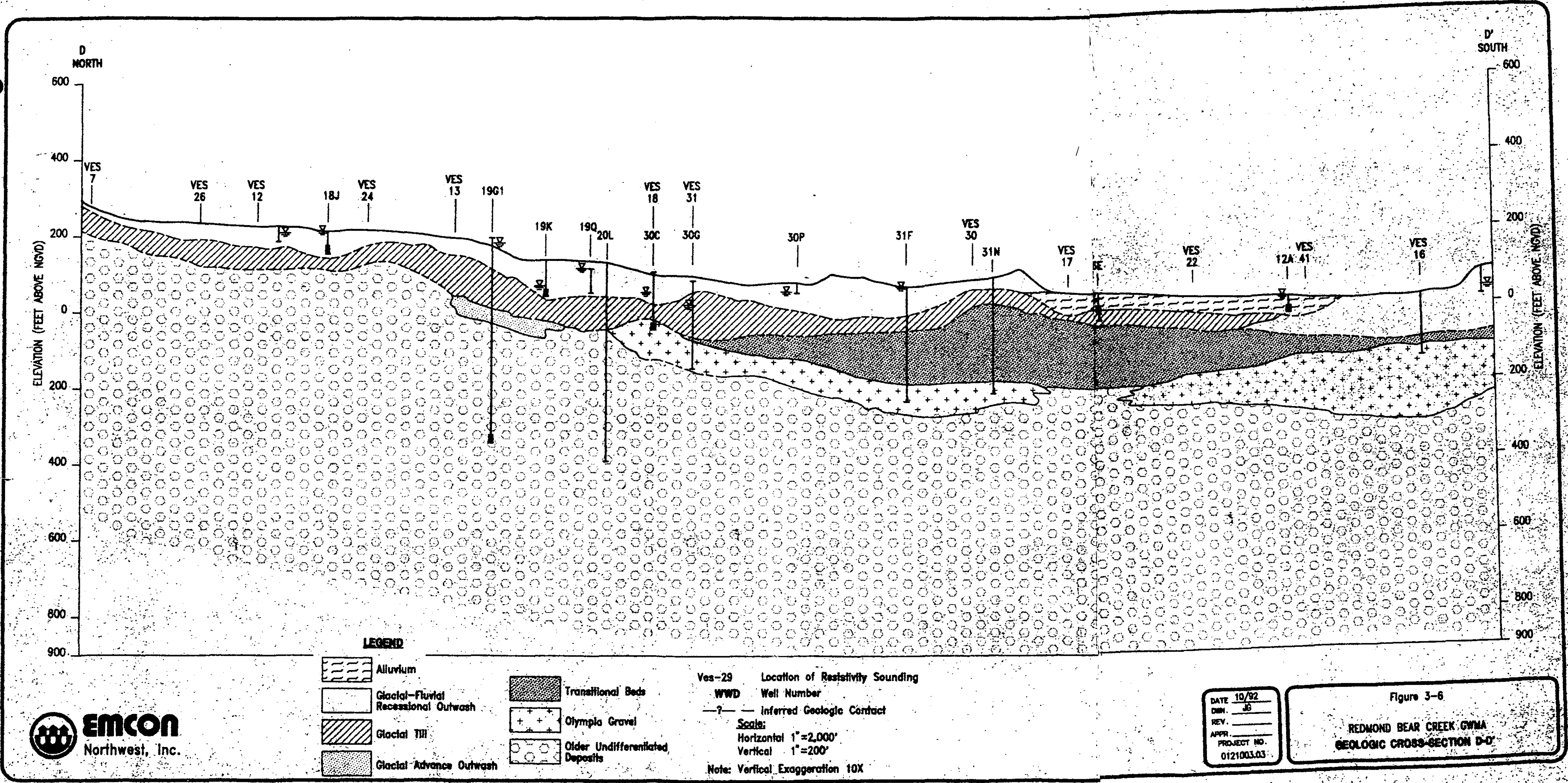


Figure 3-7

REDMOND BEAR CREEK GWMA

GEOLOGIC CROSS-SECTION E-E' AND F-F'

1= 1 11-15-92 D:\0121\003\03C14



1= 1 11-16-92 D:\0121\003\03C13

2 DATA COLLECTION ACTIVITIES

New data collection activities were accomplished to expand and refine the understanding of geology, hydrogeology, and ground water quality in the Redmond-Bear Creek GWMA. The new data collection activities performed for this study consisted of:

- design of a regional geophysical investigation and collection of electrical resistivity data at 37 locations in the study area
- installation of five test wells to evaluate the geology, aquifer conditions, and water quality in areas where data were lacking
- pump testing of three test wells to obtain information on aquifer properties
- collection and analysis of precipitation data from seven stations in the study area
- collection and analysis of stream flow data from six sites in the study area
- collection of periodic water level data from 80 private and public wells
- sampling and chemical analysis of ground water samples from 36 wells

The specific activities and interpretation of the data are discussed below.

2.1 Geophysical Investigations

Geophysical resistivity is a tool used to aid in the interpretation of regional stratigraphy. When used in conjunction with a well drilling program, it is useful in providing stratigraphic correlation between known data points (wells) and in investigating deep subsurface geologic conditions where no data are available. The geophysical investigation program consisted of

41 vertical electrical soundings completed from November 7, 1988, to December 18, 1988, and from March 1, 1989, to March 29, 1989. Field work was performed by a three-person field crew from GeoRecon International of Seattle, Washington. Each electrical sounding site is shown on Figure 2-1. The soundings were performed within the existing road right-of-way to alleviate any legal access problems. Locations of underground utilities were noted throughout the project area when possible, and sounding locations were adjusted to decrease the impact of utilities on the results. A description of the electrical resistivity data collection methodology and general resistivity theory is presented in Appendix A.

2.1.1 Discussion of Results

Five geophysical cross-sections were developed through the study area and are shown in Figures 2-2 through 2-6. The assigned number of each VES is shown above the interpreted solution on the geo-electrical sections. Each geo-electrical section has a geologic interpretation of the electrical resistivity values. Table 2-1 shows typical resistivity values representatives of the types of geologic materials found in the study area.

The cross-sections were constructed by using existing well logs, surficial geologic data, and geophysics to identify apparent resistivity patterns and corresponding geologic conditions. These cross-sections were expanded to other areas and depths lacking direct geologic information. The sections show a mixture of fine to coarse-grain soil units, which range from clay to gravels. Generally, these are not discrete units of clay or gravel, but mixtures of each material type with the resistivity indicating the predominant grain-size present. Bedrock was also interpreted to exist at depth in three of the sections (Figures 2-2, 2-4, and 2-6).

Section 1 (Figure 2-2) is oriented west-east along Northeast 116th Street from the Sammamish River to 209th Avenue Northeast. This section shows a general trend of geologic material dipping to the west. There is an apparent change in the dip near VES-3 where it appears that the low resistivity marker units (32 ohm meters overlying much lower resistivities) may rise toward the surface. The low resistivities found above the interpreted rock surface may indicate interbedded sand, silts, and gravels.

Section 2 (Figure 2-3) is oriented in a west-east direction along the Woodinville-Duvall Road, centered approximately at Avondale Road. Along this section, the upper resistivity values are considerably higher than those encountered along Section 1. The high resistivity values found within 100 to

200 feet of the surface in this section may indicate the presence of relatively coarse-grained units which could be water-bearing.

Section 3 (Figure 2-4) is a west-east section along the Redmond-Fall City Road from Redmond to the roadway adjacent to approximately 236th Avenue Northeast. This section is similar to Sections 1 and 2 in that it is generally underlain by an approximate 30-ohm-meter to 66-ohm-meter unit. Like the two previous sections, this section may exhibit an apparent dip to the West. Additionally, soundings completed in March 1989 indicate there may be considerable variation in the electrical properties of the interpreted bedrock material. This may depend upon grain size, saturation, and depth of burial. VES-40 was completed near a bedrock outcrop. The resistivities interpreted for VES-40 are shown in Table 2-2. Field observation indicates the probable occurrence of bedrock, at the sounding location, to be near 40 feet in depth. This corresponds to an interpreted electrical layer at 36 feet where the resistivity drops from 539 ohm meters to 246 ohm meters.

VES-37 was completed at a Northeast Lake Sammamish Water District well site (TW-1), approximately 2,500 feet south of this section. A section was planned from well TW-1 to soundings north of Section 3, but unusually high influences from utilities and fencing did not permit completion on north of Section 3. The data for VES-37 (well TW-1) are also shown on Table 2-2.

Also, of considerable interest are the extremely high resistivity values encountered west of VES-15. These values indicate very coarse-grained alluvial deposits.

Section 4 (Figure 2-5) is a north-south section along Avondale Road from the Woodinville-Duvall Road to Northeast 85th Place. The southern end of this section correlates well with Section 3 which ends just east of Section 4. The central portion is indicative of interbedded silt/sand/gravel deposits seen elsewhere in the Puget Sound area. From VES-12 north, it was not possible to establish any direct correlation in the deeper portion of this section. Considerable lateral changes appear to occur in the northern 3,000 feet of this section. Further study will be required to define the nature of these lateral changes.

Section 5 (Figure 2-6) is a north-south section along 208th Avenue Northeast from Northeast 100th Street to the Fall City Road. Based on the previously established premise for identifying bedrock along Section 3, interpretation of the local bedrock projects north along this section. In the vicinity of VES-27 northward to VES-9, a thick section of 90- to 100-ohm-

Table 2-1

Typical Resistivity Values of Materials

Material Description	Resistivity
Silt/clay mixture (full to partial saturation)	10 to 100
Sandy silts and clays and possible sandstone/shale bedrock (full to partial saturation)	50 to 150 shale
Silty sand and saturated sand/gravel	100 to 500
Sand to gravel (fine to coarse) Dry sandstone/shale bedrock	200 to 1,500
Gravel (full to partial saturation)	1,000 to 2,000
Gravel (dry)	1,500 and above

meter material may represent an extensive thickness of silty to coarse-grained materials between a depth of 200 to more than 900 feet.

2.2 Monitoring Well Installation and Pump Testing

As part of the Redmond-Bear Creek GWMA study five test wells were completed to collect stratigraphic and hydrologic data for characterization of subsurface conditions and evaluation of ground water resource potential. Well location selections, shown on Figure 2-7, were based on two primary factors:

1. areas where subsurface data were absent
2. current or future potential ground water supply areas

At each of the selected sites, a 6-inch-diameter test well was drilled to a depth between 160 and 500 feet. Subsurface materials were collected every 5 feet to evaluate geologic conditions. During drilling, water bearing zones (aquifers) were noted, and (if significant in terms of water resource potential) a 6-inch test well was installed. At two sites, no significant water resource was identified so small diameter (2-inch) monitoring well(s) were installed. In addition to well drilling, aquifer testing was performed in three of the test wells to evaluate certain aquifer parameters such as potential pumping capacity and aquifer transmissivity. The testing consisted of a variable rate and a 24-hour constant rate pump test. A synopsis of drilling, well completion, and aquifer testing details is provided in Table 2-3. Copies of the water well report for each well are included in Appendix B. Copies of the pump testing data are included in Appendix C.

recovery time from initial draw & vertical contact.

A brief description of the findings and interpretations derived from the drilling and testing at each of the five sites is given below.

2.2.1 Woodinville Test Well

The Woodinville test well site is located in the extreme northwestern portion of the study area just north of the Woodinville-Duvall Road. Drilling work was accomplished between February 26 and March 2, 1990. The test hole was drilled to a depth of 490 feet below ground surface (bgs). The geologic material encountered consisted of unconsolidated glaciofluvial and lacustrian deposits of sand, gravel, silt, and clay.

Table 2-3

Summary of Well Drilling and Aquifer Testing Data

					Pump Testing Results			
Test Well Site	Total Depth of Hole (ft)	Depth of Well(s) (ft)	Screened Intervals (ft)	Well Casing Diameter (mhos)	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Potential Yield (gpm)	Transmissivity (gpd/ft)
Woodinville	490	85	75-85	6	200	18	1200	80,000
Redmond	500	75	65-75	2	NA	NA	NA	NA
Lower Evans Creek	160	153	143-153	6	150	6	700	20,000
Upper Evans Creek	237	160/200	140-160/ 180-200	2	NA	NA	NA	NA
Marymoor	170	161	151-161	6	100	4	100	5,000

NOTE: NA Not applicable.

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Table 2-2

VES Interpretation

Depth (feet)	Resistivity (in ohm meters)	Geologic Interpretation
VES-37		
0 to 11	300+	Silty sandy gravel
11 to 17	173	
17 to 24	91	
24 to 35	75	Sandy silt and gravel layers
35 to 78	84	
		Silty sand and gravel
78 to 115	65	Fine to coarse sand
115 to 171	51	Fine sand
171 to 254	64	Silty sand and gravel and layers of silt
254 to 366	116	Gray fine sand, silt and clay
366 to 546	69	
546 to 600 +/-	low	Gray water-bearing silty fine sand
VES-40		
0 to 4	5,000+	Coarse dry sand and gravel
4 to 6	3,275	
6 to 8	771	Siltier material
8 to 11	149	Water table
11 to 14	33	Silty layer
14 to 24	261	Coarse sand and gravel
24 to 36	539	beneath the water table
36 to 93	250	Interpreted top of rock at 36
93 to 142	390	Sandstone

During drilling, a sandy silt (Till) was present to a depth of 10 feet. Between 10 and 85 feet bgs, a saturated fine-to-coarse sand and occasional silt layers were encountered. A significant (>200 gpm) water bearing zone was identified between 72 and 88 feet. Below a depth of approximately 90 feet, the material was predominantly dense silt and clay deposits with occasional interbeds of sand and gravel. No significant aquifers were found below a depth of 90 feet.

Following drilling, a 6-inch stainless steel well screen was installed between 75 and 85 feet bgs to evaluate aquifer conditions. A 24-hour pump test was performed on May 3, 1990. Results of the pumping test are presented in Table 2-3. In summary, the pump test indicated a moderately permeable aquifer with a potential well yield of 700 to 1,200 gpm. Water quality testing showed relatively low (below secondary drinking water standards) levels of iron and manganese and no elevated levels of primary standards.

2.2.2 Redmond Test Well

The Redmond test well site is located in the south central portion of the study area on the southwest corner of Union Hill Road and 196 Avenue Northeast. Drilling work was accomplished between February 8 and 14, 1990. The test hole was drilled to a depth of 500 feet bgs. The geologic materials encountered were from depositional environments similar to those in the Woodinville well.

From ground surface to a depth of 75 feet, geologic materials consisted of fine to coarse sand and gravel. A significant (>200 gpm) aquifer was present between 20 and 70 feet. Below a depth of 75 feet, the material consisted predominately of silt and clay mixtures with occasional interbeds of sand and gravel. No significant aquifers were found below the upper water bearing zone.

Since the upper water bearing zone is currently being used by the City of Redmond wells, significant aquifer data have already been collected. For this reason, plus limited funds for pump testing, one 2-inch monitoring well was installed at the base of the shallow aquifer. Water quality testing of this well did not indicate any parameters exceeding primary or secondary drinking water standards.

2.2.3 Lower Evans Creek Test Well

The site for this test well is the lower Evans Creek Valley on the north side of State Route 202. Drilling work was accomplished between March 8 and March 9, 1990. The test hole was drilled to a depth of 160 feet bgs. The geologic materials encountered were predominantly sand and gravel glaciofluvial deposits.

The borehole penetrated predominantly sandy gravel and gravelly sand from ground surface to a depth of 156 feet. The bottom of the boring (156 to 160 feet) encountered a clayey silt. A significant water bearing zone (50 to 100 gpm) was present between 90 and 100 feet, but there was a strong hydrogen sulphide odor. A more productive zone (>200 gpm) was found from 120 to 156 feet. A slight hydrogen sulphide odor was also present in the lower zone.

After drilling, a 6-inch stainless steel well screen was installed between 143 and 153 feet bgs. A 24-hour pump test was performed on April 30, 1990. Results of the pumping test are presented in Table 2-3. The pump test indicated a moderately permeable aquifer with a potential well yield of 400 to 700 gpm. Water quality testing showed elevated levels of iron and manganese.

2.2.4 Upper Evans Creek Test Well

The upper Evans Creek test well site is in the Upper Evans Creek Valley on the south side of State Route 202. Drilling work was accomplished between March 6 and 8, 1990. The test hole was drilled to a depth of 237 feet and encountered geologic materials with depositional histories similar to those at the Lower Evans Creek site.

Drilling at this site encountered a sandy gravel from ground surface to 44 feet overlying a silt/sandy silt zone between 44 and 80 feet. Interbedded layers of fine sand, silty, and silty gravel were found from a depth of 80 feet to about 120 feet.

Potential yields in this interval appeared to be less than 50 gpm. At a depth of 122 feet and continuing to 160 feet, the material became predominantly gravelly sand. Potential yields appeared to increase slightly, but are probably less than 100 gpm. From 160 to 237 feet, the geologic material consisted of fine to medium sand. The water bearing capacity of the lower sand did not appear significant.

Since no significant water bearing zones were encountered, pump testing was not performed at this site. The borehole was completed with two 2-inch diameter monitoring wells installed at different depths (see Table 2-3). In addition to providing information on water quality and water levels, these wells may provide information on hydrologic and geologic conditions within the Evans Creek aquifer(s) if aquifer testing is performed on new or existing production wells in the valley.

2.2.5 Marymoor Park Test Well

The well site is located in the southwestern portion of the study area just south of the East Lake Sammamish Parkway. Drilling work was accomplished between August 30 and September 5, 1990. The test hole was drilled to a depth of 180 feet bgs. The geologic materials encountered reflect deltaic and lacustrian depositional environments.

The drilling encountered coarse sand and gravel, typical of deltaic deposits from ground surface to a depth of 115 feet. Saturated conditions existed below about 8 feet. Very significant quantities of water appear to exist in this aquifer. From 120 to 140 feet, a dense silt and clay unit was penetrated. Below this low permeability unit, a gravelly sand and sand unit was encountered from about 145 to 165 feet. This confined aquifer also appears to have the potential for producing significant quantities of water. From 165 to 180 feet, the material encountered consisted predominantly of fine to medium sand which appeared to be getting finer with depth.

After drilling was completed, a 6-inch diameter well screen was installed from 151 to 161 feet bgs. Due to budget constraints a 24-hour pump test could not be performed on this well. Two short-term pump tests (40 and 60 minutes) indicated a potential well yield of at least 100 gpm. No p. test

2.3 Precipitation

Precipitation data were compiled from measurements at seven weather stations in the Redmond-Bear Creek watershed during 1989, 1990, and 1991. The location of each precipitation collection station is shown on Figure 2-8. Monthly precipitation data are compiled in Table 2-4. Daily precipitation data are included in Appendix D.

The RBC watershed receives an average of 42 inches of rainfall annually, approximately 8 inches more than the Everett weather station to the north.

Figure 2-8 Location of New Test Wells

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YEAR	MONTH	STATION						
		Woodinville	Union Hill	Sahalee	Redmond	Hollywood	North Ridge	Blakely Ridge
1989	Jan	ND	ND	5.85	2.72	3.97	5.81	ND
	Feb	ND	ND	3.07	1.11	3.34	4.46	ND
	Mar	5.09	ND	6.85	3.04	5.56	6.79	ND
	Apr	1.47	2.00	2.45	0.97	1.32	2.30	ND
	May	3.33	3.78	3.95	3.81	3.54	4.28	ND
	June	1.58	1.36	1.72	1.20	1.21	1.45	ND
	July	0.19	ND	1.07	0.54	0.73	0.80	ND
	Aug	ND	1.37	1.05	ND	0.87	1.21	ND
	Sept	ND	0.37	0.35	0.13	0.38	0.42	ND
	Oct	ND	4.17	4.40	3.51	4.19	4.48	4.48
	Nov	ND	5.59	7.05	4.29	4.36	5.86	5.86
	Dec	ND	5.73	5.60	4.28	4.60	5.97	5.97
	total	11.66	24.37	43.41	25.60	34.07	43.83	16.31
1990	Jan	ND	9.02	9.70	7.68	8.02	9.99	9.99
	Feb	3.83	4.66	3.15	2.89	2.91	3.88	3.88
	Mar	3.02	3.89	3.50	3.11	3.92	4.14	4.14
	Apr	3.40	3.66	2.75	2.32	3.58	3.91	3.91
	May	2.52	3.42	2.35	1.81	2.50	2.78	2.78
	June	3.34	3.78	4.10	2.82	3.13	3.97	3.73
	July	0.77	0.98	1.20	0.74	0.74	1.09	0.86
	Aug	1.06	1.66	1.75	0.87	0.72	1.35	1.29
	Sept	0.08	0.04	ND	0.02	0.11	0.21	0.41
	Oct	7.03	8.38	7.85	5.80	6.87	8.30	8.76
	Nov	8.04	8.05	7.95	6.29	6.91	6.06	6.83
	Dec	4.86	4.39	5.35	4.02	5.10	4.34	5.29
	total	37.95	51.93	49.65	38.37	44.51	50.02	51.87
1991	Jan	3.82	4.86	5.00	3.72	3.68	5.02	4.60
	Feb	5.98	5.08	5.15	4.38	5.51	5.26	5.86
	Mar	5.04	5.82	6.05	4.24	4.79	7.27	6.52
	Apr	5.83	6.57	6.40	5.35	5.46	6.41	5.87
	May	ND	2.63	2.45	1.28	1.73	2.55	2.10
	June	ND	2.79	2.75	1.58	2.16	2.78	2.54
	July	ND	0.08	0.30	0.36	0.39	0.42	0.04
	Aug	ND	ND	1.80	1.41	1.62	1.75	1.83
	Sept	ND	ND	0.00	0.44	0.33	0.38	0.36
	Oct	ND	ND	1.70	1.64	ND	ND	ND
	Nov	ND	ND	2.38	ND	ND	ND	ND
	Dec	ND	ND	0.00	ND	ND	ND	ND
	total	20.67	27.83	33.98	24.40	25.67	31.84	29.72

ND - No Data Available

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Table 2-4
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

MONTHLY PRECIPITATION DATA (inches)

Total monthly precipitation for each weather station during the years 1989, 1990, and 1991 is shown in Figures 2-9, 2-10, and 2-11 in a particular month have not been plotted for that month. Incomplete or no data were available for a few months at certain stations. For example the Union Hill Site from August through November 1990. Similarly, data were missing or absent for the Woodinville Station between September and December 1989.

The monthly precipitation plots illustrate how precipitation varies seasonally in the watershed with approximately 75 percent of the annual precipitation falling during the fall and winter months from October through March. On average over the three-year period, the month of January had the greatest amount of precipitation. The GWMA-wide averages of precipitation for January ranged from approximately 4.5 to 9.1 inches. The highest recorded monthly rainfall, 10 inches, occurred at the North Ridge Station in January of 1990. Precipitation decreases sharply during the summer with the least precipitation typically occurring during September. Average precipitation over the watershed during the month of September ranged from 0.15 to 0.30 inches during the three years of study.

To evaluate precipitation patterns within the GWMA, monthly precipitation totals for each station were plotted for both a high and low precipitation month. July and October of 1990 were selected because there are data at all of the precipitation stations for both months. The isohyetal maps, Figures 2-12 and 2-13, show the distribution of precipitation during July and October of 1990, respectively. The maps show that precipitation generally increases from west to east across the watershed. As expected, rainfall was usually greatest at the higher elevations along the western boundary of the GWMA and lowest in the lower Bear Creek Valley around the cities of Redmond and Woodinville. As shown graphically on Figure 2-14, the Sahalee and north ridge stations consistently recorded the highest monthly precipitation totals.

2.4 Streamflow

The Redmond-Bear Creek GWMA is drained by four major streams: Cottage Lake Creek, Daniels Creek, Bear Creek, and Evans Creek. Daniels Creek, located in the northern part of the watershed, flows south into Cottage Lake which is drained by Cottage Lake Creek. Evans Creek originates in a marshland at the southern end of the watershed and flows northwest toward the Sammamish River. Cottage Lake Creek and Bear Creek both flow south until they merge north of Avondale and empty into

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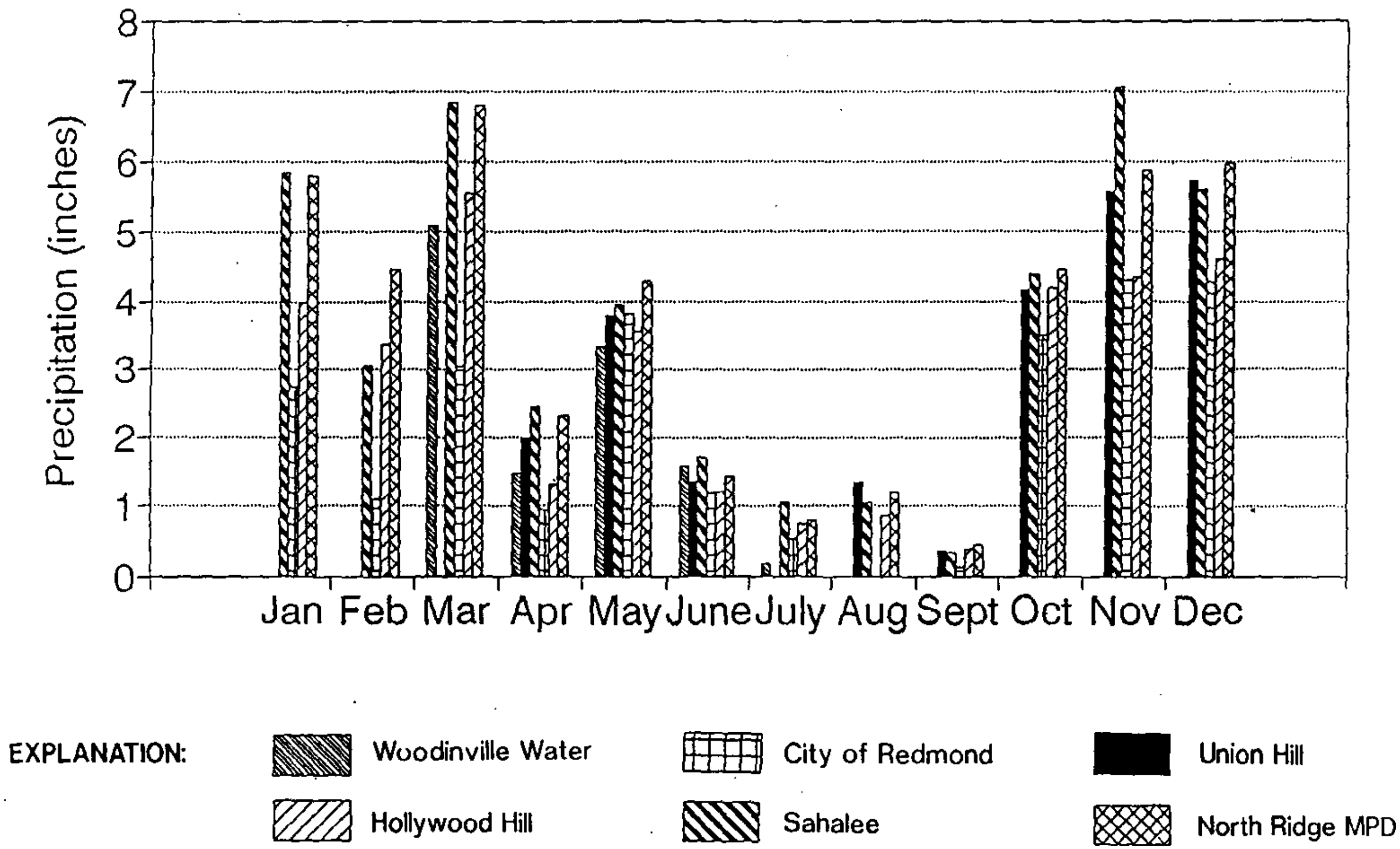

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Figure 2-9
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

MONTHLY PRECIPITATION 1989

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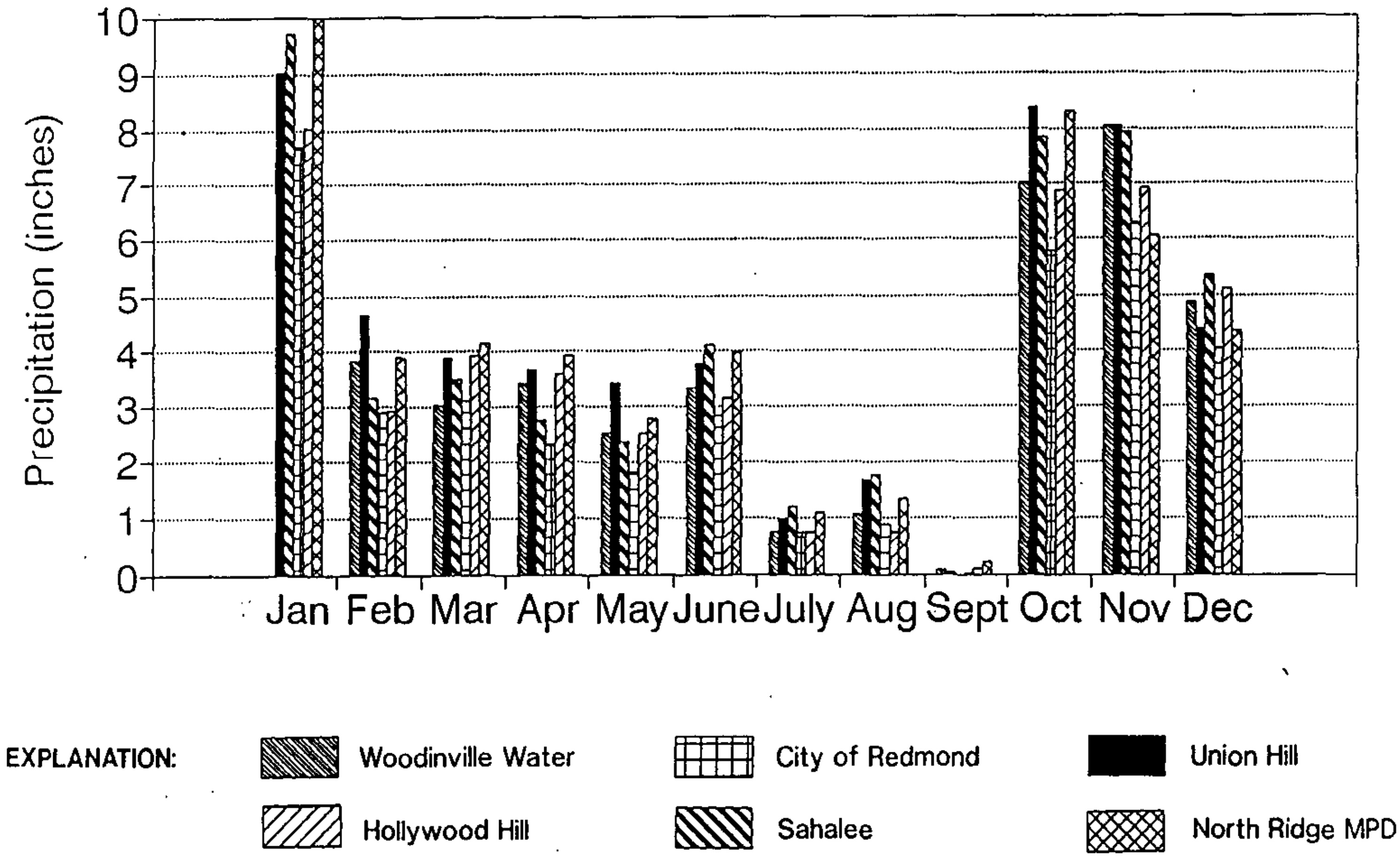

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Figure 2-10
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

MONTHLY PRECIPITATION 1990

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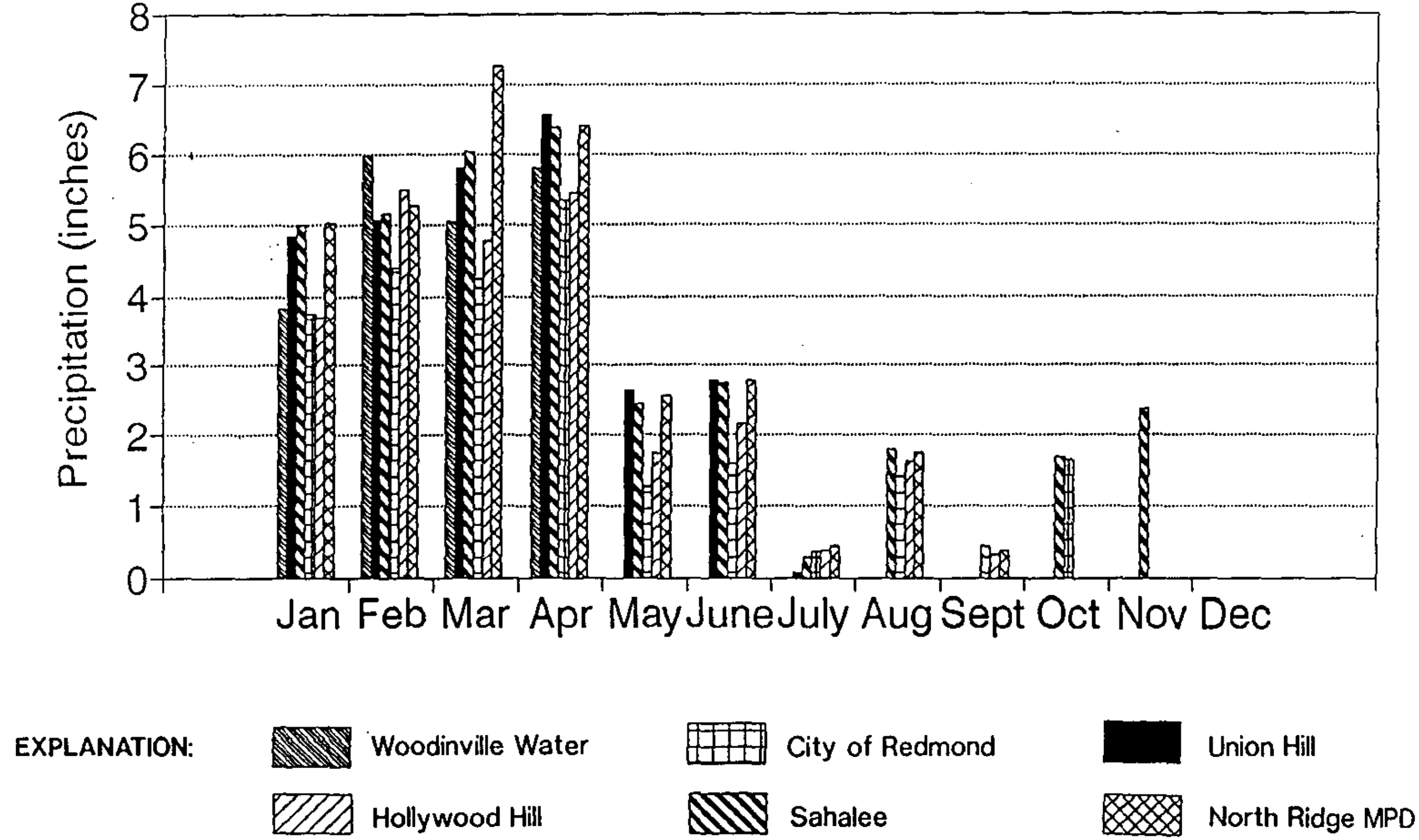

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Figure 2-11
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

MONTHLY PRECIPITATION 1991

Evans Creek at Union Hill Road just east of Redmond. Evans Creek eventually discharges to the Sammamish River.

During this study, stream discharge data were collected for six gauging stations in the GWMA from 1989 through 1991 (Figure 2-15). Station Number 1 was located on Daniels Creek at the Woodinville-Duvall Road, Station Number 2 on Upper Bear Creek along the Woodinville-Duvall Road, Station Number 3 on Cottage Lake Creek at Avondale Road, and Station Number 4 on Lower Bear Creek at Northeast 132nd Street. Two stations (Numbers 5 and 6) were located on Evans Creek at Union Hill Road, approximately 1.5 miles apart. At stations 1 and 2, stream flow data were collected periodically by EMCON personnel. Data from Station Number 3 were collected by the Seattle-King County Health Department, using a continuous recorder. Data from the Lower Bear Creek station Number 4 were collected by the USGS with a continuous recorder, and data from Evans Creek stations 5 and 6 were collected by the King County Surface Water Management Division, using continuous recorders.

2.4.1 Gauging Methods

At each site, an attempt was made to collect measurements from a reach of stream with a smooth shoreline, no brush hanging in the water, no large rocks, and no back-eddies. These optimum conditions were found only in culverts beneath roads, so they were the location of choice for stream gauging. Stream sections exhibiting fair to good conditions were used where culverts were not available.

At the Daniels Creek, upper and lower Bear Creek sites, stream velocity measurements were made with a Swoffer impeller-type current meter, number M-1-01-K. Velocity and water depth were measured at 6 to 24 equally spaced points along a tape stretched perpendicularly across the stream. Each point represents the midpoint of a flow segment whose vertical sides are located midway between neighboring measurement points on the tape. Velocity measurements at each point were made at a depth corresponding to six-tenths of the depth of the stream. At each point, at least three 20-second velocity measurements were collected and averaged.

Discharge for each segment is the product of the average velocity and the area of the segment. Discharges for each segment were summed to determine the total stream discharge at each site. Stream flow measurements collected during the study are presented in Appendix E.

Hydrographs of stream discharge were prepared for the two Evans Creek stations and for the Lower Bear Creek station for the years 1989 through 1991. These streams flow throughout the year. Seasonal variations in stream flow appear to correspond to changes in precipitation and are generally characterized by high flows in the winter and spring and low flows in the summer and fall. Hydrographs for Evans Creek at Union Hill Road (Station 5) are shown in Figures 2-16, 2-17, and 2-18. Hydrographs for Evans Creek at Union Hill Road (Station 6) are shown in Figures 2-19, 2-20, and 2-21, and hydrographs for Lower Bear Creek near Redmond (Station 4) are shown in Figures 2-22, 2-23, and 2-24. Stream discharge data for the Daniels Creek and Upper Bear Creek stations are summarized in Table 2-5. Discharge data for Cottage Creek are not included in this draft report due to data reduction problems.

During each year, base flow comprised most of the flow in each creek during the summer months from July through September. This period also corresponds with the months of lowest precipitation. Storm flows typically occur between November and April, with the largest peak flow in each stream recorded in January 1990. Along Evans Creek, baseflow increases greatly between the upstream and downstream gauging stations, indicating ground water discharge to Evans Creek. In 1990, baseflow ranged from approximately 5 cubic feet per second (cfs) upstream to 25 cfs downstream. Base flow in Evans Creek was highest in 1991 and lowest in 1990.

The Evans Creek hydrographs (Figure 2-16 through 2-21) show that flow varied from about 5 cfs to 200 cfs from January 1989 to September 1991 at the upstream Union Hill Road station and from 15 cfs to 1332 cfs during the same period at the downstream station near Avondale. At the Bear Creek gauging station near Redmond, streamflow varied from about 5 cfs to 250 cfs from April 1989 through September 1991 as shown on the Bear Creek hydrographs (Figures 2-22 to 2-24).

2.5 Water Level Monitoring

Existing ground water data available prior to this study were too limited and too sporadic to use in determining long-term water level trends or ground water flow directions. In the winter of 1989, a water level monitoring network was developed, including 81 private and public water supply wells and monitoring wells. Water levels were collected periodically, generally

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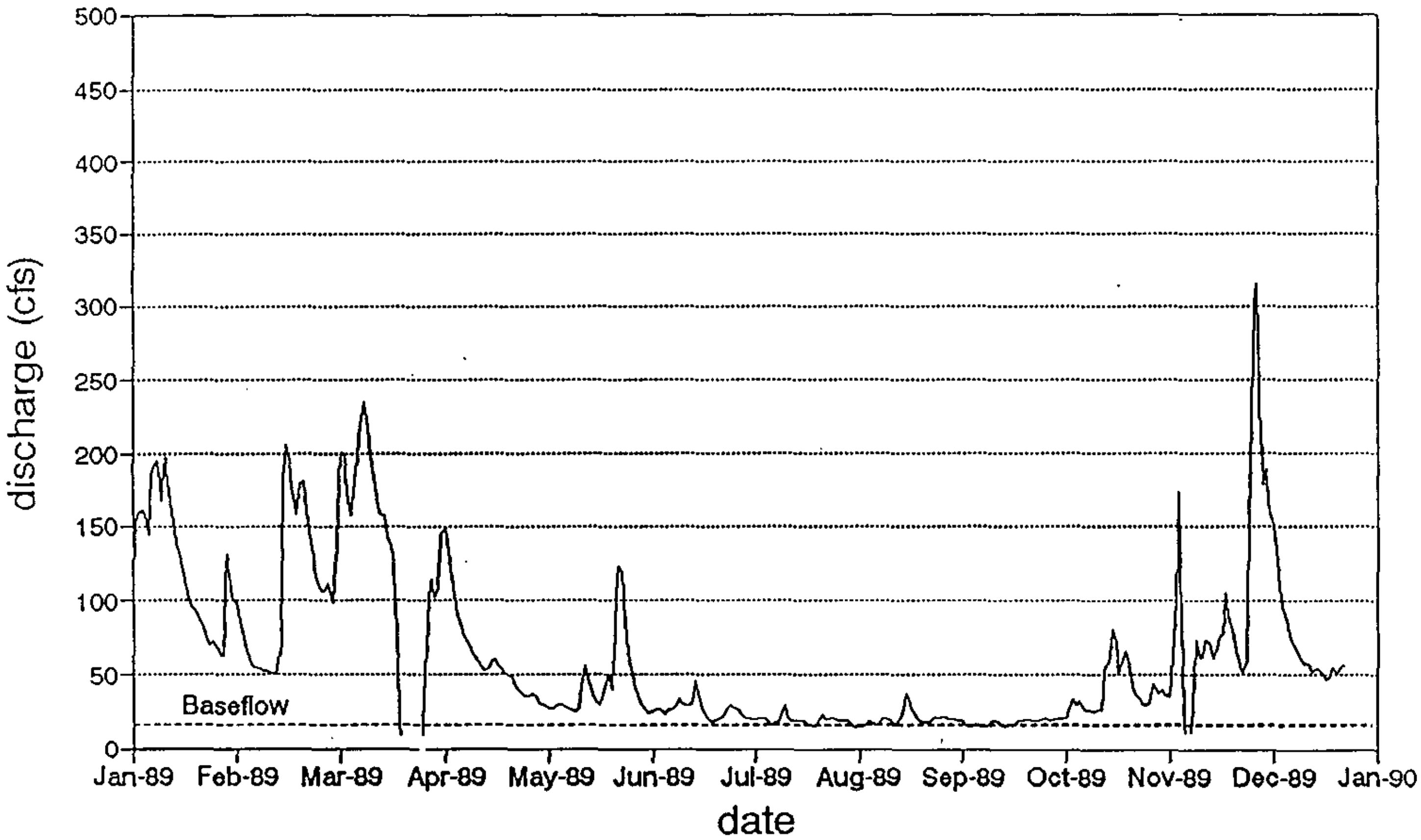

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Figure 2-16
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

STATION 5 - EVANS CREEK

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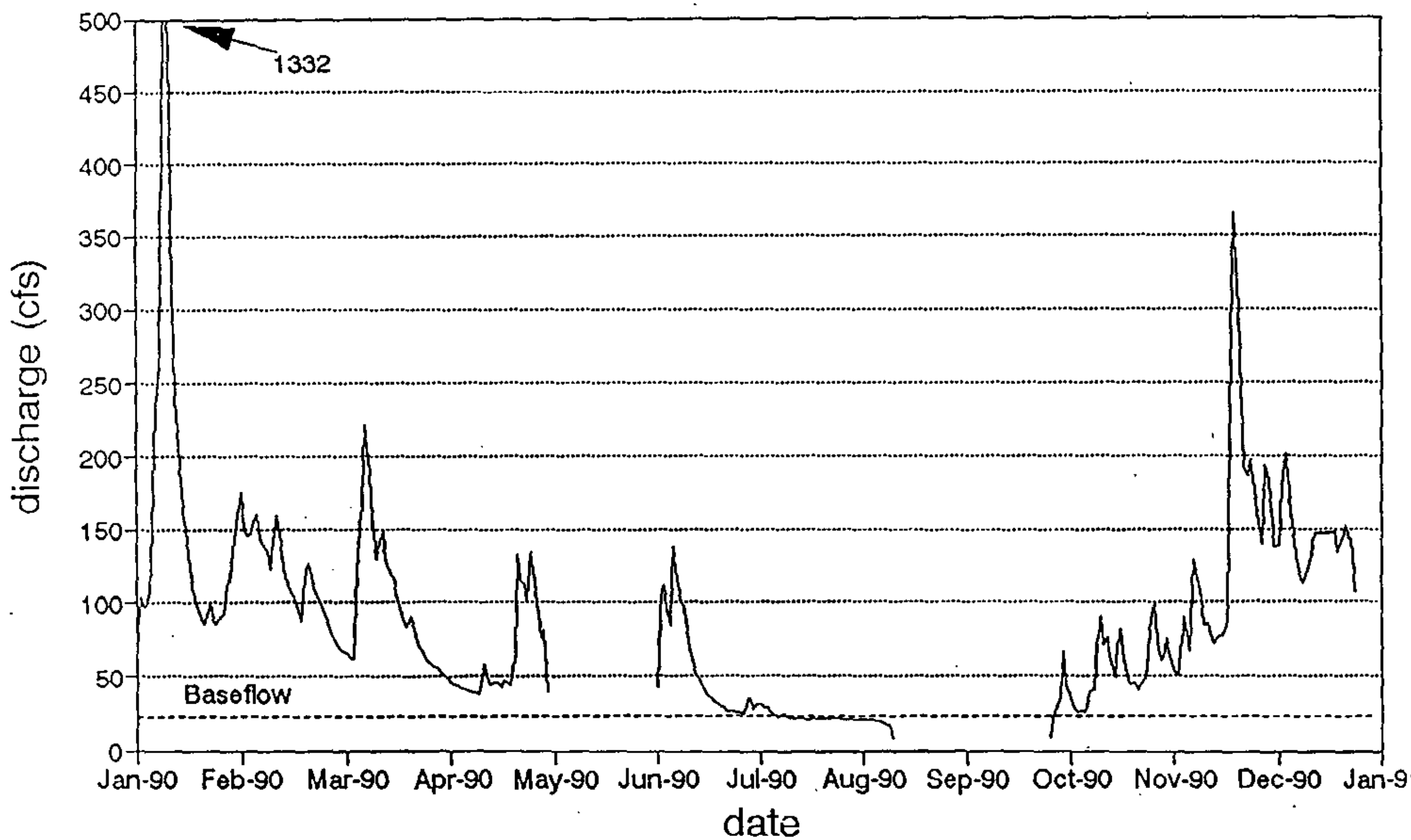

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Figure 2-17
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

STATION 5 - EVANS CREEK (1990)

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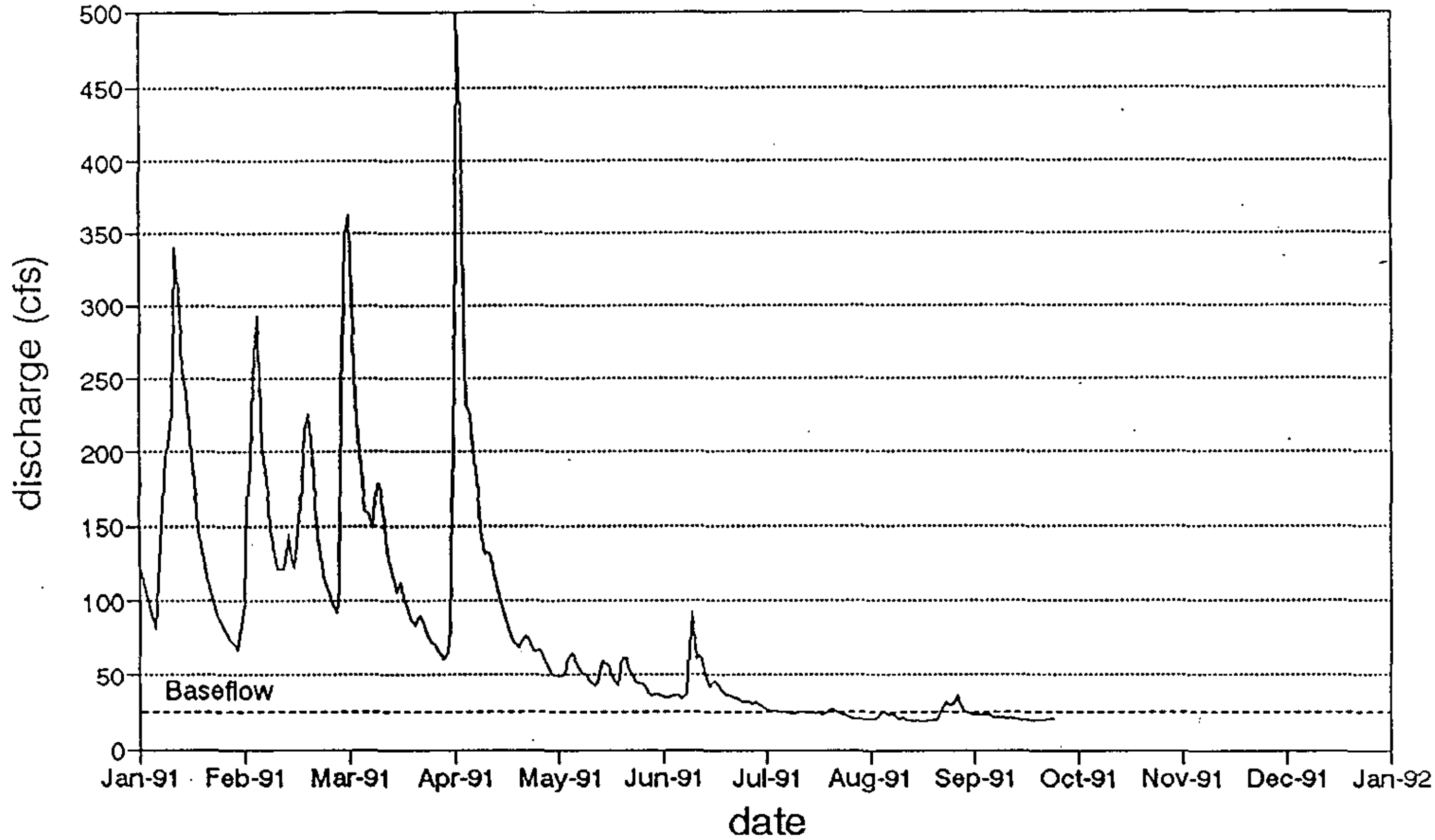

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Figure 2-18
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

STATION 5 - EVANS CREEK (1990)

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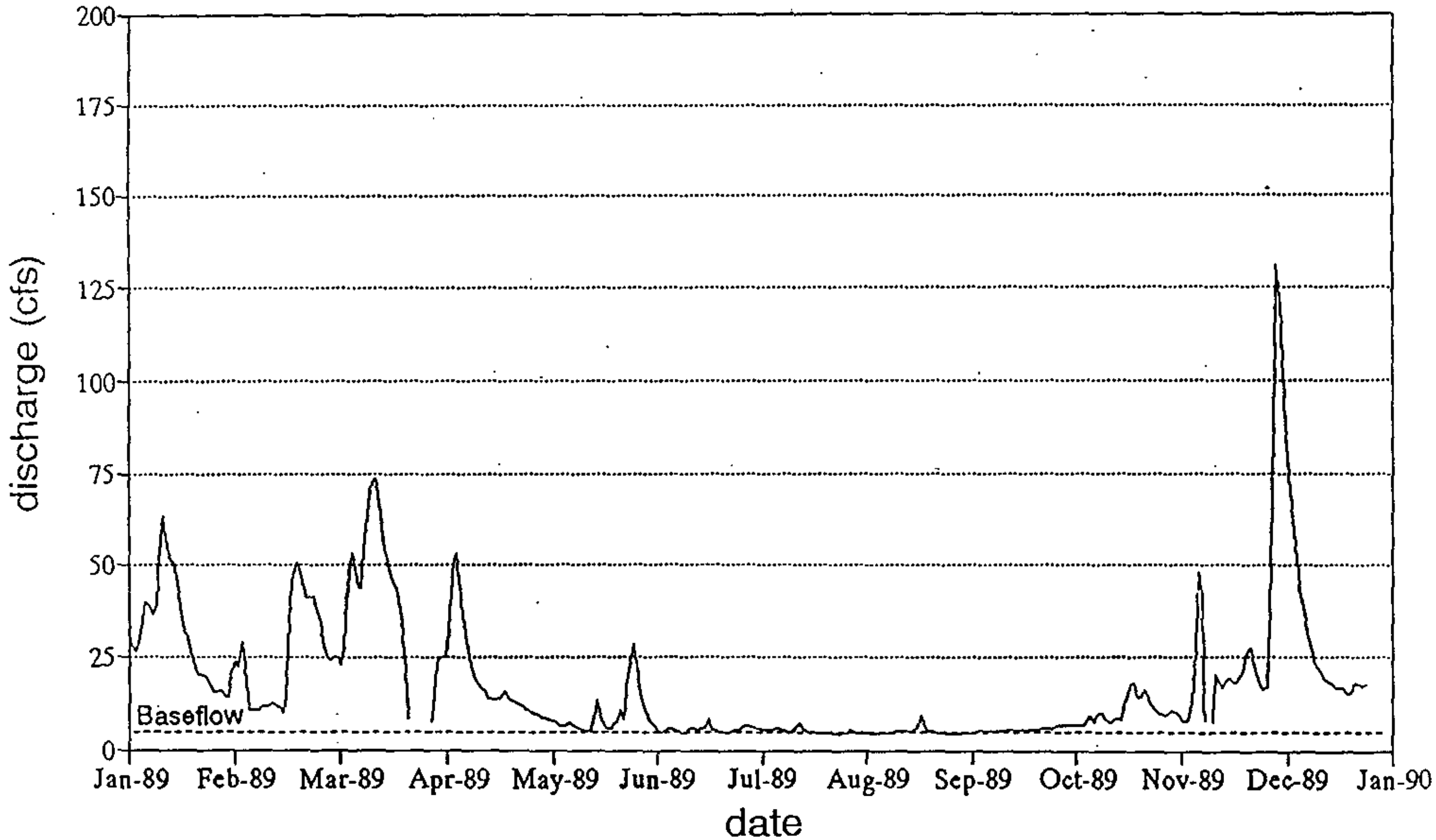

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Figure 2-19
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

STATION 6 - EVANS CREEK (1989)

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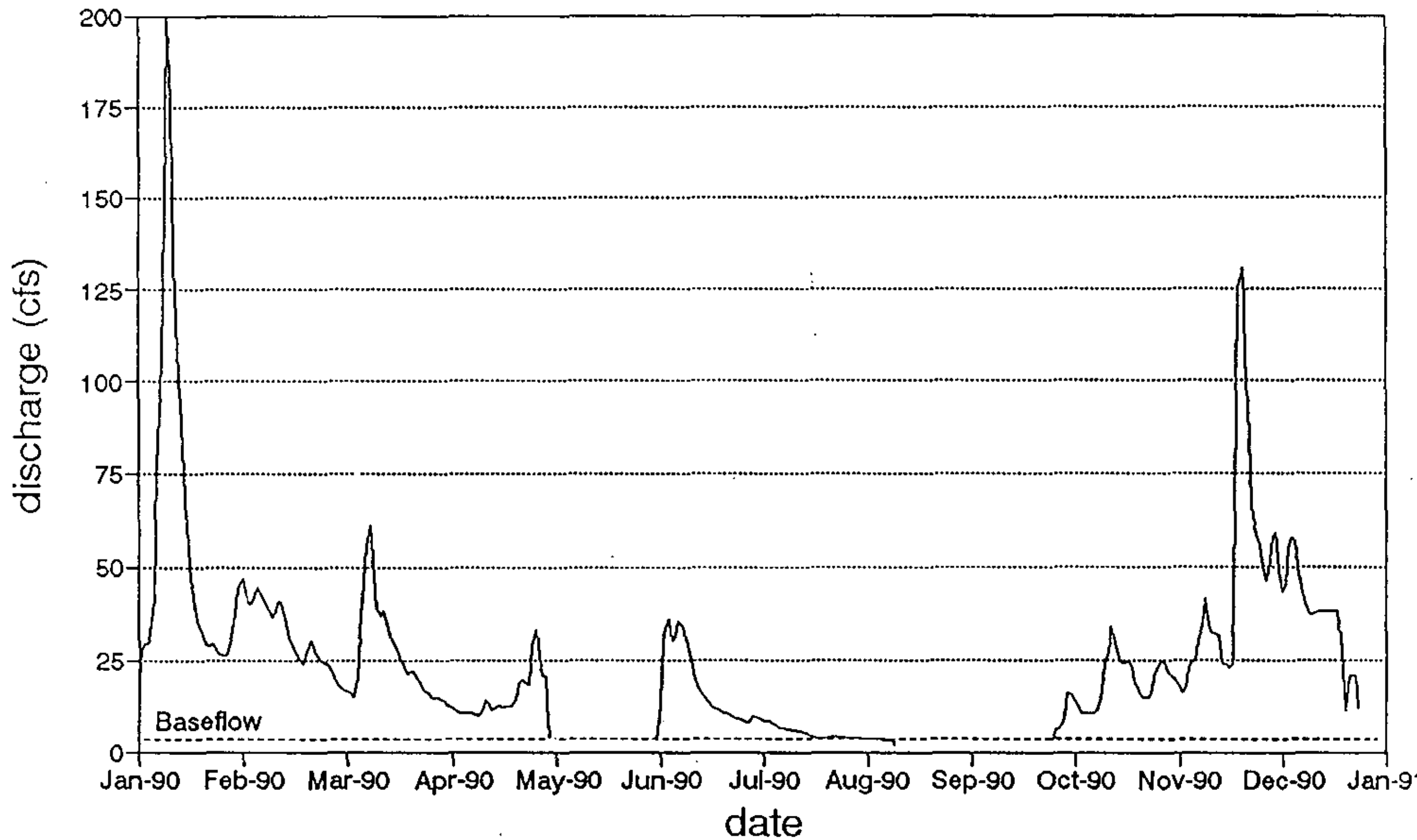

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Figure 2-20
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

STATION 6 - EVANS CREEK (1990)

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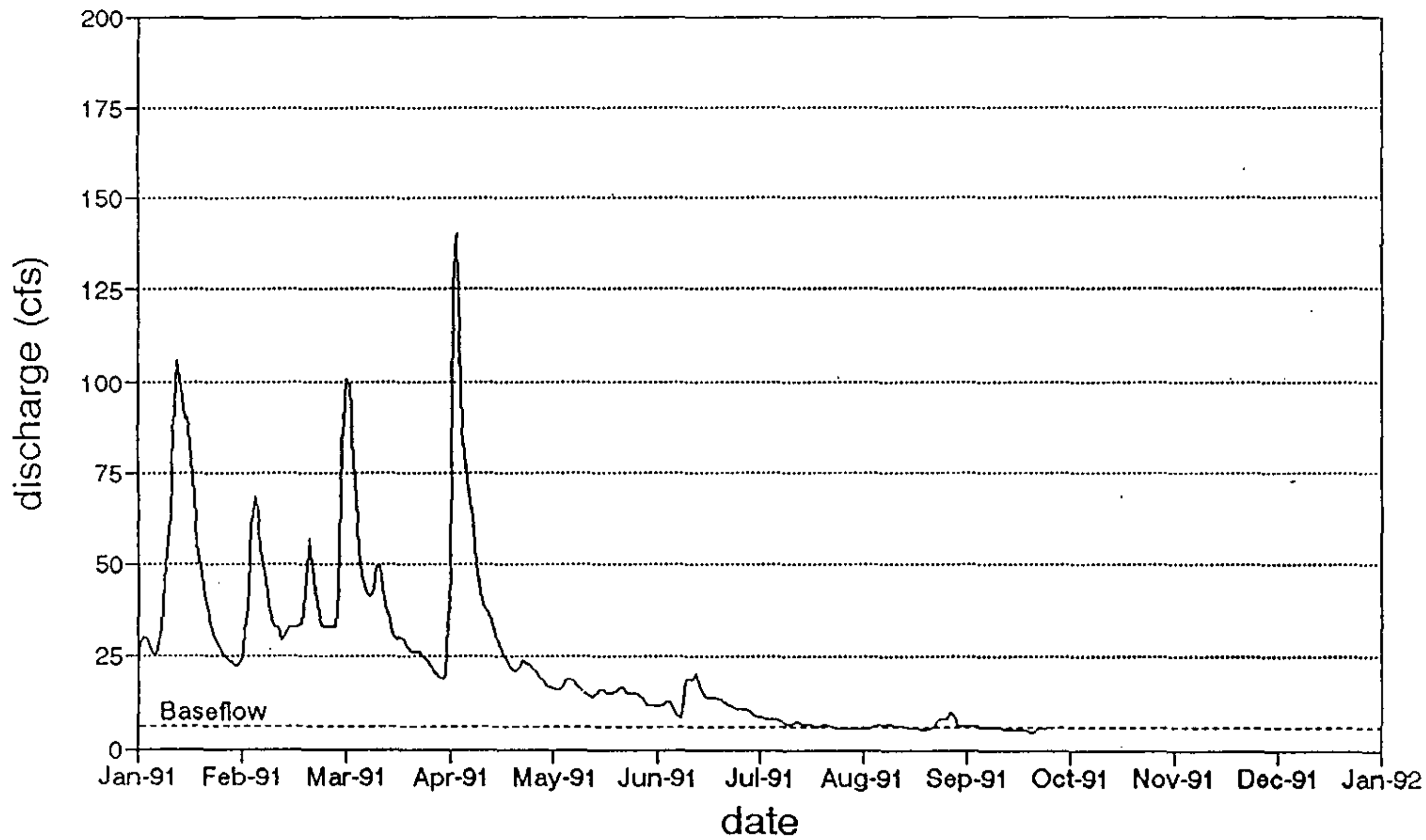

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Figure 2-21
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

STATION 6 - EVANS CREEK (1991)

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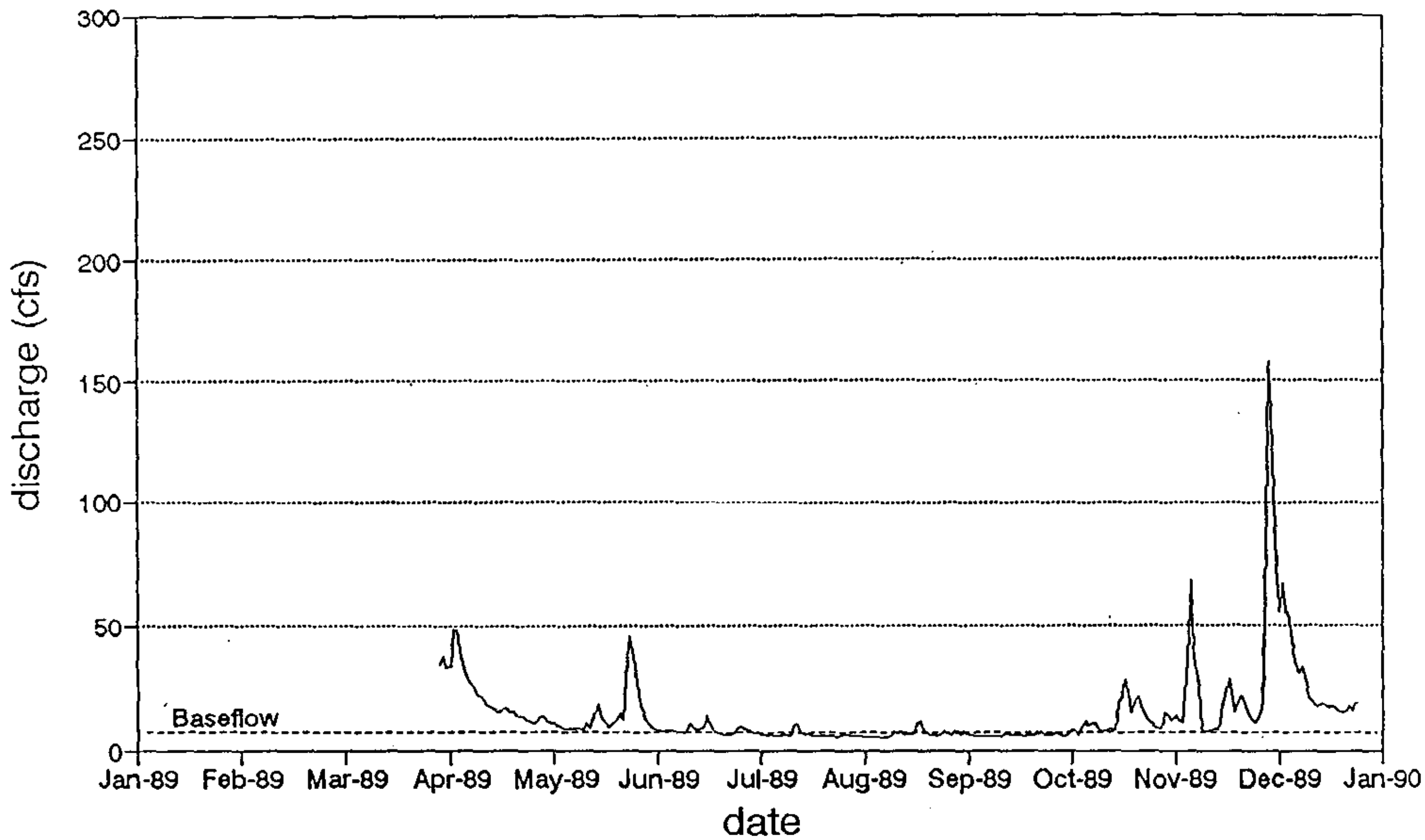

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Figure 2-22
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

STATION 4 - BEAR CREEK (1989)

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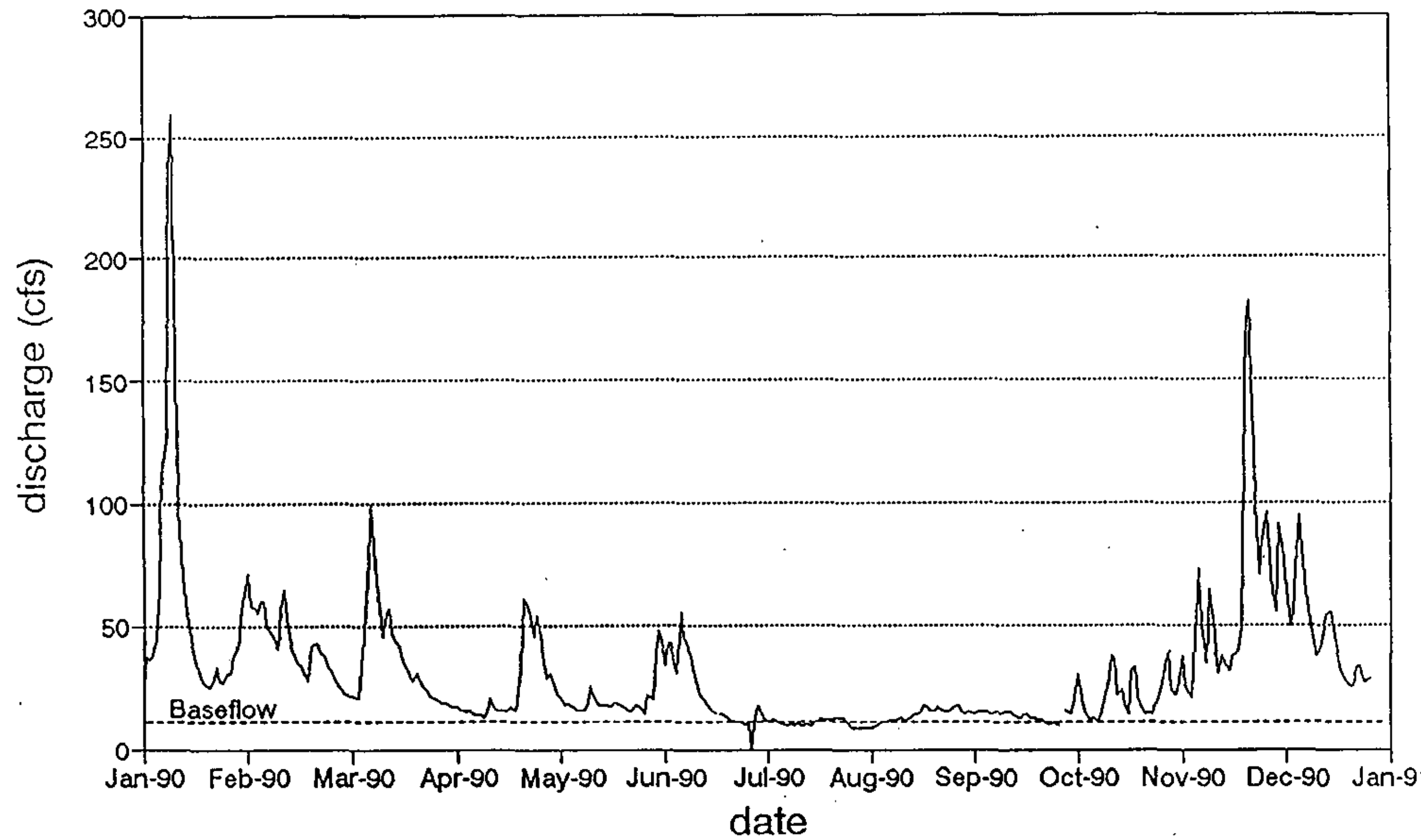

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Figure 2-23
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

STATION 4 - BEAR CREEK (1990)

150969

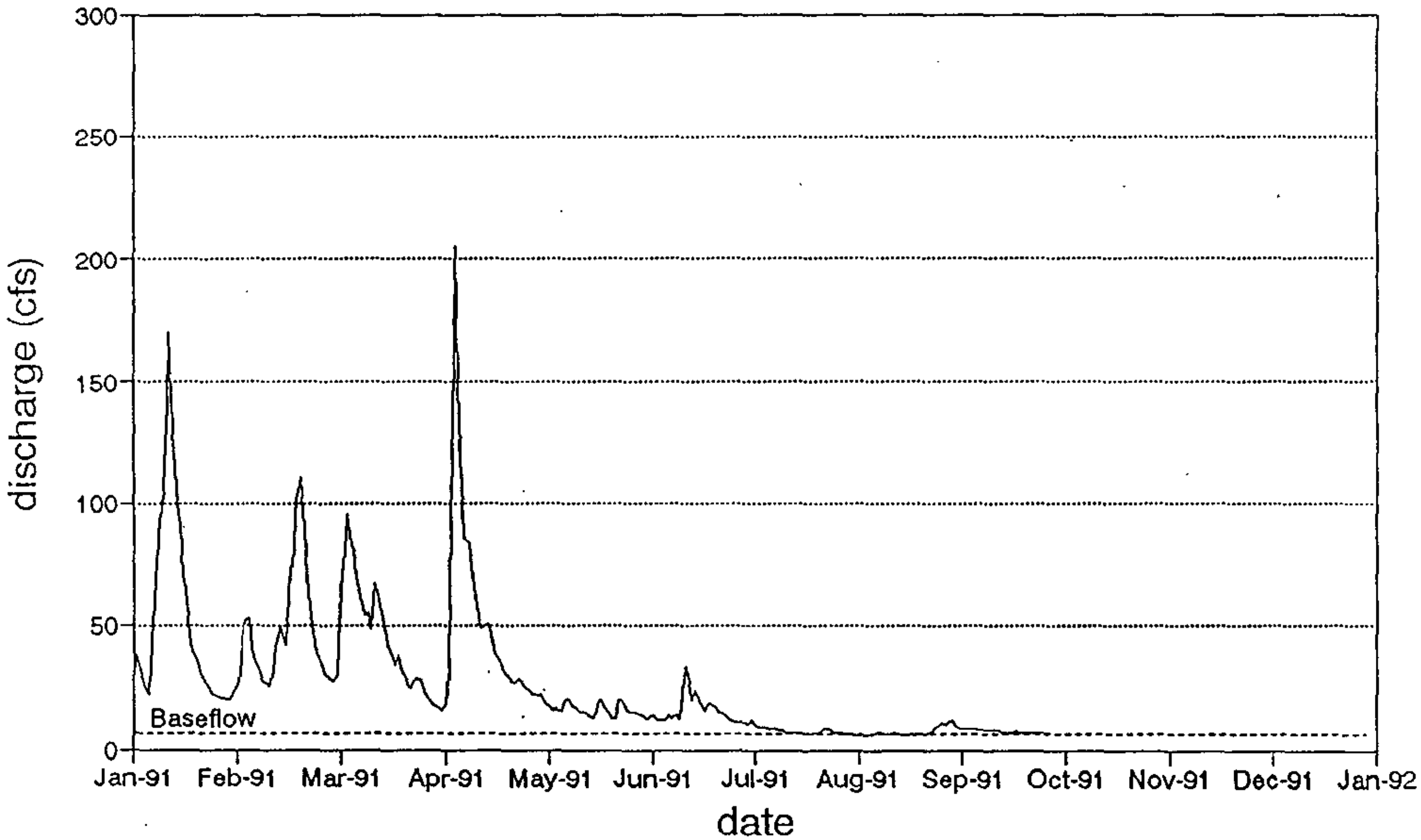

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Figure 2-24
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

STATION 4 - BEAR CREEK (1991)

Table 2-5 Summary of Stream Discharge Gauging Data

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once a month, beginning in February 1989 and continuing through July 1991. Not all wells were monitored the entire period and monitoring of some wells is still ongoing. Table 2-6 is a summary of the wells used in the monitoring network. Well locations are shown on Figure 2-25.

2.5.1 Well Selection

Well driller's logs obtained from the Department of Ecology were reviewed, several wells were selected for possible monitoring, and each potential well was field checked. Wells were selected for monitoring based on the following criteria: (1) location of the well within the study area, (2) well construction, (3) aquifer zone, and (4) usefulness of data on the well logs. Each well was identified as producing from a shallow aquifer zone or a lower deep aquifer zone. Representative wells were selected to provide a uniform distribution for aquifers throughout the study area. Finally, each owner's permission was obtained before water levels were measured. Driller's well logs for the wells selected for monitoring are presented in Appendix F.

3.5.2 Water Level Measurements

Water level measurements were obtained by personnel from the City of Redmond, Seattle-King County Health Department (SKCHD), EMCON Northwest, Union Hill, and Northeast Lake Sammamish Water Districts and Volunteers from the Redmond Ground Water Advisory Committee. Water level data forms were used to record depth-to-water measurements. The data were then entered into the SKCHD Data Base. Copies of water level measurements for each well are provided in Appendix G.

Water levels were measured with a Slope Indicator Model 51453 water level indicator, an electronic measuring device which indicates the point at which a probe lowered into the well makes contact with water. The distance from the top of the well casing to the probe is then recorded to the nearest 0.01 foot. Before lowering the probe into each well, it was disinfected with liquid chlorine bleach, then rinsed with distilled water.

The water level elevation for each well was calculated by subtracting depth-to-water from the elevation at the top of the well casing. Elevations were obtained from survey data collected by Phillips and Associates, Engineers of Bellevue, Washington.

Table 2-6

Ground Water Monitoring Sites

Well Identification	Well Name	Use	Monitoring Type
1	Doughty, Lee	D	WL/WQ
2	Woodinville Water	D	WL/WQ
3	Paradise Park	D	WL/WQ
4	Bondo, Paul	D	WL/WQ
5	Odegard, David	D	WL/WQ
6	Kloepfer, Ryan	D	WL/WQ
7	Hosey #1	D	WL/WQ
8	Morgan, James	D	WL
9	Rigger Assoc.	D	WL
10	Tainter, Gordon	D	WL/WQ
11	Smith, Don	D	WL
12	Sharp, Grant	D	WL/WQ
13	Nelson, Gordon	D	WL/WQ
14	Thenos Dairy	D	WL/WQ
15	Thompson, Steve	D	WL
16	Ulrich Meats	D	WL/WQ
17	Heller, Charles	D	WL
18	Whyte, Myrna	D	WL
19	O'Leary, Chris	D	WL
20	Weide, Mike	D	WL/WQ
21	Stern, William	D	WL/WQ
22	Fischer, Leo	D	WL
23	Lien, William	D	WL/WQ
24	Larson (Stetler)	D	WL
25	Tollfeldt, Harvey	D	WL
26	Bauman, John	D	WL
27	Webster, Walt	D	WL/WQ
28	Sorenson	D	WL
29	Goss, Gordon	D	WL/WQ
30	Hutchinson, Ron	D	WL
31	Macklin	D	WL

Table 2-6

Ground Water Monitoring Sites
(Continued)

Well Identification	Well Name	Use	Monitoring Type
32	McGlothlin, Del	D	WL
33	Home Port Farm	D	WL/WQ
34	Patterson, Stan	D	WL/WQ
35	Bowman, Carl	D	WL/WQ
36	Loveless (Stensland)	D	WL
37	Redmond Well #3	P	WL/WQ
38	McClan, Robert	D	WL/WQ
39	Keller Dairy	D	WL
40	Olympian Precast	I	WL/WQ
41	King County Shops	I	WL/WQ
42	Eastside Masonary	I	WL
43	Barrett, Del	D	WL/WQ
44	Redmond GWMA Test Well	MW	WL/WQ
45	Lacher	D	WL
46	Science Park B-1	MW	WL
47	Science Park B-2	MW	WL
48	Redmond Well #5	P	WL/WQ
49	Redmond Test Well #5	MW	WL
50	Redmond Cemetary	I	WL
51	Cedar Lawns Cem.	I	WL/WQ
52	Redmond Well #1	P	WL/WQ
53	Redmond Well #2	P	WL/WQ
54	Redmond Oil Co. #1	MW	WL
55	Redmond Oil Co. #2	MW	WL
56	Town Center I	I	WL
57	Washington Voc-Tech	I	WL
58	Gateway Piezometer #1	MW	WL
59	Gateway Piezometer #2/3		
60	Redmoor Corporation	I	WL
61	Campton Community	D	WQ

Table 2-6

Ground Water Monitoring Sites (Continued)

Well Identification	Well Name	Use	Monitoring Type
62	Sportsman Park	I	WL/WQ
63	Welcome	D	WL
64	Evans Creek Test Well 1	MW	WL/WQ
65	Turpsmith	D	WL
66	Ingalls, Robert	D	WL
67	Zimmerman, Margret	D	WL
68	Ramsey	D	WL
69	Tutko Landscape	D	WL/WQ
70	NEL Samm #6	P	WL
71	Varney	D	WL
72	Robretson, Richard	D	WL
73	Union Hill	P	WL/WQ
74	Evans Creek Test Well 2	MW	WL/WQ
75	NELS Test Well #1	MW	WL/WQ
76	NE L Samm #2	P	WL/WQ
76	NE L Sam #2R	MW	WL
77	NE L Sam #4	P	WL/WQ
78	NE L Sam #5	P	WL
79	NE L Sam #3	P	WQ
80	Sahalee	I	WL
81	Marymoor	MW	WL/WQ
82	Flippen	D	WL

NOTES:
WL = Water Level Monitoring
WQ = Water Quality Monitoring
D = Domestic Water Supply (includes irrigation use)
P = Public Water Supply
MW = Dedicated Monitoring Well
I = Industrial as Commercial

Figure 2-25 Locations of Monitoring Wells in GWMA

D

R

A

F

T

2.6 Ground Water Quality Sampling

Ground water samples were collected from each of 35 wells in the GWMA. Samples were collected in December 1989 and May 1990. For the December 1989 ground water sampling, samples were collected from all wells and analyzed for primary and secondary drinking water standard analytes and characteristic constituents (including major and minor ions). Selected wells were also tested for total organic halogen (TOX). For the May 1990 ground water sampling, analysis of ground water from selected wells was expanded to include volatile organic compounds (VOCs), semivolatile organic compounds (BNAs), chlorinated pesticides and polychlorinated biphenyls (PCBs), and the priority pollutant metals which were not already included in drinking water standard constituent testing. During the May 1990 sampling, a reduced number of wells were tested for TOX.

Analytical testing parameters were selected to allow characterization of ground water quality and characteristics in the GWMA. All wells were tested for primary and secondary drinking water standard constituents to determine whether ground water in the GWMA generally meets national drinking water standards. TOX analyses were used to scan for potential ground water contamination. VOC, BNA, and additional priority pollutant metals testing were used to assess potential ground water contamination. The locations of wells sampled for this study are shown on Figure 2-25. Constituents tested at each well are listed in Table 2-7.

All ground water samples were collected in accord with standard procedures described in the Redmond-Bear Creek Ground Water Management Area Quality Assurance Project Plan (SE/E, March 2, 1990), and the Redmond-Bear Creek Ground Water Management Area Data Collection and Analysis Plan (SE/E, March 5, 1990). All chemical data were reviewed and are considered valid for the purposes and within the limitations of this report. Copies of the laboratory testing results for each well are included in Appendix H.

Table 2-7

Redmond-Bear Creek Ground Water Management Area
Ground Water Sampling Locations and Parameters

Well Identification		Analyses Performed	
Well Number	Well Owner's Name	December 1989 Sampling	May 1990 Sampling
1	Doughty, Lee	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
3	Paradise Park	PDW, SDW, GWC, TOX	PDW, SDW, GWC
4	Bondo, Paul	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
5	Odegard, David	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
6	Kloepfer, Ryan	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
7	Hosey #1	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
10	Tainter, Gordon	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
12	Sharp, Grant	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
13	Nelson, Gordon	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
14	Thenos Dairy	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
16	Ulrich Meats	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
20	Weide, Mike	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
21	Stern, William	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
23	Lein, William	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
27	Webster, Walt	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
29	Goss, Gordon	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
33	Home Port Farm	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
34	Patterson, Stan	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
35	Bowman, Carl	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
38	McClan, Robert	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
40	Olympian Precast	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX, Others
41	King County Shops	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
43	Barrett, Del	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
48	Redmond Well #5	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
51	Cedar Lawns	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
53	Redmond Well #2	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX, Others
61	Campton Community	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
62	Sportsman Park	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
64	Evans Creek Well #1	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX

Table 2-7

Redmond-Bear Creek Ground Water Management Area (Continued)

Well Identification		Analyses Performed	
Well Number	Well Owner's Name	December 1989 Sampling	May 1990 Sampling
69	Tutko Landscape	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
73	*Union Hill	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
74	Evans Creek Well #2	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
76	NE Sammamish #2	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
77	NE Sammamish #4	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX
79	NE Sammamish #	PDW, SDW, GWC, TOX	PDW, SDW, GWC, TOX

NOTES:
PDW: Primary Drinking Water Analytes (see Section 5.2.1)
SDW: Secondary drinking water analytes (see Section 5.2.2)
GWC: Ground water characteristic constituents (see Section 5.2.3)
TOX: Total organic halogen (see Section 5.2.4)
Others: Cyanide, phenol, volatile and semivolatile organic compounds, chlorinated pesticides, PCVs, antimony, beryllium, nickel, and thallium (see Section 5.2.4)

3 GEOLOGY

3.1 General Description

The Redmond-Bear Creek study area contains three basic rock types: Tertiary or older sedimentary and crystalline bedrocks, semi-consolidated to unconsolidated fluvial, glacial, and marine Pleistocene sediments, and Recent alluvium (Figure 3-1)

The depth to bedrock in the study area ranges from 0 feet to 1,500+ feet below ground surface. Bedrock may occur at the surface only in a small outcrop near Peterson Pond in the southeast corner of the GWMA.

In most of the study area, Bedrock exists beneath 400 to 1,200 feet of Pleistocene sediments (Hall & Othberg, 1974). These sediments appear to be thickest near the City of Redmond at the north end of Lake Sammamish.

Glacial deposits typically include outwash deposits, glacial till, and interglacial lacustrine deposits. Outwash deposits are composed of sands and gravels deposited as the glacial ice advanced (advance outwash) or receded (recessional outwash). Glacial till, a compact mixture of gravel, sand, silt, and clay, is formed by glaciers overriding, grinding, and compacting outwash material. Lacustrine (lake) sediments typically include finer-grained materials such as clay, silt, and fine sand and often contain organic debris.

Individual geologic units in the GWMA are difficult to distinguish based only on the descriptions provided on driller's well logs. Using data derived from a combination of sources including well logs, field investigations, and geophysical surveys, seven geologic units have been identified beneath the GWMA. The units, from youngest to oldest, are as follows:

- Alluvium
- Vashon Recessional Outwash
- Vashon Glacial Till
- Vashon Advance Outwash
- Transitional Beds

Figure 3-1 Generalized Geologic Map

- Olympia Gravel
- Older Undifferentiated Deposits

A stratigraphic column indicating the estimated age relationships of these units is shown in Figure 3-2.

3.2 Geologic History

The Puget Sound basin has been in existence since Tertiary times when sedimentary and volcanic basement rocks were folded downward between the Olympic and Cascade ranges. The resulting basin provided an avenue for several episodes of piedmont or ice sheet-type glacial flow from southwestern Canada, with concurrent sedimentary deposition during the Pleistocene and Recent post-glacial topographic modifications by erosion and deposition have been minor, occurring primarily along river floodplains.

Two and perhaps four glacial episodes occurred during the Pleistocene age. A maximum of 1,000 feet of glacial, river, lake, and marine sediments was deposited in the study area during the first glacial episodes and interglacial periods (Thorsen, 1983). The final episode of glaciation, termed the Vashon stade, was the most significant geologic influence on the development of ground water in the study area. Approximately 20,000 years ago, the ice sheet was in the vicinity of Vancouver, British Columbia; 18,00 years ago, the ice sheet had reached the Port Townsend area and effectively isolated the Puget Sound Basin from the Strait of Juan de Fuca.

A large lake developed in front of the ice front, and thick sequences of fine-grained sediments were deposited in the basin. As the ice advanced and reached the maximum southern limits 14,000 years ago, lateral streams from the Olympic and Cascade ranges were blocked by ice, diverting flow through temporary channels. Thick sequences of coarse sands and gravels flowed from the ice front, spreading over the basin and mixing with river sediments. The ice front overrode the coarse sediments and deposited a veneer of till (a mixture of clay, silt, and fine gravel). The ice reached a maximum thickness of 3,000 feet and an elevation of approximately 5,000 feet above mean sea level (AMSL) in King County. The weight of the ice compressed the till and depressed the basin. Soon after the glacial maximum, the ice front began to recede as the rate of accumulation of snow and ice became lower than the rate of melting. By 12,500 years ago, the ice had retreated from the study area. Isolated lenses of sand and

GEOLOGIC			FORMATION	
PERIOD	EPOCH	YEARS BEFORE PRESENT	DESCRIPTION	YEARS BEFORE PRESENT
		0		0
QUATERNARY	HOLOCENE	12,000 yr	ALLUVIUM (Qal) AND RECESSIONAL OUTWASH (Qvr)	12,000 yr
	PLEISTOCENE		VASHON GLACIAL DEPOSITS (Qvt & Qva)	20,000 yr
			OLYMPIA INTERGLACIAL (Qtb & Qog)	40,000 yr
		2 my	OLDER UNDIFFERENTIATED GLACIAL AND NONGLACIAL DEPOSITS	2 my
TERTIARY	PLIOCENE	5 my	NO UNITS PRESENT IN STUDY AREA	4.7 my ? 6.5 my
	MIOCENE	24 my		17 my
	OLIGOCENE	38 my	SEDIMENTARY ROCKS (Ts)	
	EOCENE	55 my		
	PALEOCENE	63 my		63 my
PRETERTIARY			PRETERTIARY METAMORPHIC AND VOLCANIC ROCKS UNDIFFERENTATED	

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Figure 3-2

REDMOND BEAR CREEK GWMA

GENERALIZED STRATIGRAPHIC COLUMN

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gravel were deposited from the ice margins as the glacier retreated. After the ice had retreated beyond the lateral streams and into the strait, rivers returned to former channels and marine deposition continued (Thorsen, 1983).

The geologic history throughout King County includes the following chronology (listed from youngest to oldest):

- non-glacial recent deposits
- Frasier Glaciation
- Olympia Interglaciation
- Possession Glaciation
- Pre-Possession Interglaciation
- Double Bluff Glaciation
- Pre-Double Bluff fluvial and lacustrine deposition
- compaction of sediments into layers of shale, sandstone, and peat
- deposition of volcanic debris and sedimentary material into a subsiding basin which covered most of western Washington during the Tertiary Period

The surficial and subsurficial geologic deposits form distinct layers exposed at the surface and in deep borings in the study area. These deposits are presented in five geologic cross-sections shown in Figures 3-3 to 3-7. Well logs used to prepare these cross-sections are presented in Appendix I.

3.3 Geologic Units

3.3.1 Alluvium

Post-glacial depositional and erosional processes have modified the glacial land forms and former stream and river valleys. Today, alluvial sediments are found primarily in the Evans Creek and Bear Creek valleys and in the downtown portion of the City of Redmond, north of Lake Sammamish. The alluvial deposits are composed of organic-rich fine sand, silt and clay. Their maximum thickness is approximately 40 feet.

Vashon Recessional Outwash. The Recessional Outwash consists primarily of well-drained stratified sand and gravel with some silt and clay deposited from meltwater flowing from the receding glacier. In the study area, Recessional Outwash deposits range up to 90 feet in thickness. The Recessional Outwash deposits are generally discontinuous and occur as

Figure 3-3 Geologic Cross-Section A-A'

D

R

A

F

T

Figure 3-4 Geologic Cross-Section B-B'

Figure 3-5 Geologic Cross-Section C-C'

D R A F T

Figure 3-6 Geologic Cross-Section D-D'

D R A F T

Figure 3-7 Geologic Cross-Section E-E' and F-F' isolated surface deposits in the upper Bear Creek Valley, around Cottage Lake, on the western edge of Union Hill, and in the Evans Creek Valley.

Vashon Till. Commonly known as "hardpan" due to its compacted nature, the Vashon Till consists of non-sorted clay, silt, sand, gravel, and boulders deposited directly by glacial ice and compacted by the weight of the overriding glacier. The Vashon Till is present at the surface over much of the GWMA, including Education Hill, Hollywood Hill, Novelty Hill, and Union Hill. The till is typically only slowly permeable and causes water percolating down from the surface to pond or perch on the top of the unit, forming a perched water table and swampy areas. The till ranges up to 100 feet thick in the study area and appears to be thickest in the northern portion of the GWMA.

Vashon Advance Outwash. Vashon Advance Outwash deposits underlie the Vashon Till and consist of stratified clean sand and gravel with some thin clay beds. The thickness of this unit ranges up to 90 feet in King County and comprises one of the thickest and most extensive aquifers in the area.

Deposits of Advance Outwash are exposed on the upper portions of the steep slopes bordering the Snoqualmie River, Evans Creek, Bear Creek, and Cottage Lake Creek. In the study area, Advance Outwash generally underlies the Vashon Till except where it has been eroded away by creeks.

3.3.2 Pre-Vashon Deposits

Transitional Beds. The Transitional Beds are made up of glacial and non-glacial lacustrine deposits which consist mainly of laminated or thin-bedded to thick-bedded blocky jointed clay, silt, and fine sand. This unit was formed mainly from sediments deposited in a large lake which 14,000 years ago, covered much of the Puget Sound region between the Olympia Interglacial period and the early Frasier Glaciation. The Transitional Beds range up to 180 feet thick in King County, with the thickest exposures visible along the west bank of the Snoqualmie River. The Transitional Beds are also visible at the surface on the slopes along Evans Creek and in a small area of the Hollywood Hills.

Olympia Gravel. The Olympia Gravel consists of stratified fine to very coarse sand and gravel with minor thin silt and clay beds deposited by streams. This unit ranges up to 135 feet in thickness and is visible in the GWMA on the lower slopes bordering Lake Sammamish and the Evans Creek Valley. Elsewhere, the Olympia Gravel underlies the transitional beds at elevations ranging from 200 feet amsl to 200 feet below mean sea level.

Older Undifferentiated Deposits. Older undifferentiated deposits include both glacial and non-glacial sediments deposited by glacial events older than the Vashon Glaciation 18,000 years ago. The materials consist of stratified and unstratified silt, sand, gravel, and clay deposited as glacial drift and interglacial lacustrine clay and silt. These deposits are generally not visible at the surface in the GWMA, but underlie most of the region. These deposits have been penetrated by several of the deep wells in the GWMA, including the Woodinville Water District and Redmond test wells. Where present in the GWMA, the deposits have a minimum thickness of 400 feet.

4 HYDROGEOLOGY

This section describes the occurrence, movement, recharge, and discharge of ground water within the Redmond-Bear Creek GWMA. The GWMA is underlain by at least four major water-bearing zones which, for the purpose of this report, have been termed the Alluvial Aquifers, the Sea Level Aquifers, the Local Upland Aquifers, and the Regional Aquifers.

The Alluvial Aquifers consist of a number of different deposits including recent and older alluvium deposited in and along stream channels in the GWMA. The Sea Level Aquifers consist of the Olympia Gravel and some older undifferentiated deposits found at elevations near mean sea level. The Local Upland Aquifers are made up of discontinuous Advance Outwash deposits and permeable zones within the Vashon Till. The upland aquifers underlie the ridges on the eastern, western, and southern boundaries of the GWMA. The Regional Aquifers are composed of the older undifferentiated glacial and interglacial deposits which underlie most of the GWMA (refer to Figures 3-3 to 3-7).

4.1 Occurrence of Ground Water

Geologic materials able to store and transmit ground water are considered to be aquifers. In the Redmond-Bear Creek area, the major aquifer systems can be divided into shallow, intermediate, and deep ground water systems. Shallow ground water systems occur as alluvial deposits along the major streams and the shallow portions of the upland aquifers. Intermediate ground water systems occur as Sea Level Aquifers and the deeper portions of the Local Upland Aquifers. Below the intermediate and shallow aquifer systems, the deeper Regional aquifers are contained in older undifferentiated deposits of sand, gravel, and silt deposited during past glacial, interglacial, and pre-glacial periods.

4.2 Major Hydrostratigraphic Units

The hydrostratigraphy of the Redmond-Bear Creek GWMA includes a number of aquifers and aquitards. The major hydrostratigraphic units delineated based on field activity findings discussed in Section 2 of this report include four aquifer zones (Alluvial, Local upland, sea level, and Regional) and at least two major aquitards (Vashon Till and Transitional Beds). Each of the wells used to collect water level and water quality data were delineated based on location and water intake elevation into one of the four aquifer zones. Table 4-1 shows which aquifer zone each well was assigned to and the corresponding water intake elevations. The distribution of wells monitored for this study in each aquifer zone is shown on Figure 4-1. Each of the major aquifer zones contains more than one water-bearing zone which may or may not be in hydraulic connection with other water bearing zones in the same unit. For example, the local upland aquifers include discontinuous shallow perched water bearing zones which are separated by an aquitard (a geologic material that retards the flow of water) from underlying water bearing zones. Similarly, the regional aquifers include all water bearing zones below approximately 100 feet below sea level. In the future, as more data become available, these hydrostratigraphic units may be further subdivided into additional, more distinct units. The remainder of this section provides a brief description of the major hydrostratigraphic units in the study area.

4.2.1 Alluvial Aquifers

The Alluvial Aquifers appear restricted to alluvial deposits along Cottage Lake Creek, Bear Creek, and Evans Creek. These deposits consist of sand, gravel, and silt deposited in and along stream channels as alluvium, alluvial fan deposits, and older alluvium. The deposits range up to 40 feet in thickness.

At least 36 wells used in this study are screened in the Alluvial Aquifers. Depth to water ranges from less than 10 feet to about 100 feet bgs. Static ground water elevations measured in wells screened in these aquifers range from approximately 140 feet amsl near Evans Creek at the eastern boundary of the GWMA and 100 feet amsl at the northern boundary to less than 20 feet amsl at the discharge area near the northern edge of Lake Sammamish. Monthly ground water elevations in the alluvial aquifers appear to vary by up to 6 feet with seasonal changes in precipitation (Figure 4-2), however, seasonal variations are not large.

Table 4-1

Delineation of Wells by Aquifer Zone

Alluvial Aquifers		Local Upland Aquifers		Sea Level Aquifers		Regional Aquifers	
Well ID	Approximate Intake Elevation	Well ID	Approximate Intake Elevation	Well ID	Approximate Intake Elevation	Well ID	Approximate Intake Elevation
8	68	1	292	6	54	14	-156
9	64	2	210	15	-124	16	-175
23	-59	3	216	26		34	-278
24		4	219	27		35	-224
33	-9	5	171	28	-31	36	-224
37	22	7	171	29		75	-631
40	-66	10	187	30	44	79	-205
41	12	11	161	31	-15		
42	-10	12	231	32	51		
43	50	13	186	68			
44	-10	17	172	74			
45	4	18	227	77	-2		
46	23	19	272	78			
47	24	20	251	79			
48		21	184	80	49		
50	15	22					
51	-37	69	424				
52	-23	71					
53	-23	72	388				
54	10	82					
55	10						
56	-8						
57	2						
58							
59	23						
60	10						
62	1						
63	6						
64	-73						
65	60						
66	31						
67	40						
70	-9						
73	-54						
76	8						
81	-129						

NOTE: 1 Elevation = feet above or below mean sea level.

Figure 4-1 Distribution of Monitoring Wells in Area Aquifers

D

R

A

F

T

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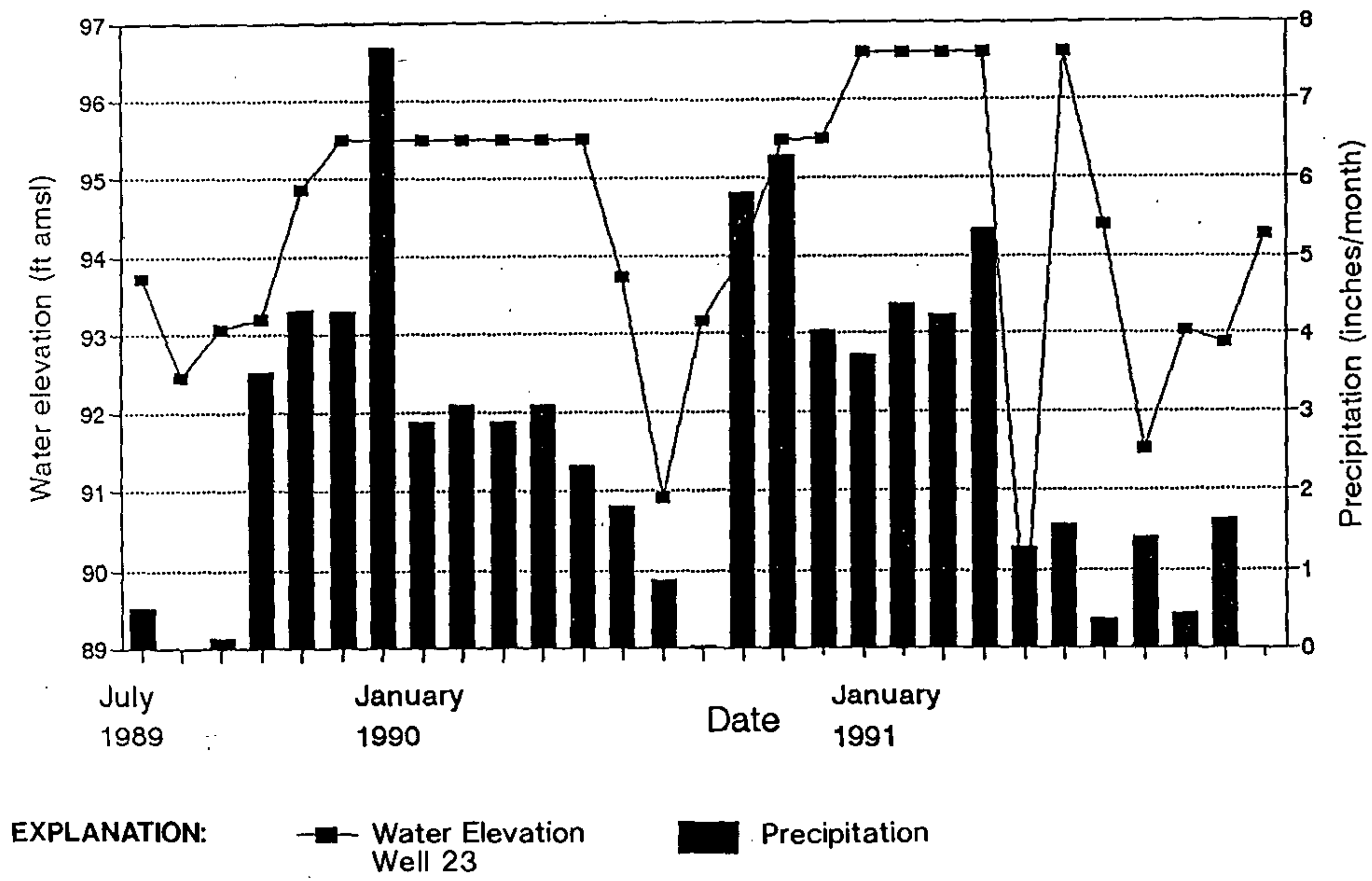

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Figure 4-2
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
WATER LEVEL VS. PRECIPITATION HYDROGRAPH
ALLUVIAL AQUIFERS

4.2.2 Vashon Till

The Vashon till typically forms a low permeability barrier to downward water percolation on the upland surfaces of the study area. Shallow ground water may occur at the base of the upper 8 feet of weathered till, perching on the upper surface of the unweathered till. The presence of till close to the surface is manifested by swampy areas and poor drainage. Ground water is sometimes found within the unweathered portion of the Vashon till, typically restricted to thin, discontinuous lenses of sand and gravel. These sources of water are occasionally tapped by older private wells yielding up to 25 gpm, but are subject to seasonal fluctuation and may completely dry up during the summer months.

Recharge of rain water to the unweathered Vashon till is slow because of low infiltration capacities, and most water is lost through surface runoff. Increased infiltration occurs in the locally higher permeable zones with the ability to transmit and store ground water. Topographic depressions in the upper surface of the unweathered till will trap ground water that slowly infiltrates into underlying geologic units and aquifers.

4.2.3 Sea Level Aquifers

The Sea Level Aquifers underlie the entire GWMA and appear to be relatively independent of topography. These aquifers consist of the Olympia Gravel and may include some of the older undifferentiated deposits. The thickness of these aquifer units is not known, but appears to range from 50 to 135 feet.

At least 13 wells in the GWMA are screened in the Sea Level Aquifers. Depth to water ranges from less than 50 feet to almost 400 feet, depending on surface topography. Ground water levels are higher in the fall than in the spring as shown on Figure 4-3. Seasonal variations in ground water elevation of 10 to 20 feet may result from higher precipitation during the autumn months and lower precipitation in the spring.

4.2.4 Local Upland Aquifers

The Local Upland Aquifers occur beneath the ridge of the GWMA and may be discontinuous. Their occurrence appears to be largely controlled by topography. These aquifers are mainly comprised of Vashon Advance Outwash which ranges up to 90 feet thick in the GWMA. The Local Upland

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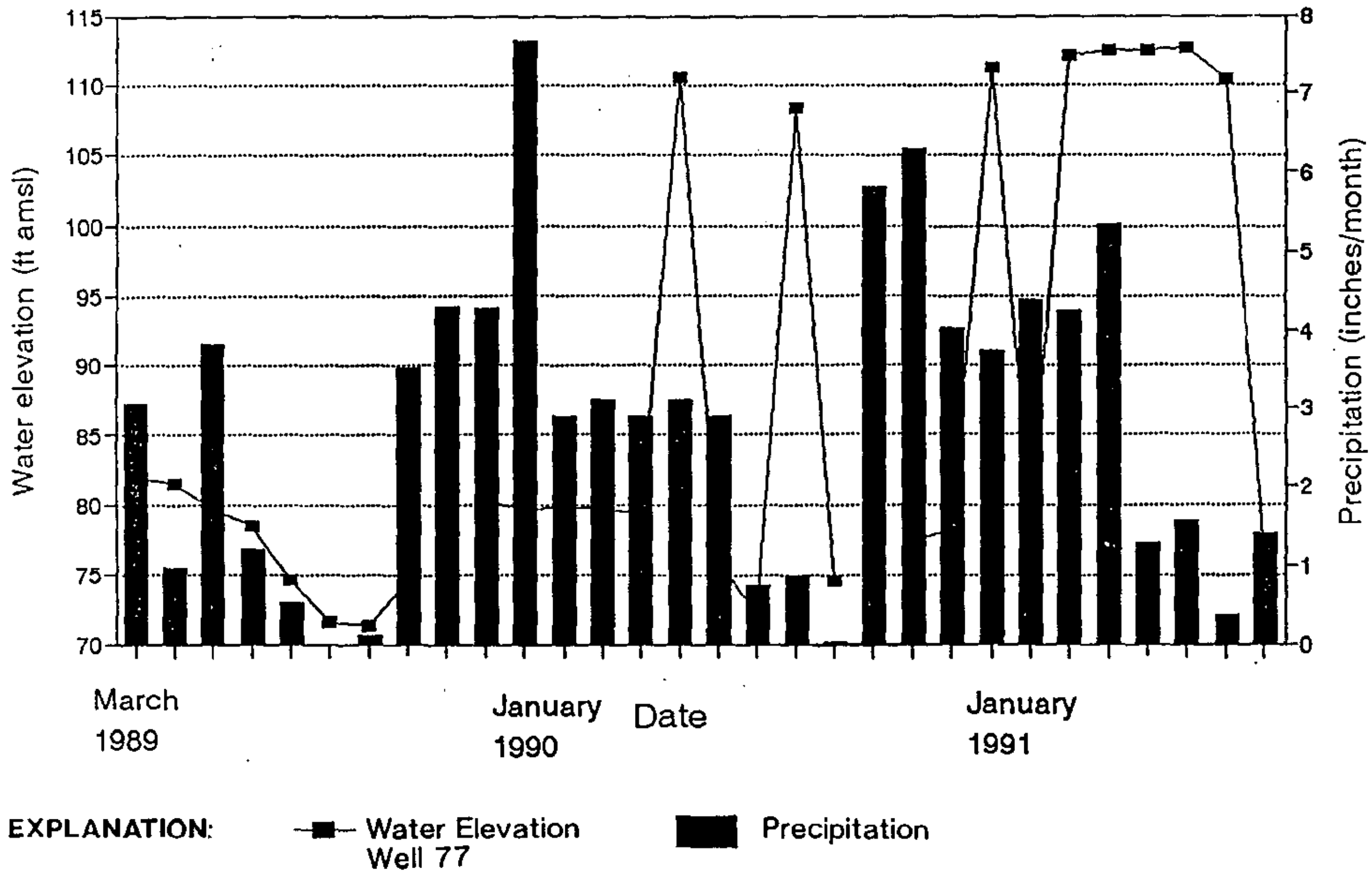

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Figure 4-3
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
WATER LEVEL VS. PRECIPITATION HYDROGRAPH
SEA LEVEL AQUIFERS

Aquifers may also include the more permeable portions of the Vashon Till.

At least 18 wells in the GWMA are screened in the Local Upland Aquifers. Depth to water ranges from less than 10 feet in perched water bearing zones to about 350 feet. The Local Upland Aquifers may recharge the Alluvial Aquifers along the valley walls. The typical response of ground water levels to precipitation is shown in Figure 4-4. Ground water levels in these aquifers show some seasonal variation (generally less than 5 feet).

4.2.5 Transitional Beds

This major hydrostratigraphic unit is an important aquitard separating the Local Upland Aquifers from the Sea Level Aquifers. The unit consists of fifty to hundreds of feet of continuous fine-grained lake-bed deposits that restrict vertical ground water movement between aquifers. Scattered isolated lenses of sand within the transitional beds are locally capable of supplying less than 100 gpm of water. The transitional beds are recharged from above by advance outwash sediments and from below by Olympia gravels and deeper units.

4.2.6 Regional Aquifers

The Regional Aquifers underlie the entire GWMA and are independent of topography. They are composed of the older undifferentiated deposits more than 400 feet thick in the GWMA. In portions of the GWMA, the Regional Aquifers occur below the Olympia gravel and Transitional Beds, usually under confined conditions.

Only five wells used in this study are screened in these aquifers. Depth to water in the regional aquifer can range from about 100 feet to over 400 feet. Static ground water elevations range from 31 to 123 feet amsl. That ground water levels in the Regional Aquifers respond to changes in precipitation is evident from the graph of ground water elevation and precipitation over time (Figure 4-5); however, the variations are less than 3 feet.

4.3 Ground Water Flow Conditions

Water level elevation data collected during this study were plotted and contoured for the Alluvial, Local Upland and Sea Level aquifers. Because of the paucity of wells in the Regional Aquifers, there were insufficient data to contour. After review of the water level elevation data, maps were

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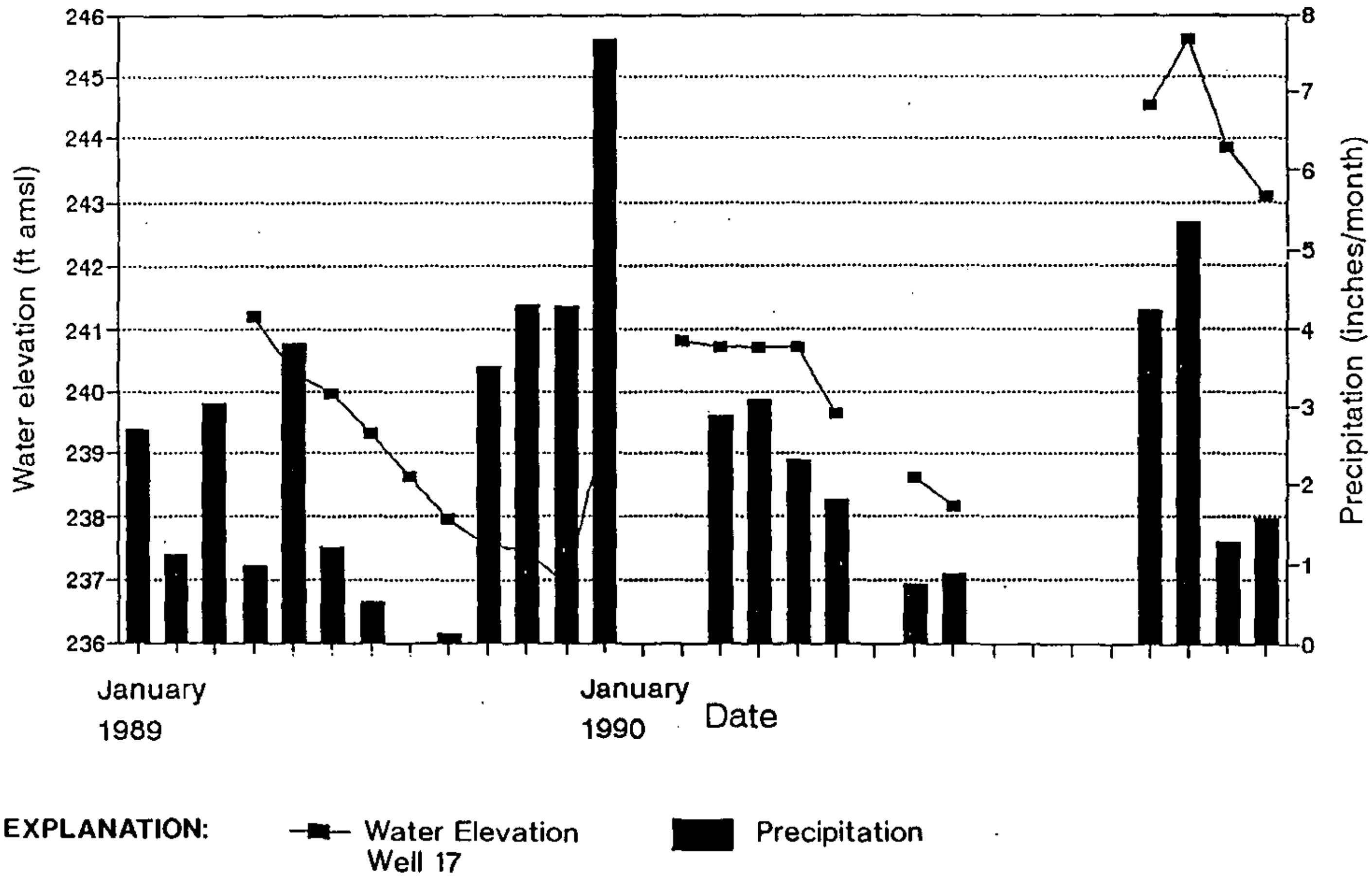

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DATE 10-92
DWN. MLP
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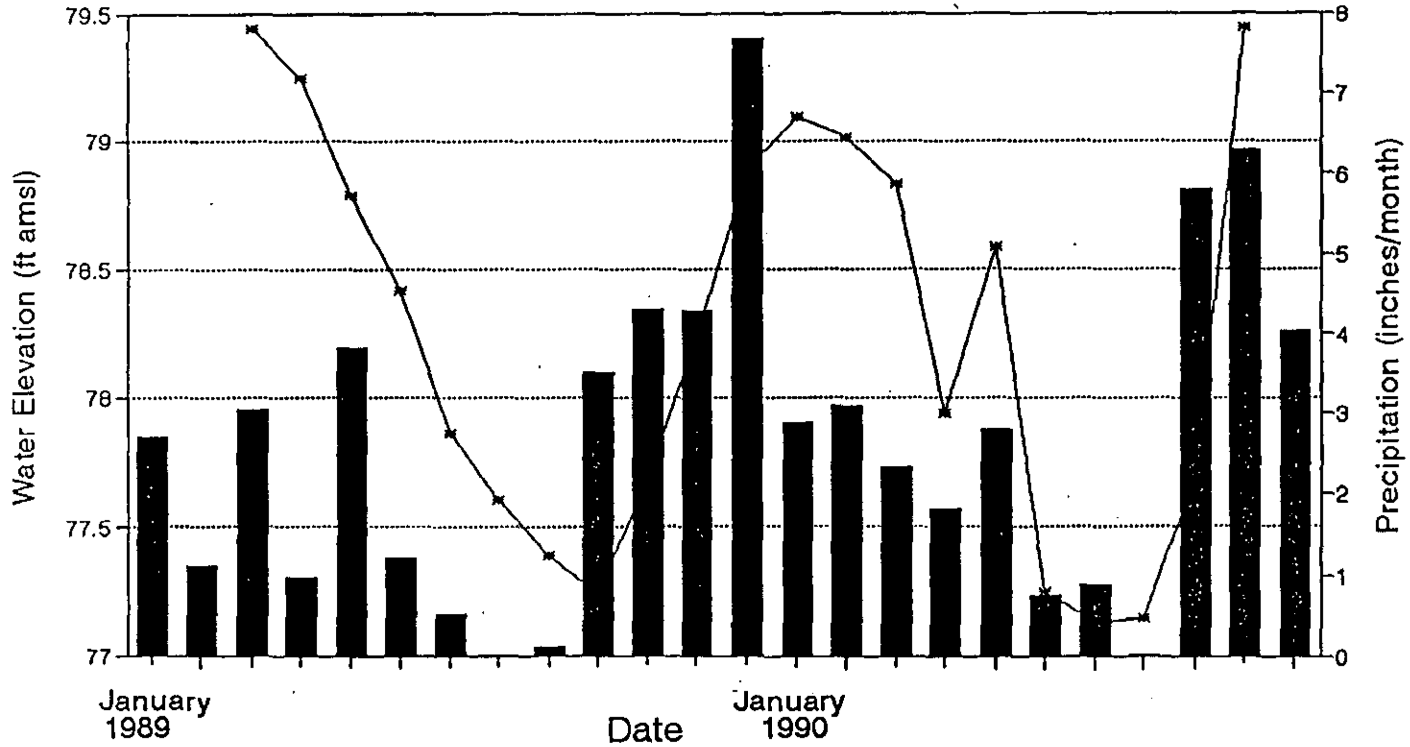
REVIS.
PROJECT NO. 0121-003.07

Figure 4-4
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
WATER LEVEL VS. PRECIPITATION HYDROGRAPH
LOCAL UPLAND AQUIFERS

150969



EXPLANATION: Water Elevation Well 35 — Precipitation

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PROJECT NO. 0121-003.07

Figure 4-5
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
WATER LEVEL VS. PRECIPITATION HYDROGRAPH
REGIONAL AQUIFERS

produced from the October 1989 and April 1990 data. These months were selected as good representations of the average potentiometric surfaces during generally low and high annual water table periods.

4.3.1 Alluvial Aquifers

Ground water in the alluvial aquifers is usually under unconfined or semi-confined conditions. In general, ground water in the Alluvial Aquifers flows toward local discharge points along valley streams, the Sammamish River and in Lake Sammamish. Ground water flow maps (Figures 4-6 and 4-7) indicate that ground water flows south along Bear Creek and Cottage Lake Creek and west along Evans Creek. Horizontal gradients range from 0.004 ft/ft from north to south to 0.01 ft/ft from east to west.

4.3.2 Sea Level Aquifers

Because the sea level aquifers occur beneath one or more aquitards, ground water in this zone is under confined conditions. Except for the extreme southern part of the GWMA, ground water in the Sea Level Aquifers generally flows west from high elevations of 160 to 200 feet amsl near the Redmond watershed to low elevations ranging from 60 to 80 feet amsl near the western boundary of the GWMA (Figures 4-8 and 4-9). Horizontal gradients range from 0.002 to 0.01 ft/ft. In the extreme southern part of the GWMA, ground water in these aquifers flows southwest toward Lake Sammamish.

4.3.3 Local Upland Aquifers

Ground water conditions in the local upland aquifers may be unconfined or confined depending on the depth and presence of overlying aquitards. In the Local Upland Aquifers, ground water flows away from the highland area north of the City of Redmond toward the Alluvial Aquifer along the Sammamish River and Bear Creek. At the eastern edge of the GWMA, ground water in these aquifers flows west toward Bear Creek and southwest toward Evans Creek (Figures 4-10 and 4-11). In these aquifers, horizontal gradients range from 0.02 to 0.05 ft/ft.

Figure 4-6 Ground Water elevation Contours - Alluvial Aquifers October 1989

Figure 4-7 Ground Water Elevation Contours - Alluvial Aquifers April 1990

D

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A

F

T

Figure 4-8 Ground Water Elevation Contours - Sea Level Aquifers October 1989

D

R

A

F

T

Figure 4-9 Ground Water Elevation Contours - Sea Level Aquifers April 1990

D

R

A

F

T

Figure 4-10 Ground Water Elevation Contours - Local Upland Aquifers October 1989

D

R

A

F

T

Figure 4-11 Ground Water elevation Contours - Local Upland Aquifers April 1990

D R A F T

4.3.4 Regional Aquifers

Ground water in the regional aquifer is under confined conditions. From the limited data available on these aquifers, it appears that ground water generally flows toward the west. In the deeper zones, the discharge area is probably Puget Sound.

4.4 Ground Water Recharge

Aquifer recharge areas are permeable geologic materials through which water percolates down to the water table and into an aquifer system. Using USGS surficial geologic maps (Minard, 1983; Minard, 1988) and USDA soil maps (Snyder, Gale, and Pringle, 1973), the locations of surficial permeable deposits in the GWMA were determined and mapped.

4.4.1 Recharge Potential Mapping Criteria

Ground water systems are replenished (recharged) by the addition of water to the zone of saturation (aquifer) through precipitation, runoff, and infiltration from surface water bodies. An area in which water reaches an aquifer by surface infiltration, and where there is a downward component of hydraulic head (pressure head), is considered a recharge area. The likelihood that water will infiltrate and pass through the surface materials to recharge the underlying aquifer system (recharge potential) depends on a number of relatively static (non-changing) physical conditions. These include:

- soil permeability
- surficial geologic materials
- depth to water
- topography

For this study only existing information was used to evaluate the occurrence of these physical conditions in the Redmond area. In addition, only the recharge potential of the uppermost aquifer system was evaluated. The presence of a downward component of hydraulic head cannot be determined without extensive research on water levels, well completion and well location data. To provide a conservative estimate, a downward component of hydraulic head is assumed to be present in all areas.

The specific approach used to evaluate the physical conditions is described briefly below for each condition (criterion).

Soils. The recharge potential of the surface material (soils) will be mapped by grouping soil units (defined by the Soil Conservation Service [SCS] in the Soil Survey of the King County Area [SCS, 1973]) by recharge potential classifications. These classifications are based on the permeabilities of each soil unit, as defined by the SCS. A summary of the soil units and their recharge potential classification is provided in Table 4-2.

Geologic Materials. Information on the surficial geologic materials was obtained from USGS geologic maps. The relative recharge potential of each major geologic unit in the study area was classified using a conservative approach that assumes internal uniformity of each unit. For example, glacial outwash will have a relatively high recharge potential, even though in some areas the outwash materials are fine-grained and may not permit a significant amount of recharge. The relative recharge potential of geologic materials in the study area is provided in Table 4-3.

Depth to Water. Depth to water below ground surface was determined from driller's logs and previous investigations. Perched or seasonal water bearing zones were not used. Water table elevation maps generated during this study were used to derive the depth to water by subtracting the elevation of the water table from the elevation of the land surface. In areas of rapidly changing topography, an average value was used. The relative recharge potential based on the depth to ground water is shown on Table 4-4.

Topography. The effect of topography on the recharge potential was determined by evaluating the slope of the land surface. The percent slope of an area was determined both from information in the SCS soil survey of King County and from topographic maps. The relative recharge potential based on topographic slope is also shown on Table 4-4.

4.4.2 Recharge Mapping Rationale

An overlay map was prepared for each of the physical parameters (criterion). The relative recharge potential of any one area compared to another area was then determined using a qualitative rating system. Each criterion in a given area was subdivided into a number of potential conditions present in the study area. Each condition was assigned a

Table 4-2

Recharge Potential of SCS Soil Units

SCS Map Symbol	SCS Soil Unit Name	Recharge Potential Classification
AgC	Alderwood	moderate
AgD	Alderwood	moderate
AkF	Alderwood	moderate
AmC	Arents	moderate
Bh	Bellingham	low
Br	Briscot	moderate
EvB	Everett	high
EvC	Everett	high
EvD	Everett	high
Ea	Earlmont	moderate
InA	Indianola	high
InC	Indianola	high
KpB	Kitsap	moderate
KpD	Kitsap	moderate
No	Norma	moderate
Os	Oridia	moderate
Pu	Puget	low
Pc	Pilchuck	high
RdC	Ragnar-Indianola	high
Re	Renton	high
So	Snohomish	moderate
Su	Sultan	moderate
Sk	Seattle muck	moderate
Tu	Tukwila muck	moderate

Table 4-3

Recharge Potential of USGS Geologic Units

Geologic Symbol	Geologic Unit Name	Recharge Potential Classification
Qaf	Alluvial fan deposits	high
Qyal	Younger alluvium	moderate
Qual	Older alluvium	high
Qsw	Swamp deposits	low
Qc	Colluvium	moderate
Qls	Landslide deposits	moderate
Qmw	Mass wasting deposits	moderate
Qvr	Recessional outwash	high
Qvry	Recessional outwash	high
Qvrc	Clay	low
Qvrb	Recessional outwash	high
Qvrd	Redmond delta	high
Qvro	Older recessional outwash	high
Qvt	Glacial till	low
Qva	Advance outwash	moderate
Qtb	Transitional beds	low
Qob	Olympia beds	moderate

Table 4-4

Recharge Potential for Slopes and Depth to Water Criteria

DEPTH TO WATER	
Depth Below Ground Surface (feet)	**Recharge Potential Classification**
0 - 25	high
25 - 75	moderate
>75	low
SLOPE	
Percent Slope	
0 - 40%	high
40 - 80%	moderate
>80%	low

qualitative rating factor of low, moderate, or high to describe its relative recharge potential. A combined rating "score" (e.g., high-high-moderate-low) was assigned to each portion of the mapped area based on the rating factor for each criterion in a given area. Table 4-5 shows the possible combined rating scores and associated recharge classification. After the combined rating scores were determined for each portion of the study area, a composite map was prepared showing the relative surface recharge potential for the Redmond area. The resulting surficial recharge potential map for the GWMA is shown on Figure 4-12.

4.4.3 Recharge Potential

Areas of high and medium recharge potential were determined from the composite recharge map prepared for the GWMA. The areas which show the highest potential for recharge are the Cottage Lake Creek, Bear Creek, and Evans Creek valleys. The remainder of the GWMA appears to have a medium recharge potential based on the criteria discussed above.

Although not evident from the map of recharge potential, the Redmond watershed area also appears to be a ground water recharge area in the GWMA. Vertical potential head gradients between wells in the Sea Level Aquifers (82 and 10) and the Local Upland Aquifers (27, 28, and 30) suggest the possibility of downward flow from the Sea Level Aquifers to the Local Upland Aquifers which may indicate recharging conditions in this area. Along Bear Creek in the center of the GWMA, the Local Upland Aquifers (well 26) appear to recharge the Alluvial Aquifers (well 23). In the western part of the GWMA, the Local Upland Aquifers (well 15) seem to recharge the Regional Aquifers (well 16).

Table 4-5

Physical Conditions Rating Criteria

Criterion Classifications	Composite Classification
H-H-H-H	High
H-H-H-M	High
H-H-M-M	High
H-H-H-L	High
H-M-M-L	Moderate
H-M-M-M	Moderate
H-H-L-L	Moderate
H-M-L-L	Moderate
H-L-L-L	Moderate
M-M-M-M	Moderate
M-M-M-L	Moderate
M-M-L-L	Moderate
M-L-L-L	Low
L-L-L-L	Low

Figure 4-12 Surficial Recharge Potential Map

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5 GROUND WATER QUALITY

The chemical quality of ground water in the Redmond-Bear Creek Ground Water Management Area (GWMA) affects the potential development and use of the area's ground water resources. Ground water chemistry in the GWMA was evaluated using the results of samples collected from wells throughout the area and analyzed for a variety of constituents. The analyzed constituents were selected to provide information about the quality of ground water in the GWMA aquifers.

Ground water must meet strict standards before it can be developed or used as a drinking water supply. These standards are defined in the Washington Drinking Water Regulations (WAC 248-54), the Washington Ground Water Quality Standards (WAC 173-200), the National Primary Drinking Water Regulations (40 CFR 141), and the National Secondary Drinking Water Standards (40 CFR 143). Ground water samples from the GWMA were collected and analyzed for selected primary and secondary drinking water standard constituents, and the results were compared with state and national primary and secondary drinking water standards. The significance of each selected primary and secondary drinking water standard analyte is discussed in Sections 5.1.1 and 5.1.2 respectively, and the results of the analyses are presented and discussed in Section 5.2.

Potential ground water resource development for applications other than drinking water supply is determined by deciding which constituents affect the proposed application, and evaluating the concentrations of those constituents with respect to the specific resource application. This report does not address applications other than drinking water supply.

The concentrations of major and minor ions are evaluated to determine the general characteristics and type(s) of ground water in the management area aquifer(s) and can sometimes be used as indicators of associations and/or connections between aquifers. The significance of the major and minor ions evaluated for this study is discussed in Section 5.1.3, and the results of the analyses are presented and discussed in Section 5.2.

Chemical analyses of priority pollutant metals, phenol, cyanide, and other potential contaminants can be used as indicators of ground water contamination. The significance of each of these analytes is discussed in Section 5.1.4., and the results of these analyses are summarized and discussed in Section 5.2.

5.1 Significance of Analyzed Constituents

Inorganic and organic materials occur in ground water as dissolved solids. Some of these materials occur naturally in ground water, and some occur only as introduced contaminants. The relative abundance of naturally occurring dissolved solids analyzed for this study are listed in Table 5-1. This section describes the analytes examined during this study and discusses the occurrence of each analyte in natural (uncontaminated) ground water and in samples collected from wells within the GWMA. The analytes were selected by the Seattle-King County Department of Public Health (SKCDPH) in accord with Ecology guidelines.

Sources used to develop the discussions presented in this section include Callahan et al (1979a, 1979b)., Hem (1985), Davis and DeWiest (1966), Driscoll (1986), Salomons and Forstner (1984), Stumm and Morgan (1981), Todd (1980), and Tuerkian and Wedepohl (1961).

5.1.1 Primary Drinking Water Standard Analytes

Primary drinking water standard analytes are defined by the National Primary Drinking Water Regulations (40 CFR 141), which have been adopted by the state of Washington in the Ground Water Quality Standards (WAC 173-200). These regulations address constituents which potentially affect public health if consumed in drinking water. Ground water must meet all primary drinking water standards to be suitable for development as a drinking water supply. All public water supplies must be regularly tested for all of the primary drinking water analytes. For this study, ground water samples were collected and analyzed for the following selected primary drinking water standard analytes: arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, nitrate, and total and fecal coliform bacteria. Each of the selected analytes is described in this section.

Arsenic. Arsenic is considered ubiquitous in rocks and soil, generally occurring at concentrations ranging from 1 to 13 parts per million (ppm). Higher concentrations of naturally occurring arsenic are associated with some types of ore deposits. Concentrations of arsenic in ground water are typically low (less than 0.010 ppm), but greater concentrations can occur

Table 5-1

Normal Abundance of Inorganic Dissolved Solids in Ground Water

Category	Normal Concentration Range[a]	Analytes Examined for this Study
Major constituents	1.0 to 1000 mg/L	Bicarbonate, calcium, chloride, magnesium, silica, sodium, sulfate
Secondary constituents	0.01 to 10.0 mg/L	Carbonate, iron, fluoride, nitrate, potassium
Minor constituents	0.0001 to 0.1 mg/L	Antimony, arsenic, barium, cadmium, chromium, copper, lead, manganese, nickel, phosphate, selenium, zinc
Trace constituents	<0.001 mg/L	Beryllium, silver, thallium

[a] Modified from Davis and DeWiest, 1966.

either naturally or due to contamination. The primary drinking water standard for total arsenic is 0.05 ppm. In the GWMA, arsenic was not detected above the primary drinking water standard except for one well (64) completed in the alluvial aquifers, where it was detected at 0.43 ppm.

Barium. Barium is abundant in rocks and soils, ranging in concentration from less than 1 to greater than 2,000 ppm. The most common barium mineral is barite (barium sulfate). Barium concentrations in natural waters are generally about 0.045 ppm, with greater concentrations found under special conditions (such as in oil field brines). The primary drinking water standard for total barium is 1.0 ppm. Barium concentrations in the ground water samples from the GWMA were below the primary drinking water standard in all but well 64. The sample from well 64 contained 5.4 ppm of barium.

Cadmium. Cadmium is a relatively rare, naturally occurring element concentrated in zinc-bearing ores. As a result, low concentrations of cadmium are found in all zinc products. Cadmium concentrations in natural rocks and soils are generally less than 0.6 ppm. Many cadmium-bearing minerals are soluble. The normal concentration of cadmium in sea water is less than 0.0002 ppm, and the normal concentration of cadmium in surface waters is generally about 0.001 ppm. Little information is available about the normal concentrations of cadmium in ground water. The primary drinking water standard for total cadmium is 0.01 ppm. Cadmium was not detected above the laboratory method reporting limit (MRL) in any of the ground water samples from the GWMA.

Chromium. Chromium occurs naturally in soils and rocks. Although chromium concentrations of 1,600 ppm have been reported for some ultrabasic igneous rocks, concentrations are generally lower than 200 ppm. Chromium-bearing minerals generally have low solubilities. Although chromium concentrations in natural waters are usually very low (less than 0.01 ppm), naturally occurring chromium concentrations up to 0.2 ppm have been reported for ground water. The primary drinking water standard for total chromium is 0.05 ppm. Chromium concentrations were below the laboratory MRL in all ground water samples from the GWMA.

Fluoride. Fluoride is an element that occurs naturally and commonly in soils and rocks. Fluoride is an essential nutrient and component of bones and teeth. Excessive fluoride can, however, cause mottling of tooth enamel and cause teeth and bones to become brittle. Fluoride is a component of many minerals, the most common being fluorite (calcium fluoride). The concentration of fluoride in soils and rocks is generally less than 1,500 ppm. Although fluoride concentrations in natural water are generally less than 1 ppm, concentrations as high as 50 ppm have been reported. Relatively high fluoride concentrations can occur in water with high (greater than 9) pH values, thermal water, and water affected by volcanism. The primary drinking water standard for fluoride is 4.0 ppm. Fluoride was not detected above the primary drinking water standard in any ground water sample from the GWMA. Fluoride concentrations exceeded the laboratory MRL only in well 16 which is completed in the Regional aquifers.

Lead. Lead occurs naturally in soils and rocks at concentrations up to 80 ppm, but may range to percent levels in some ore deposits. The most common lead-bearing mineral is galena (lead sulfide). Natural lead compounds have low solubilities, so lead concentrations in natural waters are generally low (less than 0.01 ppm). However, synthetic lead compounds (including the organic lead compounds added to leaded gasoline), have much higher solubilities, and lead concentrations in urban rainwater and snow can exceed 0.1 ppm. The primary drinking water standard for total lead is 0.05 ppm. Lead was not detected above the primary drinking water standard in ground water samples from the GWMA with the exception of one well in the regional aquifer (16), where it was detected at 0.33 and 0.13 ppm, and one well (64) in the Alluvial aquifers where it was detected at 0.31 ppm.

Mercury. Mercury is a trace element which usually occurs in trace (less than 1 ppm) concentrations in rocks and soils, but can be concentrated in ore deposits. Mercury concentrations in water are generally lower than 0.001 ppm, with the typical concentration in seawater of 0.0002 ppm. Mercury concentrations up to 0.01 ppm can occur in water associated with thermal ground water or mercury ore deposits. The primary drinking water standard for total mercury is 0.002 ppm. Mercury concentrations were below the laboratory MRL in all samples from the GWMA except well 64 in which it was detected at 0.0028 ppm.

Selenium. Selenium is a trace element that occurs naturally in soils and rocks, with concentrations in soils and fine-grained sediments generally being 1 ppm or lower, and concentrations in other rocks generally being lower (0.1 ppm or lower). Although metal selenides have low solubilities, other selenium compounds are soluble. Although selenium concentrations in surface and ground water are usually lower than 0.001 ppm, concentrations up to 3 ppm have been reported for irrigation water draining through soils with naturally high selenium concentrations. The primary drinking water standard for total selenium is 0.01 ppm. Reported selenium concentrations in the GWMA were generally at or below the laboratory MRL. There was no reported concentrations above the primary drinking water standard in any ground water samples from the GWMA.

Silver. Silver is a trace element which occurs naturally in rocks and soils, normally at concentrations lower than 0.4 ppm. In ore deposits, silver usually occurs as a native metal (often in a mixture with native gold), as argentite (silver sulfide), or associated with the sulfides of lead, copper, or other metals. Although metallic silver and argentite are virtually insoluble in natural waters, some silver compounds are slightly soluble. Silver concentrations in sea water and river water are generally about 0.0003 ppm. Little is known about the normal concentrations of silver in ground water. The primary drinking water standard for total silver is 0.05 ppm. Silver concentrations were all at or below the laboratory MRL in ground water samples from the GWMA.

Nitrate. Nitrogen occurs naturally in rocks and soils, generally at concentrations of 30 ppm or lower. There are two nitrate minerals; niter (potassium nitrate, or saltpeter), and soda niter (sodium nitrate). These minerals are easily dissolved in water, and are, therefore, only found in arid climates. They are thought to be formed by processes like evaporation or come from the accumulation of materials such as bat guano. Atmospheric nitrogen combines with oxygen to form nitrate through common metabolic processes of several types of bacteria and fungi found in soils. Concentrations of nitrate in natural water are generally lower than 1.0 ppm. The concentration of nitrogen (which normally occurs as nitrate) in seawater is generally lower than 1 ppm. The natural concentration of nitrate in surface and ground water is not well understood, since the nitrate contributions from natural sources (human waste, barnyard waste, and fertilizers) vary widely. The primary drinking water standard for nitrate is 10 ppm. Nitrate concentrations ranged from the laboratory MRL to 3.6 ppm in ground water samples from the GWMA. In the alluvial aquifers, nitrate concentrations ranged from the MRL to 3.1 ppm. In the local upland aquifers, nitrate lands ranged from the MRL to 3.6 ppm. Nitrate concentrations in the sea level aquifers ranged from the MRL to 1 ppm. Nitrate samples from wells in the regional aquifers did not exceed the MRL.

Total and Fecal Coliform Bacteria. Large populations of coliform bacteria occur naturally in the intestinal tracts of all warm-blooded animals. Coliform bacteria also occur naturally in both surface and (less commonly) ground water. Coliform bacteria usually are not harmful in and of themselves, but are used as an index of fecal pollution since they are numerous, and the test is easy and inexpensive. Large counts of any fecal coliform bacteria, indicate other pathogenic organisms may be present. The tests for these other pathogenic organisms, which include other bacteria, protozoans, and viruses, are considerably more difficult and expensive to perform. The primary drinking water standard for total coliforms is 1/100 ml. Total and fecal coliform bacteria were detected in ground water samples from all four aquifers. In the Alluvial aquifers, coliform bacteria were detected in these wells at concentrations ranging from 2 to 110 organisms per 100 ml. In the local upland aquifers, coliform bacteria were detected in four wells at concentrations from 7 to 17 organisms per 100 ml, respectively. Coliform bacteria were detected at 11 org/100 ml in one well in the Sea Level aquifers, and at 2 org/100 ml in one well in the Regional aquifers. Fecal coliform bacteria were not detected in any ground water samples submitted for analysis.

5.1.2 Secondary Drinking Water Standard Analytes

Secondary drinking water standard analytes are defined by the National Secondary Drinking Water Regulations (40 CFR 143), which have been adopted by the state of Washington in the Ground Water Quality Standards (WAC 173-200). The federal regulations are not enforceable and were prepared as guidelines for the states. These regulations address ground water constituents primarily affecting the aesthetic qualities (and, therefore, public acceptance) of drinking water. For this study, ground water samples were collected and analyzed for the following selected secondary drinking water standard analytes: chloride, copper, fluoride, iron, manganese, sulfate, total dissolved solids, and zinc. The primary drinking water standard analyte, fluoride, has been discussed in Section 5.2.1. Chloride, copper, iron, manganese, sulfate, total dissolved solids, and zinc are discussed in this section.

Chloride. Chlorine is a common element which occurs naturally in deep sea sediments and clays at concentrations around 21,000 ppm and in rocks and soils at concentrations generally less than 600 ppm. More than three-fourths of the chlorine on earth is found in the oceans, with concentration of chlorine in seawater generally being about 19,000 ppm. Chlorine normally occurs in water as the chloride ion (Cl^-). Chloride is present in all natural water and is considered a major component of ground water. Natural chloride concentrations in ground water vary widely and can range from less than 10 ppm in some spring water up to 189,000 ppm in brines. The concentration of chloride in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for chloride is 250 ppm. Chloride concentrations ranged from 1.3 to 15 ppm in ground water samples from the GWMA, well below the secondary drinking water standard of 250 ppm.

Copper. Copper is an essential nutrient and occurs naturally as a trace metal in rocks and soils. Copper commonly occurs as a native metal as chalcocite (copper sulfide) and in sulfides in conjunction with other metals (e.g., chalcopyrite and bornite are important iron/copper sulfide minerals). Average concentrations of copper in natural rocks and soils range to 1,000 ppm in clays and to 100 ppm in other rocks and soils. Copper concentrations in natural water are normally lower than 0.01 ppm, but can exceed 300 ppm in water affected by acid mine drainage. The concentration of copper in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for total copper is 1.0 ppm. Copper was not detected above the laboratory MRL in any of the ground water samples from the GWMA with the exception of well 64 where it was detected at 1.5 ppm.

Iron. Iron is an essential nutrient, and is one of the most abundant elements on earth. It occurs naturally at high concentrations (up to 7 percent in rocks and soils with higher concentrations in ore deposits). Iron occurs in most natural water, usually as the ferrous iron ion (Fe^{+2}). The concentration of iron in natural water depends upon the concentration of oxygen and oxygen-containing compounds. Where oxygen concentrations are high (for example, in a flowing stream), iron concentrations are typically 0.01 mg/l or less. Iron concentrations in ground water often range from 1 to 10 ppm and can exceed 50 ppm. The concentration of iron in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for total iron is 0.30 ppm. Iron concentrations were detected above the secondary drinking water standard in several wells in each of the four principal aquifer systems in the GWMA. It was detected in five wells in the Alluvial aquifers at concentrations ranging from 0.71 to 1,000 ppm and in six wells in the Local Upland aquifers at concentrations ranging from 0.31 to 9.1 ppm. Iron concentrations in the Sea Level aquifers were above the standard in samples from three wells and ranged from 0.31 to 29 ppm. Iron concentrations in the Regional aquifers were above the standard in three wells and ranged from 0.31 to 11 ppm.

Manganese. Manganese is an essential nutrient, and is an abundant element. Manganese concentrations in rocks and soils generally range up to 6,700 ppm. Manganese occurs commonly in silicate minerals and can occur in other forms (for example, oxides and carbonates). Manganese occurs in most natural water, usually as the ion Mn^{+2}. Manganese concentrations in seawater are generally about 0.002 ppm and are usually less than 1 ppm in surface and ground water. The concentration of manganese in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for total manganese is 0.05 ppm. Manganese concentrations were detected above the secondary drinking water standard in ground water samples from several wells in the GWMA. In the Alluvial aquifers, manganese concentrations were above the standard in seven wells and ranged from 0.055 to 0.111 ppm. In the Local Upland aquifers, manganese was detected above the standard in five wells at concentrations ranging from 0.055 to 0.161 ppm. Manganese concentrations in the Sea Level aquifers were above the standard in ground water samples from one well at 0.056 and 0.07 ppm and in four wells in the Regional aquifers at concentrations ranging from 0.06 to 0.21 ppm.

Sulfate. Sulfur is a common element which occurs at concentrations ranging to 2,400 ppm in rocks and soils. Sulfur often occurs as sulfide minerals, such as pyrite (iron sulfide) and galena (lead sulfide). Many of the most important ore minerals are sulfides. Although some sulfate minerals like calcium sulfate (gypsum) are easily dissolved, some (like barite, which is barium sulfate) are virtually insoluble in water. Sulfate occurs naturally in most water and is almost always present in brackish or saline water. Seawater generally contains about 2,700 ppm of sulfate. The sulfate concentration in ground water is generally expected to be the same as the sulfate concentration in rainwater, about 1 to 3 ppm. Where sulfate is absent from ground water, it has generally been transformed into sulfide by microorganisms. The concentration of sulfate in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for sulfate is 250 ppm. Sulfate concentrations in ground water samples from the GWMA ranged from the MRL to 75 ppm, well below the secondary drinking water standard.

Total Dissolved Solids. The total dissolved solids (TDS) in a sample is determined by filtering the water sample into a weighed evaporation dish, evaporating the filtered water, and weighing the dish with the dried residue. After correcting for the volume of sample filtered, the TDS of the sample is calculated as the difference in weight between the unused dish and the dish-plus-residue. The concentration of total dissolved solids in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for total dissolved solids is 500 ppm.

Waters with high (greater than 500 ppm) TDS concentrations may have an unpleasant flavor and may be difficult to digest for new consumers of the supply. Since total dissolved solids is a rough measure of the mineralization of the sample, waters with high dissolved solids concentrations may be unsuitable for industrial applications. In these cases, the analyses of individual elements of concern (such as calcium and iron) should be reviewed to determine whether further testing is necessary prior to approving the supply. Total dissolved solids concentrations in ground water samples from the GWMA ranged from 6 to 590 ppm, with the highest concentrations found in the samples from the Regional aquifers.

Zinc. Zinc is an essential nutrient which occurs naturally and is fairly common in rocks and soils. Zinc concentrations in soils and rocks are generally less than 200 ppm, but percent concentrations are found in ore deposits. The most common zinc mineral is zinc sulfide (sphalerite). Zinc concentrations in ground water are generally low (less than 1 ppm) under most conditions. The concentration of zinc in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for zinc is 5 ppm. Zinc was not detected above the secondary drinking water standard in any ground water samples submitted for analysis. Zinc concentrations ranged from the MRL to 3.2 ppm.

5.1.3 Ground Water Characteristic Constituents

For the purposes of this study, ground water characteristic constituents are those dissolved solids which are major and secondary constituents of potable water (see Table 5-1). These materials occur as both natural constituents of and introduced contaminants in ground water. The primary drinking water standard analytes fluoride and nitrate have been discussed in Section 5.1.1. The secondary drinking water standard analytes chloride, iron, and sulfate have been discussed in Section 5.1.2. Bicarbonate, carbonate, and hydroxide, calcium, magnesium, nitrite, potassium, silica, sodium, and total hardness are discussed in this section.

Alkalinity. Alkalinity measures the ability of a water sample to neutralize an acid. All ground water typically has measurable alkalinity. Alkalinity is caused by carbon dioxide gas dissolved in the ground water. The main sources of dissolved carbon dioxide gas are carbon dioxide in the atmosphere, soil gas, and carbonate minerals in the aquifer.

The total alkalinity of a sample equals the sum of all titratable bases in that sample and, for natural waters, is typically a function of the carbonate, bicarbonate, and/or hydroxide concentrations in the sample. The measurement method assumes that carbonate, bicarbonate or hydroxide are the only bases which occur in the sample. This is a reasonable assumption, as other naturally occurring bases (such as borates, phosphates, and silicates) are generally minor and will not contribute much to the total.

In practice, a laboratory measures alkalinity by titrating a sample using two different pH indicators (i.e., methyl orange and phenolphthalein). The laboratory calculates the relative contribution(s) of the carbonate, bicarbonate, and hydroxide alkalinities using the ratio between the methyl-orange ("total") and phenolphthalein alkalinities. The laboratory reports the total alkalinity and the calculated carbonate, bicarbonate, and hydroxide alkalinities. Alkalinity concentrations in drinking water and ground water are not regulated. The total alkalinity of the ground water samples from the GWMA ranged from 2 to 300 mg/L as $CaCO3$. Alkalinity was generally less than 100 mg/L in most Local Upland aquifer samples and approximately 100 mg/L in the Alluvial aquifer samples. The highest alkalinity was measured in ground water samples from wells in the Regional aquifer.

Calcium. Calcium is an essential nutrient common in rocks and soils. Calcium occurs in a wide variety of minerals. The general concentrations of calcium in rocks and soils range from about 5,100 ppm in some granites to over 312,000 ppm in some carbonates. Calcium is a major constituent of natural waters, where it occurs only as the ion Ca^{+2}. The general concentration of calcium in seawater is about 410 ppm. Calcium concentrations in ground water range from lower than 50 ppm in some limestones, to greater than 93,500 ppm in an oil-field brine. Calcium concentrations in drinking water and ground water are not regulated. Calcium concentrations in ground water samples from the GWMA ranged from 4.7 to 260, with the highest concentration occurring in the ground water sample from well 64 in the Alluvial aquifers.

Magnesium. Magnesium is an essential nutrient common in rocks and soils. Magnesium occurs in a wide variety of minerals, with concentrations in rocks and soils ranging from 1,600 ppm in some granites, to over 200,000 ppm in ultrabasic rocks. Magnesium is a major constituent of natural waters, where normally it occurs only as the ion Mg^{+2}. The general concentration of magnesium in sea water is about 1,350 ppm. Magnesium concentrations in ground water range from less than 4 ppm in some limestones, to greater than 12,000 ppm in an oil-field brine. Magnesium concentrations in drinking water and ground water are not regulated. Magnesium concentrations in all but one of the wells sampled ranged from 0.01 ppm up to 19 ppm. Magnesium was detected at 400 ppm in well 64.

Nitrite. Nitrogen has been addressed in the discussion of nitrates (see Section 5.2.1). Unlike nitrate, nitrite does not occur as a mineral. Nitrite (NO^{2-}) is formed by removing one oxygen atom from nitrate (NO^{3-}). This process is called "nitrate reduction," and generally results from the metabolic processes of some microorganisms which occur naturally in soil and ground water. Although nitrate is common in ground water, nitrite is uncommon. Little is known about the natural concentrations of nitrites in surface or ground water. Nitrite concentrations in drinking water and ground water are regulated as total nitrogen and must meet the primary drinking water standard of 10 mg/L. Nitrite was detected at or below the laboratory MRL of 0.5 ppm in all ground water samples from the GWMA.

Potassium. Potassium is an essential nutrient common in rocks and soils. Although potassium concentrations are about 40 ppm in ultrabasic rocks, they generally range from 2,700 to 48,000 ppm in rocks and soils. Potassium occurs in most natural waters and is normally found as the potassium ion (K^+). Potassium concentrations in seawater are generally 390 ppm. Concentrations of potassium in ground water generally range from 1 to 20 ppm, but can exceed 120 ppm in oil field brine. Potassium concentrations in drinking water and ground water are not regulated. Potassium concentrations in ground water samples from the GWMA generally ranged from 1 to 12 ppm with the highest concentrations in wells in the Regional aquifers. Elevated potassium was also detected at 135 ppm in well 64.

Silica. Silicon is the second most abundant element in the earth's crust (oxygen is the most abundant). Although the concentration of silicon in carbonates is usually low (less than 50,000 ppm) the general concentration of silicon in rocks and soils usually exceeds 200,000 ppm. Many minerals contain some silicon. Silicon occurs in most natural waters, usually as a form of dissolved silicic acid $Si(OH)_4$. By convention, dissolved silicon ions are represented as silica (the oxide, SiO_2). Concentrations of silica in natural water generally range from 1 to 30 ppm, although concentrations of 100 ppm are not typical for some ground water systems. Elevated silica concentrations are usually associated with elevated ground water temperatures and silica-rich aquifer materials. Silica concentrations in drinking water and ground water are not regulated. Silica concentrations generally ranged from 11 to 58 ppm in ground water samples. Silica was detected at 300 ppm in the sample from well 64.

Sodium. Sodium is an essential nutrient common in rocks and soils. Sodium occurs in a wide variety of minerals, ranging from silicates like feldspars to evaporites like halite (NaCl, or common table salt). Sodium is found in most natural waters and generally occurs as the sodium ion (Na^+). Sodium concentrations in sea water are generally about 10,500 ppm. Concentrations of sodium in ground water vary widely, from less than 1 ppm in some limestones to over 10,000 ppm in some brines. Sodium concentrations in drinking water and ground water are not regulated. Sodium concentrations ranged from 0.02 ppm to 130 ppm with the highest concentrations occurring in wells in the Regional aquifers.

Total Hardness. Total hardness is a measure of the calcium and magnesium cations in water which form an insoluble precipitate with soap. In practice, the calcium and magnesium concentrations are measured, combined, and expressed as the equivalent concentration of calcium carbonate. (Note that this is not the same as simply adding the concentrations of calcium and magnesium, and reporting their sum). Therefore, the total hardness of a sample is proportional to its relative concentrations of calcium and magnesium. The actual hardness concentrations for the RBC GWMA samples are meaningful only in relationship to each other. The total hardness of drinking water and ground water is not regulated. Total hardness of the ground water samples in the GWMA ranged from 31 to 128 mg/L as CaCO3, indicating soft to moderately hard water in most areas. The sample from well 64 had a hardness of 2,300 mg/L as CaCO3 and is considered very hard.

5.2.4 Additional Potential Contaminants

All ground water samples collected during the December 1989 sampling were analyzed for TOX. All ground water samples collected during the May 1990 sampling were analyzed for TOX except for the Doughty, Paradise

Park, Kloepfer, Sharp, Thenos Dairy, King County Shops, and Campton Community wells. The Doughty, Bondo, Kloepfer, Sharp, Thenos Dairy, Olympian Precast, King County Shops, and Campton Community wells and Redmond Well 2 were sampled for cyanide, phenol, VOCs, BNAs, chlorinated pesticides, PCBs, and the additional priority pollutant metals (antimony, beryllium, nickel, and thallium) during the May 1990 sampling.

Generally, the organic compounds detected using TOX, phenol, VOC, and BNA analyses do not occur naturally in ground water. The compounds detected using cyanide and chlorinated pesticide and PCB analyses do not occur naturally in water. The detection of any of these compounds may be indicative of ground water contamination.

The primary drinking water standard analytes arsenic, cadmium, chromium, lead, mercury, selenium, and silver are priority pollutant metals which have been discussed in Section 5.2.1. The secondary drinking water standard analytes copper and zinc are priority pollutant metals which have been discussed in Section 5.2.2. Antimony, beryllium, nickel, and thallium are discussed in this section. These metals can occur naturally in ground water, and their presence does not necessarily indicate ground water contamination. The concentrations of these metals in ground water are not regulated by either Washington State or the federal government.

Total Organic Halogen. The total organic halogen (TOX) analysis refers to compounds which contain the halogens chlorine, bromine, and iodine. The TOX method is used to estimate the total quantity of organic halogens in a sample. This analysis returns a total concentration of organic chloride, bromide, and iodide, but does not detect fluorinated organics. Compounds which contribute to the reported total include trihalomethanes, some halogenated organic solvents, chlorinated and brominated pesticides and herbicides, PCBs, and several other halogenated volatile and semivolatile organic compounds. Since no halogenated organic compounds occur naturally in ground water, this analysis provides a relatively inexpensive screening tool which can be used to determine whether more expensive tests for specific organic contaminants are warranted. However, if the natural ground water concentrations of inorganic halogens (such as chloroform, which is commonly produced by microorganisms in ground water) are high, then some of the inorganic halogens may be included in the TOX result, giving a "false positive" result, or an overestimated TOX concentration.

Concentrations of TOX in ground water are not regulated as such. If TOX are detected in ground water, then the sample source must be retested to determine which specific organic compounds are present and at what concentrations. Total Organic Halides were detected above the analytical detection limit in eight samples at concentrations ranging from 7 to 23 ppb.

Antimony. Antimony occurs naturally as a trace (0.2 to 0.5 ppm) constituent of rocks and soils, but also as an ore mineral. Little is known about the normal concentrations of antimony in ground water. Antimony concentrations in drinking water and ground water are not regulated. Antimony was not detected above the laboratory MRL in any of the ground water samples from the GWMA.

Beryllium. Beryllium is a rather rare element which occurs naturally in rocks and soils. The most important source of beryllium is the mineral beryl, a silicate compound which occurs in some igneous rocks. The solubility of beryllium is extremely low (in the ppb range), and few data on normal concentrations of beryllium in ground water exist. Beryllium concentrations in drinking water and ground water are not regulated. Beryllium was not detected above the laboratory MRL in any of the ground water samples.

Chlorinated Pesticides. Chlorinated pesticides include a wide variety of compounds with widely varying physical, chemical, and biological properties. These compounds are created by chemical synthesis. Examples of chlorinated pesticides include DDD, DDE, DDT, chlordane, endrin, and toxaphene. Where data are available, chlorinated pesticides are usually considered potential human carcinogens. Although chlorinated pesticides usually have very low solubility in water, they tend to bioaccumulate. Because of the potential health concerns, the Washington State water quality standards for chlorinated pesticide concentrations in drinking water and ground water are generally less than 0.001 mg/L. These standards are set on a compound-by-compound basis.

No chlorinated pesticides were detected in any of the ground water samples collected during this study.

Cyanide. Cyanides are a group of organic and inorganic compounds which contain the cyanide ion (CN^-). Although cyanides are produced by many natural metabolic processes in plants and animals (for instance, apple seeds contain low concentrations), they do not normally occur in rocks or soils. The most common and toxic form of cyanide is hydrogen cyanide gas, which can dissolve in water. When low concentrations of cyanide are present in water, it tends to form insoluble metal compounds and, therefore, be removed from the water. At higher concentrations, however, cyanide forms soluble complexes with many cations (such as sodium, iron, gold, nickel, copper, or zinc). This is why the cyanide "heap-leaching" process (where mined ore is washed with a cyanide solution) is so effective at dissolving and recovering gold from ore. Cyanides do not occur naturally in ground water. When present, cyanides generally occur as either hydrogen cyanide gas, or as the cyanide ion complexed with some cation (such as sodium or a metal). Cyanide concentrations are not regulated in drinking water and ground water. Cyanide was not detected above the laboratory MRL in any of the ground water samples from the GWMA.

Nickel. Nickel is a common metal which occurs naturally in rocks and soils. Economically important nickel deposits are generally associated with igneous ores. Concentrations of nickel in ground water are generally low (less than 50 ppb). Nickel concentrations in drinking water and ground water are not regulated. Nickel was not detected above the laboratory MRL in any of the ground water samples from the GWMA.

Phenol. Phenol, or carbolic acid, is a benzene ring with one attached hydroxyl (OH^-) group which dissolves easily in water. Phenols occur naturally and are found in seawater at low (less than 2 ppb) concentrations. Little is known about the natural concentrations of phenol in ground water. Phenol concentrations are not regulated in drinking water and ground water. Phenol was not detected above the detection limit in any of the ground water samples from the GWMA submitted for analysis.

Polychlorinated Biphenyls. Polychlorinated biphenyls (PCBs), are a family of compounds with widely varying physical, chemical, and biological properties. These compounds are created by chemical synthesis and do not occur naturally. The name "polychlorinated biphenyls" refers to the basic chemical structure of the family where two phenyl groups are joined by a single bond and have varying numbers of chlorine atoms attached in various positions. About 100 of the possible 209 PCB compounds have actually been synthesized. Because of the variety of possible PCB chemical structures, PCBs have wide uses. PCBs are used as heat-transfer liquids in transformers, as insulators for electrical condensers, as additives in very high pressure lubricants, and to synthesize a variety of other compounds (such as epoxies and polyvinyl acetate). Normally, mixtures of PCBs (called Aroclors) are used, rather than the individual PCB compounds.

Where data are available, PCBs are considered potential human carcinogens. Although PCBs (and, therefore, Aroclors) have very low solubility in water, they tend to bioaccumulate. Because of the potential health concerns, the Washington State water quality standards for total PCB concentrations in drinking water and ground water are 0.00001 mg/L (one hundredth of a part per billion). These standards effectively reflect the lowest possible detection limit for this family of compounds, which usually cannot be achieved for natural water samples due to normal matrix interference effects. No PCBs were detected in selected samples tested for these constituents.

Semivolatile Organic Compounds. Semivolatile organic compounds include a wide variety of compounds with varying physical, chemical, and biological properties. Because they are extracted from a sample and analyzed as separate base, neutral, and acid fractions, semivolatile compounds are often referred to as "BNAs." Although many of these compounds are created by chemical synthesis and do not occur naturally, some (such as the coal tar derivatives, including acenapthene, anthracene, fluorene, naphthalene, and other polycyclic aromatic hydrocarbons) occur in natural organic deposits such as coal, tar, and oil. BNAs are widely used, and occur in a wide variety of products including dyes, medications, mothballs, wood preservatives, and petroleum derivatives. Some BNAs are considered potential human carcinogens. Because of the potential health concerns, the Washington State water quality standards for BNA concentrations in drinking water and ground water are generally less than 0.001 mg/L. These standards are set on a compound by compound basis. No semivolatile compounds were detected above the laboratory MRL in the selected samples tested.

Thallium. Thallium occurs naturally in the earth's crust at concentrations around 1 ppm. Although thallium is soluble in most aquatic systems, there is little known about natural concentrations of thallium in ground water. Thallium concentrations in drinking water and ground water are not regulated. Thallium was not detected above the laboratory MRL in any of the ground water samples from the GWMA.

Volatile Organic Compounds. Volatile organic compounds (VOCs) include a wide variety of compounds with widely varying physical, chemical, and biological properties. Although many of these compounds are created by chemical synthesis and do not occur naturally, some (such as benzene) occur in natural organic (petroleum) deposits. VOCs are widely used and occur in a wide variety of products including gasoline and other petroleum derivatives, medications, and solvents. Some VOCs are considered potential human carcinogens. Because of the potential health concerns, the Washington State water quality standards for VOC concentrations in drinking water and ground water are generally less than 0.001 mg/L. These standards are set on a compound-by-compound basis. Methylene chloride, carbon tetrachloride, and acetate were detected at very low levels in several samples. The specific significance of this is discussed in Section 5.2.3.

5.2 Results and Discussion of Analytical Testing

This section presents the analytical testing results for ground water samples collected from wells in the GWMA in December 1989 and May 1990. The results of all chemical analyses are presented in Table 5-2. The classification of each analyte and its maximum permissible suggested concentration in drinking water (if any) are listed in Table 5-3.

5.2.1 Primary and Secondary Drinking Water Standard Analytes

Ground water must meet all primary drinking water standards to be suitable for development as a drinking water supply. Ground water which meets primary, but does not meet secondary, drinking water standards can be developed as a drinking water supply, but the supply may be aesthetically unappealing. For example, water with elevated iron concentrations may be safe to drink, but can stain sinks and clothes and have an offensive flavor. The maximum acceptable concentrations for primary and secondary ground water standard constituents are presented in Table 5-3.

Ground water need not meet primary and secondary drinking water standards to be suitable for development as an irrigation, stock, or industrial water supply. The suitability of a ground water resource for any purpose other than drinking water supply depends on the nature and concentrations of its constituents and the proposed use of the resource. For example, ground water with elevated fluoride concentrations may be unfit for drinking, but usable for industrial cooling purposes. Water which is usable as drinking water but has elevated silica concentrations may be unsuitable as an industrial cooling supply, since the silica may foul the cooling system piping.

At least one sample from each of eight wells (Wells 1, 5, 12, 16, 29, 62) failed to meet the primary drinking water total coliform standard, a most probable number (MPN) of 1 total coliform bacterium per 100 milliliters of ground water. Total lead concentrations exceeded the primary drinking water standard, and total iron and manganese exceeded the secondary drinking water standard in well 12. Total arsenic, barium, chromium, mercury, and lead exceeded the primary drinking water standards, and total copper, iron, and manganese exceeded secondary drinking water standards for well 64. Ground water from all other sampled wells met primary drinking water standards.

One ground water sample from well 14 did not meet the secondary drinking water standards for total dissolved solids, total iron, or total manganese. One or more ground water samples from wells 1, 3, 6, 10, 12, 14, 16, 20, 21, 27, 33, 35, 38, 40, 43, 51, 62, 64, 69, 73, 74 76, and 79, did not meet the secondary water quality standards for iron and/or manganese.

5.2.2 Ground Water Characteristic Constituents

All samples were analyzed for selected ground water characteristic constituents. These constituents include major ions (i.e., ions which are normally found at ppm to percent concentrations), and minor ions (ions which are normally found at concentrations less than a few ppm). Piper diagram plots of major ions were used to type the ground water and to group similar types of ground water. Major ions analyzed include bicarbonate, calcium, carbonate, chloride, hydroxide, magnesium, potassium, sodium, and sulfate. Minor ions are used to confirm and/or subdivide ground water types. Minor ions which were analyzed include nitrite and silica. The major cation and anion concentrations as well as some common minerals were also graphed according to distribution and occurrence in each of the four primary aquifer systems. In addition to the major and minor ions, arsenic, copper, lead, nitrate, iron, and manganese were also evaluated and graphed.

In the GWMA, all sampled ground water is characterized as being a bicarbonate type. Samples from wells 4, 5, 34, 61, and 62, have relatively elevated sulfate concentrations (see Figure 5-1). Samples from wells 14 and 16, which are located in the Sammamish River valley, have relatively elevated sodium concentrations (see Figure 5-2). These samples also have relatively high total bicarbonate and total sodium concentrations (see Figure 5-1 and 5-2). Typically, concentrations of arsenic, copper, lead, iron, and manganese appear to be relatively uniform in all four aquifer systems (Figures 5-3 through 5-6). Although elevated levels of iron and manganese occur in well 74 in the sea level aquifers and well 16 in the deep aquifer, other wells in these aquifers do not show significantly higher levels of those is the small group from the alluvial aquifers. Although the differences between the aquifer groups are small, a general trend can be seen. The trends starts with the small group of the alluvial aquifers in the Ca+Mg-Cl+SO4 field, then progressing to the Ca+Mg-HCO3 field where most of the data plot. The data trend then crosses into the HCO3+CO3 field and progresses towards the sodium apex. The cause of the trend is unclear, but may represent the geochemical evolution from the Alluvial Aquifers to the Regional Aquifers. The data are plotted as relative percents, so differences in absolute concentration will be overlooked with this diagram.

5.2.3 Additional Potential Contaminants

Total organic halogen (TOX) was reported at concentrations ranging from 7 to 23 μg/l for one or more ground water samples from the Kloepfer, Sharp, Thenos Dairy, Goss, King County Shops, Cedar Lawns, Campton Community wells, and Evans Creek Well 1. TOX were reported at 8 μg/l in the December 1989 sample and were not detected at or exceeding 5 μg/l in the May 1990 sample from Redmond Well 5.

Methylene chloride was reported for several samples. Since the laboratory method blank(s) associated with every sample reported methylene chloride, and since the concentrations of methylene chloride reported for the laboratory method blanks are similar to the concentrations reported for the associated samples, all occurrences of methylene chloride in these samples are considered to result from laboratory contamination. Acetone was reported at 0.0207 mg/l in the May 1990 sample, and carbon tetrachloride was reported at 0.0016 mg/l in the duplicate from the King County Shops well. Since each compound was detected in only one of the duplicated samples, the detection of these compounds probably reflects laboratory error or laboratory contamination of the sample rather than ground water contamination. Acetone is not a regulated ground water contaminant. The concentration of carbon tetrachloride reported for the duplicate King County Shops sample is less than the national Drinking Water Standard of 0.005 mg/l, but exceeds the Washington State Drinking Water standard of 0.0003 mg/l. No other volatile organic compounds, pesticides, PCBs, or semivolatile organic compounds were detected in the analyzed samples.

5.2.4 Summary of Results

The ground water samples collected from the RBC GWMA generally meet all primary and secondary state and federal drinking water standards. Several wells did not meet the primary water quality standards for coliform. These wells penetrate different aquifers in different parts of the study area, indicating microbial contamination problems are restricted to individual wells, and there is no general microbial contamination of ground water in the RBC GWMA. The Sharp well failed to meet the primary state drinking water standards for coliform or lead and the secondary drinking water standards for iron or manganese. The source of the metals in the Sharp water samples may be the water supply piping system rather than the ground water.

Many wells in the RBC GWMA do not meet state secondary (aesthetic) drinking water standards for total dissolved solids, iron, and manganese. Although this does not impact consumer health, these water supplies are less desirable, and their industrial use may be restricted.

Although TOX were reported for several wells, no specific organic contaminants were confirmed by resampling. It is possible acetone and carbon tetrachloride occur in ground water samples from the King County Shops well. Since these compounds were present only in low concentrations, however, and only in one of two duplicated samples, their presence in ground water has not been confirmed. The methylene chloride detected in several samples is likely present due to laboratory contamination and does not reflect contamination of the ground water supply. No other organic contaminants were detected in ground water samples. Although the King County Shops well should be resampled to confirm the absence of organic contaminants, ground water in the RBC GWMA is generally free from the organic compounds tested.

6 GLOSSARY OF COMMON HYDROGEOLOGIC AND WATER-RESOURCE RELATED TERMS AND ACRONYMS

Alluvium — Sediment such as clay, silt, sand, gravel, or other similar material deposited by running water.

Ammonia — A gas composed of NH_3 and commonly used as fertilizer.

Aquifer — A body of rock or sediment able to store and conduct significant quantities of ground water.

Aquitard — A layer of rock or sediment that retards the flow of ground water to or from an adjacent layer of rock or sediment.

Artesian — Refers to ground water under sufficient hydrostatic head to rise above the aquifer containing it.

Bedrock — A term for the solid rock that underlies soil or uncompacted sediments.

Chloride — A compound of chlorine with one other positive element or radical.

Coliform Bacteria — Bacteria (*E. coli*) associated with human waste.

Colluvium — Loose clastic material usually found at the base of a hill or cliff.

Confined — A condition of an aquifer bounded above and below by lower permeability rock or sediment layers.

Contaminant — A naturally occurring or man-made compound that is undesirable or injurious and is found in ground water.

Cross-bedding — Inclined laminations, deposited by currents.

Cross-section	A schematic representation of geologic layers as seen in a side view.
Discharge	Ground water that flows out of an aquifer into an adjacent aquifer or to the surface into a spring or river.
DOH	Washington Department of Health.
Drinking Water Standards	Federal or state water quality regulations that limit the contaminant levels of certain compounds for drinking water.
Ecology	Washington Department of Ecology.
Effluent Stream	A stream or reach of a stream that receives water from the zone of saturation and provides base flow; its channel lies below the water table. Synonym: gaining stream. A stream whose flow is increased due to contributions from the zone of saturation or aquifer.
Eolian	Sediments transported by wind action.
Erosion	The physical and chemical processes that remove and transport natural materials at the surface.
Fluvial	Deposits produced by river action.
Fossil	The remains or traces of animals or plants which have been preserved by natural processes.
Geology	The study of earth materials, processes, and history.
Glaciofluvial	Deposits created from streams or floods flowing from glaciers.
Glaciolacustrine	Deposits created in lake environments from glacial silts and clays.
gmp	Gallons per minute.
GMA	Ground Water Management Act.

Ground Water All water that is located below the surface; more specifically, subsurface water below the water table.

GWMA Ground Water Management Area.

GWMP Ground Water Management Program.

Hazardous Waste Federally regulated man-made waste that is ignitable, corrosive, reactive, or toxic.

Hydraulic Conductivity The rate of flow of water through an area of permeable material at a constant pressure.

Hydraulic Connection The condition in which two water-bearing layers or bodies may freely transmit water between them.

Hydrogeologic Pertaining to subsurface water and water-bearing rock or sediment layers.

Hydrostratigraphy The assemblage of layers of aquifers and aquitards.

Igneous A type of rock solidified from molten material.

Impermeable An adjective used to describe rock, soils, or sediments that impede the flow of water.

Infiltration The downward movement of rain water or surface water into soil.

Interflow Zone The zone between two basalt flows where weathering, fracturing, and deposition of sediments create a permeable zone in an otherwise primarily impermeable environment.

Lacustrine Lake environment.

Laminated The layering or thin bedding in sedimentary rocks.

Leucocratic A term applied to light-colored rocks.

Mesozoic	A broad period of earth's history estimated to be 225 to 65 million years ago.
Metamorphic	A rock that has been physically and/or chemically changed from an original texture and/or composition, usually by very high temperatures or pressures below the earth's surface.
mg/l	Milligrams per liter; a unit of concentration in water equivalent to a part per million or 0.0001 percent.
Microorganisms	Microscopic organisms such as any of the bacteria, protozoans, or viruses.
Nitrate	A compound commonly associated with domestic and agricultural waste.
Peat	A non-compacted deposit of organic material commonly developed from bogs or swamps.
Permeable	The condition under which water may be transmitted through rock or sediment.
Pleistocene	A period of earth's history estimated to be 2 million to 10,000 years ago.
Potentiometric Surface	The surface to which water will rise in an aquifer under hydrostatic pressure.
ppm	Parts/per million. A unit of concentration equivalent to 0.0001 percent.
Recent	Less than 10,000 years ago in earth's history.
Recharge	The process of absorption and addition of water to a layer of soil, rock, or sediment.
SDWA	Safe Drinking Water Act.
Sedimentary	A rock type formed from fragments of weathered natural material.

Storage Coefficient	The volume of water released from storage per unit-volume of porous medium per unit change in head.
Stratigraphic	Pertaining to the composition and position of layers of rock or sediment.
Tertiary	A period of earth's history estimated to have occurred between 65 and 2 million years ago.
Till	A complex non-layered mixture of clay, silt, sand, and gravel deposited directly by and underneath an active glacier.
Topographic	Pertaining to the general configuration of a land surface.
Transmissivity	The rate at which ground water flows through a certain thickness of aquifer under a certain pressure.
Unconfined	Ground water in an aquifer that is not covered by an impermeable layer.
Water Table	The subsurface level between the zone of saturation (ground water) and the zone of aeration.
Weathering	The destructive process(es) by which the atmosphere and surface water chemically change the character of a rock.

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minerals. Nitrate concentrations (Figure 5-7) do appear to be higher in the alluvial and upland aquifers. This is expected since these aquifers are generally closer to the surface and at greater risk from land use activities such as septic tank drainfields and agricultural practices.

Of the minor ions reviewed (Figures 5-7 and 5-8) no trends in analyte distribution or aquifer association were apparent. Most of the waters sampled can be characterized as bicarbonate type waters. Figure 5-9, shows a plot of selected water quality data, presented in a trilinear diagram developed by Piper (1944). The diagram is a plot of the normalized major ion concentrations, in millequilivents per liter, expressed as percents of the total ion concentration. Figures 5-10 through 5-13 are plots of the ground water chemistry data segregated into aquifer groups; Alluvial Aquifers, Local Upland Aquifers, Sea Level Aquifers, and Regional Aquifers, respectively.

Data for the Alluvial Aquifer (Figure 5-10) plot in two groups. The Smaller group consist of data for wells 51, 61, and 62. This group has anion levels higher in percent sulfate and lower in percent alkalinity than the larger group. Anion data for the smaller group plot in the HCO3-SO4-Cl, mixed anion type, field. These anion data are the only data collected for the Redmond-Bear Creek study to plot outside the bicarbonate type field. The cation data plot in the Ca-Mg-Na+K, mixed cation type, field.

Local Upland Aquifers data plot in a single group (Figure 5-11). The waters can be characterized as mixed cation and magnesium type and bicarbonate type.

Sea Level Aquifers data plot in two groups (Figure 5-12). The smaller group consists of data for wells 20 and 29. Water from the smaller group can be characterized as sodium-bicarbonate type, whereas waters from the larger group can be characterized as calcium-mixed cation types and bicarbonate type. The difference in the two groups is distinguished by the level of percent sodium. Waters from the smaller group are higher in percent sodium and lower in percentage of other major cations.

Water from the regional aquifers plot in two groups (Figure 5-13). The smaller group is composed of wells 14 and 16. Data from these two wells plot in the sodium plus potassium apex of the cation triangle. The larger group of wells plot in the mixed cation-calcium fields.

Figure 5-9 is an overlay of all the data on one trilinear diagram. Generally, the anion data overlap the ranges in the bicarbonate field. The exception

150969

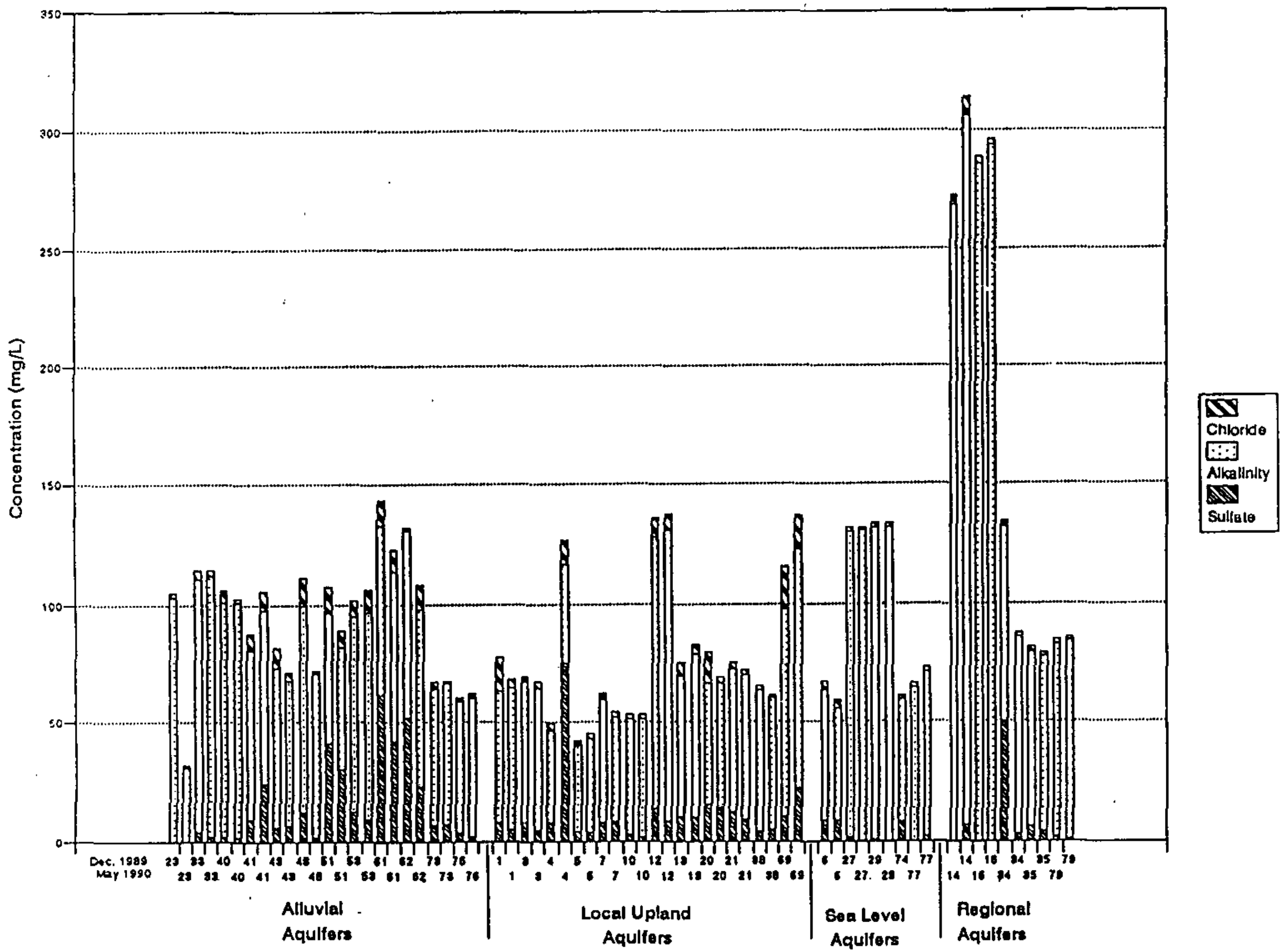

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Figure 5-1
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
DISTRIBUTION OF MAJOR ANION CONCENTRATIONS IN GROUND WATER

150969

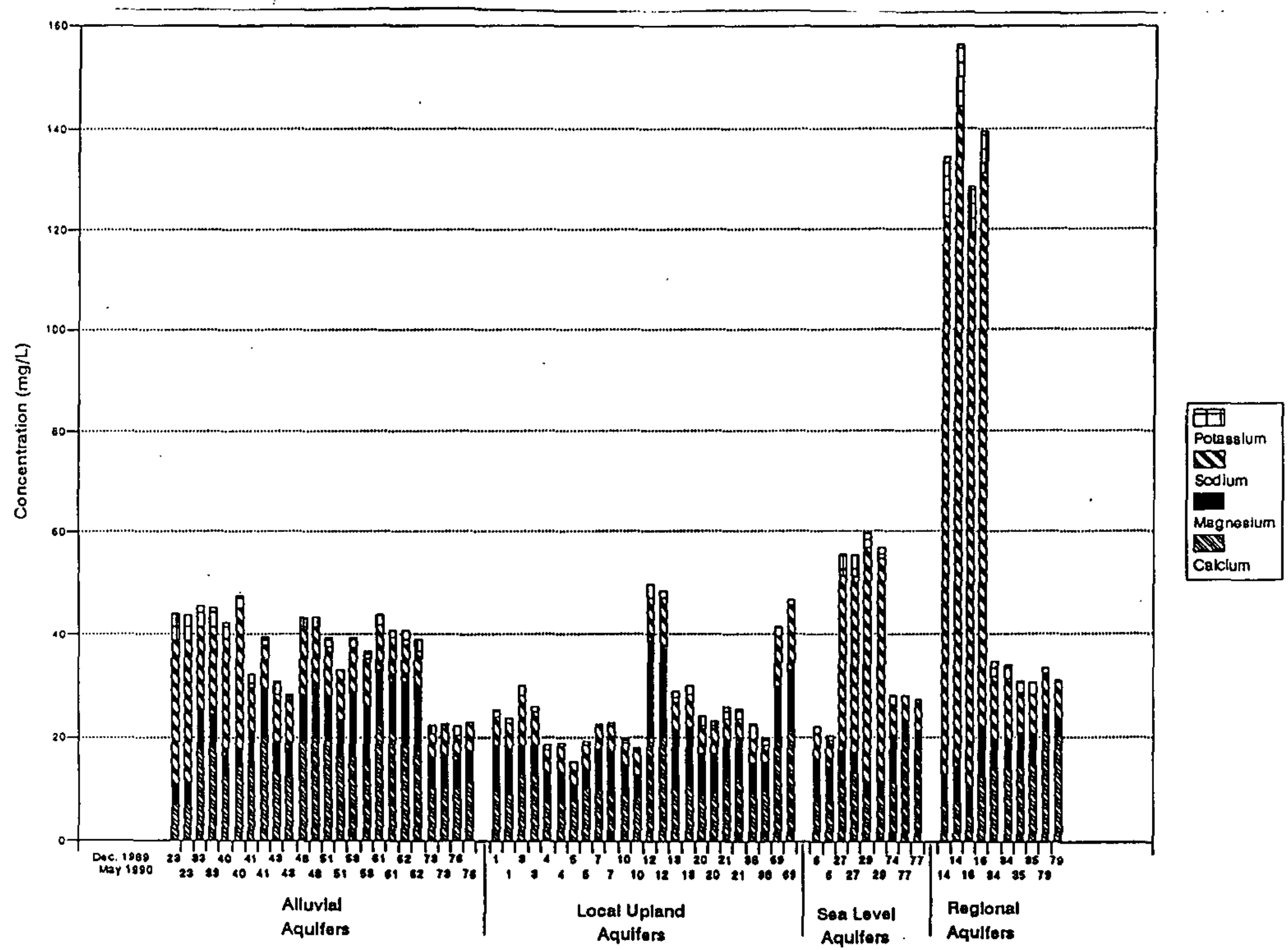

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Figure 5-2
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
MAJOR CATION CONCENTRATIONS IN GROUND WATER

142322

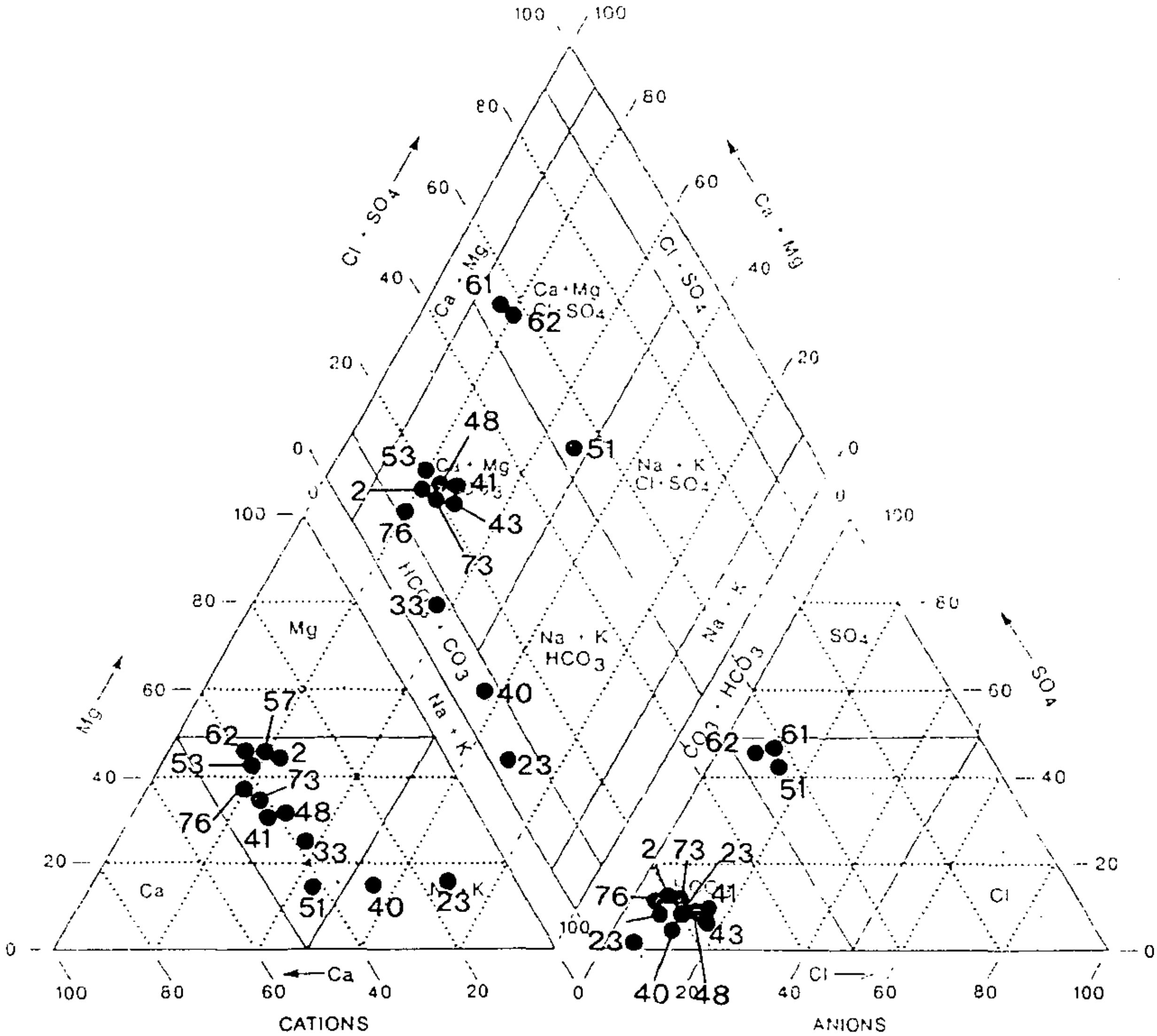

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Figure 5-10
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
TRILINEAR PLOT OF MAJOR ION CONCENTRATIONS FOR ALLUVIAL AQUIFERS

142322

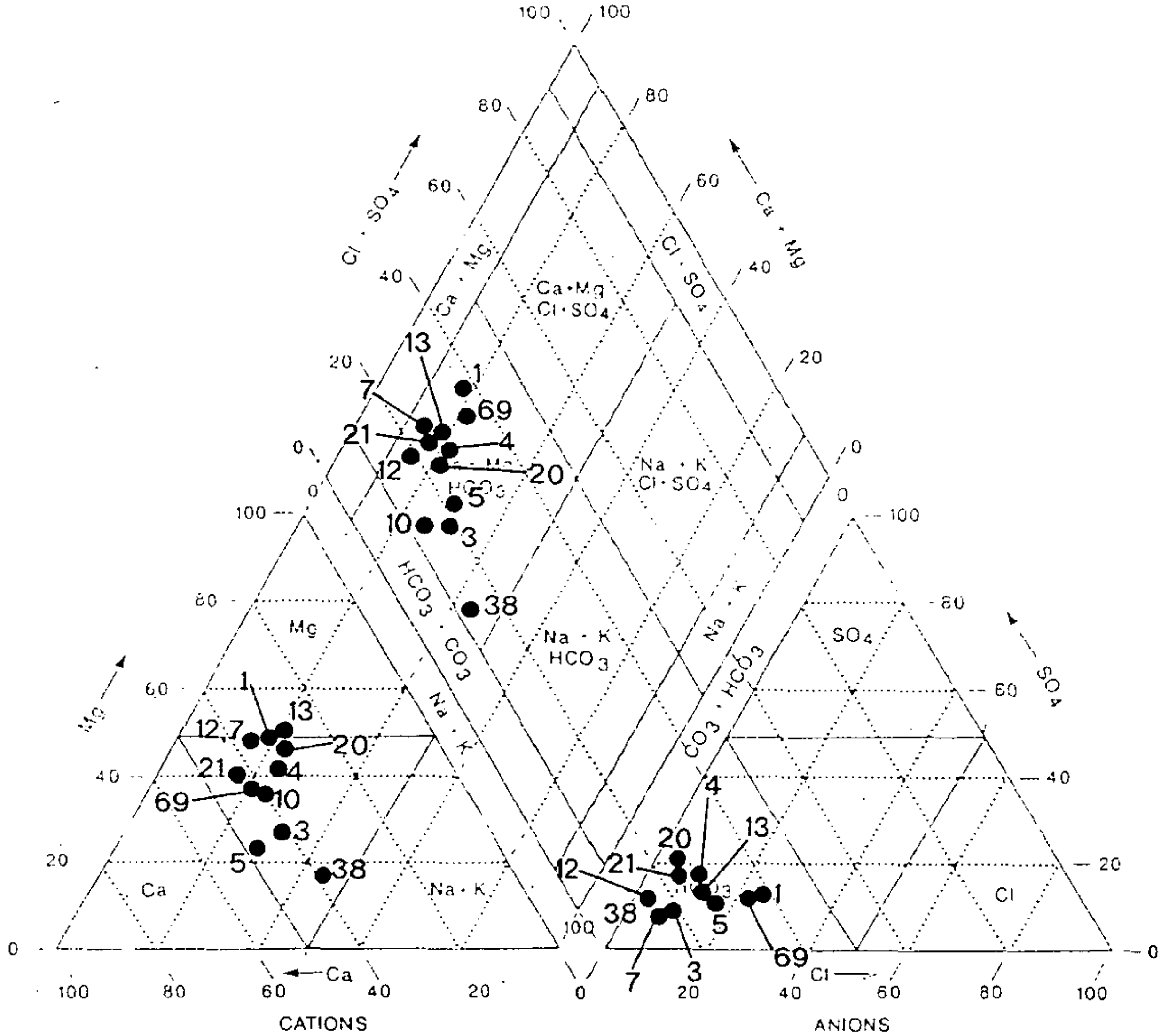

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Figure 5-11
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
TRILINEAR PLOT OF MAJOR ION CONCENTRATIONS FOR LOCAL UPLAND AQUIFERS

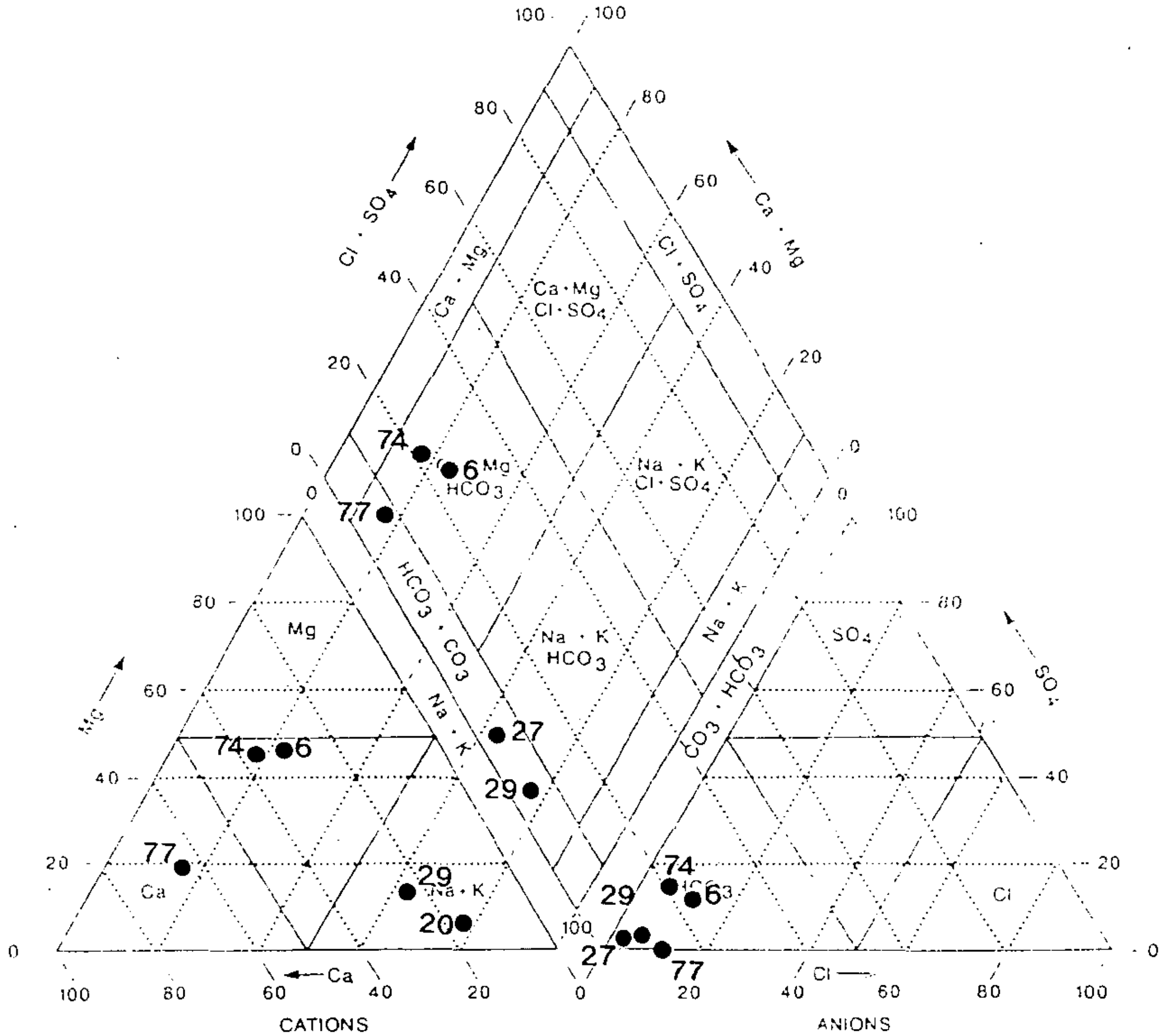

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Figure 5-12
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
TRILINEAR PLOT OF MAJOR ION CONCENTRATIONS FOR SEA LEVEL AQUIFERS

142322

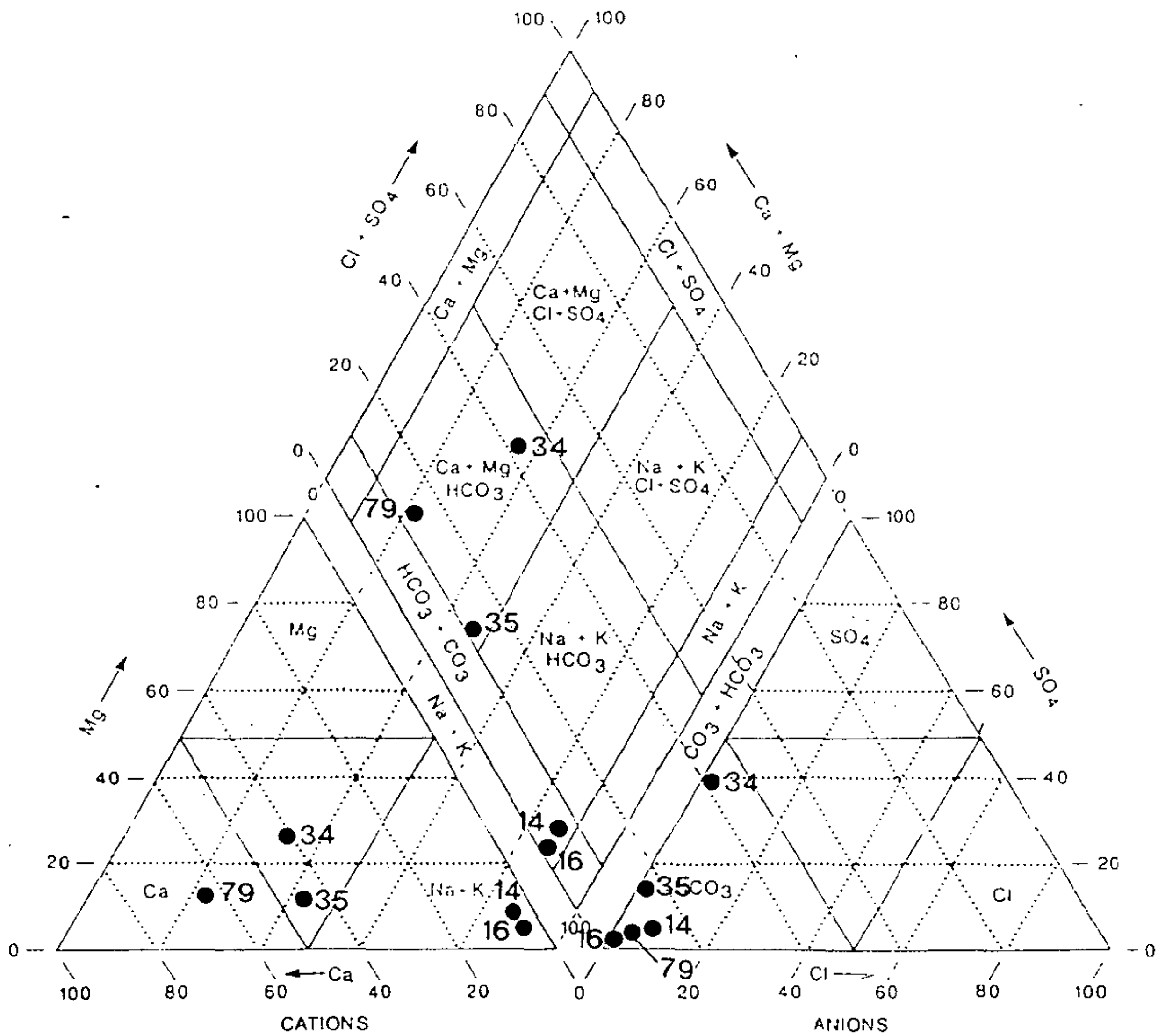

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Figure 5-13
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
TRILINEAR PLOT OF MAJOR ION CONCENTRATIONS FOR REGIONAL AQUIFERS

Table 5-2
Redmond-Bear Creek GWMP
Summary of Ground Water Quality Testing Results

Well ID (map)	Sample Number	Well Name	Sampling Date	Total Coliforms (MPN/100ml)	Fecal Coliforms (MPN/100ml)	TDS (mg/l)	Total Hardness (mg/l as CaCO3)	Total Alkalinity (mg/l as CaCO3)	Carbonate Alkalinity (mg/l as CaCO3)	Bicarbonate Alkalinity (mg/l as CaCO3)	Hydroxide Alkalinity (mg/l as CaCO3)	TOX (ug/l)	Calcium (mg/l)	Iron (mg/l)	Manganese (mg/l)	Magnesium (mg/l)	Potassium (mg/l)	Sodium (mg/l)	Silica (mg/l)	Zinc (mg/l)
41	D-30	KING C. SHOPS DUPL	05/14/90	1 L	1 L	188	87	74	1 L	74	1 L		19	0.05	0.002 L	9.5	1.7	8.3	28	0.1
8	R-7	KLOEPFER, RYAN	05/14/90	1 L	1 L	104	48	48	1 L	48	1 L		7.5	0.25	0.003	7.2	0.69	5.2	30	0.27
61	R-16	CAMPTON COMMUNITY	05/14/90	1 L	1 L	178	84	72	1 L	72	1 L		21	0.01 L	0.005	10	1.4	8.8	28	0.02 L
51	R-17	CEDAR LAWNS	05/14/90	1 L	1 L	136	71	52	1 L	52	1 L		18	0.74	0.005	7.5	0.17	8.9	23	0.2
41	R-30	KING C. SHOPS	05/14/90	1 L	1 L	158	90	74	1 L	74	1 L		20	0.03	0.002 L	8.7	1.7	8.8	30	0.1
	S-11	TRIP BLANKS	05/14/90	1 L	1 L	6	1 L	2	1 L	2	1 L		0.01 L	0.01 L	0.002 L	0.01 L	1 L	0.02 L	11	0.02 L
29	R-5	GOSS, GORDON	05/14/90	1 L	1 L	284	31	131	1 L	131	1 L	5 L	8.4	0.03	0.015	2.5	2.2	44	23	0.03
13	R-9	NELSON, GORDON	05/14/90	1 L	1 L	134	73	70	1 L	70	1 L	5 L	11	0.03	0.002 L	11	1.9	8.5	34	0.02
10	R-11	TAINTER, GORDON	05/14/90	1 L	1 L	82	39	50	1 L	50	1 L	5 L	8.2	0.72	0.061	4.5	0.51	3.2	26	0.22
20	R-13	WEIDE, MIKE	05/14/90	1 L	1 L	110	55	53	1 L	53	1 L	5 L	9	8.1	0.03	7.9	1.5	5	30	0.21
18	R-24	ULRICH MEATS	05/14/90	2	1 L	448	68	293	1 L	293	1 L	5 L	12	11	0.21	9.3	6.6	110	51	0.12
3	D-4	PARADISE PARK DUPL	05/15/90	1 L	1 L	114	55	82	1 L	82	1 L		13	0.1	0.181	5.5	1.3	8.9	30	0.02 L
1	R-3	DOUGHTY, LEE	05/15/90	7	1 L	110	57	80	1 L	80	1 L		8.9	0.01	0.002 L	6.4	1	5.6	23	0.01
3	R-4	PARADISE PARK	05/15/90	1 L	1 L	114	54	80	1 L	80	1 L		13	0.11	0.151	5.2	1.2	6.6	30	0.45
4	R-1	BONDO, PAUL	05/15/90	1 L	1 L	88	41	42	1 L	42	1 L		7.7	0.02	0.002 L	5.3	0.87	5.3	23	0.12
12	R-21	SHARP, GRANT	05/15/90	6	1 L	220	124	122	1 L	122	1 L		20	0.48	0.023	18	1.5	9.2	28	0.37
7	R-06	HOSEY #1	05/15/90	1 L	1 L	120	55	44	1 L	44	1 L	5 L	9.2	0.19	0.03	7.8	0.92	5	23	0.15
5	R-10	ODEGARD, DAVID	05/15/90	5	1 L	92	39	40	1 L	40	1 L	5 L	10	0.08	0.02	3.3	0.63	5.6	23	0.03
27	R-14	WEBSTER, WALT	05/15/90	1 L	1 L	196	51	130	1 L	130	1 L	5 L	13	0.31	0.07	4.4	4.2	34	30	0.03
34	R-20	PATTERSON, STAN	05/15/90	1 L	1 L	142	54	84	1 L	84	1 L	5 L	14	0.18	0.043	4.7	2.7	13	28	0.05
21	R-23	STERN, WILLIAM	05/15/90	1 L	1 L	132	56	82	1 L	82	1 L	5 L	12	0.04	0.114	6.9	2	5	28	0.01
77	D-27	NE SAMMAMISH #4 DUPL	05/16/90	1 L	1 L	110	83	86	1 L	86	1 L	5 L	18	0.03	0.048	3.6	0.72	6.1	26	0.02 L
23	R-8	LEIN, WILLIAM	05/16/90	1 L	1 L	180	33	31	1 L	31	1 L	5 L	8.7	0.1	0.047	3.9	5.4	28	32	0.02 L
35	R-15	BOWMAN, CARL	05/16/90	1 L	1 L	140	61	74	1 L	74	1 L	5 L	15	7.1	0.085	5.7	2.4	7.8	32	0.88
33	R-18	HOME PORT FARM	05/16/90	1 L	1 L	184	72	110	1 L	110	1 L	5 L	18	0.11	0.057	8.5	4	17	30	0.02
82	R-22	SPORTSMAN PARK	05/16/90	6	1 L	250	82	78	1 L	78	1 L	5 L	17	1.2	0.086	12	2.4	7.7	20	0.08
78	R-25	NE SAMMAMISH #2	05/16/90	1 L	1 L	110	51	58	1 L	58	1 L	5 L	11	1.3	0.045	5.8	0.72	5.7	26	0.04
79	R-26	NE SAMMAMISH #3	05/16/90	1 L	1 L	120	63	84	1 L	84	1 L	5 L	20	0.03	0.041	3.1	0.64	7.7	21	0.02 L
77	R-27	NE SAMMAMISH #4	05/16/90	1 L	1 L	102	58	70	1 L	70	1 L	5 L	18	0.01 L	0.042	3.5	0.61	5.3	23	0.02 L
46	R-35	REDMOND WELL #5	05/16/90	2	1 L	180	89	70	1 L	70	1 L	5 L	20	0.01 L	0.012	8.5	2.4	12	28	0.02 L
53	R-37	REDMOND WELL #2	05/16/90	1 L	1 L	198	83	88	1 L	88	1 L	5 L	15	0.01 L	0.025	11	1.6	8.5	28	0.02
40	D-32	OLYMPIAN PRECAST	05/17/90	1 L	1 L	138	40	88	1 L	86	1 L	5 L	13	0.05	0.089	3.4	2.6	26	34	0.06
43	R-28	BARRET, DEL	05/17/90	1 L	1 L	122	54	62	1 L	62	1 L	5 L	12	0.17	0.111	5.8	1.3	8.8	30	0.03
38	R-31	McCLAN, ROBERT	05/17/90	1 L	1 L	108	48	56	1 L	56	1 L	5 L	8.7	0.04	0.086	5.8	1.8	3.5	41	0.02
69	D-33	TUTKO LANDSCAPE	05/17/90	1 L	1 L	200	100	100	1 L	100	1 L	5 L	21	0.15	0.057	12	1.1	13	30	0.02 L
73	R-34	UNION HILL	05/17/90	1 L	1 L	85	48	60	1 L	60	1 L	5 L	10	0.11	0.095	5.8	1.1	6.2	32	0.02
74	D-50	EVANS CREEK WELL #2	05/17/90	17	1 L	82	65	52	1 L	52	1 L	5 L	11	29	0.374	8.2	2	5.9	58	0.06
64	R-51	EVANS CREEK WELL #1	05/17/90	110	1 L	220	2300	170	1 L	170	1 L	23	280	1000	13	400	135	100	300	3.2
14	R-12	THENOS DAIRY	05/17/90	1 L	1 L	500	47	300	1 L	300	1 L		7.6	0.48	0.06	6.7	12	130	47	0.03
40	R-32	OLYMPIAN PRECAST	05/17/90	1 L	1 L	180	50	100	1 L	100	1 L		14	0.11	0.084	3.6	2.3	28	38	0.02
43	R-28	BARRETT, DEL	12/06/88	1 L	1 L	188	59	68	1 L	68	1 L	5 L	13	0.71	0.078	6.4	2.8	9.3	24	0.054
4	R-1	BONDO, PAUL	12/06/88	1 L	1 L	120	42	39	1 L	39	1 L	5 L	7.6	0.01 L	0.002 L	5.5	1.3	4.6	24	0.12
29	RD-5	GOSS, GORDON DUPL	12/06/88	1 L	1 L	74	42	40	1 L	40	1 L	15	7.7	0.04	0.002 L	5.6	1.2	4.7	24	0.121
38	RD-73	McCLAN, ROBERT DUPL	12/06/88	1 L	1 L	178	48	52	1 L	52	1 L	5 L	8.5	0.29	0.048	5.6	2.3	4.6	32	0.374

Table 5-2
Redmond-Bear Creek GWMP
Summary of Ground Water Quality Testing Results

Well ID (map)	Sample Number	Well Name	Sampling Date	Total Coliforms (MPN/100ml)	Fecal Coliforms (MPN/100ml)	TDS (mg/l)	Total Hardness (mg/l as CaCO3)	Total Alkalinity (mg/l as CaCO3)	Carbonate Alkalinity (mg/l as CaCO3)	Bicarbonate Alkalinity (mg/l as CaCO3)	Hydroxide Alkalinity (mg/l as CaCO3)	TOX (ug/l)	Calcium (mg/l)	Iron (mg/l)	Manganese (mg/l)	Magnesium (mg/l)	Potassium (mg/l)	Sodium (mg/l)	Silica (mg/l)	Zinc (mg/l)
69	R-33	TUTKO LANDSCAPE	12/06/89	1 L	1 L	180	83	88	1 L	88	1 L	5 L	18	0.32	0.012	11	1.8	9.8	28	0.032
73	R-34	UNION HILL	12/06/89	1 L	1 L	148	48	58	1 L	58	1 L	5 L	10	0.15	0.077	5.8	1.8	5.1	24	0.021
51	RD-17	CEDAR LAWNS DUPL	12/05/89	1 L	1 L	88	84	56	1 L	56	1 L	11	18	2	0.068	8.6	1.5	10	21	0.139
33	R-18	HOME PORT FARM	12/05/89	1 L	1 L	78	73	107	1 L	107	1 L	5 L	16	0.16	0.065	6.8	4.1	17	20	0.014
23	R-8	LEIN, WILLIAM	12/05/89	1 L	1 L	144	33	103	1 L	103	1 L	5 L	6.7	0.1	0.025	3.9	5.8	26	30	0.018
79	RD-67	NE SAMMAMISH #3 DUPL	12/05/89	1 L	1 L	100	66	63	1 L	63	1 L	5 L	21	0.01 L	0.021	3.3	1.2	6	18	0.014
76	R-25	NE SAMMAMISH #2	12/05/89	1 L	1 L	80	46	56	1 L	56	1 L	5 L	6.8	0.14	0.003	5.6	1.7	4.8	21	0.018
62	R-22	SPORTSMAN PARK	12/05/89	19	1 L	96	86	78	1 L	76	1 L	5 L	18	1.4	0.085	13	2.0	7.3	14	0.055
29	R-5	GOSS, GORDON	12/04/89	11	1 L	202	32	131	1 L	131	1 L	5 L	8.8	0.01 L	0.019	2.5	2.9	46	17	0.006
10	R-11	TAINTER, GORDON	12/04/89	1	1 L	114	42	49	1 L	49	1 L	5 L	8.7	0.18	0.082	4.9	1.1	5.3	21	0.14
13	R-9	NELSON, GORDON	12/04/89	1 L	1 L	158	70	60	1 L	60	1 L	5 L	10	0.04	0.002 L	11	2.2	8.2	30	0.108
13	RD-9	NELSON, GORDON DUPL	12/04/89	1 L	1 L	168	70	60	1 L	60	1 L	5 L	10	0.01 L	0.002 L	11	2.3	8.2	15	0.14
12	R-21	SHARPE, GRANT	12/04/89	118	1 L	182	128	114	1 L	114	1 L	14	20	2.1	0.055	19	2.8	8.1	15	0.248
14	R-12	THENOS DAIRY	12/04/89	1 L	1 L	348	42	268	1 L	268	1 L	7	6.6	0.28	0.044	6	12	110	19	0.018
7	R-6	HOSEY #1	12/04/89	1 L	1 L	91	58	52	1 L	52	1 L	5 L	6.5	0.84	0.017	8.3	1 L	5	23	0.215
6	R-7	KLOEPFER, RYAN	12/04/89	1 L	1 L	106	52	56	1 L	56	1 L	13	8	0.47	0.002 L	7.8	1.2	5.2	26	0.318
5	R-10	ODEGARD, DAVID	12/04/89	21	1 L	80	32	36	1 L	36	1 L	5 L	7.6	0.17	0.002 L	3.1	1 L	4.5	23	0.067
27	R-14	WEBSTER, WALT	12/04/89	1 L	1 L	141	81	128	1 L	128	1 L	5 L	13	0.14	0.058	4.5	4.4	34	32	0.013
53	R-37	REDMOND WELL #2	12/04/89	1 L	1 L	129	89	84	1 L	84	1 L	5 L	18	0.01 L	0.003	12	2.1	9.3	26	0.022
48	R-35	REDMOND WELL #5	12/04/89	1	1 L	114	86	88	1 L	88	1 L	8	19	0.01 L	0.002 L	8.3	2.3	13	23	0.02
35	R-15	BOWMAN, CARL	12/04/89	1 L	1 L	89	82	74	1 L	74	1 L	5 L	15	0.31	0.036	8	2.3	7.8	26	0.068
77	R-27	NE SAMMAMISH #4	12/05/89	1 L	1 L	90	83	65	1 L	65	1 L	5 L	18	0.01 L	0.025	3.7	1 L	5.4	19	0.01
78	R-26	NE SAMMAMISH #3	12/05/89	1 L	1 L	86	80	62	1 L	62	1 L	5 L	21	0.01 L	0.02	3.4	1.2	6	18	0.011
61	R-16	CAMPTON COMMUNITY	12/05/89	1 L	1 L	186	100	71	1 L	71	1 L	15	22	0.01 L	0.004	11	2.2	8.1	22	0.015
51	R-17	CEDAR LAWNS	12/05/89	1 L	1 L	120	84	56	1 L	56	1 L	5 L	18	2	0.069	8.6	1.9	10	21	0.145
34	R-20	PATTERSON, STAN	12/05/89	1 L	1 L	98	55	62	1 L	62	1 L	5 L	14	0.18	0.032	4.9	2.9	13	28	0.027
21	R-23	STERN, WILLIAM	12/05/89	1 L	1 L	88	59	61	1 L	61	1 L	5 L	12	0.11	0.105	7.1	2.5	4.8	30	0.059
16	R-24	ULRICH MEATS	12/05/89	1 L	1 L	185	32	285	1 L	285	1 L	5 L	4.7	0.27	0.037	4.8	9.4	110	39	0.019
20	R-13	WEIDE, MIKE	12/06/89	1 L	1 L	82	55	52	1 L	52	1 L	5 L	6.7	0.85	0.036	8.1	2.7	4.9	24	0.018
40	R-32	OLYMPIAN PRECAST	12/06/89	1 L	1 L	218	47	100	1 L	100	1 L	5 L	13	0.01 L	0.055	3.6	3.4	23	28	0.017
41	R-30	KING C. SHOPS	12/06/89	1 L	1 L	198	63	72	1 L	72	1 L	20	14	0.01 L	0.002 L	6.8	2.7	9	22	0.052
38	R-31	McCLAN, ROBERT	12/06/89	1 L	1 L	138	47	60	1 L	60	1 L	5 L	8.3	0.14	0.047	5.7	2.8	4.8	32	0.304
1	R-3	DOUGHTY, LEE	12/07/89	1 L	1 L	82	61	56	1 L	56	1 L	5 L	8.5	0.01 L	0.002 L	8.1	1.8	5.4	28	0.0004 ???
3	R-4	PARADISE PARK	12/12/89	1 L	1 L	130	65	60	1 L	60	1 L	5 L	13	0.31	0.167	5.5	2.1	10	34	0.04

Table 5-2
Redmond-Bear Creek GWMP
Summary of Ground Water Quality Testing Results

Well ID (MAP)	Sample Number	Well Name	Sampling Date	Silver (mg/l)	Selenium (mg/l)	Mercury (mg/l)	Barium (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Lead (mg/l)	Chromium (mg/l)	Arsenic (mg/l)	Chloride (mg/l)	Nitrite (mg/l)	Sulfate (mg/l)	Nitrate (mg/l)	Fluoride (mg/l)	Antimony (mg/l)	Beryllium (mg/l)	Nickel (mg/l)	Thallium (mg/l)	Cyanide (mg/l)	Phenol (mg/l)
41	D-30	KING C. SHOPS DUPL	05/14/90	0.01 L	0.001 L	0.0002 L	0.007	0.062	0.002 L	0.001	0.006 L	0.002	8.1	0.5 L	24	3.1	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
6	R-7	KLOEPFER, RYAN	05/14/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.003	0.002 L	0.005	0.006 L	0.002	3.7	0.5 L	8.4	0.85	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
61	R-16	CAMPTON COMMUNITY	05/14/90	0.01 L	0.001 L	0.0002 L	0.009	0.002 L	0.002 L	0.001	0.006 L	0.001	8.5	0.5 L	42	0.2 L	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
51	R-17	CEDAR LAWNS	05/14/90	0.01 L	0.001 L	0.0002 L	0.006	0.017	0.002 L	0.006	0.006 L	0.001	7.6	0.5 L	30	0.2 L	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
41	R-30	KING C. SHOPS	05/14/90	0.01 L	0.001 L	0.0002 L	0.006	0.061	0.002 L	0.001	0.006 L	0.003	5.9	0.5 L	24	3.1	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
	5-11	TRIP BLANKS	05/14/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.001	0.5 L	0.5 L	0.5 L	0.2 L	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
29	R-5	GOSS, GORDON	05/14/90	0.01 L	0.001 L	0.0002 L	0.005	0.002 L	0.002 L	0.001	0.006 L	0.025	2	0.5 L	0.5 L	0.2 L	0.2 L						
13	R-9	NELSON, GORDON	05/14/90	0.01 L	0.001 L	0.0002 L	0.004	0.002 L	0.002 L	0.001	0.006 L	0.004	4.4	0.5 L	8.6	3.6	0.2 L						
10	R-11	TAINTER, GORDON	05/14/90	0.01 L	0.001 L	0.0002 L	0.004	0.003	0.002 L	0.006	0.006 L	0.006	2.1	0.5 L	1.8	0.2 L	0.2 L						
20	R-13	WEIDE, MIKE	05/14/90	0.01 L	0.001 L	0.0002 L	0.02	0.002 L	0.002 L	0.006	0.006 L	0.027	2.5	0.5 L	14	0.2 L	0.2 L						
18	R-24	ULRICH MEATS	05/14/90	0.01 L	0.001 L	0.0002 L	0.043	0.128	0.002 L	0.01	0.014	0.004	2.8	0.5 L	0.5 L	0.2 L	0.2 L						
3	D-4	PARADISE PARK DUPL	05/15/90	0.01 L	0.001 L	0.0002 L	0.016	0.002 L	0.002 L	0.001	0.006 L	0.001	3.6	0.5 L	4.8	0.2 L	0.2 L						
1	R-3	DOUGHTY, LEE	05/15/90	0.01 L	0.001 L	0.0002 L	0.004	0.002 L	0.002 L	0.001	0.006 L	0.002	3.8	0.5 L	5.1	1.3	0.2 L						
3	R-4	PARADISE PARK	05/15/90	0.01 L	0.001 L	0.0002 L	0.016	0.002 L	0.002 L	0.015	0.006 L	0.001	3.7	0.5 L	4.4	0.2 L	0.2 L						
4	R-1	BONDO, PAUL	05/15/90	0.01 L	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.001	0.006 L	0.005	10	0.5 L	75	1.3	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
12	R-21	SHARP, GRANT	05/15/90	0.01 L	0.001 L	0.0002 L	0.015	0.004	0.002 L	0.13	0.014	0.007	7.8	0.5 L	6.1	3.6	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
7	R-06	HOSEY #1	05/15/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.005	0.002 L	0.009	0.006 L	0.002	2.8	0.5 L	8.3	1.8	0.2 L						
5	R-10	ODEGARD, DAVID	05/15/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.005	0.002 L	0.002	0.006 L	0.001 L	2.9	0.5 L	3.5	2.8	0.2 L						
27	R-14	WEBSTER, WALT	05/15/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.01	0.002 L	0.002	0.006 L	0.004	1.6	0.5 L	0.5 L	0.2 L	0.2 L						
34	R-20	PATTERSON, STAN	05/15/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.001 L	1.9	0.5 L	2.9	0.2 L	0.2 L						
21	R-23	STERN, WILLIAM	05/15/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.001	2.2	0.5 L	8	0.2 L	0.2 L						
77	D-27	NE SAMMAMISH #4 DUPL	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.002	0.006 L	0.009	2	0.5 L	2.2	0.2 L	0.2 L						
23	R-8	LEIN, WILLIAM	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.002	0.006 L	0.001 L	1.3	0.5 L	0.5 L	0.2 L	0.2 L						
35	R-15	BOWMAN, CARL	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.003	0.002 L	0.018	0.006 L	0.001	2	0.5 L	4	0.2 L	0.2 L						
33	R-18	HOME PORT FARM	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.023	2.8	0.5 L	2.4	0.2 L	0.2 L						
62	R-22	SPORTSMAN PARK	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.003	0.002 L	0.001	0.006 L	0.003	10	0.5 L	23	0.2 L	0.2 L						
78	R-25	NE SAMMAMISH #2	05/16/90	0.01 L	0.001 L	0.0002 L	0.003	0.006	0.002 L	0.017	0.006 L	0.003	2.5	0.5 L	2.3	0.2	0.2 L						
78	R-26	NE SAMMAMISH #3	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.003	0.002 L	0.001	0.006 L	0.01	2	0.5 L	0.8	0.2 L	0.2 L						
77	R-27	NE SAMMAMISH #4	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.002	0.006 L	0.009	2	0.5 L	2.2	0.2 L	0.2 L						
44	R-35	REDMOND WELL #5	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.006	0.002 L	0.001	0.006 L	0.002	1.7	0.5 L	1.4	0.4	0.2 L						
53	R-37	REDMOND WELL #2	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.017	0.002 L	0.003	0.006 L	0.001	10	0.5 L	9	2	0.2 L						
40	O-32	OLYMPIAN PRECAST	05/17/90	0.01 L	0.001	0.0002 L	0.003 L	0.002 L	0.002 L	0.003	0.006 L	0.005	1.8	0.5 L	1.6	0.2 L	0.2 L						
43	R-28	BARRET, DEL	05/17/90	0.01 L	0.001	0.0002 L	0.003 L	0.002 L	0.002 L	0.006	0.006 L	0.001	3.9	0.5 L	6.5	0.31	0.2 L						
36	R-31	McCLAN, ROBERT	05/17/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.003	0.006 L	0.012	1.3	0.5 L	4.6	0.2 L	0.2 L						
69	D-33	TUTKO LANDSCAPE	05/17/90	0.01 L	0.001 L	0.0002	0.003 L	0.004	0.002 L	0.001	0.006 L	0.001	15	0.5 L	22	0.59	0.2 L						
73	R-34	UNION HILL	05/17/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.005	1.7	0.5 L	7.3	0.2 L	0.2 L						
74	D-50	EVANS CREEK WELL #2	05/17/90	0.01 L	0.001 L	0.0002 L	0.1	0.055	0.002 L	0.026	0.022	0.018	2.1	0.5 L	7.7	0.2 L	0.2 L						
64	R-51	EVANS CREEK WELL #1	05/17/90	0.01 L	0.006	0.0028	8.4	1.5	0.002 L	0.31	1.3	0.43	10	0.5 L	40	0.2 L	0.2 L						
14	R-12	THENOS DAIRY	05/17/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.008	0.002 L	0.001 L	0.008 L	0.003	8.3	0.5 L	6.6	0.2 L	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
40	R-32	OLYMPIAN PRECAST	05/17/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.005	2.7	0.1 L	1.6	0.1 L	0.1 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
43	R-28	BARRETT, DEL	12/06/88	0.01	0.001 L	0.0002 L	0.012	0.002 L	0.002 L	0.005	0.013	0.001	6.58	0.1 L	6.7	0.369	0.1 L						
4	R-1	BONDO, PAUL	12/06/88	0.01 L	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.001	0.015	0.003	3.21	0.1 L	7.78	0.77	0.1 L						
29	RO-5	GOSS, GORDON DUPL	12/06/88	0.01 L	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.001	0.014	0.003	7.29	0.1 L	7.48	0.77	0.1 L						
34	RO-73	McCLAN, ROBERT DUPL	12/06/88	0.01 L	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.002	0.011	0.009	2.4	0.1 L	3.9	0.1 L	0.1 L						

Table 5-2
Redmond-Bear Creek GWMP
Summary of Ground Water Quality Testing Results

Well ID (MAP)	Sample Number	Well Name	Sampling Date	Silver (mg/l)	Selenium (mg/l)	Mercury (mg/l)	Barium (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Lead (mg/l)	Chromium (mg/l)	Arsenic (mg/l)	Chloride (mg/l)	Nitrite (mg/l)	Sulfate (mg/l)	Nitrate (mg/l)	Fluoride (mg/l)	Antimony (mg/l)	Beryllium (mg/l)	Nickel (mg/l)	Thallium (mg/l)	Cyanide (mg/l)	Phenol (mg/l)
69	R-33	TUTKO LANDSCAPE	12/06/89	0.01 L	0.001 L	0.0002 L	0.008	0.014	0.002 L	0.002	0.015	0.001 L	18	0.1 L	8.8	3.5	0.1 L						
73	R-34	UNION HILL	12/06/89	0.01	0.001 L	0.0002 L	0.007	0.002 L	0.002 L	0.002	0.012	0.004	3.4	0.1 L	8.1	0.1 L	[illegible] L						
51	RD-17	CEDAR LAWNS DUPL	12/05/89	0.01 L	0.001 L	0.0002 L	0.008	0.108	0.002 L	0.005	0.009	0.001	10	0.1 L	[illegible]	1 L	[illegible] L						
33	R-18	HOME PORT FARM	12/05/89	0.01 L	0.001 L	0.0002 L	0.017	0.018	0.002 L	0.001 L	0.009	0.024	4.2	0.1 L	[illegible]	1 L	[illegible] L						
23	R-8	LEIN, WILLIAM	12/05/89	0.01 L	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.001 L	0.007	0.001 L	2.1	0.28	0.2 L	0.1 L	0.1 L						
79	RD-67	NE SAMMAMISH #3 DUPL	12/05/89	0.01 L	0.001 L	0.0002 L	0.008	0.007	0.002 L	0.001 L	0.008	0.003	2	0.33	1.5	0.1 L	0.1 L						
76	R-25	NE SAMMAMISH #2	12/05/89	0.01	0.001 L	0.0002 L	0.009	0.002 L	0.002 L	0.003	0.012	0.003	2.3	0.1 L	3.8	0.33	0.1 L						
82	R-22	SPORTSMAN PARK	12/05/89	0.01 L	0.001 L	0.0002 L	0.018	0.005	0.002 L	0.002	0.012	0.003	2.4	0.1 L	32	1.7	1 L						
29	R-5	GOSS, GORDON	12/04/89	0.01 L	0.001 L	0.0002 L	0.005	0.002 L	0.002 L	0.001 L	0.008 L	0.027	2	0.1 L	0.48	0.1 L	0.1 L						
10	R-11	TAINTER, GORDON	12/04/89	0.01 L	0.001	0.0002	0.003	0.008	0.002 L	0.001	0.008 L	0.005	21	0.1 L	2.7	0.1 L	0.1 L						
13	R-9	NELSON, GORDON	12/04/89	0.01 L	0.001 L	0.0003	0.004	0.004	0.002 L	0.001 L	0.01	0.004	5.9	0.1 L	10	2.7	0.1 L						
13	RD-9	NELSON, GORDON DUPL	12/04/89	0.01 L	0.001 L	0.0002 L	0.004	0.002 L	0.002 L	0.001	0.008 L	0.004	5.8	0.1 L	10	2.7	0.1 L						
12	R-21	SHARPE, GRANT	12/04/89	0.01 L	0.001 L	0.0003	0.02	0.031	0.002 L	0.33	0.042	0.011	6.8	0.1 L	13	3.6	0.1 L						
14	R-12	THENOS DAIRY	12/04/89	0.01 L	0.001 L	0.0002 L	0.007	0.02	0.002 L	0.004	0.008 L	0.002	4.7	0.1 L	0.2 L	0.1 L	0.1 L						
7	R-6	HOSEY #1	12/04/89	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.005	0.01	0.002	3.5	0.1 L	7.7	1.4	0.1 L						
6	R-7	KLOEPFER, RYAN	12/04/89	0.01 L	0.001 L	0.0002	0.003	0.01	0.002 L	0.002	0.01	0.003	4	0.1 L	6.5	1	0.1 L						
5	R-10	ODEGARD, DAVID	12/04/89	0.01 L	0.001 L	0.0002 L	0.004	0.008	0.002 L	0.001	0.008	0.001 L	2.9	0.1 L	4.1	0.87	0.1 L						
27	R-14	WEBSTER, WALT	12/04/89	0.01 L	0.001 L	0.0002 L	0.008	0.01	0.002 L	0.001	0.02	0.003	1.9	0.1 L	1.5	0.1 L	0.1 L						
53	R-37	REDMOND WELL #2	12/04/89	0.01 L	0.001 L	0.0002 L	0.009	0.013	0.002 L	0.002	0.009	0.001	6.7	0.1 L	12	1.5	0.1 L						
48	R-35	REDMOND WELL #5	12/04/89	0.01 L	0.001 L	0.0002 L	0.009	0.002 L	0.002 L	0.001	0.009	0.002	12	0.1 L	12	1.3	0.1 L						
35	R-15	BOWMAN, CARL	12/04/89	0.01 L	0.001 L	0.0003	0.011	0.002 L	0.002 L	0.001	0.008 L	0.001	2.5	0.1 L	5.6	0.1 L	0.1 L						
77	R-27	NE SAMMAMISH #4	12/05/89	0.01 L	0.001 L	0.0002 L	0.004	0.007	0.002 L	0.002	0.011	0.008	2.3	0.33	0.1 L	0.1 L	0.1 L						
79	R-26	NE SAMMAMISH #3	12/05/89	0.01 L	0.001 L	0.0002 L	0.008	0.002 L	0.002 L	0.001	0.006	0.007	2	0.32	1.8	0.1 L	0.1 L						
61	R-16	CAMPTON COMMUNITY	12/05/89	0.01 L	0.001 L	0.0002 L	0.011	0.008	0.002 L	0.001 L	0.01	0.001 L	11	1 L	82	0.24	1 L						
51	R-17	CEDAR LAWNS	12/05/89	0.01 L	0.001 L	0.0002 L	0.009	0.118	0.002	0.008	0.011	0.001	11	1 L	41	0.55	1 L						
34	R-20	PATTERSON, STAN	12/05/89	0.01 L	0.001 L	0.0002 L	0.012	0.005	0.002 L	0.001 L	0.006	0.001 L	2.7	1 L	50	1 L	1 L						
21	R-23	STERN, WILLIAM	12/05/89	0.01 L	0.001 L	0.0002 L	0.008	0.008 L	0.002 L	0.001 L	0.009	0.002	2.5	1 L	12	1 L	1 L						
16	R-24	ULRICH MEATS	12/05/89	0.01 L	0.001 L	0.0002 L	0.006	0.017	0.002 L	0.001	0.007	0.003	3.3	0.8	0.1 L	0.1 L	0.45						
20	R-13	WEIDE, MIKE	12/06/89	0.01 L	0.001 L	0.0002 L	0.01	0.013	0.002 L	0.001 L	0.009	0.003	13	0.1 L	15	0.1 L	0.1 L						
40	R-32	OLYMPIAN PRECAST	12/06/89	0.01	0.001 L	0.0002 L	0.011	0.013	0.002 L	0.001 L	0.012	0.004	5.2	0.1 L	1.4	0.1 L	0.1 L						
41	R-30	KING C. SHOPS	12/06/89	0.01	0.001 L	0.0003	0.008	0.024	0.002 L	0.001 L	0.012	0.003	7.8	0.1 L	8.8	0.1 L	0.1 L						
38	R-31	McCLAN, ROBERT	12/06/89	0.01	0.001 L	0.0002 L	0.007	0.006	0.002 L	0.001	0.015	0.009	2.4	0.1 L	3.8	0.1 L	0.1 L						
1	R-3	DOUGHTY, LEE	12/07/89	0.01 L	0.001 L	0.0002 L	0.005	0.002 L	0.002 L	0.001	0.014	0.002	15	0.1 L	7.5	1.8	0.1 L						
3	R-4	PARADISE PARK	12/12/89	0.01 L	0.001 L	0.0002 L	0.017	0.002 L	0.002 L	0.002	0.008 L	0.001 L	2.6	0.1 L	7.5	0.1 L	0.1 L						

Note: Well number corresponds to numbers on map in Figure 5-1.
mg/l = milligrams per liter (parts per million)
L = laboratory method reporting limit.

Table 5-3

Analyte Classifications and Standards

Analyte	National Primary Drinking Water MCL[a] (mg/l)	National Secondary Drinking Water MCL[b] (mg/l)	Ground Water Characteristic Constituent	Priority Pollutant	Regulated Pollutant
Alkalinity					
Total	NR	NR	Yes	No	No
Bicarbonate	NR	NR	Yes	No	No
Carbonate	NR	NR	Yes	No	No
Hydroxide	NR	NR	Yes	No	No
Arsenic	0.05	NR	No	Yes	Yes
Barium	1	NR	No	No	Yes
Beryllium	NR	NR	No	Yes	No
Cadmium	0.010	NR	No	Yes	Yes
Calcium	NR	NR	Yes	No	No
Chloride	NR	250	Yes	No	No
Chlorinated Pesticides and PCBs	[c]	NR	Yes	No	Yes
Chromium	0.05	NR	No	Yes	Yes
Coliforms					
Total	1/100 ml	NR	No	No	Yes
Fecal	1/100 ml	NR	No	No	Yes
Copper	NR	1	No	Yes	No
Cyanide	NR	NR	No	Yes	No
Fluoride	4.0	2.0[d]	Yes	No	Yes
Iron	NR	0.3	Yes	No	No
Lead (at tap)	0.05	NR	No	Yes	Yes
Magnesium	NR	NR	Yes	No	No
Manganese	NR	0.05	No	No	No
Mercury	0.002	NR	No	Yes	Yes
Nickel	NR	NR	No	Yes	Yes
Nitrate (as N)	10	NR	Yes	No	Yes
Nitrite (as N)	NR	NR	No	No	Yes

Table 5-3

Analyte Classifications and Standards (Continued)

Analyte	National Primary Drinking Water MCL[a] (mg/l)	National Secondary Drinking Water MCL[b] (mg/l)	Ground Water Characteristic Constituent	Priority Pollutant	Regulated Pollutant
Nitrate + Nitrite (as N)	NR	NR	No	No	Yes
Phenol	NR	NR	No	Yes	Yes
Potassium	0.01	NR	No	Yes	Yes
Selenium	NR	NR	Yes	No	No
Semivolatile Organic Compounds (BNAs)	[c]	NR	No	No	Yes
Silica	NR	NR	Yes	No	No
Silver	0.05	NR	No	Yes	Yes
Sodium	NR	NR	Yes	No	No
Sulfate	NR	250	Yes	No	No
Thallium	NR	NR	No	Yes	No
Total Dissolved Solids	NR	500	No	No	No
Total Hardness	NR	NR	Yes	No	No
Total Organic Halides (TOX)	NR[e]	NR	No	No	No[e]
Volatile Organic Compounds (VOCs)					
Acetone	NR	NR	No	No	Yes
Carbon Tetrachloride	0.005[f]	NR	No	No	Yes
Others	[c]	NR	No	No	Yes
Zinc	NR	5	No	Yes	No

NOTES:
- MCL Maximum Contaminant Level permitted under federal law.
- mg/l micrograms per liter (parts per million)
- NR Not Regulated

[a] These values are exactly equal to the Washington State Primary Drinking Water Contaminant Criteria and Primary Ground Water Contaminant Criteria.
[b] These values are exactly equal to the Washington State Secondary Drinking Water Contaminant Criteria and Secondary Ground Water Contaminant Criteria unless otherwise noted.
[c] MCL depends upon specific analyte.
[d] Washington State has no secondary ground water contaminant criterion for fluoride.
[e] Although concentrations of TOX are not regulated as TOX, the concentrations of some individual organic halides which contribute to the total concentration are regulated under National Interim Primary Drinking Water Regulations.
[f] The Washington State ground water quality standard for carbon tetrachloride is 0.0003 mg/l.

150969

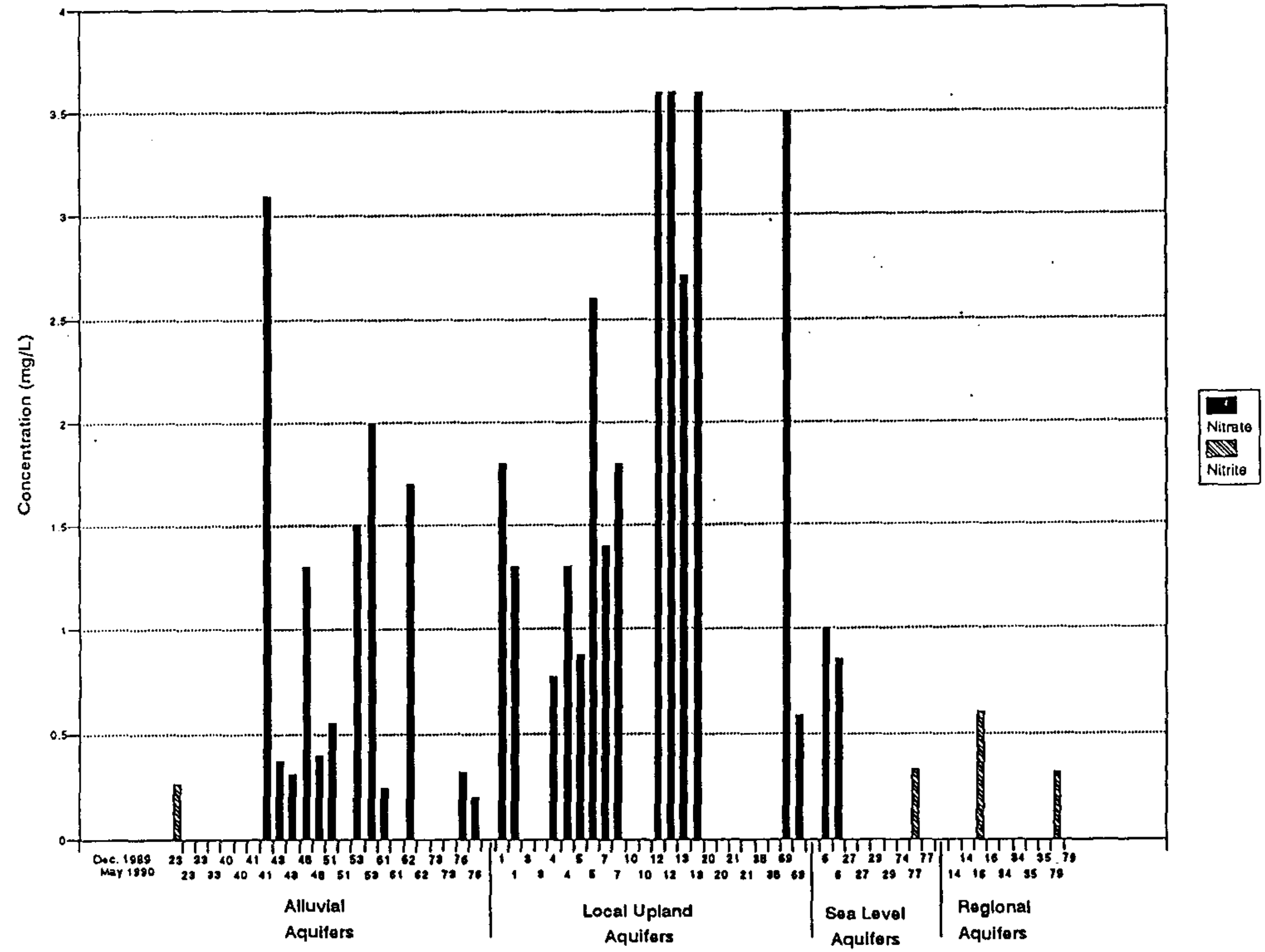

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Figure 5-7
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
NITRATE AND NITRITE CONCENTRATIONS IN GROUND WATER

142322

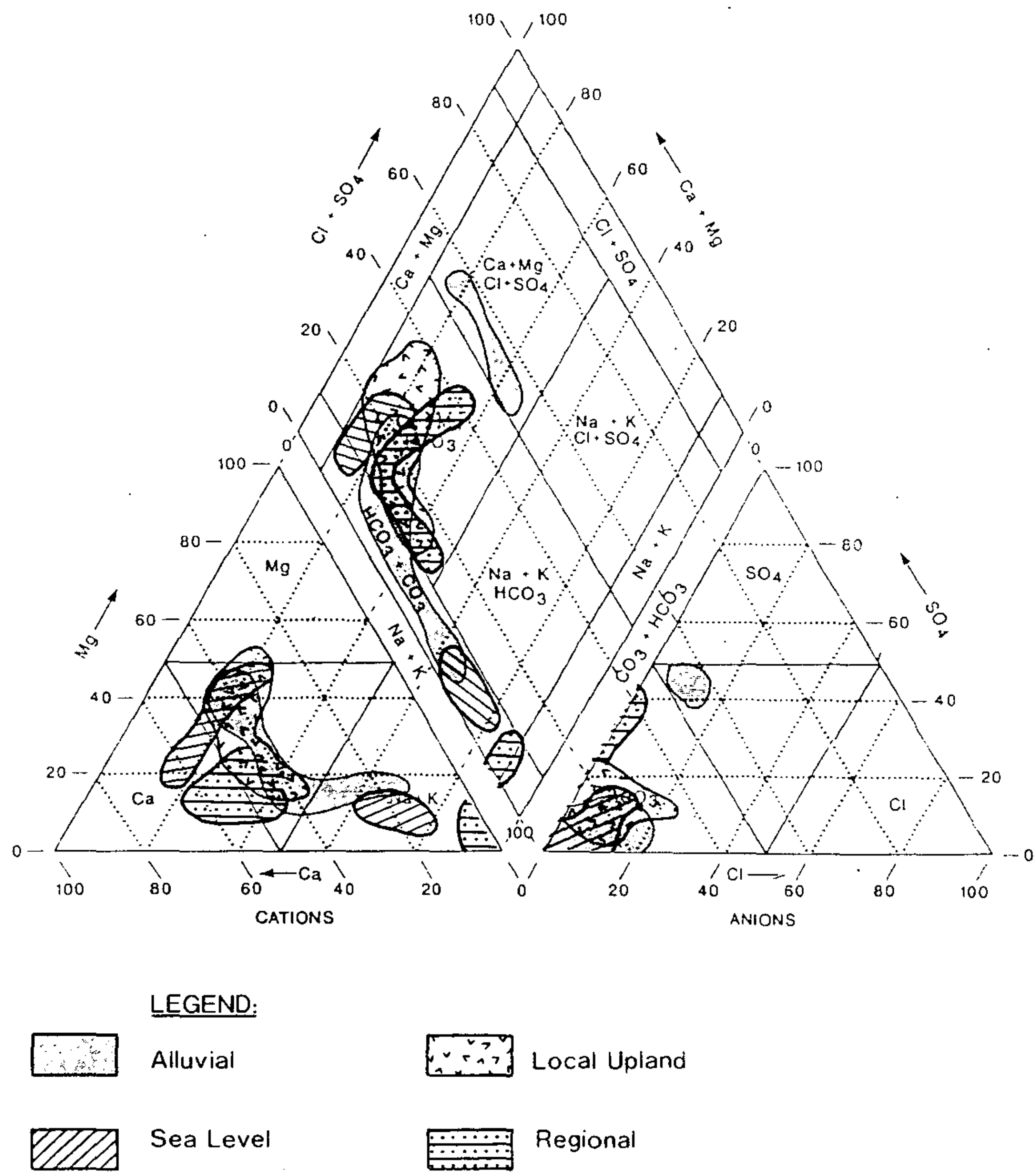

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Figure 5-9
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
TRILINEAR PLOT OF MAJOR ION CONCENTRATIONS AQUIFER ZONE

150969

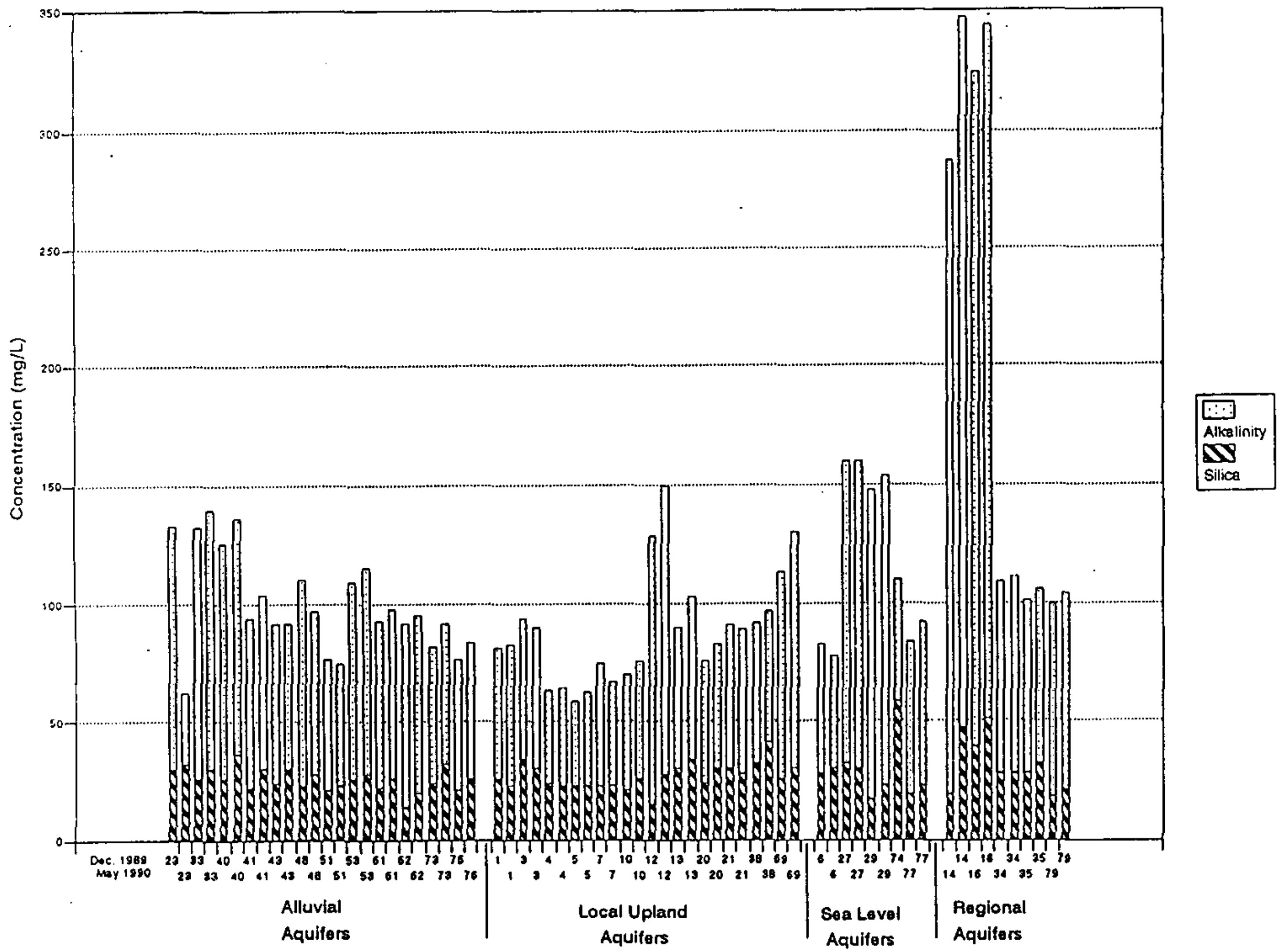

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Figure 5-8
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
SILICA AND ALKALINITY CONCENTRATIONS IN GROUND WATER

150969

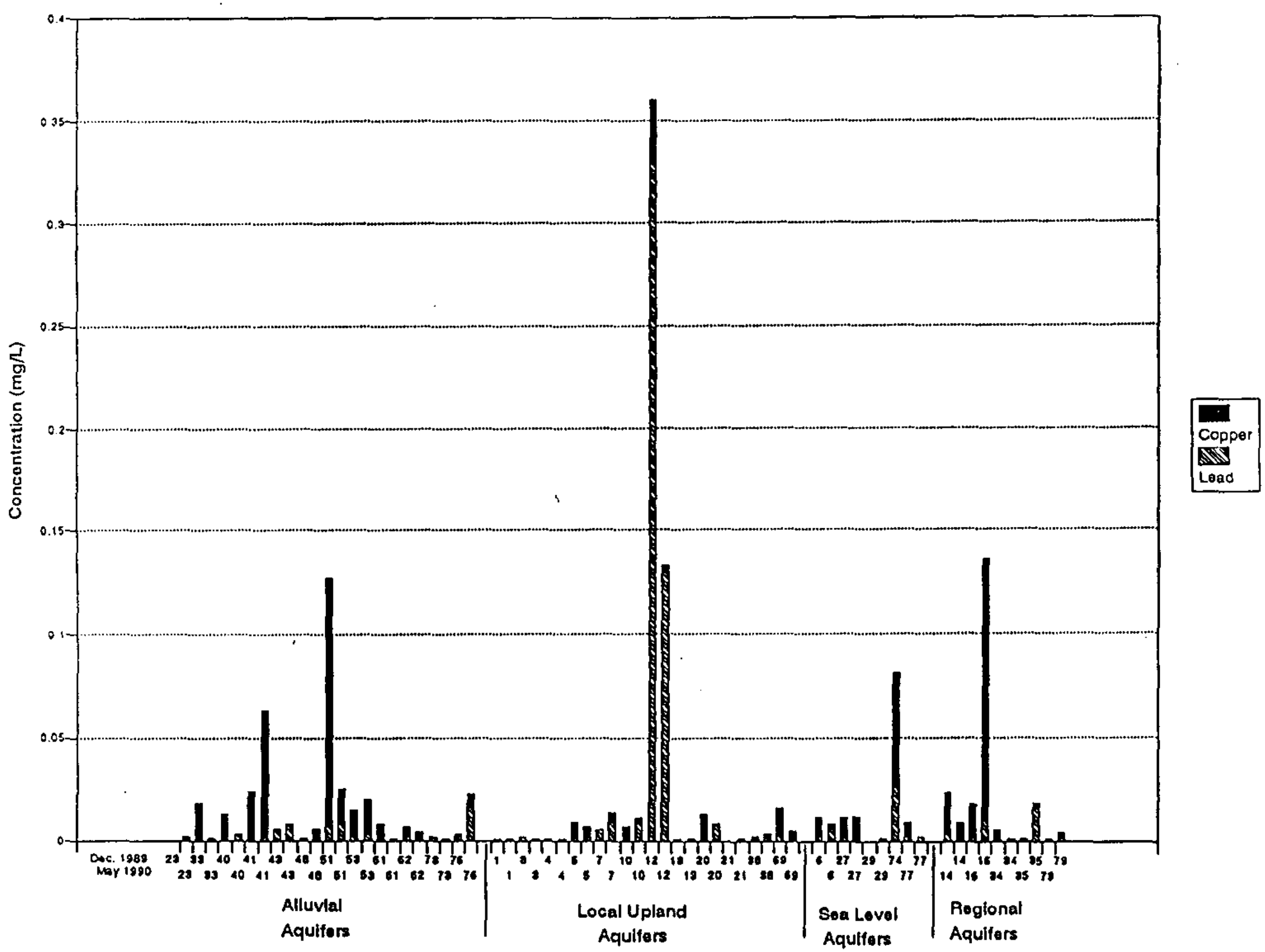

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Figure 5-4

REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

COPPER AND LEAD CONCENTRATIONS IN GROUND WATER

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Washington Administrative Code (WAC) 248-54, Washington Drinking Water Regulations.

150969

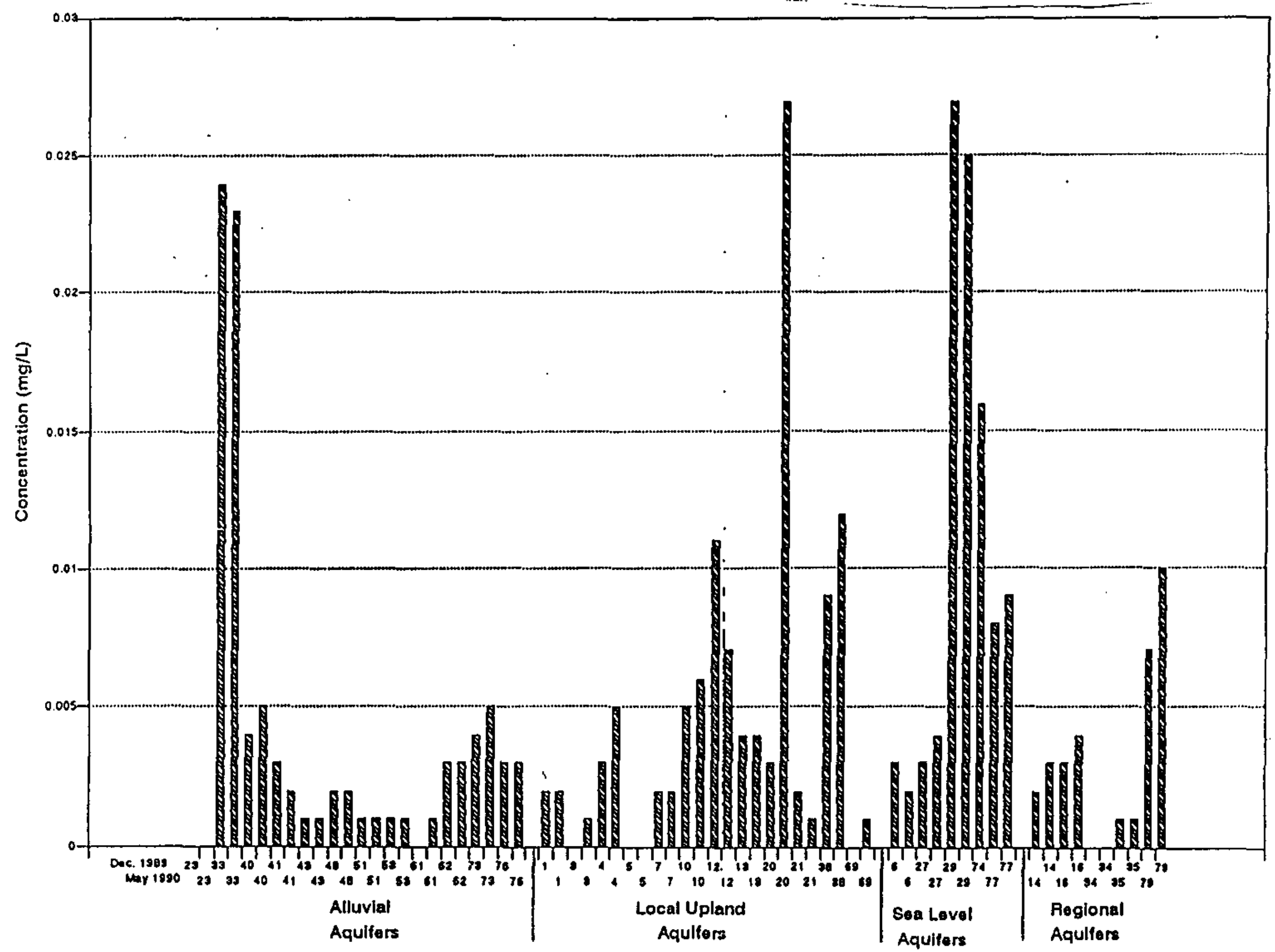

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Figure 5-3
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA
ARSENIC CONCENTRATIONS IN GROUND WATER

150989

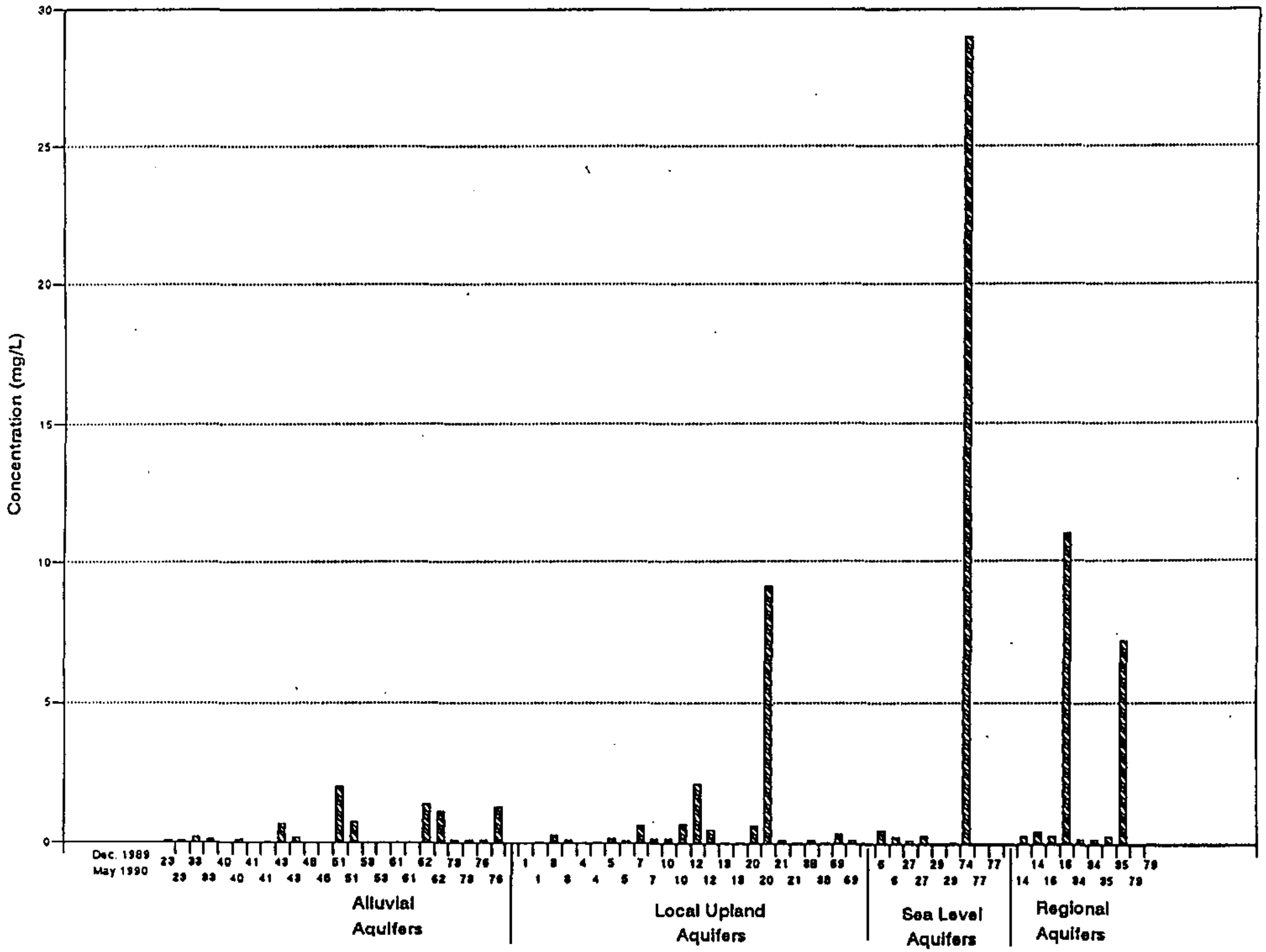

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Figure 5-5
REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

IRON CONCENTRATIONS IN GROUND WATER

150969

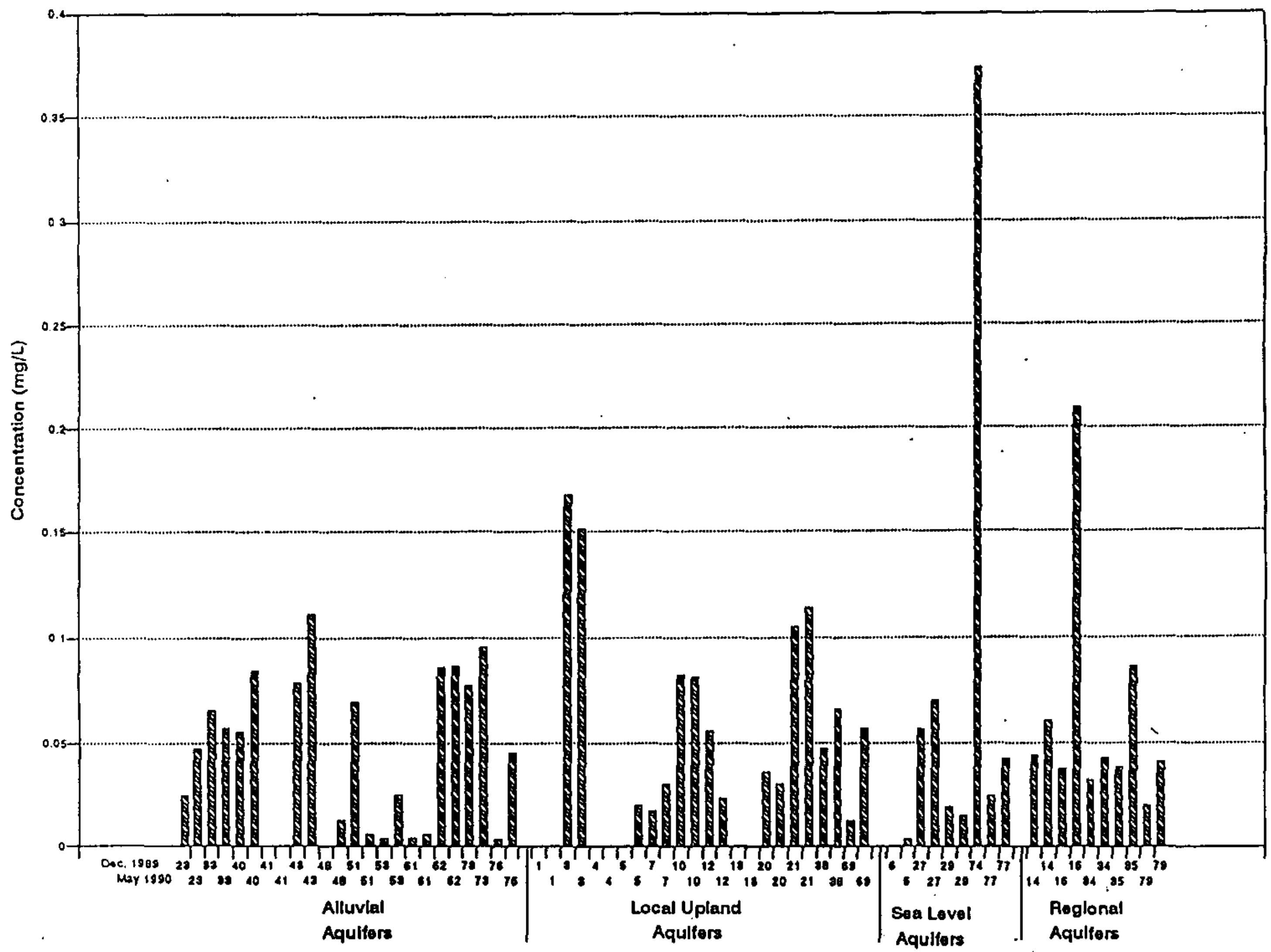

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Figure 5-6

REDMOND BEAR CREEK
GROUND WATER MANAGEMENT AREA

MANGANESE CONCENTRATIONS IN GROUND WATER