

**KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 98-24**

**EQUUS BEDS MINERAL INTRUSION PROJECT REPORT
FY 1998**

by

**D. P. Young
R. W. Buddemeier
D. O. Whittemore**

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Kansas Geological Survey

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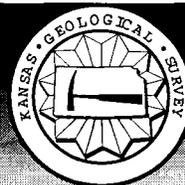
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I. Introduction

The Equus Beds Aquifer Mineral Intrusion (EBMI) project is a joint effort of the U.S. Bureau of Reclamation, Equus Beds Groundwater Management No. 2 (GMD2), Kansas Geological Survey (KGS), U.S. Geological Survey (USGS), and the Kansas Water Office. The background and purpose are discussed in detail by Whittemore and Sophocleous (1995) in an appraisal investigation for the study.

The study is focused on interactions between the Arkansas River and its tributaries, the underlying alluvial aquifer, and Permian-age bedrock beneath the aquifer. Both surface waters and bedrock of Permian age may be sources of saline water to the aquifer. The main study area lies between Nickerson and Hutchinson in the extended western portion of GMD2 in north-central Reno County (Figure I-1). The general study area encompasses the sixteen townships shown in Figure I-1. Fresh water is present in the aquifer north of the Arkansas River while saline ground water occurs along and south of the river. The cities of Hutchinson and Nickerson obtain their water supplies from the fresh ground water. Whittemore and Sophocleous (1995) identified specific needs and purposes for investigating the salinity problem in the Equus Beds aquifer in the western part of GMD2.

Intrusion of saline water is both natural and human-induced in the Great Bend Prairie and Equus Beds alluvial aquifers in south-central Kansas. Buddemeier et al. (1995) provided an overview of the issue and identified areas with known or suspected saltwater contamination (see Figure I-2). The recent Big Bend Aquifer Mineral Intrusion project studied the saltwater intrusion problem in the Great Bend Prairie aquifer in the eastern portion of Groundwater Management District No. 5 (GMD5), which is just upgradient (west) of the present study area (Figure I-2). Another study concerning hydrologic and chemical interactions between the Arkansas River and the Equus Beds aquifer was recently conducted downgradient between Hutchinson and Wichita (see Myers et al., 1996).

Information on the groundwater monitoring network installed by the project, general hydrology and geology, and initial monitoring results were presented by Young et al. (1997). Following is a brief description of the network.

A network of 41 monitoring wells at 21 sites was installed for groundwater data collection. The wells are used primarily for monitoring water levels and water quality at different depths in the Equus Beds aquifer. Each site has at least one well screened in the Equus Beds aquifer. Most sites consist of two or more wells completed at different depths in the aquifer. Nearly all the sites have a deep well, the "C" well, completed directly above bedrock. Some sites have a well of intermediate depth in the aquifer, the "B" well. Most sites have at least one well of shallow to intermediate depth, the "A" well. And one site has four wells; the shallowest well has the designation "AA". See Table I-1 for a listing of sites and wells.

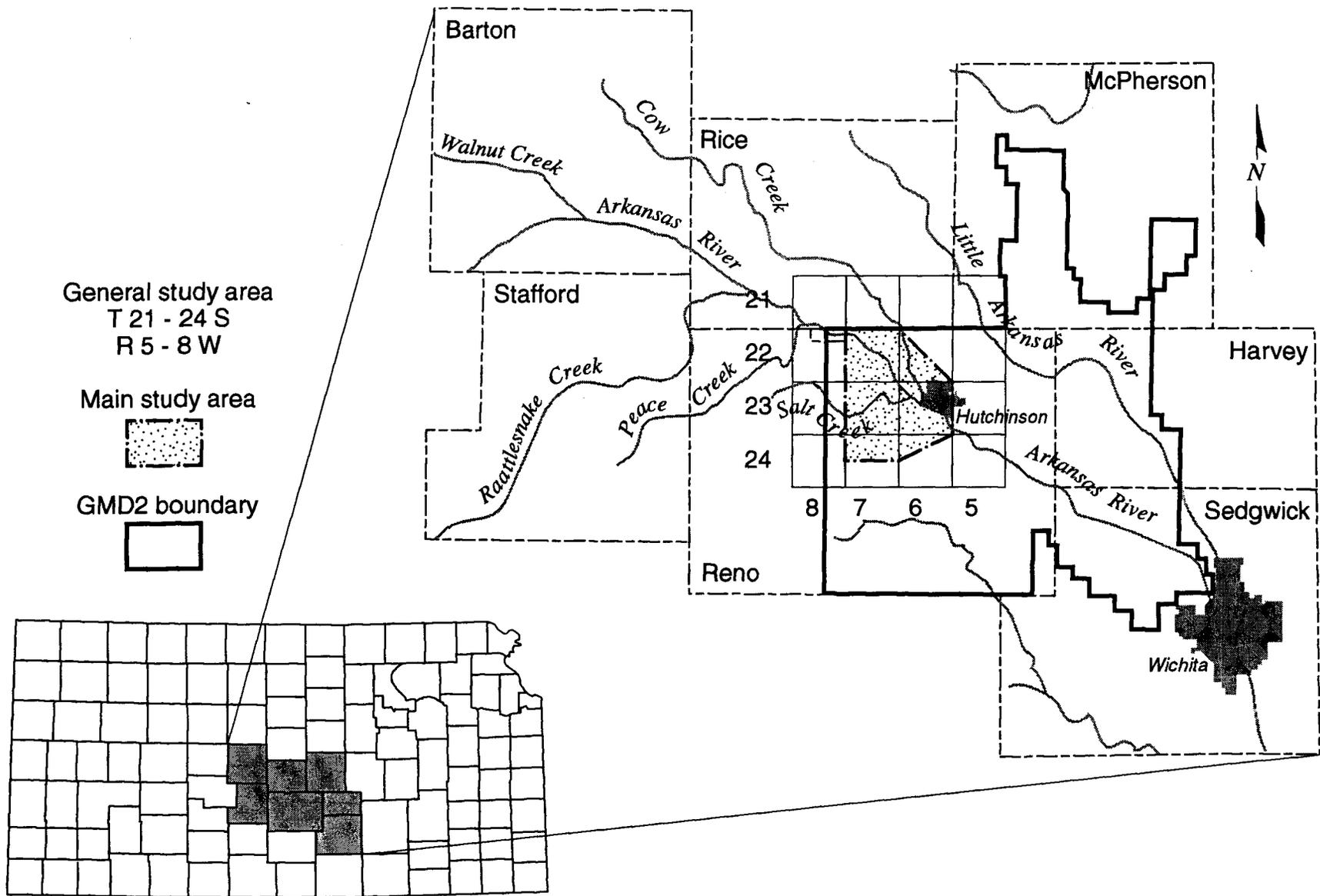


Figure I-1. Location of main study area within general study area (township-range grid) and study region (7 county area).

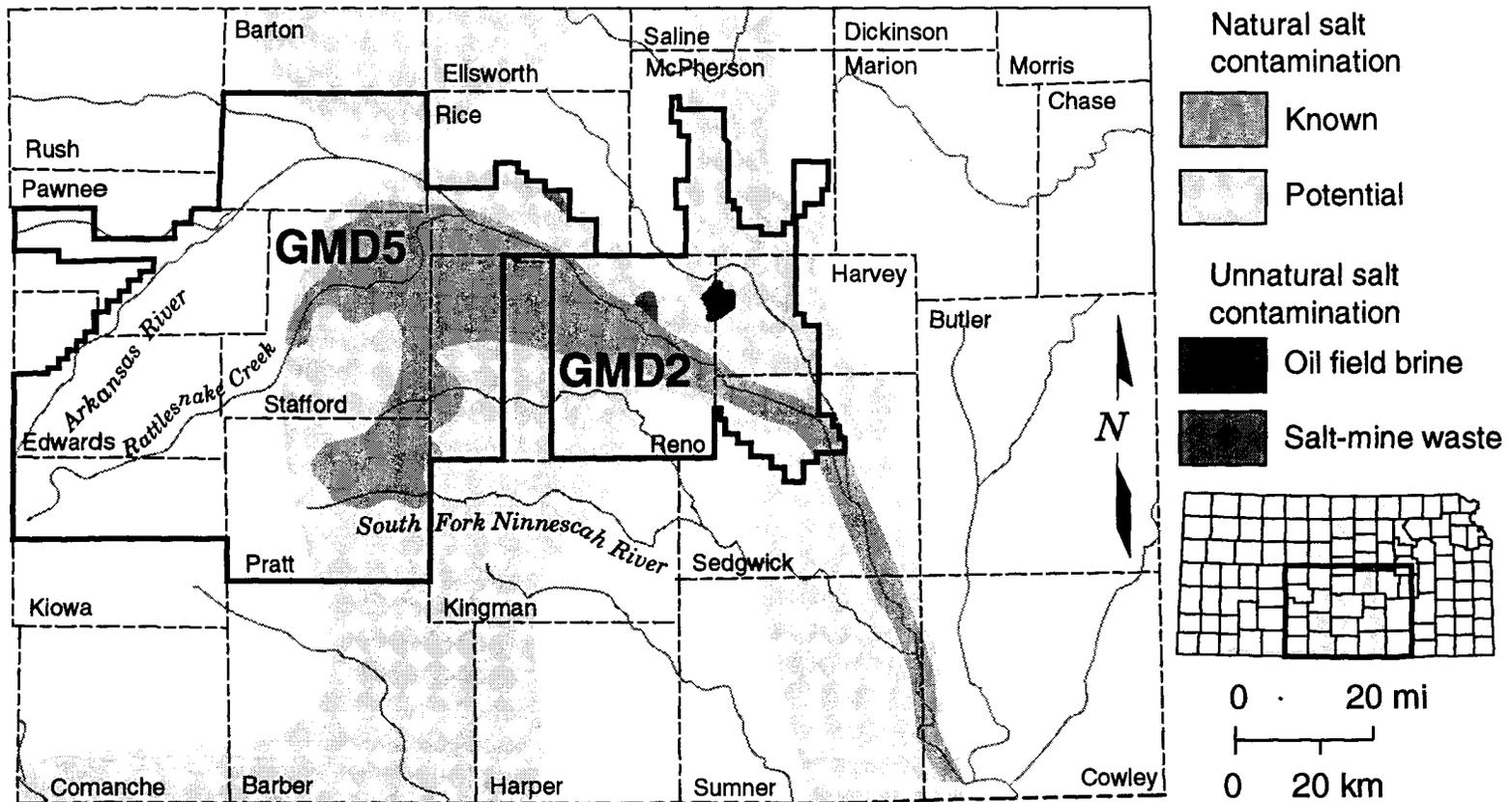


Figure I-2. Areas with known or potential saltwater contamination in south-central Kansas. Areas identified as "known" natural salt contamination have saltwater within the freshwater aquifer. In the areas labeled "potential" natural salt contamination, subsurface bedrock formations containing salt or saltwater are in contact with the overlying freshwater aquifers (from Buddemeier et al., 1995).

Table I-1. Well and site information from the the EBMI groundwater monitoring network.

ID	LOCATION				LAND ELEV (ft)	DEPTH		SCREEN DEPTH (ft)
	SUBD	SEC	TWP	RGE		TO BEDROCK (ft)	BEDROCK ELEV (ft)	
EB250C EB250A	NENENW	19	23	04W	1496.49	67	1429.5	57-67 38-48
EB251C EB251A	SESESE	14	22	06W	1627.26	65	1562.3	52-62 20-30
EB252C EB252A	NENENE	27	22	06W	1556.28	66	1490.3	56-66 37-47
EB253C	SESW	27	22	06W	1554.71	61	1493.7	49.5-59.5
EB254C	NENENE	5	23	06W	1555.46	46	1509.5	36-46
EB255C EB255A	SWSWNE	5	23	06W	1556.48	75	1481.5	63-73 20-30
EB256C EB256B EB256A	NESENE	12	23	07W	1563.60	85	1478.6	74-84 51-61 12-22
EB257C EB257B EB257A	NWNENE	23	23	07W	1602.24	186	1416.2	176-186 140-150 84-94
EB258B EB258A	NENENE	33	23	07W	1614.07	127	1487.1	96-106 64-74
EB259B EB259A	SESESE	33	21	06W	1696.84	106	1590.8	75-85 10-20
EB260C	NENENE	18	22	06W	1573.99	73	1501.0	63-73
EB261C EB261A	SESESE	23	22	07W	1581.32	120	1461.3	112-122 20-76
EB262C	NENENE	19	21	06W	1650.06	2	1648.1	55-65
EB263C	NENENE	35	21	07W	1590.02	67	1523.0	56-66
EB264C EB264A	NENENE	3	22	07W	1593.84	55	1538.8	45-55 20-51

(continued)

Table I-1. Well and site information from the EBMI groundwater monitoring network (continued).

ID	LOCATION				LAND ELEV (ft)	DEPTH		SCREEN DEPTH (ft)
	SUBD	SEC	TWP	RGE		TO BEDROCK (ft)	BEDROCK ELEV (ft)	
EB265C	SESESE	4	22	07W	1594.96	55	1540.0	44.5-54.5
EB266B EB266A	SESWSE	8	22	07W	1601.24	108	1493.2	85-95 37-47
EB267C EB267B EB267A	SWSWSW	17	22	07W	1634.04	206	1428.0	196-206 105-115 63-73
EB268C EB268B EB268A	SWSWNW	30	22	07W	1638.84	152	1486.8	141.5-151.5 88-98 33-43
EB269C EB269B EB269A	SWSWSW	31	22	07W	1634.75	187	1447.8	177-187 101-111 35-45
EB270C EB270B EB270A EB270AA	NWNWNW	18	23	07W	1625.30	170	1455.3	160-170 127-137 82-92 40-50

The monitoring sites were situated to form transects across the Arkansas River. An effort was made to complete some wells in alluvial materials deposited in deep bedrock channels, which may be significant pathways for saltwater transport. Figure I-3 shows locations of new (EB250-EB270) and existing groundwater monitoring sites in the general study area. Figure I-4 includes the labeled transects and surface water data collection sites. Table I-1 summarizes basic well and site information, including groundwater monitoring site and well ID, legal location, land surface elevation, depth to bedrock, bedrock surface elevation, and screen intervals. Estimated elevations listed in the previous report have been replaced with surveyed elevation measurements made by the U.S. Bureau of Reclamation using a Global Positioning System (GPS).

This report summarizes progress to date, with emphasis on the accomplishments of Fiscal Year 1998 (July 1, 1997 – June 30, 1998). Results are presented in sections dealing with Groundwater Levels (Section II), Groundwater Quality (Section III), Surface Water (Section IV), and Salt Budgets and Models (Section V). Literature references are listed in Section VI.

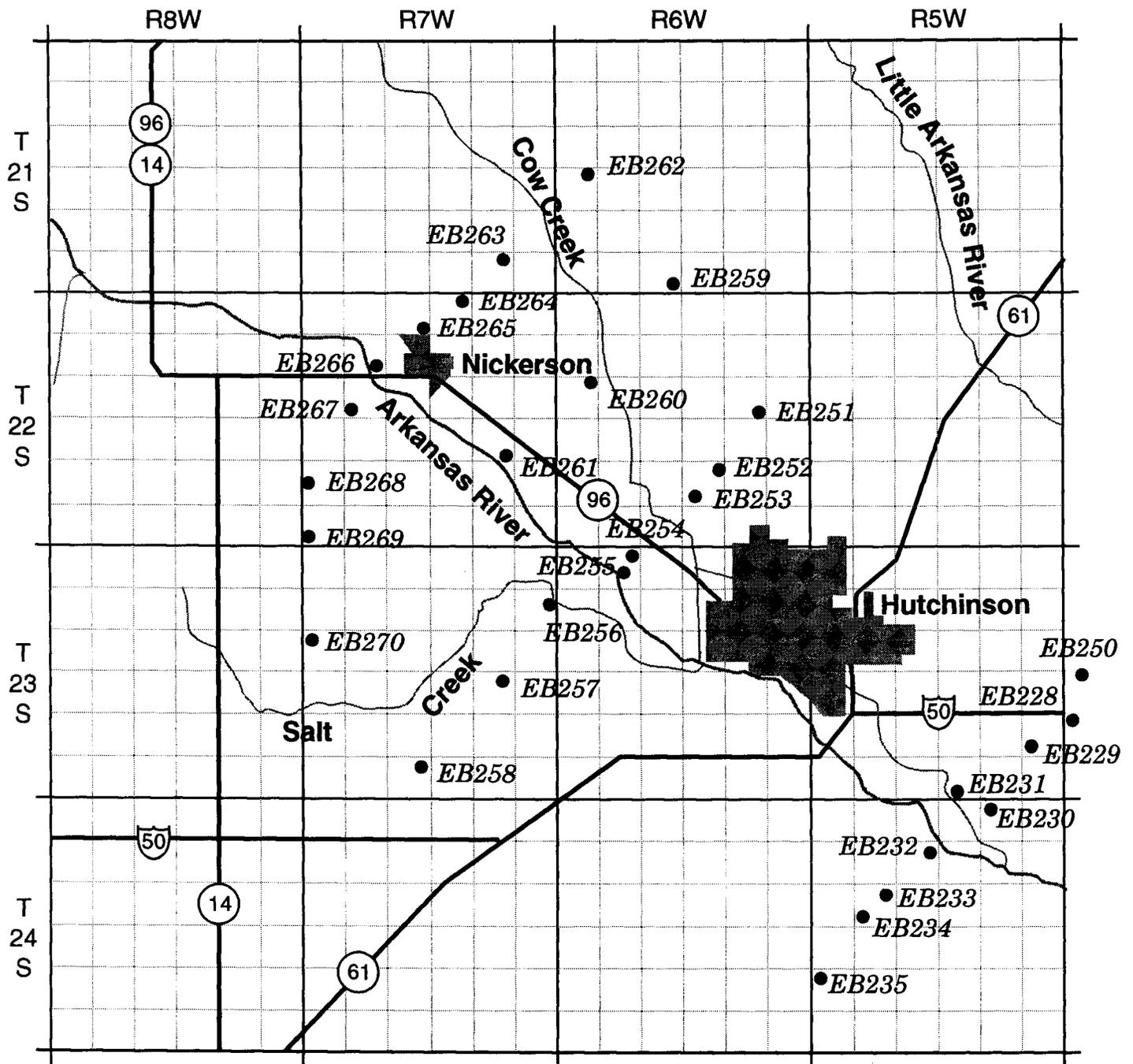


Figure I-3. Locations of groundwater monitoring sites and other physical features in the EBMI general study area.

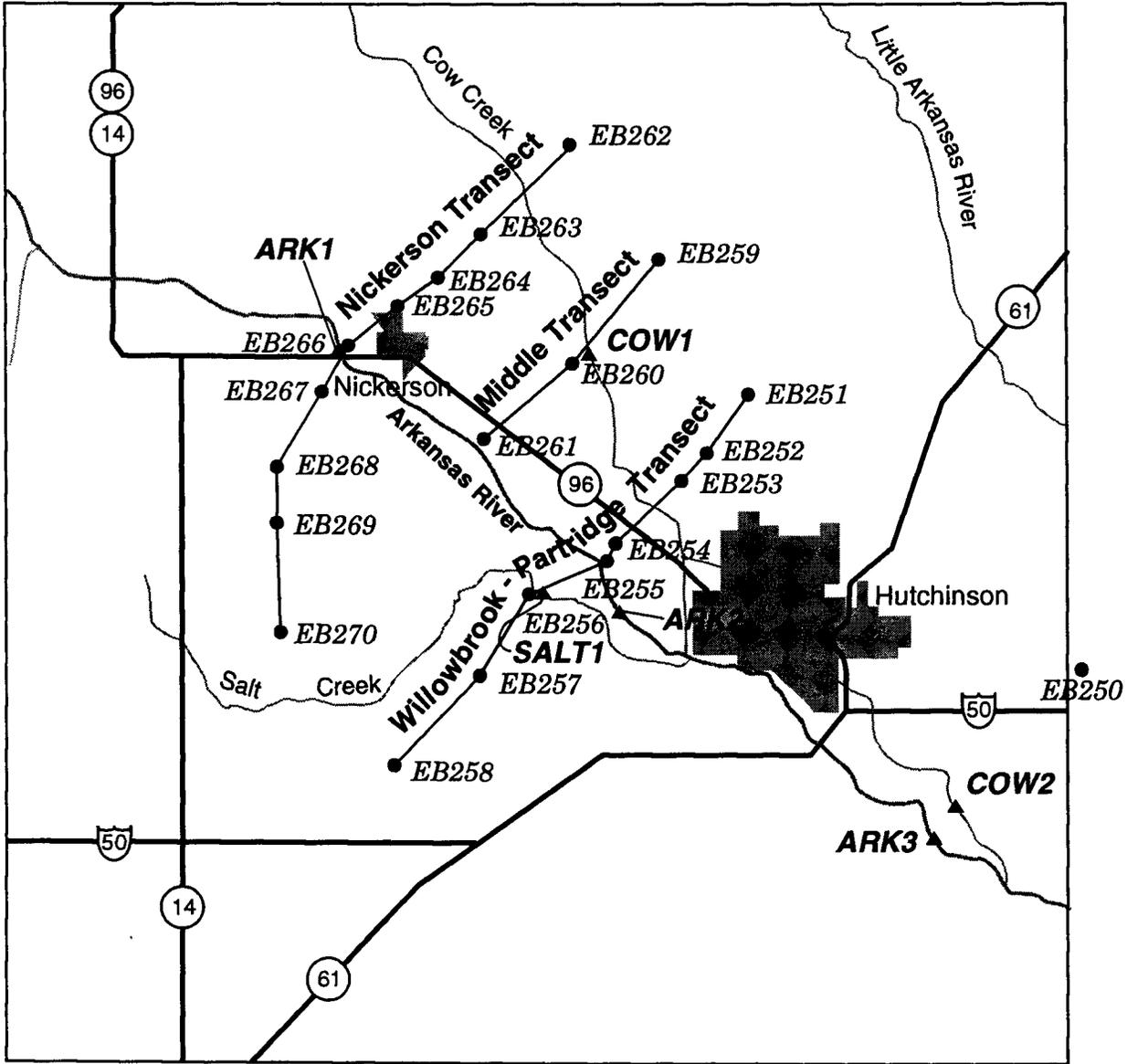


Figure I-4. Transect locations and surface water data collection points in the EBMI general study area.

II. Groundwater Levels

Water levels in the monitoring wells were measured approximately monthly, beginning in January of 1997. Depth-to-water measurements and water-level elevations are listed in Appendix II-A. Well hydrographs are presented in Appendix II-B.

Depth-to-water measurements for the new monitoring wells range from above land surface to about 40 feet below land surface. The water table is shallower north of the Arkansas River, and is within 10 ft of land surface at most sites north of the river. The water table was within 1 ft of land surface at site EB259 on March 31, 1998. Artesian conditions occur at site EB262, and the water level was above land surface on that same date. The well at site EB262 is screened in Cheyenne Sandstone. Depth to water is greatest, approximately 40 ft below land surface at sites EB257 and EB258, the southernmost sites in the Willowbrook-Partridge transect.

Similar patterns are observed on most hydrographs (Appendix II-B). The highest water levels in all wells were observed in the spring of 1998 (generally in March, when a lot of precipitation fell). Water levels were generally lowest in July and August of 1997. Water levels in some wells, particularly north of the river, show drawdowns caused by nearby groundwater pumping, most of which occurs during the summer months. At the southernmost sites in the Nickerson transect (EB269 and EB270), water levels were lowest in May of 1997. These wells are located the farthest from water rights locations, and thus are the least affected by groundwater pumping.

At sites with more than one well, water-level changes were generally synchronous in the different wells, particularly north of the Arkansas River. In fact, north of the river, where clay lenses are less common, virtually no vertical hydraulic gradient was observed at most of the sites, indicating very good vertical hydraulic connection. Exceptions are sites EB266 and EB261, which are located just north of the River, where upward vertical hydraulic gradients were observed.

At sites south of river, where clay layers or lenses are more widespread (see Plates 1 and 2 presented by Young et al., 1997), water-level fluctuations were less synchronous in wells of different depths. At site EB257, the water level in the C well rose above those in the A and B wells in October of 1997, and has remained above, resulting in conditions favorable for upward flow. Upward vertical hydraulic gradients also occur at sites EB256, EB267 and EB270. These observations could be signs of semiconfined conditions, which could have significant implications for the lateral transport of salt and water, discussed in Section V. Future work may look into further lithologic characterization, including the question of continuity of clay layers.

Higher water-level elevations in deeper wells could also be a reflection of a high Permian head, which in turn could relate to increased local bedrock discharge (see Section V). Boreholes were generally drilled a few feet into bedrock for freeboard to ensure that screens could be placed as close to the bedrock contact as possible. Most of

the sites with upward gradients are located near the Arkansas River or Salt Creek, and are indicative of groundwater discharge zones.

The hydrogeologic cross sections in Figures II-1 and II-2 show the water-level elevation plotted at the midscreen of each well, and inferred equipotential lines and flow arrows. The water-level data from March of 1998 were used to coincide with the time of water sample collection. Similar patterns were observed for sections produced using March 1997 and November 1997 data. Although lithologic variations were not considered and would actually alter the flow arrows, these sections show evidence of a northeastward component of flow, including under the Arkansas River. This has great implications for transport of salt water into the freshwater aquifer north of the river, which will be discussed in subsequent sections of this report.

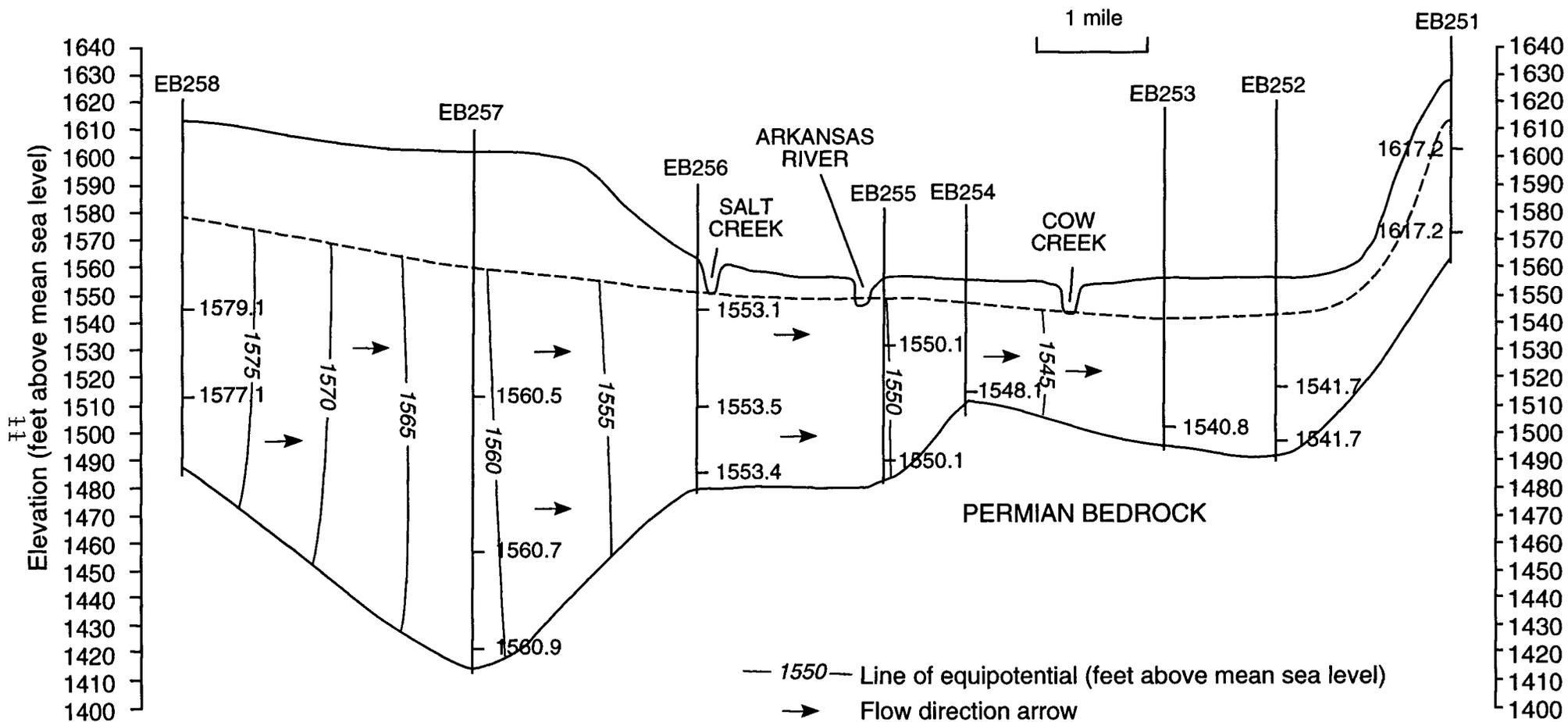


Figure II-1. Hydrogeologic section through Willowbrook-Partridge transect showing inferred equipotentials and flow arrows. Water-level data from Spring 1998.

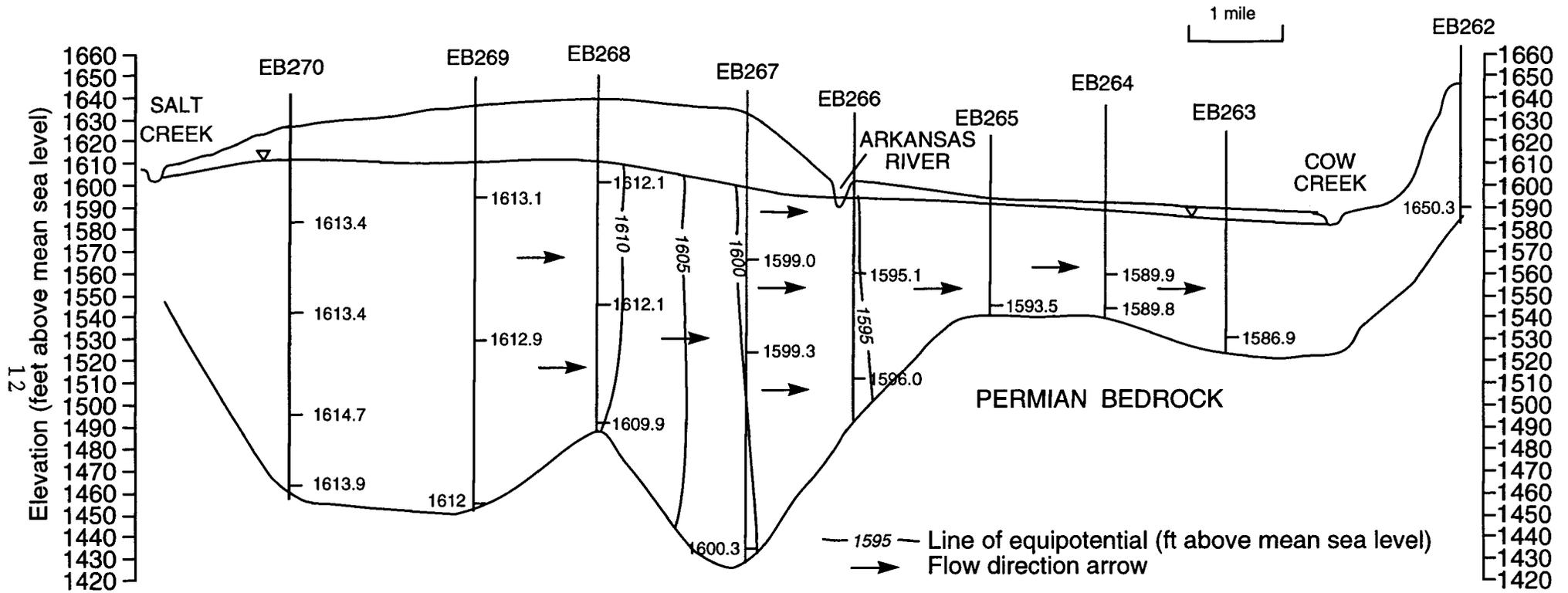


Figure II-2. Hydrogeologic section through Nickerson transect showing inferred equipotentials and flow arrows. Water-level data from Spring 1998.

Appendix II-A

Depth-to-Water Measurements and Water-Level Elevations in the EBMI Monitoring Wells

DEPTH TO WATER
(ft below land surface)

WATER-LEVEL ELEVATION
(ft above mean sea level)

Date	EB250A	EB250C	EB250A	EB250C
1/22/97	8.67	8.67	1487.82	1487.82
2/25/97	7.82	7.82	1488.67	1488.67
3/18/97	7.63	7.64	1488.86	1488.85
4/23/97	6.16	6.20	1490.33	1490.29
5/22/97	7.45	7.47	1489.04	1489.02
6/18/97	5.42	5.43	1491.07	1491.06
7/24/97	7.19	7.20	1489.30	1489.29
8/21/97	8.50	8.49	1487.99	1488.00
9/16/97	8.75	8.74	1487.74	1487.75
10/16/97	6.66	6.67	1489.83	1489.82
11/24/97	7.45	7.46	1489.04	1489.03
12/16/97	7.61	7.62	1488.88	1488.87
1/30/98	5.99	6.01	1490.50	1490.48
2/19/98	5.62	5.64	1490.87	1490.85
3/25/98	3.49	3.52	1493.00	1492.97
4/22/98	4.31	4.36	1492.18	1492.13
5/18/98	4.71	4.75	1491.78	1491.74

Date	EB251A	EB251C	EB251A	EB251C
1/22/97	15.54	15.60	1611.72	1611.66
2/25/97	14.96	15.02	1612.30	1612.24
3/18/97	14.81	14.87	1612.45	1612.39
4/24/97	14.00	14.06	1613.26	1613.20
5/22/97	14.49	14.56	1612.77	1612.70
6/19/97	14.23	14.28	1613.03	1612.98
7/24/97	16.42	16.46	1610.84	1610.80
8/20/97	16.94	16.99	1610.32	1610.27
9/16/97	17.62	17.66	1609.64	1609.60
10/16/97	16.37	16.45	1610.89	1610.81
11/21/97	15.25	15.31	1612.01	1611.95
12/16/97	14.98	15.03	1612.28	1612.23
1/30/98	13.43	13.49	1613.83	1613.77
2/19/98	12.68	12.75	1614.58	1614.51
3/31/98	10.03	10.07	1617.23	1617.19
4/23/98	9.34	9.41	1617.92	1617.85
5/19/98	9.67	9.74	1617.59	1617.52

Date	EB252A	EB252C	EB252A	EB252C
1/22/97	14.74	14.76	1541.54	1541.52
2/25/97	14.85	14.87	1541.43	1541.41
3/18/97	14.95	14.98	1541.33	1541.30
4/24/97	15.20	15.23	1541.08	1541.05
5/22/97	15.41	15.43	1540.87	1540.85
6/19/97	15.66	15.67	1540.62	1540.61
7/24/97	16.68	16.69	1539.60	1539.59
8/20/97	16.40	16.41	1539.88	1539.87
9/16/97	15.83	15.85	1540.45	1540.43
10/16/97	15.20	15.23	1541.08	1541.05

11/21/97	14.77	14.78	1541.51	1541.50
12/16/97	14.70	14.71	1541.58	1541.57
1/30/98	14.68	14.71	1541.60	1541.57
2/19/98	14.79	14.81	1541.49	1541.47
3/31/98	14.55	14.58	1541.73	1541.70
4/23/98	14.20	14.21	1542.08	1542.07
5/19/98	14.45	14.47	1541.83	1541.81

Date		EB253C		EB253C
1/22/97		13.53		1541.18
2/25/97		13.60		1541.11
3/25/97		14.65		1540.06
4/24/97		15.17		1539.54
5/22/97		14.96		1539.75
6/19/97		14.54		1540.17
7/24/97		14.89		1539.82
8/20/97		15.22		1539.49
9/16/97		13.58		1541.13
10/16/97		13.29		1541.42
11/21/97		13.16		1541.55
12/16/97		13.25		1541.46
1/30/98		13.76		1540.95
2/19/98		13.73		1540.98
3/31/98		13.96		1540.75
4/23/98		12.94		1541.77
5/19/98		12.79		1541.92

Date		EB254C		EB254C
1/22/97		8.83		1546.63
2/25/97		8.82		1546.64
3/24/97		8.78		1546.68
4/24/97		8.65		1546.81
5/22/97		8.81		1546.65
6/19/97		8.26		1547.20
7/24/97		8.85		1546.61
8/21/97		9.20		1546.26
9/16/97		8.64		1546.82
10/16/97		8.13		1547.33
11/21/97		8.08		1547.38
12/16/97		9.56		1545.90
1/30/98		9.17		1546.29
2/19/98		8.22		1547.24
3/31/98		7.38		1548.08
4/23/98		6.92		1548.54
5/19/98		7.02		1548.44

Date	EB255A	EB255C	EB255A	EB255C
1/22/97	8.39	8.44	1548.09	1548.04
2/25/97	8.36	8.38	1548.12	1548.10
3/24/97	8.48	8.49	1548.00	1547.99
5/22/97	8.68	8.70	1547.80	1547.78
6/19/97	8.26	8.28	1548.22	1548.20

7/24/97	8.90		8.94	1547.58		1547.54
8/21/97	8.16		8.21	1548.32		1548.27
9/16/97	8.40		8.42	1548.08		1548.06
10/16/97	8.48		8.51	1548.00		1547.97
11/21/97	8.26		8.30	1548.22		1548.18
12/16/97	8.40		8.46	1548.08		1548.02
1/30/98	7.71		7.77	1548.77		1548.71
2/19/98	7.38		7.42	1549.10		1549.06
3/31/98	6.36		6.41	1550.12		1550.07
4/23/98	6.66		6.71	1549.82		1549.77
5/19/98	7.34		7.40	1549.14		1549.08

Date	EB256A	EB256B	EB256C	EB256A	EB256B	EB256C
1/23/97	11.74	10.89	11.07	1551.86	1552.71	1552.53
2/25/97	11.64	10.94	11.12	1551.96	1552.66	1552.48
3/25/97	11.80	10.98	11.13	1551.80	1552.62	1552.47
4/24/97	11.73	10.93	11.05	1551.87	1552.67	1552.55
5/21/97	11.67	10.99	11.17	1551.93	1552.61	1552.43
6/19/97	11.24	10.74	10.87	1552.36	1552.86	1552.73
7/23/97	11.86	11.05	11.22	1551.74	1552.55	1552.38
8/20/97	11.49	11.05	11.22	1552.11	1552.55	1552.38
9/15/97	11.83	10.99	11.15	1551.77	1552.61	1552.45
10/15/97	11.18	10.58	10.73	1552.42	1553.02	1552.87
11/19/97	11.74	10.77	10.92	1551.86	1552.83	1552.68
12/15/97	11.78	10.89	11.03	1551.82	1552.71	1552.57
1/29/98	11.66	10.76	10.91	1551.94	1552.84	1552.69
2/18/98	11.57	10.66	10.80	1552.03	1552.94	1552.80
3/30/98	10.54	10.08	10.22	1553.06	1553.52	1553.38
4/22/98	11.37	10.23	10.36	1552.23	1553.37	1553.24
5/18/98	11.56	10.44	10.58	1552.04	1553.16	1553.02

Date	EB257A	EB257B	EB257C	EB257A	EB257B	EB257C
1/23/97	41.50	41.62	41.69	1560.74	1560.62	1560.55
2/25/97	41.55	41.63	41.70	1560.69	1560.61	1560.54
3/26/97	41.60	41.66	41.75	1560.64	1560.58	1560.49
4/24/97	41.63	41.72	41.82	1560.61	1560.52	1560.42
5/21/97	41.66	41.81	41.92	1560.58	1560.43	1560.32
6/16/97	41.66	41.78	41.83	1560.58	1560.46	1560.41
7/23/97	41.71	41.81	41.93	1560.53	1560.43	1560.31
8/19/97	41.72	41.82	41.93	1560.52	1560.42	1560.31
9/15/97	41.76	41.81	41.84	1560.48	1560.43	1560.40
10/15/97	41.79	41.80	41.74	1560.45	1560.44	1560.50
11/20/97	41.78	41.73	41.64	1560.46	1560.51	1560.60
12/16/97	41.79	41.75	41.71	1560.45	1560.49	1560.53
1/29/98	41.77	41.74	41.62	1560.47	1560.50	1560.62
2/18/98	41.75	41.70	41.54	1560.49	1560.54	1560.70
3/30/98	41.70	41.58	41.31	1560.54	1560.66	1560.93
4/22/98	41.67	41.55	41.28	1560.57	1560.69	1560.96
5/18/98	41.62	41.50	41.26	1560.62	1560.74	1560.98

Date	EB258A	EB258B	EB258A	EB258B
1/23/97	35.40	37.34	1578.67	1576.73

2/25/97	35.50	37.41	1578.57	1576.66
3/26/97	35.60	37.52	1578.47	1576.55
4/24/97	35.64	37.53	1578.43	1576.54
5/21/97	35.75	37.59	1578.32	1576.48
6/19/97	35.47	37.53	1578.60	1576.54
7/23/97	35.70	37.57	1578.37	1576.50
8/19/97	35.70	37.59	1578.37	1576.48
9/15/97	35.60	37.57	1578.47	1576.50
10/15/97	35.34	37.45	1578.73	1576.62
11/20/97	35.16	36.91	1578.91	1577.16
12/16/97	35.28	37.27	1578.79	1576.80
1/29/98	35.17	37.21	1578.90	1576.86
2/18/98	35.09	37.14	1578.98	1576.93
3/30/98	34.96	37.00	1579.11	1577.07
4/22/98	34.84	36.60	1579.23	1577.47
5/18/98	34.72	36.47	1579.35	1577.60

Date	EB259A	EB259B	EB259A	EB259B
1/24/97	6.79	8.36	1690.05	1688.48
2/25/97	6.38	8.16	1690.46	1688.68
3/25/97	6.09	8.01	1690.75	1688.83
4/24/97	5.14	7.40	1691.70	1689.44
5/21/97	5.74	7.84	1691.10	1689.00
6/19/97	5.44	7.14	1691.40	1689.70
7/24/97	7.68	8.39	1689.16	1688.45
8/21/97	8.00	8.62	1688.84	1688.22
9/16/97	8.05	8.70	1688.79	1688.14
10/16/97	6.94	8.07	1689.90	1688.77
11/21/97	6.05	7.46	1690.79	1689.38
12/16/97	6.01	7.79	1690.83	1689.05
1/29/98	4.31	6.45	1692.53	1690.39
2/19/98	3.07	5.81	1693.77	1691.03
3/31/98	0.86	3.92	1695.98	1692.92
4/23/98	1.59	3.89	1695.25	1692.95
5/19/98	2.32	3.76	1694.52	1693.08

Date	EB260C	EB260C
1/24/97	8.47	1565.52
2/25/97	8.29	1565.70
3/24/97	8.31	1565.68
4/24/97	8.16	1565.83
5/22/97	8.49	1565.50
6/19/97	7.98	1566.01
7/24/97	8.71	1565.28
8/21/97	8.55	1565.44
9/16/97	7.57	1566.42
10/16/97	7.24	1566.75
11/21/97	7.41	1566.58
12/16/97	7.72	1566.27
1/30/98	7.33	1566.66
2/19/98	6.67	1567.32
3/31/98	4.66	1569.33

4/23/98	5.58	1568.41
5/19/98	6.46	1567.53

Date	EB261A	EB261C	EB261A	EB261C
1/24/97	11.58	11.37	1569.74	1569.95
2/25/97	11.62	11.41	1569.70	1569.91
3/24/97	11.61	11.49	1569.71	1569.83
4/24/97	11.61	11.50	1569.71	1569.82
5/22/97	11.97	11.76	1569.35	1569.56
6/19/97	11.93	11.76	1569.39	1569.56
7/24/97	12.15	11.94	1569.17	1569.38
8/21/97	11.70	11.72	1569.62	1569.60
9/16/97	11.59	11.58	1569.73	1569.74
10/16/97	11.62	11.52	1569.70	1569.80
11/21/97	11.44	11.41	1569.88	1569.91
12/16/97	11.59	11.44	1569.73	1569.88
1/30/98	10.95	11.14	1570.37	1570.18
2/19/98	10.57	10.88	1570.75	1570.44
3/31/98	9.75	10.39	1571.57	1570.93
4/23/98	9.60	10.31	1571.72	1571.01
5/19/98	10.25	10.37	1571.07	1570.95

Date	EB262C	EB262C
1/24/97	2.34	1647.72
2/25/97	1.55	1648.51
3/21/97	1.65	1648.41
4/24/97	1.59	1648.47
5/21/97	2.27	1647.79
6/19/97	2.03	1648.03
7/24/97	4.03	1646.03
8/20/97	3.98	1646.08
9/16/97	3.50	1646.56
10/16/97	1.98	1648.08
11/24/97	1.60	1648.46
12/16/97	1.30	1648.76
1/29/98	0.83	1649.23
2/19/98	0.52	1649.54
3/31/98	-0.26	1650.32
4/23/98	0.63	1649.43
5/19/98	0.88	1649.18

Date	EB263C	EB263C
1/24/97	7.91	1582.11
2/25/97	7.63	1582.39
3/21/97	7.45	1582.57
4/24/97	7.49	1582.53
5/21/97	8.00	1582.02
6/19/97	7.73	1582.29
7/24/97	9.26	1580.76
8/20/97	9.14	1580.88
9/16/97	7.29	1582.73
10/16/97	6.32	1583.70

11/24/97	6.43	1583.59
12/16/97	6.72	1583.30
1/29/98	6.07	1583.95
2/19/98	5.23	1584.79
3/31/98	3.15	1586.87
4/23/98	3.97	1586.05
5/19/98	4.96	1585.06

Date	EB264A	EB264C	EB264A	EB264C
1/24/97	8.67	8.72	1585.17	1585.12
2/25/97	8.46	8.49	1585.38	1585.35
3/21/97	8.23	8.26	1585.61	1585.58
4/24/97	8.13	8.18	1585.71	1585.66
5/21/97	8.59	8.63	1585.25	1585.21
6/19/97	8.33	8.38	1585.51	1585.46
7/24/97	9.17	9.21	1584.67	1584.63
8/20/97	9.29	9.32	1584.55	1584.52
9/16/97	8.81	8.82	1585.03	1585.02
10/16/97	7.90	7.92	1585.94	1585.92
11/24/97	7.69	7.71	1586.15	1586.13
12/16/97	7.81	7.82	1586.03	1586.02
1/29/98	7.16	7.18	1586.68	1586.66
2/19/98	6.45	6.45	1587.39	1587.39
3/31/98	3.98	4.00	1589.86	1589.84
4/23/98	5.04	5.05	1588.80	1588.79
5/19/98	5.41	5.44	1588.43	1588.40

Date	EB265C	EB265C
1/24/97	5.92	1589.04
2/25/97	5.74	1589.22
3/21/97	5.66	1589.30
4/24/97	5.65	1589.31
5/21/97	5.81	1589.15
6/19/97	5.84	1589.12
7/24/97	6.24	1588.72
8/20/97	6.31	1588.65
9/16/97	6.10	1588.86
10/16/97	5.63	1589.33
11/24/97	5.46	1589.50
12/16/97	5.52	1589.44
1/29/98	5.01	1589.95
2/19/98	4.27	1590.69
3/31/98	1.42	1593.54
4/23/98	2.79	1592.17
5/19/98	2.98	1591.98

Date	EB266A	EB266B	EB266A	EB266B
1/23/97	8.81	6.54	1592.43	1594.70
2/25/97	8.67	6.49	1592.57	1594.75
3/21/97	8.91	6.56	1592.33	1594.68
4/24/97	9.04	6.71	1592.20	1594.53
5/21/97	9.21	6.87	1592.03	1594.37

6/19/97	9.23	6.81	1592.01	1594.43
8/20/97		6.60		1594.64
9/16/97		6.75		1594.49
10/16/97		6.74		1594.50
11/24/97	8.85	6.62	1592.39	1594.62
12/16/97	8.84	6.62	1592.40	1594.62
1/29/98	7.87	6.24	1593.37	1595.00
2/19/98	7.66	6.02	1593.58	1595.22
3/31/98	6.10	5.28	1595.14	1595.96
4/23/98	7.15	5.47	1594.09	1595.77
5/18/98	7.95	5.59	1593.29	1595.65

Date	EB267A	EB267B	EB267C	EB267A	EB267B	EB267C
1/23/97	36.51	36.11	35.02	1597.53	1597.93	1599.02
2/25/97	36.54	36.15	35.09	1597.50	1597.89	1598.95
3/21/97	36.43	36.07	35.04	1597.61	1597.97	1599.00
4/24/97	36.49	36.19	35.18	1597.55	1597.85	1598.86
5/21/97	36.73	36.41	35.42	1597.31	1597.63	1598.62
6/19/97	36.68	36.36	35.38	1597.36	1597.68	1598.66
7/23/97	37.02	36.64	35.57	1597.02	1597.40	1598.47
8/20/97	37.03	36.69	35.56	1597.01	1597.35	1598.48
9/16/97	36.71	36.35	35.36	1597.33	1597.69	1598.68
10/16/97	36.30	35.93	34.98	1597.74	1598.11	1599.06
11/24/97	35.97	35.63	34.70	1598.07	1598.41	1599.34
12/16/97	35.99	35.65	34.60	1598.05	1598.39	1599.44
1/29/98	35.77	35.43	34.38	1598.27	1598.61	1599.66
2/19/98	35.62	35.27	34.20	1598.42	1598.77	1599.84
3/31/98	35.07	34.71	33.70	1598.97	1599.33	1600.34
4/23/98	34.78	34.47	33.50	1599.26	1599.57	1600.54
5/18/98	34.84	34.49	33.34	1599.20	1599.55	1600.70

Date	EB268A	EB268B	EB268C	EB268A	EB268B	EB268C
1/23/97	29.10	29.20	31.69	1609.74	1609.64	1607.15
2/25/97	29.31	29.41	31.92	1609.53	1609.43	1606.92
3/20/97	29.37	29.47	31.97	1609.47	1609.37	1606.87
4/24/97	29.55	29.64	32.16	1609.29	1609.20	1606.68
5/21/97	29.71	29.79	32.35	1609.13	1609.05	1606.49
6/19/97	29.71	29.75	32.23	1609.13	1609.09	1606.61
7/23/97	29.75	29.77	32.26	1609.09	1609.07	1606.58
8/20/97	29.69	29.65	32.19	1609.15	1609.19	1606.65
9/16/97	28.97	28.99	31.45	1609.87	1609.85	1607.39
10/16/97	28.26	28.27	30.73	1610.58	1610.57	1608.11
11/20/97	27.79	27.83	30.29	1611.05	1611.01	1608.55
12/16/97	27.84	27.91	30.42	1611.00	1610.93	1608.42
1/29/98	27.75	27.82	30.33	1611.09	1611.02	1608.51
2/19/98	27.61	27.64	30.12	1611.23	1611.20	1608.72
3/31/98	26.75	26.70	28.98	1612.09	1612.14	1609.86
4/23/98	26.21	26.17	28.35	1612.63	1612.67	1610.49
5/18/98	25.86	25.86	28.17	1612.98	1612.98	1610.67

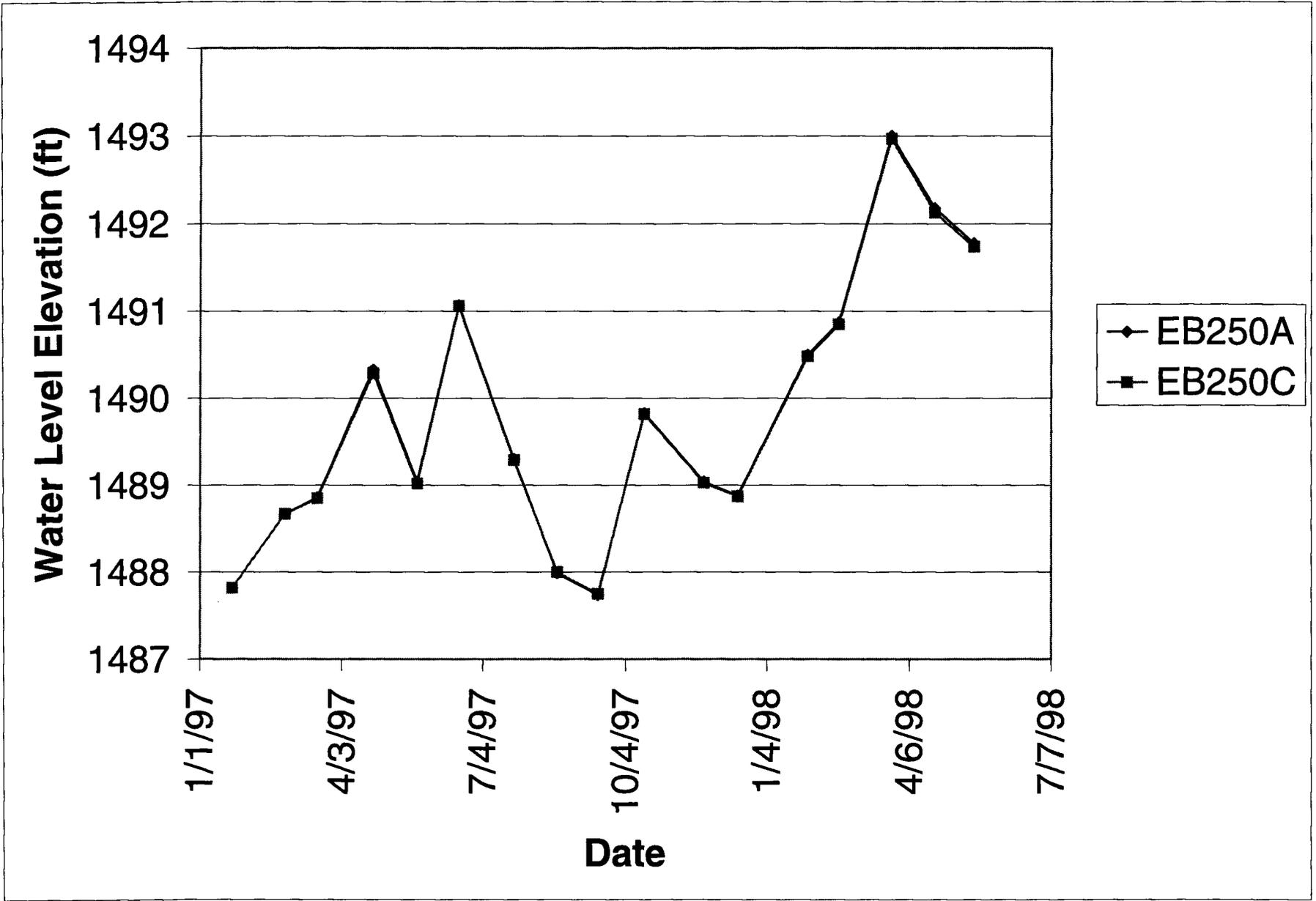
Date	EB269A	EB269B	EB269C	EB269A	EB269B	EB269C
1/23/97	24.68	24.92	25.73	1610.07	1609.83	1609.02

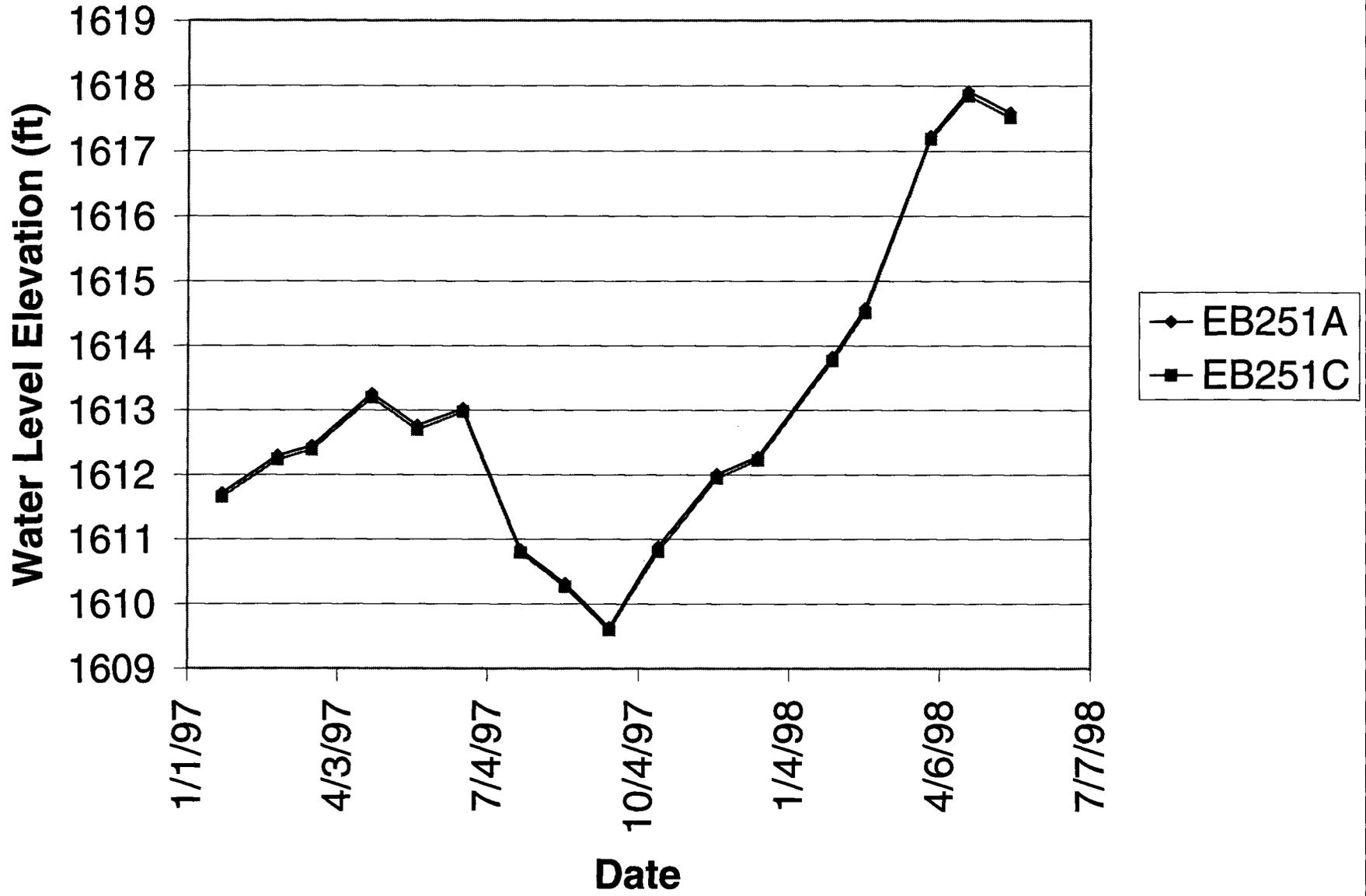
2/25/97	25.00	25.19	26.01	1609.75	1609.56	1608.74
3/20/97	25.03	25.19	26.00	1609.72	1609.56	1608.75
4/24/97	25.16	25.30	26.09	1609.59	1609.45	1608.66
5/21/97	25.49	25.59	26.30	1609.26	1609.16	1608.45
6/19/97	24.94	24.99	25.79	1609.81	1609.76	1608.96
7/23/97	25.15	25.14	25.90	1609.60	1609.61	1608.85
8/20/97	24.58	24.75	25.60	1610.17	1610.00	1609.15
9/16/97	23.84	24.01	24.89	1610.91	1610.74	1609.86
10/16/97	23.18	23.32	24.18	1611.57	1611.43	1610.57
11/20/97	22.83	23.02	23.89	1611.92	1611.73	1610.86
12/16/97	23.18	23.37	24.25	1611.57	1611.38	1610.50
1/29/98	23.10	23.28	24.13	1611.65	1611.47	1610.62
2/19/98	22.86	23.02	23.85	1611.89	1611.73	1610.90
3/27/98	21.61	21.83	22.73	1613.14	1612.92	1612.02
4/23/98	20.54	20.67	21.64	1614.21	1614.08	1613.11
5/18/98	20.49	20.68	21.66	1614.26	1614.07	1613.09

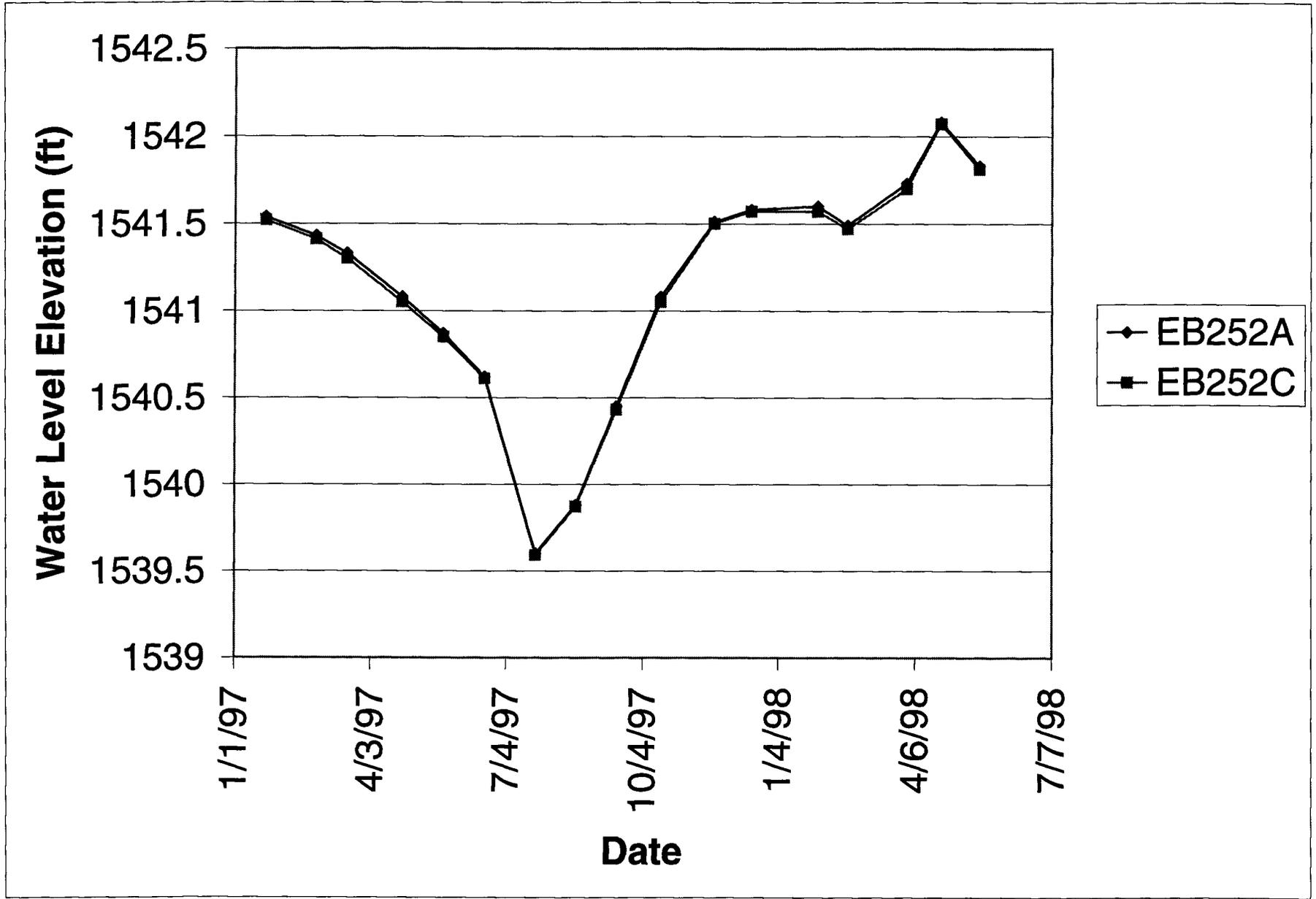
Date	EB270AA	EB270A	EB270B	EB270C	EB270AA	EB270A	EB270B	EB270C
1/23/97	15.63	15.72	13.34	14.12	1609.67	1609.58	1611.96	1611.18
2/25/97	15.86	16.00	13.69	14.40	1609.44	1609.30	1611.61	1610.90
3/19/97	15.71	15.81	13.64	14.34	1609.59	1609.49	1611.66	1610.96
4/24/97	15.58	15.69	13.59	14.36	1609.72	1609.61	1611.71	1610.94
5/21/97	15.88	15.99	13.82	14.57	1609.42	1609.31	1611.48	1610.73
6/19/97	14.86	14.99	13.20	13.98	1610.44	1610.31	1612.10	1611.32
7/23/97	15.06	15.20	13.26	14.01	1610.24	1610.10	1612.04	1611.29
8/20/97	14.94	15.07	13.13	13.91	1610.36	1610.23	1612.17	1611.39
9/16/97	14.65	14.79	12.59	13.35	1610.65	1610.51	1612.71	1611.95
10/15/97	13.62	13.75	11.93	12.72	1611.68	1611.55	1613.37	1612.58
11/20/97	13.63	13.76	11.77	12.47	1611.67	1611.54	1613.53	1612.83
12/16/97	14.19	14.32	12.10	12.87	1611.11	1610.98	1613.20	1612.43
1/29/98	13.75	13.88	11.89	12.64	1611.55	1611.42	1613.41	1612.66
2/19/98	13.43	13.54	11.63	12.38	1611.87	1611.76	1613.67	1612.92
3/27/98	11.86	11.98	10.61	11.40	1613.44	1613.32	1614.69	1613.90
4/23/98	10.79	10.94	9.44	10.23	1614.51	1614.36	1615.86	1615.07
5/18/98	11.39	11.51	9.66	10.43	1613.91	1613.79	1615.64	1614.87

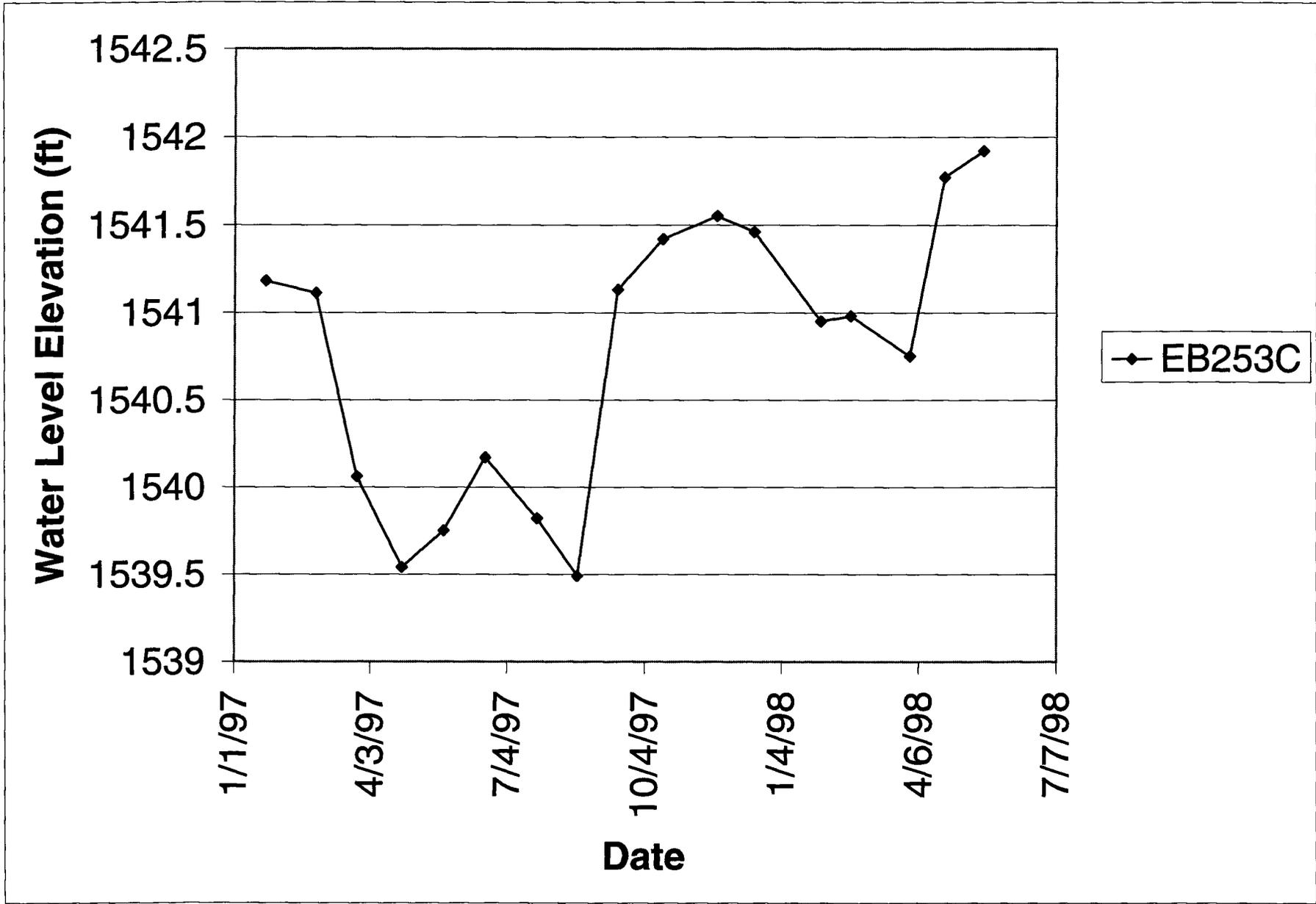
Appendix II-B

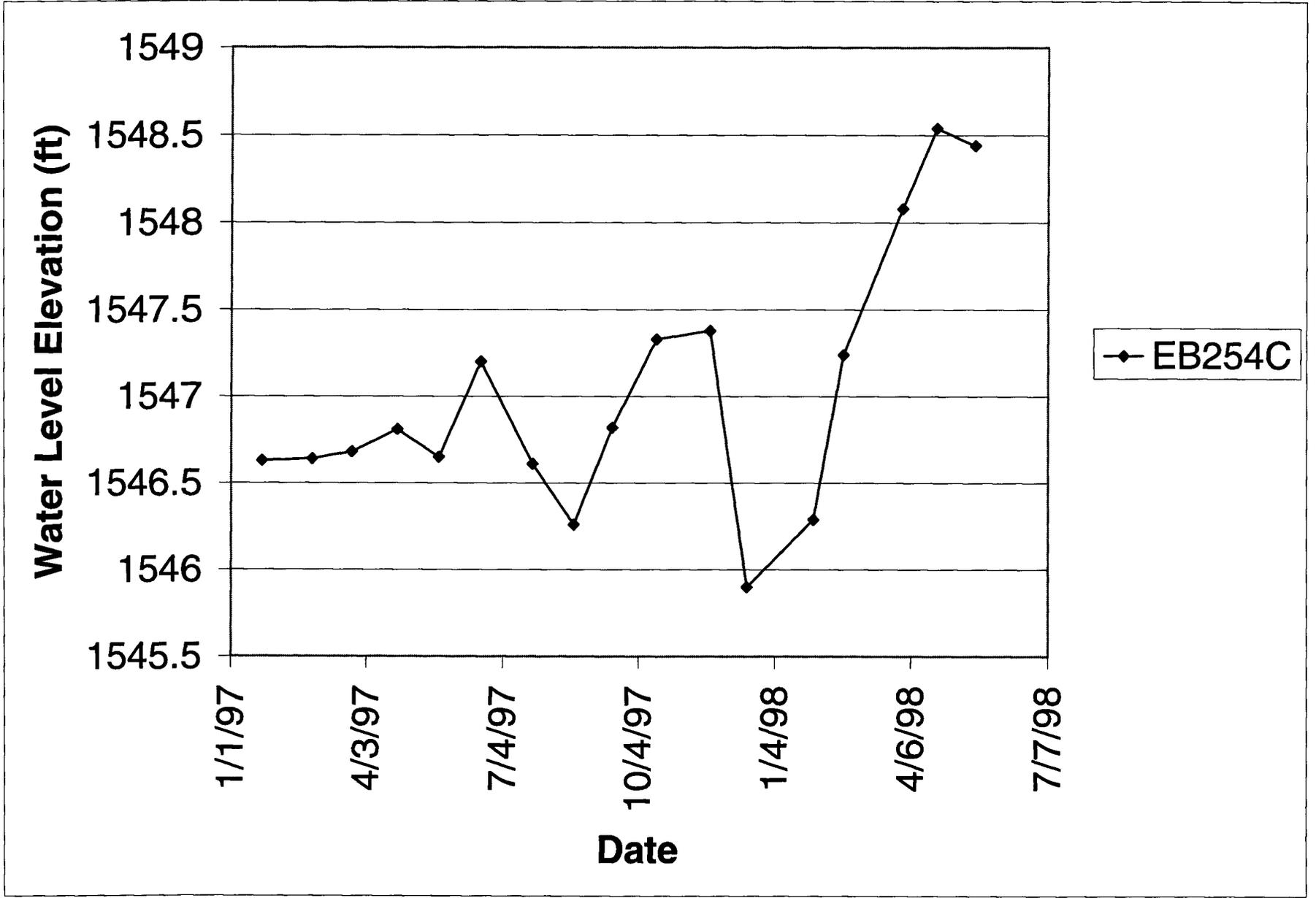
Well Hydrographs for the EBMI Monitoring Wells

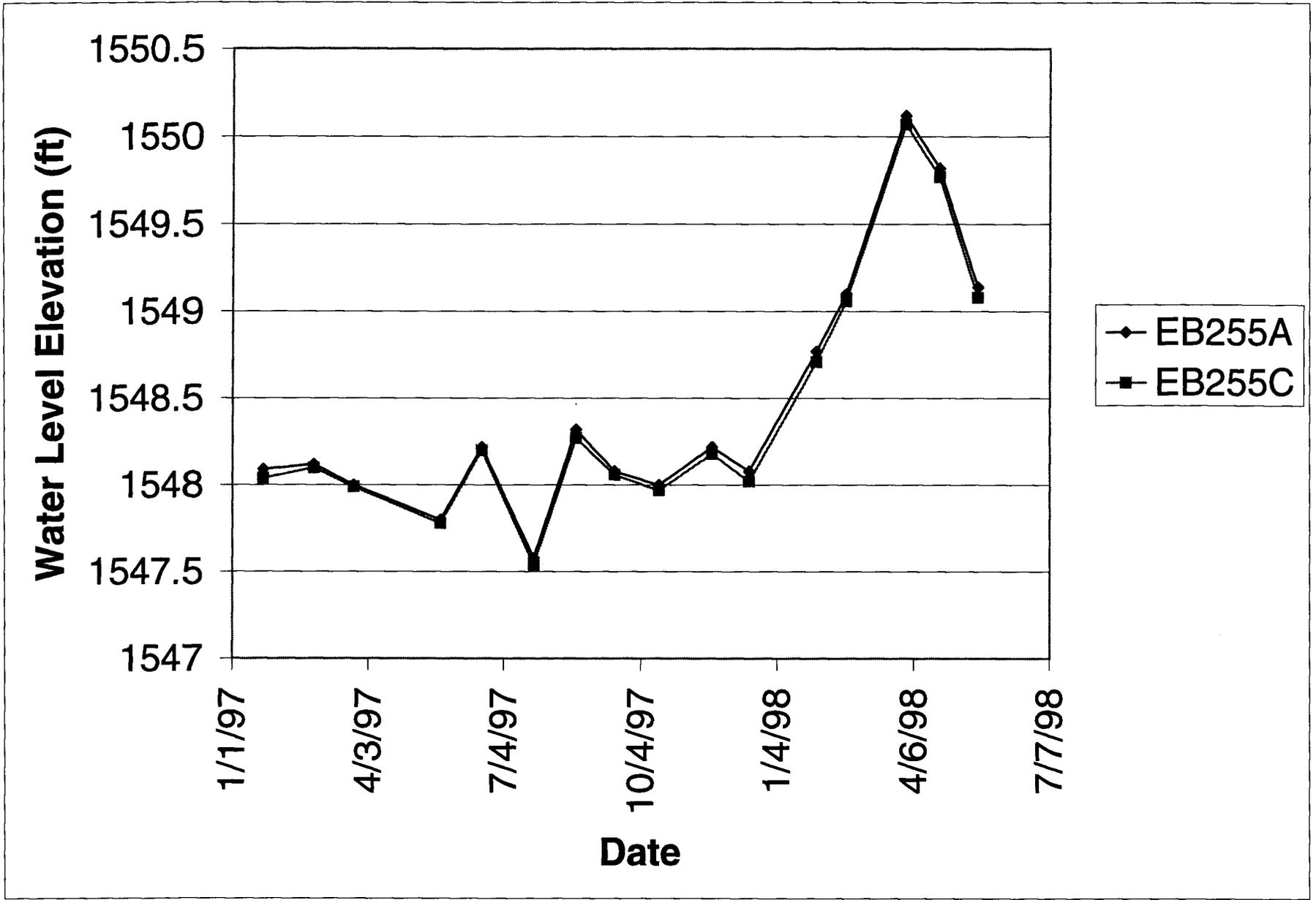


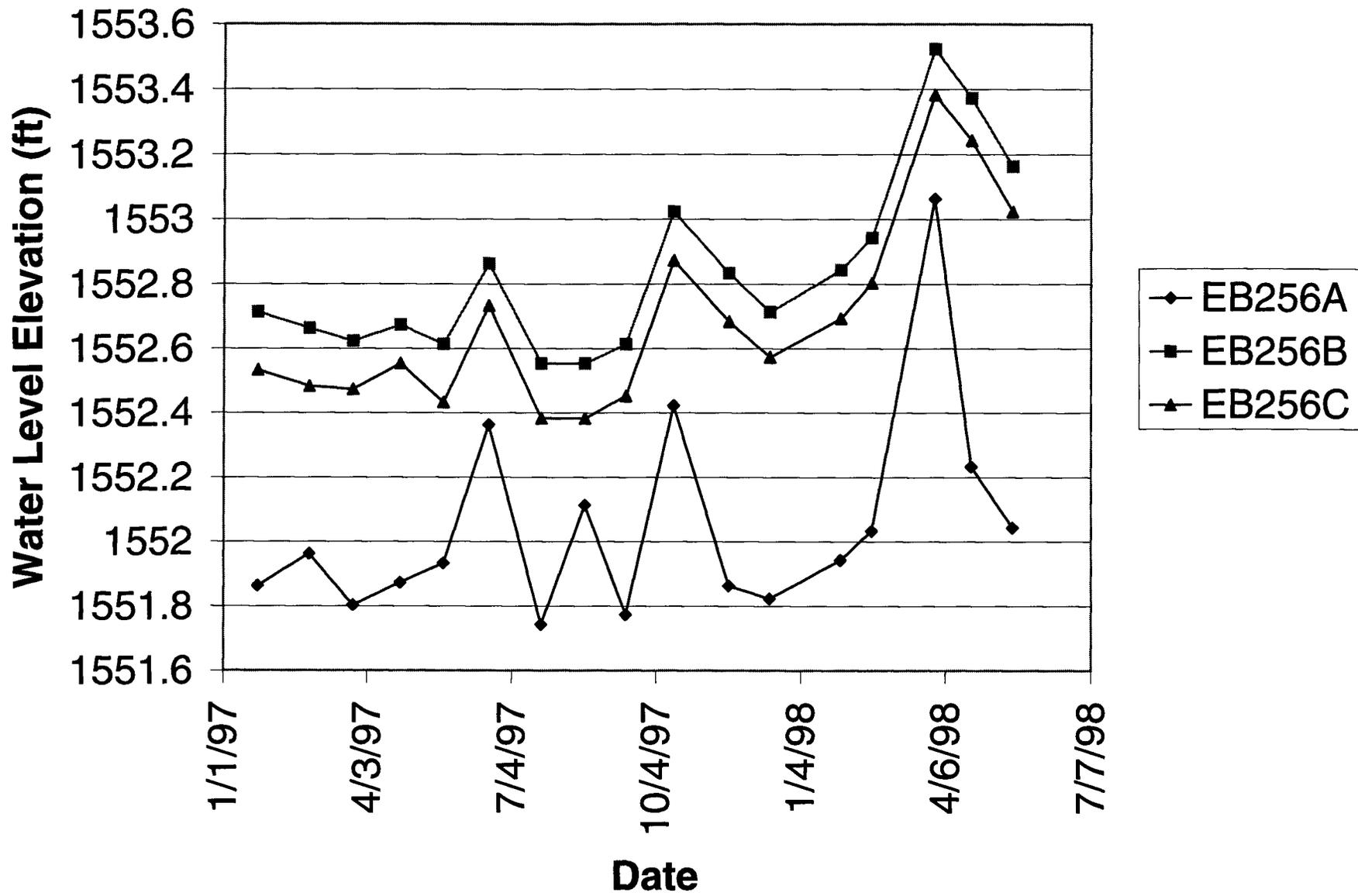


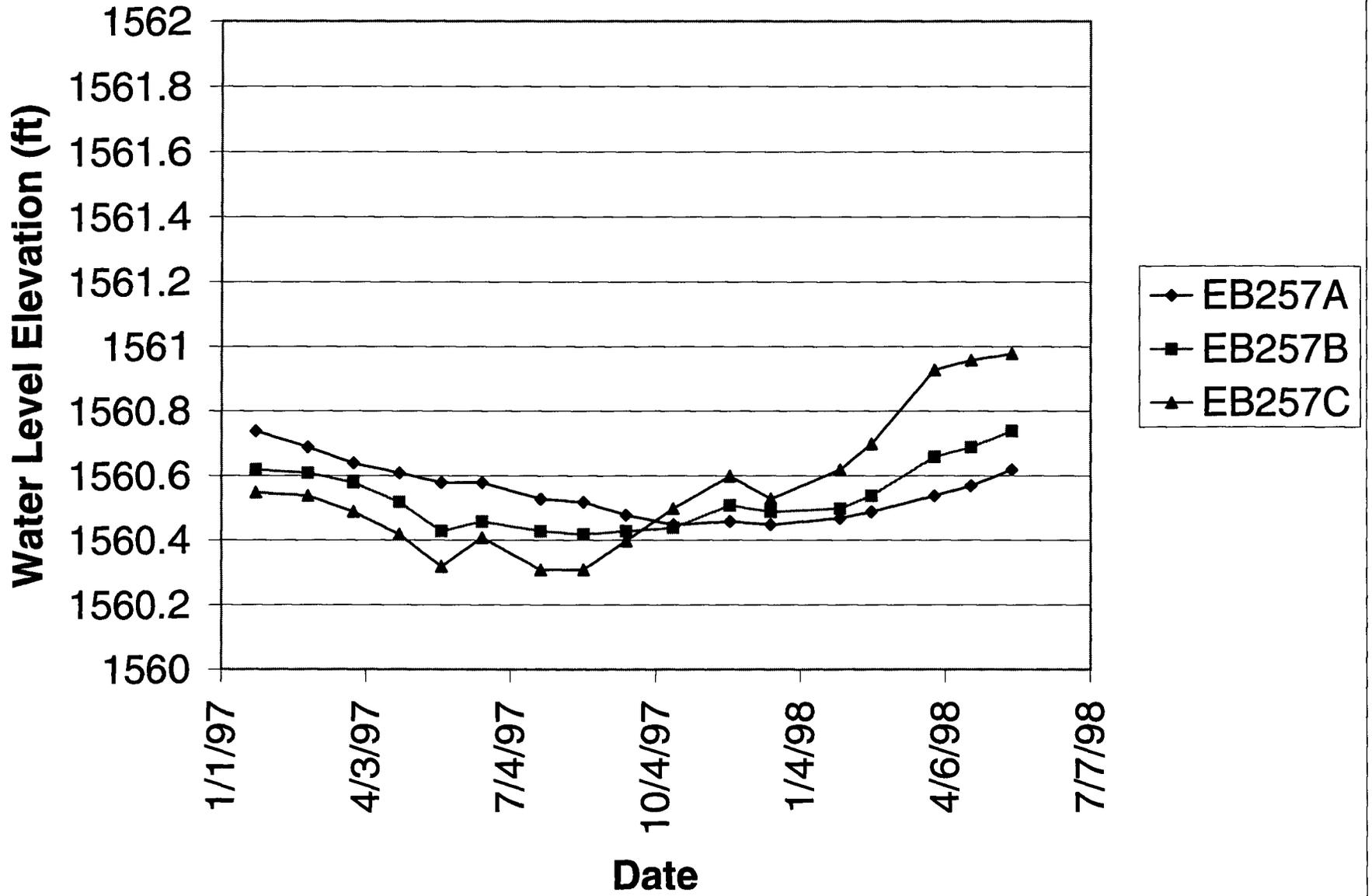


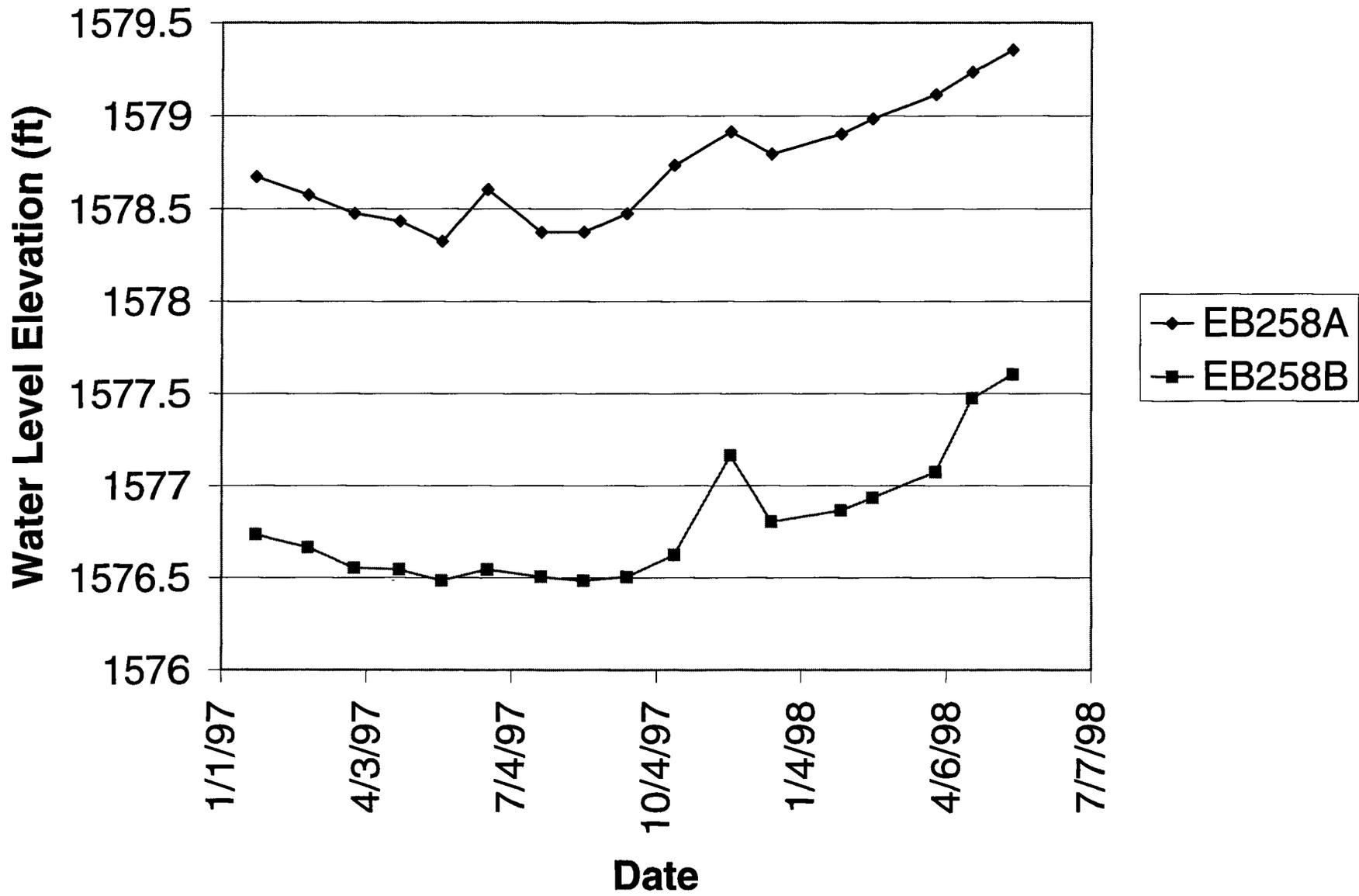


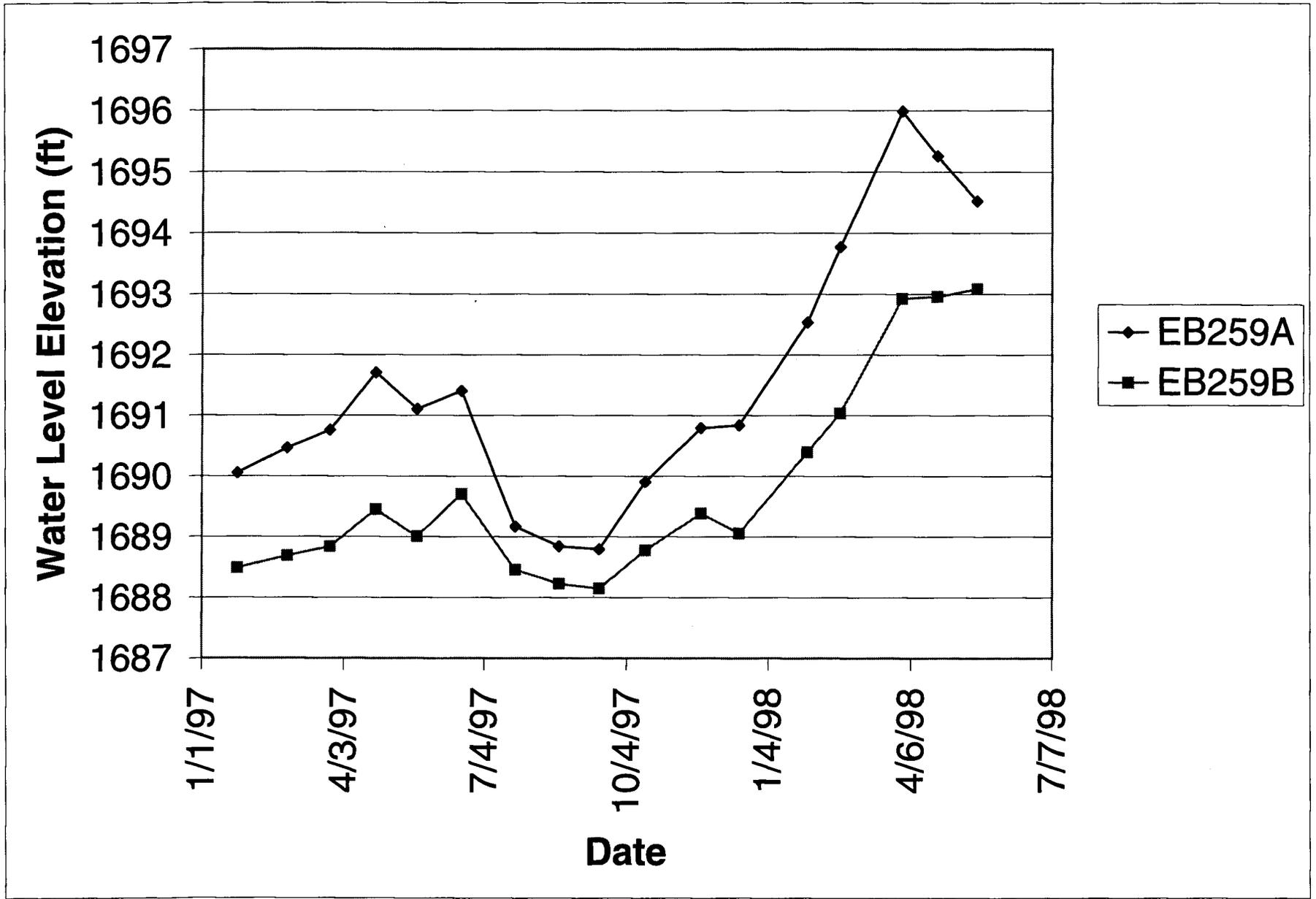


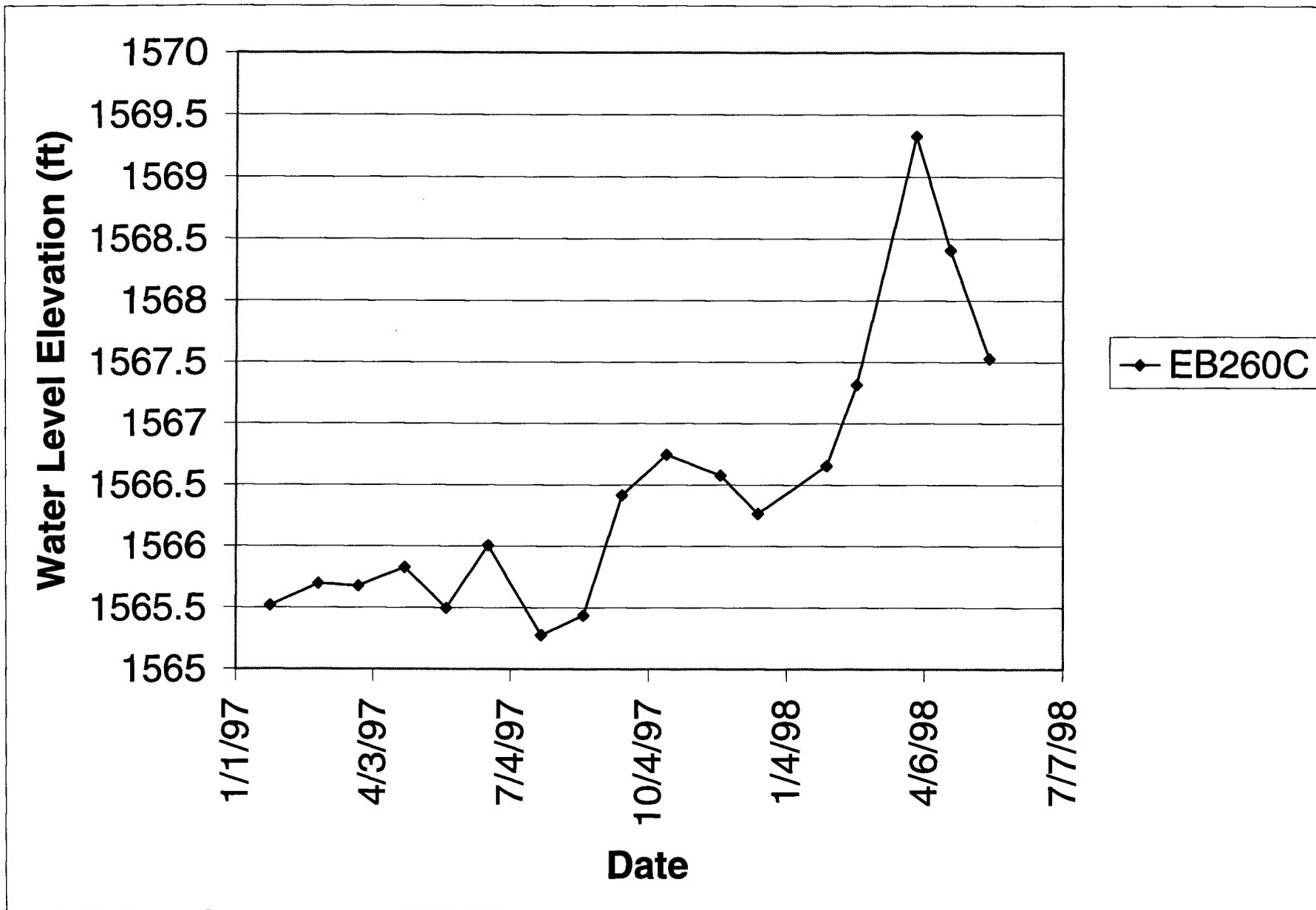


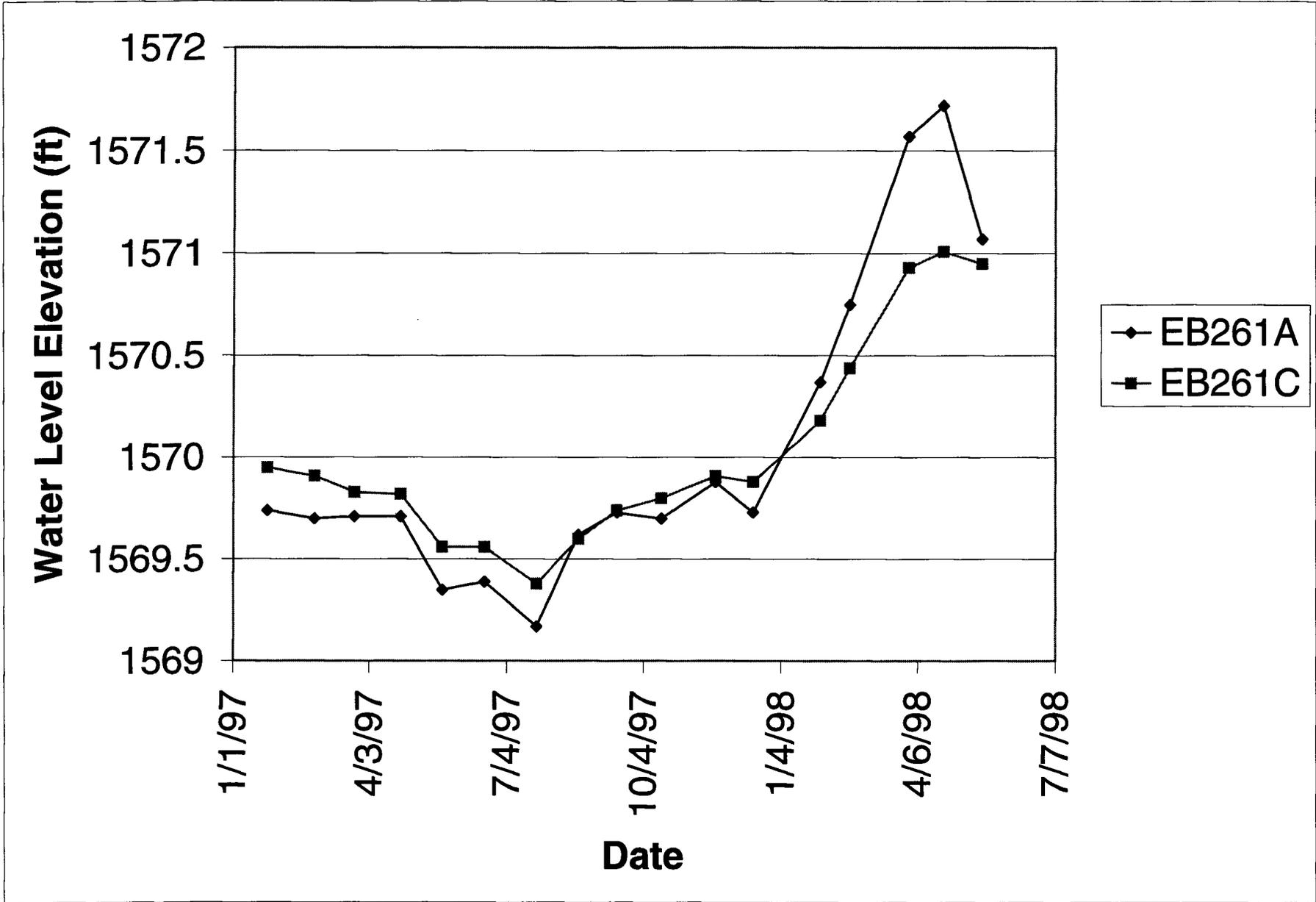


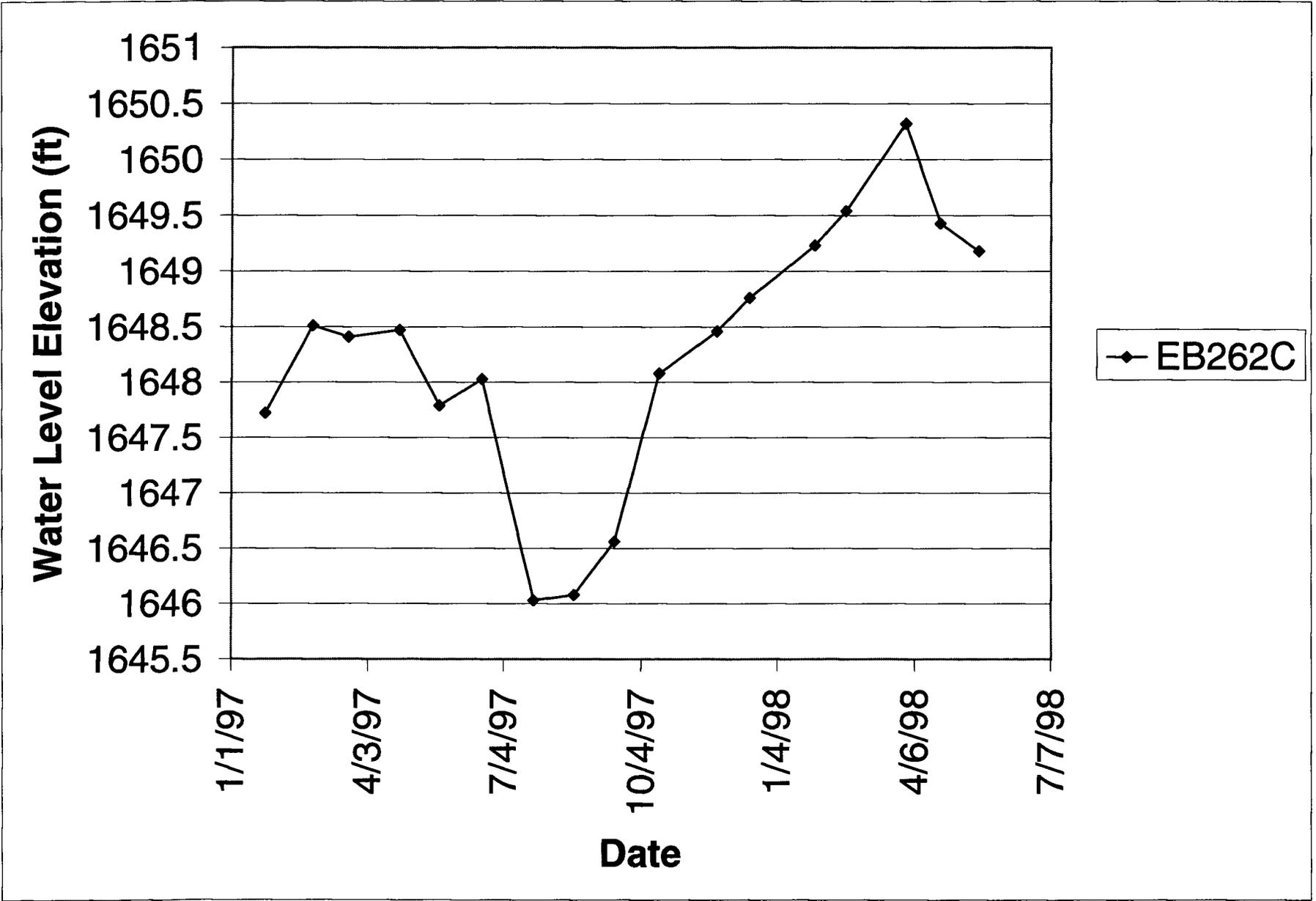


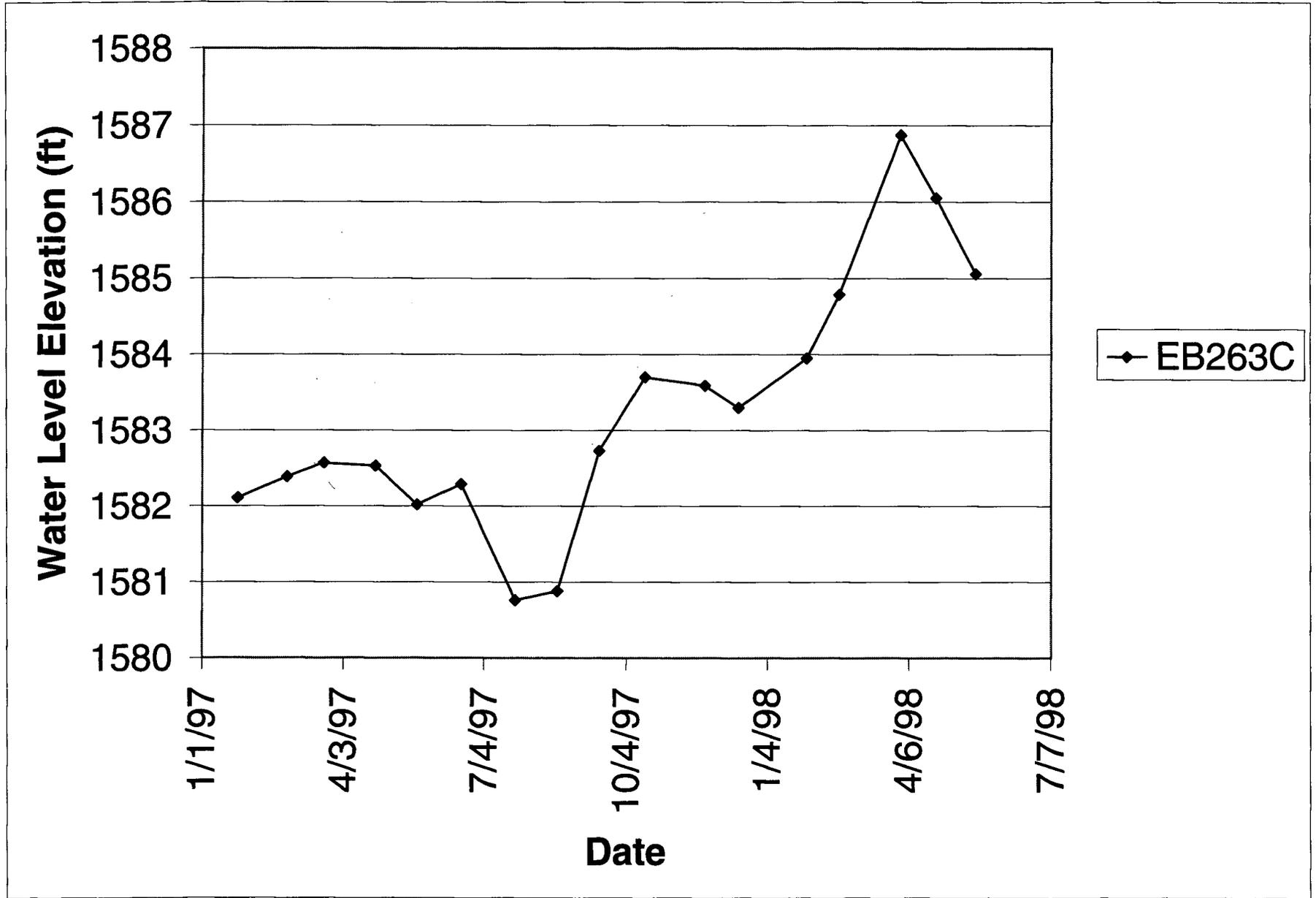


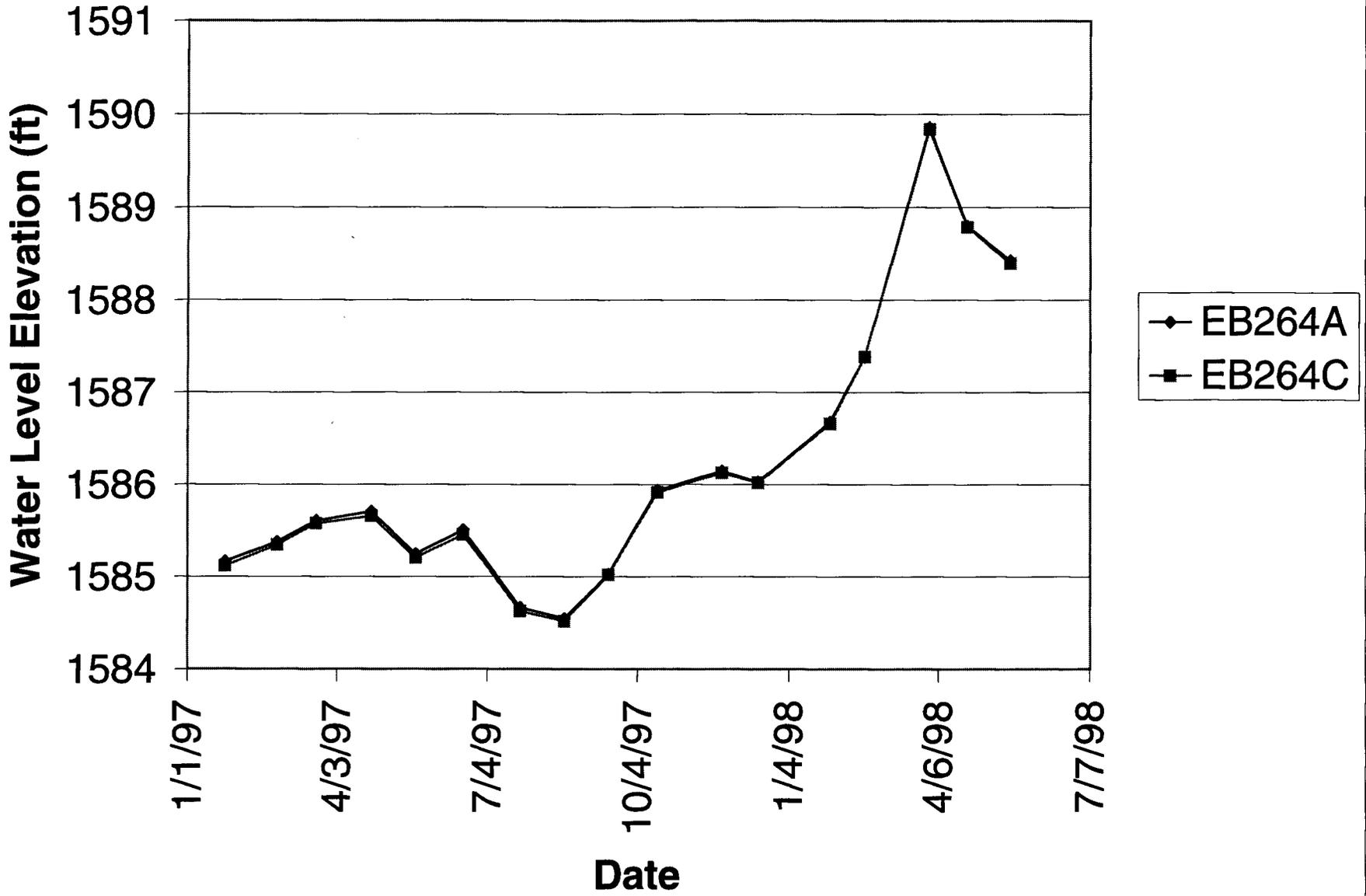


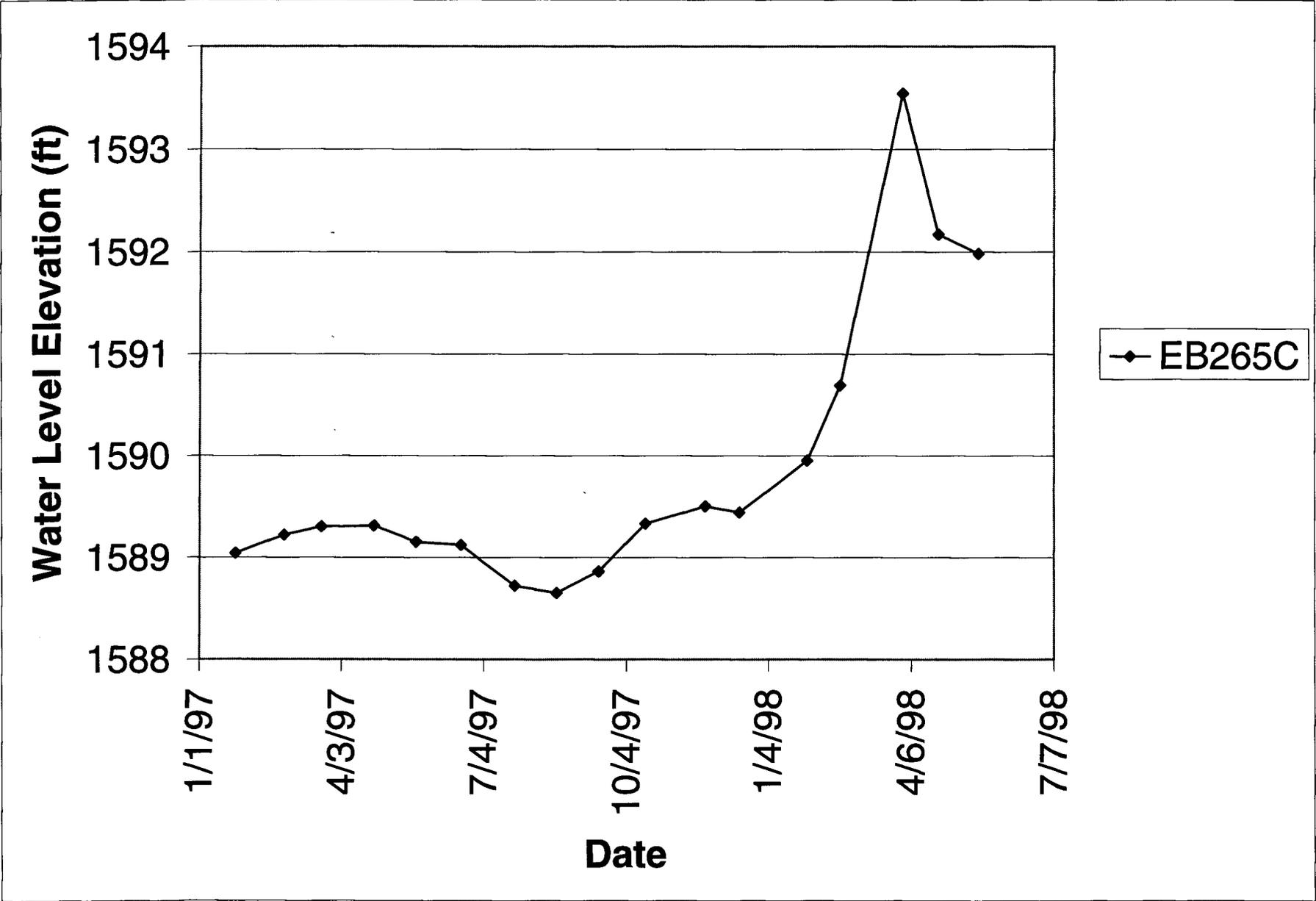


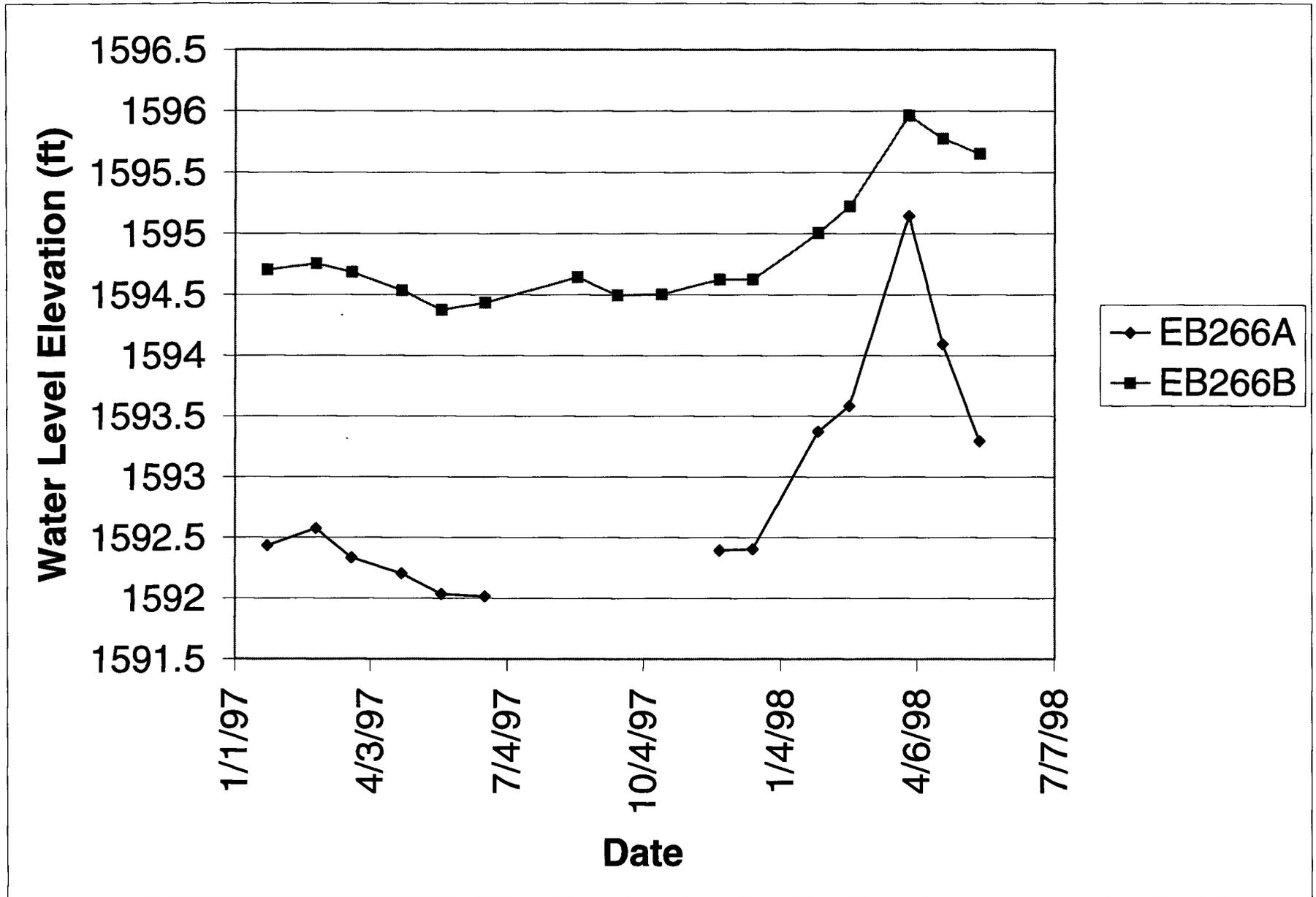


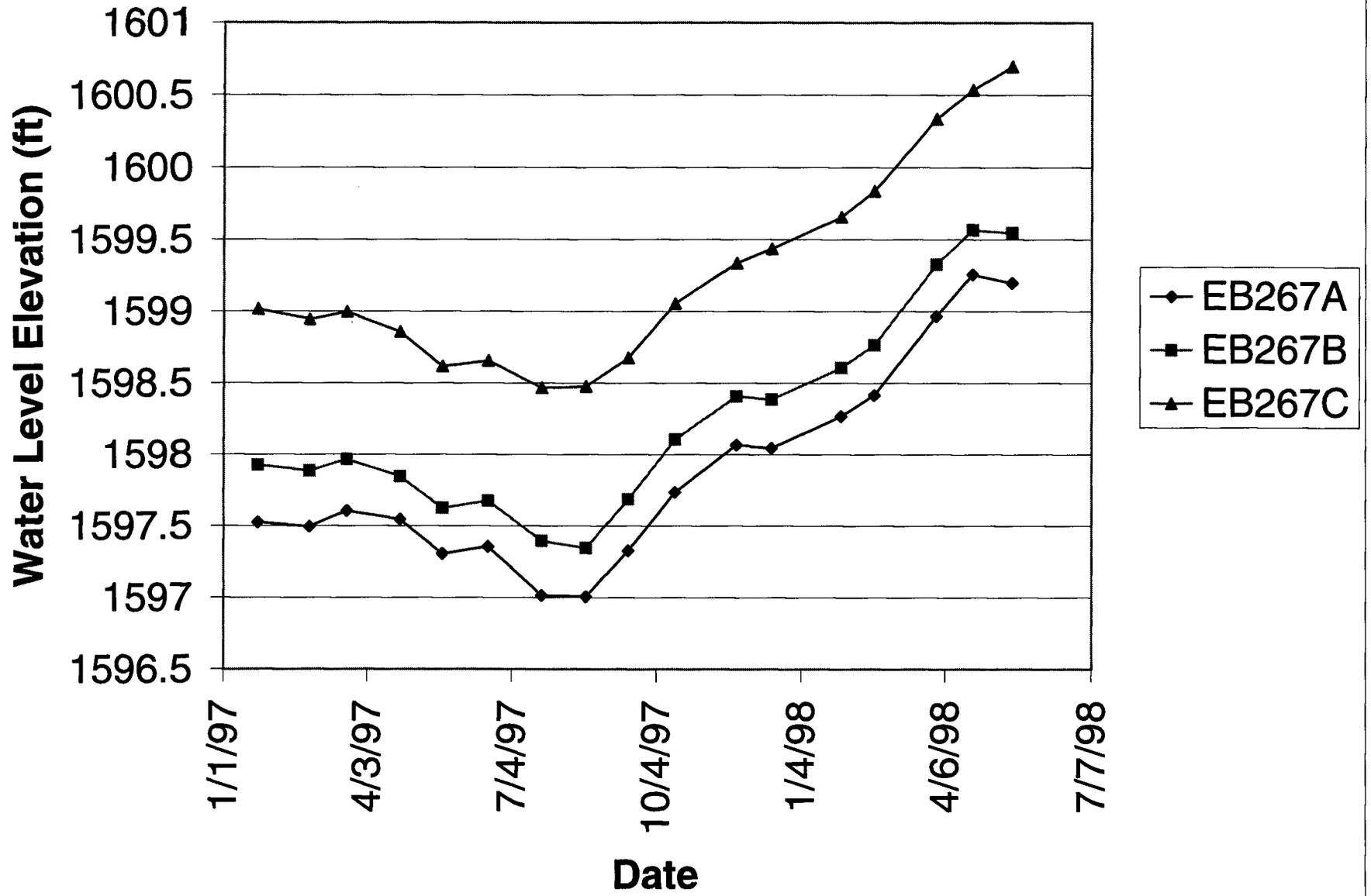


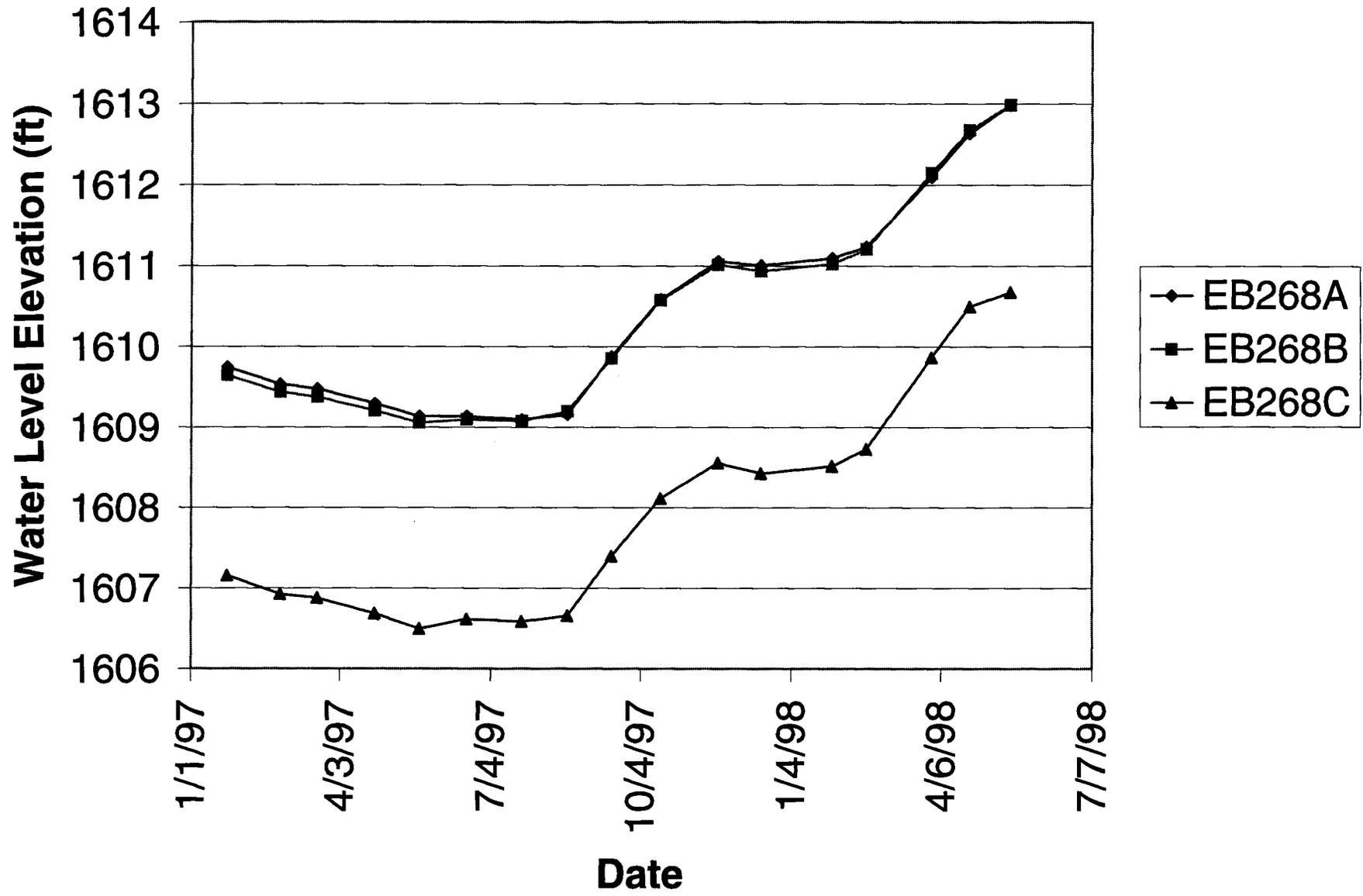


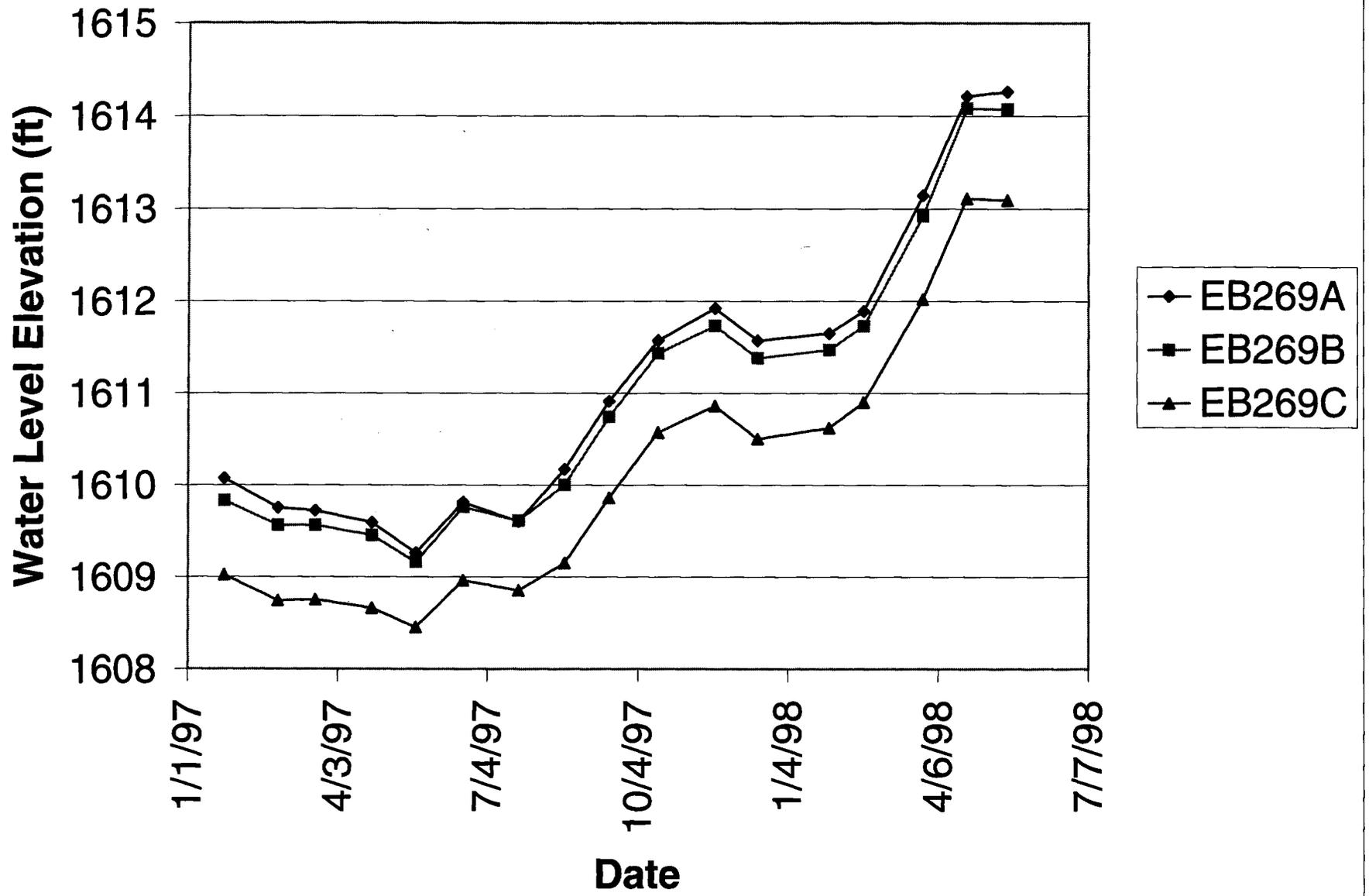


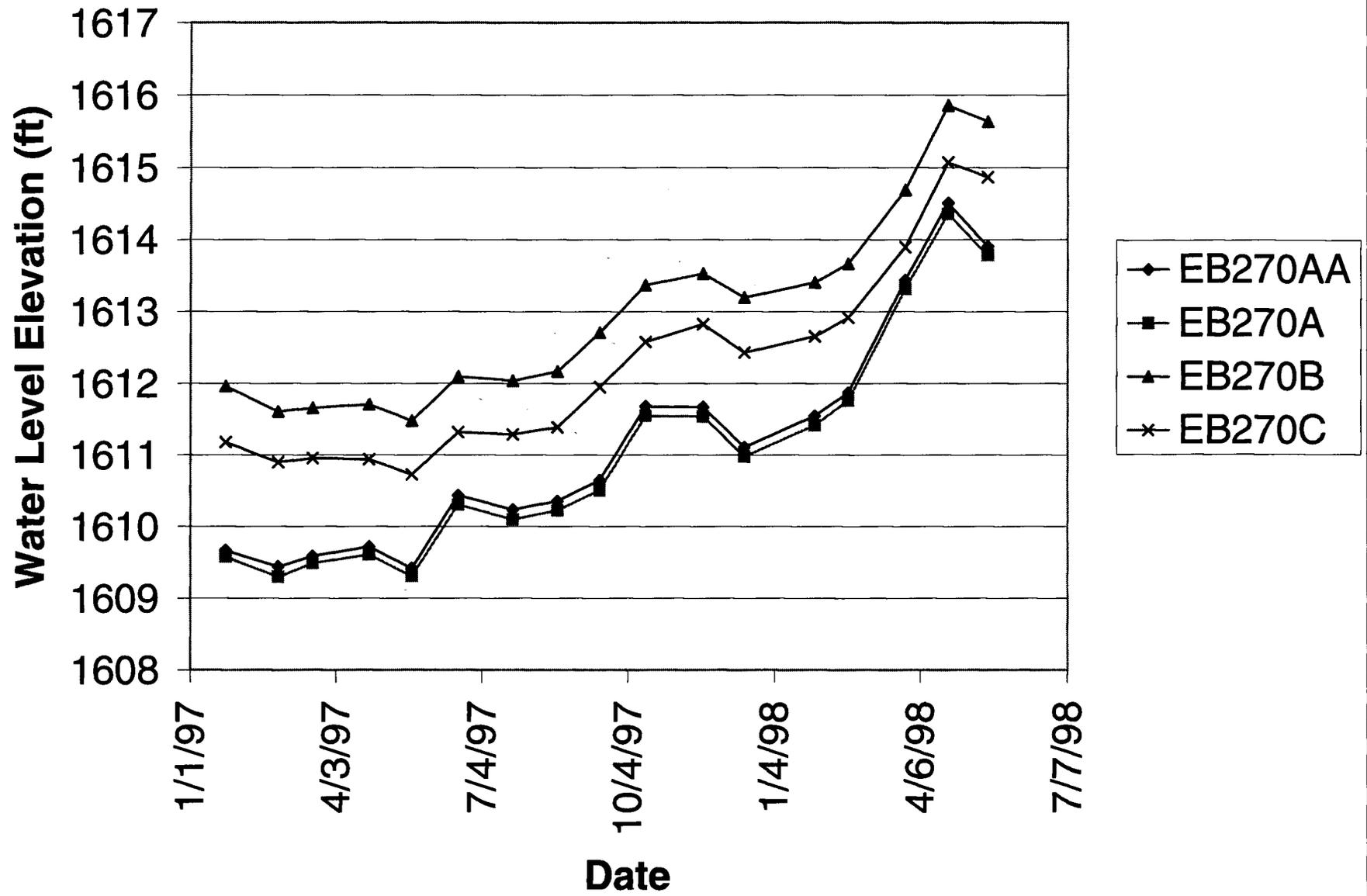












III. Groundwater Quality

Three sets of samples have been collected from the EBMI monitoring wells. The three sampling times were: Spring 1997 (mainly in March), Fall 1997 (November), and Spring 1998 (March and April). Two existing monitoring wells within the study area (EB400C and EB401C) were also sampled, as well as the monitoring wells just east of Hutchinson comprising part of the earlier Hutchinson to Wichita salinity study. Waters were also collected from 3 sites on the Arkansas River, two sites on Cow Creek, and one site on Salt Creek. Analyses of the surface waters will be discussed in Section IV. Samples were shipped to the Kansas Geological Survey for analysis. Procedures for the sampling and analyses, and results from the Spring '97 sampling were presented by Young et al. (1997) and will not be repeated in this report.

Combined field collection information and results of the chemical analyses for the Fall '97 and Spring '98 samples, as well as the KGS lab and project numbers, are included in Appendix III-A. The groundwaters from the EBMI wells range from very fresh to highly saline. Chloride concentrations ranged from 2 mg/L in EB259B to 5,812 mg/L in the Spring '98 sample from EB257C. Where saline waters occur, the salinity increases with depth as indicated by sites with wells completed at multiple levels. Some sites contain freshwaters of similar salinity at different depths. The waters with the highest salt contents occur south of the Arkansas River, confirming that groundwater salinities are greater in that region. The most saline water is from a well (EB257C) screened in a bedrock channel in the southern part of the study area.

Figures III-1 through III-3 show chloride concentrations and changes for wells in each of the transects. The hydrogeologic sections in Figures III-4 and III-5 illustrate with contours the distribution of chloride and the changes in chloride concentration from Spring '97 to Spring '98. Figs. III-1 through III-5 show that groundwaters are generally fresh north of the Arkansas River. Exceptions to this are wells at sites just north of the river (EB255C, EB261C, and EB266A & B), which have chloride concentrations greater than 500 mg/L. Concentrations in this range are above the recommended drinking water standard of 250 mg/L, and are not recommended for irrigation. Elsewhere north of the river, groundwater samples yielded fresh water, except in wells EB263C, which had a chloride concentration as high as 484 mg/L in the Fall '97 sample, and EB265C, where the concentration was steady at 360 mg/L.

Examination of the chemical data indicates that there is a wide range in the chemical character of the ground and surface waters. For example, sulfate/chloride ratios differ substantially for some of the saline groundwaters. Nitrate concentrations range from undetectable to over the maximum contaminant limit of 45 mg/L for water from wells EB254C, EB255A, EB258A, EB268A, and EB270AA in the network. In general, nitrate concentrations decreased with depth for sites with multiple-level wells. The chemistry of water from site EB263C indicates that oil-field brine could contribute a major portion of the chloride concentration, which averaged 467 mg/L.

Willowbrook-Partridge Transect Chloride Concentrations and Changes

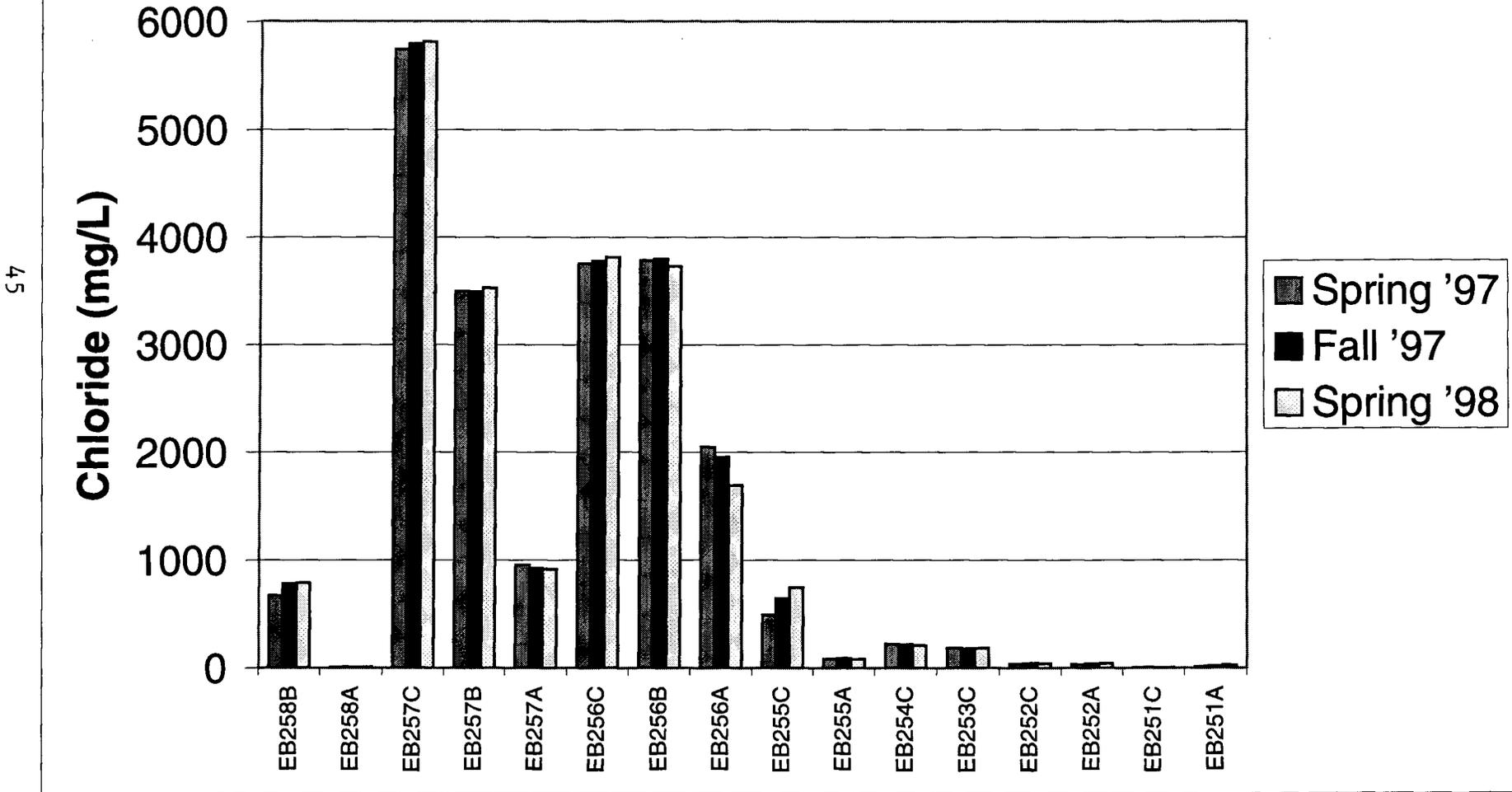


Figure III-1. Chloride concentrations and changes for wells in the Willowbrook-Partridge transect.

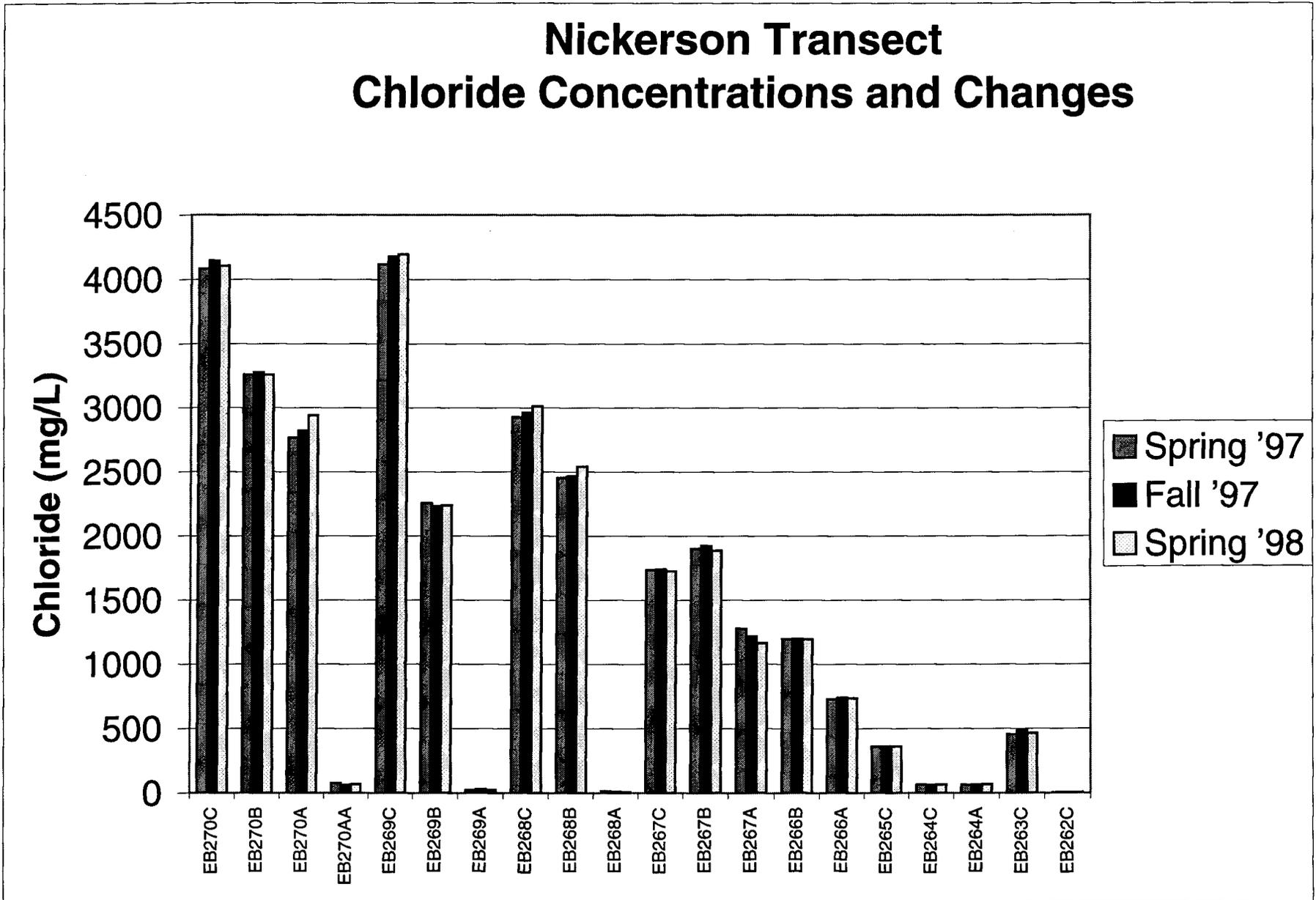


Figure III-2. Chloride concentrations and changes for wells in the Nickerson transect.

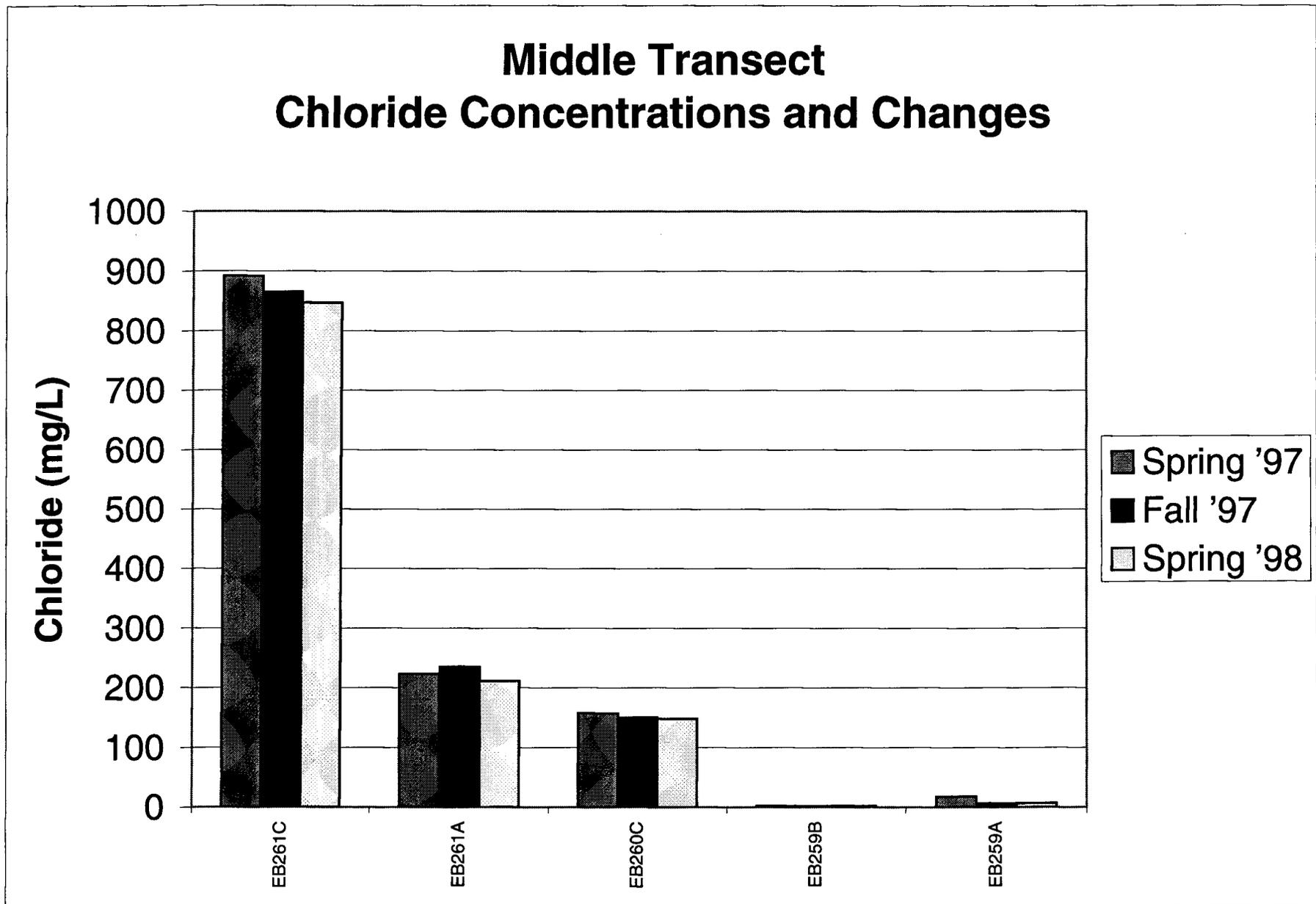


Figure III-3. Chloride concentrations and changes for wells in the Middle transect.

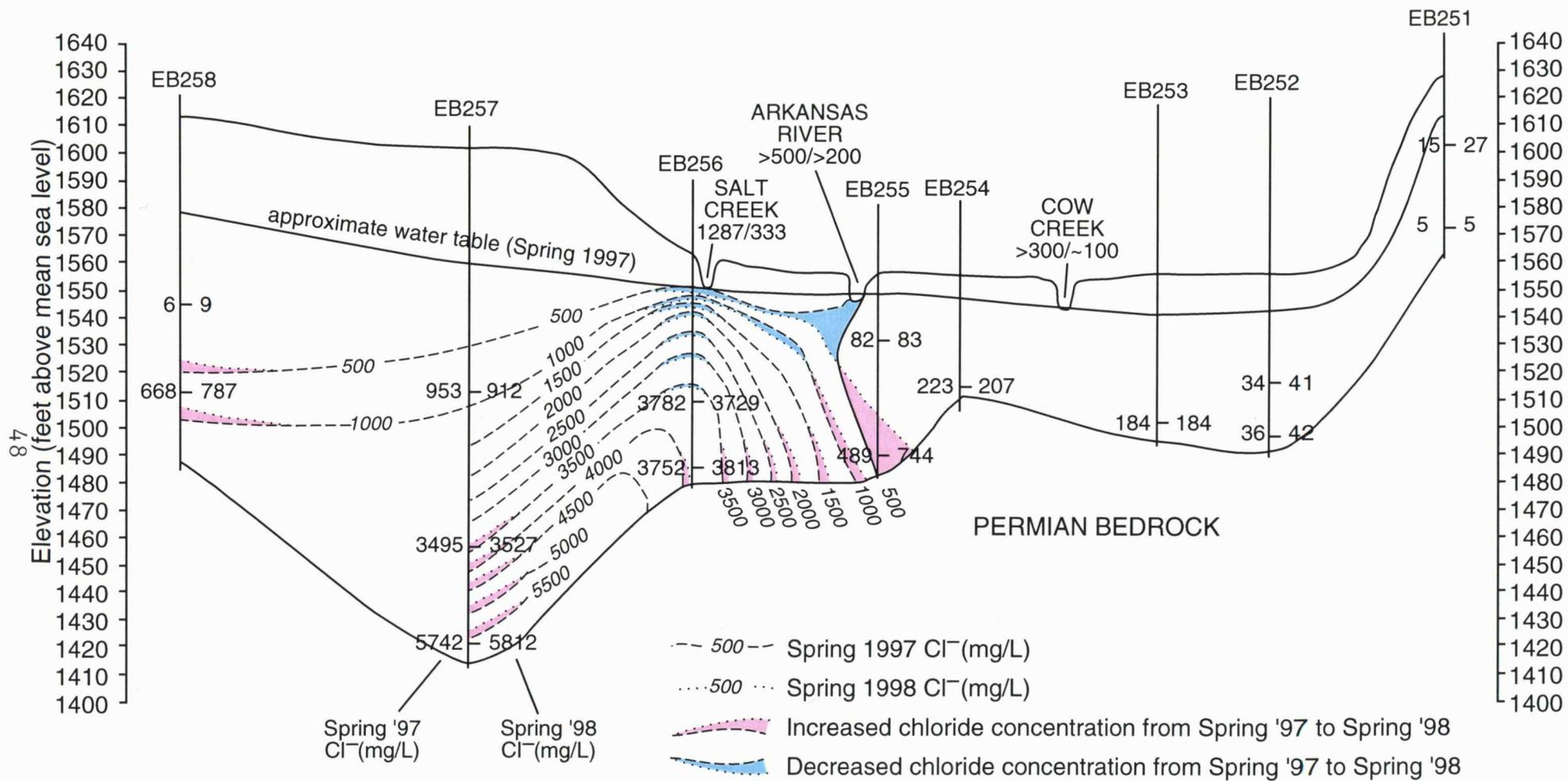


Figure III-4. Hydrogeologic section through Willowbrook-Partridge transect showing changes in inferred distribution of chloride - Spring 1997 to Spring 1998.

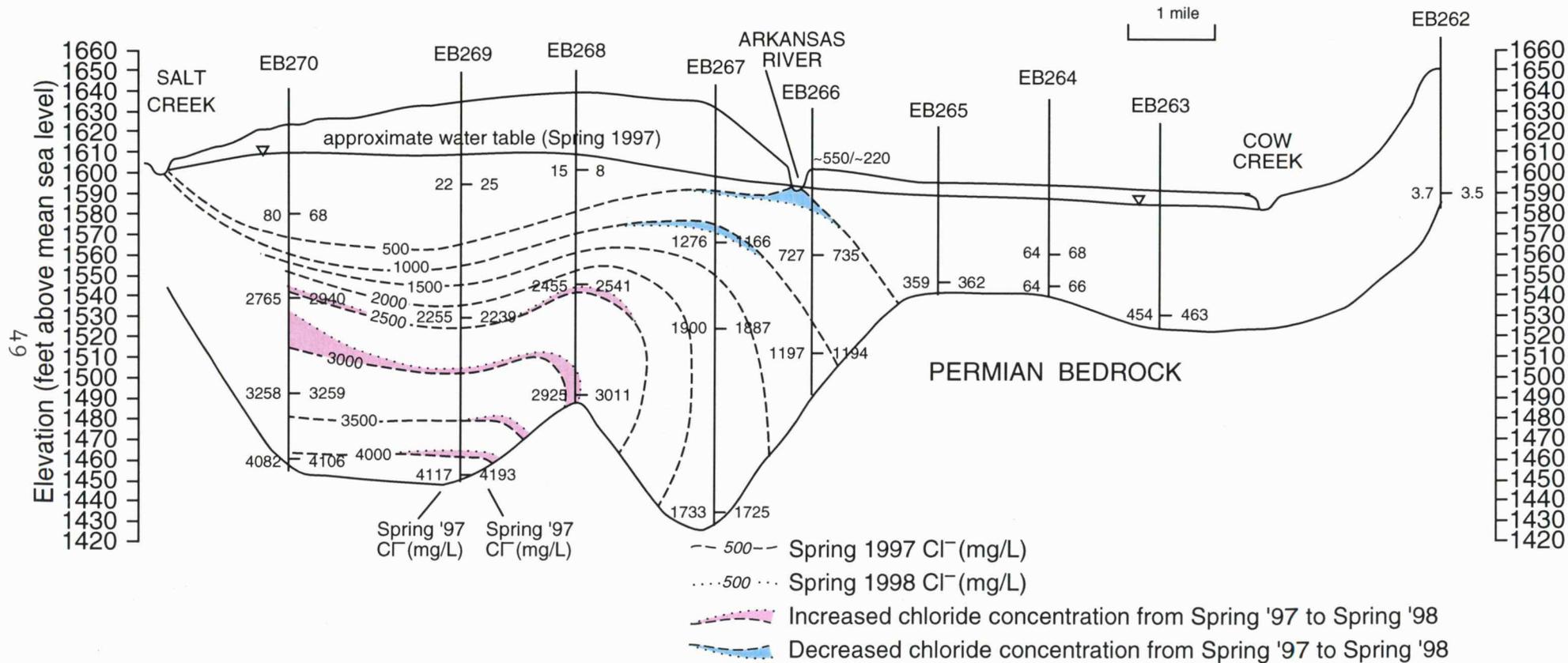


Figure III-5. Hydrogeologic section through Nickerson transect showing changes in inferred distribution of chloride - Spring 1997 to Spring 1998.

The chemical data also show some interesting temporal changes in some the wells. Tables III-1 through III-4 list changes between the three sampling times for specific conductance, chloride, sulfate, and nitrate-N, respectively. The well with the greatest increase in chloride (and the most noteworthy change) was EB255C, which is located north of the Arkansas River. In that well, the chloride concentration increased 255 mg/L from Spring '97 to Spring '98 (from 489 mg/L in Spring '97, to 643 mg/L in Fall '97, to 744 mg/L in Spring '98). Notice the shift in the 500 mg/L chloride contour on Figure III-4. If this represents consistent penetration of the salt front below the river, it could have serious implications for water quality in the vicinity. We may be fortunate in the timeliness of this study in that we are actually witnessing the beginning of the salination of the aquifer north of the river in that area, and thus may be better able to identify pathways, mechanisms, and means of mitigation.

Chloride concentrations at the other monitoring sites bordering the river on the north remained fairly consistent for the three sampling times: EB261A averaged about 220 mg/L, EB261C dropped from 892 to 847 mg/L, EB266A averaged about 735 mg/L, and EB266B remained at about 1200 mg/L.

Chloride concentrations appear to continue rising in many deep wells south of the Arkansas River, particularly in EB256C, EB257C, EB268B&C, EB269C, (and EB248C, which is located south of Hutchinson, east of the main study area). Chloride concentration showed a net increase in the deepest well at all sites south of the Arkansas River except at site EB267. EB270A showed a somewhat surprising increase in chloride concentration from 2765 mg/L in Spring '97 to 2940 mg/L in Spring '98, possibly resulting from local bedrock discharge or from perched salt water transported from upgradient. The steep bedrock slope near site EB270 (see Figure III-5) could be conducive to bedrock discharge, especially if relatively permeable horizons are exposed. Clay layers below the well screen of EB270A (see Plate 2 in Young et al., 1997) could allow perched salt water to be transported from upgradient.

The greatest decrease in chloride concentration from Spring '97 to Spring '98 occurred in EB256A, adjacent to the Salt Creek collection point (SALT 1). This substantial decline reflects the dilution from heavy precipitation and is a strong indication of stream-aquifer interaction. The chloride concentration in the creek (SALT 1) dropped from 1287 mg/L to 333 mg/L over the same period (discussed in Section IV). The chloride contours in Figures III-4 and III-5 show both the discharge of salt water to Salt Creek and the Arkansas River, and the freshening of the surface waters and shallow groundwaters in these vicinities from Spring '97 to Spring '98, both of which are signs of the stream-aquifer interactions occurring.

Geophysical Logs

Geophysical logs of the deep well or borehole at each site were initially collected during drilling operations to assist in the design and placement of shallow wells. The natural gamma log responds primarily to fine-grained sediments such as clays. The

Table III-1. Specific conductance values and changes.

ID	Spring	Fall	Spring	Spr. '97 to	Spr. '97 to	Fall '97 to	Fall '97 to	Spr. '97 to	Spr. '97 to
	1997	1997	1998	Fall '97	Fall '97	Spr. '98	Spr. '98	Spr. '98	Spr. '98
Lab	Lab	Lab	Change	Change	in	in	change	in	change
Sp.C.	Sp.C.	Sp.C.	in	in	Sp.C.	in	in	Sp.C.	in
uS/cm	uS/cm	uS/cm	Sp.C.	Sp.C.	uS/cm	Sp.C.	Sp.C.	uS/cm	Sp.C.
ARK 1	2970	3500	1810	530	17.8	-1690	-48.3	-1160	-39.1
ARK 2	2930	3440	1800	510	17.4	-1640	-47.7	-1130	-38.6
ARK 3	2870	3250	1760	380	13.2	-1490	-45.8	-1110	-38.7
COW1	1615	1370	612	-245	-15.2	-758	-55.3	-1003	-62.1
COW 2	2375	2150	1790	-225	-9.5	-360	-16.7	-585	-24.6
SALT 1	4619	4397	1440	-222	-4.8	-2957	-67.3	-3179	-68.8
EB228A	810	850	830	40	4.9	-20	-2.4	20	2.5
EB228B	523	563	558	40	7.6	-5	-0.9	35	6.7
EB228C	447	449	450	2	0.4	1	0.2	3	0.7
EB229A	2490	2530	2530	40	1.6	0	0.0	40	1.6
EB229B	4289	4278	4274	-11	-0.3	-4	-0.1	-15	-0.3
EB229C	7078	7009	7283	-69	-1.0	274	3.9	205	2.9
EB230AA	2380	2400	2400	20	0.8	0	0.0	20	0.8
EB230A	2530	2500	2500	-30	-1.2	0	0.0	-30	-1.2
EB230B	3300	3290	3260	-10	-0.3	-30	-0.9	-40	-1.2
EB230C	2550	2580	2580	30	1.2	0	0.0	30	1.2
EB231A	2010	1850	1870	-160	-8.0	20	1.1	-140	-7.0
EB231B	2460	2375	2420	-85	-3.5	45	1.9	-40	-1.6
EB231C	3710	3580	3580	-130	-3.5	0	0.0	-130	-3.5
EB232A	530	528	525	-2	-0.4	-3	-0.6	-5	-0.9
EB232B	2090	2020	2020	-70	-3.3	0	0.0	-70	-3.3
EB232C	3580	3570	3580	-10	-0.3	10	0.3	0	0.0
EB233A	638	636	640	-2	-0.3	4	0.6	2	0.3
EB233B	640	638	645	-2	-0.3	7	1.1	5	0.8
EB233C	468	470	463	2	0.4	-7	-1.5	-5	-1.1
EB234A	652	559	583	-93	-14.3	24	4.3	-69	-10.6
EB234C	620	650	623	30	4.8	-27	-4.2	3	0.5
EB235A	808	833	824	25	3.1	-9	-1.1	16	2.0
EB235C	568	607	565	39	6.9	-42	-6.9	-3	-0.5
EB239A	3800	3830	3830	30	0.8	0	0.0	30	0.8
EB239C	4039	4053	4097	14	0.3	44	1.1	58	1.4

Table III-1. Specific conductance values and changes.

ID	Spring	Fall	Spring	Spr. '97 to	Spr. '97 to	Fall '97 to	Fall '97 to	Spr. '97 to	Spr. '97 to
	1997	1997	1998	Fall '97	Fall '97	Spr. '98	Spr. '98	Spr. '98	Spr. '98
Lab	Lab	Lab	Change	Change	in	Change	Percent	Change	Percent
Sp.C.	Sp.C.	Sp.C.	in	in	Sp.C.	in	change	in	change
uS/cm	uS/cm	uS/cm	Sp.C.	Sp.C.	uS/cm	Sp.C.	in	Sp.C.	in
			uS/cm	uS/cm		uS/cm	Sp.C.	uS/cm	Sp.C.
EB240AA	1555	2250	1860	695	44.7	-390	-17.3	305	19.6
EB240A	3130	3130	3100	0	0.0	-30	-1.0	-30	-1.0
EB240B	4128	4053	4000	-75	-1.8	-53	-1.3	-128	-3.1
EB240C	9579	9596	9558	17	0.2	-38	-0.4	-21	-0.2
EB248A	671	687	674	16	2.4	-13	-1.9	3	0.4
EB248B	1430	1610	1380	180	12.6	-230	-14.3	-50	-3.5
EB248C	12090	12030	12040	-60	-0.5	10	0.1	-50	-0.4
EB250A	362	430	449	68	18.8	19	4.4	87	24.0
EB250C	448	416	414	-32	-7.1	-2	-0.5	-34	-7.6
EB251A	278	297	388	19	6.8	91	30.6	110	39.6
EB251C	255	258	257	3	1.2	-1	-0.4	2	0.8
EB252A	725	769	760	44	6.1	-9	-1.2	35	4.8
EB252C	705	735	738	30	4.3	3	0.4	33	4.7
EB253C	1230	1210	1225	-20	-1.6	15	1.2	-5	-0.4
EB254C	1670	1670	1670	0	0.0	0	0.0	0	0.0
EB255A	1065	1110	1095	45	4.2	-15	-1.4	30	2.8
EB255C	2350	2780	3070	430	18.3	290	10.4	720	30.6
EB256A	7065	6744	6099	-321	-4.5	-645	-9.6	-966	-13.7
EB256B	11940	12010	12080	70	0.6	70	0.6	140	1.2
EB256C	11980	11950	11980	-30	-0.3	30	0.3	0	0.0
EB257A	3700	3550	3440	-150	-4.1	-110	-3.1	-260	-7.0
EB257B	11150	11210	11200	60	0.5	-10	-0.1	50	0.4
EB257C	17720	17740	17840	20	0.1	100	0.6	120	0.7
EB258A	609	620	620	11	1.8	0	0.0	11	1.8
EB258B	2760	3180	3160	420	15.2	-20	-0.6	400	14.5
EB259A	227	130	175	-97	-42.7	45	34.6	-52	-22.9
EB259B	144	133	131	-11	-7.6	-2	-1.5	-13	-9.0
EB260C	1260	1250	1235	-10	-0.8	-15	-1.2	-25	-2.0
EB261A	1680	1720	1675	40	2.4	-45	-2.6	-5	-0.3
EB261C	3500	3440	3430	-60	-1.7	-10	-0.3	-70	-2.0
EB262C	355	357	357	2	0.6	0	0.0	2	0.6

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Table III-1. Specific conductance values and changes.

ID	Spring	Fall	Spring	Spr. '97 to	Spr. '97 to	Fall '97 to	Fall '97 to	Spr. '97 to	Spr. '97 to
	1997	1997	1998	Fall '97	Fall '97	Spr. '98	Spr. '98	Spr. '98	Spr. '98
Lab	Lab	Lab	Change	Change	Percent	Change	Percent	Change	Percent
Sp.C.	Sp.C.	Sp.C.	in	in	change	in	change	in	change
uS/cm	uS/cm	uS/cm	Sp.C.	Sp.C.	in	Sp.C.	in	Sp.C.	in
			uS/cm	uS/cm	Sp.C.	uS/cm	Sp.C.	uS/cm	Sp.C.
EB263C	2150	2180	2140	30	1.4	-40	-1.8	-10	-0.5
EB264A	918	985	1015	67	7.3	30	3.0	97	10.6
EB264C	940	933	942	-7	-0.7	9	1.0	2	0.2
EB265C	1860	1855	1880	-5	-0.3	25	1.3	20	1.1
EB266A	2950	3000	3000	50	1.7	0	0.0	50	1.7
EB266B	6286	6374	6388	88	1.4	14	0.2	102	1.6
EB267A	4625	4510	4402	-115	-2.5	-108	-2.4	-223	-4.8
EB267B	6463	6504	6490	41	0.6	-14	-0.2	27	0.4
EB267C	7117	7197	7189	80	1.1	-8	-0.1	72	1.0
EB268A	521	545	489	24	4.6	-56	-10.3	-32	-6.1
EB268B	8255	8246	8292	-9	-0.1	46	0.6	37	0.4
EB268C	9715	9770	9718	55	0.6	-52	-0.5	3	0.0
EB269A	578	618	602	40	6.9	-16	-2.6	24	4.2
EB269B	7725	7653	7504	-72	-0.9	-149	-1.9	-221	-2.9
EB269C	13240	13370	13210	130	1.0	-160	-1.2	-30	-0.2
EB270AA	867	817	813	-50	-5.8	-4	-0.5	-54	-6.2
EB270A	9325	9398	10230	73	0.8	832	8.9	905	9.7
EB270B	10650	10660	10620	10	0.1	-40	-0.4	-30	-0.3
EB270C	13710	13090	13020	-620	-4.5	-70	-0.5	-690	-5.0
EB400C	11050	11140	11100	90	0.8	-40	-0.4	50	0.5
EB401C	5595	5599	5564	4	0.1	-35	-0.6	-31	-0.6

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Table III-2. Chloride concentrations and changes.

	Spring 1997 Cl mg/L	Fall 1997 Cl mg/L	Spring 1998 Cl mg/L	Spr. '97 to Fall '97 Change in Cl mg/L	Spr. '97 to Fall '97 Percent change in Cl	Fall '97 to Spr. '98 Change in Cl mg/L	Fall '97 to Spr. '98 Percent change in Cl	Spr. '97 to Spr. '98 Change in Cl mg/L	Spr. '97 to Spr. '98 Percent change in Cl
ARK 1	549	466	216	-83	-15.1	-250	-53.6	-333	-60.7
ARK 2	542	474	218	-68	-12.5	-256	-54.0	-324	-59.8
ARK 3	549	452	247	-97	-17.7	-205	-45.4	-302	-55.0
COW1	325	233	102	-92	-28.3	-131	-56.2	-223	-68.6
COW 2	545	450	371	-95	-17.4	-79	-17.6	-174	-31.9
SALT 1	1287	1198	333	-89	-6.9	-865	-72.2	-954	-74.1
EB228A	47.2	49.4	46.8	2.2	4.7	-2.6	-5.3	-0.4	-0.8
EB228B	37.1	48.6	48.1	11.5	31.0	-0.5	-1.0	11	29.6
EB228C	14.2	14.8	14.2	0.6	4.2	-0.6	-4.1	0	0.0
EB229A	591	602	603	11	1.9	1	0.2	12	2.0
EB229B	1213	1213	1184	0	0.0	-29	-2.4	-29	-2.4
EB229C	2213	2197	2242	-16	-0.7	45	2.0	29	1.3
EB230AA	552	559	549	7	1.3	-10	-1.8	-3	-0.5
EB230A	588	583	597	-5	-0.9	14	2.4	9	1.5
EB230B	852	852	860	0	0.0	8	0.9	8	0.9
EB230C	642	657	671	15	2.3	14	2.1	29	4.5
EB231A	414	381	378	-33	-8.0	-3	-0.8	-36	-8.7
EB231B	561	531	541	-30	-5.3	10	1.9	-20	-3.6
EB231C	982	944	922	-38	-3.9	-22	-2.3	-60	-6.1
EB232A	25.4	25.2	23.4	-0.2	-0.8	-1.8	-7.1	-2	-7.9
EB232B	441	424	417	-17	-3.9	-7	-1.7	-24	-5.4
EB232C	891	877	895	-14	-1.6	18	2.1	4	0.4
EB233A	25.6	23.3	22.9	-2.3	-9.0	-0.4	-1.7	-2.7	-10.5
EB233B	25.1	23.0	21.9	-2.1	-8.4	-1.1	-4.8	-3.2	-12.7
EB233C	11.8	11.7	11.0	-0.1	-0.8	-0.7	-6.0	-0.8	-6.8
EB234A	24.4	22.2	21.6	-2.2	-9.0	-0.6	-2.7	-2.8	-11.5
EB234C	17.4	18.2	16.0	0.8	4.6	-2.2	-12.1	-1.4	-8.0
EB235A	28.4	27.0	26.1	-1.4	-4.9	-0.9	-3.3	-2.3	-8.1
EB235C	13.5	13.0	12.4	-0.5	-3.7	-0.6	-4.6	-1.1	-8.1
EB239A	1036	1044	1052	8	0.8	8	0.8	16	1.5
EB239C	1071	1100	1113	29	2.7	13	1.2	42	3.9

Table III-2. Chloride concentrations and changes.

	Spring 1997 Cl mg/L	Fall 1997 Cl mg/L	Spring 1998 Cl mg/L	Spr. '97 to Fall '97 Change in Cl mg/L	Spr. '97 to Fall '97 Percent change in Cl	Fall '97 to Spr. '98 Change in Cl mg/L	Fall '97 to Spr. '98 Percent change in Cl	Spr. '97 to Spr. '98 Change in Cl mg/L	Spr. '97 to Spr. '98 Percent change in Cl
EB240AA	328	544	417	216	65.9	-127	-23.3	89	27.1
EB240A	788	784	767	-4	-0.5	-17	-2.2	-21	-2.7
EB240B	1094	1073	1034	-21	-1.9	-39	-3.6	-60	-5.5
EB240C	2908	2951	2887	43	1.5	-64	-2.2	-21	-0.7
EB248A	27.4	25.1	26.9	-2.3	-8.4	1.8	7.2	-0.5	-1.8
EB248B	253	310	235	57	22.5	-75	-24.2	-18	-7.1
EB248C	3729	3764	3814	35	0.9	50	1.3	85	2.3
EB250A	24.2	32.0	32.1	7.8	32.2	0.1	0.3	7.9	32.6
EB250C	33.7	29.7	29.0	-4	-11.9	-0.7	-2.4	-4.7	-13.9
EB251A	14.7	19.6	26.7	4.9	33.3	7.1	36.2	12	81.6
EB251C	5.4	5.5	5.2	0.1	1.9	-0.3	-5.5	-0.2	-3.7
EB252A	34.0	40.2	40.8	6.2	18.2	0.6	1.5	6.8	20.0
EB252C	36.0	41.5	41.6	5.5	15.3	0.1	0.2	5.6	15.6
EB253C	184	180	184	-4	-2.2	4	2.2	0	0.0
EB254C	223	219	207	-4	-1.8	-12	-5.5	-16	-7.2
EB255A	82.2	90.2	82.8	8	9.7	-7.4	-8.2	0.6	0.7
EB255C	489	643	744	154	31.5	101	15.7	255	52.1
EB256A	2046	1953	1688	-93	-4.5	-265	-13.6	-358	-17.5
EB256B	3782	3798	3729	16	0.4	-69	-1.8	-53	-1.4
EB256C	3752	3777	3813	25	0.7	36	1.0	61	1.6
EB257A	953	924	912	-29	-3.0	-12	-1.3	-41	-4.3
EB257B	3495	3492	3527	-3	-0.1	35	1.0	32	0.9
EB257C	5742	5792	5812	50	0.9	20	0.3	70	1.2
EB258A	6.4	9.4	8.8	3	46.9	-0.6	-6.4	2.4	37.5
EB258B	668	782	787	114	17.1	5	0.6	119	17.8
EB259A	17.6	6.2	6.9	-11.4	-64.8	0.7	11.3	-10.7	-60.8
EB259B	2.2	1.9	2.2	-0.3	-13.6	0.3	15.8	0	0.0
EB260C	157	150	148	-7	-4.5	-2	-1.3	-9	-5.7
EB261A	223	235	211	12	5.4	-24	-10.2	-12	-5.4
EB261C	892	865	847	-27	-3.0	-18	-2.1	-45	-5.0
EB262C	3.7	3.4	3.5	-0.3	-8.1	0.1	2.9	-0.2	-5.4

Table III-2. Chloride concentrations and changes.

	Spring 1997 Cl mg/L	Fall 1997 Cl mg/L	Spring 1998 Cl mg/L	Spr. '97 to Fall '97 Change in Cl mg/L	Spr. '97 to Fall '97 Percent change in Cl	Fall '97 to Spr. '98 Change in Cl mg/L	Fall '97 to Spr. '98 Percent change in Cl	Spr. '97 to Spr. '98 Change in Cl mg/L	Spr. '97 to Spr. '98 Percent change in Cl
EB263C	454	484	463	30	6.6	-21	-4.3	9	2.0
EB264A	63.9	65.0	67.9	1.1	1.7	2.9	4.5	4	6.3
EB264C	63.6	64.8	65.8	1.2	1.9	1	1.5	2.2	3.5
EB265C	359	359	362	0	0.0	3	0.8	3	0.8
EB266A	727	739	735	12	1.7	-4	-0.5	8	1.1
EB266B	1197	1200	1194	3	0.3	-6	-0.5	-3	-0.3
EB267A	1276	1218	1166	-58	-4.5	-52	-4.3	-110	-8.6
EB267B	1900	1923	1887	23	1.2	-36	-1.9	-13	-0.7
EB267C	1733	1739	1725	6	0.3	-14	-0.8	-8	-0.5
EB268A	14.6	12.1	7.6	-2.5	-17.1	-4.5	-37.2	-7	-47.9
EB268B	2455	2466	2541	11	0.4	75	3.0	86	3.5
EB268C	2925	2962	3011	37	1.3	49	1.7	86	2.9
EB269A	22.1	30.7	24.5	8.6	38.9	-6.2	-20.2	2.4	10.9
EB269B	2255	2234	2239	-21	-0.9	5	0.2	-16	-0.7
EB269C	4117	4176	4193	59	1.4	17	0.4	76	1.8
EB270AA	79.4	64.6	68.4	-14.8	-18.6	3.8	5.9	-11	-13.9
EB270A	2765	2820	2940	55	2.0	120	4.3	175	6.3
EB270B	3258	3276	3259	18	0.6	-17	-0.5	1	0.0
EB270C	4082	4143	4106	61	1.5	-37	-0.9	24	0.6
EB400C	3442	3443	3406	1	0.0	-37	-1.1	-36	-1.0
EB401C	1604	1593	1584	-11	-0.7	-9	-0.6	-20	-1.2

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Table III-3. Sulfate concentrations and changes.

	Spring 1997 SO4 mg/L	Fall 1997 SO4 mg/L	Spring 1998 SO4 mg/L	Spr. '97 to Fall '97 Change in SO4 mg/L	Spr. '97 to Fall '97 Percent change in SO4	Fall '97 to Spr. '98 Change in SO4 mg/L	Fall '97 to Spr. '98 Percent change in SO4	Spr. '97 to Spr. '98 Change in SO4 mg/L	Spr. '97 to Spr. '98 Percent change in SO4
ARK 1	514	970	442	456	88.7	-528	-54.4	-72.0	-14.0
ARK 2	519	931	440	412	79.4	-491	-52.7	-79.0	-15.2
ARK 3	468	850	355	382	81.6	-495	-58.2	-113.0	-24.1
COW1	96.0	85.3	40.0	-10.7	-11.1	-45.3	-53.1	-56.0	-58.3
COW 2	170	151	127	-19	-11.2	-24	-15.9	-43.0	-25.3
SALT 1	161	151	49.7	-10	-6.2	-101.3	-67.1	-111.3	-69.1
EB228A	91.2	99.5	86.9	8.3	9.1	-12.6	-12.7	-4.3	-4.7
EB228B	74.6	75.8	75.9	1.2	1.6	0.1	0.1	1.3	1.7
EB228C	66.0	64.8	65.7	-1.2	-1.8	0.9	1.4	-0.3	-0.5
EB229A	119	118	117	-1	-0.8	-1	-0.8	-2.0	-1.7
EB229B	155	152	152	-3	-1.9	0	0.0	-3.0	-1.9
EB229C	154	153	153	-1	-0.6	0	0.0	-1.0	-0.6
EB230AA	121	122	123	1	0.8	1	0.8	2.0	1.7
EB230A	136	131	133	-5	-3.7	2	1.5	-3.0	-2.2
EB230B	163	158	158	-5	-3.1	0	0.0	-5.0	-3.1
EB230C	140	137	137	-3	-2.1	0	0.0	-3.0	-2.1
EB231A	144	134	135	-10	-6.9	1	0.7	-9.0	-6.3
EB231B	177	165	167	-12	-6.8	2	1.2	-10.0	-5.6
EB231C	216	208	210	-8	-3.7	2	1.0	-6.0	-2.8
EB232A	16.3	15.2	15.3	-1.1	-6.7	0.1	0.7	-1.0	-6.1
EB232B	91.7	86.7	85.3	-5	-5.5	-1.4	-1.6	-6.4	-7.0
EB232C	171	164	163	-7	-4.1	-1	-0.6	-8.0	-4.7
EB233A	27.6	25.4	26.1	-2.2	-8.0	0.7	2.8	-1.5	-5.4
EB233B	27.4	25.4	25.6	-2	-7.3	0.2	0.8	-1.8	-6.6
EB233C	12.5	11.7	12.2	-0.8	-6.4	0.5	4.3	-0.3	-2.4
EB234A	14.0	6.3	7.1	-7.7	-55.0	0.8	12.7	-6.9	-49.3
EB234C	2.0	2.0	1.9	0	0.0	-0.1	-5.0	-0.1	-5.0
EB235A	22.6	21.4	21.8	-1.2	-5.3	0.4	1.9	-0.8	-3.5
EB235C	15.3	13.9	13.9	-1.4	-9.2	0	0.0	-1.4	-9.2
EB239A	168	164	162	-4	-2.4	-2	-1.2	-6.0	-3.6
EB239C	241	225	221	-16	-6.6	-4	-1.8	-20.0	-8.3

Table III-3. Sulfate concentrations and changes.

	Spring 1997	Fall 1997	Spring 1998	Spr. '97 to Fall '97 Change in SO4 mg/L	Spr. '97 to Fall '97 Percent change in SO4	Fall '97 to Spr. '98 Change in SO4 mg/L	Fall '97 to Spr. '98 Percent change in SO4	Spr. '97 to Spr. '98 Change in SO4 mg/L	Spr. '97 to Spr. '98 Percent change in SO4
EB240AA	84.4	111	94.8	26.6	31.5	-16.2	-14.6	10.4	12.3
EB240A	249	246	246	-3	-1.2	0	0.0	-3.0	-1.2
EB240B	275	271	272	-4	-1.5	1	0.4	-3.0	-1.1
EB240C	379	371	372	-8	-2.1	1	0.3	-7.0	-1.8
EB248A	33.0	34.3	33.4	1.3	3.9	-0.9	-2.6	0.4	1.2
EB248B	54.6	58.6	52.6	4	7.3	-6	-10.2	-2.0	-3.7
EB248C	487	478	479	-9	-1.8	1	0.2	-8.0	-1.6
EB250A	40.9	49.1	60.9	8.2	20.0	11.8	24.0	20.0	48.9
EB250C	56.8	53.4	53.8	-3.4	-6.0	0.4	0.7	-3.0	-5.3
EB251A	33.8	32.8	39.2	-1	-3.0	6.4	19.5	5.4	16.0
EB251C	13.8	13.1	12.9	-0.7	-5.1	-0.2	-1.5	-0.9	-6.5
EB252A	90.2	93.4	92.7	3.2	3.5	-0.7	-0.7	2.5	2.8
EB252C	83.0	86.1	86.5	3.1	3.7	0.4	0.5	3.5	4.2
EB253C	125	120	122	-5	-4.0	2	1.7	-3.0	-2.4
EB254C	205	200	211	-5	-2.4	11	5.5	6.0	2.9
EB255A	134	136	140	2	1.5	4	2.9	6.0	4.5
EB255C	250	251	251	1	0.4	0	0.0	1.0	0.4
EB256A	253	234	211	-19	-7.5	-23	-9.8	-42.0	-16.6
EB256B	430	425	428	-5	-1.2	3	0.7	-2.0	-0.5
EB256C	433	425	425	-8	-1.8	0	0.0	-8.0	-1.8
EB257A	127	123	122	-4	-3.1	-1	-0.8	-5.0	-3.9
EB257B	422	415	415	-7	-1.7	0	0.0	-7.0	-1.7
EB257C	701	692	688	-9	-1.3	-4	-0.6	-13.0	-1.9
EB258A	22.3	22.8	23.4	0.5	2.2	0.6	2.6	1.1	4.9
EB258B	100	115	113	15	15.0	-2	-1.7	13.0	13.0
EB259A	32.0	21.3	37.0	-10.7	-33.4	15.7	73.7	5.0	15.6
EB259B	2.0	1.5	0.9	-0.5	-25.0	-0.6	-40.0	-1.1	-55.0
EB260C	136	133	128	-3	-2.2	-5	-3.8	-8.0	-5.9
EB261A	254	261	245	7	2.8	-16	-6.1	-9.0	-3.5
EB261C	312	305	305	-7	-2.2	0	0.0	-7.0	-2.2
EB262C	4.1	3.9	2.7	-0.2	-4.9	-1.2	-30.8	-1.4	-34.1

Table III-3. Sulfate concentrations and changes.

	Spring 1997 SO4 mg/L	Fall 1997 SO4 mg/L	Spring 1998 SO4 mg/L	Spr. '97 to Fall '97 Change in SO4 mg/L	Spr. '97 to Fall '97 Percent change in SO4	Fall '97 to Spr. '98 Change in SO4 mg/L	Fall '97 to Spr. '98 Percent change in SO4	Spr. '97 to Spr. '98 Change in SO4 mg/L	Spr. '97 to Spr. '98 Percent change in SO4
EB263C	182	150	172	-32	-17.6	22	14.7	-10.0	-5.5
EB264A	97.2	108	116	10.8	11.1	8	7.4	18.8	19.3
EB264C	103	98.5	99.5	-4.5	-4.4	1	1.0	-3.5	-3.4
EB265C	139	136	135	-3	-2.2	-1	-0.7	-4.0	-2.9
EB266A	174	179	180	5	2.9	1	0.6	6.0	3.4
EB266B	1479	1479	1468	0	0.0	-11	-0.7	-11.0	-0.7
EB267A	177	167	162	-10	-5.6	-5	-3.0	-15.0	-8.5
EB267B	276	269	267	-7	-2.5	-2	-0.7	-9.0	-3.3
EB267C	1046	1038	1026	-8	-0.8	-12	-1.2	-20.0	-1.9
EB268A	21.2	24.0	19.6	2.8	13.2	-4.4	-18.3	-1.6	-7.5
EB268B	261	255	255	-6	-2.3	0	0.0	-6.0	-2.3
EB268C	331	324	324	-7	-2.1	0	0.0	-7.0	-2.1
EB269A	17.0	20.3	19.9	3.3	19.4	-0.4	-2.0	2.9	17.1
EB269B	238	234	231	-4	-1.7	-3	-1.3	-7.0	-2.9
EB269C	475	475	470	0	0.0	-5	-1.1	-5.0	-1.1
EB270AA	23.2	19.5	19.9	-3.7	-15.9	0.4	2.1	-3.3	-14.2
EB270A	312	313	323	1	0.3	10	3.2	11.0	3.5
EB270B	386	382	380	-4	-1.0	-2	-0.5	-6.0	-1.6
EB270C	491	488	480	-3	-0.6	-8	-1.6	-11.0	-2.2
EB400C	384	377	374	-7	-1.8	-3	-0.8	-10.0	-2.6
EB401C	206	202	200	-4	-1.9	-2	-1.0	-6.0	-2.9

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Table III-4. Nitrate-N concentrations and changes.

	Spring 1997	Fall 1997	Spring 1998	Spr. '97 to Fall '97 Change in NO3-N mg/L	Spr. '97 to Fall '97 Percent change in NO3-N	Fall '97 to Spr. '98 Change in NO3-N mg/L	Fall '97 to Spr. '98 Percent change in NO3-N	Spr. '97 to Spr. '98 Change in NO3-N mg/L	Spr. '97 to Spr. '98 Percent change in NO3-N
ARK 1	1.72	2.58	0.79	0.86	50.0	-2.58	-69.3	-1.72	-54.0
ARK 2	1.04	2.62	0.72	1.58	152.2	-2.62	-72.4	-1.04	-30.5
ARK 3	1.24	2.60	0.97	1.36	109.1	-2.60	-62.6	-1.24	-21.9
COW1	0.36	2.21	1.22	1.85	512.5	-2.21	-44.9	-0.36	237.3
COW 2	1.69	2.12	1.65	0.43	25.3	-2.12	-22.4	-1.69	-2.7
SALT 1	0.18	0.86	0.86	0.68	375.0	-0.86	-0.1	-0.18	374.7
EB228A	10.4	11.7	13.61	1.24	11.9	-11.66	16.8	-10.41	30.7
EB228B	0.09	0.07	0.05	-0.02	-25.0	-0.07	-33.4	-0.09	-50.0
EB228C	0.05	0.05	0.05	0.00	0.0	-0.05	-0.1	-0.05	-0.1
EB229A	6.10	6.10	6.39	0.00	0.0	-6.10	4.7	-6.10	4.7
EB229B	1.45	1.40	1.60	-0.05	-3.1	-1.40	14.4	-1.45	10.9
EB229C	0.59	0.54	0.65	-0.05	-7.7	-0.54	20.8	-0.59	11.5
EB230AA	0.11	0.02	0.20	-0.09	-80.0	-0.02	799.4	-0.11	79.9
EB230A	0.18	<0.02	0.16	<0.18	Neg.		Pos.	-0.18	-12.6
EB230B	0.09	<0.02	0.14	<0.09	Neg.		Pos.	-0.09	49.9
EB230C	0.02	0.05	0.05	0.02	100.0	-0.05	-0.1	-0.02	99.9
EB231A	<0.02	0.05	0.14	<0.05	Pos.	-0.05	199.8		Pos.
EB231B	0.09	0.14	0.14	0.05	50.0	-0.14	-0.1	-0.09	49.9
EB231C	0.18	0.18	0.14	0.00	0.0	-0.18	-25.1	-0.18	-25.1
EB232A	3.70	3.57	3.57	-0.14	-3.7	-3.57	-0.1	-3.70	-3.7
EB232B	0.70	0.72	0.77	0.02	3.2	-0.72	6.2	-0.70	9.6
EB232C	0.56	0.59	0.63	0.02	4.0	-0.59	7.6	-0.56	11.9
EB233A	9.17	9.44	9.73	0.27	3.0	-9.44	3.0	-9.17	6.1
EB233B	9.06	9.35	9.46	0.29	3.2	-9.35	1.1	-9.06	4.4
EB233C	1.90	1.76	1.83	-0.14	-7.1	-1.76	3.8	-1.90	-3.6
EB234A	2.62	0.25	0.84	-2.37	-90.5	-0.25	236.1	-2.62	-68.1
EB234C	0.09	<0.02		<0.09	Neg.				
EB235A	13.6	13.3	13.45	-0.23	-1.7	-13.33	0.9	-13.55	-0.7
EB235C	2.71	3.12	2.60	0.41	15.0	-3.12	-16.7	-2.71	-4.2
EB239A	0.56	0.75	0.79	0.18	32.0	-0.75	6.0	-0.56	39.9
EB239C	0.09	0.14	0.09	0.05	50.0	-0.14	-33.4	-0.09	-0.1

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Table III-4. Nitrate-N concentrations and changes.

	Spring 1997 NO3-N mg/L	Fall 1997 NO3-N mg/L	Spring 1998 NO3-N mg/L	Spr. '97 to Fall '97 Change in NO3-N mg/L	Spr. '97 to Fall '97 Percent change in NO3-N	Fall '97 to Spr. '98 Change in NO3-N mg/L	Fall '97 to Spr. '98 Percent change in NO3-N	Spr. '97 to Spr. '98 Change in NO3-N mg/L	Spr. '97 to Spr. '98 Percent change in NO3-N
EB240AA	0.02	0.50	0.23	0.47	2100.0	-0.50	-54.6	-0.02	899.3
EB240A	0.29	0.38	0.41	0.09	30.8	-0.38	5.8	-0.29	38.4
EB240B	0.32	0.36	0.34	0.05	14.3	-0.36	-6.3	-0.32	7.1
EB240C	0.29	0.02	0.23	-0.27	-92.3	-0.02	899.3	-0.29	-23.1
EB248A	10.3	11.4	10.02	1.06	10.3	-11.36	-11.8	-10.30	-2.7
EB248B	5.74	5.13	5.87	-0.61	-10.6	-5.13	14.5	-5.74	2.3
EB248C	0.52	0.54	0.54	0.02	4.3	-0.54	-0.1	-0.52	4.3
EB250A	4.43	7.07	5.46	2.64	59.7	-7.07	-22.7	-4.43	23.4
EB250C	6.01	4.83	4.74	-1.17	-19.5	-4.83	-1.9	-6.01	-21.1
EB251A	5.38	5.76	8.87	0.38	7.1	-5.76	54.0	-5.38	65.0
EB251C	3.14	3.34	3.41	0.20	6.5	-3.34	2.0	-3.14	8.6
EB252A	1.13	1.33	1.24	0.20	18.0	-1.33	-6.8	-1.13	9.9
EB252C	0.95	0.93	0.86	-0.02	-2.4	-0.93	-7.4	-0.95	-9.6
EB253C	2.94	2.85	2.80	-0.09	-3.1	-2.85	-1.7	-2.94	-4.7
EB254C	20.9	21.5	24.60	0.63	3.0	-21.55	14.2	-20.92	17.6
EB255A	11.1	11.8	11.56	0.77	6.9	-11.84	-2.4	-11.07	4.4
EB255C	2.48	2.55	2.39	0.07	2.7	-2.55	-6.3	-2.48	-3.7
EB256A	1.22	1.33	1.53	0.11	9.3	-1.33	15.2	-1.22	25.8
EB256B	<0.02	<0.02	0.05	<0.02	Same				Pos.
EB256C	<0.02	0.02	0.05	<0.02	Pos.	-0.02	99.9		Pos.
EB257A	2.46	3.25	3.70	0.79	32.1	-3.25	13.8	-2.46	50.4
EB257B	0.23	0.25	0.23	0.02	10.0	-0.25	-9.2	-0.23	-0.1
EB257C	0.11	0.11	0.09	0.00	0.0	-0.11	-20.1	-0.11	-20.1
EB258A	12.6	11.9	11.85	-0.79	-6.2	-11.86	-0.1	-12.65	-6.3
EB258B	1.08	1.51	1.33	0.43	39.6	-1.51	-12.0	-1.08	22.8
EB259A	0.07	0.11	0.18	0.05	66.7	-0.11	59.9	-0.07	166.5
EB259B	3.28	3.05	3.32	-0.23	-6.9	-3.05	8.8	-3.28	1.3
EB260C	3.82	3.84	3.84	0.02	0.6	-3.84	-0.1	-3.82	0.5
EB261A	7.00	5.71	6.91	-1.29	-18.4	-5.71	20.9	-7.00	-1.4
EB261C	<0.02	0.02	0.05	<0.02	Pos.	-0.02	99.9		Pos.
EB262C	1.20	1.31	1.35	0.11	9.4	-1.31	3.4	-1.20	13.1

Table III-4. Nitrate-N concentrations and changes.

	Spring 1997 NO3-N mg/L	Fall 1997 NO3-N mg/L	Spring 1998 NO3-N mg/L	Spr. '97 to Fall '97 Change in NO3-N mg/L	Spr. '97 to Fall '97 Percent change in NO3-N	Fall '97 to Spr. '98 Change in NO3-N mg/L	Fall '97 to Spr. '98 Percent change in NO3-N	Spr. '97 to Spr. '98 Change in NO3-N mg/L	Spr. '97 to Spr. '98 Percent change in NO3-N
EB263C	4.00	4.20	4.02	0.20	5.1	-4.20	-4.4	-4.00	0.5
EB264A	3.68	5.67	5.76	1.99	54.0	-5.67	1.5	-3.68	56.3
EB264C	4.65	4.00	3.97	-0.66	-14.1	-4.00	-0.6	-4.65	-14.6
EB265C	3.07	2.76	3.18	-0.32	-10.3	-2.76	15.5	-3.07	3.6
EB266A	3.07	3.48	3.39	0.41	13.2	-3.48	-2.7	-3.07	10.2
EB266B	0.02	0.02		0.00	0.0				-100.0
EB267A	2.01	6.26	9.46	4.25	211.2	-6.26	51.2	-2.01	370.5
EB267B	0.43	0.50	0.36	0.07	15.8	-0.50	-27.3	-0.43	-15.8
EB267C	<0.02	0.02		<0.02	Pos.				
EB268A	17.1	15.7	13.30	-1.36	-7.9	-15.72	-15.4	-17.08	-22.1
EB268B	0.02	0.05		0.02	100.0				
EB268C	0.07	0.05		-0.02	-33.3				
EB269A	8.88	9.98	9.16	1.11	12.5	-9.98	-8.2	-8.88	3.2
EB269B	1.76	1.90	1.85	0.14	7.7	-1.90	-2.4	-1.76	5.1
EB269C	0.45	0.47	0.41	0.02	5.0	-0.47	-14.3	-0.45	-10.1
EB270AA	13.4	13.1	12.37	-0.25	-1.9	-13.12	-5.7	-13.37	-7.5
EB270A	0.36	0.36	0.43	0.00	0.0	-0.36	18.7	-0.36	18.7
EB270B	0.72	0.72	0.79	0.00	0.0	-0.72	9.3	-0.72	9.3
EB270C	0.72	0.72	0.84	0.00	0.0	-0.72	15.5	-0.72	15.5
EB400C	0.47	0.47	0.52	0.00	0.0	-0.47	9.4	-0.47	9.4
EB401C	1.13	1.15	1.24	0.02	2.0	-1.15	7.8	-1.13	9.9

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electromagnetic (EM) or conductivity log responds primarily to salt concentration and secondarily to clays. The first round of geophysical logs (and the initial driller's logs) were presented by Young et al. (1997). Those logs were used in the production of the hydrogeologic sections presented in that report.

Geophysical logs of the deep well at each monitoring site were collected again in October 1997 and in April 1998, primarily to identify changes in salinity from the conductivity log if possible. Subtle changes were observed and generally reflected changes in salinity that were observed in the water-quality analyses. Data from the logs were used in the production of the cross sections in Figures III-4 and III-5. Because the changes in conductivity are minor and difficult to distinguish on paper, the logs are not reproduced in this report. Paper and electronic copies of the logs are available from the KGS.

Appendix III-A

Combined field collection information and results of chemical analyses
for the Fall '97 and Spring '98 EBMI samples

Equus Beds Mineral Intrusion Study
 Combined Field Collection Information and Chemical Analyses for Fall, 1997 Samples
 Ordered by KGS lab number Don Whittemore 12/16/97

Well ID	CO	KGS lab no.	Project number	Sample date	Sample time	Name of sampler	Temp., begin, deg.F	Temp., end, deg.F	Sp.C. begin, uS/cm	Sp.C. end, uS/cm	Pumping rate, gpm	Minutes pumped	Lab Sp.C.	SO4 mg/L	Cl mg/L	NO3 mg/L	NO3-N mg/L
EB228A	RN	970433	EBMI-086	11/19/97	1233	Boese	61	61	780	750	13	13	850	99.5	49.4	51.6	11.66
EB228B	RN	970434	EBMI-087	11/19/97	1248	Boese	58	58	490	470	30	10	563	75.8	48.6	0.3	0.07
EB228C	RN	970435	EBMI-088	11/19/97	1353	Boese	58	58	400	380	30	10	449	64.8	14.8	0.2	0.05
EB229A	RN	970436	EBMI-089	11/18/97	1704	Boese	58	57	2220	2390	20	10	2530	118	602	27.0	6.10
EB229B	RN	970437	EBMI-090	11/18/97	1719	Boese	57	58	3930	4040	35	9	4278	152	1213	6.2	1.40
EB229C	RN	970438	EBMI-091	11/18/97	1734	Boese	58	58	5080	6530	38	10	7009	153	2197	2.4	0.54
EB230AA	RN	970439	EBMI-092	11/19/97	1055	Boese	58	58	2110	2200	20	10	2400	122	559	0.1	0.02
EB230A	RN	970440	EBMI-093	11/19/97	1112	Boese	58	58	2290	2330	28	11	2500	131	583	<0.1	<0.02
EB230B	RN	970441	EBMI-094	11/19/97	1127	Boese	58	58	2450	3040	32	10	3290	158	852	<0.1	<0.02
EB230C	RN	970442	EBMI-095	11/19/97	1149	Boese	58	59	2320	2350	14	16	2580	137	657	0.2	0.05
EB231A	RN	970443	EBMI-096	11/18/97	1426	Boese	60	60	1700	1670	15	12	1850	134	381	0.2	0.05
EB231B	RN	970444	EBMI-097	11/18/97	1443	Boese	58	58	2080	2220	22	10	2375	165	531	0.6	0.14
EB231C	RN	970445	EBMI-098	11/18/97	1500	Boese	58	58	3030	3350	25	12	3580	208	944	0.8	0.18
EB232A	RN	970446	EBMI-099	11/18/97	1251	Boese	58	58	500	510	26	9	528	15.2	25.2	15.8	3.57
EB232B	RN	970447	EBMI-100	11/18/97	1308	Boese	59	59	1750	1790	31	10	2020	86.7	424	3.2	0.72
EB232C	RN	970448	EBMI-101	11/18/97	1325	Boese	60	60	3040	3110	35	10	3570	164	877	2.6	0.59
EB233A	RN	970449	EBMI-102	11/18/97	1140	Boese	58	58	740	760	8	19	636	25.4	23.3	41.8	9.44
EB233B	RN	970450	EBMI-103	11/18/97	1202	Boese	58	58	790	750	10	17	638	25.4	23.0	41.4	9.35
EB233C	RN	970451	EBMI-104	11/18/97	1217	Boese	58	58	550	560	20	10	470	11.7	11.7	7.8	1.76
EB234A	RN	970452	EBMI-105	11/18/97	1046	Boese	58	59	720	590	8	13	559	6.3	22.2	1.1	0.25
EB234C	RN	970453	EBMI-106	11/18/97	1103	Boese	58	59	660	670	12	11	650	2.0	18.2	<0.1	<0.02
EB235A	RN	970454	EBMI-107	11/18/97	941	Boese	57	57	860	780	12	15	833	21.4	27.0	59.0	13.33
EB235C	RN	970455	EBMI-108	11/18/97	1010	Boese	57	57	570	640	5	22	607	13.9	13.0	13.8	3.12
EB239A	RN	970456	EBMI-109	11/19/97	1340	Boese	58	58	3180	3470	11	14	3830	164	1044	3.3	0.75
EB239C	RN	970457	EBMI-110	11/19/97	1357	Boese	58	58	3590	3670	17	12	4053	225	1100	0.6	0.14
EB240AA	RN	970458	EBMI-111	11/18/97	1542	Boese	58	58	1340	2090	6	16	2250	111	544	2.2	0.50
EB240A	RN	970459	EBMI-112	11/18/97	1600	Boese	58	59	2850	2860	36	10	3130	246	784	1.7	0.38
EB240B	RN	970460	EBMI-113	11/18/97	1617	Boese	58	59	3570	3800	37	11	4053	271	1073	1.6	0.36
EB240C	RN	970461	EBMI-114	11/18/97	1635	Boese	58	59	6080	8830	37	13	9596	371	2951	0.1	0.02
EB248A	RN	970462	EBMI-115	11/19/97	1433	Boese	59	58	640	590	15	13	687	34.3	25.1	50.3	11.36
EB248B	RN	970463	EBMI-116	11/19/97	1448	Boese	58	58	710	1460	25	10	1610	58.6	310	22.7	5.13
EB248C	RN	970464	EBMI-117	11/19/97	1507	Boese	58	58	8810	11010	22	12	12030	478	3764	2.4	0.54
EB256A	RN	970465	EBMI-118	11/19/97	1602	Boese	58	58	4760	6060	3	23	6744	234	1953	5.9	1.33
EB256B	RN	970466	EBMI-119	11/19/97	1617	Boese	57	57	10870	11030	30	10	12010	425	3798	<0.1	<0.02
EB256C	RN	970467	EBMI-120	11/19/97	1634	Boese	57	58	10830	10910	30	11	11950	425	3777	0.1	0.02
ARK3		970468	EBMI-121	11/18/97	1340	Boese		44		2880			3250	850	452	11.5	2.60
COW2		970469	EBMI-122	11/18/97	1358	Boese		54		1890			2150	151	450	9.4	2.12
SALT1		970470	EBMI-123	11/19/97	1553	Boese		44		4030			4397	151	1198	3.8	0.86
EB250A	RN	970471	EBMI-124	11/24/97	1536	Boese	58	57	380	380	20	10	430	49.1	32.0	31.3	7.07
EB250C	RN	970472	EBMI-125	11/24/97	1550	Boese	58	58	450	380	27	10	416	53.4	29.7	21.4	4.83
EB251A	RN	970473	EBMI-126	11/21/97	1559	Boese	58	58	350	270	2	15	297	32.8	19.6	25.5	5.76
EB251C	RN	970474	EBMI-127	11/21/97	1616	Boese	58	58	230	230	4	13	258	13.1	5.5	14.8	3.34

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Equus Beds Mineral Intrusion Study
 Combined Field Collection Information and Chemical Analyses for Fall, 1997 Samples
 Ordered by KGS lab number Don Whittemore 12/16/97

Well		KGS	Project	Sample	Sample	Name	Temp.,	Temp.,	Sp.C.	Sp.C.	Pumping	Minutes	Lab	SO4	Cl	NO3	NO3-N
						of	begin,	end,	begin,	end,	rate,						
EB252A	RN	970475	EBMI-128	11/21/97	1638	Boese	57	57	690	670	25	10	769	93.4	40.2	5.9	1.33
EB252C	RN	970476	EBMI-129	11/21/97	1652	Boese	57	57	680	670	30	10	735	86.1	41.5	4.1	0.93
EB253C	RN	970477	EBMI-130	11/21/97	1715	Boese	57	57	1080	1130	24	10	1210	120	180	12.6	2.85
EB254C	RN	970478	EBMI-131	11/21/97	1221	Boese	58	58	1510	1520	27	10	1670	200	219	95.4	21.55
EB255A	RN	970479	EBMI-132	11/21/97	1130	Boese	57	57	1030	1010	15	12	1110	136	90.2	52.4	11.84
EB255C	RN	970480	EBMI-133	11/21/97	1144	Boese	57	57	2510	2560	27	10	2780	251	643	11.3	2.55
EB257A	RN	970481	EBMI-134	11/20/97	1110	Boese	57	58	3340	3320	11	14	3550	123	924	14.4	3.25
EB257B	RN	970482	EBMI-135	11/20/97	1125	Boese	57	58	10000	10110	27	10	11210	415	3492	1.1	0.25
EB257C	RN	970483	EBMI-136	11/20/97	1142	Boese	58	58	15410	15920	27	12	17740	692	5792	0.5	0.11
EB258A	RN	970484	EBMI-137	11/20/97	1339	Boese	58	58	560	570	6	12	620	22.8	9.4	52.5	11.86
EB258B	RN	970485	EBMI-138	11/20/97	1358	Boese	58	58	2470	2890	6	15	3180	115	782	6.7	1.51
EB259A	RC	970486	EBMI-139	11/21/97	1508	Boese	60	60	130	120	25	30	130	21.3	6.2	0.5	0.11
EB259B	RC	970487	EBMI-140	11/21/97	1523	Boese	57	58	130	120	30	10	133	1.5	1.9	13.5	3.05
EB260C	RN	970488	EBMI-141	11/21/97	1356	Boese	58	58	1150	1130	34	10	1250	133	150	17.0	3.84
EB261A	RN	970489	EBMI-142	11/21/97	1307	Boese	58	58	1700	1580	18	12	1720	261	235	25.3	5.71
EB261C	RN	970490	EBMI-143	11/21/97	1325	Boese	58	58	2540	3170	8	13	3440	305	865	0.1	0.02
EB262C	RC	970491	EBMI-144	11/24/97	1450	Boese	59	59	320	310	15	12	357	3.9	3.4	5.8	1.31
EB263C	RC	970492	EBMI-145	11/24/97	1426	Boese	58	58	2060	1950	30	10	2180	150	484	18.6	4.20
EB264A	RN	970493	EBMI-146	11/24/97	1350	Boese	58	58	850	850	18	10	985	108	65.0	25.1	5.67
EB264C	RN	970494	EBMI-147	11/24/97	1404	Boese	58	58	810	820	30	10	933	98.5	64.8	17.7	4.00
EB265C	RN	970495	EBMI-148	11/24/97	1327	Boese	58	58	1680	1630	30	10	1855	136	359	12.2	2.76
EB266A	RN	970496	EBMI-149	11/24/97	1036	Boese	58	58	2880	2720	25	11	3000	179	739	15.4	3.48
EB266B	RN	970497	EBMI-150	11/24/97	1142	Boese	57	58	5700	5680	1	62	6374	1479	1200	0.1	0.02
EB267A	RN	970498	EBMI-151	11/24/97	1219	Boese	58	59	2010	4040	10	13	4510	167	1218	27.7	6.26
EB267B	RN	970499	EBMI-152	11/24/97	1237	Boese	59	59	5850	5830	6	14	6504	269	1923	2.2	0.50
EB267C	RN	970500	EBMI-153	11/24/97	1255	Boese	59	60	6350	6590	30	11	7197	1038	1739	0.1	0.02
EB268A	RN	970501	EBMI-154	11/20/97	1640	Boese	57	57	560	500	2	14	545	24.0	12.1	69.6	15.72
EB268B	RN	970502	EBMI-155	11/20/97	1654	Boese	57	58	5020	7480	18	10	8246	255	2466	0.2	0.05
EB268C	RN	970503	EBMI-156	11/20/97	1708	Boese	58	58	8880	8700	22	10	9770	324	2962	0.2	0.05
EB269A	RN	970504	EBMI-157	11/20/97	1538	Boese	57	57	580	560	2	14	618	20.3	30.7	44.2	9.98
EB269B	RN	970505	EBMI-158	11/20/97	1553	Boese	57	58	5870	6980	27	10	7653	234	2234	8.4	1.90
EB269C	RN	970506	EBMI-159	11/20/97	1608	Boese	58	58	11160	11930	32	10	13370	475	4176	2.1	0.47
EB270AA	RN	970507	EBMI-160	11/20/97	1427	Boese	58	58	820	740	20	10	817	19.5	64.6	58.1	13.12
EB270A	RN	970508	EBMI-161	11/20/97	1441	Boese	58	58	8340	8470	34	10	9398	313	2820	1.6	0.36
EB270B	RN	970509	EBMI-162	11/20/97	1455	Boese	58	58	9650	9470	34	10	10660	382	3276	3.2	0.72
EB270C	RN	970510	EBMI-163	11/20/97	1510	Boese	58	59	11380	11680	30	10	13090	488	4143	3.2	0.72
EB400C	RN	970511	EBMI-164	11/20/97	1231	Boese	57	58	10000	10060	3	25	11140	377	3443	2.1	0.47
EB401C	RN	970512	EBMI-165	11/20/97	1304	Boese	57	57	5080	5090	3	14	5599	202	1593	5.1	1.15
ARK1		970513	EBMI-166	11/24/97	1100	Boese		45		3210			3500	970	466	11.4	2.58
ARK2		970514	EBMI-167	11/21/97	1042	Boese		42		3190			3440	931	474	11.6	2.62
COW1		970515	EBMI-168	11/21/97	1412	Boese		45		1260			1370	85.3	233	9.8	2.21

EQUUS BEDS AQUIFER MINERAL INTRUSION STUDY
 Combined Field Collection Information and Chemical Analyses for Major Constituents, Spring 1998

Site		KGS	Project	Sample	Sample		Temp.	Temp.	Sp.C.	Sp.C.	Pump	Minutes	Lab				
ID	CO	NUMBER	Number	date	time	Sampler	begin	end	begin	end	rate	pumped	SpC	SO4	Cl	NO3-UV	
							deg.F	deg.F	uS/cm	uS/cm	gpm		uS/cm	ppm	ppm	ppm	
ARK 1		980110	EMBI-229	4/1/98	1142	BOESE		51		1620			1810	442	216		3.5
ARK 2		980111	EMBI-230	4/1/98	1528	BOESE		54		1640			1800	440	218		3.2
ARK 3		980083	EMBI-210	3/26/98	1425	BOESE		59		1640			1760	355	247		4.3
COW1		980132	EMBI-251	4/6/98	1058	BOESE		53		510			612	40.0	102		5.4
COW 2		980084	EMBI-211	3/26/98	1128	BOESE		63		1640			1790	127	371		7.3
SALT 1		980085	EMBI-212	3/30/98	1144	BOESE		57		1360			1440	49.7	333		3.8
EB228A	RN	980062	EMBI-189	3/26/98	1035	BOESE	55	57	760	730	13	10	830	86.9	46.8		60.3
EB228B	RN	980063	EMBI-190	3/26/98	1049	BOESE	58	58	500	470	30	10	558	75.9	48.1		0.2
EB228C	RN	980064	EMBI-191	3/26/98	1104	BOESE	58	58	390	400	30	10	450	65.7	14.2		0.2
EB229A	RN	980042	EMBI-169	3/23/98	1456	BOESE	56	57	2250	2380	20	14	2530	117	603		28.3
EB229B	RN	980043	EMBI-170	3/25/98	1022	BOESE	58	59	3980	3990	35	11	4274	152	1184		7.1
EB229C	RN	980044	EMBI-171	3/25/98	1040	BOESE	58	59	5180	6670	38	10	7283	153	2242		2.9
EB230AA	RN	980045	EMBI-172	3/25/98	1130	BOESE	59	59	2110	2240	20	11	2400	123	549		0.9
EB230A	RN	980046	EMBI-173	3/25/98	1148	BOESE	59	60	2290	2360	28	10	2500	133	597		0.7
EB230B	RN	980047	EMBI-174	3/25/98	1216	BOESE	60	60	2330	3050	32	10	3260	158	860		0.6
EB230C	RN	980048	EMBI-175	3/25/98	1246	BOESE	60	60	2370	2320	14	16	2580	137	671		0.2
EB231A	RN	980065	EMBI-192	3/26/98	1140	BOESE	57	57	1620	1690	15	10	1870	135	378		0.6
EB231B	RN	980066	EMBI-193	3/26/98	1155	BOESE	57	58	2020	2220	22	10	2420	167	541		0.6
EB231C	RN	980067	EMBI-194	3/26/98	1210	BOESE	57	58	3050	3280	25	11	3580	210	922		0.6
EB232A	RN	980068	EMBI-195	3/26/98	1450	BOESE	58	59	470	480	26	10	525	15.3	23.4		15.8
EB232B	RN	980069	EMBI-196	3/26/98	1504	BOESE	59	59	1860	1890	31	10	2020	85.3	417		3.4
EB232C	RN	980070	EMBI-197	3/26/98	1518	BOESE	60	60	3300	3320	35	10	3580	163	895		2.8
EB233A	RN	980071	EMBI-198	3/26/98	1328	BOESE	57	58	550	560	8	14	640	26.1	22.9		43.1
EB233B	RN	980072	EMBI-199	3/26/98	1348	BOESE	58	59	580	580	10	13	645	25.6	21.9		41.9
EB233C	RN	980073	EMBI-200	3/26/98	1404	BOESE	59	60	400	410	20	11	463	12.2	11.0		8.1
EB234A	RN	980074	EMBI-201	3/26/98	1239	BOESE	58	58	530	520	12	12	583	7.1	21.6		3.7
EB234C	RN	980075	EMBI-202	3/26/98	1255	BOESE	58	59	530	560	12	12	623	1.9	16.0		<0.1
EB235A	RN	980049	EMBI-176	3/23/98	1203	BOESE	57	57	750	710	12	13	824	21.8	26.1		59.6
EB235C	RN	980050	EMBI-177	3/23/98	1229	BOESE	56	57	520	540	5	21	565	13.9	12.4		11.5
EB239A	RN	980051	EMBI-178	3/25/98	1322	BOESE	60	60	3130	3610	11	15	3830	162	1052		3.5
EB239C	RN	980052	EMBI-179	3/25/98	1341	BOESE	60	60	3720	3810	17	13	4097	221	1113		0.4
EB240AA	RN	980053	EMBI-180	3/23/98	1317	BOESE	54	58	1250	1710	6	15	1860	94.8	417		1.0
EB240A	RN	980054	EMBI-181	3/23/98	1333	BOESE	58	58	2830	2860	36	10	3100	246	767		1.8
EB240B	RN	980055	EMBI-182	3/23/98	1348	BOESE	58	59	3620	3700	37	10	4000	272	1034		1.5
EB240C	RN	980056	EMBI-183	3/23/98	1408	BOESE	59	60	6600	8710	37	12	9558	372	2887		1.0
EB248A	RN	980057	EMBI-184	3/25/98	1419	BOESE	59	59	610	610	15	14	674	33.4	26.9		44.4
EB248B	RN	980058	EMBI-185	3/25/98	1434	BOESE	60	60	740	1270	25	10	1380	52.6	235		26.0
EB248C	RN	980059	EMBI-186	3/25/98	1450	BOESE	60	60	8660	11070	22	11	12040	479	3814		2.4

EQUUS BEDS AQUIFER MINERAL INTRUSION STUDY
 Combined Field Collection Information and Chemical Analyses for Major Constituents, Spring 1998

Site ID	CO	KGS NUMBER	Project Number	Sample date	Sample time	Sampler	Temp. begin deg.F	Temp. end deg.F	Sp.C. begin uS/cm	Sp.C. end uS/cm	Pump rate gpm	Minutes pumped	Lab SpC uS/cm	SO4 ppm	Cl ppm	NO3-UV ppm
EB250A	RN	980060	EMBI-187	3/25/98	1528	BOESE	59	59	500	420	20	10	449	60.9	32.1	24.2
EB250C	RN	980061	EMBI-188	3/25/98	1543	BOESE	58	59	450	390	27	10	414	53.8	29.0	21.0
EB251A	RN	980112	EMBI-231	4/6/98	1143	BOESE	58	58	430	330	2	17	388	39.2	26.7	39.3
EB251C	RN	980113	EMBI-232	4/6/98	1203	BOESE	58	60	230	220	4	15	257	12.9	5.2	15.1
EB252A	RN	980114	EMBI-233	4/6/98	1226	BOESE	59	59	600	700	25	10	760	92.7	40.8	5.5
EB252C	RN	980115	EMBI-234	4/6/98	1242	BOESE	59	59	670	650	30	10	738	86.5	41.6	3.8
EB253C	RN	980116	EMBI-235	4/6/98	1307	BOESE	60	59	1050	1120	24	10	1225	122	184	12.4
EB254C	RN	980117	EMBI-236	4/2/98	1131	BOESE	58	59	1530	1490	27	10	1670	211	207	109
EB255A	RN	980118	EMBI-237	4/2/98	1048	BOESE	56	57	1010	980	25	10	1095	140	82.8	51.2
EB255C	RN	980119	EMBI-238	4/2/98	1103	BOESE	57	57	2360	2550	27	10	3070	251	744	10.6
EB256A	RN	980094	EMBI-213	3/30/98	1230	BOESE	52	54	2230	5550	3	22	6099	211	1688	6.8
EB256B	RN	980095	EMBI-214	3/30/98	1245	BOESE	56	57	10830	11160	30	10	12080	428	3729	0.2
EB256C	RN	980096	EMBI-215	3/30/98	1259	BOESE	57	57	10710	10930	30	10	11980	425	3813	0.2
EB257A	RN	980097	EMBI-216	3/30/98	1346	BOESE	56	57	3130	3180	11	15	3440	122	912	16.4
EB257B	RN	980098	EMBI-217	3/30/98	1401	BOESE	56	57	10180	10230	27	10	11200	415	3527	1.0
EB257C	RN	980099	EMBI-218	3/30/98	1417	BOESE	57	58	15960	15780	27	10	17840	688	5812	0.4
EB258A	RN	980100	EMBI-219	4/1/98	1444	BOESE	57	58	530	540	6	14	620	23.4	8.8	52.5
EB258B	RN	980101	EMBI-220	4/1/98	1504	BOESE	58	59	2830	2890	6	15	3160	113	787	5.9
EB259A	RC	980120	EMBI-239	4/2/98	1710	BOESE	53	53	160	160	0.25	42	175	37.0	6.9	0.8
EB259B	RC	980121	EMBI-240	4/2/98	1724	BOESE	57	57	140	120	30	10	131	0.9	2.2	14.7
EB260C	RN	980122	EMBI-241	4/2/98	1608	BOESE	58	58	1120	1120	34	10	1235	128	148	17.0
EB261A	RN	980123	EMBI-242	4/2/98	1526	BOESE	59	59	1530	1510	18	11	1675	245	211	30.6
EB261C	RN	980124	EMBI-243	4/2/98	1544	BOESE	58	58	2530	3190	8	14	3430	305	847	0.2
EB262C	RC	980125	EMBI-244	4/2/98	1450	BOESE	59	59	290	290	15	12	357	2.7	3.5	6.0
EB263C	RC	980126	EMBI-245	4/2/98	1418	BOESE	59	59	1960	1910	30	10	2140	172	463	17.8
EB264A	RN	980127	EMBI-246	4/2/98	1344	BOESE	58	58	900	920	25	10	1015	116	67.9	25.5
EB264C	RN	980128	EMBI-247	4/2/98	1358	BOESE	58	58	820	830	30	10	942	99.5	65.8	17.6
EB265C	RN	980129	EMBI-248	4/2/98	1323	BOESE	58	58	1720	1690	30	10	1880	135	362	14.1
EB266A	RN	980102	EMBI-221	4/1/98	1103	BOESE	57	58	3210	2750	25	11	3000	180	735	15.0
EB266B	RN	980103	EMBI-222	4/1/98	1210	BOESE	56	57	5750	5760	1	61	6388	1468	1194	<0.1
EB267A	RN	980104	EMBI-223	4/1/98	1233	BOESE	58	59	2150	4190	10	13	4402	162	1166	41.9
EB267B	RN	980105	EMBI-224	4/1/98	1252	BOESE	58	59	5740	5780	6	15	6490	267	1887	1.6
EB267C	RN	980106	EMBI-225	4/1/98	1306	BOESE	59	60	6360	6560	30	10	7189	1026	1725	<0.1
EB268A	RN	980107	EMBI-226	4/1/98	1335	BOESE	57	57	520	440	2	15	489	19.6	7.6	58.9
EB268B	RN	980108	EMBI-227	4/1/98	1350	BOESE	57	57	4920	7620	18	10	8292	255	2541	<0.1
EB268C	RN	980109	EMBI-228	4/1/98	1406	BOESE	57	57	9050	8900	22	10	9718	324	3011	<0.1
EB269A	RN	980076	EMBI-203	3/26/98	1345	BOESE	57	58	970	540	2	15	602	19.9	24.5	40.6
EB269B	RN	980077	EMBI-204	3/26/98	1400	BOESE	58	58	5760	6680	27	10	7504	231	2239	8.2

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EQUUS BEDS AQUIFER MINERAL INTRUSION STUDY
 Combined Field Collection Information and Chemical Analyses for Major Constituents, Spring 1998

Site		KGS	Project	Sample	Sample		Temp.	Temp.	Sp.C.	Sp.C.	Pump	Minutes	Lab				
ID	CO	NUMBER	Number	date	time	Sampler	deg.F	deg.F	uS/cm	uS/cm	gpm	pumped	SpC	SO4	Cl	NO3-UV	
													uS/cm	ppm	ppm	ppm	
EB269C	RN	980078	EMBI-205	3/26/98	1414	BOESE	58	58	11090	12080	32	10	13210	470	4193	1.8	
EB270AA	RN	980079	EMBI-206	3/26/98	1222	BOESE	58	58	740	740	20	10	813	19.9	68.4	54.8	
EB270A	RN	980080	EMBI-207	3/26/98	1236	BOESE	58	58	5930	8740	34	10	10230	323	2940	1.9	
EB270B	RN	980081	EMBI-208	3/26/98	1251	BOESE	58	58	9760	9560	34	10	10620	380	3259	3.5	
EB270C	RN	980082	EMBI-209	3/26/98	1305	BOESE	58	58	11560	11690	30	10	13020	480	4106	3.7	
EB400C	RN	980130	EMBI-249	4/2/98	1222	BOESE	57	59	10040	10200	3	24	11100	374	3406	2.3	
EB401C	RN	980131	EMBI-250	4/2/98	1253	BOESE	58	58	5190	5120	3	15	5564	200	1584	5.5	

Equus Beds Aquifer Mineral Intrusion Project
Chemical Analyses for Minor Constituents, Spring 1998

Site	Sample collection	Sample	Lab	SpC	LAB	SiO2	Ca	Mg	Na	K	Sr	HCO3	UNCORR	I	IO3-I	B
ID	date	time	Sampler	uS/cm	pH	ppm	ppm	ppm	ppm	ppm	ppm	ppm	Br-ppm	ppb	ppb	ppb
ARK 1	4/1/98	1142	BOESE	1810	8.00	10.2	105	40.4	225	7.7	1.44	175	0.1048	16.3	90.4	154
ARK 2	4/1/98	1528	BOESE	1800	8.00	10.2	104	39.9	223	7.7	1.42	175	0.1000	16.3	89.4	168
ARK 3	3/26/98	1425	BOESE	1760	8.00	12.3	105	34.2	221	8.2	1.25	193	0.1232	14.9	70.6	146
COW1	4/6/98	1058	BOESE	612	8.10	11.6	53.0	7.5	46.2	7.8	0.30	113	0.0791	12.6	98.4	18
COW 2	3/26/98	1128	BOESE	1790	8.05	13.9	93.3	18.8	246	6.8	0.73	219	0.2270	9.4	39.8	134
SALT 1	3/30/98	1144	BOESE	1440	7.95	14.5	43.7	8.1	231	7.4	0.30	151	0.0722	9.4	161	<62
EB240AA	3/23/98	1317	BOESE	1860	7.95	24.5	83.5	14.3	278	3.2	0.62	250	0.2250	13.1		77
EB255C	4/2/98	1103	BOESE	3070	7.95	16.5	206	41.9	371	5.5	1.66	250	0.2498	8.4		<83
EB258B	4/1/98	1504	BOESE	3160	8.10	27.5	120	19.5	526	3.5	0.79	384	0.2373	5.9		<125
EB263C	4/2/98	1418	BOESE	2140	7.75	21.4	155	33.4	231	5.1	1.57	264	1.192	12.3		<54

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IV. Surface Water

The primary surface water data collection points include three on the Arkansas River (ARK 1, ARK 2, and ARK 3), two on Cow Creek (COW 1 and COW 2), and one on Salt Creek (SALT 1); their locations are shown in Figure I-4. ARK 1 is adjacent to monitoring site EB266 and SALT 1 is adjacent to EB256. Stream levels were determined by monthly tapedown measurements from bridges. Elevations are to be surveyed in the future. Figures IV-1 through IV-6 show stream-level hydrographs based on these measurements as well as quarterly specific conductance and chloride determinations made by GMD2. These data are listed in Table IV-1.

Peak stream levels were observed at all but one surface site in August of 1997 and March of 1998, primarily in response to locally heavy precipitation. Cow Creek at COW 1 was flooded at the time of these observations. The peaks at COW 2 (downstream from Hutchinson) are generally subdued and delayed relative to those at COW 1 due to flood-control features in and around Hutchinson.

Water-quality data collected for the project include the three sets of samples at the surface-water collection points (Appendix III-A), quarterly specific conductance and chloride determinations by GMD2 (Table IV-1), and results of a Salt Creek conductivity survey (discussed below). Tables III-1 through III-4 list changes between the three sampling times for specific conductance, chloride, sulfate, and nitrate, respectively.

Figure IV-7 shows chloride concentrations for the three sampling times. The same data are listed in Table III-2. For the 1997 samples, Salt Creek (SALT 1) had more than twice the chloride concentration of any other surface site, 1,287 mg/L in the spring and 1198 mg/L in the fall. Chloride concentrations were similar for the three Arkansas River sites in 1997, and dropped from about 550 mg/L in the spring to slightly above 450 mg/L in the fall. The 1997 spring and fall chloride concentrations were 325 and 233 mg/L at COW 1, and 545 and 450 mg/L at COW 2.

All Spring '98 surface water samples had lower salinity than previous samples due to dilution from precipitation. At the Salt Creek and Cow Creek data collection points the salinity indicators (specific conductance, chloride, and sulfate; Tables III-1 through III-3) decreased in each of the subsequent samples. However, at the Arkansas River collection points, chloride concentration dropped in each subsequent sample, but specific conductance and sulfate concentrations were highest in the Fall '97 samples. Also, specific conductance and chloride were well correlated on Cow and Salt Creeks, but not on the Arkansas River. These observations indicate different salinity source areas: western Kansas/eastern Colorado for sulfate in the Arkansas River water compared the more local source areas for chloride in Salt and Cow Creeks and the Arkansas River. On the subject of sources, part of the chloride content at COW 2 appears to be have a chloride contribution from oil brine.

A Salt Creek conductivity survey was undertaken on October 23, 1997. Specific conductance was measured at ten locations on Salt Creek and on one tributary, Sugar

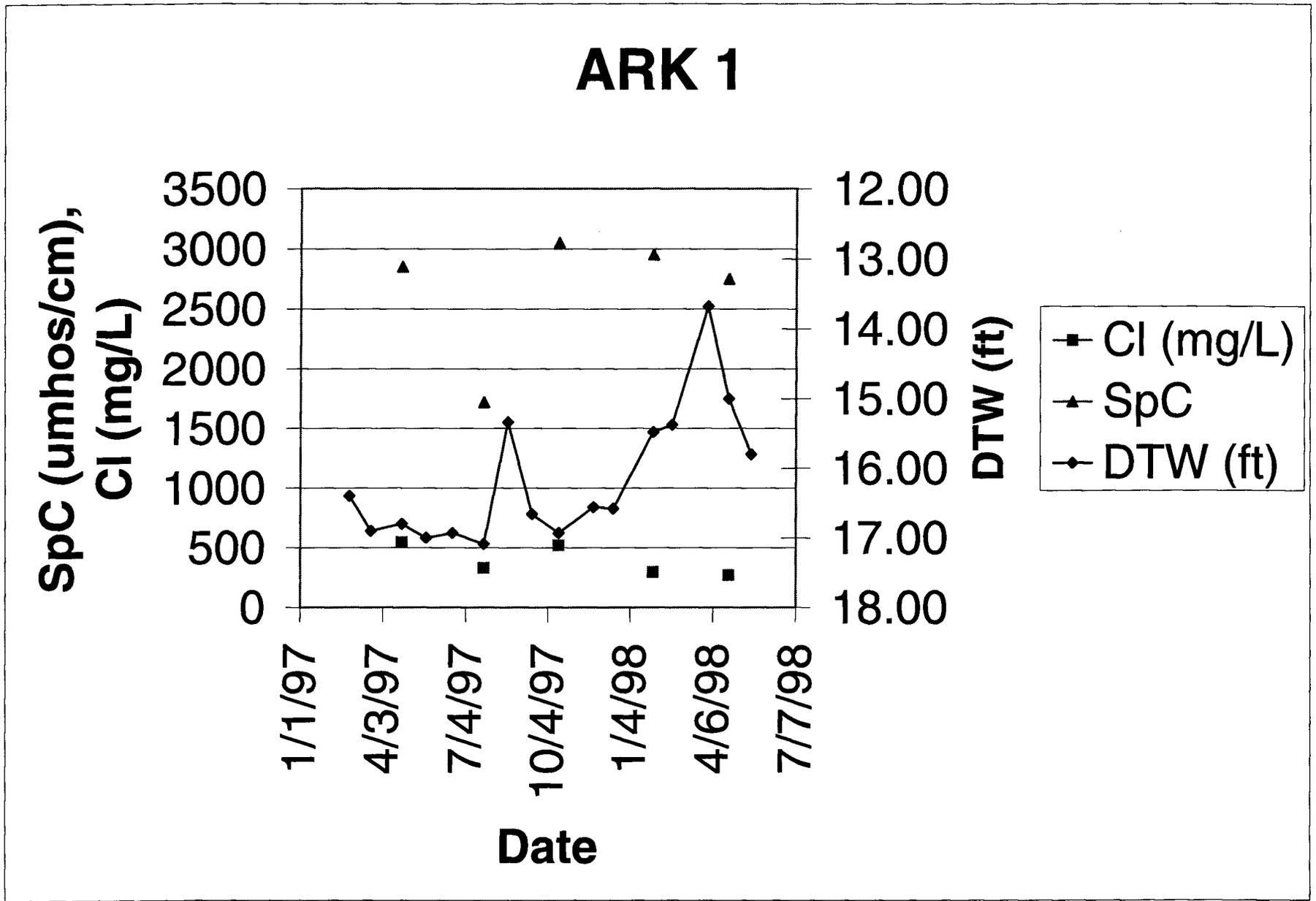


Figure IV-1. Stream levels and specific conductance and chloride determinations for surface water site ARK 1.

ARK 2

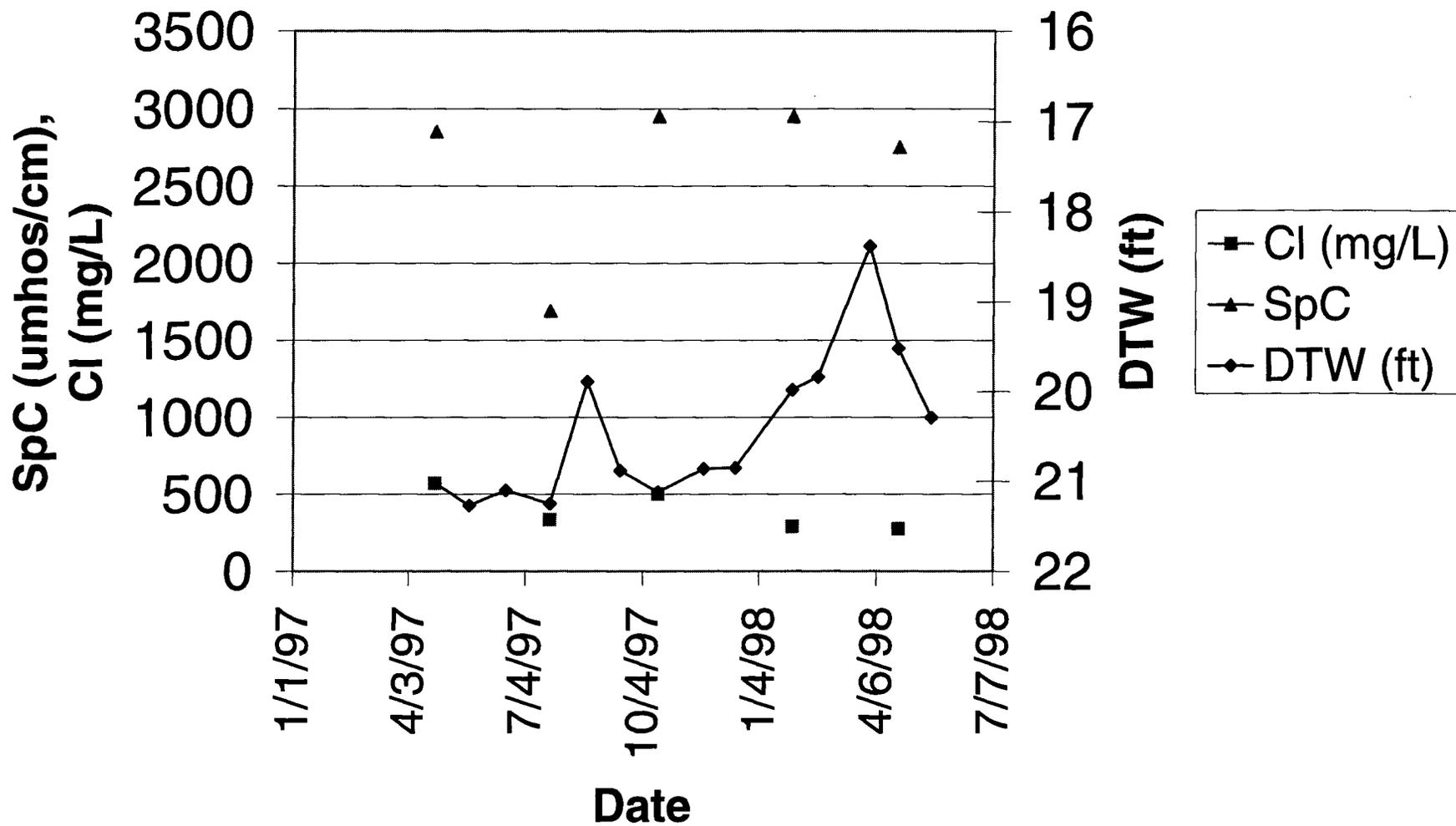


Figure IV-2. Stream levels and specific conductance and chloride determinations for surface water site ARK 2.

ARK 3

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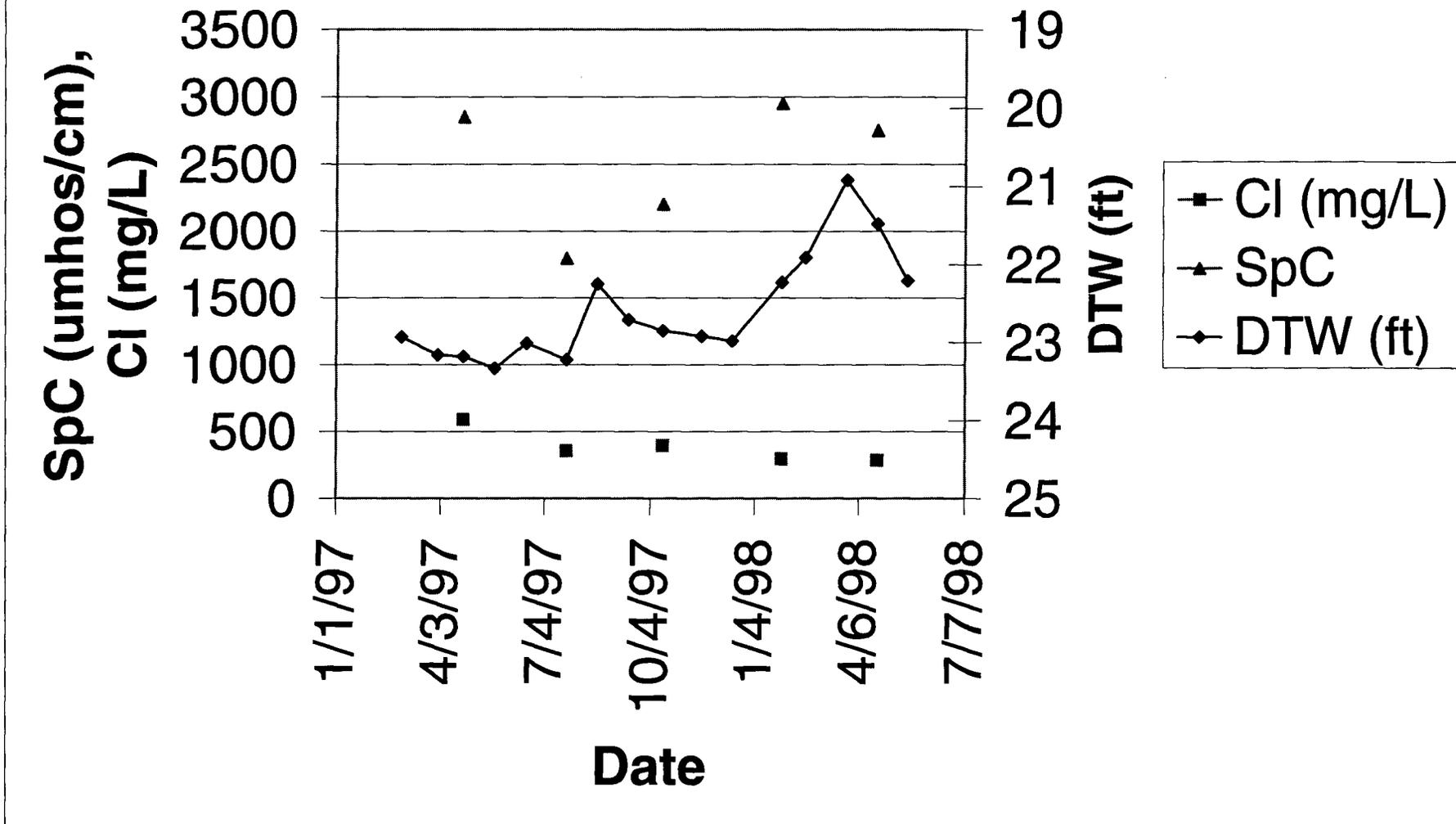


Figure IV-3. Stream levels and specific conductance and chloride determinations for surface water site ARK 3.

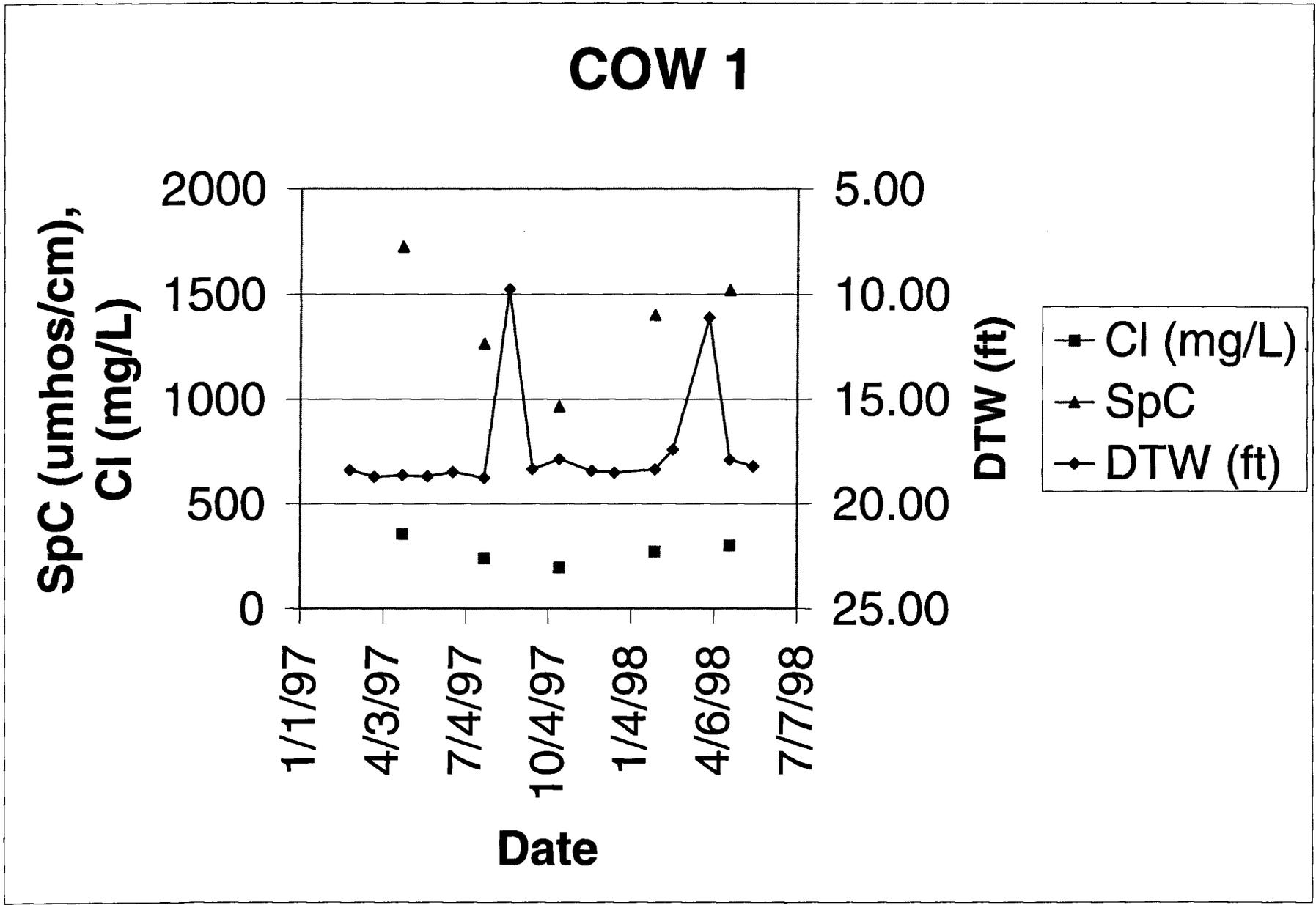


Figure IV-4. Stream levels and specific conductance and chloride determinations for surface water site COW 1.

COW 2

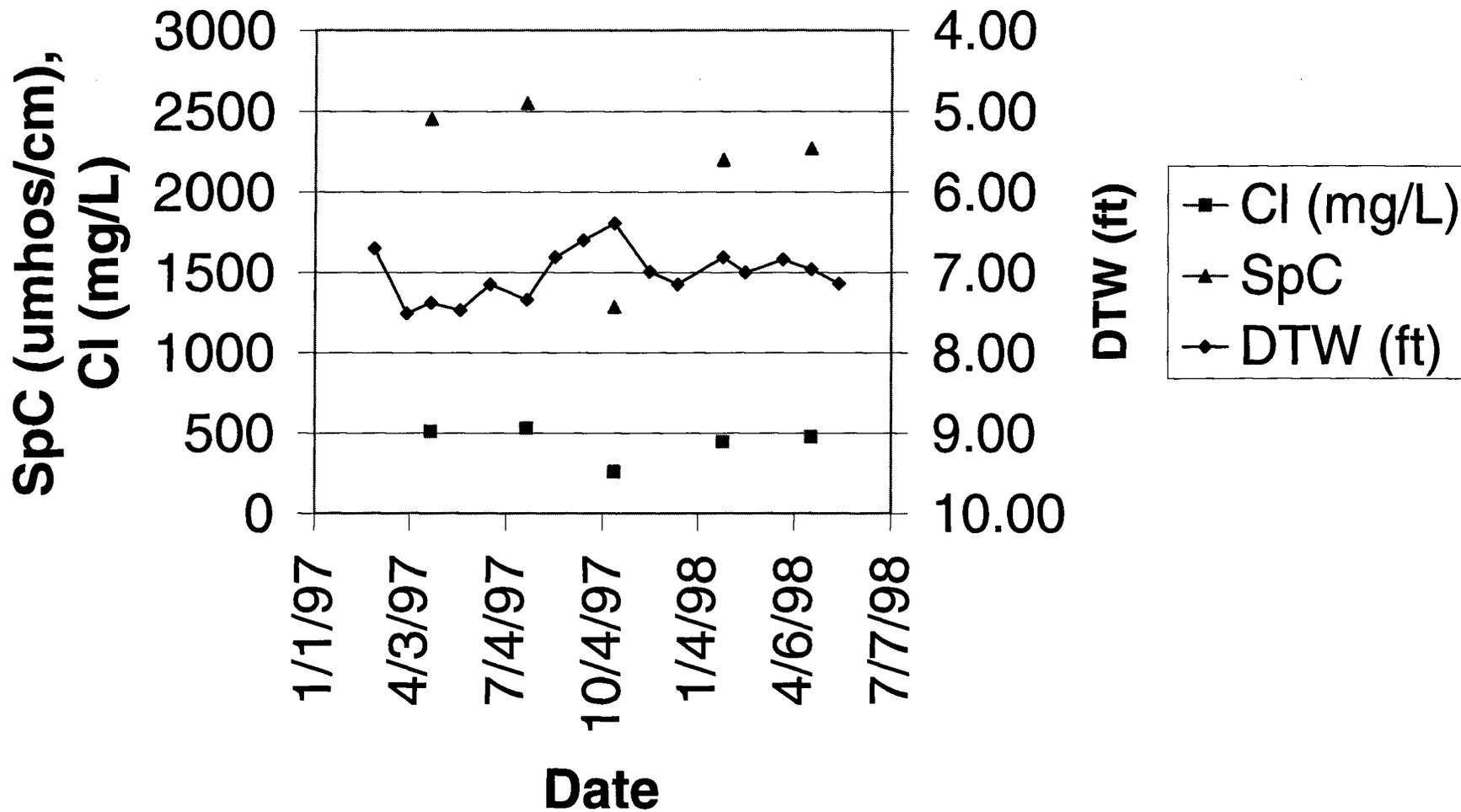


Figure IV-5. Stream levels and specific conductance and chloride determinations for surface water site COW 2.

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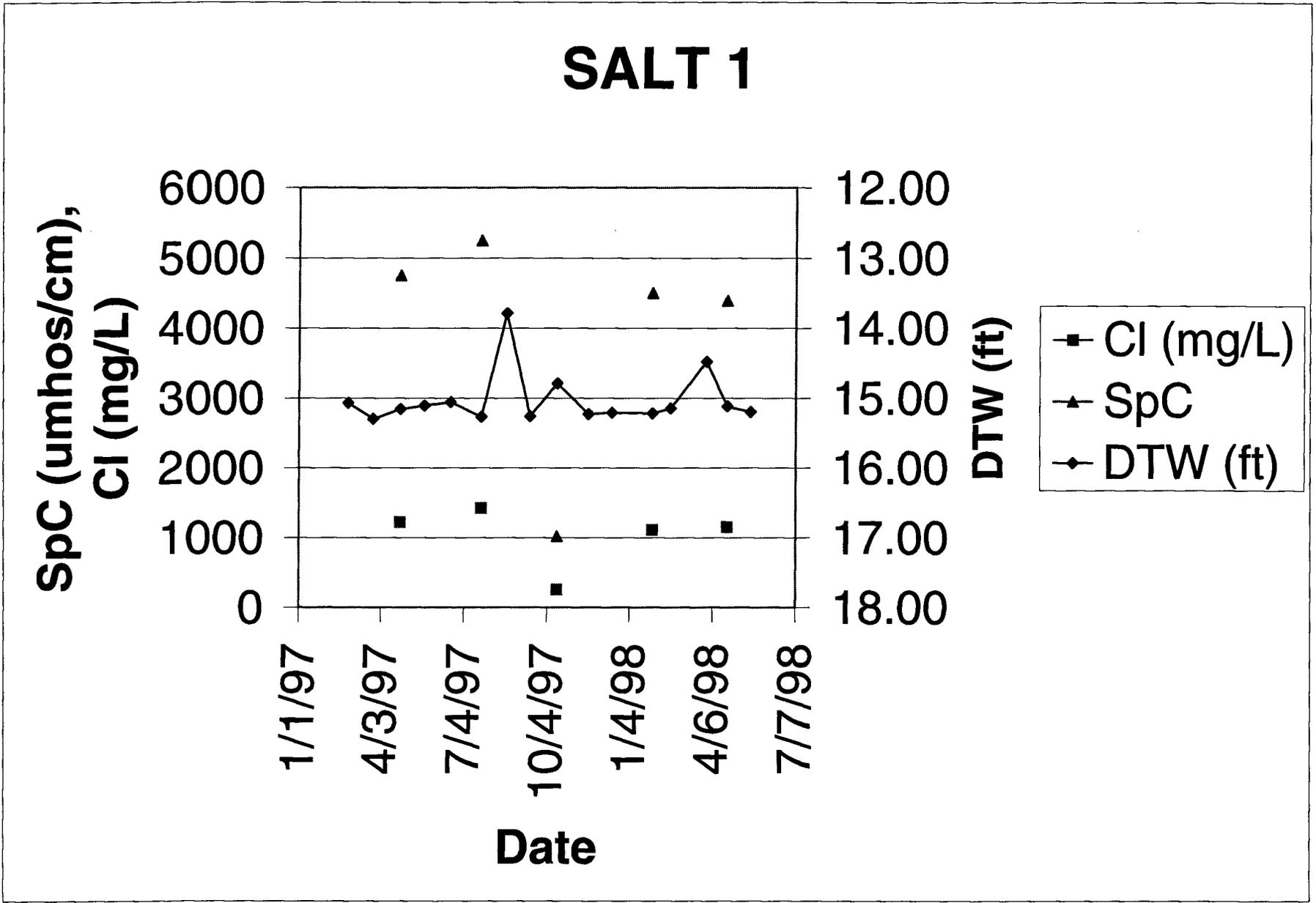


Figure IV-6. Stream levels and specific conductance and chloride determinations for surface water site SALT 1.

Table IV-1. Data from surface water collection points.

	Depth to Water *	Chloride Concentration	Specific Conductance	Depth to Water *	Chloride Concentration	Specific Conductance	Depth to Water *	Chloride Concentration	Specific Conductance		
	(ft)	(mg/L)	(umhos/cm)	(ft)	(mg/L)	(umhos/cm)	(ft)	(mg/L)	(umhos/cm)		
ARK 1				ARK 2			ARK 3				
2/25/97	16.40			2/25/97	No Measurement, pipeline const.		2/27/97	22.93			
3/21/97	16.90			3/25/97	No Measurement, pipeline const.		3/31/97	23.16			
4/24/97	16.80	545	2850	4/24/97	21.02	570	2850	4/23/97	23.18	590	2850
5/21/97	17.00			5/21/97	21.27			5/21/97	23.33		
6/19/97	16.93			6/19/97	21.1			6/18/97	23.01		
7/24/97	17.09	330	1720	7/23/97	21.25	335	1690	7/23/97	23.22	355	1795
8/20/97	15.34			8/21/97	19.89			8/19/97	22.25		
9/16/97	16.66			9/16/97	20.88			9/15/97	22.71		
10/16/97	16.93	520	3050	10/16/97	21.12	500	2950	10/15/97	22.85	395	2200
11/24/97	16.56			11/21/97	20.86			11/18/97	22.92		
12/16/97	16.58			12/16/97	20.85			12/15/97	22.98		
1/29/98	15.48	295	2950	1/30/98	19.98	290	2950	1/28/98	22.23	295	2950
2/19/98	15.38			2/19/98	19.84			2/18/98	21.91		
3/31/98	13.68			3/31/98	18.38			3/26/98	20.92		
4/23/98	15.00	270	2750	4/23/98	19.52	275	2750	4/22/98	21.48	285	2750
5/18/98	15.80			5/19/98	20.29			5/18/98	22.21		

* Tapedown measurement from bridge.

(continued)

Table IV-1 (continued). Data from surface water collection points.

	Depth to Water *	Chloride Concentration	Specific Conductance		Depth to Water *	Chloride Concentration	Specific Conductance		Depth to Water *	Chloride Concentration	Specific Conductance
	(ft)	(mg/L)	(umhos/cm)		(ft)	(mg/L)	(umhos/cm)		(ft)	(mg/L)	(umhos/cm)
COW 1				COW 2				SALT 1			
2/25/97	18.39			2/27/97	6.70			2/25/97	15.07		
3/24/97	18.71			3/31/97	7.51			3/25/97	15.30		
4/24/97	18.64	355	1725	4/23/97	7.38	510	2450	4/24/97	15.16	1220	4750
5/22/97	18.69			5/21/97	7.47			5/21/97	15.11		
6/19/97	18.48			6/18/97	7.15			6/19/97	15.06		
7/24/97	18.76	240	1265	7/23/97	7.34	530	2550	7/23/97	15.27	1420	5250
8/21/97	9.77			8/19/97	6.81			8/20/97	13.79		
9/16/97	18.34			9/15/97	6.60			9/15/97	15.26		
10/16/97	17.86	195	965	10/15/97	6.39	260	1285	10/15/97	14.79	255	1020
11/21/97	18.42			11/18/97	6.99			11/19/97	15.23		
12/16/97	18.51			12/15/97	7.15			12/15/97	15.21		
1/30/98	18.36	270	1400	1/28/98	6.81	445	2200	1/29/98	15.22	1110	4500
2/19/98	17.42			2/18/98	7.00			2/18/98	15.15		
3/31/98	11.12			3/26/98	6.84			3/30/98	14.48		
4/23/98	17.90	300	1520	4/22/98	6.96	475	2270	4/22/98	15.12	1150	4390
5/19/98	18.21			5/18/98	7.14			5/18/98	15.20		

* Tapedown measurement from bridge.

Surface Water Data Collection Points Chloride Concentrations and Changes

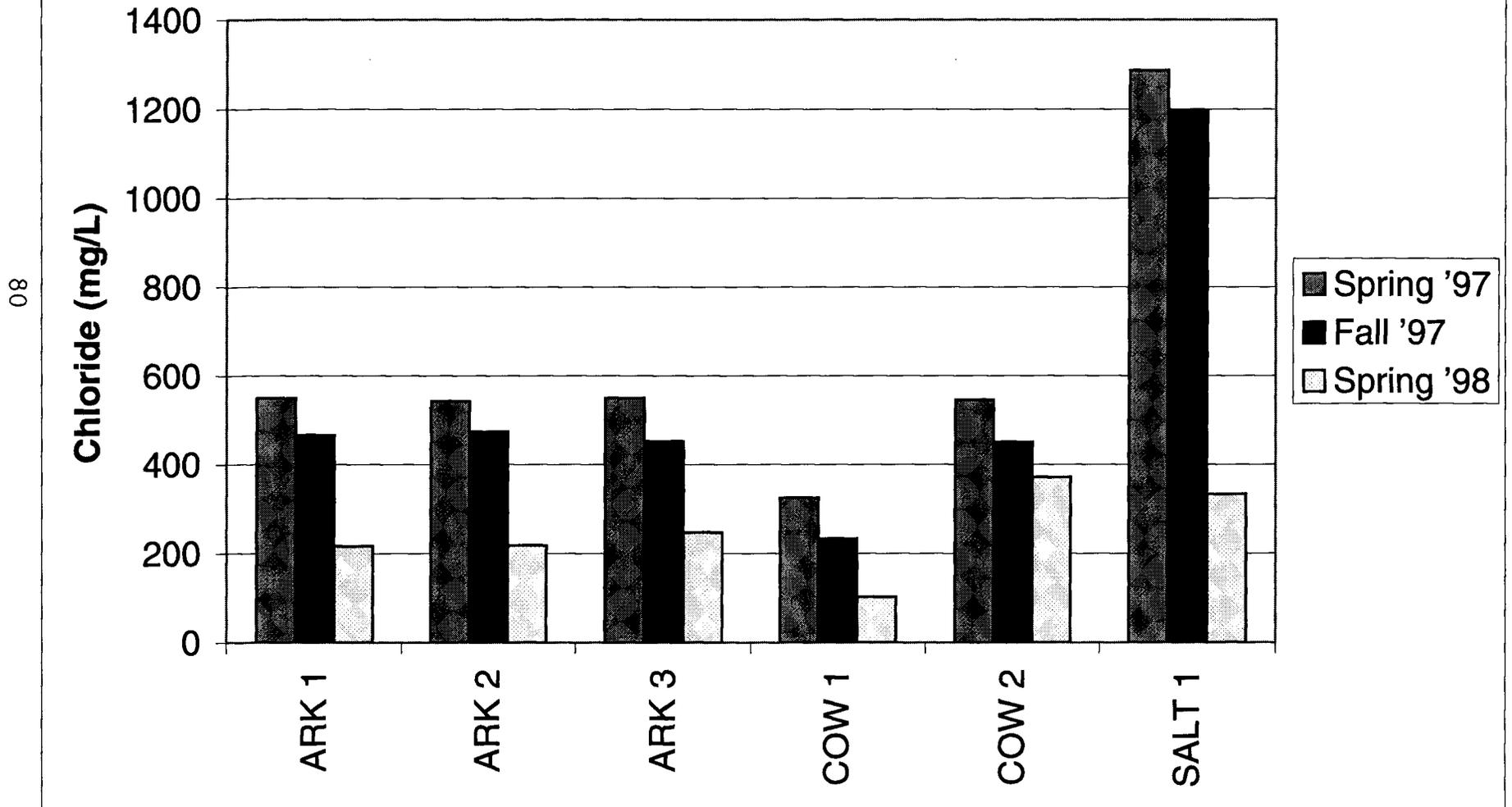


Figure IV-7. Chloride concentrations and changes for surface water data collection points.

Creek, to determine variations in salinity. The stretch of the creek surveyed was from the K14 bridge to the 4th Street bridge just west of Hutchinson. A map of the area showing the conductivity measurements is presented in Figure IV-8. Since specific conductance is well correlated with chloride concentration on Salt Creek, as shown in Figure IV-9, these measurements can be used to estimate chloride concentrations. Also two water samples were collected and analyzed for specific conductance, chloride, sulfate, and nitrate at KGS. Results of those analyses are listed on Figure IV-8.

Unfortunately, conditions were wet and the salinity was diluted somewhat from freshwater runoff. However some interesting observations were made. Increases in conductivity were observed in very localized reaches of the stream; these areas were where the stream flows in a generally southeastward direction, or has a southward component of flow (Figure IV-8). In the mile east of K14, the conductivity increased from 2120 to 3520 $\mu\text{S}/\text{cm}$, and in the vicinity of EB256, it increased from 3520 to 4460 $\mu\text{S}/\text{cm}$ in about 2 miles. Little or no net increase was observed elsewhere—3520 $\mu\text{S}/\text{cm}$ was measured one mile east of K14 and 3520 $\mu\text{S}/\text{cm}$ was measured one mile west of EB256. This pattern is indicative of subsurface interactions in terms of salt discharge and/or transport.

Another observation, based on these measurements, is that Sugar Creek is at least as saline as Salt Creek (but it does have a lower flow). The conductivity measurement on Sugar Creek was higher than those on Salt Creek near their confluence. This may imply that some of the smaller tributaries play an important part in the salt budgets discussed in Section V.

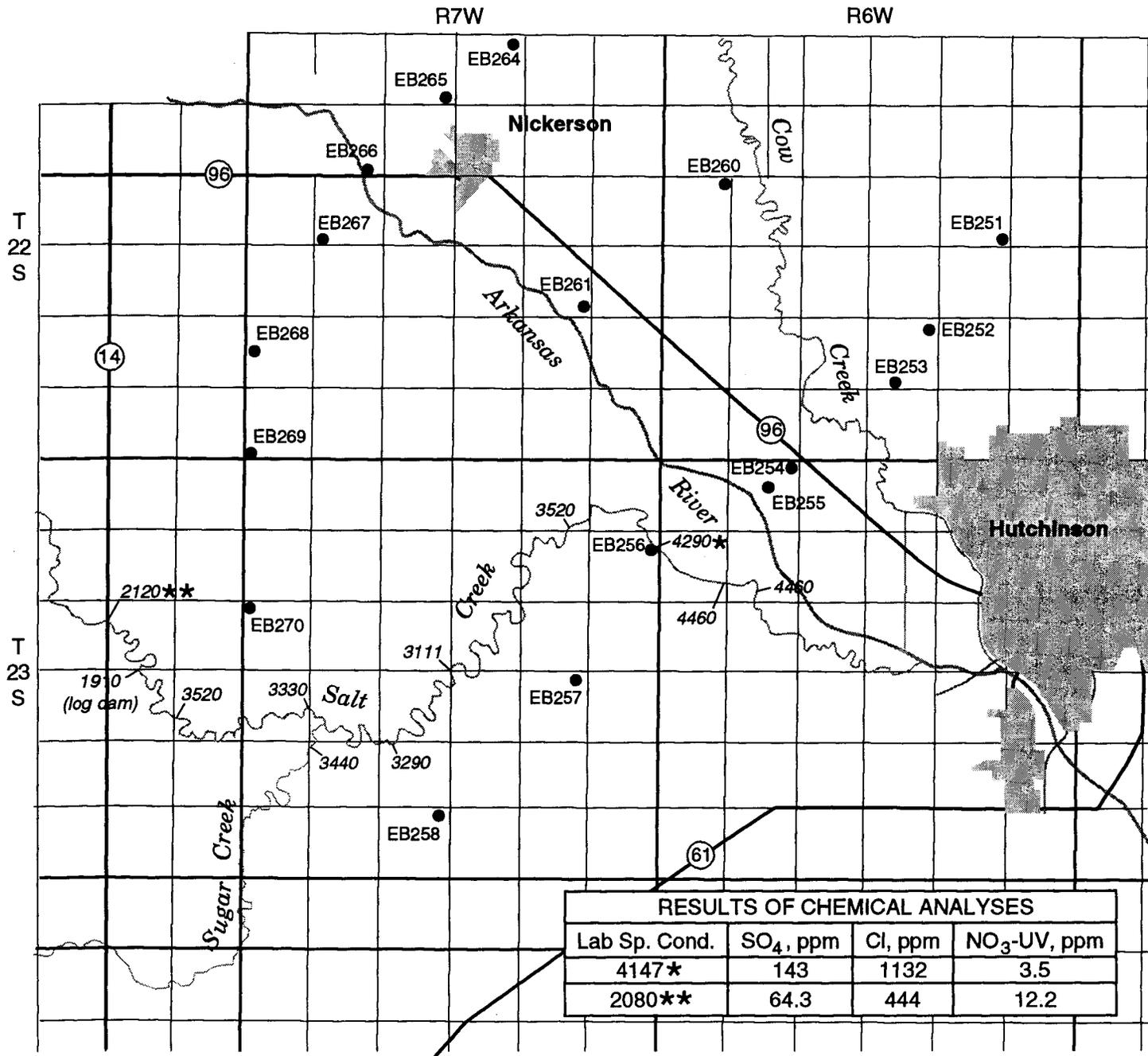


Figure IV-8. Specific conductance values (μS/cm) from Salt Creek conductivity survey, October 23, 1997.

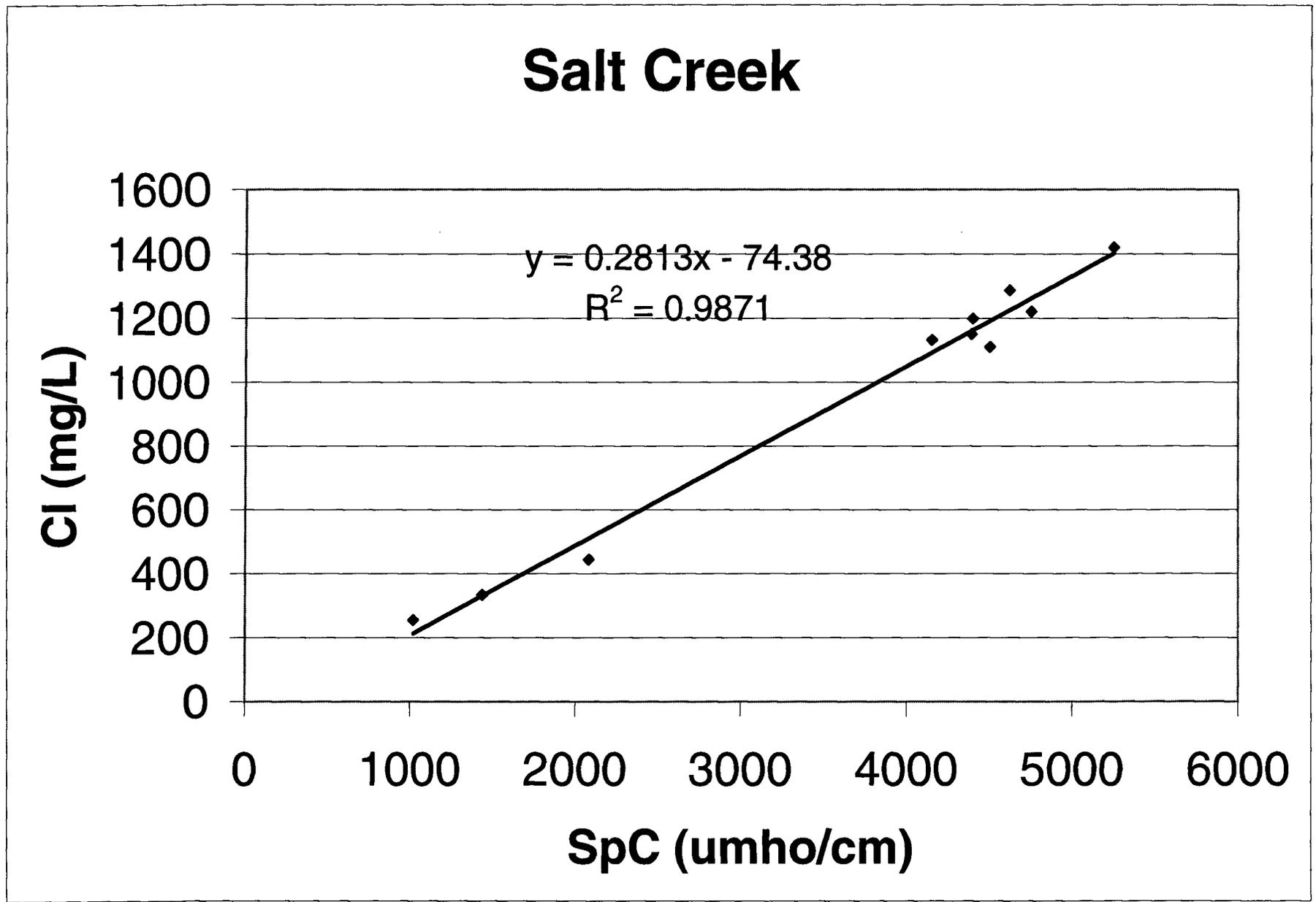


Figure IV-9. Chloride v. specific conductance for Salt Creek.

V. Salt Budgets and Models

A. Introduction

A major goal of KGS EBMI research is identification of the sources, pathways, inventories and fluxes of salt in the study area. The emphasis is on development of quantifiable conceptual models, based on monitoring data, hydrogeologic information, and physical principles. These are intended to provide hypotheses to be tested with more detailed numerical models, and scenarios for long-term projections involving regional scales and the influence of such factors as land and water use, climate, etc.

This work will be drawn to a conclusion in the upcoming final year of the project; this report outlines the issues and progress to date, with indications of future activities.

B. Sources of Salt

1. Geochemical/geological

Salinity in the groundwater of the study area can potentially have several ultimate origins -- intrusion of natural brines from the Permian bedrock formations, contamination by oilfield brines or salt-mining waste, or evaporative concentration (of natural saline waters, or as a result of agricultural salinization due to irrigation). Although all are undoubtedly present, enough is known about their locations and relative amounts to be confident that the large-scale salinity problem is completely dominated by the first source -- natural brines from the bedrock underlying the region. It is important to note that although this salinity is of natural origin, its distribution and movement may be due in part to human as well as natural hydrologic influences.

2. Geographic

Although the study area contains the well fields of the cities of Hutchinson and Nickerson and their local hydrogeologic environment north of the Arkansas River, our work focuses on the region south of the Arkansas River, where the salinity concentrations are high and variable, and where we find the source of the most critical threat to the municipal water supplies -- salinity migration to the east and northeast beneath the river, into the presently fresh water supplies.

In terms of physical origins and pathways, the salt of interest (brine from Permian bedrock) in the region of interest (the EBMI study area south of river) may enter the area:

1. by direct discharge from the bedrock underlying the area;
2. by inflow of saline surface water transporting salt discharged elsewhere; or,
3. by inflow of groundwater transporting salt discharged elsewhere.

One of the major findings of recent investigation is that the third path, groundwater transport, needs to be subdivided into two categories:

- a. "bulk" groundwater flow, in which the entire saturated thickness can be characterized in terms of concentration profiles and total salt load, moving at the regional water flux rates, and,
- b. "channel" flow, wherein bedrock channels or other preferred flow paths provide more rapid transport of high-density, high-salinity water near the base of the aquifer.

When these classes are viewed in more detail, two other considerations arise -- one is that bedrock topography may play a role in preferential local discharge as well as longer range transport, and the other is that it becomes necessary to develop some concept or understanding of the lateral and vertical mixing of salt contaminant plumes arising from sources that approximate points or lines on the bedrock surface.

To complete the budgetary assessment, we point out that the pathways for export from the system are conceptually the same; however, we are confident that the return of salt from the alluvial aquifer to the bedrock is negligible, so the loss term only includes surface discharge and the two types of groundwater flow. Input considerations can also be simplified by noting that there are virtually no significant surface water inflows into the southern part of the study area -- Salt Creek arises almost entirely within the study area, while Peace Creek and Rattlesnake Creek discharge to the Arkansas River to the west of the EBMI study area. These surface flows are therefore significant in terms of the budget of each "compartment," but can be neglected in terms of transport into the study area.

The Arkansas River, used here as the boundary of the budget and flow assessment, is a major hydrologic feature, with varying salinity, flow rates, and recharge/discharge characteristics with respect to the groundwater. The complexity of the river interactions and the fact that their time constants are much shorter than those associated with groundwater puts them outside of the scope of this specific effort, one of the goals of which is to provide relevant input and boundary data to the much more detailed dynamic model of the river corridor that will be developed by the US Bureau of Reclamation.

In Summary: input pathways for salt in the study area south of the river may include direct bedrock discharge and both "bulk" and "channel" groundwater flow from the west; output pathways include groundwater outflow and surface water (groundwater discharge) outflow.

C. Flux and Inventory Budgets

The methodological approach adopted for this activity is the box model approach that has been formalized in the software package STELLA (® High performance Systems Inc.). This technique allows basic constraints to be imposed by conservation of mass and available data, solving simultaneous equations to compute unknowns or explore the

effects of assumptions or uncertainties. It is appropriate to problems such as groundwater assessments, where the data density is rarely if ever adequate to support the development of high resolution models without extensive approximations and assumptions. Box models may be subdivided and refined to correspond to either conceptual models to be tested, or the availability of specific data or knowledge about a particular region or process.

The general approach has been described in an earlier report (Quinodoz and Buddemeier 1997) that addressed the process and applied it to the data obtained in GMD5 Mineral Intrusion Project. Budgeting salt fluxes out of the northern part of GMD5 is a critical component of EBMI evaluation, since these outflows are virtually identical to the groundwater input terms for the EBMI study area.

Below, we first summarize the findings of the GMD5 budget effort most critical to the EBMI study, present the results of an initial salt inventory in the portion of the study area south of the Arkansas River, and then discuss the implications of these results and the plans for further budgeting/modeling efforts.

1. Salt efflux, northern GMD5

A simple budget model (Quinodoz and Buddemeier 1997), based on measured or calculated water flows and salt concentrations, was constructed for the northern portion of GMD5 (Rattlesnake Creek basin), which is up-gradient from the area of concern in GMD2 (see Figure V-1 below). This permitted estimates of the amounts of salt entering the GMD5 region from bedrock seepage, and the amounts of both salt and water leaving that region by surface water discharge into the Arkansas River and by groundwater flow to the east. Two intervals of the streamflow records were used to approximate the early and late stages of groundwater development in the region, determining the probable range of values experienced over the past (and presumably the next) several decades.

Table V-1 shows the surface and ground water outflows in Mm^3/yr (one $\text{Mm}^3 = 811$ acre-feet), and the groundwater and surface water residence times in years for the two extreme cases. Groundwater outflow, as estimated from water table gradients at the eastern boundary, has remained relatively constant as surface water outflow has decreased and groundwater pumping has increased. An important point for management and assessment, however, is the great difference in the time constants of the two systems, with surface water responses observable on a scale of months to years, while groundwater responses are spread over decades.

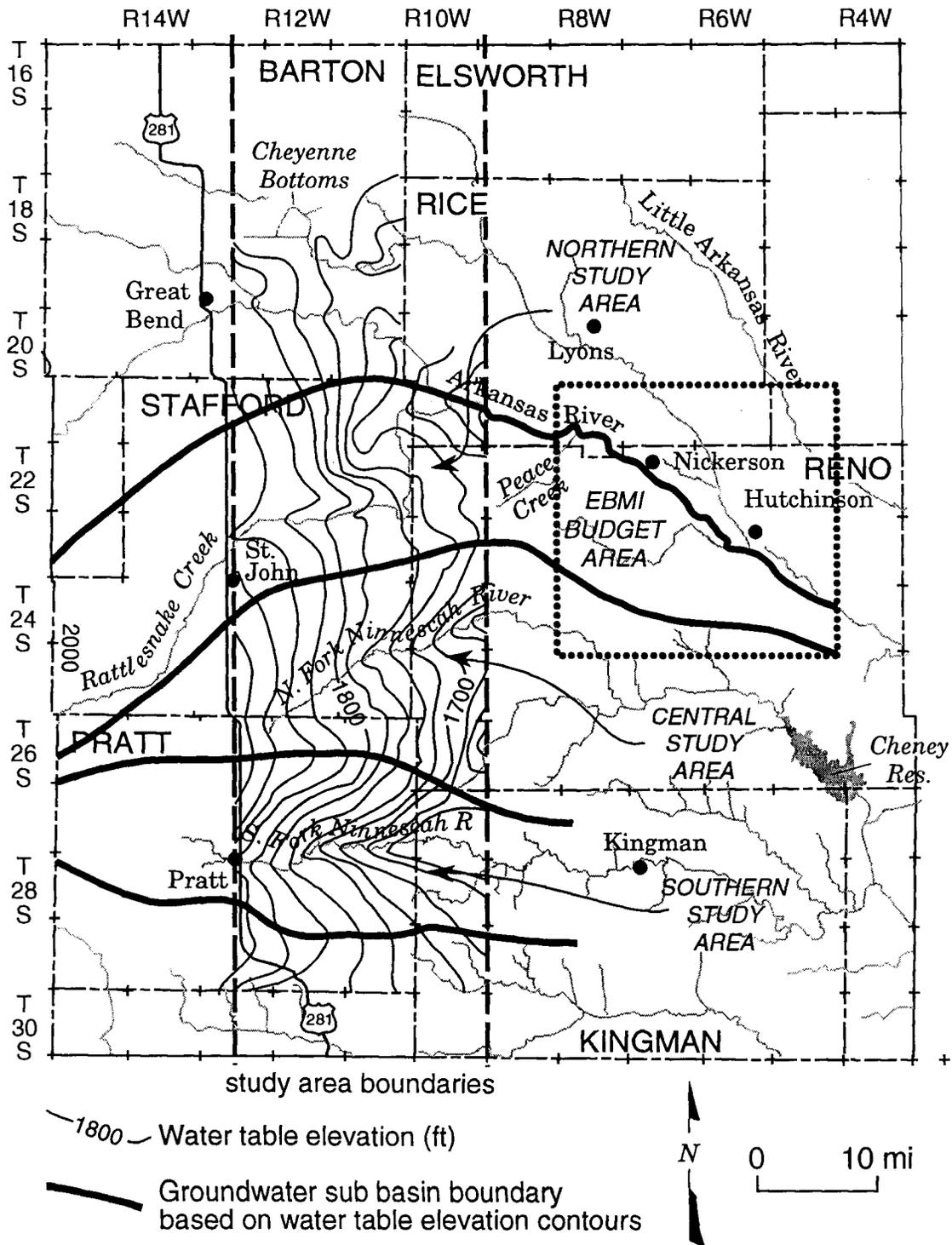


Figure V-1: Study and budget model areas. The dotted line shows the overall EBMI study area; the heavy solid lines show the limits of the groundwater flow systems (Rattlesnake basin, and Arkansas basin south of the river) used in GMD5 and EBMI salt and water budgeting.

Table V-1. Northern GMD5 Water Budget: Fluxes in Mm³/yr.

Interval	SW Outflow	GW Outflow	SW Res. Time (yr.)	GW Res. Time (yr.)
1961-1980	52	10	0.14	100
1981-1995	32	10	0.20	50

Table V-2 shows the salt flux estimates for the same periods and pathways, expressed in Mkg/yr Cl⁻ (one of these units is equivalent to about 4,000 US tons of sodium chloride). Apart from the magnitude of the salt flux, three points are important: (1) most of the salt leaves the region via surface water flow; (2) as surface outflow decreases, the salt load of the groundwater outflow increases (if Rattlesnake Creek dried up, all of the salt input would leave via groundwater flow); and (3) the time scale of salinity effects is controlled by the time constants of the water bodies -- a change in Rattlesnake Creek water quality affects the quality of the Arkansas River at Hutchinson almost immediately, but the related changes in groundwater quality may be felt at the same location only decades later.

Table V-2. Northern GMD5 Salt Budget: Fluxes in Mkg/yr. as Cl⁻

Interval	Salt Input Bedrock	Salt Outgo SW	Salt Outgo GW	Salt SW/GW
1961-1980	106	81	25	3.25
1981-1995	120	80	40	2.00

These two estimates provide a reasonable first approximation of the range of groundwater inputs from GMD5 into the study area (see Figure V-1). Because of the century-scale time constants of the groundwater systems, the 'predevelopment' estimate is more likely to be reflected in the present EBMI groundwater, since changes on a scale of a few decades may not have propagated that far yet. The budget model approach also provides useful estimates of other parameters, such as the rate of bedrock discharge (which cannot be directly measured and has only been very roughly estimated in the past). The differences in calculated bedrock discharge between the two cases shown in Table 2 is simply derived from budgetary constraints on the outflow, and is well within the uncertainties in the other budget numbers. However, we note that it is consistent with the effect expected if lowered water tables result in reduced hydrostatic confining pressure countering a consistent bedrock pressure head (discussed below). An extremely important finding in terms of scenario development and projections (discussed below) is the sensitivity of salt transport to surface water discharge.

2. EBMI study area salt inventory and fluxes

From the estimates of residence time and water outflow in northern GMD5 we can develop estimates of the groundwater flux and residence time in the portion of the study area of interest (Figure V-1). Since the salt inventory in the study area is the result of a combination of groundwater inflow, for which some estimates have been developed, and local bedrock discharge, development of a salt inventory estimate for the EBMI area will permit a first-approximation estimate of the relative significance of the different sources -- an important piece of knowledge for development of scenarios and projections.

a. Water inventory:

The region of interest is the area bounded by the boundaries of the complete EBMI study area on the east and west, and by the Arkansas River on the north and the groundwater divide between the Arkansas and Ninescah drainages on the south (Figure V-1). These north-south boundaries are also those of northern GMD5 budget estimates, so we assume continuity of easterly groundwater flow.

To establish the water inventory, an Arc-Info coverage bedrock surface was prepared from the updated bedrock map (Schloss et al. 1997), and a water table surface coverage from the 1996 annual water level measurements in the region. These surface coverages were aligned and trimmed to the boundaries of the region of interest, and then sampled at quarter-section centers to prepare a file of saturated thicknesses and water column elevations. The sampled saturated thickness values were converted to water volumes using the same porosity estimates applied to the GMD5 estimates, and summed to estimate the groundwater inventory in the region of interest. The total area of significant saturated thickness within the boundaries described above is approximately 500 km², and the estimated water volume is 4,600 Mm³.

In order to estimate residence time of the groundwater system, we assumed conservative through-flow of groundwater originating from the GMD5 area, augmented by net local recharge, as the water input to a steady-state system. This is an approximation, as it includes within the recharge term the budgetary effects of surface water discharge and ET from shallow groundwater bodies, both of which would tend to increase the residence time of the residual groundwater (but which would have opposing effects on the salt load). Also neglected are the details of recharge-discharge relationships along the Arkansas River, but since this is clearly a net outflow boundary for the system as a whole, this is probably justified.

The groundwater flux into the system is approximately 10 Mm³/yr (from the GMD5 budget study). Recharge in the area is considered to be 0.15 m/year; we use 0.1 m/yr to compensate for neglect of the surface discharge and loss terms, which yields approximately 50 Mm³ as an average annual recharge for the region of interest, or a total annual water flux of about 60 Mm³. This corresponds to a residence time of 75 years,

which in turn would suggest a salt load of about 3000 Mkg of Cl⁻, if the 40 Mkg/yr influx with GMD5 groundwater were the only source of salt. At the estimated earlier output of 25 Mkg/yr (see Table V-2), the salt inventory in the region of interest would be slightly less than 2000 Mkg Cl⁻.

b. Salt inventory:

The actual salt inventory was calculated on the basis of the observation that salinity in the monitoring well installations was highly correlated with the elevation of the well screen. Figure V-2 shows chloride vs. elevation for all wells south of the river for Spring 1997 (differences between sampling periods were trivial). There is a strong correlation when all wells are considered, and an even stronger relationship when 4 of the low-salinity outliers are excluded from the regression. Salinity-elevation relationships for the area were calculated from the regression equations in Figure V-2. Note that the intercepts of the two regression equations are similar to, and in fact straddle, the value of 42,000 mg/L Cl⁻ derived by Whittemore (1993) as an estimate of the typical maximum concentration of Permian bedrock brine discharged to the aquifer in GMD5.

The depth distribution of the groundwater volume was determined by dividing the elevation range of the aquifer (1200-1700' a.s.l.) into 50' bins, and sorting the total height (volume) of the water column in each of the quarter-section saturated thickness values into the appropriate bins. The mean Cl⁻ concentration for each bin was determined from the regression equations and the mid-point elevation of the bin; this was multiplied by the total water volume in that 50' aquifer slice to obtain the Cl⁻ load, and the loads of all slices were summed to obtain the aquifer load. This procedure, using the 'all points' regression equation, yielded a salt load estimate of 6,100 Mkg Cl⁻; using the equation generated by dropping the low-salinity outliers produced a estimated load of 7,000 Mkg.

[Note: The data sets used to calculate the water and salt budget terms are available on request from the authors of this report.]

c. Interpretation and discussion:

The estimated inventory and the groundwater input calculation differ by a factor of two to three. Although these are rather rough approximations, this level of disagreement would require significant, reinforcing errors in several of the variables. We take the discrepancy as an indication that there are probably other significant sources of salt input to the study area besides the bulk groundwater pathway, but that the groundwater inflow is itself an important source.

The two possibilities already named are local bedrock discharge, and localized, preferred transport via bedrock channels. Both are possible; channel transport of additional salt from GMD5 is not constrained by the existing budget because it did not consider a separate channel system, and because the bedrock discharge flux was calculated to balance all the estimated surface and groundwater fluxes.

EBMI MONITORING WELLS SOUTH OF
ARKANSAS RIVER

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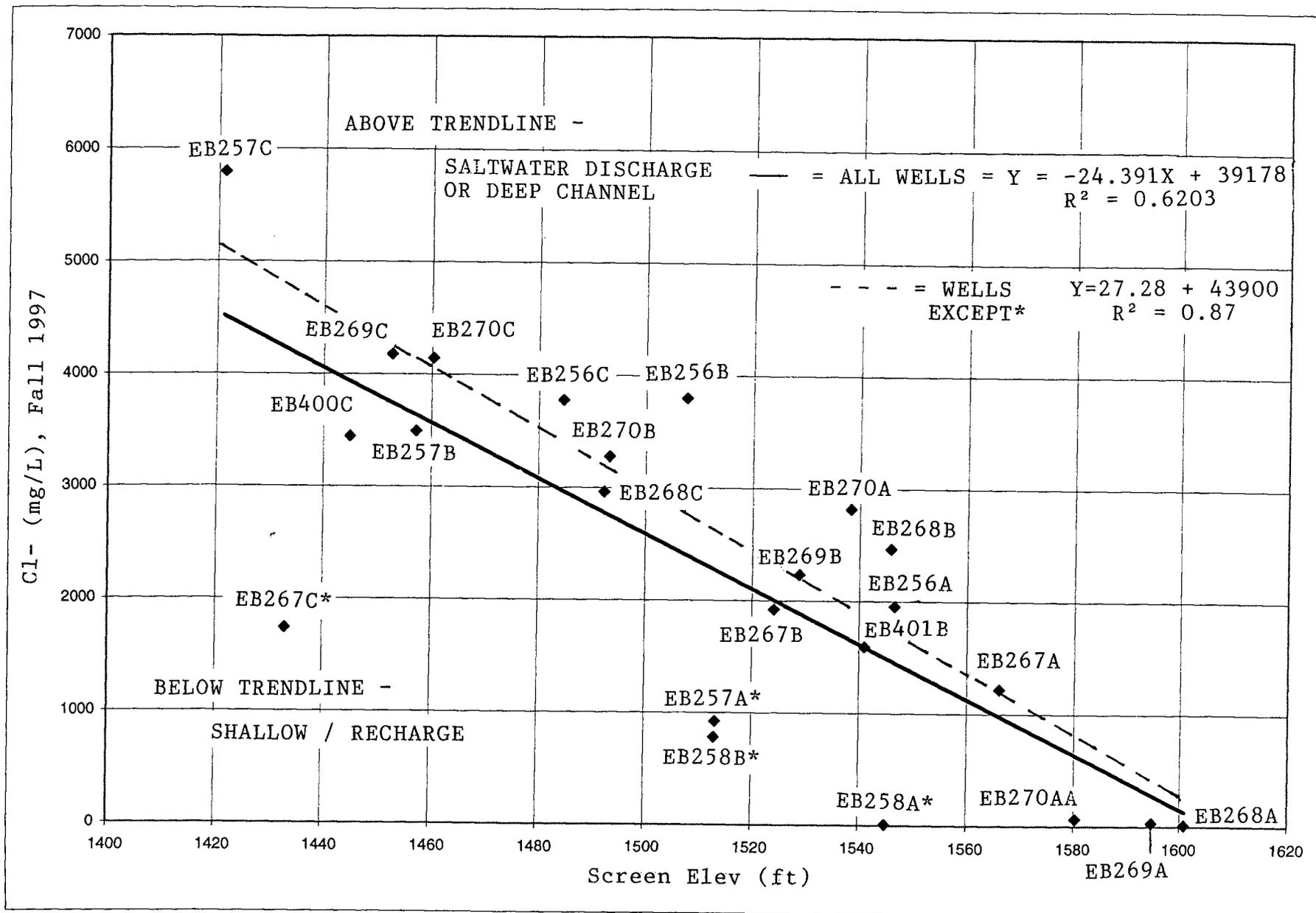


Figure V-2: Chloride concentration (mg/L Cl⁻) as a function of well screen elevation for all EBMI monitoring wells south of the Arkansas River. Two linear regressions are shown; one for all wells, and one for all wells except for four low-salinity outliers.

Distinction between the two possible sources is difficult, because both would result in localized brine concentrations associated with lows in the bedrock topography. Further, it is impractical to design a field investigation program that would resolve the question; determinations will need to be made largely on the basis of existing data, supported by modeling efforts. The question of the nature and relative magnitudes of the salt sources is an important one, however, because they will have distinctly different responses (or lack thereof) to management strategies and changes in the hydrologic system, and channel flow might be much more rapid than the overall groundwater residence times would suggest.

d. Implications – climate and management issues:

The fluxes of groundwater and groundwater-borne salt in the system under study are critically dependent on two factors that may be sensitive to both climatic variation and human interactions with the hydrologic system. These are the rate of salt discharge from the Permian bedrock, and the rate of saline groundwater discharge and outflow (to and in the Arkansas River) as surface water. These are or may be sensitive to water level, which in turn is a function of recharge (primarily a climate variable) and pumping (a managed human intervention).

It has been documented that a number of locations in the salt-affected areas of GMDs 5 and 2 exhibit vertical hydraulic gradients with the potential for upward flow from the bedrock and/or the deep aquifer (Garneau 1995; this report, section II). In principle, these areas may represent sources of brine discharge, and may be sensitive to the potential confining effects of hydrostatic pressure related to the elevation of the water table. In practice, this relationship has been neither demonstrated nor disproven, partly as a result of the complex effects of local stratigraphy, semi-confined conditions, etc. However, processes (e.g., drought, pumping, etc.) that would tend to reduce heads above local regions of upward or neutral hydraulic gradient could have the effect of increasing the rate of salt discharge.

The effect of water level on groundwater discharge is much more readily demonstrated. The data and models presented by Quinodoz and Buddemeier (1997) clearly demonstrate that discharge to surface water can remove a substantial inventory of salt from the system, while concurrently slowing the flow of groundwater and the salt it still carries (see also Tables V-1 and V-2 above, and Figure V-3 below). It appears that maintaining a water table high enough so that stream channels can carry discharge flow a significant percentage of the time is critical to the salt balance, and that as long as this is the case, recharge events act to flush salt from the system through enhanced discharge. If the water table has dropped far enough below the stream channels so that discharge rarely occurs, then there is probably relatively little effect of recharge.

It thus appears at this point that groundwater level and streamflow management may be critical factors in influencing the amount of salt transported into and through the aquifer,

especially in an era when climate change as well as changing water demand may be anticipated. An important issue is that some of the required management actions may be in jurisdictions other than the one primarily concerned with the water resource. As indicated by the discussion above, a significant fraction of the salt in GMD2 groundwater originates in GMD5, and may be affected by management policies there that are designed around other considerations.

D. Work in progress and planned

1. Budget modeling

Figure V-3 shows the ‘post-development’ budget model scenario for northern GMD5. This model, used to explore different ranges of input values, has provided valuable understanding of the salt-water system, and a range of input scenarios for the EBMI investigations. As noted above, the one additional factor that needs to be explored in this model is the effect of saline water discharge into and transport through deep bedrock channels.

An extended STELLA model has been developed that will permit investigations to be extended into the EBMI study area. A schematic of this model is shown in Figure V-4. It incorporates a three-region system (the original northern GMD5 study area, the connecting (Peace Creek subbasin) region, and the southern portion of the EBMI area. All of the groundwater boxes have an additional deep channel connection, and there are stream-aquifer interaction zones along the Arkansas River corridor.

In actual practice, it is unlikely that the full extended model will ever be implemented – there simply are not enough data to subdivide the system to that level with confidence. However, it provides the opportunity to explore sensitivities and scenarios involving various parts of the system, and thus to develop the best compromise between desired detail and realistic understanding. The primary focus will be on investigating the potential effects of deep channel transport, bedrock discharge, and upgradient streamflow on the salinity of groundwater approaching the Arkansas River in the vicinities of Hutchinson and Nickerson.

2. Bedrock channel structure and function

As discussed above, the existence and characteristics of bedrock channels is a focal point of interest in terms of saltwater transport into and within the EBMI study area. The present map of bedrock topography (Figure V-5) in the GMD5 area shows the expected locations of several bedrock channels; based on groundwater quality observations, we suspect that the more southerly channels may transmit a significant amount of salt water, while the northern channels (closest to and north of the present Arkansas River) contain fresher water.

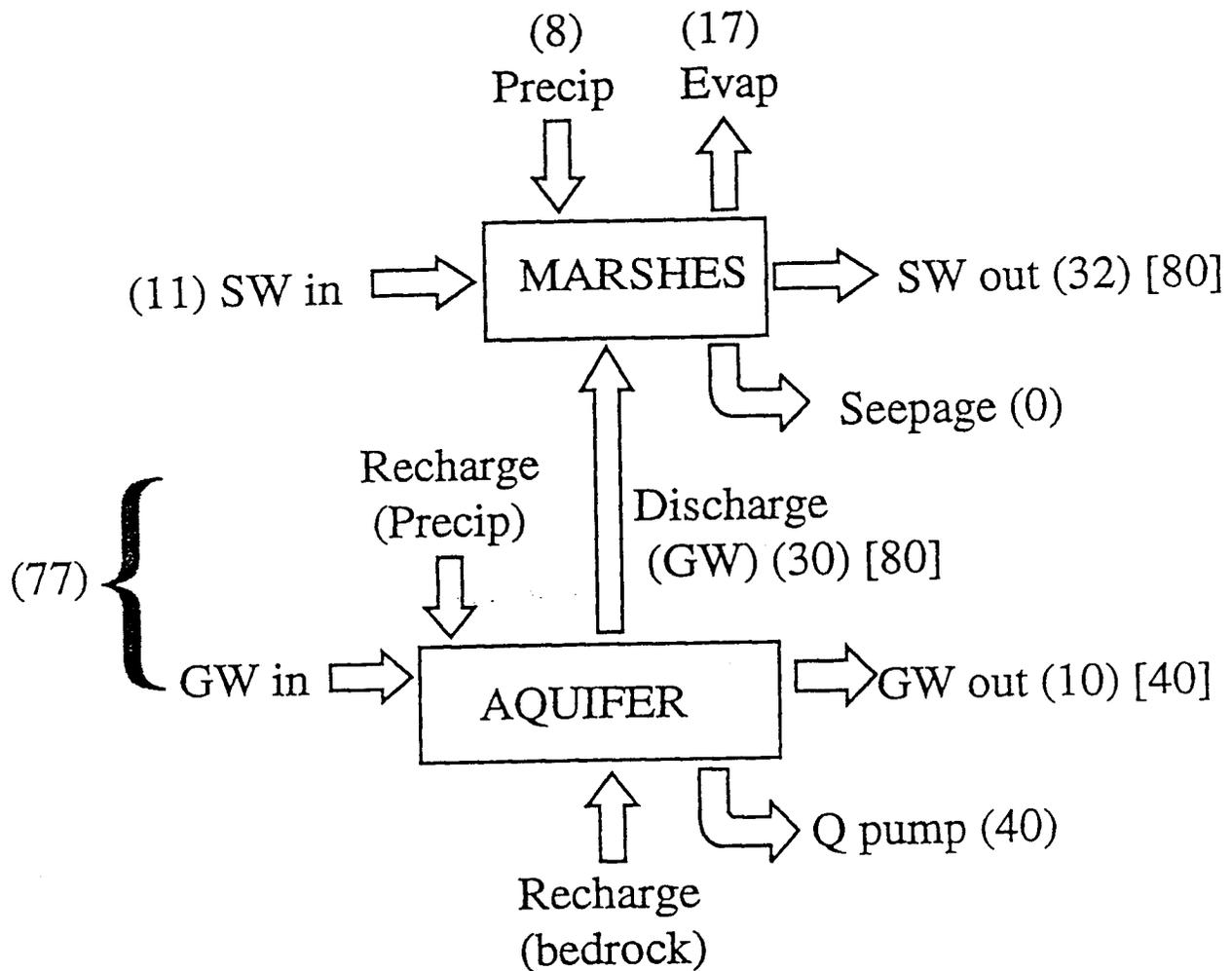


Figure V-3: Northern GMD5 budget model schematic. This illustration represents the 'post-development' version of the salt and water budget (Quinodoz and Buddemeier, 1997) -- the second lines in tables V-1 and V-2. Water fluxes (in parentheses) are in units of million cubic meters per year (Mm^3/yr); salt fluxes [in brackets] are in units of millions of kilograms of chloride ion per year ($Mkg\ Cl^-/yr$).

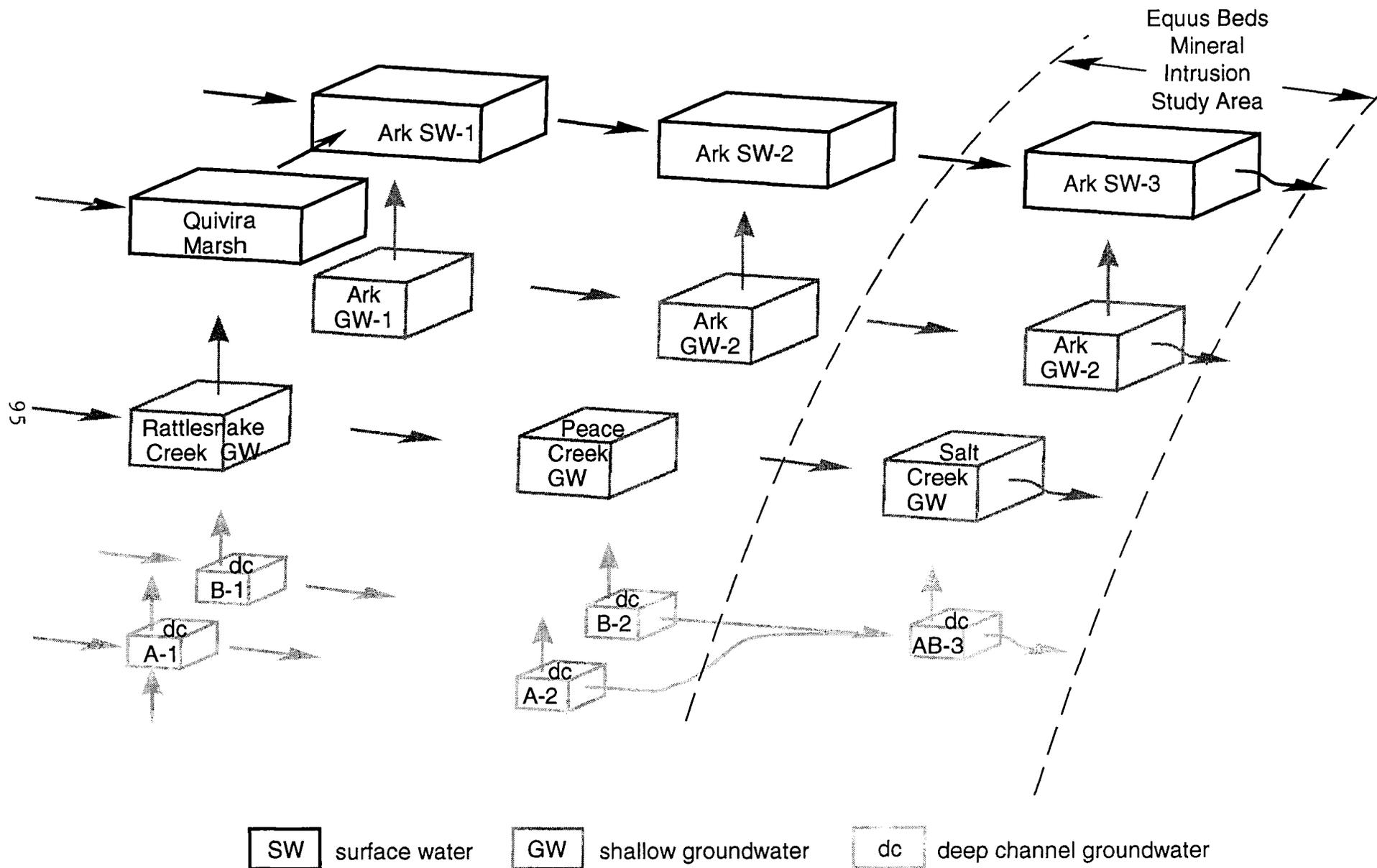


Figure V-4: The 'maximum complexity' budget model framework for the EBMI study. This permits inclusion of deep channel flow and stream-aquifer interactions, but can be simplified to any desired level by 'turning off' selected pathways or fixing compartments.

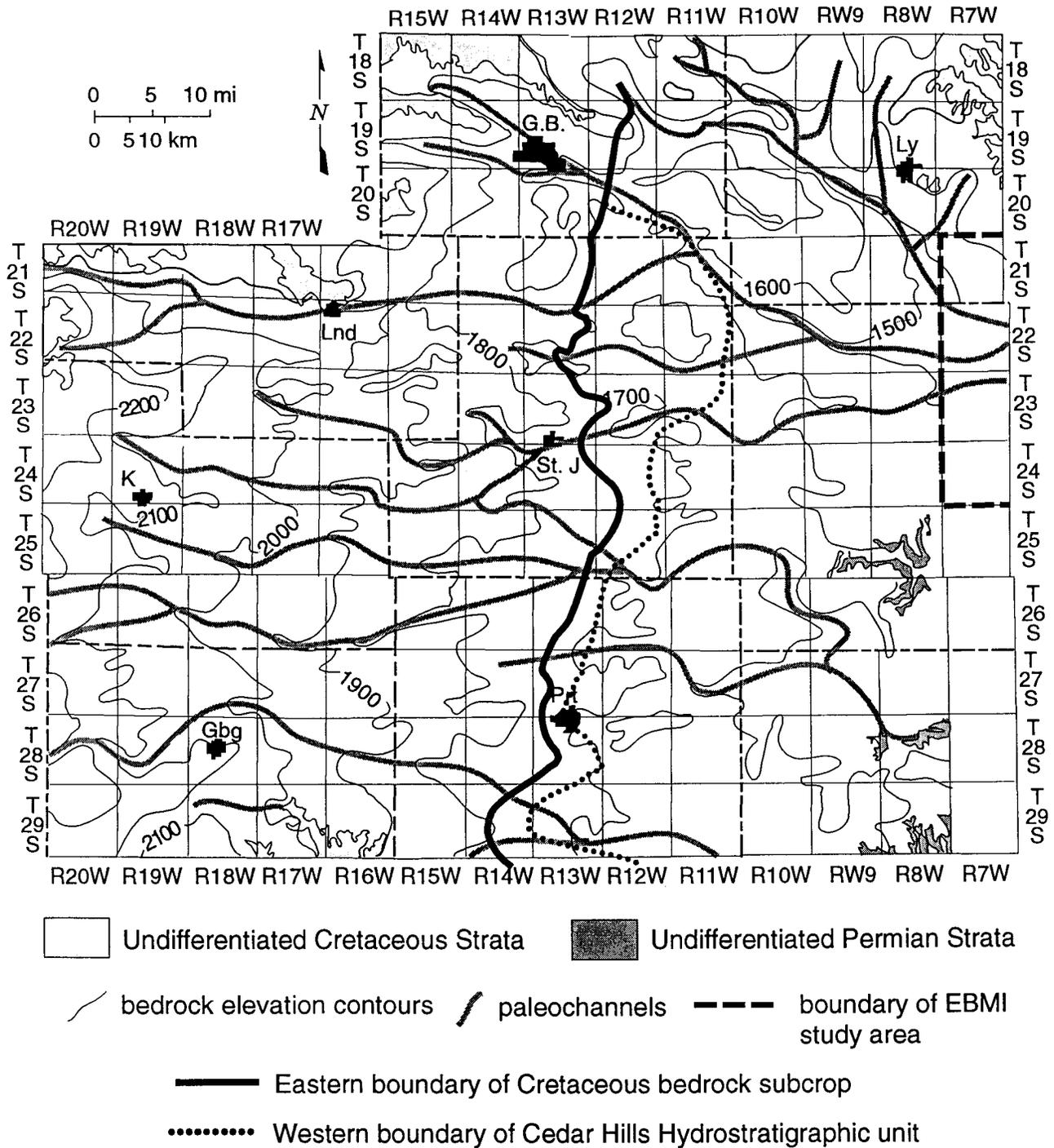


Figure V-5: Pre-Cenozoic bedrock map of the Great Bend Prairie region of south-central Kansas, with inferred paleodrainage (bedrock) channels. Channels north of Township 24 South may contribute to the EBMI study area. County seats are shown with abbreviated names.

a. Mapping and lithology

An expanded bedrock database has already been compiled and mapped for the EBMI area and some surrounding regions of GMD2. In cooperation with GMD5, work has started on updating and refinement of the bedrock map for that region; during FY 1999 the regional map will be updated, reviewed and published, and the improved depiction of existing or suspected bedrock channels will be used to model and interpret the observed salt distributions.

An additional important feature of channel characterization will be lithologic descriptions and estimates of hydraulic conductivity, as this factor is critical in determining the differential rates of transport in channel and bulk groundwater flow. Available logs and other information will be reviewed to arrive at the best possible estimates of channel characteristics.

b. Salinity

A critical component of examining the channel transport hypothesis will be plotting distributions of salinities in and adjacent to bedrock channels. This aspect of the work will rely heavily on the new data being accumulated by the GMD5 drilling and monitoring program to characterize the salinities associated with bedrock channel groundwater.

3. Flow and mixing

As noted elsewhere, groundwater concentrations of salt are far from uniform, and understanding of the patterns and mechanisms of salt mixing are important to evaluating both the overall system function and the management implications. In work already inspired by the need to explain mineral intrusion and salt-mixing phenomena, the Top-Specified Boundary Layer (TSBL) approach to describing the process of dispersive vertical mixing has been developed and applied to situations relevant to south-central Kansas (Rubin and Buddemeier 1996; Rubin and Buddemeier 1996; Rubin and Buddemeier 1998; Rubin and Buddemeier 1998). A report specifically applying the method to channel flow situations has been drafted and is undergoing final revision at this time (Rubin and Buddemeier 1997). Further refinement and application of the TSBL model (scheduled for summer/fall, 1998) will permit improved understanding of channel characteristics to be used as the basis for more realistic models and scenario tests, against which the groundwater observations may be compared.

4. System-level analysis and projections

Research during the final year of the project will be focused on the key questions of salt contribution to the region of interest in GMD2. Design of monitoring or management strategies will be critically dependent on the time constants and relative importance of groundwater inflow, local bedrock seepage, and possible groundwater “short circuits” in the form of bedrock paleochannels that may form conduits for the rapid flow of deep brines.

The ultimate combined goals of the activities described above are the development of boundary conditions and scenarios suitable for the use by the U. S. Bureau of Reclamation in detailed numerical modeling of the Arkansas River corridor, and the preparation of management-oriented simulations and scenarios that will help the agencies involved make improved projections and plans for resources use and protection.

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