1999

Hydrothermal water/groundwater interaction: a comparative study of electromagnetic terrain-conductivity mapping and standard hydrogeochemical techniques

Matthew L. Gibson
The University of Montana

Maureen and Mike

MANSFIELD LIBRARY

The University of **MONTANA**

Permission is granted by the author to reproduce this material in its entirety, provided that this material is used for scholarly purposes and is properly cited in published works and reports.

*** Please check "Yes" or "No" and provide signature ***

Yes, I grant permission X

No, I do not grant permission ____

Author's Signature [illegible]

Date 5/28/99

Any copying for commercial purposes or financial gain may be undertaken only with the author's explicit consent.

Hydrothermal Water/Groundwater Interaction:

A Comparative Study of Electromagnetic Terrain-Conductivity Mapping

and Standard Hydrogeochemical Techniques

By

Matthew L. Gibson

B.A., University of Colorado

Presented in partial fulfillment of the requirements

for the degree of Master of Science

University of Montana

May, 1999

Approved by:

Chairperson, Board of Examiners

Dean, Graduate School

5-28-99

Date

Matthew L. Gibson, M.S., May 1999
Geology

Hydrothermal Water/Groundwater Interaction: A Comparaitive Study of Electromagnetic Terrain-Conductivity Mapping and Standard Hydrogeochemical Techniques

Director: Nancy W. Hinman

Electromagnetic (EM) terrain-conductivity surveys were conducted at two thermally-influence drainages in Yellowstone National Park (YNP) to assess the feasibility of this technique to detect the interaction of hot spring discharge with shallow groundwater. This nonintrusive geophysical technique was successful in mapping the zones of mixing of distinct waters in the subsurface at two sites that vary significantly in size and hydrogeothermal morphology. Results compared closely with those indicated by standard hydrogeologic and geochemical characterizations.

Data from the two sites, Sentinel Meadows and Octopus Spring, revealed EM terrain-conductivity anomalies that reflect the influx of highly conductive hot spring discharge into the local groundwater systems. The anomalies are indicative of the higher temperatures and conductance of the Na-Cl-rich hydrothermal waters compared to the receiving groundwaters.

Potentiometric surface and water quality data were obtained to determine the hydrogeochemistry of both areas. Groundwater flow at Sentinel Meadows is predominantly to the south but is deflected by siliceous sinter mound features in the valley. EM terrain-conductivity mapping closely approximates the groundwater flow patterns and the distribution of more highly conductive waters near zones of hot spring discharge. Two groundwater systems present at Octopus Spring are distinct with respect to temperature and conductive solutes. EM terrain-conductivity mapping reflects these variations of data.

Study of subaerial microbial siliceous sinter has focused mainly at or near thermal vents. It is speculated that silica mineralizing zones may form in the subsurface, resulting in microbial fossilization that is not evident from the surface. EM terrain-conductivity surveys appears to provide a means to identify such areas without disruptive and intrusive exploration of the system.

ACKNOWLEDGEMENTS

This study was funded by NASA-EPSCoR and the Montana Space Grant Program. I owe special thanks to many National Park Service employees at Yellowstone National Park for providing me with access, technical assistance, transportation, and lodging at the Park, especially Rick Hutchinson, Tim Thompson, and Bob Lindstrom. I would like to thank Bonnie Ertel, Steve Helgen, and Amy Burgess for their field assistance and Lynn Biegelson for helping me with my laboratory work. My committee members, Bill Woessner and Garon Smith, provided me with valuable advice and critiques on my work. A special thanks goes to Nancy Hinman, my committee chairman, for her guidance and support (both technical advice and equipment-hauling ability) in completing this project. And, of course, I can't forget the many bison and their friends who provided me with companionship and inspiration during my many long hours in the field.

TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	vii
1.0 INTRODUCTION	1
1.1 Goals and Objectives	3
1.2 Thesis Organization	4
2.0 BACKGROUND	5
2.1 Site Descriptions	5
2.1.1 Sentinel Meadows Study Area	5
2.1.2 Octopus Spring Study Area	9
2.2 Electromagnetic Conductivity Surveys	12
2.3 Hot Spring Geochemistry	14
2.4 Role of Silica in a Hot Spring Environment	15
3.0 METHODOLGY	19
3.1 Hydrogeology and Geochemistry	19
3.1.1 Groundwater Monitoring Wells and Staff Gauges	20
3.1.2 Groundwater and Surface Water Sampling	23
3.1.3 Stream Flow Estimates	24
3.1.4 Hydraulic Conductivity and Porosity Measurements	25
3.2 Electromagnetic Conductivity Surveys	28
3.3 Temperature Probe Survey	29
4.0 RESULTS	31
4.1 Sentinel Meadows Study Area	31
4.1.1. Hydrogeology	31
4.1.2 Surface Water Hydraulics	34
4.1.3 Geochemistry	36
4.1.4 Electromagnetic Terrain-Conductivity	41
4.2 Octopus Spring Study Area	46
4.2.1 Hydrogeology	46
4.2.2 Surface Water Hydraulics	50
4.2.3 Geochemistry	51

4.2.4. Electromagnetic Terrain-Conductivity 56

5.0 DISCUSSION 60
5.1 Sentinel Meadows Study Area 60
5.2 Octopus Spring Study Area 64
5.3 Conceptual Models of the Study Areas 67

6.0 CONCLUSIONS 73

REFERENCES 74

APPENDIX A: Boring Logs 77

APPENDIX B: Water Levels, Potentiometric Surface Elevations, and Hydrographs 82

APPENDIX C: Slug Test Graphs 91

APPENDIX D: EM Terrain-Conductivity Maps and Transects 97

APPENDIX E: Temperature Probe Survey Plots 118

APPENDIX F: Analytical Data and Data Quality 121

LIST OF TABLES

Table 1. Chemical Analysis of Selected Thermal Waters from Yellowstone National Park 16

Table 2. Sentinel Meadows Slug Testing Results (9/30/95) 33

Table 3. Sentinel Meadows Constant -Head Permeameter and Porosity Testing Results 34

Table 4. Sentinel Creek Flow Measurements (8/29/95) 34

Table 5. Sentinel Creek Flow Measurements (8/29/95) 35

Table 6. Sentinel Meadows Spring Discharge Rates (8/29/95) 35

Table 7. Surface Water/Groundwater Chemical Interaction, Sentinel Meadows 41

Table 8. Groundwater Temperature Variation, Octopus Spring Sinter Mound 48

Table 9. Octopus Spring Falling-Head Permeameter and Porosity Testing, OW-1A Sinter Cores 49

Table10. White Creek Stream Flow Measurements (8/31/95) 50

Table 11. Comparison of White Creek's Stream Surface with Stream Bed Head (8/31/95) 50

Table 12. Octopus Spring Area Discharge Rates (8/31/95) 51

LIST OF FIGURES

Figure 1. Locations of Study Areas 6

Figure 2. Sentinel Meadows Study Area 7

Figure 3. Octopus Spring Study Area 10

Figure 4. Sentinel Meadows, Potentiometric Surface Map (9/4/96) 32

Figure 5. Sentinel Meadows, Stiff Diagrams 37

Figure 6. Sentinel Meadows, Variance of Means of Select Chemical Constituents 38

Figure 7. Sentinel Meadows, EM Terrain-Conductivity (1.5 m Depth) 42

Figure 8. Sentinel Meadows, EM Terrain-Conductivity (4.5 m Depth) 43

Figure 9. Sentinel Meadows, EM Terrain-Conductivity versus Depth at Select Locations 45

Figure 10. Octopus Spring , Inferred Local Groundwater Flow Directions (9/3/96) 47

Figure 11. Octopus Spring, Stiff Diagrams 52

Figure 12. Octopus Spring, Variance of Means of Select Chemical Constituents 54

Figure 13. Octopus Spring, EM Terrain-Conductivity (1.5 m Depth) 57

Figure 14. Octopus Spring, EM Terrain-Conductivity (4.5 m Depth) 58

Figure 15. Octopus Spring, EM Terrain-Conductivity versus Depth at Select Locations 59

Figure 16. Sentinel Meadows, Conceptual Model for Hydrothermal-Groundwater-Meteoric Water Mixing 68

Figures 17A, B, C. Octopus Spring Development. 70

Figure 18. Octopus Spring, Conceptual Model for Hydrothermal-Groundwater-Meteoric Water Mixing 71

1.0 INTRODUCTION

Sinter mounds develop around alkaline hot springs as a result of silica precipitation from thermal discharge waters. Precipitation of siliceous sinter occurs as silica-saturated waters cool. Thermophyllic microbial mats in pools and outflow channels are entombed by the silica precipitate (Walter and others, 1996; Hinman and Lindstrom, 1996). Around the aprons of many hot springs, the discharge flows into extensive marshes of diatomaceous earth. Diatoms in these areas receive the surface flows and use the silica in their frustule. Other marsh plants live in these brackish waters but not in close proximity to the hot springs The hot spring discharge ultimately flows into nearby streams or infiltrates into the ground; thus, recharging local groundwater. The hydrothermal system, therefore, is actually more extensive than just the sinter mounds and outflow channels. The resulting hydrothermal features cover extensive areas and contain physical, chemical, and biological signatures of the processes that shaped feature development.

Study of these unique geologic features has focused on processes that govern silica mineralization and microbial fossilization mainly at or very close to the thermal vent and strictly on the surface (White and others, 1956; White and others, 1964; White and others, 1988; Ertel, 1995; Hinman, 1995; Hinman, 1998)). The pathways for precipitation of these biolithologic features are not fully understood but the resulting entombment of the microbial morphotypes is recognizable in the geologic record (Walter and others, 1996). As yet, no contributions have been made to understanding the subsurface processes that are responsible for translating these microbial sinters into the geological record. Nor has any work been done on the extensive distal deposits of silica found in surrounding marshes.

The surficial distribution of marshes around thermal features appears to be controlled by the volume of thermal discharge and the geomorphology. These areas must represent zones of mixing between thermal waters and meteoric waters. Hence, it is likely that these are zones in which dynamic changes are occurring as chemical reactions, physical mixing, and biological activity take place. In a hot spring environment, local groundwater composition (mostly meteoric with perhaps some hydrothermal mixing) will be altered by these processes. Influx from surface water springs and streams will further change the groundwater's makeup, especially influx from Na-Cl-rich hot spring discharge. Traditional methods used to study the hydrodynamics and geochemistry of a groundwater system are often impractical to apply and can be intrusive to the surrounding environment. Ground-based geophysical techniques can be employed to identify conductivity anomalies in the subsurface and may be useful identifying the flow of brackish waters in the subsurface. These methods also may be used to locate potential mineralizing zones that can not be identified from the surface.

This study examined two thermally-influenced drainages in Yellowstone National Park to determine the extent of interaction between surface and subsurface thermal water with local groundwater. Electromagnetic (EM) conductivity mapping was used to identify areas with distinct geochemical signatures based on the type of geologic materials, temperature and dissolved solids in the soil/water matrix. EM mapping results were compared with those obtained using standard hydrogeologic and geochemical techniques to evaluate if this nonintrusive geophysical technique can be used in determining the interaction among thermal and non-thermal surface waters with local groundwater.

1.1 Goals and Objectives

The thermal and chemical signature of mixing between hydrothermal and meteoric waters should be easily detectable, provided a site can be sufficiently instrumented. But, appropriate restrictions on such instruments in Yellowstone National Park prompt the search for an alternative means of evaluating subsurface mixing zones and flow paths. Therefore, a nonintrusive geophysical technique was used along with standard hydrogeological and geochemical techniques to study the interaction of alkaline hot spring discharge with the local environment. The primary goal of this project was to evaluate the effectiveness of using electromagnetic (EM) terrain-conductivity to map the flow of groundwater at the two study areas by comparing the results with those of standard hydrogeological investigations. As an important secondary goal, hydrochemical models of two thermally influenced areas in Yellowstone National Park, Sentinel Meadows and Octopus Spring, were developed. These models include evaluation of the potential for hydrothermal fluids to control subsurface conductivity through mineral solution and precipitation processes.

Specifically, by comparing EM terrain-conductivity mapping with standard groundwater investigative techniques, this research has been used to describe the hydrogeology and geochemistry of the two areas by:

- determining the interaction among thermal water, non-thermal surface water, and local groundwater;
- mapping the flow of thermal water in the shallow subsurface; and
- predicting areas of mineral deposition in the shallow subsurface.

1.2 Thesis Organization

The remainder of this thesis is organized into five parts. Chapter 2 provides a description of the two areas of study followed by discussions of the principles and applications of electromagnetic conductivity mapping, the principles of hot spring geochemistry, and the role of silica in the environment. Chapter 3 describes the methodologies used to determine the surface and hydrogeologic settings of the two areas of study. Chapter 4 presents the results of this study. Chapter 5 provides discussion of the findings. Chapter 6 presents the conclusions.. The appendices present data obtained during this study, including boring logs, potentiometric data, slug testing graphs, EM terrain-conductivity maps, temperature probe data, and water chemistry data.

2.0 BACKGROUND

This chapter is divided into four sections which provide background information on the study areas (Sentinel Meadows and Octopus Spring), the principles and applications of EM terrain-conductivity mapping, the relevant aspects of hot spring geochemistry, and the behavior of silica in a hydrothermal environment.

2.1 Site Descriptions

The two study areas, Sentinel Meadows and Octopus Spring, are located in the Lower Geyser Basin of Yellowstone National Park. The locations of the study areas are shown in Figure 1. The differences in the size of the two areas has provided an opportunity to determine the efficacy of EM conductivity mapping on different scales.

This study was conducted with the permission and cooperation of the National Park Service (NPS Permit No.1671). The NPS stipulated that the two sites be mostly out of view of the public.

2.1.1 Sentinel Meadows Study Area

Sentinel Meadows is a relatively large drainage that has both thermal and non-thermal springs. The valley is drained to the east by Sentinel Creek and the study area is located approximately 2.3 km upstream from the confluence with the Firehole River. A topographic base map of the study area is shown in Figure 2. The study area measures approximately 750 meters by 550 meters and includes three major alkaline thermal springs:

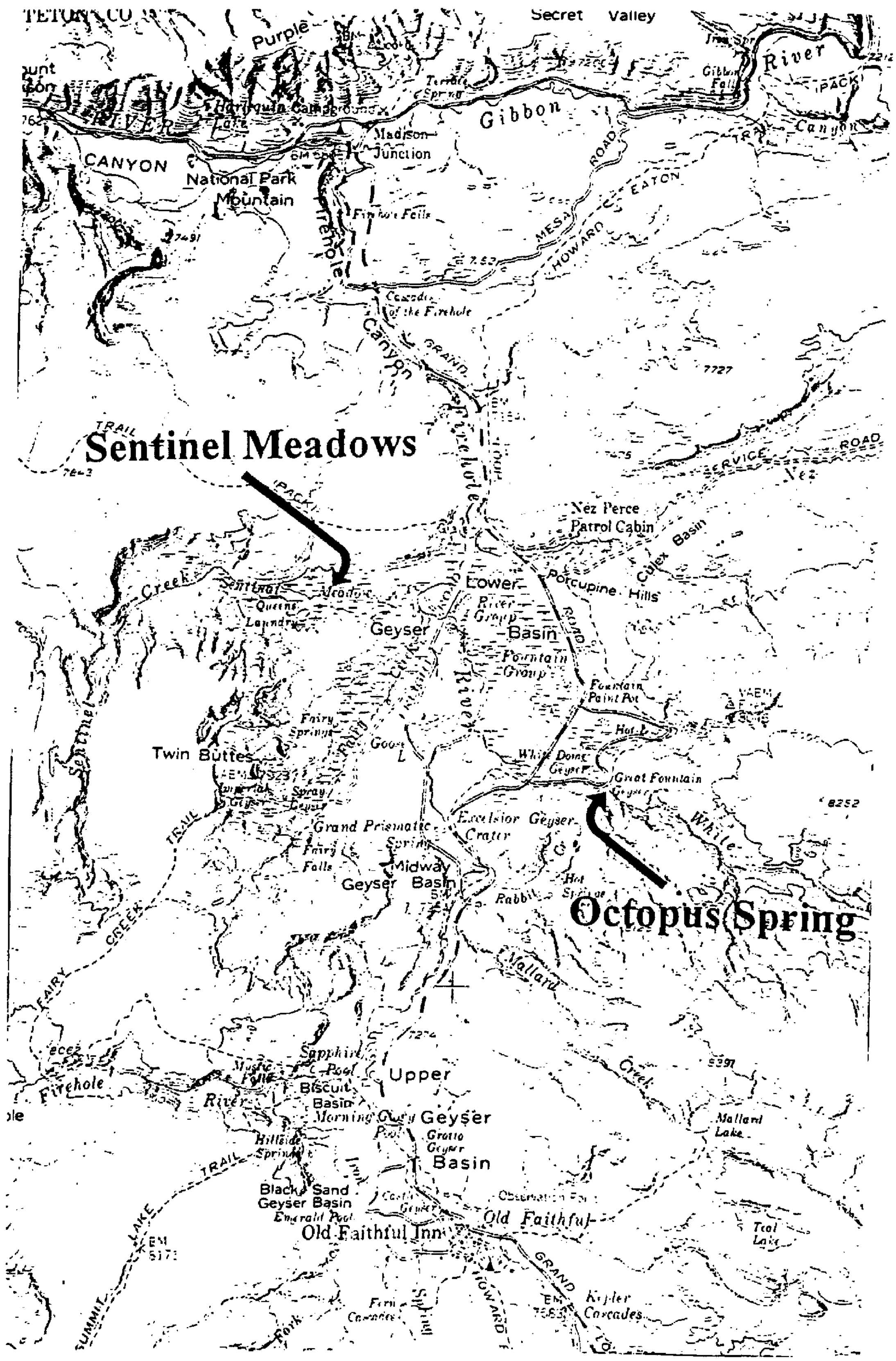


Figure 1. Location of Study Areas

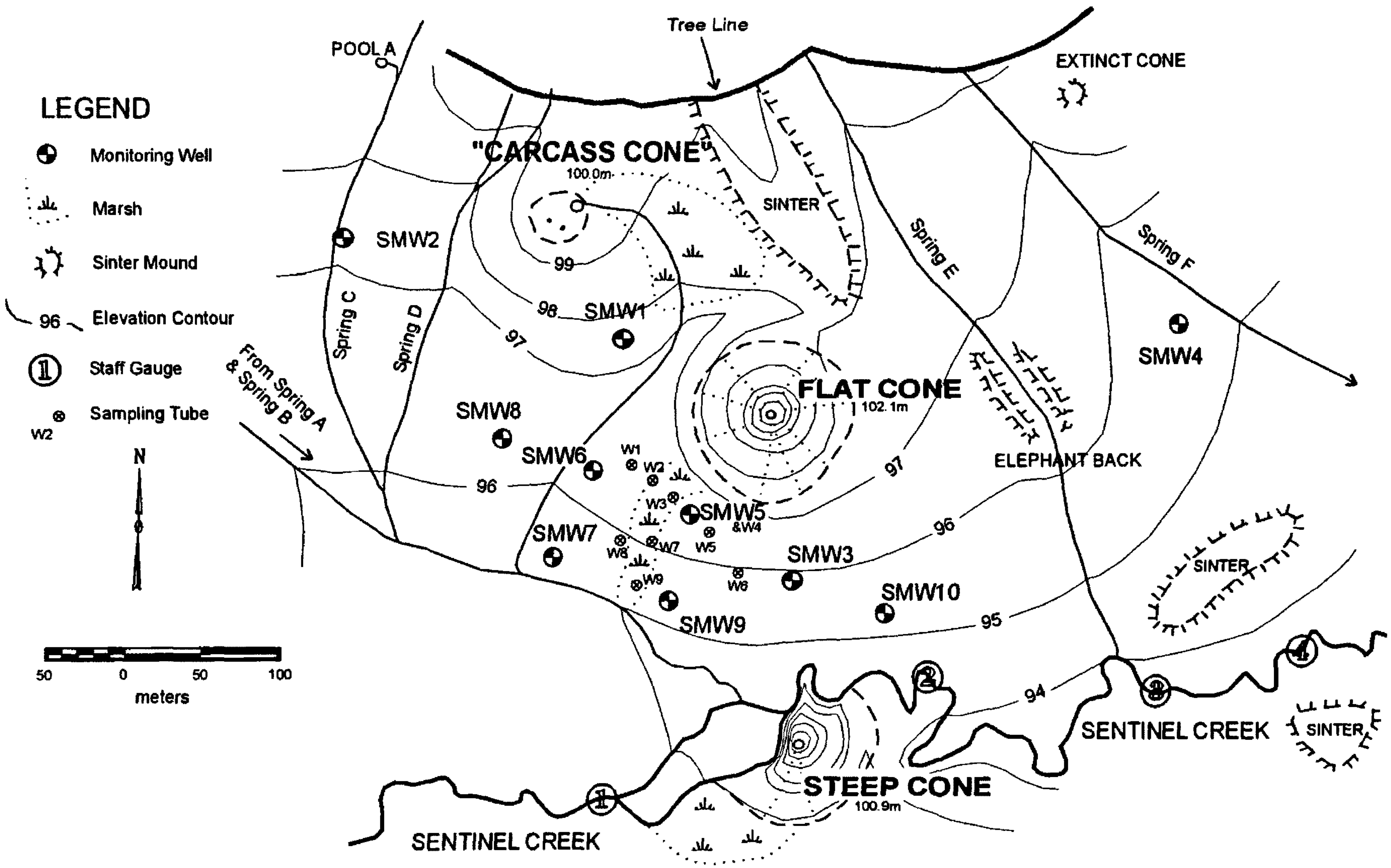


Figure 2. Sentinel Meadows Study Area

Flat Cone; Steep Cone; and a previously unnamed thermal spring that will be referred to as "Carcass Cone". Two other significant hydrothermal features, Red Terrace and Queen's Laundary are located south of the study area.

The area has a shallow water table and marshy soils. Flat Cone (SFC) and Steep Cone (SSC) are radially symmetrical and extend above the surrounding plain approximately 5 to 6 meters. Both of these springs surge periodically in minor eruptions, though the time and patterns of the eruptions are not regular. Given the shape of the two cones, the discharge patterns likely change from time to time, providing for the symmetrical development. Currently, the discharge from Flat Cone builds slowly and flows through a channel to the southwest. After some time (typically less than 1 hour), the spring erupts to a height of less than 1 meter and flows radially across the cone. The discharge spills out onto the cone and quickly becomes channelized as it descends to the plain below. A thumping, likely related to the release of gases, can be felt underfoot when it erupts. After a relatively short eruption interval, the spring drops below the top of the cone (approximately 1 meter) and the eruption process begins again. Steep Cone has a similar eruption pattern as Flat Cone, though the time-interval is not necessarily the same. This cone has been eroded by Sentinel Creek along its western side. Discharge flows primarily to the south and off extensive bacterial mats hanging over the creek to the west. Carcass Cone (SCC) has a sinter apron to the south and west but rises just slightly above the surrounding plain to the north. Carcass Cone discharges continually to the east, but its outflow surges. At the base of the sinter cones, their alkaline discharges flow into marshes that are vegetated with marsh grasses.

Several minor streams (designated Spring A (SSA) through Spring F (SSF)) originate from cold-water springs at the base of hills to the north. They flow south across the study area and into Sentinel Creek (SC). Outcrops in the surrounding hillside are composed of flow-banded rhyolite with vesicular black obsidian. The bedding and band thickness of the outcrops vary across the area. Phenocrysts consists of euhedral plagioclase and quartz.

In the northwest portion of the area is a small, neutral pH, tepid pool (designated as Pool A (SPA)) that discharges to Spring C. North of Flat Cone is a large mound of sinter and sinter breccia that does not exhibit any thermal activity. This mound likely impacts the groundwater flow dynamics of the area but is otherwise dormant. To the east of Flat Cone are two parallel sinter ridges that are bisected by Spring E, herein labeled Elephant Back (SEB). At the southwest end of Elephant Back's western ridge is a minor, neutral pH tepid spring that flows into Spring E. A small, radially symmetrical sinter mound exists in the northeast portion of the study area and appears to be an extinct cone.

The lineament of surface features in Sentinel Meadows appear to suggests that the hydrothermal features may be aligned along fractures in the subsurface.

2.1.2 Octopus Spring Study Area

The Octopus Spring site is a smaller area located near the lower-most reach of the White Creek. White Creek drains a fault-incised valley to the south and the numerous thermal springs discharging to the creek constitute most of its flow. A topographic base map of the study area is shown on Figure 3. The study area has one main spring (Octopus

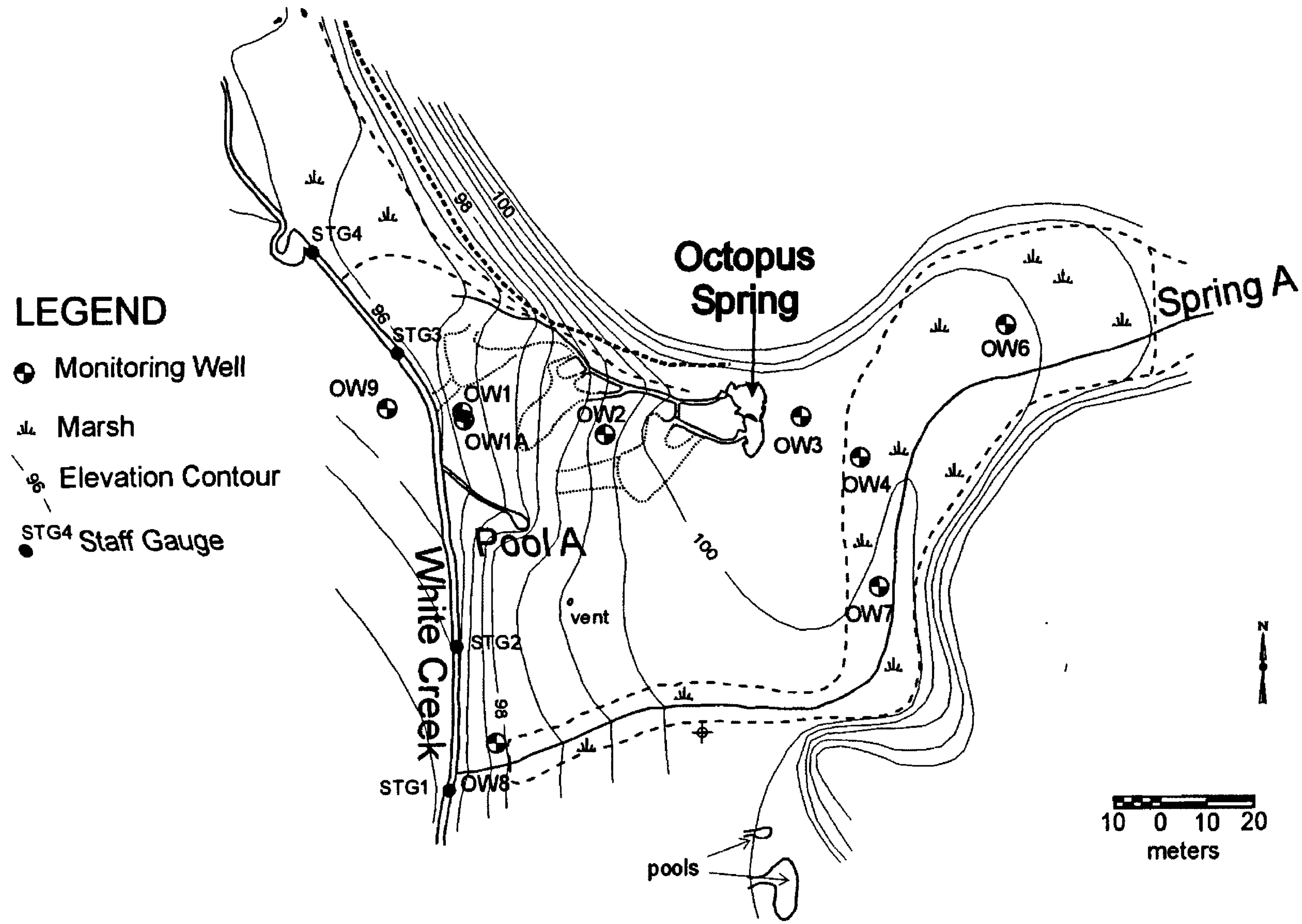


Figure 3. Octopus Spring Study Area

Spring (OCT)) and two smaller springs (identified as Pool A (OPA) and Spring A (OSA)). Immediately south of the site are additional thermal springs with similar morphologic structures.

The Octopus Spring area has an asymmetrical structure that is controlled by topography. Octopus Spring is an alkaline hot spring that abuts a hillslope on the north and a marsh to the east. The siliceous sinter and sinter breccia mound slopes predominantly to the west toward White Creek (OWC). The spring and marsh are separated by a siliceous sinter and sinter breccia apron which also extends to the south. This portion of the mound is vegetated with pine trees and grasses. Octopus Spring rises approximately 4 meter above White Creek (OWC) and continually discharges with periodic surges through two well-defined, silica-lined outflow channels. As the discharge flows across the sinter mound breccias, it is slowed in structural pools inhabited by extensive microbial mats. Discharge from the pools is not channelized by the time it reaches the creek.

Pool A is an alkaline hot spring that is located 1 to 2 meters above White Creek. It continuously discharges, also with surging, to the creek though a well-defined, silica-lined channel.

Spring A originates up a draw to the east and is fed by several small thermal springs. It appears that as the Octopus Spring sinter mound (and sinter mounds to the south) developed, the flow of Spring A was blocked. Today, the flow (designated OMO) exits from south end of the marsh and flows overland into White Creek.

Outcrops in the hillslopes immediately north and east of Octopus Spring are composed of a matrix-supported conglomerate with rounded clasts (1 to 10 cm) of unknown origin. The clasts exhibit crude bedding and imbrication overlain in sharp contact by well-bedded welded rhyolite tuff. The matrix material is also a welded tuff.

2.2 Electromagnetic Conductivity Surveys

Electromagnetic conductivity (EM) instruments, such as the Geonics EM-31, measure subsurface conductivity by inducing electromagnetic fields into the earth and measuring the effect the terrain has on the induced fields. Surface EM methods have been successfully used to delineate groundwater contamination from landfill leachates (Mack and Maus, 1986) and to map the salt water-fresh water interface in coastal areas (Stewart, 1989; McNew and Arav, 1995). EM surveys have also been used to delineate the migration of acidic groundwater from pyritic tailings at an abandoned mine (Brooks and others, 1991).

Measurable conductivity changes in the earth are caused by difference in porosity, conductivity of the pore water, shape of soil/rock pore spaces, degree of water saturation, temperature, and clay content with moderate to high cation exchange capacity (CEC). As described by McNeill (1990) an empirically based relationship (Archie's Law) states, for fully saturated soils, that

$$\sigma_a = \sigma_w \phi^m$$

where

σ_a is the bulk conductivity of soil (S/m)
σ_w is the conductivity of soil water (S/m)
ϕ is the soil porosity

m is a factor which varies with the particle shape (1.2 for spheres to 1.9 for platey fragments)

The conductivity of dilute concentrations of electrolyte is given by

$$\sigma_w = 96500 \sum C_i M_i$$

where

Ci is number of gram equivalent weights of the i^{th} ion per m^3 of water
M_i is ionic mobility of the i^{th} ion (m^2/sV)

For soil that is partially saturated, the conductivity varies approximately as

$$\sigma_d = \sigma_a s^k$$

where

σ_d is the conductivity of partially saturated soil
s is the fraction of total pore volume filled with electrolyte
k is a factor experimentally determined to be approximately 2

The temperature dependence of the conductivity of bulk soil is determined (for temperatures above freezing) by the temperature dependence on the ionic mobility, which is of the order of 2 percent per degree celcius for common ions. Based on this relatively large coefficient, soil conductivity can be expected to vary significantly with temperature.

The presence of clay having a polar alignment can add an additional component to the electrical conductivity. The clay content and type (a function of cation exchange capacity (CEC)) is essentially independent of the ionic component. Thus

$$\sigma_a = \sigma_w \phi^m + \sigma_{clay}$$

The contribution of clay is largest when the ionic concentrations of pore water are low but becomes negligible relative to water at high ionic concentrations, especially for clays with low to moderate CEC.

The EM-31 instrument induces a time-varying magnetic field from the transmitter coil located at one end of the instrument, and the resulting circular eddy current loops penetrate earth. As the primary field spreads out (both above and below ground), induced currents in the subsurface give rise to secondary EM fields that distort the primary field. The receiving coil will pick up both the primary and secondary fields that will differ in intensity, phase, and direction, and reveal the presence of conductive zones (Sharma, 1997). The ratio of the secondary and primary magnetic field is linearly proportional to the terrain conductivity (McNeill, 1980b).

The EM-31 has an intercoil spacing of 3.7 meters and can be operated in either a vertical or horizontal dipole mode. In the vertical dipole mode, the instrument provides twice the effective depth of exploration as the horizontal dipole mode, 6 meters and 3 meters; respectively.

EM terrain-conductivity mapping of subsurface conditions in hydrothermal areas should provide data that identify groundwater systems of higher temperatures and/or conductivities resulting from mixing with hot spring discharge.

2.3 Hot Spring Geochemistry

The hydrothermal fluids of Yellowstone National Park originate from deeply circulating meteoric waters. These waters circulate at minimum depths of 100 to 550 m and reach temperatures of 180° to 270°C. These reservoirs are situated within thick sequences of rhyolitic lava flows and ash-tuff. As the fluids circulate, they react to dissolve the minerals of the rhyolite parent rock. Upon reaching the surface, these mineral-rich fluids cool leaving mineral deposits in unique morphological structures. There may some contribution to the hydrothermal systems from briny-magmatic waters, though it cannot be more than 0.2 to 0.4% (Fournier, 1989).

The availability and solubility of salts leached from the parent rock control the total dissolved solids of the hydrothermal fluids. As the hydrothermal waters rise, they mix with local groundwater, and further react with country rock. The resulting fluids are rich in sodium, silica and bicarbonate. Anions such as chloride and sufate are added to hydrothermal fluids as a result of outgassing of hydrochloric and sulfuric acids. Hydrothermal waters are typically highly conductive as a consequence of the high Na^+ and Cl^- contents..

Dissolved silica is a major constituent of thermal springs. It is found primarily in the monomeric form as silicic acid. Chemical and physical factors control the distribution of this neutrally charged constituent in the subsurface. The solubility of silica is dependent on a number of factors including pH, temperature, and the chemical composition of the fluid. Hence, as fluids move away from the sinter mounds, changes in these factors can cause silica to precipitate or dissolve. Thus, precipitation of silica could impact the groundwater flow dynamics. Table 1 shows representative chemical analysis of hydrothermal waters from various basins in Yellowstone National Park.

2.4 Role of Silica in a Hot Spring Environment

Silica can exist in several phases at lower temperatures. Initially, silica precipitates as amorphous silica (opal-A). It will recrystallize first to a poorly-ordered, low cristobolite with low tridymite domains (opal-CT) and eventually to quartz. The increase

TABLE 1

Chemical Analysis of Selected Thermal Waters from Yellowstone National Park

Number	1	2	3	4	5	6	7	8	9	10
Locality	Mammoth, Hot Springs	West Thumb	Shoshone Basin	Heart Lake Basin	Lower Basin	Upper Basin	Upper Basin	Grand Canyon	Norris Basin	Norris Basin
Name	Y-10 drill hole	Lakeshore Geyser	Washtub Spring	Unnamed	Ojo Caliente	Punch Bowl	Ear Spring	Unnamed Sevenmile Hole	Porcelain Terrace	Cinder Pool
Sample No.	Y-10	J7484	T7214	T7348	J7560	J7836	J7956	J7613	J7528	J7908
Date	09/13/69	10/09/74	09/72	09/73	—	—	—	09/29/76	—	—
Temp. (°C)	70	90	81	93.5	95	94	94	91	93.5	92
pH	7.48	7.76	9.00	9.48	7.74	8.33	8.49	8.61	—	3.57
SiO_2 (mg kg^{-1})	88	—	328	366	230	312	371	534	654	329
Al	0.01	—	0.14	—	—	—	—	—	0.06	—
Fe	2.4	—	0.05	—	—	—	—	—	—	—
Ca	450	2.0	0.4	0.9	0.75	0.67	0.82	0.5	2.12	6.3
Mg	80	0.51	0.05	0.01	0.01	0.02	0.01	0.02	0.03	0.12
Na	161	408	365	382	330	420	319	366	404	346
K	69	20	16	21	10	17	27	58	81	81
Li	1.8	3.24	1.0	6.6	3.6	3.8	4.9	3.45	5.8	3.9
NH_4	1.0	—	0.1	—	—	—	—	—	—	—
HCO_3	997	531	406	306	246	590	146	223	47	0
SO_4	800	55	48	100	26	19	19	65	31	147
Cl	171	261	328	365	326	289	415	427	669	569
F	4.2	14.5	25.5	36	30	28	24	12.8	5.8	6
B	3.8	3.3	2.8	2.4	3.8	3.8	3.6	16	9.9	8
Reference*	1	2	3	3	2	2	4	2	2	4

Number	11	12	13	14	15	16	17	18	19	20
Locality	Norris Basin	Crater Hills	Upper Basin	Hot Springs Basin	Josephs Coat Hot Springs	Josephs Coat Hot Springs	Upper Basin	Boundary Creek	Washburn Hot Springs	Washburn Hot Springs
Name	Echinus Geyser	Crater Hills Geyser	Iron Spring	Unnamed	Unnamed	Unnamed	Hillside group	Unnamed	Unnamed	Unnamed
Sample No.	J7846	J7804	—	YF448	YF451	YF452	T9-10	J7930	J7304	YF429
Date	—	09/28/78	1920s	06/22/69	06/26/69	06/26/69	—	—	09/22/73	06/22/69
Temp. (°C)	93	88	91	89	86	94	83	92	91	86
pH	3.2	3.18	3.7	2.66	1.82	9.38	8.62	7.94	8.00	—
SiO_2 (mg kg^{-1})	278	676	365	317	333	236	170	210	247	—
Al	0.60	—	—	—	—	—	0.13	—	—	0.2
Fe	—	—	—	—	—	—	—	—	—	—
Ca	4.9	5.64	2	37.1	4.1	3.4	7.9	4.1	2	17.2
Mg	0.52	1.04	Trace	3.75	0.39	0.01	0.27	0.10	4.10	9.3
Na	166	640	77	187	7	109	150	181	9.7	27.1
K	50	133	28	16	17.1	19	7.7	11.2	6.5	13.7
Li	0.7	6.9	—	0.04	0.01	0.18	0.83	1.2	0.1	0.1
NH_4	—	—	4	171	57.3	22.4	0.1	0.51	270	658
HCO_3	0	0	0	0	0	335	251	259	107	8.2
SO_4	337	566	231	1530	1830	24	14.2	10	900	1950
Cl	108	890	1	0.1	0.1	5.4	72	107	7	2
F	5.6	27.5	1.2	0.8	—	3.7	12	19.1	0.1	0.5
B	3.0	20	2.2	5.05	0.07	0.36	1.17	1.0	6.6	7.84
Reference*	4	4	5	3	3	3	3	6	3	5

*References:
(1) Unpublished data, USGS (R. Barnes, analyst)
(2) Thompson & Yadav (1979)
(3) Thompson et al (1975)
(4) Unpublished data, USGS (J. M. Thompson, analyst)
(5) Allen & Day (1935)
(6) Thompson & Hutchinson (1980)

from Fournier, 1989

in molecular ordering and decrease in spacing of the subsequent phases result in more stable, less soluble silica polymorphs (Hinman, 1998). In most aqueous environments, the solubility of silica is quite low. However, the solubility of silica increases with increasing temperature. Thus, in hot spring environments, the waters become saturated with respect to the silica phases, particularly quartz. These waters cool as they ascend and eventually will become supersaturated with respect to the dissolved silica phases. Understanding the controls on silica solubility is important for determining its behavior in the environment.

Dissolved silica exists primarily in the monomeric form as monosilicic acid (H_4SiO_4). Monosilicic acid's structure involves silicon coordination with four oxygen atoms as in amorphous silica and crystalline quartz. It is essentially nonionic in neutral and weakly acidic solution but may be ionized in alkaline solution (Iler, 1979). Dissolved silica will remain in the monomeric state for long periods of time at 25°C, as long as the concentration is less than about 2×10^{-3} M (i.e., 56 mg/L). At higher concentrations it will rapidly polymerize, initially forming polysilicic acids of low molecular weight and eventually larger polymeric colloidal particles (Iler, 1979). White and others (1956) state that even when highly saturated, most of the dissolved silica will exist in the monomeric form.

The solubility equilibrium existing between the dissolved, monomeric form and amorphous silica is not easily defined. The concentration of dissolved silica is dependent on the morphology and crystal structure of the solid, but also includes: (1) the temperature; (2) the pH of the water; (3) the type and concentration of other dissolved silica polymorphs and complexes; and (4) the presence of additional minerals in the system

(Williams and Crerar, 1985). Reported solubility values range from ~60 to 130 ppm at 25°C (Iler, 1979; Williams and Crerar, 1985).

Increasing temperature greatly affects silica solubility. At Steamboat Springs, Nevada, the amorphous silica solubility at 90°C was measured at about 315 ppm (White and others, 1956). Iler (1979) reports equilibrium solubilities of 117 mg/kg at 25°C and 321 mg/kg at 100°C. Silica solubility is mostly independent of pH below 9 (White and others, 1956). From pH of 9 to 10.7, there is an apparent increase in the solubility of amorphous silica resulting from the formation of silicate ion. Silica precipitation is aided by the presence of other colloidal silica polymers by Ostwald ripening. The presence of electrolytes in solution can also affect silica solubility. Increased pressure will increase silica solubility, but realistically for a near surface environment, this is not an important factor in silica behavior (Iler, 1979).

Silica is first deposited as amorphous opal or silica gel in the subaerial, hydrothermal environment. The behavior of dissolved silica in a Yellowstone hot spring was studied by White and others (1956). He stated that silica was precipitated largely by inorganic processes. The aqueous concentrations of silica and chloride initially increased as a result of evaporation, but some polymerization of dissolved silica occurred almost immediately downstream of the vent. Though he predicted biological controls influencing the deposition of siliceous sinter, he primarily attributed the polymerization and precipitation of silica to contact with siliceous sinter. Apparently, the rate of polymerization is increased if some polymeric molecules already exist in the system.

3.0 METHODOLOGY

The studies at Sentinel Meadows and Octopus Spring were conducted concurrently and employed similar investigation techniques. Suitable topographic basemaps were needed to provide necessary spatial control at each study area. Therefore, a land survey of each area was conducted using a rod and transit and the resulting baseline maps were developed (Figures 2 and 3). It was not feasible to accurately establish a datum point based on USGS MSL, as these datums were quite far away and a transit level is only accurate over a few hundred feet. At each site, a reference benchmark was established with an assigned datum at 100 meters. Subsequent discussion of elevation is based on these assigned datums.

3.1 Hydrogeology and Geochemistry

The baseline hydrogeologic and geochemical characterizations of both Sentinel Meadows and Octopus Springs study areas were accomplished by examining the physical and chemical characteristics of local groundwater, streams and hot spring effluent. Work completed at each site included: (1) installing a network of groundwater monitoring wells and staff gauges; (2) collecting and chemically analyzing groundwater and surface water samples; (3) measuring stream and hot spring flow; and (4) estimating hydraulic conductivity and apparent porosity of soil and subsurface sinter facies.

3.1.1 Groundwater Monitoring Wells and Staff Gauges

Groundwater monitoring wells were installed at both Sentinel Meadows and Octopus Spring study areas to: (1) develop potentiometric surface data; and (2) allow for the sampling of local groundwaters at each site.

In Sentinel Meadows, wells SMW-1 to SMW-10 were installed in borings using a 2-inch diameter hand auger at the locations shown on Figure 2. Lithologic descriptions of soils removed during auguring were recorded and logs are presented in Appendix A. The wells were completed using 1-1/4-inch PVC with 6-inch screen intervals. Spoils generated during boring were used for backfilling the annular space around a well and were replaced at depths roughly corresponding to their depths of removal. At SMW-5, SMW-7, and SMW-8, soils representative of the screened-interval of the aquifer were collected for laboratory determination of hydraulic conductivity and porosity (discussed below).

Well SMW-1 encountered saturated conditions during boring but was dry during subsequent sampling and monitoring activities and was abandoned. Depth of the remaining wells ranged from 1.01 m (SMW-9) to 1.59 m (SMW-6).

During September 1996, nine ½-inch polyethylene sampling tubes (SFCW-1 through SFCW-9) were installed southwest of Flat Cone. These sampling tubes were installed by driving a steel conduit, inserting the tubing inside, then removing the conduit. The sampling tubes were installed to depths ranging from 74 to 114 cm. The purpose for installing the small-diameter tubing was to limit the groundwater's exposure to the atmosphere and thus, limit effects of oxygen on the groundwater's geochemistry. Two sets of groundwater samples were collected from the sampling tubes, but difficulties in sample collection (only small volumes of water could be removed at a time and the silty water samples were very difficult to filter in the field) likely resulted in agitation and lengthy exposure of the water to the atmosphere. Upon returning later in the winter, several of the sampling tubes had been pulled-up and chewed upon by bison. Results from these sampling tubes are presented in the chemical data but are not integral to evaluating the geochemistry of the area. These results will not be discussed in Section 4.

A total of ten wells were installed at the Octopus Spring site at the locations shown on Figure 3. Wells OW-1 to OW-7 and OW-9 were installed in borings using a 2-inch diameter hand auger. Well OW-8 was installed by boring with a 2-inch diameter gas-powered solid-stem auger spinning at a relatively high rpm. Well OW-1A was bored adjacent to and deeper than OW-1 using a 1-1/8-inch diameter rock core. Lithologic descriptions of soils removed during auguring and drilling were recorded (logs are presented in Appendix A) and the resultant spoils were set aside for well completion.

At OW-1A, cores of sinter were obtained during drilling within the following depth intervals: 0 to 23 cm; 66 to 76 cm; 76 to 86 cm; 86 to 91 cm; and 102 to 112 cm. Between the zones of hard ground, the coring encountered relatively soft material that was likely sinter breccias. These sinter cores were retained for hydraulic conductivity and porosity determination (discussed below).

With the exception of OW-1A, wells were completed using 1-1/4-inch PVC with 6-inch screen intervals. Well OW-1A was completed using a 3/4-inch by 6-inch plastic fuel-tank siphon with a nylon screen. Spoils generated from each boring were used to backfill the annular space of that well and were replaced at depths roughly corresponding to their depths of removal.

Three wells (OW-2, OW-3, and OW-5) were installed within the developed sinter mound and did not yield water. When OW-2 was bored, water was initially noted at approximately 41 cm below the surface, but upon completion, the well was dry. These wells were subsequently abandoned. Depths of the remaining wells ranged from 0.66 meters (OW-1) to 1.52 meters (OW-6).

Staff gauges were installed in both Sentinel Creek and White Creek for comparing the creeks surface elevations with the groundwater potentiometric elevations. The staff gauges were installed by driving 3/8-inch rebar into the stream beds.

The top of PVC well casings and staff gauges at both sites were surveyed to determine horizontal locations and apparent vertical elevations. The elevations were referenced to a temporary reference benchmark established at each site.

Static water level and stream level measurements were obtained several times during this study, except during spring runoff when the areas were closed for the grizzly bear recovery program. Appendix B presents tables of water level and staff gauge monitoring and hydrographs showing the relative elevations for both study areas.

A steel conduit was driven into the stream beds of both Sentinel and White Creek near the locations of the staff gauges. The water levels inside these temporary piezometers were allowed to equilibrate for several hours and the depth to water inside the pipe and outside the pipe was then measured. This testing, completed on 30 August 1995, was conducted to determine if the creeks are losing or gaining across their reach.

Temporary piezometers were installed in the stream bed and 4.6 m north of the creek at the locations of Staff Gauge 2 and 3. Water samples were collected from the piezometers and from Sentinel Creek. This work was performed to provide water quality samples to determine variations in chemistry related to the interaction between surface water and groundwater in the area. The work was completed on 22 September 1995.

3.1.2 Groundwater and Surface Water Sampling

Groundwater and surface water samples were collected several times during summer, fall, and winter seasons from August 1994 through September 1996. The sites were not accessible during spring due to closure by the NPS for the grizzly bear recovery program. These samples were analyzed for major cations and anions. Field measurements for pH and temperature were obtained. During the September 1996 sampling event, the dissolved oxygen of the the groundwater and cooler surface water (<50°C) was also measured.

Groundwater monitoring wells were purged prior to sampling using a hand-held peristaltic pump until pH and temperature stabilized. For both groundwater and surface water (streams and hot springs), samples were collected with an acid-cleaned syringe that was rinsed several times prior to collection. Samples taken for cations and anions were filtered in the field with 0.45 um filters. Samples were filtered into acid-cleaned polyethylene bottles. (The bottles were rinsed several times with filtered water to remove residual acid). The cation samples were acidified with trace-metal grade nitric acid to a pH<2. The anion samples were not acidified. In addition, a 20-ml sample of unfiltered water was collected for an alkalinity titration. Samples were kept refrigerated until analysis.

Cations were analyzed by inductively coupled argon plasma emission spectroscopy (ICAPES - Jerrell-Ash Atom Comp 800) with the exception of dissolved lithium, which was analyzed with an Instumentation Laboratory 151 aa/ae Spectrophotometer. Anions were analyzed with a Dionex 2000i ion chromatograph. Alkalinity was determined using a Hach kit's colorimetric titrator within 24 to 48 hours after collection.

3.1.3 Stream Flow Estimates

Flow measurements of creeks, springs, and hot spring effluent were obtained from each site. This work was completed during the period of 29 to 31 August 1995 when daily precipitation was relatively low. Therefore, it was assumed that surface water flow may be primarily attributed to groundwater and spring discharge.

Stream flow measurements for Sentinel and White Creeks were obtained using Pace AA and Pygmy flow meters, respectively. A Pygmy flow meter is recommended for low-flow streams (<10 cfs). Flow calculations were obtained for cross-sectional areas of each creek adjacent to the staff gauge locations. Flow measurement and flux calculation followed procedures outlined by USGS guidelines (Rantz and others, 1982). Flow measurements were obtained at closely spaced stations located perpendicular to stream alignment at 0.6 depth of the stream. Essentially, each station measures flux across a defined portion of a stream's cross-section. The flux across each station can be integrated for the width and depth of the stream to calculate volume discharge. Station spacing and flow velocities were recorded directly from the flow meter using a JBS AquaCalc 5000 Streamflow Computer (v. 2.1) instrument that determines flux per unit time at each station and calculates the mean stream velocity and total discharge for each location.

Station spacing ranged from 0.2 to 1.0 ft across each creek. Stream flow measurements were performed twice at each location.

Flow estimates for the springs flowing across the Sentinel Meadows site (Springs A to F) and for Octopus Spring, Pool A, and Spring A and for were obtained using a bobber and stopwatch method at the same locations where surface water samples were collected. (It was not possible to measure the periodic discharge from Flat Cone and Steep Cone in Sentinel Meadows). The cross-sectional area of each spring was measured and the time for a small-diameter fishing bobber (approximately 1/2-inch) to float a distance of 5 ft was recorded. This procedure was repeated 10 times. The average time to travel 5 ft multiplied by the springs cross-sectional area produces the volumetric discharge of each spring at the time of testing.

3.1.4 Hydraulic Conductivity and Porosity Measurements

Determination of the hydraulic conductivity of the Sentinel Meadows aquifer was accomplished by *in situ* testing of wells SMW-8, MSW-9, and SMW-10. Rising-head and falling-head slug tests (Hvorslev, 1951) were performed on 26 September 1995. A transducer was installed near the bottom of each well and head measurements were allowed to equilibrate. The water column in each well was induced to rise by rapidly lowering a 1-inch diameter slug into the well. During the falling-head tests, the water level in the well was recorded prior to and immediately after insertion of the slug. Water levels were then recorded at timed intervals as the water table fell back toward the static water level (at approximate 5 second intervals for the first minute then at 10 second intervals). After the water level fell to static, the slug was pulled out inducing an immediate drop of the water level in a well. Water levels were recorded as described above as the water level rose toward static water level. The height of the water level's rise (or fall) immediately after inserting (or removing) the slug is h_0. The height of the water level relative to the static water level at some time, t, after the slug is lowered or removed is h. A semilogarithmic plot of the ratios h/h_0 versus time was made and the time at 0.37 h/h_0 was recorded. The hydraulic conductivity (K) is given by the following formula:

$$K = r^2 \ln \frac{(L / R)}{2 L t_0}$$

where

r is the radius of well casing
R is the radius of well screen
L is the length of well screen
t_0 is the time for water level to rise or fall 37% of initial change

A computer designed for data recording was not functioning so early time data during the slug tests (0 to 5 sec) could not be accurately obtained. Head data were read directly from the pressure transducer's readout. Plots of the head ratios versus time for each test are presented in Appendix D.

The hydraulic conductivity of soils collected from borings for SMW-5, SMW-7 and SMW-8 were tested in the laboratory using a constant-head permeameter (described in Fetter, 1988). These soils were collected from the approximate depth of each well's screened interval. The hydraulic conductivity (K) is determined from a variation of Darcy's Law:

$$K = \frac{VL}{Ath}$$

where

V is the volume of water discharging in time t
L is the length of sample
A is the cross-sectional area of the sample
h is the hydraulic head
t is time

Laboratory determination of hydraulic conductivity of some of the sinter cores collected during well construction of well OW-1A in the Octopus Spring site were determined by falling-head permeameter testing. Hydraulic conductivity, K, is found by the formula

$$K = \frac{d_t^2}{d_c^2}\frac{L}{t}\ln\left(\frac{h_o}{h}\right)$$

where

d_t is the diameter of the falling head tube
L is the length of the sample
d_c is the diameter of the sample
h_0 is the initial water level above the outlet of the falling head tube
h is the water level after some time t

Following the permeameter testing, the porosity of these soils and sinter cores were also determined. For the Sentinel Meadows samples, the soils were saturated and recompacted in a beaker. For the Octopus Spring cores, it was assumed that the cores' pore space was fully-saturated following permeameter testing. The saturated material was weighed and then the soils and sinter cores were dried and weighed again. Dry bulk density was then determined. A particle density of 2.65 g/cm^3 was assumed to be representative of the particle density of the obsidian soil matrix from the Sentinel Meadows aquifer. For the Octopus Spring sinter core, a particle density of 2.25 g/cm^3 was assumed (based on Hurlbut and Klein, 1977). For opal, particle density ranges from 2-2.25 g/cm^3).

Porosity for material from each study area were computed using the relationship

$$S_t = \left(1 - \frac{P_p}{P_b}\right)$$

where

P_p is the particle density
P_b is the dry bulk density
S_t is the total porosity

3.2 Electromagnetic Conductivity Surveys

Terrain conductivity was determined for the Sentinel Meadows site on 23 and 24 August 1994. A follow-up survey focussing on the area south of the primary hot spring discharge from Flat Cone was completed on 23 September 1995. A site-wide EM conductivity survey was completed at the Octopus Spring site on 21 to 22 August 1994.

Electromagnetic conductivity surveys were performed at both study areas using transects shown on figures presented in Appendix E. Transects created for each site were designed to provide sufficient areal spacing. A Brunton compass was used to determine transect orientation. Distances between measuring stations were determined in the field by pacing and adjusted as needed when plotted on the maps.

The instrument was operated in both vertical and horizontal dipole orientation at each station. The vertical dipole mode provides twice the effective depth of exploration as the horizontal dipole mode (6 m and 3 m, respectively). Both horizontal and vertical dipole measurements were taken at 0 m, 0.5 m, 1.0 m, 1.5 m, and 2.0 m above ground level. Employing both the horizontal and vertical dipole positions produced vertical spacing of 0.5 m across a range from 1.0 m to 6.0 m. During the focussed survey at Sentinel Meadows during September 1995, full vertical conductivity profiles were completed only at wells in the area. Depth specific conductivities at SMW-3 were an average of 4.9% higher (ranging from 3.2% to 8.7% difference) during the September 1995 events when compared with the August 1994 event.

Apparent conductivity of the ground at each depth was recorded in millisiemens per meter (mS/m). (mS/m are the same as millimhos per meter (mmho/m). Appendix E contains plots of the terrain conductivity for each site using the contouring program SURFER 5.0.

3.3 Temperature Probe Survey

A temperature probe survey was conducted at each site to evaluate the heat distribution in vicinity of hot springs. Establishing the heat flux within an area can be used to predict groundwater flow regimes (Smith and Chapman, 1985; Forster and Smith, 1989; and Deming, 1993). The shallow-depth heat distribution surveys were completed at Sentinel Meadows on 24 September 1995 and at Octopus Spring on 25 September 1995. On both days, the weather was clear and calm (approximate air temperature was 15°C) and it was assumed that heat loss to the atmosphere would be uniform across the sites.

A Barnant 100 Model No. 600-2820 (JKT) Thermocouple-Thermistor was used to obtain temperature of shallow soils and sinter at transect stations for both sites. At

Sentinel Meadows, the thermistor was pushed into a hole approximately 20 cm below ground surface and allowed to equilibrate for 1 minute. At Octopus Spring, a small diameter rod was driven approximately 9.5 cm into the ground and the thermistor was pushed into the hole and allowed to equilibrate for 1 minute.

At Sentinel Meadows, ground temperatures of the diatomatious soils typically ranged from 7.3°C to 18.3°C. However, a temperature of 65.9°C was measured in sinter located approximately 5 m from the Carcass Cone pool. At Octopus Spring, ground temperatures ranged from 6.5°C (near well OW-1) to 43.3°C (between Pool A and the vent located to the east).

Isotherms of the data do not provide regular contours of heat distribution around the thermal features, contrary to what was expected. The shallow-ground temperatures may be influenced by varying moisture content of soils and the insulating properties of sinter and the results appear inconclusive. Ground temperatures obtained during these surveys were plotted on maps presented in Appendix F but are not discussed further.

4.0 RESULTS

This chapter is divided into two sections, presenting the results from the study of Sentinel Meadows and Octopus Spring. Though similar research methodologies were used, the sites differ in context and scale and are presented as separate section.

4.1 Sentinel Meadows Study Area

4.1.1 Hydrogeology

Sentinel Meadows is underlain by a shallow groundwater system that is predominantly composed of obsidian and rhyolitic sands with some fine gravels. The overlying diatomacous clays that cap the area range in thickness from 45 to 91 cm and likely produce semi-confining conditions in areas of very shallow groundwater. The small streams (Spring A through Spring F) that flow south across the site are perched above the groundwater. The subangular to subrounded coarse-grained aquifer soils have eroded from rhyolite and obsidian bedrock from the surrounding hillsides. The thickness of the aquifer was not determined during this study.

In several of the borings, an orange precipitate was noted in the obsidian sands near the water table. These conditions are likely the result of water table fluctuations resulting in the precipitation of ferric iron oxides. In some areas (SMW-7 and SMW-8) this zone of precipitation was noticeably hard and difficult to bore through.

A potentiometric surface map of the area (Figure 4) shows that groundwater flow is primarily to the south, but radial patterns exist near the sinter mounds. This suggests that the sinter deposits present no flow/low flow areas that deflect groundwater flow.

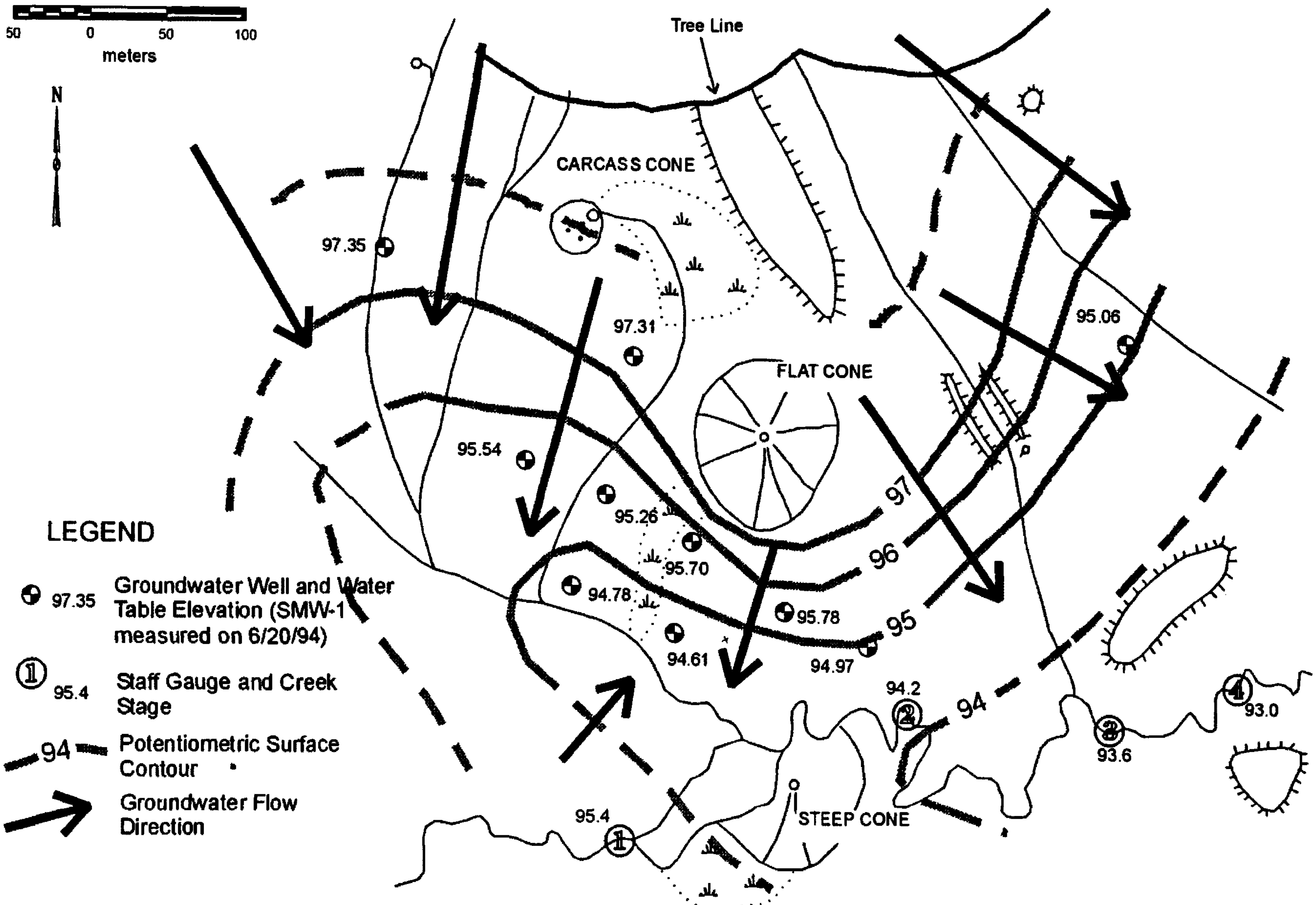


Figure 4.Sentinel Meadows, Potentiometric Surface Map (9/4/96)

that the sinter deposits present no flow/low flow areas that deflect groundwater flow. Water level measurements, potentiometric surface elevations, and hydrographs are presented in Appendix B.

Results from *in situ* and laboratory determination for hydraulic conductivity compare favorably. The hydraulic conductivities range from 10^{-1} to 10^{-3} cm/sec for the Sentinel Meadows aquifer (Tables 2 and 3). These results likely underestimate the actual permeability of the aquifer. Early-time data from the slug tests could not by recorded as a computer designed to record these data was not functioning. Permeameter testing and porosity determination also required the reworking of the soils. Measured porosities ranged from 36% to 39%, but the relatively high values may be the result of loose compaction.

TABLE 2
Sentinel Meadows Slug Testing Results (9/30/95)

Well No.	T_0 (time for .37 of h/h_0)	Hydraulic Conductivity (Horslev, 1956)
SMW-8 (Slug Out)	447 sec	1.67×10^{-3} cm/sec
SMW-9 (Slug In)	157 sec	4.7×10^{-3} cm/sec
SMW-9 (Slug Out)	177 sec	4.3×10^{-3} cm/sec
SMW-10 (Slug In)	5.2 sec	1.4×10^{-1} cm/sec
SMW-10 (Slug Out)	22.3 sec	3.4×10^{-2} cm/sec

TABLE 3
Sentinel Meadows Constant -Head Permeameter and Porosity Testing Results

Wells No.	Depth of Sample	Porosity	Hydraulic Conductivity
SMW-5	101-122 cm	36%	4.3×10^{-3} cm/sec
SMW-7	89-99 cm	39%	3.5×10^{-3} cm/sec
SMW-8	90-114 cm	38%	8.3×10^{-3} cm/sec

4.1.2 Surface Water Hydraulics

It has been assumed that Sentinel Creek represents a regional discharge area for the Sentinel Meadows aquifer. Stream flow measurements of the creek were made at the staff gauge locations (Table 4). The results indicate that the creek may be losing in vicinity of Staff Gauge 3. Interestingly, the stream bed along this reach of the stream is heavily armored with a silica-cemented matrix.

TABLE 4
Sentinel Creek Flow Measurements (8/29/95)

Location	Discharge Rate	Mean Velocity
Staff Gauge 1	245 L/sec ± 3	0.20 m/sec
Staff Gauge 2	275 L/sec ±3	0.30 m/sec
Staff Gauge 3	252 L/sec ±3	0.39 m/sec
Staff Gauge 2	274 L/sec ±8	0.40 m/sec

Comparison of the creek's surface level with the water level inside temporary peizometers driven into the stream bed shows a net upward potential between groundwater and surface (Table 5) along most of the study site. It should be noted that a piezometer could not be driven into the silica-armored stream bed at the location of Staff

Gauge 3. A piezometer was driven into the soils next to the bank and the depth to the creek's water surface was estimated.

TABLE 5
Comparison of Sentinel Creek with Stream Bed Head (8/30/95)

Location	Depth to Stream Bed's Water Level[1]	Depth to Creek's Water Surface	Relative Head Difference
Staff Gauge 1	47.3 cm	47.9 cm	+ 0.6 cm
Staff Gauge 2	81.8 cm	83.0 cm	+ 1.2 cm
Staff Gauge 3[2]	20.0 cm	21.9 cm	+ 1.9 cm
Staff Gauge 4	59.8 cm	61.3 cm	+ 1.5 cm

[1] Measured from the top of a temporary piezometer driven into the stream bed.
[2] The pipe could not be driven into silica-armored stream bed at this location. A pipe was driven into the stream bank approximately 43 cm from the creek.

Total discharge from the small streams (including the spring that flows from the Carcass Cone discharge downstream of the salt marsh) that flow across the study area into Sentinel Creek is estimated at 33.4 L/sec (Table 6). The total contribution of Spring A through D and the Carcass Cone spring to Sentinel Creek was approximately 25.9 L/sec. Since the discharge rates from Steep Cone and Flat Cone could not be measured, their flow contribution to the water budget is unknown.

TABLE 6
Sentinel Meadows Spring Discharge Rates (8/29/95)

Spring Name	Spring Width	Discharge Rate
Carcass Cone spring	12.7 cm	0.85 L/sec ±0.14
Spring A	86.4 cm	0.57 L/sec ±0.16
Spring B	81.3 cm	5.75 L/sec ±1.22
Spring C	91.4 cm	16.9 L/sec ±1.85
Spring D	43.2 cm	1.78 L/sec ±0.41
Spring E	45.7 cm	7.03 L/sec ±1.01
Spring F	38.1 cm	0.54 L/sec ±0.06

4.1.3 Geochemistry

Graphical comparison of the geochemistry of thermal springs, surface water, and groundwater is shown with modified stiff diagrams (Figure 5) that represent the distribution of cations (Na^+, Ca^{2+}, Li^+) and anions (Cl^-, F^-, SO_4^{2-}, and HCO_3^- (presented as $CaCO_3$)) in area waters. Also included is non-charged, dissolved silica (most likely as the monomeric form of amorphous silica (opal-A).

An analysis of the variability in concentrations of select chemical constituents (Na^+, Cl^-, Si, Li^+, F^-, and B^{3+}) was performed by determining the analytical means and confidence intervals of the distinct area waters. The waters were grouped as hot spring waters (Flat Cone(SFC), Carcass Cone(SCC), and Steep Cone(SSTC)), Sentinel Creek surface waters (SC1 through SC4), groundwater influence by thermal discharge (wells SMW-3 and SMW-5 through SMW-10), and groundwater not influence by thermal discharge (SMW-2 is assumed to represent background groundwater concentration). Figure 6 shows the graphical results of this comparison of the distinct waters at the site. A table summarizing the results of the chemical analyses of waters obtained over a two year period is presented in Appendix G. For the grouped waters and other area waters with chemical data from 3 or more sampling events, the means, standard deviations (σ), and confidence intervals ($k(0.95) * \sigma / \text{sqrt}(n)$) have been calculated. Also included in Appendix G is an evaluation of the data quality comparing the results with those from field and laboratory duplicates.

All the waters are NaCl-type waters. The results indicate that thermal water discharge and groundwater near the hot springs are comparable with respect to the

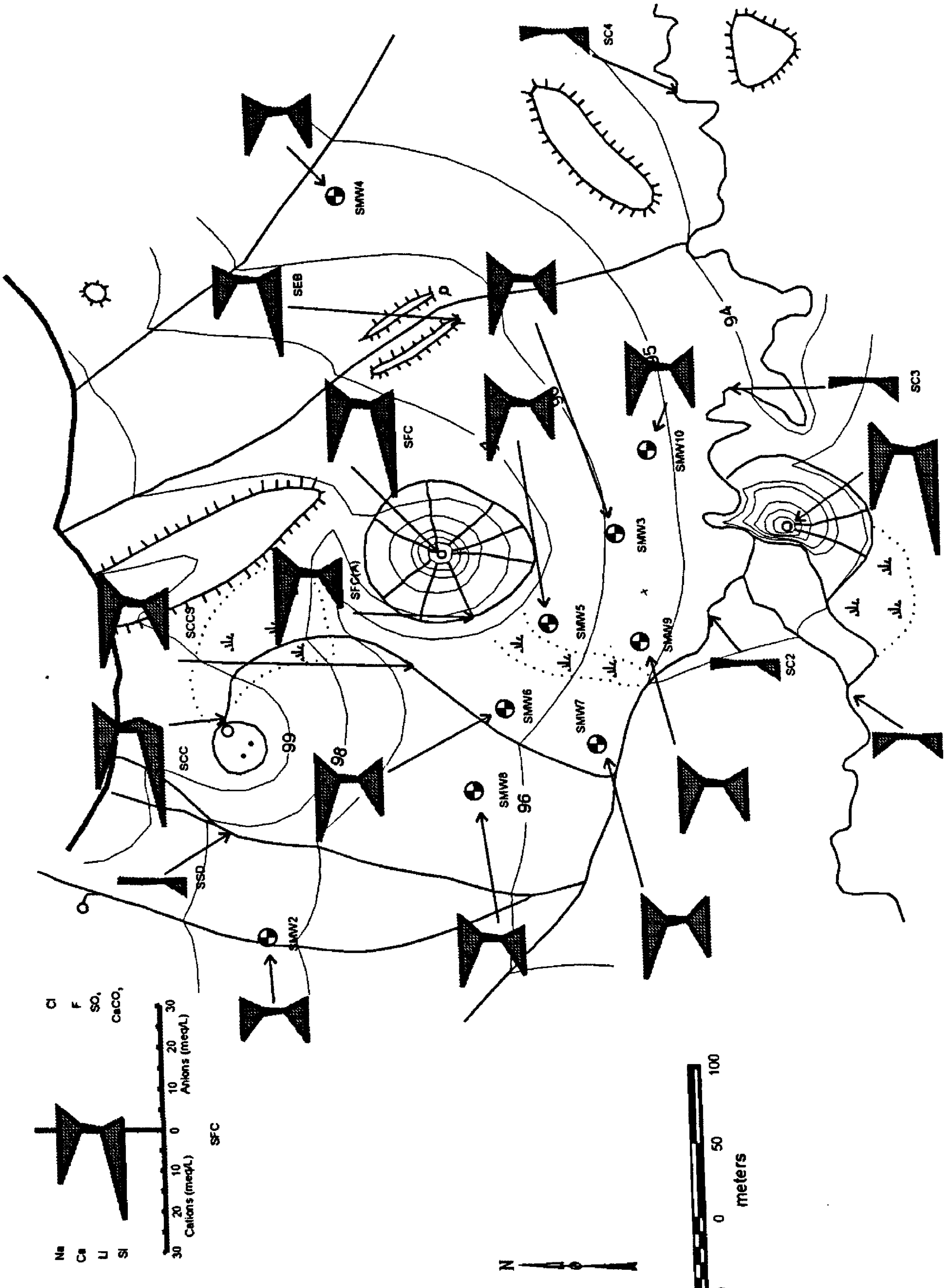


Figure 5. Sentinel Meadows, Stiff Diagrams

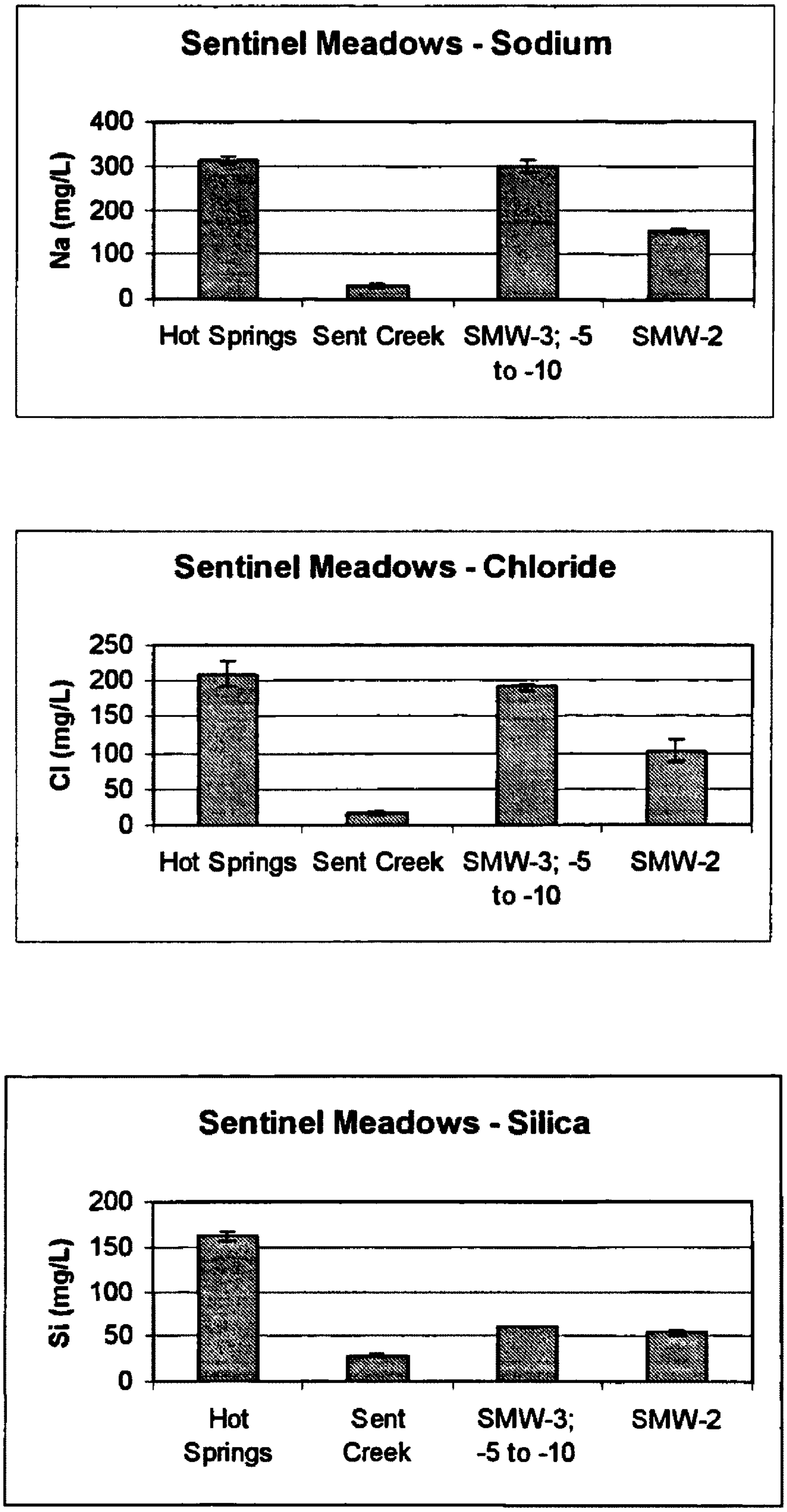
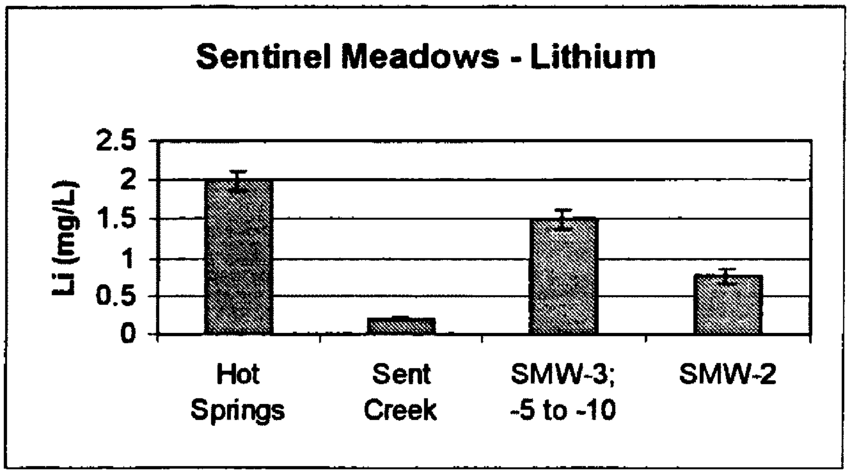
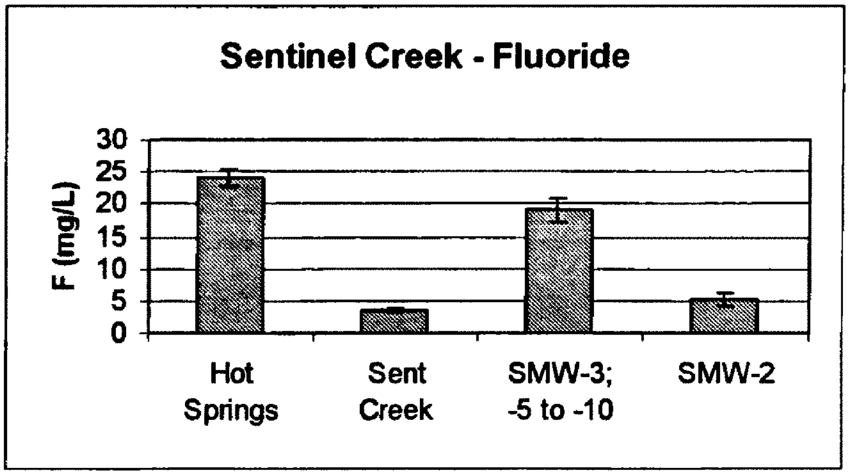


Figure 6. Sentinel Meadows, Variance of Means of Select Chemical Constituents





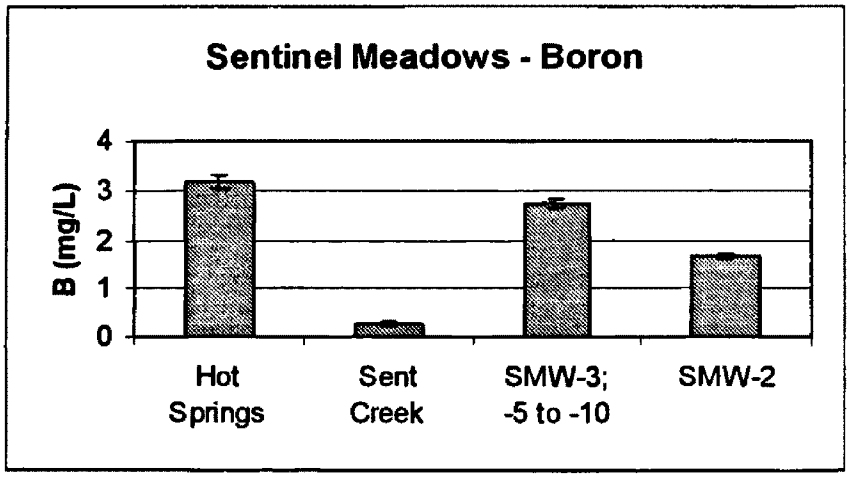


Figure 6 cont. Sentinel Meadows, Variance of Means of Select Chemical Constituents primary cationic and anionic species, Na^+ and Cl^-, though the groundwater is significantly lower in dissolved-silica. These waters are chemically distinct from the surface water and from background groundwater concentrations. The distribution of the minor chemical constituents, Li^+, F^-, and B, are also shown on Figure 6. The thermal waters and local groundwater near the hot spring are similar with respect to these constituents though the groundwater concentrations are slightly lower.

The thermal waters have appreciable dissolved-silica concentrations. The receiving groundwater has significantly lower Si concentrations. This is an expected observation as the hot springs' discharge flow across sinter and into diatomaceous marshes. Thermal water discharged from Flat Cone is higher in dissolved silica compared to water emerging from the base of the sinter cone to the southwest (sampling location SFCa). A similar reduction in silica concentrations was observed between water discharged from Carcass Cone and water downstream of a marsh in the small spring (SCCS). The silica-saturated, alkaline hot spring waters are reduced in dissolved silica in the near-surface environment before mixing with local groundwater. The dissolved-silica concentrations of the hot springs ranged from 146 mg/L to 182 mg/L. Dissolved silica in groundwater was near saturation, ranging from 46.3 mg/L (SM-2 on 2/22/95) to 67.5 (SMW-10 on 9/28/95).

There is little variability in groundwater temperatures. During the last two sampling events (September 1995 and 1996), temperatures varied no more than 6.2°C across the site and these variations cannot be correlated with proximity to the thermal features.

across the site and these variations cannot be correlated with proximity to the thermal features.

Sentinel Creek waters and streams (Spring C through Spring F) have significantly reduced concentrations of Na^+, Cl^-, Si and $CaCO_3$ compared to the thermal waters and groundwater.

Table 7 summarizes the analytical results of water samples collected from the creek and from temporary piezometers installed in the streambed and stream bank at the locations of Staff Gauge 2 and Staff Gauge 3. This testing was done to evaluate the interaction between surface water and groundwater.

TABLE 7
Surface Water/groundwater Chemical Interaction
Sentinel Meadows

	pH	T°C	Cl	$CaCO_3$	Na	Si
Staff Gauge 2						
Streambed	6.48	13.0	84.1	200	155	65.3
Stream Bank[1]	7.10	15.5	173	400	241	48.4
Creek Water	8.26	9.3	15.4	50	29.1	31.9
Staff Gauge 3						
Streambed	7.58	11.0	18.7	150	41	37.1
Stream Bank[1]	6.88	13.5	178	276	226	49.2
Creek Water	8.35	9.1	16.2	58	28.5	31.0

Concentrations in mg/L
[1] Sample location 4.6 m from creek

4.1.4 Electromagnetic Terrain-Conductivity

Results of the EM terrain-conductivity mapping at 1.5 and 4.5 meters below the surface are shown on Figure 7 and 8, respectively. Results of the depth discrete mapping (from 1 m to 6 m below the surface) are presented in Appendix E.

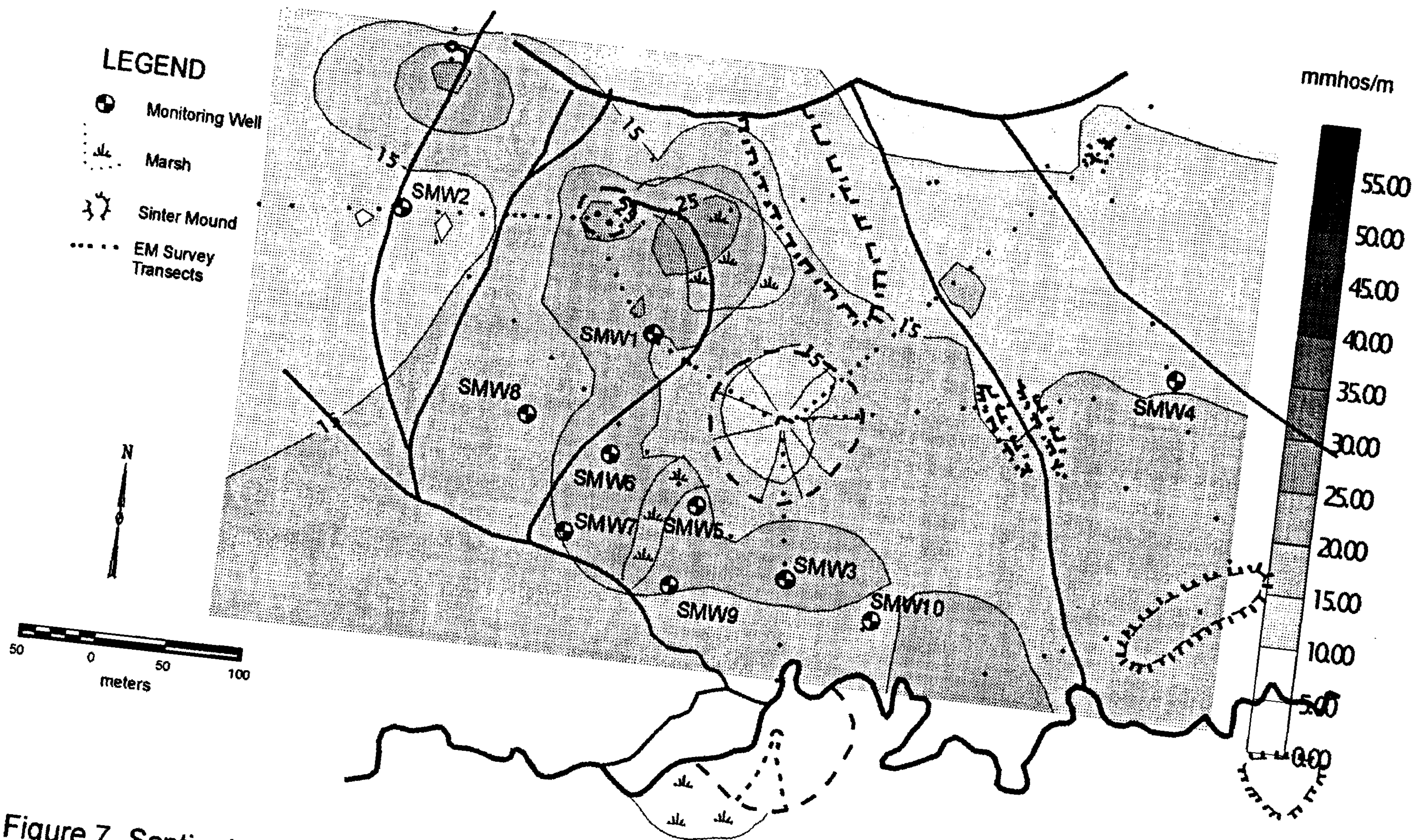


Figure 7. Sentinel Meadows, EM Terrain-Conductivity (1.5 m Depth)

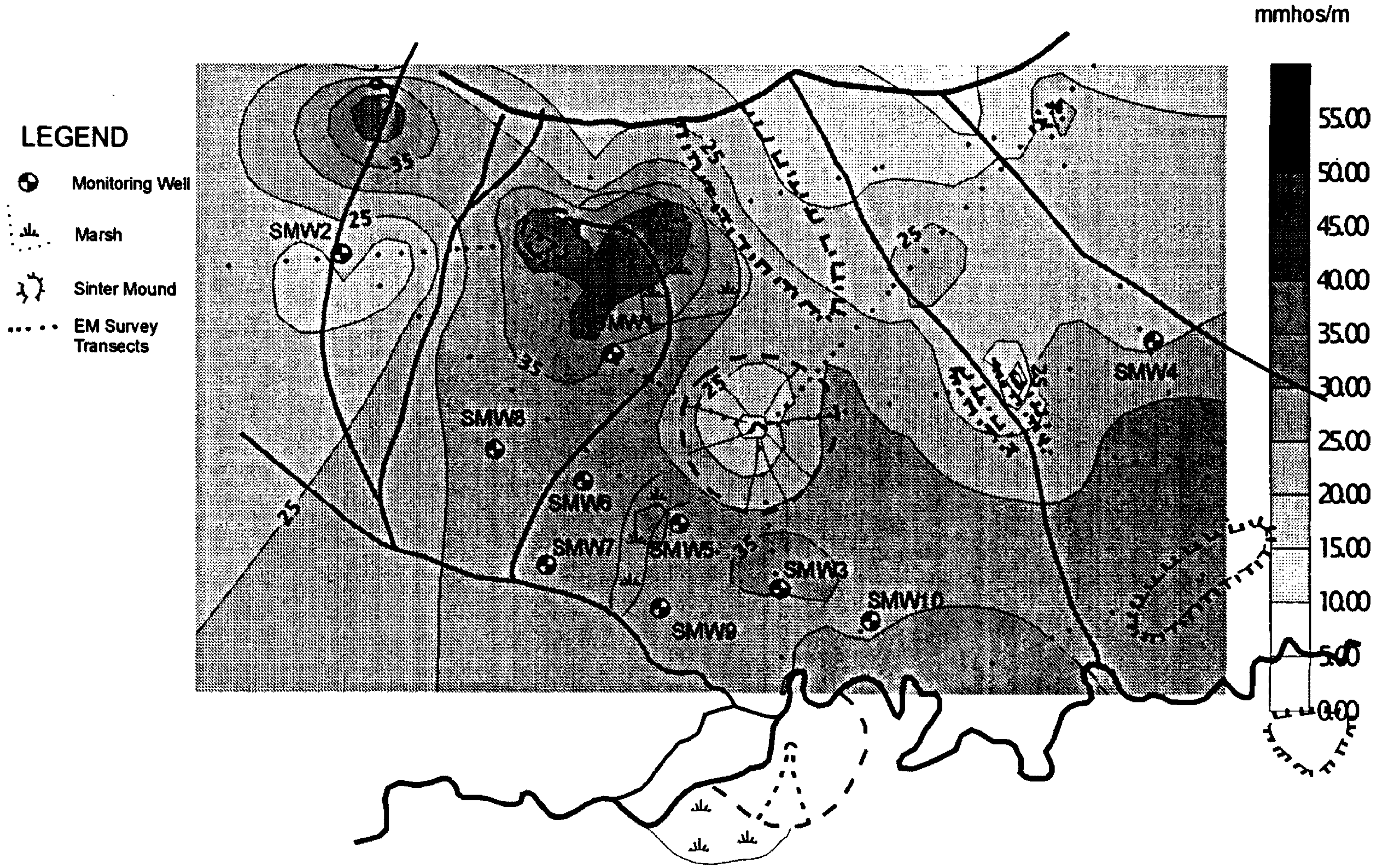


Figure 8. Sentinel Meadows, EM Terrain-Conductivity (4.5 m Depth)

The terrain-conductivity mapping of the site indicates that there are zones of higher conductivity originating near Carcass Cone (and the marsh to the east of its discharge) and Pool A (located in the northwest portion of the site). The primary zone of higher conductivity emerging from the Carcass Cone area remains relatively uniform, extending to the south of Flat Cone and toward Sentinel Creek. The area of higher-conductivity detected near Pool A is limited in extent and was not found to the south near well SMW-2.

Relatively low terrain-conductivity was mapped near SMW-2, at Flat Cone, and in the northeast quadrant of the site, including: the inactive sinter ridge north of Flat Cone, north of the Elephant Back's parallel ridges; and near the small extinct cone.

The configuration of mapped conductivity in the area approximates the potentiometric surface map which indicates that groundwater flow is primarily to the south (and to the southeast from Carcass Cone area) toward Sentinel Creek.

Figure 9 is a plot of measured terrain-conductivity versus depth at various locations across the site. The conductivity values increase with depth with the highest values noted at the Carcass Cone marsh, near Pool A, and at SMW-3. Relatively low terrain-conductivity values were found within Flat Cone's sinter mound and the inactive sinter ridge to the north. The conductivity values spike at 3 m followed by a drop in conductivity at 4 m depth. The 1 m to 3 m measurements were taken with the EM instrument in the horizontal dipole mode. The 4 m to 6 m measurements were taken with the EM instrument in the vertical dipole mode. The anomalous spikes are possibly an

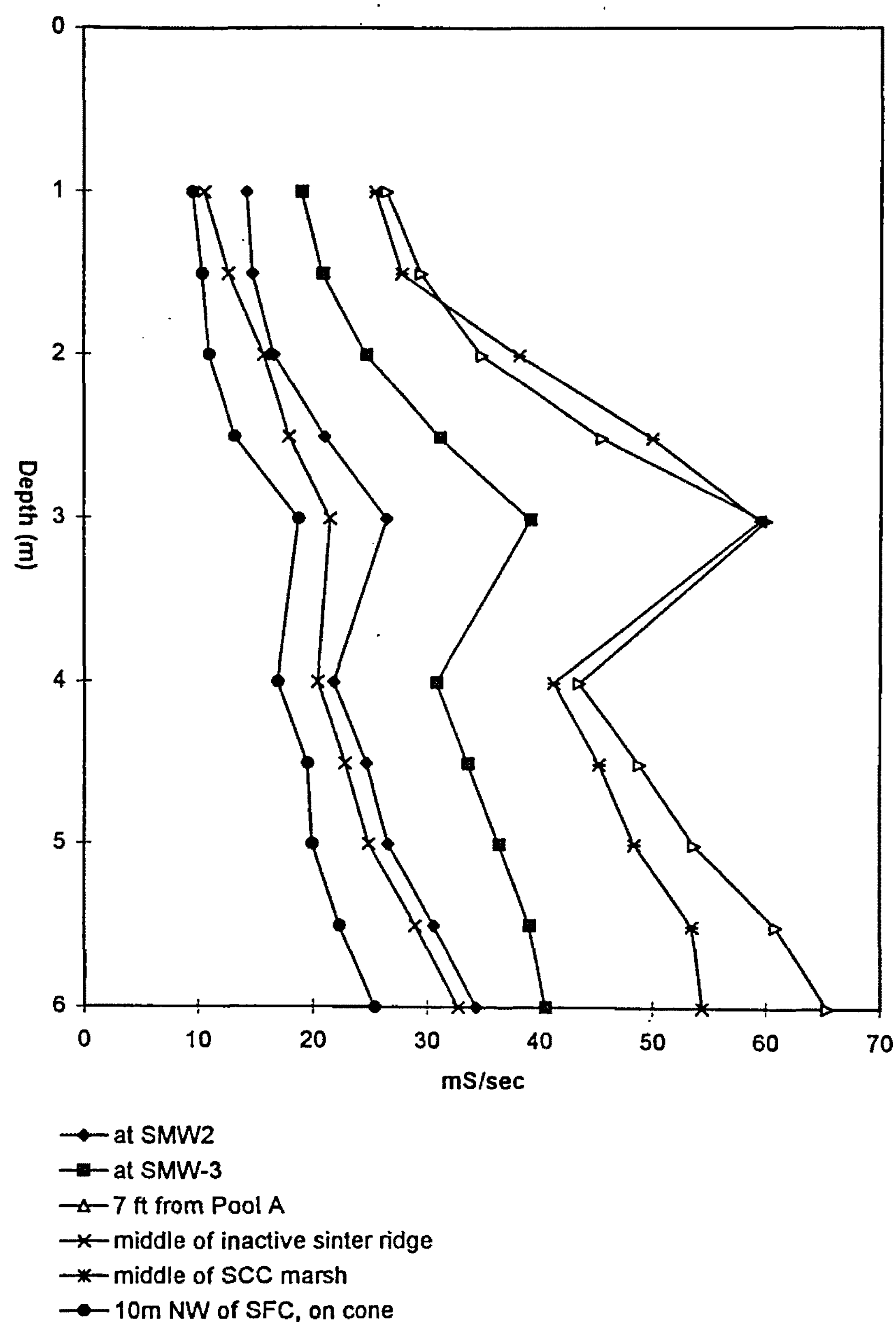


Figure 9. Sentinel Meadows, EM Terrain-Conductivity versus Depth at Select Locations

artifact of the instrument's operation in the horizontal and vertical dipole modes. Perhaps the induction coil or detector induces or receives the EM fields of slightly differing intensity, phase, or direction in the two modes.

4.2 Octopus Spring Study Area

4.2.1 Hydrogeology

Two distinct groundwater systems exist near Octopus Spring. Shallow groundwater occurs in the sinter mound west of the pool. A second system is present in the marsh to the east. The two groundwater systems are separated by a no flow/low flow boundary created by the eastern edge of the sinter apron.

Wells OW-3, and OW-5 did not produce water during this study, whereas, saturated conditions do exist in the western and southern potions of the sinter mound (OW-1, OW-1A, and OW-8) and in the marsh (OW-4, OW-6, OW-7). Saturated conditions also occur west of White Creek (OW-9). Figure 10 shows the inferred groundwater flow direction for the site. Water level measurements, potentiometric surface elevations and hydrographs for wells at this site are presented in Appendix B.

Groundwater was encountered at 40 cm during the construction of well OW-2, but upon completion of the well at 53 cm, the well was dry. The water encountered likely represents interflow perched upon a zone of relatively impermeable siliceous sinter.

Saturated conditions were present in the siliceous sinter and sinter breccias of the mound. Groundwater at the location of OW-1 and OW-1A had a net upward vertical potential. OW-1A was completed deeper into the saturated zone and its potentiometric

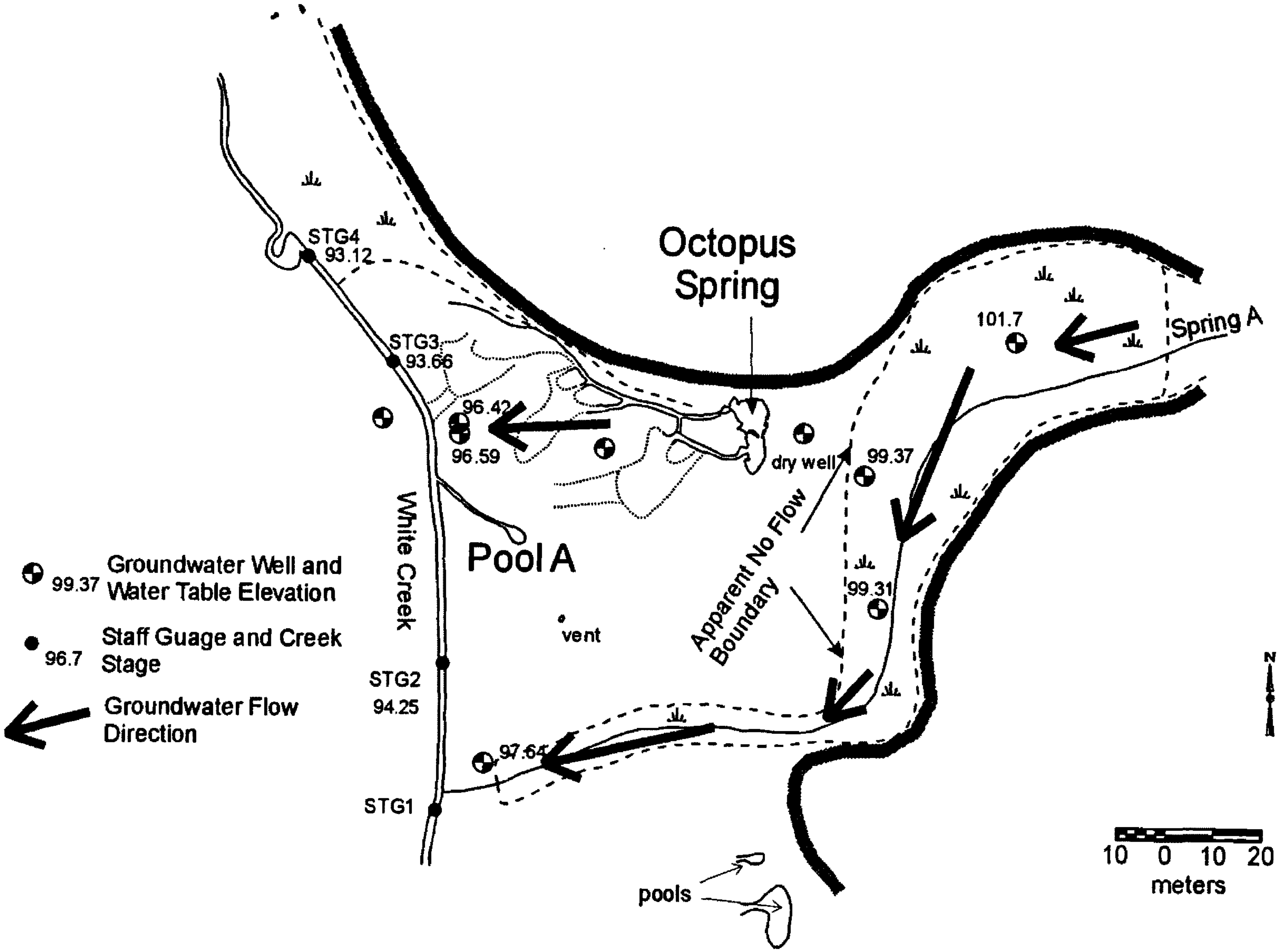


Figure 10. Octopus Spring, Inferred Local Groundwater Flow Directions (9/3/96)

surface was typically higher than in OW-1. Upward vertical gradients of 0.19cm/cm and 0.49cm/cm were measured between the wells on 14 January 1996 and 3 September 1996, respectively. The potentiometric surface in OW-1A was 0.3cm lower than in OW-1 on 22 November 1995, just 4 days after it was installed. It could be that the water level in the well had not yet equilibrated.

The groundwater temperature increased with depth (Table 8) at the location of OW-1 and OW-1A. The temperature of the nearby creek ranged from 15.3°C (November 1994) to a maximum of 52.1°C (July 1995).

TABLE 8
Groundwater Temperature Variation
Octopus Spring Sinter Mound

	OW-1	OW-1A	Change	Temperature Gradient[1]
11/22/95	4.3°C	19.1°C	+14.8°C	0.43°C/cm
1/14/96	7.2°C	17.9°C	+10.7°C	0.31°C/cm
9/3/96	17.5°C	24.6°C	+7.1°C	0.21°C/cm

[1] OW-1A is 34.3 cm deeper into the saturated zone

The marsh located to the east of the pool is composed of plant material and soft, organic-rich muds. The marsh is fed by Spring A that enters this area from the east. Groundwater flow in marsh is to the south. Artesian conditions existed at OW-6, at the eastern end of the marsh. Groundwater flowed slowly from the well casing, which was completed approximately 15 cm above the marsh's surface.

Well OW-8 was completed 38 cm into solid sinter next to the marsh's outflow channel. The sinter has laminar structure and water could be seen seeping into the boring from between laminations at a very shallow depth.

Well OW-9 was completed to the west of White Creek and a very shallow water table exists in this area. The local groundwater system of this area is separated from the groundwater system of the sinter mound by the creek.

Several cores of siliceous sinter were obtained when OW-1A was being bored. A falling-head permeameter was designed to measure the vertical hydraulic conductivity of the cores. Porosity determinations were also made and the results of this testing are summarized on Table 9. The hydraulic conductivity of the most-shallow core (obtained from 0-22 cm below the surface) was likely overestimated. This core was very short and there may not have been a good seal with the permeameter's tubing; thus, allowing water to easily flow around the edges. The measured hydraulic conductivity of the deeper cores ranged from 10^{-5} to 10^{-6} cm/sec. Measured porosities of the cores ranged from 12% to 24%.

TABLE 9
Octopus Spring Falling-Head Permeameter and Porosity Testing
OW-1A Sinter Cores

Core Interval (cm)	Core Length (cm)	Time Elapsed	Hydraulic Conductivity	Porosity
0-22	1.3	60 sec	3.0×10^{-2} cm/sec	20%
66-76	3.0	49hr39min	4.2×10^{-5} cm/sec	12%
76-86	4.1	49hr37min	1.3×10^{-6} cm/sec	19%
86-91	4.9	43hr15min	5.5×10^{-6} cm/sec	24%
102-112	3.0	38hr35min	2.3×10^{-6} cm/sec	22%

4.2.2 Surface Water Hydraulics

White Creek flow measurements were made at the staff gauge locations (Table 10). The flow of the creek increases from 88 L/sec (STG1) to 103 L/sec (STG3) in the downstream direction.

TABLE 10
White Creek Stream Flow Measurements (8/31/95)

Staff Gauge/Spring ID	Discharge Rate	Mean Velocity
OSTG-1	88 L/sec ±3	0.55 m/sec
OSTG-2	97 L/sec ±3	0.53 m/sec
OSTG-3	103 L/sec ±7	0.52 m/sec
OSTG-2	102 L/sec ±0.4	0.43 m/sec

The surface level of White Creek was compared with the water level measured inside temporary piezometers driven into the stream bed near the location of the staff gauges (Table 11). The creek was losing water upstream of the marsh's outflow (STG1) and downstream of the Octopus Spring surface discharge (STG4). White Creek was gaining water in the reach along the sinter mound (STG2 and STG3). Interestingly, the water level inside the piezometer at Staff Gauge 2 was noticeably fluctuating about 3 cm.

TABLE 11
Comparison of White Creek's Stream Surface with Stream Bed Head (8/31/95)

Location	Depth to Stream Bed's Water Level	Depth to Creek's Water Surface	Relative Head Difference
Staff Gauge 1	82.2 cm	65.7 cm	- 16.7 cm
Staff Gauge 2[1]	111.9 cm	117.3 cm	+ 5.4 cm
Staff Gauge 3	96.4 cm	101.1 cm	+ 4.7 cm
Staff Gauge 4	98.3 cm	92.6 cm	- 5.7 cm

[1] During this testing, the water level inside the peizometer was fluctuating 3.0 cm.

Total discharge from Octopus Spring, Pool A, and the marsh's outflow (Table 12) was measure at 9.23 L/sec when the spings' flow rates were the highest. At low flow, the total discharge was measured at 5.34 L/sec. The marsh's outflow was very shallow as it flowed across the sinter mound and the measured discharge was difficult to obtain.

TABLE 12
Octopus Spring Area Discharge Rates (8/31/95)

Spring Name	Flow Level	Spring Width	Discharge Rate
Octopus Spring	high	22.9 cm	4.11 L/sec ±0.54
(north channel)	low		1.55 L/sec ±0.19
Octopus Spring	high	21.0 cm	1.57 L/sec ±0.15
(south channel)	low		0.64 L/sec ±0.10
Pool A	high	28.0 cm	3.02 L/sec ±0.13
	low		2.62 L/sec ±0.26
Spring A (into marsh)		29.2 cm	3.15 L/sec ±0.40
Marsh Outflow		45.7 cm	0.53 L/sec ±0.15

4.2.3 Geochemistry

Graphical comparison of the geochemistry of thermal springs, surface water, and groundwater is shown with modified stiff diagrams (Figure 11) that represent the distribution of cations (Na^+, Ca^{2+}, Li^+, along with neutrally-charged dissolved silica) and anions (Cl^-, F^-, SO_4^{2-}, and HCO_3^- (presented as $CaCO_3$)) in area waters.

An analysis of the variability in concentrations of select chemical constituents (Na^+, Cl^-, Si, Li^+, F^-, and B) was performed by determining the analytical means and confidence intervals of the distinct area waters. The waters were grouped as hot spring waters (Octopus Spring (OCT) and Pool A (OPA), White Creek surface waters (OWC1 through

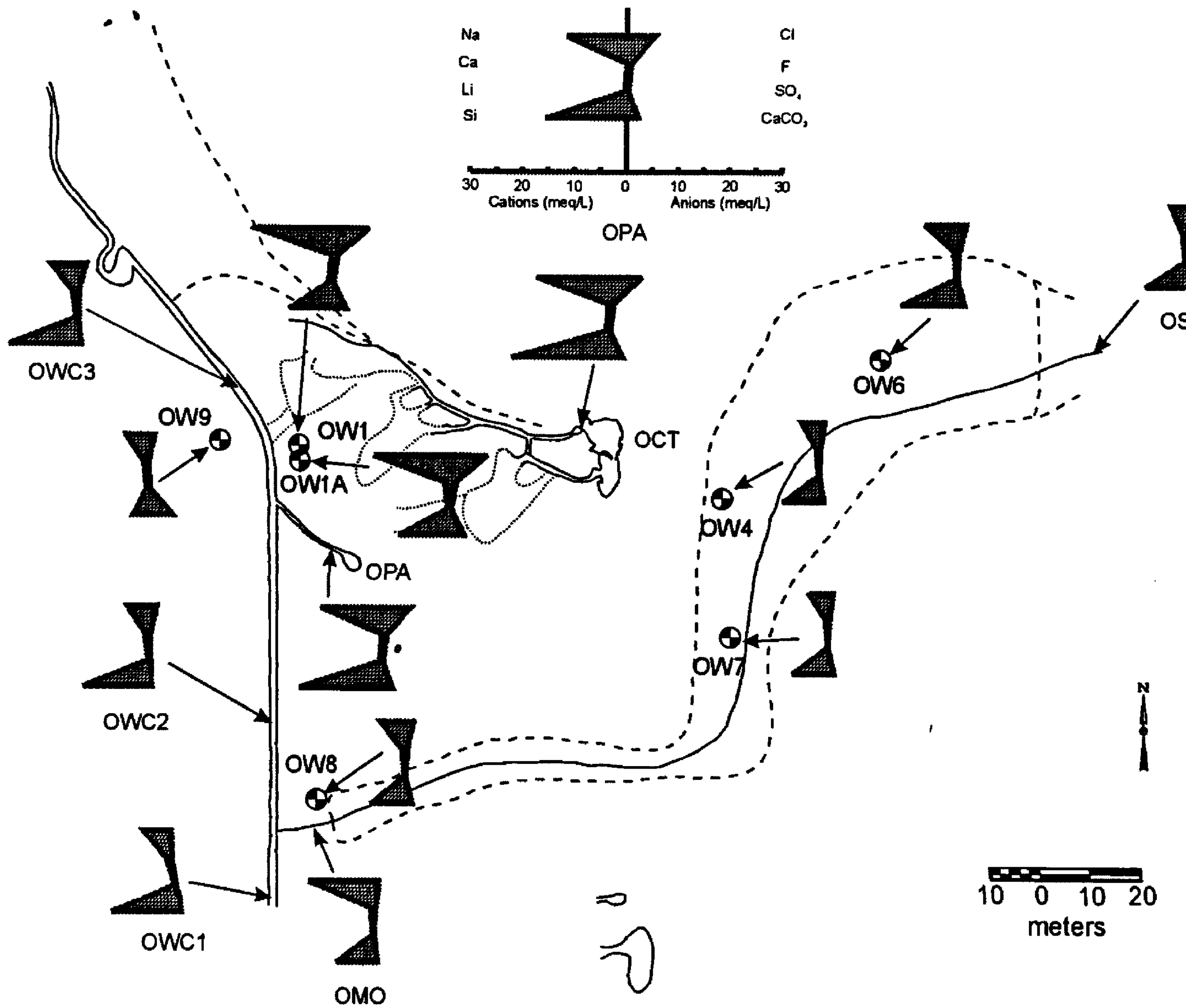
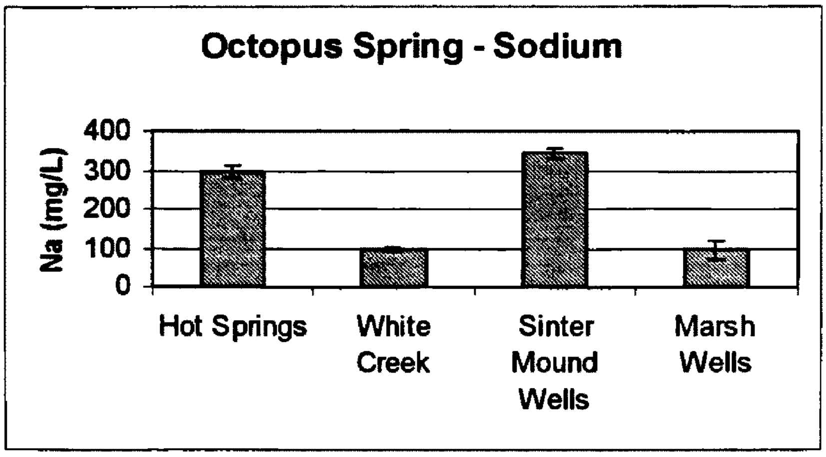
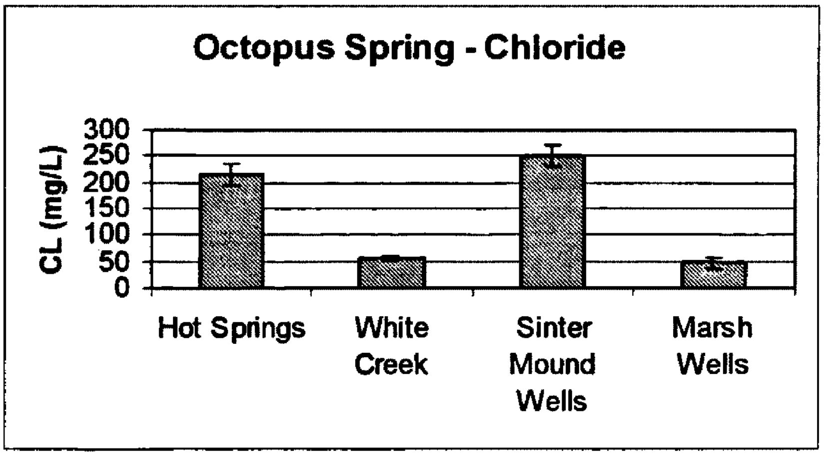


Figure 11. Octopus Spring, Stiff Diagrams

OWC-3), groundwater within the sinter mound (wells OW-1 and OW-1A), and groundwater within the swamp to the east of the hot springs (OW-4, OW-6, and OW-7). Figure12 shows the graphical results of this comparison of the distinct waters at the site. A table summarizing the results of the chemical analyses of waters obtained over a two year period is presented in Appendix G. For the grouped waters and other area waters with chemical data from 3 or more sampling events, the means, standard deviations (σ), and confidence intervals ($k(0.95) * \sigma / \mathrm{sqrt}(n)$) have been calculated. Also included in Appendix G is an evaluation of the data quality comparing the results with those from field and laboratory duplicates.

All the waters are NaCl-type waters, with the exception of water at OW-9 which is $NaHCO_3$-type. The results indicate that hot springs' discharge and the sinter mound's groundwater are comparable with respect to the primary cationic and anionic species, Na^+ and Cl^-, though the groundwater is significantly lower in dissolved-silica. The hot spring waters and the sinter mound's groundwater are chemically distinct from White Creek and from the marsh's groundwater system. The distribution of the minor chemical constituents, Li^+, F^-, and B, are also shown on Figure 12. The hot spring waters and the sinter mound's groundwater are similar with respect to these constituents though the groundwater concentrations are slightly higher.





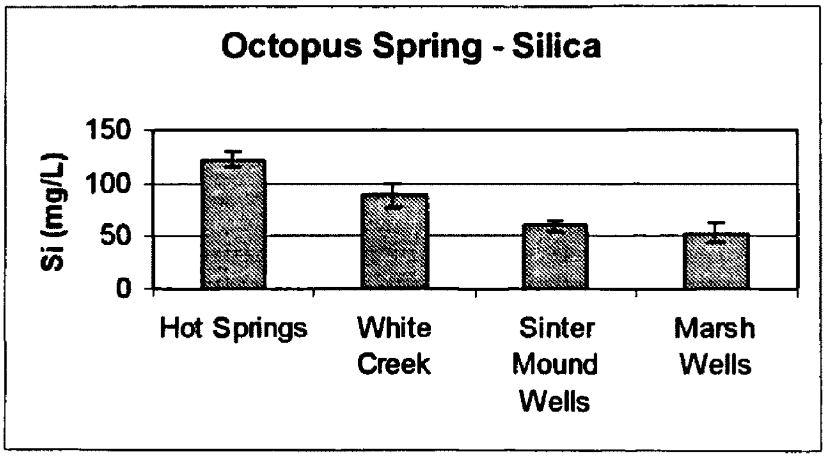
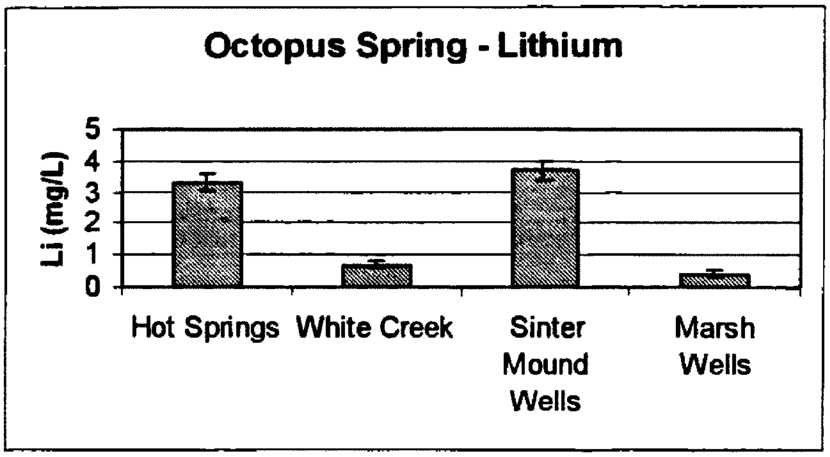
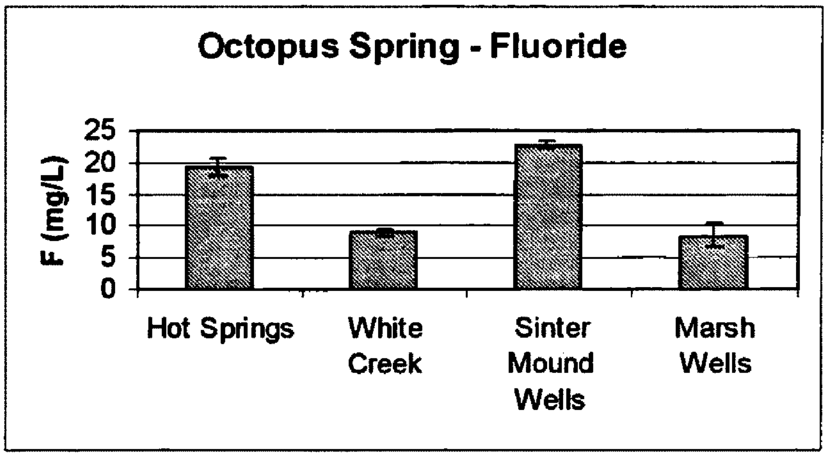


Figure 12. Octopus Spring, Variance of Means of Select Chemical Constituents





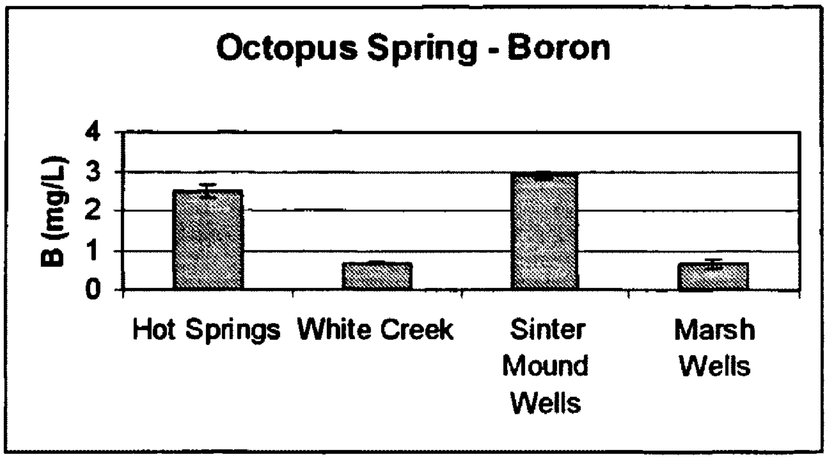


Figure 12 cont. Octopus Spring, Variance of Means of Select Chemical Constituents

4.2.4 Electromagnetic Terrain-Conductivity

Results of the EM terrain-conductivity mapping at 1.5 and 4.5 meters below the surface are shown on Figure 13 and 14, respectively. Results of the depth discrete mapping (from 1 m to 6 m below the surface) are presented in Appendix E.

The terrain-conductivity mapping of the site indicates that there is a zone of higher conductivity originating from Octopus Spring and extending to the west toward White Creek. The marsh's groundwater system to the east of Octopus Spring has a significantly lower measured terrain-conductivity when compared to the sinter mound. Separating the two groundwater systems is an apparent no-flow boundary created by the sinter apron between the hot spring and the marsh. The lowest measured conductivities are present in the sinter immediately west of the marsh near OW-7 and are especially evident from the mapping at 4.5 m depth.

Figure 15 is a plot of measured terrain-conductivity versus depth at various locations across the site. The conductivity values increase with depth with the highest increase noted near OW-2 and OW-1, within the sinter mound groundwater system. The plots for conductivity at OW-3 and on the rhyolite hillslope north of the hot spring have relatively low conductivities indicative that these areas are not saturated.

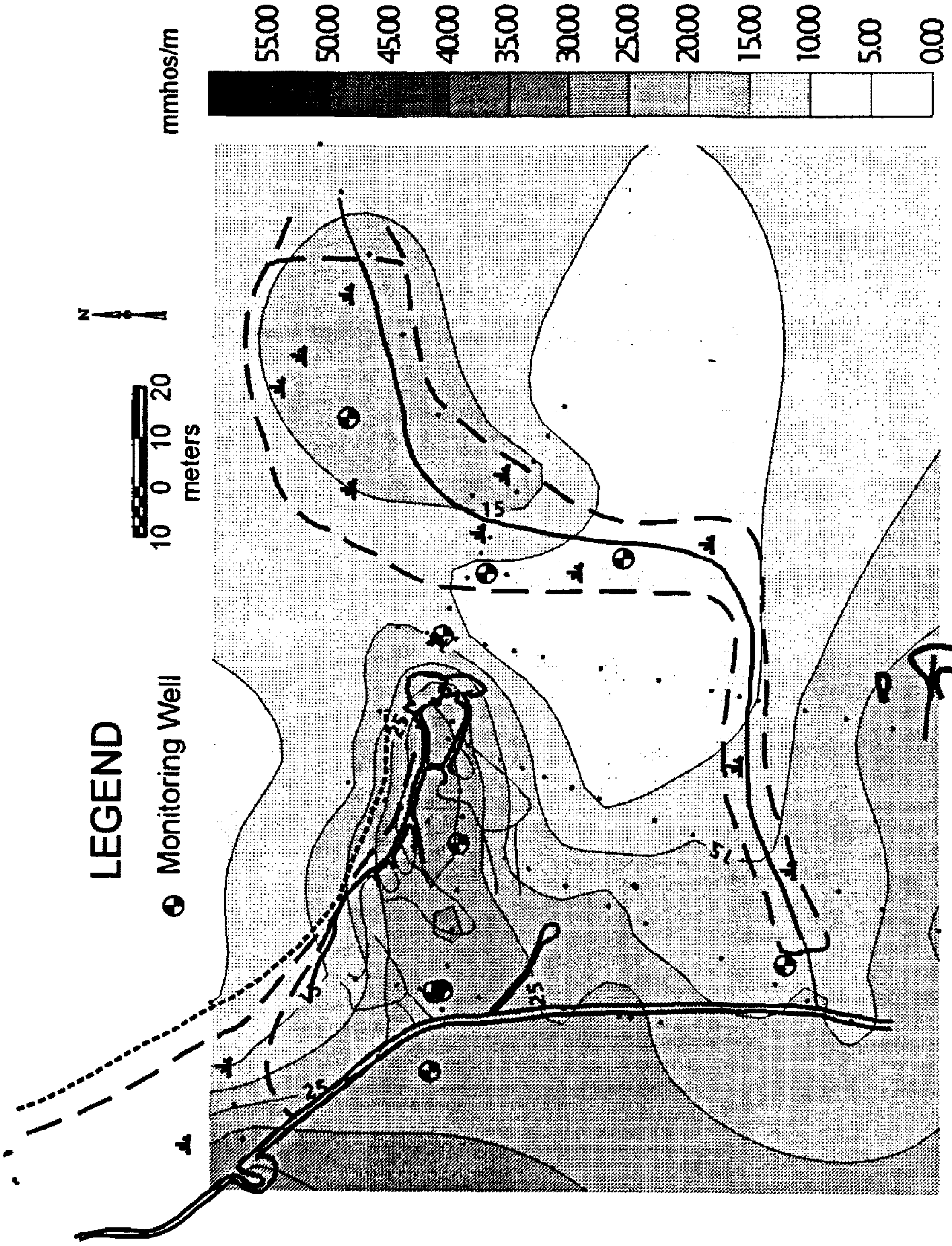


Figure 13. Octopus Spring, EM Terrain-Conductivity (1.5 m Depth)

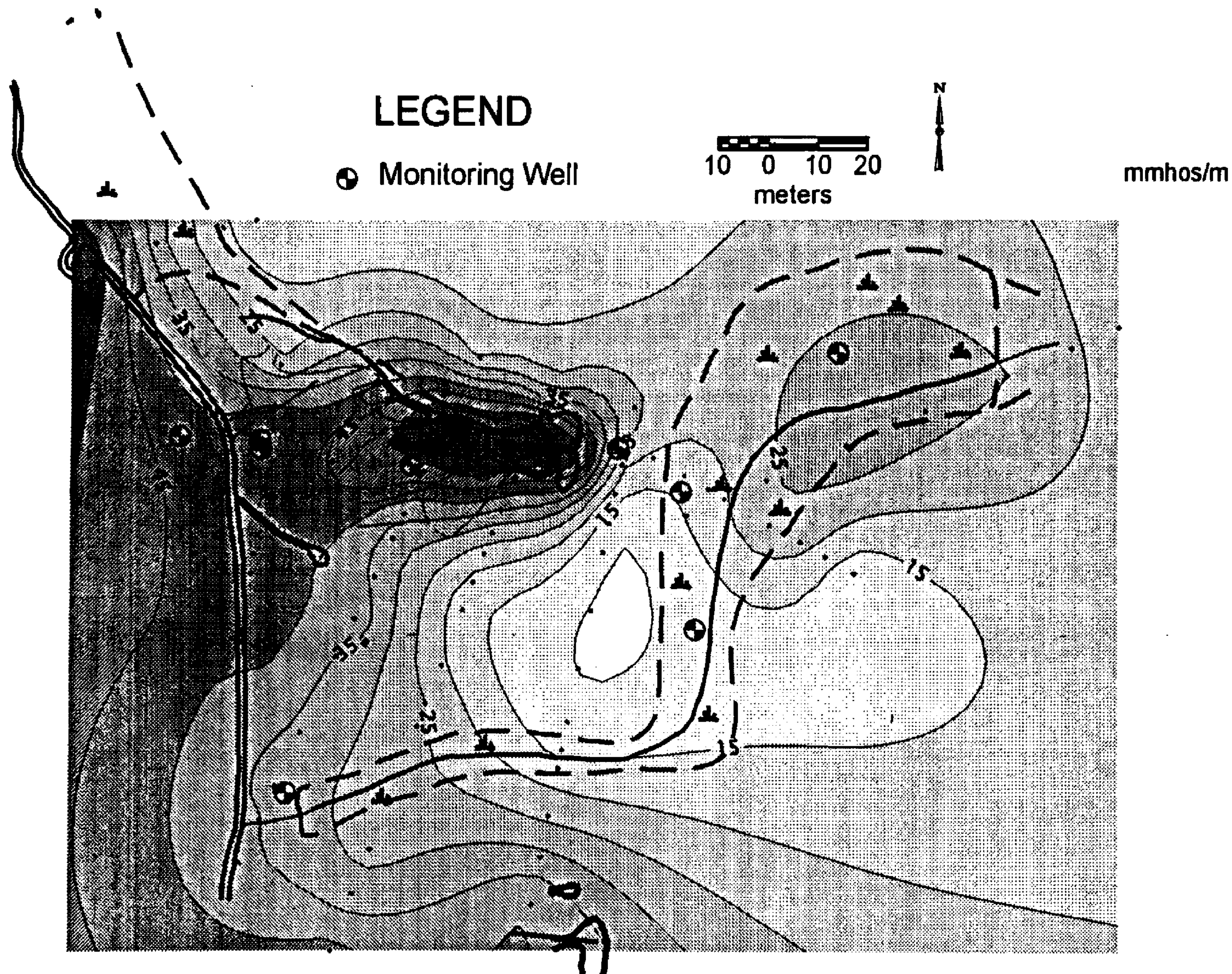


Figure 14. Octopus Spring, EM Terrain-Conductivity (4.5 m Depth)

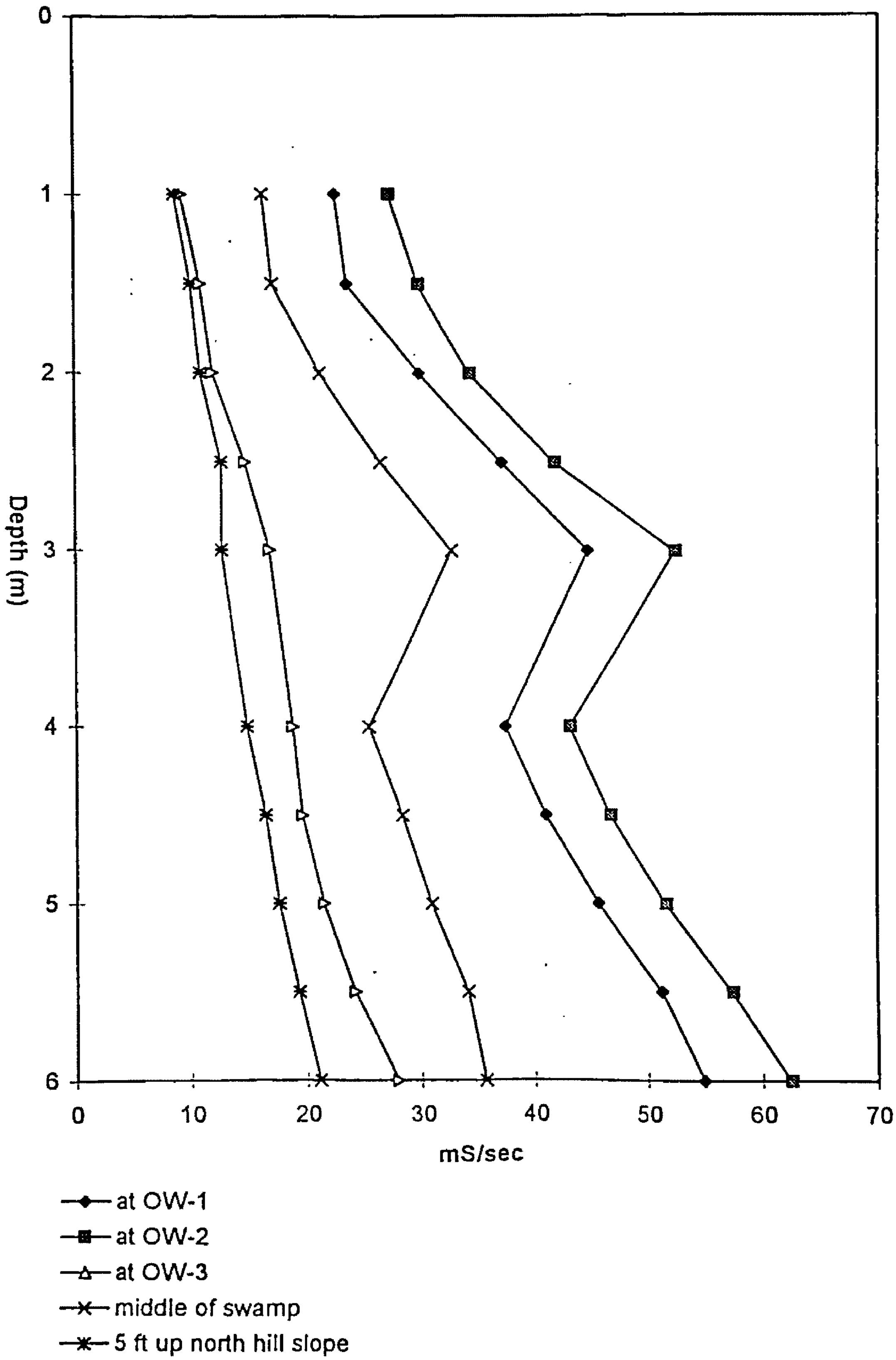


Figure 15. Sentinel Meadows, EM Terrain-Conductivity versus Depth at Select Locations

5.0 DISCUSSION

5.1 Sentinel Meadows Study Area

The Sentinel Meadows aquifer is composed primarily of obsidian sand with some gravels and is overlain by over 45 cm of relatively impermeable diatomaceous earth. The streams crossing the site are perched above the aquifer. The aquifer is a relatively permeable system and the groundwater flow paths appears to be controlled by the active and inactive thermal features in the area. Groundwater flow is primarily to the south, but appears to be somewhat radial near the cones.

It has been assumed that the aquifer discharges to Sentinel Creek, as there are no other receiving surface water bodies in the area. However, the interaction of the aquifer with the creek may be a little more complex. Stream gauging of Sentinel Creek indicates that the creek is gaining in flow by approximately 30 L/sec along the reach from just above Steep Cone to Staff Gauge 2 but is losing in the area of Staff Gauge 3. The discharge contribution from Steep Cone and Flat Cone could not be determined but the streams crossing the study area may contribute almost 26 L/sec flow to the creek. There was likely some error in estimating spring discharge, but the estimated surface water contribution to the creek suggest that there is only minor influx to the creek from groundwater.

Observations that the creek is losing near Staff Gauge 3 is supported by analytical results obtained from the temporary piezometer installed to determine the surface water/groundwater interaction. The results for the area near Staff Gauge 2 indicate that the water chemistry in the stream bed is similar in chemistry to groundwater. However, near Staff Gauge 3, the chemistry of the stream bed water looks more like the creek's water chemistry. Interestingly, it is in this reach of Sentinel Creek the stream bed is silica-armored. DeMonge (1999) has investigated silica-armoring in other areas of YNP and has found that it appears to only occur where streams are losing.

The silica-rich, alkaline hot spring water discharging from Flat Cone is reduced in dissolved silica concentration as the water percolates into and flows from the base of the sinter cone to the southwest (sampling location SFCa). The silica is lost through precipitation as the silica-saturated waters cool. The emerging water at the base of the cone is slightly higher in pH (likely resulting from the loss of CO_2). A similar reduction in silica concentrations (with increased pH) was observed as waters discharged from Carcass Cone flowed through the marsh and into its small spring (SCCS).

Local groundwater south of Carcass Cone and Flat Cone is only slightly lower in Na-Cl than the thermal waters. The groundwater is much lower in dissolved silica, which can be partly be attributed to the precipitaion of amorphous silica on the sinter mounds. The groundwater chemistry in wells located south of the active thermal features (SMW-3, and SMW-5 through SMW-10) are similar with respect to Na-Cl but the concentration of these more conductive salts are significantly lower in wells further from the hot springs (i.e. SMW-2 and SMW-4). Additionally, the Li^+ and F^- concentrations within this zone of higher conductivity are only slightly lower than in the thermal water. However, in SMW-2, the groundwater's F^- concentration is >50% lower than at other well locations. This can likely be attributed to this well being away from the hot spring sources.

Given the similarity in concentration of the more conductive constituents (i.e., Na^+ Li^+, Cl^-, and F^-) in both groundwater and the thermal waters near Carcass Cone and Flat

Cone, there must be a zone of mixing of hot spring discharge waters with groundwater in the area. The groundwater chemistry near the active hot springs contrasts sharply when compared to the areas further away from the thermal sources. The groundwater chemistry at SMW-2 and SMW-4 is significantly lower in conductive solutes and can be considered to be somewhat representative of the background chemistry in the Sentinel Meadows area. It is evident that that there is some interaction between thermal waters and local groundwater near the hot springs.

Two possible mechanisms for the mixing of thermal waters and meteoric waters, as end members, are proposed. First, the hot springs in this area (and most, if not all, areas of the Park) discharge to marshes. The marshes are filled with diatoms that use the silica-rich water for their frustules. Perhaps these areas also provide zones of mixing between thermal waters and meteoric waters. Downgradient of the marshes would represent the areas for mixing of marsh water with local groundwater, resulting in the observed chemistry of the system. Hence, these marshes may be zones in which dynamic changes are occurring as chemical reactions, physical mixing, and biological activity take place.

A second proposed mechanism may be the mixing of hydrothermal water leaking into groundwater in the subsurface. Potential sources for this subsurface activity could be Carcass Cone and the tepid Pool A located to the northwest. The zones of higher terrain-conductivity observed in vicinity of Carcass Cone and Pool A may be indicative of their relative age. Thermal features such as Flat Cone and Steep Cone are likely relatively old (perhaps developing since the last ice age) given their relatively large size and height above the valley floor. These older thermal features may have a well-established vents that are sealed-off and insulated from the surrounding subsurface environment. Assuming that Carcass Cone and Pool A are relatively younger features, they may not have well-developed vent systems and may be losing some discharge (and/or radiating more heat) that mixes with groundwater. This mechanism also would produce the observed chemical patterns. It is not possible to eliminate either proposed mixing model, based on the available hydrogeochemical data.

The EM terrain-conductivity mapping (Figures 7 and 8) compares favorably with findings of the groundwater geochemistry. The EM mapping defines a zone of more conductive groundwater extending south from the active hot springs toward the creek. The marsh area near Carcass Cone has the highest terrain-conductivity for the area. It appears that this marsh area is where much of the mixing of hot spring discharge and groundwater occurs; thus, supporting the first mechanism for mixing.

Results of EM mapping across the edge of Flat Cone show that the sinter mound is a sink with respect to conductivity. It may be that the cone is relatively impermeable below the water table resulting in lower conductivities (related to the degree of saturation). If this is the case, then this finding indicates that Flat Cone is insulated from the groundwater environment. Conversely, the relatively high conductivity observed near Carcass Cone and Pool A suggest that the vent systems in these areas may have some influence on the groundwater system. This observation supports the second mechanism for mixing.

The configuration of EM terrain-conductivity contouring is similar to the potentiometric surface mapping of the area. Since there is little observed variability in groundwater temperatures in wells near Flat Cone, the conductivity may be mostly attributed to higher concentrations of conductive solutes. However, the Carcass Cone area was not instrumented with groundwater wells, so the impact of temperature on measured terrain-conductivity cannot be dismissed.

The EM mapping also shows a reach of lower conductivity between Flat Cone and the inactive sinter mound to the north. This gap is slightly higher in elevation than the plain to the east or west and it appears from the surface to be an obstruction to groundwater flow. The low terrain-conductivity of the area suggests that these closely space structures do, in fact, limit groundwater flow across this area.

5.2 Octopus Spring Study Area

The sinter mound and marsh groundwater systems are separated by a sinter apron that appears to be relatively impervious. EM mapping shows that this area has low terrain-conductivity compared to the two groundwater systems, indicating that it represents a no-flow boundary.

Within the sinter mound, a component of the Octopus Spring discharge infiltrates the siliceous sinter and sinter breccias and recharges a shallow groundwater system to the west of the pool. There are competent layers of relatively impermeable siliceous sinter within the mound occurring both in the vadose and saturated zones. It is unknown if these subsurface sinter deposits are laterally continuous, but water was present on a perching layer when OW-2 was constructed. Further downslope, an upward vertical gradient is observed between OW-1A and OW-1. This vertical potential may be related to groundwater discharge to White Creek; however, relatively extensive areas of sinter in the saturated zone could result in confining conditions within the mound.

There was a measured increase of 15 L/sec in the flow volume of White Creek as it flowed past the sinter mound. This increase represents the total discharge to the creek from the hot springs (Octopus Spring and Pool A), the outflow from the marsh, and discharge from the sinter mound's groundwater system. Some error in determining the total discharge contribution from the thermal springs and marsh outflow was likely (resulting from difficulty in determining the cross-sectional area of the outflow channels). However, if the total volume of surface water discharged is assumed to be representative of the area, then the groundwater flux into the creek is estimated to be between 5.77 L/sec and 9.66 L/sec.

The results indicate that the geochemistry of the sinter mound's shallow groundwater system is distinct from the marsh's groundwater system. However, the sinter mound's groundwater is comparable to the hot springs' discharge waters (both are Na-Cl rich); evidence that mixing is occurring. The thermal spring's discharge has an appreciable dissolved-silica concentration. Dissolved silica concentration in this groundwater system is up to 50% lower than the discharge water from Octopus Spring; evidence that silica is precipitating as the surface waters cool and infiltrate into the sinter mound.

The chemistry of the surface water entering (OSA) and exiting the marsh (OMO) shows little change in chemical composition. The chemistry of White Creek's water increases slightly in Na-Cl and alkalinity as it flows past the sinter mound, likely a result of discharges from groundwater and surface water.

On the west side of White Creek (OW-9), there is sodium-bicarbonate type groundwater that is distinct from the sinter mound's and marsh's groundwater systems east of the creek.

The sinter mound's and marsh's groundwater systems differ significantly in temperature and groundwater chemistry. Interpretations of the results from the EM terrain-conductivity mapping needs to consider the impacts of both variables on measured conductivity.

The terrain-conductivity is highest in the area of the sinter mound west of Octopus Spring. The results verify that saturated conditions do exists in this area. The conductivity distribution patterns remain mostly constant with depth but increase in intensity, which would be expected when mapping saturated conditions. Conductivity will increase as the EM signal penetrates deeper into the subsurface, travelling through a greater cross-sectional area of saturated sinter and sinter breccia.

The groundwater temperature is as much as 15°C warmer in OW-1A than in OW-1. Moving closer to Octopus Spring, it is likely that groundwater temperature will increase nearer the spring and at increasing depth, due to heating by the spring's vent. In fact, the EM survey of this area indicates significantly higher conductivities near Octopus Spring than at the western edge of the sinter mound.

The chemistry of the hot spring waters and groundwater in the sinter mound do not differ with respect to the presence of conductive salts (i.e. Na^+ and Cl^-). Hence, increases in terrain-conductivity within the sinter mound nearer the pool indicates that temperature variations have a significant impact on measured conductivity values near this thermal source.

The marsh's groundwater system has significantly lower conductivities than the sinter mound's system. Comparing the terrain-conductivity results of the groundwater systems may be reflective of the impact of both temperature and chemistry. Groundwater near the western edge of the sinter mound is warmer than in the marsh. At the time of the EM survey (August 1994), groundwater temperature in OW-1 and OW-4 were 30.0°C and 16.7°C, respectively. During subsequent sampling events, the temperature was up to 9.8°C higher in the sinter mound (November 1995). The groundwater in the marsh is significantly lower in conductive salts (i.e. Na^+ and Cl^-) compared to the water in the sinter mound that would result in lower detected terrain-conductivities. Hence, both temperature and chemistry must be considered when evaluating the results from EM mapping, though distinguishing the impacts between the two cannot be made without direct-measurement of the systems.

5.3 Conceptual Models of the Study Areas

The geochemistry of the Sentinel Meadows aquifer is influenced by the influx and mixing with hot spring discharge and the infiltration of meteoric water. Figure 16 presents a conceptual model for this site. Vents may either be closed (Flat Cone) or leaky (Carcass Cone) conduits. Different patterns of groundwater interaction are observed in each case.

Groundwater in the area flows to the south past two dominant hot spring systems, Carcass Cone and Flat Cone. Based on the geochemical and EM terrain-conductivity

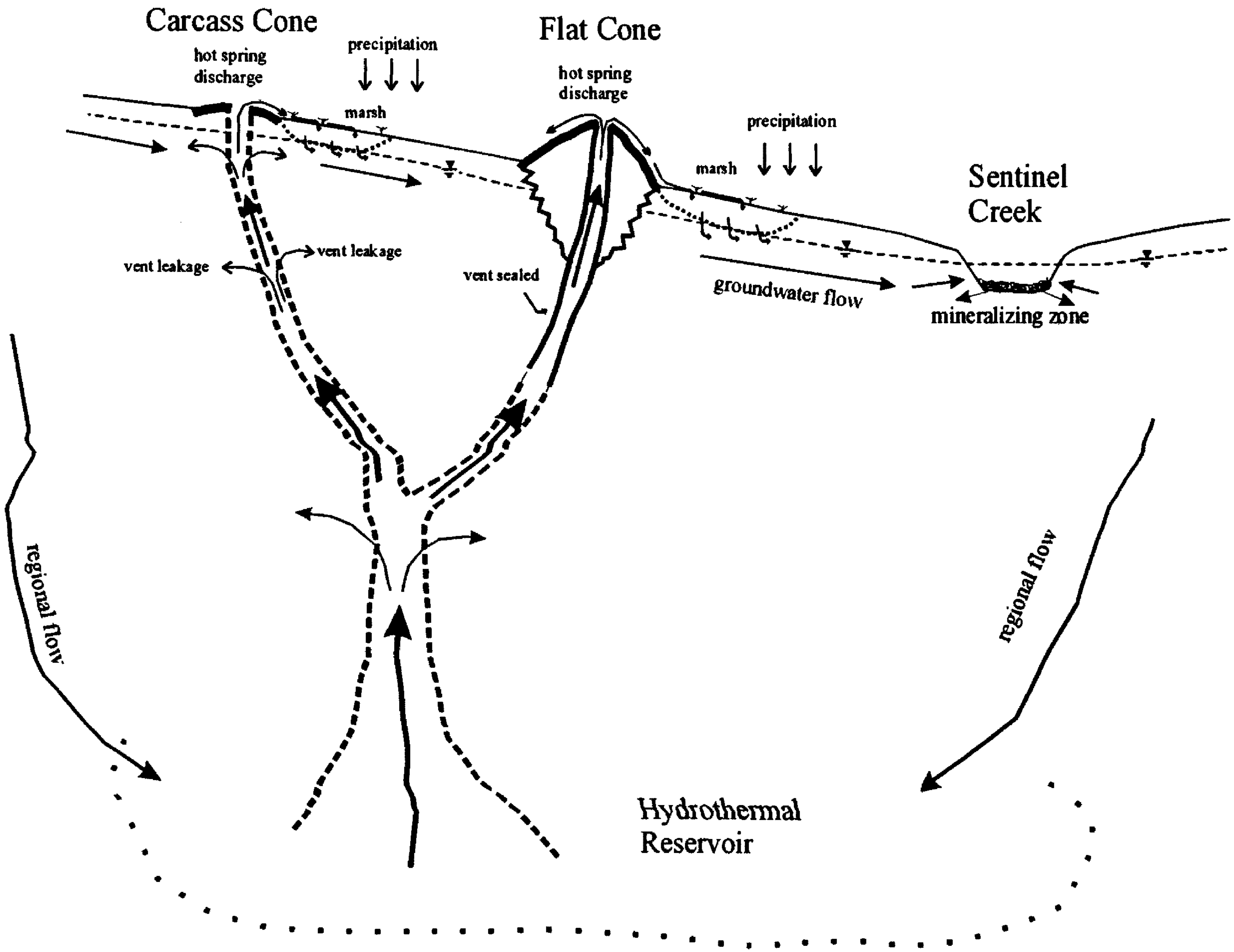


Figure 16. Sentinel Meadows - Conceptual Model for Hydrothermal-Groundwater-Meteoric Water Mixing

studies, it appears that the marshes are the primary areas where the mixing of the hydrothermal water and groundwater occurs. There also may be some subsurface contribution to the groundwater system from leakage of the hydrothermal vents. The study did not look at the geochemical influence associated with the influx of meteoric water, but it is obvious that precipitation (in the form of rain and snowmelt) is a component of the water cycle. Further down the flow path, the groundwater interacts with Sentinel Creek. Along most of the creek, groundwater likely discharges to this surface water body. However, in some areas it appears that the creek discharges to groundwater. It is in these losing sections of the stream that the streambed becomes armored with silica-cemented matrix.

The Octopus Spring study area has two distinct groundwater systems that are separated by a relatively impermeable apron of siliceous sinter. Figure 17A-C offers a conceptual model for the emergence and development of the Octopus Spring hydrothermal system over time. Figure 18 presents a conceptual model for the site as it exists today.

The asymmetrical Octopus Spring sinter mound abuts a rhyolite hillside and slopes to the west. As the hot spring system developed, the amorphous silica being deposited appears to have created a structure that has blocked the flow of Spring A. The marsh formed as the sinter mound grew. Today, flow from the marsh exits the system at the south end and flows overland into White Creek.to the south. The marsh's groundwater is chemically distinct from the groundwater within the sinter mound west of the hot spring. This study identified a no-flow boundary created by the sinter apron east of Octopus Spring. Results from the EM terrain-conductivity mapping

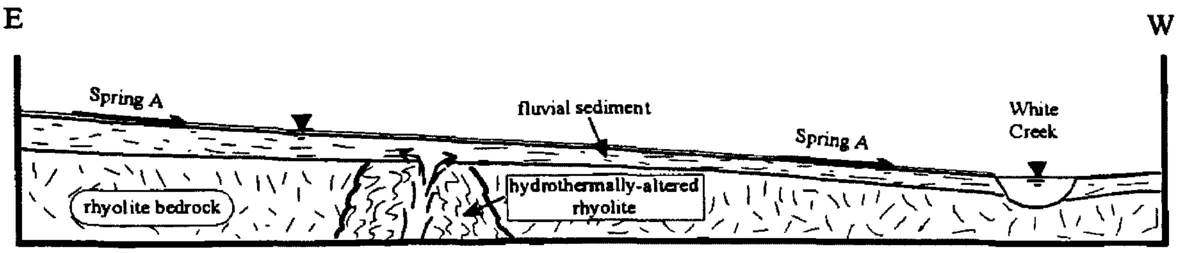


Figure 17A. Octopus Spring Development. The Octopus Spring vent becomes sealed in the subsurface through hydrothermal-alteration of the country rock. The silica-saturated waters eventually contact the relatively cool fluvial waters of Spring A.

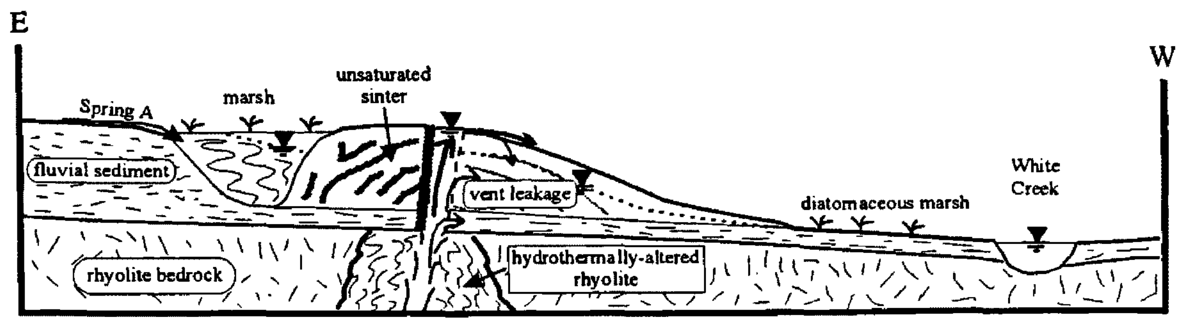


Figure 17B. The thermal water rapidly cools and silica precipitates upon contact with Spring A waters. The resulting amorphous-silica precipitate east of the vent has a relatively-fine crystalline structure and the young Octopus Spring vent becomes sealed-off on this side of the sinter mound. On the west side of the vent, the thermal water flows across the sinter mound, cooling and precipitating and resulting in the vertical and lateral growth of the system. Percolation and vent leakage likely contributes to a groundwater system within the mound.

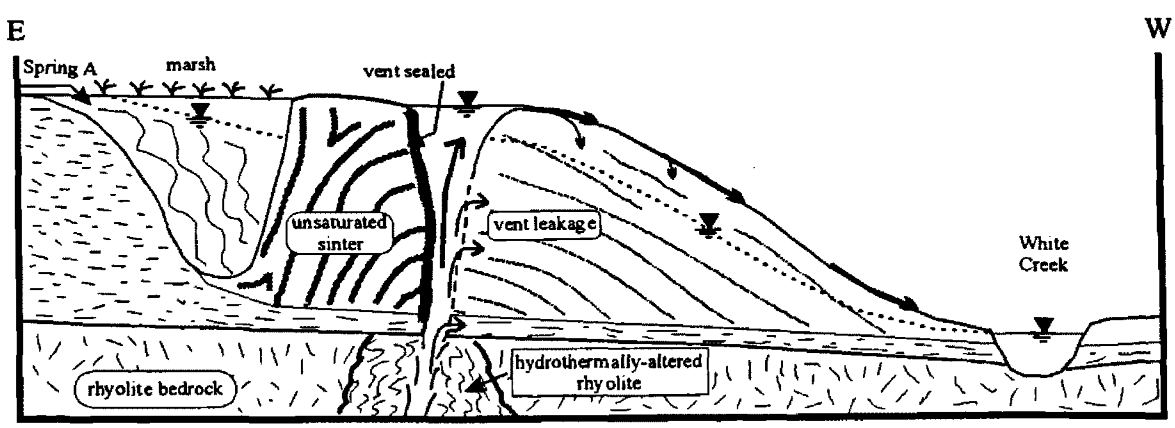


Figure 17C. The Octopus Spring sinter mound continues to grow vertically and laterally to the west. Discharge is primarily to the west. However, any discharge to the east will rapidly cool and precipitate, further damming the flow of Spring A. The resulting marsh groundwater system is forced to discharge to the south of Octopus Spring. Vent leakage and thermal discharge water continues to percolate into the mound, feeding the mound's groundwater system.

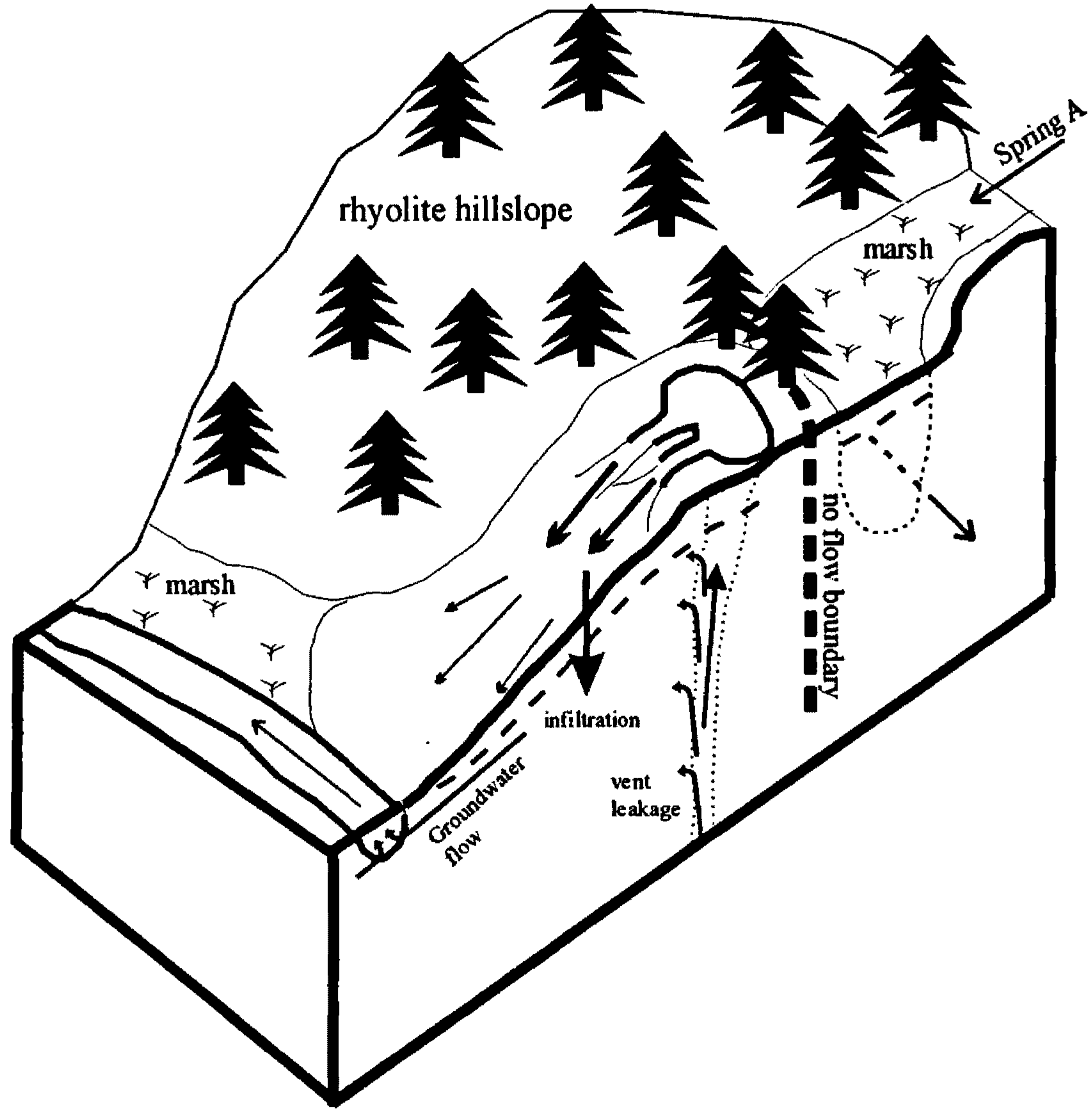


Figure 18. Octopus Spring, Conceptual Model for Groundwater/Spring Interaction. Octopus Spring abuts a rhyolite hillslope. As the sinter mound developed, it dammed the flow of Spring A and created a marsh. Two groundwater systems exist at the site; the sinter mound system, and the marsh system. An apparent no flow boundary exists between the sinter mound and the marsh.

and hydrogeological study concur that this area is not saturated and has dammed the flow of Spring A.

6.0 CONCLUSIONS

EM terrain-conductivity mapping can be used to indirectly determine the areas of chemical mixing of hot spring waters with local groundwaters. This non-intrusive geophysical technique can also be used to identify and contrast aquifer systems with distinct physical and geochemical signatures. Correlating the geophysical data with hydrogeologic and water quality data may provide a more reliable understanding of the hydrogeochemical setting than either type of information used by itself (Fetter, 1988)

The EM-31 instrument was tested in two hydrothermal settings that significantly differ in size and geology. Results obtained during this study indicates that the EM-31 was effective in locating the interface of surface water/groundwater mixing zones that vary in conductivity (due to the presence of conductive salts) and/or temperature in both areas.

Within a sinter mound system, it appears that the hot spring waters infiltrate directly into the siliceous sinter and sinter breccias. However, the mechanisms for mixing with local groundwater are not known. Two possibilities have been considered. First, most hot springs not located next to rivers and creeks discharge in to marshes. These marshes are filled with diatoms. Perhaps these areas provide zones of mixing between thermal waters and meteoric waters. These marshes represent zones in which chemical reactions, physical mixing, and biological activity take place, resulting in dynamic changes in the subsurface environment. A second mechanism could be that seepage from the hot spring vents could mix directly with local groundwater.

REFERENCES

Berner, R.A., and Berner, K.B. 1987. The Global Water Cycle, Geochemistry and Environment, New Jersey, Prentice-Hall, Inc.

Brooks, G.A., Olyphant, G.A., and Harper, D. 1991. Application of electromagnetic techniques in survey of contaminated groundwater at an abandoned mine complex in southwestern Indiana, U.S.A. Environmental Geology and Water Sciences. 18(1): 39-47.

Deming, D., 1993. Regional permeability estimates from investigation of coupled heat and groundwater flow, North Slope of Alaska. Journal of Geophysical Research 98(B9):16,271-16,286.

DeMonge, J.M. 1999. Streambed armoring in Iron Spring, Yellowstone National Park, Wyoming: Ground Water-Surface Water Interactions. Master's Thesis, University of Montana, Missoula, Montana.

Ertel, B.J. 1995. Lithofacies distribution at McGuiness Hills, Nevada. M.S. Thesis, University of Montana, Missoula, Montana.

Fetter, C.W. 1988. Applied Hydrogeology. New York, Macmillan Publishing Company.

Fournier, R.O. 1989. Geochemistry and dynamics of the Yellowstone National Park hydrothermal system. Annual Review of Earth and Planetary Science. 17:13-53.

Forster, C., and Smith, L. 1989. The influence of groundwater flow in thermal regimes in mountainous terrain: A model study. Journal of Geophysical Research 94(B7):9439-9451.

Hinman, N.W. 1998. Sequences of silica phase transitions: Effects of Na, Mg, K, Al, and Fe ions. Marine Geology 147:13-24.

Hinman, N.W. 1997. Hydrological processes in microbial preservation. Proceedings of the International Society for Optical Engineering; Instruments, Methods, and Missions for the Investigation of Extraterrestial Microorganisms. Volume 3111.

Hinman, N.W., and Lindstrom, R.F. 1996. Seasonal changes in silica deposition in hot spring systems. Chemical Geology 132:237-246.

Hinman, N.W. 1995. Silica diagenesis: Mortar Geyser Complex, Yellowstone National Park, USA. Proceedings of the Eighth International Symposium on Water-Rock Interaction, WRI-8, Vladivostok, Russia, 15-19 August 1995.

Hinman, N.W. 1995. Silica diagenesis: Mortar Geyser Complex, Yellowstone National Park, USA. Proceedings of the Eighth International Symposium on Water-Rock Interaction, WRI-8, Vladivostok, Russia, 15-19 August 1995.

Hvorslev, M.J. 1951. Time lag and soil permeability in ground water observations. U.S. Army Corps of Engineers Waterways Experimentation Station, Bulletin 36, 50p.

Hurlbut, C.S., and Klein, C. 1977. Manual of Mineralogy, 19th Edition. New York, John Wiley and Sons, Inc.

Iler, R.K. 1979. The Chemistry of Silica: Solubility, Polymerization, Colloid and Surface Properties, and Biochemistry. New York, John Wiley and Sons, Inc.

Ingebritsen S.E., Sherrod, D.R. and Mariner, R.H. 1992. Rates and patterns of groundwater flow in the Cascade Range volcanic arc, and the effect on subsurface temperatures. Journal of Geophysical Research, 97(B4):4599-4627.

Lee, D.R. 1977. Notes - A device for measuring seepage flux in lakes and estuaries. Limnology and Oceanography 22(1):140-147.

Mack, T.J., and Maus, P.E. 1986. Detection of contaminant plumes in fround water of Long Island, New York, by electromagnetic rerrain-conductivity surveys. U.S. Geological Survey Water Resources Investigation Report 86-4045. 39p.

McNeill, J.D. 1990. Use of electromagnetic methods for groundwater studies. Geotechnical and Environmental Geophysics, S.H. Ward, editor. V. 1 Society of Exploration Geophysics. 191-218.

McNeill, J.D. 1980a. Technical Note TN-5: Electrical conductivity of soils and rocks. Geonics Limited EM31 Ground Conductivity Meter Operating Manual:5-22

McNeill, J.D. 1980b. Technical Note TN-6: Electromagnetic terrain conductivity measurement at low induction numbers. Geonics Limited EM31 Ground Conductivity Meter Operating Manual:5-15.

McNew, E.R., and Arav, S. 1995. Surface geophysical surveys of the freshwater-saltwater interface in a coastal area of Long Island. Ground Water, 33(4): 615-626.

Nordstrom, D.K., and Everett, A.J. 1977. Fluorite solubility equilibria in selected geothermal waters. Geochemica et Cosmochimica Acta, 41:175-188.

Rantz, S.E., and others. 1982. Measurement and computation of stream flow: Volume 1. Measurement of stage and discharge. U.S. Geological Survey Water-Supply Paper 2175. 284p.

Sharma, P.V. 1997. Environmental and Engineering Goephysics. Cambridge, England, Cambridge University Press. 265-306.

Smith, L. and Chapman, D.S. 1985. The Influence of water table configuration on the near-surface thermal regime. Journal of Geodynamics 4:183-198.

Sorey, M.L. 1991. Effects of potential geothermal development in the Corwin Springs known geothermal resources area, Montana, On the thermal features of Yellowstone National Park. U.S. Geological Survey Water-Resources Investigations Report 91-4052.

Stewart, M.T. 1989. Electromagnetic mapping of fresh-water lenses on small oceanic islands. Ground Water. 27(2): 187-191.

SURFER Ver. 5.00. 1994. Surface Mapping System. Golden Software, Inc. Golden, Colorado.

Walter, M.R., DesMarais, D., Farmer, J.D., and Hinman, N.W. 1996. Lithofacies and biofacies of mid-Paleozoic thermal spring deposits in the Drummond Basin, Queensland, Australia. Palaios 11:497-518.

White, D.E., Hutchison, R.A., and Keith, T.E.C. 1988. The geology and remarkable thermal activity of Norris Geyser Basin, Yellowstone National Park, Wyoming. U.S. Geological Survey Professional Paper 1456. 84p.

White, D.E., Thompson, G.A., and Sandberg, C.H. 1964. Rocks, structure, and geologic history of Steamboat Springs thermal area, Washoe County Nevada. U.S. Geological Survey Professional Paper 458-B. 61p.

White, D.E., Brannock, W.W., and Murata, K.J. 1956. Silica in hot -spring waters. Geochemica et Cosmochimica Acta, 10:27-59.

Williams, L.A., and Crerar, D.A. 1985. Silica diagenisis, I. Solubility controls. Journal of Sedimentary Petrology, 55(3):301-311.

Williams, L.A., and Crerar, D.A. 1985. Silica diagenisis, II. General mechanisms. Journal of Sedimentary Petrology, 55(3):312-321.

APPENDIX A

BORING LOGS

BORING LOGS

Sentinel Meadows

SMW-1 (6/19/94)

0-66 cm	Gray diatomaceous clay with some sinter breccia, moist to wet.
66-85 cm	Black with some reddish obsidian sand, some plagioclase, subangular to angular, wet.

Screen Interval: 60-85 cm

SMW-2 (6/19/94)

0-71 cm	Brown to dark brown clayey, fine sand (diatoms?), some obsidian sand, some orange staining (ferric), moist to wet.
71-91 cm	Gray/green clayey, fine to coarse obsidian sand, subangular, wet.
91-152 cm	Black medium to coarse sand with angular pebbles (at 95cm), some plagioclase, wet.

Screen Interval: 137-152 cm

SMW-3 (6/19/94)

0-81 cm	Gray diatomaceous clay, some fine obsidian flecks, moist to wet.
81-140 cm	Black fine to coarse obsidian sand and fine gravel.

Screen Interval: 115-130 cm

SMW-4 (6/19/94)

0-74 cm	Gray silty diatomaceous clay.
74-84 cm	Mottled gray and greenish clayey sands, meadium to coarse sand., wet (related to water table fluctuations?)
84-141 cm	Black fine to coarse obsidian sand, subangular, wet.

Screen Interval: 126-141 cm

SMW-5 (9/15/95)

0-74 cm	Gray diatomaceous clay, root zone 0-30 cm
74-91 cm	Gray silt grading to obsidian sand and clay
91-128 cm	Black fine to coarse obsidian sand and fine garavel, subangular.

Screen Interval: 113-128 cm

SMW-6 (9/15/95)

0-51 cm	Gray diatomaceous clay, root zone 0-25 cm, dry.
51-74 cm	Brown silt with fine obsidian gravel, dry to damp
74-91 cm	Black fine to medium obsidian sand with some reddish rhyolite flecks, wet.
91-160 cm	Dark gray and green silty fine to coarse obsidian sand, hard drilling at 107 cm. Mostly fine gravel at 152 cm

Screen Interval: 145-160 cm

SMW-7 (9/15/95)

0-41 cm	Gray diatomaceous clay, dry,
41-56 cm	Grading to light brown silt with coarse obsidian sand and fien gravel.
56-64 cm	Very hard drilling, with yellowish staining
64-107 cm	Black fine to medium obsidian sand with some silt.

Screen Interval: 92-107 cm

SMW-8 (9/21/95)

0-59 cm	Gray diatomaceous clay, dry to damp.
59-89 cm	Olive brown silt and fine obsidian sand, some fine gravel, orange stained at 59 cm (hard drilling), moist at 84 cm
89-150 cm	Greenish black silty fine to medium obsidian sand, some fine gravel, (appears reduced)

Screen Interval: 135-150

SMW-9 (9/21/95)

0-51 cm	Gray diatomaceous clay, moist.
51-76 cm	Greenish gray silty fine to coarse sand and fine gravel, subangular, some orange (ferric) staining at 51 cm
76-112 cm	Black obsidian sand and fine gravel, subangular

Screen Interval: 97-102 cm

SMW-10 (9/21/95)

0-46 cm	Gray diatomaceous clay, dry
46-61 cm	Greenish black fine to medium obsidian sand. Some orange (ferric) staining at 51 cm
61-152 cm	Black fine to coarse obsidian sand and fine gravel, subrounded to subangular, some rhyolite, silt interbeds at 127 cm and 152 cm

Screen Interval: 137-152 cm

BORING LOGS

Octopus Spring

OW-1 (6/19/94)

0-66 cm	Gray sinter breccia, hard layer at 8 cm; water at 41 cm.

Screen Interval: 51-66 cm

OW-1A (11/18/95)

0-112 cm Gray sinter and sinter breccia. Zones of solid sinter were encountered and cores were collected within the follows intervals:

0-23 cm	2 sinters cores (~1.4 cm length)
23-48 cm	1 sinter core (~1.8 cm length)
66-76 cm	2 sinter cores (~3.0 cm and 3.2 cm length)
76-84 cm	2 sinter cores (~4.3 cm and 3.0 cm length)
84-91 cm	2 sinter cores (~4.4 cm and 2.2 cm length)
102-112 cm	1 sinter core (~3.2 cm length)

Screen Interval: 87-102 cm

OW-2 (6/19/94)

0-53 cm	Gray sinter breccia, (initial water at 41 cm but well is dry upon completion).

Screen Interval: 38-53 cm

OW-3 (6/19/94)

0-135 cm	Gray sinter and sinter breccia, some brown to black fleck in upper 40 cm, dry to moist.

Screen Interval: 120-135 (well remains dry)

OW-4 (6/19/94)

0-46 cm	Dark brown organic debris and mud, very soft, wet,
46-79 cm	Dark brown organic muds mixed with some gray sinter breccia or diatomaceous clay. Hard drilling at 79 cm

Screen Interval: 64-79 cm

OW-5 (6/19/94)

0-61 cm	Brown weathered rhyolite, clayey with some reddish streaks (possibly geothermally altered), warm
61-109 cm	Buff clay with reddish streaks.

Screen Interval: 94-109 (well remains dry)

OW-6 (6/19/94)

0-152 cm	Dark brown organic debris and muds, very soft, little returns.

Screen Interval: 137-152 cm

OW-7 (6/19/94)

0-46 cm	Dark brown organic debris and root material.
46-61 cm	Yellowish brown root material, some roots up to ¼-inch.
61-137 cm	Dark brown organic debris and clay, some sinter material at 130 cm.

Screen Interval: 122-137 cm

OW-8 (6/19/94)

0-4 cm	Gray sinter breccia.
4-38 cm	Gray sinter, very solid (hard drilling)

Screen Interval: 23-38 cm

OW-9 (6/19/94)

0-15 cm	Grass and roots with some clayey soil.
15-36 cm	Brown to gray clay
36-48 cm	Brown sand and fine gravel with clay.
48-69 cm	Gray clay (weathered sinter)

Screen Interval: 54-69 cm

APPENDIX B

WATER LEVELS, POTETIOMETRIC SURFACE ELEVATIONS, AND HYDROGRAPHS

WATER LEVELS - SENTINEL MEADOWS

Well No.	Depth of Well (meters)	Casing Elevation (meters)	Depth To Water (meters) 06/20/94	07/31/94	08/26/94	09/18/94	11/12/94	02/22/95	07/29/95	09/01/95	09/16/95	09/26/95	09/27/95	09/04/96
SMW1	0.851	97.69	0.362											
SMW2	1.372	97.909	0.479	0.511	0.574	0.47	0.014	0.111	0.536	0.522	0.584		0.498	0.562
SMW3	1.295	95.977	0.527	0.82	0.859	0.704			0.757	0.665	0.695		0.489	0.198
SMW4	1.41	95.242	0.002	0.262	0.305	0.018			0.118	0.183				0.182
SMW5	1.283	96.11									0.237		0.025	0.411
SMW6	1.588	96.172									0.805		0.716	0.916
SMW7	1.143	95.425									0.481		0.379	0.641
SMW8	1.435	96.358										0.552	0.545	0.819
SMW9	1.008	95.215										0.349	0.311	0.603
SMW10	1.472	95.309										0.366	0.346	0.343

Staff Guage	Top of Guage Elevation (meters)	Depth to Water 06/20/94	07/31/94	08/26/94	09/18/94	11/12/94	02/22/95	07/29/95	08/29/95	09/16/95	09/26/95	09/27/95	09/04/96
SSTG1	96.178						0.776	0.729	0.705				
SSTG2	95.309						1.084	1.122	1.099				1.059
SSTG3	95.029						1.389	1.446	1.421				1.367
SSTG4	93.828						0.749	0.772	0.772				0.705

Potentiometric Surface

Well No.	Depth of Well (meters)	Casing Elevation (meters)	Groundwater Elevation 06/20/94	07/31/94	08/26/94	09/18/94	11/12/94	02/22/95	07/29/95	09/01/95	09/16/95	09/26/95	09/27/95	09/04/96
SMW1	0.851	97.69	97.328											
SMW2	1.372	97.909	97.43	97.398	97.335	97.439	97.895	97.798	97.373	97.387	97.325		97.411	97.347
SMW3	1.295	95.977	95.45	95.157	95.118			95.977	95.22	95.312	95.282		95.488	95.779
SMW4	1.41	95.242	95.24	94.98	94.937			95.242	95.124	95.059	95.242			95.06
SMW5	1.283	95.309									95.873		96.085	95.699
SMW6	1.588	96.172									95.367		95.456	95.256
SMW7	1.143	95.425									94.944		95.046	94.784
SMW8	1.435	96.358										95.806	95.813	95.539
SMW9	1.008	95.215										94.866	94.904	94.612
SMW10	1.472	95.309										94.943	94.963	94.966

Staff Guage	Top of Guage Elevation (meters)	Sentinel Creek Stage 06/20/94	07/31/94	08/26/94	09/18/94	11/12/94	02/22/95	07/29/95	08/29/95	09/16/95	09/26/95	09/27/95	09/04/96
SSTG1	96.178						95.402	95.449	95.473				
SSTG2	95.309						94.225	94.187	94.21				94.25
SSTG3	95.029						93.64	93.583	93.608				93.662
SSTG4	93.828						93.079	93.056	93.056				93.123

WATER LEVELS - OCTOPUS SPRINGS

Well No.	Depth of Well (meters)	Casing Elevation (meters)	Depth To Water (meters) 06/20/94	08/02/94	08/25/94	09/18/94	11/12/94	02/18/95	06/20/95	07/28/95	08/31/95	11/22/95	01/14/96	09/03/96
OW1	0.66	96.865	0.448	0.466	0.466	0.457	0.436	0.411	0.433	0.436	0.42	0.392	0.411	0.443
OW1A	1.024	96.823										0.354	0.305	0.233
OW4	0.787	100.266	0.246	0.174	0.426	0.219	0.177	0.208	0.449	0.571	0.652			0.894
OW8	1.52	100.736							>TOC	>TOC	>TOC			
OW7	1.37	100.137							0.184	0.212	0.344	0.403		0.83
OW8	0.381	97.883							0.205	0.25	0.213	0.176		0.248
OW9	0.686	96.124							0.202	0.407	0.478			

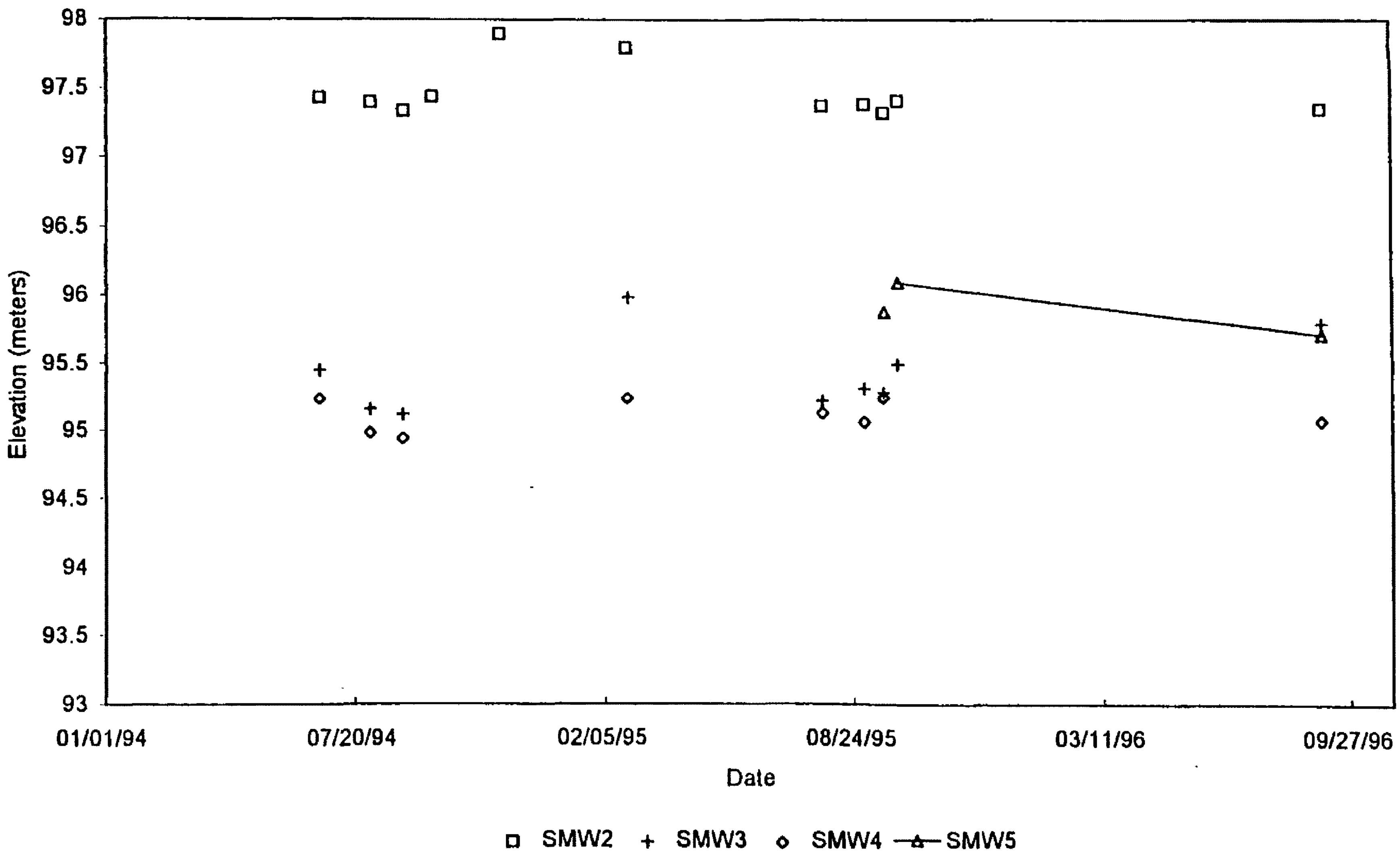
Staff Guage	Top of Guage Elevation (meters)	Depth to Water 06/20/94	08/02/94	08/25/94	09/18/94	11/12/94	02/18/95	06/20/95	07/28/95	08/31/95	11/22/95	01/14/96	09/03/96
OSTG1	97.462						0.753	0.656	0.692	0.718			
OSTG2	96.93						1.015	0.889	0.843	0.883			
OSTG3	96.121						0.585	0.587	0.548	0.583			
OSTG4	95.902						0.539	0.537	0.495	0.537			

Potentiometric Surface

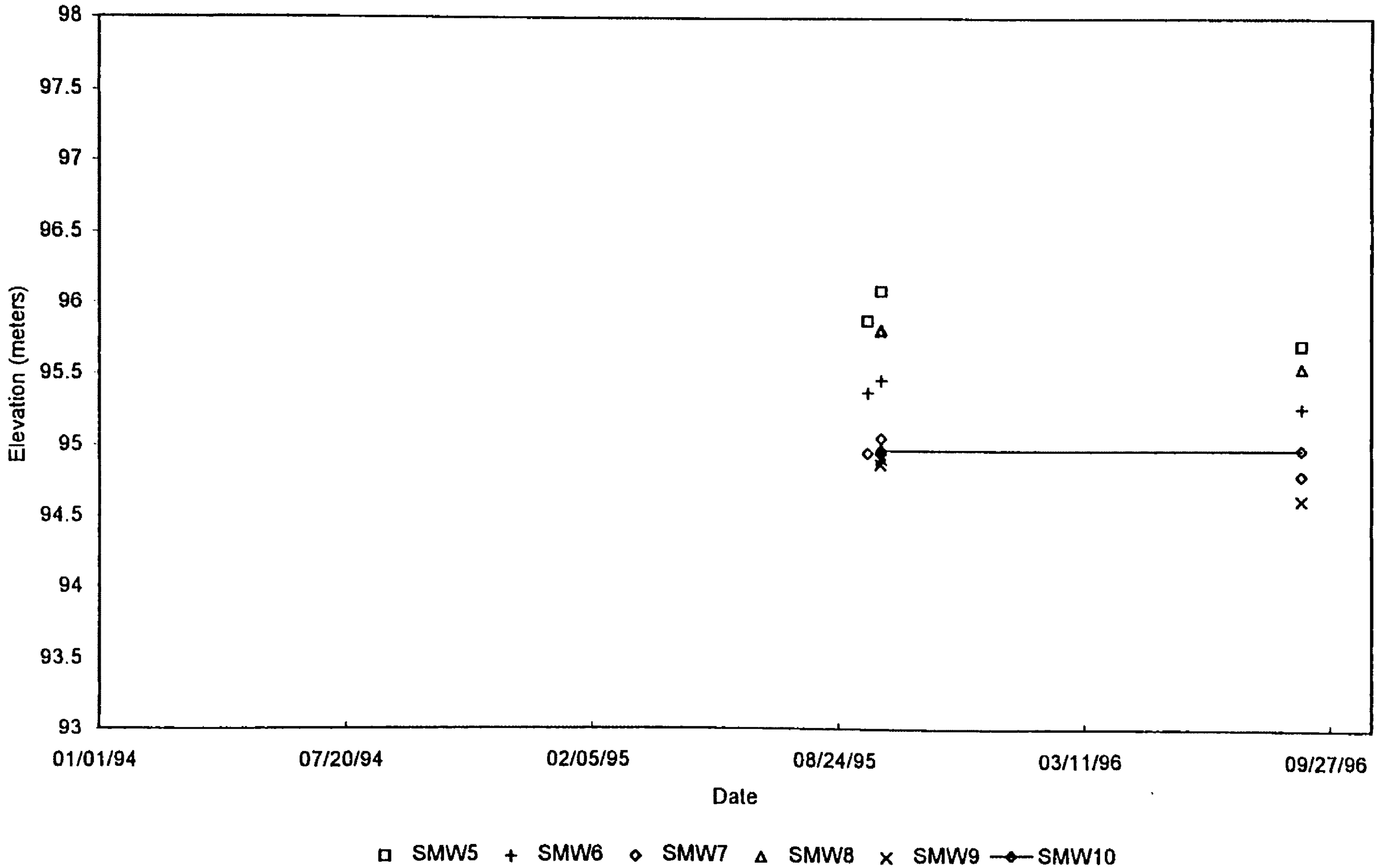
Well No	Depth of Well (meters)	Casing Elevation (meters)	Groundwater Elevation 06/20/94	08/02/94	08/25/94	09/18/94	11/12/94	02/18/95	06/20/95	07/28/95	08/31/95	11/22/95	01/14/96	09/03/96
OW1	0.66	96.865	96.417	96.399	96.399	96.408	96.429	96.454	96.432	96.429	96.445	96.473	96.454	96.422
OW1A	1.024	96.823										96.469	96.518	96.59
OW4	0.787	100.266	100.02	100.092	99.84	100.047	100.089	100.058	99.817	99.695	99.614			99.372
OW6	1.52	100.736							>100.736	>100.736	>100.736			>100.736
OW7	1.37	100.137							99.953	99.925	99.793	99.734		99.307
OW8	0.381	97.883							97.678	97.633	97.67	97.707		97.635
OW9	0.686	96.124							95.922	95.717	95.646			

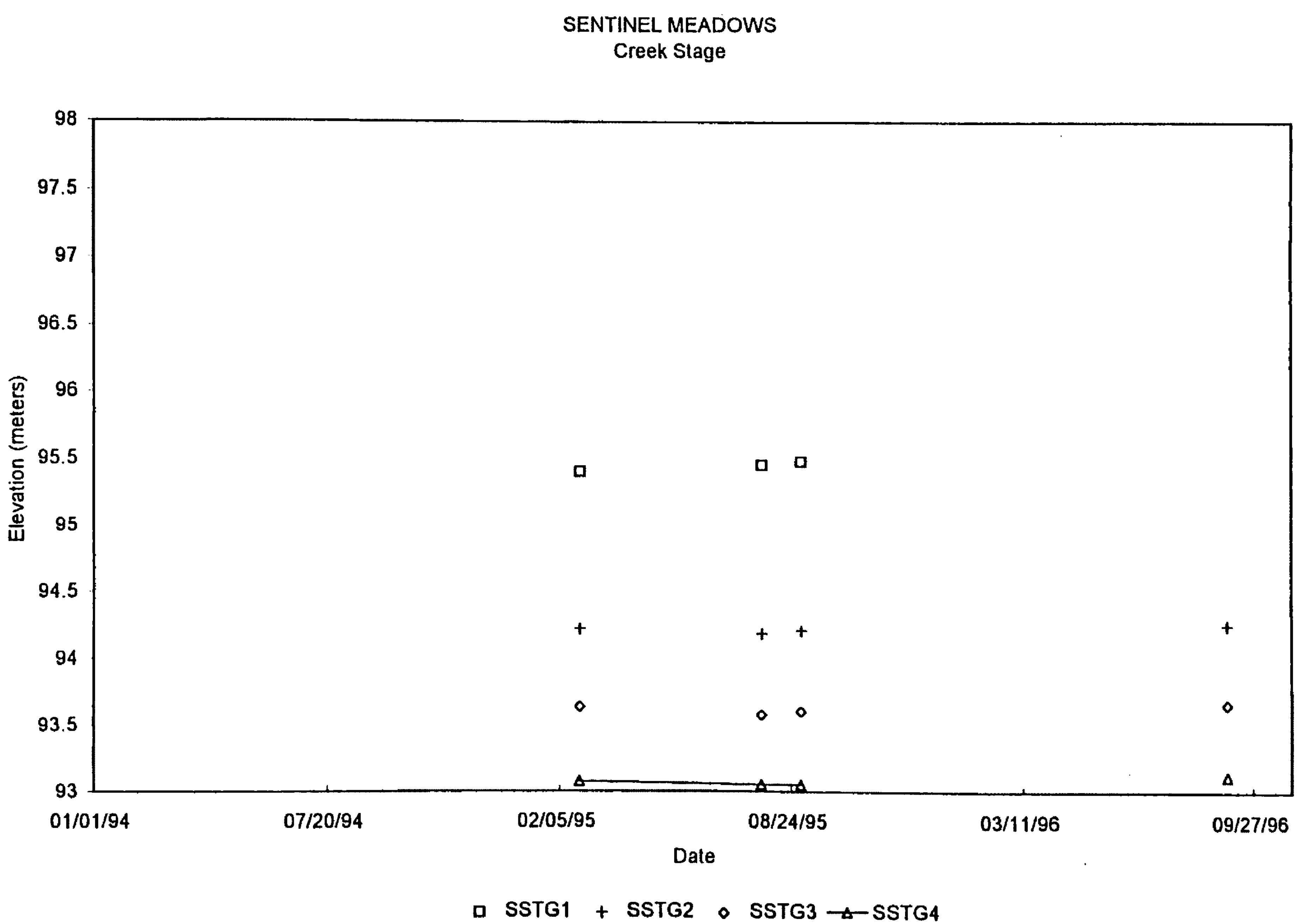
Staff Guage	Top of Guage Elevation (meters)	White Creek Stage								
OSTG1	97.462						96.709	96.806	96.77	96.744
OSTG2	96.93						95.915	96.041	96.087	96.047
OSTG3	96.121						95.536	95.534	95.573	95.538
OSTG4	95.902						95.363	95.365	95.407	95.365

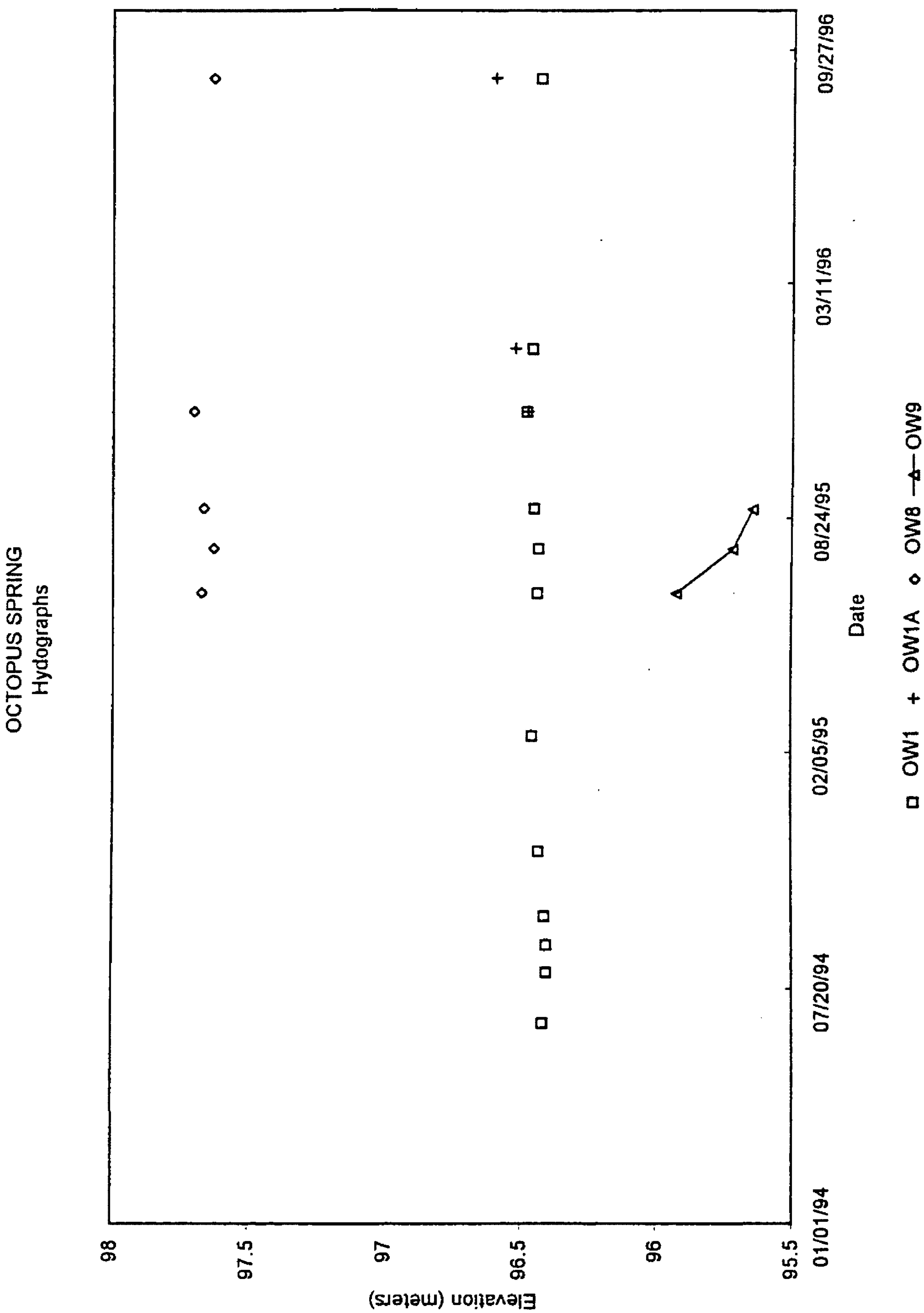
SENTINEL MEADOWS
Hydographs



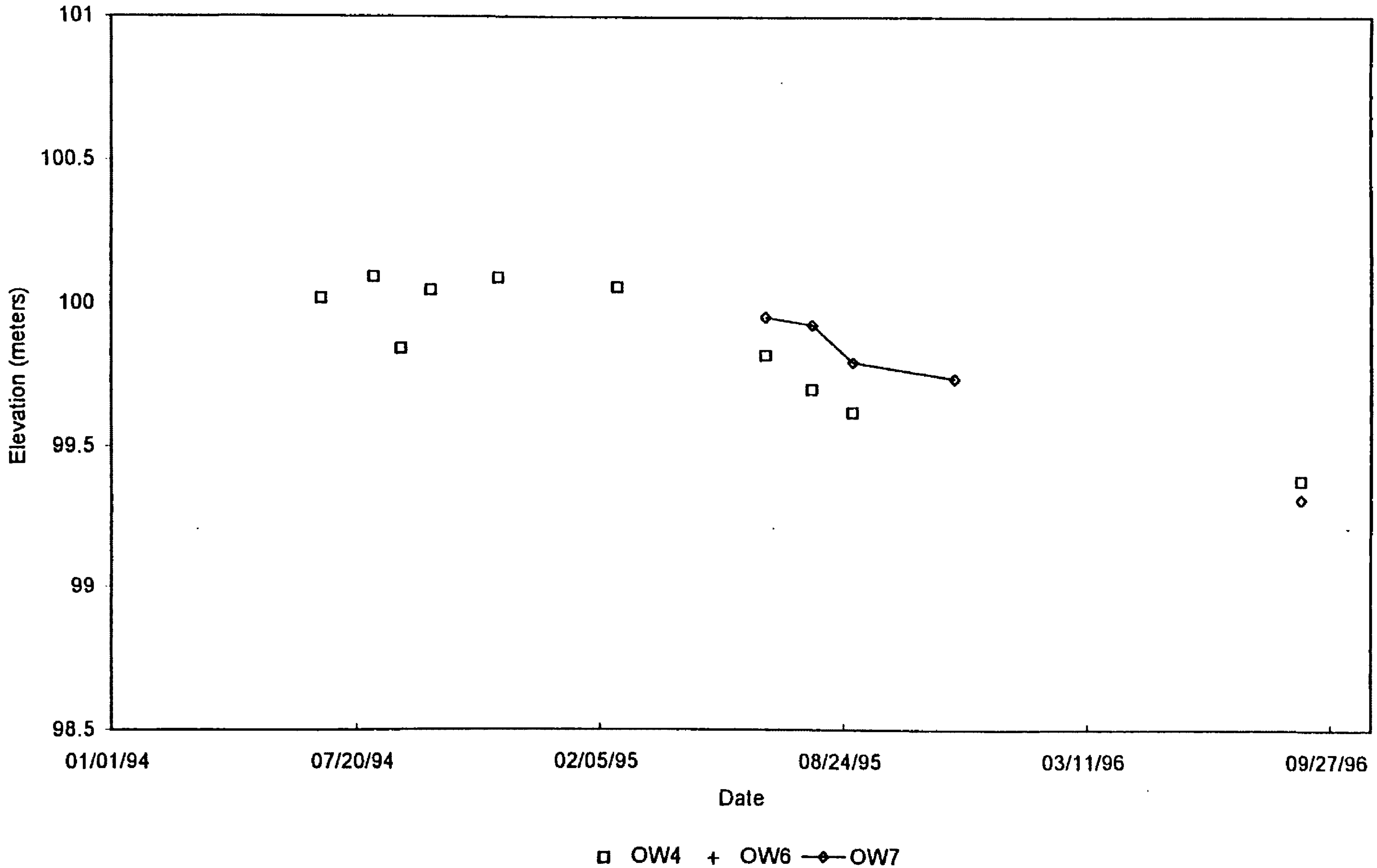
SENTINEL MEADOWS
Hydographs

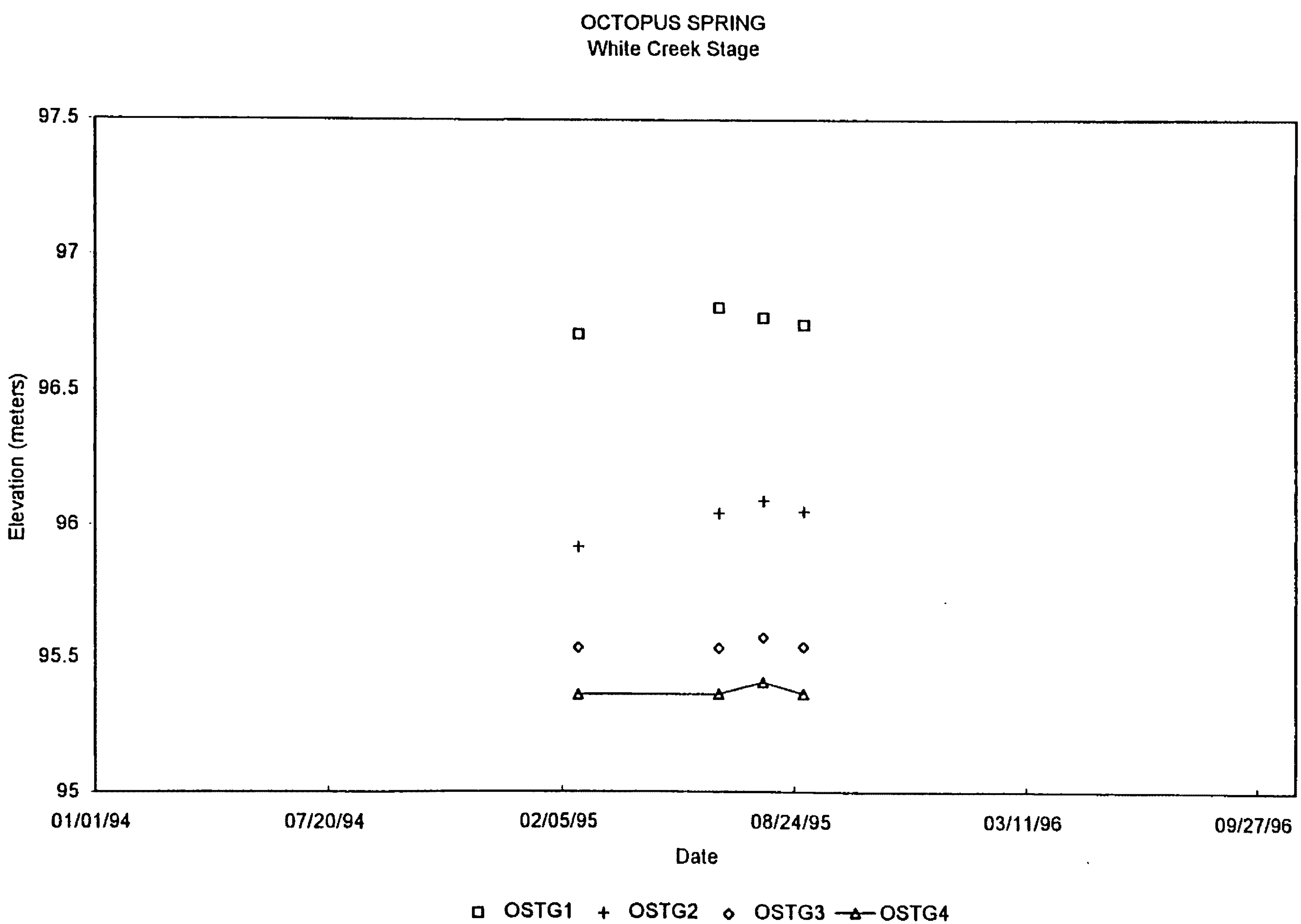



SENTINEL MEADOWS
Creek Stage
98
97.5
97
96.5
96
95.5
95
94.5
94
93.5
93
Elevation (meters)
01/01/94
07/20/94
02/05/95
08/24/95
03/11/96
09/27/96
Date
SSTG1
SSTG2
SSTG3
SSTG4


OCTOPUS SPRING
Hydrographs
Elevation (meters)
98
97.5
97
96.5
96
95.5
01/01/94
07/20/94
02/05/95
08/24/95
03/11/96
09/27/96
Date
OW1
OW1A
OW8
OW9

OCTOPUS SPRING
Hydographs

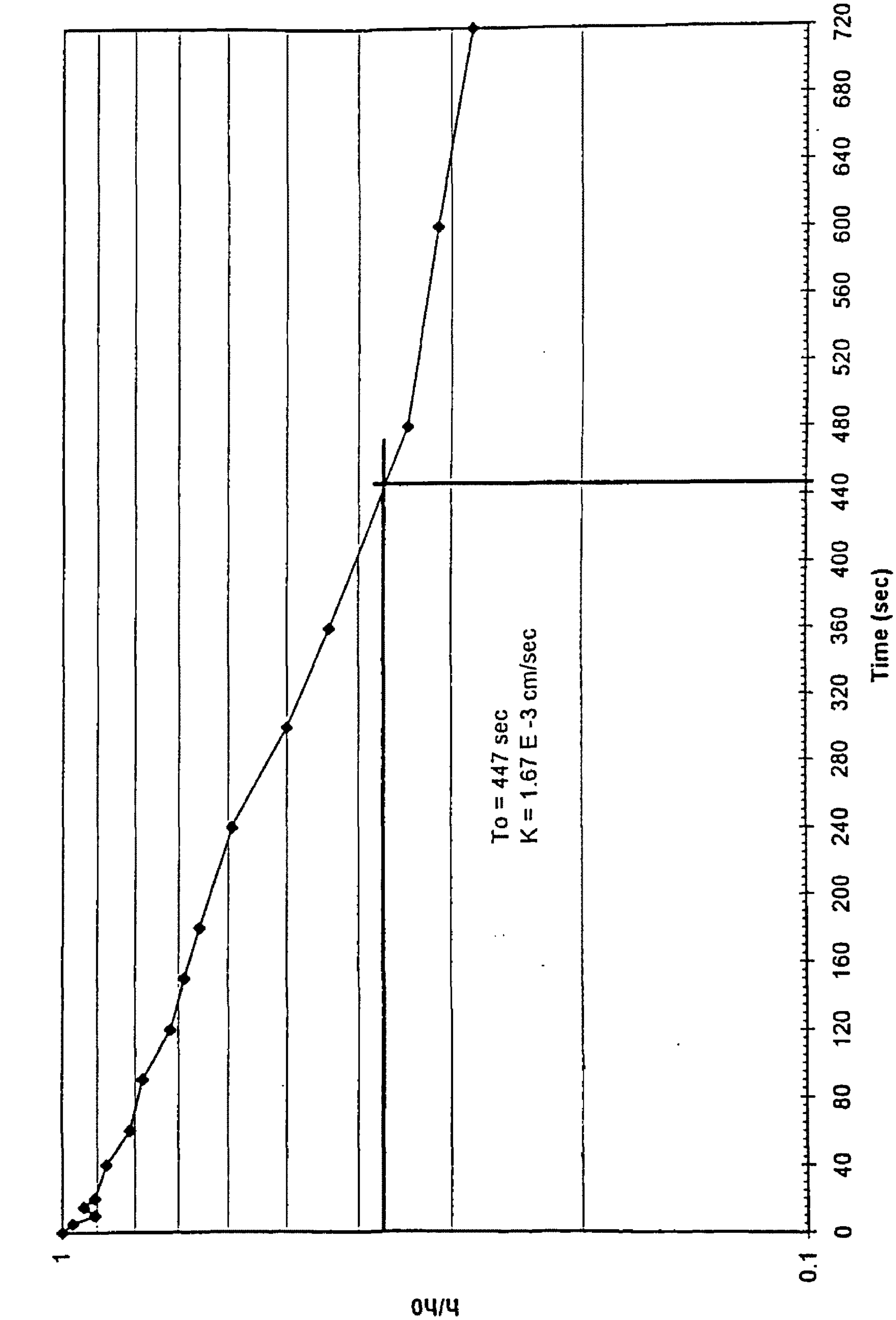



OCTOPUS SPRING
White Creek Stage
97.5
97
96.5
96
95.5
95
Elevation (meters)
01/01/94
07/20/94
02/05/95
08/24/95
03/11/96
09/27/96
Date
OSTG1
OSTG2
OSTG3
OSTG4

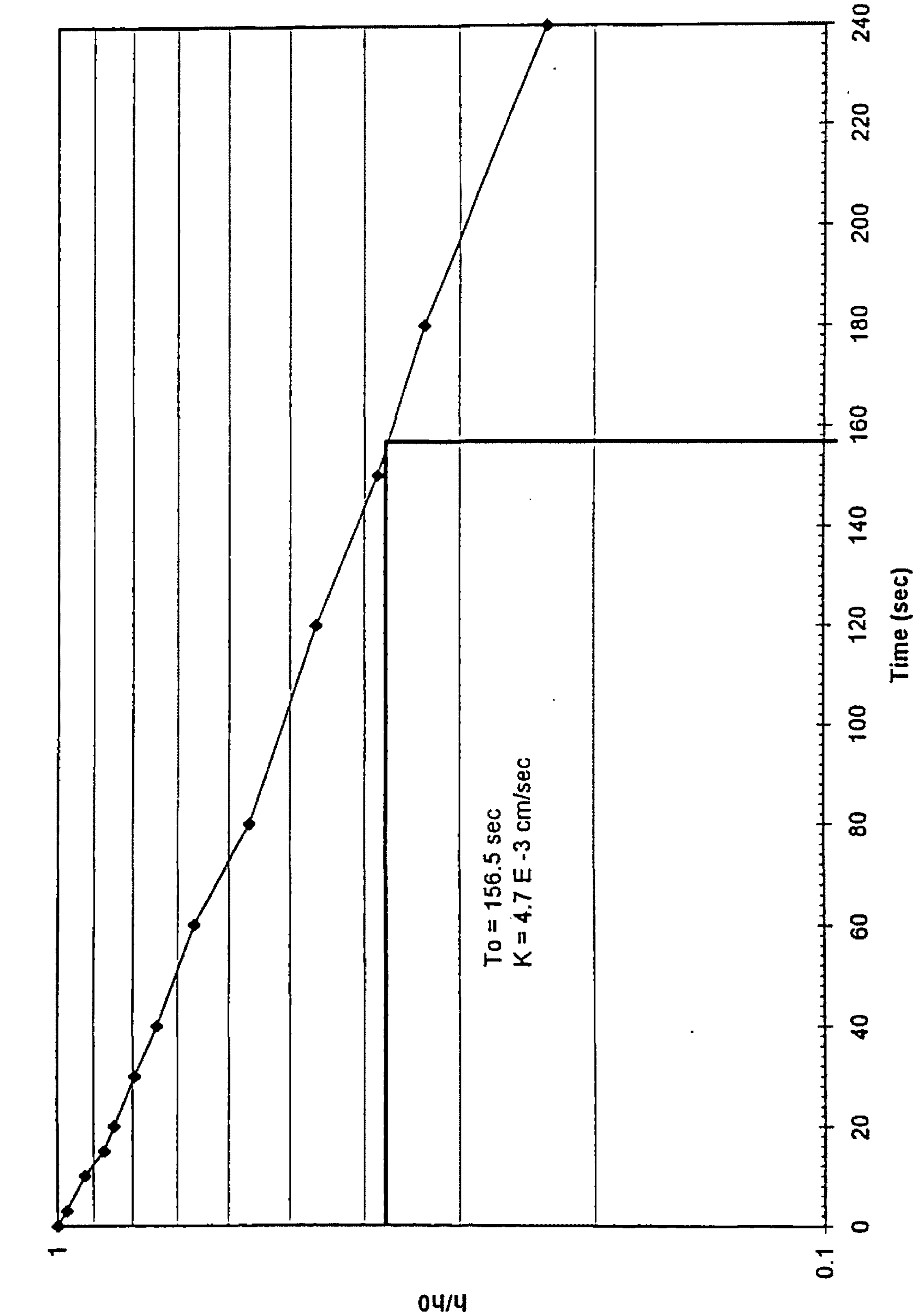
APPENDIX C

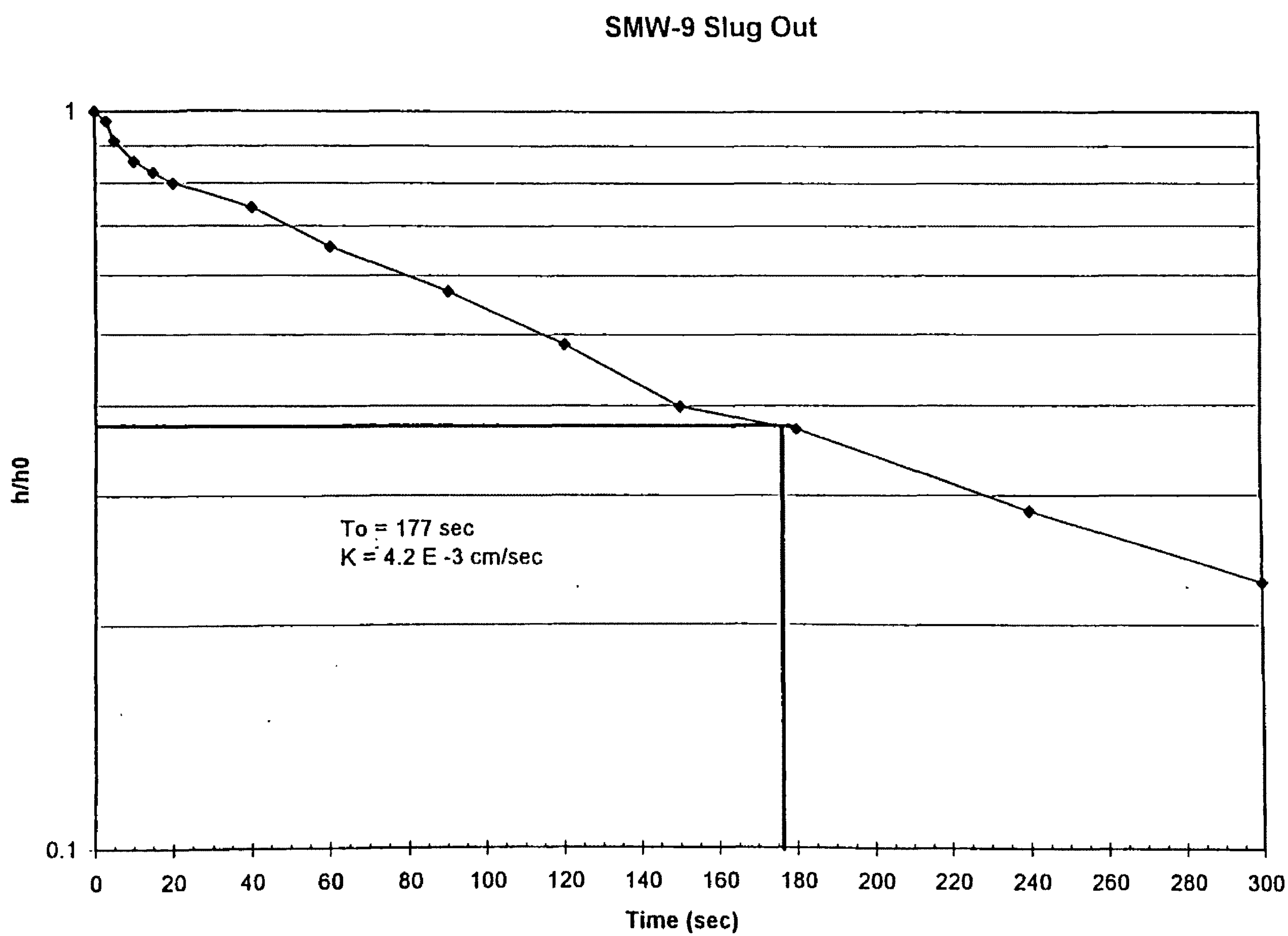
SLUG TEST GRAPHS

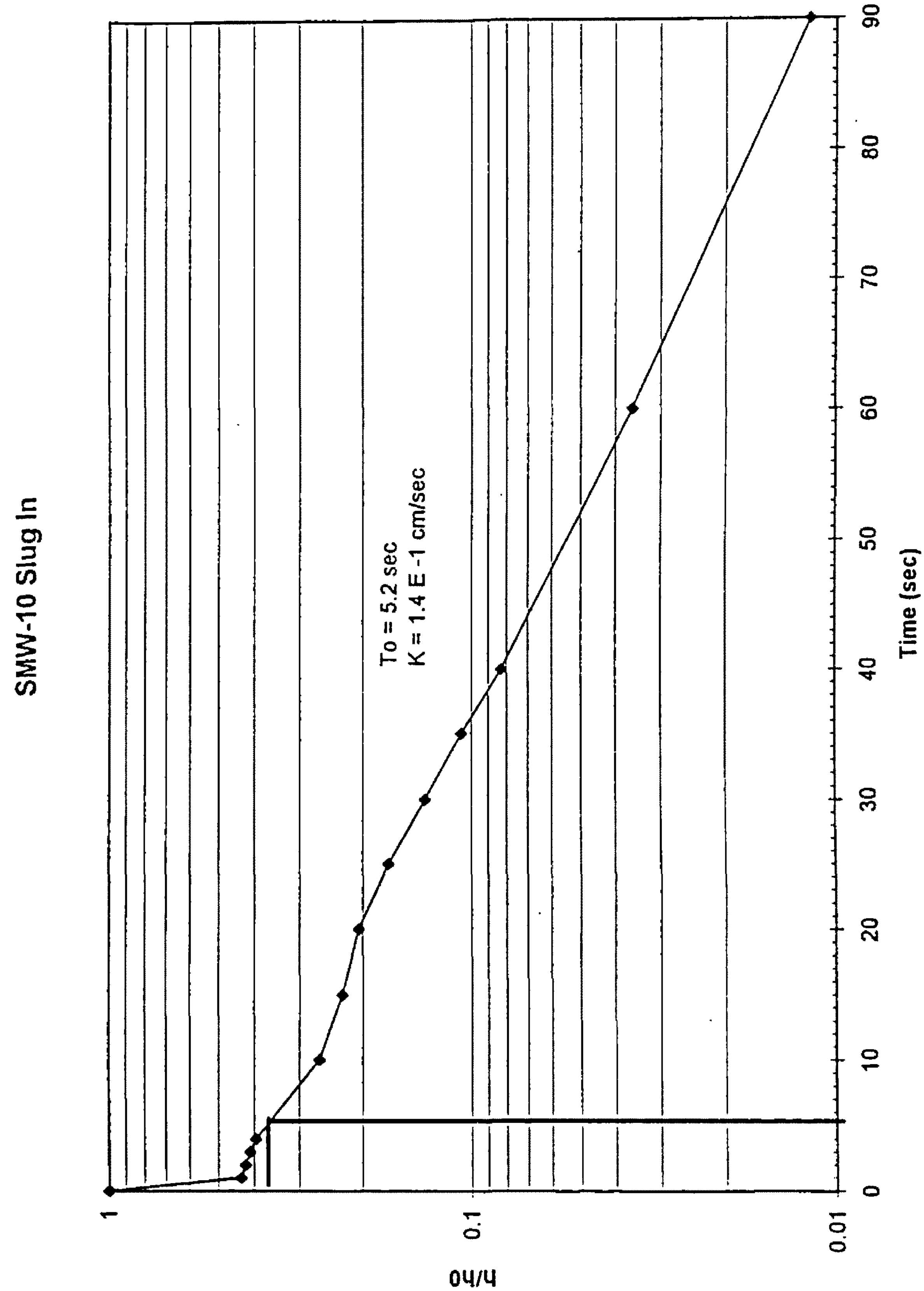
SMW-8 Slug Out

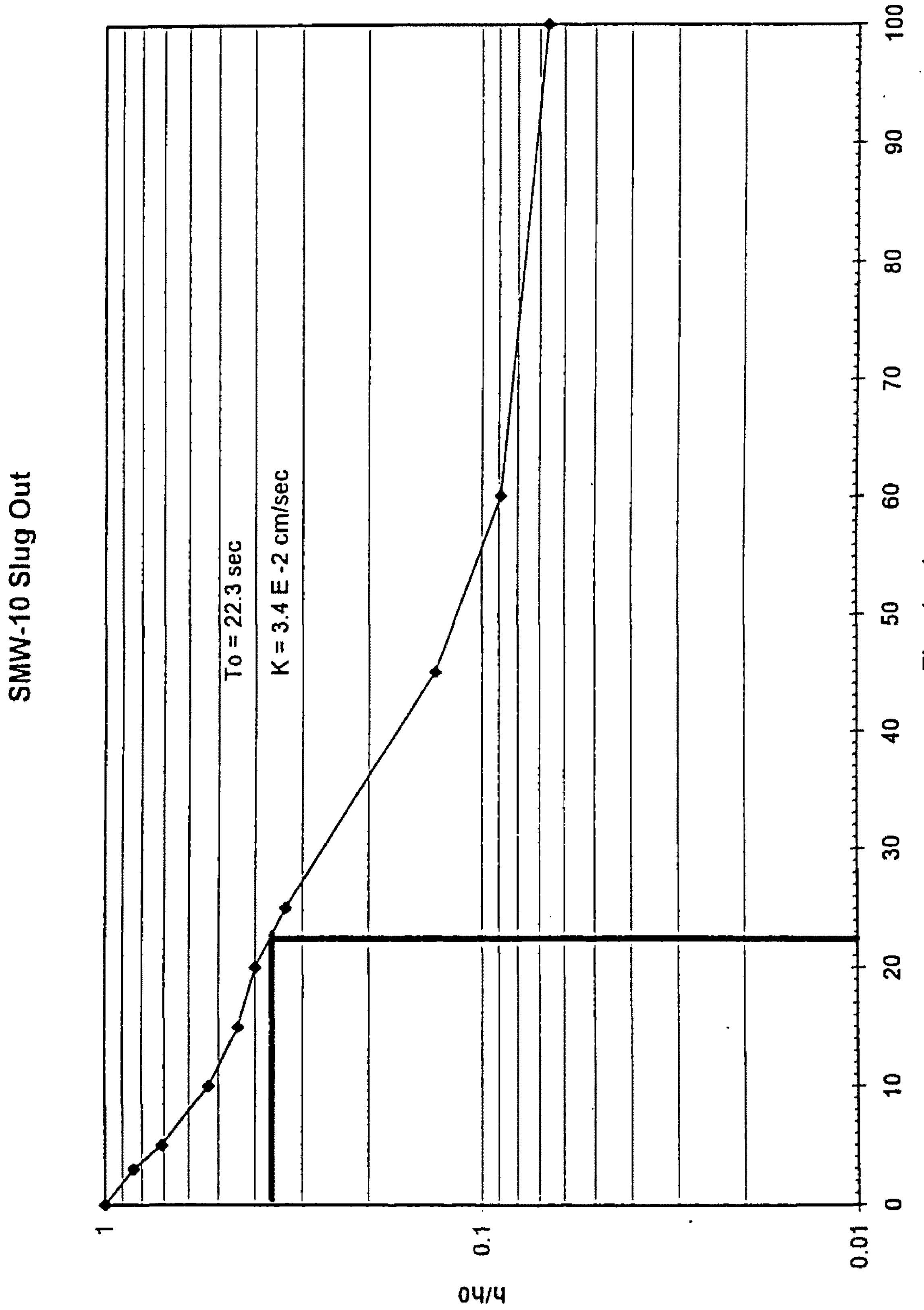


SMW-9 Slug In


To = 156.5 sec
K = 4.7 E -3 cm/sec
h/ho
1
0.1
0
20
40
60
80
100
120
140
160
180
200
220
240
Time (sec)

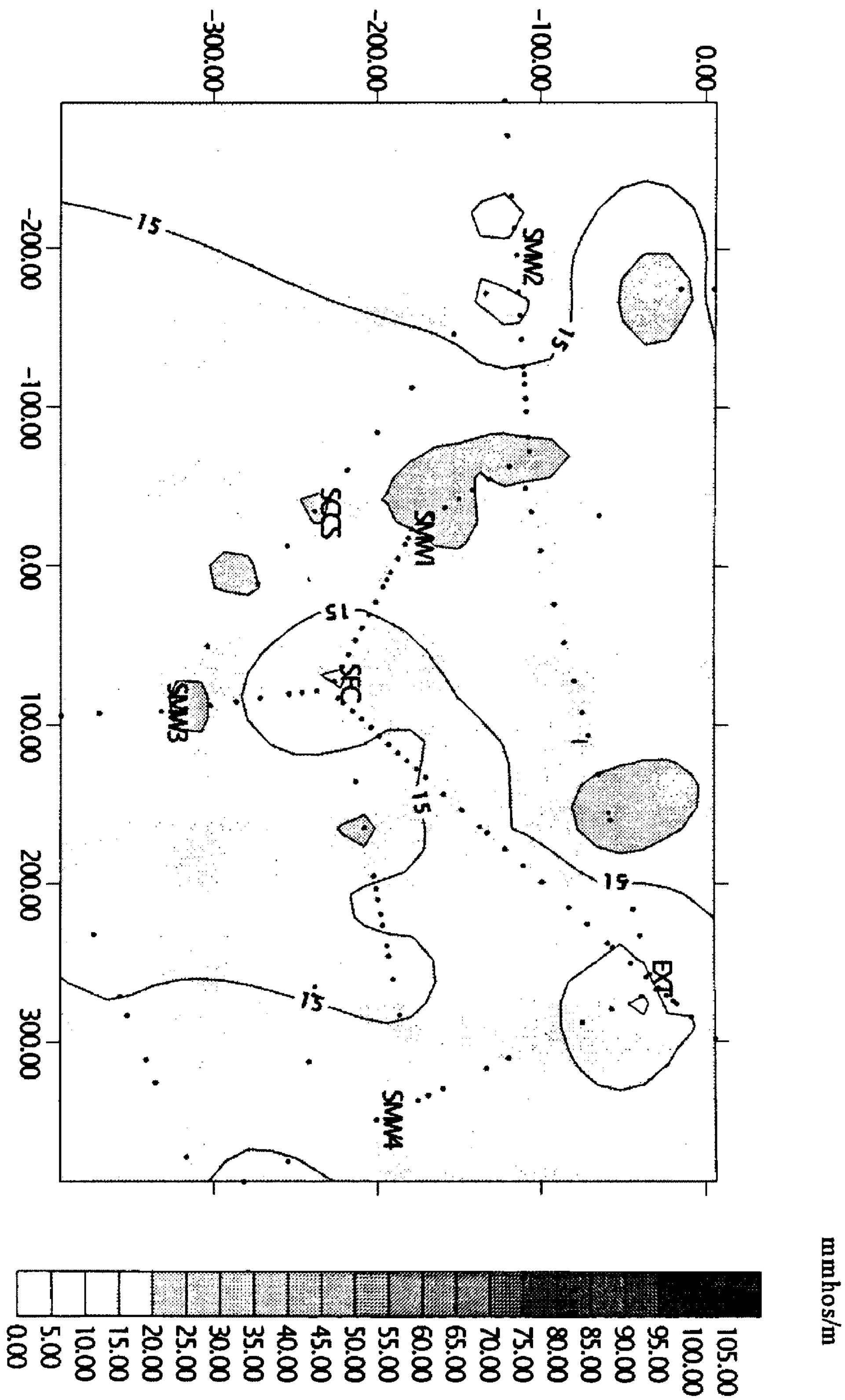

SMW-9 Slug Out
h/h0
1
0.1
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Time (sec)
To = 177 sec
K = 4.2 E -3 cm/sec


SMW-10 Slug In
To = 5.2 sec
K = 1.4 E -1 cm/sec
h/ho
1
0.1
0.01
Time (sec)
0
10
20
30
40
50
60
70
80
90

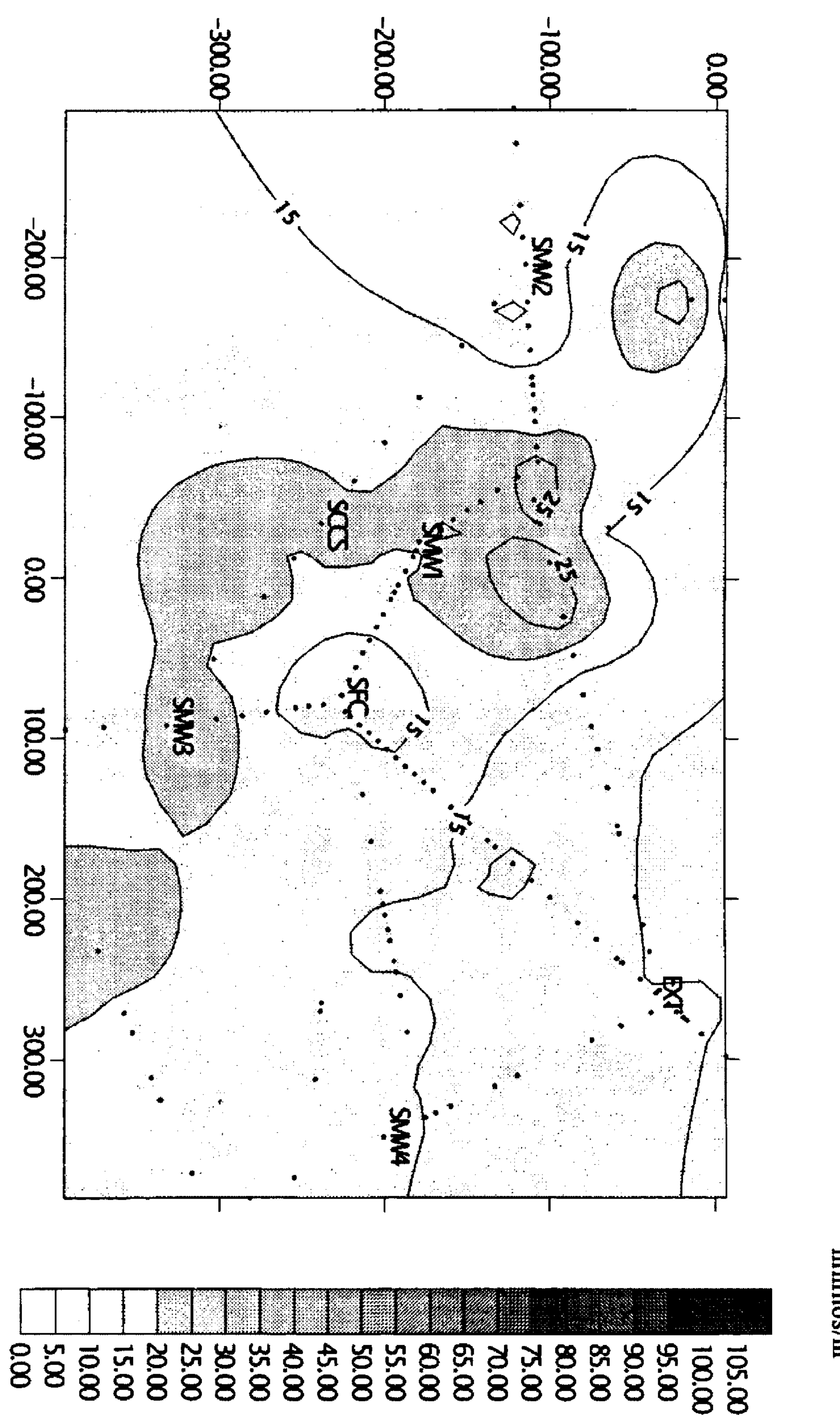

SMW-10 Slug Out
To = 22.3 sec
K = 3.4 E -2 cm/sec
h/ho
1
0.1
0.01
Time (sec)
0
10
20
30
40
50
60
70
80
90
100

APPENDIX F

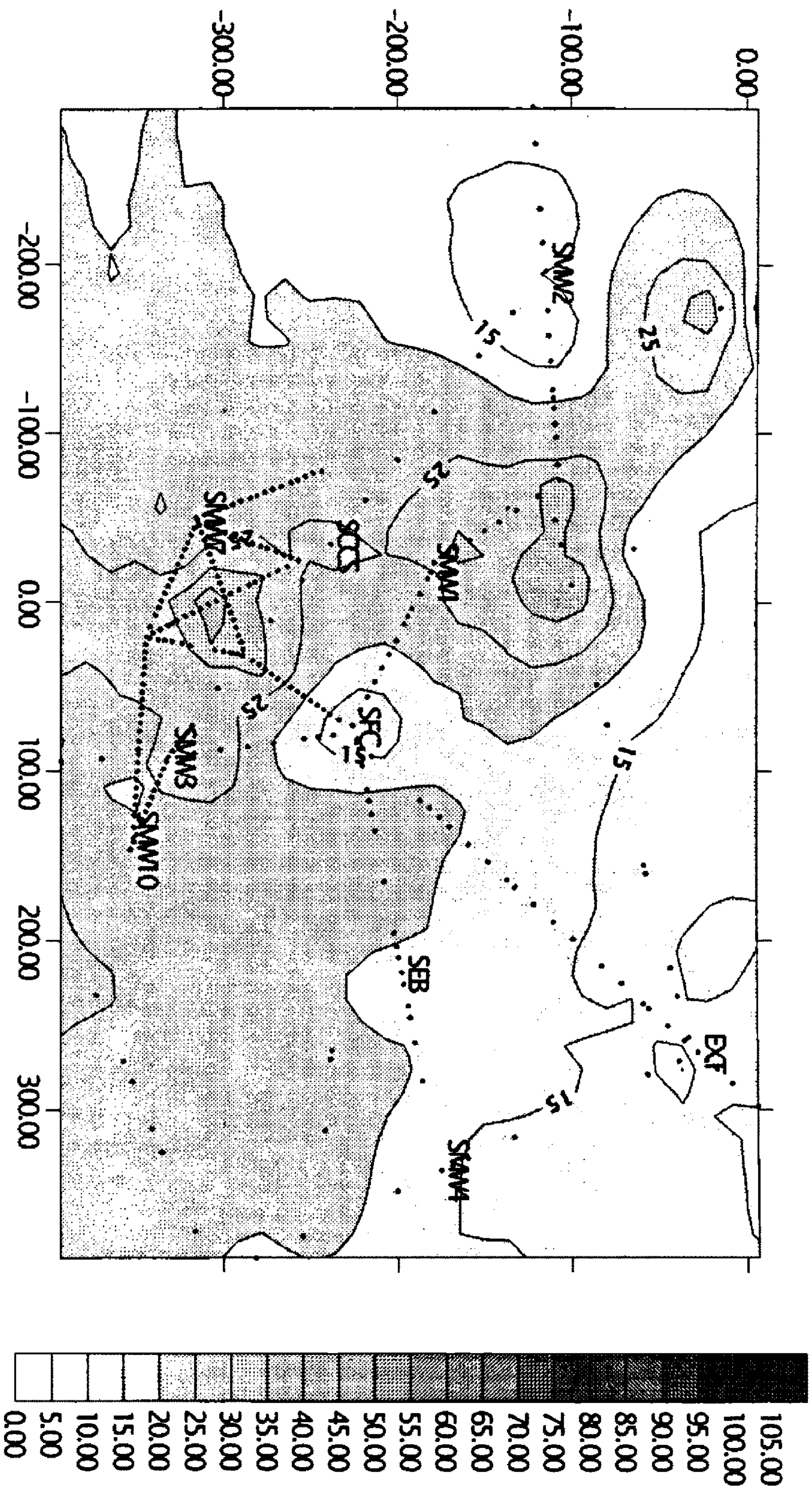
EM TERRAIN-CONDUCTIVITY MAPS AND TRANSECTS



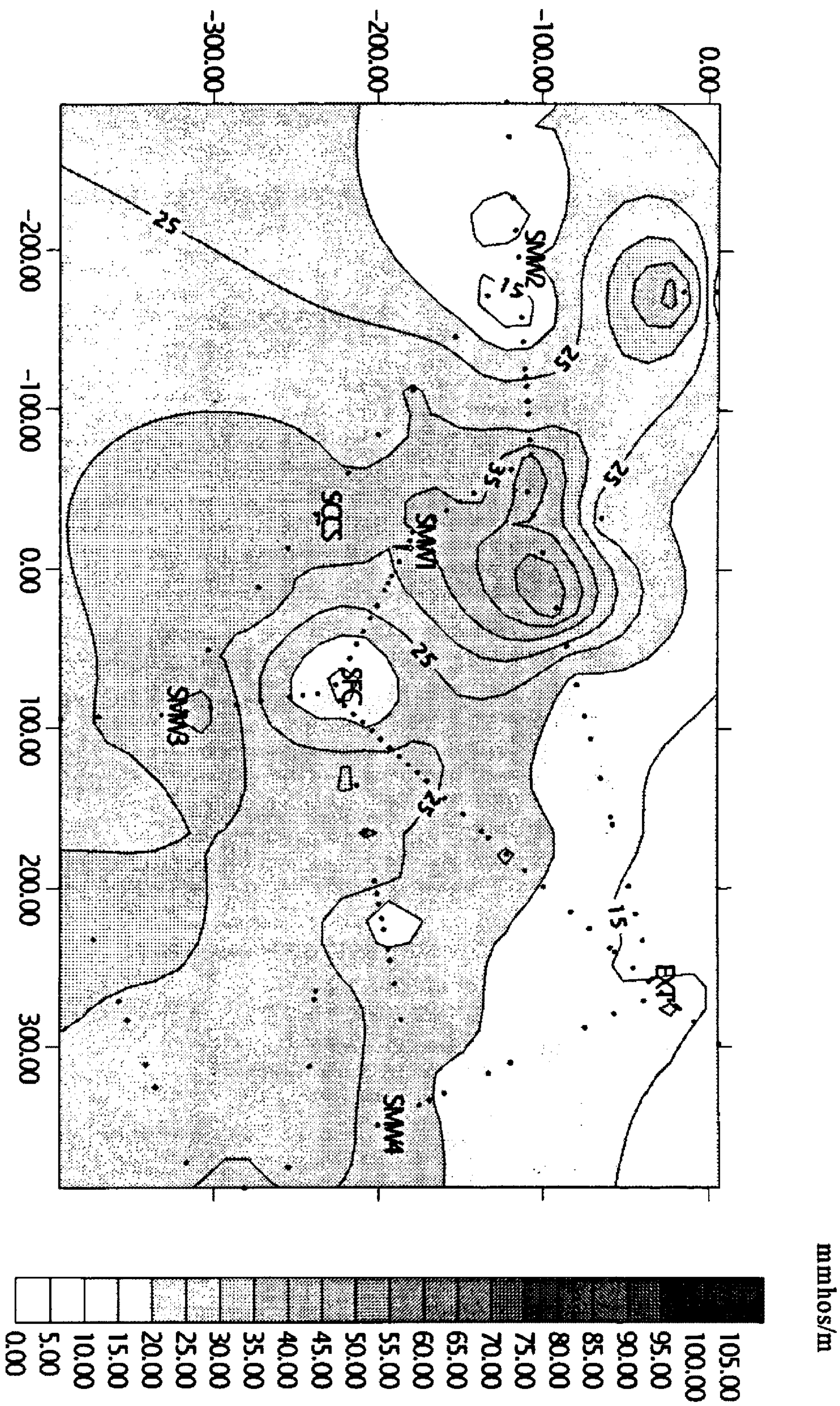
Sentinel Meadows EM31 at 1 m



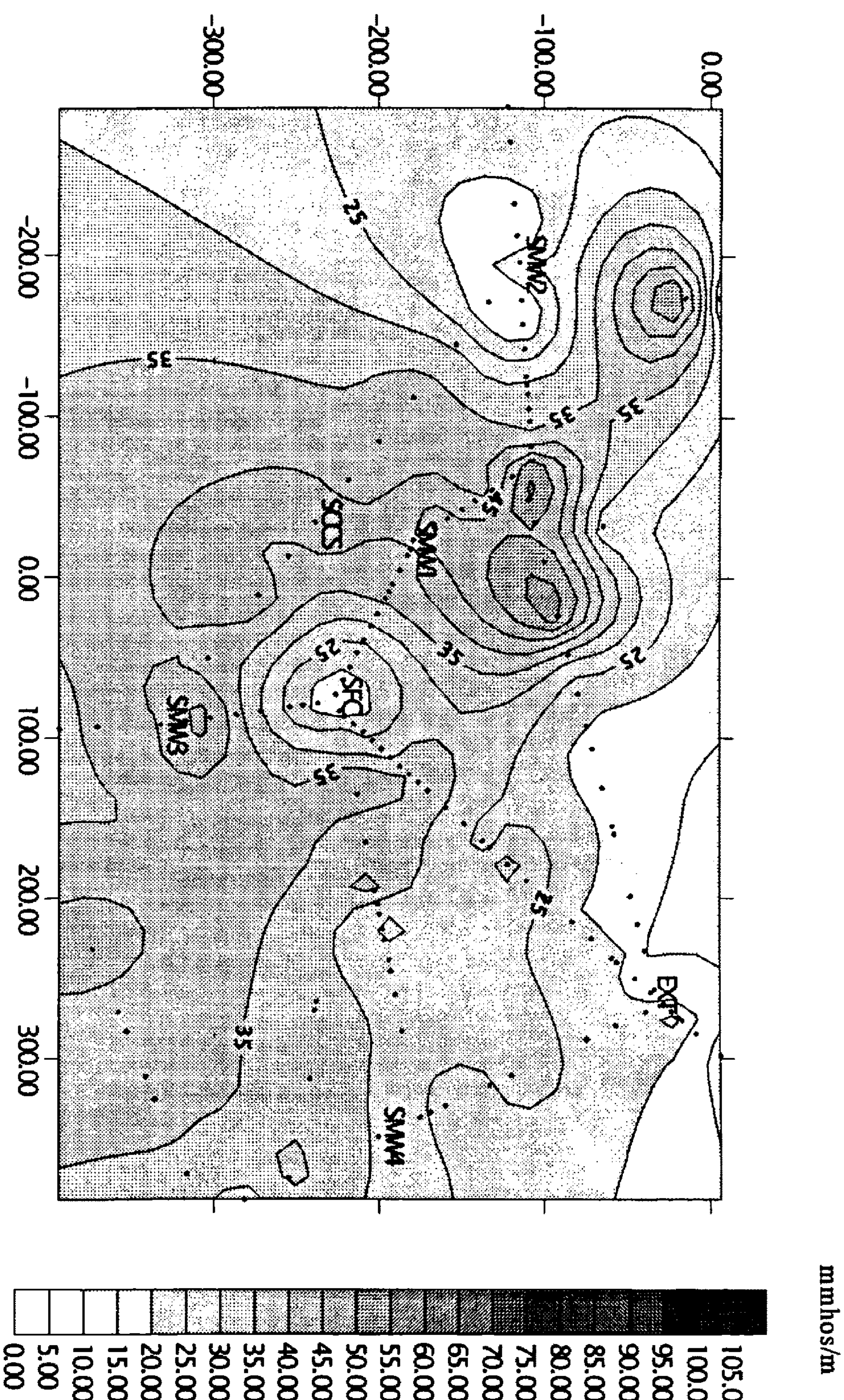
Sentinel Meadows EM31 at 1.5 m



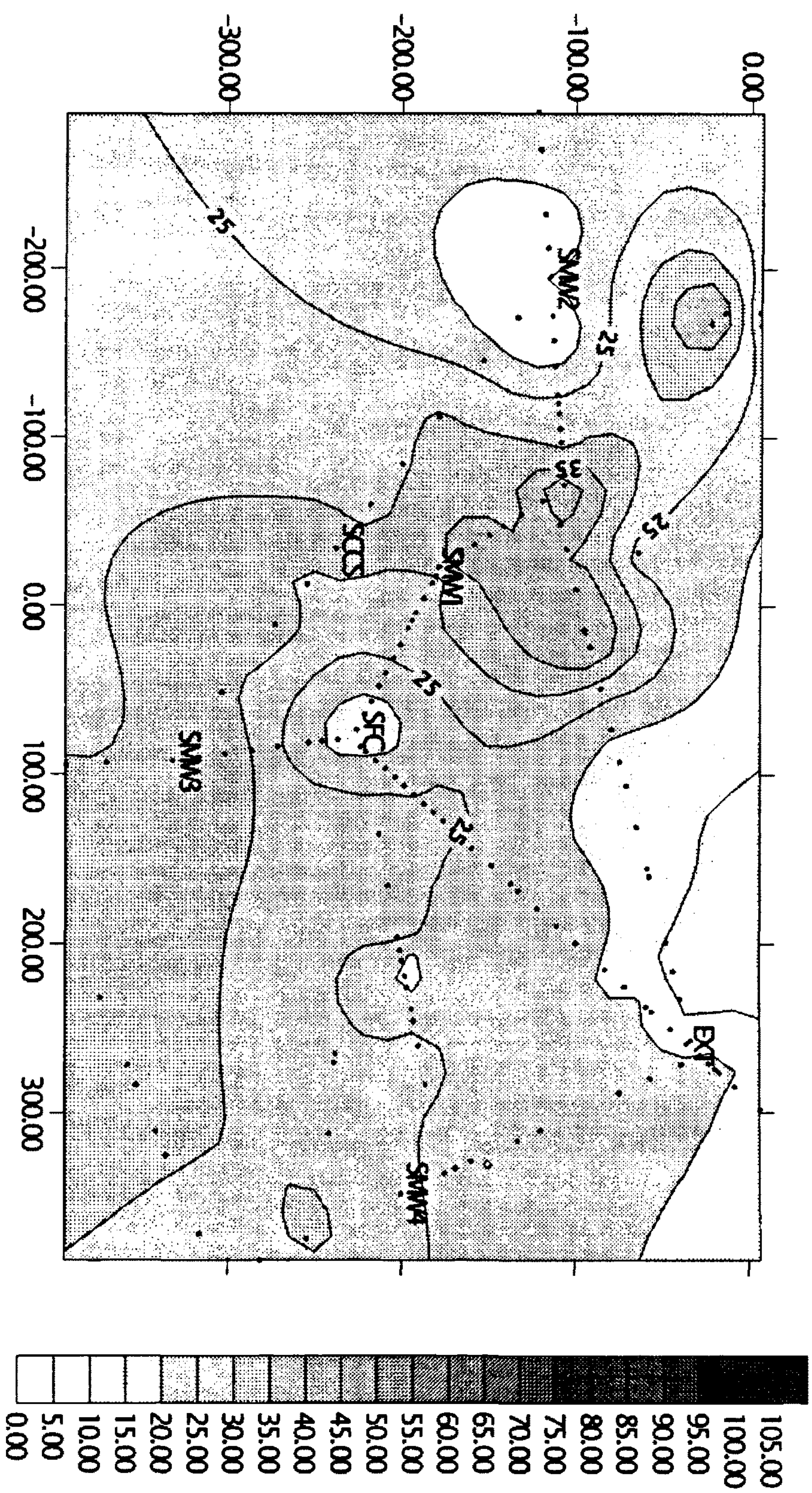
Sentinel Meadows EM31 at 2 m



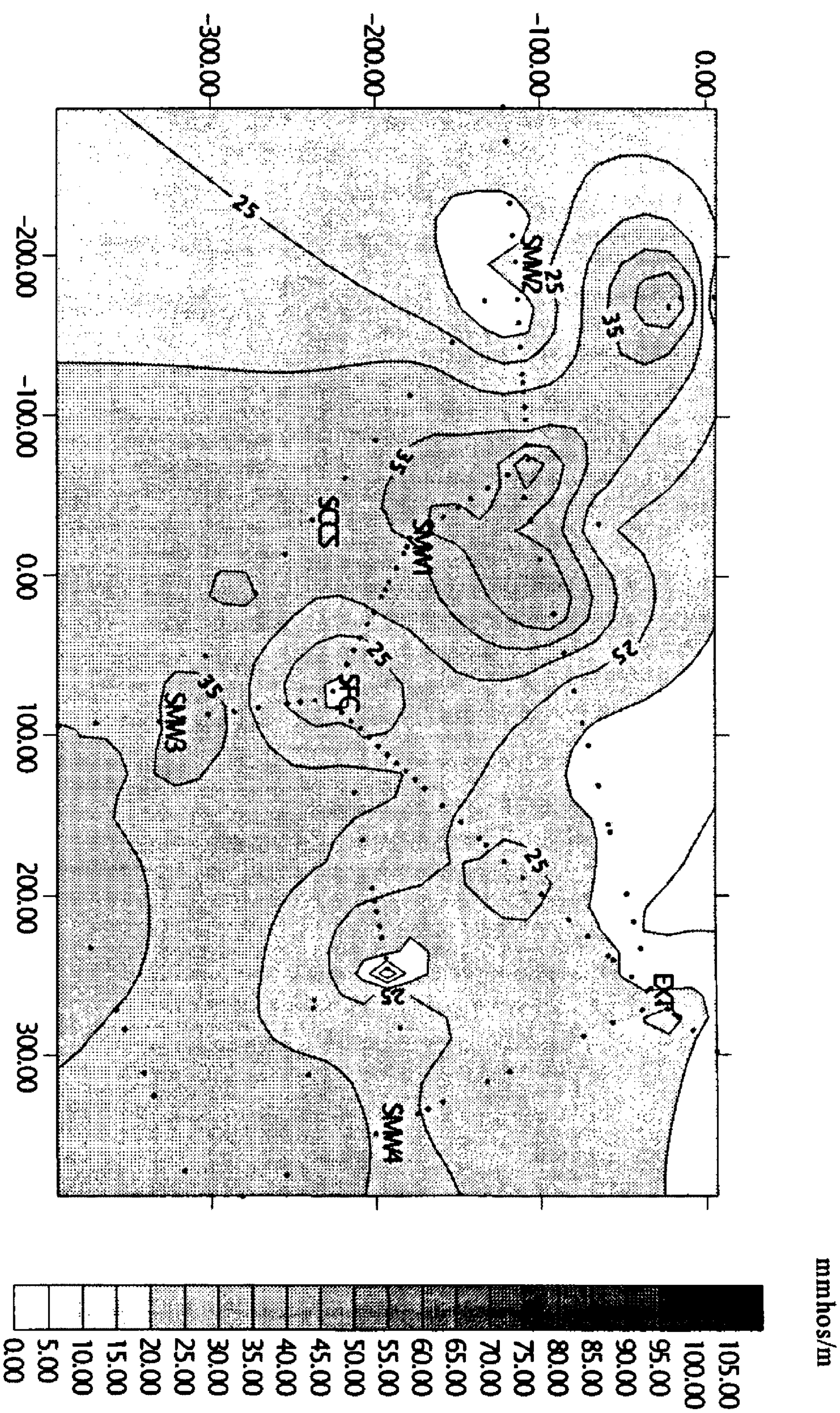
Sentinel Meadows EM31 at 2.5 m



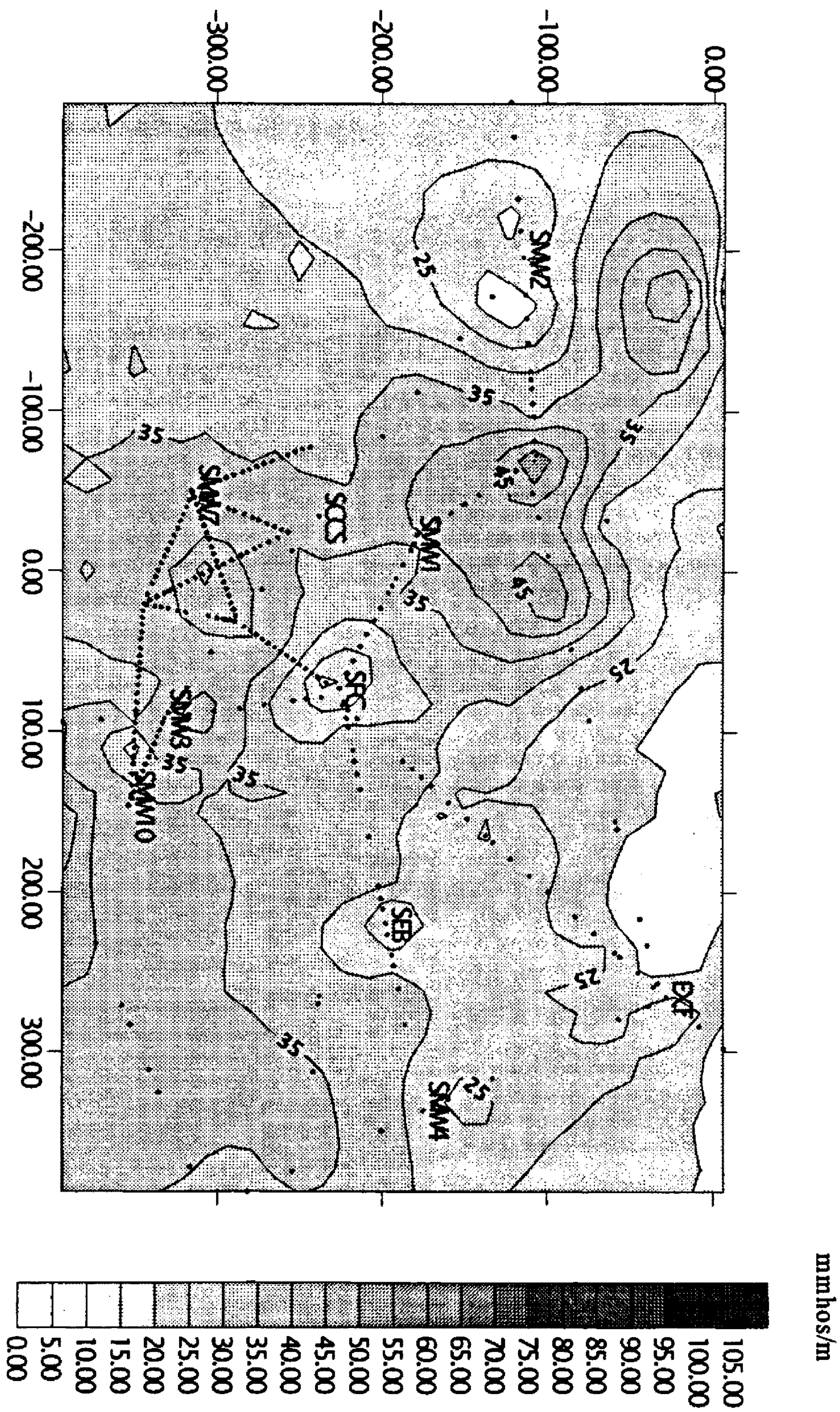
Sentinel Meadows EM31 at 3 m



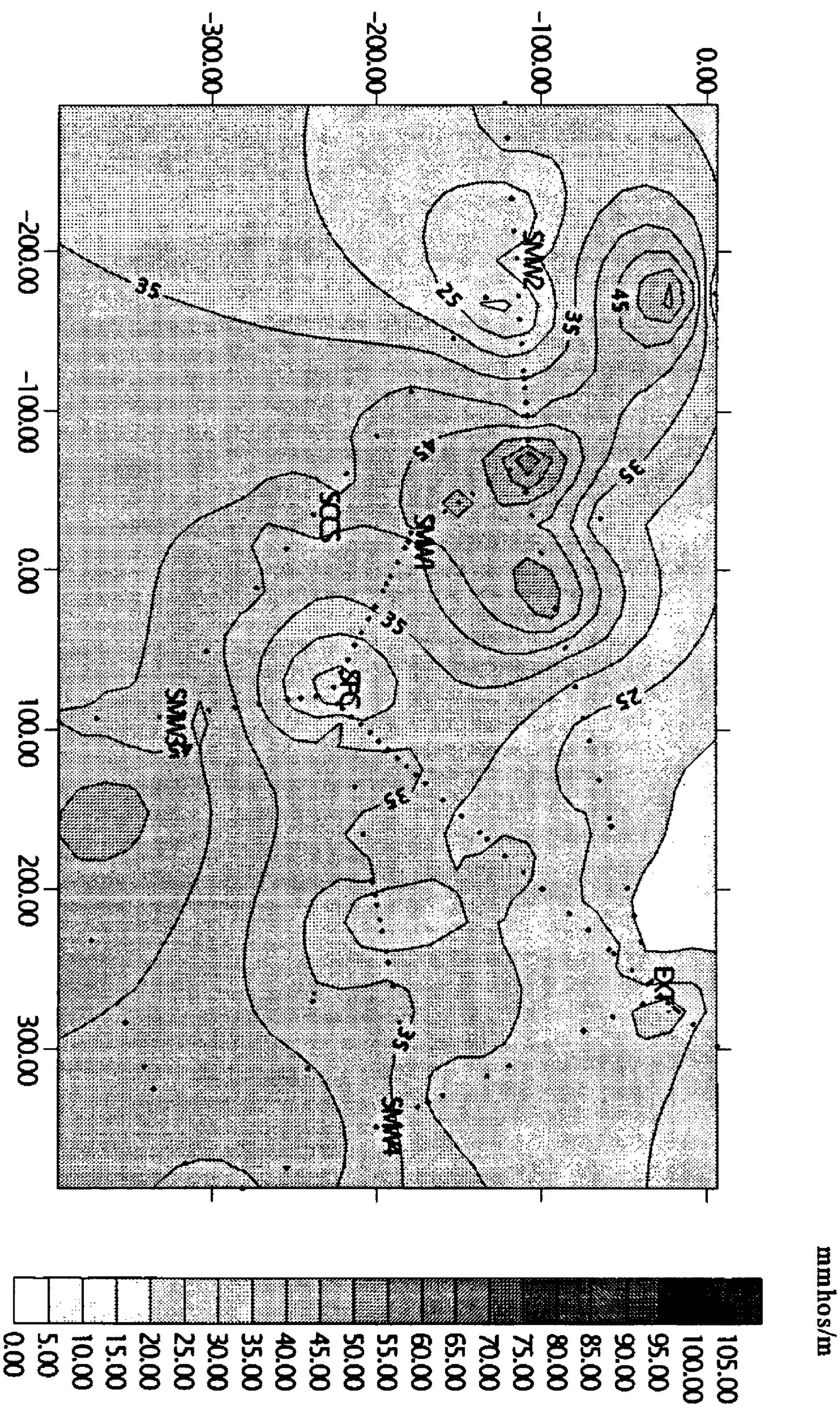
Sentinel Meadows EM31 at 4 m



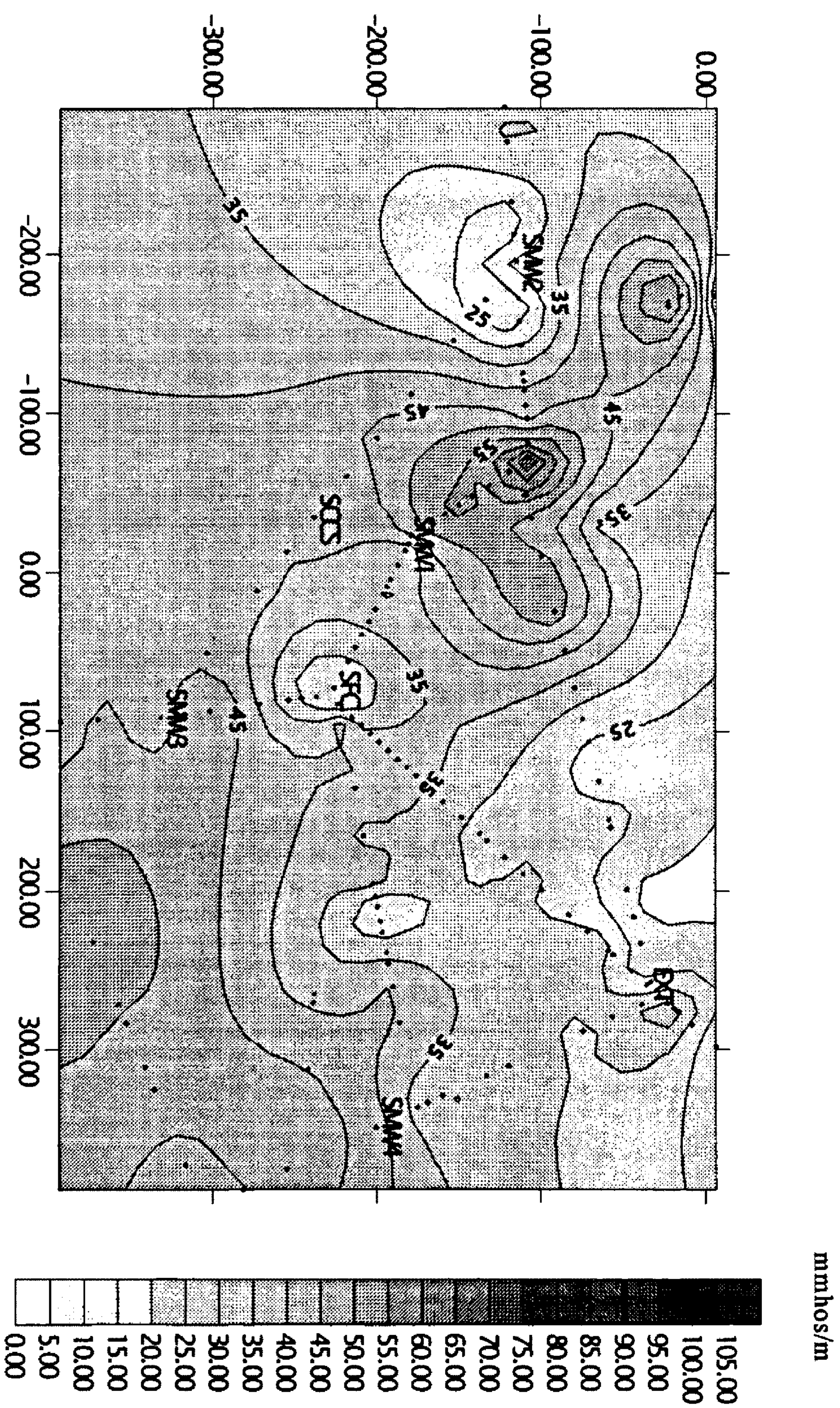
Sentinel Meadows EM31 at 4.5 m



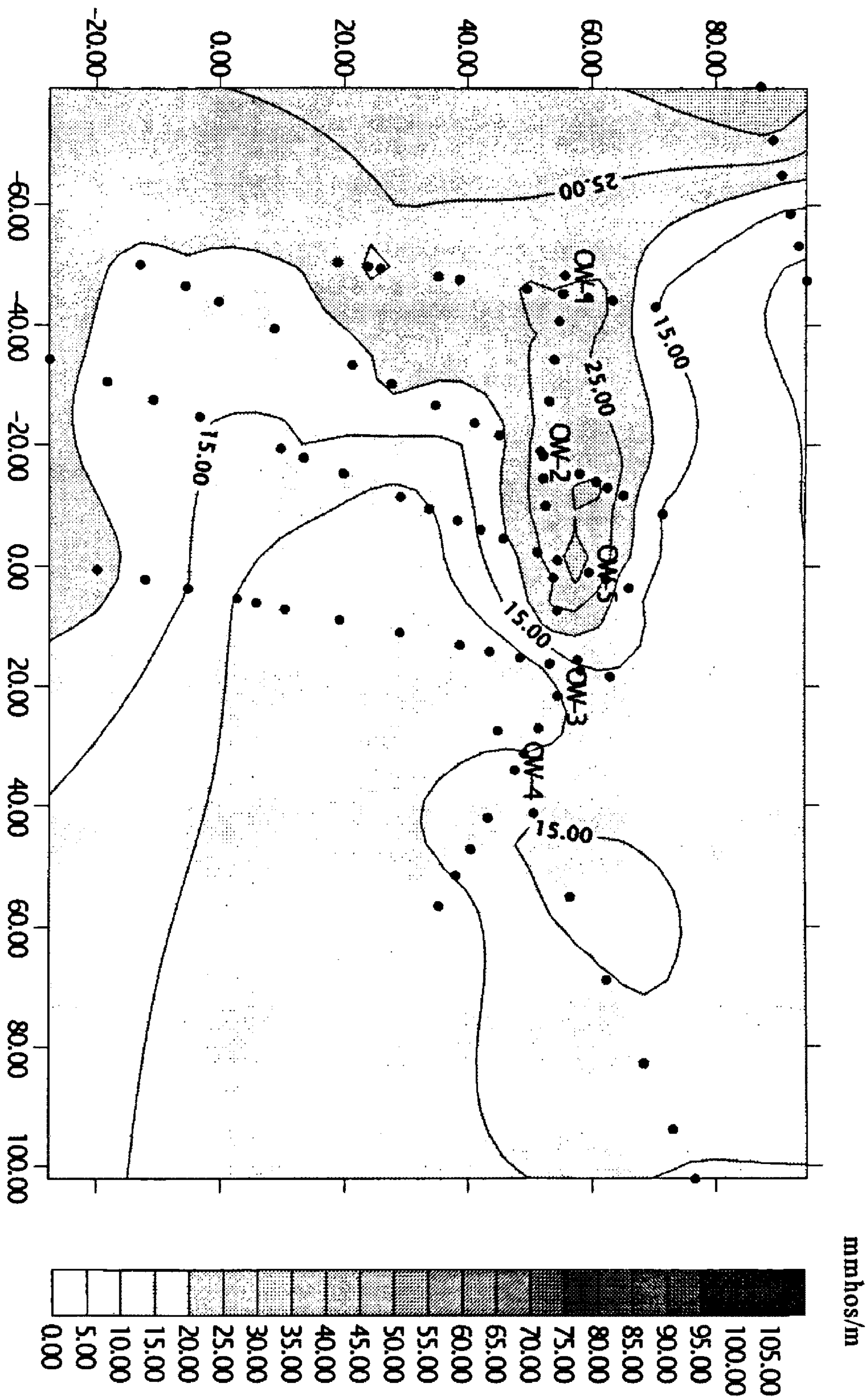
Sentinel Meadows EM31 at 5 m



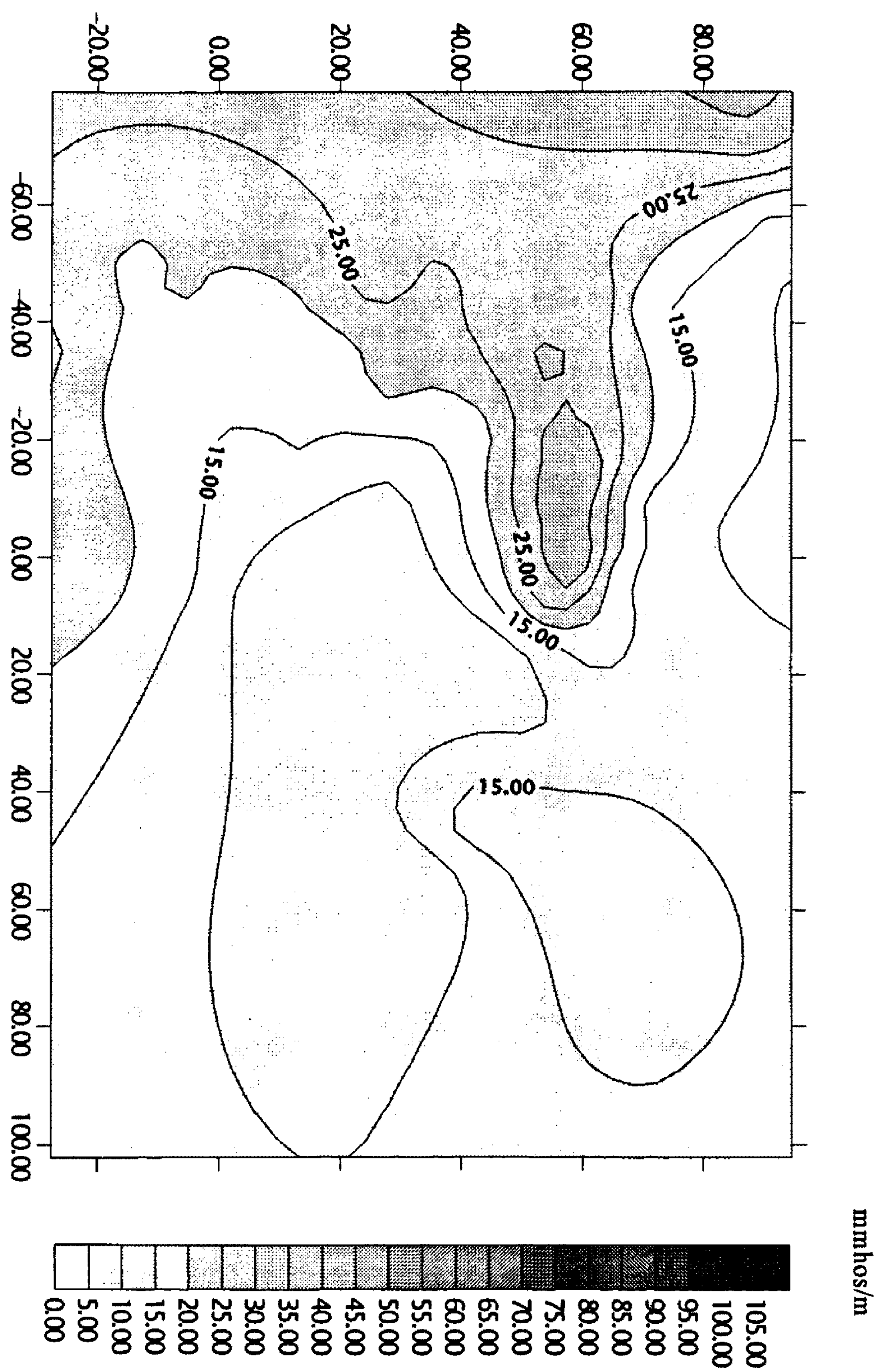
Sentinel Meadows EM31 at 5.5 m



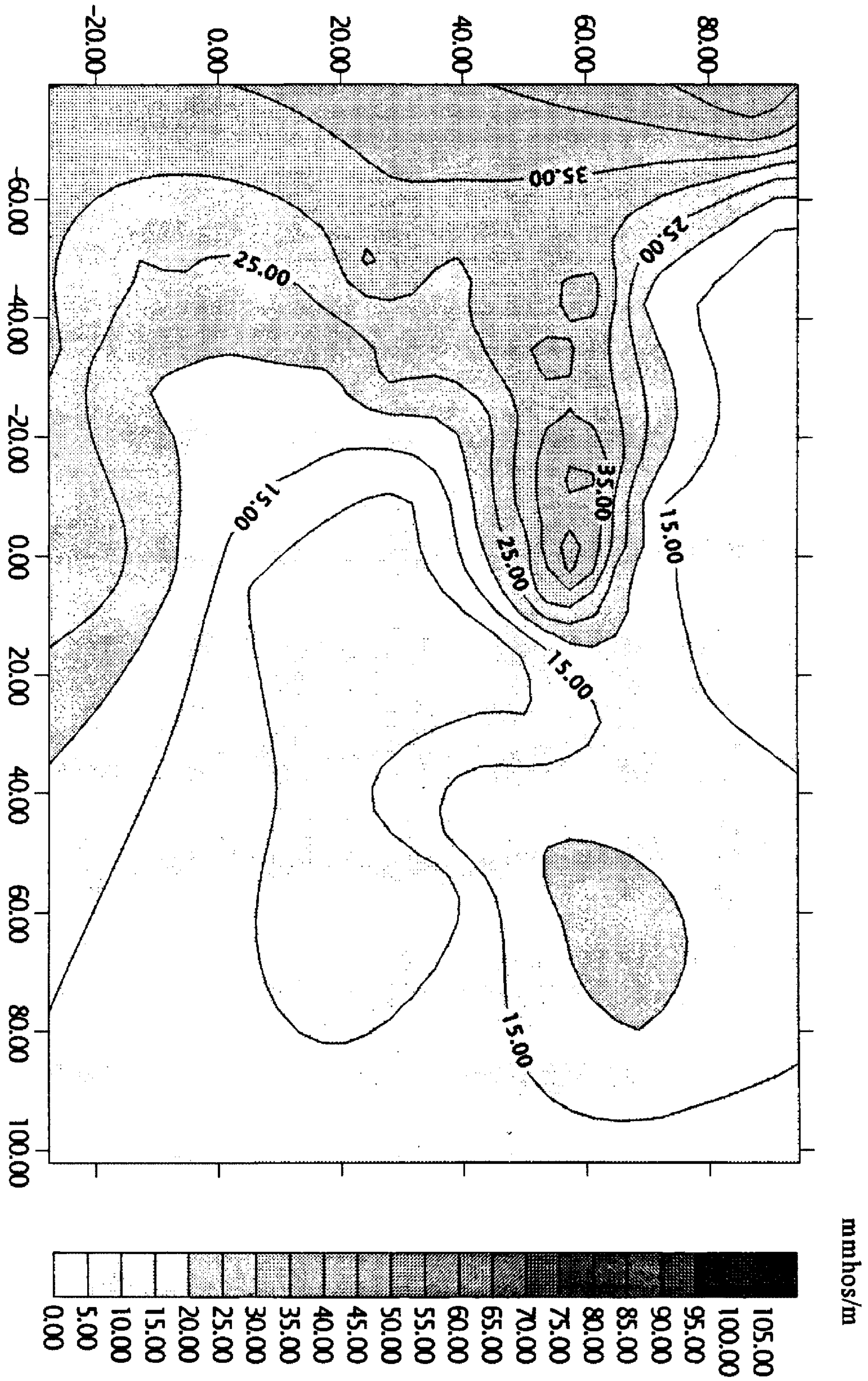
Sentinel Meadows EM31 at 6 m



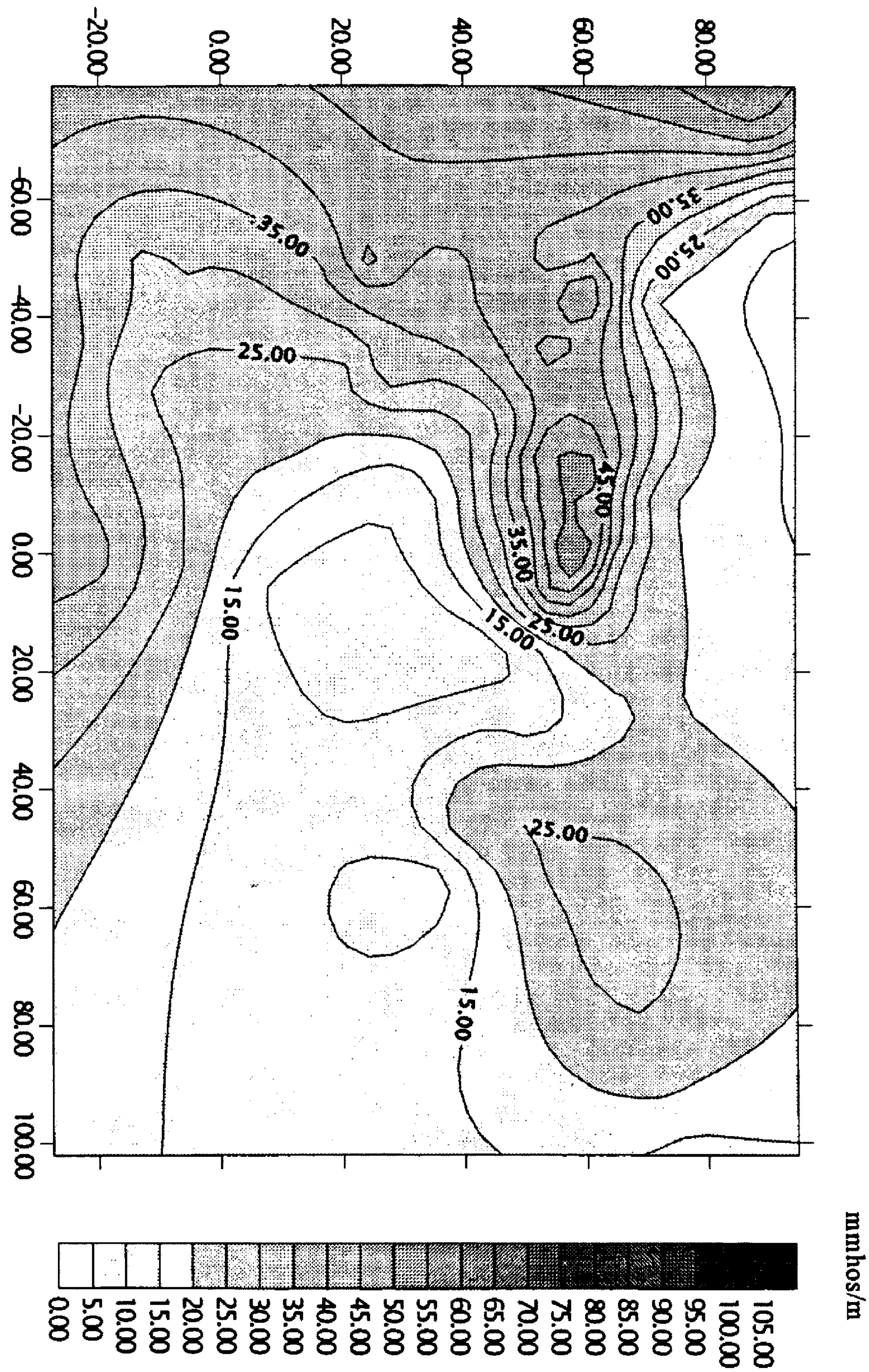
Octopus Spring EM31 at 1 m



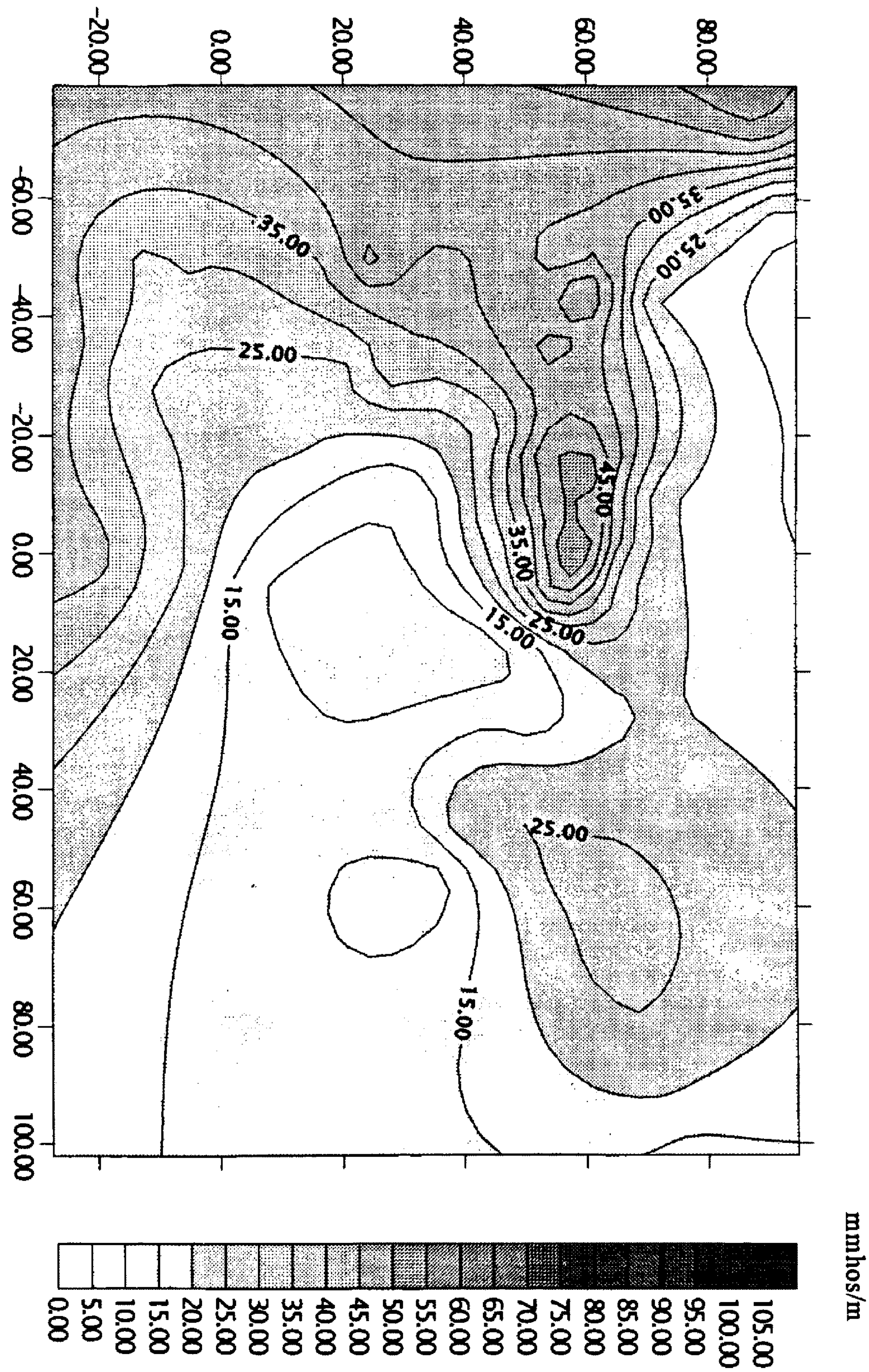
Octopus Spring EM31 at 1.5 m



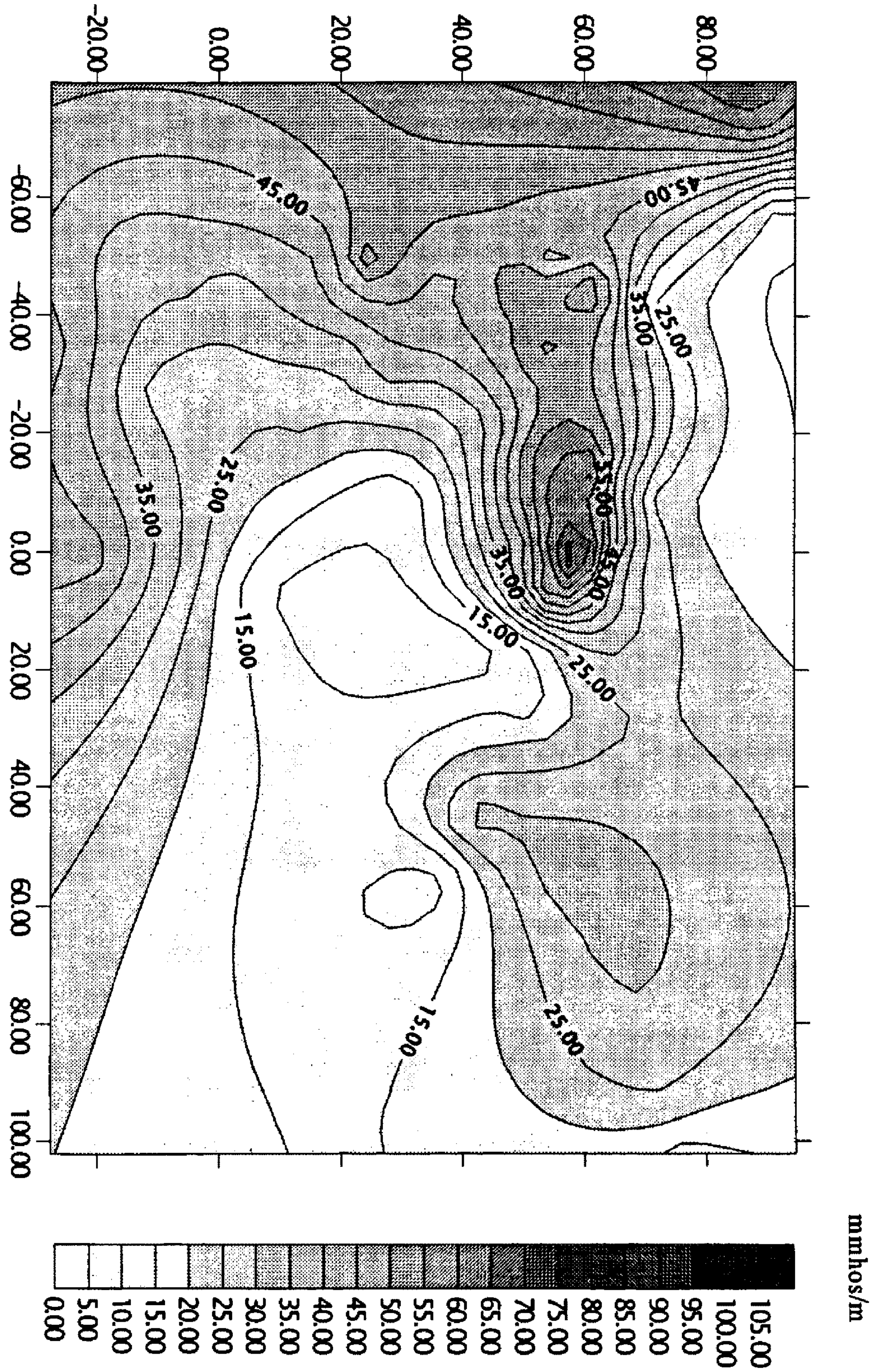
Octopus Spring EM31 at 2 m



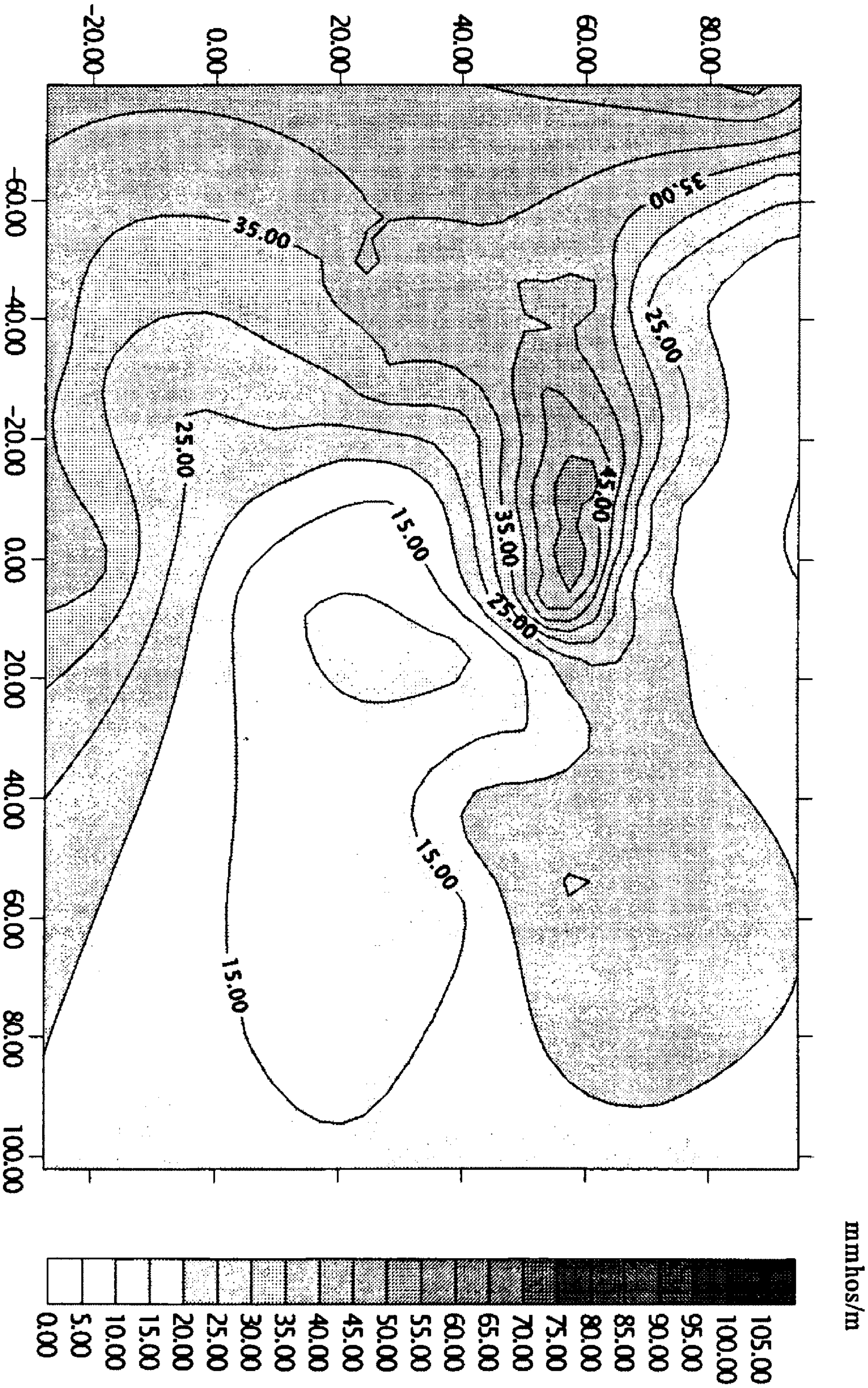
Octopus Spring EM31 at 2.5 m



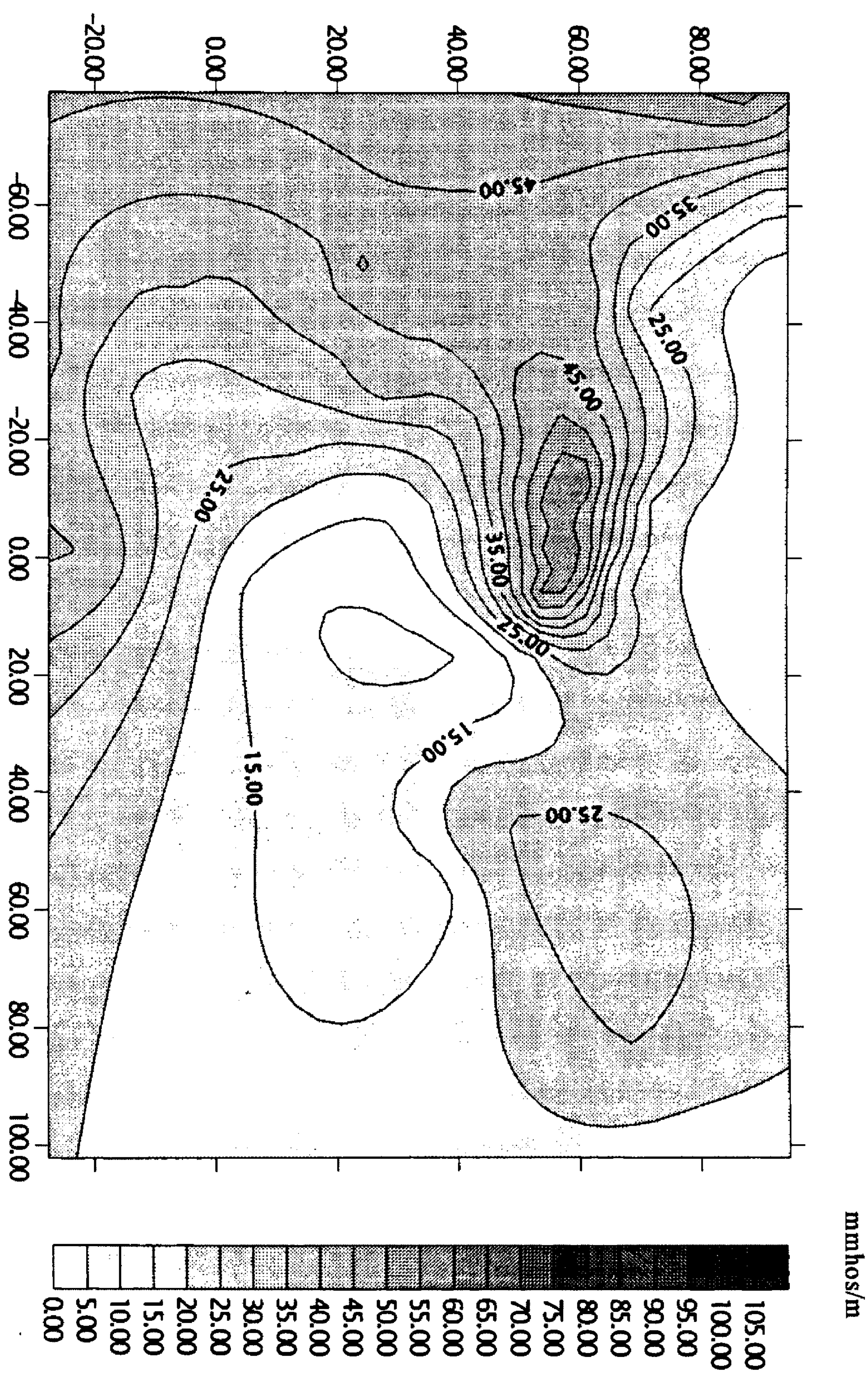
Octopus Spring EM31 at 2.5 m



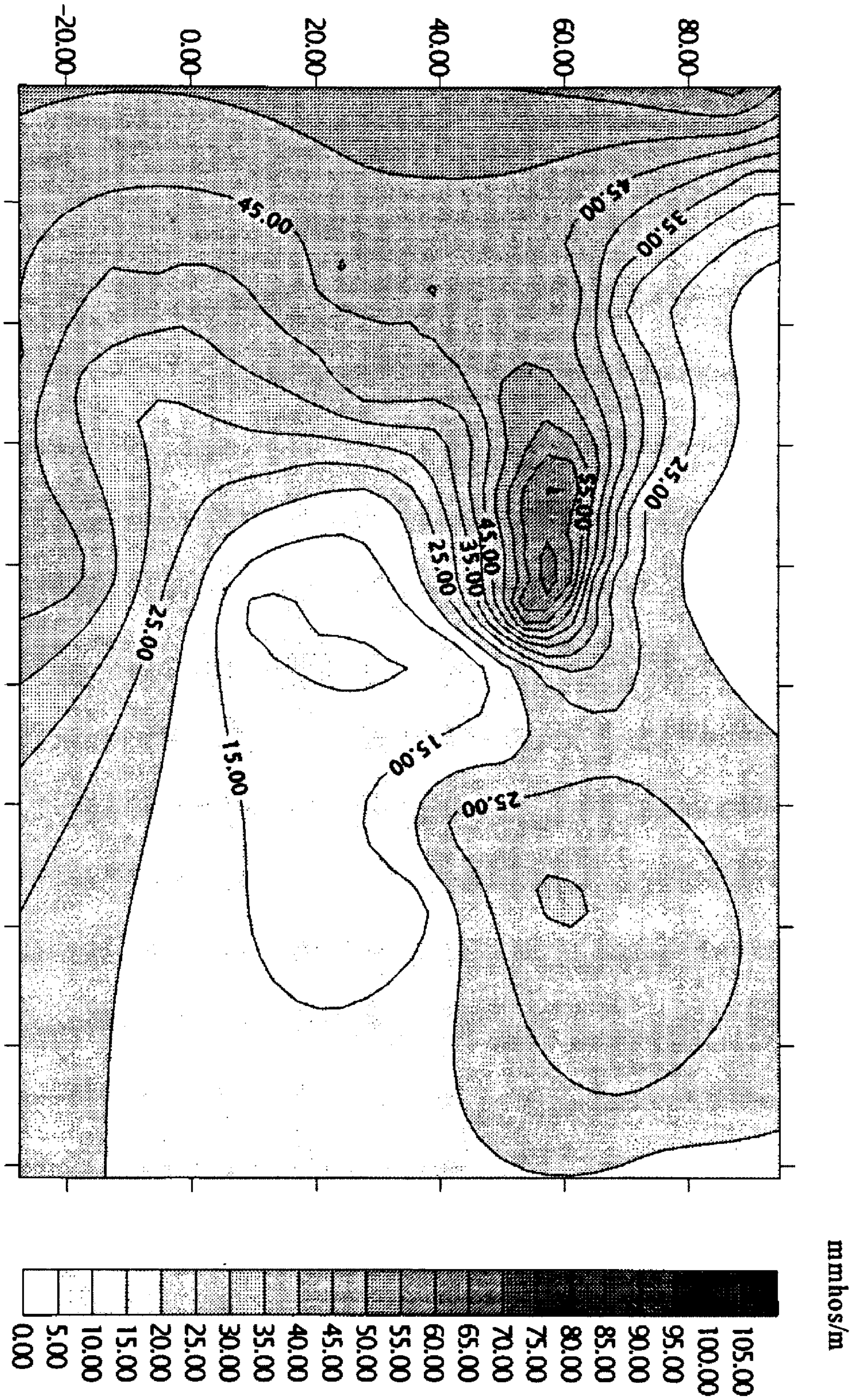
Octopus Spring EM31 at 3 m



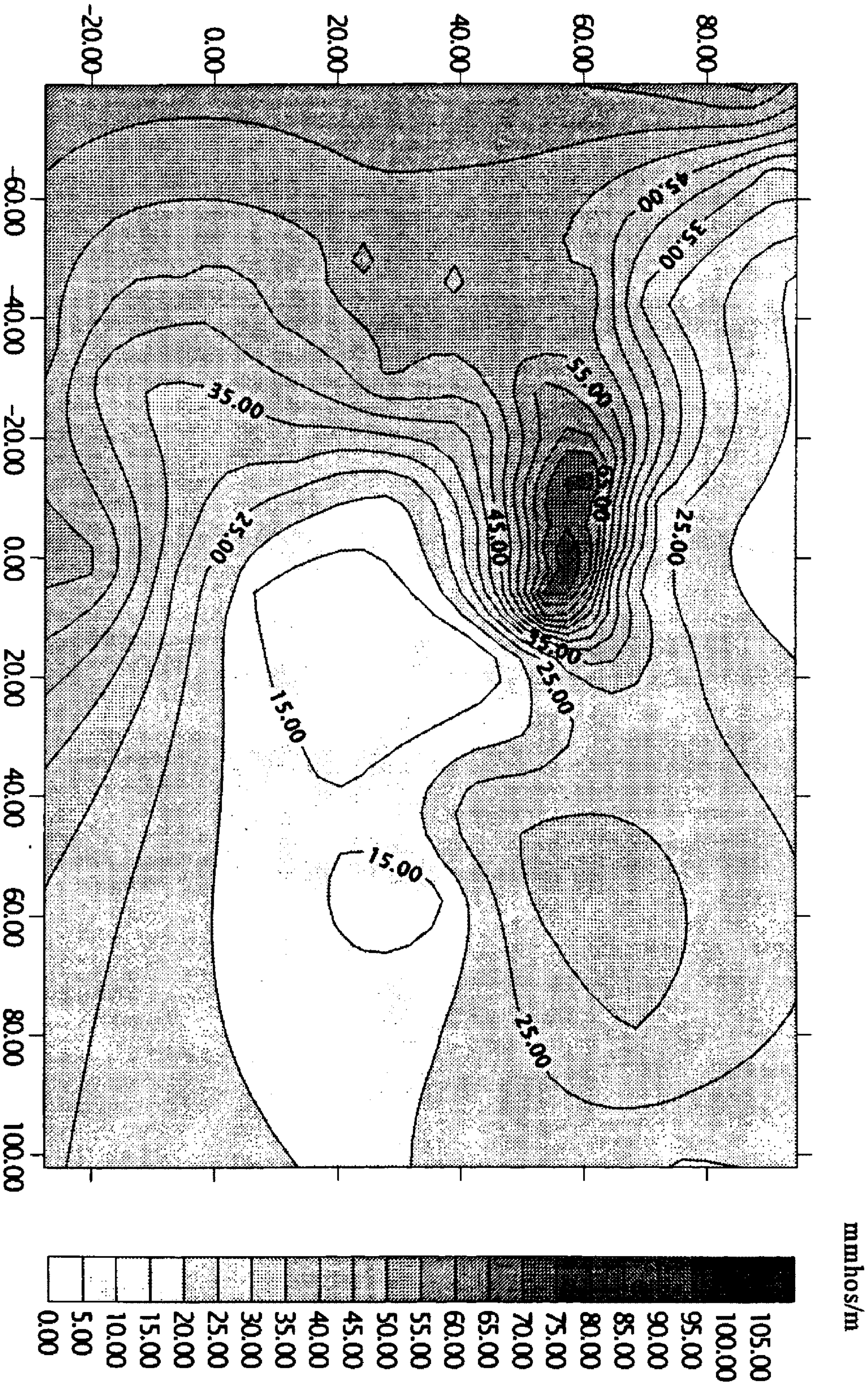
Octopus Spring EM31 at 4 m



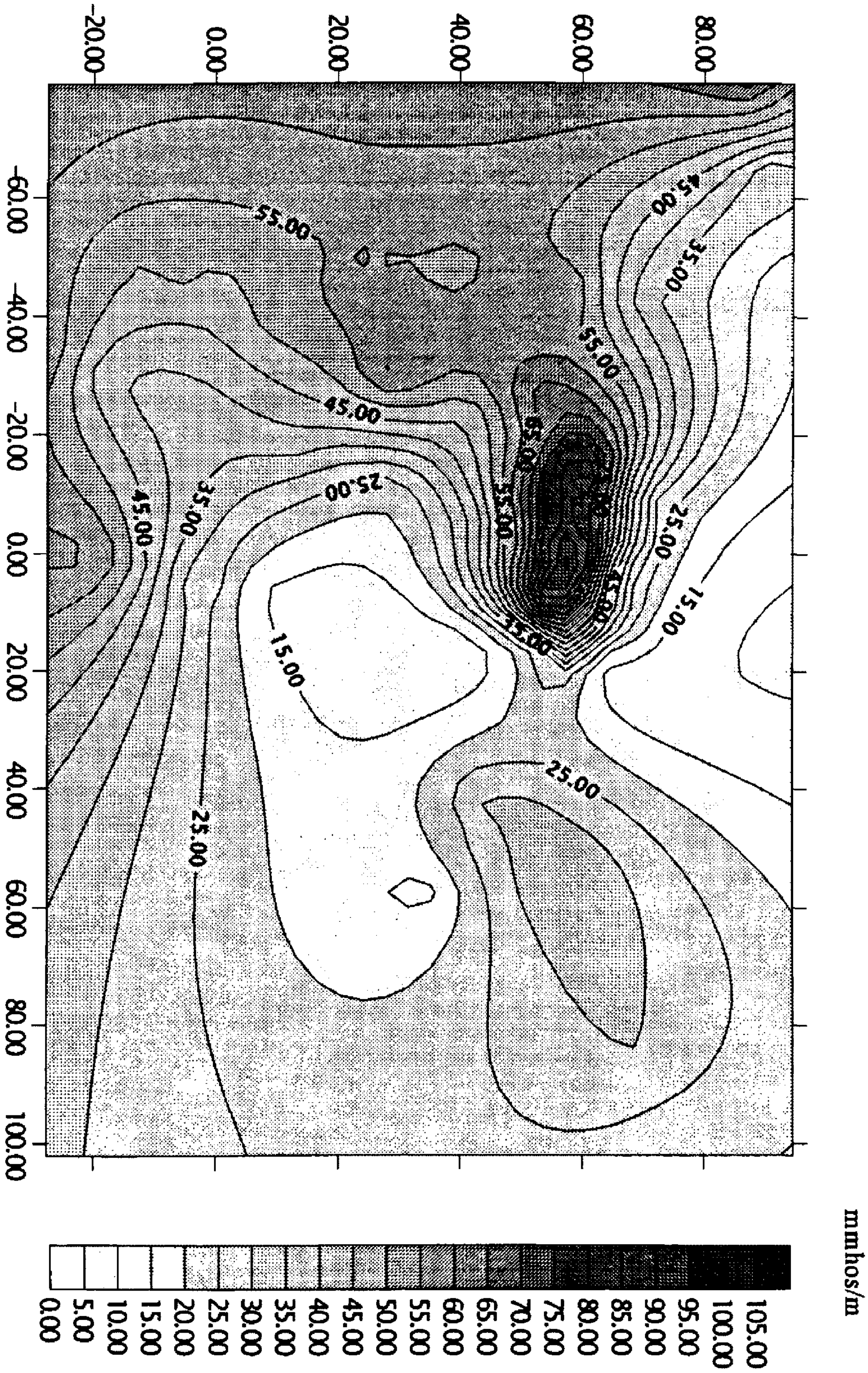
Octopus Spring EM31 at 4.5 m



Octopus Spring EM31 at 5 m



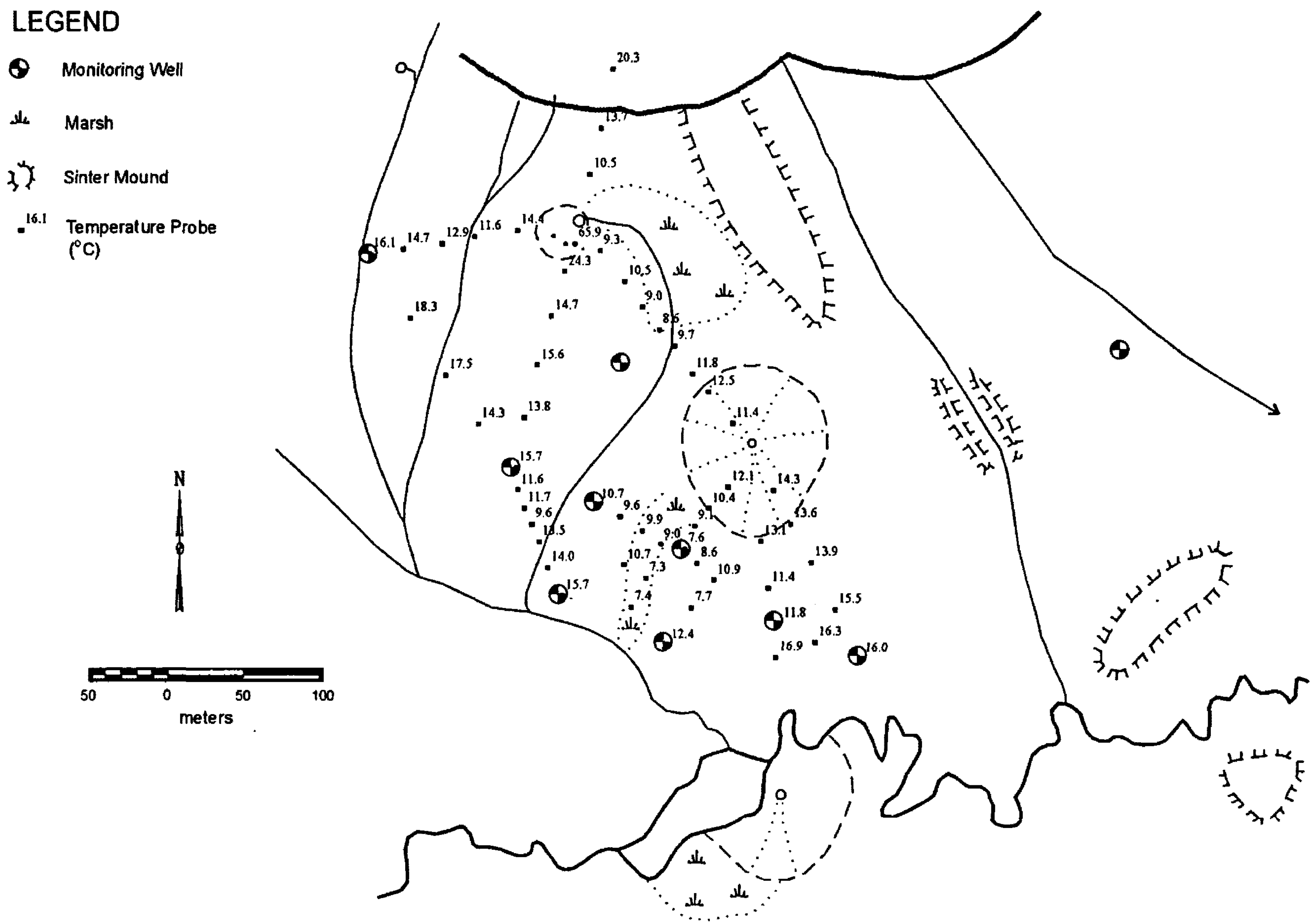
Octopus Spring EM31 at 5.5 m



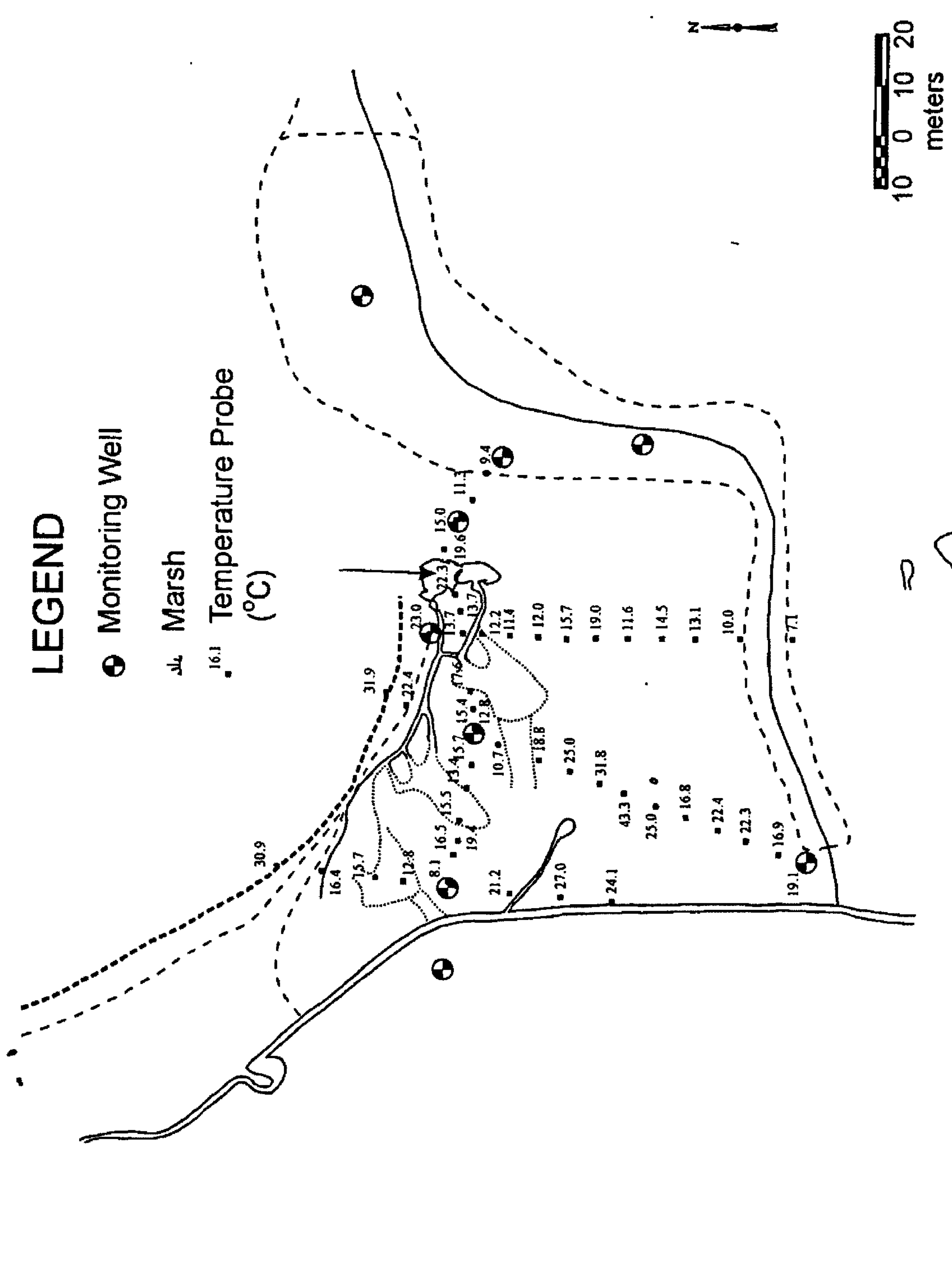
Octopus Spring EM31 at 6 m

APPENDIX E

TEMPERATURE PROBE SURVEY PLOTS



Sentinel Meadows Temperature Probe Survey



Octopus Spring Temperature Probe Survey

APPENDIX F

ANALYTICAL DATA AND DATA QUALITY

This appendix presents the water chemistry data and data quality for water samples collected from Sentinel Meadows and Octopus Springs. Water chemistry data including field measurement (pH, T°C, and dissolved oxygen) and anions are presented in the tables on pages 122-128. Water chemistry data including cations are presented in the tables on pages 129-135.

An analysis of variability in concentration of the various analytes was performed by determining analytical means, standard deviations (σ), and confidence intervals ($k(0.95) * \sigma / \mathrm{sqrt}(n)$) for waters at each site. The waters were grouped as hot spring waters, surface waters, and groundwater to compare the variability between the different waters. The means, standard deviations and confidence intervals for the grouped waters and for other waters with 3 or more sets of analyses are highlighted below the various analytes. Graphical comparison of select chemical constituents of the distinct waters at each site are shown on the figures on pages 136-151.

A total of 167 water samples were collected from the 2 sites during this study. There were 113 total samples collected from Sentinel Meadows and 54 total samples collected from Octopus Spring. During analysis of the waters, instrument precision was monitored by running standards and blanks after every 10 sample analyses. The resulting standard and blank analyses were compared with previous runs to ensure that random variation of the data remained within ±10% for the instrument. The accuracy of analysis of the waters was determined by analyzing a total of 18 field duplicate samples, 5 laboratory duplicate samples and 8 laboratory spike samples. These samples were compared with the results for the primary water samples to ensure that the data for the primary cationic and anionic species was accurate to ±10%. The relative percent difference of the data (water samples compared with quality control samples) are shown in the tables on pages 152-153.

Water Chemistry and Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	pH	T(C)	DO	F	Cl	Br	NO3	SO4	CaCO3
detection limits					2	0.5		NO3@0.15	2	
OCTOPUS SPRING										
Hot Springs										
OCT	8/25/94	8.26	85.9		18.8	248	0.643		16.4	262
	11/12/94	6.21	77.8		21.9	180	0.578		17.8	290
	2/19/95	8.13	82.6		21.6	246		0.085	17.9	265
	7/28/95	7.87	86.7		20.2	222			17.0	270
	1/14/96	7.82	84.2		20.9	233		0.13	16.2	250
	9/3/96	7.76	85.8		21.7	260		0.12	17.2	328
OPA	8/25/94	7.6	84.1		16.1	221			14.1	268
	11/12/94	8.74			19.3	157	0.512		16.2	210
	2/18/95				17.6	204			15.4	210
	7/28/95	7.18	87.1		15.8	178			13.7	203
	9/3/96	7.27	80.4		17	200			13.9	220
mean		**7.68**	**83.8**		**19.2**	**214**			**16.0**	**252**
std dev		**0.692**	**3.10**		**2.28**	**32.8**			**1.52**	**38.7**
k(0.95)*std dev/sqrt(n)		**0.429**	**2.03**		**1.35**	**19.4**			**0.900**	**22.9**
	n=	**10**	**9**		**11**	**11**			**11**	**11**
White Creek										
OWC1	8/25/94	8.12	50.7		7.15	54.6			20.1	134
	11/12/94	8.76	15.5		8.1	55.6			21.0	21.5
	2/18/95	8.09	44.1		9.12	55.2			20.2	108
	7/28/95	8.18	52.1		9.62	48.4			20.3	115
	9/3/96	7.63	46.3		9.21	51.8		0.037	18.2	112.5
OWC2	8/25/94	8.16	50.5		7.05	55.3			20.1	124
	11/12/94	8.92	15.3		8.12	56.4		0.121	20.6	26
	2/18/95	8.11	44		9.09	55.4			20.1	130
	7/28/95	8.24	51.7		9.66	51.8			19.8	120
OWC3	8/25/94	8.14	50.1							152
	11/12/94	9.15			9.37	71.6			20.6	28
	2/18/95	8.22	43.4		9.896	70			19.9	140
	7/28/95	8.38	50.1		10.6	64.1			20.0	137.5
	9/3/96	8.02	45.8		10	61.2		0.043	18.1	132.5
mean		**8.29**	**43.8**		**9.00**	**57.8**			**19.9**	**106**
std dev		**0.396**	**12.6**		**1.09**	**6.99**			**0.852**	**45.2**
k(0.95)*std dev/sqrt(n)		**0.207**	**6.88**		**0.591**	**3.80**			**0.463**	**23.7**
	n=	**14**	**13**		**13**	**13**			**13**	**14**

Water Chemistry and
Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	pH	T(C)	DO	F	Cl	Br	NO3	SO4	CaCO3
detection limits					2	0.5		NO3@0.15	2	
Sinter Mound Wells										
OW1	8/25/94	8.67	30.0		21.9	282			18.5	300
	11/12/94	9.60	15.6		23.7	189	0.891	0.108	18.8	285
	2/18/95	9.44	2.30		22.5	255		0.094	18.5	285
	7/28/95	8.84	24.4		22.5	243			18.5	280
	11/22/95	9.12	4.30		23.6	255			20.5	278
	1/14/96	9.01	7.20	7.4	23.1	251			19.5	290
	9/3/96	8.96	17.5	4.4	24.1	296		0.131	20.1	322
OW1A	11/22/95	8.57	19.1		21.5	225			28.5	285
	1/14/96	8.52	17.9	4.5	22.0	242			17.9	315
	9/3/96	8.32	24.6	1.8	22.6	280			29.9	335
mean		**8.91**	**16.3**		**22.8**	**252**			**21.1**	**297**
std dev		**0.407**	**9.17**		**0.854**	**30.8**			**4.37**	**19.8**
k(0.95)*std dev/sqrt(n)		**0.252**	**5.69**		**0.529**	**19.1**			**2.71**	**12.3**
	n=	**10**	**10**		**10**	**10**			**10**	**10**
Marsh Wells										
OW4	8/25/94	6.58	16.7		5.68	46.2			2.45	136
	11/12/94	8.35			7.11	47.4			17.4	95
	2/18/95	7.5	3.7		7.35	42.8			9.64	95
	7/28/95	6.49	23		5.78	28.4			3.71	100
OW6	7/28/95	7.61	24.1		10	56.4			7.87	140
	9/3/96	7.94	21.3	3.7	14.9	82.4		0.037	15.5	185
OW7	7/28/95	6.37	19.4		8.99	30.9			4.78	142.5
	11/22/95	7.17	9.3		8.76	44.3			4.93	130
	9/3/96	6.12	17.4	1.1	8.91	41.8		0.044	3.83	115
mean		**7.13**	**16.9**		**8.61**	**46.7**			**7.79**	**127**
std dev		**0.776**	**7.04**		**2.79**	**15.8**			**5.40**	**29.1**
k(0.95)*std dev/sqrt(n)		**0.507**	**4.88**		**1.82**	**10.3**			**3.53**	**19.0**
	n=	**9**	**8**		**9**	**9**			**9**	**9**
Other Waters										
OMO	2/23/95	8.36	5.3		9.18	70.1			11.9	110
	7/28/95	8.54	32.4		8.38	39.8			8.49	85
OSA	8/25/94	8.29	37.1		5.31	38.3			12.2	96
	11/12/94	9.46			6.1	38.9		18.5	12.7	85
	2/18/95	8.58	29.5		7.45	38.7			12.5	85
	7/28/95	8.29	39.7		7.56	32.3			11.4	67.5
mean		**8.66**	**35.4**		**6.61**	**37.1**			**12.2**	**83.4**
std dev		**0.554**	**5.30**		**1.09**	**3.18**			**0.572**	**11.8**
k(0.95)*std dev/sqrt(n)		**0.543**	**6.00**		**1.07**	**3.11**			**0.560**	**11.5**
	n=	**4**	**3**		**4**	**4**			**4**	**4**

Water Chemistry and
Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	pH	T(C)	DO	F	Cl	Br	NO3	SO4	CaCO3
detection limits					2	0.5		NO3@0.15	2	
OW8	7/28/95	6.80	31.2		7.77	42.9			1.46	150
	11/22/95	7.31	6.30		10.3	78.6			15.9	95
	9/3/96	6.88	20.4	3.10	11.0			0.069	4.82	203
mean		**7.00**	**19.3**		**9.69**	**60.8**			**7.39**	**149**
std dev		**0.274**	**12.5**		**1.70**				**7.56**	**53.8**
k(0.95)*std dev/sqrt(n)		**0.310**	**14.1**		**1.92**				**8.55**	**60.8**
	n=	**3**	**3**		**3**				**3**	**3**
	7/28/95	6.91	31.7		7.66	28.7			11.3	100
SENTINEL MEADOWS										
Hot Springs										
SCC	11/13/94	7.72	86.6		24.5	152	0.533		14.7	278
	2/22/95	7.84	83.6		24.1	219			14.8	285
	7/30/95	7.65	87.5		18.5	199			11.8	243
	9/4/96	7.63	82		23.1	231			14.1	273
SFC	8/26/94	8.33	66.6		21.7	220	0.672		14.7	272
	11/13/94	7.89	66.8		25.2	155	0.534		14.2	260
	2/22/95	8.42	80		24.5	218			13.3	255
	7/30/95	8.26	78.8		22.1	193			13.6	245
	9/1/95	8.14	82.4		23.7	183	5.61		12.9	250
	9/4/96	8.38	81		23.8	219		0.104	13.4	238
SSTC	8/26/94	7.89	67.6		25.4	264	0.743		17.5	264
	11/13/94	8.06	80.4		28.6	193	0.546		14.5	248
	2/22/95	7.99	80.8		27.9	258			14.0	240
	7/30/95	7.83	87.4		23.7	231			14.1	230
mean		**8.00**	**79.4**		**24.1**	**210**			**14.1**	**256**
std dev		**0.268**	**7.25**		**2.49**	**33.1**			**1.273**	**16.7**
k(0.95)*std dev/sqrt(n)		**0.141**	**3.80**		**1.30**	**17.3**			**0.667**	**8.73**
	n=	**14**	**14**		**14**	**14**			**14**	**14**
Other Hydrothermal Water										
SCCS	8/26/94	9.15	21.4		29.3	298	0.838		20.7	360
	11/13/94	8.87	2.00		25.3	163	0.244		15.7	290
	2/22/95	6.42	15.1		22	206			13.2	293
	7/30/95	8.67	21.9		28.1	263			16.9	315
	9/4/96	9.22	20.1		29.4	332		0.131	22.6	328
mean		**8.47**	**16.1**		**26.8**	**252**			**17.8**	**317**
std dev		**1.16**	**8.33**		**3.16**	**68.3**			**3.80**	**28.6**
k(0.95)*std dev/sqrt(n)		**1.02**	**7.30**		**2.77**	**59.9**			**3.33**	**25.1**
	n=	**5**	**5**		**5**	**5**			**5**	**5**

Water Chemistry and
Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	pH	T(C)	DO	F	Cl	Br	NO3	SO4	CaCO3
detection limits					2	0.5		NO3@0.15	2	
SEB	11/13/94	6.51	35.8							
	2/22/95	6.14	33.9		14.4	73.7		0.046	6.59	240
	7/30/95	6.10	51.2		13.3	120			4.96	225
	9/4/96	6.26	42.4		16.1	142		0.065	6.05	270
mean		**6.25**	**40.8**		**14.6**	**112**			**5.87**	**245**
std dev		**0.160**	**6.77**		**1.15**	**28.5**			**0.68**	**18.7**
k(0.95)*std dev/sqrt(n)		**0.157**	**6.63**		**1.30**	**32.2**			**0.77**	**21**
	n=	**4**	**4**		**3**	**3**			**3**	**3**
SFC(A)	9/1/95	8.92	12.7		30.0	214			19.2	323
	9/27/95	8.98	10.9		30.3	256		0.328	20.2	298
	9/4/96	9.03	13.2		29.9	250		0.17	20	283
mean		**8.98**	**12.27**		**30.1**	**240**			**19.8**	**301**
std dev		**0.06**	**1.21**		**0.208**	**22.7**			**0.529**	**20.2**
k(0.95)*std dev/sqrt(n)		**0.06**	**1.37**		**0.236**	**25.7**			**0.599**	**22.8**
	n=	**3**	**3**		**3**	**3**				
SPA	2/22/95	6.39	27.4		14.9	185		0.081	15	263
	7/30/95	6.28	30.3		14.1	172			14.1	290
Sentinel Creek										
SC1	8/26/94	8.62	13.8		3.64	14.0			3.64	48
	11/13/94	8.1	2.30		4.60	19.1		0.095	5.03	50
	2/22/95	7.16	2.80		3.91	16.7			3.59	55
	7/30/95	8.33	14.2		3.34	12.1			2.95	40
	9/4/96	8.18	12.1	8.4	2.71	9.74			2.42	45
SC2	8/26/94	9.58	21.2		3.8	16.3			3.26	48
	2/22/95	7.37	1.00		3.72	18.4			3.11	60
	7/30/95	8.52	21.2		3.45	13.4			2.7	
SC3	8/26/94	8.53	15.5		3.64	14.1			3.24	48
	11/13/94	8.99	3.1		2.48	24.0			5.42	56
	2/22/95	7.64	6.5		4.14	19.7			3.62	25
	7/30/95				3.56	13.8			2.96	27.5
	9/4/96	8.14	12	8.4	2.85	11.7			2.51	27.5
SC4	8/26/94	8.67	15.5		3.75	15.2			3.21	48
	11/13/94	8.89	2.6		3.51	29.8			5.84	62
	2/22/95	7.8	5.7		4.54	23.4			3.69	92.5
	7/30/95	8.24	13.2		3.74	15.2			3.08	37.5
mean		**8.30**	**10.2**		**3.61**	**16.9**			**3.55**	**48.1**
std dev		**0.618**	**6.77**		**0.563**	**5.12**			**0.98**	**16.3**
k(0.95)*std dev/sqrt(n)		**0.294**	**3.22**		**0.260**	**2.37**			**0.45**	**7.75**
	n=	**17**	**17**		**18**	**18**			**18**	**17**

Water Chemistry and
Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	pH	T(C)	DO	F	Cl	Br	NO3	SO4	CaCO3
detection limits					2	0.5		NO3@0.15	2	
Surface Springs										
SSC	8/26/94	8.67	15.7		1.93	1.07			2.06	34.0
	11/13/94	7.03	3.40		1.83	1.56			2.42	18.0
	2/22/95	7.55	4.50		1.75	1.04			1.94	27.5
	7/30/95	7.89	10.1		1.85	1.07			2.07	50.0
SSD	8/26/94	8.76	21.5		2.27	1.28			5.22	32.0
	11/13/94		1.10		5.16	4.49			27.1	34.0
	7/30/95	7.94	15.4		2.08	1.37			1.87	30.0
SSE	8/26/94	7.74	21.1		2.18	0.965			2.11	30.0
	11/13/94	8.16	1.14		3.24	11.5			2.76	46.0
	2/22/95	7.78	1.30		2.82	9.94			1.80	52.5
	7/30/95	7.51	17.1		2.19	3.00			1.99	25.0
SSF	8/26/94	8.29	21.8		2.15	1.05			2.79	28.0
	11/13/94	7.84	1.00		4.13	4.22			3.06	24.0
	7/30/95	7.6	20.0		1.95	1.17			2.35	32.5
mean		**7.90**	**11.1**		**2.54**	**3.12**			**4.25**	**33.1**
std dev		**0.476**	**8.68**		**1.00**	**3.44**			**6.63**	**9.94**
k(0.95)*std dev/sqrt(n)		**0.259**	**4.54**		**0.52**	**1.80**			**3.47**	**5.21**
	n=	**13**	**14**		**14**	**14**			**14**	**14**
Groundwater Wells										
SMW2	8/26/94	6.39	21.5		4.62	121			2.45	272
	11/13/94	7.95	4.9		3.47	69.9	0.222	0.157	4.77	242
	2/22/95	6.20	4.3		5.51	115			4.84	260
	7/30/95	6.23	17.2		6.32	108			2.75	255
	9/27/95	6.24	16.4		6.86	113		0.136	5.25	243
	9/4/96	6.00	18.1	2.3	5.58	91.8		0.099	3.69	240
mean		**6.502**	**13.7**		**5.39**	**103**			**3.96**	**252**
std dev		**0.720**	**7.29**		**1.21**	**19.0**			**1.18**	**12.6**
k(0.95)*std dev/sqrt(n)		**0.576**	**5.83**		**0.971**	**15.2**			**0.94**	**10.1**
	n=	**6**	**6**		**6**	**6**			**6**	**6**
SMW4	8/26/94	7.53	19.5		13.1	139			8.88	338
	7/30/95	6.85	17.5		15.9	131			4.85	312.5

Water Chemistry and Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	pH	T(C)	DO	F	Cl	Br	NO3	SO4	CaCO3
detection limits					2	0.5		NO3@0.15	2	
SMW3, SMW5 through SMW10										
SMW3	8/26/94	6.60	23.0		15.7	193			10.3	368
	7/30/95	6.58	20.3		17.3	176			2.79	370
	9/19/95	6.58	20.0		18.4	185		0.326	10.5	368
	9/27/95	6.68	17.8		18.4	185			11.1	385
	9/4/96	6.26	21.1	1.5	18.3	202		0.084	9.96	423
SMW5	9/19/95	7.03	15.5		25.8	205		0.372	11.6	323
	9/27/95	7.42	13.1		25.5	202			11.3	320
	9/4/96	7.40	19.8	2.5	24.0	210		0.041	0.766	303
SMW6	9/19/95	6.26	17.5		16.8	187		0.326	14.5	430
	9/27/95	6.21	16.1		17.3	186			14.3	435
	9/4/96	6.13	18.8	1.2	18.1	204		0.087	13.8	415
SMW7	9/19/95	6.56	17.5		11.1	175			12.7	555
	9/27/95	6.58	15.8		11.4	180			12.8	565
	9/4/96	6.53	23.9	1	10.8	195		0.093	3.94	585
SMW8	9/21/95	6.74			22.7	187			13.7	270
	9/27/95	6.47	15.3		23.5	193			15.9	260
	9/4/96	6.36	19.1	1.1	23.7	209		0.071	8	280
SMW9	9/21/95	6.73			20.0	186			11.7	328
	9/27/95	6.53	15.0		20.7	187			12	323
	9/4/96	6.49	19.7	1.5	21.3	212		0.089	12	360
SMW10	9/21/95	6.54			18.2	177			9.54	438
	9/28/95	6.2	19.3		17.5	172			9.79	363
	9/4/96	6.06	23.1	0.8	19.5	195		0.091	9.27	405
mean		**6.56**	**18.6**		**19.0**	**191**			**10.5**	**386**
std dev		**0.348**	**2.93**		**4.23**	**11.9**			**3.73**	**89.2**
k(0.95)*std dev/sqrt(n)		**0.142**	**1.28**		**1.73**	**4.85**			**1.52**	**36.5**
	n=	**23**	**20**		**23**	**23**			**23**	**23**
Sampling Tubes										
SFCW1	9/19/95	6.74	15.5		20.3	180			9.52	325
	9/27/95	6.89	15.9		18.9	169			8.61	268
SFCW2	9/19/95	6.75	14.1		25.6	200		0.329	8.56	425
	9/27/95	6.89	14.5		20.5	173		0.186	4.34 --	
SFCW3	9/19/95	6.89	13.7		26.3	255		2.27	12.3	440
	9/27/95	6.94	14.4		23.7	197			13.2	385
SFCW4	9/19/95	7.03	12.8		26.5	210		1.29	9.83	340
	9/27/95	7.10	12.9		25.0	199		0.347	10	318
SFCW5	9/19/95	7.04	13.8		26.5	204		3.51	20.9	380
	9/27/95	7.15	13.1		24	193			17	282
SFCW6	9/19/95	6.78	15.8		27.8	203		2.45	12.4	270
	9/27/95	6.91	14		26.8	198			13	225

Water Chemistry and Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	pH	T(C)	DO	F	Cl	Br	NO3	SO4	CaCO3
detection limits					2	0.5		NO3@0.15	2	
SFCW7	9/19/95	6.78	13.8		32.9	378		1.45	83.5	280
	9/27/95	6.61	15.6		27.6	296			73.1	245
SFCW8	9/28/95	6.8	15.6		28.0	280			19.3	505
SFCW9	9/19/95	6.74	13.2		21.1	242		1.47	27.6	290
	9/28/95	6.82	15.6		19.2	225		0.302	25.3	270
Groundwater/Stream Interaction										
SSTG2A(Stream Bed)	9/22/95	6.48	13.0		12.2	84.1		0.117	4.79	220
SSTG2B(4.6m from bank)	9/22/95	7.1	15.5		15.0	173			1.31	400
SSTG2C(Creek Water)	9/22/95	8.26	9.30		3.87	15.4			3.62	50
SSTG3A(Stream Bed)	9/22/95	7.58	11.0		5.04	18.7		0.145	5.08	150
SSTG3B(4.6m from bank)	9/22/95	6.88	13.5		20.3	178			3.66	276
SSTG3C(Creek Water)	9/22/95	8.35	9.10		3.94	16.2			3.7	58

Water Chemistry and Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	Al	As	B	Ca	Fe	K	Li	Mg	Mn	Mo	Na	P	Si	Sr	Ti	Zn
detection limits		0.07	0.07	0.03	0.1	0.03	3	0.1	0.1	0.005	0.01	0.1	0.2	0.1	0.005	0.005	0.005
OCTOPUS SPRING																	
<u>Hot Springs</u>																	
OCT	8/25/94	0.253	1.48	2.63	0.569	bdl	18.4	3.68	bdl	bdl	0.0234	309	bdl	126	bdl	bdl	0.0152
	11/12/94	0.244	1.54	2.63	0.529	bdl	19.3	3.68	bdl	bdl	0.0262	303	bdl	123	bdl	bdl	0.0039
	2/19/95	0.264	1.53	2.75	0.58	bdl	20.2	3.68	bdl	bdl	0.0260	318	bdl	134	bdl	bdl	0.0052
	7/28/95	0.274	1.54	2.75	0.559	bdl	20.8	3.37	bdl	bdl	0.0231	319	bdl	134	bdl	bdl	0.0045
	1/14/96	0.257	1.50	2.73	0.597	bdl	23.1	3.52	bdl	bdl	0.0232	317	bdl	137	bdl	bdl	0.0351
	9/3/96	0.260	1.61	2.66	0.673	0.126	14.8	2.98	bdl	bdl	0.0222	353	bdl	133	bdl	bdl	0.0161
OPA	8/25/94	0.141	1.39	2.28	1.80	bdl	18.1	3.38	bdl	0.0089	0.0207	275	bdl	111	bdl	bdl	0.0193
	11/12/94	0.123	1.40	2.42	1.81	bdl	21.7	3.92	bdl	0.0091	0.024	288	bdl	117	bdl	bdl	0.0372
	2/18/95	0.116	1.30	2.21	2.02	bdl	15.1	2.86	bdl	0.0097	0.0182	266	bdl	104	bdl	bdl	0.0126
	7/28/95	0.175	1.30	2.21	1.98	bdl	16.9	3.10	bdl	0.0096	0.021	258	bdl	111	bdl	bdl	0.0172
	9/3/96	0.152	1.29	2.03	1.928	0.113	12.9	2.43	bdl	0.0110	0.0136	267	bdl	108	bdl	bdl	0.160
mean		**0.205**	**1.44**	**2.48**	**1.186**		**18.3**	**3.33**		**0.00966**	**0.0220**	**298**		**122**			**0.0296**
std dev		**0.0634**	**0.113**	**0.260**	**0.695**		**3.15**	**0.444**		**0.00082**	**0.00361**	**29.2**		**11.9**			**0.0445**
k(0.95)*std dev/sqrt(n)		**0.0375**	**0.0668**	**0.154**	**0.411**		**1.86**	**0.262**		**0.000719**	**0.00213**	**17.3**		**7.05**			**0.0263**
	n=	**11**	**11**	**11**	**11**		**11**	**11**		**5**	**11**	**11**		**11**			**11**
<u>White Creek</u>																	
OWC1	8/25/94	bdl	0.176	0.619	15.0	bdl	19.7	0.676	0.27	0.196	bdl	94.2	bdl	89.9	0.0143	0.0053	0.0263
	11/12/94	bdl	0.192	0.635	14.2	bdl	19.7	0.676	0.285	0.165	bdl	92.5	bdl	84.5	0.0135	bdl	0.0166
	2/18/95	bdl	0.188	0.644	15.9	bdl	17.1	0.701	0.288	0.192	bdl	96.3	0.300	84.6	0.0141	0.0050	0.0170
	7/28/95	bdl	0.197	0.589	14.8	bdl	19.2	0.582	0.266	0.204	bdl	88.2	0.200	8.62	0.0138	bdl	0.0088
	9/3/96	bdl	0.140	0.551	15.4	0.0942	17.4	0.447	0.251	0.202	bdl	82.9	bdl	86.5	bdl	bdl	0.0018
OWC2	8/25/94	bdl	0.178	0.631	14.9	bdl	19.5	0.676	0.278	0.193	bdl	94.5	bdl	89.3	0.0144	bdl	0.0224
	11/12/94	bdl	0.193	0.642	14.0	bdl	19.5	0.691	0.293	0.160	bdl	94.1	bdl	84.1	0.0131	bdl	0.0150
	2/18/95	bdl	0.177	0.636	15.9	bdl	17.0	0.714	0.287	0.189	bdl	95.8	0.300	84.1	0.0142	bdl	0.0123
	7/28/95	bdl	0.226	0.638	14.7	bdl	19.2	0.601	0.286	0.203	bdl	92.4	0.210	86.8	0.0138	bdl	0.0100
OWC3	8/25/94	bdl	0.277	0.751	13.7	bdl	19.4	0.887	0.258	0.178	bdl	107	bdl	89.6	0.013	bdl	0.0351
	11/12/94	bdl	0.318	0.813	12.8	bdl	19.9	0.962	0.27	0.144	bdl	113	bdl	85.5	0.0119	bdl	0.0161
	2/18/95	0.194	0.255	0.799	15.0	0.049	16.9	0.908	0.266	0.186	bdl	113	0.330	85.8	0.0137	0.0064	0.0192
	7/28/95	0.073	0.316	0.789	13.9	bdl	20.1	0.784	0.263	0.185	bdl	111	bdl	90.5	0.0129	bdl	0.0139
	9/3/96	bdl	0.225	0.659	14.5	0.0993	16.9	0.620	0.2788	0.202	bdl	93.7	bdl	88.6	bdl	bdl	0.0097
mean			**0.218**	**0.671**	**14.6**		**18.7**	**0.709**	**0.274**	**0.186**		**97.8**		**81.3**	**0.0136**		**0.0160**
std dev			**0.0543**	**0.0821**	**0.857**		**1.28**	**0.138**	**0.0128**	**0.0181**		**9.41**		**21.0**	**0.000727**		**0.00819**
k(0.95)*std dev/sqrt(n)			**0.0284**	**0.0430**	**0.449**		**0.669**	**0.0725**	**0.00668**	**0.00949**		**4.93**		**11.0**	**0.000411**		**0.00429**
	n=		**14**	**14**	**14**		**14**	**14**	**14**	**14**		**14**		**14**	**12**		**14**

Water Chemistry and
Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	Al	As	B	Ca	Fe	K	Li	Mg	Mn	Mo	Na	P	Si	Sr	Ti	Zn
detection limits		0.07	0.07	0.03	0.1	0.03	3	0.1	0.1	0.005	0.01	0.1	0.2	0.1	0.005	0.005	0.005
Sinter Mound Wells																	
OW1	8/25/94	bdl	1.69	2.98	0.719	bdl	22.7	4.74	bdl	bdl	0.0273	351	bdl	67.7	bdl	bdl	0.0226
	11/12/94	bdl	1.59	2.89	0.682	bdl	22.2	3.97	bdl	bdl	0.0261	346	bdl	57.0	bdl	bdl	0.0146
	2/18/95	bdl	1.58	2.81	0.75	bdl	16.9	3.57	bdl	bdl	0.0236	328	0.350	44.6	bdl	0.0055	0.0055
	7/28/95	bdl	1.68	2.98	0.751	bdl	26.8	3.57	bdl	0.0114	0.0277	343	0.250	59.9	bdl	bdl	0.0111
	11/22/95	bdl	1.64	2.93	0.609	bdl	22.0	3.84	bdl	0.0057	0.0266	342	bdl	53.5	bdl	bdl	0.0501
	1/14/96	bdl	1.78	3.10	0.644	bdl	25.5	3.73	bdl	bdl	0.0299	354	bdl	58.3	bdl	bdl	0.0255
	9/3/96	bdl	1.86	3.00	0.771	0.068	17.8	3.50	bdl	bdl	0.0244	384	bdl	63.9	bdl	bdl	bdl
OW1A	11/22/95	bdl	bdl	2.56	2.63	0.139	24.8	3.21	bdl	0.006	0.0351	306	0.450	64.4	bdl	bdl	0.0323
	1/14/96	0.101	0.980	2.94	1.76	0.112	23.3	3.60	bdl	0.008	0.0279	334	0.230	63.8	bdl	bdl	0.0798
	9/3/96	bdl	0.747	2.83	1.82	0.128	20.0	3.135	bdl	0.0143	0.0221	367	bdl	67.9	bdl	bdl	0.0283
mean			**1.51**	**2.90**	**1.11**	**0.112**	**22.2**	**3.69**		**0.00908**	**0.0271**	**345**	**0.320**	**60.1**			**0.0300**
std dev			**0.379**	**0.147**	**0.700**	**0.0311**	**3.19**	**0.449**		**0.00370**	**0.00363**	**21.2**	**0.101**	**7.16**			**0.0228**
k(0.95)*std dev/sqrt(n)			**0.247**	**0.0909**	**0.434**	**0.0305**	**1.98**	**0.278**		**0.00362**	**0.00225**	**13.2**	**0.0993**	**4.44**			**0.0149**
	n=		**10**	**10**	**10**	**4**	**10**	**10**		**4**	**10**	**10**	**4**	**10**			**9**
Marsh Wells																	
OW4	8/25/94	0.121	0.101	0.643	14.3	0.188	13.9	0.466	0.332	0.175	0.0106	85.2	bdl	50.3	0.0071	0.0088	0.138
	11/12/94	bdl	0.193	0.525	6.98	0.067	10.7	0.421	0.178	0.0154	0.0141	74.6	bdl	41.7	bdl	bdl	0.065
	2/18/95	0.095	0.142	0.473	10.5	0.112	10.8	0.348	0.228	0.0478	bdl	73.2	0.37	45.1	0.0054	0.0085	0.0602
	7/28/95	0.289	bdl	0.583	12.7	0.385	14.4	0.310	0.296	0.187	bdl	70.4	bdl	55.4	bdl	0.0059	0.0537
OW6	7/28/95	0.675	0.547	0.733	10.4	0.210	12.9	0.582	0.186	0.0064	0.0392	109	bdl	66.2	bdl	0.0133	0.0303
	9/3/96	bdl	1.07	1.05	5.76	0.099	15.4	0.781	bdl	bdl	0.0152	180	bdl	85.21	bdl	bdl	0.0657
OW7	7/28/95	1.69	bdl	0.643	8.13	1.08	8.73	0.310	0.205	0.065	bdl	89.7	0.23	51.5	0.0066	0.0292	0.0379
	11/22/95	0.195	bdl	0.526	8.95	0.219	8.03	0.337	0.137	0.0057	bdl	90.6	bdl	44.2	0.0062	bdl	0.213
	9/3/96	0.307	bdl	0.578	9.30	0.255	8.55	0.338	0.1276	0.103	bdl	78.88	bdl	43.59	bdl	bdl	0.0525
mean		**0.482**	**0.411**	**0.640**	**9.67**	**0.291**	**11.5**	**0.433**	**0.211**	**0.076**	**0.0198**	**94.6**		**53.7**	**0.00633**	**0.0131**	**0.0796**
std dev		**0.567**	**0.409**	**0.174**	**2.68**	**0.311**	**2.76**	**0.158**	**0.072**	**0.073**	**0.0131**	**34.1**		**14.0**	**0.000718**	**0.00936**	**0.0587**
k(0.95)*std dev/sqrt(n)		**0.420**	**0.358**	**0.113**	**1.75**	**0.203**	**1.80**	**0.103**	**0.050**	**0.051**	**0.0128**	**22.3**		**9.18**	**0.000704**	**0.00821**	**0.0383**
	n=	**7**	**5**	**9**	**9**	**9**	**9**	**9**	**8**	**8**	**4**	**9**		**9**	**4**	**5**	**9**
Other Waters																	
OMO	2/23/95	bdl	0.335	0.799	8.91	bdl	11.1	0.85	0.157	bdl	bdl	104	0.34	53	bdl	0.006	0.0053
	7/28/95	0.0740	0.114	0.521	9.12	0.074	9.04	0.349	0.218	bdl	bdl	67.1	bdl	45.8	bdl	bdl	0.0453
OSA	8/25/94	bdl	0.091	0.434	11.6	bdl	10.8	0.361	0.121	bdl	bdl	65.2	bdl	53.7	bdl	0.0058	0.0216
	11/12/94	bdl	0.129	0.453	11.7	bdl	12.7	0.346	0.159	bdl	bdl	67.9	bdl	55.3	bdl	bdl	0.0145
	2/18/95	bdl	0.085	0.469	13.2	bdl	10.6	0.337	0.143	bdl	bdl	68 6	0.32	53.8	bdl	0.0058	0.0126
	7/28/95	0.0950	0.142	0.421	11.2	0.034	10.4	0.353	0.213	bdl	bdl	61 8	bdl	53.9	bdl	bdl	0.0097
mean			**0.11**	**0.44**	**11.9**		**11.1**	**0.35**	**0.16**			**65.9**		**54.2**			**0.01**
std dev			**0.028**	**0.021**	**0.877**		**1.06**	**0.010**	**0.039**			**3.09**		**0.754**			**0.005**
k(0.95)*std dev/sqrt(n)			**0.027**	**0.021**	**0.859**		**1.04**	**0.010**	**0.038**			**3.03**		**0.739**			**0.005**
	n=		**4**	**4**	**4**		**4**	**4**	**4**			**4**		**4**			**4**

Water Chemistry and
Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	Al	As	B	Ca	Fe	K	Li	Mg	Mn	Mo	Na	P	Si	Sr	Ti	Zn
detection limits		0.07	0.07	0.03	0.1	0.03	3	0.1	0.1	0.005	0.01	0.1	0.2	0.1	0.005	0.005	0.005
OW8	7/28/95	bdl	0.096	0.535	15.1	0.581	16.9	0.407	0.594	0.5082	bdl	86.8	0.39	42.1	0.0074	bdl	0.0594
	11/22/95	1.94	0.248	0.786	10.6	1.10	12.3	0.846	0.662	0.0952	0.0152	100	0.39	48.4	0.0066	0.0173	0.1114
	9/3/96	bdl	0.130	0.876	16.12	0.176	18.4	0.770	0.763	0.0306	bdl	124.2	bdl	45	bdl	bdl	0.0207
mean			**0.16**	**0.73**	**13.9**	**0.62**	**15.9**	**0.67**	**0.67**	**0.211**		**104**	**0.390**	**45.2**			**0.064**
std dev			**0.080**	**0.177**	**2.94**	**0.463**	**3.16**	**0.235**	**0.085**	**0.259**		**19.0**		**3.15**			**0.046**
k(0.95)*std dev/sqrt(n)			**0.090**	**0.200**	**3.32**	**0.524**	**3.57**	**0.266**	**0.096**	**0.293**		**21.5**		**3.57**			**0.052**
	n=		**3**	**3**	**3**	**3**	**3.0**	**3**	**3**	**3**		**3**		**3**			**3**
OW9	7/28/95	0.070	0.172	0.388	11.9	0.384	18.1	0.504	0.491	0.1435	bdl	75.6	0.41	62	0.0108	bdl	0.1087
SENTINEL MEADOWS																	
Hot Springs																	
SCC	11/13/94	0.356	0.909	2.96	0.423	bdl	16.7	2.45	bdl	bdl	0.0278	303	bdl	157	bdl	bdl	0.0053
	2/22/95	0.372	0.909	3.04	0.584	bdl	13.5	2.2	bdl	bdl	0.029	322	0.2	159	bdl	bdl	0.0175
	7/30/95	0.416	0.981	3.11	0.473	bdl	16.2	2.3	bdl	bdl	0.0317	309	bdl	168	bdl	bdl	0.0188
	9/4/96	0.387	1.08	3.03	0.522	0.156	12.8	2.16	bdl	bdl	0.0264	355	bdl	167	bdl	bdl	0.197
SFC	8/26/94	0.388	0.876	2.82	0.527	bdl	11.2	2.12	bdl	bdl	0.0288	282	bdl	146	bdl	bdl	0.0099
	11/13/94	0.382	0.917	2.97	0.465	bdl	13.6	2.07	bdl	bdl	0.0297	297	bdl	152	bdl	bdl	bdl
	2/22/95	0.377	0.919	3.02	0.626	bdl	10.6	1.83	bdl	bdl	0.029	303	0.27	150	bdl	bdl	0.0092
	7/30/95	0.431	0.972	3.12	0.519	bdl	12.7	1.86	bdl	bdl	0.0294	303	bdl	163	bdl	bdl	0.0108
	9/1/95	0.425	0.993	3.07	0.517	bdl	12.4	1.84	bdl	bdl	0.0307	299	bdl	159	bdl	bdl	0.0105
	9/4/96	0.396	1.06	2.99	0.607	0.15	9.50	1.69	bdl	bdl	0.027	331	bdl	157	bdl	bdl	0.0359
SSTC	8/26/94	0.311	1.13	3.44	0.284	bdl	14.1	2.13	bdl	bdl	0.0301	308	bdl	169	bdl	bdl	0.0151
	11/13/94	0.310	1.12	3.54	0.257	bdl	16.8	1.92	bdl	bdl	0.0305	319	bdl	172	bdl	bdl	0.0204
	2/22/95	0.299	1.12	3.60	0.298	bdl	12.7	1.71	bdl	bdl	0.0284	330	0.29	172	bdl	bdl	0.0135
	7/30/95	0.337	1.19	3.59	0.277	bdl	15.7	1.78	bdl	bdl	0.0291	325	bdl	182	bdl	bdl	0.042
mean		**0.371**	**1.01**	**3.16**	**0.456**		**13.5**	**2.00**			**0.0291**	**313**	**0.253**	**162**			**0.0312**
std dev		**0.0427**	**0.102**	**0.261**	**0.128**		**2.26**	**0.232**			**0.00143**	**18.3**	**0.0473**	**9.90**			**0.0510**
k(0.95)*std dev/sqrt(n)		**0.0224**	**0.0536**	**0.137**	**0.067**		**1.18**	**0.122**			**0.000751**	**9.61**	**0.0535**	**5.19**			**0.0277**
	n=	**14**	**14**	**14**	**14**		**14**	**14**			**14**	**14**	**3**	**14**			**13**
Other Hydrothermal Water																	
SCCS	8/26/94	0.076	1.21	3.94	0.691	0.067	20.4	3.13	bdl	0.0197	0.0359	371	bdl	80.9	bdl	0.00520	0.0378
	11/13/94	0.152	0.850	3.06	1.31	0.275	20.1	2.51	0.371	0.113	0.0237	322	bdl	65.3	bdl	bdl	bdl
	2/22/95	0.123	0.649	2.79	2.57	1.02	22.1	1.98	0.681	0.270	0.0182	306	0.25	68.0	0.006	bdl	0.0085
	7/30/95	0.147	1.25	4.06	0.797	0.224	23.8	2.73	0.125	0.261	0.0399	382	bdl	86.8	bdl	bdl	0.0168
	9/4/96	bdl	1.41	4.28	0.70	0.156	16.5	2.66	bdl	0.033	0.0357	441	bdl	82.8	bdl	bdl	0.00570
mean		**0.125**	**1.07**	**3.63**	**1.21**	**0.348**	**20.6**	**2.60**	**0.392**	**0.139**	**0.031**	**364**		**76.8**			**0.0172**
std dev		**0.035**	**0.314**	**0.658**	**0.800**	**0.383**	**2.70**	**0.416**	**0.279**	**0.121**	**0.009**	**53.4**		**9.52**			**0.0145**
k(0.95)*std dev/sqrt(n)		**0.034**	**0.275**	**0.576**	**0.702**	**0.336**	**2.37**	**0.364**	**0.315**	**0.106**	**0.008**	**46.8**		**8.34**			**0.0127**
	n=	**4**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**		**5**			**4**

Water Chemistry and
Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	Al	As	B	Ca	Fe	K	Li	Mg	Mn	Mo	Na	P	Si	Sr	Ti	Zn
detection limits		0.07	0.07	0.03	0.1	0.03	3	0.1	0.1	0.005	0.01	0.1	0.2	0.1	0.005	0.005	0.005
SEB	11/13/94																
	2/22/95	bdl	0.241	1.85	3.70	0.191	39.3	0.999	1.37	0.2397	0.0101	208	0.33	124	0.0079	bdl	0.0137
	7/30/95	bdl	0.431	1.87	3.57	1.20	50.3	0.891	1.49	0.2687	0.0128	203	0.57	132	0.0071	bdl	0.0081
	9/4/96	bdl	0.444	1.84	3.69	1.09	39.6	0.82	1.476	0.2625	0.0073	221	bdl	137	bdl	bdl	0.0158
mean			**0.372**	**1.85**	**3.65**	**0.828**	**43.1**	**0.904**	**1.45**	**0.257**	**0.010**	**211**		**131**			**0.0125**
std dev			**0.114**	**0.014**	**0.071**	**0.554**	**6.25**	**0.089**	**0.066**	**0.015**	**0.003**	**9.46**		**6.56**			**0.0040**
k(0.95)*std dev/sqrt(n)			**0.111**	**0.013**	**0.070**	**0.543**	**6.13**	**0.087**	**0.064**	**0.015**	**0.003**	**9.27**		**6.43**			**0.0039**
	n=		**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**		**3**			**3**
SFC(A)	9/1/95	bdl	1.25	3.84	0.473	bdl	17.9	2.22	bdl	bdl	0.0348	365	bdl	57.7	bdl	bdl	bdl
	9/27/95							2.15									
	9/4/96	bdl	1.33	3.69	0.795	0.0733	16.3	2.03	bdl	bdl	0.0335	411.4	bdl	58.7	bdl	bdl	0.0094
mean								**2.13**									
std dev								**0.10**									
k(0.95)*std dev/sqrt(n)								**0.109**									
	n=							**3**									
SPA	2/22/95	0.108	0.322	2.63	6.97	0.184	32.56	1.35	0.596	0.408	bdl	266	0.34	84.0	0.0274	bdl	0.0069
	7/30/95	0.167	0.351	2.70	6.85	0.294	45.02	1.47	0.635	0.635	bdl	270	bdl	88.9	0.0268	bdl	0.0239
<u>Sentinel Creek</u>																	
SC1	8/26/94	bdl	bdl	0.182	5.55	0.046	3.60	0.18	0.828	0.0138	bdl	27.3	bdl	31.1	bdl	bdl	0.0267
	11/13/94	0.080	0.124	0.284	4.9	0.091	4.38	0.21	0.85	0.0155	bdl	37.5	bdl	30.2	bdl	bdl	0.0246
	2/22/95	0.125	0.096	0.282	5.75	0.148	4.86	0.208	0.823	0.0364	bdl	38.1	0.280	30.4	0.00580	0.008	0.0062
	7/30/95	0.084	0.081	0.195	5.71	0.105	bdl	bdl	0.84	0.0192	bdl	23.9	0.21	29.4	bdl	bdl	0.0158
	9/4/96	bdl	bdl	0.126	6.03	0.0949	bdl	bdl	0.821	0.0097	bdl	18.1	bdl	27.9	bdl	bdl	0.021
SC2	8/26/94	bdl	0.09	0.204	7.66	0.099	3.70	0.225	0.963	0.0080	bdl	27.3	bdl	24.8	0.00860	0.0054	0.0083
	2/22/95	0.149	bdl	0.306	8.33	0.178	5.04	0.219	1.09	0.0201	bdl	35.4	0.320	24.3	0.0104	0.0102	0.0113
	7/30/95	0.083	0.088	0.224	8.87	0.139	2.68	0.158	1.08	0.0276	bdl	24.1	bdl	24.1	0.00960	bdl	0.0219
SC3	8/26/94	bdl	0.07	0.186	5.64	0.046	3.47	0.18	0.841	0.0101	bdl	27.7	bdl	30.7	0.00510	bdl	0.0245
	11/13/94	0.076	0.145	0.359	5.28	0.105	5.94	0.256	0.897	0.0186	bdl	43.3	bdl	30.7	0.006	0.0084	bdl
	2/22/95	0.121	0.082	0.336	5.87	0.156	5.35	0.219	0.843	0.0350	bdl	41.6	0.320	29.7	0.00630	0.0083	0.0056
	7/30/95	0.083	0.105	0.225	6.01	0.095	bdl	0.158	0.885	0.0180	bdl	27.3	0.2	29.9	0.00520	bdl	0.0262
	9/4/96	bdl	bdl	0.170	6.07	0.0915	bdl	0.102	0.801	0.0102	bdl	20.3	bdl	28.0	bdl	bdl	0.172
SC4	8/26/94	bdl	0.085	0.203	5.68	0.045	3.53	0.195	0.857	0.0129	bdl	29.2	bdl	31.0	0.00530	bdl	0.03
	11/13/94	0.091	0.158	0.430	5.24	0.122	6.28	0.301	0.893	0.0196	bdl	50.3	bdl	30.7	0.00570	bdl	0.0126
	2/22/95	0.140	0.100	0.385	5.81	0.182	5.70	0.260	0.854	0.0376	bdl	47.8	0.300	30.1	0.00640	0.0084	0.0169
	7/30/95	0.080	0.096	0.257	6.19	0.101	3.09	0.170	0.889	0.0192	bdl	29.6	bdl	30.5	0.00540	bdl	0.0048
mean		**0.101**	**0.102**	**0.256**	**6.15**	**0.108**	**4.43**	**0.203**	**0.886**	**0.0195**		**32.3**	**0.272**	**29.8**	**0.00665**	**0.00812**	**0.0267**
std dev		**0.027**	**0.0259**	**0.084**	**1.09**	**0.042**	**1.18**	**0.049**	**0.084**	**0.0094**		**9.48**	**0.0538**	**2.39**	**0.00183**	**0.00154**	**0.0395**
k(0.95)*std dev/sqrt(n)		**0.016**	**0.0141**	**0.039**	**0.504**	**0.019**	**0.64**	**0.024**	**0.039**	**0.0043**		**4.38**	**0.0431**	**1.10**	**0.00103**	**0.00124**	**0.0188**
	n=	**11**	**13**	**18**	**18**	**18**	**13**	**16**	**18**	**18**		**18**	**6**	**18**	**12**	**6**	**17**

Water Chemistry and
Statistical Analysis (mean, standard deviation, confidence interval)

Sample I.D.	Date	Al	As	B	Ca	Fe	K	Li	Mg	Mn	Mo	Na	P	Si	Sr	Ti	Zn
detection limits		0.07	0.07	0.03	0.1	0.03	3	0.1	0.1	0.005	0.01	0.1	0.2	0.1	0.005	0.005	0.005
Surface Springs																	
SSC	8/26/94	bdl	bdl	bdl	9.29	0.049	3.14	bdl	1.19	bdl	bdl	5.32	bdl	22.2	0.0099	bdl	0.0180
	11/13/94	0.167	bdl	bdl	8.16	0.12	bdl	bdl	1.15	bdl	bdl	5.51	bdl	21.6	0.0088	0.0075	0.0127
	2/22/95	0.156	bdl	bdl	9.23	0.117	3.50	bdl	1.11	0.0079	bdl	5.58	0.3	21.3	0.01	0.0096	0.0074
	7/30/95	bdl	bdl	0.037	10.0	0.070	2.19	bdl	1.24	0.0086	bdl	5.00	bdl	2.19	0.0101	bdl	0.0119
SSD	8/26/94	bdl	bdl	bdl	8.36	0.084	3.38	bdl	0.955	bdl	bdl	5.35	bdl	22.1	0.0092	0.0054	0.0139
	11/13/94	0.236	bdl	0.707	6.35	0.299	6.51	0.541	0.871	0.0116	bdl	7.17	bdl	24.4	0.0075	0.0115	0.0156
	7/30/95	0.081	bdl	0.039	10.2	0.103	2.18	bdl	1.11	0.0068	bdl	5.02	bdl	22.0	0.0104	bdl	0.0094
SSE	8/26/94	bdl	bdl	bdl	8.88	0.081	3.39	bdl	0.992	0.0155	bdl	5.72	bdl	22.3	0.0102	0.0065	0.0507
	11/13/94	bdl	bdl	0.160	7.18	0.101	5.60	0.135	0.98	0.0163	bdl	22.0	bdl	24.3	0.0078	bdl	0.0266
	2/22/95	bdl	bdl	0.155	7.52	0.097	6.00	0.117	0.967	0.0219	bdl	22.7	0.3	24.4	0.0095	0.0055	0.0062
	7/30/95	bdl	bdl	0.066	10.6	0.151	bdl	bdl	1.15	0.0194	bdl	8.24	bdl	22.9	0.0108	bdl	0.0290
SSF	8/26/94	bdl	bdl	bdl	8.24	0.057	3.87	bdl	0.905	0.0073	bdl	5.17	bdl	22.4	0.0101	0.0058	0.0303
	11/13/94	0.788	bdl	0.194	2.01	0.699	5.82	0.105	0.393	0.0124	bdl	18.6	bdl	22.6	bdl	0.0243	0.0162
	7/30/95	0.091	bdl	0.045	9.62	0.065	bdl	bdl	1.08	0.013	bdl	4.89	bdl	21.4	0.0117	bdl	0.0753
mean		**0.253**		**0.175**	**8.26**	**0.150**	**4.14**	**0.225**	**1.01**	**0.013**		**9.02**		**21.1**	**0.00969**	**0.00951**	**0.0231**
std dev		**0.268**		**0.224**	**2.165**	**0.170**	**1.56**	**0.211**	**0.209**	**0.005**		**6.67**		**5.56**	**0.00115**	**0.00635**	**0.0191**
k(0.95)*std dev/sqrt(n)		**0.214**		**0.155**	**1.134**	**0.089**	**0.92**	**0.207**	**0.109**	**0.003**		**3.49**		**2.91**	**0.00063**	**0.00440**	**0.0100**
	n=	**6.000**		**8**	**14**	**14**	**11**	**4**	**14**	**11**		**14**		**14**	**13**	**8**	**14**
Groundwater Wells																	
SMW2	8/26/94	0.392	0.185	1.67	18.9	9.87	46.17	0.857	6.67	0.663	0.0143	151	0.22	55.1	0.0685	0.0158	0.135
	11/13/94	bdl	0.048	1.73	16.5	0.154	48.18	0.902	6.27	0.083	bdl	156	bdl	52.1	0.0607	bdl	0.069
	2/22/95	0.175	0.256	1.59	16.5	5.97	38.58	0.734	5.7	0.382	0.0101	150	0.35	46.3	0.0598	0.005	0.133
	7/30/95	0.414	0.269	1.67	13.8	6.59	48.74	0.772	5.84	0.281	bdl	151	0.76	55.1	0.0583	0.0117	0.052
	9/27/95	0.154	0.144	1.69	12.3	4.72	45.37	0.74	5.66	0.248	bdl	148	bdl	56.2	0.0553	0.0013	0.059
	9/4/96	1.12	0.200	1.72	12.9	5.13	36.0	0.545	5.44	0.230	bdl	163	bdl	58.6	0.0496	0.0223	0.066
mean		**0.451**	**0.184**	**1.68**	**15.2**	**5.41**	**43.8**	**0.758**	**5.93**	**0.315**		**153**	**0.443**	**53.9**	**0.0587**	**0.011**	**0.0857**
std dev		**0.393**	**0.081**	**0.050**	**2.55**	**3.16**	**5.30**	**0.124**	**0.455**	**0.196**		**5.35**	**0.282**	**4.27**	**0.0063**	**0.008**	**0.0381**
k(0.95)*std dev/sqrt(n)		**0.344**	**0.065**	**0.040**	**2.04**	**2.52**	**4.24**	**0.099**	**0.364**	**0.157**		**4.28**	**0.319**	**3.42**	**0.0050**	**0.007**	**0.0305**
	n=	**5**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**		**6**	**3**	**6**	**6**	**5**	**6**
SMW4	8/26/94	bdl	0.295	2.03	11.6	0.784	48.5	1.02	3.98	0.311	0.0642	238	bdl	57.3	0.0307	bdl	0.166
	7/30/95	bdl	3	2.04	12.7	15.1	55.1	0.871	4.39	0.498	0.0213	234	0.24	56.2	0.0390	bdl	0.081

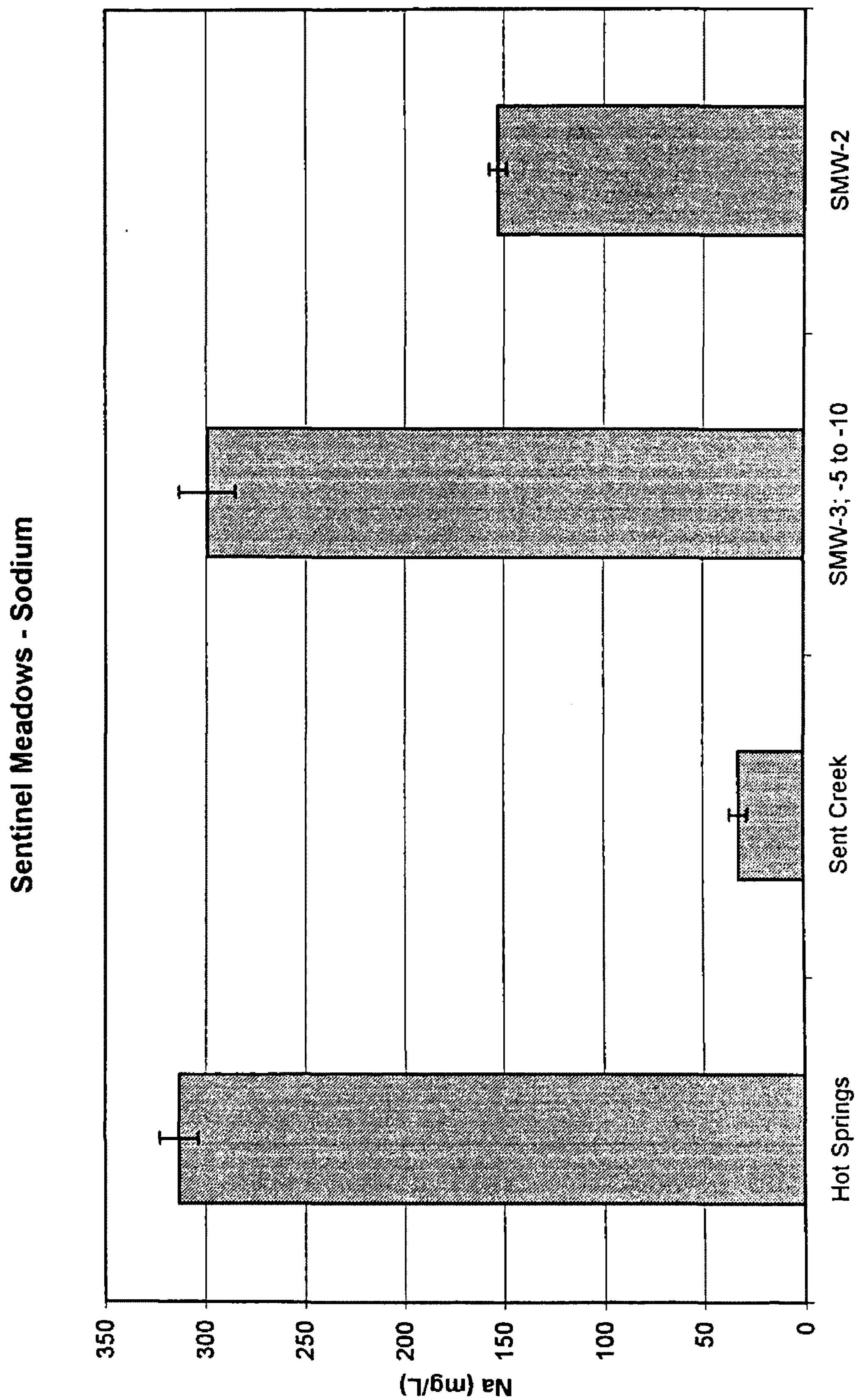
Water Chemistry and Statistical Analysis (mean, standard deviation, confidence interval)

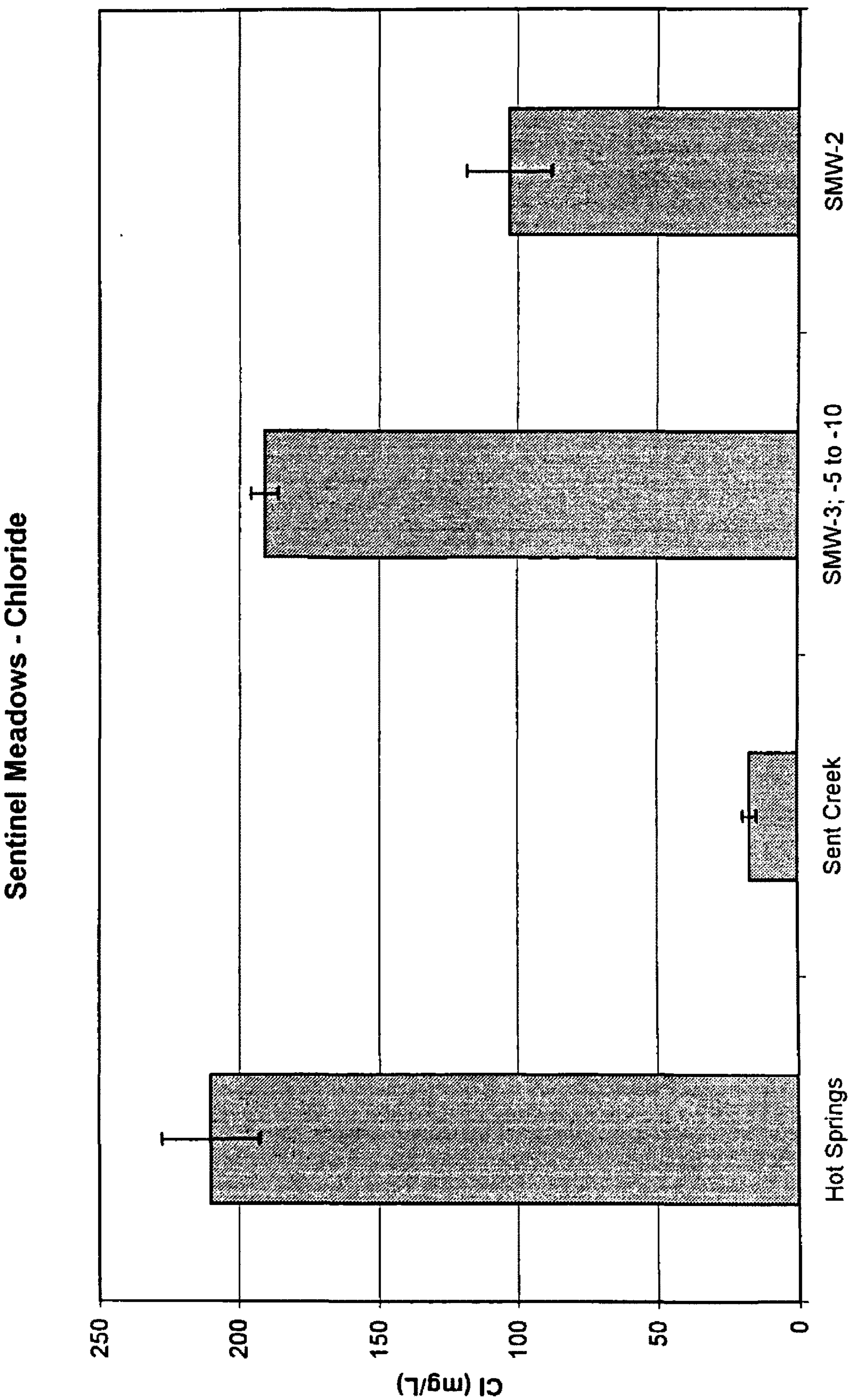
Sample I.D.	Date	Al	As	B	Ca	Fe	K	Li	Mg	Mn	Mo	Na	P	Si	Sr	Ti	Zn
detection limits		0.07	0.07	0.03	0.1	0.03	3	0.1	0.1	0.005	0.01	0.1	0.2	0.1	0.005	0.005	0.005
SMW3, SMW5 through SMW10																	
SMW3	8/26/94	bdl	1.08	2.64	4.80	2.72	68.2	1.53	2.06	1.51	0.011	293	0.370	57.0	0.0102	bdl	0.0664
	7/30/95	bdl	0.178	2.73	4.80	3.15	78.1	1.35	2.07	0.744	0.0032	301	0.670	58.4	0.0096	bdl	0.0281
	9/19/95	bdl	0.203	2.74	4.67	0.571	76.9	1.33	2.10	0.567	bdl	303	bdl	61.6	0.0089	bdl	0.0427
	9/27/95	bdl	0.236	2.79	4.38	0.341	73.4	1.30	2.05	0.292	bdl	307	bdl	61.9	0.0087	bdl	0.0378
	9/4/96	bdl	0.945	2.77	4.81	2.36	53.6	1.20	2.02	0.338	bdl	326	bdl	58.3	bdl	bdl	0.0461
SMW5	9/19/95	0.153	0.489	3.25	8.90	0.673	26.5	1.89	0.689	0.144	0.0204	303	0.250	62.1	0.0083	bdl	0.105
	9/27/95	bdl	0.415	3.22	4.49	0.812	22.2	1.81	0.579	0.110	0.0154	317	bdl	59.1	bdl	bdl	0.0405
	9/4/96	bdl	2.35	3.02	1.49	2.09	16.1	1.68	0.474	0.010	0.018	322	bdl	54.0	bdl	bdl	0.0275
SMW6	9/19/95	0.360	0.868	2.77	6.27	7.62	78.1	2.04	2.45	0.774	0.0156	319	0.240	62.1	0.0184	bdl	0.0878
	9/27/95	0.390	0.776	2.77	6.08	7.20	75.5	2.04	2.57	0.691	0.0149	326	0.250	61.9	0.0191	0.0059	0.0456
	9/4/96	0.4	0.209	2.75	6.10	1.27	54.6	1.86	2.60	0.627	bdl	354	bdl	60.1	bdl	bdl	0.0313
SMW7	9/19/95	bdl	0.491	2.66	29.1	3.79	83.0	1.28	10.6	0.197	bdl	315	bdl	60.6	0.0637	bdl	0.0807
	9/27/95	bdl	0.086	2.55	26.0	0.077	78.5	1.30	10.7	0.161	bdl	309	0.220	57.8	0.0633	0.0132	0.0329
	9/4/96	bdl	0.740	2.67	27.3	8.86	58.0	1.23	11.1	0.165	bdl	369	bdl	62.4	0.0528	bdl	0.0161
SMW8	9/21/95	0.596	0.719	2.70	5.23	2.84	36.5	1.75	1.40	0.128	0.0292	245	0.240	60.1	0.0172	0.0084	0.1223
	9/27/95	0.274	0.486	2.65	3.10	0.897	34.4	1.70	1.07	0.097	0.0237	244	0.290	60.2	0.0156	0.0196	0.0652
	9/4/96	0.276	1.94	2.85	2.86	8.13	30.4	1.60	1.18	0.088	0.0101	303	0.279	63.7	bdl	bdl	0.0572
SMW9	9/21/95	0.187	1.08	2.64	5.85	4.37	49.8	1.46	1.42	0.439	0.0639	255	0.410	62.0	0.0133	0.0122	0.150
	9/27/95	bdl	0.678	2.52	4.00	0.756	49.3	1.43	1.39	0.149	0.0418	250	0.500	58.0	0.0142	0.0284	0.448
	9/4/96	bdl	1.05	2.77	4.22	1.917	38.5	1.29	1.47	0.166	0.0329	317	bdl	62.2	bdl	bdl	0.0155
SMW10	9/21/95	0.327	0.77	2.47	12.0	4.04	70.9	1.17	4.49	0.472	0.0127	248	0.470	66.6	0.0216	0.0147	0.0888
	9/28/95	0.126	0.683	2.51	9.41	3.24	74.5	1.15	4.80	0.539	0.01	254	0.730	67.5	0.0261	0.0426	0.0992
	9/4/96	0.135	0.842	2.566	9.065	4.69	52.5	1.06	4.73	0.433	bdl	305	bdl	65.8	bdl	0.0023	0.0223
mean		**0.293**	**0.753**	**2.74**	**8.47**	**3.15**	**55.6**	**1.498**	**3.22**	**0.384**	**0.022**	**299**	**0.378**	**61.0**	**0.0232**	**0.0164**	**0.0764**
std dev		**0.142**	**0.535**	**0.199**	**7.88**	**2.63**	**20.8**	**0.295**	**3.23**	**0.339**	**0.015**	**34.7**	**0.170**	**3.15**	**0.0190**	**0.0125**	**0.0886**
k(0.95)*std dev/sqrt(n)		**0.084**	**0.219**	**0.081**	**3.22**	**1.08**	**8.52**	**0.121**	**1.32**	**0.139**	**0.008**	**14.2**	**0.100**	**1.29**	**0.0093**	**0.0081**	**0.0362**
	n=	**11**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**15**	**23**	**11**	**23**	**16**	**9**	**23**
Sampling Tubes																	
SFCW1	9/19/95	0.523	0.644	2.63	1.32	2.42	24.1	1.24	0.443	0.0839	0.0215	268	0.730	62.5	bdl	0.0279	0.196
	9/27/95	0.518	0.628	2.5	1.14	1.07	20.9	1.48	0.375	0.0865	0.0165	262	0.360	59.5	bdl	0.0233	0.135
SFCW2	9/19/95	0.703	0.394	2.89	3.13	2.70	35.7	--	1.36	0.879	0.0218	295	3.00	59.4	0.0088	0.0309	0.675
	9/27/95	0.377	0.632	2.74	2.93	2.61	29.7	1.63	1.22	0.779	0.0158	300	0.89	58.2	0.0061	0.0107	0.540
SFCW3	9/19/95	3.32	0.201	3.21	6.68	5.80	84.1	2.18	2.19	0.906	0.0801	315	2.80	69.8	0.0159	0.139	1.53
	9/27/95	2.91	0.611	3.12	4.65	5.29	33.4	1.85	1.70	0.765	0.0591	320	0.640	75.1	bdl	0.0949	1.09
SFCW4	9/19/95	0.520	0.586	2.94	1.81	1.40	32.3	1.70	0.794	0.151	0.0306	266	2.40	56.8	0.0079	0.0447	0.239
	9/27/95	0.082	0.639	3.10	2.00	0.475	24.6	1.70	0.665	0.171	0.0244	299	bdl	56.2	0.005	0.0047	0.262
SFCW5	9/19/95	4.44	0.569	2.79	4.9	9.79	33.9	2.39	2.09	1.01	0.0769	269	3.30	110	0.0125	0.2381	0.517
	9/27/95	3.17	0.609	2.94	5.00	7.28	26.3	1.61	1.61	0.915	0.0741	285	0.620	90.6	0.0092	0.1431	0.717
SFCW6	9/19/95	0.555	0.82	2.74	2.63	2.80	32.4	1.63	0.74	0.662	0.0545	236	3.30	64.9	0.0086	0.0387	0.231
	9/27/95	2.60	0.889	2.94	3.29	6.28	30.2	1.48	1.17	0.764	0.0428	267	0.410	95.8	0.0092	0.128	0.236

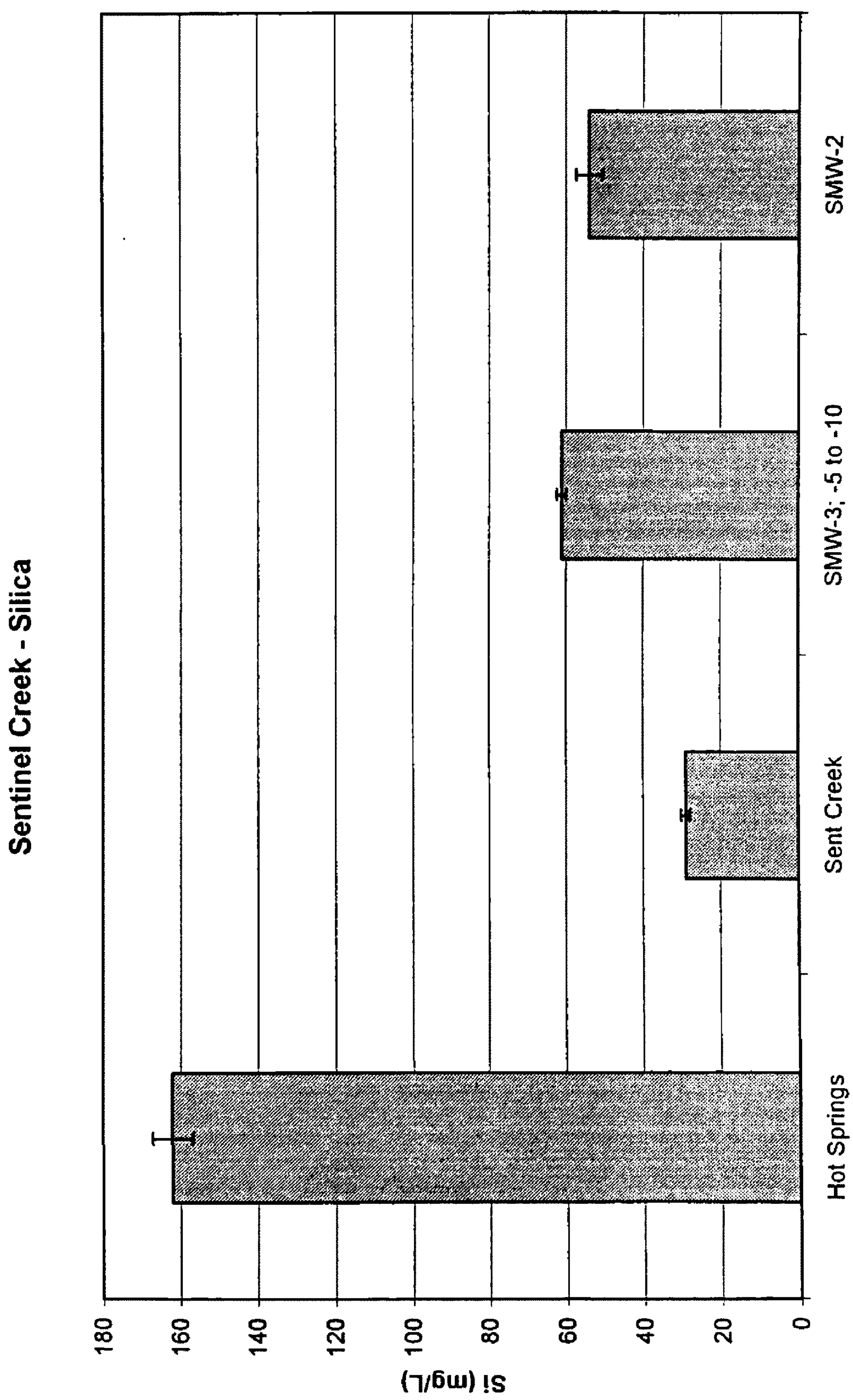
Water Chemistry and

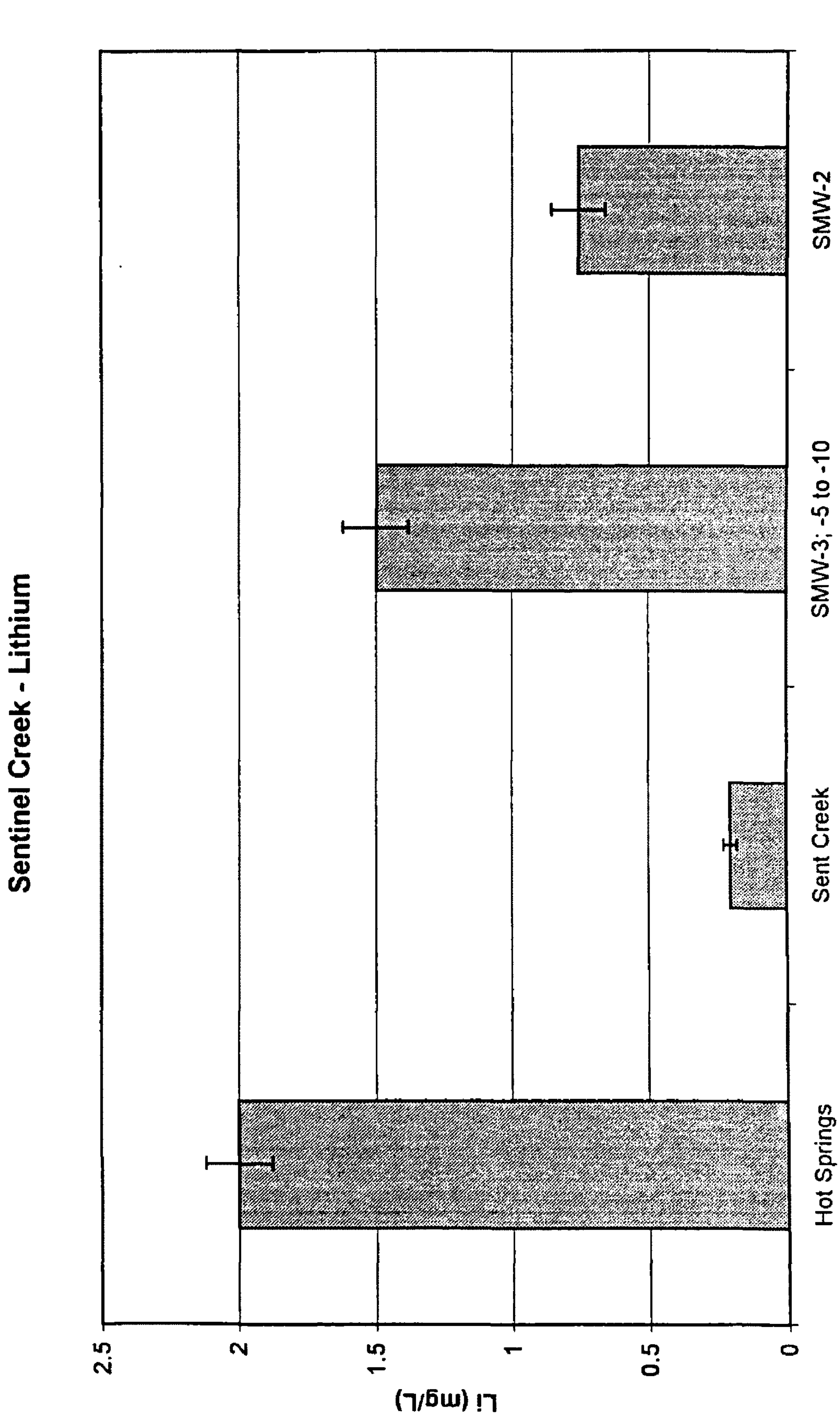
Statistical Analysis (mean, standard deviation, confidence interval)

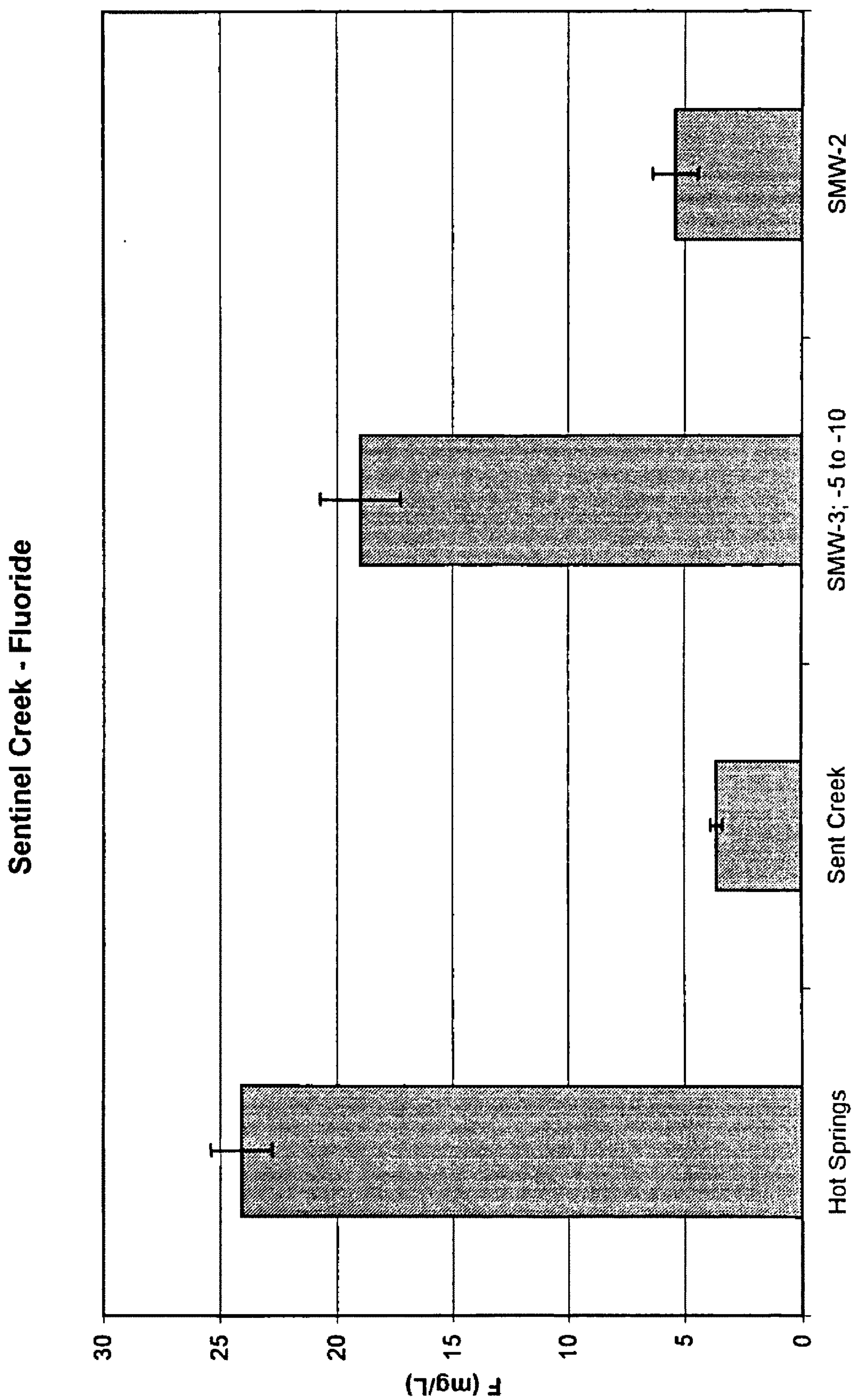
Sample I.D.	Date	Al	As	B	Ca	Fe	K	Li	Mg	Mn	Mo	Na	P	Si	Sr	Ti	Zn
detection limits		0.07	0.07	0.03	0.1	0.03	3	0.1	0.1	0.005	0.01	0.1	0.2	0.1	0.005	0.005	0.005
SFCW7	9/19/95	0.366	1.08	4.32	6.22	1.97	47.1	3.41	4.50	7.38	0.0631	349	5.70	37.0	0.0193	0.0323	0.184
	9/27/95	0.247	1.53	4.14	5.92	5.25	37.4	3.03	4.29	7.70	0.0642	349	0.62	33.4	0.0169	0.0148	0.252
SFCW8	9/28/95	14.5	0.692	2.64	18.4	31.5	48.5	--	11.2	3.42	0.1027	244	1.10	62.5	0.0407	0.2902	1.15
SFCW9	9/19/95	3.21	0.142	2.80	2.79	7.02	35.8	2.19	1.59	1.74	0.0484	287	3.10	76.5	0.0129	0.1758	1.28
	9/28/95	1.15	0.361	2.57	3.65	2.77	27.7	1.70	1.39	1.66	0.0312	267	0.880	39.9	0.0115	0.0559	1.12
<u>**Groundwater/Stream Interaction**</u>																	
SSTG2A(Stream Bed)	9/22/95	1.91	0.514	1.26	4.32	3.18	43.4	0.481	2.17	0.283	0.0193	155	0.360	65.3	0.0112	0.0902	0.0962
SSTG2B(4.6m from bank)	9/22/95	0.176	0.241	2.06	11.3	5.58	75.9	0.796	4.64	0.687	0.0137	241	0.440	48.4	0.024	0.0102	0.612
SSTG2C(Creek Water)	9/22/95	bdl	0.082	0.225	5.73	0.052	48.0	0.174	0.855	0.010	bdl	29.1	bdl	31.9	0.0057	bdl	0.055
SSTG3A(Stream Bed)	9/22/95	0.68	2.90	0.278	1.28	0.782	11.2	0.191	0.377	0.039	0.222	41.0	0.230	37.1	0.0048	0.0495	0.216
SSTG3B(4.6m from bank)	9/22/95	0.37	0.417	2.21	6.93	3.46	69.5	0.741	2.55	0.522	0.012	226	bdl	49.2	0.0156	0.0383	0.868
SSTG3C(Creek Water)	9/22/95	bdl	0.081	0.231	5.57	0.057	5.52	0.185	0.804	0.011	bdl	28.5	0.200	31.0	0.0063	0.0112	0.036

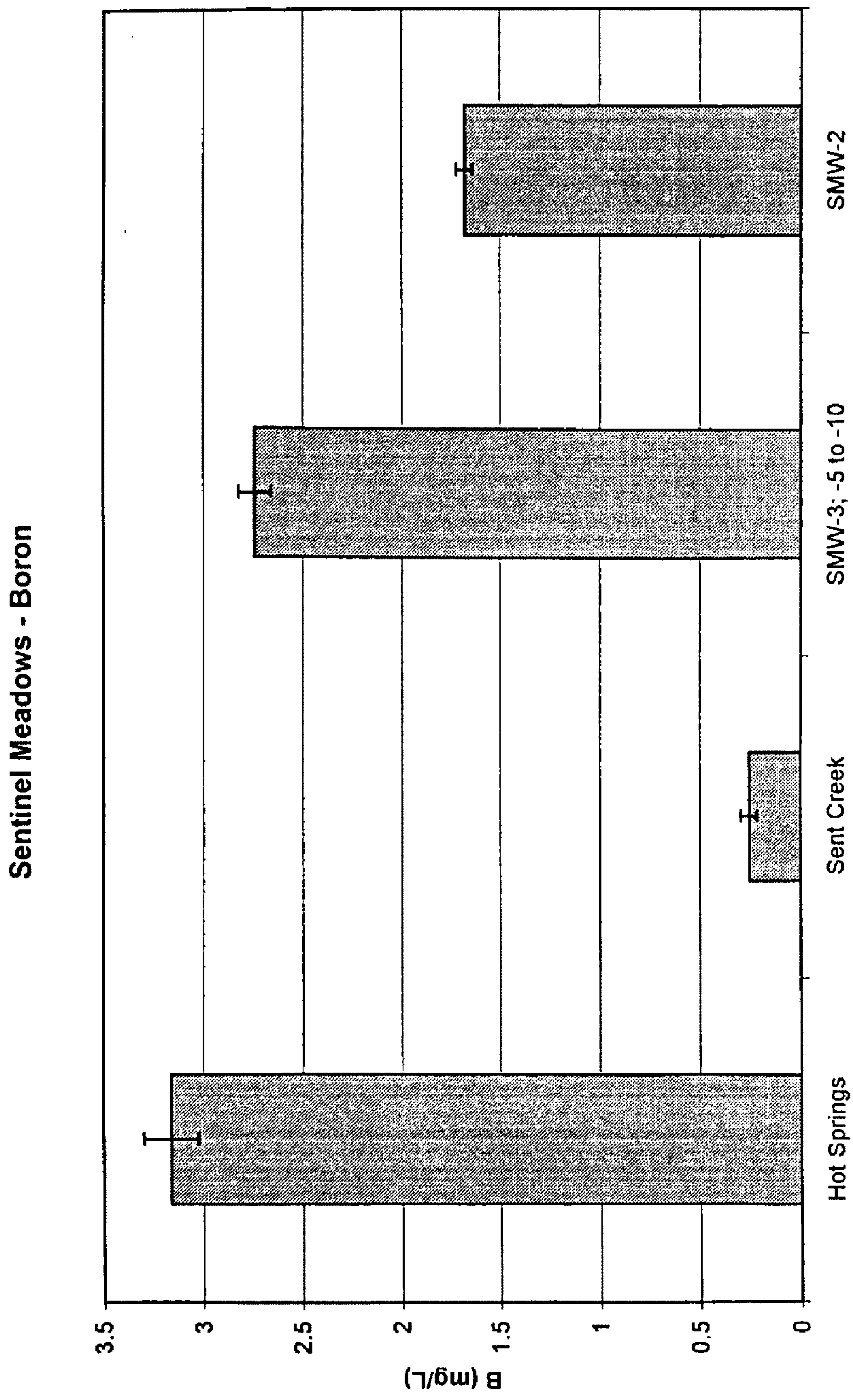

Sentinel Meadows - Sodium
Na (mg/L)
350
300
250
200
150
100
50
0
Hot Springs
Sent Creek
SMW-3; -5 to -10
SMW-2

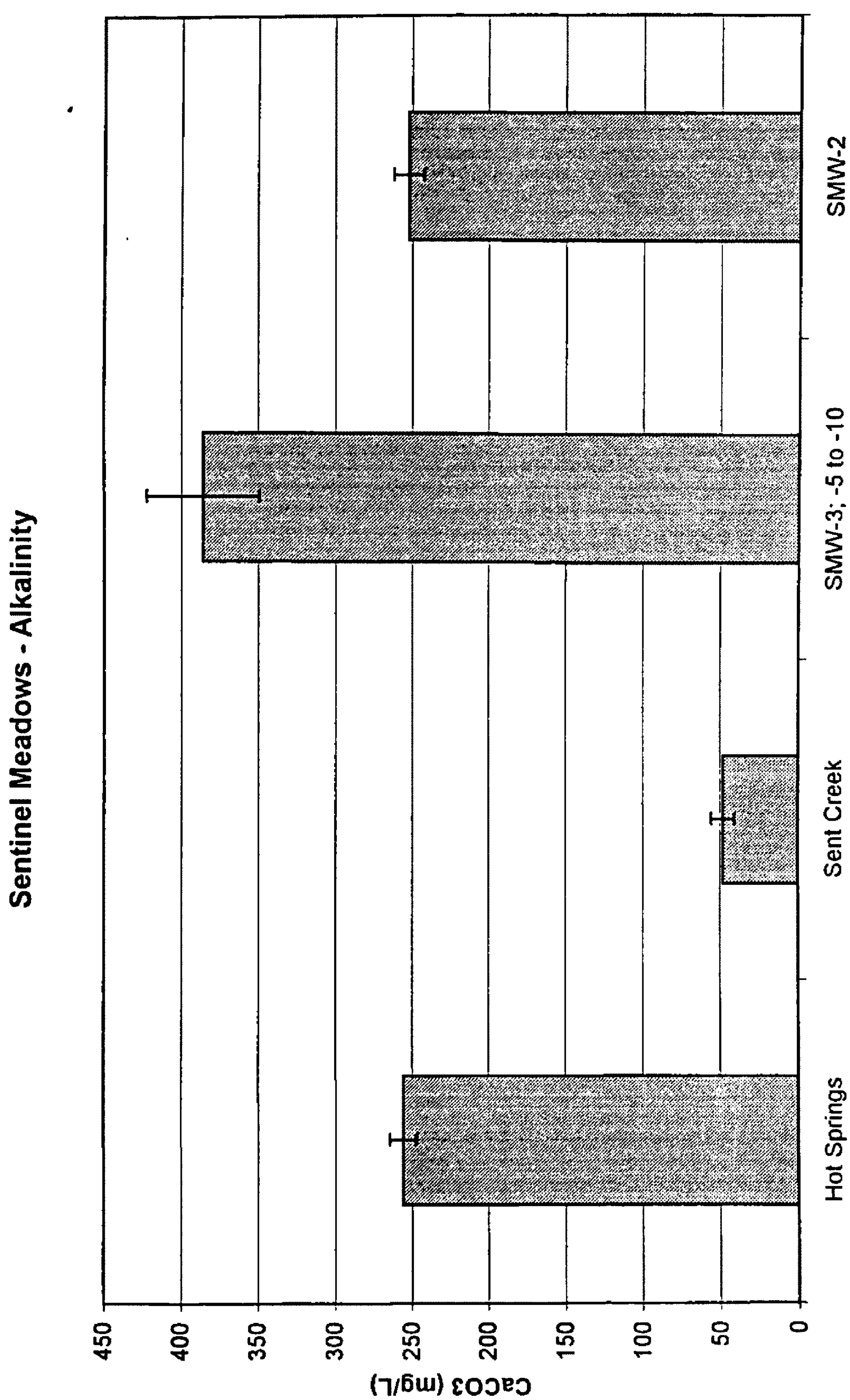

Sentinel Meadows - Chloride
Cl (mg/L)
0
50
100
150
200
250
Hot Springs
Sent Creek
SMW-3; -5 to -10
SMW-2


Sentinel Creek - Silica
Si (mg/L)
180
160
140
120
100
80
60
40
20
0
Hot Springs
Sent Creek
SMW-3; -5 to -10
SMW-2

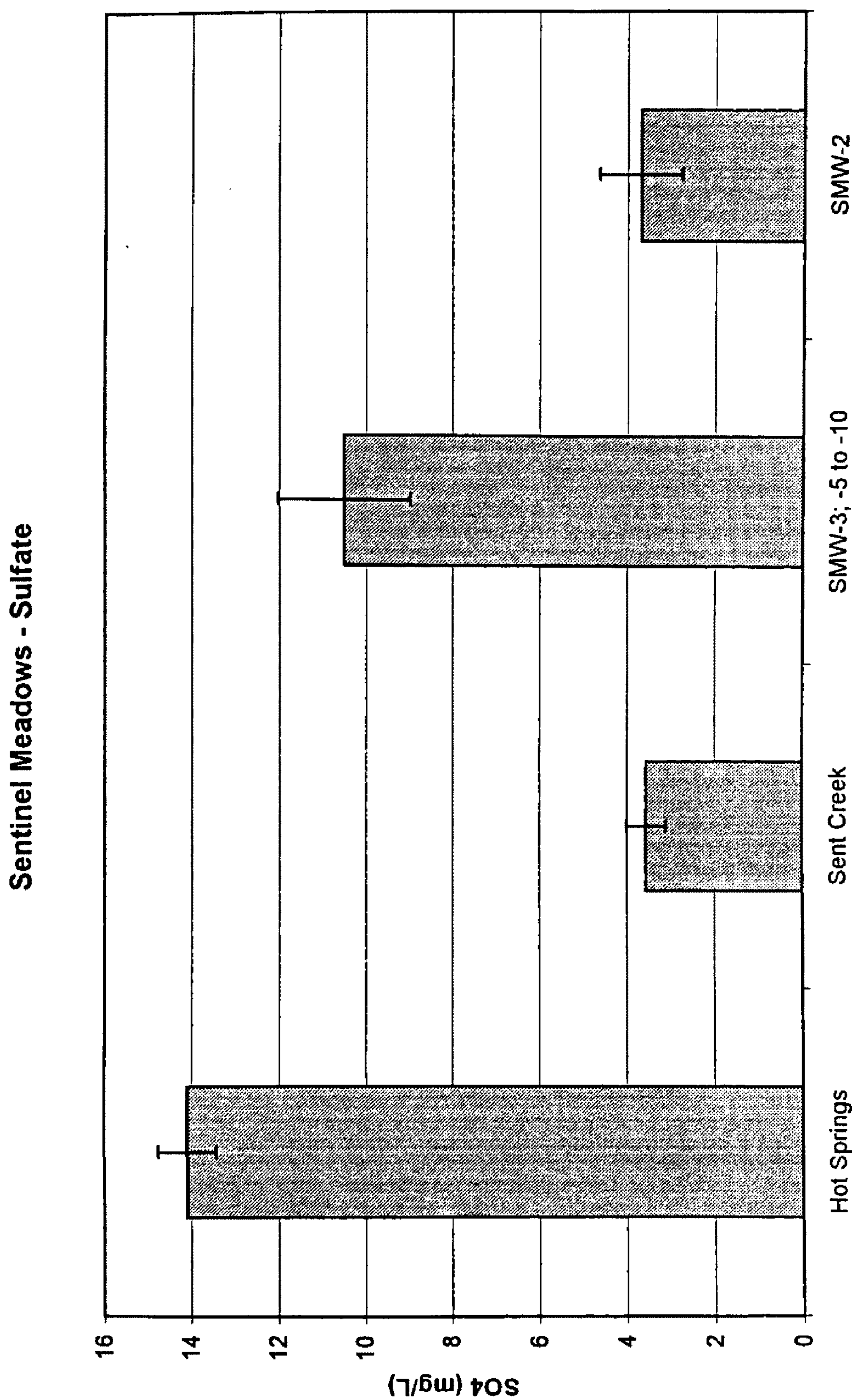

Sentinel Creek - Lithium
Li (mg/L)
2.5
2
1.5
1
0.5
0
Hot Springs
Sent Creek
SMW-3; -5 to -10
SMW-2


Sentinel Creek - Fluoride
F (mg/L)
30
25
20
15
10
5
0
Hot Springs
Sent Creek
SMW-3; -5 to -10
SMW-2

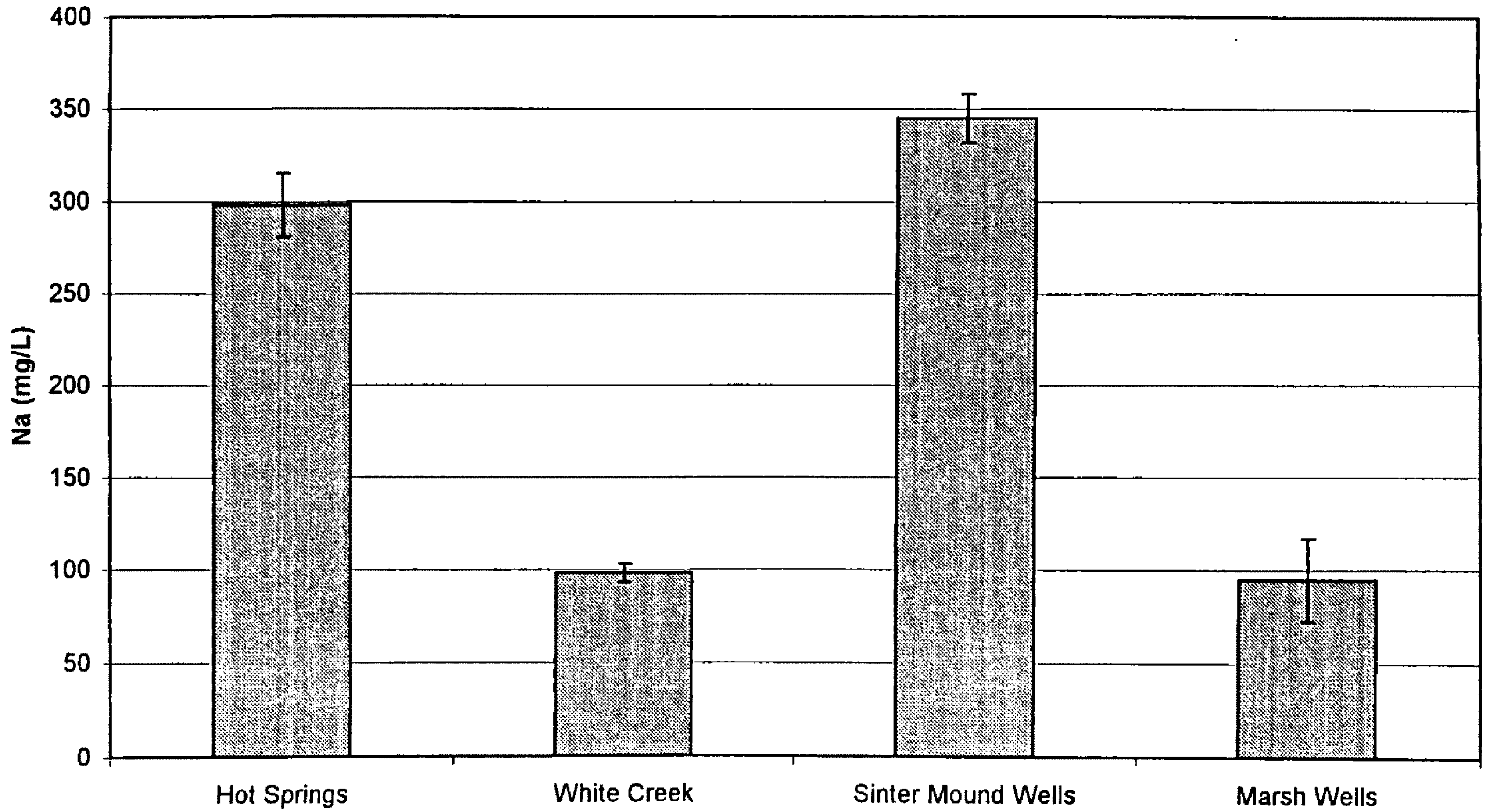

Sentinel Meadows - Boron
B (mg/L)
0
0.5
1
1.5
2
2.5
3
3.5
Hot Springs
Sent Creek
SMW-3; -5 to -10
SMW-2

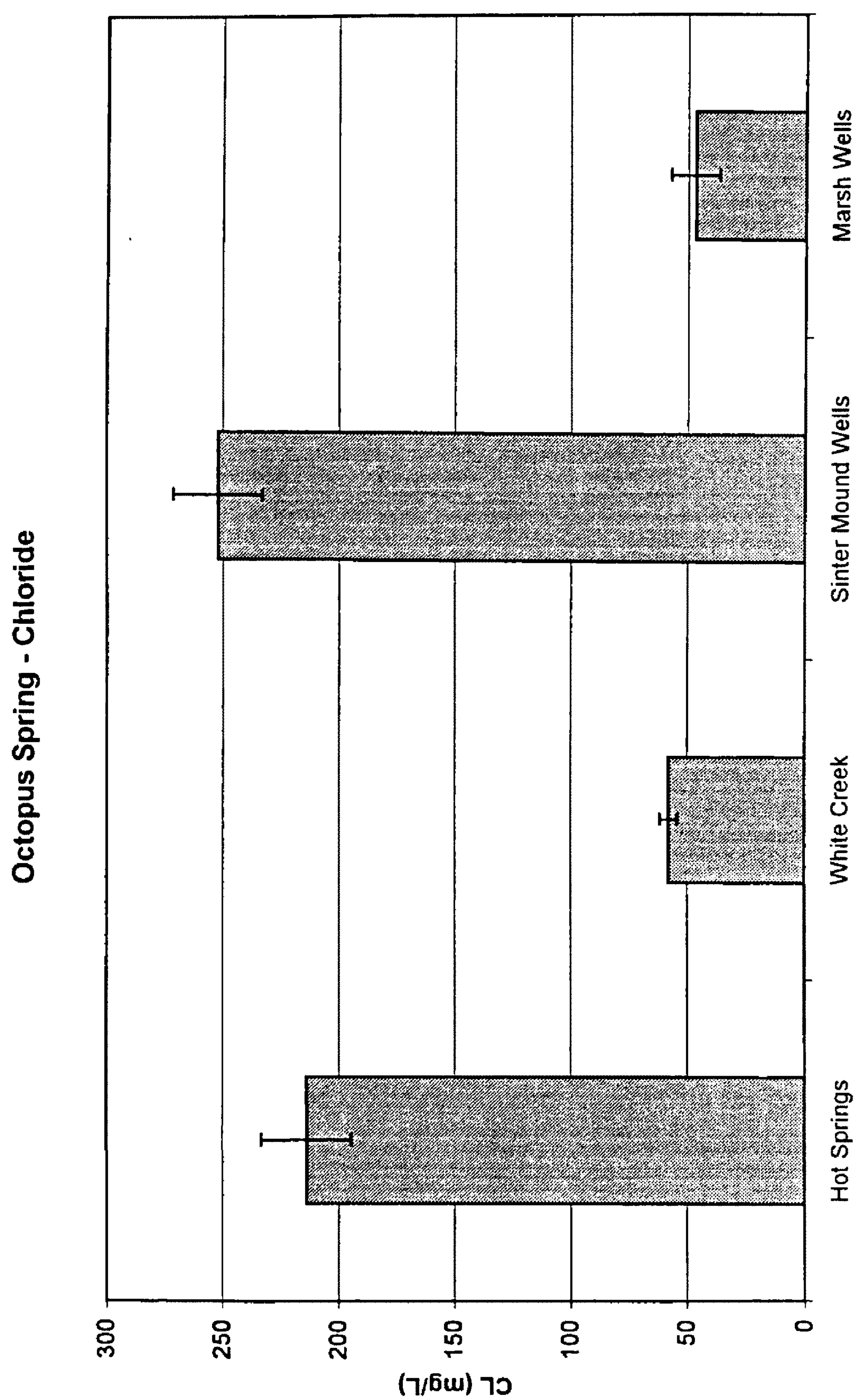


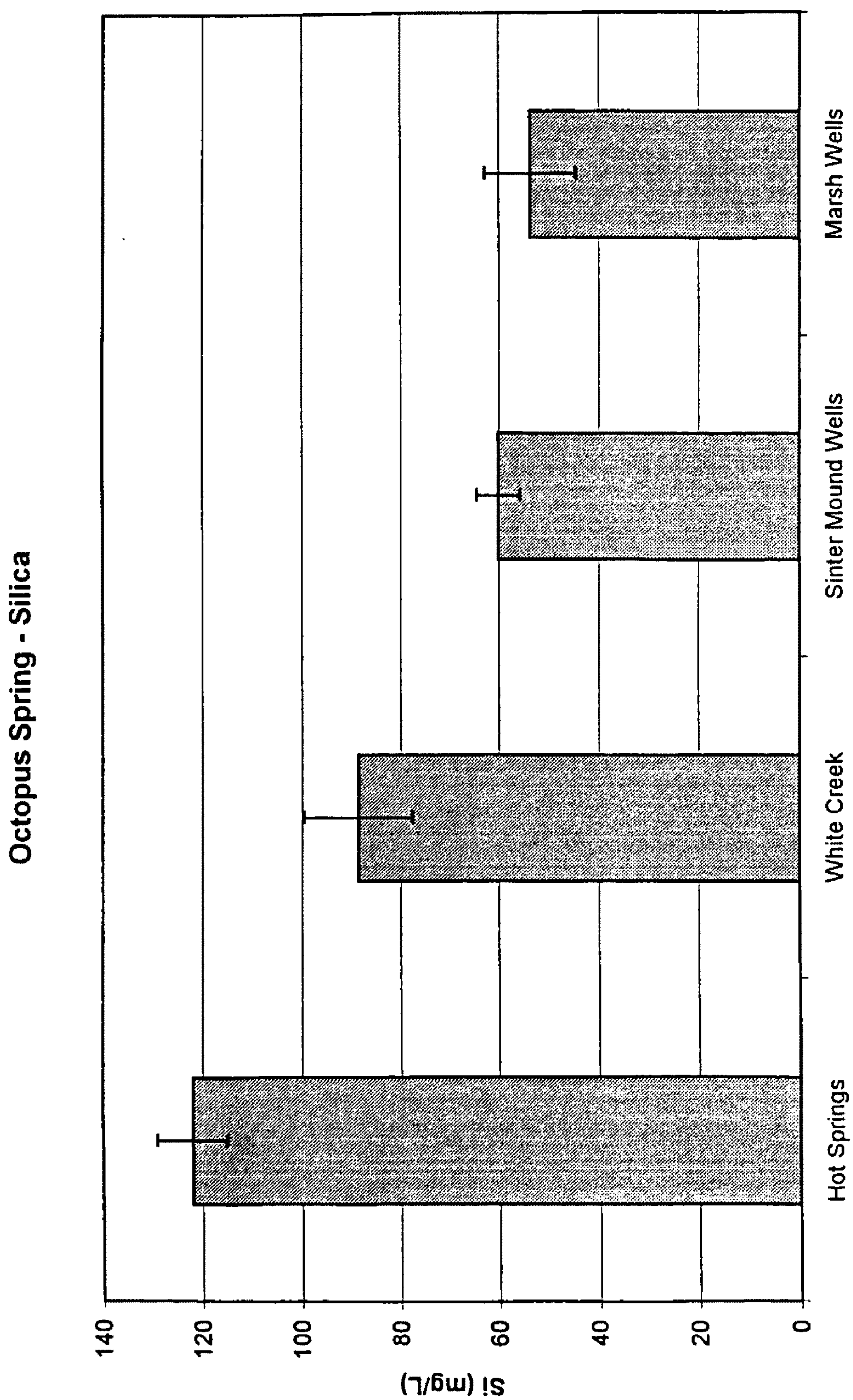
Sentinel Meadows - Alkalinity
CaCO3 (mg/L)
0
50
100
150
200
250
300
350
400
450
Hot Springs
Sent Creek
SMW-3; -5 to -10
SMW-2

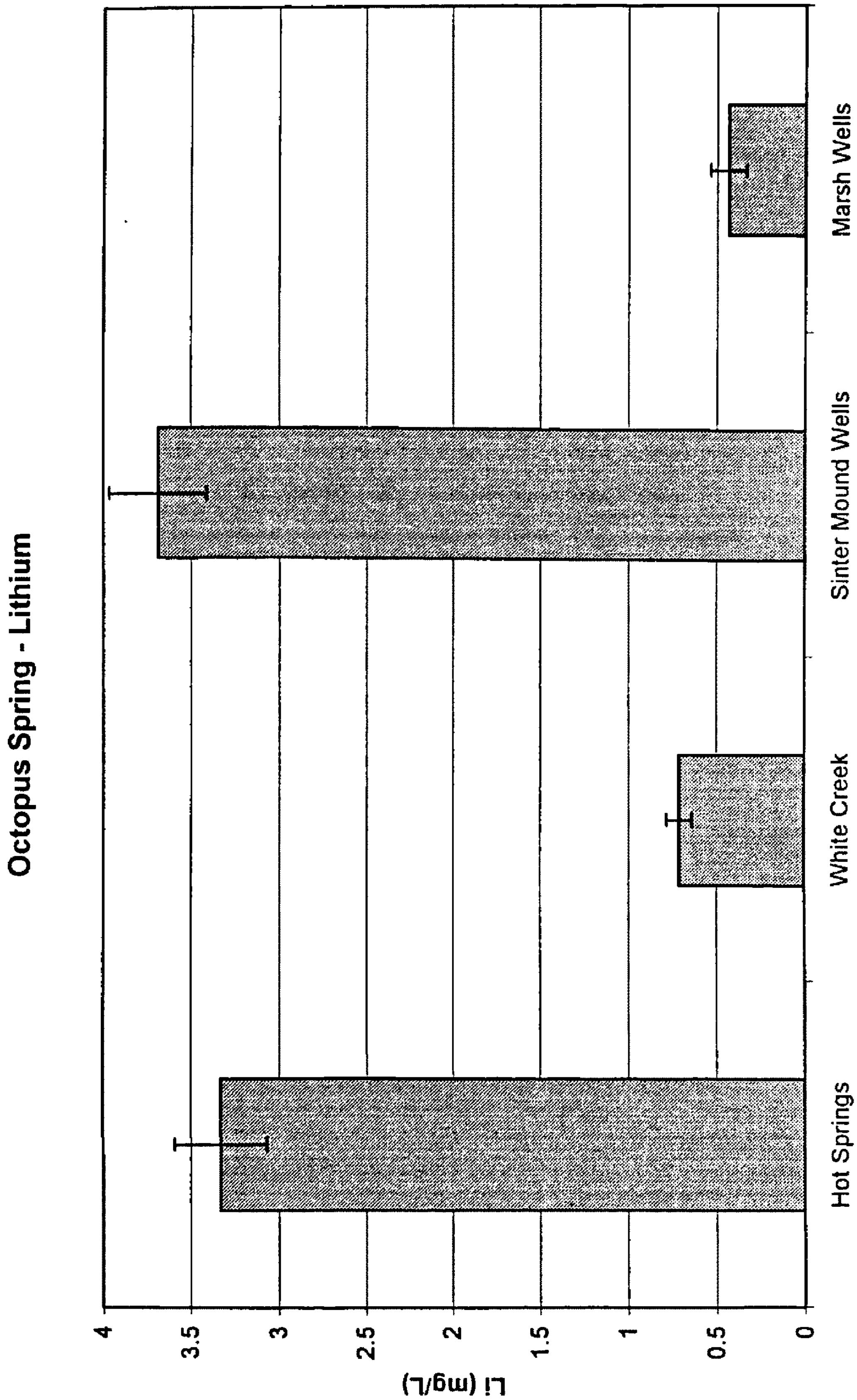

Sentinel Meadows - Sulfate
SO4 (mg/L)
0
2
4
6
8
10
12
14
16
Hot Springs
Sent Creek
SMW-3; -5 to -10
SMW-2

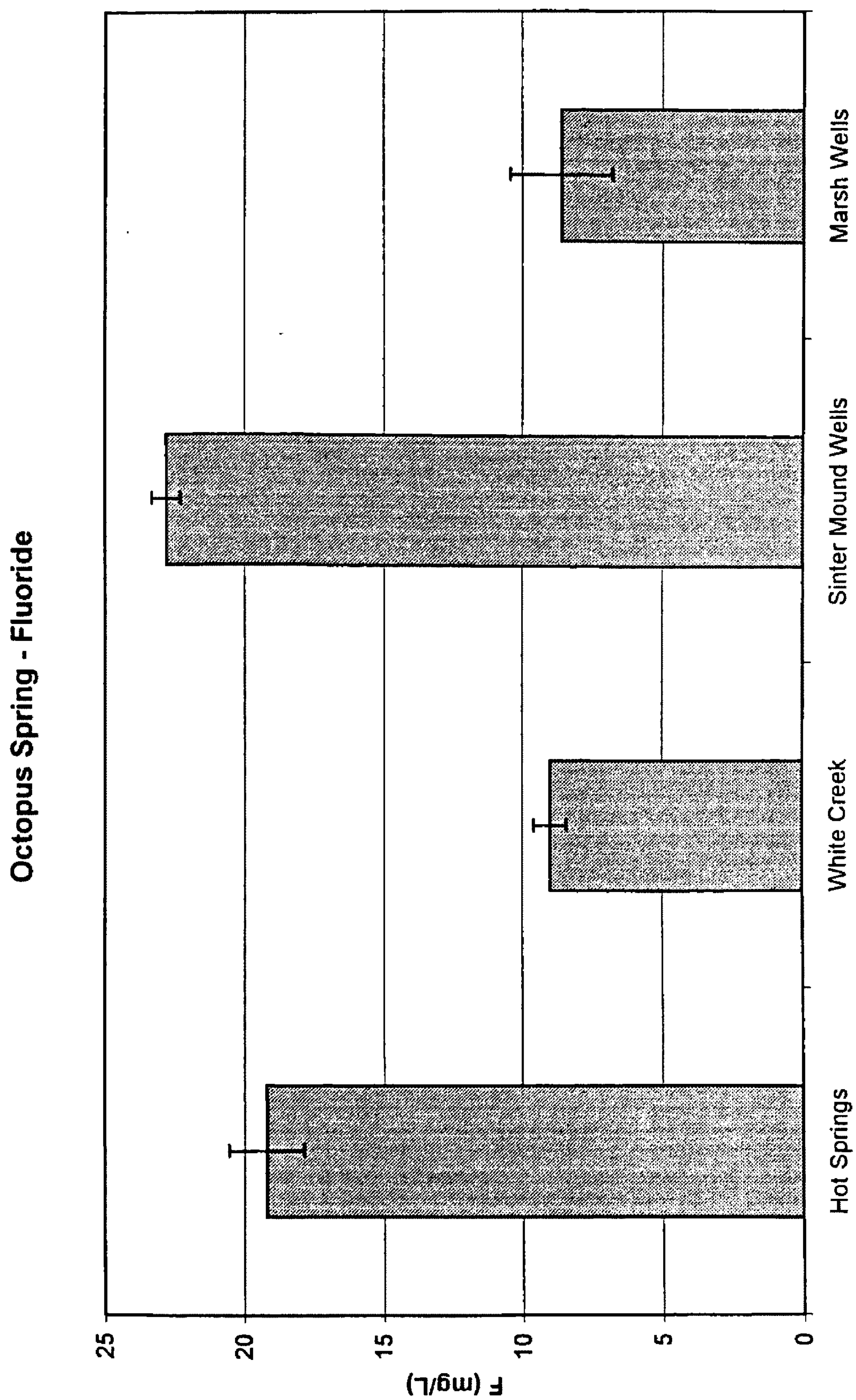
Octopus Spring - Sodium

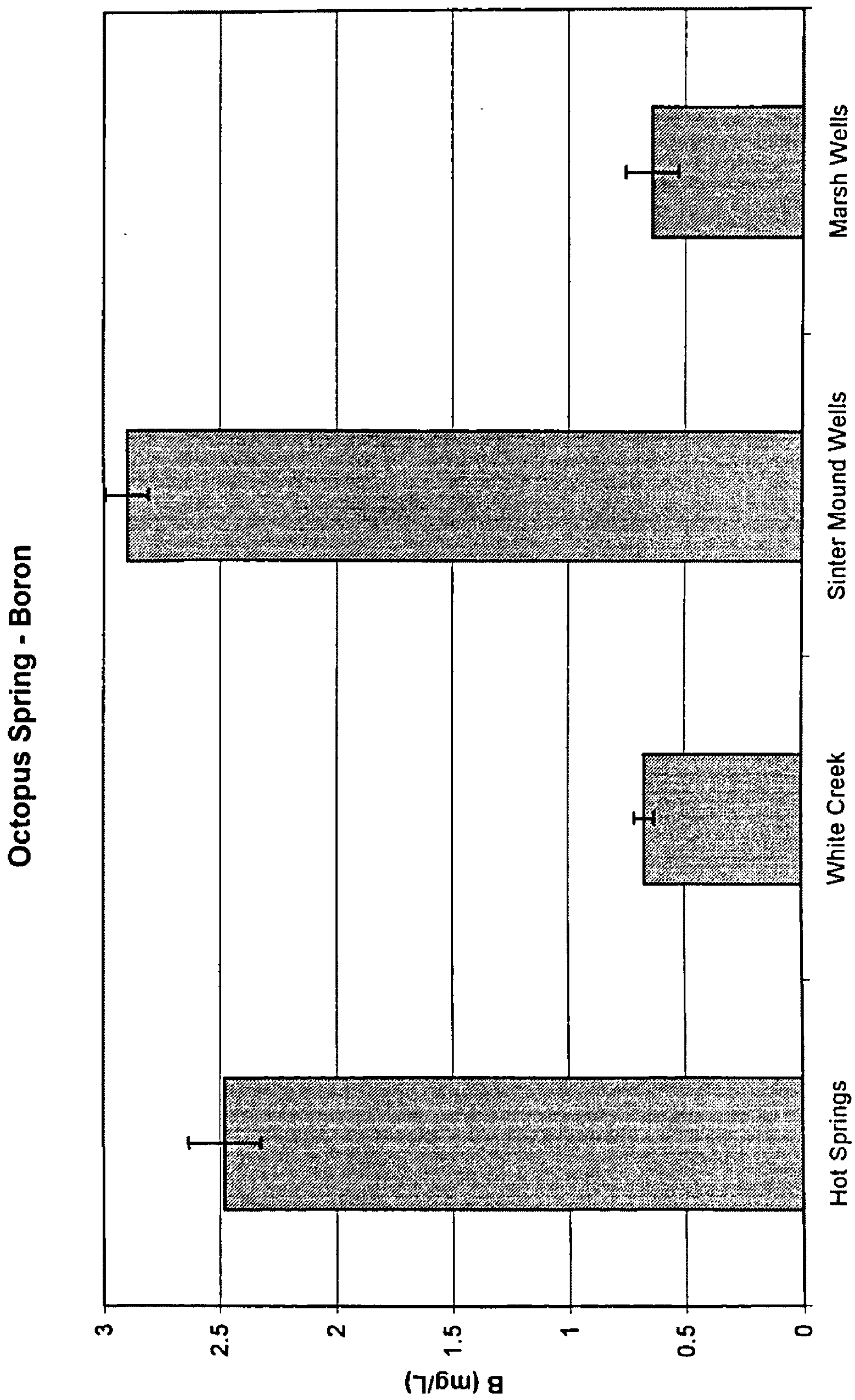


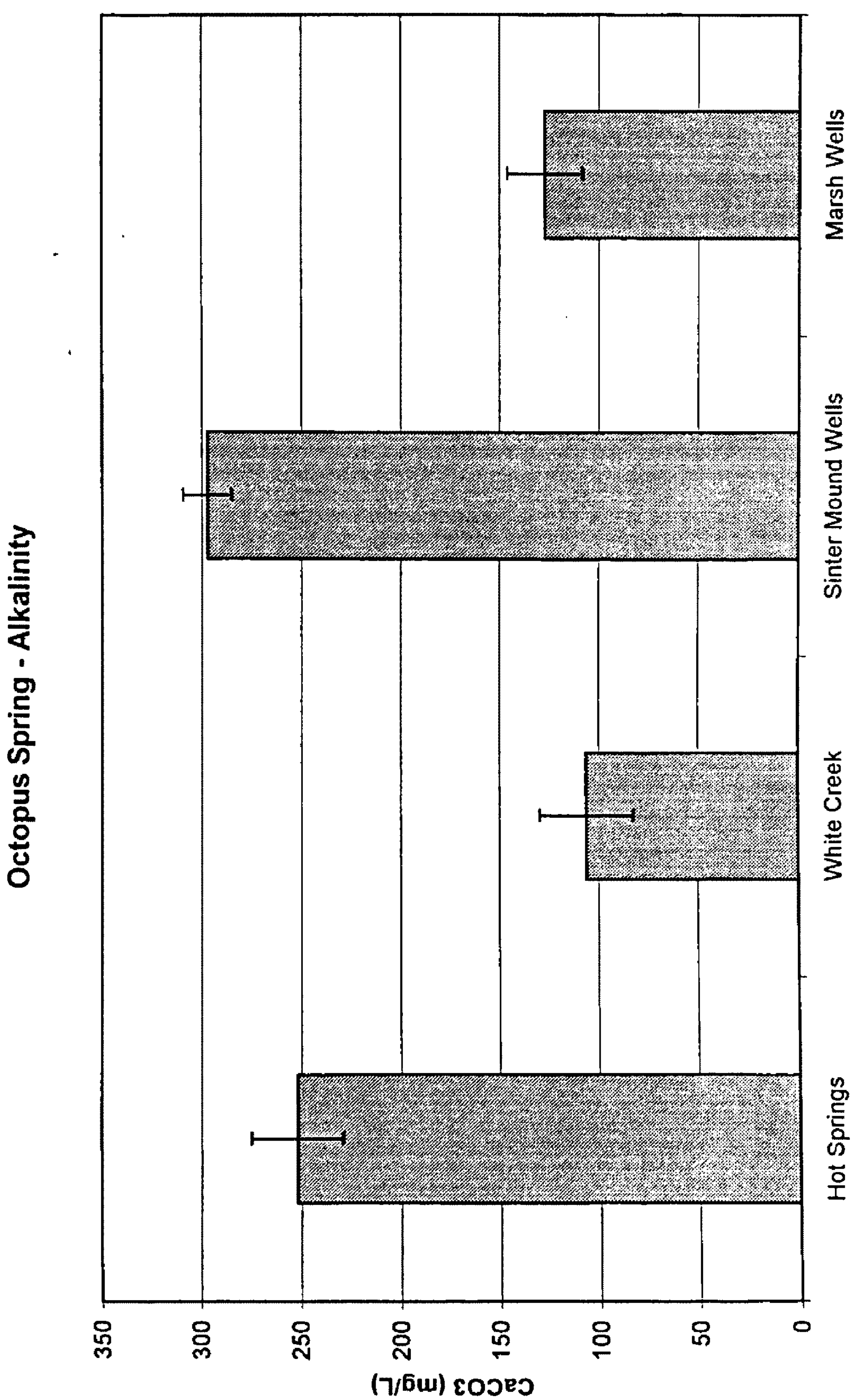

Octopus Spring - Chloride
CL (mg/L)
300
250
200
150
100
50
0
Hot Springs
White Creek
Sinter Mound Wells
Marsh Wells


Octopus Spring - Silica
Si (mg/L)
140
120
100
80
60
40
20
0
Hot Springs
White Creek
Sinter Mound Wells
Marsh Wells


Octopus Spring - Lithium
Li (mg/L)
0
0.5
1
1.5
2
2.5
3
3.5
4
Hot Springs
White Creek
Sinter Mound Wells
Marsh Wells

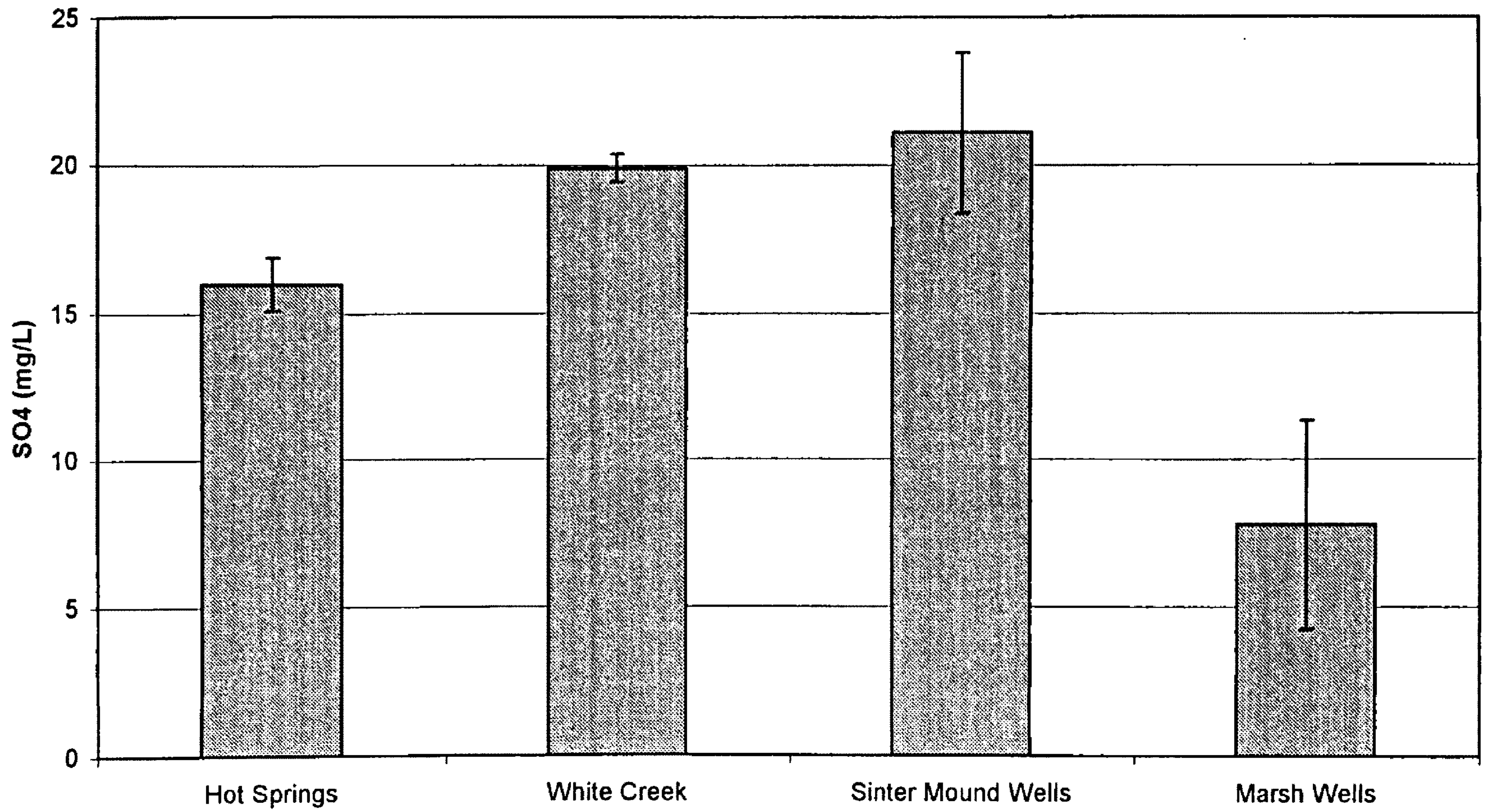

Octopus Spring - Fluoride
F (mg/L)
25
20
15
10
5
0
Hot Springs
White Creek
Sinter Mound Wells
Marsh Wells


Octopus Spring - Boron
B (mg/L)
3
2.5
2
1.5
1
0.5
0
Hot Springs
White Creek
Sinter Mound Wells
Marsh Wells



Octopus Spring - Alkalinity
CaCO3 (mg/L)
350
300
250
200
150
100
50
0
Hot Springs
White Creek
Sinter Mound Wells
Marsh Wells

Octopus Spring - Sulfate



QUALITY CONTROL

Field and Lab Duplicates; Lab Spikes (mg/L)

	Date	F	Cl	SO4	CaCO3	Al	As	B	Ca	Fe	K	Li	Mg	Mn	Mo	Na	P	Si	Sr	Ti	Zn
detection limits mg/L		2	0.5	2		0.07	0.07	0.03	0.1	0.03	3	0.1	0.1	0.005	0.01	0.1	0.2	0.1	0.005	0.005	0.005
OCT	07/28/95	20.2	222	17	270	0.274	1.54	2.75	bdl	bdl	20.8	3.37	bdl	bdl	0.0231	319	bdl	134	bdl	bdl	bdl
OCT DUP	07/28/95	20.8	223	16.7	265	0.275	1.56	2.73	bdl	bdl	21.2		bdl	bdl	0.0267	318	bdl	134	bdl	bdl	bdl
	%DIFFERENCE	2.9	0.4	-1.8	-1.9	0.4	1.3	-0.7			1.9				13.5	-0.3		0.0			
OMO	07/28/95	8.38	39.8	8.49	85	0.074	0.114	0.521	9.12	0.074	9.043	0.349	0.218	bdl	bdl	67.1	bdl	45.8	bdl	bdl	0.0453
OMO DUP	07/28/95	8.46	39.7	8.76	80	0.061	0.128	0.512	9	0.074	9.02	0.349	0.212	bdl	bdl	66.8	bdl	45.3	bdl	bdl	0.0293
	%DIFFERENCE	0.9	-0.3	3.1	-6.3	-21.3	10.9	-1.8	-1.3	0.0	-0.3	0.0	-2.8			-0.4		-1.1			-34.6
OPA	02/18/95	17.6	204	15.4	210	0.116	1.3	2.21	2.02	bdl	15.05	2.86	bdl	0.0097	0.0182	266	bdl	104	bdl	bdl	0.0126
OPA SPK	02/18/95					0.467	1.52	2.95	72.7	2.15	21.5		38.6	2.367	0.1312	287	1.3	116	0.1087	0.0303	2.287
OW1	11/12/94	23.7	189	18.8	285	bdl	1.59	2.89	0.682	bdl	22.22	3.97	bdl	bdl	0.0261	346	bdl	57	bdl	bdl	0.0146
OW1 DUP	11/12/94					bdl	1.57	2.9	0.678	bdl	22.08		bdl	bdl	0.0255	341	bdl	55.6	bdl	bdl	0.0071
	%DIFFERENCE						-1.3	0.3	-0.6		-0.6				-2.4	-1.5		-2.5			-105.6
OW1 SPK	11/12/94					0.783	1.77	4.09	119	4.01	37.61		79.9	4.038	0.2306	363	1.6	77.4	0.2112	0.045	4.069
OW1	01/14/96	23.1	251	19.5	290	bdl	1.78	3.1	0.644	bdl	25.45	3.73	bdl	bdl	0.0299	354	bdl	58.3	bdl	bdl	0.0255
OW1 DUP	01/14/96	22.7	251	18.2	287	bdl	1.72	3.01	0.635	bdl	26.31	3.6	bdl	bdl	0.0317	348	bdl	56.3	bdl	bdl	0.0309
	%DIFFERENCE	-1.8	0.0	-7.1	-1.0		-3.5	-3.0	-1.4		3.3	-3.6			5.7	-1.7		-3.6			17.5
OW1 LAB DUP	01/14/96					bdl	1.71	2.97	0.606	bdl	23.6		bdl	bdl	0.0287	351	bdl	55.9	bdl	bdl	0.0243
OW4	08/25/94	5.68	46.2	2.45	136	0.121	0.101	0.643	14.3	0.188	13.94	0.466	0.332	0.1753	0.0106	85.2	bdl	50.3	0.0071	0.0088	0.1375
OW4 LAB DUP	08/25/94					0.119	0.109	0.612	13.8	0.181	13.46		0.324	0.1694	0.0104	83.6	bdl	49	0.0068	0.0078	0.1334
	%DIFFERENCE						7.3	-5.1	-3.6	-3.9	-3.6		-2.5	-3.5	-1.9	-1.9		-2.7	-4.4	-12.8	-3.1
OW4 SPK	08/25/94					0.467	0.289	1.21	69.3	2.05	18.16		36.9	2.064	0.1063	103	0.97	57.1	0.1004	0.0296	2.097
OW6	09/03/96	14.9	82.4	15.5	185	bdl	1.07	1.054	5.763	0.099	15.42	0.7808	bdl	bdl	0.0152	180	bdl	85.21	bdl	bdl	0.0657
OW6 SPK	09/03/96					1.25	3.57	2.339	61.29	22.56	32.39	0.6071	10.46	1.016	0.5318	199.2	2.305	133.2	1.088	bdl	1.083
OW7	07/28/95	8.99	30.9	4.78	142.5	1.69	bdl	0.643	8.13	1.08	8.728	0.31	0.205	0.065	bdl	89.7	0.23	51.5	0.0066	0.0292	0.0379
OW7 DUP	07/28/95				142.5	1.69	bdl	0.654	8.11	1.08	8.973	0.31	0.222	0.0648	bdl	89.7	0.24	51.5	0.0066	0.0294	0.0378
	%DIFFERENCE					0.0		1.7	-0.2	0.0	2.7	0.0	7.7	-0.3		0.0	4.2	0.0	0.0	0.7	-0.3
OW7	11/22/95				130	0.195	bdl	0.526	8.95	0.219	8.031	0.337	0.137	0.0057	bdl	90.6	bdl	44.2	0.0062	bdl	0.2132
OW7 DUP	11/22/95					0.227	bdl	0.541	9.3	0.226	8.33	0.365	0.17	0.0063	bdl	91.4	bdl	45.5	0.0064	0.005	0.222
	%DIFFERENCE					14.1		2.8	3.8	3.1	3.6	7.7	19.4	9.5		0.9		2.9	3.1		4.0
OW7 SPK	11/22/95					1.46	2.85	2.08	66.1	23.3	31.98		10.8	1.123	0.5903	128	2.9	108	1.06	0.0058	1.373
OWC1	02/18/95	9.12	55.2	20.2	108	bdl	0.188	0.644	15.9	bdl	17.13	0.701	0.288	0.1919	bdl	96.3	0.3	84.6	0.0141	0.005	0.017
OWC1 DUP	02/18/95		55	20.1	100																
	%DIFFERENCE		-0.4	-0.5	-8.0																
OWC2	08/25/94	7.05	55.3	20.1	124	bdl	0.178	0.631	14.9	bdl	19.54	0.676	0.278	0.1929	bdl	94.5	bdl	89.3	0.0144	bdl	0.0224
OWC2 DUP	08/25/94					bdl	0.17	0.581	13.7	bdl	17.38		0.252	0.1765	bdl	86.1	bdl	81.3	0.0134	0.0056	0.0213
	%DIFFERENCE						-4.7	-8.6	-8.8		-12.4		-10.3	-9.3		-9.2		-9.8	-7.5		-5.2
OWC2 SPK	08/25/94					0.388	0.348	1.22	70.6	1.91	23.05		37.4	2.184	0.1045	111	0.95	89.7	0.1085	0.0261	2.025
OWC3	02/18/95	9.896	70	19.9	140	0.194	0.255	0.799	15	0.049	16.93	0.908	0.266	0.1864	bdl	113	0.33	85.8	0.0137	0.0064	0.0192
OWC3 DUP	02/18/95					0.211	0.274	0.799	15	0.057	16.98		0.282	0.1859	bdl	111	0.38	85.5	0.0138	0.0084	0.0201
	%DIFFERENCE					8.1	6.9	0.0	0.0	14.0	0.3		5.7	-0.3		-1.8	13.2	-0.4	0.7	23.8	4.5
SC1	11/13/94	4.6	19.1	5.03	50	0.08	0.124	0.284	4.9	0.091	4.384	0.21	0.85	0.0155	bdl	37.5	bdl	30.2	bdl	bdl	0.0246
SC1 LAB DUP	11/13/94					0.074	0.123	0.29	4.96	0.094	4.518		0.822	0.0152	bdl	37.7	bdl	30.5	bdl	bdl	0.0239
	%DIFFERENCE					-8.1	-0.8	2.1	1.2	3.2	3.0		-3.4	-2.0		0.5		1.0			-2.9
SC1	02/22/95	3.91	16.7	3.59	55	0.125	0.096	0.282	5.75	0.148	4.859	0.208	0.823	0.0364	bdl	38.1	0.28	30.4	0.0058	0.008	0.0062
SC1 DUP	02/22/95					0.12	0.086	0.286	5.7	0.146	4.795		0.812	0.0357	bdl	38.7	0.27	30.3	0.0057	0.0073	0.0056
	%DIFFERENCE					-4.2	-11.6	1.4	-0.9	-1.4	-1.3		-1.4	-2.0		1.6	-3.7	-0.3	-1.8	-9.6	-10.7

QUALITY CONTROL
Field and Lab Duplicates; Lab Spikes (mg/L)

	Date	F	Cl	SO4	CaCO3	Al	As	B	Ca	Fe	K	Li	Mg	Mn	Mo	Na	P	Si	Sr	Ti	Zn
detection limits mg/L		2	0.5	2		0.07	0.07	0.03	0.1	0.03	3	0.1	0.1	0.005	0.01	0.1	0.2	0.1	0.005	0.005	0.005
SC1	07/30/95	3.34	12.1	2.95	40	0.084	0.081	0.195	5.71	0.105	bdl	bdl	0.84	0.0192	bdl	23.9	0.21	29.4	bdl	bdl	0.0158
SC1 DUP	07/30/95	3.31	11.9	2.96	42.5	0.078	0.093	0.199	5.76	0.103	bdl	0.139	0.865	0.0192	bdl	24.1	bdl	29.6	bdl	bdl	0.0213
	%DIFFERENCE	-0.9	-1.7	0.3	5.9	-7.7	12.9	2.0	0.9	-1.9			2.9	0.0		0.8		0.7			25.8
SC1	09/04/96	2.71	9.74	2.42	45	bdl	bdl	0.1259	6.033	0.0949	bdl	0.09	0.8214	0.0097	bdl	18.12	bdl	27.88	bdl	bdl	0.021
SC1 SPK	09/04/96					1.24	2.78	1.596	61.82	22.86	22.45	0.0706	11	1.03	0.5253	64.38	2.438	88.81	1.108	bdl	1.039
SC3	09/04/96	2.85	11.7	2.51	27.5	bdl	bdl	0.1697	6.072	0.0915	bdl	0.1021	0.8014	0.0102	bdl	20.25	bdl	28.04	bdl	bdl	0.1715
SC3 DUP	09/04/96	3.17	12.1	2.45	35	bdl	bdl	0.1571	6.114	0.0954	bdl	0.1033	0.782	0.0103	bdl	20.24	bdl	28.19	bdl	bdl	0.0951
	%DIFFERENCE	10.1	3.3	-2.4	21.4			-8.0	0.7	4.1		1.2	-2.5	1.0		0.0		0.5			-80.3
SC4	02/22/95	4.54	23.4	3.69	92.5	0.14	0.1	0.385	5.81	0.182	5.695	0.26	0.854	0.0376	bdl	47.8	0.3	30.1	0.0064	0.0084	0.0169
SC4 DUP	02/22/95	4.6	23.1	3.72	80	0.129	0.107	0.393	5.86	0.187	5.801	0.232	0.851	0.0384	bdl	48.1	0.33	30.3	0.0065	bdl	0.0121
	%DIFFERENCE	1.3	-1.3	0.8	-15.6	-8.5	6.5	2.0	0.9	2.7	1.8	-12.1	-0.4	2.1		0.6	9.1	0.7	1.5		-39.7
SCC	07/30/95	1.85	199	11.8	242.5	0.416	0.981	3.11	0.473	bdl	16.21	2.3	bdl	bdl	0.0317	309	bdl	168	bdl	bdl	0.0188
SCC LAB DUP	07/30/95					0.428	1	3.08	0.474	bdl	16.18	2.3	bdl	bdl	0.031	306	bdl	166	bdl	bdl	0.0202
	%DIFFERENCE					2.8	1.9	-1.0	0.2		-0.2	0.0			-2.3	-1.0		-1.2			6.9
SCCS	02/22/95	22	206	13.2	293	0.123	0.649	2.79	2.57	1.02	22.06	1.98	0.681	0.2696	0.0182	306	0.25	68	0.0064	bdl	0.0085
SCCS SPK	02/22/95					0.464	0.881	3.49	72.1	3.14	28.12		38.6	2.599	0.1297	314	1.3	81.4	0.1122	0.0315	2.247
	%DIFFERENCE					73.5	26.3	20.1	96.4	67.5	21.6		98.2	89.6	86.0	2.5	80.8	16.5	94.3		99.6
SFC	07/30/95	22.1	193	13.6	245	0.431	0.972	3.12	0.519	bdl	12.73	1.86	bdl	bdl	0.0294	303	bdl	16.3	bdl	bdl	0.0108
SFC DUP	07/30/95	21.9	192	13.7	265	0.444	0.988	3.12	0.499	bdl	12.74	1.86	bdl	bdl	0.031	307	bdl	16.4	bdl	bdl	0.0309
	%DIFFERENCE	-0.9	-0.5	0.7	7.5	2.9	1.6	0.0	-4.0		0.1	0.0			5.2	1.3		0.6			65.0
SMW2	09/27/95	6.86	113	5.25	243	0.154	0.144	1.69	12.3	4.72	45.37	0.74	3.66	0.2479	bdl	148	bdl	56.2	0.0553	0.0013	0.0594
SMW2 DUP	09/27/95	6.88	113	5.1	233	0.294	0.161	1.7	12.6	3.92	46.02	0.74	3.73	0.2557	bdl	149	bdl	56.7	0.0555	bdl	0.0463
	%DIFFERENCE	0.3	0.0	-2.9	-4.3	47.6	10.6	0.6	2.4	-20.4	1.4	0.0	1.2	3.1		0.7		0.9	0.4		-28.3
SMW3	09/19/95	18.4	185	10.5	368	bdl	0.203	2.74	4.67	0.571	76.85	1.33	2.1	0.5672	bdl	303	bdl	61.6	0.0089	bdl	0.0427
SMW3 LAB DUP	09/19/95				385	bdl	0.201	2.71	4.57	0.576	74.16	1.27	2.03	0.5566	bdl	294	bdl	61.2	0.0092	bdl	0.0456
	%DIFFERENCE				4.4		-1.0	-1.1	-2.2	0.9	-3.6	-4.7	-3.4	-1.9		-3.1		-0.7	3.3		6.4
SMW5	09/19/95	25.8	205	11.6	323	0.153	0.489	3.25	8.9	0.673	26.53	1.89	0.689	0.1437	0.0204	303	0.25	62.1	0.0083	bdl	0.1046
SMW5 DUP	09/19/95	25.6	205		323	0.143	0.43	3.18	8.38	0.666	23.91	1.83	0.634	0.1389	0.0212	300	bdl	60	0.007	bdl	0.102
	%DIFFERENCE	-0.8	0.0		0.0	-7.0	-13.7	-2.2	-6.2	-1.1	-11.0	-3.3	-8.7	-3.5	3.8	-1.0		-3.5	-18.6		-2.5
SMW6	09/19/95	16.8	187	14.5	430	0.36	0.868	2.77	6.27	7.62	78.05	2.04	2.45	0.7739	0.0156	319	0.24	62.1	0.0184	bdl	0.0878
SMW6 DUP	09/19/95	16.8	187		430							1.96									
	%DIFFERENCE	0.0	0.0		0.0							-4.1									
SSF	07/30/95	1.95	1.17	2.35	32.5	0.091	bdl	0.045	9.62	0.065	bdl	bdl	1.08	0.013	bdl	4.89	bdl	21.4	0.0117	bdl	0.0753
SSF DUP	07/30/95					0.087	bdl	0.03	9.51	0.062	bdl	bdl	1.05	0.0122	bdl	4.83	bdl	21.2	0.0116	bdl	0.0757
	%DIFFERENCE					-4.6		-50.0	-1.2	-4.8			-2.9	-6.6		-1.2		-0.9	-0.9		0.5