MBMG Open-File Report 646

Hydrogeologic Investigation of the Scratchgravel Hills Study Area
Lewis and Clark County, Montana
Technical Report
2013

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TABLE OF CONTENTS

PREFACE

This report has been prepared by the Montana Bureau of Mines and Geology (MBMG) Ground Water Investigations Program (GWIP). The purpose of GWIP is to investigate specific areas, as prioritized by the Ground Water Assessment Steering Committee (2-15-1523 MCA), where factors such as current and anticipated growth of industry, housing, and commercial activity or changing irrigation practices have created an elevated level of concern over groundwater issues. Additional program information and project ranking details can be accessed at: http://www.mbmg.mtech.edu/gwip/gwip.asp. GWIP collects and compiles groundwater and surface-water data for each study area and uses various tools to interpret how the groundwater resource has responded to past stresses and to project future responses.

The final products of the Scratchgravel Hills study include:

- An Interpretive Report that presents interpretations of the data and summarizes the project results within the context of the study area and the issues to be addressed. The Interpretive Report includes all results and is intended for use by the general public, special interest groups, decision-makers and hydrogeologists. The reference for this report is:

  Bobst, A., Waren, K., Butler, J., Swierc, J., and Madison, J.D., 2013, Hydrogeologic investigation of the Scratchgravel Hills study area, Lewis and Clark County, Montana, Interpretive Report: MBMG Open-File Report 636, 63 p.

- A Groundwater Modeling Report (Butler and others, 2013; MBMG Open-File Report 643) that documents in detail the procedures, assumptions, and results for the numeric groundwater flow models. This report is designed so that qualified individuals can evaluate and use the groundwater flow models to test specific scenarios of interest, or to provide a starting point for a site-specific analysis. The files needed to run the models are posted to the GWIP website (http://www.mbmg.mtech.edu/gwip/gwip.asp). The reference for this report is:

  Butler, J., Bobst, A., and Waren, K., 2013, Hydrogeologic investigation of the Scratchgravel Hills study area, Lewis and Clark County, Montana, Groundwater Modeling Report: MBMG Open-File Report 643, 68 p.

- A Technical Report (this report) that is a collection of stand-alone chapters that provide detailed data and information about study components, such as aquifer tests and analyses. This report provides the technical foundation for the Interpretive and Modeling Reports.

- A comprehensive data set is permanently stored on MBMG's Groundwater Information Center (GWIC) online database (http://mbmggwic.mtech.edu/).

INTRODUCTION

The purpose of the Scratchgravel Hills Groundwater Investigation was to scientifically assess the sustainability of current and potential future groundwater withdrawals from aquifers, the potential for impacts to senior water-rights holders from groundwater withdrawals, and the potential for impacts to groundwater quality from septic effluent. Most of the data collected during this study are stored in the Ground Water Information Center database (http://mbmggwic.mtech.edu/).

Groundwater availability varies within the Scratchgravel Hills. Unconsolidated materials can produce significant volumes of water, but bedrock units (granite, argillite, metagabbro, and carbonates) do not always provide adequate water to wells. Current levels of development have not resulted in regional depletion of groundwater; however, some wells are being used at rates that exceed the capacity of the aquifer, which can cause local water levels to decline.

Groundwater samples were collected at 25 sites. Drinking water standards were exceeded for nitrate (3 sites), arsenic (1 site), and uranium (1 site). The most likely source of nitrate is septic effluent. Thin soils and fractured bedrock aquifers have limited ability to breakdown septic effluent due to low biological activity and rapid recharge. Elevated arsenic and uranium concentrations are associated with alteration zones near the Bald Butte Fault and adjacent to igneous intrusions.

Report Structure

This report supports the Scratchgravel Hills Interpretive Report (Bobst and others, 2013), and contains a collection of technical information that has been prepared in support of the Scratchgravel Hills Groundwater Investigation. The sections of this report are as follows:

Site List: Includes all sites used in this study, their purpose of use, their location, and their GWIC ID numbers. A site’s GWIC ID number can be used at the GWIC website to access all data associated with that site.

Aquifer Tests Summary: Presents results from all known (at the time of publication) aquifer tests conducted in the Scratchgravel Hills. Included are tests conducted for DNRC water-rights applications, tests conducted in association with previous groundwater studies, and tests conducted as a part of this study.

Skinner Aquifer Test Report: Presents, describes, and evaluates data from a series of aquifer tests conducted by the MBMG on private land in the Scratchgravel Hills Stock (granite).

BLM Head Lane Aquifer Test Report: Presents, describes, and evaluates data from a series of aquifer tests conducted by the MBMG on BLM land in the Scratchgravel Hills Stock (granite).

BLM West Fault Aquifer Test Report: Presents, describes, and evaluates data from an aquifer test conducted by the MBMG on BLM land that evaluated the hydrologic properties of the Silver

Creek Fault. Monitoring wells on the fault's east side were completed in the Empire Formation, and on the fault's west side wells were completed in the Helena Formation.

Hydrographs: Includes a series of hydrographs demonstrating long-term groundwater level changes.

Potentiometric Surface Maps: Includes maps developed to evaluate seasonal changes in the overall Scratchgravel Hills potentiometric surface, and comparisons of current surfaces to surfaces developed by previous studies.

Surface Water–Groundwater Interactions: Includes surface-water and groundwater elevation and temperature graphs for several sites along Silver and Sevenmile Creeks.

Water Budget: Includes a detailed evaluation of the groundwater budget for the Scratchgravel Hills.

Water Chemistry: Provides supplemental details of water chemistry results.

Acknowledgments

We thank the many landowners and residents of the Scratchgravel Hills study area for their interest, and for their permissions to conduct various aspects of the investigation on their properties. Lewis and Clark County Local Water Quality Protection District provided significant assistance by contracting the services of Gary Burton for monthly measuring of water levels in 40 wells, and allowing hydrogeologist James Swierc to contribute to this project. Pat Faber assisted with the collection and collation of previous aquifer test data. Russell Levens and James Beck of the Montana Department of Natural Resources and Conservation contributed substantially by providing comments and direction regarding water rights, surface-water monitoring, Controlled Groundwater Areas, and groundwater modeling efforts.

Richard Berg, Jeff Lonn, Tom Patton, and Gary Icopini from the MBMG provided technical assistance for various aspects of this study. Allison Brown, a Montana Tech student, provided assistance in field and office aspects.

The Tenmile Creek and Lake Helena watershed groups provided opportunities for our program to discuss the study, and for improving our understanding of local issues. The Montana Watershed Coordinating Council Groundwater Work Group provided a forum in which to share our plans and activities with hydrologists and geologists from other agencies. The Lewis and Clark County Conservation District provided permissions for stream access. The Helena Valley Irrigation District (HVID) provided permissions for access to the HVID canal and agricultural drains to measure flows and to instrument drains.

SITE LIST

The following table shows those sites that were used for the Scratchgravel Hills study. Data from these sites are stored in GWIC. This includes sites that were periodically monitored, used for aquifer tests, or provided historical data. The table is organized by site type, then by GWIC ID number.

Site uses included:

Transducer: Static groundwater level was measured, and a pressure transducer was installed for the remainder of the study. Data were recorded hourly, and the site was visited periodically (typically monthly) to download the transducer and obtain manual groundwater elevation measurements. These manual measurements were used to evaluate the transducer data and correct for drift.

Monthly GWE: Groundwater levels (depth to water from a designated measuring point) were collected from these sites monthly. The depth to water readings were converted to groundwater elevations based on the surveyed measuring point elevation.

Water Quality: Sites sampled for water quality. Analytical results, depending on site, may have included major ions, metals, nutrients, oxygen isotopes of water, hydrogen isotopes of water, sulfur isotopes of sulfate, nitrogen isotopes of nitrate, oxygen isotopes of nitrate, and/or radon.

Surface Water: Surface-water sites where the MBMG or others made discharge measurements, stage readings, continuous stage readings (digital logger), and temperature readings.

Spring: Monitoring typically included monthly measurements of flow, pH, temperature, and specific conductance (SC).

Aquifer Test: A site that participated in at least one aquifer test. Transducers were installed before the start of the test (to collect background data), and manual water-level measurements were done during and after the test to evaluate the transducer data.

Historical: Historical data such as lithologic descriptions or water levels were used from these sites.

Site types included:

Stream: A surface-water site located on a naturally occurring moving body of water. A staff gauge and stilling well were typically installed.

Crest Gauge: A surface-water site located on a naturally occurring ephemeral drainage. A crest gauge (indicating the highest stage experienced between visits) was installed.

Canal: A surface-water site located on a man-made channel used to conduct water to irrigated fields.

Drain: A surface-water site located on a man-made channel used to conduct water away from irrigated fields. In the Helena Valley the drains have been dug deep enough to intersect shallow groundwater and prevent water logging of fields. Water logging became a problem with increased irrigation in the valley due to the recharge of groundwater from canal leakage and excess water applied to fields (variously called irrigation recharge, incidental recharge, or leaching fraction).

Spring: Developed springs where flow and water quality were measured at discharge pipes.

Well: Domestic or monitoring wells that are completed in various Scratchgravel Hills aquifers.

Scratchgravel Site List

		Use												
GWIC ID	Site Name	Transducer	Monthly GWE	Water Quality	Surface Water	Spring	Aquifer Test	Historical	Installed for this study	Lat	Lon	Geomethod	Altitude	Type
254993	SILVER CREEK_SC-SW3 * SC-SW3				X				X	46.7019232	-112.0920440	SUR-GPS	3954.58	STREAM
254994	SILVER CREEK; SW-SC1			X	X				X	46.7002856	-112.1077221	SUR-GPS	4022.42	STREAM
255000	SEVENMILE CREEK * 7M-SW1			X	X				X	46.6495686	-112.1218299	SUR-GPS	4080.97	STREAM
255001	SILVER CREEK; SC-2 * SC-SW2			X	X				X	46.7044776	-112.0763440	SUR-GPS	3888.94	STREAM
255059	TENMILE AT GREEN MEADOWS * 10M-SW1			X	X				X	46.631808	-112.046985	NAV-GPS	3815	STREAM
257316	TENMILE CREEK AT MCHUGH LANE			X	X				X	46.63397	-112.03163	MAP	3790	STREAM
260287	SEVENMILE - HEAD LANE (7M-SW2)				X				X	46.636881	-112.084333	SUR-GPS	3925.71	STREAM
254995	THREE MILE CREEK * 3M-CG1				X				X	46.698688	-112.176617	NAV-GPS	4412	CREST GAUGE
257661	BLM/HEAD LANE CREST GAGE				X				X	46.667834	-112.095758	NAV-GPS	4340	CREST GAUGE
257662	IOWA GULCH CREST GAGE				X				X	46.688411	-112.112518	NAV-GPS	4200	CREST GAUGE
255321	SUNNY VISTA DITCH * SVD				X				X	46.648780	-112.119869	SUR-GPS	4077.58	CANAL
256972	HVID-1 (MCHUGH LN)			X	X				X	46.63437	-112.03322	MAP	3790	CANAL
256973	HVID-2 (JOHN G MINE RD)				X				X	46.68979	-112.04617	MAP	3787	CANAL
255052	HVID D-2-2.3-1 (DA)			X	X				X	46.703765	-111.999963	SUR-GPS	3704.08	DRAIN
255069	HVID D-2-2.3-2L (DC)			X	X				X	46.689623	-112.000095	SUR-GPS	3686.18	DRAIN
255071	HVID D-2-0.7-1 (DD)			X	X				X	46.693193	-111.978974	SUR-GPS	3660.59	DRAIN
255072	HVID D-1_UPPER (DE)			X	X				X	46.704672	-111.973009	SUR-GPS	3664.49	DRAIN
255074	HVID D-0 ARMSTRONG (DG)			X	X				X	46.705889	-111.957346	SUR-GPS	3665.10	DRAIN
254439	JENSE, FRED AND PAT					X			X	46.653202	-112.086367	NAV-GPS	4085	SPRING
254441	STEAD, KAREN					X			X	46.659054	-112.089406	NAV-GPS	4165	SPRING
254446	ZOOK, DARRELL					X			X	46.661297	-112.091274	NAV-GPS	4210	SPRING
254450	GRAY, MARK					X			X	46.667697	-112.095551	NAV-GPS	4335	SPRING
254452	BLM - BIRDSEYE SPRING					X			X	46.683436	-112.104735	NAV-GPS	4350	SPRING
254453	BLM - HIDDEN SPRING					X			X	46.685988	-112.109530	NAV-GPS	4260	SPRING
254455	BLM - IOWA GULCH SPRING					X			X	46.687035	-112.111997	NAV-GPS	4230	SPRING
5581	HOFF * HELENA MT							X		46.6583	-112.0208	MAP	3734	WELL
5585	JAKOVAC TONY * HELENA MT							X		46.6588	-112.0308	MAP	3739	WELL
5589	PHELPS ROY * HELENA MT							X		46.6536	-112.0275	MAP	3749	WELL
5590	SPEER ELMER * HELENA MT							X		46.6530	-112.0025	MAP	3760	WELL
5592	USGS RESEARCH WELL * FORESTVALE WEST							X		46.6525	-112.0272	MAP	3746.9	WELL
5597	USGS RESEARCH WELL * FORESTVALE EAST							X		46.6525	-112.0269	MAP	3746.9	WELL
5599								X		46.6461	-112.0233	MAP	3758	WELL
5600	PAUL'S * HELENA MT							X		46.6447	-112.0225	MAP	3759	WELL
5601	MOREHOUSE GARY * HELENA MT							X		46.6402	-112.0133	MAP	3778	WELL
5602	WILKINS JOHN * HELENA MT							X		46.6416	-112.0230	MAP	3767	WELL
5603								X		46.6455	-112.0316	MAP	3768	WELL
5609	MCHUGH LAND AND LIVESTOCK CO							X		46.6347	-112.0205	MAP	3787	WELL
5743	TINKLEBURG DAVE * HELENA MT							X		46.6602	-112.0455	MAP	3748	WELL
5744	SCRATCHGRAVEL LANDFILL * 2 MI S HELENA MT							X		46.6463	-112.0550	MAP	3865	WELL
5745	TILTON DENNIS * HELENA MT							X		46.6527	-112.0433	MAP	3765	WELL
5746	BYFORD VIRGIL * HELENA MT							X		46.6527	-112.0447	MAP	3765	WELL
5747	RACICOT MARC							X		46.6513	-112.0477	MAP	3779	WELL
5748	WESTERN HILLS SUB. * 2 MI S HELENA							X		46.648096	-112.049125	SURVEY	3802	WELL
5749	GREEN MEADOW ANIMAL CLINIC * 2 MI S HELENA							X		46.6466	-112.0472	MAP	3830	WELL
5752	USGS RES. WELL * .5 MI NE VET HOSPITAL *							X		46.6316	-112.0850	MAP	3915	WELL
5756	MEEK JOSEPH							X		46.643954	-112.046558	SURVEY	3791	WELL
5757	RIPPENGALE JUDY *							X		46.645437	-112.047932	SURVEY	3810	WELL
5758	RANIERI, LARRY		X							46.6421960	-112.0495720	SUR-GPS	3810.80	WELL
5760	MAYNARD BOB * 2.5 MILES SOUTH HELENA							X		46.6411	-112.0513	MAP	3820	WELL
5764	USGS RES WELL * 3 MI NE VET ADM CENTER							X		46.6391	-112.0469	MAP	3800	WELL
5766	FERGUSON *							X		46.6425	-112.0552	MAP	3841	WELL
5767	MRS. NETTLETON * 2.5 MI SOUTH HELENA							X		46.6458	-112.0580	MAP	3885	WELL
5768	HAAS JOHN *							X		46.6436	-112.0586	MAP	3870	WELL
5770	USGS RES WELL * 2.5 MI NE VET ADM CENTER							X		46.6355	-112.0533	MAP	3830	WELL
5774	SCHMIDT RUDY * HELENA MT							X		46.6363	-112.0508	MAP	3822	WELL

GWIC ID	Site Name	Use							Installed for this study	Lat	Lon	Geomethod	Altitude	Type
		Transducer	Monthly GWE	Water Quality	Surface Water	Spring	Aquifer Test	Historical						
5775	ALLEN MADGE * HELENA MT							X		46.6269	-112.0469	MAP	3822	WELL
5776	PAYNTER BOB * HELENA MT							X		46.6186	-112.0480	MAP	3856	WELL
5866	USGS RES WELL * 6 MI NE VET ADM CENTER							X		46.6894	-112.0313	MAP	3750	WELL
5868	DECREVEL J. L. * HELENA MT							X		46.6894	-112.0413	MAP	3770	WELL
5869	APPLEGATE CLARENCE							X		46.6808	-112.0411	MAP	3750	WELL
5870	UNNAMED SITE * HELENA VALLEY							X		46.6802	-112.0211	MAP	3721	WELL
5873	USGS RES. WELL *							X		46.6691	-112.0211	MAP	3715	WELL
5879	USGS RES. WELL *							X		46.6805	-112.0211	MAP	3715	WELL
5885	OSBORNE ELMER * HELENA MT							X		46.6797	-112.2133	MAP	3730	WELL
5888	USGS RES. WELL * .25 MI S HELENA MT.							X		46.6677	-112.0236	MAP	3715	WELL
5893	UNNAMED SITE * HELENA VALLEY							X		46.6652	-112.0211	MAP	3718	WELL
5897	HELLER MICHAEL L.							X		46.6638	-112.0213	MAP	3722	WELL
61368	BROWNE, SUSAN AND TERRY		X	X						46.6442441	-112.0296648	SUR-GPS	3766.54	WELL
62350	PEARSON THOMAS							X		46.646420	-112.047911	SURVEY	3835	WELL
62369	ELLIOT JIM	X	X	X						46.6524045	-112.0795444	SUR-GPS	4052.88	WELL
62385	WOODEN GILBERT	X	X							46.6593527	-112.0942661	SUR-GPS	4193.35	WELL
62406	BREWER, RICHARD		X							46.6501093	-112.1202709	SUR-GPS	4102.05	WELL
62471	BAUM ED			X						46.636550	-112.066103	TRS-SEC	3870	WELL
62523	WALKER, GILES E.	X	X	X						46.6330207	-112.0619270	SUR-GPS	3853.03	WELL
62571	GILMORE CAROL AND GARY * EAST							X		46.6236	-112.0477	MAP	3835	WELL
62575	GILMORE CAROL AND GARY * WEST							X		46.6236	-112.0477	MAP	3832	WELL
62593	ODD FELLOWS HOME * WELL #2							X		46.63064	-112.08046	TRS-SEC	3905	WELL
62594	ODD FELLOWS HOME * WELL #1							X		46.63064	-112.08046	TRS-SEC	3905	WELL
65088	HELM, SCOTT		X	X						46.6661126	-112.0194995	SUR-GPS	3714.33	WELL
65315	SMELKO DANIEL B							X		46.7055460	-112.0795844	SUR-GPS	3905.10	WELL
65316	SMELKO, DANIEL B.	X	X	X						46.7045986	-112.0771691	SUR-GPS	3897.52	WELL
65346	MURPHY TERRY J.							X		46.7005	-112.1455	UNKNOWN	4450	WELL
65348	ESCHENBURG BETTY G							X		46.6916	-112.1352	UNKNOWN	4390	WELL
65352	LYNDES JEFF		X							46.6981541	-112.1020285	SUR-GPS	4007.54	WELL
65422	MOOTS JOHN A AND LINDA M		X							46.7008055	-112.0497409	SUR-GPS	3815.41	WELL
65536	SELVA ADOLFO	X	X	X						46.6854243	-112.0712195	SUR-GPS	4092.01	WELL
65541	LINDGREN ROBERT		X	X						46.6747944	-112.1435158	SUR-GPS	4376.11	WELL
65554	ROSS THOMAS							X		46.6833	-112.1569	UNKNOWN	4550	WELL
65615	SHIELDS, RONALD	X	X	X						46.6628530	-112.0935292	SUR-GPS	4244.51	WELL
65618	NORRIS, JOSEPH * SOUTH WELL		X	X						46.6627843	-112.0803525	SUR-GPS	4253.90	WELL
65696	EICHHORN, SCOTT * WEST WELL		X							46.6911696	-112.1785039	SUR-GPS	4575.25	WELL
87539	CRUM, GERALD		X							46.6521376	-112.0678825	SUR-GPS	4009.21	WELL
120893	L AND C COUNTY LAGOONS * FT HARRISON							X		46.6366	-112.0850	MAP	3930	WELL
121040	WALKER GILES							X		46.6330975	-112.0619057	SUR-GPS	3854.27	WELL
121041	RANIERI BOBBI							X		46.6425	-112.0477	MAP	3820	WELL
121146	FLATT							X		46.6808	-112.0252	MAP	3725	WELL
123610	BODNER, JOE		X							46.6680995	-112.1316145	SUR-GPS	4330	WELL
123839	WINDLE COLE & JUDY		X							46.6311822	-112.1007802	SUR-GPS	3974.31	WELL
131355	HUGHS DOUG		X							46.6627873	-112.1201589	SUR-GPS	4254.34	WELL
135317	NEAL CHUCK	X	X	X						46.6865489	-112.1195377	SUR-GPS	4223.22	WELL
137209	WHITESITT ANDY		X							46.6379080	-112.2460655	SUR-GPS	4791.39	WELL
140662	EPSTEIN SUSAN & SHROPSHIRE SPENSER		X							46.6471690	-112.0894887	SUR-GPS	4027.92	WELL
147130	WESTFALL JEFF		X							46.6545180	-112.2162663	SUR-GPS	4608.67	WELL
147289	WALL JOHN		X	X						46.6636601	-112.0491683	SUR-GPS	3758.77	WELL
155613	MURRAY MAURICE		X							46.7079498	-112.2066564	SUR-GPS	4753.24	WELL
165013	THOMAS CRUSE MINING & DEVELOPMENT * 2							X		46.6402484	-112.0685255	SUR-GPS	3898.05	WELL
165015	THOMAS CRUSE MINING & DEVELOPMENT #3	X	X							46.6404059	-112.0715796	SUR-GPS	3917.17	WELL
189417	MOOTS JOHN		X							46.7007064	-112.0497670	SUR-GPS	3815.51	WELL
191539	LCWQPD - HORSESHOE BEND ROAD		X							46.6239350	-112.0488323	NAV-GPS	3860	WELL
191552	LCWQPD - APPLEGATE AND NORRIS SOUTH WELL							X		46.675300	-112.041800	NAV-GPS	3735	WELL

GWIC ID	Site Name	Use: Transducer	Use: Monthly GWE	Use: Water Quality	Use: Surface Water	Use: Spring	Use: Aquifer Test	Use: Historical	Installed for this study	Lat	Lon	Geomethod	Altitude	Type
191555	LCWQPD - APPLEGATE AND NORRIS NORTH WELL	X	X	X						46.6752360	-112.0426011	SUR-GPS	3736.68	WELL
191557	LCWQPD - HEAD LANE WELL		X							46.6306825	-112.0843906	SUR-GPS	3916.27	WELL
193809	KERSHAW BRUCE	X								46.674696	-112.110060	NAV-GPS	4445	WELL
198414	HIGGINS FLORAN C		X							46.6567725	-112.1293232	SUR-GPS	4137.35	WELL
199976	SKINNER ANDY							X		46.647281	-112.043593	NAV-GPS	3780	WELL
199999	OBERST, GEORGE AND JUDITH							X		46.702904	-112.124599	NAV-GPS	4180	WELL
217191	RELLER, MARK AND ROXA							X		46.686378	-112.149017	NAV-GPS	4690	WELL
224335	CORNERSTONE VILLAGE C/O DBEC CONSULTING	X	X							46.6392674	-112.0831276	SUR-GPS	3965.87	WELL
227906	STEVENS, JERRY		X	X						46.7015786	-112.1092621	SUR-GPS	4030.25	WELL
228212	PERLINSKI, JEREMY		X							46.6811124	-112.0554389	SUR-GPS	3823.66	WELL
232194	SMITH JAMES E. & DIANNA M.			X						46.689310	-112.149076	NAV-GPS	4724.95	WELL
237166	LEVIN GORDON G AND HENSLEY JUDITH A							X		46.662109	-112.055709	NAV-GPS	3930	WELL
237167	SMELKO, DAN	X	X							46.7046599	-112.0765438	SUR-GPS	3896.04	WELL
239912	SKINNER ANDY & CAROL (WEST WELL)	X	X				X			46.6487044	-112.0834169	SUR-GPS	4031.95	WELL
239913	SKINNER ANDY & CAROL (EAST WELL)	X	X				X			46.6486855	-112.0821219	SUR-GPS	4026.52	WELL
246101	SMELKO, DAN * EAST IRR WELL		X							46.7055738	-112.0747729	SUR-GPS	3896.46	WELL
248640	FORT HARRISON - MW-04		X							46.6244563	-112.1071554	SUR-GPS	4013.81	WELL
254216	MBMG - UPPER SILVER CREEK (MW-SC1)	X	X						X	46.7002911	-112.1076760	SUR-GPS	4024.3	WELL
254227	MBMG - LOWER SILVER CREEK - SHALLOW (MW-SC2A)	X	X						X	46.7045114	-112.0763347	SUR-GPS	3895.44	WELL
254237	MBMG - LOWER SILVER CREEK - DEEP (MW-SC2B)	X	X						X	46.7045082	-112.0763241	SUR-GPS	3895.41	WELL
254242	MBMG - MIDDLE SILVER CREEK (MW-SC3)	X	X						X	46.7019067	-112.0920183	SUR-GPS	3958.23	WELL
254247	SMITH SOUTH WELL	X	X							46.6888170	-112.1503143	SUR-GPS	4716.13	WELL
254301	THOMAS PEARSON (UNUSED)							X		46.646857	-112.050437	SUR-GPS	3820	WELL
254302	THOMAS PEARSON (CORRAL)							X		46.645871	-112.048704	SURVEY	3837	WELL
254304	THOMAS RIPPENGALE (UNUSED)							X		46.644870	-112.047959	SURVEY	3801	WELL
254305	LEWIS AND CLARK CO. (LC-01)							X		46.642318	-112.043683	SURVEY	3880	WELL
254306	LEWIS AND CLARK CO. (LC-05)							X		46.644490	-112.050855	SURVEY	3823	WELL
254307	LEWIS AND CLARK CO. (LC-06)							X		46.645610	-112.050632	SURVEY	3825	WELL
254308	LEWIS AND CLARK CO. (LC-08)							X		46.644773	-112.048877	SURVEY	3811	WELL
254309	SKINNER, ANDY	X	X							46.6491086	-112.0461766	SUR-GPS	3778.07	WELL
254310	LEWIS AND CLARK CO. (LC-10)							X		46.645616	-112.052097	SURVEY	3839	WELL
254391	HOFLAND, JOHN AND MISTI							X		46.68752	-112.05980	TRS-SEC	3880	WELL
254573	NORRIS, JOSEPH * NORTH WELL							X		46.6628698	-112.0803736	SUR-GPS	4255.03	WELL
254574	SMELKO, DAN							X		46.704441	-112.077004	NAV-GPS	3896	WELL
254576	WAMPLER, TODD							X		46.660716	-112.064185	NAV-GPS	4130	WELL
254703	JOSHUA DONAIK		X	X						46.6860269	-112.0614987	SUR-GPS	3899.13	WELL
254740	EICHHORN, SCOTT * EAST WELL		X	X						46.6912584	-112.1778390	SUR-GPS	4571.84	WELL
254811	GEORGE OBERST IRRIGATION WELL							X		46.701523	-112.123811	NAV-GPS	4150	WELL
254948	BADOVINAC, PATRICK		X							46.6979376	-112.1462008	SUR-GPS	4386	WELL
255141	MBMG - SEVENMILE (7M-MW1)	X	X						X	46.6495920	-112.1218088	SUR-GPS	4088.01	WELL
255143	MBMG - SEVENMILE (7M-MW2)	X	X						X	46.6367329	-112.0843053	SUR-GPS	3930.19	WELL
256998	MBMG - SK2 (WEST) * SKINNER						X		X	46.6467686	-112.0834964	SUR-GPS	4012.99	WELL
256999	MBMG - SK1 (EAST) * SKINNER						X		X	46.6468134	-112.0820975	SUR-GPS	4008.62	WELL
257063	MBMG APPLEGATE & NORRIS	X	X	X					X	46.6753038	-112.0425936	SUR-GPS	3737.36	WELL
257312	MBMG-BLM-HL1						X		X	46.6738521	-112.0997453	SUR-GPS	4536.71	WELL
257314	MBMG-BLM-HL2	X	X				X		X	46.6741393	-112.0995922	SUR-GPS	4544.70	WELL
257369	MBMG-BLM-S.27	X	X						X	46.6781300	-112.0982336	SUR-GPS	4605.84	WELL
257370	MBMG-BLM-WF2						X		X	46.6774301	-112.1230996	SUR-GPS	4484.21	WELL
257560	MBMG-BLM-WF1	X	X				X		X	46.6775480	-112.1227940	SUR-GPS	4481.45	WELL
257561	MBMG-BLM-WF3						X		X	46.6773461	-112.1236658	SUR-GPS	4485.05	WELL
257562	MBMG-BLM-WF4	X	X				X		X	46.6772679	-112.1238795	SUR-GPS	4484.35	WELL
258347	ZOOK DARRELL & CARINA			X						46.660809	-112.089183	TRS-SEC		WELL
706001	CLARK, DONALD		X	X						46.6498847	-112.0850372	SUR-GPS	4048.60	WELL
706014	CHAPMAN, KELLY		X	X						46.6485809	-112.1039605	SUR-GPS	4119.31	WELL
706019	DANZER MIKE							X		46.6575	-112.0777	UNKNOWN	4160	WELL

		Use												
GWIC ID	Site Name	Transducer	Monthly GWE	Water Quality	Surface Water	Spring	Aquifer Test	Historical	Installed for this study	Lat	Lon	Geomethod	Altitude	Type
706020	RAMSEY JS							X		46.6500	-112.0897	UNKNOWN	4060	WELL
706021	DECKER, GEORGE		X							46.6521530	-112.0847770	SUR-GPS	4067.60	WELL
706022	HELLHAKE							X		46.6513	-112.0930	UNKNOWN	4156	WELL
706024	ANDERSON HOWARD		X							46.6523122	-112.0772471	SUR-GPS	4054.24	WELL
706025	MAHONEY							X		46.6547	-112.0872	UNKNOWN	4110	WELL
706028	PATTON, JEFF		X							46.6488140	-112.0932738	SUR-GPS	4075.67	WELL
706031	COX DAN & SUSIE							X		46.6702	-112.1425	UNKNOWN	4315	WELL
706039	WARFORD, CAROL		X	X						46.6748499	-112.1405408	SUR-GPS	4388	WELL
706044	BREWER, FRANK II		X							46.6955249	-112.1652120	SUR-GPS	4467.72	WELL
706046	WAMPLER, TODD		X							46.661061	-112.063312	NAV-GPS	4130	WELL
706055	MAULORICO AL		X	X						46.6667323	-112.0889736	SUR-GPS	4361.99	WELL
706058	FOWLER, SANDRA		X	X						46.6457164	-112.0775182	SUR-GPS	3982.47	WELL
890557	SWAN DAVID							X		46.6816	-112.0275	MAP	3728	WELL
890558	HALL, MARY LYNN							X		46.6816	-112.0266	MAP	3726	WELL
890559	ROSENBAUM KEN							X		46.6825	-112.0297	MAP	3732	WELL
890560	PAUL JACK							X		46.6805	-112.0291	MAP	3728	WELL
890562	KALLESTAD KIM							X		46.6794	-112.0247	MAP	3723	WELL
890563	ROBUCK HELEN							X		46.6797	-112.0244	MAP	3722	WELL
890564	GOODSELL HAL							X		46.6791	-112.0283	MAP	3727	WELL
890565	ZIMMERMAN STEVE							X		46.6783	-112.0263	MAP	3725	WELL
890566	GREANY JIM							X		46.6661	-112.0194	MAP	3714	WELL
890587	BRIDGES JIM							X		46.6177	-112.0497	MAP	3850	WELL
890588	GARDNER RUTH							X		46.6177	-112.0500	MAP	3850	WELL
890590	LIGHTNER NORMAN * HELENA MT							X		46.6171	-112.0496	TRS-SEC	3870	WELL
890591	MILLIRON EUGENE							X		46.6183	-112.0469	MAP	3860	WELL
890592	FLAMM VINCENT							X		46.6177	-112.0469	MAP	3860	WELL
890593	BILLINGTON JERRY							X		46.6189	-112.0483	TRS-SEC	3850	WELL
890594	O'NEAL VIDA							X		46.6180	-112.0477	MAP	3860	WELL
890595	O'NEAL VIDA							X		46.6180	-112.0477	MAP	3860	WELL
892195	USGS * MILL ROAD		X							46.6458651	-112.0159111	SUR-GPS	3746.26	WELL

SUMMARY OF AQUIFER TESTS

Aquifer test results were obtained from several area aquifers. From youngest to oldest, these aquifers are:

(1) the Helena Valley aquifer;

(2) the Tertiary aquifer;

(3) the Granite aquifer;

(4) the Metagabbro aquifer;

(5) the Helena Formation (carbonate); and

(6) the Argillite aquifer (Greyson and Spokane Formations).

The Helena Valley aquifer and the Tertiary aquifer are in unconsolidated materials. The rest of the aquifers are in consolidated bedrock. For some aquifer tests, the aquifer being tested was not clearly defined. These tests are included in table AQ1; however, they are not included in the summary statistics (tables AQ2 and AQ3; fig. AQ1).

Table AQ1 includes results from DNRC groundwater rights applications (DNRC, 2011), from previous hydrogeologic studies (Moreland and others, 1979; Moreland and Leonard, 1980; Briar and Madison, 1992; Thamke, 2000, Stahly, 2008), from aquifer tests recently conducted by the MBMG in the North Hills (Bobst and others, in preparation), and for the Scratchgravel Hills Groundwater Investigation. These data were used to evaluate the likely range of aquifer properties in the Scratchgravel Hills. Where possible, the results of aquifer tests are included in table AQ1; however, in some cases there was not sufficient information to allow inclusion.

Five aquifer tests were completed by the USGS in the late 1970s (Moreland and others, 1979; Moreland and Leonard, 1980). Moreland and Leonard (1980) concluded that "because of lack of knowledge about the lithology and degree of penetration of the aquifer by the well casing and the necessarily short duration of the tests, complete quantitative analysis of the data was not justified." However, Moreland and Leonard (1980) were able to show that the confining layers in the Helena Valley aquifer were not continuous over large distances and that a reasonable estimate of the transmissivity was about 10,000 ft^2/d.

Seven additional aquifer tests were completed by the USGS (Briar and Madison, 1992) in the Helena Valley; however, these tests "…were affected by many of the same problems experienced by previous investigators." Despite the problems, Briar and Madison (1992) concluded that the Helena Valley aquifer transmissivity of about 10,000 ft^2/d developed by Moreland and Leonard (1980) appeared to be reasonable, and that the effective horizontal hydraulic conductivity was about 200 ft/d.

Thamke (2000, p. 54) evaluated aquifer properties in bedrock units near the Helena Valley, and concluded that their hydraulic conductivities would be in the range of 1×10^{-8} to 1 ft/d.

Individual aquifer test evaluations (tables AQ1, AQ2, and AQ3; fig. AQ1) provide further information on the variability of aquifer properties. In general, geometric mean hydraulic conductivity values are lower than mean values, and for any particular hydrogeologic unit values range over about three orders of magnitude. Granite values are more variable and range across four orders of magnitude. The range for gabbro is quite narrow; however, these values are from three closely spaced wells (table AQ1).

The aquifer test results provide an understanding of how aquifer properties vary in each hydrogeologic unit, and provide a first-order estimate of aquifer properties so that the values calculated through inverse modeling can be critically evaluated.

Table AQ1
Results of Aqufier Tests conducted near Helena, MT

GWIC ID	Site	Township/ Range	Section	Lat (DD N)	Long (DD W)	Test Date	Rate (gpm)	Duration (hrs)	Max dh (ft)	T (ft^2/d)	S (unitless)	Analysis Method	Sat Z (ft)	K (ft/d)	Source
Helena Valley Aquifer															
230734	GMCC	T10NR4W	SESE14	46.618221	112.066071	10/3/2006	80	24	12	13300	NC	CJ	91.5	145	DNRC
208453	Frontier	T11NR4W	SWSE13	46.704896	112.047500	10/31/2003	175	24	25	1630	0.01	CJ	114	14	DNRC
209187	Frontier	T11NR4W	SWSE13	46.707404	112.051703	5/19/2004	211	72	34	228	NC	N	108	2.1	DNRC
—	Frontier	T11NR4W	SWSE13	46.706570	112.050354	1/12/2004	40	24	53	108	NC	CJ	108	1.0	DNRC
228861	Lincoln Heights	T11NR4W	SWSE14	46.706185	112.072238	8/4/2006	11	24	22	2580	NC	TR	45	57	DNRC
211564	Bridge Cr	T11NR3W	NESW17	46.710075	112.019138	10/2/2003	33	24	4	1600	NC	TR	24	67	DNRC
204558	Bridge Cr	T11NR3W	NWSW17	46.709402	112.017404	3/21/2003	608	78	20	7870	NC	TR	261	30	DNRC
204557	Bridge Cr	T11NR3W	NWSW17	46.709597	112.017099	4/10/2003	560	24	39	7950	0.002	TR	200	40	DNRC
204558	Bridge Cr	T11NR3W	NWSW17	46.709402	112.017404	7/26/2004	505	72	25	10900	NC	HJ	261	42	DNRC
204554	VF	T11NR3W	NWSW17	46.709699	112.017405	4/14/2003	565	24	15	8590	NC	CJ	200	43	DNRC
207597	Bridge Cr	T11NR3W	SENW17	46.713746	112.013575	10/21/2003	50	24	5	4240	NC	TR	17	249	DNRC
207596	Bridge Cr	T11NR3W	SENW17	46.713746	112.013575	10/8/2003	38	24	9	3990	NC	TR	27	148	DNRC
180982	Fieldstone	T11NR3W	SWNE17	46.709000	112.011102	3/8/2000	900	24	21	15855	NC	TR	176	90	DNRC
180981	Fieldstone	T11NR3W	SWNE17	46.713797	112.003496	11/15/2002	894	72	16	15100	0.008	TR	176	86	DNRC
64824	Ranch View III	T11NR3W	SWNW17	46.714655	112.020518	5/13/1997	600	4	7	52300	0.0008	CJ	76	688	DNRC
204563	Silver Cr Commer	T11NR3W	SWSW17	46.706505	112.020097	4/5/2003	470	24	89	5790	NC	CJ	163	36	DNRC
204564	Silver Cr Commer	T11NR3W	SWSW17	46.706199	112.020109	4/8/2003	540	24	75	6030	NC	CJ	164	37	DNRC
64846	Lone Wolf	T11NR3W	NENE18	46.717379	112.024377	2/7/2000	75	8	1	26700	NC	TR	40	668	DNRC
216639	Polaris	T11NR3W	SENE18	46.714625	112.023069	12/8/2004	108	24	5	33100	NC	TR	63	525	DNRC
237114	Frontier Village	T11NR3W	NESW19	46.694400	112.035158	3/23/2007	953	24	14	19500	0.05	CJ	125	156	DNRC
248761	Libation Station	T11NR3W	NWNW19	46.702721	112.040446	1/13/2009	86	24	3	34800	NC	TR	38	916	DNRC
156462	Applegate	T11NR4W	NESE24	46.695257	112.045604	4/16/1997	175	9	4	75500	NC	TR	94	803	DNRC
—	Rosemary Acres	T11NR4W	SESW24	46.694992	112.056233	5/11/2002	20	24	13	3710	NC	TR	100	37	DNRC
Helena Valley Aquifer or Tertiary Aquifer															
163866	Big Valley 11B2A	T11NR3W	NWSE7	46.724645	112.029340	8/29/2005	29	72	65	1890	NC	TR	90	21	DNRC
223771	North 40	T11NR3W	SWNW7	46.727411	112.033308	6/8/2006	20	24	5	2420	NC	CJ	64	38	DNRC
206648	Big Valley Lot 17	T11NR3W	SWSW7	46.719897	112.037105	8/8/2003	12	24	110	25.5	NC	CJ	202	0.13	DNRC
65293	Lincoln Heights	T11NR4W	SESW14	46.705282	112.073557	8/18/2006	17	24	61	1630	NC	TR	53	31	DNRC
Tertiary Aquifer															
252821	Panoramic Meadows	T11NR3W	NE&SE13	46.709739	111.920398	11/18/2009	38	144	3	15000	0.006	CJ	94	160	MBMG
254311	Panoramic Meadows	T11NR3W	NESE13	46.710220	111.915614	5/23/2006	43	24	13	1410	NC	TR	62	23	DNRC
252835	Panoramic Meadows	T11NR3W	NWNE13	46.716206	111.912510	5/26/2006	12	24	166	17	NC	TR	173	0.10	DNRC
202172	Gable Est	T11NR3W	NWNW13	46.717003	111.933293	3/13/2003	20	24	2	4890	NC	TR	43	114	DNRC
254327	Panoramic Meadows	T11NR3W	NWSE13	46.711474	111.923984	5/30/2006	37	24	66	497	NC	TR	162	3.1	DNRC
195488	Gable Est	T11NR3W	SENE14	46.714375	111.939542	3/14/2003	17	24	2	7190	NC	TR	63	114	DNRC
187343	Gable Est	T11NR3W	SWNE14	46.714109	111.943964	2/13/2001	20	4	2	6920	NC	TR	53	131	DNRC
246771	North Star	T11NR3W	SWNW7	46.728336	112.039899	8/26/2008	30	24	174	34	NC	TR	240	0.14	DNRC
154877	Foothills	T11NR3W	SWSE9	46.720162	111.985067	5/19/2005	27	24	39	477	NC	TR	50	9.5	DNRC
176013	Foothills	T11NR3W	SWSW9	46.721997	111.998364	5/21/2005	30	24	44	413	NC	CJ	50	8.3	DNRC

T = Transmisivity
S = Storativity
Sat Z = Thickness of the saturated aquifer
K = Hydrolic Conductivity

DNRC = Montana Department of Natural Resources and Conservation
NC = Not Calculated
dh = drawdown

CJ = Cooper-Jacob (1946)
N = Neuman (1974)
TR = Theis Recovery (1935)
HJ = Hantush-Jacob (1955)

Table AQ1 (cont.)
Results of Aqufier Tests conducted near Helena, MT

GWIC ID	Site	Township/ Range	Section	Lat (DD N)	Long (DD W)	Test Date	Rate (gpm)	Duration (hrs)	Max dh (ft)	T (ft^2/d)	S (unitless)	Analysis Method	Sat Z (ft)	K (ft/d)	Source
Tertiary Aquifer or Argillite Bedrock Aquifer															
193701	Northern Lights	T11NR3W	NWNW7	46.732476	112.033952	10/9/2001	51	24	14	885	NC	T	135	6.6	DNRC
—	Northern Lights	T11NR3W	NWNW7	46.731876	112.039045	6/14/2004	56	72	12	2370	0.0005	T	135	18	DNRC
—	Hillview	T11NR3W	SWNW6	46.749390	112.037248	5/17/2006	20	24	2	2780	NC	TR	160	17	DNRC
150328	Bandy	T11NR4W	NENW13	46.716353	112.055034	12/3/1999	33	24	46	119	NC	CJ	153	0.78	DNRC
Argillite Bedrock Aquifer															
258597	Helena Valley Fault	T12NR3W	SWNW30	46.759165	112.038187	5/18/2010	100	8	18	1761	NC	CJ	40	44	MBMG
258401	Helena Valley Fault	T12NR3W	SWNW30	46.758694	112.038658	5/20/2010	23	8	48	19	NC	CJ	3	6.3	MBMG
258402	Helena Valley Fault	T12NR3W	SWNW30	46.758930	112.038479	5/24/2010	104	97	83	234	0.00006	CJ	5	47	MBMG
254356	Valley Excavating	T12NR4W	NWNE35	46.761912	112.073418	6/10/2010	14	144	71	350	0.02	CJ	120	3	MBMG
257065	Purcell	T11NR3W	NWSW9	46.723644	111.993675	3/24/2011	16	24	139	70	NC	CJ	280	0.25	MBMG
257066	O'Reilly	T11NR3W	SWNE8	46.729477	112.007506	3/22/2011	46	24	117	200	0.03	H	250	0.80	MBMG
258290	State Lands East	T12NR3W	NWSW30	46.768006	112.035738	4/7/2011	30	48	27	475	0.0011	CJ	150	3.2	MBMG
258454	State Lands West	T12NR4W	SENE28	46.770455	112.106357	4/18/2011	18	48	13	575	NC	CJ	75	7.5	MBMG
159011	Gruber	T10NR4W	SESE10	46.632765	112.087910	12/17/1996	100	1	82	326	NC	D	82	4	Stahley, 2008
137168	Schatz Ranch	T10NR4W	NWNE15	46.630162	112.093799	7/14/1993	135	4	63	573	NC	D	72	8	Stahley, 2008
62588	Hiltabrand	T10NR4W	NW14	46.627420	112.079775	2/16/1984	95	3	43	591	NC	D	66	9	Stahley, 2008
62589	Hiltabrand	T10NR4W	NW14	46.627420	112.079775	6/12/1980	98	1	170	157	NC	D	192	0.82	Stahley, 2008
237817	Cornerstone	T10NR4W	SWNW14	46.625580	112.082516	8/7/2007	520	24	106	1307	0.0006	CJ	110	11.9	Stahley, 2008
237817	Cornerstone	T10NR4W	SWNW14	46.625580	112.082516	11/5/2007	594	72	139	1264	0.0005	TR	110	11.5	Stahley, 2008
240376	Cornerstone	T10NR4W	SWSW14	46.6277	112.0792	10/27/2007	228.5	24	221	179	0.0004	TR	112	1.6	Stahley, 2008
222881	Overlook	T11NR3W	NESE6	46.740212	112.025016	11/25/2005	30	24	2	11100	NC	TR	68	163	DNRC
193704	North Star	T11NR3W	NWSE7	46.721882	112.028019	9/25/2001	110	25	20	1010	NC	CJ	102	9.9	DNRC
193705	North Star	T11NR3W	NWSE7	46.721882	112.028019	2/26/2004	98	72	15	1650	NC	CJ	102	16	DNRC
194427	North Star	T11NR3W	NWSE7	46.723863	112.027235	2/19/2002	65	24	6	1110	NC	T	101	11	DNRC
64642	Southern View	T11NR3W	SWNW5	46.742504	112.018298	9/30/2005	13	24	79	416	NC	TR	60	6.9	DNRC
252485	70North Star	T11NR3W	SWNW7	46.728336	112.039900	9/17/2009	91	24	226	52	NC	TR	470	0.11	DNRC
254487	North Star	T11NR3W	SWNW7	46.723863	112.027235	1/11/2008	56	72	11	1600	0.0006	CJ	431	3.7	DNRC
246772	North Star	T11NR3W	SWNW7	46.728336	112.039900	12/4/2009	84	24	235	43	0.0002	T	470	0.090	DNRC
65152	Welsh Estates	T11NR4W	NENE1	46.746298	112.041297	4/4/2006	12	24	2	875	NC	CJ	103	8.5	DNRC
227178	Welsh Estates	T11NR4W	NENE1	46.747838	112.046139	7/3/2006	27	24	7	1120	NC	CJ	60	19	DNRC
199996	MJM	T11NR4W	NESE1	46.739269	112.044751	9/19/2002	18	24	16	165	NC	CJ	170	0.97	DNRC
166421	Hoovestal	T11NR4W	NWSW14	46.709810	112.082780	4/21/1999	65	6	3	6410	NC	TR	386	17	DNRC
228176	Dee Minor	T11NR4W	SESW2	46.736413	112.078424	8/17/2006	30	24	36	823	NC	TR	130	6.3	DNRC
231833	Belmont View	T12NR5W	SESE36	46.750036	112.172043	1/11/2007	6	24	65	22.8	NC	TR	65	0.35	DNRC
231835	Belmont View	T12NR5W	SWSE36	46.750036	112.177416	6/20/2007	5	24	95	12	NC	TR	95	0.13	DNRC

T = Transmisivity
S = Storativity
Sat Z = Thickness of the saturated aquifer
K = Hydrolic Conductivity

DNRC = Montana Department of Natural Resources and Conservation
NC = Not Calculated
dh = drawdown

CJ = Cooper-Jacob (1946)
T = Theis (1935)
TR = Theis Recovery (1935)
D = Driscoll (1986)

Table AQ1 (cont.)
Results of Aqufier Tests conducted near Helena, MT

GWIC ID	Site	Township/ Range	Section	Lat (DD N)	Long (DD W)	Test Date	Rate (gpm)	Duration (hrs)	Max dh (ft)	T (ft^2/d)	S (unitless)	Analysis Method	Sat Z (ft)	K (ft/d)	Source
Mettagabbro															
193572	Fort Harrison	T10NR4W	SWNE9	46.639694	112.114069	10/19/2004	100	27	31.36	307	0.0011	CJ	114	2.7	DNRC
193573	Fort Harrison	T10NR4W	SWNE9	46.639694	112.114069	7/8/2005	75	73	46	322	0.00067	T	157	2.1	DNRC
193573	Fort Harrison	T10NR4W	SWNE9	46.639694	112.114069	12/21/2005	109	29	45	306	NC	TR	157	1.9	DNRC
Helena Formation															
217220	Ryan Gruber	T11NR4W	NWSW30	46.681445	112.167869	2/4/2006	12	24	2	2750	NC	CJ	139.6	20	DNRC
216659	Stallion Ridge	T11NR4W	NWSW30	46.679480	112.166718	11/8/2004	60	25	17	819	NC	T	385	2.1	DNRC
216661	Stallion Ridge	T11NR4W	NESE30	46.679480	112.151130	11/9/2004	20	25	101	33.2	NC	TR	288	0.12	DNRC
216662	Stallion Ridge	T11NR4W	NENE31	46.672353	112.151098	11/15/2004	15	25	212	8.3	NC	TR	334	0.025	DNRC
217193	Stallion Ridge	T11NR4W	SWNE31	46.679480	112.166718	11/29/2004	37	24	5	1640	NC	TR	139	12	DNRC
Granite Aquifer															
127089	Maykuth	T11NR4W	NENE23	46.701741	112.068439	6/7/2000	15	2	64	13.6	NC	CJ	98	0.14	DNRC
230903	LincolnH	T11NR4W	NENW23	46.702679	112.072398	10/4/2006	17	25	51	66.6	NC	TR	90	0.74	DNRC
158499	Green Meadow Vista	T11NR4W	SWNW24	46.695259	112.062022	7/12/2007	7	26	29	146	NC	TR	100	1.5	DNRC
198164	Lazy JC	T11NR4W	SWSW24	46.690629	112.060656	11/1/2002	25	25	113	71.9	NC	TR	187	0.38	DNRC
131305	Timber Acres II	T11NR4W	SWSW24	46.692481	112.060656	9/21/2005	20	4	7	598	NC	TR	42	14	DNRC
195225	4965 Garnet Rd	T11NR4W	NWSW32	46.665048	112.145872	4/4/2002	12.5	1	75	5.9	NC	CJ	100	0.059	DNRC
120469	Liberty Baptist	T11NR4W	SESE36	46.662085	112.046476	5/28/2007	7.5	24	54	21	NC	CJ	60	0.35	DNRC
224335	Cornerstone	T10NR4W	SWNE11	46.639267	112.083128	7/7/2005	200	24	134	113	NC	TR	282	0.4	Stahley, 2008
62470	Chase	T10NR4W	SE11	46.634729	112.068875	7/1/1978	12	1	198	16.2	NC	D	180	0.09	Stahley, 2008
62469	Voelkol	T10NR4W	SE11	46.634729	112.068875	9/13/1980	15	1	164	24.5	NC	D	65	0.38	Stahley, 2008
202046	Wiseman	T10NR4W	NWSE11	46.635640	112.073034	4/1/2003	18	1	176	27.3	NC	D	136	0.20	Stahley, 2008
184602	Chistison	T10NR4W	SESE11	46.632908	112.066103	6/8/2000	12	1	284	11.3	NC	D	283	0.04	Stahley, 2008
256999	Skinner	T10NR4W	SWSW2	46.646769	112.083496	6/25/2010	54.8	121	62	130	NC	TR	138	0.94	MBMG
256998	Skinner	T10NR4W	SWSW2	46.646813	112.082098	4/13/2011	1.4	0.417	41	0.15	NC	TR	178	9E-04	MBMG
239912	Skinner	T10NR4W	SWSW2	46.648704	112.083417	4/13/2011	1.7	2	3	185	NC	TR	130	1.1	MBMG
239913	Skinner	T10NR4W	SWSW2	46.648686	112.082122	4/13/2011	1.8	2	1	225	NC	TR	205	1.5	MBMG
257312	BLM Head Ln	T11NR4W	NENW34	46.673852	112.099745	8/17/2010	2	14	86	0.75	NC	TR	205	0.004	MBMG
257312	BLM Head Ln	T11NR4W	NENW34	46.673852	112.099745	3/30/2010	0.95	48	85	0.75	NC	TR	205	0.004	MBMG

T = Transmisivity
S = Storativity
Sat Z = Thickness of the saturated aquifer
K = Hydrolic Conductivity

DNRC = Montana Department of Natural Resources and Conservation
MBMG = Montana Bureau of Mines and Geology
NC = Not Calculated
dh = drawdown

CJ = Cooper-Jacob (1946)
T = Theis (1935)
TR = Theis Recovery (1935)
D = Driscoll (1986)

Table AQ2
Statistical Summary of K values from Aquifer Tests by Hydrogeologic Unit

	maximum	minimum	mean	geometric mean	count (n)
Helena Valley	916	1.0	212	75	23
Tertiary	160	0.10	56	10.7	10
Argillite	163	0.090	14	3.9	30
Gabbro	2.7	1.9	2.2	2.2	3
Helena Fm	20	0.025	6.8	1.1	5
Granite	14	0.00088	1.2	0.18	18

Table AQ3
Statistical Summary of S values from Aquifer Tests by Hydrogeologic Unit

	maximum	minimum	mean	count (n)
Helena Valley	0.046	0.00082	0.013	5
Tertiary	0.006	0.00048	0.0032	2
Argillite	0.030	0.00006	0.0059	9
Gabbro	0.0011	0.00067	0.00089	2

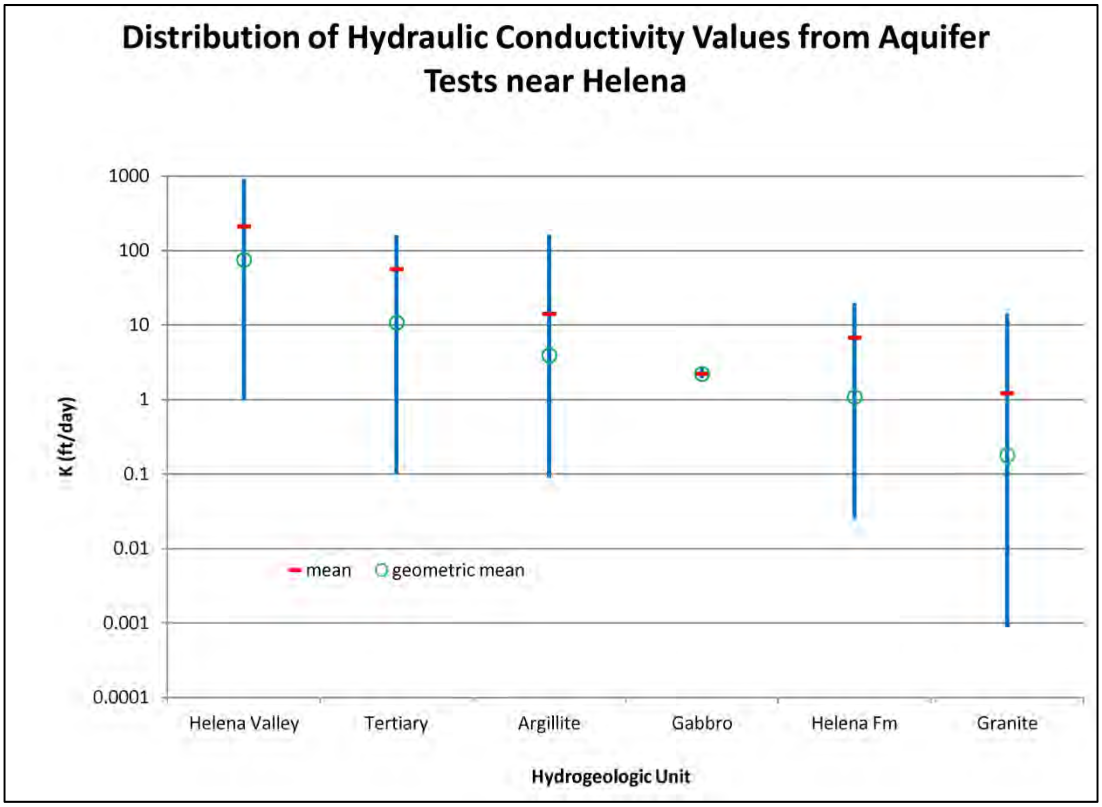


Figure AQ1. Hydraulic conductivity values for each hydrogeologic unit are variable, with the variation covering approximately three orders of magnitude. Values for the gabbro are very uniform; however, all values came from a single site. Values for granite are more variable, covering more than four orders of magnitude.

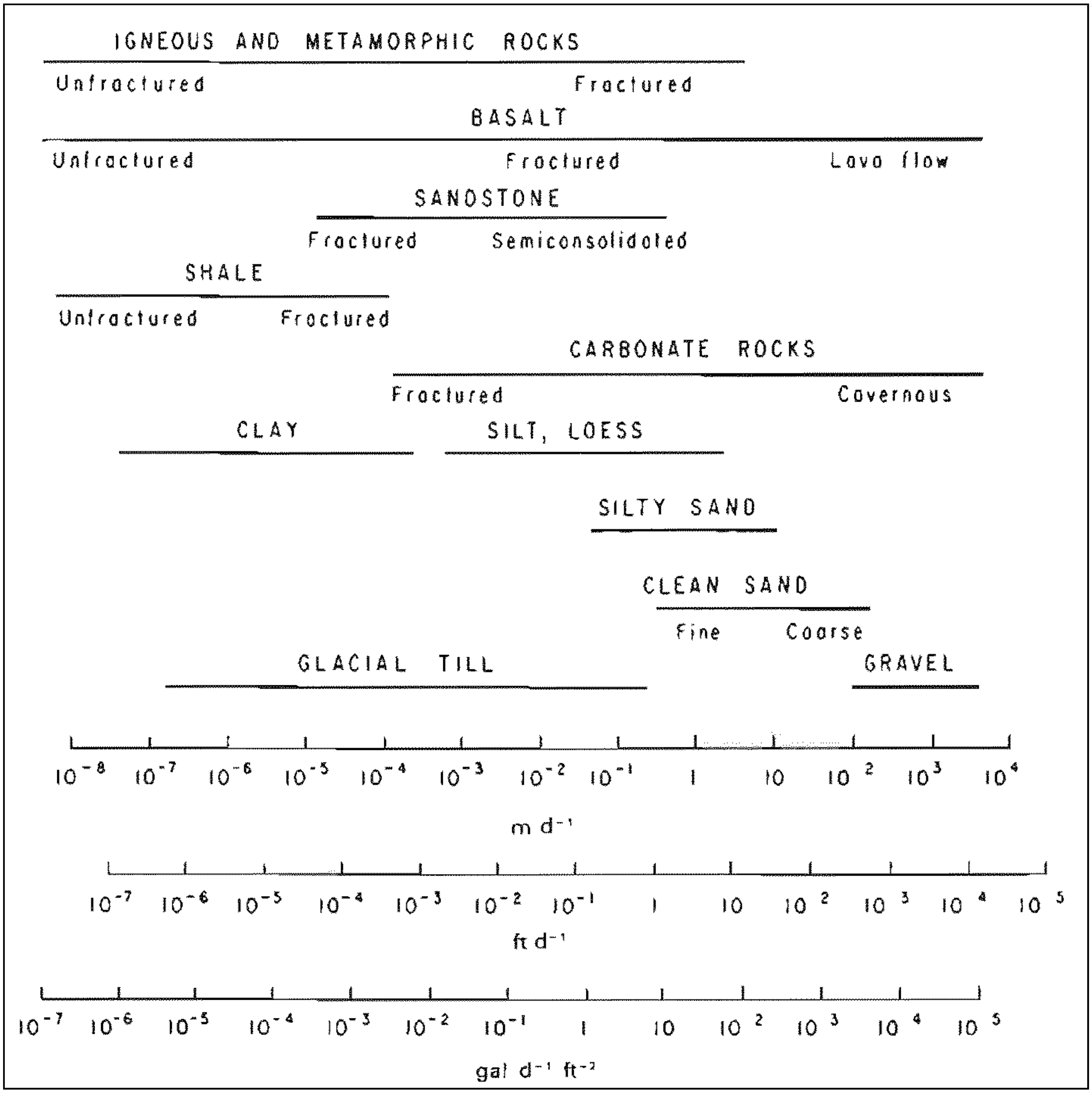


Figure AQ2. Typical hydraulic conductivity values for selected rock and sediment types (from Heath, 1983).

Bobst, A.L., Waren, K.B., Swierc, J.E., and Madison, J.D., in preparation, Hydrogeologic investigation of the North Hills study area, Lewis and Clark County, Montana, Technical Report.

Briar, D.W., and Madison, J.P., 1992, Hydrogeology of the Helena valley-fill aquifer system, west-central Montana: U.S. Geological Survey Water Resources Investigations Report 92-4023, 92 p.

DNRC, 2011, Water Rights Bureau new appropriations rules: Updated October 1, 2011: available online at http://dnrc.mt.gov/AboutUs/publications/RuleBooks/WRD/WRBNewApropRules.pdf (Accessed February 9, 2012).

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 220, 86 p.

Moreland, J.A., Leonard, R.B., Reed, T.E., Clausen, R.O., and Wood, W.A., 1979, Hydrologic data from selected wells in the Helena Valley, Lewis and Clark County, Montana: U.S. Geological Survey Open-File Report 79-1676, 54 p.

Moreland, J.A., and Leonard, R.B., 1980, Evaluation of shallow aquifers in the Helena Valley, Lewis and Clark County, Montana: U.S. Geological Survey Open-File Report 80-1102, 24 p.

Stahly Engineering, 2008, Cornerstone Village public water supply well, DEQ engineering report: Prepared for Helena Christian School Inc.

Thamke, J.N., 2000, Hydrology of the Helena area bedrock, west-central Montana, 1993–98, with a section on geologic setting and a generalized bedrock geologic map: U.S. Geological Survey Water Resources Investigations Report 00-4212, 119 p.

SKINNER AQUIFER TEST—GRANITE

SKINNER AQUIFER TEST RESULTS
GRANITE
SCRATCHGRAVEL HILLS PROJECT AREA
June/July 2010 and April 2011

STEP TEST

121-HOUR (5-DAY) CONSTANT RATE TEST
and
SHORT-TERM WELL TESTS

Background:
The Skinner site is located in the granitic core of the Scratchgravel Hills. The granitic bedrock has essentially no primary permeability, so groundwater flow is through fractures. The following are analyses of a step test and a 121-h (5-d) constant rate pumping test, conducted in June and July 2010. Also included is analysis of several short tests of three wells conducted in April 2011. The Skinner property is located northeast of the intersection between Franklin Mine Road and Head Lane. There are no homes on this parcel; the nearest home is approximately 450 ft east of the pumping well (SK1). The Sunny Vista irrigation ditch is located on the site's northern edge, approximately 750 ft north of SK1. The ditch was flowing for part of the 5-d (121-h) test, and its effects can be seen in the hydrographs.

These tests were designed to evaluate aquifer transmissivity (T), hydraulic conductivity (K), storativity, and anisotropy. Two 4-in-diameter wells (SK1 and SK2; GWIC IDs 256999 and 256998, respectively) were installed in early June 2010. A MBMG hydrogeologist was present for the installation and verified completion details. For every 10 ft of borehole, samples of cuttings were composited, described, and retained for long-term storage at the MBMG. In 2007, two earlier wells were installed on this parcel; for the purposes of this report these are named Skinner East (SKE; GWIC ID 239913) and Skinner West (SKW; GWIC ID 239912). The DNRC has monitored water levels in these wells for several years. The GWIC ID numbers provide access to well logs and all measured groundwater levels in the MBMG's GWIC database (http://mbmggwic.mtech.edu; table SK1).

In June 2010, transducers were deployed in all four wells for the duration of the aquifer tests. Sufficient drawdown to allow analysis of aquifer properties was only recorded in the pumping well (SK1). Discernible drawdown was not detected in observation wells SK2, SKE, or SKW.

In order to determine aquifer hydraulic conductivities from wells SK2, SKE, and SKW, short 2-h (or until the water level fell to near the pump) constant rate tests were conducted on each well in April 2011.

Location:
The test area is located in the Scratchgravel Hills northeast of the junction of Franklin Mine Road and Head Lane in Township 10 N., Range 4 W., section 2, W½ SW¼ SW¼, in Lewis and Clark County, Montana (figs. SK1, SK2).

Geology:
The aquifer tested is the Cretaceous intrusive Scratchgravel Hills Stock. This unit is described by Reynolds (2000) as "quartz monzonite and monzonite." This is a felsic coarse-grained igneous rock, and is generally described as "granite." There are no known faults in the immediate vicinity of the test site. The northwest–southeast Bald Butte fault zone is located approximately 1.3 miles to the southwest (fig. SK3).

Table SK1

Well Designations, Locations, and Completion Information

Skinner Aquifer Test—June/July 2010

GWIC ID	Name	Latitude*	Longitude*	Measuring Point Elevation+ (ft-amsl)	Total Depth (ft below MP)	Depth to Water 6/24/10 (ft below MP)	Groundwater Elevation 6/9/10 (ft-amsl)	Distance from SK1 (ft)	Comments
256999	SK1	46.6468134	-112.0820975	4010.14	160	22.42	3987.72	—	Pumping well
256998	SK2	46.6467686	-112.0834964	4014.50	183	5.48	4009.02	351	Observation well
239912	SKW	46.6487044	-112.0834169	4033.57	144	13.61	4019.96	766	Observation well
239913	SKE	46.6486855	-112.0821219	4028.24	224	18.79	4009.45	683	Observation well

Note. ft-amsl, feet above mean sea level; ft below MP, feet below measuring point. All locations and elevations determined by a licensed surveyor.

*Horizontal Datum is NAD83.

+Vertical Datum is NAVD88.

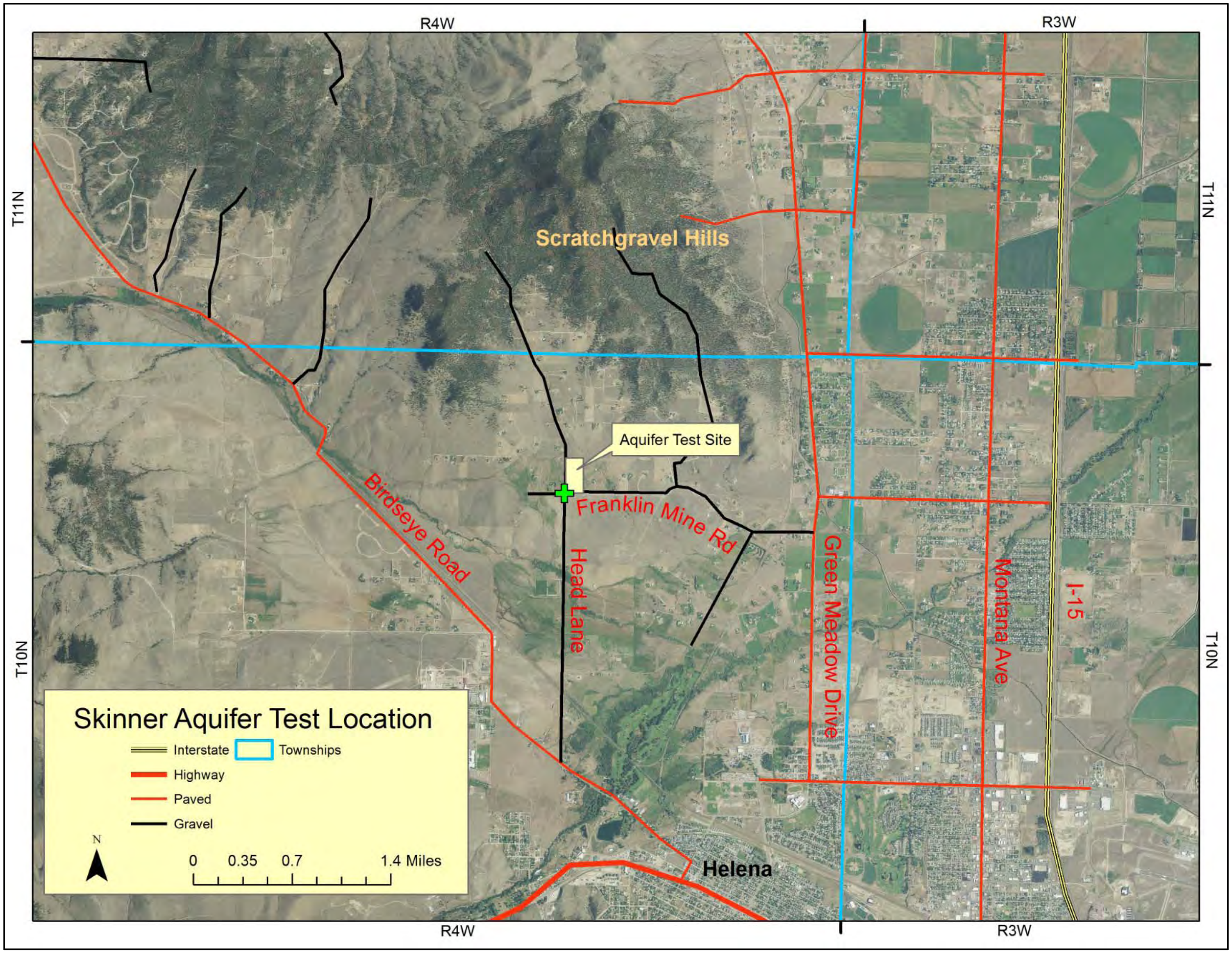


Figure SK1. Location of the Skinner Aquifer Test site, June and July 2010. The junction of Head Lane and Franklin Mine Road (green cross) is at 46.645228°N latitude and 112.084763°W longitude.

Figure SK2. Site layout for the Skinner Aquifer Test site, June and July 2010. The site is in T. 10 N., R. 4 W., sec. 2, W½ SW¼ SW¼.

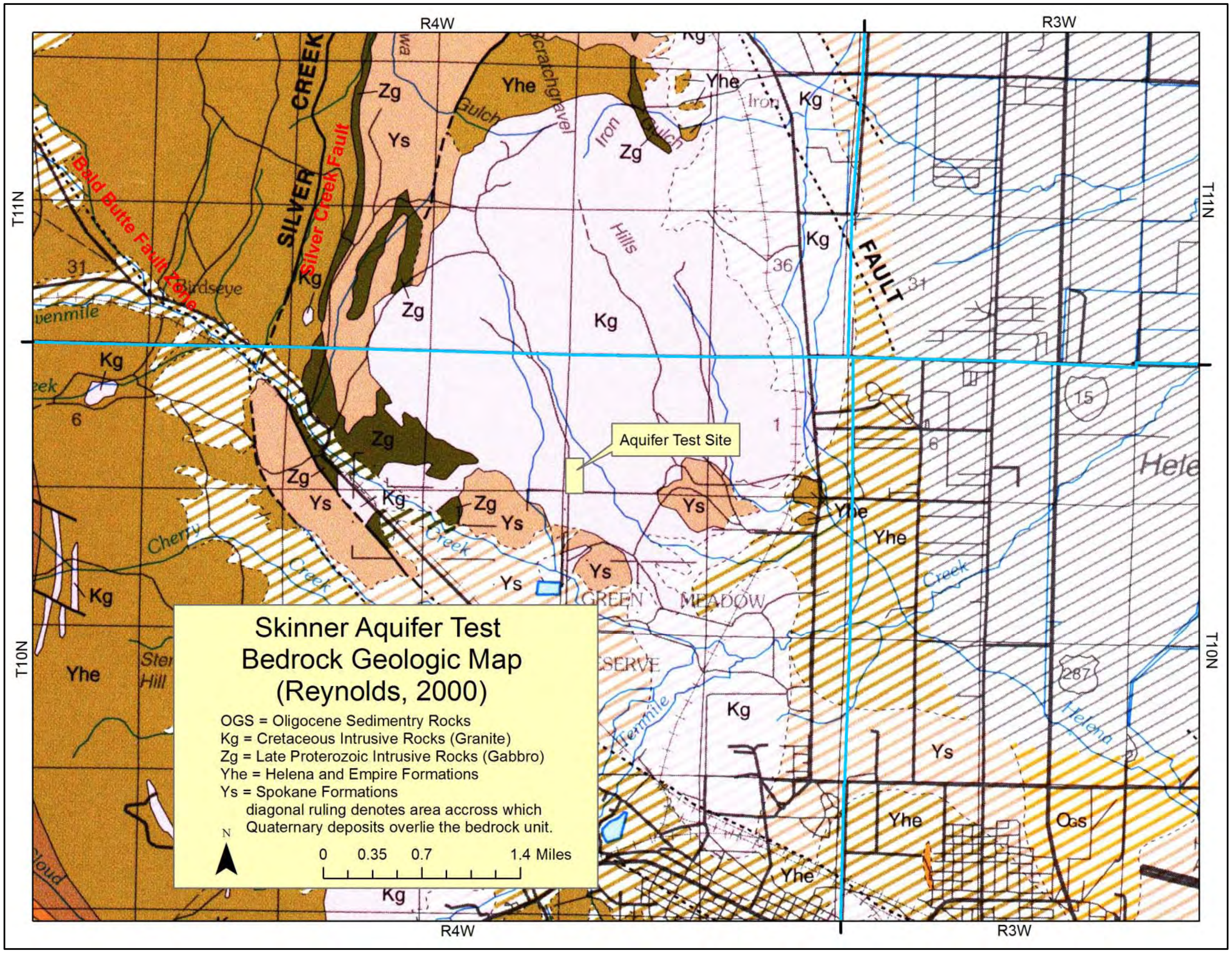


Figure SK3. Geologic map of the Skinner Aquifer Test area. Geologic map prepared by Reynolds for Thamke, 2000.

Well Details:
Two 4-in-diameter PVC-cased wells were installed at this site. Each of these wells has an 8-in-diameter steel surface casing. It was determined that SK1 would serve as the pumping well because it produced more than 30 gallons per minute (gpm) during development, while SK2 produced less than 1 gpm.

SK1 was drilled to a total depth of 160 ft; however, due to borehole collapse (fractured granite), it was completed at a depth of 134 ft, with rubble filling the lower portion of the hole. SK2 was completed at a total depth of 183 ft. These wells were gravel packed across the screened interval, and the annular space sealed with bentonite to the surface.

SKE and SKW are unused wells located on the northern edge of the property (fig. SK2). These wells have 6-in-diameter steel surface casing and 4-in-diameter PVC liners. The DNRC has been monitoring these wells using transducers since 2008 (figs. SK4, 5). Both wells show a clear response to the irrigation ditch usage; however, SKE appears to be more responsive to short-term variations, likely due to its location near the ditch (fig. SK2). SKW is reported to have a total depth of 144 ft, with 50 gpm being produced during development. SKE is reported to have a total depth of 224 ft, and produce 60 gpm during development.

Pretest depth to water (DTW) readings at the test site show groundwater elevations between 3,987.72 and 4,019.96 ft above mean sea level (ft-amsl). Plotting the elevations shows that groundwater flow is generally to the southeast (fig. SK6). During pretest monitoring, groundwater levels were rising in SK2 and SKW, but changed from rising to non-changing in SKE. Static water levels were recorded for one day on SK1 but did not show a trend (figs. SK7–SK10).

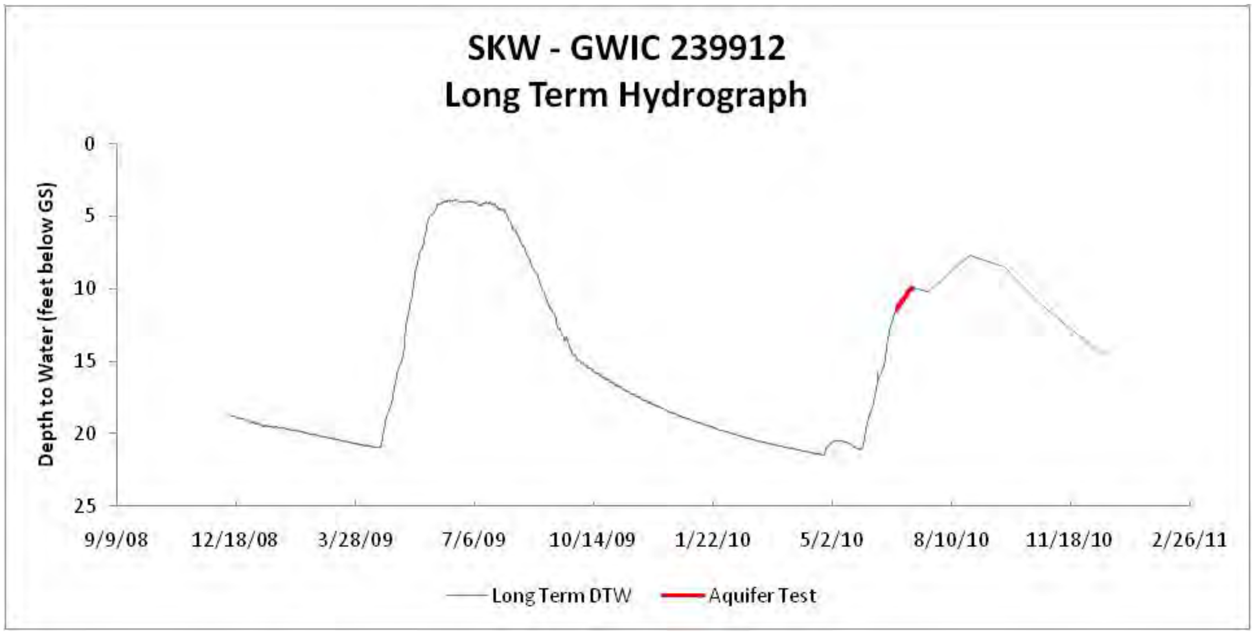


Figure SK4. Long-term hydrograph of SKW.

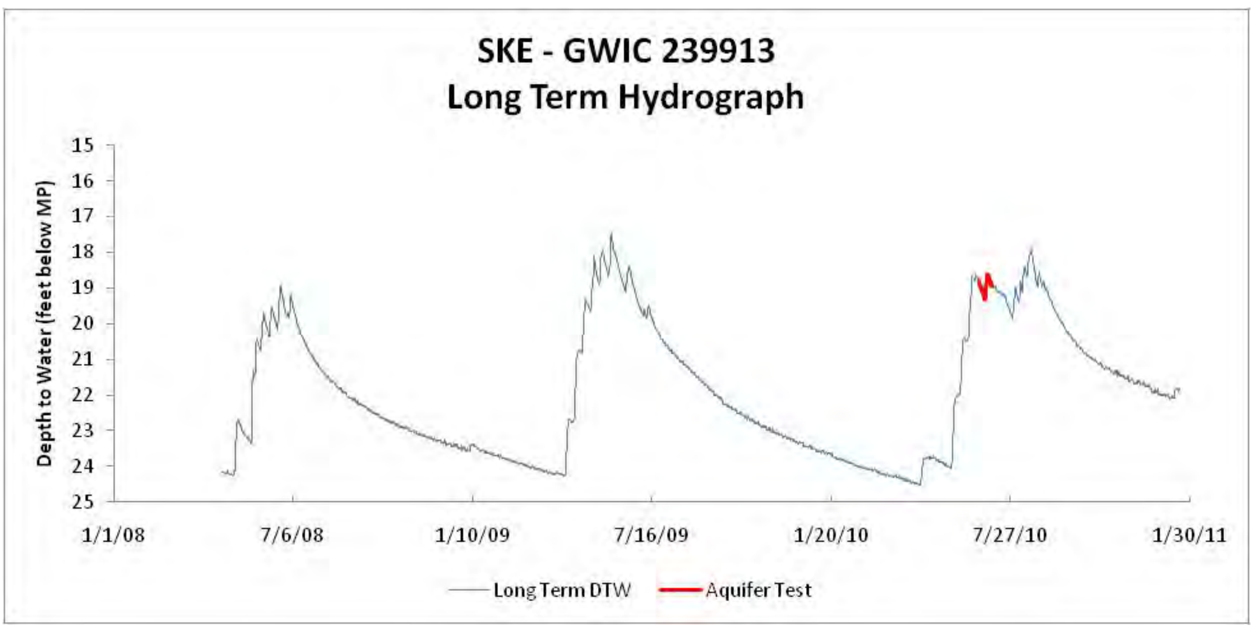


Figure SK5. Long-term hydrograph of SKE.

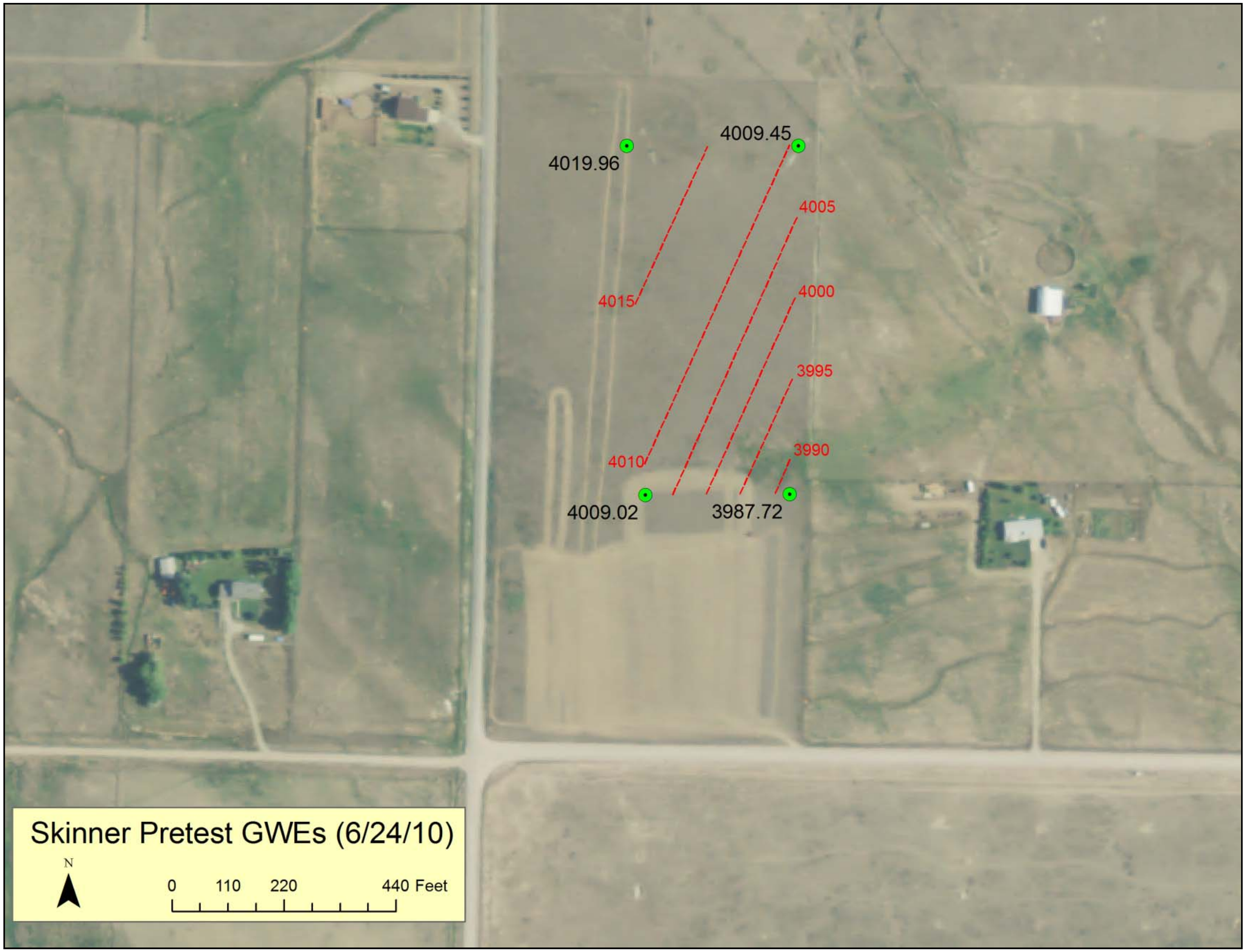


Figure SK6. Groundwater levels were measured on June 24, 2010 prior to the start of the step test and indicate that flow is towards the southeast.

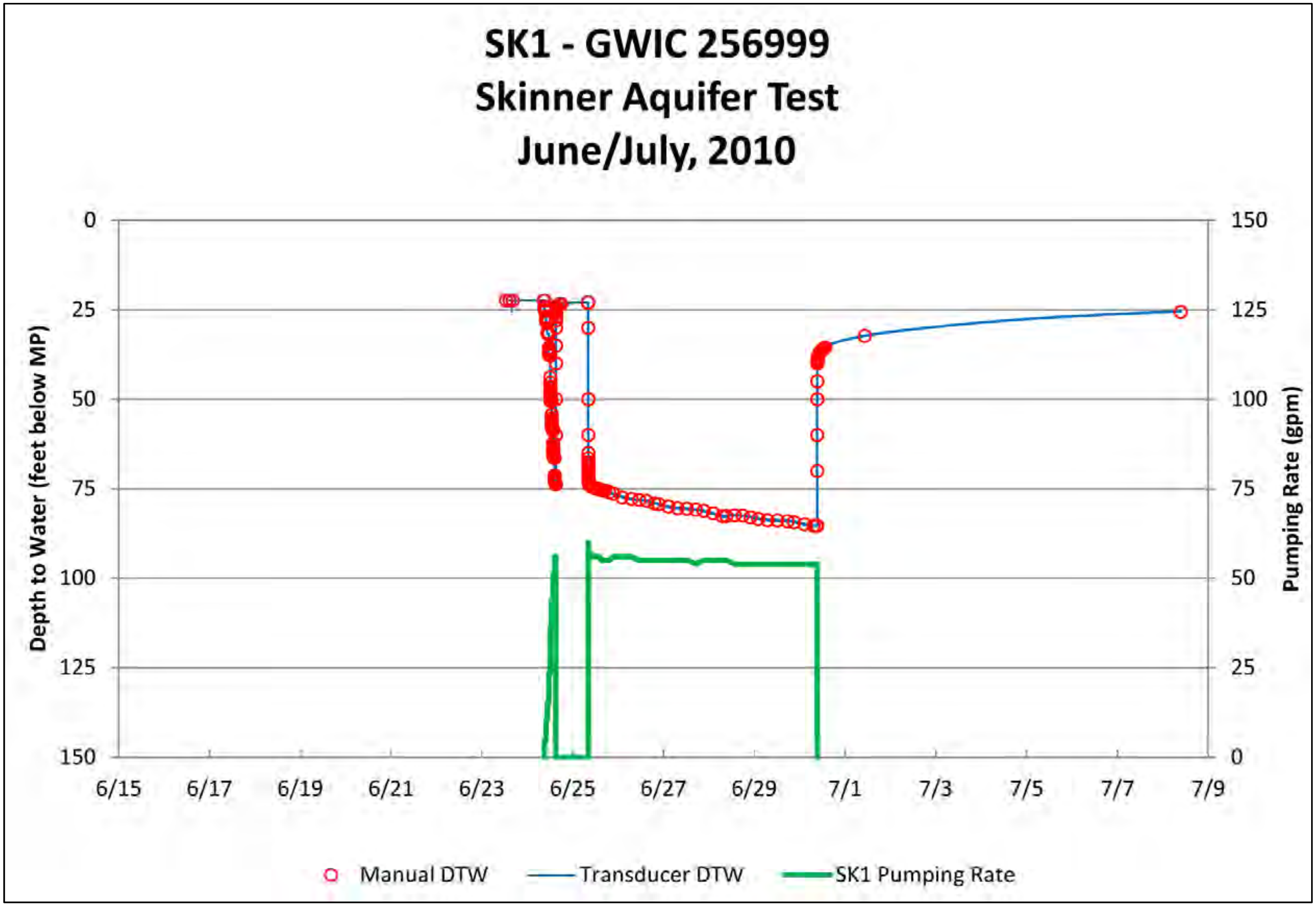


Figure SK7. Depths to water and pumping rates in well SK1 (pumping well) recorded during the Skinner aquifer tests. A step test was conducted on June 24, 2010, and the specified rate test was conducted from June 25 to June 30, 2010.

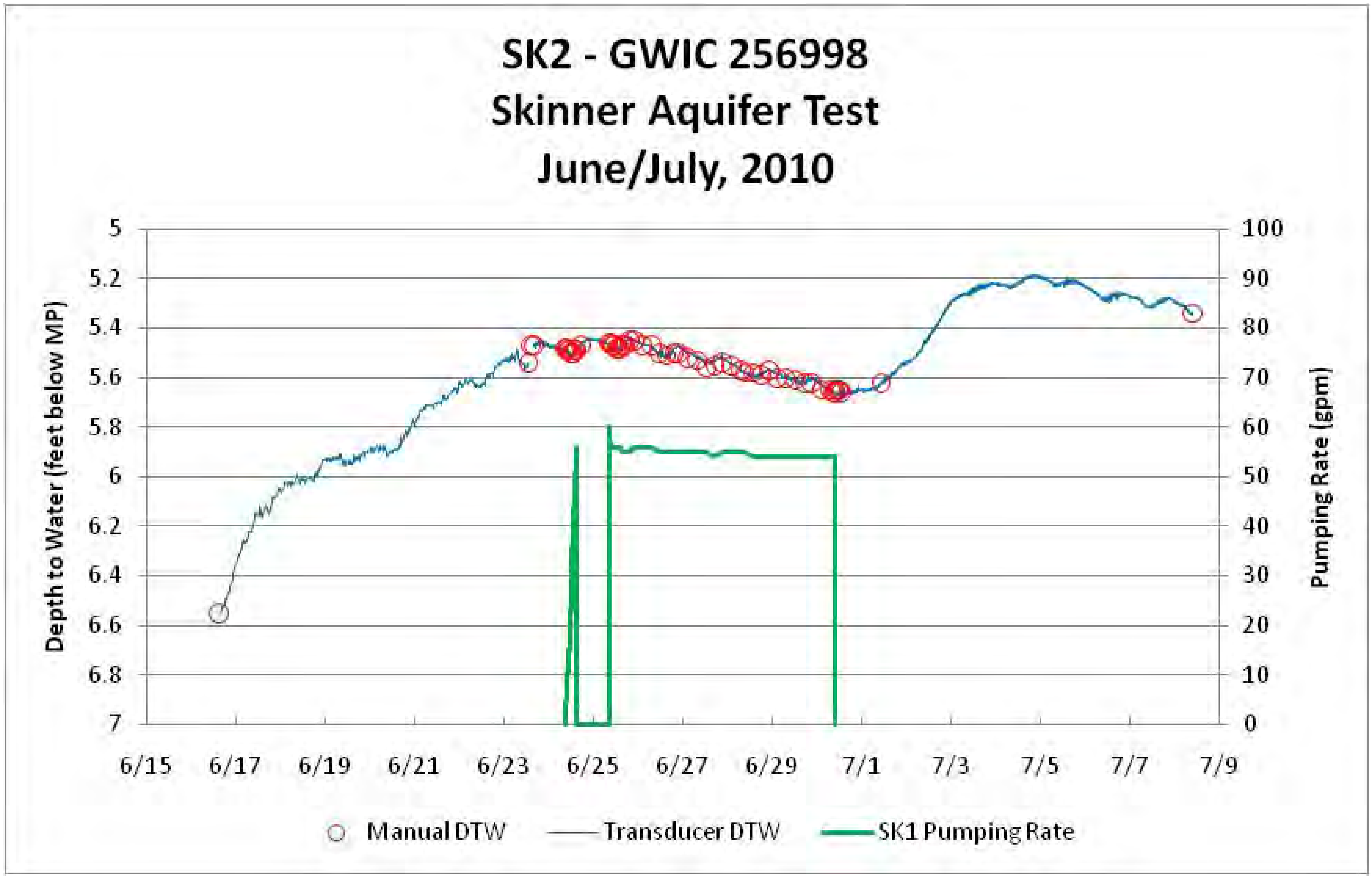


Figure SK8. Depths to water in well SK2 and pumping rates from SK1 recorded during the Skinner aquifer tests. A step test was conducted on June 24, 2010, and the specified rate test was conducted from June 25 to June 30, 2010.

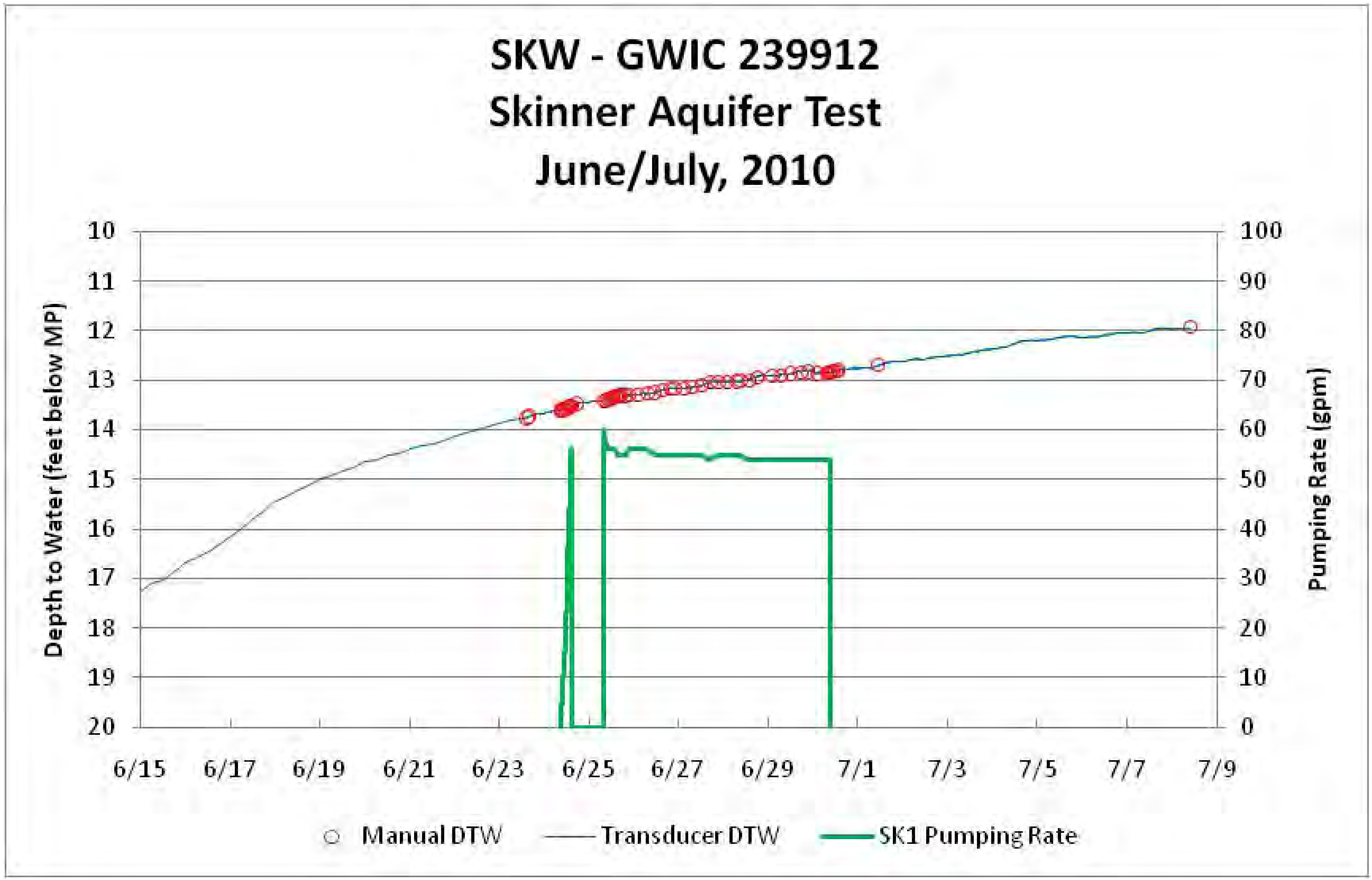


Figure SK9. Depth to water in well SKW and pumping rates from SK1 recorded during the Skinner aquifer tests. A step test was conducted on June 24, 2010, and the specified rate test was conducted from June 25 to June 30, 2010.

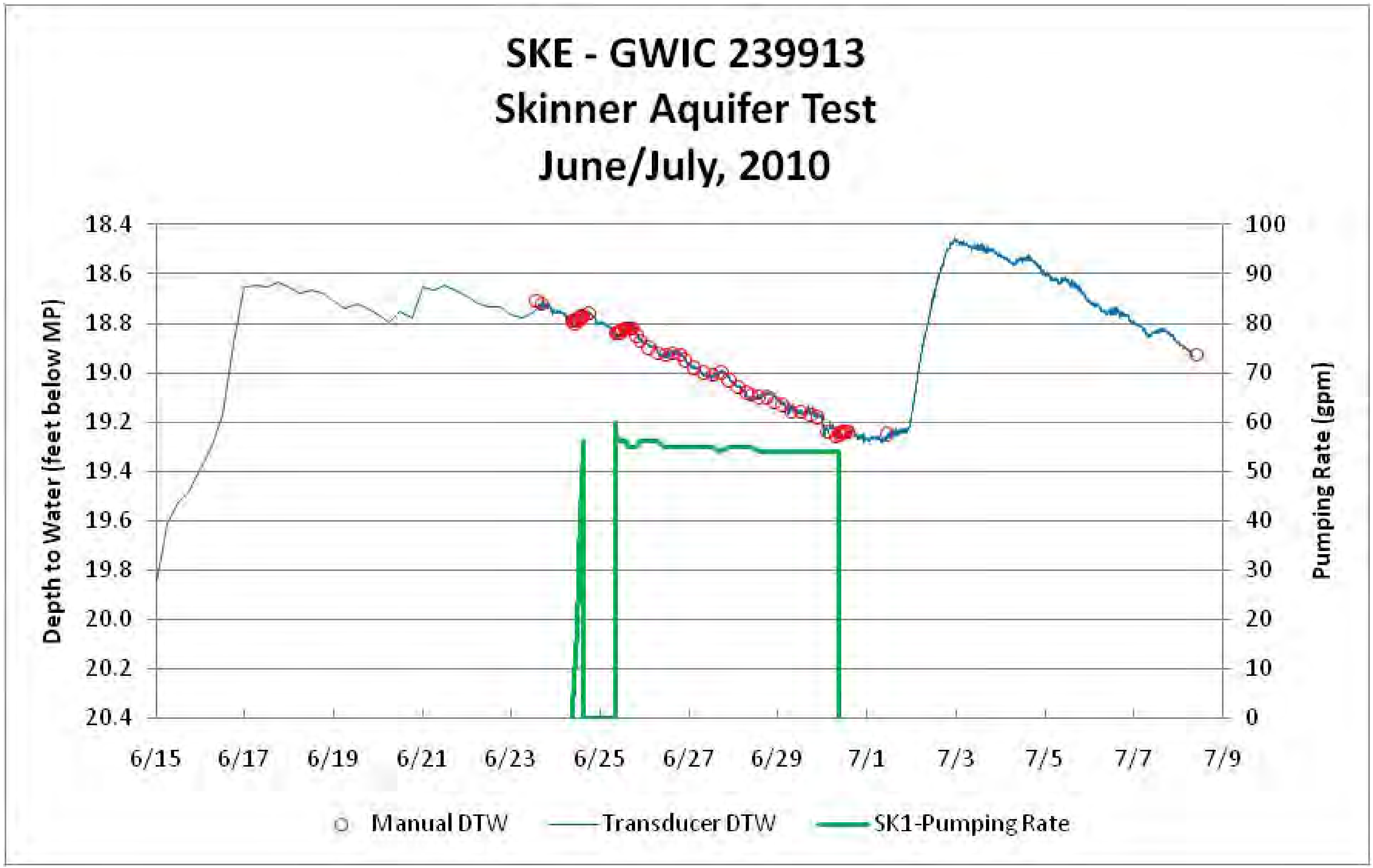


Figure SK10. Depths to water in well SKE and pumping rates from SK1 recorded during the Skinner aquifer test. A step test was conducted on June 24, 2010, and the specified rate test was conducted from June 25 to June 30, 2010.

Methodology:
This aquifer test was conducted by the MBMG by pumping well SK1 in two segments. A step test on June 24, 2010 was followed by a constant discharge test that began June 25 and lasted until June 30, 2010. During the step test, pumping rates were monitored using a flow meter and verified with manual bucket and stopwatch measurements when discharge was less than 30 gallons per minute (gpm). However, when the pumping rate reached more than 30 gpm, manual checking became impractical. There was good agreement between manual and flow meter values. During the constant rate test, discharge was measured only with the flow meter. Discharge was controlled using a gate valve and diverted approximately 300 ft to the south and away from all monitored wel ls.

Vented pressure transducers were used to record water levels in the pumping well (SK1) and the three observation wells (SK2, SKW, and SKE). The transducer used in the pumping well (SK1) was rated at 100 psig (230.7 ft), has a manufacturer-reported accuracy of ±0.05% of the rated pressure (±0.11 ft), and a resolution of ±0.005% of the rated pressure (0.011 ft). The other vented transducers were rated at 15 psig (34.61 ft), have a manufacturer-reported accuracy of ±0.05% of the rated pressure (± 0.017 ft), and a resolution of ±0.005% of the rated pressure (0.001 ft).

Manual water-level readings were made for all wells prior to placing transducers, and were made periodically during the test(s), recovery(s), and prior to uninstalling the transducers. Manual measurements were used to verify transducer response. All water-level data are available from GWIC by using the GWIC ID (http://mbmggwic.mtech.edu/).

The MBMG installed a transducer in SK2 on June 16, 2013 to determine antecedent trends. A transducer was installed in SK1 on June 23, 2010, following installation of the pump and measurement access tube. The DNRC installed transducers in SKW and SKE in 2008. The DNRC transducers recorded one reading every 6 h. The MBMG installed additional transducers in SKW and SKE on June 23, 2010 to track water levels during the tests at a rate of one reading per minute. The pumping portion of the tests ran from June 24 to June 30. All MBMG-installed transducers were left in place until July 8, 2010. The long-term DNRC transducers were left in place.

Because no drawdown was seen in the observation wells during either the step test or the 121-h constant rate test, short aquifer tests on each observation well were completed to obtain estimated aquifer properties (T and K). These short tests were conducted on April 13, 2011 using a 1- to 2-gpm submersible pump, and drawdown and recovery were monitored using non-vented transducers. Each well was pumped for 2 h, or until the water level fell to near the pump. Pumping rates were monitored using bucket and stopwatch. Manual measurements were taken when transducers were installed (April 4, 2011), during the test, and prior to transducer removal (April 19, 2011). A barologger was installed on site to provide for barometric correction.

Skinner step test analysis:
On June, 24, 2010, a step test was conducted on SK1 to determine an appropriate pumping rate (table SK2 and figs. SK11–SK14) for the constant rate test. The final rate (56 gpm) reflected the maximum pumping rate obtainable with the equipment on site. The rate was believed to be reasonable since it resulted in slightly over 50 ft of drawdown in SK1. As discussed below, the actual weighted average discharge for the constant rate test was 54.8 gpm.

The data obtained during the step test also allows the well's specific capacity (discharge per unit of drawdown, Q/s) to be determined at different pumping rates. This information can then be used to determine the maximum rate that the well can be pumped without exceeding a target drawdown value (fig. SK15). Given that the top of the screen is 114 ft below ground surface (bgs), the static water level is 24 ft bgs, and it is typically desired that the water level stay at least 10 ft above the top of screen, the target drawdown in SK1 is about 80 ft. Using the data in table SK1, a pumping rate of 84 gpm would keep the pumping water level above the screen. However, data from pumping rates greater than 15 gpm better fit a somewhat different trend line, and if only the data from these higher pumping rates are used, SK1's calculated maximum pumping rate is about 78 gpm.

Table SK2
Step Test Summary—SK1 (GWIC 256999)
Skinner Aquifer Test—June 24, 2010

Start Step	End Step	Rate (Q, gpm)	Final Drawdown (ft)	Q/s (gpm/ft)
09:00	09:50	4.65	2.74	1.70
09:50	10:35	10.35	6.15	1.68
10:35	11:20	15.1	9.36	1.61
11:20	12:05	23.2	15.37	1.51
12:05	12:50	36	28.12	1.28
12:50	13:35	44	36.23	1.21
13:35	14:20	51	43.93	1.16
14:20	15:05	56	51.33	1.09

During the step test there was no observable drawdown in any of the observation wells. In fact, water levels in some wells initially decrease, but then begin rising part way through the test (figs. SK12–SK14).

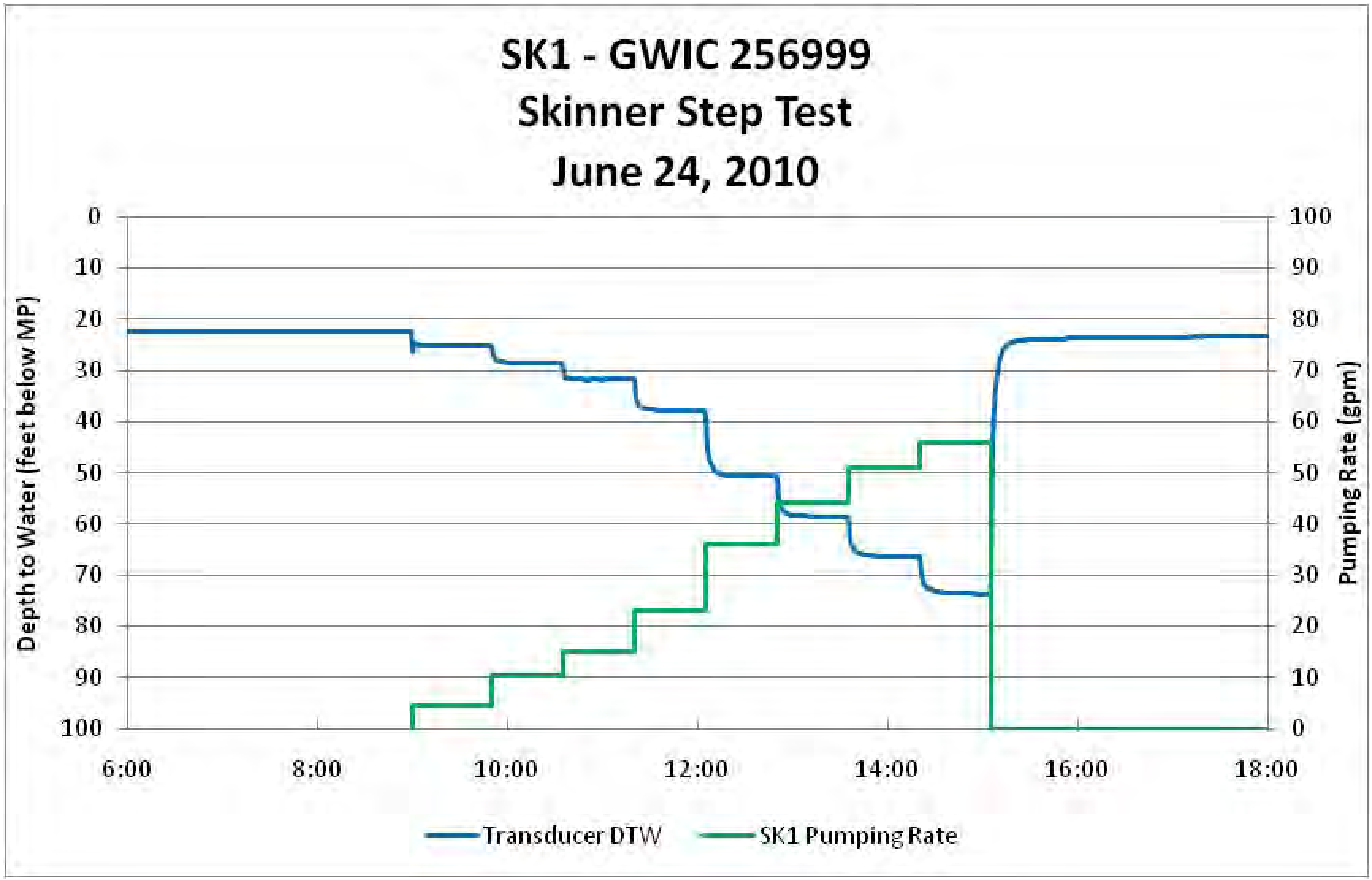


Figure SK11. Depth to water measured and pumping rates in well SK1 (pumping well) during the Skinner step test.

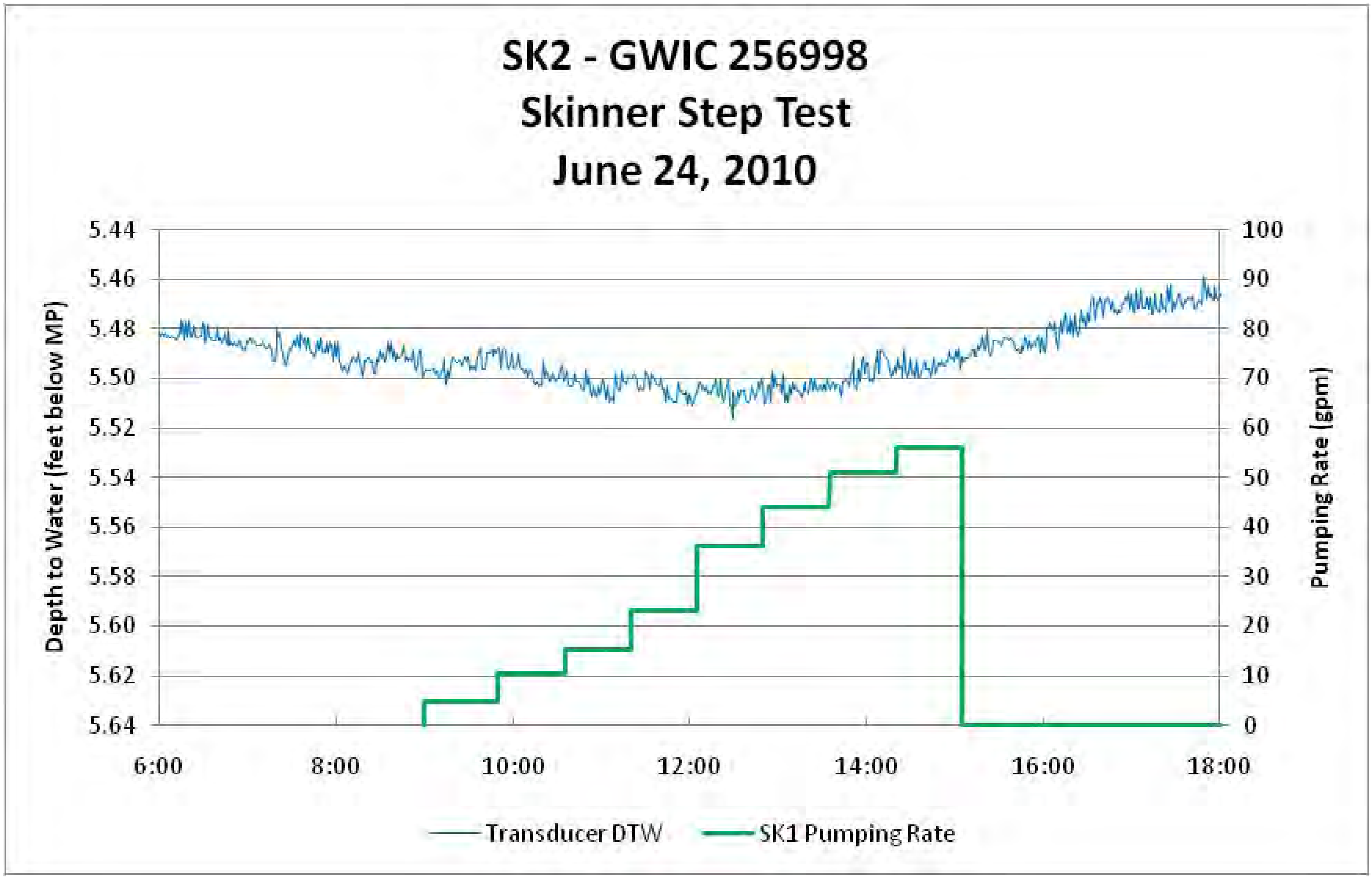


Figure SK12. Depths to water measured in well SK2 and pumping rates from SK1 during the Skinner step test.

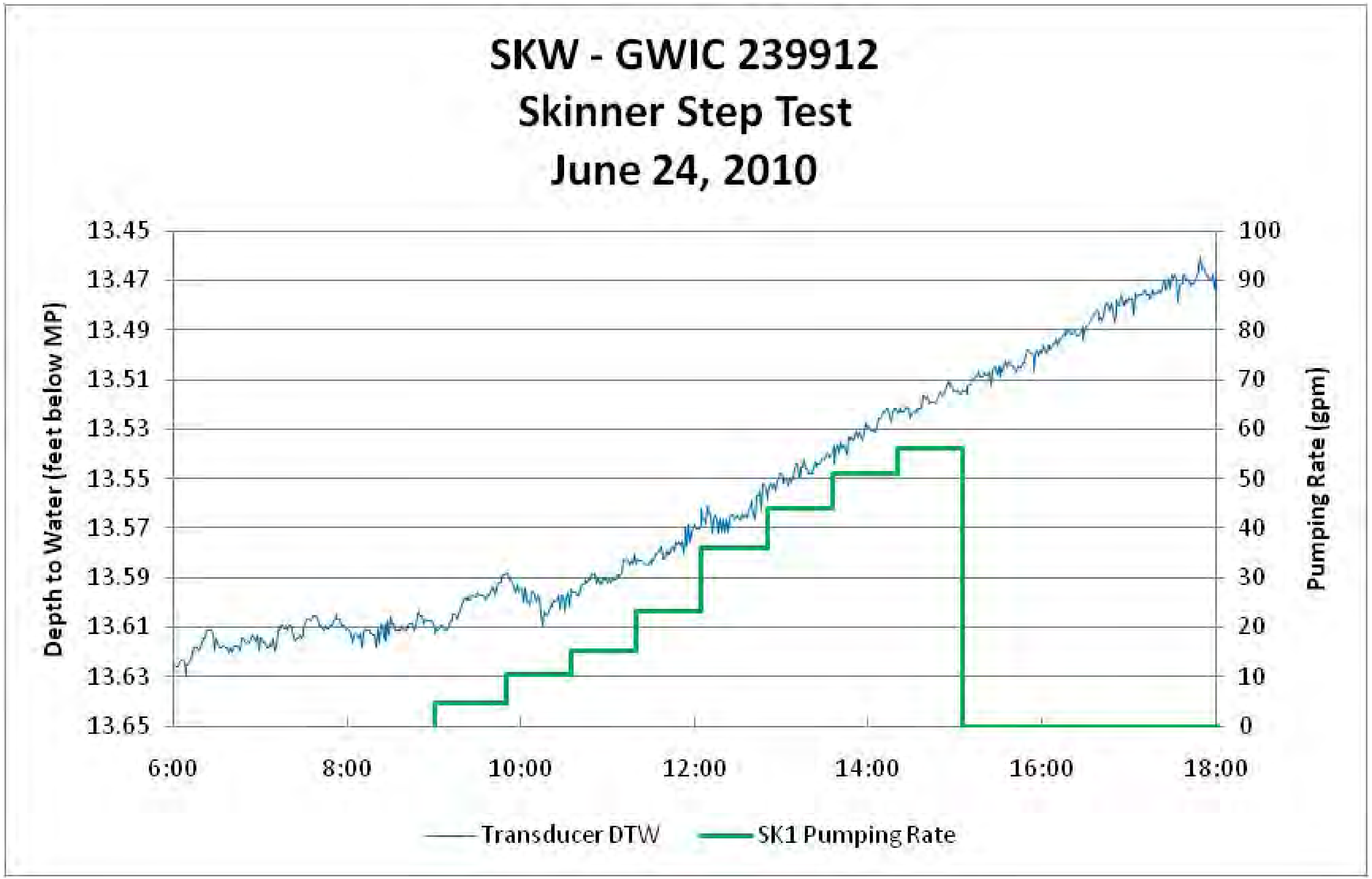


Figure SK13. Depth to water measured in well SKW and pumping rates from SK1 during the Skinner step test.

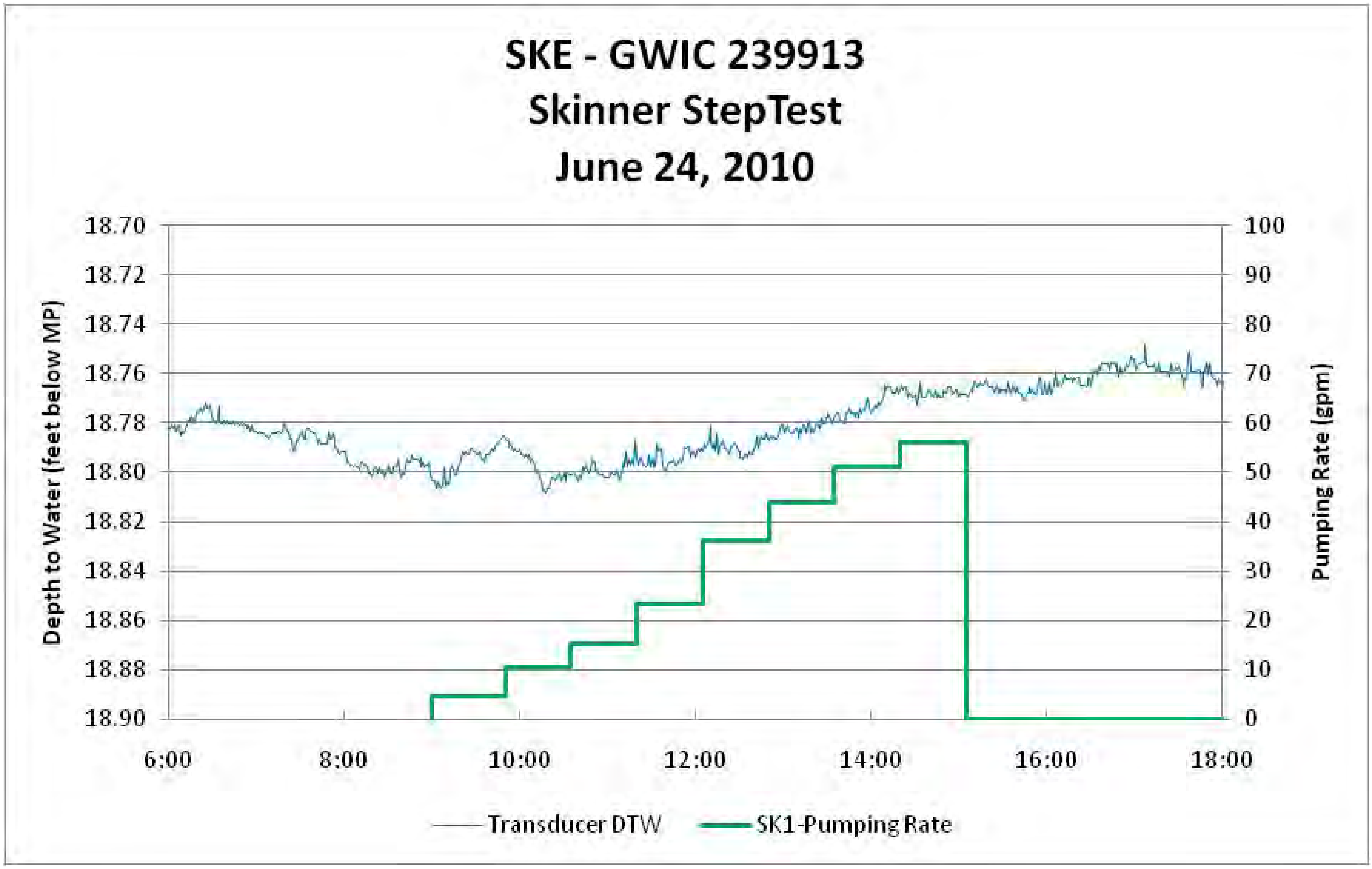


Figure SK14. Depths to water measured in well SKE and pumping rates from SK1 during the Skinner step test.

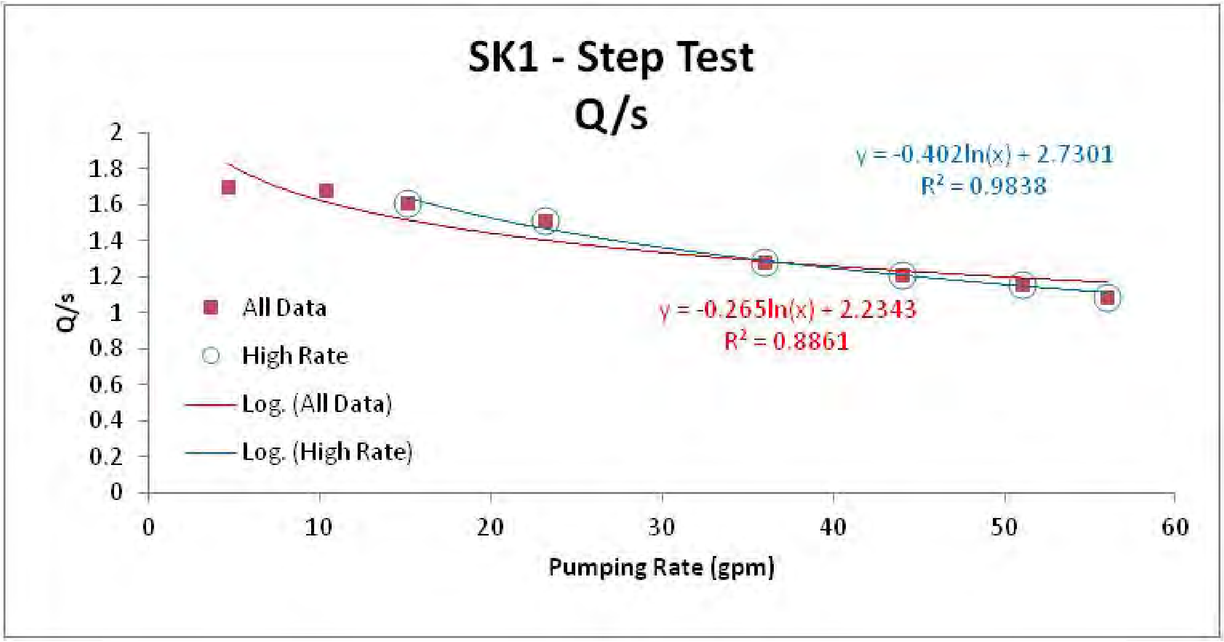


Figure SK15. Specific capacity (Q/s) vs. pumping rate (Q) for SK1. This relationship can be used to determine the maximum pumping rate for the well.

Skinner constant rate aquifer test analysis:

The Skinner constant rate test started at 8:10 on June 25, 2010 and ended at 9:10 on June 30, 2010, for a total pumping time of 121 h (5 d and 1 h). The time-weighted average pumping rate was 54.8 gpm. The maximum recorded pumping rate was 60 gpm (for a short period at the start of the test) and the minimum rate was 54 gpm. Thus, the maximum deviation from average was 9.5%. The maximum recorded drawdown in well SK1 was 62.49 ft. Water levels in well SK1 initially declined rapidly but then fell slowly throughout the rest of the test (fig. SK7). The rate of drawdown was increasing slightly at the end of the test's pumping portion, with 0.04 ft of drawdown occurring over the last hour. After pumping ceased, the well initially recovered rapidly, but the rate quickly slowed and it took just over 3 days to reach 90% recovery.

Discernible drawdown was not seen in any observation well. While SK2 and SKE show water-level changes that appear similar to drawdown and recovery, detailed examination of the data shows that these changes are not the result of pumping stress (figs. SK2–SK14). During the step test, water levels in each of these wells rose for at least part of the time and did not show noticeable deviation in response to pumping. It is likely that lack of monitoring-well response is due to SK1 being completed in a productive fracture zone that was not intersected by SK2, and although SKW and SKE were productive wells, they apparently are not completed in the same fracture zone as SK1.

Due to the lack of response from the observation wells, only the data from SK1 can be analyzed. Given these data, only T and K can be calculated. Storativity requires at least one observation well, and anisotropy requires at least two observation wells. Data from SK1 can be plotted on a log-log plot of drawdown vs. time (fig. SK16) to assess the nature of the aquifer. Evaluation of this plot shows a semi-confined response (Freeze and Cherry, 1979, p. 346). Because the recovery data contains the least noise, it was analyzed first using the Theis recovery method in AQTESOLV. This analysis shows that T is approximately 130 ft^2/d. This T value also accounts for all observations during drawdown and the step test (appendix SKA). Given that the saturated thickness in SK1 is 138 ft (assuming that the rubble in the bottom of the well does not impede flow), K is calculated to be 0.94 ft/d.

Storativity values were also calculated using AQTESOLV; however, these have no physical significance since the effect of well skin (Sw) cannot be separated from aquifer storage without an observation well. A leaky model (Hantush-Jacob) was used for the step test, while a confined model (Theis) was used for the constant rate test. The method choice allowed proper handling of gravity drainage early in the test.

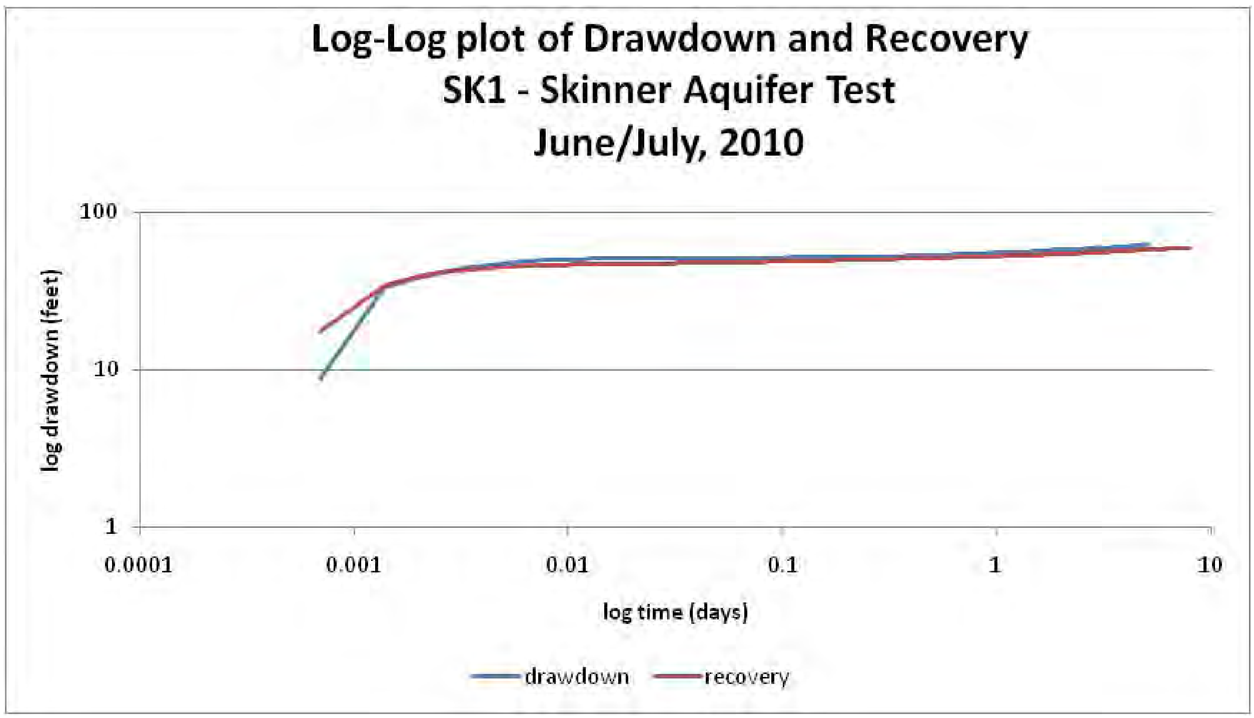


Figure SK16. Log-log plot of drawdown vs. time in SK1. This response is indicative of a semi-confined aquifer.

Skinner short-term single well aquifer tests:
Short term tests of SK2, SKE, and SKW produced drawdown and recovery data from which aquifer parameters could be estimated (e.g., fig. SK17).

The short tests were analyzed using AQTESOLV (appendix SKA). In each case the recovery data appear to be the most reliable and the drawdown data are consistent with the recovery data. Recovery data were analyzed using the Theis recovery method. Drawdown was analyzed using the Theis or Cooper–Jacob methods. Calculated T values were 185 ft^2/d for SKW, 225 ft^2/d for SKE, and 0.15 ft^2/d for SK2 (K values of 1.5, 1.1, and 8.8 x 10^{-4} ft/d, respectively). SK2 is much less productive than the other wells, and during drilling it did not appear to intersect any significant water-producing fractures. For SK2 the line defined by the T value from the recovery data does not fit the drawdown data well; however, this well was only pumped for 25 min, during which time well-bore storage would have a significant effect on the data.

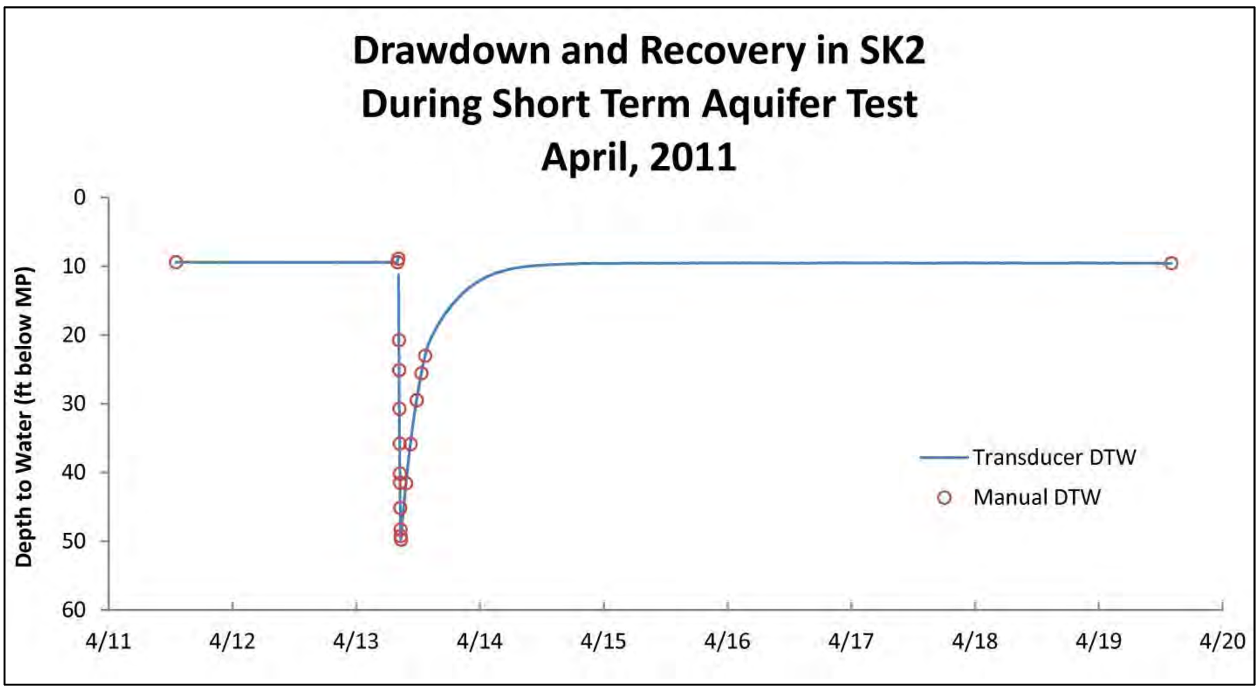


Figure SK17. Results of the short-term test on SK2.

Conclusions:

For comparison, PBS&J (2008) conducted a groundwater availability study for the land directly south of this test site (the proposed Cornerstone Village Subdivision). This study showed that for a well completed on that property in the granite (CV-1), aquifer test data showed a K of 0.8 ft/d. PBS&J also conducted rough calculations of K for intrusive (granite) using an empirical relationship of specific capacity to transmissivity defined by Driscoll (1986). These calculations showed that for four wells in the area completed in the granite, the average K is 0.16 ft/d, with the range being from 0.04 to 0.38 ft/d.

It appears that the most representative K value for the Skinner site is about 1 ft/d; however, this value depends on the availability of fractures. In SK2, where no noticeable fractures were intersected, K was about 8.8×10^{-4}. It is also notable that the K is quite variable over short distances and K values cannot be used quantitatively away from the immediate well location where they were generated. Modeling may provide a better estimate of bulk K.

References:

ASTM, 2008, Standard test method (field procedure) for withdrawal and injection well tests for determining hydraulic properties of aquifer systems, D4050-96 (Reapproved 2008).

ASTM, 2008, Standard test method (analytical procedure) for determining transmissivity and storage coefficient of nonleaky confined aquifers by the modified Theis nonequilibrium method, D4105-96 (Reapproved 2008).

Cooper, H.H., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history, Transactions, American Geophysical Union, v. 24, p. 526–534.

Driscoll, F.G., 1986, Groundwater and wells, 2nd ed.: St. Paul, Minn., Johnson Division.

Fetter, C.W., 1994, Applied hydrogeology, 3rd ed.: New York, Macmillan College Publishing, 691 p.

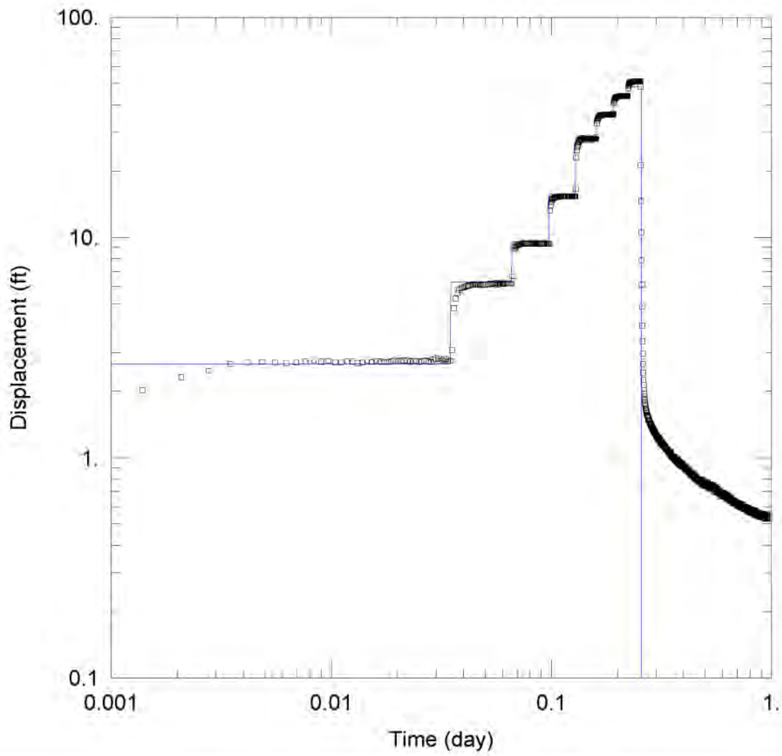
Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice Hall, 604 p.

Jacob, C.E., 1950, Flow of ground-water, *in* Engineering Hydraulics, Rouse, H., *ed*.: New York, John Wiley Press.

PBS&J, 2008, Groundwater availability assessment for Cornerstone Village Subdivision, Lewis and Clark County, Montana.

Reynolds, Mitchell W., 2000, Generalized bedrock geologic map of the Helena area, west-central Montana, *in* Thamke, J.N., 2000, Hydrology of area bedrock west-central Montana, 1993–98, U.S. Geological Survey Water Resources Investigations Report 00-4212.

Appendix SKA—AQTESOLV Analysis



SKINNER AQUIFER TEST - JUNE-JULY 2010 - STEP TEST

Data Set: M:\...\SK_Steptest.aqt
Date: 05/02/11 Time: 12:28:32

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: SK-1
Test Date: 6/23/10 - 7/8/10

AQUIFER DATA

Saturated Thickness: 138. ft
Anisotropy Ratio (Kz/Kr): 1.
Aquitard Thickness (b'): 1. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SK-1	0	0

Observation Wells

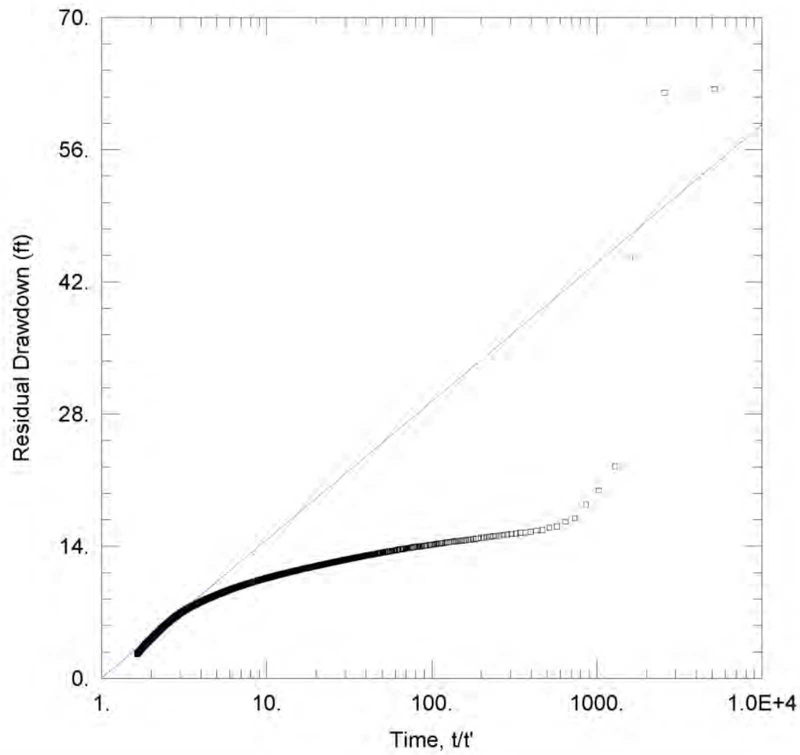
Well Name	X (ft)	Y (ft)
▫ SK-1	0	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush-Jacob

T = 130. ft^2/day
S = 0.15
r/B = 1.196
Sw = 2.
C = 1.547E-7 day^2/ft^5
P = 2.

Analysis of step test data from well SK1.



SKINNER CONSTANT RATE TEST

Data Set: M:\...\SK1_B1_Rec.aqt
Date: 05/02/11 Time: 11:22:39

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: SK-1
Test Date: 6/23/10 - 7/8/10

AQUIFER DATA

Saturated Thickness: 138. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SK1	0	0

Observation Wells

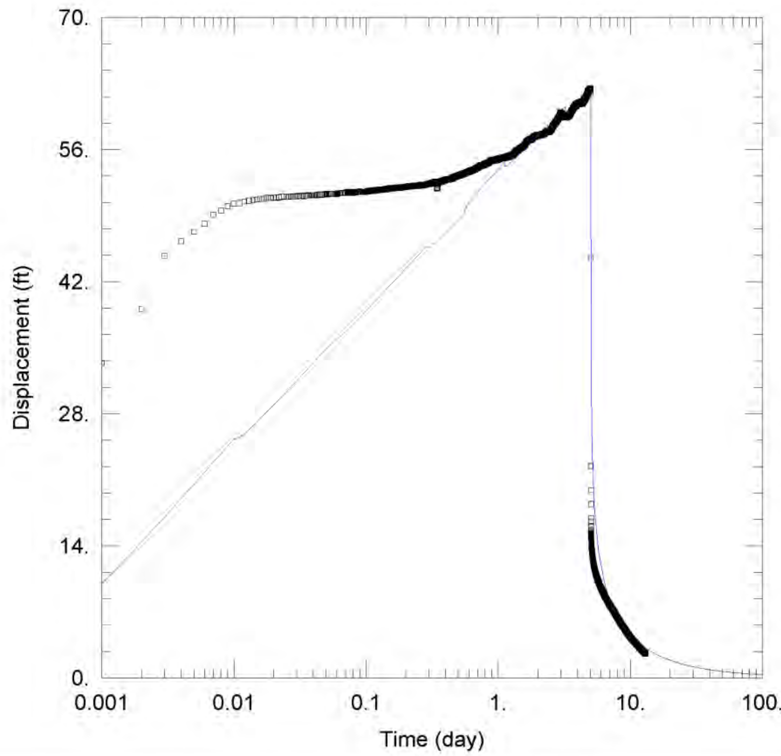
Well Name	X (ft)	Y (ft)
▫ SK1	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 130. ft^2/day S/S' = 1.

Analysis of recovery data from well SK1.



SKINNER CONSTANT RATE TEST

Data Set: M:\...\SK1_B2_dh&R.aqt
Date: 05/02/11 Time: 11:26:36

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: SK-1
Test Date: 6/23/10 - 7/8/10

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SK1	0	0

Observation Wells

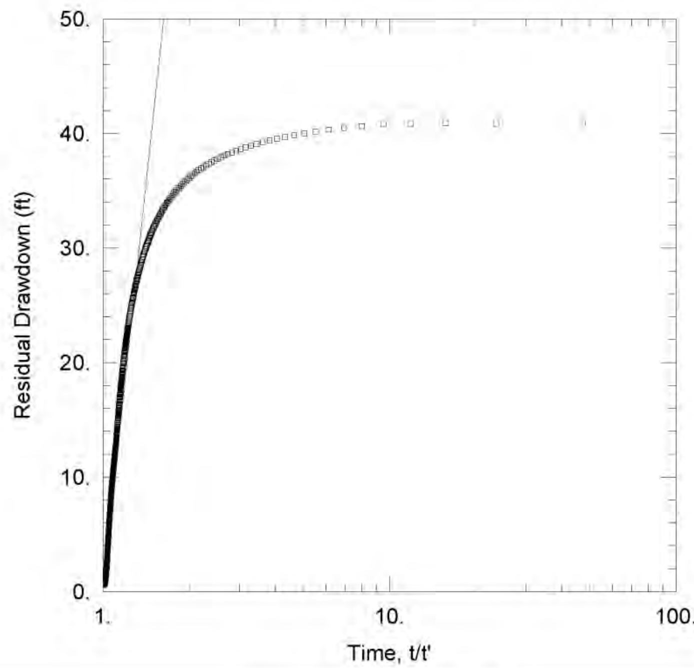
Well Name	X (ft)	Y (ft)
▫ SK1	0	0

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 130. ft^2/day
S = 0.7467
Kz/Kr = 1.
b = 138. ft

Analysis of drawdown and recovery data from well SK1.



SK2 SHORT TERM TEST

Data Set: M:\...\A4.aqt
Date: 05/02/11 Time: 10:51:48

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: SK2
Test Date: 4/13/11

AQUIFER DATA

Saturated Thickness: 170. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SK2	0	0

Observation Wells

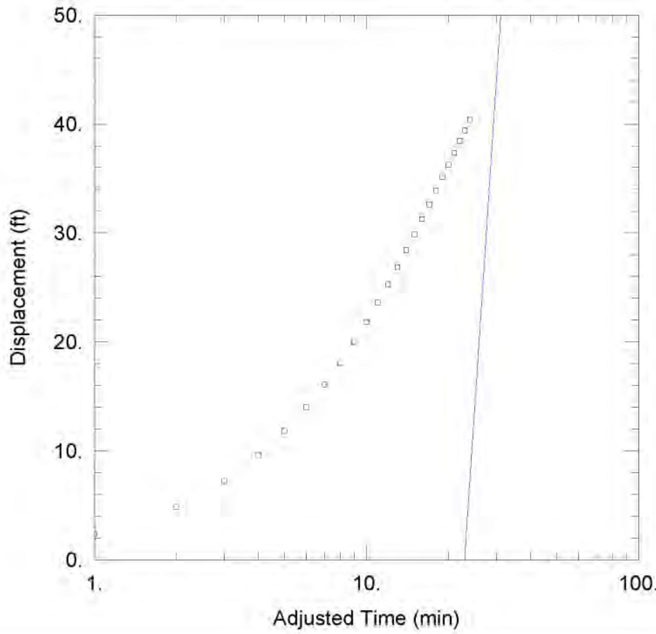
Well Name	X (ft)	Y (ft)
□ SK2	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 0.15 ft^2/day S/S' = 1.

Analysis of recovery data from well SK2.



SK2 SHORT TERM TEST

Data Set: M:\...\A5.aqt
Date: 05/02/11 Time: 10:58:17

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: SK2
Test Date: 4/13/11

AQUIFER DATA

Saturated Thickness: 170. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SK2	0	0

Observation Wells

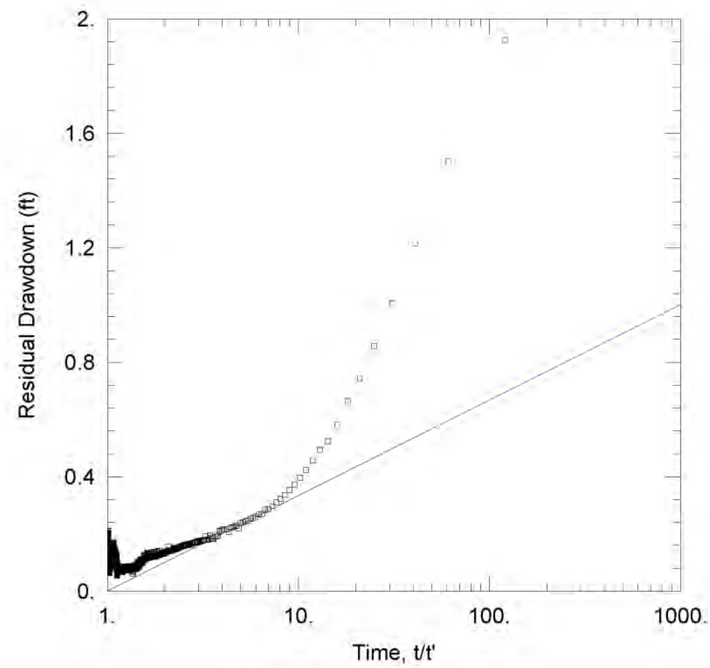
Well Name	X (ft)	Y (ft)
▫ SK2	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 0.15 ft^2/day S = 0.005369

Analysis of drawdown data from well SK2. Note that observations do not fall on the line defined by a T value of 0.15 ft^2/d (determined from recovery). However, this test was only 25 min long and stopped to avoid the water level reaching the pump. Well bore storage is believed to have substantially affected the early drawdown data.



SKW SHORT TERM TEST

Data Set: M:\...\SKW_A2.aqt
Date: 05/02/11 Time: 10:55:54

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: SKW
Test Date: 4/13/11

AQUIFER DATA

Saturated Thickness: 124. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SKW	0	0

Observation Wells

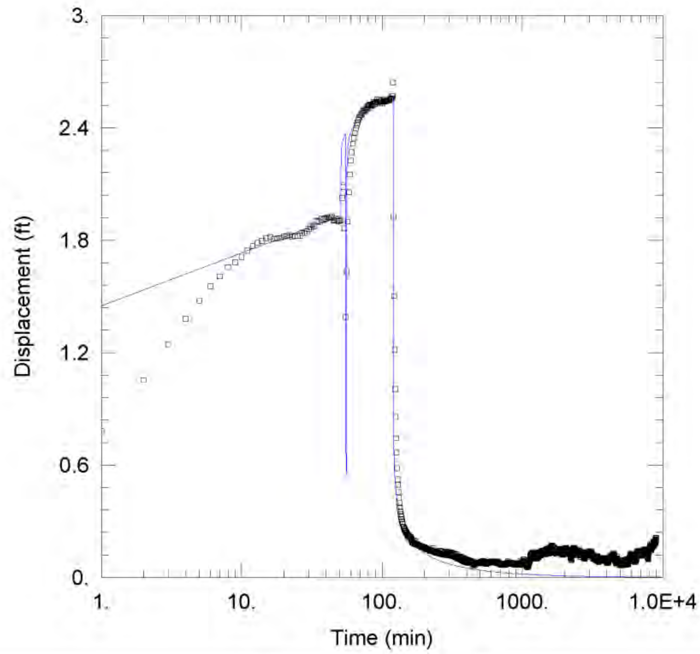
Well Name	X (ft)	Y (ft)
▫ SKW	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 185. ft^2/day S/S' = 1.

Analysis of recovery data from well SKW. Note that a barrier to flow is apparent as the observations are above the trendline as time goes to infinity (t/t' =1 at infinity).



SKW SHORT TERM TEST

Data Set: M:\...\SKW_A3.aqt
Date: 05/02/11 Time: 10:57:10

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: SKW
Test Date: 4/13/11

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SKW	0	0

Observation Wells

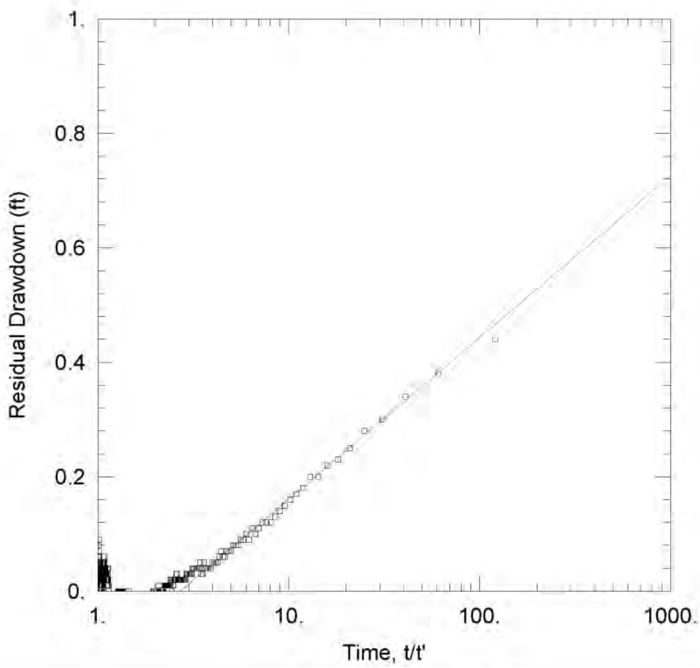
Well Name	X (ft)	Y (ft)
▫ SKW	0	0

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 185. ft^2/day
S = 2.106E-6
Kz/Kr = 1.
b = 124. ft

Analysis of drawdown and recovery data from SKW. Note that pumping rates changed substantially, and the pump shut off for a brief period during this test. A flow barrier is indicated by the incomplete recovery.



SKE SHORT TERM TEST

Data Set: M:\...\SKE_A3.aqt
Date: 05/02/11 Time: 11:00:19

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: SKE
Test Date: 4/13/11

AQUIFER DATA

Saturated Thickness: 196. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SKE	0	0

Observation Wells

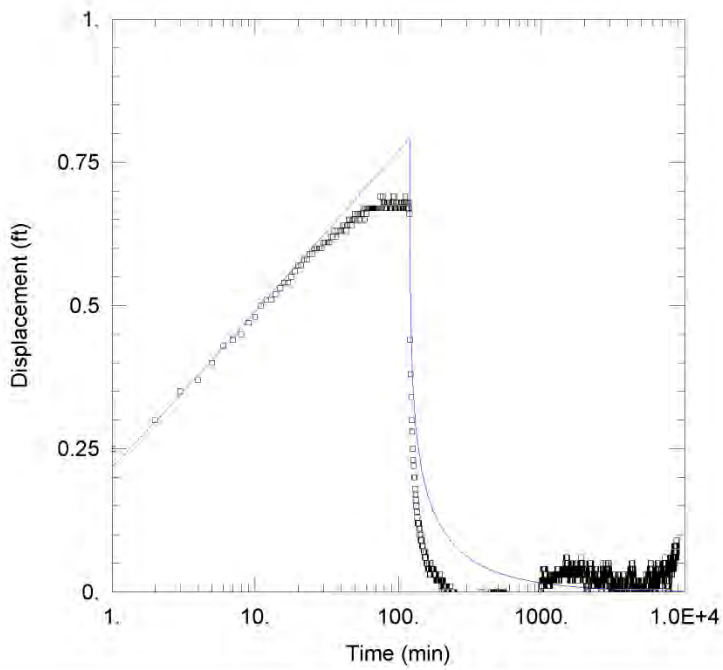
Well Name	X (ft)	Y (ft)
▫ SKE	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 225. ft^2/day S/S' = 2.7

Analysis of recovery data from well SKE. Note that a recharge boundary is apparent by the fact that the trend line is not intercepting the X axis at infinite time (t/t’ = 1 = infinity).



SKE SHORT TERM TEST

Data Set: M:\...\SKE_A5.aqt
Date: 05/02/11 Time: 11:01:12

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: SKE
Test Date: 4/13/11

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SKE	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
▫ SKE	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Theis

T = 225. ft^2/day S = 0.066
Kz/Kr = 1. b = 196. ft

Analysis of drawdown and recovery data from well SKE. Note that a recharge boundary is indicated due to the flattening of the drawdown curve and rapid initial recovery.

Appendix SKB—Well Logs

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site
View scanned aquifer test (12/15/2011 2:03:49 PM)
View scanned aquifer test (12/15/2011 2:59:28 PM)

Site Name: MBMG - SK1 (EAST) * SKINNER
GWIC Id: 256999

Section 1: Well Owner

Owner Name
MONTANA BUREAU OF MINES & GEOLOGY
Mailing Address
1300 WEST PARK

City	State	Zip Code
BUTTE	MT	59701

Section 2: Location

Township	Range	Section	Quarter Sections
10N	04W	2	NE¼ SW¼ SW¼ SW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.6468134	112.0820975	SUR-GPS	WGS84

Ground Surface Altitude	Method	Datum	Date
4008.62	SUR-GPS	NAVD88	4/18/2011

Measuring Point Altitude	Method	Datum	Date Applies
4010.14	SUR-GPS	NAVD88	6/3/2010

Addition	Block	Lot

Section 3: Proposed Use of Water
MONITORING (1)

Section 4: Type of Work
Drilling Method: ROTARY

Section 5: Well Completion Date
Date well completed: Friday, June 04, 2010

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	18	14
18	160	8

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
0	134	4		200.0	FLUSH THREAD	PVC-SDR 17
2	18	8	0.25		WELDED	A53B STEEL
2	78	6	0.25		WELDED	A53B STEEL

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description

Section 7: Well Test Data

Total Depth: 160
Static Water Level: 27
Water Temperature:

Air Test *

_30_ gpm with drill stem set at _134_ feet for _1_ hours.
Time of recovery _0.08_ hours.
Recovery water level _27_ feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log
Geologic Source
211SCGR - SCRATCHGRAVEL HILLS STOCK

From	To	Description
0	1	TOPSOIL
1	11	WEATHERED GRANITE
11	160	FRACTURED GRANITE

Driller Certification
All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name: SHAWN TONEY
Company: H & L DRILLING INC
License No: WWC-447
Date Completed: 6/4/2010

114	134	4		.020	FACTORY SLOTTED

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	18	CEMENT	Y
0	98	SUPER GEL	Y
98	102	BENTONITE CHIPS	Y
102	134	SAND PACKED	Y
134	160	CAVED GRANITE	

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site
View scanned aquifer test (12/20/2011 11:29:48 AM)

Site Name: MBMG - SK2 (WEST) * SKINNER
GWIC Id: 256998

Section 1: Well Owner

Owner Name
MONTANA BUREAU OF MINES & GEOLOGY
Mailing Address
1300 WEST PARK

City	State	Zip Code
BUTTE	MT	59701

Section 2: Location

Township	Range	Section	Quarter Sections
10N	04W	2	NE¼ SW¼ SW¼ SW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.6467686	112.0834964	SUR-GPS	WGS84

Ground Surface Altitude	Method	Datum	Date
4012.99	SUR-GPS	NAVD88	4/18/2011

Measuring Point Altitude	Method	Datum	Date Applies
4014.5	SUR-GPS	NAVD88	6/4/2010

Addition	Block	Lot

Section 3: Proposed Use of Water
MONITORING (1)

Section 4: Type of Work
Drilling Method:

Section 5: Well Completion Date
Date well completed: Friday, June 04, 2010

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	18	14
18	183	8

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
0	183	4		200.0	FLUSH THREAD	PVC-SDR 17
2	18	8	0.25		WELDED	A53B STEEL
2	118	6	0.25		WELDED	A53B STEEL

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description

Section 7: Well Test Data

Total Depth: 183
Static Water Level: 27
Water Temperature:

Air Test *

1 gpm with drill stem set at 183 feet for 1 hours.
Time of recovery 4 hours.
Recovery water level 27 feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log
Geologic Source
211SCGR - SCRATCHGRAVEL HILLS STOCK

From	To	Description
0	1	TOPSOIL
1	20	LIGHT BROWN CLAY WITH SOME SILT AND SAND, AND LITTLE FRAGMENTS OF WEATHERED GRANITE
20	38	WEATHERED GRANITE
38	60	GRANITE
60	142	FRACTURED GRANITE
142	183	GRANITE

Driller Certification
All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:	SHAWN TONEY
Company:	H AND L DRILLING
License No:	MWC-97
Date Completed:	6/4/2010

163	183	4		.020	FACTORY SLOTTED

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	18	CEMENT	Y
0	153	SUPER GEL	Y
153	183	SAND PACKED	Y

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site
View scanned aquifer test (12/20/2011 2:32:12 PM)

Site Name: SKINNER ANDY & CAROL (EAST WELL)
GWIC Id: 239913
DNRC Water Right: C30030457

Section 1: Well Owner

Owner Name
SKINNER, STEVE
Mailing Address
BOX 5447

City	State	Zip Code
HELENA	MT	59604

Section 2: Location

Township	Range	Section	Quarter Sections
10N	04W	2	NE¼ NW¼ SW¼ SW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.6486855	112.0821219	SUR-GPS	WGS84

Ground Surface Altitude	Method	Datum	Date
4026.52	SUR-GPS	NAVD88	4/18/2011

Measuring Point Altitude	Method	Datum	Date Applies
4028.24	SUR-GPS	NAVD88	10/31/2007

Addition	Block	Lot
EAST WELL		59

Section 3: Proposed Use of Water
DOMESTIC (1)

Section 4: Type of Work
Drilling Method: ROTARY

Section 5: Well Completion Date
Date well completed: Wednesday, October 31, 2007

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	224	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	18	6	0.25		WELDED	A53B STEEL
14	224	4		200.0	WELDED	PVC-SDR 17

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
184	224	4		.020	FACTORY SLOTTED

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	18	BENTONITE	

Section 7: Well Test Data

Total Depth: 224
Static Water Level: 28
Water Temperature:

Air Test *

60 gpm with drill stem set at 224 feet for 1 hours.
Time of recovery 0.08 hours.
Recovery water level 28 feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log
Geologic Source
211SCGR - SCRATCHGRAVEL HILLS STOCK

From	To	Description
0	1	TOPSOIL
1	7	SAND, GRAVEL & CLAY
7	103	FRACTURED GRANITE
103	224	HARD GRANITE

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name: SHAWN TONEY
Company: H & L DRILLING INC
License No: WWC-447
Date Completed: 10/31/2007

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site
View scanned aquifer test (12/20/2011 3:12:01 PM)

Site Name: SKINNER ANDY & CAROL (WEST WELL)
GWIC Id: 239912
DNRC Water Right: C30030456

Section 1: Well Owner

Owner Name
SKINNER, STEVE
Mailing Address
BOX 5447

City	State	Zip Code
HELENA	MT	59604

Section 2: Location

Township	Range	Section	Quarter Sections
10N	04W	2	NW¼ NW¼ SW¼ SW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.6487044	112.0834169	SUR-GPS	WGS84

Ground Surface Altitude	Method	Datum	Date
4031.95	SUR-GPS	NAVD88	4/18/2011

Measuring Point Altitude	Method	Datum	Date Applies
4033.57	SUR-GPS	NAVD88	10/31/2007

Addition	Block	Lot
SUNNY VISTA		58

Section 3: Proposed Use of Water
DOMESTIC (1)

Section 4: Type of Work
Drilling Method: ROTARY

Section 5: Well Completion Date
Date well completed: Wednesday, October 31, 2007

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	144	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	77	6	0.25		WELDED	A53B STEEL
64	144	4		200.0	WELDED	PVC-SDR 17

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
104	144	4		.020	FACTORY SLOTTED

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	77	BENTONITE	

Section 7: Well Test Data

Total Depth: 144
Static Water Level: 25
Water Temperature:

Air Test *

50 gpm with drill stem set at 144 feet for 1 hours.
Time of recovery 0.07 hours.
Recovery water level 25 feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source
211SCGR - SCRATCHGRAVEL HILLS STOCK

From	To	Description
0	1	TOPSOIL
1	9	SAND, GRAVEL & CLAY
9	97	FRACTURED GRANITE
97	144	HARD GRANITE

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name: SHAWN TONEY
Company: H & L DRILLING INC
License No: WWC-447
Date Completed: 10/31/2007

BLM HEAD LANE AQUIFER TEST—GRANITE

BLM-HEAD LANE AQUIFER TEST RESULTS
GRANITE SCRATCHGRAVEL HILLS PROJECT AREA
August 2010—March/April 2011

STEP TEST

14-HOUR CONSTANT RATE TEST
and
48-HOUR CONSTANT RATE TEST

Background:
The Head Lane site is located in the granitic core of the Scratchgravel Hills. The granitic bedrock has essentially no primary permeability, so groundwater flow is through fractures. The following are analyses of a step test (August 2010), a 14-h constant rate aquifer test (August 2010), and a 48-h constant rate aquifer test (March and April 2011) in wells installed on BLM lands in the Scratchgravel Hills. The nearest domestic well is located at a home approximately 2,600 ft west of the pumping well (HL1).

These tests were designed to evaluate aquifer transmissivity and storativity. One 4-in-diameter pumping well (HL1) and one 2-in observation well (HL2) were installed at this site. HL1 and HL2 (GWIC IDs 257312 and 257314, respectively) were installed in early August 2010. A MBMG geologist was present for the installation and verified completion details. For every 10 ft of borehole, samples of cuttings were composited, described, and retained for long-term storage at the MBMG. The GWIC ID numbers provide access to well logs and all measured groundwater levels in the MBMG's GWIC database (http://mbmggwic.mtech.edu; table HL1 and appendix HLB).

For the tests conducted in August 2010, vented transducers were deployed in both wells for the duration of the test. A step test was conducted on HL1, and a constant rate test was run for 14 h. This constant rate test was cut short due to the water falling too near the pump head. Sufficient drawdown to allow analysis of aquifer properties was only recorded in the pumping well (HL1). Measurable drawdown was not detected in HL2.

In March/April 2011, a 48-h constant rate test was conducted at this site. HL1 was again used as the pumping well, and transducers were installed in the wells for the duration of the test. A smaller pump was used to allow discharge to be maintained at a lower rate, but would not cause pump damage. During this test, drawdown was observed in both wells; however, the drawdown in HL2 was sufficiently delayed to indicate that it is not in direct communication with HL1, and as such quantitative analysis of the data was not conducted.

Location:
The test area is located on BLM land in the Scratchgravel Hills, at the north end of Head Lane, in Township 11 N., Range 4 W., section 34, NW¼ NW¼ NE¼ NW¼, in Lewis and Clark County, Montana (figs. HL1, HL2).

Geology:
The aquifer tested is the Cretaceous intrusive Scratchgravel Hills Stock. This unit is described by Reynolds (2000) as "quartz monzonite and monzonite." This is a felsic coarse-grained

Table HL1
Well Designations, Locations, and Completion Information
BLM Head Lane Aquifer Test

GWIC ID	Name	Latitude*	Longitude*	Measuring Point Elevation⁺ (ft-amsl)	Total Depth (ft below MP)	Depth to Water 3/28/11 (ft below MP)	Groundwater Elevation 3/28/11 (ft-amsl)	Distance from HL1 (ft)	Comments
257312	HL1	46.6738521	-112.0997453	4538.19	305	100.94	4437.25	—	Pumping well
257314	HL2	46.6741393	-112.0995922	4545.76	300	91.90	4453.86	112	Observation well
257369	s. 27	46.6781300	-112.0982336	4608.17	400	123.21	4484.96	1600	Upgradient well
65615	Shields	46.6628530	-112.0935292	4245.49	125	17.06	4228.43	4300	Downgradient well

Note. ft-amsl, feet above mean sea level; ft below MP, feet below measuring point. All locations and elevations determined by a licensed surveyor.

*Horizontal Datum is NAD83.

⁺Vertical Datum is NAVD88.

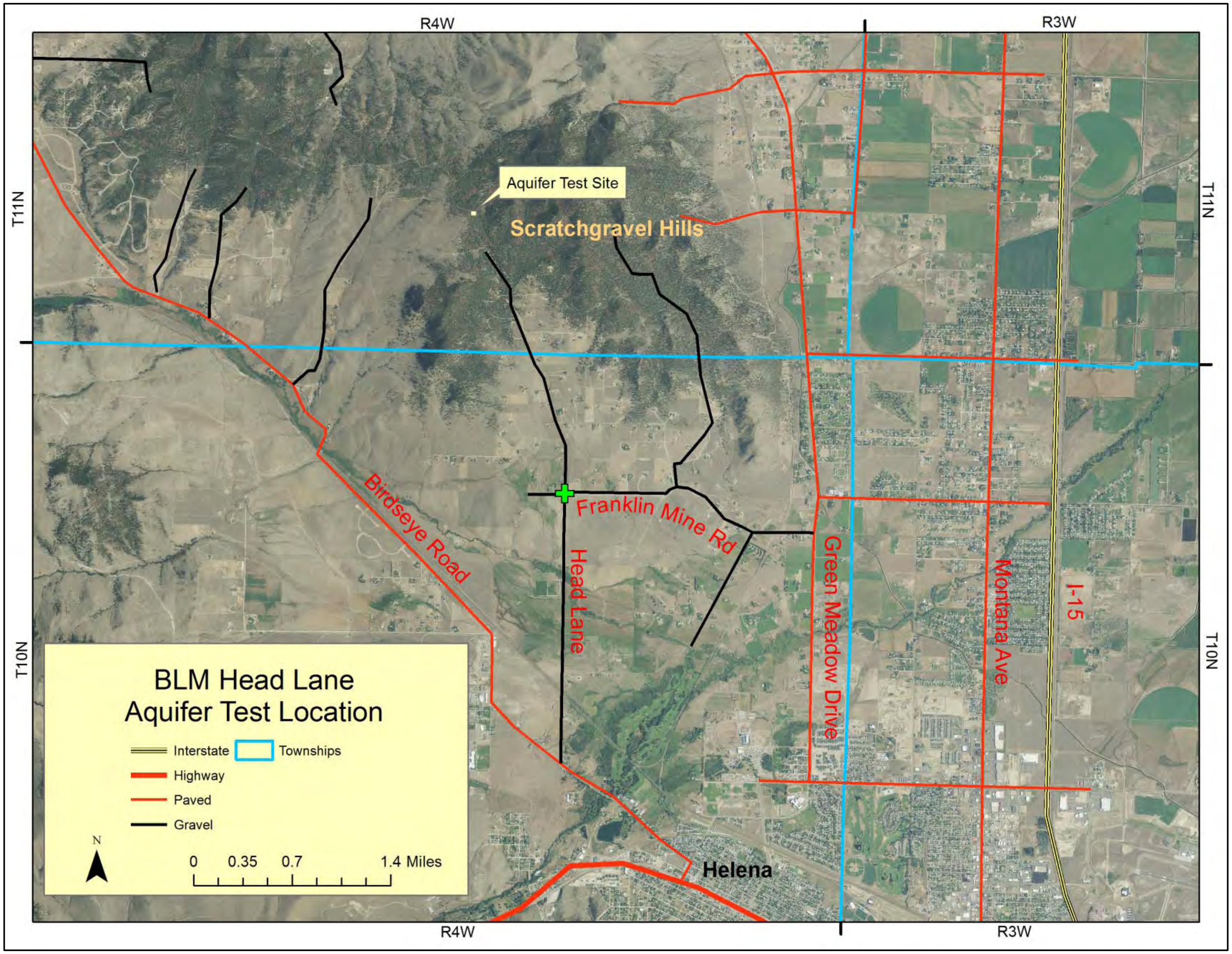


Figure HL1. Location of the BLM-Head Lane Aquifer Test site. The junction of Head Lane and Franklin Mine Road (green cross) is at 46.645228°N latitude and 112.084763°W longitude.

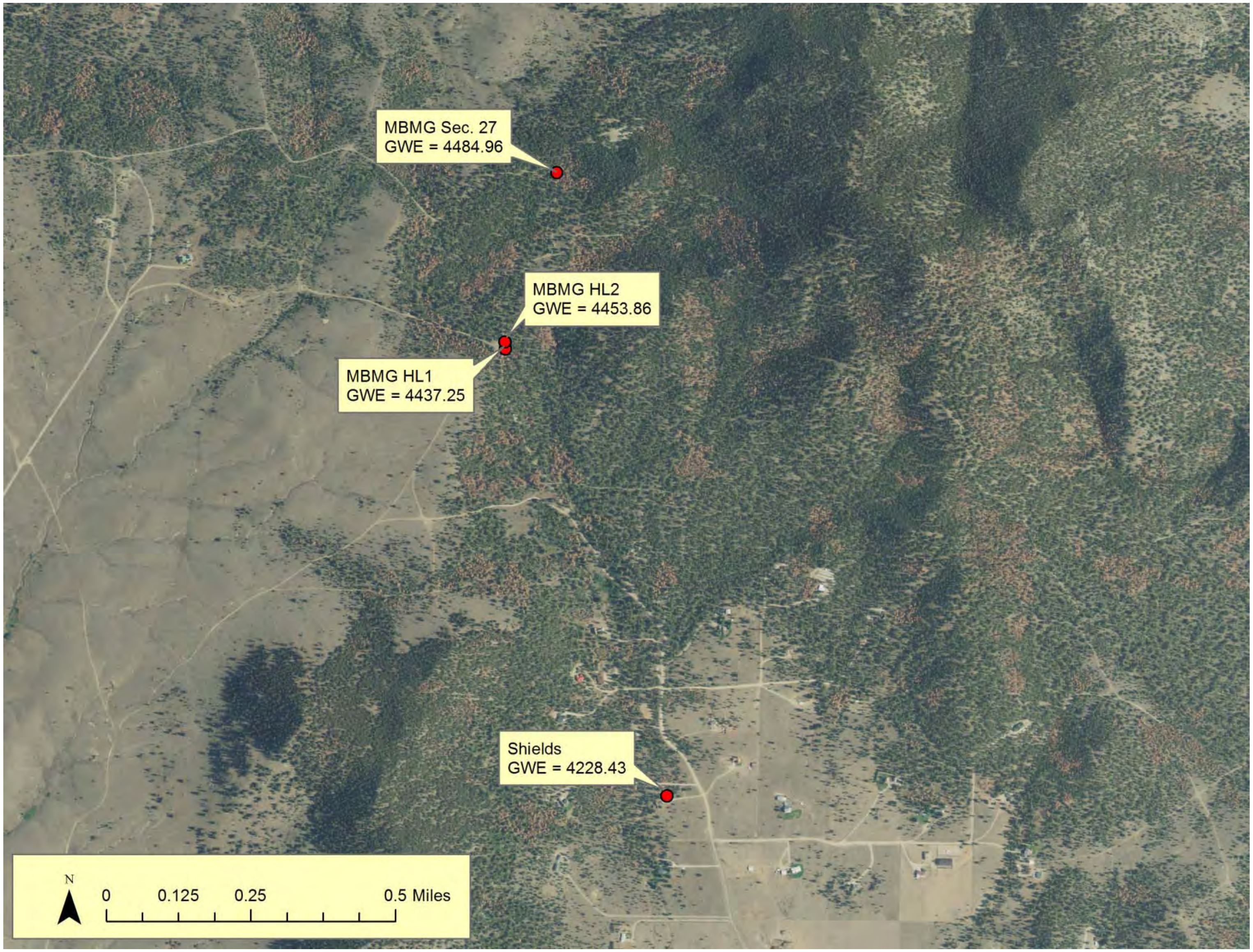


Figure HL2. Site layout and groundwater elevations (March 28, 2011) for the BLM-Head Lane Aquifer Test. This site is located in T. 11 N., R. 4 W., sec. 34, NW¼ NW¼ NE¼ NW¼. Well MBMG HL1 is located at 46.6738521°N latitude and 112.0997453°W longitude.

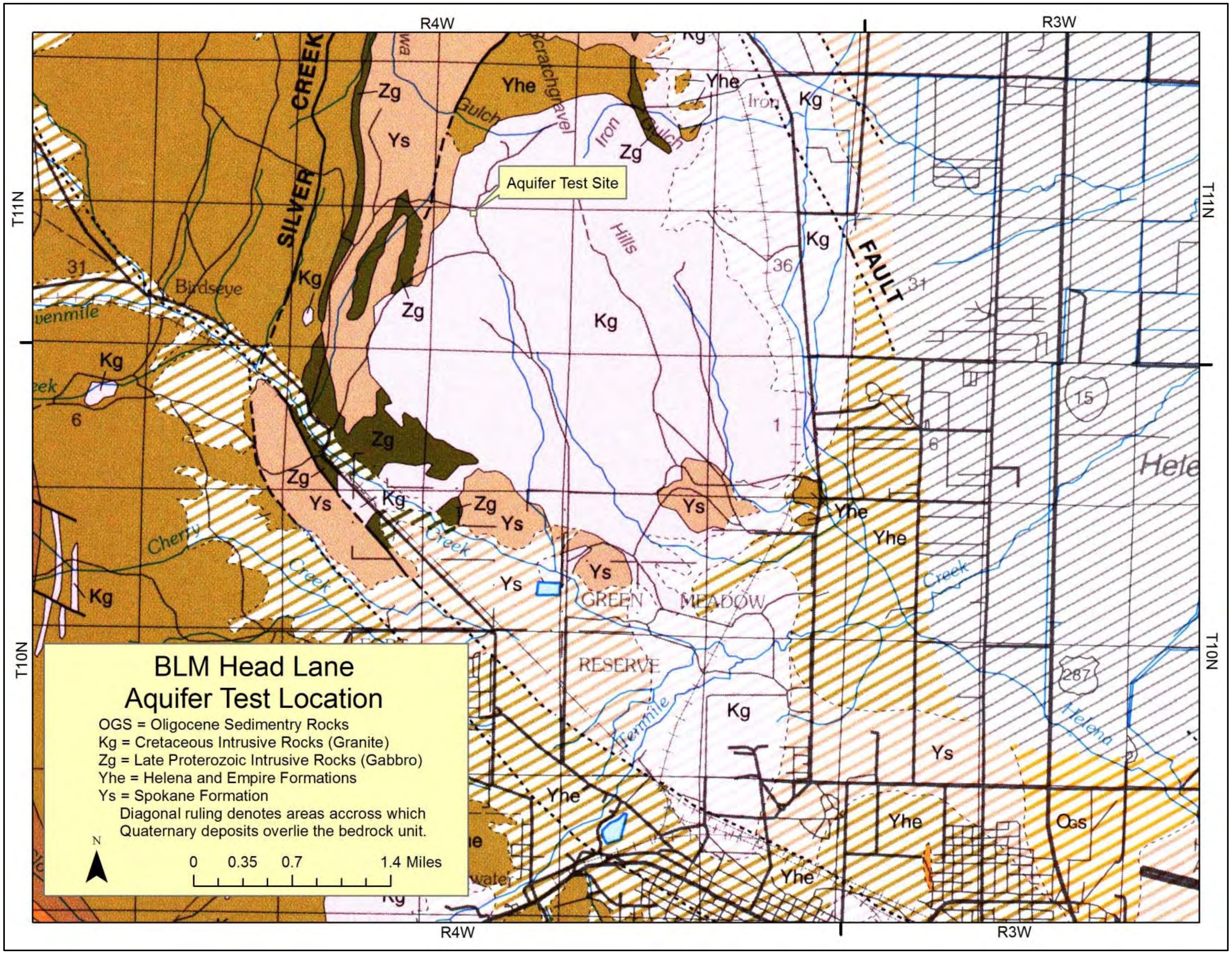


Figure HL3. Geologic map of the Head Lane Aquifer Test area. Geologic map prepared by Reynolds for Thamke, 2000.

igneous rock, and is generally described as “granite.” There are no known faults in the immediate vicinity. There is an unnamed fault mapped approximately 0.3 miles to the west, and the Silver Creek Fault is approximately 1.1 miles west. The northwest–southeast Bald Butte fault zone is located approximately 2 miles to the southwest (fig. HL3).

Well Details:
One 4-in-diameter and one 2-in-diameter PVC-cased wells were installed at this site. The 4-in well has an 8-in steel surface casing, and the 2-in well has a 6-in steel surface casing. The 4-in well (HL1) served as the pumping well and the 2-in well (HL2) served as an observation well.

HL1 was drilled to a total depth of 305 ft and was screened from 236 to 296 ft. HL2 was drilled to 300 ft and was screened from 258 to 298 ft. Both wells were drilled into “white granite” with red, green, and yellow stain.

Static measurements (March 28, 2011; fig. HL2) show that the depth to water in HL1 was 100.94 ft, and depth to water in HL2 was 91.90 ft (elevations of 4437.25 and 4453.86 ft-amsl, respectively). These elevations, in context with a water-level elevation in a well to the north (GWIC 257369) and a water level from a well to the south (GWIC 65615), show that flow is generally southward with an overall gradient of 0.0450 ft/ft. The gradient between HL1 and HL2 is 0.142 ft/ft, which is about three times greater than the overall gradient, indicating that there is not a direct hydrologic connection between these wells.

Water-level monitoring in HL2 between August 2010 and March 2011 (fig. HL4) shows a general rise in groundwater levels, and that short-term variations on the order of 0.3 ft commonly occur. It appears that these variations are due to earth tides, which is an indication that the aquifer is confined.

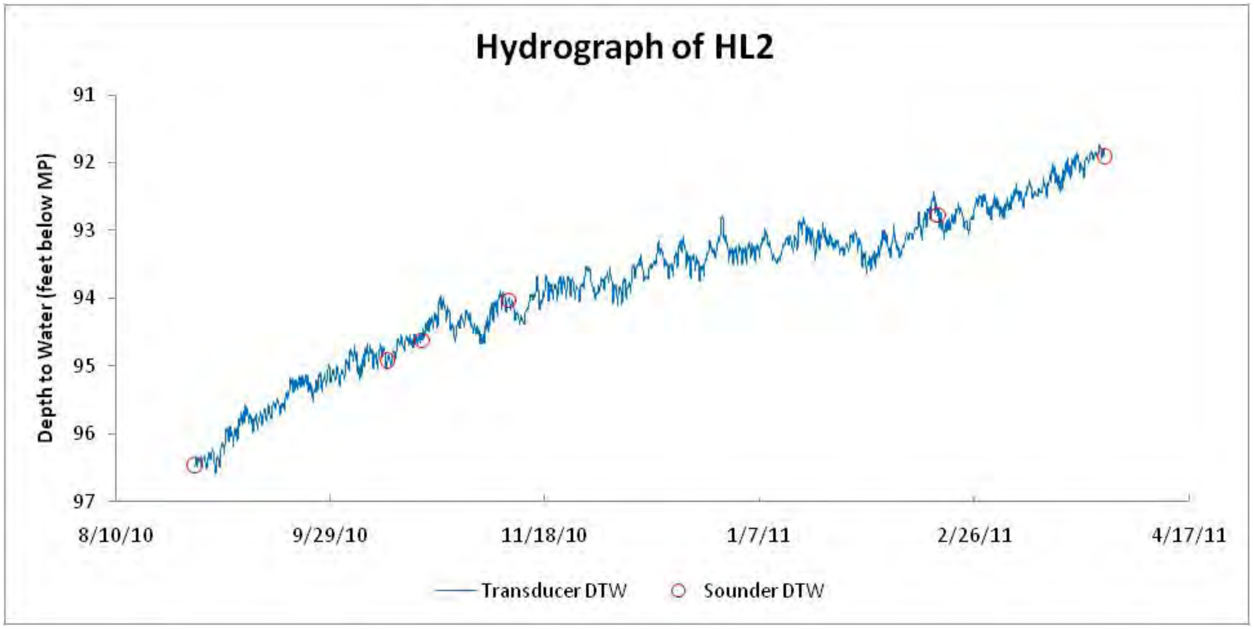


Figure HL4. Hydrograph for HL2 from August 28, 2010 to March 28, 2011.

Methodology:

<u>August 2010 Tests</u>

These aquifer tests were conducted by the MBMG. The pumping rate (1.7 to 3.4 gpm) was monitored throughout the test using a totalizing flow meter. The flow meter was checked throughout the tests using bucket and stopwatch, and there was good agreement between the flow meter and the bucket and stopwatch measurements. Discharge was controlled using a gate valve and diverted from HL1 approximately 200 ft east and away from HL2.

Vented pressure transducers were used to record water levels in the pumping well (HL1) and the observation well (HL2). The transducer used in the pumping well (HL1) is rated at 100 psig (230.7 ft), has a manufacturer-reported accuracy of ±0.05% of the rated pressure (±0.11 ft), and a resolution of ±0.005% of the rated pressure (0.011 ft). The vented transducer used in HL2 is rated at 15 psig (34.61 ft) and has a manufacturer-reported accuracy of ±0.05% of the rated pressure (±0.017 ft), and a resolution of ±0.005% of the rated pressure (0.001 ft).

Manual readings of water levels were made for all wells prior to placing transducers, and were made periodically during the test, during recovery, and prior to uninstalling the transducers. These manual measurements have been used to calibrate transducer response. All water-level data are available from GWIC by using the wells' GWIC ID (http://mbmggwic.mtech.edu/).

The transducers were installed immediately following the development of HL1 on August 12, 2010. Due to its recent development, recovering water levels are apparent in the early data (fig. HL5). The pumping portion of the tests ran from August 16 to August 18, 2010. The vented transducers were left in place until August 28, 2010. Additional recovery data were recorded by the remaining unvented transducer in HL2 until October 20, 2011 (fig. HL6).

March/April 2011 Test

The pumping rate (0.76 to 1.23 gpm) was monitored throughout the test using a totalizing flow meter and an orifice bucket flow meter with a transducer in the piezometer tube (Kaur and others, 2010). The flow meters were checked throughout the test using bucket and stopwatch. There was good agreement between the flow meters and the bucket and stopwatch measurements. Discharge was controlled using a gate valve. The discharge from the pumping well (HL1) was diverted approximately 200 feet east into a drainage and away from HL2.

Non-vented pressure transducers were used to record water levels in the pumping well (HL1), the observation well (HL2), and in the orifice bucket flow meter. The transducer used in the pumping well (HL1) is rated at 100 psia (200 ft), has a manufacturer reported accuracy of ±0.1% of the rated pressure (±0.20 ft), and a resolution of ±0.01% of the rated pressure (0.02 ft). The transducer used in HL2 is rated at 30 psia (35 ft) and has a manufacturer-reported accuracy of ±0.1% of the rated pressure (±0.03 ft) and a resolution of ±0.01% of the rated pressure (0.003 ft). All transducer values were corrected for barometric variation through the use of a barologger rated for 7 to 30 psia with a reported accuracy of 0.1% of the range (±0.05 ft) and a reported resolution of 0.01% of the range (0.005 ft).

Manual readings of water levels were made for all wells prior to placing transducers, and were made periodically during the test, recovery, and prior to uninstalling the transducers. These manual measurements were used to verify transducer response. All water-level data are available from GWIC by using the wells' GWIC ID (http://mbmggwic.mtech.edu/).

The transducers were installed on March 28, 2011 to determine antecedent trends. This was immediately following the installation of the pump, so recovering water levels are apparent in the early data (fig. HL7). The valve was set on March 29, so a short period of drawdown is apparent at that time. The pumping portion of the test ran from March 30 to April 1. All transducers were left in place until April 8. Additional recovery data were recorded via transducer in HL2 until April 19 (fig. HL8).

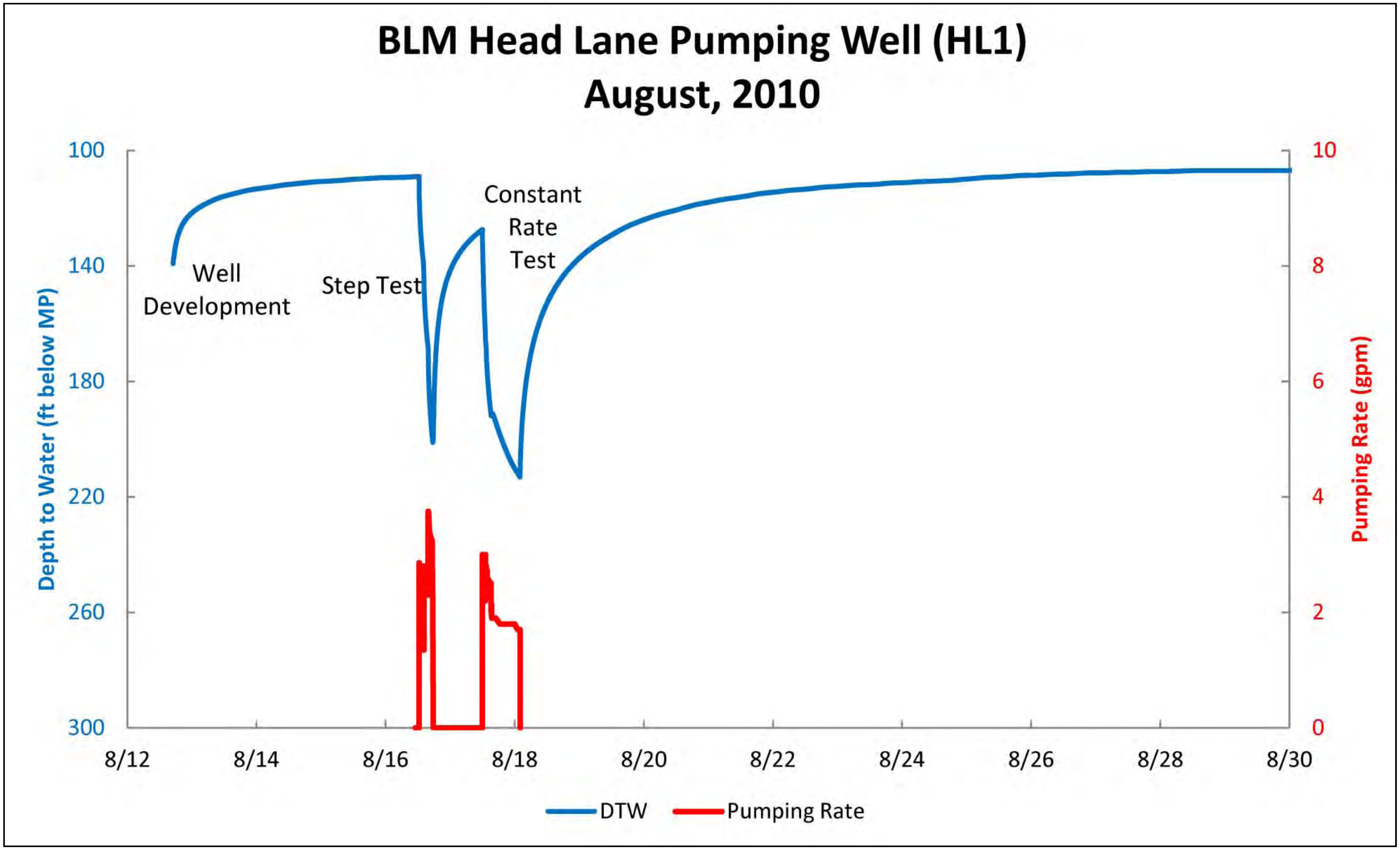


Figure HL5. Depths to water and pumping rates for well HL1 (pumping well) recorded during the 2010 aquifer tests.

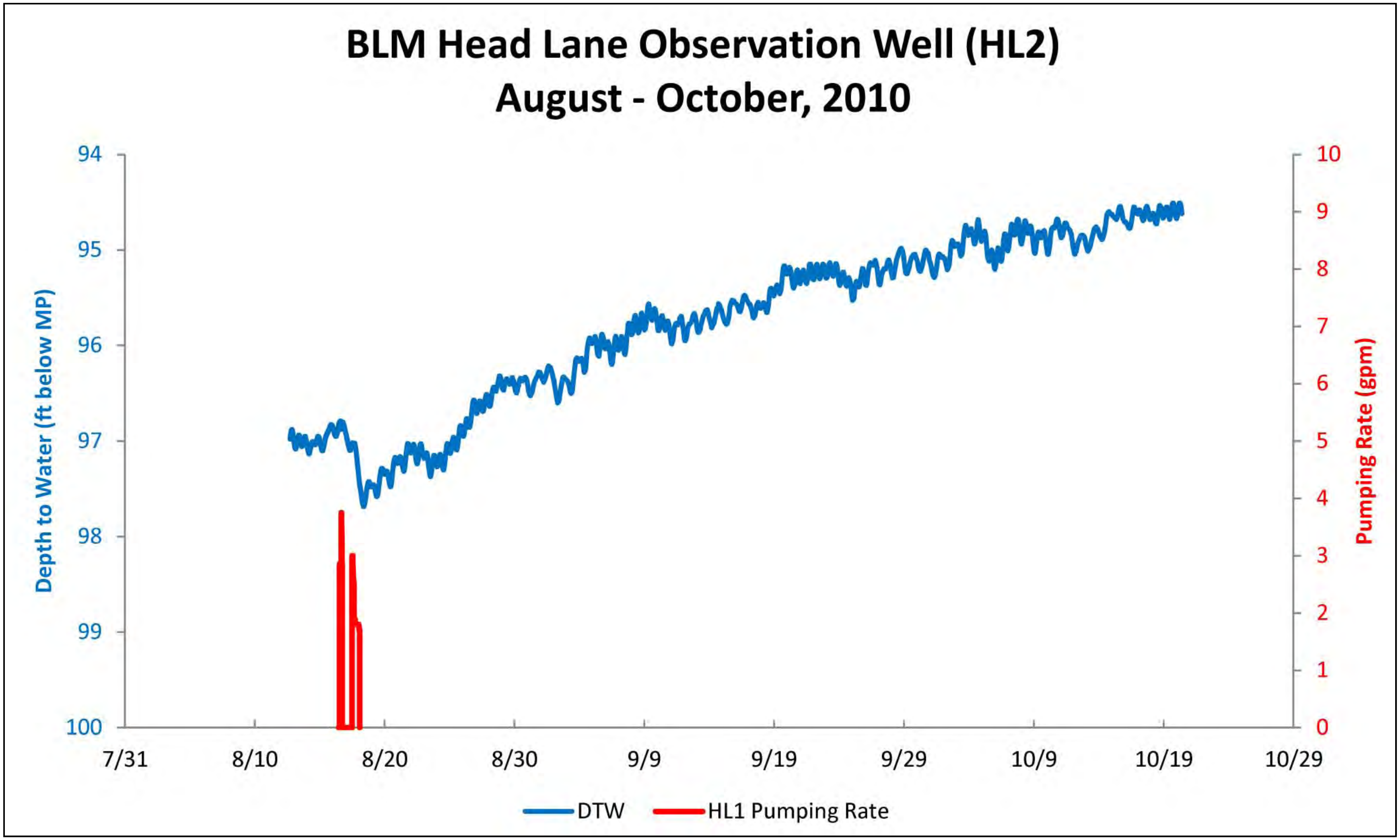


Figure HL6. Depths to water for well HL2 and pumping rates in well HL1 recorded during the 2010 aquifer tests.

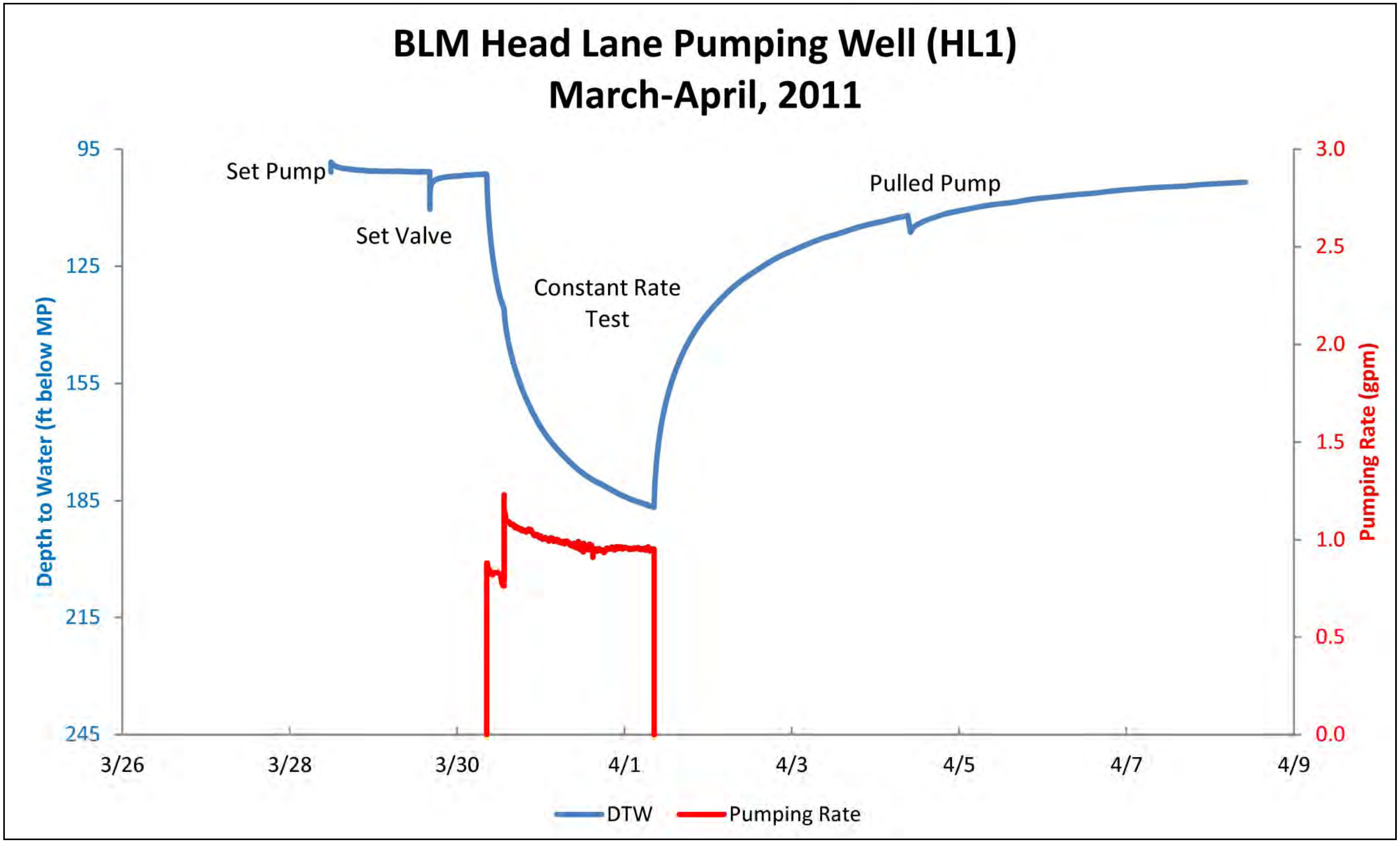


Figure HL7. Depths to water and pumping rates for well HL1 (pumping well) recorded during the 2011 aquifer test.

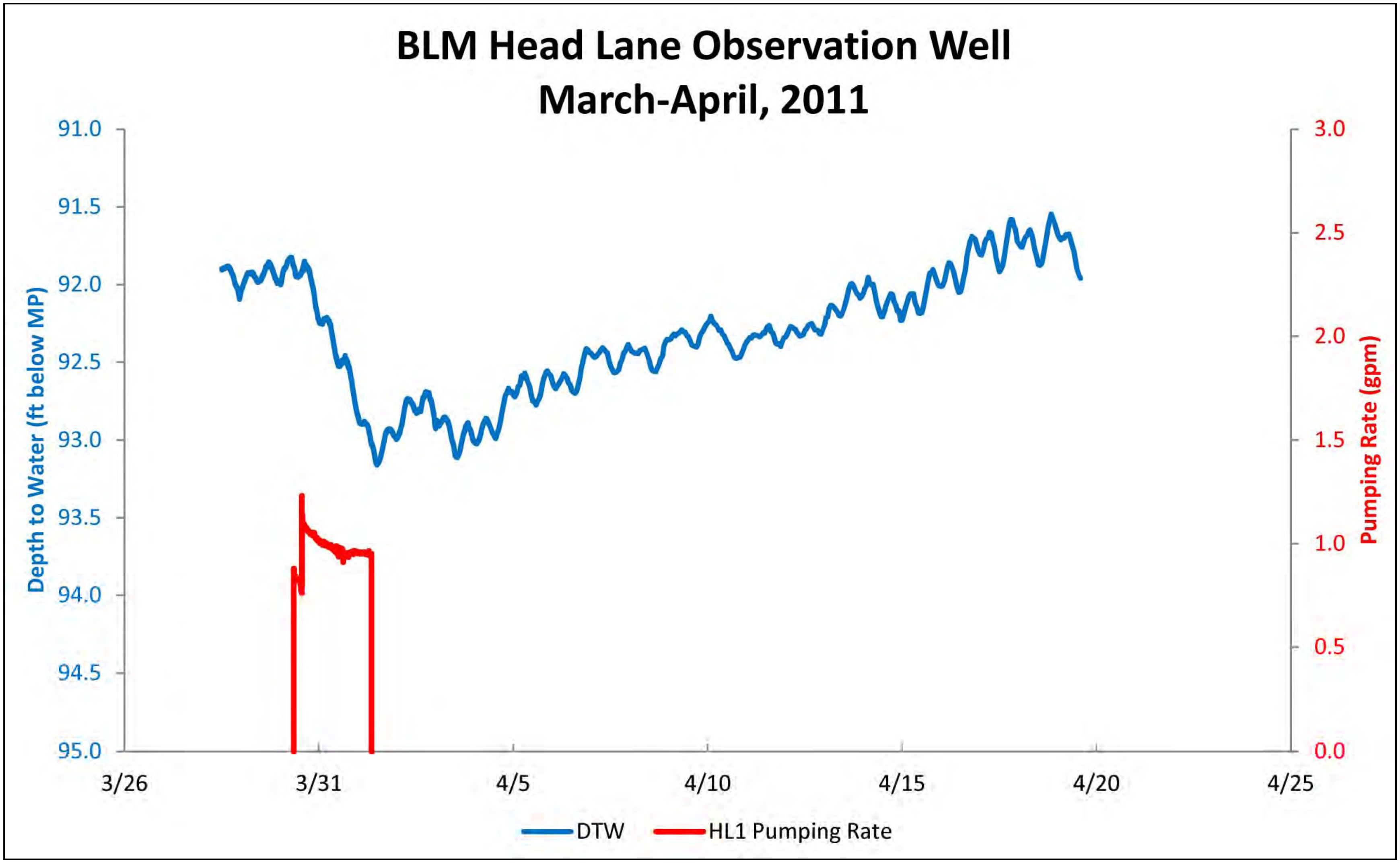


Figure HL8. Depths to water for well HL2 and pumping rates from HL1 recorded during the 2011 aquifer test.

Step Test:

On August 16, 2010, a step test was conducted on HL1 to determine an appropriate constant pumping rate (table HL2, fig. HL9). Because the drawdown did not stabilize during any of the time steps (even though each step was held for more than an hour), and pumping rates were rather variable, further analysis of the data was not warranted. Based on these results it was anticipated that a pumping rate of approximately 2.5 gpm would be sustainable for a 48-h test, with the pump set at 215 ft (115 ft of potential drawdown). As discussed below, the test was stopped at 14 h due to the continued pumping water-level decline.

Table HL2
Step Test Summary
BLM Head Lane—August 16, 2010

Start Step	End Step	Average Rate (Q, gpm)	Final Drawdown (ft)	Q/s (gpm/ft)
12:30	14:15	1.63	30.61	0.053
14:15	15:50	2.46	59.51	0.041
15:50	17:18	3.49	89.97	0.039

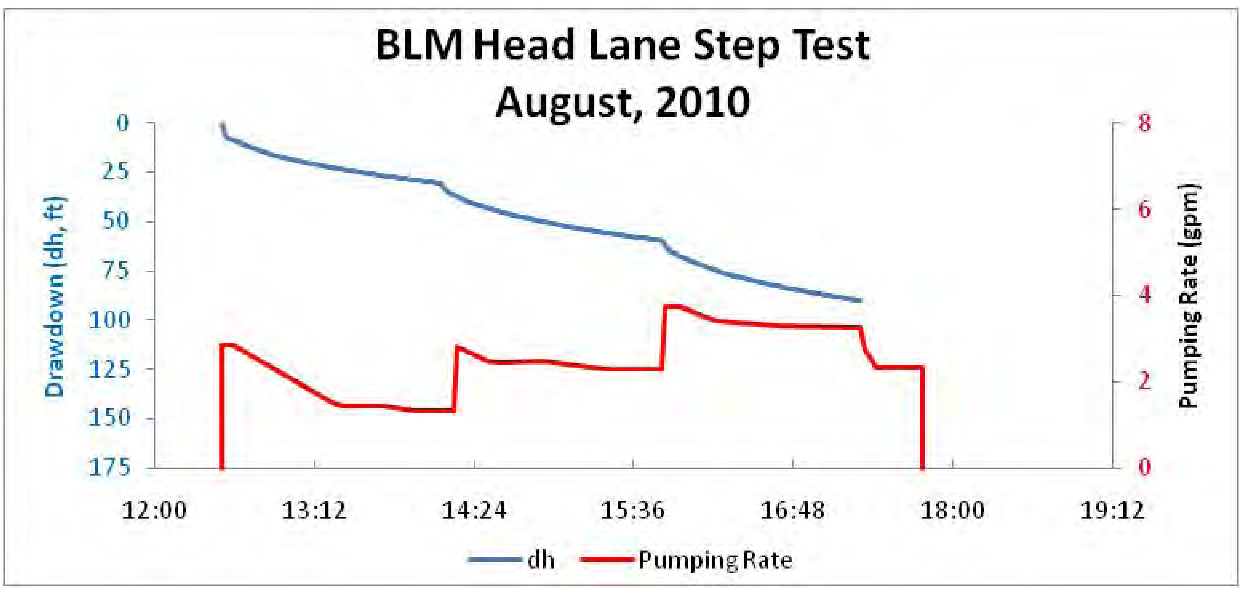


Figure HL9. Drawdown and pumping rates during the step test of well HL1.

The recovery data from this step test (which is less variable than the pumping data) can be analyzed using the Theis recovery method in AQTESOLV (appendix HLA). The analysis produces a calculated transmissivity of 0.75 ft^2/d, which equates to a hydraulic conductivity (K) of $4x10^{-3}$ ft/d.

Constant Rate Test 1:
This test started at 12:00 on August 17, 2010 and ended at 2:00 on August 18, 2010, for a total pumping time of 14 h. The time-weighted average pumping rate was 2.01 gpm. The maximum recorded pumping rate was 3 gpm, and the minimum recorded pumping rate was 1.7 gpm. Due to this relatively high percentage of variability, the aquifer test was analyzed using variable flow solutions in AQTESOLV. The maximum recorded drawdown in well HL1 was 85.61 ft. Pumped water levels in well HL1 showed a rapid initial decline followed by a steady decline (fig. HL5). Pumping water levels declined steadily throughout the pumping period and fell by 1.40 ft during the last hour of pumping. After pumping ceased, well HL1 exhibited rapid initial recovery; however, it took almost 1 day to reach 90% recovery.

Some drawdown was apparent in HL2; however, its delayed onset indicates that the two wells are not directly connected, and so detailed analysis of the data is not warranted. It appears that over short distances the fractured bedrock aquifer does not function as a porous media; however, across large areas potentiometric surfaces can be mapped, showing that approximating the aquifer as porous media at larger scales is reasonable.

Due to the lack of response from the observation well, only the data from HL1 can be analyzed. Given these data, only transmissivity and hydraulic conductivity can be calculated. Storativity requires at least one observation well. Since the recovery data contain the least noise, these data were analyzed first using the Theis recovery method in AQTESOLV. The result is a calculated transmissivity of 0.75 ft^2/d, which equates to a hydraulic conductivity of 4×10^{-3} ft/d. This T value accounts for all observations during the drawdown and step tests (appendix HLA).

Constant Rate Test 2:
This test started at 8:30 on March 30, 2010 and ended at 8:30 on April 1, for a total pumping time of 48 h. The time-weighted average pumping rate was 0.95 gpm. The maximum recorded pumping rate was 1.23 gpm, and the minimum recorded pumping rate was 0.76 gpm. Due to this relatively high percentage of variability, the aquifer test was analyzed using variable flow solutions in AQTESOLV. The maximum recorded drawdown in well HL1 was 84.94 ft. Pumped water levels in well HL1 showed a rapid initial decline followed by a slow, steady decline (fig. HL7). The drawdown increased by 0.29 ft during the last hour of pumping. After pumping ceased, well HL1 exhibited a rapid initial recovery; however, about 3.5 days were needed to reach 90% recovery.

Transmissivity and hydraulic conductivity were calculated using data from the pumping well (HL1). Analysis using AQTESOLV shows that a transmissivity of 0.75 ft^2/d, which equates to a hydraulic conductivity of 4×10^{-3} ft/d, reasonably explains the data from this test (appendix HLA).

Some drawdown was apparent in HL2; however, it was again delayed. The response of this well can be reasonably simulated using a dual porosity model, the K-value determined from the pumping well data (4 x 10^{-3} ft/d) and reasonable values for storativity (Moench, 1984; appendix HLA). Since the storativity of matrix blocks and the storativity of the fractures both influence the resonance in the observation well, nether can be solved for explicitly, and these values should be treated as rough estimates.

Summary:

It appears that the most representative K value for this test is about 4 x 10^{-3} ft/d. The well could only sustain a yield of approximately 1 gpm. It is also seen that over short distances the aquifer does not function as a porous media, even though other work shows that the aquifer can be approximated as porous media across wider areas.

References:

ASTM, 2008, Standard test method (field procedure) for withdrawal and injection well tests for determining hydraulic properties of aquifer systems, D4050-96 (Reapproved 2008).

ASTM, 2008, Standard test method (analytical procedure) for determining transmissivity and storage coefficient of nonleaky confined aquifers by the modified Theis nonequilibrium method, D4105-96 (Reapproved 2008).

Cooper, H.H., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history, Transactions, American Geophysical Union, v. 24, p. 526–534.

Driscoll, F.G., 1986, Groundwater and wells, 2nd ed: St. Paul, Minn., Johnson Division..

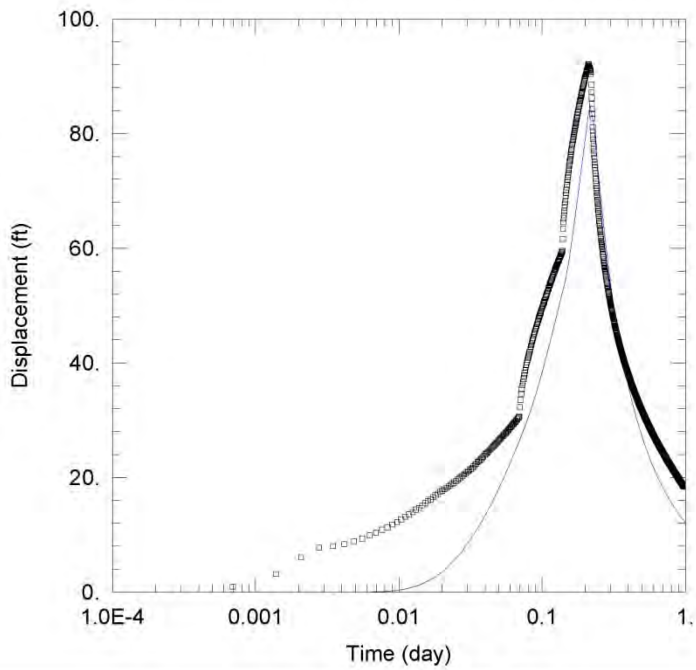
Fetter, C.W., 1994, Applied hydrogeology, 3rd ed.: New York, Macmillan College Publishing, 691 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice Hall, 604 p.

Monech, A.F., 1984, Double-porosity models for a fissured groundwater reservoir with fracture skin, Water Resources Research, v. 20, no. 7, p. 831–846.

Reynolds, Mitchell W., 2000, Generalized bedrock geologic map of the Helena area, west-central Montana, *in* Thamke, J.N., 2000, Hydrology of area bedrock west-central Montana, 1993–98, U.S. Geological Survey Water Resources Investigations Report 00-4212.

Appendix HLA—AQTESOLV Analysis



HEAD LANE AQUIFER TEST

Data Set: M:\...\steptest Recovery.aqt
Date: 05/03/11 Time: 14:26:32

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: HL1
Test Date: Aug, 2010

AQUIFER DATA

Saturated Thickness: 200. ft
Anisotropy Ratio (Kz/Kr): 1.
Aquitard Thickness (b'): 1. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
HL1	0	0

Observation Wells

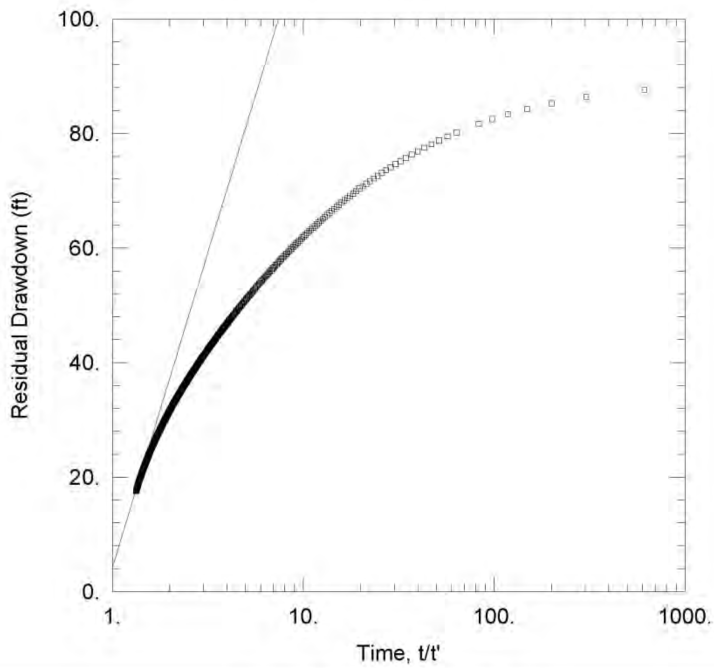
Well Name	X (ft)	Y (ft)
▫ HL1	0	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush

T = 0.75 ft^2/day
S = 0.85
r/B' = 1.0E-5
ß' = 1.0E-5
r/B" = 0.
ß" = 0.

Analysis of step test from well HL1.



HEAD LANE AQUIFER TEST

Data Set: M:\...\Recovery from steptest.aqt
Date: 05/05/11 Time: 15:20:09

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: HL1
Test Date: Aug, 2010

AQUIFER DATA

Saturated Thickness: 200. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
HL1	0	0

Observation Wells

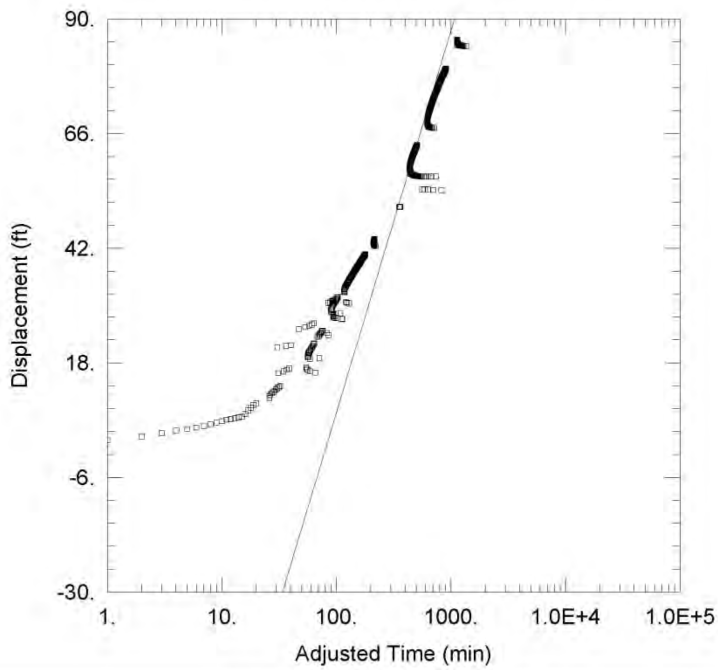
Well Name	X (ft)	Y (ft)
▫ HL1	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 0.75 ft^2/day S/S' = 0.92

Analysis of recovery data from well HL1 step test.



HEAD LANE AQUIFER TEST #1

Data Set: M:\...\dh_CJ.aqt
Date: 05/03/11 Time: 14:23:54

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: HL1
Test Date: 8/17/10

AQUIFER DATA

Saturated Thickness: 200. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
HL1	0	0

Observation Wells

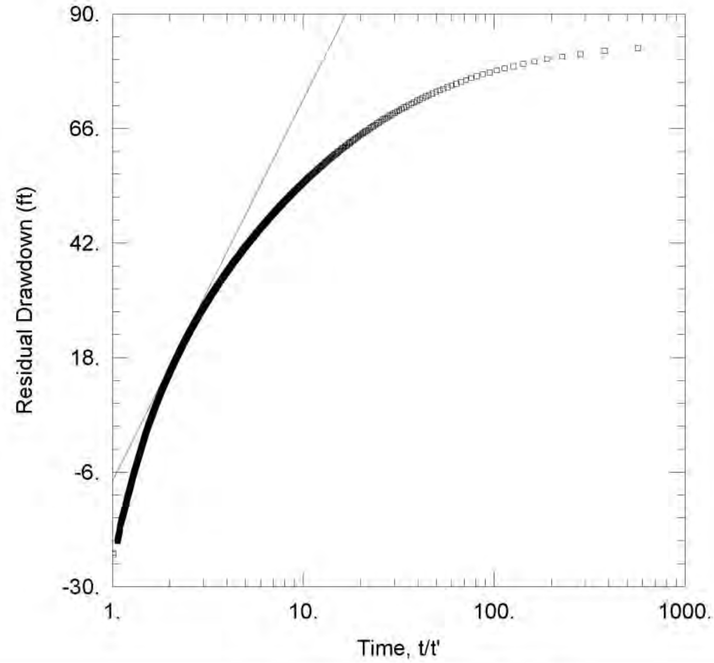
Well Name	X (ft)	Y (ft)
▫ HL1	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 0.75 ft^2/day S = 0.85

Analysis of drawdown data from well HL1 Constant Rate Test 1.



HEAD LANE AQUIFER TEST #1

Data Set: M:\...\Recovery.aqt
Date: 05/03/11 Time: 14:23:01

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: HL1
Test Date: 8/17/10

AQUIFER DATA

Saturated Thickness: 200. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
HL1	0	0

Observation Wells

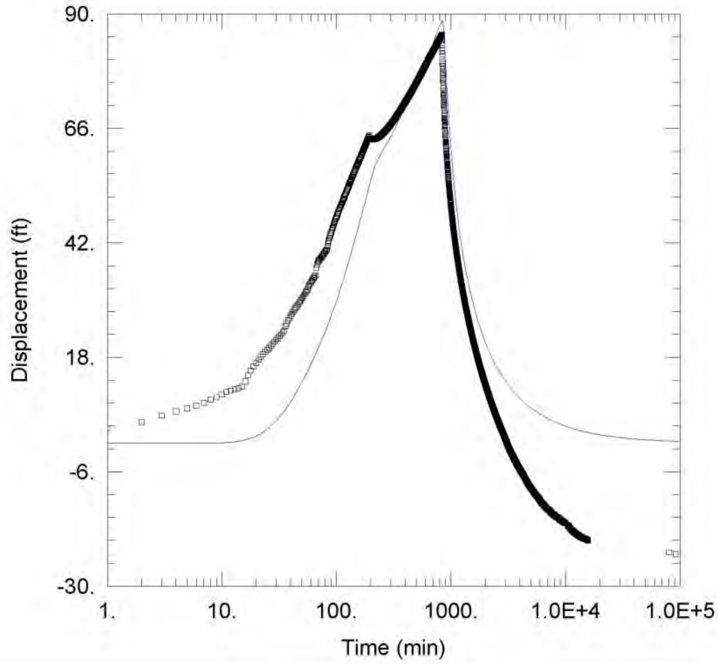
Well Name	X (ft)	Y (ft)
▫ HL1	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 0.75 ft^2/day S/S' = 1.259

Analysis of recovery data from well HL1 Constant Rate Test 1.



HEAD LANE AQUIFER TEST #1

Data Set: M:\...\dh_T.aqt
Date: 05/05/11
Time: 15:34:44

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: HL1
Test Date: 8/17/10

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
HL1	0	0

Observation Wells

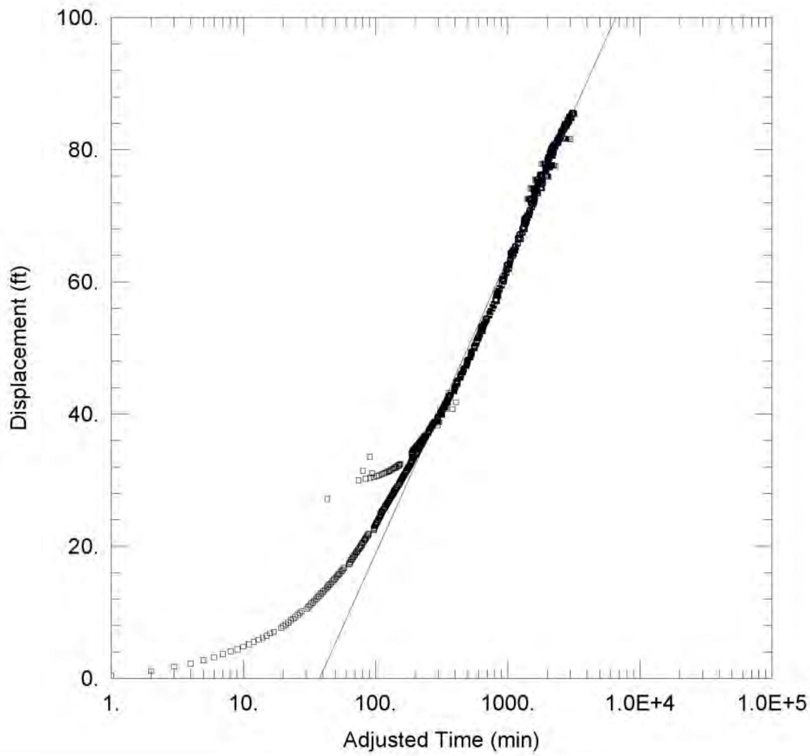
Well Name	X (ft)	Y (ft)
▫ HL1	0	0

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 0.75 ft^2/day
S = 0.9509
Kz/Kr = 1.
b = 200. ft

Analysis of drawdown and recovery data from well HL1 Constant Rate Test 1.



BLM HEAD LANE TEST SITE

Data Set: M:\...\HL1_CR_T.aqt
Date: 05/05/11 Time: 15:47:27

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: HL1
Test Date: 3/30/11 - 4/1/11

AQUIFER DATA

Saturated Thickness: 200. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
HL1	0	0

Observation Wells

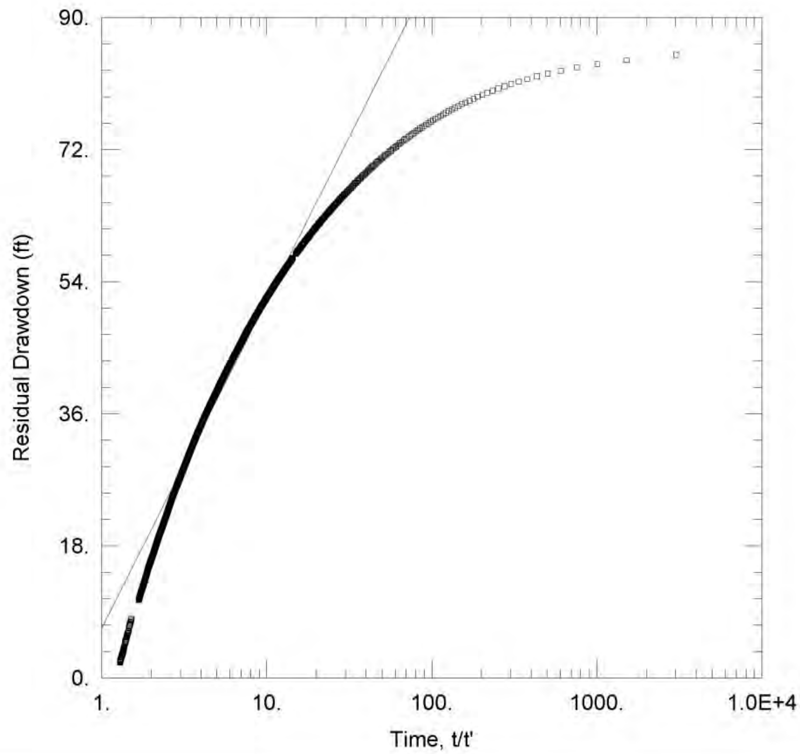
Well Name	X (ft)	Y (ft)
□ HL1	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 0.75 ft^2/day S = 0.4

Analysis of drawdown data from well HL1 Constant Rate Test 2.



BLM HEAD LANE TEST SITE

Data Set: M:\...\HL1_CR_T.aqt
Date: 05/05/11 Time: 15:48:08

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: HL1
Test Date: 3/30/11 - 4/1/11

AQUIFER DATA

Saturated Thickness: 200. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
HL1	0	0

Observation Wells

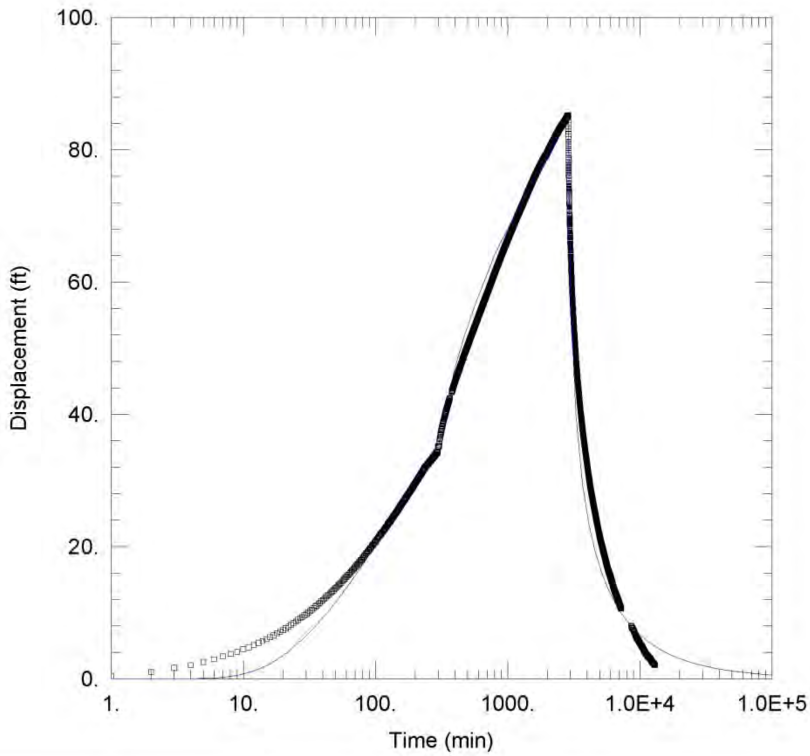
Well Name	X (ft)	Y (ft)
▫ HL1	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 0.75 ft^2/day S/S' = 0.7079

Analysis of recovery data from well HL1 Constant Rate Test 2.



BLM HEAD LANE TEST SITE

Data Set: M:\...\HL1_CR_T.aqt
Date: 05/05/11 Time: 15:47:01

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: HL1
Test Date: 3/30/11 - 4/1/11

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
HL1	0	0

Observation Wells

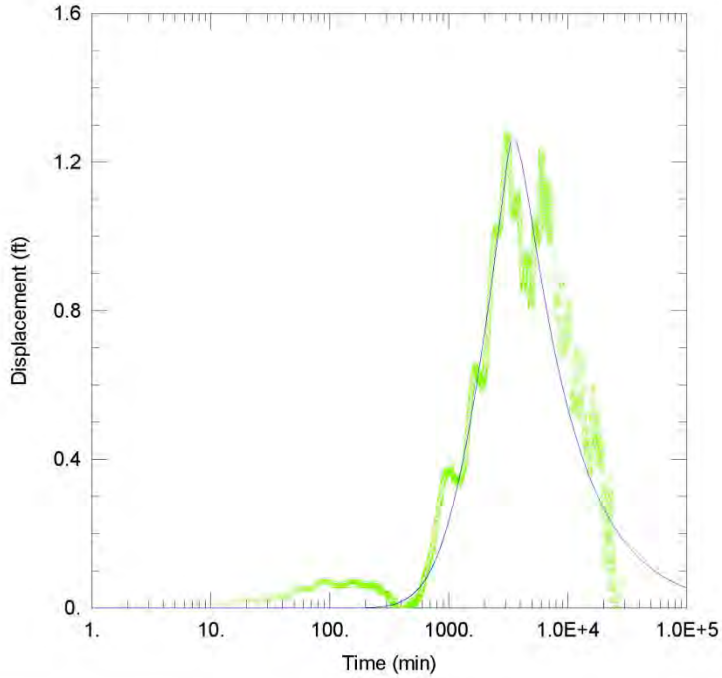
Well Name	X (ft)	Y (ft)
▫ HL1	0	0

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 0.75 ft^2/day
S = 0.4
Kz/Kr = 1.
b = 200. ft

Analysis of drawdown and recovery data from well HL1 Constant Rate Test 2.



BLM HEAD LANE TEST SITE

Data Set: M:\...\HL2_CR_frac.aqt
Date: 09/23/13
Time: 13:26:07

PROJECT INFORMATION

Company: MBMG
Client: GWIP - Scratchgravel Hills
Project: BWIPSG
Location: Helena, MT
Test Well: HL1
Test Date: 3/30/11 - 4/1/11

AQUIFER DATA

Saturated Thickness: 200. ft
Spherical Block Diameter: 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
HL1	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
HL2	0	112

SOLUTION

Aquifer Model: Fractured
Solution Method: Moench w/spherical blocks

K = 0.04 ft/day
K' = 1.0E-5 ft/day
Sw = 0.
r(w) = 0.333 ft
Ss = 1.0E-5 ft^{-1}
Ss' = 2.0E-6 ft^{-1}
Sf = 5.
r(c) = 0.1667 ft

Analysis of drawdown and recovery data from well HL2 Constant Rate Test 2, using a dual porosity model.

Appendix HLB—Well Logs

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site
View scanned update/correction (10/21/2010 1:04:32 PM)
View scanned aquifer test (12/14/2011 9:38:57 AM)
View scanned aquifer test (12/14/2011 5:01:16 PM)
View scanned aquifer test (12/15/2011 10:23:06 AM)

Site Name: MBMG-BLM-HL1
GWIC Id: 257312

Section 1: Well Owner

Owner Name
BLM
Mailing Address

City	State	Zip Code
BUTTE	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
11N	04W	34	NW¼ NW¼ NE¼ NW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.6738521	112.0997453	SUR-GPS	WGS84

Ground Surface Altitude	Method	Datum	Date
4536.71	SUR-GPS	NAVD88	4/18/2011

Measuring Point Altitude	Method	Datum	Date Applies
4538.19	SUR-GPS	NAVD88	7/28/2010

Addition	Block	Lot

Section 3: Proposed Use of Water

MONITORING (1)

Section 4: Type of Work

Drilling Method: ROTARY

Section 5: Well Completion Date

Date well completed: Tuesday, August 03, 2010

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	26	12
26	305	8

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	26	8	0.25		WELDED	A53B STEEL
-2	296	4.5			SPLINE	PVC

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
236	296	4.5			SCREEN-CONTINUOUS-PVC

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?

Section 7: Well Test Data

Total Depth: 305
Static Water Level: 110
Water Temperature:

Air Test *

_10_ gpm with drill stem set at _300_ feet for _1_ hours.
Time of recovery _1_ hours.
Recovery water level _110_ feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source
211SCGR - SCRATCHGRAVEL HILLS STOCK

From	To	Description
0	1	TOPSOIL
1	25	WEATHERED WHITE GRANITE WITH LITTLE ORANGE STAIN
25	30	WHITE GRANITE WITH LITTLE ORANGE STAIN
30	160	WHITE GRANITE WITH LITTLE ORANGE STAIN AND TRACE GREEN STAIN
160	190	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE STAIN
190	200	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE, STAIN. SOME FELDSPAR IS ALTERED.
200	210	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE, STAIN.
210	240	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE, STAIN. SOME FELDSPAR IS ALTERED.
240	270	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE, STAIN.
270	300	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE, STAIN AND TRACE WHITE FRACTURE FILL
300	305	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE, STAIN.

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of

0	26	BENTONITE	Y
0	225	BENTONITE GROUT	
225	230	BENTONITE CHIPS	
230	305	GRAVEL PACK	

my knowledge.

Name:	BRITT LINDSAY
Company:	LINDSAY DRILLING
License No:	WWC-570
Date Completed:	8/3/2010

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site

Site Name: MBMG-BLM-HL2
GWIC Id: 257314

Section 1: Well Owner

Owner Name
BLM

Mailing Address

City	State	Zip Code
BUTTE	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
11N	04W	34	NW¼ NW¼ NE¼ NW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.6741393	112.0995922	SUR-GPS	WGS84

Ground Surface Altitude	Method	Datum	Date
4544.7	SUR-GPS	NAVD88	4/18/2011

Measuring Point Altitude	Method	Datum	Date Applies
4545.76	SUR-GPS	NAVD88	7/30/2010

Addition	Block	Lot

Section 3: Proposed Use of Water
MONITORING (1)

Section 4: Type of Work
Drilling Method: ROTARY

Section 5: Well Completion Date
Date well completed: Friday, August 06, 2010

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	26	8
26	300	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	26	6	0.25		WELDED	ABS-SCHED 80
-2	298	2			FLUSH THREAD	PVC

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
258	298	2		40 SLOT	SCREEN-CONTINUOUS-PVC

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?

Section 7: Well Test Data

Total Depth: 300
Static Water Level: 96
Water Temperature:

Air Test *

5 gpm with drill stem set at 300 feet for 1 hours.
Time of recovery 1 hours.
Recovery water level 100 feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source
211SCGR - SCRATCHGRAVEL HILLS STOCK

From	To	Description
0	1	TOPSOIL
1	20	WEATHERED WHITE GRANATE WITH LITTLE GREEN STAIN AND LITTLE BROWN SILTY CLAY
20	40	WHITE GRANITE WITH SOME ORANGE STAIN AND LITTLE GREEN STAIN (SOFT)
40	120	WHITE GRANITE WITH RED STAIN AND LITTLE GREEN STAIN (SOFT)
120	140	WHITE GRANITE WITH RED STAIN AND SOME GREEN STAIN (SOFT)
140	300	WHITE GRANITE WITH RED AND GREEN STAIN

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name: BRITT LINDSAY
Company: LINDSAY DRILLING CO INC
License No: WWC-570
Date Completed: 8/6/2010

0	26	BENTONITE	Y
0	214	BENTONITE GROUT	
214	248	BENTONITE CHIPS	
248	300	GRAVEL PACK	

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site

Site Name: MBMG-BLM-S.27
GWIC Id: 257369

Section 1: Well Owner

Owner Name
BLM
Mailing Address

City	State	Zip Code
BUTTE	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
11N	04W	27	SE¼ SW¼ NE¼ SW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.67813	112.0982336	SUR-GPS	WGS84

Ground Surface Altitude	Method	Datum	Date
4605.84	SUR-GPS	NAVD88	4/18/2011

Measuring Point Altitude	Method	Datum	Date Applies
4608.17	SUR-GPS	NAVD88	8/12/2010

Addition	Block	Lot

Section 3: Proposed Use of Water

MONITORING (1)

Section 4: Type of Work

Drilling Method: ROTARY

Section 5: Well Completion Date

Date well completed: Monday, August 09, 2010

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	27	10
27	400	8

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	27	8	0.25		WELDED	A53B STEEL
-2	398	4			SPLINE	PVC

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
318	398	4	160	5/16"	PERFORATED CASING

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	27	BENTONITE	Y
0	300	BENTONITE	

Section 7: Well Test Data

Total Depth: 400
Static Water Level: 135
Water Temperature:

Air Test *

2 gpm with drill stem set at 390 feet for 1 hours.
Time of recovery 1 hours.
Recovery water level 135 feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source
211SCGR - SCRATCHGRAVEL HILLS STOCK

From	To	Description
0	1	TOPSOIL
1	3	WEATHERED WHITE GRANITE
3	10	WHITE GRANITE WITH SOME ORANGE AND LITTLE GREEN STAIN
10	20	WHITE GRANITE WITH RED STAIN, LITTLE GREEN AND ORANGE STAIN, TRACE PINK STAINED RYOLITE
20	25	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE STAIN, TRACE PINK RYOLITE
25	60	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE STAIN
60	70	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE STAIN, AND TRACE WHITE VAIN MATERIAL
70	90	WHITE GRANITE WITH RED, GREEN, AND ORANGE STAIN
90	100	WHITE GRANITE WITH RED AND GREEN STAIN, LITTLE ORANGE STAIN
100	110	WHITE GRANITE WITH RED, GREEN, AND ORANGE STAIN
110	120	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE ORANGE STAIN
120	150	WHITE GRANITE WITH RED AND GREEN STAIN
150	160	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE ORANGE STAIN
160	170	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE ORANGE STAIN AND TRACE WHITE FRACTURE FILL
170	190	WHITE GRANITE WITH RED AND GREEN STAIN

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of

300	400	GRAVEL PACK	

my knowledge.

Name: BRITT LINDSAY
Company: LINDSAY DRILLING
License No: MWC-337
Date Completed: 8/9/2010

Site Name: MBMG-BLM-S.27
GWIC Id: 257369
Additional Lithology Records

From	To	Description
190	200	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE PYRITE
200	250	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE ORANGE STAIN
250	260	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE ORANGE STAIN, TRACE PYRITE, TRACE WHITE FRACTURE FILL
260	290	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE ORANGE STAIN, TRACE WHITE FRACTURE FILL
290	350	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE ORANGE STAIN
350	370	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE ORANGE STAIN, TRACE PYRITE
370	390	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE ORANGE STAIN
390	400	WHITE GRANITE WITH RED AND GREEN STAIN, TRACE ORANGE STAIN, TRACE WHITE FRACTURE FILL

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site
View water quality for this site
View scanned well log (12/1/2006 9:40:35 AM)

Site Name: SHIELDS, RONALD
GWIC Id: 65615
DNRC Water Right: C007867-00

Section 1: Well Owner

Owner Name
SHIELDS RONALD
Mailing Address
6184 HEAD DR

City	State	Zip Code
HELENA	MT	59601

Section 2: Location

Township	Range	Section	Quarter Sections
11N	04W	34	NE¼ NW¼ SW¼ SE¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.662853	112.0935292	SUR-GPS	WGS84

Ground Surface Altitude	Method	Datum	Date
4244.51	SUR-GPS	NAVD88	4/18/2011

Measuring Point Altitude	Method	Datum	Date Applies
4245.49	SUR-GPS	NAVD88	11/24/2004 1:10:00 PM

Addition	Block	Lot
SUNNY VISTA		

Section 3: Proposed Use of Water

DOMESTIC (1)

Section 4: Type of Work

Drilling Method: AIR ROTARY

Section 5: Well Completion Date

Date well completed: Wednesday, February 25, 1976

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	125	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
0	20	6				STEEL
10	125	4				PVC

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
85	125	4			SLOTS

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	20	MUD	

Section 7: Well Test Data

Total Depth: 125
Static Water Level: 10
Water Temperature:

Air Test *

_8_ gpm with drill stem set at _ feet for _3_ hours.
Time of recovery _ hours.
Recovery water level _ feet.
Pumping water level _120_ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source
211SCGR - SCRATCHGRAVEL HILLS STOCK

From	To	Description
0	4	TOPSOIL
4	12	DECOMPOSED RYOLITE
12	125	RYOLITE BEDROCK

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:
Company: LINDSAY DRILLING CO INC
License No: WWC-38
Date Completed: 2/25/1976

BLM WEST FAULT AQUIFER TEST—
HELENA AND EMPIRE FORMATIONS

WEST FAULT AQUIFER TEST RESULTS
HELENA AND EMPIRE FORMATIONS
SCRATCHGRAVEL HILLS PROJECT AREA
March–April 2011

STEP TEST
and
24-HOUR CONSTANT RATE TEST

Background:
This site straddles the Silver Creek Fault, with the Empire Formation to the east and the Helena Formation to the west. These units have essentially no primary permeability, and groundwater flow is through fractures. The following are analyses of a step test and a 24-h constant rate pumping test performed using wells installed on BLM lands in the Scratchgravel Hills Study Area in March and April 2011. The purpose of the test was to evaluate the hydraulic function of the fault. There are no residences in the area. The closest pumped well is approximately 1,800 ft distant.

Two wells were installed on the east side of the fault (WF1 and WF2), and two wells were installed on the west side of the fault (WF3 and WF4). All wells were installed in August 2010. A MBMG geologist was present for the installation, and completion details were verified. For every 5 ft of borehole, samples of cuttings were composited, described, and retained for long-term storage at the MBMG. The east side wells were drilled to depths where the fractured bedrock was saturated and able to produce water. West side wells were drilled until fault gouge was encountered, then backfilled with bentonite and completed in the western (upper) block. Well logs and all measured groundwater levels are available on the MBMG's GWIC database (http://mbmggwic.mtech.edu) by using the GWIC ID. A summary of completion details are provided in table WF1.

Transducers were deployed in WF1 (east side) and WF4 (west side) in August 2010 for long-term monitoring. Information from these transducers shows that water-level elevations in WF1 are consistently higher than those in WF4 and have more short-term variability (fig. WF1). These differences suggests that recharge is from the east (higher topography areas of the Scratchgravel Hills) and that the fault is likely a barrier to flow.

Location:
The test area is located in the Scratchgravel Hills northwest of Helena, MT. This is in Township 11 N., Range 4 W., section 28, SW¼ SW¼, in Lewis and Clark County, Montana (figs. WF2, WF3).

Geology:
This site is located on the Silver Creek Fault, with the Helena Formation to the west and the Empire Formation to the east (fig. WF4).

Well Details:
WF1 is a 340-ft-deep, 4-in PVC well with screen from 238 to 338 ft. WF2 is a 405-ft, 4-in PVC well with screen from 303 to 403 ft. WF3 is a 72-ft, 2-in PVC well, with screen from 62 to 72 ft. WF4 is a 180-ft, 2-in PVC well, with screen from 158 to 178 ft.

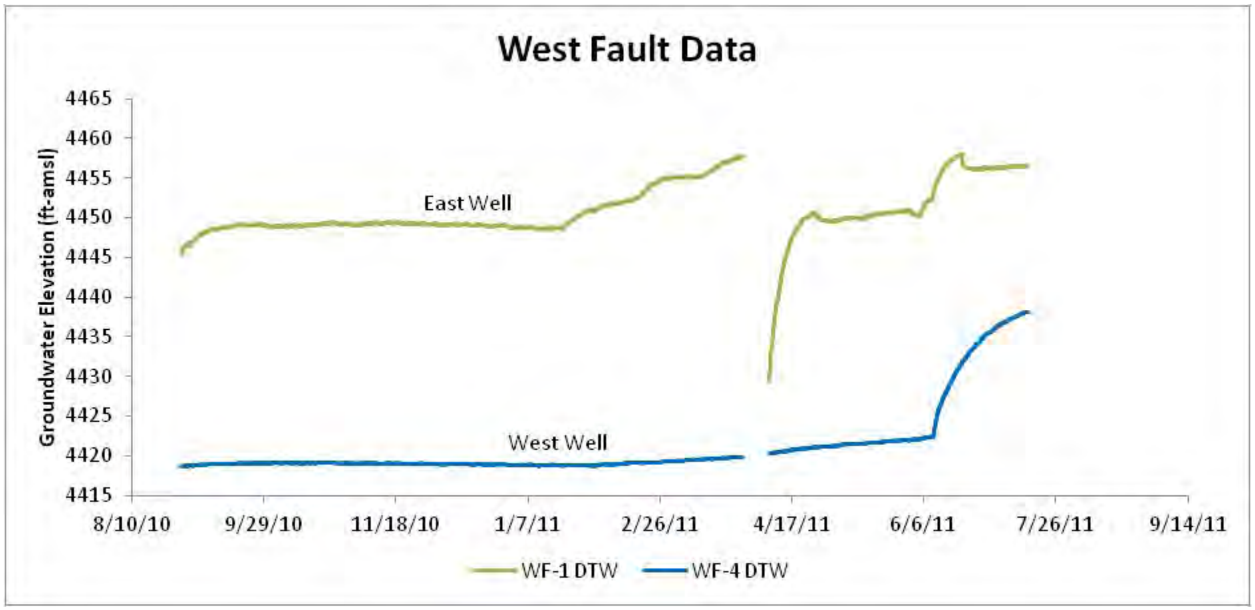


Figure WF1. Hydrograph of WF1 and WF4 from August 2010 to July 2011. Comparing the traces indicates that recharge is likely to the east and that a barrier is present between the wells. The aquifer test is responsible for the change in groundwater levels in the east well in late March 2011.

Table WF1

Well Designations, Locations, and Completion Information

West Fault (Silver Creek Fault) Aquifer Test—March-April 2011

GWIC ID	Name	Latitude*	Longitude*	Measuring Point Elevation+ (ft-amsl)	Total Depth (ft below MP)	Depth to Water 3/29/11 (ft below MP)	Groundwater Elevation 3/29/11 (ft-amsl)	Distance from WF2 (ft)	Comments
257370	WF2	46.6774301	-112.1230996	4485.48	405	32.38	4453.10	—	Pumping well
257560	WF1	46.6775480	-112.1227940	4483.18	340	25.50	4457.68	88	Observation well east of fault
257561	WF3	46.6773461	-112.1236658	4486.87	72	60.17	4426.70	145	Observation well west of fault
257562	WF4	46.6772679	-112.1238795	4486.06	180	66.20	4419.86	204	Observation well west of fault

Note. ft-amsl, feet above mean sea level; ft below MP, feet below measuring point. All locations and elevations determined by a licensed surveyor.

*Horizontal Datum is NAD83.

+Vertical Datum is NAVD88.

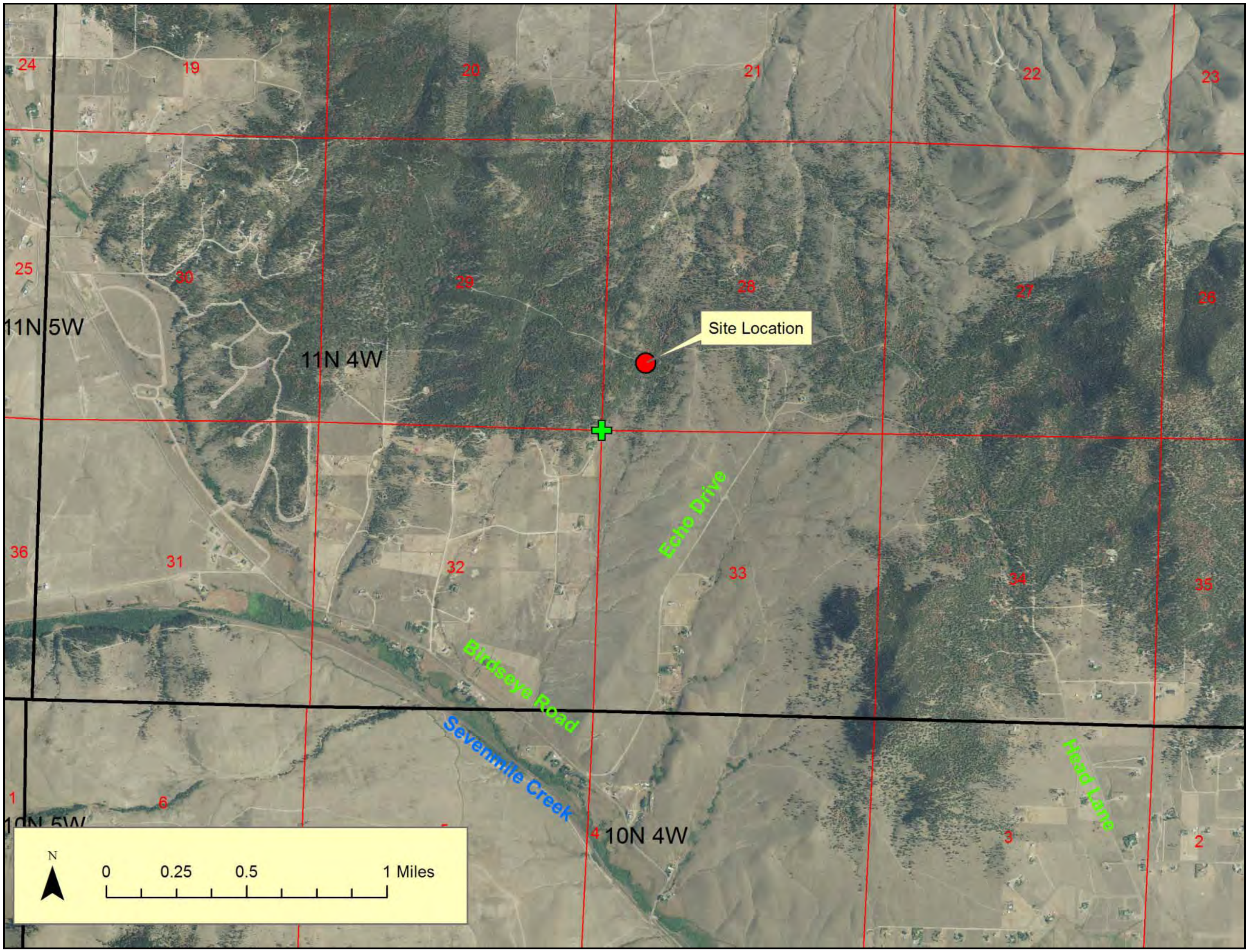


Figure WF2. Location of the West Fault Aquifer Test site. Note that the southwest corner of section 28 (green cross) is at 46.673935° N latitude and 112.126450° W longitude.

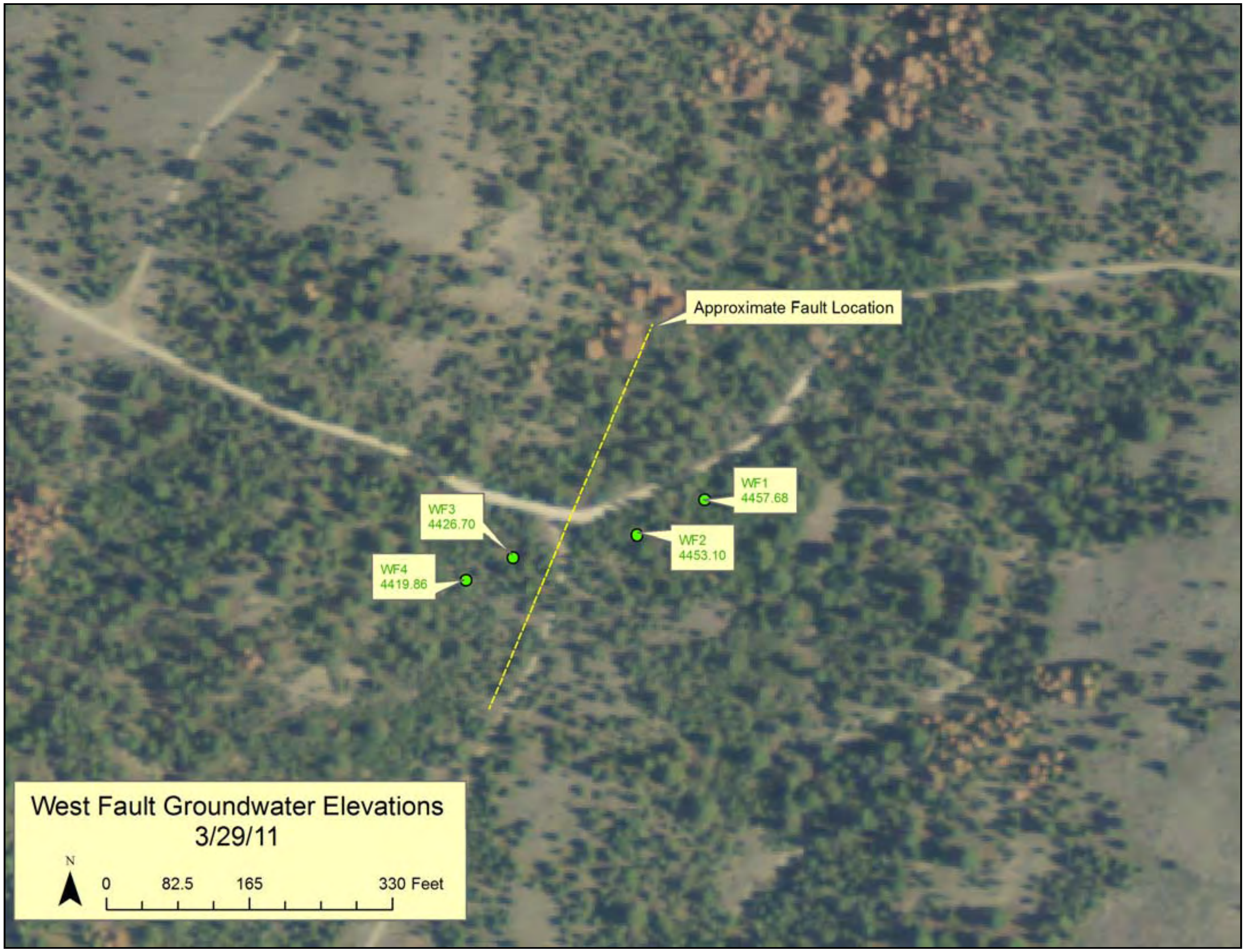


Figure WF3. Site layout for the West Fault Aquifer Test (fault dips to the west) and groundwater elevations from March 29, 2011. Because the fault appears to function as a barrier, and there are only two wells on each side, it would not be appropriate to draw potentiometric contours. Potentiometric mapping over a larger area indicates that groundwater flow in this area is likely to the west (Bobst and others, 2013).

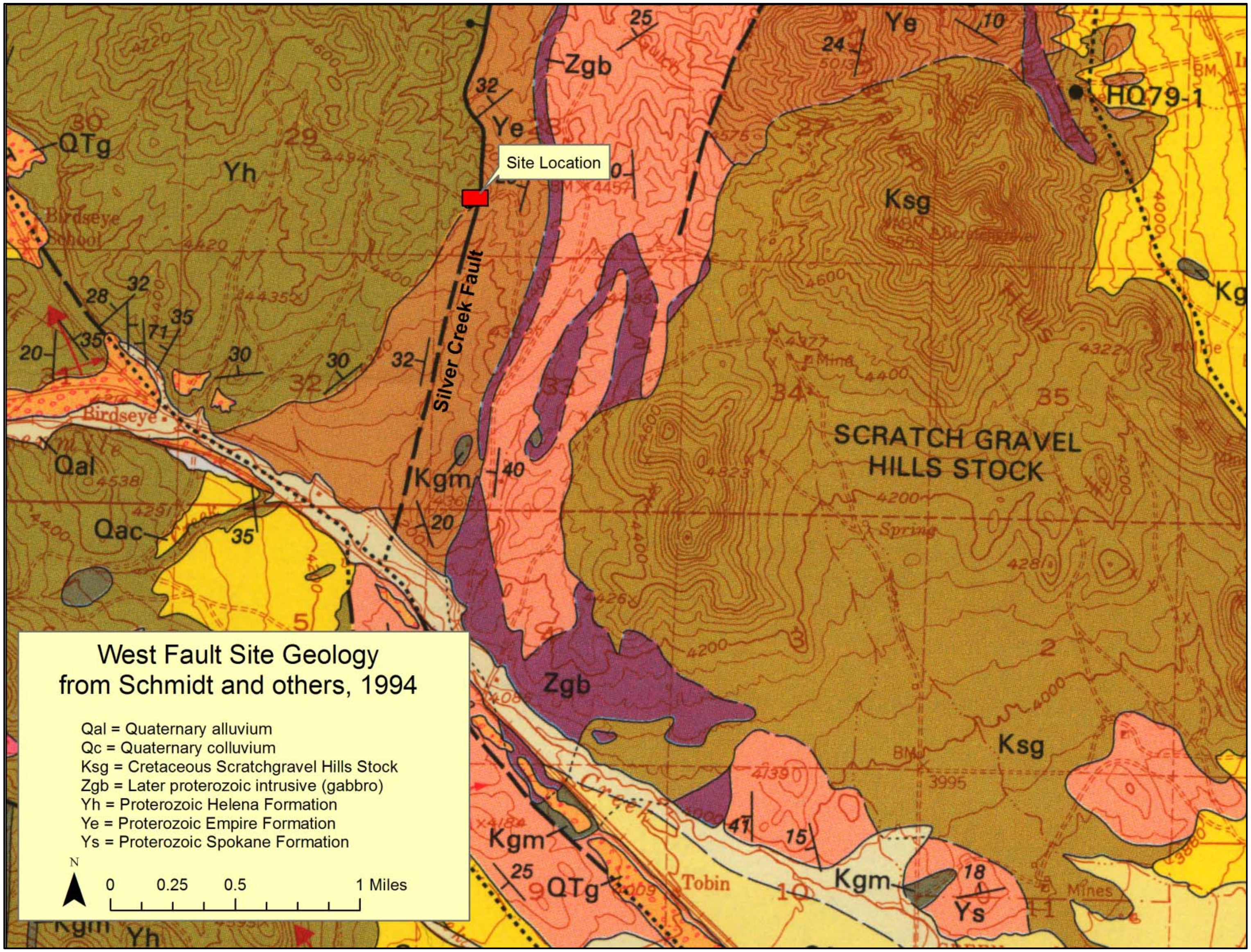


Figure WF4. Geologic map of the West Fault Aquifer Test area. Geologic map prepared by Schmidt and others (1994). The site is located on the Silver Creek Fault.

Pretest DTW readings show groundwater elevations from 4419.86 to 4457.68 ft-amsl. The large change in groundwater elevations between WF2 and WF3 suggests that the fault functions as a barrier to flow (fig. WF3). Pretest monitoring shows stable groundwater levels in all wells (figs. WF5–WF8).

Methodology:

The pumping rate was monitored throughout the test using a totalizing flow meter and an orifice bucket with a transducer in the piezometer tube (Kaur and others, 2010). The flow meter was also checked using a bucket and stopwatch. At times when measurements using the flow meter and the bucket and stopwatch were concurrently made, there was good agreement in the flow rates. Discharge was controlled using a gate valve. Discharge rates varied from 1.1 to 6.7 gpm. The discharge water was diverted approximately 200 ft south of the pumping well (WF2).

Non-vented pressure transducers were used to record water levels in the pumping well, all observation wells, and in the orifice bucket flow meter. All transducers are rated at 30 psia (35 ft), have a manufacturer-reported accuracy of ±0.1% of the rated pressure (±0.03 ft), and a resolution of ±0.01% of the rated pressure (0.003 ft). All transducer values were corrected for barometric variation through the use of a barologger rated for 7 to 30 psia with a reported accuracy of 0.1% of the range (±0.05 ft) and a reported resolution of 0.01% of the range (0.005 ft).

Manual readings of water levels were made for all wells prior to placing transducers, and were made periodically during the test, during recovery, and prior to uninstalling the transducers. The manual measurements were used to verify transducer response. All water-level data are available from GWIC by using the GWIC ID (http://mbmggwic.mtech.edu/).

Step Test:

On March 29, 2011, a step test was conducted on WF2 to determine an appropriate constant pumping rate. Time steps, pumping rates, and maximum drawdown are shown in table WF2. This information is also shown in figure WF9. Since the pump was set at 275 ft below ground, and the screen extends up to 303 ft, it was desired that the long-term pumping rate not cause water levels to drop below 270 ft (240 ft of drawdown). Analysis of the step test data suggests that the specific capacity of this well is about 0.025 gpm/ft; however, since the water level did not stabilize during any of the steps, this specific capacity is considered to be an overestimate. If 0.025 gpm/ft is used, the target drawdown (240 ft) would be achieved with a pumping rate of 6 gpm. Therefore it was determined that the constant rate test would be conducted at approximately half the rate suggested by the step test (3 gpm). This rate turned out to be too high, and it was adjusted downward after the test began. As discussed below, the weighted average discharge for the constant rate test was 1.93 gpm.

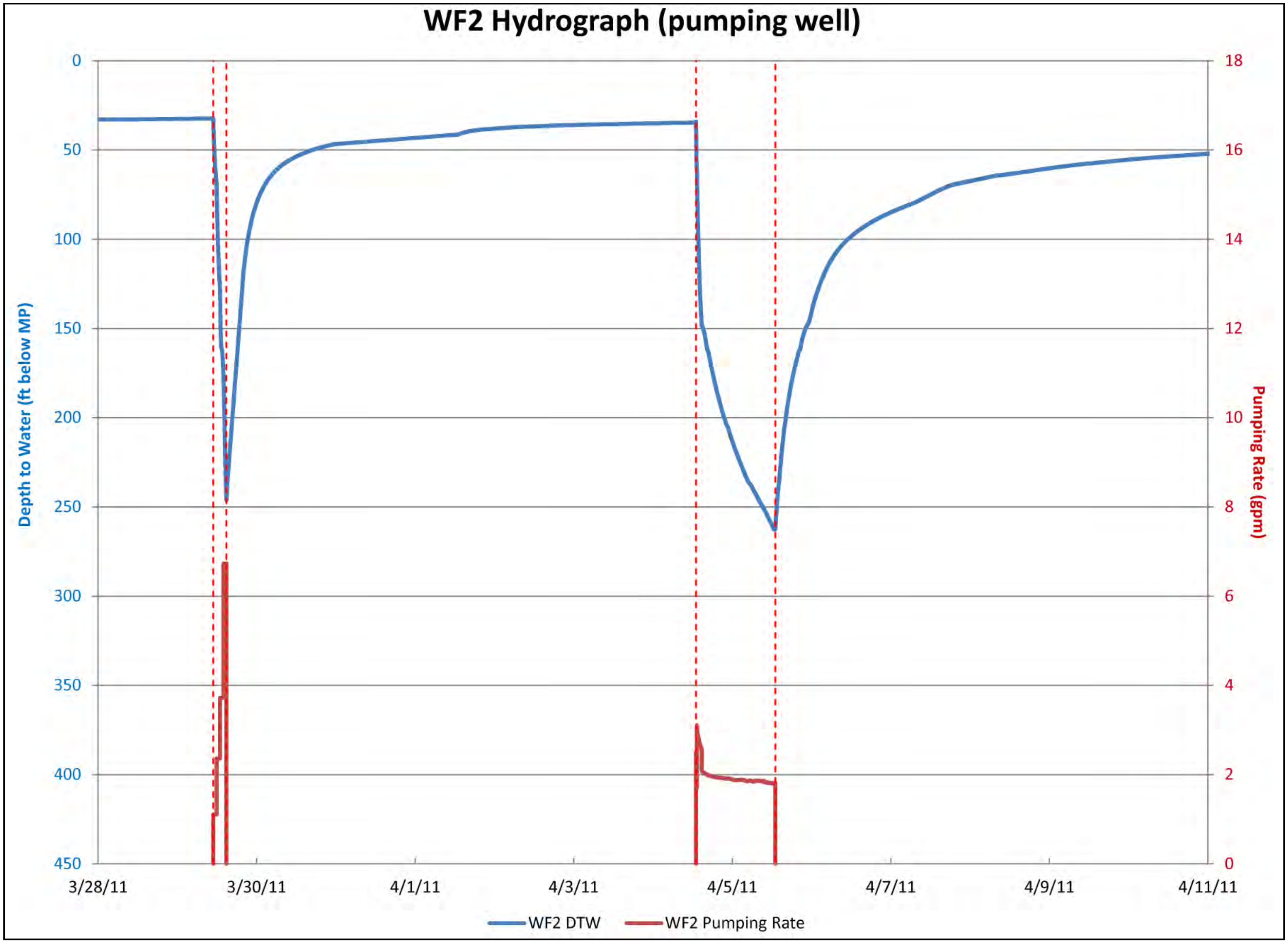


Figure WF5. Depths to water and pumping rates in well WF2 (pumping well) recorded during the West Fault Aquifer Test.

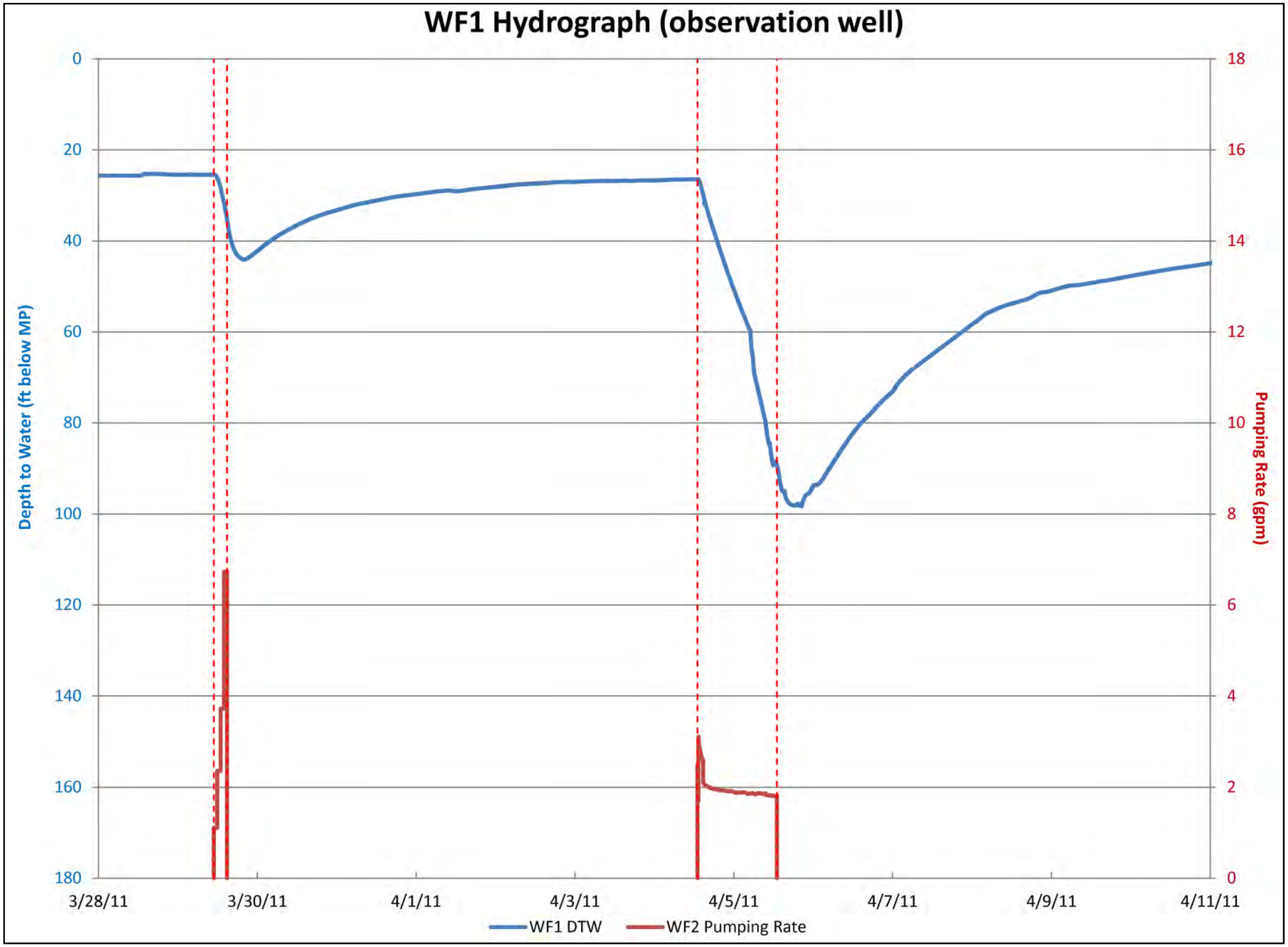


Figure WF6. Depths to water in well WF1 and pumping rates from WF2 recorded during the West Fault Aquifer Test.

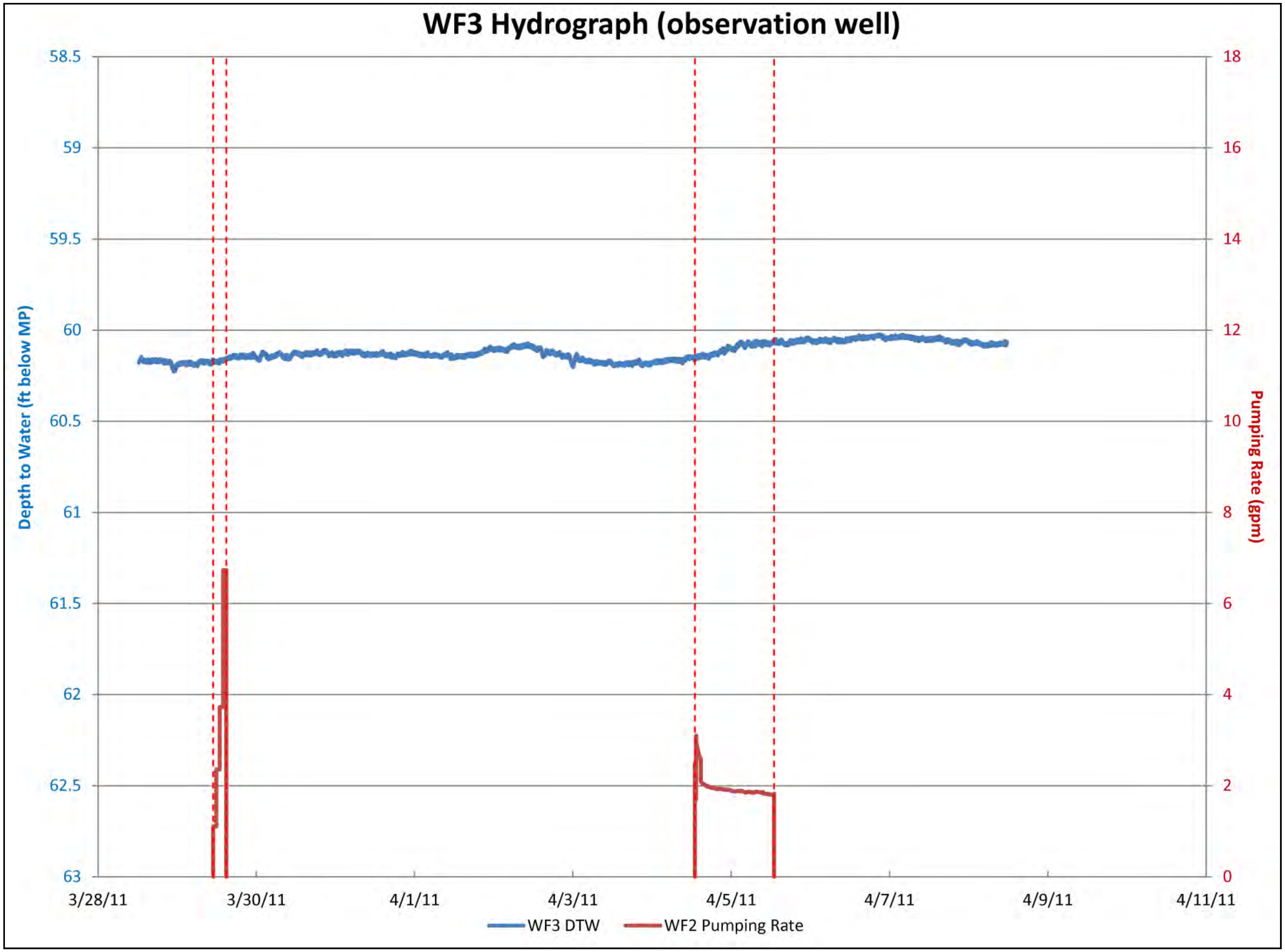


Figure WF7. Depths to water in well WF3 and pumping rates from WF2 recorded during the West Fault Aquifer Test.

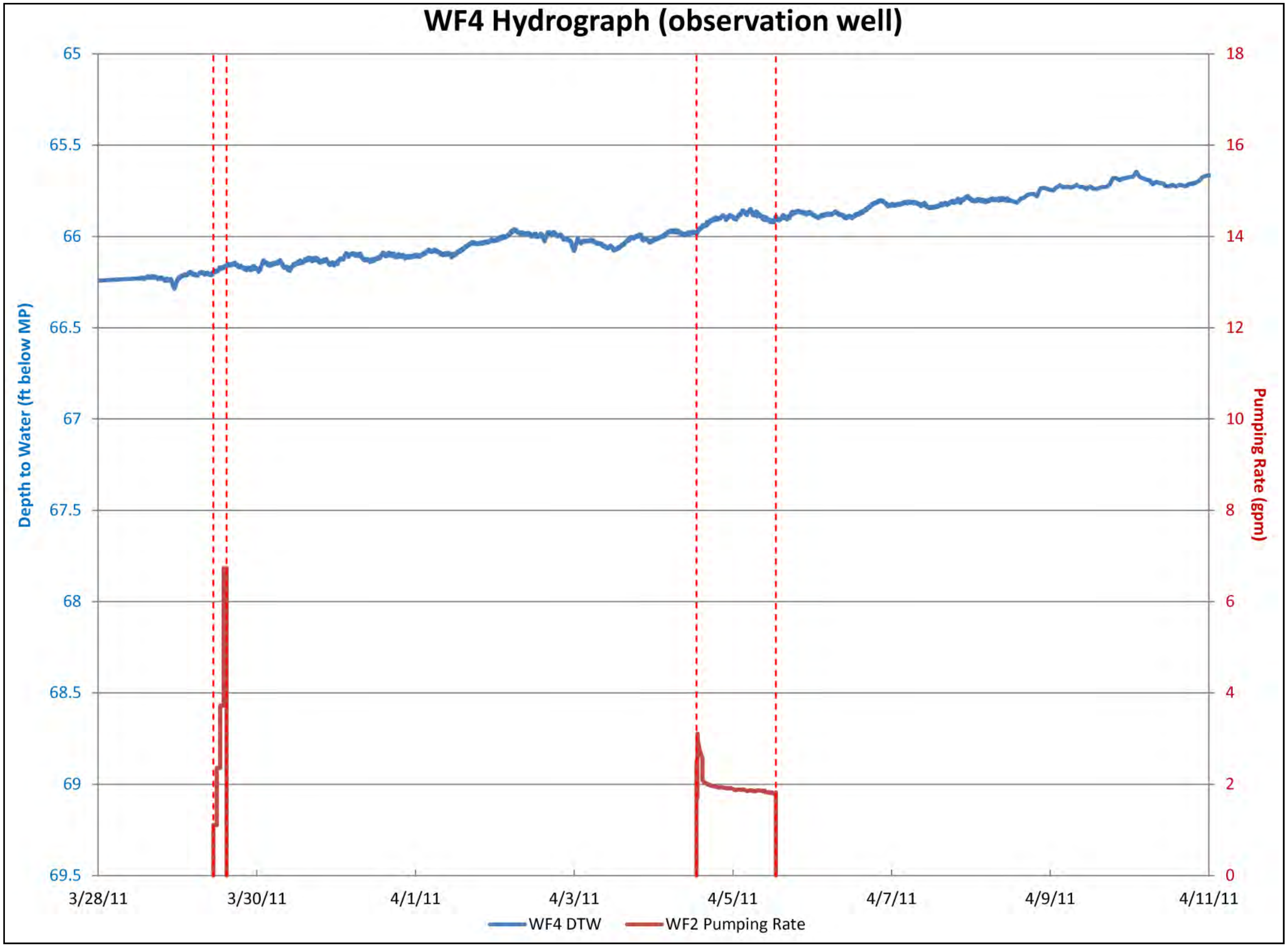


Figure WF8. Depths to water in well WF4 and pumping rates from WF2 recorded during the West Fault Aquifer Test.

Table WF2
WF2—Step Test Summary
West Fault Aquifer Test—March 29, 2011

Start Step	End Step	Rate (Q, gpm)	Maximum Drawdown (s, ft)	Specific Capacity (Q/s)
10:52	11:52	1.1	37.81	0.029
11:52	12:55	2.4	96.22	0.025
12:55	13:56	3.7	140.87	0.026
13:56	14:52	6.7	213.85	0.031

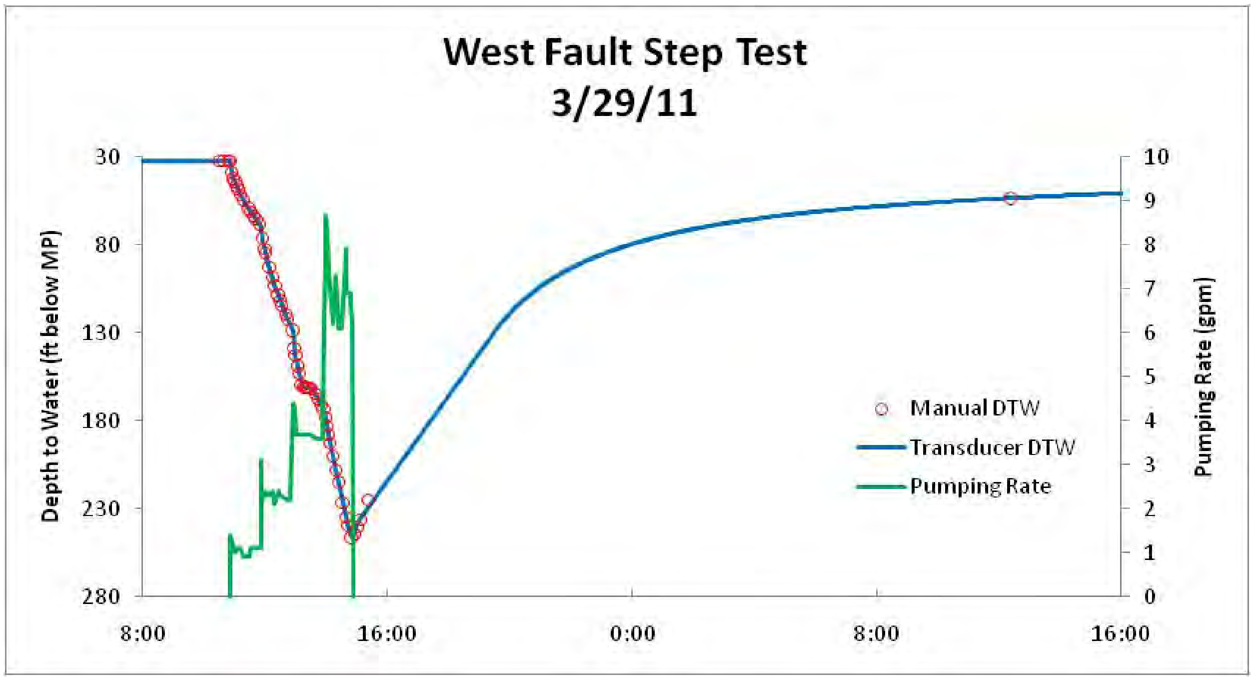


Figure WF9. Depth to water in WF2 and pumping rates recorded during step test.

Simulation of the step test data using AQTESOLV software was attempted; however, because it appears that the fault affects the data very early in the test, quantitative analysis could not be done with confidence. The assumption of radial flow appears to be violated.

Constant Rate Test Analysis:
The constant rate test started at 13:00 on April 4, 2011 and ended at 13:00 on April 5, for a total pumping time of 24 h. The time-weighted average pumping rate was 1.93 gpm. The maximum recorded pumping rate was 3.1 gpm (for a short period near the start of the test) and the minimum recorded pumping rate was 1.7 gpm. Thus the maximum deviation from average was 61%. The analysis was attempted using AQTESOLV software, which allows for variable pumping rates; however, due to the early effect of the fault, quantitative analysis was not possible.

The maximum recorded drawdown in pumping well WF2 was 228.45 ft. Water levels in well WF2 showed a rapid initial decline, which then leveled off somewhat when pumping rates were lowered. Water levels then steadily declined. After pumping ceased, well WF2 exhibited rapid initial water-level recovery; however, more than 4 days were needed for water levels to recover to 90% of their initial values. This slow response suggests that this well was completed in a fractured zone near the fault, and the water level responded as for a bounded fracture zone, rather than for a laterally extensive aquifer. As such, assumptions of radial flow are violated, and quantitative analysis of the data was not conducted.

The maximum recorded drawdown in observation well WF1 was 71.78 ft, which occurred 7 h and 32 min after the pump was shut off. This delayed response clearly shows that while these wells are hydraulically connected, it is not direct. As such, quantitative analysis of the data from WF1 was not conducted.

No drawdown was recorded in the wells (WF3 and WF4) constructed west of the fault.

Summary:
Analysis of this aquifer test indicates that at this site the Silver Creek Fault is a barrier to horizontal flow. Production of water is from limited fractured zones near the fault. No drawdown was observed across the fault, and the drawdown observed in an observation well on the same side of the fault as the pumping well was delayed.

References:

ASTM, 2008, standard test method (field procedure) for withdrawal and injection well tests for determining hydraulic properties of aquifer systems, D4050-96 (Reapproved 2008).

ASTM, 2008, Standard test method (analytical procedure) for determining transmissivity and storage coefficient of nonleaky confined aquifers by the modified Theis nonequilibrium method, D4105-96 (Reapproved 2008).

Bobst, A.L., Waren, K.B., Ahern, J.A., Swierc, J.E., and Madison, J.D., 2013, Hydrogeologic investigation of the Scratchgravel Hills study area, Lewis and Clark County, Montana, Interpretive Report: Montana Bureau of Mines and Geology Open-File Report 636, 55 p.

Cooper, H.H., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history, Transactions, American Geophysical Union, v. 24, p. 526–534.

Fetter, C.W., 1994, Applied hydrogeology, 3rd ed.: New York, Macmillan College Publishing, 691 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice Hall, 604 p.

Hantush, M.S., 1960. Modification of the theory of leaky aquifers, Journal of Geophysical Research, v. 65, no. 11, p. 3713–3725.

Jacob, C.E., 1950, Flow of ground-water, *in* Engineering hydraulics, Rouse, H., ed.: New York, John Wiley Press.

Kaur, S., Aggarwal, R., Singh, S, and Gulari, H.S., 2010, A simple mechanical device for the measurement of discharge in a tubewell: Journal of Engineering and Technology Reseach, v. 2, no. 60, p. 111–117.

Schmidt, R.G., Loen, J.S., Wallace, C.A., and Mehnert, H.H., 1994, Geology of the Elliston region, Powell and Lewis and Clark Counties, Montana: U.S. Geological Survey Bulletin 2041.

Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Transactions, American Geophysical Union, v. 16, p. 519–524.

APPENDIX WFA—Well Logs

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site

Site Name: MBMG-BLM-WF1
GWIC Id: 257560

Section 1: Well Owner

Owner Name
BLM
Mailing Address

City	State	Zip Code
BUTTE	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
11N	04W	28	NW¼ NE¼ SW¼ SW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.677548	112.122794	SUR-GPS	WGS84

Altitude	Method	Datum	Date
4481.45	SUR-GPS	NAVD88	4/18/2011

Addition	Block	Lot

Section 3: Proposed Use of Water
MONITORING (1)

Section 4: Type of Work
Drilling Method: ROTARY

Section 5: Well Completion Date
Date well completed: Wednesday, August 18, 2010

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	27	10
27	340	8

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	27	8	0.25		WELDED	A53B STEEL
-2	338	4			SPLINE	PVC

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
238	338	4	200	5/16"	PERFORATED CASING

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	27	BENTONITE	Y
27	210	BENTONITE	

Section 7: Well Test Data

Total Depth: 340
Static Water Level: 100
Water Temperature:

Air Test *

5 gpm with drill stem set at 330 feet for 1 hours.
Time of recovery 1 hours.
Recovery water level 100 feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source
400SPKN - SPOKANE SHALE

From	To	Description
0	1	TOPSOIL WITH CLASTS OF REDDISH BROWN AND GREENISH GRAY ARGILLITE
1	5	WEATHERED REDDISH BROWN ARGILLITE, TRACE GREENISH GRAY ARGILLITE
5	10	REDDISH BROWN AND GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
10	25	REDDISH BROWN ARGILLITE, TRACE GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
25	30	REDDISH BROWN ARGILLITE, TRACE GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
30	35	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, LITTLE TAN ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
35	50	REDDISH BROWN ARGILLITE, LITTLE GREENISH GRAY ARGILLITE, LITTLE TAN ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
50	59	REDDISH BROWN ARGILLITE, LITTLE GREENISH GRAY ARGILLITE, LITTLE TAN ARGILLITE, LITTLE WHITE FRACTURE FILL, TRACE ORANGE STAIN
59	67	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
67	70	REDDISH BROWN ARGILLITE, TRACE GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
70	83	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL
83	90	REDDISH BROWN AND GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
		REDDISH BROWN AND GREENISH GRAY

210	340	GRAVEL PACK	

90	95	ARGILLITE, TRACE WHITE FRACTURE FILL, LITTLE ORANGE STAIN
95	100	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
100	110	GREENISH GRAY ARGILLITE, TRACE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:	BRITT LINDSAY
Company:	LINDSAY DRILLING
License No:	MWC-337
Date Completed:	8/18/2010

Site Name: MBMG-BLM-WF1
GWIC Id: 257560
Additional Lithology Records

From	To	Description
110	115	GREENISH GRAY ARGILLITE, TRACE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, SOME ORANGE STAIN
115	125	GREENISH GRAY ARGILLITE, TRACE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
125	130	GREENISH GRAY ARGILLITE, TRACE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, LITTLE ORANGE STAIN
130	135	GREENISH GRAY ARGILLITE, SOME GRAY CLAY CLUMPS, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
135	140	GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
140	145	GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, LITTLE ORANGE STAIN
145	150	GREENISH GRAY ARGILLITE, SOME GRAY CLAY CLUMPS, TRACE WHITE FRACTURE FILL, LITTLE ORANGE STAIN
150	160	GREENISH GRAY ARGILLITE, SOME GRAY CLAY CLUMPS, TRACE ORANGE STAIN
160	165	GREENISH GRAY ARGILLITE, SOME GRAY CLAY CLUMPS, LITTLE GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE ORANGE STAIN
165	175	GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, LITTLE ORANGE STAIN
175	185	GREENISH GRAY ARGILLITE, TRACE REDDISH BROWN AND GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, LITTLE ORANGE STAIN
185	190	REDDISH BROWN AND GREENISH GRAY ARGILLITE, TRACE TAN ARGILLITE, TRACE ORANGE STAIN
190	205	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, TRACE ORANGE STAIN
205	215	GREENISH GRAY ARGILLITE, SOME GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, LITTLE ORANGE STAIN
215	230	REDDISH BROWN AND GREENISH GRAY ARGILLITE, LITTLE GRAY ARGILLITE, LITTLE ORANGE STAIN
230	235	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, TRACE GRAY ARGILLITE, LITTLE ORANGE STAIN
235	240	REDDISH BROWN ARGILLITE, LITTLE GREENISH GRAY ARGILLITE, TRACE GRAY ARGILLITE, LITTLE ORANGE STAIN
240	245	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, TRACE GRAY ARGILLITE, LITTLE ORANGE STAIN
245	260	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN AND GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
260	285	GREENISH GRAY ARGILLITE, SOME REDDISH BROWN ARGILLITE, LITTLE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN

285	305	REDDISH BROWN ARGILLITE, LITTLE GREENISH GRAY ARGILLITE, TRACE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
305	310	REDDISH BROWN AND GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN - LARGER CHUNKS
310	320	GREENISH GRAY ARGILLITE, SOME REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
320	330	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
330	340	GREENISH GRAY ARGILLITE, TRACE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site

Site Name: MBMG-BLM-WF2
GWIC Id: 257370

Section 1: Well Owner

Owner Name
BLM
Mailing Address

City	State	Zip Code
BUTTE	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
11N	04W	28	NW¼ NE¼ SW¼ SW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.6774301	112.1230996	SUR-GPS	WGS84

Altitude	Method	Datum	Date
4484.21	SUR-GPS	NAVD88	4/18/2011

Addition	Block	Lot

Section 3: Proposed Use of Water
MONITORING (1)

Section 4: Type of Work
Drilling Method: ROTARY

Section 5: Well Completion Date
Date well completed: Friday, August 13, 2010

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	27	10
27	405	8

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	27	8	0.25		WELDED	A53B STEEL
-2	403	4			SPLINE	PVC

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
303	403	4	200	5/16"	PERFORATED CASING

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	27	BENTONITE	Y
27	133	BENTONITE	

Section 7: Well Test Data

Total Depth: 405
Static Water Level: 100
Water Temperature:

Air Test *

4 gpm with drill stem set at 390 feet for 1 hours.
Time of recovery 1 hours.
Recovery water level 100 feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source
400SPKN - SPOKANE SHALE

From	To	Description
0	1	TOPSOIL WITH CLASTS OF REDDISH BROWN AND GREENISH GRAY ARGILLITE, SOME DOLOMITE CLASTS
1	5	REDDISH BROWN AND GREENISH GRAY ARGILLITE, SOME WEATHERED TO CLAY
5	25	REDDISH BROWN AND GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
25	35	REDDISH BROWN ARGILLITE WITH LITTLE GRAY ARGILLITE
35	40	REDDISH BROWN AND GRAY ARGILLITE, LITTLE ORANGE STAIN
40	45	GRAY AND REDDISH BROWN ARGILLITE, TRACE ORANGE STAIN
45	50	REDDISH BROWN AND GREENISH GRAY ARGILLITE, TRACE ORANGE STAIN
50	55	REDDISH BROWN ARGILLITE WITH LITTLE GREENISH GRAY ARGILLITE
55	65	REDDISH BROWN ARGILLITE, LITTLE GREENISH GRAY ARGILLITE, TRACE ORANGE STAIN
65	70	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE
70	75	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, SOME CLUMPS OF GRAY CLAY
75	80	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, FEW CLUMPS OF GRAY CLAY
80	90	REDDISH BROWN ARGILLITE, LITTLE GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
90	95	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
95	100	REDDISH BROWN ARGILLITE, LITTLE GREENISH GRAY ARGILLITE, LITTLE WHITE FRACTURE FILL

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:	BRITT LINDSAY
Company:	LINDSAY DRILLING
License No:	MWC-337
Date Completed:	8/13/2010

Site Name: MBMG-BLM-WF2
GWIC Id: 257370
Additional Lithology Records

From	To	Description
100	110	GREENISH GRAY AND REDDISH BROWN ARGILLITE, TRACE ORANGE STAIN
110	115	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, TRACE ORANGE STAIN
115	135	REDDISH BROWN ARGILLITE, LITTLE GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
135	145	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL
145	150	GREENISH GRAY AND REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL
150	155	GREENISH GRAY ARGILLITE, SOME GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE
155	160	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL
160	165	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, SOME GRAY CLAY CLUMPS
165	180	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL
180	185	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, LITTLE WHITE FRACTURE FILL
185	195	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL
195	200	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE
200	205	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL
205	210	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE METALLIC MINERAL IN FRACTURE FILL (GALENA?)
210	215	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL
215	220	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, TRACE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
220	225	GREENISH GRAY, DULL REDDISH BROWN, AND GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
225	230	GREENISH GRAY AND DULL REDDISH BROWN ARGILLITE, SOME GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
230	235	GREENISH GRAY ARGILLITE, LITTLE DULL REDDISH BROWN ARGILLITE, LITTLE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
235	240	GREENISH GRAY ARGILLITE, LITTLE DULL REDDISH BROWN ARGILLITE, LITTLE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE GREY CLAY CLUMPS
240	250	GREENISH GRAY ARGILLITE, LITTLE DULL REDDISH BROWN ARGILLITE, LITTLE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
250	255	REDDISH BROWN AND GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
255	265	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, TRACE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
265	270	GREENISH GRAY ARGILLITE, SOME REDDISH BROWN ARGILLITE, TRACE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL

270	285	GREENISH GRAY AND REDDISH BROWN ARGILLITE, LITTLE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
285	305	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, TRACE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
305	310	GREENISH GRAY ARGILLITE, SOME REDDISH BROWN ARGILLITE, LITTLE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
310	315	REDDISH BROWN AND GREENISH GRAY ARGILLITE, LITTLE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
315	320	GREENISH GRAY, REDDISH BROWN, AND GRAY ARGILLITE, TRACE WHITE FRACTURE FILL
320	330	GREENISH GRAY, REDDISH BROWN, AND GRAY ARGILLITE, LITTLE WHITE FRACTURE FILL
330	335	GREENISH GRAY ARGILLITE, SOME REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL
335	340	GREENISH GRAY ARGILLITE, SOME REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, LITTLE ORANGE STAIN
340	345	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, LITTLE ORANGE STAIN
345	350	REDDISH BROWN ARGILLITE, LITTLE GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
350	355	REDDISH BROWN ARGILLITE, SOME GREENISH GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
355	370	GREENISH GRAY AND REDDISH BROWN ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN
370	405	GREENISH GRAY ARGILLITE, LITTLE REDDISH BROWN ARGILLITE, LITTLE GRAY ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE ORANGE STAIN

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site

Site Name: MBMG-BLM-WF3
GWIC Id: 257561

Section 1: Well Owner

Owner Name
BLM
Mailing Address

City	State	Zip Code
BUTTE	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
11N	04W	28	NW¼ NE¼ SW¼ SW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.6773461	112.1236658	SUR-GPS	WGS84

Altitude	Method	Datum	Date
4485.05	SUR-GPS	NAVD88	4/18/2011

Addition	Block	Lot

Section 3: Proposed Use of Water
MONITORING (1)

Section 4: Type of Work
Drilling Method: ROTARY

Section 5: Well Completion Date
Date well completed: Friday, August 20, 2010

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	25	8
25	100	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	25	6	0.25		WELDED	A53B STEEL
-2	72	2			FLUSH THREAD	PVC

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
62	72	2		40 SLOT	SCREEN-CONTINUOUS-PVC

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?

Section 7: Well Test Data

Total Depth: 100
Static Water Level: 70
Water Temperature:

Air Test *

0 gpm with drill stem set at 80 feet for 1 hours.
Time of recovery 1 hours.
Recovery water level 70 feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source
400HELN - HELENA DOLOMITE

From	To	Description
0	1	TOPSOIL
1	5	BROKEN ROCKS; TAN AND GRAY DOLOMITE WITH BROWN WEATHERING RIND, SOME GREENISH GRAY ARGILLITE
5	15	WEATHERED GRAY DOLOMITE
15	25	WEATHERED GRAY DOLOMITE, SOME GRAY CLAY CLUMPS
25	35	GRAY DOLOMITE, SOME GRAY CLAY CLUMPS, SOME FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE)
35	40	GRAY DOLOMITE WITH LITTLE FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE)
40	45	FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE), SOME GRAY CLAY CLUMPS
45	60	FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE)
60	70	FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE), SOME DOLOMITE
70	75	FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE), TRACE DOLOMITE, ABUNDANT MUD IN RETURNS
75	80	FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE), LITTLE DOLOMITE, ABUNDANT MUD IN RETURNS
80	85	GREENISH GRAY ARGILLITE, TRACE REDDISH BROWN ARGILLITE
85	90	GREENISH GRAY ARGILLITE, LITTLE FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE), TRACE REDDISH BROWN ARGILLITE

0	25	BENTONITE	Y
25	58	BENTONITE	
58	72	GRAVEL PACK	
72	100	BENTONITE CHIPS	

90	95	GREENISH GRAY ARGILLITE, SOME CLAY CLUMPS, LITTLE REDDISH BROWN ARGILLITE
95	100	GREENISH GRAY ARGILLITE, SOME CLAY CLUMPS, LITTLE REDDISH BROWN ARGILLITE, LITTLE WHITE FRACTURE FILL

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:	BRITT LINDSAY
Company:	LINDSAY DRILLING
License No:	MWC-337
Date Completed:	8/20/2010

MONTANA WELL LOG REPORT

This well log reports the activities of a licensed Montana well driller, serves as the official record of work done within the borehole and casing, and describes the amount of water encountered. This report is compiled electronically from the contents of the Ground Water Information Center (GWIC) database for this site. Acquiring water rights is the well owner's responsibility and is NOT accomplished by the filing of this report.

Other Options

Plot this site on a topographic map
View hydrograph for this site

Site Name: MBMG-BLM-WF4
GWIC Id: 257562

Section 1: Well Owner

Owner Name
BLM
Mailing Address

City	State	Zip Code
BUTTE	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
11N	04W	28	NE¼ NW¼ SW¼ SW¼

County	Geocode
LEWIS AND CLARK	

Latitude	Longitude	Geomethod	Datum
46.6772679	112.1238795	SUR-GPS	WGS84

Altitude	Method	Datum	Date
4484.35	SUR-GPS	NAVD88	4/18/2011

Addition	Block	Lot

Section 3: Proposed Use of Water
MONITORING (1)

Section 4: Type of Work
Drilling Method: ROTARY

Section 5: Well Completion Date
Date well completed: Monday, August 23, 2010

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	26	8
26	200	6

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	26	6	0.25		WELDED	A53B STEEL
-2	178	2			FLUSH THREAD	PVC

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
158	178	2		40 SLOT	SCREEN-CONTINUOUS-PVC

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?

Section 7: Well Test Data

Total Depth: 200
Static Water Level: 80
Water Temperature:

Air Test *

5 gpm with drill stem set at 190 feet for 1 hours.
Time of recovery 1 hours.
Recovery water level 80 feet.
Pumping water level _ feet.

** During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log

Geologic Source
400HELN - HELENA DOLOMITE

From	To	Description
0	1	TOPSOIL
1	5	WEATHERED GRAY DOLOMITE, LITTLE CLAY
5	20	GRAY DOLOMITE WITH BROWN WEATHERING RIND
20	25	GRAY DOLOMITE, TRACE CLAY CLUMPS
25	40	GRAY DOLOMITE
40	45	GRAY DOLOMITE, SOME GRAY CLAY CLUMPS
45	50	GRAY DOLOMITE, TRACE GRAY CLAY CLUMPS
50	60	GRAY DOLOMITE
60	80	GRAY DOLOMITE AND PURPLE ARGILLITE
80	85	GRAY DOLOMITE, LITTLE PURPLE ARGILLITE
85	90	GRAY DOLOMITE
90	100	GRAY DOLOMITE AND PURPLE ARGILLITE
100	105	GRAY DOLOMITE AND PURPLE ARGILLITE, LITTLE WHITE FRACTURE FILL
105	110	GRAY DOLOMITE, TRACE WHITE FRACTURE FILL, TRACE CLAY CLUMPS
110	115	GRAY DOLOMITE, LITTLE PURPLE ARGILLITE, TRACE WHITE FRACTURE FILL, TRACE CLAY CLUMPS

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name: BRITT LINDSAY
Company: LINDSAY DRILLING
License No: MWC-337
Date

0	26	BENTONITE	Y
26	155	BENTONITE	Y
155	180	GRAVEL PACK	
180	200	BENTONITE CHIPS	

Completed: 8/23/2010

Site Name: MBMG-BLM-WF4
GWIC Id: 257562
Additional Lithology Records

From	To	Description
115	120	PURPLE AND BLUE GREEN ARGILLITE, SOME GRAY DOLOMITE
120	125	PURPLE ARGILLITE, LITTLE GRAY DOLOMITE
125	130	GRAY DOLOMITE, TRACE WHITE FRACTURE FILL
130	135	GRAY DOLOMITE, SOME BLUE GREEN ARGILLITE, LITTLE PURPLE ARGILLITE
135	140	GRAY DOLOMITE AND BLUE GREEN ARGILLITE, TRACE WHITE FRACTURE FILL
140	145	GRAY DOLOMITE AND BLUE GREEN ARGILLITE, LITTLE PURPLE ARGILLITE, TRACE WHITE FRACTURE FILL
145	162	PURPLE ARGILLITE, SOME GRAY DOLOMITE
162	182	PURPLE ARGILLITE, SOME GRAY DOLOMITE, TRACE WHITE FRACTURE FILL
182	185	FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE)
185	190	FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE), SOME PURPLE AND BLUE GREEN ARGILLITE
190	200	FINE GRAINED WHITE ROCK WITH BLACK BLEBS (FAULT GOUGE), SOME PURPLE AND BLUE GREEN ARGILLITE, LITTLE CLAY CLUMPS

HYDROGRAPHS

Hydrographs are used to present time series groundwater-level data. Time is plotted on the X axis, and depths to water, water-level elevation, or both are plotted on the Y axis. Over short time periods, hydrographs allow the timing and magnitude of changes in groundwater levels to be evaluated. Over longer time periods, hydrographs can be used to assess trends.

For the Scratchgravel Hills study, the focus is on the long-term trends. To test for water-level trends, best-fit linear regression relations were developed for wells with groundwater-level data from 1995 or 1996, and also gathered from the current study in 2010. The linear regression lines are fit to the water level vs. time data and have the form of $y = mx+b$, where m is the slope of the regression line in ft/d. In table H1 and on the hydrographs, the slopes have been recalculated as feet of elevation change per year. The geographic distribution of trends can be used to evaluate the regional or local nature of groundwater-level change.

The 1995 and 1996 data are from the USGS (Thamke, 2000), and represent the most consistent data set previously collected in the study area. Any other data collected at a site were used qualitatively to ensure that the resulting trend is representative of water levels at the site (e.g., that the seasonality of data collected does not bias the result). Historical data are from a variety of sources, including the USGS, Lewis and Clark Water Quality Protection District, and the MBMG's Groundwater Assessment Monitoring Network.

Thamke, J.N., 2000, Hydrology of Helena area bedrock, west-central Montana, 1993–98, U.S. Geological Survey Water Resources Investigations Report 00-4212.

Table H1.

Scratchgravel Hills Monitoring Network - Water Level Trends 1995&1996 vs. 2010

Gwic Id	Site Name	Twn	Rng	Sec	Span of Data (years)	Slope (ft/yr) (95-96 vs. 2010)*
5758	RANIERI, LARRY	10N	04W	12	17	-0.18
62369	ELLIOT JIM	10N	04W	2	35	-0.02
62385	WOODEN	10N	04W	3	16	0.05
62523	WALKER, GILES E.	10N	04W	12	21	-0.01
65432	DRAKE	11N	04W	24	16	-0.03
65615	SHIELDS, RONALD	11N	04W	34	34	-0.04
65618	NORRIS, JOSEPH * WEST WELL	11N	04W	35	19	-1.67
65696	EICHHORN, SCOTT * WEST WELL	11N	05W	24	15	0.92
123610	BODNER, JOE	11N	04W	32	17	0.16
123839	WINDLE COLE & JUDY	10N	04W	10	17	0.74
254309	SKINNER, ANDY	10N	04W	1	20	-0.03
706001	CLARK, DONALD	10N	04W	3	22	-0.05
706014	CHAPMAN, KELLY	10N	04W	3	19	0.01
706021	DECKER, GEORGE	10N	04W	3	19	-0.09
706024	ANDERSON HOWARD	10N	04W	2	19	-0.17
706028	PATTON, JEFF	10N	04W	3	18	0.34
706039	WARFORD, CAROL	11N	04W	29	15	-0.70
706044	FRANK BREWER III	11N	04W	19	16	-0.41
706055	MAULORICO AL	11N	04W	34	19	-0.29
706058	FOWLER, SANDRA	10N	04W	2	18	0.10
892195	USGS * MILL ROAD	10N	03W	8	32	0.00

< -1.0 ft/yr
-0.5 to -1.0 ft/yr
-0.5 to 0.5 ft/yr
0.5 to 1.0 ft/yr

*Slope determined by liner regression: y=mx+b, where m is the slope.
Negative values indicate water levels have declined during this time.

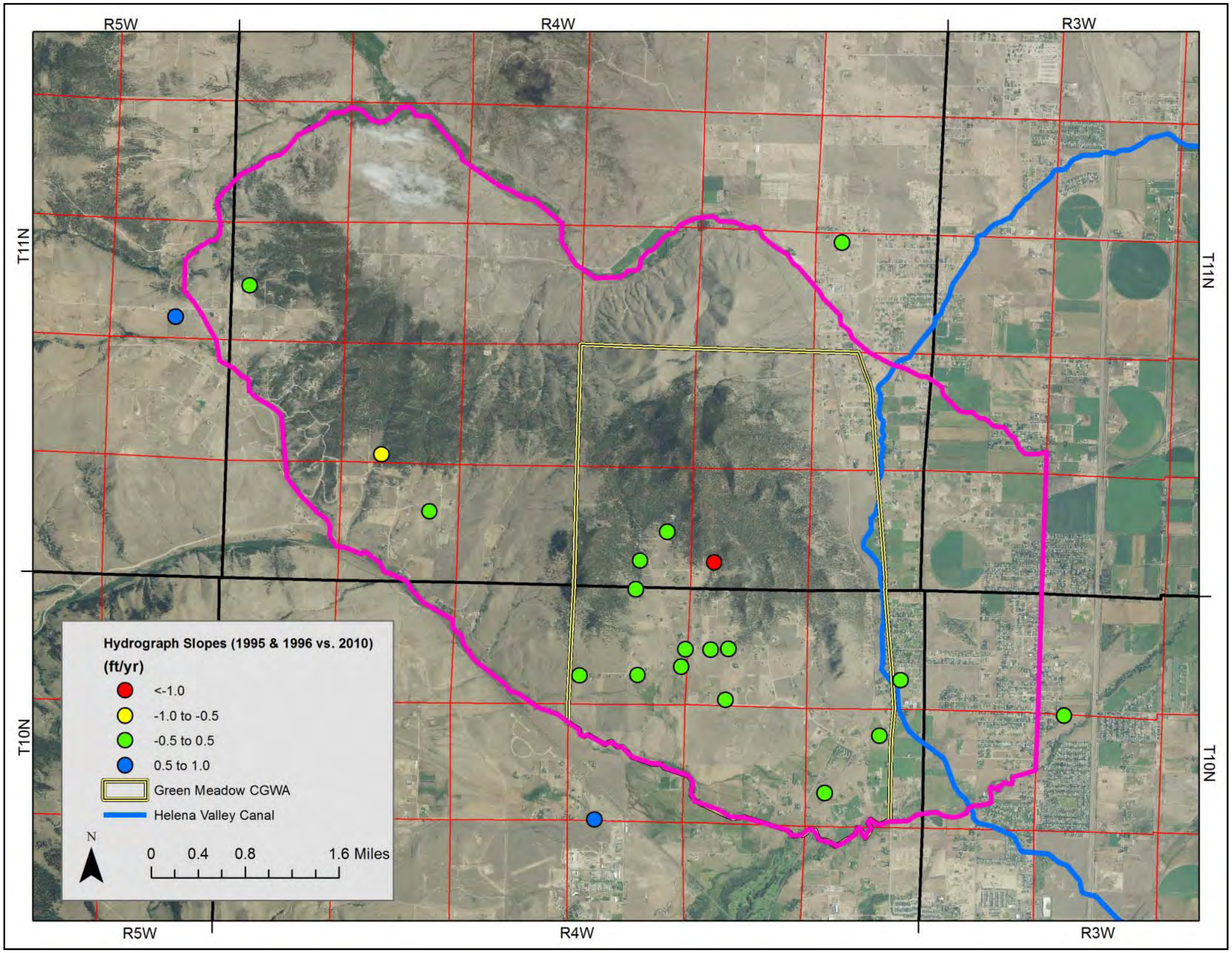
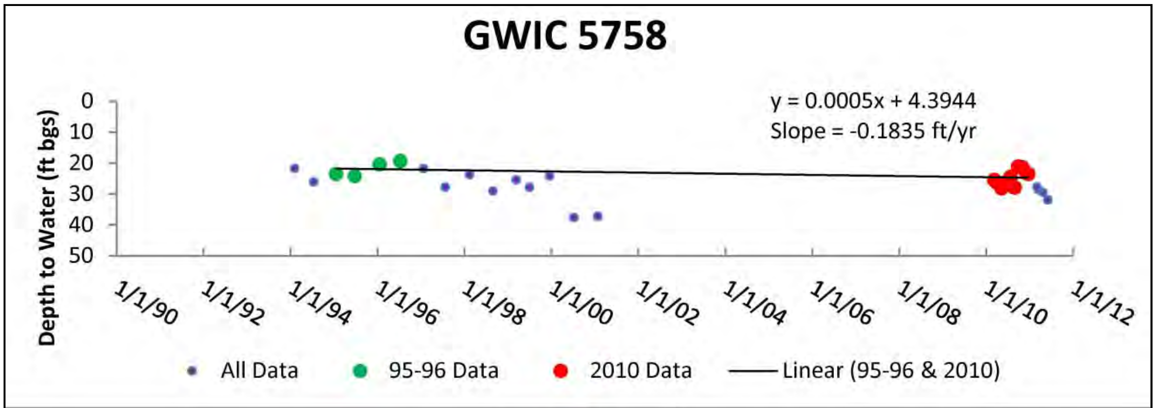
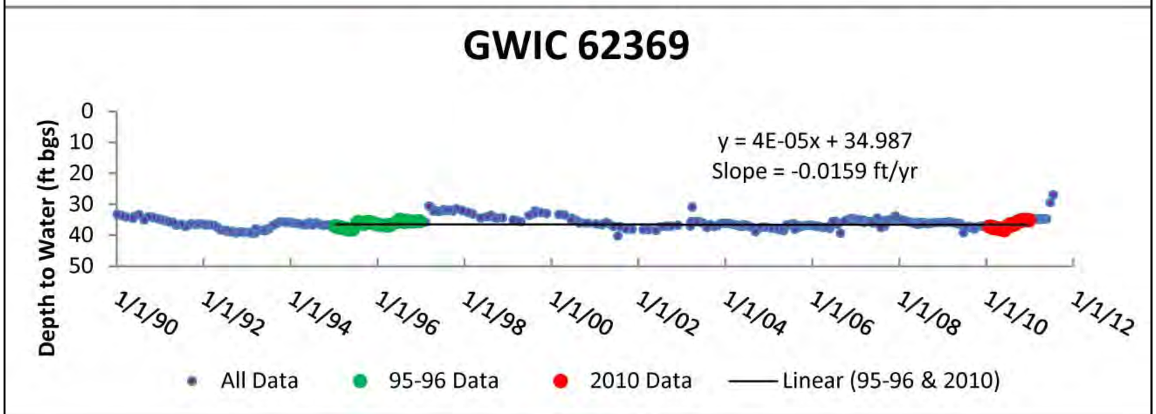
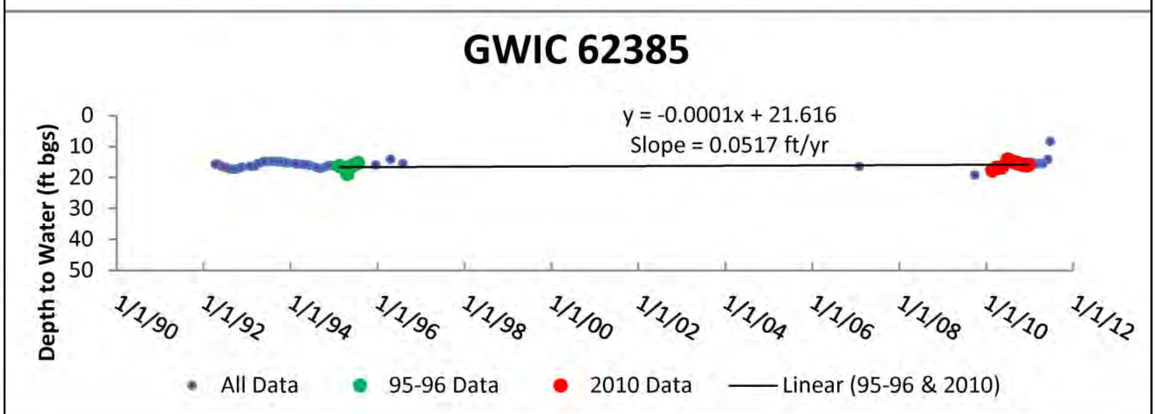
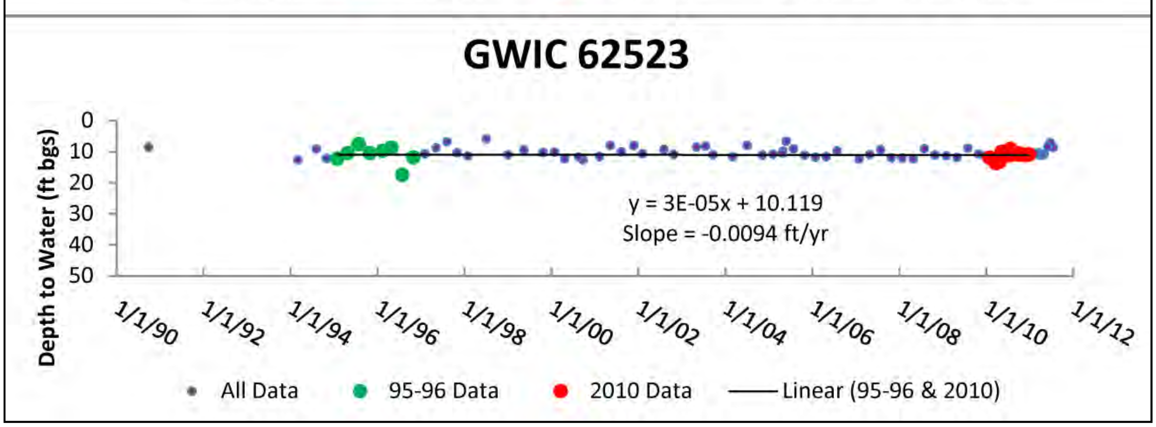


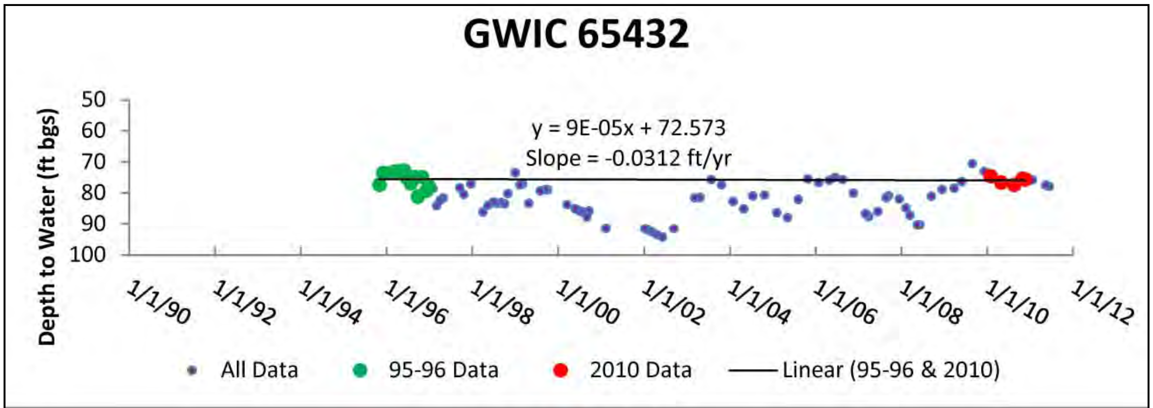
Figure H1. Geographic distribution and magnitudes of downward or upward trends based on linear regressions of long-term water-level data. Downward trends are negative and upward trends are positive. Most sites do not show either upward or downward movement; however, some active wells show long-term declines due to usage at rates greater than the aquifer can locally sustain. There is no indication of regional drawdown.

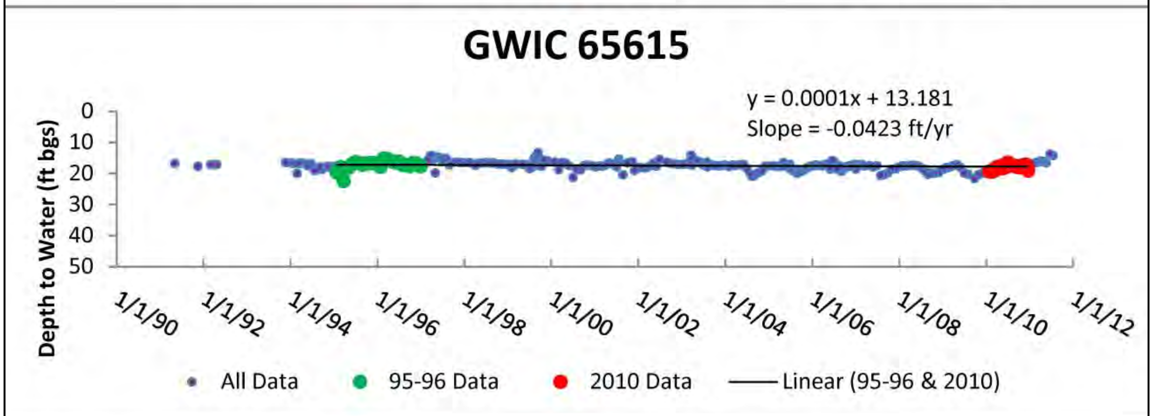

GWIC 5758
y = 0.0005x + 4.3944
Slope = -0.1835 ft/yr
Depth to Water (ft bgs)
0
10
20
30
40
50
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)

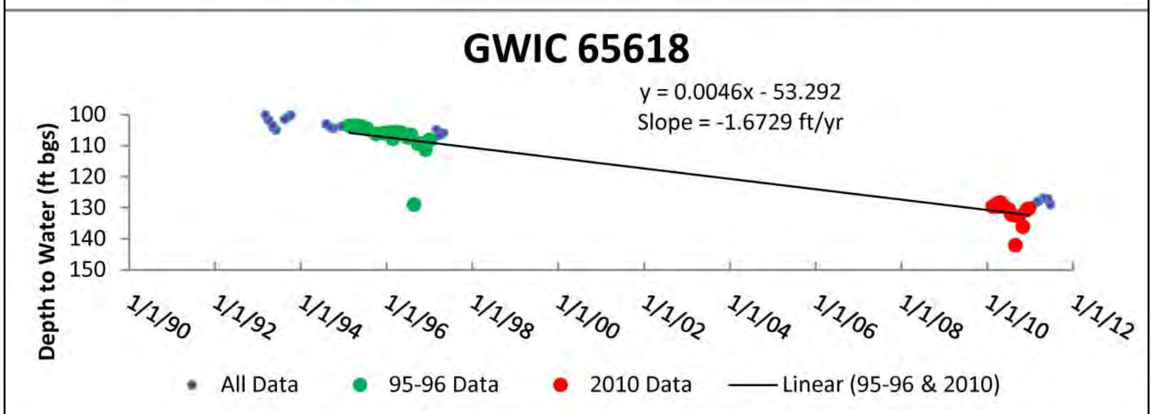

GWIC 62369
y = 4E-05x + 34.987
Slope = -0.0159 ft/yr
Depth to Water (ft bgs)
0
10
20
30
40
50
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)

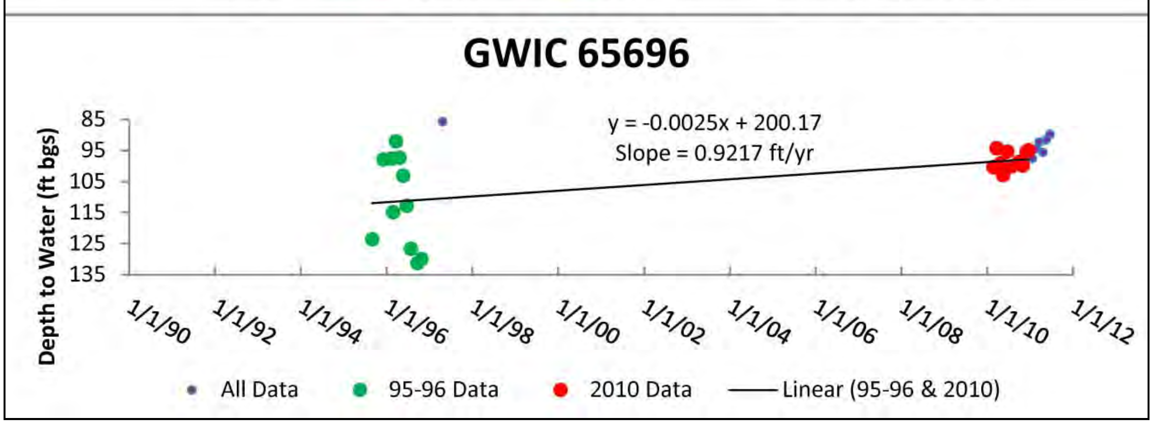

GWIC 62385
y = -0.0001x + 21.616
Slope = 0.0517 ft/yr
Depth to Water (ft bgs)
0
10
20
30
40
50
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)

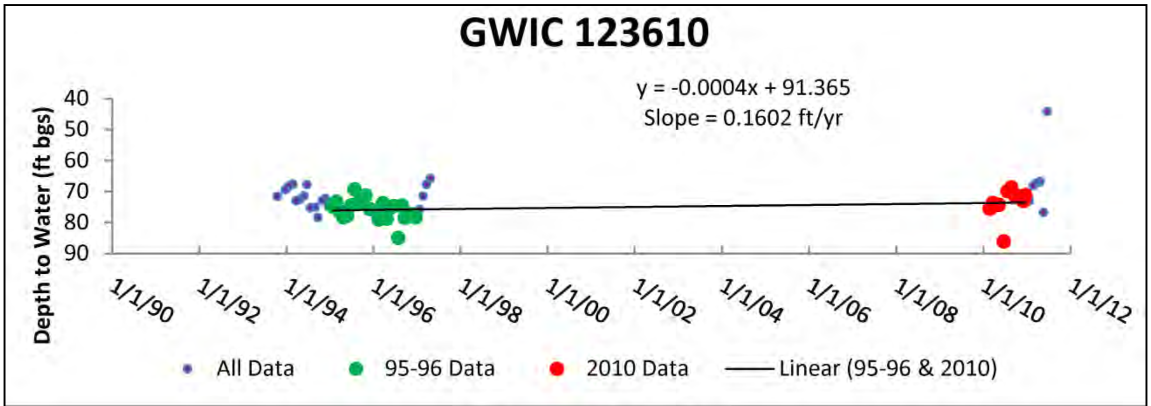

GWIC 62523
y = 3E-05x + 10.119
Slope = -0.0094 ft/yr
Depth to Water (ft bgs)
0
10
20
30
40
50
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)

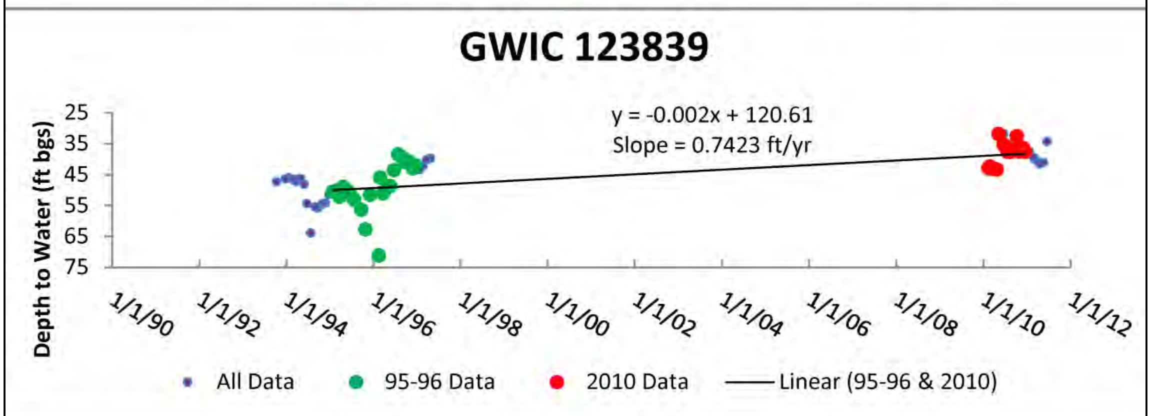

GWIC 65432
y = 9E-05x + 72.573
Slope = -0.0312 ft/yr
Depth to Water (ft bgs)
50
60
70
80
90
100
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)

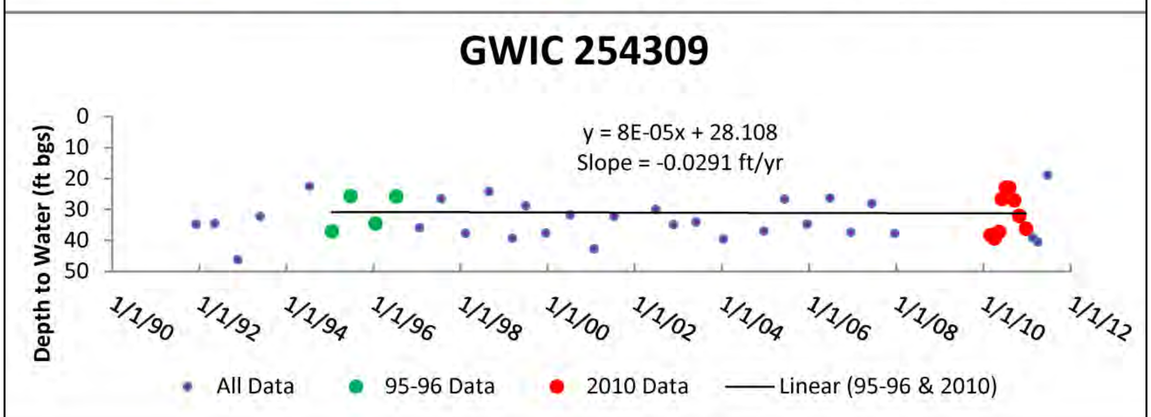

GWIC 65615
y = 0.0001x + 13.181
Slope = -0.0423 ft/yr
Depth to Water (ft bgs)
0
10
20
30
40
50
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)

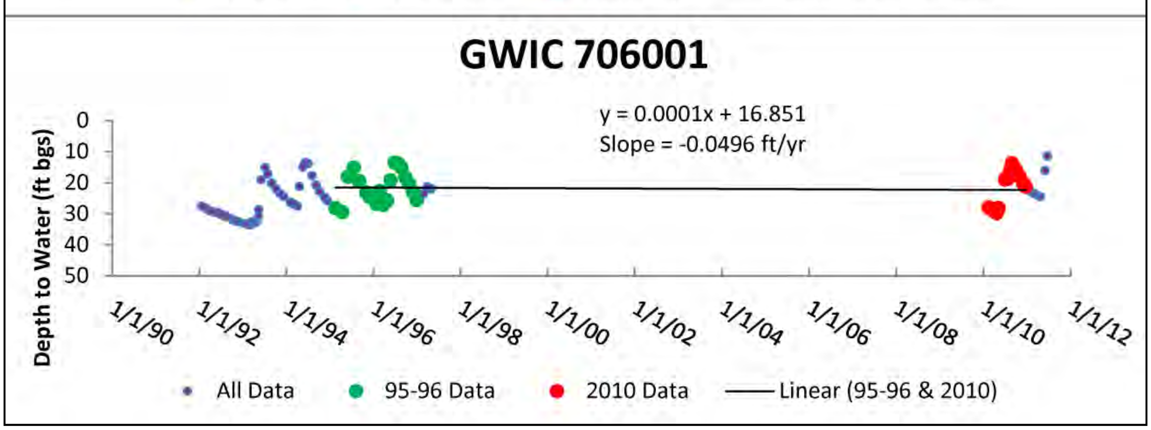

GWIC 65618
y = 0.0046x - 53.292
Slope = -1.6729 ft/yr
Depth to Water (ft bgs)
100
110
120
130
140
150
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)


GWIC 65696
y = -0.0025x + 200.17
Slope = 0.9217 ft/yr
Depth to Water (ft bgs)
85
95
105
115
125
135
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)

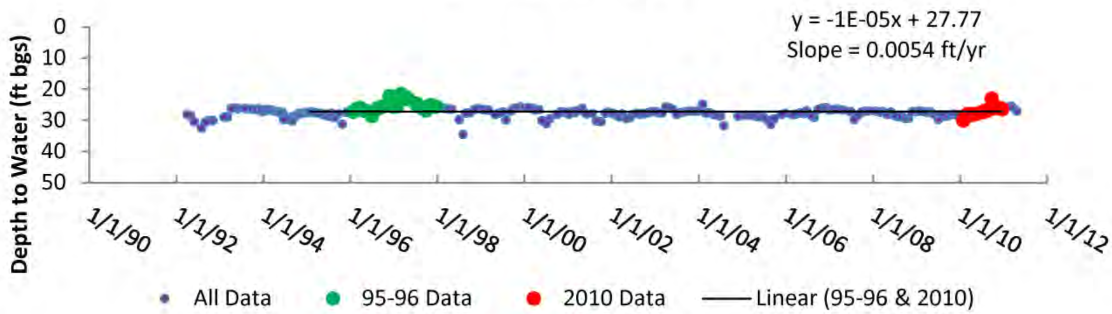

GWIC 123610
y = -0.0004x + 91.365
Slope = 0.1602 ft/yr
Depth to Water (ft bgs)
40
50
60
70
80
90
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)


GWIC 123839
y = -0.002x + 120.61
Slope = 0.7423 ft/yr
Depth to Water (ft bgs)
25
35
45
55
65
75
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)

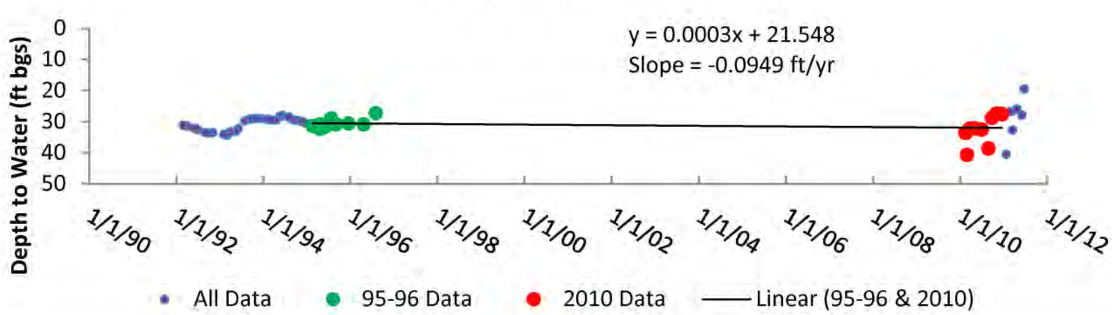

GWIC 254309
y = 8E-05x + 28.108
Slope = -0.0291 ft/yr
Depth to Water (ft bgs)
0
10
20
30
40
50
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)


GWIC 706001
y = 0.0001x + 16.851
Slope = -0.0496 ft/yr
Depth to Water (ft bgs)
0
10
20
30
40
50
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)

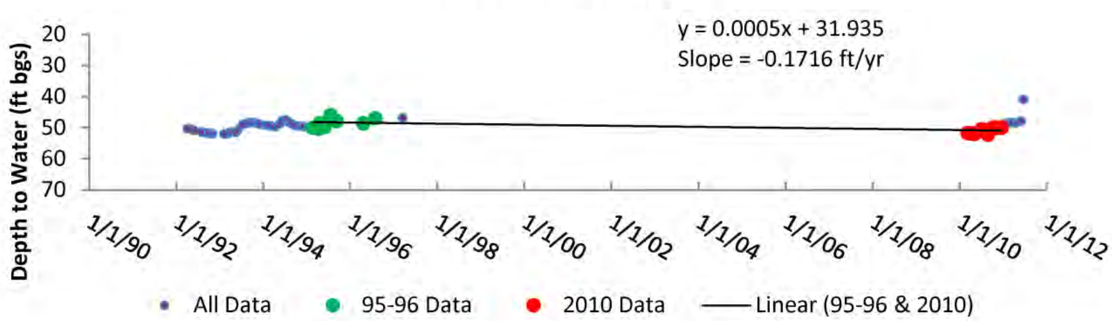
GWIC 706014



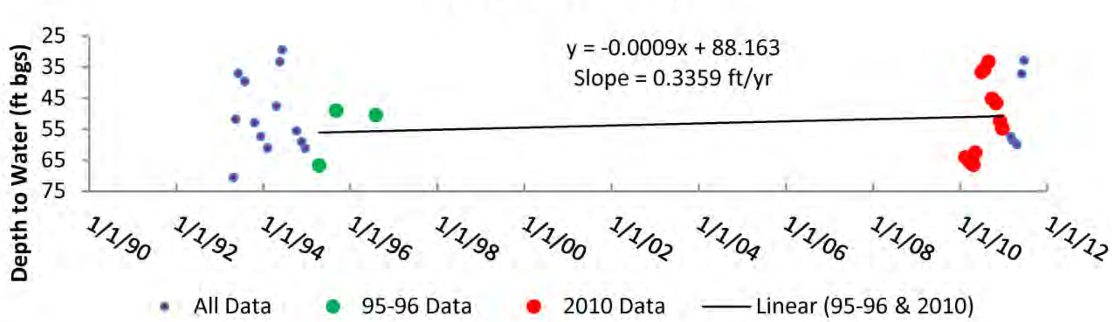
GWIC 706021

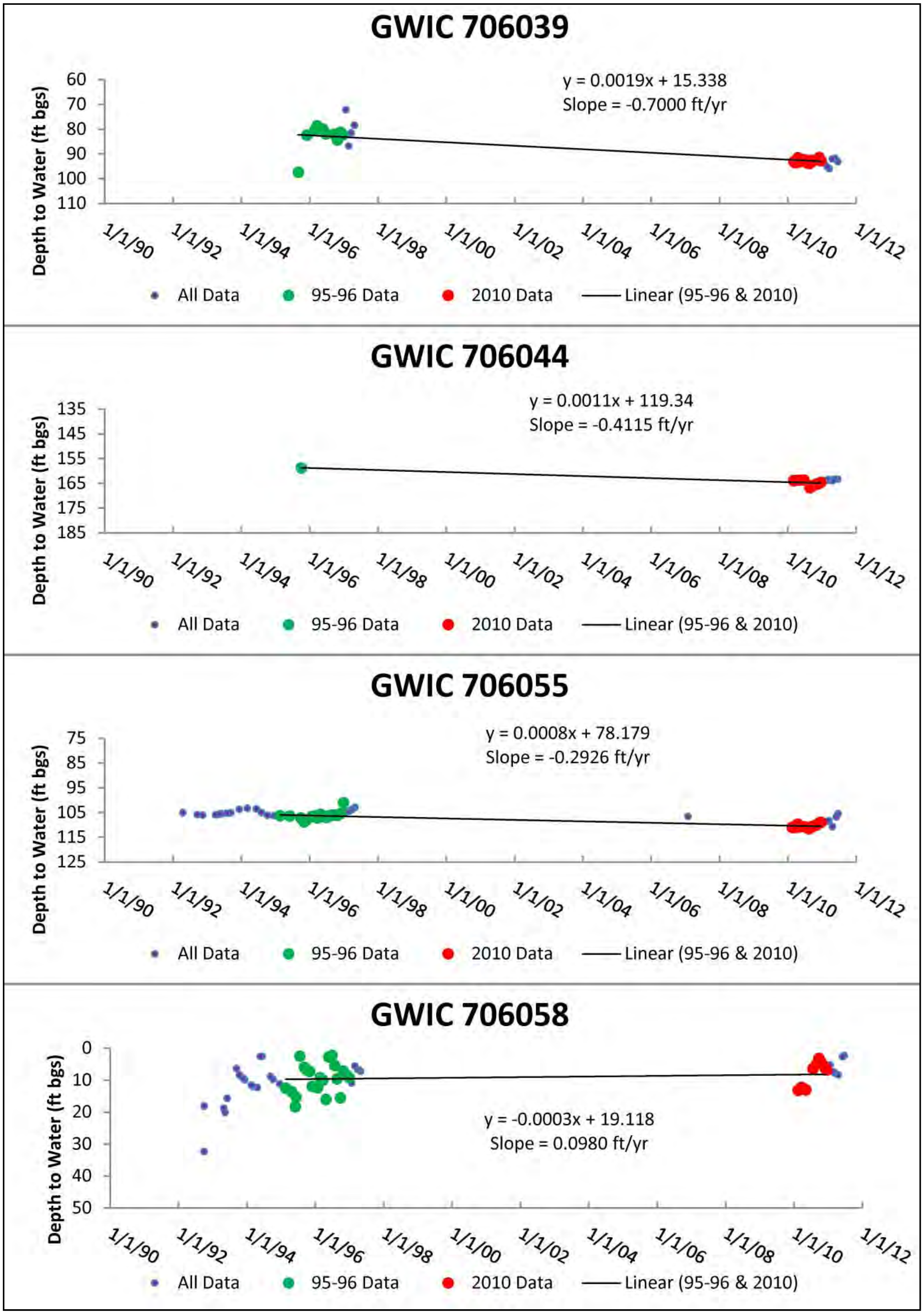


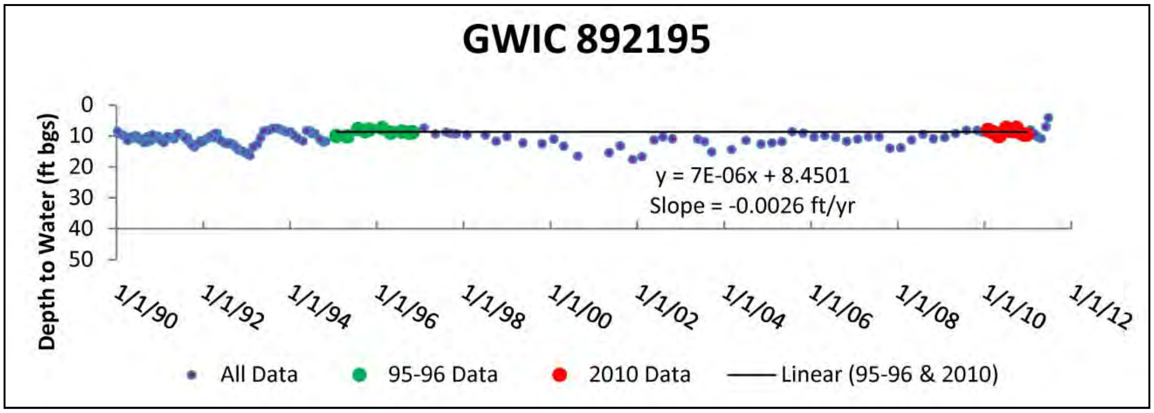
GWIC 706024



GWIC 706028




GWIC 706039
y = 0.0019x + 15.338
Slope = -0.7000 ft/yr
Depth to Water (ft bgs)
60
70
80
90
100
110
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)
GWIC 706044
y = 0.0011x + 119.34
Slope = -0.4115 ft/yr
Depth to Water (ft bgs)
135
145
155
165
175
185
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)
GWIC 706055
y = 0.0008x + 78.179
Slope = -0.2926 ft/yr
Depth to Water (ft bgs)
75
85
95
105
115
125
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)
GWIC 706058
y = -0.0003x + 19.118
Slope = 0.0980 ft/yr
Depth to Water (ft bgs)
0
10
20
30
40
50
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)


GWIC 892195
Depth to Water (ft bgs)
0
10
20
30
40
50
y = 7E-06x + 8.4501
Slope = -0.0026 ft/yr
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
All Data
95-96 Data
2010 Data
Linear (95-96 & 2010)

POTENTIOMETRIC SURFACE MAPS

A potentiometric surface is an imaginary surface representing the total head of groundwater, and is defined at any point on the surface as the height at which water will stabilize in a well. A potentiometric surface map shows this surface using contours of equal water-level elevation. Flowlines run perpendicular to potentiometric contours (Fetter, 1994, p. 114–115).

For this project, potentiometric surface maps were developed for selected months. For most monthly data sets, the potentiometric contours were drawn using interpolation software, and were not further refined (referred to as raw contours on the following maps). For October 2010 (the first event for which all monitoring wells were available), the raw contours were further refined based on topography, surface-water features, data from outside the study area, and previous work.

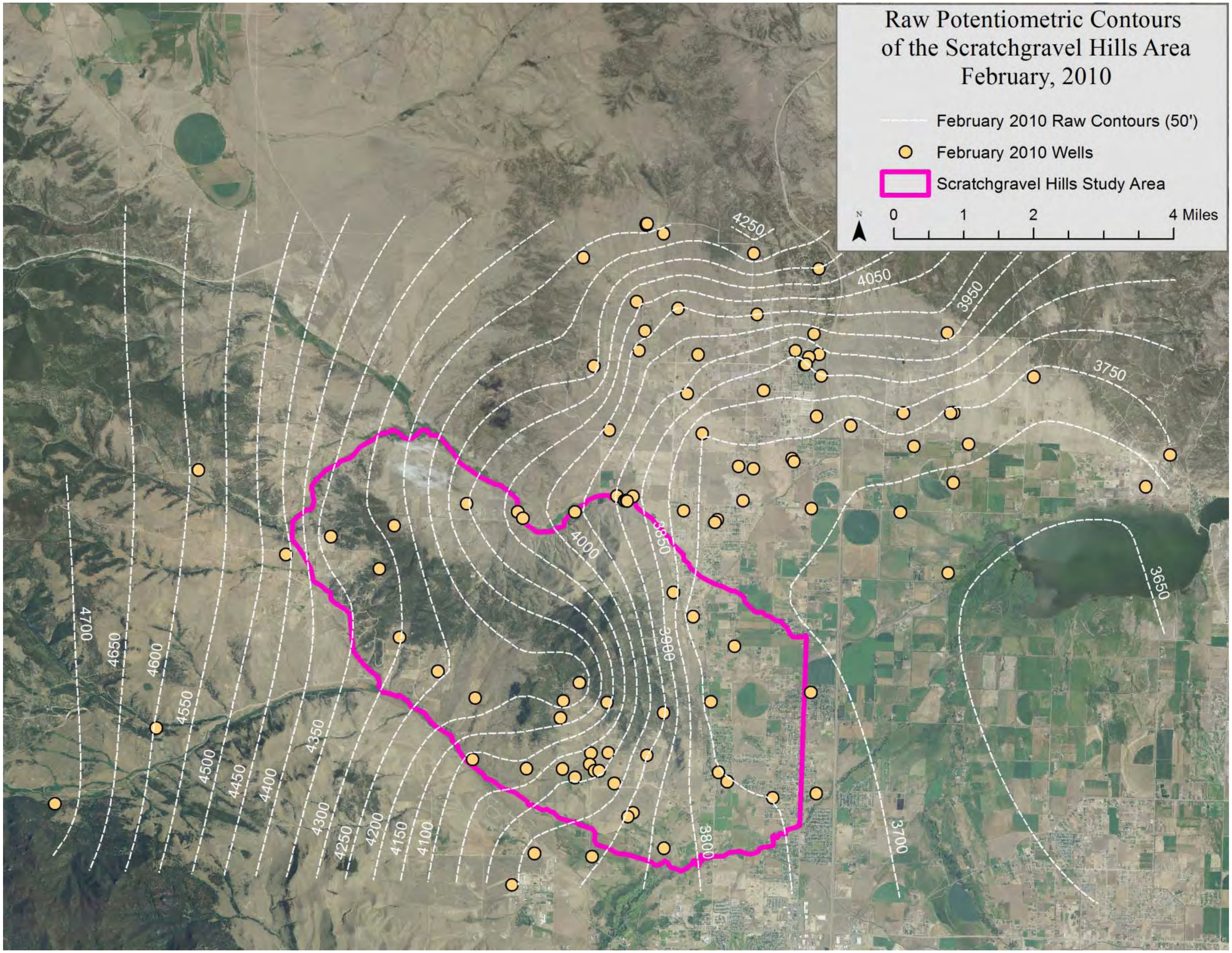
Comparison of the contour maps shows that there is little seasonal variation in the potentiometric surface's overall shape and that where the current maps overlap with previous maps, the surfaces are comparable (Lorenz and Swenson, 1951; Briar and Madison, 1992).

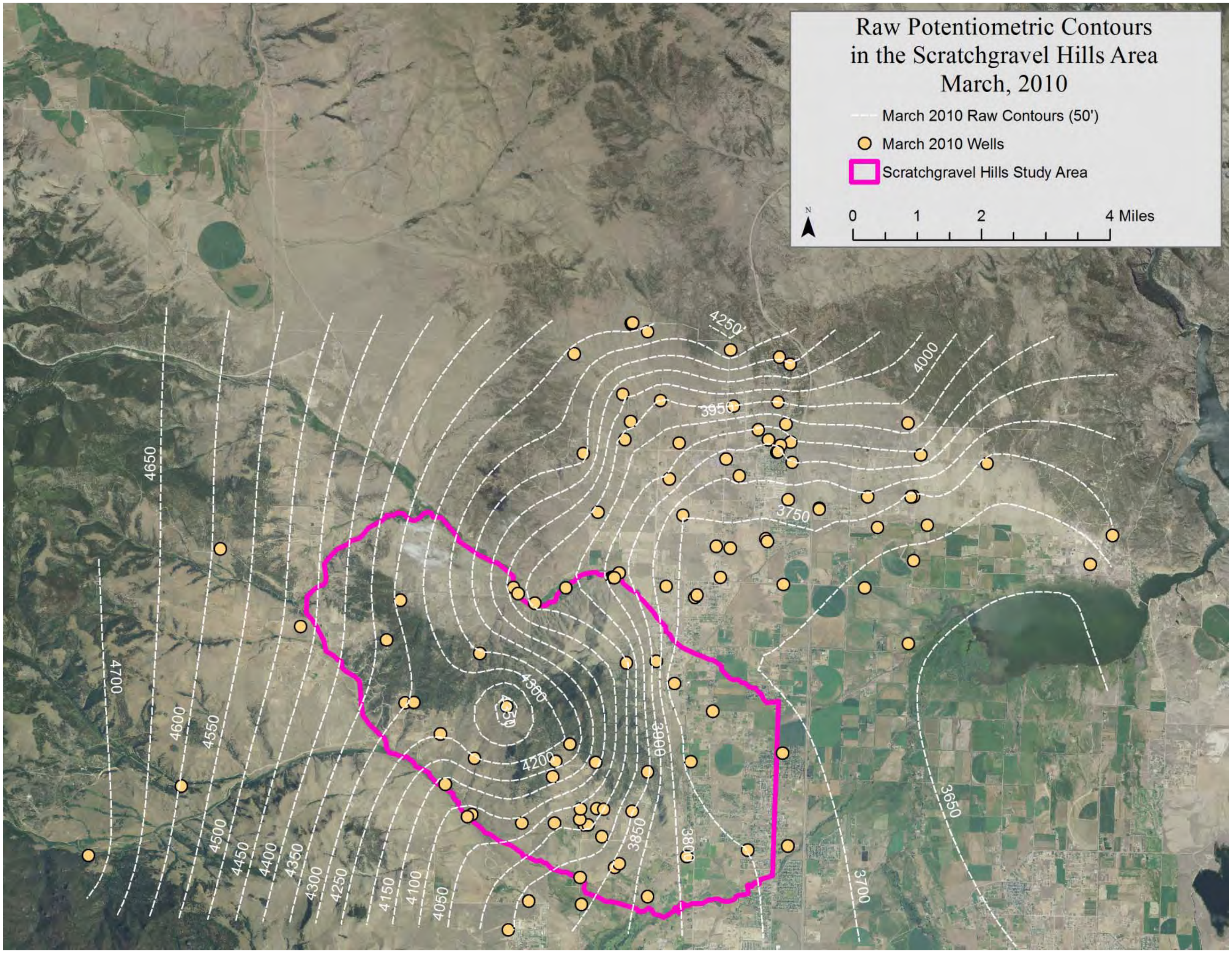
The potentiometric surface in the Scratchgravel Hills is generally a subdued reflection of the topography. Groundwater altitudes are high at high-altitude upland locations where there is more precipitation. In the core of the Scratchgravel Hills this high-altitude area is also underlain by low-permeability granite, which limits outward groundwater flow. These factors combine to form a mound beneath the top of the Scratchgravel Hills, and groundwater flow is away from the mound in all directions. Because there is flow coming into the study area from the mountains to the west, western flow off of the mound forces this eastward regional flow to divert to the north and south, and discharge into the alluvial materials underlying Silver and Sevenmile Creeks. The shape of the potentiometric surface shows that flow lines are parallel to Silver Creek and Sevenmile Creek. Flow lines can also be drawn to encompass the Green Meadow CGWA, which shows that all recharge to this area is local. Unless diverted, all groundwater in this area eventually flows to Lake Helena.

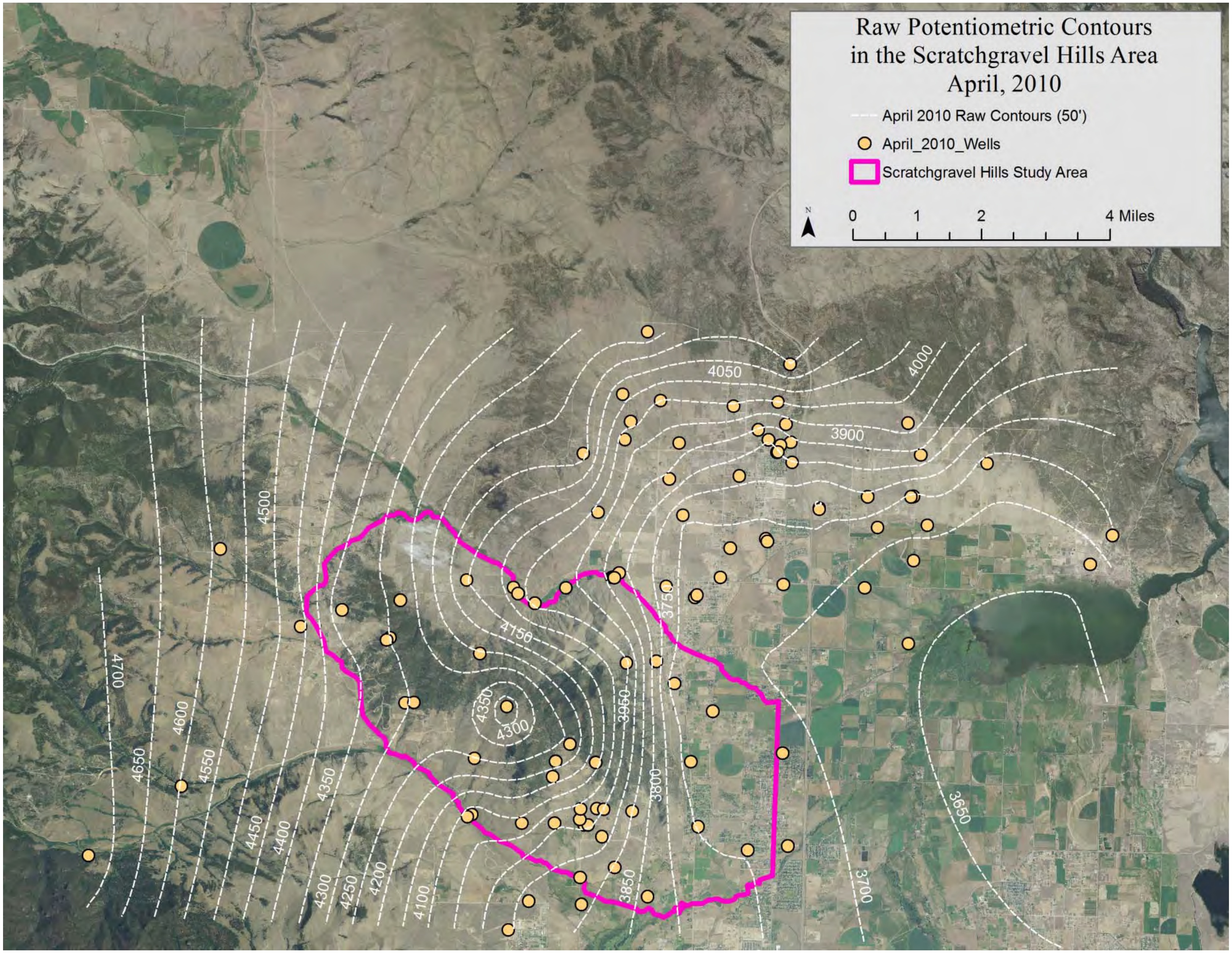
Briar, D.W., and Madison, J.P., 1992, Hydrogeology of the Helena valley-fill aquifer system, west-central Montana: U.S. Geological Survey Water Resources Investigations Report 92-4023, 92 p.

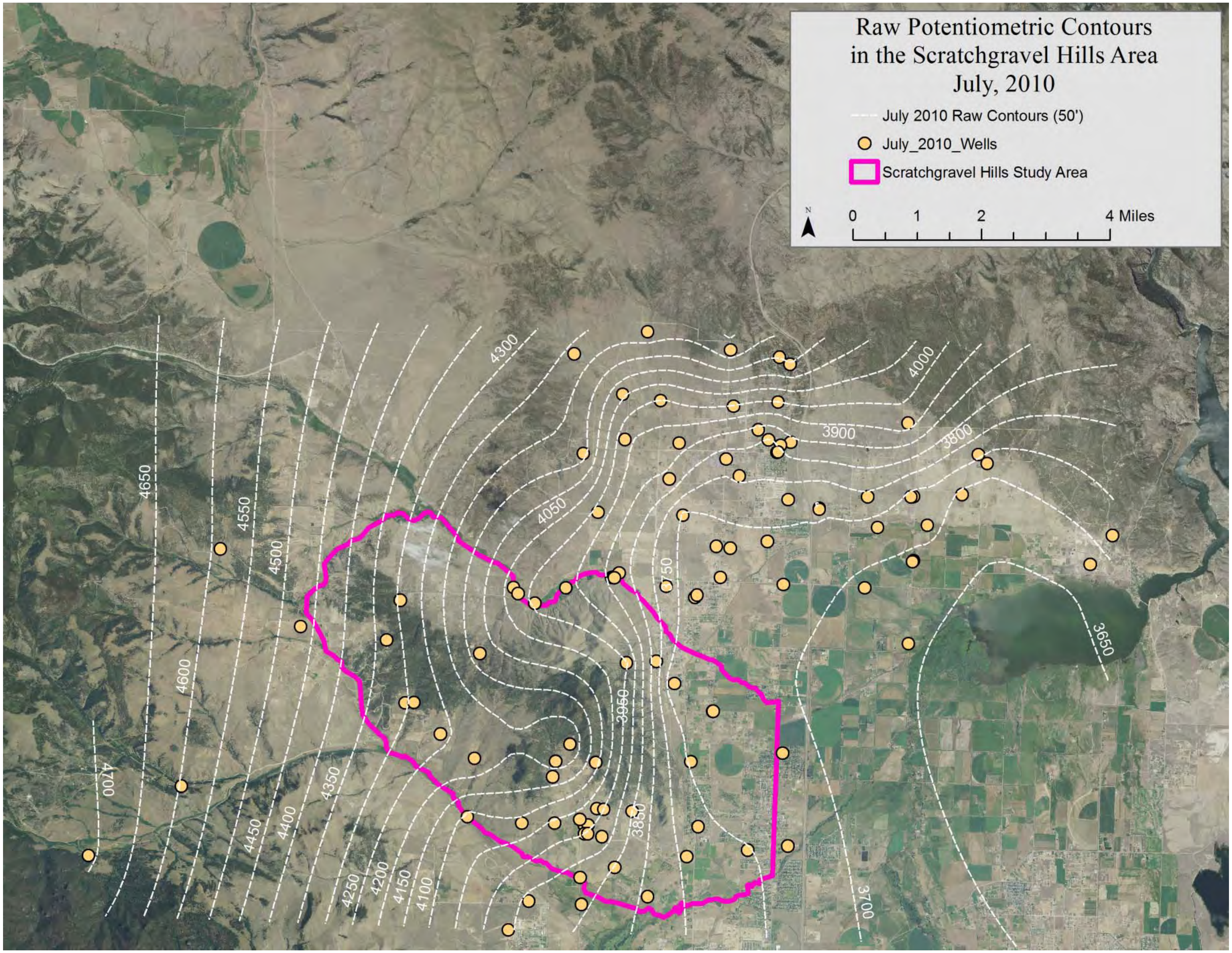
Fetter, C.W., 1994, Applied hydrogeology, 3d ed.: New York, Macmillan College Publishing, 691 p.

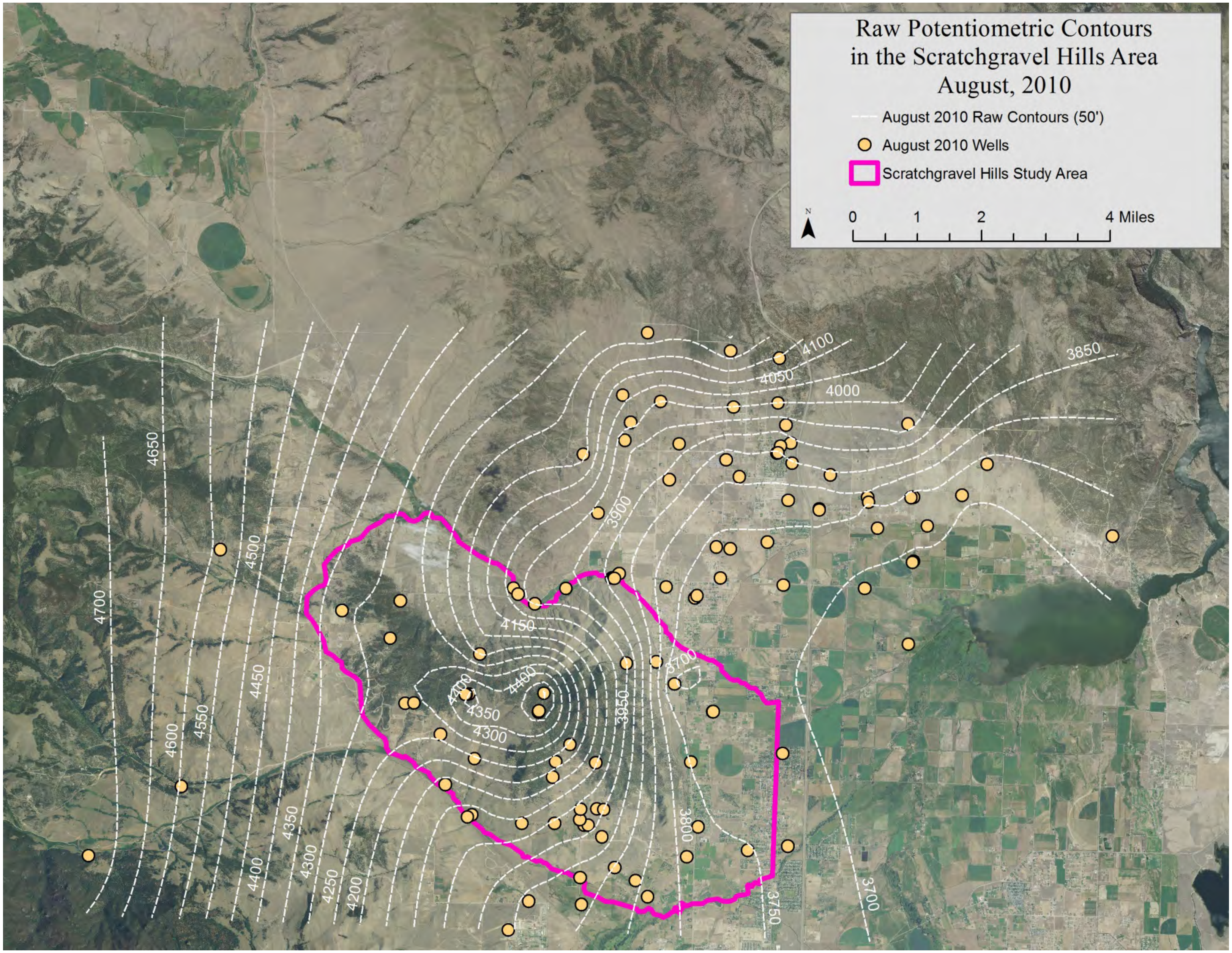
Lorenz, H.W., and Swenson, F.A., 1951, Geology and ground-water resources of the Helena Valley, Montana, with a section on the chemical quality of the water by H.A. Swenson: U.S. Geological Survey Circular 83, 68 p.

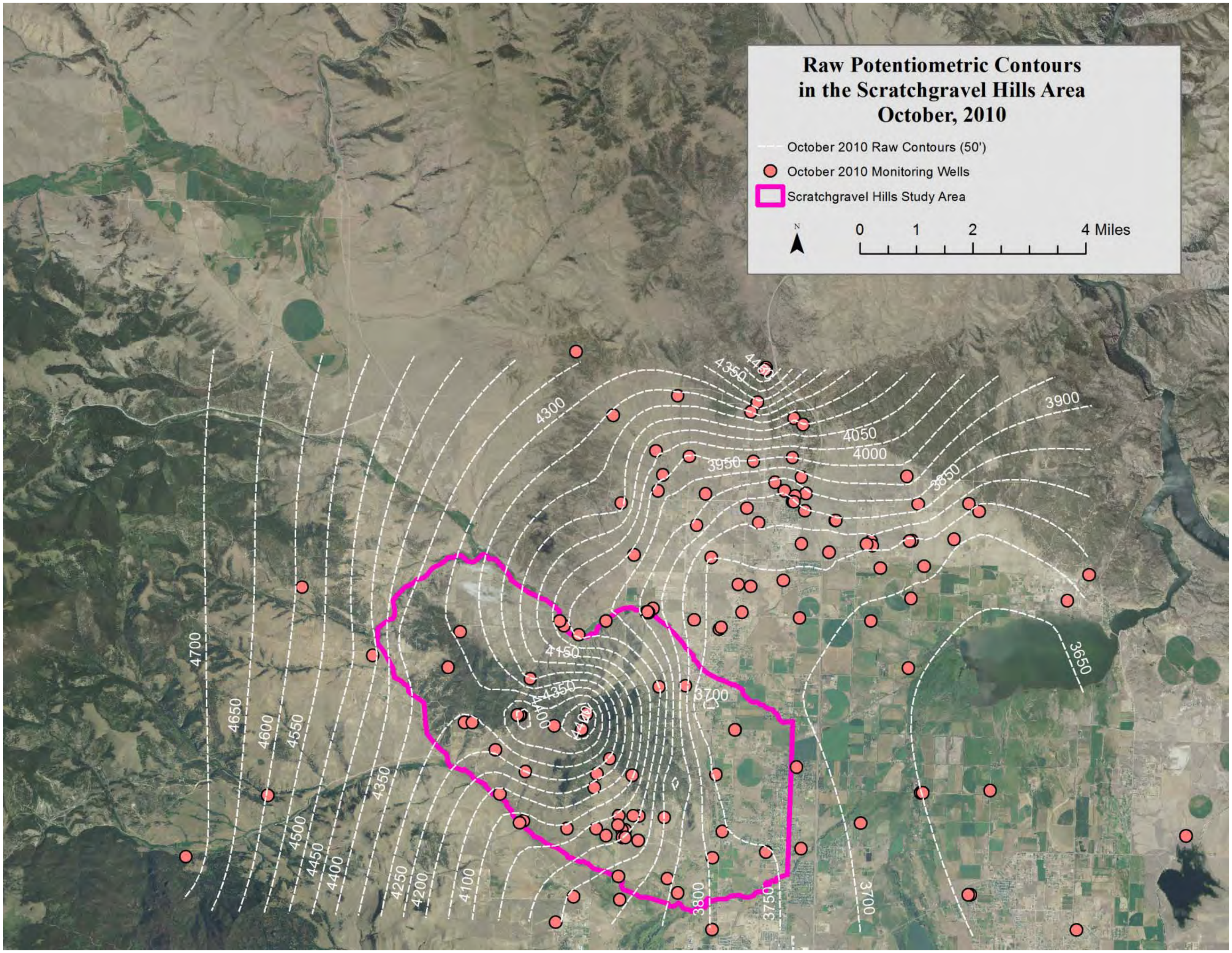

Raw Potentiometric Contours
of the Scratchgravel Hills Area
February, 2010
February 2010 Raw Contours (50')
February 2010 Wells
Scratchgravel Hills Study Area
N
0
1
2
4 Miles
4700
4650
4600
4550
4500
4450
4400
4350
4300
4250
4200
4150
4100
4250
4050
3950
3750
4000
3850
3900
3800
3700
3650


Raw Potentiometric Contours in the Scratchgravel Hills Area March, 2010
March 2010 Raw Contours (50')
March 2010 Wells
Scratchgravel Hills Study Area
N
0
1
2
4 Miles
4700
4650
4600
4550
4500
4450
4400
4350
4300
4250
4150
4100
4050
4350
4300
4200
4250
4000
3950
3900
3850
3800
3750
3700
3650

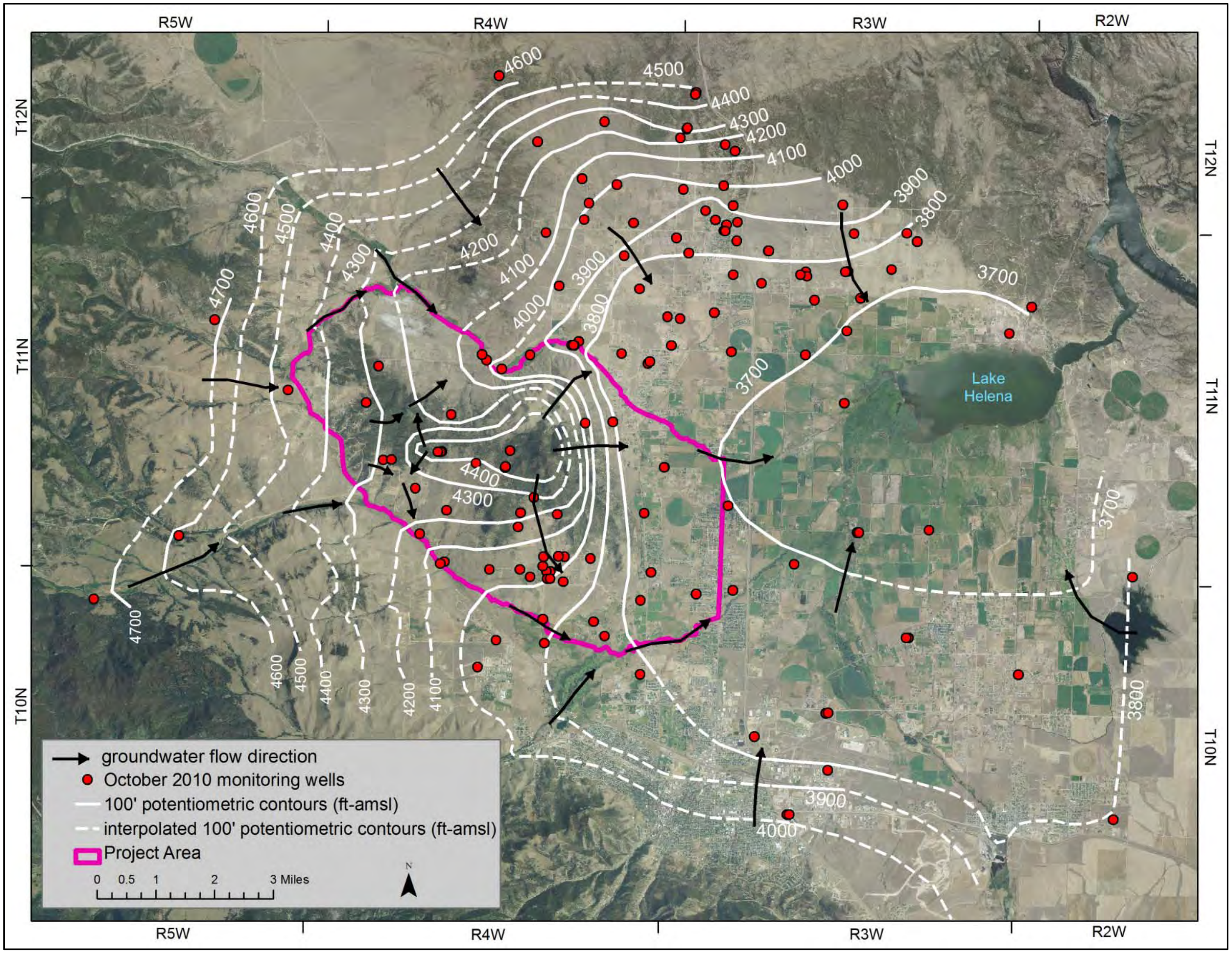

Raw Potentiometric Contours in the Scratchgravel Hills Area April, 2010
April 2010 Raw Contours (50')
April_2010_Wells
Scratchgravel Hills Study Area
N
0 1 2 4 Miles
4050
4000
3900
4500
4150
3750
4700
4600
4650
4550
4350
4300
3950
3800
4450
4400
4350
4300
4250
4200
4100
3850
3650
3700


Raw Potentiometric Contours in the Scratchgravel Hills Area July, 2010
July 2010 Raw Contours (50')
July_2010_Wells
Scratchgravel Hills Study Area
N
0
1
2
4 Miles
4700
4650
4600
4550
4500
4450
4400
4350
4300
4250
4200
4150
4100
4050
4000
3950
3900
3850
3800
3750
3700
3650

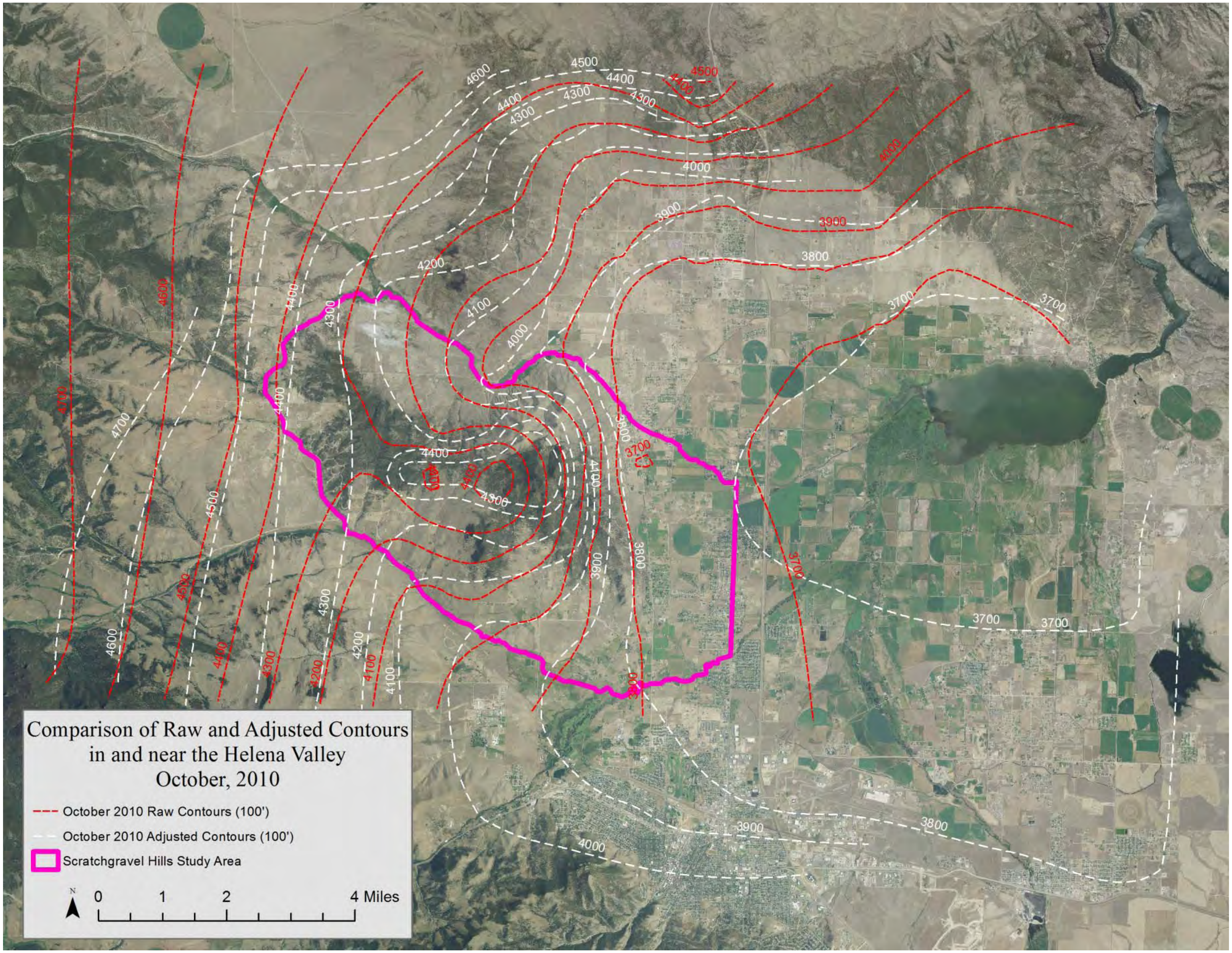

Raw Potentiometric Contours
in the Scratchgravel Hills Area
August, 2010
August 2010 Raw Contours (50')
August 2010 Wells
Scratchgravel Hills Study Area
N
0
1
2
4 Miles
4700
4650
4600
4550
4500
4450
4400
4350
4300
4250
4200
4150
4100
4050
4000
3950
3900
3850
3800
3750
3700

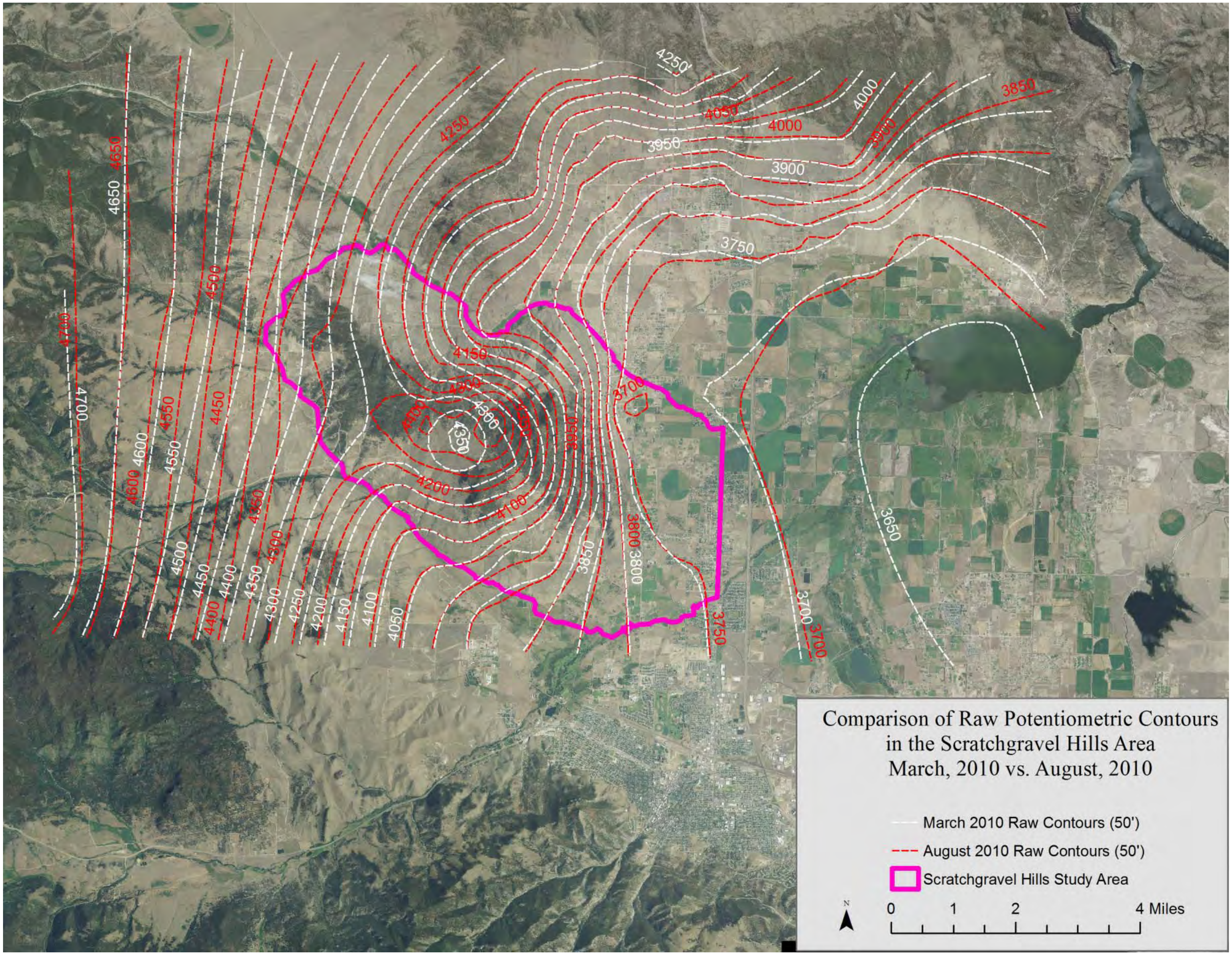


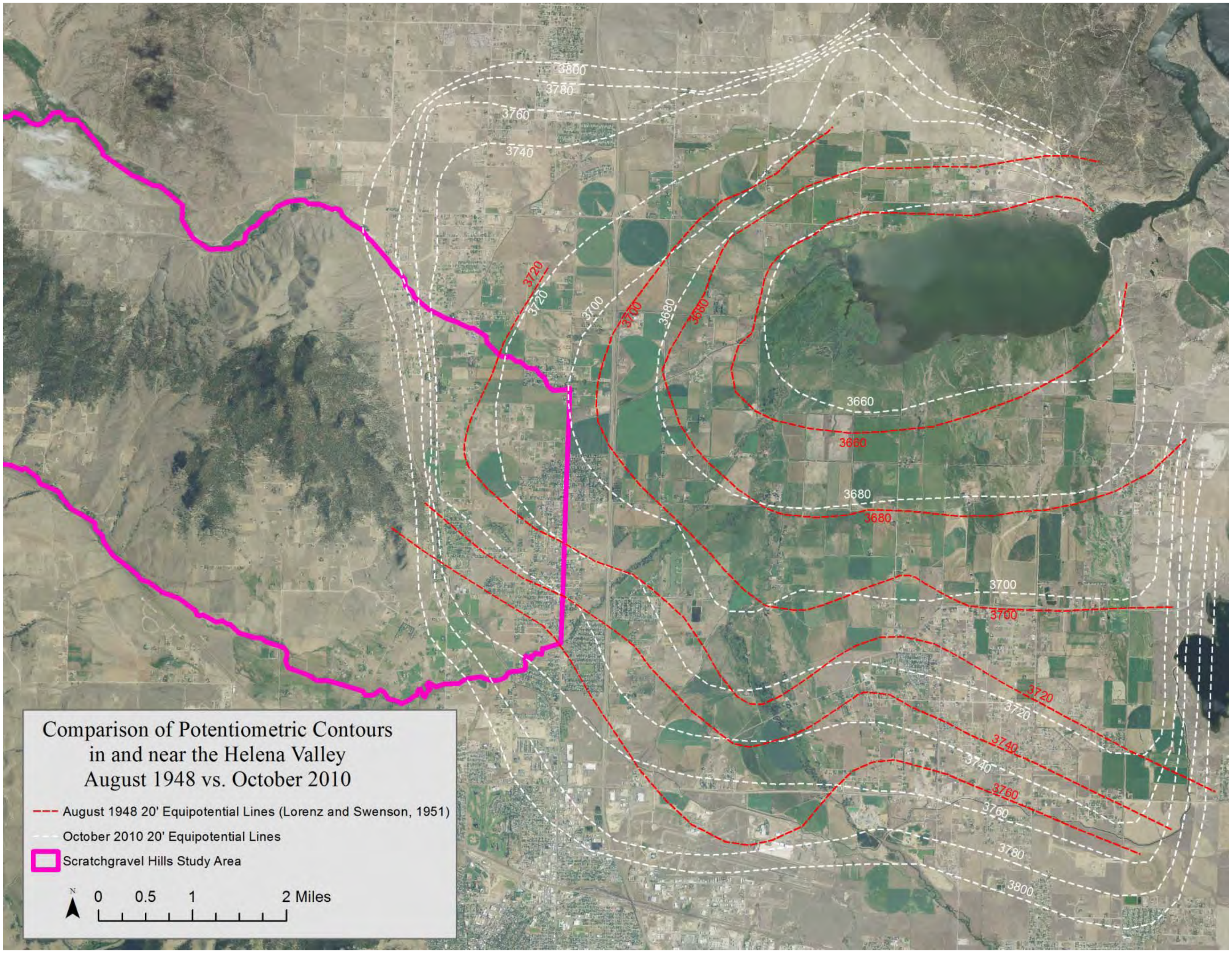
Raw Potentiometric Contours in the Scratchgravel Hills Area October, 2010
October 2010 Raw Contours (50')
October 2010 Monitoring Wells
Scratchgravel Hills Study Area
0 1 2 4 Miles

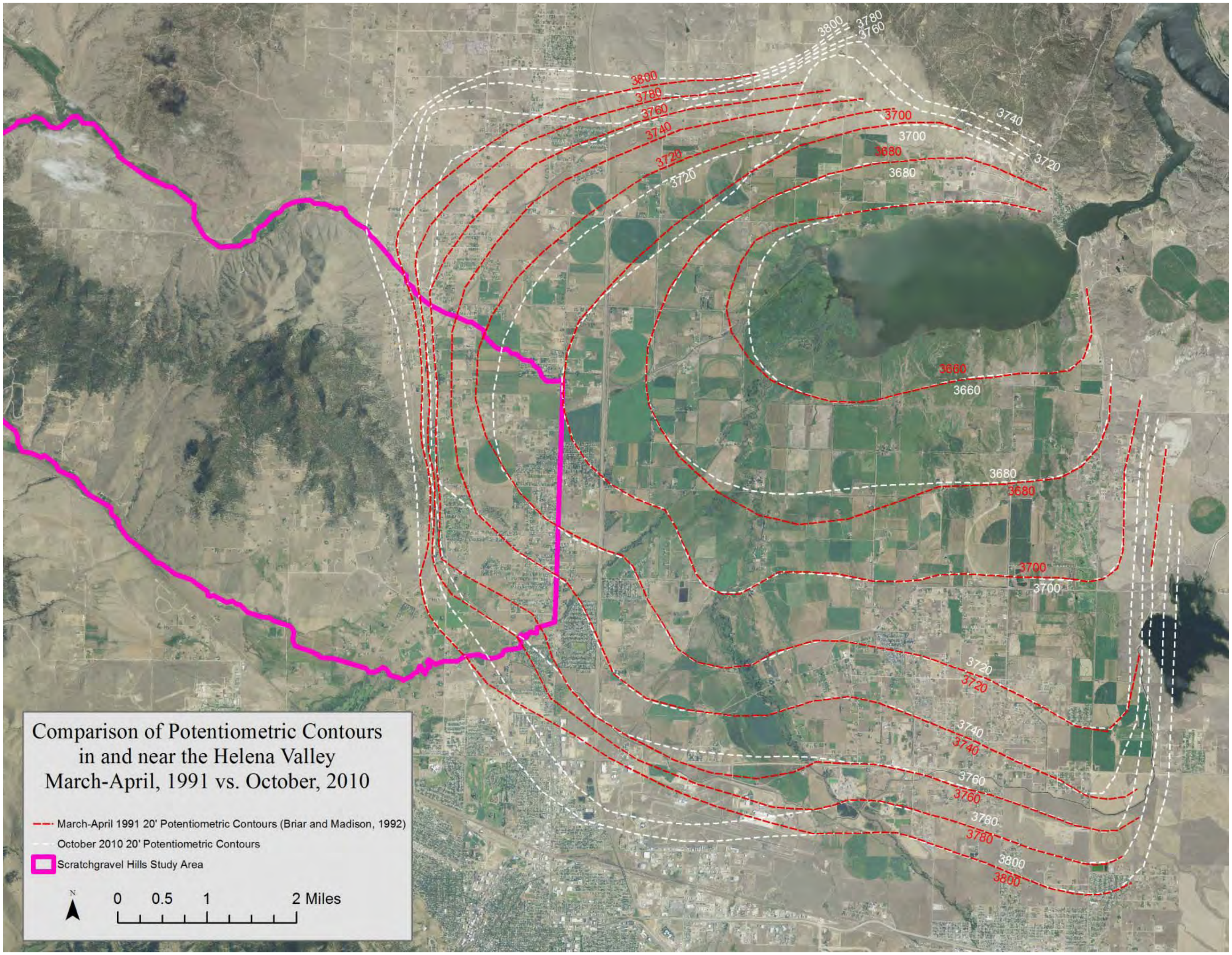


Manually adjusted October 2010 potentiometric surface.


Comparison of Raw and Adjusted Contours
in and near the Helena Valley
October, 2010
October 2010 Raw Contours (100')
October 2010 Adjusted Contours (100')
Scratchgravel Hills Study Area
0 1 2 4 Miles
N


Comparison of Raw Potentiometric Contours
in the Scratchgravel Hills Area
March, 2010 vs. August, 2010
March 2010 Raw Contours (50')
August 2010 Raw Contours (50')
Scratchgravel Hills Study Area
0 1 2 4 Miles
N


Comparison of Potentiometric Contours
in and near the Helena Valley
August 1948 vs. October 2010
August 1948 20' Equipotential Lines (Lorenz and Swenson, 1951)
October 2010 20' Equipotential Lines
Scratchgravel Hills Study Area
0 0.5 1 2 Miles
3800
3780
3760
3740
3720
3700
3680
3660


Comparison of Potentiometric Contours
in and near the Helena Valley
March-April, 1991 vs. October, 2010
March-April 1991 20' Potentiometric Contours (Briar and Madison, 1992)
October 2010 20' Potentiometric Contours
Scratchgravel Hills Study Area
N
0 0.5 1 2 Miles
3800
3780
3760
3740
3720
3700
3680
3660

SURFACE WATER/GROUNDWATER INTERACTIONS

The direction that water flows between surface-water bodies and groundwater at any time is determined by the relative elevations of the water-body surface and the unconfined groundwater table at that time (Winter and others, 1998; Rosenberry and others, 2008). The timing of water-level changes can also be used qualitatively to assess how direct the connection is. Comparison of groundwater and surface-water temperature changes (e.g., diurnal variations) can also be used to assess the direction and magnitude of flow (Constantz and others, 2008). The overall change in stream flow can also indicate gains or losses; however, knowledge of all flow into or out of the stream between the measurement locations (e.g., tributary inputs or irrigation withdrawals) are needed for this technique to be used quantitatively.

For this study four wells were installed at three sites along Silver Creek (northern boundary of the study area; map below), and two wells were installed at two sites along Sevenmile Creek (southern boundary of the study area). These wells were completed in permeable zones near the top of the saturated zone. Groundwater levels and temperatures were continuously recorded at the wells. Stage and temperature were continuously recorded in the streams. GWIC IDs for the sites are included in table SC1 below.

All three sites on Silver Creek showed that stream surface elevations were typically higher than groundwater elevations; however, at the upstream and downstream sites groundwater and surface-water elevations were similar during the spring of 2011, which was a particularly high flow period. These water levels indicate that except for during extended flood events, the stream loses to the underlying groundwater. During floods, the available storage in the aquifer becomes fully saturated and there is little flux between surface and groundwater. The generally losing nature of this stream is qualitatively supported by comparison of flows at the three sites, which shows that flow generally diminished downstream (the observations were complicated due to irrigation activities). The general water-level change pattern was also closely related at all three sites. At the most downstream site, variations in groundwater levels caused by changes in stream stage were observed in wells with depths of up to 465 ft.

At all three of these sites, clear diurnal variations in stream temperature were recorded; however, changes in groundwater temperature were muted. Given the clear difference in elevations, it appears that the wells were completed too far below the stream to provide a high-resolution thermal response to surface-water infiltration (i.e., the unsaturated zone is too thick). It is notable that the shallow (12 ft deep) monitoring well at the lower site (SC-2) showed greater seasonal variation and more short-term temperature variations than the deeper well (22 ft deep). Also, both monitoring wells showed more temperature variation than the deep wells (97 and 465 ft deep).

The upstream site on Sevenmile Creek is located just above the diversion structure for the Sunny Vista Canal. Groundwater elevations were consistently above stream surface elevations. Changes in groundwater and surface-water levels were closely related in time. Thus it appears that the stream at this site was gaining for the entire monitored period. Given that Sevenmile Creek was a gaining stream, no thermal response in groundwater due to diurnal stream temperature variations was expected or observed.

The downstream site on Sevenmile Creek is located below several irrigation diversion structures. During the irrigation season, stream surface elevations and groundwater elevations were nearly identical. During the non-irrigation season the stream surface elevation was consistently and distinctly above the groundwater elevations. Changes in groundwater and stream surface elevations occurred at closely related times. It appears that the withdrawal of water from the stream during the irrigation season caused the stream surface elevation to decline until groundwater flowed into the stream, thus stabilizing the stream at the groundwater elevation. At the end of the irrigation season the stream surface elevation increased, resulting in flow to groundwater. Thus, at this location Sevenmile Creek is gaining during the irrigation season (due to depressed surface-water elevations) and losing during the non-irrigation season. There is no high-resolution thermal groundwater variability even after the end of the irrigation season, suggesting that the well was installed too deep to observe a high-resolution thermal response.

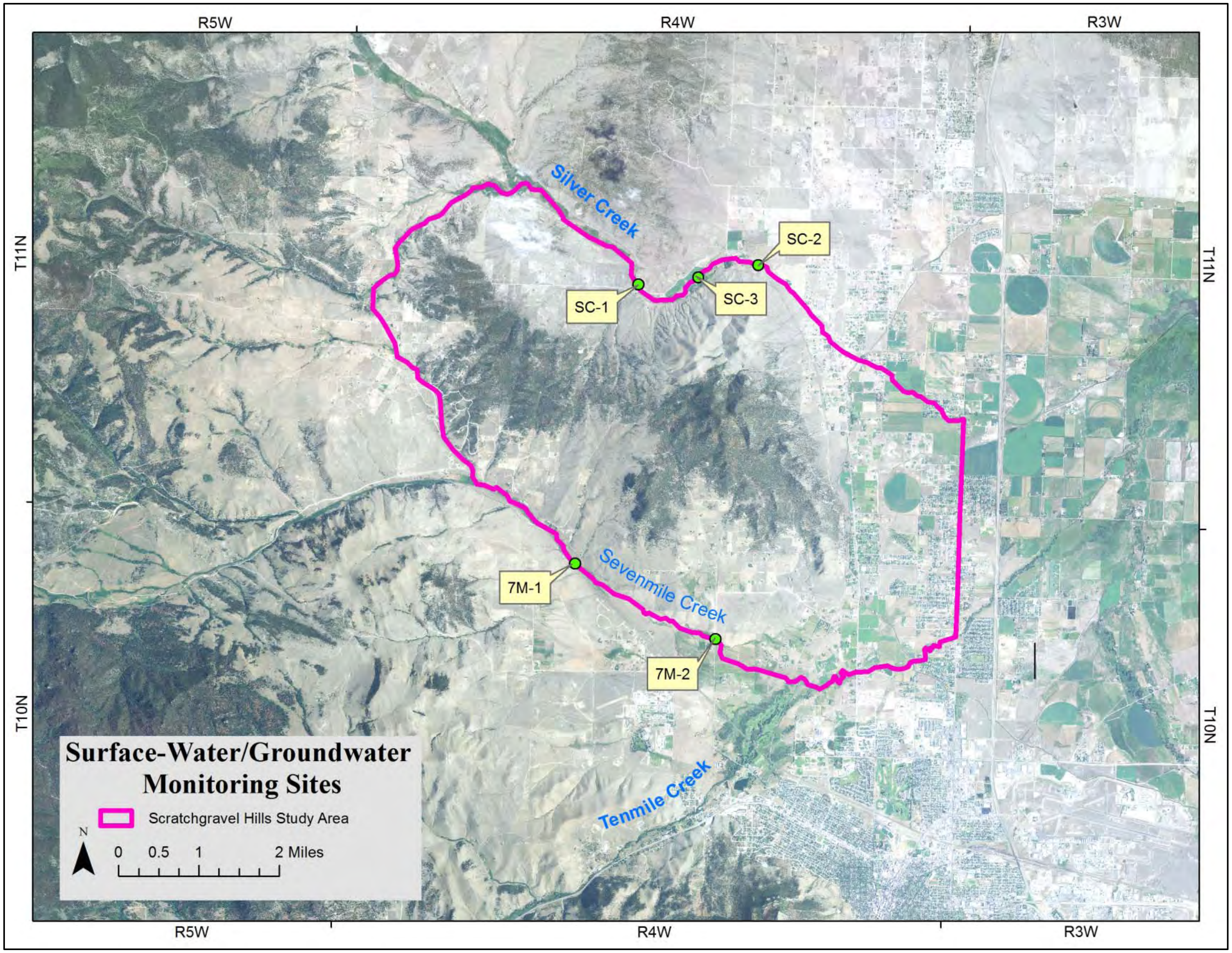
Table SC1
Scratchgravel Hills Surface-Water / Groundwater Evaluation Site Data Sources

Site	Staff Gauge GWIC ID	Piezometer GWIC IDs	GWIC IDs for nearby Water Wells
Silver Creek SC1	254994	254216	—
Silver Creek SC2	255001	254227, 254237	65316, 237167
Silver Creek SC3	254993	254242	—
Sevenmile 7M-1	255000	255141	—
Sevenmile 7M-2	260287	255143	—

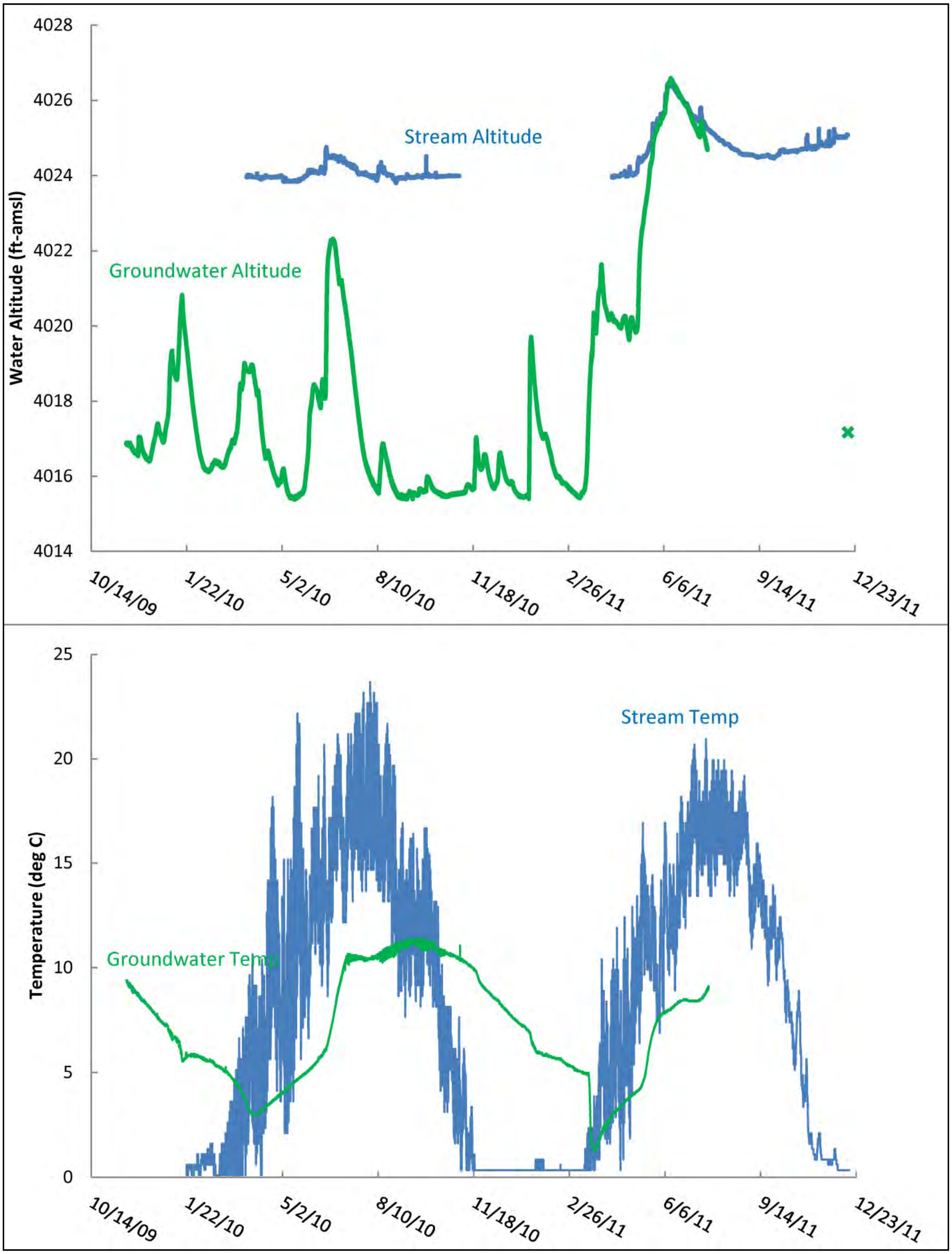
Constantz, J.E., Niswonger, R.G., and Stewart, A.E., 2008, Analysis of temperature gradients to determine stream exchanges with ground water, *in* Field techniques for estimating water fluxes between surface water and ground water, Rosenberry, D.O., and LaBaugh, J.W., eds.: U.S. Geological Survey Techniques and Methods 4-D2, 128 p.

Rosenberry, D.O., LaBaugh, J.W., and Hunt, R.J., 2008, Use of monitoring wells, portable piezometers, and seepage meters to quantify flow between surface water and ground water, *in* Field techniques for estimating water fluxes between surface water and ground water, Rosenberry, D.O., and LaBaugh, J.W., eds.: U.S. Geological Survey Techniques and Methods 4-D2, 128 p.

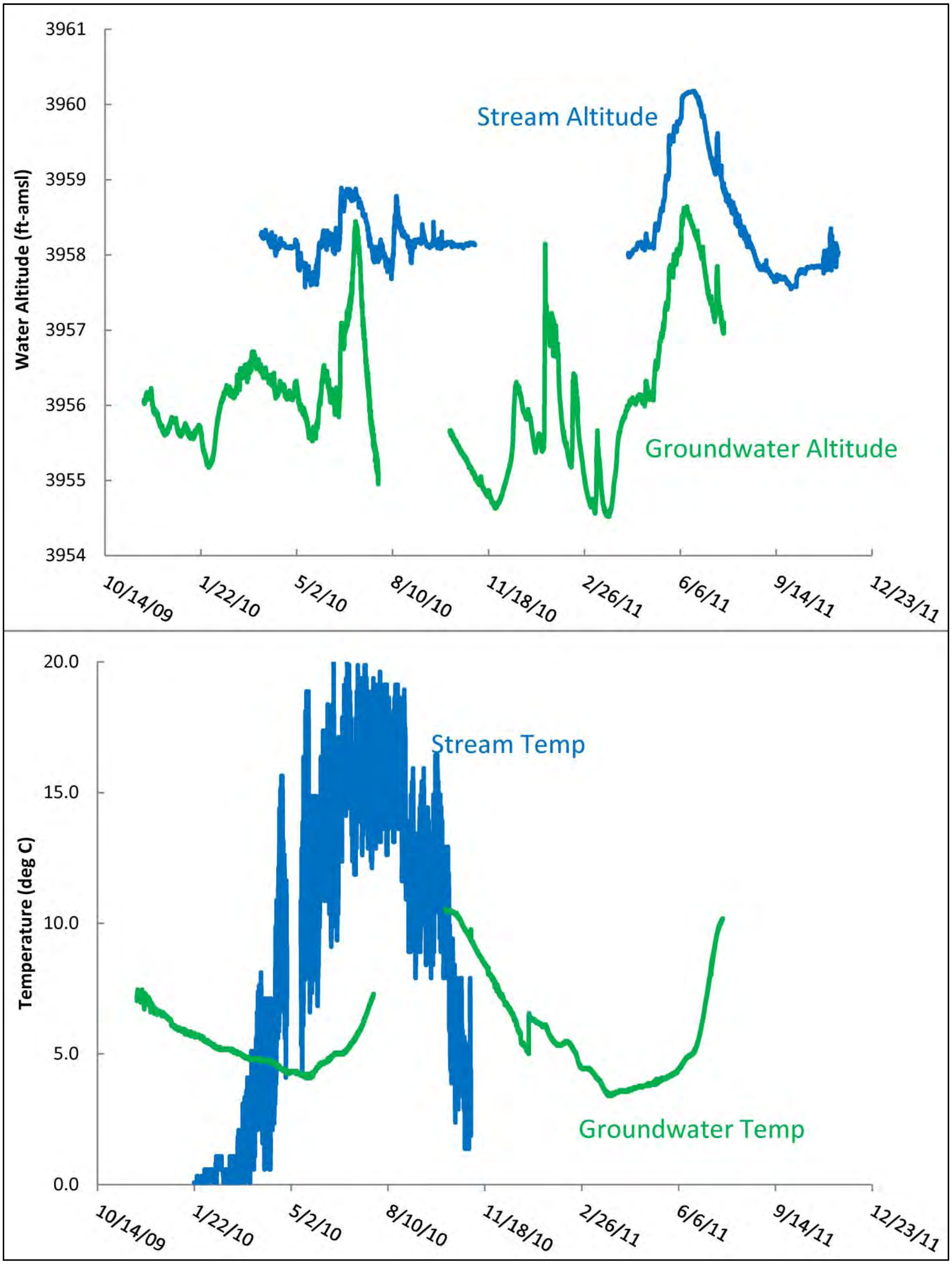
Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998, Ground water and surface water, a single resource: U.S. Geological Survey Circular 1139, 79 p.


R5W
R4W
R3W
T11N
T10N
Silver Creek
SC-1
SC-2
SC-3
7M-1
7M-2
Sevenmile Creek
Tenmile Creek
Surface-Water/Groundwater Monitoring Sites
Scratchgravel Hills Study Area
N
0 0.5 1 2 Miles

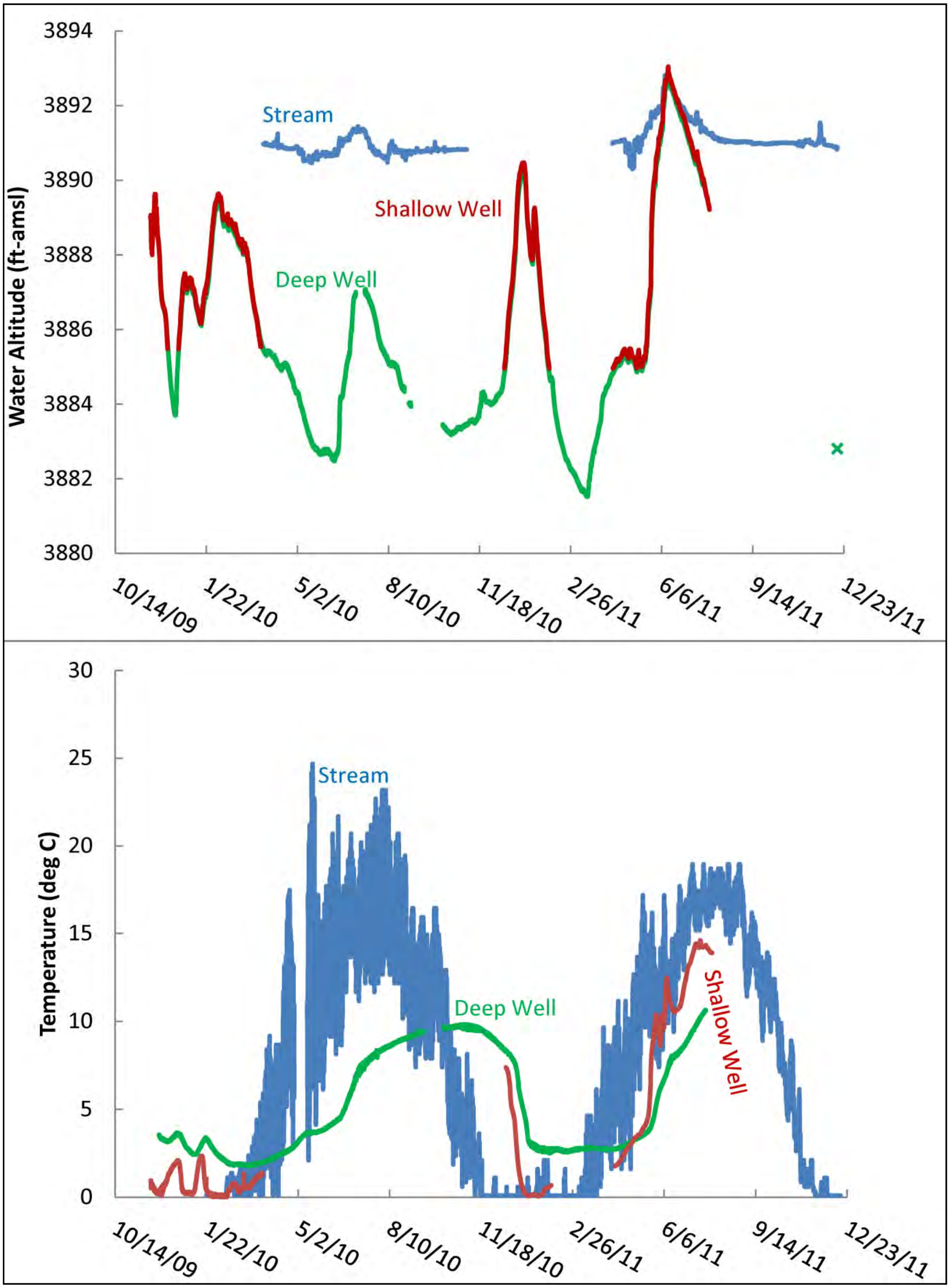
Upper Silver Creek Site (SC-1)



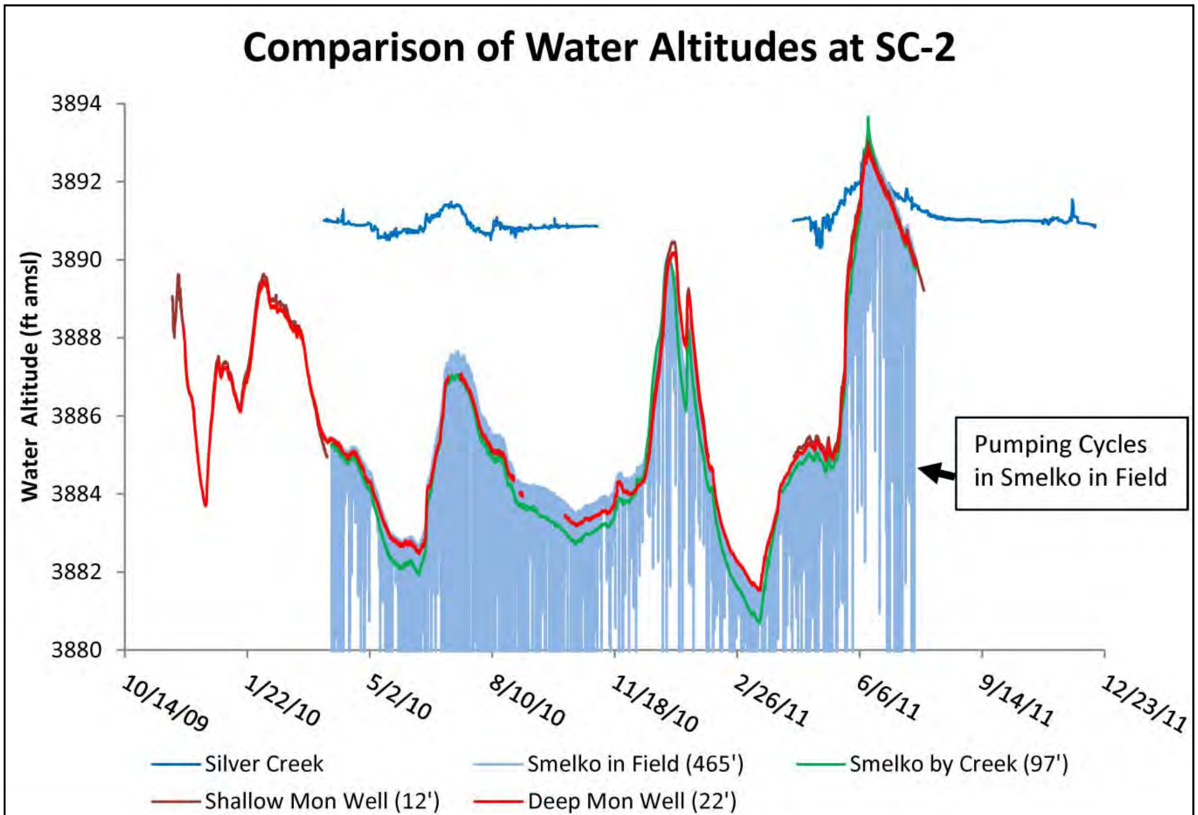
Middle Silver Creek Site (SC-3)

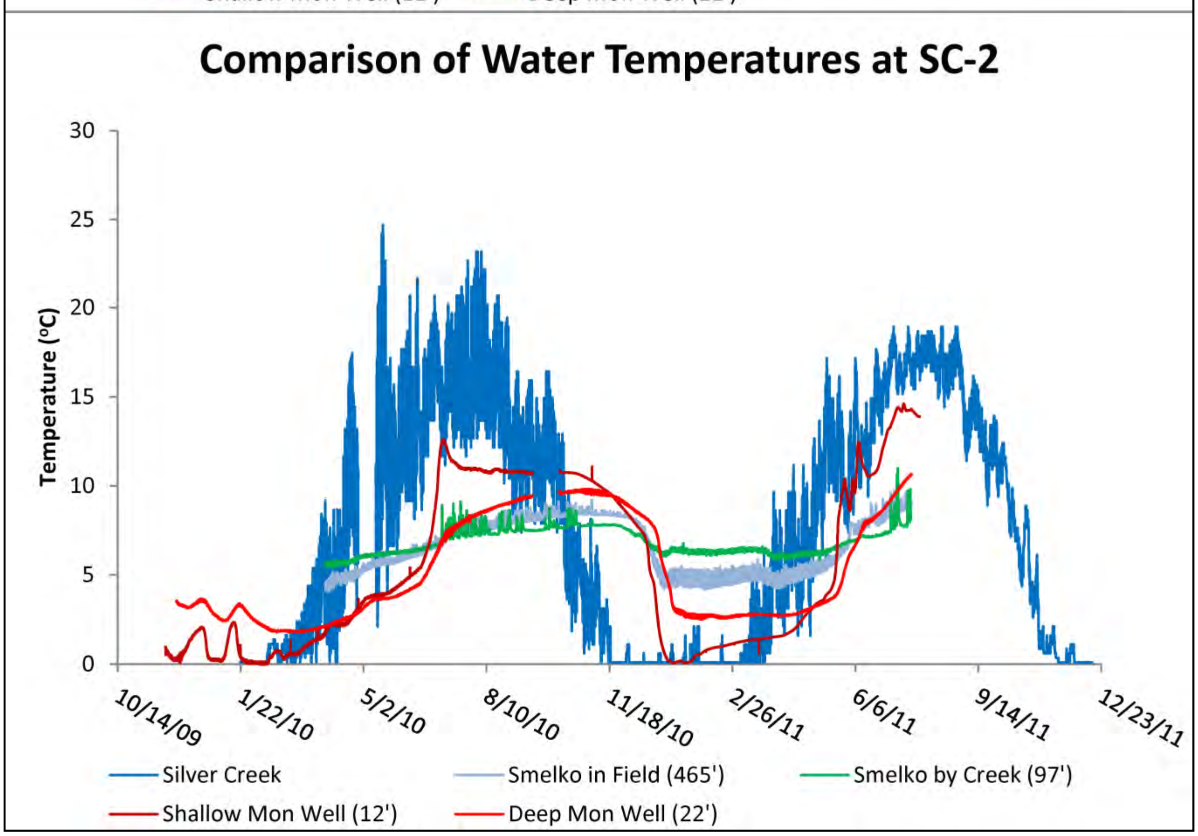


Lower Silver Creek Site (SC-2)

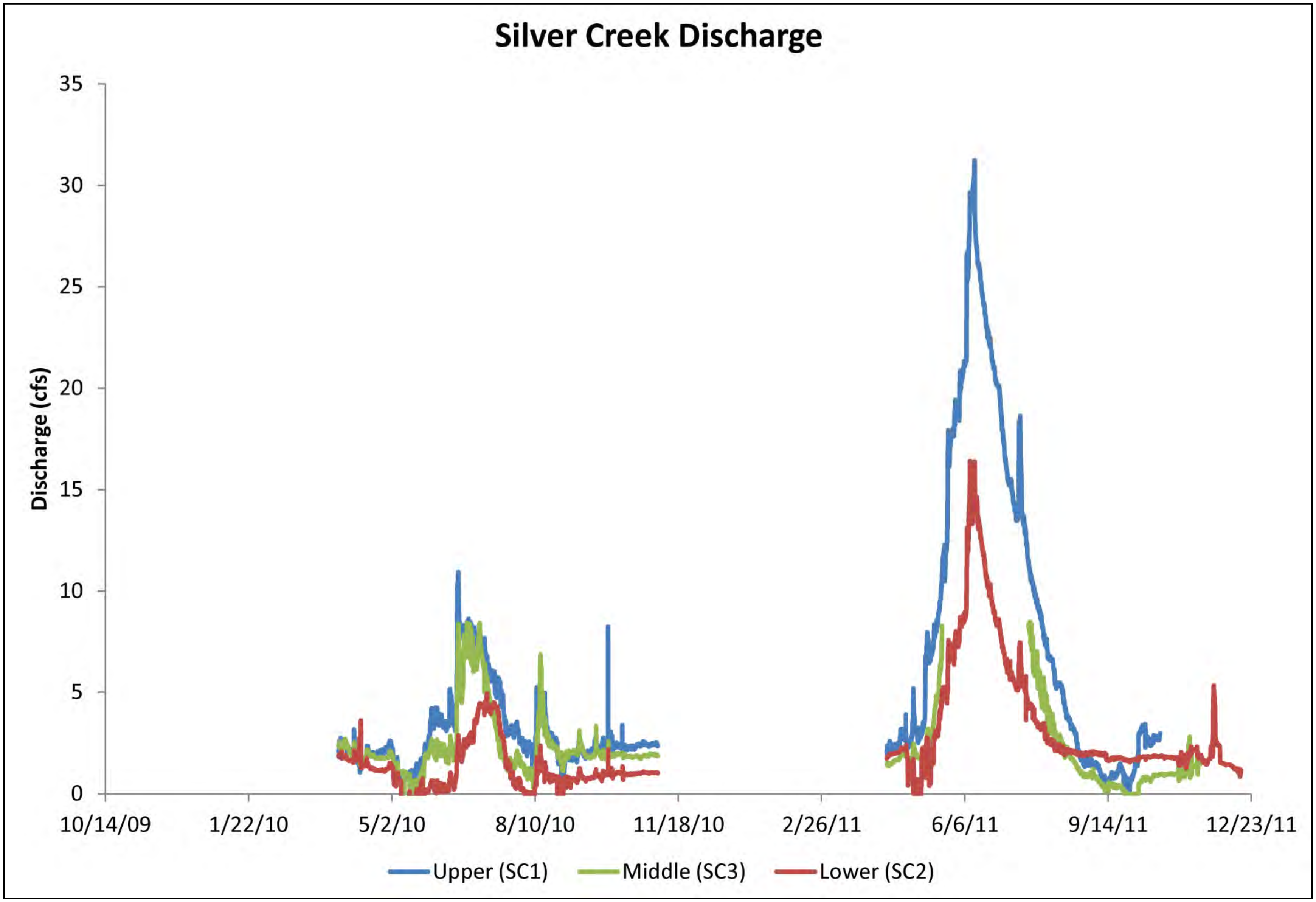


Lower Silver Creek Site (SC-2)

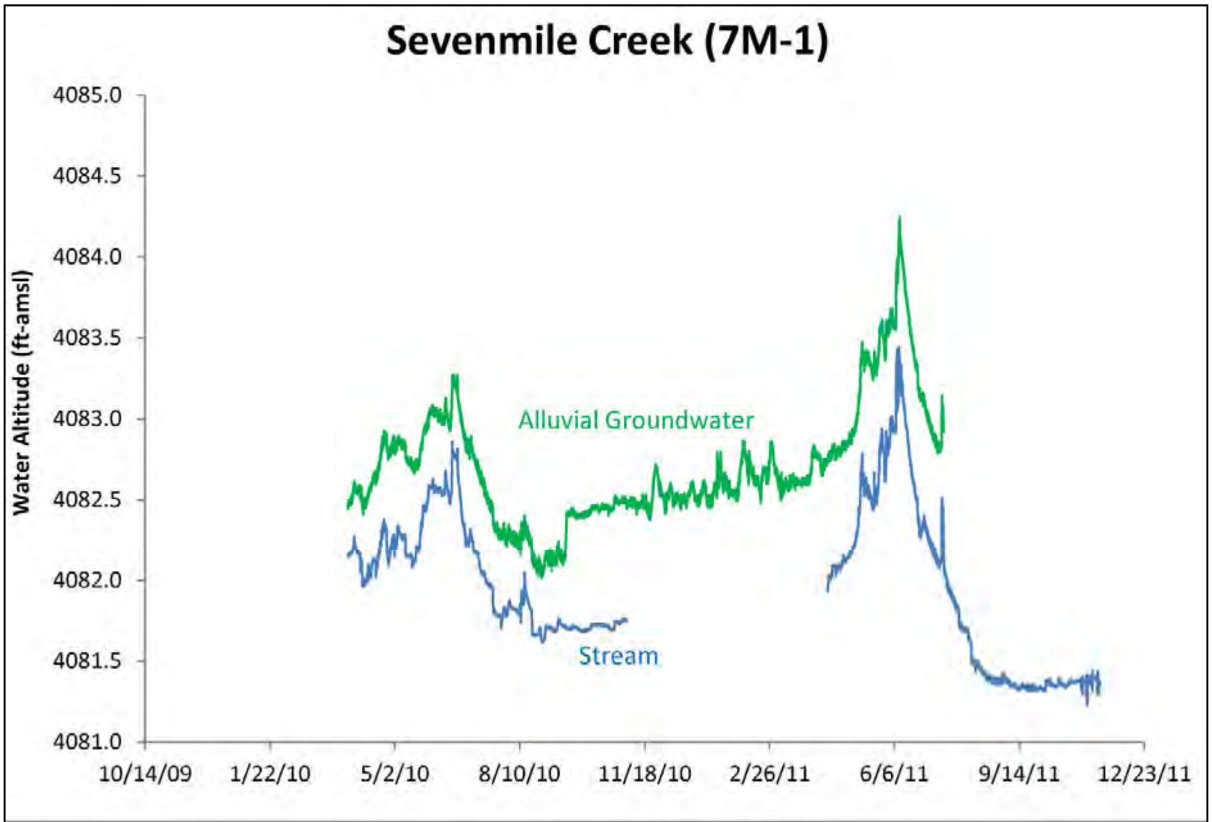


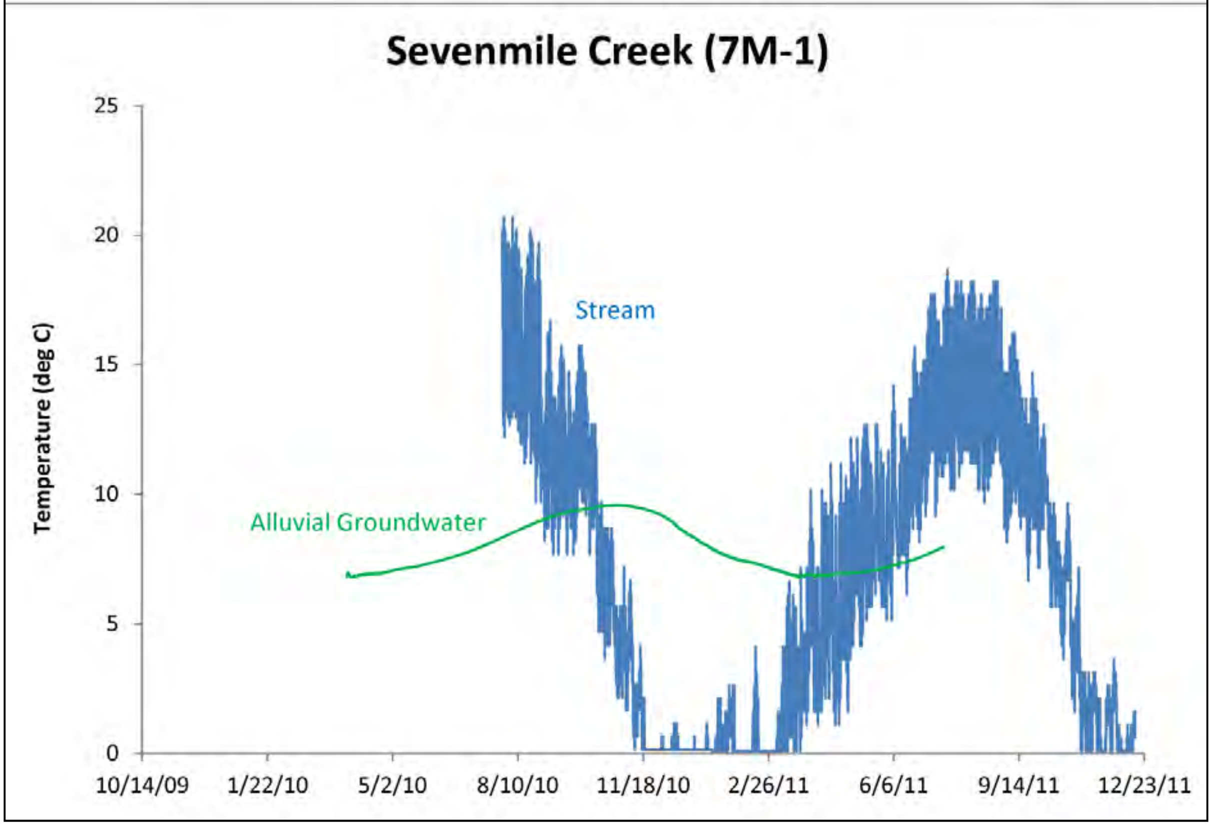


Comparison of discharge at Silver Creek Sites.

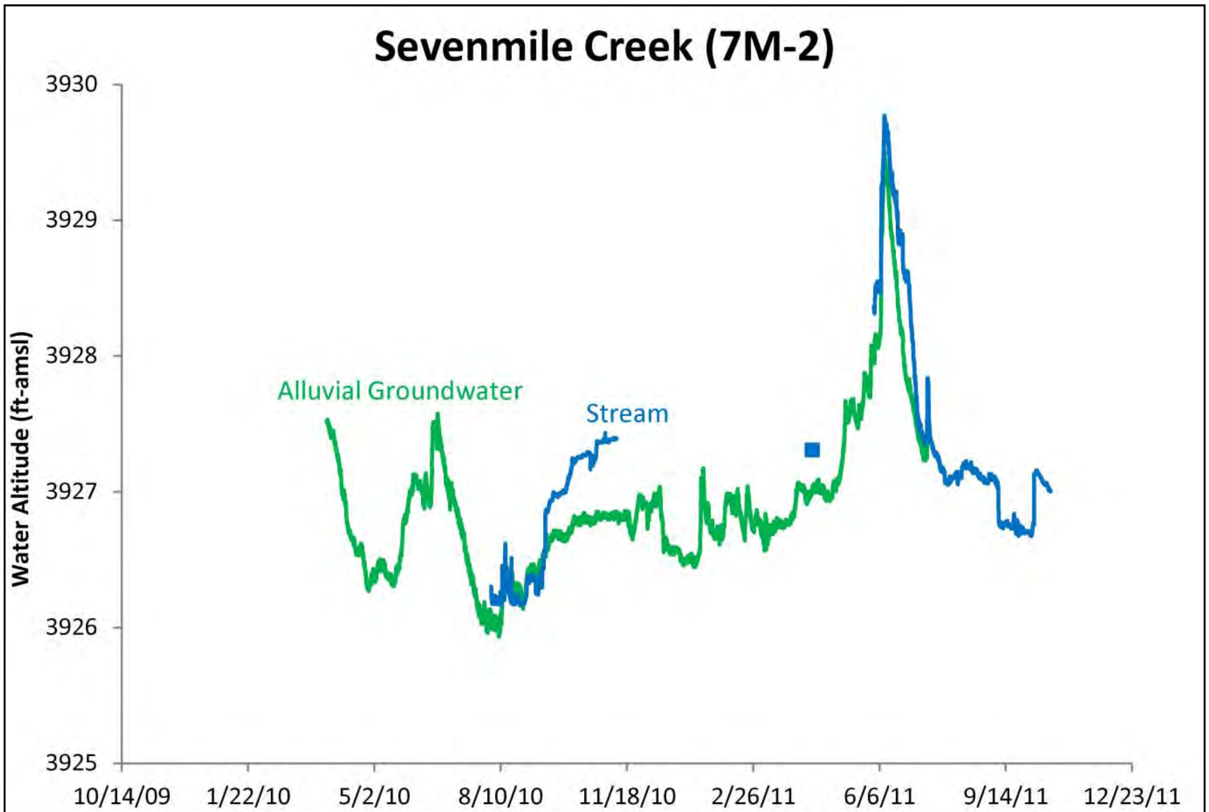


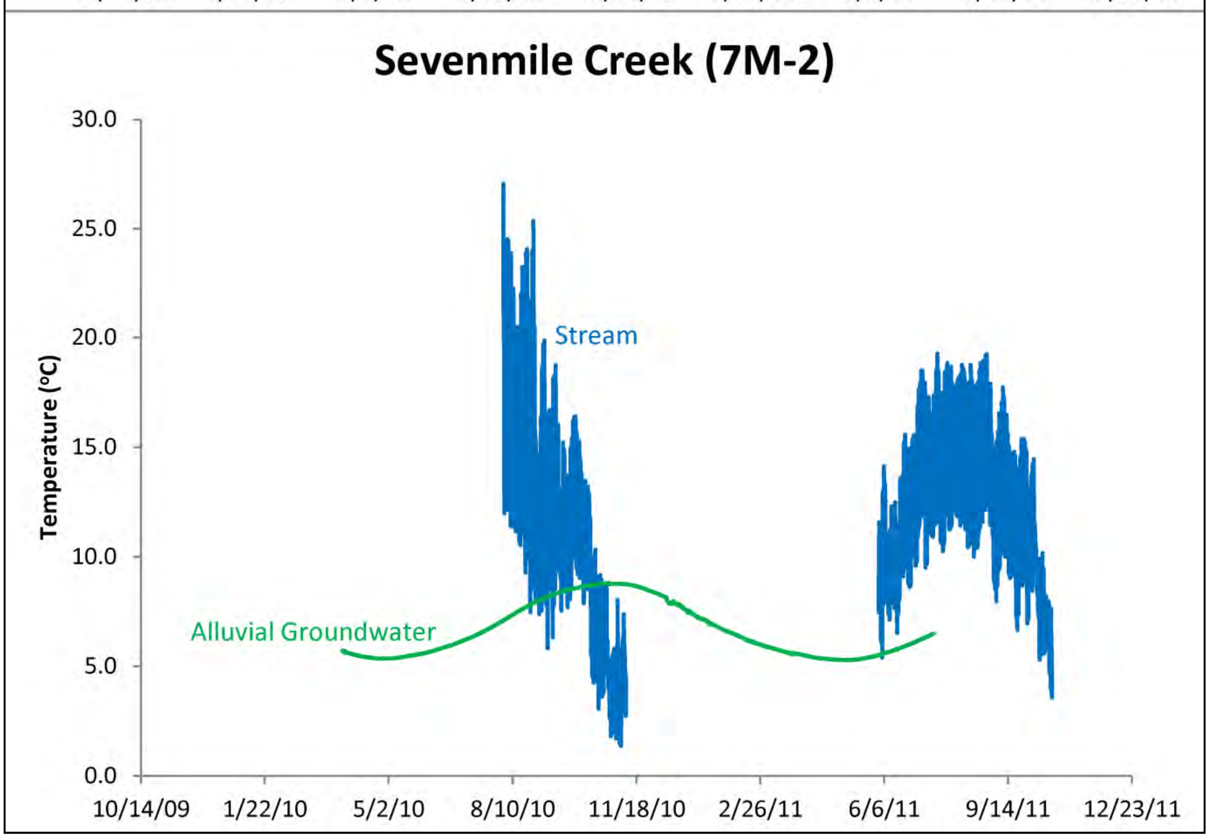
Upper Sevenmile Creek Site (7M-1)





Lower Sevenmile Creek Site (7M-2)





GROUNDWATER BUDGET

WATER BUDGET ANALYSIS

SCRATCHGRAVEL HILLS PROJECT AREA
LEWIS AND CLARK COUNTY

Background:
The Scratchgravel Hills study area is located northwest of Helena, Montana, on the western edge of the Helena Valley (fig. WB1). This section provides a detailed evaluation of the groundwater budget for the Scratchgravel Hills. The budget provided an improved understanding of the hydrogeologic system, provided inputs for the numerical hydrogeologic model (Butler and others, 2013), and provided information against which the model was calibrated.

Analysis of aerial photographs and maps showed that within the study area, the number of residences increased from 1,285 to 1,608 (25% increase) between 1995 and 2009. Additionally, there have been several proposals for high-density subdivisions, and most area homes use individual water wells and individual septic systems. As such, there are concerns regarding the long-term capacity of aquifers to supply water, and concerns regarding the potential for aquifer contamination by septic effluent.

Water budget calculations are useful in determining a reasonable range of groundwater flux values; however, there is inherently a high degree of uncertainty in such calculations. As such, they should be treated as first-order estimates.

The concept of a water budget is based on the concept of mass balance. Basically, matter cannot disappear or be created spontaneously, which is quantified by the basic equation of mass balance as applied to water:

$$\text{Water Input} = \text{Water Output} \pm \text{Changes in Storage}$$

It is important to note that local water budgets can be out of equilibrium even if the overall budget is balanced. A local imbalance can result in localized changes in groundwater levels. To evaluate this aspect, four Sub-Areas were investigated (fig. WB2). Sub-Area 1 is dominantly underlain by alluvium, and is significantly influenced by infiltration from the Helena Valley irrigation canal and from leakage through irrigated fields. Sub-Area 2 is more or less the Green Meadow Controlled Groundwater Area (CGWA) south of the divide at the top of the Scratchgravel Hills. Sub-Area 3 is north of the groundwater divide at the top of the Scratchgravel Hills. The western boundaries of Sub-Areas 2 and 3 are along flow lines. Sub-Area 4 is west of Sub-Areas 2 and 3. Along Sevenmile, Tenmile, and Silver Creeks the alluvium functions as a drain, so these are no-flow boundaries (flow lines run parallel to the creeks). There is inflow from the west into Sub-Area 4. Overall, outflow is to the alluvium along the creeks, or to the Helena Valley aquifer.

Sub-Areas 1 through 4 are 2,912; 5,561; 2,431; and 6,632 acres, respectively. Based on aerial photograph analysis, in 2009 there were 1,112 residences in Sub-Area 1; 240 residences in Sub-Area 2; 88 residences in Sub-Area 3; and 44 residences in Sub-Area 4.

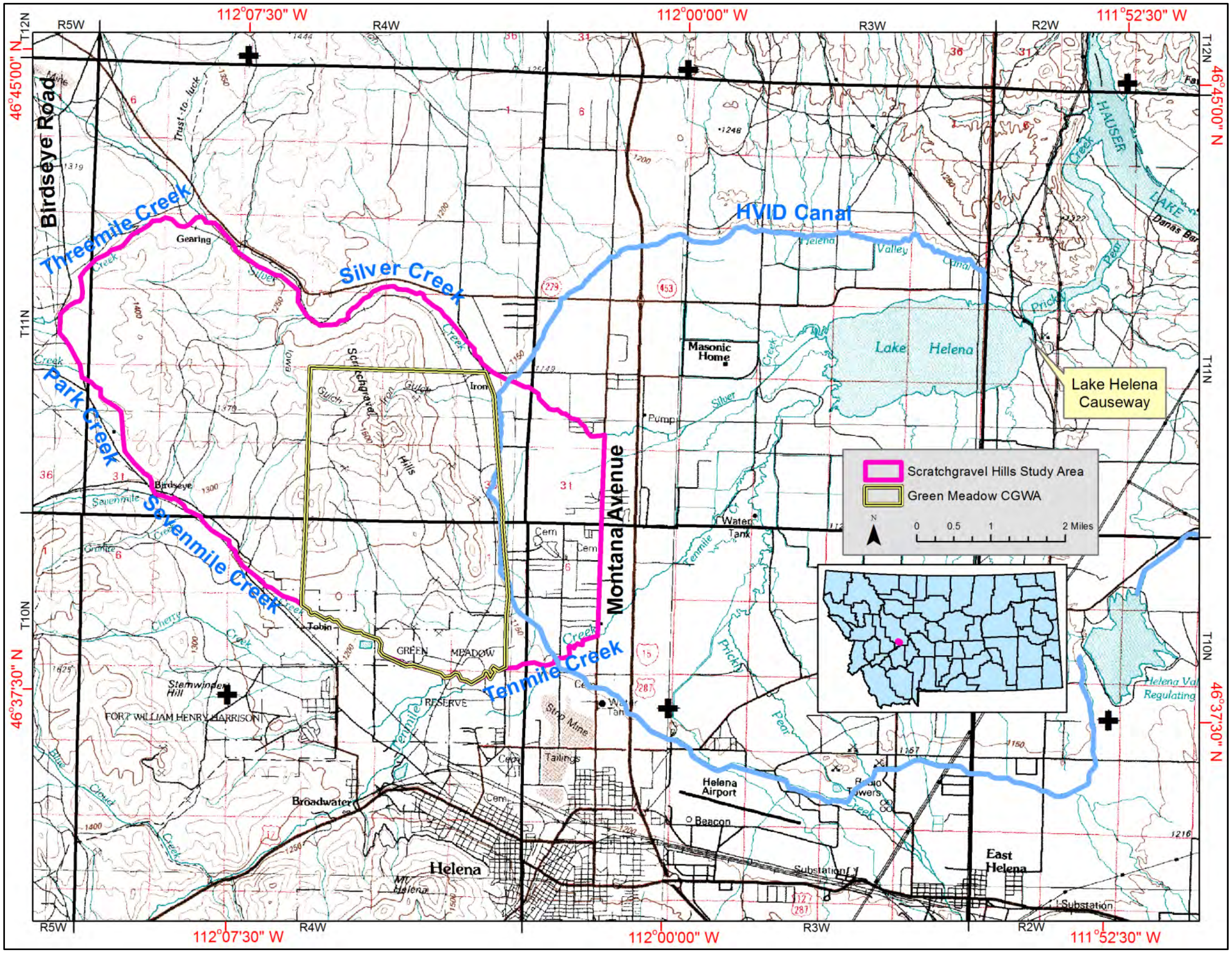


Figure WB1. The Scratchgravel Hills study area is located northwest of Helena, MT.

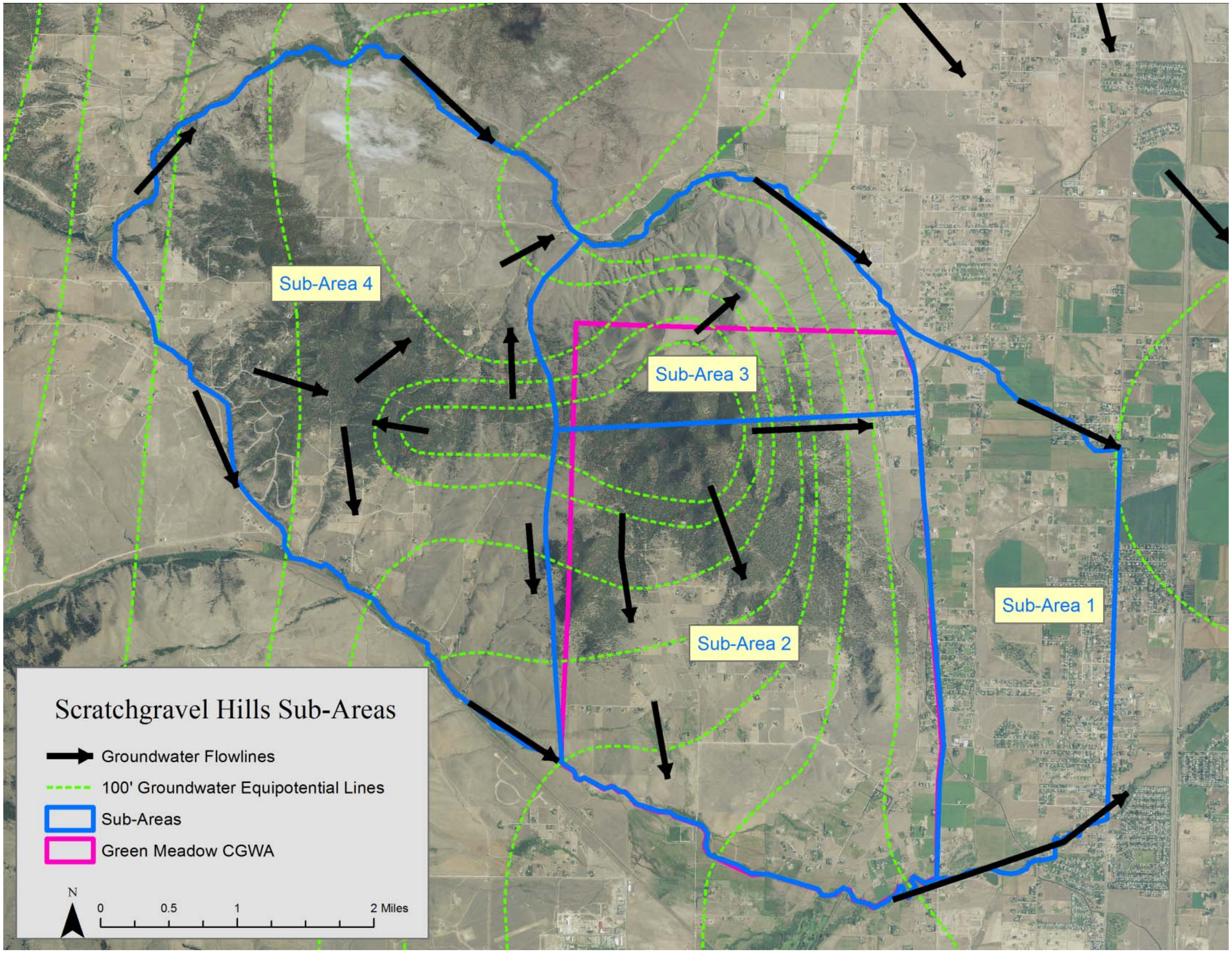


Figure WB2. This map shows the sub-areas that were examined using local water budgets, along with groundwater equipotential lines (October 2010) and flowlines.

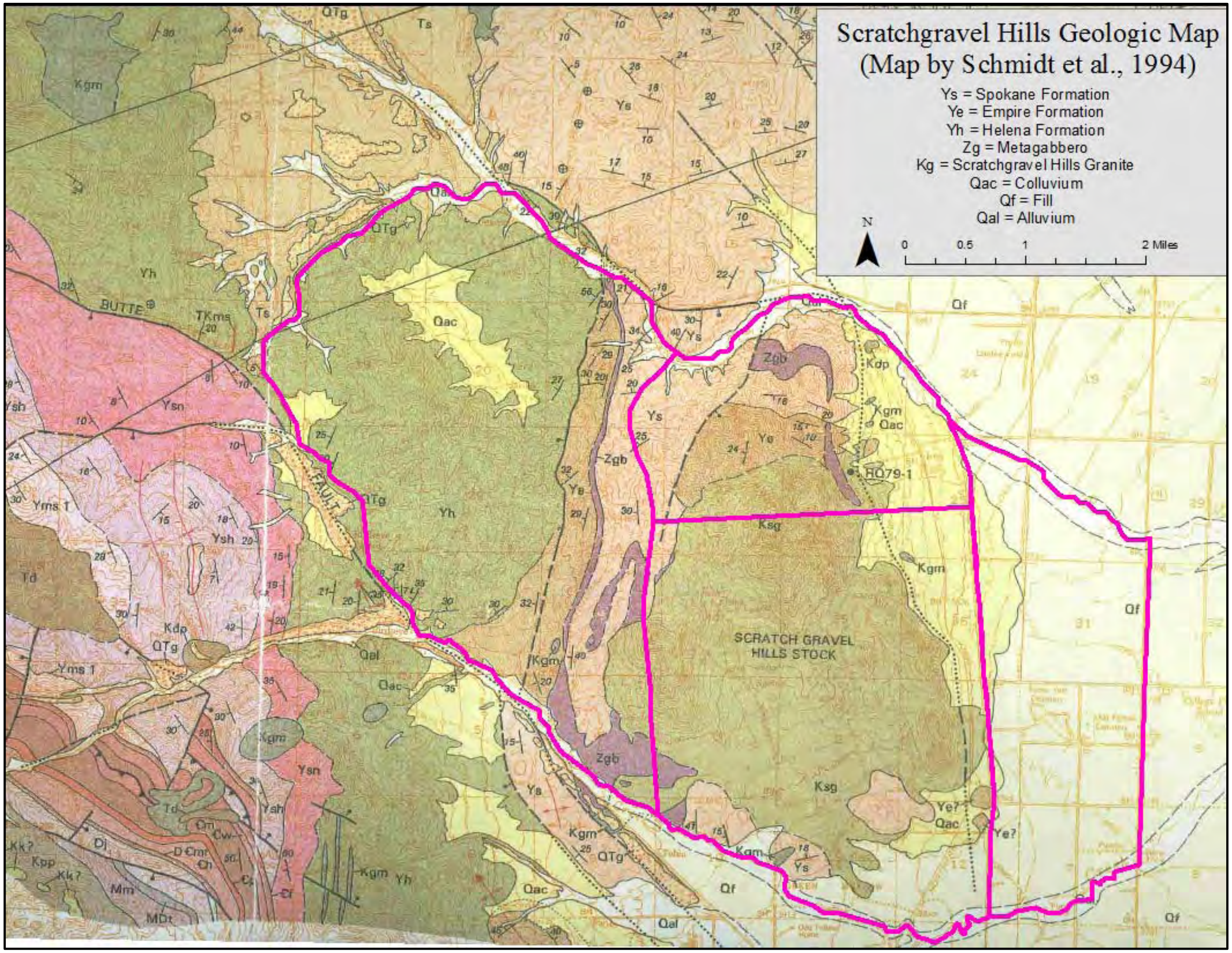


Figure WB3. Geologic map of the Scratchgravel Hills.

Sub-Area 1:
Sub-Area 1 has a total area of 2,912 acres. Expanding the basic equation above to cover individual inflow and outflow components, the water budget for Sub-Area 1 can be written as:

A2_IN + A3_IN + D_INF + 10M_INF + SC_INF + IC_INF + IR_INF =
WL_OUT + HVA_OUT ± ΔS,

where:

A2_IN, groundwater inflow from Sub-Area 2;
A3_IN, groundwater inflow from Sub-Area 3;
D_INF, diffuse infiltration (non-irrigated areas);
10M_INF, Tenmile Creek infiltration;
SC_INF, Silver Creek infiltration;
IC_INF, irrigation canal infiltration;
IR_INF, irrigation recharge (irrigated areas);
WL_OUT, withdrawals from wells;
HVA_OUT, outflow to the greater Helena Valley aquifer; and
ΔS, change in storage.

Sub-Area 1 Inputs:
Groundwater Inflow: Groundwater inflow is groundwater that enters the groundwater system from outside the area being evaluated. In the case of Sub-Area 1, there is inflow from Sub-Areas 2 and 3. These flows can be calculated using Darcy's Law (Fetter, 1994, p. 142):

$$Q = -KA\frac{dh}{dl},$$

where:

Q, inflow (ft^3/d);
K, hydraulic conductivity (ft/d);
A, cross sectional area of the aquifer (ft^2); and
dh/dl, slope of the potentiometric surface (dimensionless; ft/ft).

Inflow to Sub-Area 1 from Sub-Area 2 (A2_IN) can be calculated along the boundary between the two sub-areas. This boundary has unconsolidated Quaternary deposits along its entire length (fig. WB3).

This border is far from streams, and is composed dominantly of colluvium (Qac). Alluvial fan (Qf) deposits occur near Tenmile Creek. Schmidt and others (1994) describe the colluvium as "poorly sorted surficial debris" and the fan deposits as "composed mostly of poorly stratified sand, silt, and clay…interbedded with rare layers of gravel." These materials are anticipated to be finer grained and less permeable than the Helena Valley aquifer materials. There are no known aquifer tests from wells completed in the colluvium; however, based on typical values for sand and silty sand, a K value of 35 ft/d would be a good estimate (fig. AQ3). The range of K values to be evaluated is from 25 to 45 ft/d. Well logs in this area indicate that Quaternary materials are approximately 105 ft thick. The potentiometric surface in this area is at about 3740 ft-amsl and the ground surface is at approximately 3770 ft-amsl. The saturated thickness (b) is then about 75 ft. The length of this boundary is 18,053 ft, so the cross-sectional area is 1,353,975 ft^2. The slope of the potentiometric surface is approximately 0.004, so the flux across this border is calculated at 1,452 acre-ft/yr (K = 35 ft/d). The range is considered to be from 1,037 (K = 25 ft/d) to 1,867 acre-ft/yr (K = 45 ft/d).

The amount of water entering Sub-Area 1 from Sub-Area 3 (A3_IN) can be calculated in a manner similar to that for Sub-Area 2. This contact is 3,925 ft long, and logs indicate that saturated Quaternary materials are approximately 70 ft thick. The gradient is about 0.004. There is more colluvium relative to alluvial fan deposits along this boundary than along the Sub-Area 2 boundary; thus a somewhat lower K of 25 ft/d appears reasonable. A range of K from 20 to 30 ft/d was evaluated (see fig. AQ2). This results in 208 acre-ft/yr flowing into Sub-Area 1 (K = 25 ft/d). The probable range is from 167 (K = 20 ft/d) to 250 acre-ft/yr (K = 30 ft/d).

Diffuse Infiltration (Non-Irrigated Areas) (D_INF):

Diffuse infiltration occurs throughout the system at times when precipitation and/or snow melt are in excess of the combined rates of evaporation, transpiration (plant use), and runoff (outputs). Evaporation and transpiration are often combined in the term evapotranspiration (ET). Potential ET is equal to "the water loss which will occur if at no time there is a deficiency of water in the soil for the use of vegetation" (Thornthwaite, 1944). As is noted by Fetter (1994) "[b]ecause there is often not sufficient water available from soil moisture, the term actual evapotranspiration is used to describe the amount of evapotranspiration that occurs under field conditions."

That there is often not sufficient water from soil moisture is particularly true for semi-arid areas, such as the Scratchgravel Hills study area. Precipitation in Sub Area 1 averaged about 10.5 in per year for the 1971–2000 period (fig. WB4). Based on METRIC remote sensing techniques, ET in the non-irrigated portion of Sub-Area 1 in 2007 was about 10.9 in (fig. WB5; Trezza and others, 2011). It appears that normally all precipitation is lost to evapotranspiration, except in rare occasions where there is more water than can be used by plants and evaporation. As such, a value of zero is assigned to diffuse infiltration in the non-irrigated areas of Sub-Area 1.

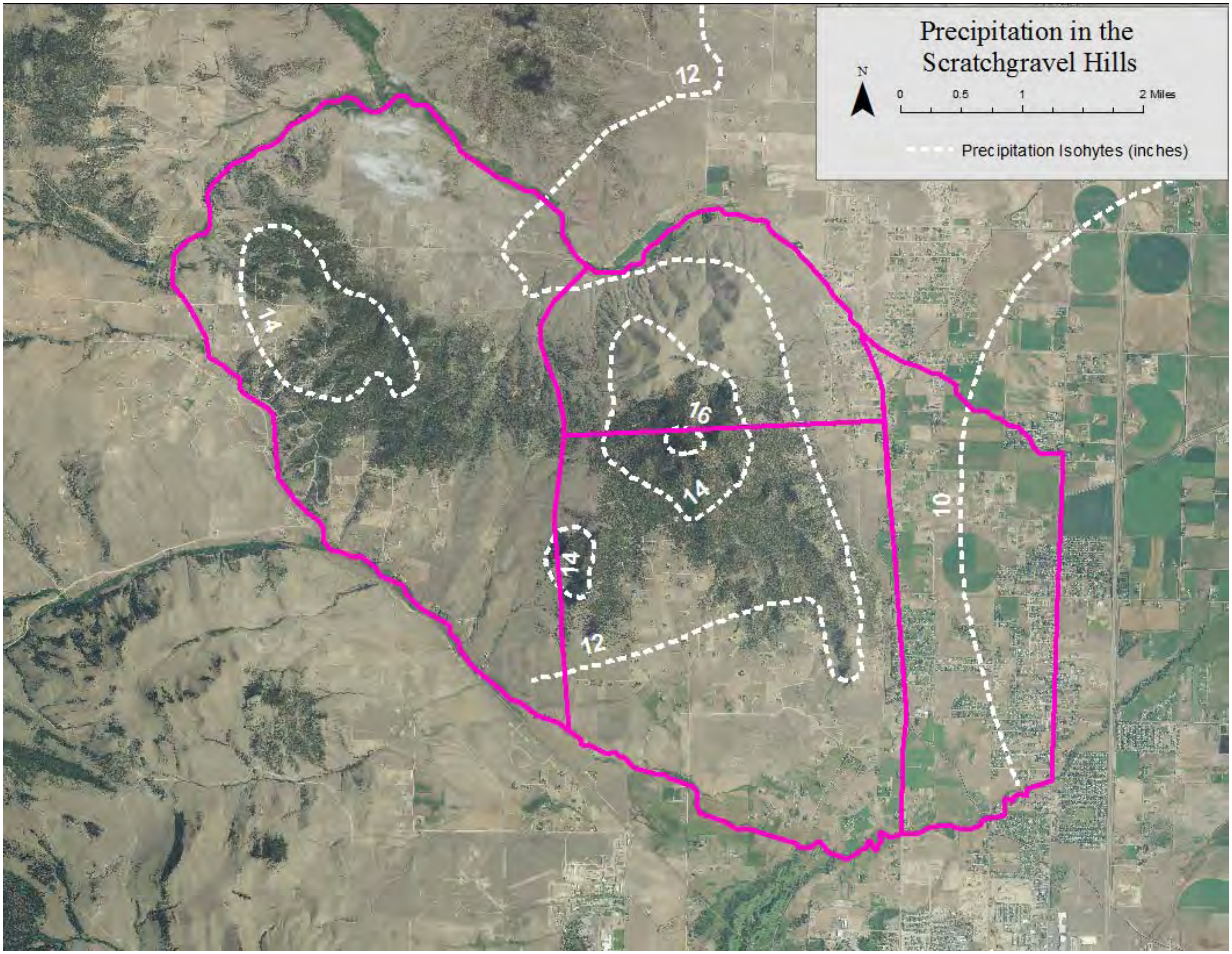


Figure WB4. Precipitation isohyets (inches) in the Scratchgravel Hills study area. These isohyets were calculated based on data for the 1971–2000 period (P. Farnes, written com).

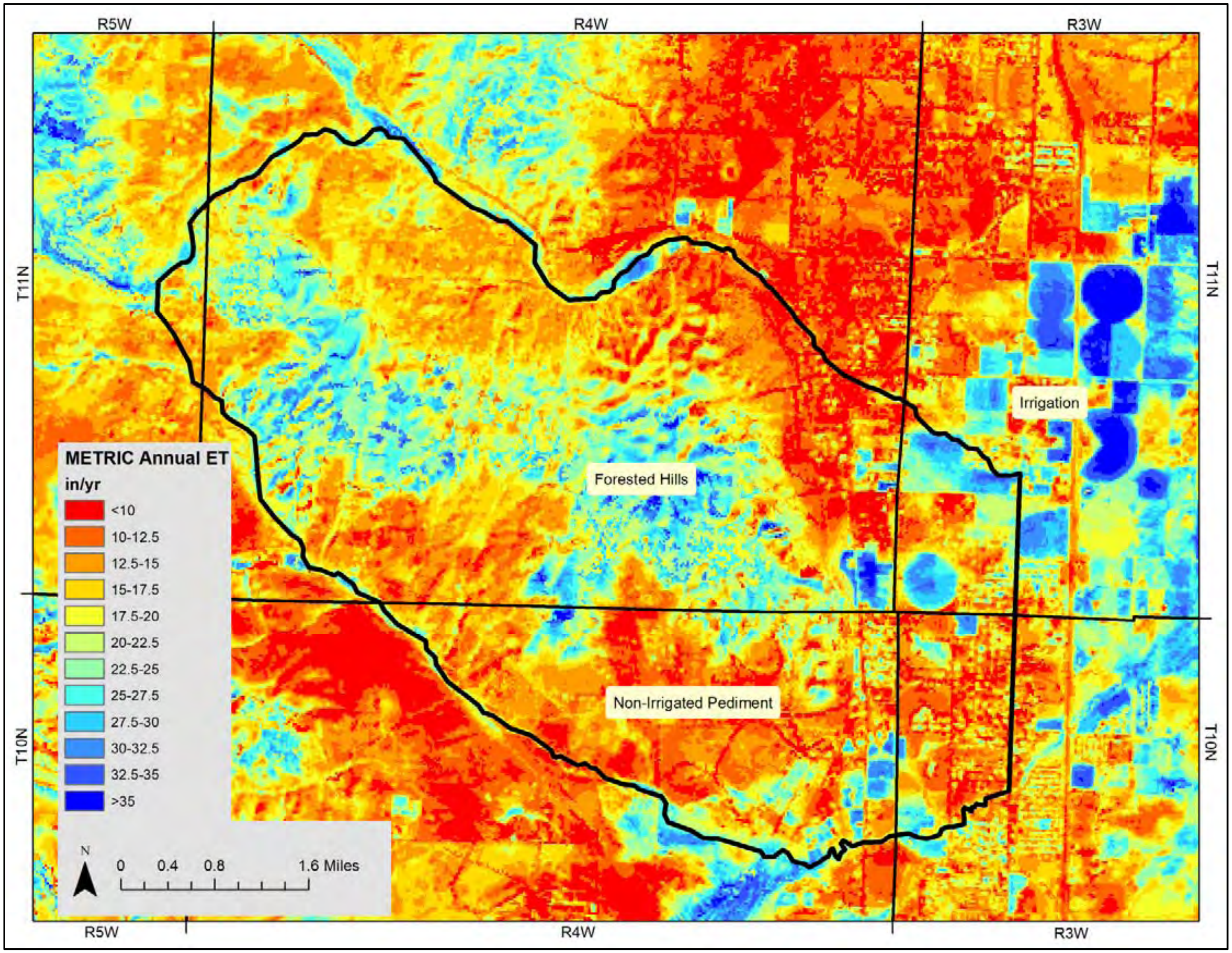


Figure WB5. The METRIC ET analysis indicates that ET is approximately 28 in per year in the irrigated area, 13 in per year on the pediment, and 22 in per year in the forested area. Note that precipitation in the forested area averages 15 in per year (fig. WB4).

Tenmile Creek Infiltration (10M_INF):

Tenmile Creek forms the southern border of Sub-Area 1, and the length of this border is 1.21 mi. Monitoring by Briar and Madison shows that during March and October low flow periods when there were no irrigation diversions, the average loss along Tenmile Creek is 2.14 cfs/mile. Assuming that half of this water flows into Sub-Area 1 and half flows to the south, this results in a 940 acre-ft/yr input. Given the uncertainties in these calculations, the range of probable values is considered to be ± 10%, or 846 to 1,034 acre-ft/yr.

Silver Creek Infiltration (SC_INF):

Silver Creek is a losing stream, and it typically infiltrates all of its water prior to reaching Green Meadow Drive. Discharge values obtained in 2010 for Silver Creek at stream gauge SC-3 were used to estimate its average annual loss.

Continuous measurements of discharge in Silver Creek at SC-3 were determined from stage recordings and a rating curve developed from biweekly flow measurements (fig. WB6). From these measurements, total monthly flow volumes for April–October 2010 were calculated to be 962 acre-ft. Tenmile Creek, based on the 1908–1998 period of record, flowed an average of 17,539 acre-ft during the April–October period (USGS, 2013). Thus, flow in Silver Creek during April–October 2010 was 5.5% of the long-term same period average flow in Tenmile Creek. Assuming this relationship holds for other times of the year, mean monthly Silver Creek discharge values for November–March 2010 were estimated. Combining the estimated values with observations results in a total flow of 1,078 acre-ft in 2010 (fig. WB7).

It must also be considered if the April–October 2010 period was climatologically “average” and usable for calculating a long-term average annual input from Silver Creek. Weather data from the Helena Regional Airport indicate that 2010 precipitation from April to October was 111% of normal, thus it would be expected that flow in Silver Creek would be about 11% greater than normal. Using this relationship, the values can be recalculated, and converted to a best estimate average annual inflow of 974 acre-ft. Assuming that half of this volume enters Sub-Area 1, the average inflow would be 487 acre-ft/yr. Given the uncertainties, the range of probable values is likely ±10%, or 438 to 535 acre-ft/yr. All this inflow is assumed to infiltrate to the groundwater system (i.e., transpiration and free water surface evaporation are negligible).

Irrigation Canal Infiltration (IC_INF):

The Helena Valley irrigation canal runs through Sub-Area 1. It enters across the southern boundary, flows from Sub-Area 1 into Sub-Area 2, re-enters Sub-Area 1, and then leaves Sub-Area 1 through its northwest corner. Several laterals leave the main canal and route water to fields. Neither the canal nor the laterals are lined. Briar and Madison (1992) evaluated infiltration from the various canals, and concluded that the main canal loses on average about 0.63 cfs/mi, and the laterals lose about 0.21 cfs/mi. This water recharges the groundwater system.

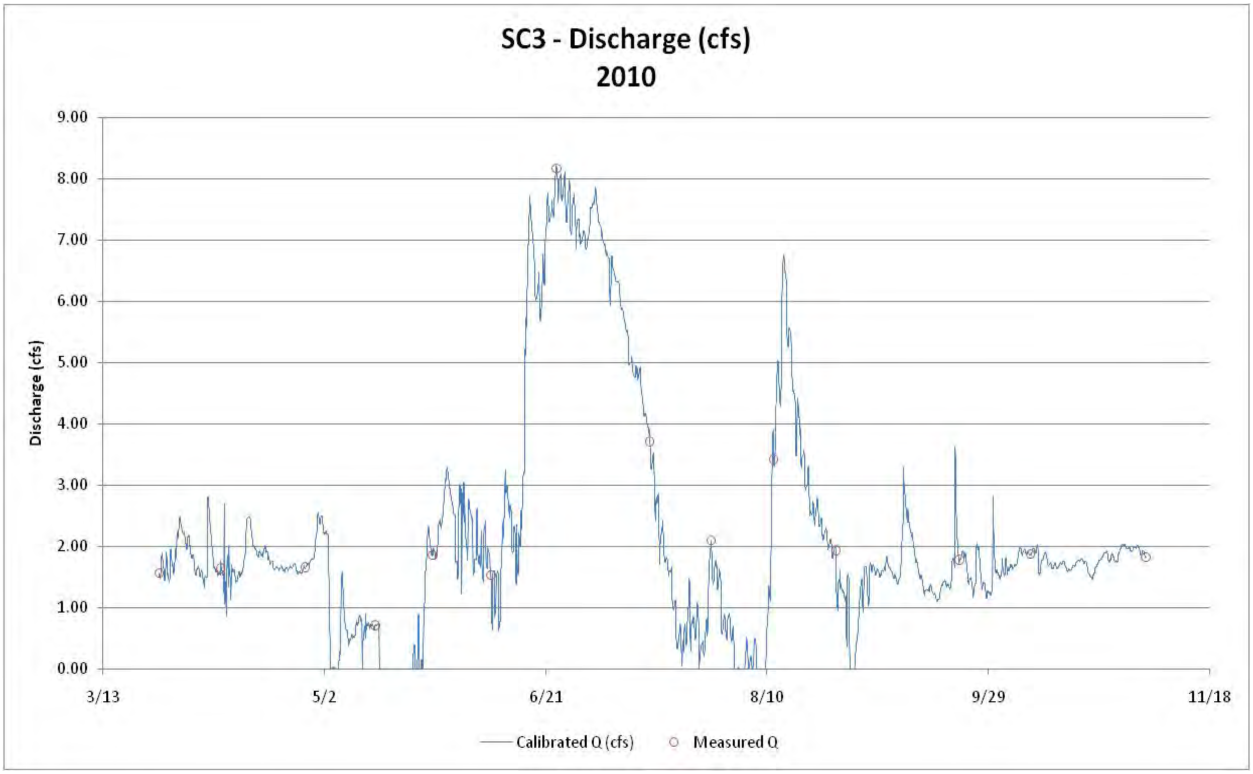


Figure WB6. Discharge measurements on Silver Creek at SC-3 during 2010.

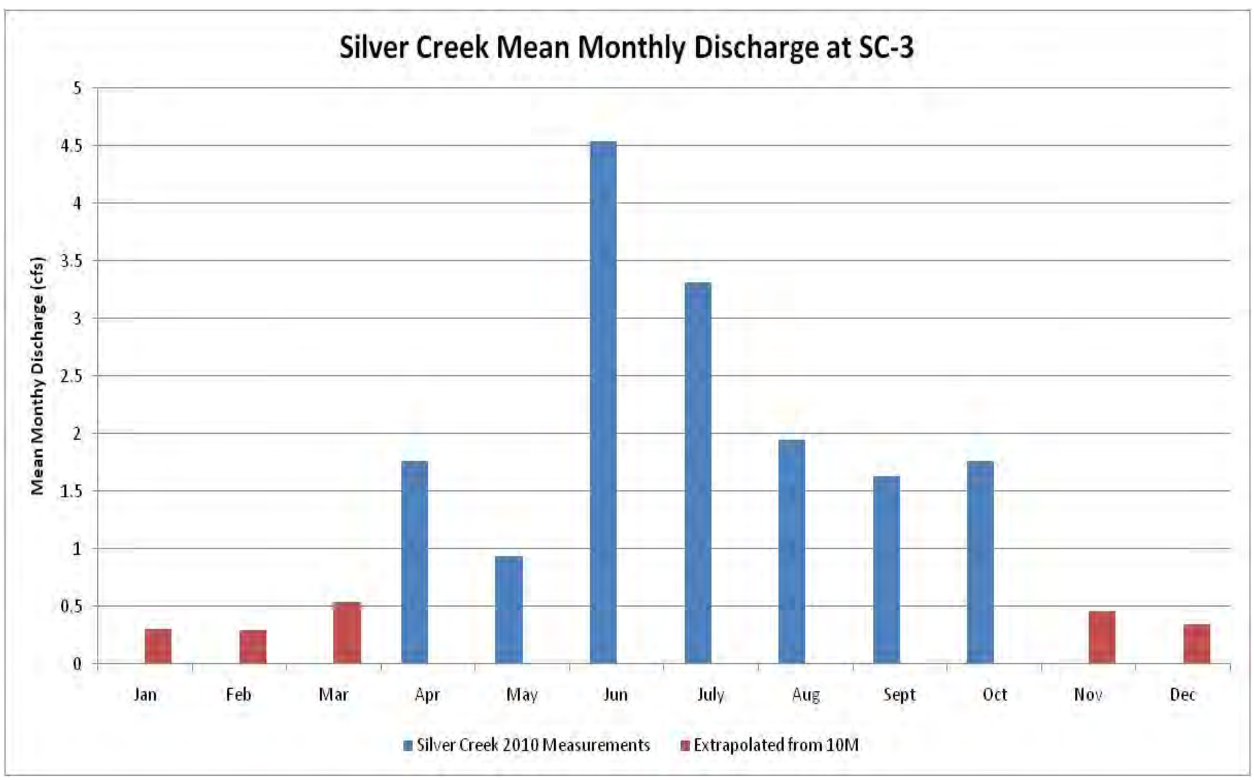


Figure WB7. Mean monthly discharge values for Silver Creek at SC-3 during 2010. November–March values are extrapolated from the longer Tenmile Creek Record.

To determine the amount of irrigation canal infiltration in Sub-Area 1, detailed maps of the irrigation infrastructure for the Helena Valley were obtained from the Helena Valley Irrigation District, and were digitized. This analysis shows that 2.5 mi of the main canal and 1.7 mi of laterals are within Sub-Area 1, where these structures lose about 1.95 cfs during the irrigation season. Monitoring of flow in the main canal indicates that the average flow into the study area is approximately 85 cfs, so 1.95 cfs represents approximately 2% of the water in the irrigation system. The irrigation canal is typically in use between April 15th and October 1st each year; thus the best estimate of annual infiltration is 656 acre-ft/yr. Given the uncertainties, the range of probable values is ±10%, or 590 to 721 acre-ft/yr.

Irrigation Recharge (IR_INF, Irrigated Areas):
In irrigated areas Briar and Madison (1992) estimated that about 1.5 ft (18 in) of water that does not run off is applied to the fields in excess of the crop demand (i.e., irrigation recharge). This water is a combination of precipitation and irrigation water. The water flows through the root zone and recharges the underlying groundwater. Some irrigation recharge is needed to prevent the buildup of salts in the root zone and to ensure that plants are not stressed by low moisture conditions. Data from the Montana Department of Revenue shows that 701 acres are irrigated in Sub-Area 1. Thus the best estimate of infiltration in irrigated areas is 1,051 acre-ft/yr. Given the uncertainties, the range of probable values is ±10%, or 946 to 1,156 acre-ft/yr.

Combining these input values results in a best estimate of inputs to Sub-Area 1 of 4,793 acre-ft/yr, with the probable range being from 4,023 to 5,563 acre-ft/yr.

Sub-Area 1 Outputs:
The northern and southern boundaries of Sub-Area 1 are no flow boundaries (flow lines parallel to the boundaries), and groundwater enters the area from the west. Thus all groundwater flows out the area's eastern edge, and into the greater Helena Valley aquifer (HVA_OUT). The only other output is by consumptive use from well withdrawals (WL_OUT).

Groundwater flow to the Greater Helena Valley Aquifer (HVA_OUT):
The flow out of Sub-Area 1 to the greater Helena Valley aquifer can be calculated using Darcy's Law. Hydraulic conductivities (K) from aquifer tests in the Helena Valley aquifer (see aquifer test section above) range from 1 to 916 ft/d. For this analysis a K of 50 ft/d is assumed. On the eastern boundary of Sub-Area 1, the saturated thickness of the Quaternary materials is 350 ft. The length of the eastern boundary is 14,333 ft, and the slope of the potentiometric surface is about 0.002. Thus the flow from Sub-Area 1 to the greater Helena Valley aquifer is approximately 4,319 acre-ft/yr. Given the uncertainties, the range of probable values is ±10%, or 3,887 to 4,751 acre-ft/yr.

Well Withdrawals (WL_OUT):
According to the U.S. EPA (2008), the average family of four in the United States diverts approximately 400 gallons of water per day (gpd), with 70% (280 gpd) of this usage for indoor purposes. This figure is for gross delivery to a home, and does not take into account that some of the water delivered may reenter the groundwater system due to infiltration from septic systems. Also, that 70% is used for indoor purposes indicates that the average home in the U.S. does not irrigate landscape/garden areas to the extent that is done in the Scratchgravel Hills. This higher irrigation rate is not surprising given that the study area is a semi-arid region, receiving only an average of 11.32 in as recorded at the Helena Airport (HLN) for the 1971–2000 period (NOAA, 2011). For comparison, for the same 1971–2000 period, the Philadelphia Airport (PHL) received an average of 42.05 in of precipitation annually (NOAA, 2011).

For Lewis and Clark County, estimated average per capita domestic water diversion is approximately 198 gpd, and average per capita consumptive use is approximately 119 gpd (Cannon and Johnson, 2004). If the per capita consumption of 119 gpd is applied to a family of 4, the result is 476 gpd/residence.

For the North Hills area, Madison (2006) used 1 year of data from the Townview subdivision and 1 year of data from the Skyview subdivision to estimate water usage. Because septic systems are also in use in these areas, water returned to the groundwater system from septic systems was also estimated. Madison calculated that on average 464 gpd was delivered to each residence. Based on winter usage Madison calculated that 162 gpd was returned by septic system. As a result, Madison calculated that on average 302 gpd is consumptively used by each residence.

During its evaluation of the North Hills CGWA, the DNRC calculated water usage using data for 747 homes. These calculations are based on the acres of irrigated yard for each home, the amount of water needed to water an acre of turf (SCS, Montana Irrigation Guide), a domestic in-home diversion of 160 gpd, and a septic return of 95% of the in-home diversion. The evaluation produced an estimate of 629 gpd delivered to each residence, 152 gpd returned by septic system, and 477 gpd being consumptively used, which included irrigation of lawns and gardens.

For this study, monthly water usage data from 1991 to 2009 were obtained for the 70-home Townview subdivision in the North Hills (immediately northeast of the Scratchgravel Hills). Annual average water delivery per home (fig. WB8) and the seasonality of delivery (fig. WB9) were evaluated, allowing average monthly deliveries to be calculated (fig. WB10). Based on these values, the average delivery to each home is 572 gpd. If it is assumed that 95% of the minimum usage month (December, 173 gpd) is returned to groundwater by septic systems, the septic return is 164 gpd. It can then be calculated that, on average, 408 gpd is consumptively used per residence.

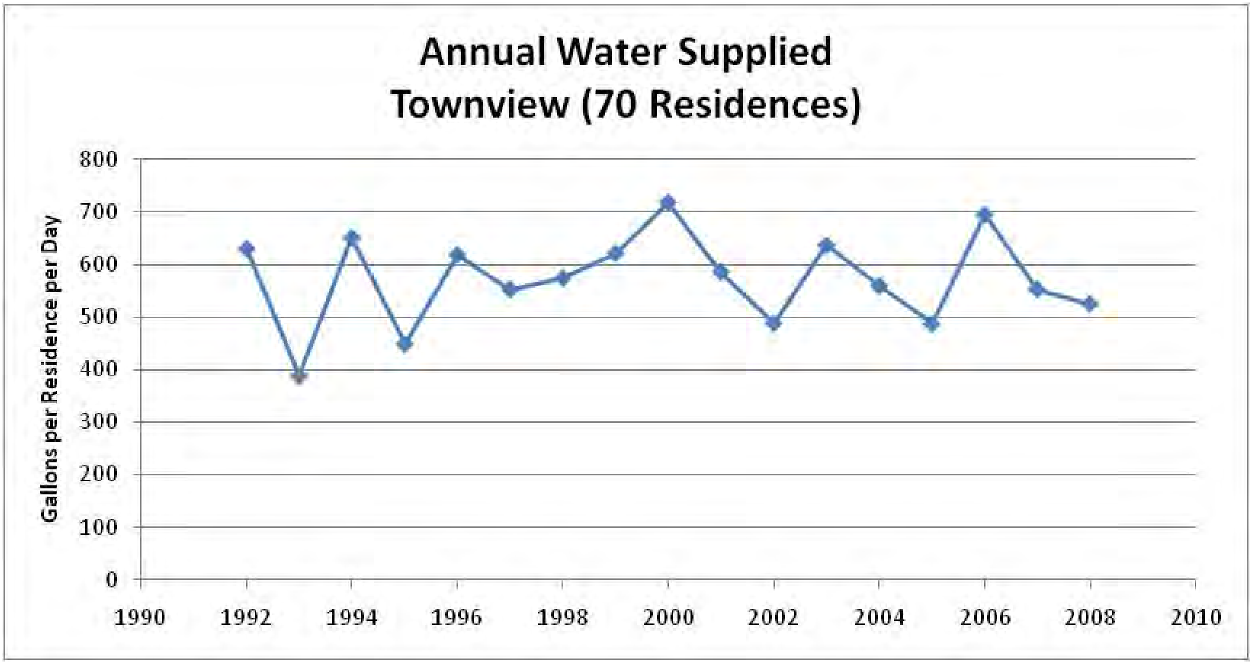


Figure WB8. Average amount of water supplied per home in the Townview subdivision, 1991–2009.

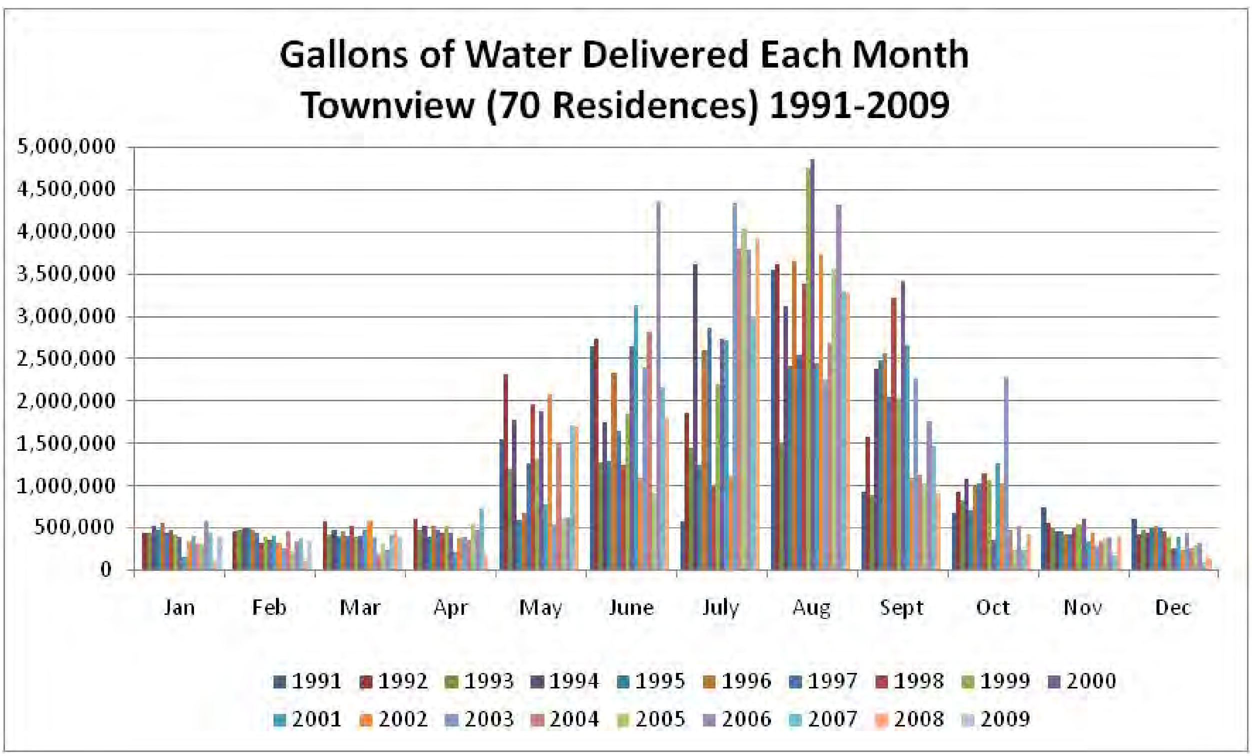


Figure WB9. Volume of water (gallons) delivered to homes in the Townview subdivision by month, 1991–2009.

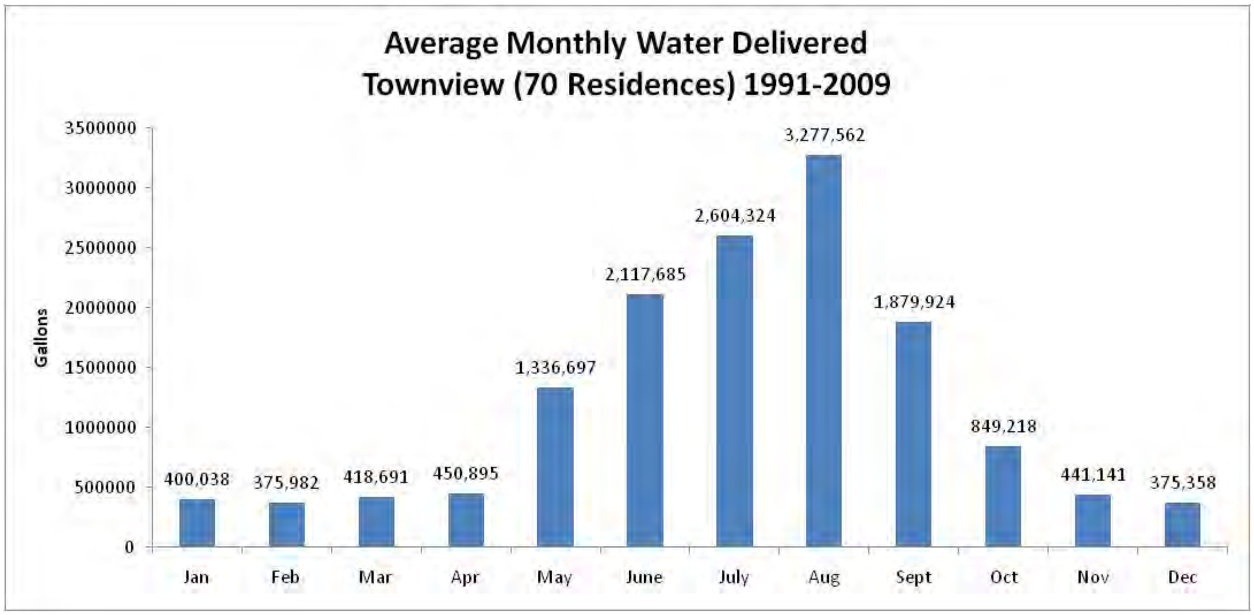


Figure WB10. Average monthly water delivered to 70 homes in the Townview subdivision.

Limited (1 year) data sets from Skyview (108 homes) and Ranchview (107 homes) were also evaluated. For these data sets, the usage for Skyview appears abnormally low (196 gpd delivered to each residence), and Ranchview appears abnormally high (1,022 gpd delivered to each residence). It may be that these subdivisions were not fully occupied during the time of data collection and/or higher irrigation rates for new lawns were being used. However, if the data are averaged, the result appears reasonable. The combined gross delivery is 607 gpd per home, septic return is calculated to be 188 gpd, and the calculated net consumption is 420 gpd.

One year of data is also available for the Northstar subdivision (93 homes). This subdivision is somewhat different from the others, because there is a community sewer system. The septic effluent is piped to a lined holding pond approximately 1 mile south, and then used for irrigation. As such, there is no septic return to groundwater. While this may benefit water quality, it decreases the quantity of water in the aquifer. (Note that irrigation recharge occurs outside of the area that was studied for North Hills, otherwise irrigation recharge would need to be accounted for). Analysis of this 1 year of data indicates that the average diversion per home is 506 gpd. Since there is no return to groundwater, the consumptive use is also 506 gpd.

A comparison of these usage values is provided in table WB1. The best estimate of water usage is considered to be 435 gpd/residence; however, a range from 400 to 500 gpd/residence is reasonable. Air photos from 2009 show that there are 1,112 homes in Sub-Area 1. Thus the best estimate of water withdrawn by wells and consumptively used in Sub-Area 1 is 542 acre-ft/yr, with the probable range being from 499 to 623 acre-ft/yr.

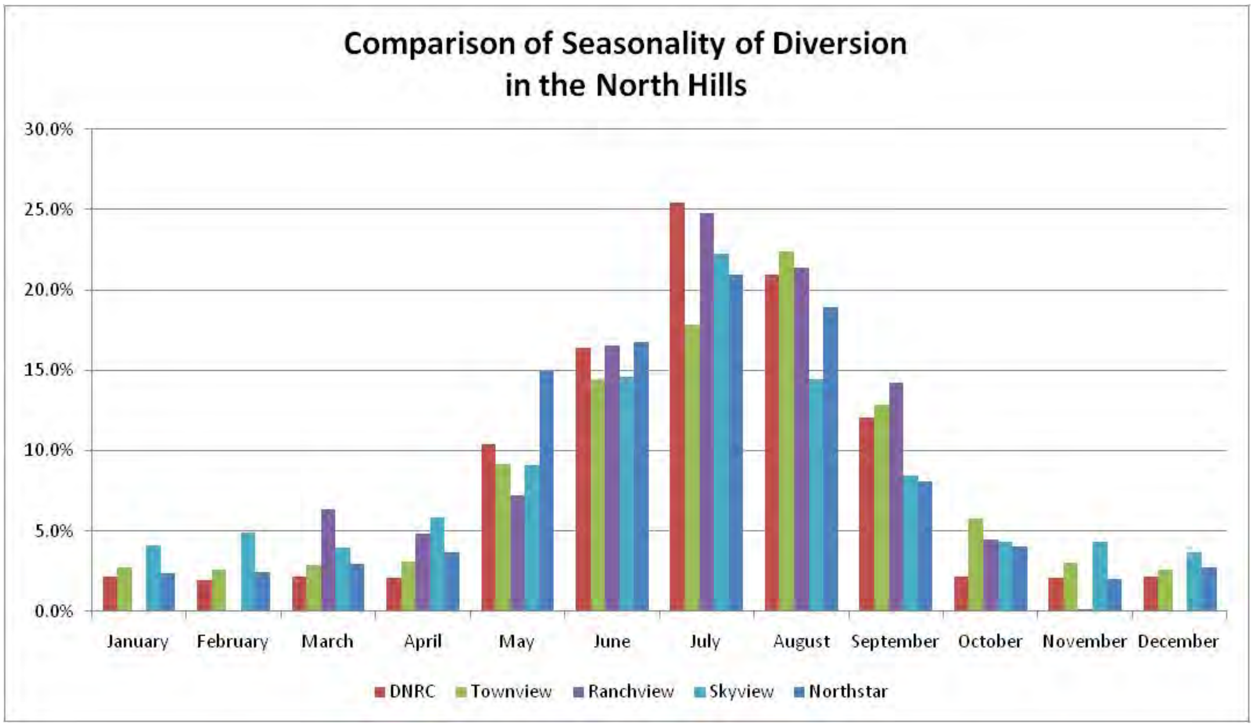


Figure WB11. Comparison of the seasonal distribution of water use in the North Hills, using empirical data from different subdivisions and theoretical values from DNRC.

All of these figures can also be compared based on average monthly diversion (fig. WB11). The distribution of use is fairly consistent. The seasonal distribution of consumptive use (as a percentage) from DNRC estimates and the 19 years of empirical data from Townview are also calculated (fig. WB12).

Summary for Sub-Area 1:
A summary of all input and output values for Sub-Area 1 is shown in table WB2. Because it can be seen from hydrographs (e.g., fig. WB13) that there is not a noticeable long-term change in groundwater levels in Sub-Area 1, it can be assumed that any change in storage is minimal, and inputs must equal outputs. The best estimated values show a 1.4% deficit. This difference can be removed by applying an adjustment based on the percentage of input or output represented by each value. The result is the Adjusted to Zero value. This causes all values to fall within the probable range.

Overall, inputs and outputs in Sub-Area 1 are about 4,800 acre-ft/yr. As such, homes withdraw and consumptively use about 11% of the total flux (538 acre-ft/yr).

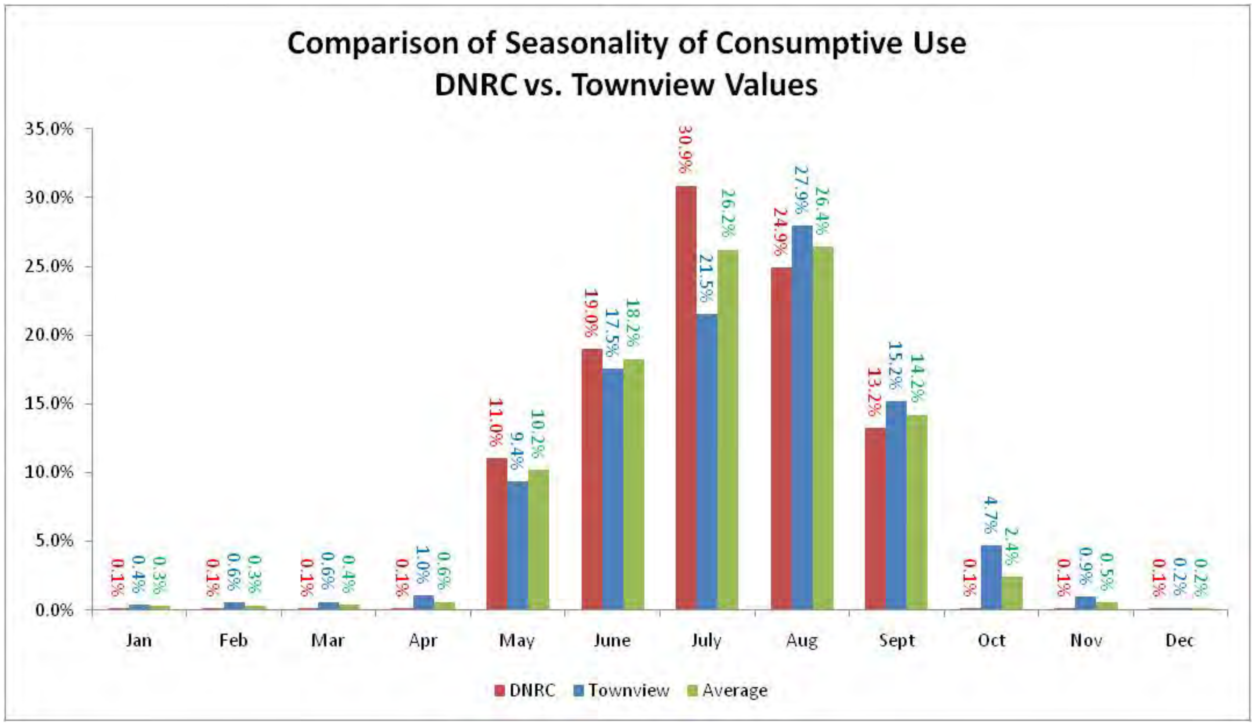


Figure WB12. Comparison of seasonality of consumptive use in the North Hills. Theoretical values from DNRC compared to 19 years of empirical data from Townview.

Table WB1
Comparison of Calculated Water Usage per Residence

Source	Delivered (gpd/residence)	Septic Return (gpd/residence)	Consumptive Use (gpd/residence)
EPA, 2008	400	NR	NR
DNRC-1986	312	NR	NR
Madison	464	162	302
DNRC	629	152	477
Townview	572	164	408
Combined Ranchview-Skyview	607	188	420
Northstar	506	NA	506
Average	499	167	423
Average (Excluding EPA, DNRC-1986, Madison, and Northstar)	603	168	435*

NR, Not Reported. NA, Not Applicable.
*Note that the 435 gpd/residence consumptive use value is applied for the remainder of this report.

Table WB2
Sub-Area 1 Groundwater Budget
(acre-ft/yr)

	Best	Probable Range		Adjusted
INPUTS	Estimate	Min	Max	to Zero
A2_IN	1,452	1,037	1,867	1,462
A3_IN	208	167	250	210
10M_INF	940	846	1,034	946
SC_INF	487	438	535	490
IC_INF	656	590	721	660
IR_INF	1,051	946	1,156	1,059
TOTAL INPUT	4,793	4,023	5,563	4,827
OUTPUTS				
WL_OUT	542	499	623	538
HVA_OUT	4,319	3,887	4,751	4,289
TOTAL OUTPUT	4,862	4,386	5,375	4,827
Difference				
Acre-ft/yr	-68	-1,351	1,177	0
% (vs. inputs)	-1.4%	-33.6%	21.2%	0.0%

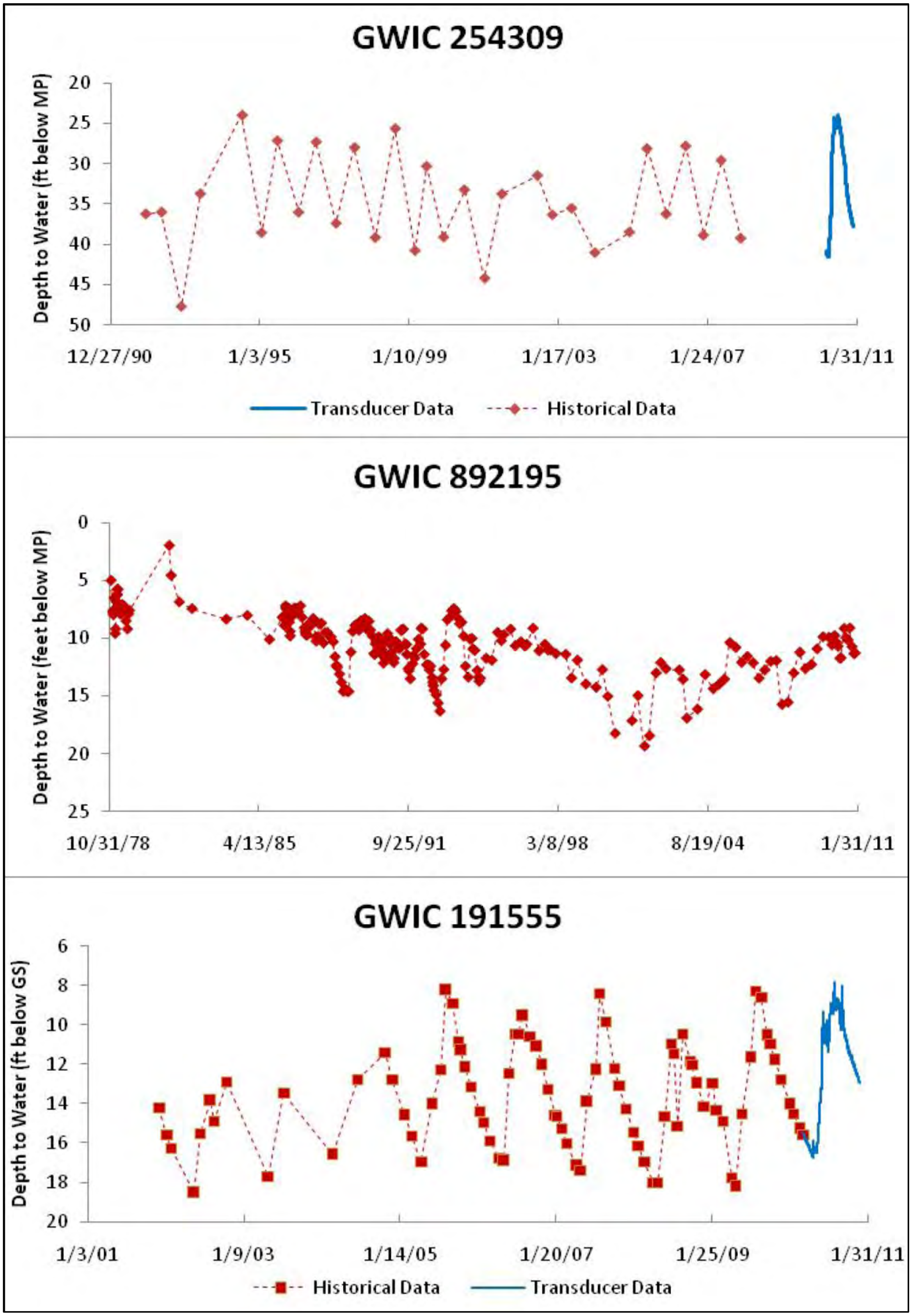


Figure WB13. Hydrographs from Sub-Area 1.

Sub-Area 2:

Sub-Area 2 has a total area of 5,561 acres. The water budget for Sub-Area 2 can be written as:

$$D\_INF + 10M\_INF + IC\_INF + IR\_INF = WL\_OUT + A1\_OUT + Qal\_OUT \pm \Delta S,$$

where:

D_INF, diffuse infiltration (non-irrigated areas);
10M_INF, Tenmile Creek infiltration;
IC_INF, irrigation canal infiltration;
IR_INF, irrigation recharge (irrigated areas);
WL_OUT, withdrawals from wells;
A1_OUT, outflow to Sub-Area 1 (same as A2_IN for Sub-Area 1);
Qal_OUT, outflow to alluvium along southern boundary; and
ΔS, changes in storage.

Sub-Area 2 Inputs:

Diffuse Infiltration (D_INF):

Precipitation in Sub-Area 2 averaged 12.1 in per year (fig. WB4) from 1971 to 2000. Based on METRIC remote sensing techniques, ET in non-irrigated areas of Sub-Area 2 averaged 10.9 in in 2007. Given that there are about 5,315 non-irrigated acres in Sub-Area 2, total recharge is approximately 544 acre-ft/yr. This recharge will not be evenly distributed, but will occur preferentially in areas receiving the most precipitation. Given the uncertainties, the range of probable recharge values is ±10%, or 490 to 599 acre-ft/yr.

Tenmile Creek Infiltration (10M_INF):

Tenmile Creek forms the southeastern border of Sub-Area 2; the length of this border is 1.03 miles. As discussed above for Sub-Area 1, monitoring by Briar and Madison (1992, p. 18) shows that Tenmile Creek loses 2.14 cfs/mi. Assuming that half of this water flows into Sub-Area 2 and half flows to the south, the result is an inflow of 800 acre-ft/yr. Given the uncertainties, the range of probable values is ±10%, or 720 to 880 acre-ft/yr.

It should be noted that monitoring by Briar and Madison (1992, p. 18) and data collected during this study indicate that there is little net flux between Sevenmile Creek and groundwater in this area. If anything, Sevenmile Creek may be a slightly gaining stream overall; if this is so, that outflow is accounted for in the flux to alluvium figure calculated below.

Irrigation Canal Infiltration (IC_INF):

The Helena Valley irrigation canal runs through the eastern side of Sub-Area 2. A small part of one lateral is also within the Sub-Area. There are also two small irrigation canals that divert water from Sevenmile Creek (Sunny Vista and “Lower Canal”). None of the canals are lined.

Briar and Madison (1992) evaluated the infiltration from the Helena Valley irrigation canal system and concluded that the main canal loses an average of about 0.63 cfs/mi, and laterals lose about 0.21 cfs/mi. The loss per mile value for laterals should also be appropriate for the Sunny Vista and Lower Canals.

With Sub-Area 2 there are 1.75 mi of the main canal, 0.03 mi of a lateral, and 3.42 mi of the small canals. The irrigation canals typically function from April 15th to October 1st; thus the best estimate of annual infiltration is 612 acre-ft/year. Given the uncertainties, the range of probable values is ±10%, or 551 to 673 acre-ft/yr.

For comparison, more detailed data were obtained for the Sunny Vista Canal (fig. WB14). This canal is split between Sub-Area 2 and Sub-Area 4. Stage was recorded where Sunny Vista diverts from Sevenmile Creek (GWIC 255321). The stage readings were converted to flows based on a rating curve developed from manual flow and stage measurements collected approximately every 2 weeks. These data show that a total of 342 acre-ft flowed into the Sunny Vista Canal in 2010. The canal was first turned on April 21 and was finally shut off on September 11. During this time it was on for a total of 92.7 d. The length of this canal is 2.4 mi, so its total leakage in the sub-area is estimated to be 0.5 cfs based on the leakage rate of 0.21 cfs/mi noted above. Thus the canal is estimated to have leaked 92 acre-ft during 2010. This leaves 250 acre-ft for irrigation. The Montana Irrigation Guide indicates that 21.48 in/yr are needed for consumptive use on pasture grass. Evaluation of false color IR photographs indicates that approximately 116 acres are irrigated by this canal. Thus, plant use would account for 208 acre-ft/yr, and irrigation recharge would be 42 acre-ft/yr.

Irrigation Recharge (IR_INF, Irrigated Areas):
In irrigated areas Briar and Madison (1992) estimated that about 1.5 ft (18 in) of water that does not run off is applied to the fields in excess of the crop demand (i.e., irrigation recharge). This water is a combination of precipitation and irrigation water. The water flows through the root zone and recharges the underlying groundwater. Some irrigation recharge is needed to prevent the buildup of salts in the root zone and to ensure that plants are not stressed by low moisture conditions. Data from the Montana Department of Revenue show that 246 acres are irrigated in Sub-Area 2. Thus the best estimate of infiltration in irrigated areas is 370 acre-ft/yr. Given the uncertainties, the range of probable values is ±10%, or 333 to 407 acre-ft/yr.

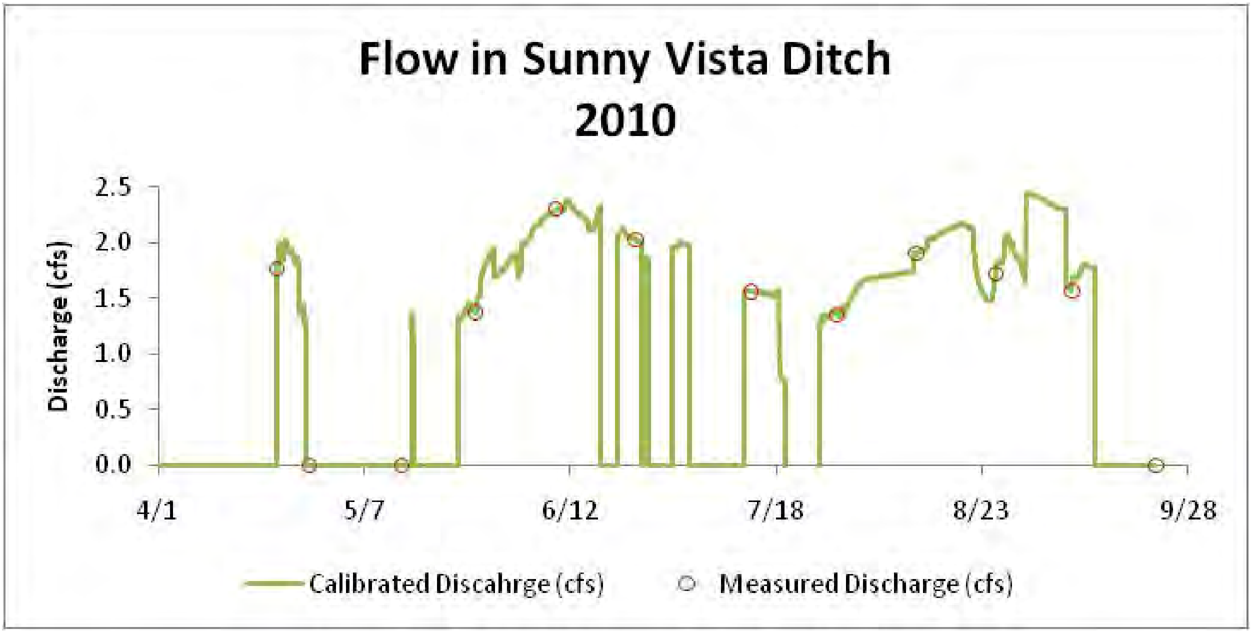


Figure WB14. Calculated flow in the Sunny Vista Canal during 2010.

Combining these input values results in a best estimate of inputs to Sub-Area 2 of 2,325 acre-ft/yr, with the probable range being from 2,093 to 2,558 acre-ft/yr.

Sub-Area 2 Outputs:

Well Withdrawals (WL_OUT):

Based on the discussion for Sub-Area 1, and that 2009 air photos show that there are 240 homes in Sub-Area 2, it appears that consumptive use from well withdrawals for Sub-Area 2 is approximately 117 acre-ft/yr, and the probable range is from 108 to 135 acre-ft/yr.

Outflow to Sub-Area 1 (A1_OUT):

As estimated for Sub-Area 1, the calculated outflow from Sub-Area 2 to Sub-Area 1 is 1,452 acre-ft/yr, and the probable range is from 1,037 to 1,867 acre-ft/yr.

Outflow to Alluvium (Qal_OUT):

The alluvium of Sevenmile and Tenmile Creeks forms a drain along the southern boundary of Sub-Area 2. The water that flows into this alluvium then flows into the greater Helena Valley aquifer. The amount of water flowing into the alluvium from Sub-Area 2 is calculated by projecting a flow line back from the intersection of the eastern boundary of Sub-Area 2 and Tenmile Creek. The western boundary of Sub-Area 2 is also a flow line, so this defines a flow tube. The flux through this flow tube is calculated at the 4,000-ft equipotential line, where the width of the flow tube is 4,414 ft. Along the equipotential line the flow is through granite (Kg; fig. WB3). The granite aquifer’s saturated thickness is taken to be 400 ft, because there are few wells in the area that exceed 400 ft, and the bedrock tends to become less permeable with depth. Using a K of 1.5 ft/d (see table AQ2 and fig. AQ1) and a gradient of 0.033 (GWIC IDs 62385 and 140662 in October 2010), the calculated flux from Sub-Area 2 to the alluvium is 727 acre-ft/yr. Using a range of K values between 1 and 2 ft/d results in a flow between 485 and 969 acre-ft/yr.

Summary for Sub-Area 2:
Based on the best-estimate values, there is a calculated excess of 30 acre-ft/yr (1.3% of inputs) in Sub-Area 2 (table WB3). Hydrographs in Sub-Area 2 are generally stable (fig. WB15); thus it is reasonable to assume that, on an annual basis, there is no net change in storage. As such, inputs and outputs can be recalculated to balance, and the result is shown in the "Adjusted to Zero" column of table WB3. Because the flow from Sub-Area 2 to Sub-Area 1 has already been defined, this value is used in the Adjusted to Zero calculation.

Total inputs and outputs for Sub-Area 2 are about 2,300 acre-ft of water per year. As such, consumptive use by wells accounts for about 5% of the total outflow (118 acre-ft/yr).

Table WB3
Sub-Area 2 Water Budget
(acre-ft/yr)

	Best	Probable Range		Adjusted
INPUTS	Estimate	Min	Max	to Zero
D_INF	544	490	599	542
10M_INF	800	720	880	796
IC_INF	612	551	673	609
IR_INF	370	333	407	368
TOTAL INPUT	2,325	2,093	2,558	2,314
OUTPUTS				
WL_OUT	117	108	135	118
A1_OUT	1,452	1,037	1,867	1,462*
Qal_OUT	727	485	969	734
TOTAL OUTPUT	2,296	1,629	2,971	2,314
Difference				
Acre-ft/yr	30	-878	929	0
% (vs. inputs)	1.3%	-41.9%	36.3%	0.0%

*Set equal to the Adjusted to Zero value for Sub-Area 1.

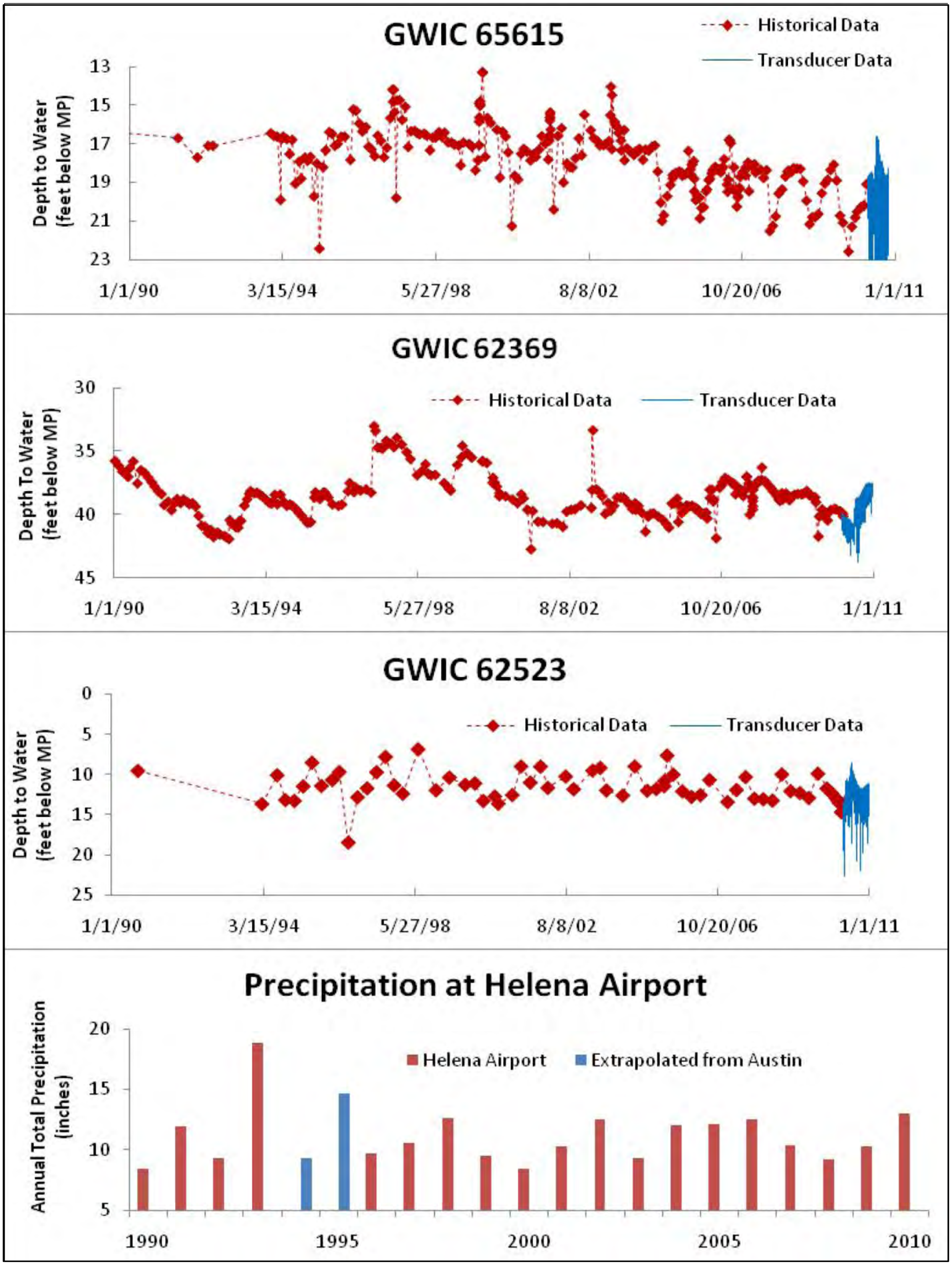


Figure WB15. Hydrographs and precipitation graph for Sub-Area 2, 1990–2010.

Sub-Area 3:

Sub-Area 3 has a total area of 2,431 acres. The water budget for Sub-Area 3 can be written as:

$$D\_INF + IC\_INF + IR\_INF = WL\_OUT + A1\_OUT + Qal\_OUT \pm \Delta S,$$

Where:

D_INF, diffuse infiltration (non-irrigated areas);
IC_INF, irrigation canal infiltration;
IR_INF, irrigation recharge (irrigated areas);
WL_OUT, withdrawals from wells;
A1_OUT, outflow to Sub-Area 1 (Same as A3_IN for Sub-Area 1);
Qal_OUT, outflow to alluvium along northern boundary; and
ΔS, changes in storage.

Sub-Area 3 Inputs:

Diffuse Infiltration (D_INF):

Precipitation in Sub-Area 3 averaged 12.9 in per year from 1971 to 2000 (fig. WB4). Based on METRIC remote sensing techniques, ET in non-irrigated areas was 10.9 in. in 2007. Because there are approximately 2,384 non-irrigated acres in Sub-Area 3, recharge is approximately 406 acre-ft/yr. Recharge will preferentially occur in areas receiving the most precipitation. Given the uncertainties, the range of probable recharge values is ±10%, or 365 to 446 acre-ft/yr.

Irrigation Canal Infiltration (IC_INF):

There are several small irrigation canals that run parallel to Silver Creek. None of these are lined. Briar and Madison (1992) evaluated the infiltration from the Helena Valley irrigation canal system, and concluded that laterals lose about 0.21 cfs/mi. The loss per mile value for laterals should also be appropriate for the small irrigation canals.

A total of 1.3 mi of the small canals are within Sub-Area 3. The irrigation canals typically function from April 15th to October 1st; thus the best estimate of annual infiltration is 94 acre-ft/year. Given the uncertainties, the range of probable values is ±10%, or 85 to 104 acre-ft/yr.

Irrigation Recharge (IR_INF, Irrigated Areas):

In irrigated areas, Briar and Madison (1992) estimated that about 1.5 ft (18 in) of water that does not run off is applied to the fields in excess of the crop demand (i.e., irrigation recharge). This water is a combination of precipitation and irrigation water. The water flows through the root zone and recharges the underlying groundwater. Some irrigation recharge is needed to prevent the buildup of salts in the root zone and to ensure that plants are not stressed by low moisture conditions. Although data from the Montana Department of Revenue shows that only 5 acres in Sub-Area 3 are irrigated; however, the Water Resources Survey for Lewis and Clark County

(Buck and Bille, 1957) shows 46.7 irrigated acres, which is consistent with false color IR photographs and field observations. Thus the best estimate of infiltration in irrigated areas is 70 acre-ft/yr. Given the uncertainties, the range of probable values is ±10%, or 63 to 77 acre-ft/yr.

Combining these input values results in a best estimate of inputs to Sub-Area 3 of 570 acre-ft/yr, with the probable range being from 513 to 627 acre-ft/yr.

Sub-Area 3 Outputs:
<u>Well Withdrawals (WL_OUT):</u>
Based on the discussion for Sub-Area 1, and that 2009 air photos show that there are 88 homes in Sub-Area 3, estimated consumptive use from well withdrawals for Sub-Area 3 is approximately 43 acre-ft/yr, and the probable range is from 39 to 49 acre-ft/yr.

<u>Outflow to Sub-Area 1 (A1_OUT):</u>
As estimated for Sub-Area 1, the outflow from Sub-Area 3 to Sub-Area 1 is approximately 210 acre-ft/yr (set to the Adjusted to Zero value for Sub-Area 1), and the probable range is from 167 to 250 acre-ft/yr.

<u>Outflow to Alluvium (Qal_OUT):</u>
The alluvium of Silver Creek forms a drain along the northern boundary of Sub-Area 3. The water then flows into the greater Helena Valley aquifer. The amount of water flowing into the alluvium from Sub-Area 3 is calculated by assuming that all water entering the sub-area must exit by wells, outflow to Sub-Area 1, or outflow to alluvium. Because inputs total 570 acre-ft/yr, and 253 acre-ft/yr are accounted for by wells and flow to Sub-Area 1, the calculated flow to the alluvium should be about 317 acre-ft/yr. Given the uncertainties, the range of probable values is ±10%, or 286 to 349 acre-ft/yr.

Summary for Sub-Area 3:
Using the best estimate values discussed above, the result is a balanced budget, due to the assumption that the amount of water entering the alluvium is equal to the difference between inputs and other outputs (table WB4).

Total inflow and outflow for Sub-Area 3 are each about 570 acre-ft/yr. As such, consumptive use by wells accounts for about 7.5% of the total outflow (43 acre-ft/yr). There is only one long-term hydrograph available from Sub-Area 3, and it is stable; however, it shows substantial fluctuation (fig. WB16). This may indicate that the aquifer in this area is not able to keep up with pumping during high-use times. Overall, it appears that this area should be in equilibrium.

Table WB4
Sub-Area 3 Water Budget
(acre-ft/yr)

INPUTS	Best Estimate	Probable Range Min	Probable Range Max
D_INF	406	365	446
IC_INF	94	85	104
IR_INF	70	63	77
TOTAL INPUT	570	513	627
OUTPUTS			
WL_OUT	43	39	49
A1_OUT	210*	167	250
Qal_OUT	317	286	349
TOTAL OUTPUT	570	492	648
Difference			
Acre-ft/yr	0	-135	135
% (vs. inputs)	0%	-26%	22%

*Set equal to the Adjusted to Zero value for Sub-Area 1.

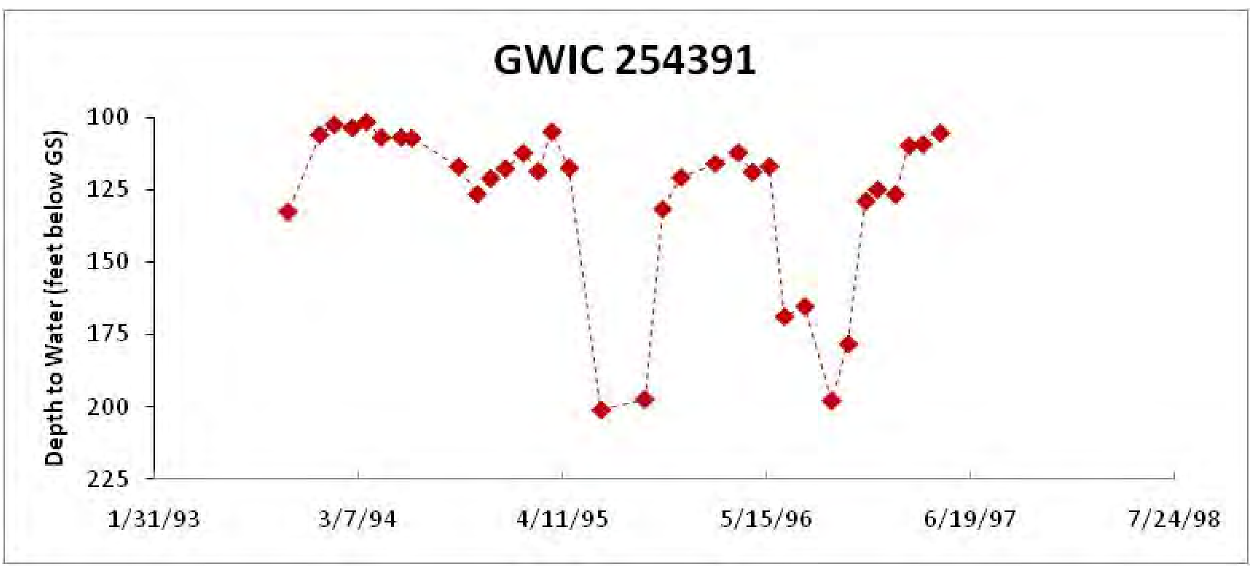


Figure WB16. This hydrograph from Sub-Area 3 shows a stable trend, but with periods of substantial water-level reductions.

Sub-Area 4:
The area of Sub-Area 4 is 2,431 acres. The water budget for Sub-Area 4 is somewhat different than the other upland areas because it includes bedrock inflow. It is also distinctive that none of the outflow from Sub-Area 4 enters any of the other sub-areas. The water budget for Sub-Area 4 can be written as:

$$BR\_IN + D\_INF + IC\_INF + IR\_INF = WL\_OUT + Qal\_OUT \pm \Delta S,$$

where:

BR_IN, bedrock inflow;
D_INF, diffuse infiltration (non-irrigated areas);
IC_INF, irrigation canal infiltration;
IR_INF, irrigation recharge (irrigated areas);
WL_OUT, withdrawals from wells;
Qal_OUT, outflow to alluvium; and
ΔS, changes in storage.

Sub-Area 4 Inputs:

Bedrock Inflow (BR_IN):
The 4,300-ft equipotential contour was used to calculate bedrock inflow between the flow lines that follow Park and Threemile Creeks. The length of this line is 18,643 ft. Using a thickness of 400 ft, a gradient of 0.02, and a K of 0.4 ft/d (Helena Formation), the flux into Sub-Area 4 from the west is 482 acre-ft/yr. If a range of K from 0.2 to 0.6 is evaluated, the flux ranges from 241 to 723 acre-ft/yr.

Diffuse Infiltration (D_INF):
Precipitation in Sub-Area 4 averaged 13.2 in per year from 1971 to 2000 (fig. 4). Based on METRIC remote sensing techniques, ET in non-irrigated areas was 10.9 in. in 2007. Because there are 6,548 non-irrigated acres in Sub-Area 4, recharge is approximately 1,235 acre-ft/yr. Recharge will occur preferentially in areas receiving the most precipitation. Given the uncertainties, the range of probable recharge values is ±10%, or 1,111 to 1,358 acre-ft/yr.

Irrigation Canal Infiltration (IC_INF):
There are several small irrigation canals that run parallel to Sevenmile Creek and Threemile Creek. None of these are lined. Briar and Madison (1992) evaluated the infiltration from the Helena Valley irrigation canal system, and concluded that laterals lose about 0.21 cfs/mi. The loss per mile value for laterals should also be appropriate for the small irrigation canals.

A total of 1.3 mi of the small canals are within Sub-Area 4. The irrigation canals typically function from April 15th to October 1st; thus the best estimate of annual infiltration is 90 acre-ft/yr. Given the uncertainties, the range of probable values is ±10%, or 81 to 99 acre-ft/yr.

<u>Irrigation Recharge (IR_INF) (Irrigated Areas):</u>
In irrigated areas Briar and Madison (1992) estimated that about 1.5 ft (18 in) of water that does not run off is applied to the fields in excess of the crop demand (i.e., irrigation recharge). This water is a combination of precipitation and irrigation water. The water flows through the root zone, and recharges the underlying groundwater. Some irrigation recharge is needed to prevent the buildup of salts in the root zone and to ensure that plants are not stressed by low moisture conditions. Data from the Montana Department of Revenue show that 84 acres in Sub-Area 4 are irrigated. Thus the best estimate of infiltration in irrigated areas is 126 acre-ft/yr. Given the uncertainties, the range of probable values is ±10%, or 113 to 139 acre-ft/yr.

Combining these input values results in a best estimate of inputs to Sub-Area 4 of 1,933 acre-ft/yr, with the probable range being from 1,546 to 2,319 acre-ft/yr.

Sub-Area 4 Outputs:
<u>Well Withdrawals (WL_OUT):</u>
Based on the discussion for Sub-Area 1 above, and that 2009 air photos show 168 homes in Sub-Area 4, consumptive use from well withdrawals for Sub-Area 4 is approximately 82 acre-ft/yr, and the probable range is from 75 to 94 acre-ft/yr.

<u>Outflow to Alluvium: (Qal_OUT):</u>
The alluvium of Park, Threemile, Silver, and Sevenmile Creek forms a drain along the northern and southern boundaries of Sub-Area 4. The water that flows into this alluvium then flows into the greater Helena Valley aquifer. The amount of water flowing into the alluvium from Sub-Area 4 is calculated by assuming that all the water entering must exit by wells or outflow to alluvium. Since inputs total 1,933 acre-ft/yr, and 82 acre-ft/yr are accounted for by wells, the calculated flow to the alluvium is 1,851 acre-ft/yr. Given the uncertainties, the range of probable values is ±10%, or 1,666 to 2,036 acre-ft/yr.

Summary for Sub-Area 4:
Using the best estimate values discussed above, the result is a balanced budget, due to the assumption that the amount of water entering the alluvium is equal to the difference between inputs and other outputs (table WB5). Total Outflow for Sub-Area 4 is about 1,930 acre-ft of water per year. As such, consumptive use by wells accounts for about 4% of the total outflow (82 acre-ft/yr).

Table WB5
Sub-Area 4 Water Budget
(acre-ft/yr)

	Best	Probable Range	
INPUTS	Estimate	Min	Max
BR_IN	482	241	723
D_INF	1,235	1,111	1,358
IC_INF	90	81	99
IR_INF	126	113	139
TOTAL INPUT	1,933	1,546	2,319
OUTPUTS			
WL_OUT	82	75	94
Qal_OUT	1,851	1,666	2,036
TOTAL OUTPUT	1,933	1,741	2,130
Difference			
Acre-ft/yr	0	-583	578
% (vs. inputs)	0%	-38%	25%

Hydrographs from Sub-Area 4 appear stable (fig. WB17); thus it is reasonable to assume that on an annual basis there is no net change in storage.

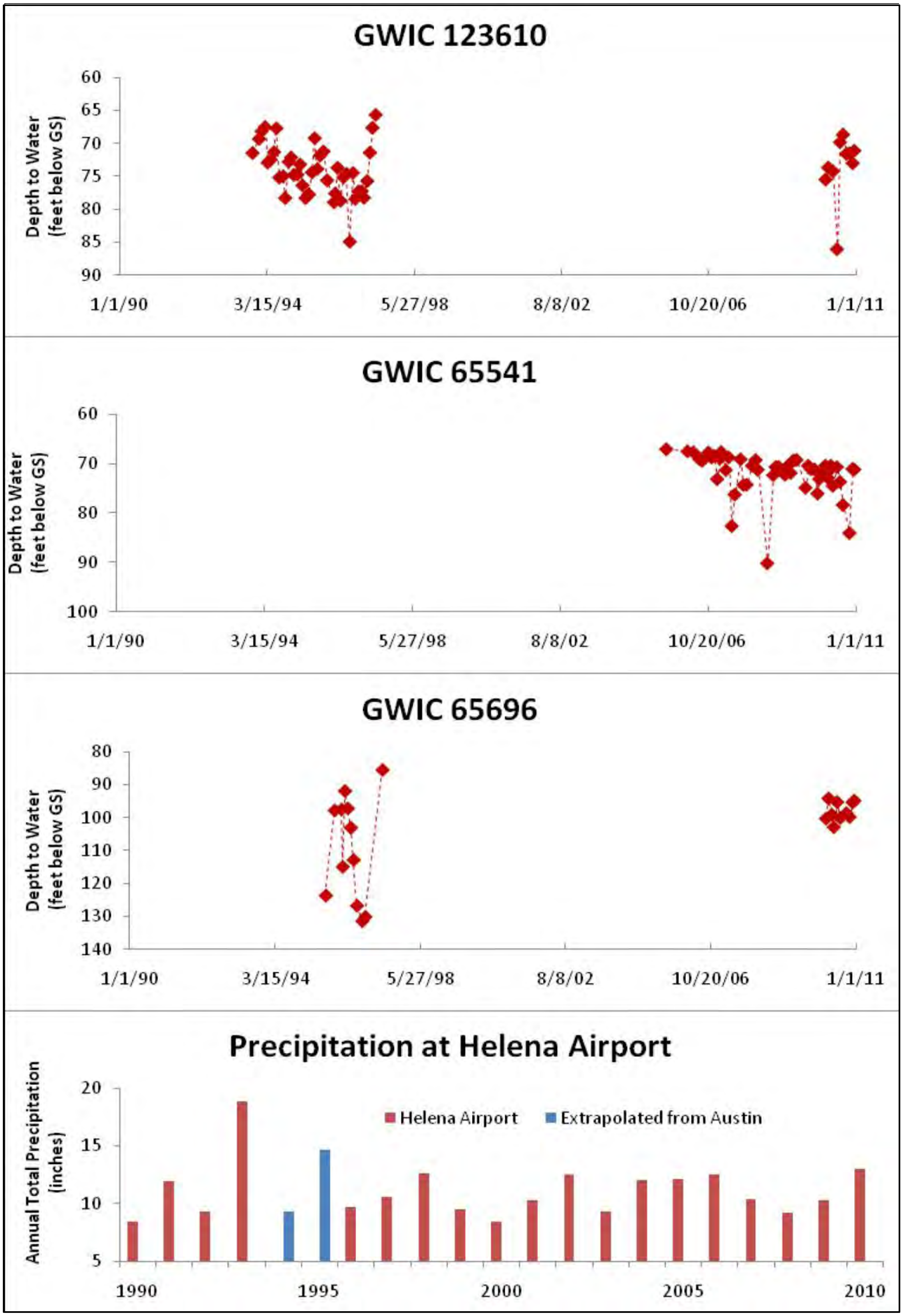


Figure WB17. Hydrographs from Sub-Area 4 show stable trends.

Combined Water Budget:
The total water budget for the Scratchgravel Hills study area is the combination of the sub-area budgets. In this calculation, the terms for flow between sub-areas cancel out. The result is:

$$BR\_IN + D\_INF + +10M\_INF + SC\_INF + IC\_INF + IR\_INF = WL\_OUT + Qal\_OUT + HVA\_OUT \pm \Delta S,$$

Where:

BR_IN, bedrock inflow at from the west;
D_INF, diffuse infiltration (non-irrigated areas);
10M_INF, Tenmile Creek infiltration;
SC_INF, Silver Creek infiltration;
IC_INF, irrigation canal infiltration;
IR_INF, irrigation recharge (irrigated areas);
WL_OUT, withdrawals from wells;
Qal_OUT, discharge to alluvium;
HVA_OUT, discharge to the Helena Valley Aquifer; and
ΔS, changes in storage.

For the combined budget, Adjusted to Zero values were used for Sub-Areas 1 and 2, and the Best Estimate Values used for the other sub-areas. The results are shown in table WB6. Interestingly, human-induced recharge (IC_INF + IR_INF = 3,075 acre-ft/yr) is almost four times greater than human-induced withdrawals (WL_OUT = 781 acre-ft/yr). Because hydrographs in all sub-areas show no apparent upward or downward trends, it is reasonable to assume that there is no long-term net change in storage.

Summary:
It appears that the Scratchgravel Hills study area is at equilibrium. Calculated inputs and outputs balance (table WB6 and fig. WB18), and hydrographs appear stable (figs. WB13, WB15, WB16, and WB17).

Overall, groundwater inputs and outputs in the Scratchgravel Hills total about 8,000 acre-ft/yr, and considering uncertainties, the probable range is between about 7,000 and 9,000 acre-ft/yr. Consumptive use from well withdrawals account for about 10% of the total flux (781 acre-ft/yr). The rest of the water flows to the Helena Valley aquifer, either directly or through the alluvium along creeks (fig. WB19).

The results of this analysis have been used to assist in development of the conceptual model and to constrain the numeric groundwater model for the Scratchgravel Hills study area (Bobst and others, 2013; Butler and others, 2013).

Table WB6
Scratchgravel Hills Water Budget
(acre-ft/yr)

INPUTS	Best Estimate	Probable Range Min	Max
BR_IN	482	241	723
D_INF	2184	1,966	2,403
10M_INF	1742	1,565	1,913
SC_INF	490	438	535
IC_INF	1453	1,306	1,597
IR_INF	1622	1,455	1,778
TOTAL INPUT	7974	6,972	8,950
OUTPUTS			
WL_OUT	781	721	901
Qal_OUT	2,902	2,436	3,354
HVA_OUT	4,290	3,887	4,751
	7,974	7,044	9,007
Difference			
Acre-ft/yr	0	-2,034	1,906
% (vs. inputs)	0.0%	-29.2%	21.3%

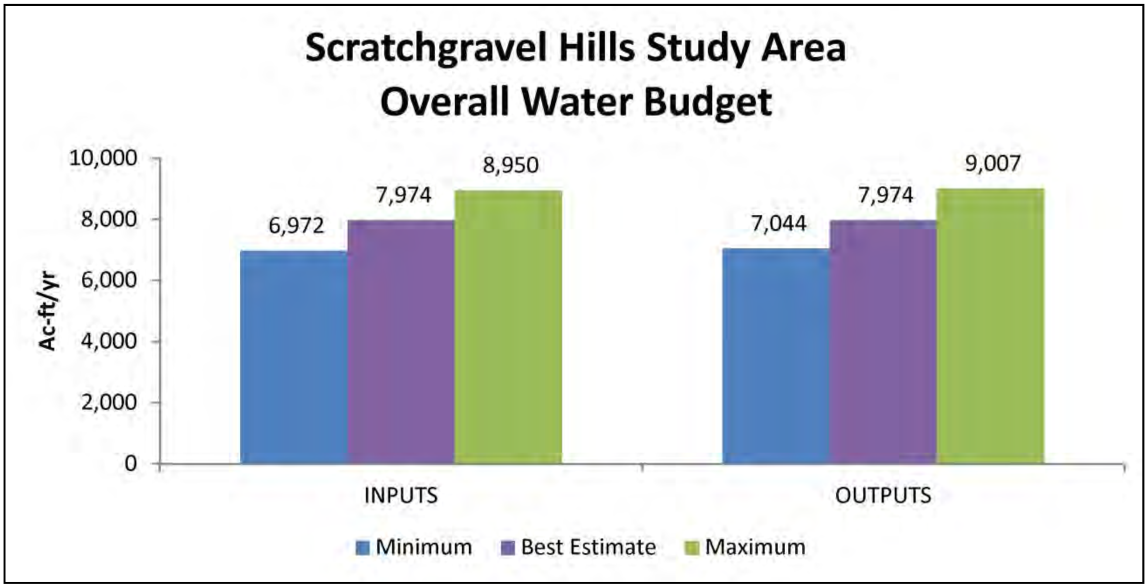


Figure WB18. Overall water budget for the Scratchgravel Hills study area.

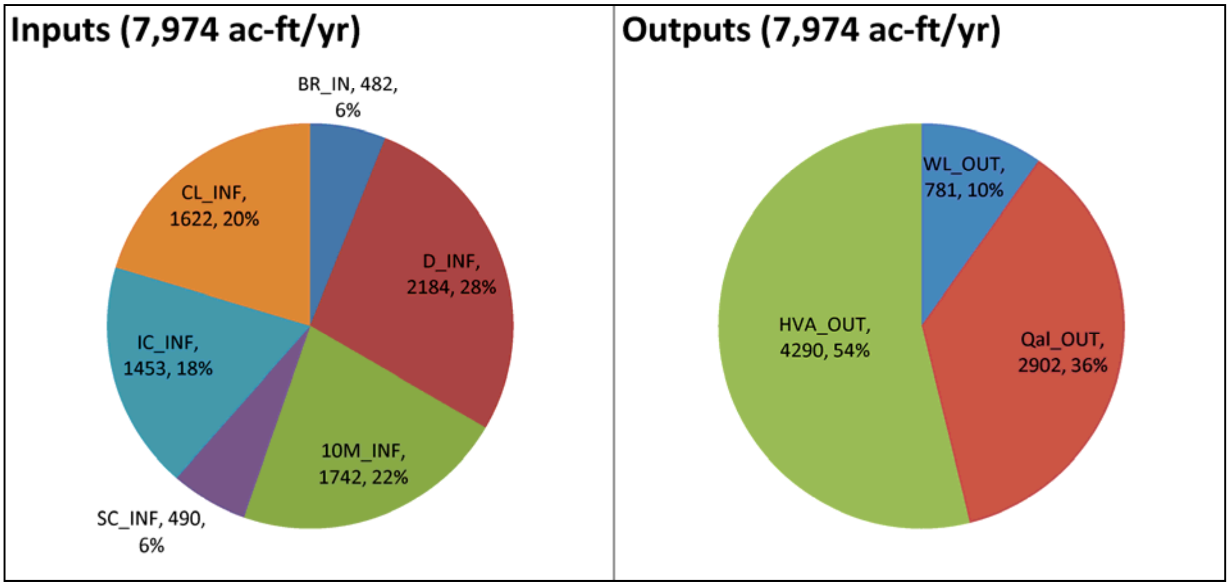


Figure WB19. Distribution of groundwater flux for the Scratchgravel Hills. Flux is in acre-feet per year.

References:

Briar, D.W., and Madison, J.P., 1992, Hydrogeology of the Helena valley-fill aquifer system, west-central Montana: U.S. Geological Survey Water Resources Investigations Report 92-4023.

Cannon, M.R, and Johnson, D.R., 2004, Estimated water use in Montana in 2000, U.S. Geological Survey Scientific Investigations Report 2004-5223, 50 p.

Department of Natural Resources Conservation (DNRC), 1986, Montana water use in 1980: Water Resources Division, 49 p.

Environmental Protection Agency (EPA), 2008, Indoor water use in the United States, EPA-832-F-06-004 (http://www.epa.gov/WaterSense/docs/ws_indoor508.pdf).

Fetter, C.W., 1994, Applied hydrogeology, 3d ed.: New York, MacMillan College Publishing, 691 p.

Madison, J.P., 2006, Hydrogeology of the North Hills, Helena, Montana: Montana Bureau of Mines and Geology Open-File Report 544, 41 p., 3 sheets, 1:24,000.

NOAA, 2011, Online Data at http://www.ncdc.noaa.gov/oa/ncdc.html

Schmidt, R.G., Loen, J.S., Wallace, C.A., and Mehnert, H.H., 1994, Geology of the Elliston region, Powell and Lewis and Clark Counties, Montana: U.S. Geological Survey Bulletin 2045, 25 p., 1 plate.

Soil Conservation Service, undated, Montana Irrigation Guide.

Thornthwaite, C.W., 1944, 1943–44 report to the Committee in transpiration and evaporation: Transactions of the American Geophysical Union, no. 25, p. 683–693.

Trezza, R., Allen, R., Robison, C.W., and Kjaersgaard, J., 2011, Completion report on the production of evapotranspiration maps for year 2007 for the Smith river, Helena, Bozeman and Dillon areas of Montana using Landsat images and the METRIC model: Unpublished report, 58 p.

United States Geological Survey (USGS), 2013, Daily discharge data, Tenmile Creek near Helena, MT (USGS 06063000), http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=06063000 [Accessed 12/6/13].

WATER CHEMISTRY

The following tables and maps summarize the Scratchgravel Hills project's water-quality sampling effort. All sample results are available on GWIC (http://mbmggwic.mtech.edu/) for each site by using its GWIC ID.

This sampling was conducted to gain information on the water quality throughout the study area, and to evaluate its seasonal variability. The effect on groundwater quality from septic system effluent was also a major focus.

Table WQ1 identifies the groundwater sites that were sampled, the dates of sampling, and the parameters analyzed. Figure WQ1 shows the locations of these sites.

Table WQ2 identifies the surface-water sites that were sampled, the dates of sampling, and the parameters analyzed. Figure WQ2 shows the locations of these sampling.

Table WQ3 provides a complete list of the analytical parameters for a standard sample. Selected samples were also analyzed for selected isotopes and Organic Waste-Water Chemicals (OWCs; aka pharmaceuticals).

Table WQ4 provides sample results for major ions, presented as milliequivalents, and as constituent percentages. These values were used for the development of Piper and Stiff diagrams. Results for other parameters are available on GWIC.

Table WQ-1. Scratchgravel Hills Groundwater Sampling Summary

GWIC ID	Site Name	Aquifer	Well Depth (ft)	Sample Dates				Isotope Sample Dates: Oxygen/Deuterium	Sulfur	Nitrate		Radon	OWCs
61368	BROWNE, SUSAN AND TERRY	110ALVM	uk	4/14/10	8/11/10	10/7/10	ns	ns	ns	ns	ns	10/7/10	ns
62369	ELLIOT JIM	211SCGR	110	4/15/10	8/9/10	10/7/10	4/27/11	4/15/10	4/15/10	8/9/10	ns	10/7/10	4/27/11
62471	BAUM ED	400HELN	120	ns	8/10/10	10/6/10	ns	ns	ns	ns	ns	10/6/10	ns
62523	WALKER, GILES E.	110ALVM	50	4/7/10	8/10/10	10/6/10	4/28/11	4/7/10	4/7/10	ns	ns	10/6/10	4/28/11
65088	HELM, SCOTT	110ALVM	52	4/15/10	8/12/10	10/6/10	4/27/11	5/27/10	4/15/10	ns	ns	10/6/10	4/27/11
65316	SMELKO, DANIEL B.	110ALVM	97	4/6/10	8/12/10	10/7/10	ns	ns	ns	ns	ns	10/7/10	ns
65536	SELVA ADOLFO	211SCGR	200	4/16/10	8/10/10	10/6/10	ns	ns	ns	8/9/10	ns	10/6/10	ns
65541	LINDGREN ROBERT	400HELN	200	4/15/10	8/11/10	10/5/10	ns	ns	ns	ns	ns	10/5/10	ns
65615	SHIELDS, RONALD	211SCGR	125	4/15/10	8/9/10	10/5/10	4/27/11	4/15/10	4/15/10	8/9/10	ns	10/5/10	4/27/11
65618	NORRIS, JOSEPH * SOUTH WELL	211SCGR	167	4/14/10	8/10/10	10/5/10	ns	ns	ns	ns	ns	10/5/10	ns
123839	WINDLE COLE & JUDY	400SPKN	201	4/14/10	8/11/10	10/5/10	ns	ns	ns	ns	ns	10/5/10	ns
135317	NEAL CHUCK	400HELN	300	4/6/10	8/11/10	10/7/10	ns	ns	ns	ns	ns	10/7/10	ns
147289	WALL JOHN	211SCGR	70	ns	8/10/10	10/6/10	ns	ns	ns	ns	ns	10/6/10	ns
191555	LCWQPD - APPLEGATE & NORRIS	110ALVM	29	4/15/10	8/19/10	10/20/10	10/20/10	6/1/10	4/15/10	ns	ns	10/20/10	ns
227906	STEVENS, JERRY	110ALVM	49	4/16/10	8/12/10	10/7/10	ns	ns	ns	ns	ns	10/7/10	ns
232194	SMITH JAMES E. & DIANNA M.	400HELN	740	4/15/10	8/11/10	10/4/10	ns	ns	ns	ns	ns	10/4/10	ns
254703	JOSHUA DONAIK	211SCGR	144	4/16/10	8/10/10	10/6/10	ns	ns	ns	8/10/10	9/10/10	10/6/10	ns
254740	EICHHORN, SCOTT * EAST WELL	400HELN	uk	4/16/10	8/9/10	10/4/10	ns	ns	ns	ns	ns	10/4/10	ns
257063	MBMG APPLEGATE & NORRIS	110ALVM	60	ns	8/19/10	10/20/10	ns	ns	ns	ns	ns	10/20/10	ns
258347	ZOOK DARRELL & CARINA	211SCGR	280	ns	ns	10/5/10	ns	ns	ns	ns	ns	10/5/10	ns
706001	CLARK, DONALD	211SCGR	90	4/15/10	8/9/10	10/4/10	ns	ns	ns	8/9/10	ns	10/4/10	ns
706014	CHAPMAN, KELLY	400UDFD	206	4/14/10	8/10/10	10/4/10	ns	ns	ns	ns	ns	10/4/10	ns
706039	WARFORD, CAROL	400HELN	205	4/15/10	8/11/10	10/5/10	ns	ns	ns	ns	ns	10/5/10	ns
706055	MAULORICO AL	211SCGR	180	4/14/10	8/12/10	10/5/10	ns	ns	ns	ns	ns	10/5/10	ns
706058	FOWLER, SANDRA	211SCGR	46	4/14/10	8/9/10	10/6/10	ns	ns	ns	9/14/10	ns	10/6/10	ns

uk = unknown
ns = not sampled
OWC = Organic Waste-Water Chemicals

Aquifer Codes
110ALVM = Quaternary Alluvium
211SCGR = Scratchgravel Hills Stock
400HELN = Helena Formation
400SPKN = Spokane Formation
400UDFD = Undifferentiated Precambrian

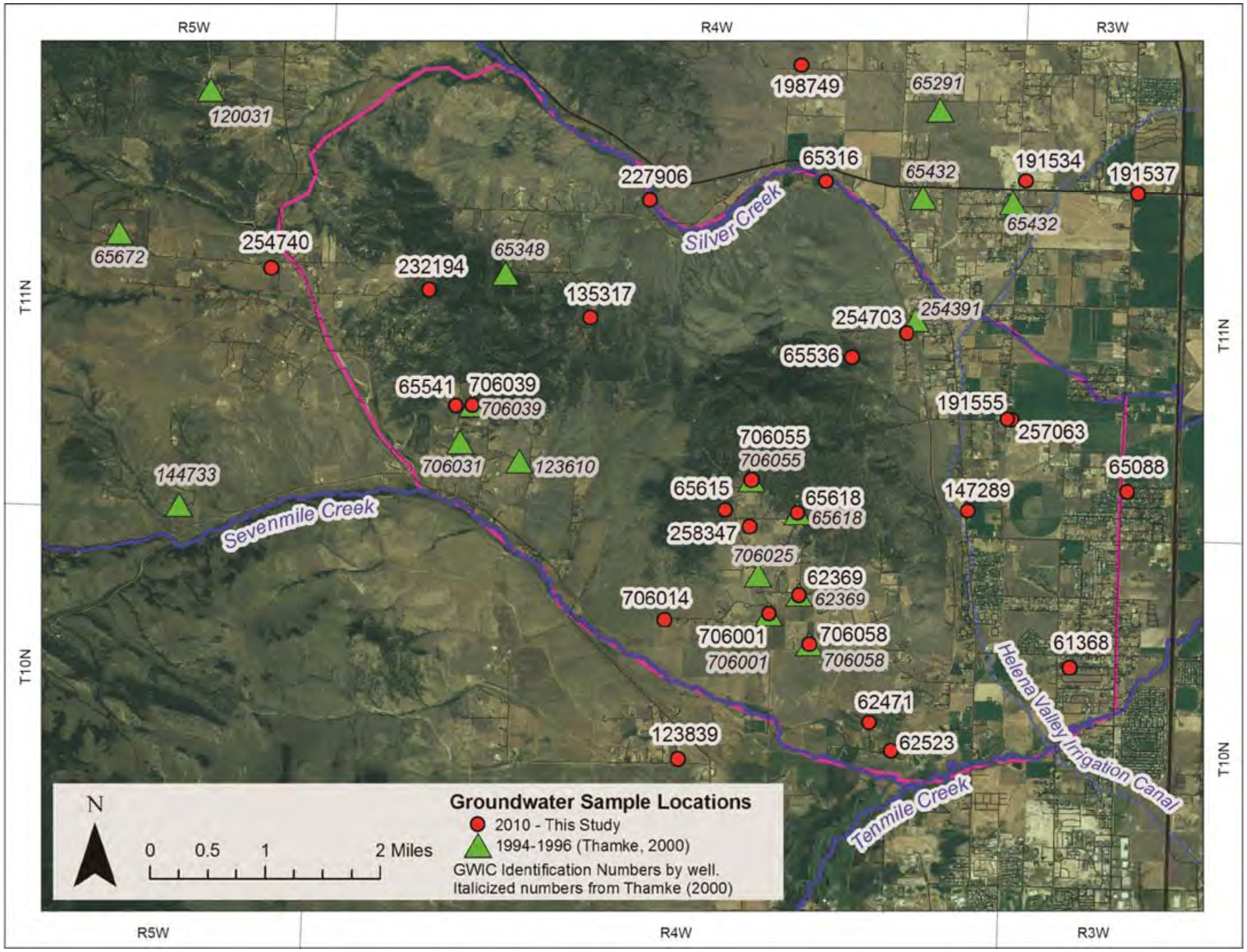


Figure WQ1. Seventy-five groundwater samples were collected at 24 sites for this study. These data were evaluated in combination with data collected during a recently completed MBMG study in the North Hills (Waren and others, 2012), and by Thamke (2000).

Table WQ-2. Scratchgravel Hills Surface-Water Sampling Summary

GWIC ID	Site Name	Site Type		Sample Dates				Isotope Sample Dates	
								Oxygen/Deuterium	Sulfur
254994	SILVER CREEK; SW-SC1	Stream		4/7/10	8/12/10	10/8/10		4/7/10	4/7/10
255000	SEVENMILE CREEK * 7M-SW1	Stream		4/7/10	8/13/10	10/11/10		4/7/10	4/7/10
255001	SILVER CREEK; SC-2 * SC-SW2	Stream		4/6/10	8/12/10	10/8/10		ns	ns
255052	HVID D-2-2.3-1 (DA)	Drain		4/6/10	8/12/10	10/11/10		3/2/10	ns
255059	TENMILE AT GREEN MEADOWS * 10M-SW1	Stream		4/6/10	ns	ns		ns	ns
256972	HVID-1 (MCHUGH LN)	Irrigation Canal		5/4/10	8/12/10	ns		5/4/10	5/4/10
257316	TENMILE CREEK AT MCHUGH LANE	Stream		ns	8/12/10	10/7/10		ns	ns

ns = not sampled

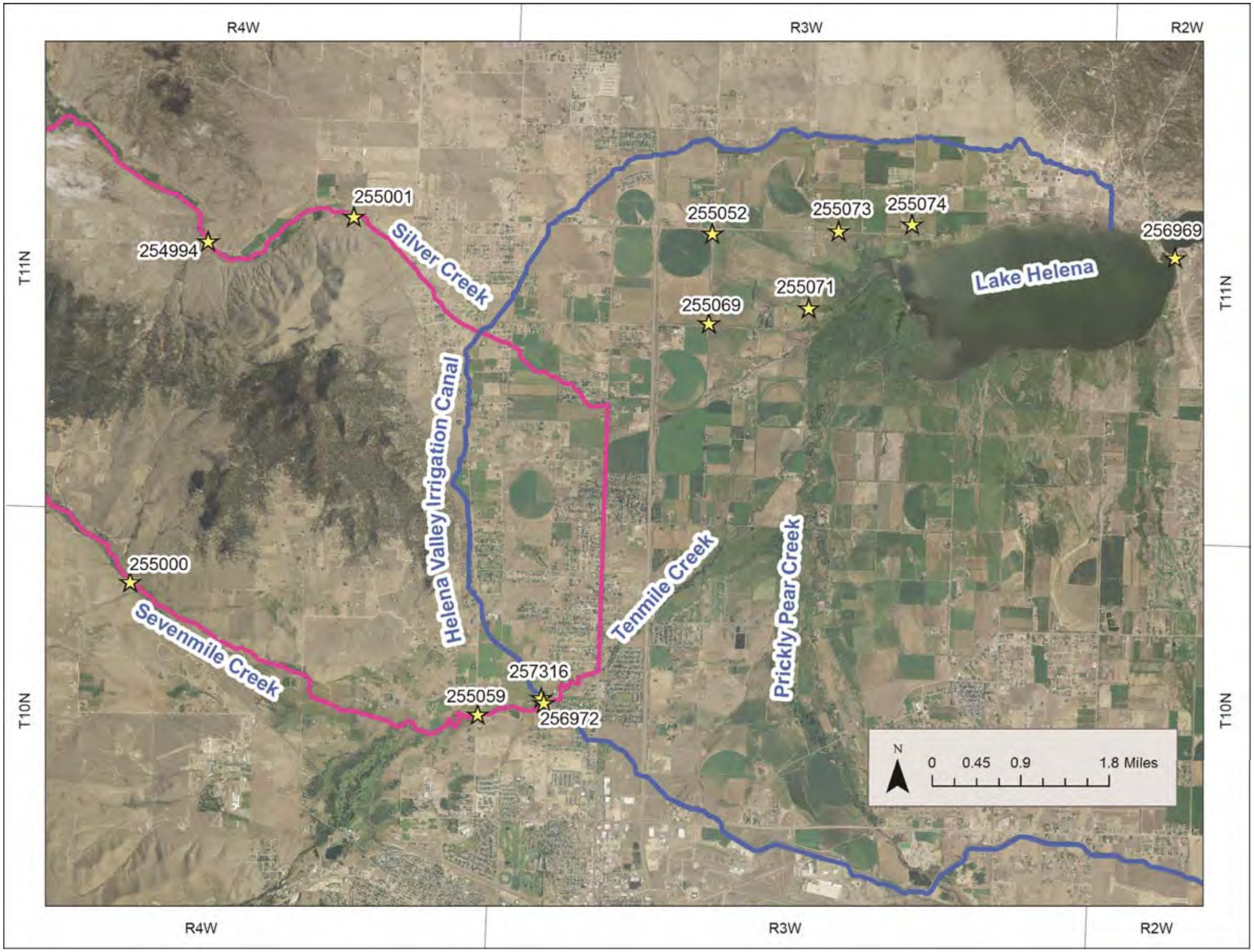

R4W
R3W
R2W
T11N
T10N
255001
254994
Silver Creek
255052
255073
255074
256969
Lake Helena
255071
255069
Helena Valley Irrigation Canal
255000
Sevenmile Creek
Tenmile Creek
Prickly Pear Creek
257316
255059
256972
N
0 0.45 0.9 1.8 Miles

Table WQ3
Analytical Parameters and Units Used for Reporting Water Samples Collected in the Scratchgravel Hills Study Area

Major Ions		
Calcium	Ca	mg/L
Magnesium	Mg	mg/L
Sodium	Na	mg/L
Potassium	K	mg/L
Iron	Fe	mg/L
Manganese	Mn	mg/L
Silica	SiO_2	mg/L
Bicarbonate	HCO_3	mg/L
Carbonate	CO_3	mg/L
Chlorine	Cl	mg/L
Sulfate	SO_4	mg/L
Nitrate	as N	mg/L
Fluoride	F	mg/L
Orthophosphate	as P	mg/L

Field Parameters		
Field Conductivity	Field SC	μmhos
Field pH	Field pH	—
Water Temperature	T	^oC

Other Parameters		
Total Dissolved Solids	TDS	mg/L
Sum of Dissolved Constituents	---	mg/L
Lab Conductivity	Lab SC	μmhos
Lab pH	Lab pH	---
Nitrite	as N	mg/L
Nitrate + Nitrite	as N	mg/L
Total Nitrogen	as N	mg/L
Hardness	as $CaCO_3$	mg/L
Alkalinity	as $CaCO_3$	mg/L
Ryznar Stability Index	—	—
Sodium Adsorption Ratio	SAR	—
Langlier Saturation Index	—	—
Phosphate (TD)	as P	mg/L

Note. mg/L, milligrams per liter; μg/L,micrograms per liter; μmhos, micromhos per centimeter at 25^{o}C.

Trace Elements		
Aluminum	Al	μg/L
Antimony	Sb	μg/L
Arsenic	As	μg/L
Barium	Ba	μg/L
Beryllium	Be	μg/L
Boron	B	μg/L
Bromide	Br	μg/L
Cadmium	Cd	μg/L
Cerium	Ce	μg/L
Cesium	Cs	μg/L
Chromium	Cr	μg/L
Cobalt	CO3	μg/L
Copper	Cu	μg/L
Gallium	Ga	μg/L
Lanthanum	La	μg/L
Lead	Pb	μg/L
Lithium	Li	μg/L
Molybdenum	Mo	μg/L
Nickel	Ni	μg/L
Niobium	Nb	μg/L
Neodymium	Nd	μg/L
Palladium	Pd	μg/L
Praseodymium	Pr	μg/L
Rubidium	Rb	μg/L
Silver	Ag	μg/L
Selenium	Se	μg/L
Strontium	Sr	μg/L
Thallium	Tl	μg/L
Thorium	Th	μg/L
Tin	Sn	μg/L
Titanium	Ti	μg/L
Tungsten	W	μg/L
Uranium	U	μg/L
Vanadium	V	μg/L
Zinc	Zn	μg/L
Zirconium	Zr	μg/L

Table WQ-4. Scratchgravel Hills Groundwater Quality Samples - Major Ions as Milliequivalents

GWIC ID	Site Name	Sample Date	Milliequivalents								Constituent Percent					
			Ca	Mg	Na	K	HCO_3	SO_4	Cl		Ca	Mg	Na + K	HCO_3	SO_4	Cl
62523	WALKER, GILES E.	4/7/10	3.77	1.70	0.47	0.06	4.90	0.85	0.16		63%	28%	9%	83%	14%	3%
135317	NEAL CHUCK	4/6/10	2.34	4.44	1.15	0.04	5.17	1.99	0.63		29%	56%	15%	66%	26%	8%
65316	SMELKO, DANIEL B.	4/6/10	4.94	3.21	1.20	0.11	6.36	2.08	0.45		52%	34%	14%	72%	23%	5%
706001	CLARK, DONALD	4/15/10	3.21	1.50	0.71	0.02	3.68	1.24	0.28		59%	28%	13%	71%	24%	5%
65615	SHIELDS, RONALD	4/15/10	4.92	2.00	0.66	0.02	4.47	1.07	2.28		65%	26%	9%	57%	14%	29%
65618	NORRIS, JOSEPH * SOUTH WELL	4/14/10	3.67	1.05	0.49	0.02	4.52	0.68	0.51		70%	20%	10%	79%	12%	9%
706055	MAULORICO AL	4/14/10	3.70	1.46	0.73	0.02	3.63	0.94	0.49		63%	25%	13%	72%	19%	10%
62369	ELLIOT JIM	4/15/10	2.82	1.43	0.77	0.03	3.37	1.24	0.22		56%	28%	16%	70%	26%	5%
123839	WINDLE COLE & JUDY	4/14/10	2.99	3.41	1.68	0.16	5.61	1.87	0.59		36%	41%	22%	70%	23%	7%
65088	HELM, SCOTT	4/15/10	3.42	1.42	0.78	0.08	4.44	1.33	0.44		60%	25%	15%	72%	21%	7%
191555	LCWQPD - APPLEGATE AND NORRIS	4/15/10	2.76	2.41	1.83	0.04	5.64	1.16	0.66		39%	34%	27%	76%	16%	9%
65536	SELVA ADOLFO	4/16/10	3.48	2.07	0.77	0.16	4.47	1.19	0.77		54%	32%	14%	69%	19%	12%
232194	SMITH JAMES E. & DIANNA M.	4/15/10	1.82	2.63	1.08	0.05	4.20	1.46	0.13		33%	47%	20%	73%	25%	2%
706039	WARFORD, CAROL	4/15/10	2.38	4.05	0.59	0.04	4.81	2.45	0.59		34%	57%	9%	61%	31%	7%
65541	LINDGREN ROBERT	4/15/10	1.74	2.64	0.24	0.03	3.75	0.96	0.21		37%	57%	6%	76%	20%	4%
61368	BROWNE, SUSAN AND TERRY	4/14/10	2.35	0.96	0.90	0.07	2.91	0.94	0.41		55%	23%	23%	68%	22%	10%
706058	FOWLER, SANDRA	4/14/10	0.08	0.05	5.83	ND	4.69	0.91	0.20		1%	1%	98%	81%	16%	3%
706014	CHAPMAN, KELLY	4/14/10	ND	ND	4.96	0.04	3.28	1.70	0.09		ND	ND	100%	65%	34%	2%
254740	EICHHORN, SCOTT * EAST WELL	4/16/10	3.85	3.67	2.05	0.06	4.32	4.53	1.02		40%	38%	22%	44%	46%	10%
227906	STEVENS, JERRY	4/16/10	4.72	3.27	1.45	0.06	6.31	2.70	0.39		50%	34%	16%	67%	29%	4%
254703	JOSHUA DONAIK	4/16/10	4.05	2.25	0.79	0.14	2.64	1.72	2.44		56%	31%	13%	39%	25%	36%
62471	BAUM ED	8/10/10	3.60	5.54	3.36	0.05	8.50	3.82	0.52		29%	44%	27%	66%	30%	4%
232194	SMITH JAMES E. & DIANNA M.	8/11/10	1.89	2.84	1.10	0.05	4.23	1.31	0.40		32%	48%	20%	71%	22%	7%
62369	ELLIOT JIM	8/9/10	2.81	1.49	0.75	0.03	3.36	1.25	0.25		55%	29%	15%	69%	26%	5%
254740	EICHHORN, SCOTT * EAST WELL	8/9/10	3.84	3.75	1.91	0.06	4.15	4.54	1.00		40%	39%	21%	43%	47%	10%
135317	NEAL CHUCK	8/11/10	2.55	5.16	1.26	0.04	5.74	2.47	0.86		28%	57%	14%	63%	27%	9%
65541	LINDGREN ROBERT	8/11/10	1.82	2.85	0.26	0.03	3.67	0.93	0.21		37%	57%	6%	76%	19%	4%
254703	JOSHUA DONAIK	8/10/10	4.14	2.31	0.74	0.14	2.50	1.66	2.43		56%	32%	12%	38%	25%	37%
706001	CLARK, DONALD	8/9/10	3.83	1.86	0.75	0.02	3.74	1.36	0.35		59%	29%	12%	69%	25%	6%
62523	WALKER, GILES E.	8/10/10	3.46	1.61	0.45	0.06	4.68	0.82	0.15		62%	29%	9%	83%	15%	3%
65536	SELVA ADOLFO	8/10/10	3.75	2.28	0.78	0.17	4.19	1.34	0.88		54%	33%	14%	65%	21%	14%
65615	SHIELDS, RONALD	8/9/10	4.88	1.96	0.64	0.02	4.34	1.03	2.13		65%	26%	9%	58%	14%	28%
706039	WARFORD, CAROL	8/11/10	2.58	4.52	0.62	0.04	4.87	2.47	0.57		33%	58%	9%	62%	31%	7%
706058	FOWLER, SANDRA	8/9/10	2.99	1.74	1.33	0.03	4.88	0.86	0.19		49%	29%	22%	82%	15%	3%
65618	NORRIS, JOSEPH * SOUTH WELL	8/10/10	3.63	1.04	0.49	0.02	4.07	0.66	0.37		70%	20%	10%	80%	13%	7%
147289	WALL JOHN	8/10/10	2.00	1.47	0.81	0.03	3.23	0.83	0.31		46%	34%	20%	74%	19%	7%
123839	WINDLE COLE & JUDY	8/11/10	2.99	3.40	1.59	0.16	5.94	1.77	0.49		37%	42%	21%	72%	22%	6%
706014	CHAPMAN, KELLY	8/10/10	2.94	1.53	0.49	0.06	3.31	1.71	0.09		59%	30%	11%	65%	33%	2%

Table WQ-4. Scratchgravel Hills Groundwater Quality Samples - Major Ions as Milliequivalents (cont.)

GWIC ID	Site Name	Sample Date	Milliequivalents							Constituent Percent					
			Ca	Mg	Na	K	HCO_3	SO_4	Cl	Ca	Mg	Na + K	HCO_3	SO_4	Cl
706055	MAULORICO AL	8/12/10	3.88	1.54	0.74	0.02	4.54	0.92	0.60	63%	25%	12%	75%	15%	10%
65088	HELM, SCOTT	8/12/10	3.70	1.51	0.81	0.08	4.40	1.32	0.44	61%	25%	15%	71%	21%	7%
61368	BROWNE, SUSAN AND TERRY	8/11/10	2.27	0.95	0.86	0.07	2.76	0.89	0.39	55%	23%	23%	68%	22%	10%
65316	SMELKO, DANIEL B.	8/12/10	5.34	3.51	1.45	0.13	7.02	3.34	0.56	51%	34%	15%	64%	31%	5%
227906	STEVENS, JERRY	8/12/10	4.60	3.24	1.29	0.05	5.73	2.61	0.38	50%	35%	15%	66%	30%	4%
191555	LCWQPD - APPLEGATE AND NORRIS	8/19/10	3.37	2.87	2.05	0.04	5.76	1.61	0.80	40%	34%	25%	71%	20%	10%
257063	MBMG APPLEGATE & NORRIS	8/19/10	2.81	2.25	1.77	0.06	5.00	1.35	0.44	41%	33%	27%	74%	20%	6%
123839	WINDLE COLE & JUDY	10/5/10	3.14	3.59	1.76	0.16	5.99	1.77	0.51	36%	41%	22%	72%	21%	6%
706001	CLARK, DONALD	10/4/10	3.72	1.80	0.79	0.02	3.95	1.28	0.33	59%	28%	13%	71%	23%	6%
232194	SMITH JAMES E. & DIANNA M.	10/4/10	2.07	3.06	1.24	0.05	4.26	1.43	0.40	32%	48%	20%	70%	23%	7%
254740	EICHHORN, SCOTT * EAST WELL	10/4/10	4.04	4.04	2.15	0.06	4.52	4.43	0.98	39%	39%	21%	46%	45%	10%
706039	WARFORD, CAROL	10/5/10	2.66	4.64	0.67	0.04	4.87	2.47	0.57	33%	58%	9%	62%	31%	7%
65541	LINDGREN ROBERT	10/5/10	1.99	3.05	0.28	0.03	3.93	0.93	0.20	37%	57%	6%	78%	18%	4%
706055	MAULORICO AL	10/5/10	3.89	1.56	0.80	0.02	4.72	0.89	0.50	62%	25%	13%	77%	14%	8%
706014	CHAPMAN, KELLY	10/4/10	3.02	1.57	0.51	0.06	3.30	1.75	0.08	58%	30%	11%	64%	34%	2%
65618	NORRIS, JOSEPH * SOUTH WELL	10/5/10	3.69	1.06	0.51	0.02	4.17	0.66	0.31	70%	20%	10%	81%	13%	6%
62471	BAUM ED	10/6/10	4.17	6.02	3.54	0.05	9.28	3.96	0.53	30%	44%	26%	67%	29%	4%
65615	SHIELDS, RONALD	10/5/10	5.19	2.11	0.67	0.02	4.50	1.04	2.41	65%	26%	9%	57%	13%	30%
258347	ZOOK DARRELL & CARINA	10/5/10	3.88	1.72	0.72	0.03	3.84	1.36	0.46	61%	27%	12%	68%	24%	8%
62523	WALKER, GILES E.	10/6/10	3.49	1.65	0.48	0.06	4.82	0.81	0.15	62%	29%	9%	83%	14%	3%
65536	SELVA ADOLFO	10/6/10	3.95	2.36	0.82	0.16	4.25	1.45	0.89	54%	32%	13%	64%	22%	13%
706058	FOWLER, SANDRA	10/6/10	2.99	1.75	1.37	0.03	5.11	0.84	0.19	49%	29%	23%	83%	14%	3%
147289	WALL JOHN	10/6/10	2.01	1.53	0.83	0.03	3.26	0.83	0.31	46%	35%	20%	74%	19%	7%
65088	HELM, SCOTT	10/6/10	3.71	1.52	0.87	0.08	4.31	1.28	0.43	60%	25%	15%	72%	21%	7%
135317	NEAL CHUCK	10/7/10	2.73	5.37	1.35	0.04	5.90	2.39	0.84	29%	57%	15%	65%	26%	9%
62369	ELLIOT JIM	10/7/10	2.96	1.50	0.81	0.03	3.46	1.20	0.21	56%	28%	16%	71%	25%	4%
227906	STEVENS, JERRY	10/7/10	4.78	3.37	1.47	0.05	6.66	2.61	0.39	49%	35%	16%	69%	27%	4%
65316	SMELKO, DANIEL B.	10/7/10	5.49	3.72	1.71	0.13	7.29	3.24	0.53	50%	34%	17%	66%	29%	5%
61368	BROWNE, SUSAN AND TERRY	10/7/10	2.34	0.97	0.91	0.07	2.94	0.86	0.41	54%	23%	23%	70%	20%	10%
254703	JOSHUA DONAIK	10/6/10	4.60	2.23	0.73	0.12	2.43	1.83	2.74	60%	29%	11%	35%	26%	39%
257063	MBMG APPLEGATE & NORRIS	10/20/10	2.72	2.30	1.68	0.06	4.79	1.34	0.43	40%	34%	26%	73%	20%	7%
191555	LCWQPD - APPLEGATE AND NORRIS	10/20/10	3.27	2.81	1.87	0.04	5.68	1.36	0.67	41%	35%	24%	74%	18%	9%
191555	LCWQPD - APPLEGATE AND NORRIS	10/20/10	3.27	2.81	1.87	0.04	5.68	1.36	0.67	41%	35%	24%	74%	18%	9%
65615	SHIELDS, RONALD	4/27/11	5.19	2.17	0.72	0.02	4.14	1.05	2.70	64%	27%	9%	52%	13%	34%
65088	HELM, SCOTT	4/27/11	3.54	1.55	0.87	0.08	4.18	1.33	0.45	59%	26%	16%	70%	22%	8%
62523	WALKER, GILES E.	4/28/11	3.37	1.64	0.50	0.06	4.54	0.83	0.15	61%	29%	10%	82%	15%	3%
62369	ELLIOT JIM	4/27/11	2.84	1.53	0.82	0.02	3.30	1.24	0.24	54%	29%	16%	69%	26%	5%