Nevada Division of Water Resources

HYDROGRAPHIC AREA SUMMARY

Hydrographic Area No. **180** *Hydrographic Area Name* **CAVE VALLEY**

Subarea Name

Hydrographic Region No. **10** *Hydrographic Region Name* **CENTRAL**

Area (sq. mi.) **362**

Counties within the hydrographic area **Lincoln, White Pine**

Nearest Communites to Hydrographic Area **Sunnyside, Preston**

Designated (Y/N, Order No.) **N** *For All or Portion of Basin*

Preferred Use **None** *For All or Portion of Basin*

State Engineer's Orders: **(Click search icons to find all designation orders or rulings for this basin)** *For All or Portion of Basin*

State Engineer's Rulings

Pumpage Inventory Status **None** *Crop Inventory Status* **None**

Water Level Measurement? **None**

Yield Values

Perennial Yield (AFY) **2000**

System Yield (AFY)

Yield Reference(s) **USGS Recon. 13**

Yield Remarks

Source of Committed Data: **NDWR Database** *Supplementally Adjusted?* **Y**

Manner Of Use	*Underground*	*Geothermal*
Commercial	0.00	0.00
Construction	0.00	0.00
Domestic	0.00	0.00
Environmental	0.00	0.00
Industrial	0.00	0.00
Irrigation (Carey Act)	0.00	0.00
Irrigation (DLE)	0.00	0.00
Irrigation	0.00	0.00
Mining and Milling	0.00	0.00
Municipal	0.00	0.00
Power	0.00	0.00
Quasi-Municipal	0.00	0.00
Recreation	0.00	0.00
Stockwater	46.58	0.00
Storage	0.00	0.00
Wildlife	0.00	0.00
Other	0.00	0.00
Totals	46.58	0.00

Related Reports

USGS Reconnaissance 13 *USGS Bulletin* 33

Other References

Comments

Nevada Division of Water Resources

Hydrographic Abstract

Number of Records: 103

Selection Criteria: basin IN ('180')

22 October 2006

Basin	Application	Change of Application	Cert	File date	App status	Source	QQ	Q	SEC	TWN	RNG	Diversion rate	Use	Irrigated Acres	Duty balance	Duty unit	CO	Owner name
180	742			12-03-07	CAN	SPR	NE	NW	16	09N	64E	14.000	PWR	0.00	0.00		LI	ROBERTSON, EDWARD L.
	1137			10-02-08	CAN	SPR	NE	SE	30	11N	63E	0.000	MM	0.00	0.00		WP	HENDRIX, E.A.
	1379			06-09-09	CAN	OSW		SW	31	10N	64E	0.000	IRR		0.00		WP	BARNES, BENN,CARTWRIGHT, A. J.,CARTWRIGHT, AGNUS M.,KEAT, E. C.,KINNEY, J. W.,OLDFIELD, T.D.
	3139		1661	10-21-14	CER	SPR	NW	SW	29	11N	63E	0.003	STK	0.00	0.42	MGS	WP	CARTER, ALICE
	3142		2334	10-23-14	CER	SPR	SW	NW	21	11N	63E	0.004	STK	0.00	0.54	MGS	WP	REID, ROBERT
	4470			06-15-17	DEN	SPR	SE	NW	16	09N	64E	1.600	IRR	160.00	0.00		LI	OLSEN, CASTEN
	4599		643	09-24-17	CER	STR	SE	SE	11	09N	63E	0.120	IRR	12.00	36.00	AFS	LI	ADAMS, MYRON
	4881		1060	01-31-18	CER	SPR	SW	NE	16	09N	64E	0.751	IRR	75.19	225.57	AFS	LI	MULL REVEOCABLE TRUST 1/13/99
	5071		540	05-13-18	CER	SPR	SW	SE	25	08N	64E	0.015	STK	0.00	2.45	MGS	LI	MULL REVOCABLE TRUST, 1/13/99
	5073		542	05-13-18	CER	SPR	NE	NE	25	08N	64E	0.015	STK	0.00	2.38	MGS	LI	MULL REVOCABLE TRUST, 1/13/99
	5747		707	09-19-19	CER	SPR	SW	SE	30	11N	63E	0.004	STK	0.00	0.49	MGS	WP	REED, G. M.
	5755			09-22-19	CAN	SPR	SE	SE	12	09N	62E	0.012	STK	0.00	0.96	MGS	LI	GREGORIO URRUTIA CO.
	5756			09-22-19	CAN	SPR	SE	NE	32	10N	63E	0.012	STK	0.00	0.00		WP	GREGORIO URRUTIA COMPANY
	5757			09-22-19	DEN	SPR	SW	NW	23	10N	64E	0.025	STK	0.00	0.00		WP	GREGORIO URRUTIA CO.
	5787			10-02-19	DEN	SPR	NW	SE	22	10N	64E	0.500	STK	0.00	0.98	MGS	WP	GREGORIO URRUTIA CO.
	5788			10-02-19	CAN	SPR	SW	NW	11	09N	64E	0.012	STK	0.00	0.96	MGS	LI	GREGORIO URRUTIA COMPANY
	5873			11-26-19	DEN	SPR	SW	SE	25	08N	64E	0.006	STK	0.00	0.00		LI	GREGORIO URRULIA COMPANY
	5874			11-26-19	CAN	SPR	NE	NW	13	09N	64E	0.006	STK	0.00	0.24	MGS	LI	GREGORIO URRUTIA COMPANY
	6598			12-05-21	CAN	UG				06N	63E	0.000	STK	0.00	0.00		LI	WHIPPLE, J.L.
	6[illegible]			01-20-22	WDR	SPR	SE	NW	16	09N	[illegible]	0.800	IRR	80.00	0.00		LI	STEPHENS, CA[illegible]

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22 October 2006

Basin	Application	Change of Application	Cert	File date	App status	Source	QQ	Q	SEC	TWN	RNG	Diversion rate	Use	Irrigated Acres	Duty balance	Duty unit	CO	Owner name
	6638		2105	02-27-22	CER	UG	NE	SE	21	05N	63E	0.003	STK	0.00	0.70	MGA	LI	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	7397		1175	06-14-25	CER	UG	SW	SE	31	06N	63E	0.015	STK	0.00	0.61	MGS	LI	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	7485		1876	08-20-25	CER	UG	SW	SE	36	09N	64E	0.012	STK	0.00	2.92	MGA	LI	KIRKEBY, GORDON A.,KIRKEBY, KAYE A.,KIRKEBY, MARY
	9001		4209	07-26-29	CER	SPR	SW	NE	16	09N	64E	0.044	DOM	0.00	0.00		LI	GREAT WESTERN MINING &DEVELOPMENT CO
	9002			07-26-29	DEN	SPR	NE	SE	04	09N	63E	0.000	PWR	0.00	0.00		LI	GREAT WESTERN MINING & DEVELOPMENT
	9003			07-26-29	DEN	SPR	NE	SE	04	09N	63E	0.000	MM	0.00	0.00		LI	GREAT WESTERN MINING & DEVELOPMENT
	9702		2135	10-09-33	CER	SPR	SE	NE	19	06N	63E	0.010	STK	0.00	2.36	MGA	LI	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	9720		2269	02-08-34	CER	SPR	NW	NE	14	09N	64E	0.025	STK	0.00	5.84	MGA	LI	CAVE VALLEY RANCHES
	9721		2270	02-08-34	CER	SPR	SW	SW	02	09N	64E	0.025	STK	0.00	5.84	MGA	LI	CAVE VALLEY RANCHES
	13102		4059	10-13-49	CER	SPR	NE	SE	33	11N	64E	0.019	STK	0.00	1.82	MGS	WP	CAVE VALLEY RANCHES
	19299			10-26-60	CAN	OSW	SW	NE	09	08N	64E	0.000	IRR	360.00	0.00		LI	BLM
	22692			07-15-65	CAN	SPR	SE	NW	06	09N	64E	0.000	IRR	360.00	0.00		LI	CAVE VALLEY RANCHES INC.
	22693			07-15-65	CAN	SPR	NW	SW	04	09N	64E	0.000	IRR	440.00	0.00		LI	CAVE VALLEY RANCHES INC.
	22694			07-15-65	CAN	SPR	SW	NE	16	09N	64E	0.000	IRR	400.00	0.00		LI	CAVE VALLEY RANCHES INC.
	22695			07-15-65	CAN	SPR	NW	NW	09	09N	64E	0.000	IRR	240.00	0.00		LI	CAVE VALLEY RANCHES INC.
	23093			04-11-66	CAN	UG	SE	SE	19	07N	64E	0.000	IND	0.00	0.00		LI	GULF OIL CORPORATION
	25322		8358	10-15-69	CER	STR	SE	SW	03	09N	63E	0.890	IRR	60.00	240.00	AFA	LI	LEWIS, LOU JEANNE,LEWIS, MELANIE,LEWIS, PAUL C.,LEWIS, RICHARD C.,LEWIS, ROBERT
	25411		8359	01-05-70	CER	SPR	SW	NW	11	09N	63E	0.564	IRR	19.80	79.20	AFA	LI	LEWIS, LOU JEANNE,LEWIS, MELANIE,LEWIS, PAUL C.,LEWIS, RICHARD C.,LEWIS, ROBEPT
	25.			01-05-70	CAN	SPR	SW	NE	04	09N	[illegible]	1.000	IRR	80.00	320.00	AFA	LI	MURRY WHIPPL [illegible]ANCH

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22 October 2006

Basin	Application	Change of Application	Cert	File date	App status	Source	QQ	Q	SEC	TWN	RNG	Diversion rate	Use	Irrigated Acres	Duty balance	Duty unit	CO	Owner name
	27814		9654	10-05-73	CER	SPR	SW	NW	11	09N	63E	0.670	IRR	31.50	126.00	AFA	LI	LEWIS, JEANNE LOU,LEWIS, MELANIE,LEWIS, PAUL C.,LEWIS, RICHARD C.,LEWIS, ROBERT
	41696			07-14-80	WDR	UG	NW	SE	33	07N	63E	0.000	QM	0.00	0.00		LI	MX
	41697			07-14-80	WDR	UG	SW	NW	08	06N	64E	0.000	QM	0.00	0.00		LI	MX
	41698			07-14-80	WDR	UG	SW	SW	21	06N	63E	0.000	QM	0.00	0.00		LI	MX
	41699			07-14-80	WDR	UG	NE	NW	09	08N	64E	1.000	QM	0.00	0.00		LI	MX
	41700			07-14-80	WDR	UG	SW	NW	03	07N	64E	0.000	QM	0.00	0.00		LI	MX
	41701			07-14-80	WDR	UG	NE	NW	14	07N	63E	0.000	QM	0.00	0.00		LI	MX
	53987			10-17-89	RFP	UG	SW	NW	22	06N	63E	6.000	MUN	0.00		AFA	LI	SOUTHERN NEVADA WATER AUTHORITY
	53988			10-17-89	RFP	UG	SE	SE	21	07N	63E	10.000	MUN	0.00		AFA	LI	SOUTHERN NEVADA WATER AUTHORITY
	64670			12-11-98	RFP	UG	SE	NE	08	05N	63E	10.000	IRR			AFA	LI	LINCOLN COUNTY WATER DISTRICT,VIDLER WATER COMPANY, INC.
	64671			12-11-98	RFP	UG	NE	SE	09	08N	64E	10.000	IRR			AFA	LI	LINCOLN COUNTY WATER DISTRICT,VIDLER WATER COMPANY, INC.
	66123		16617	03-08-00	CER	UG	NW	SE	15	07N	63E	0.016	STK	0.00	3.65	MGA	LI	JENSEN, BRUCE A. & PAMELA G.
	66125		16619	03-08-00	CER	UG	SE	SW	30	08N	64E	0.016	STK	0.00	3.65	MGA	LI	JENSEN, BRUCE A. & PAMELA G.
	66129			03-08-00	PER	SPR	SE	SW	33	07N	64E	0.150	IRR	20.00	80.00	AFA	LI	JENSEN, BRUCE A. & PAMELA G.
	68487			02-11-02	RFP	UG	NE	NE	14	07N	63E	3.500	IRR	0.00		AFA	LI	JENSEN, PAMELA G.
	68488			02-11-02	RFP	UG	NE	NE	14	07N	63E	3.500	IRR	0.00		AFA	LI	JENSEN, BRUCE A.
	73168			08-19-05	PER	UG	SW	NW	27	09N	64E	0.050	STK	0.00	11.20	AFA	LI	MULL REVOCABLE TRUST 1/15/1999
	73169			08-19-05	PER	UG	SW	NW	15	08N	64E	0.050	STK	0.00	11.20	AFA	LI	MULL REVOCABLE TRUST 1/15/1999
	73170			08-19-05	PER	UG	NW	NE	25	10N	63E	0.050	STK	0.00	11.20	AFA	WP	MULL REVOCABLE TRUST 1/15/1999
	73815			02-09-06	RFA	UG	NE	SE	04	09N	63E	4.000	IRR	0.00	0.00	AFA	LI	LEWIS, PAUL
	73816			02-09-06	RFA	UG	SE	SW	03	09N	63E	4.000	IRR	0.00	0.00	AFA	LI	LEWIS, PAUL
	73			02-09-06	RFA	UG	SE	NE	10	09N	[illegible]	4.000	IRR	0.00	0.00	AFA	LI	LEWIS, PAUL

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22 October 2006

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	R09414			04-06-04	RES	SPR	SE	NE	19	06N	63E	0.002	STK	0.00	0.00	AFA	LI	BLM
	R09416			04-06-04	RES	SPR	SW	SE	31	06N	63E	0.002	STK	0.00	0.00	AFA	LI	BLM
	R09417			04-06-04	RES	SPR	NE	SW	30	06N	63E	0.002	STK	0.00	0.00	AFA	LI	BLM
	V01416			08-30-15	VST	SPR	NE	SE	30	11N	63E	0.100	STK	0.00	0.00	*	WP	ADAMS MCGILL COMPANY
	V01486			12-08-16	VST	SPR	NE	SE	20	11N	63E	0.250	STK	0.00	0.00	*	WP	ADAMS MCGILL COMPANY
	V01559			04-08-18	VST	SPR	NW	SW	10	10N	64E	0.500	STK	0.00	0.00		WP	CAVE VALLEY RANCHES
	V01658			12-06-19	VST	SPR	SW	NW	23	10N	64E	0.300	STK	0.00	2.43	MGS	WP	CAVE VALLEY RANCHES
	V01659			12-06-19	VST	SPR	SE	SE	22	10N	64E	0.300	STK	0.00	2.43	MGS	WP	MULL REVOCABLE TRUST, 1/13/1999
	V01660			12-06-19	VST	SPR	NW	SE	22	10N	64E	0.300	STK	0.00	2.43	MGS	WP	CAVE VALLEY RANCHES
	V01675			12-26-19	VST	SPR	SE	SW	27	10N	64E	0.025	STK	0.00	2.43	MGS	WP	MULL REVOCABLE TRUST, 1/13/1999
	V01678			12-29-19	VST	STR	NE	SE	34	10N	64E	1.000	STK	0.00	0.00		WP	MULL REVOCABLE TRUST, 1/13/1999
	V01679			12-29-19	VST	STR	NW	NW	02	09N	64E	1.000	STK	0.00	0.00		LI	CAVE VALLEY RANCHES INC.
	V01680			01-08-20	VST	STR	NW	NE	04	09N	64E	1.000	STK	0.00	0.00		LI	MULL REVOCABLE TRUST, 1/13/1999
	V01681			01-08-20	VST	STR	NE	NW	26	10N	64E	1.000	STK	0.00	0.00		WP	MULL REVOCABLE TRUST, 1/13/1999
	V01696			05-03-20	VST	SPR	SW	SW	02	09N	64E	0.025	STK	0.00	0.00		LI	GEYSER LAND & CATTLE CO.
	V01697			05-03-20	VST	SPR	NW	SE	11	09N	64E	0.025	STK	0.00	0.00		LI	MULL REVOCABLE TRUST, 1/13/1999
	V01698			05-03-20	VST	SPR	NW	NE	14	09N	64E	0.025	STK	0.00	0.00		LI	GEYSER LAND & CATTLE CO.
	V01699			05-03-20	VST	SPR	NE	SW	14	09N	64E	0.025	STK	0.00	0.00		LI	CAVE VALLEY RANCHES INC.
	V01807			08-18-21	VST	STR	NW	SW	31	10N	64E	0.004	IRR	117.27	0.00		WP	MULL REVOCABLE TRUST, 1/13/1999
	V01878			04-18-25	VST	STR	SW	SE	15	11N	63E	0.250	STK	0.00	0.00		WP	ADAMS MCGILL COMPANY
	V01881			04-18-25	VST	SPR	SE	SE	03	11N	63E	0.250	STK	0.00	0.00		WP	ADAMS MCGILL COMPANY
	V01882			04-18-25	VST	SPR	NE	NW	10	11N	63E	0.250	STK	0.00	0.00		WP	ADAMS MCGILL COMPANY
	V01883			04-18-25	VST	SPR	SE	SW	10	11N	63E	0.050	STK	0.00	0.00		WP	ADAMS MCGILL COMPANY
	V01964			01-11-26	VST	SPR	SE	NE	19	06N	63E	0.004	STK	0.00	0.00	*	LI	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	V0[illegible]			01-11-26	VST	SPR	NE	SW	30	06N	[illegible]	0.002	STK	0.00	0.00	*	LI	JENSEN, BRUC[illegible]

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												0.002						JENSEN, PAMELA G.
	V02075			03-21-27	VST	SPR	NW	SE	09	10N	63E	0.250	STK	0.00	2.19	MGS	WP	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	V02079			04-08-27	VST	SPR	SW	SE	17	10N	63E	0.250	STK	0.00	2.19	MGS	WP	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	V02692			11-25-70	VST	SPR	SW	NE	04	09N	63E	0.414	IRR	60.00	0.00		LI	LEWIS, LOU JEANNE,LEWIS, MELANIE,LEWIS, PAUL C.,LEWIS, RICHARD C.,LEWIS, ROBERT
	V02693			11-25-70	VST	SPR	SE	SW	03	09N	63E	0.414	IRR	60.00	0.00		LI	LEWIS, LOU JEANNE,LEWIS, MELANIE,LEWIS, PAUL C.,LEWIS, RICHARD C.,LEWIS, ROBERT
	V02694			11-25-70	VST	SPR	SW	NW	11	09N	63E	0.120	IRR	19.80	0.00		LI	LEWIS, LOU JEANNE,LEWIS, MELANIE,LEWIS, PAUL C.,LEWIS, RICHARD C.,LEWIS, ROBERT
	V09231			03-08-00	VST	SPR	NE	SE	06	09N	63E	0.013	STK	0.00	0.00		LI	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	V09232			03-08-00	VST	SPR	NW	SE	12	09N	62E	0.013	STK	0.00	0.00		LI	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	V09233			03-08-00	VST	SPR	SW	SE	32	10N	63E	0.013	STK	0.00	1.10	MGS	WP	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	V09234			03-08-00	VST	SPR	NE	NE	32	09N	63E	0.100	STK	0.00	0.00		LI	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	V09235			03-08-00	VST	SPR	SE	SW	33	07N	64E	0.050	STK	0.00	0.00		LI	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	V09236			03-08-00	VST	SPR	SE	NW	13	09N	62E	0.025	STK	0.00	0.00		LI	JENSEN, BRUCE A.,JENSEN, PAMELA G.
	V09522			08-19-05	VST	SPR	SW	SE	02	09N	64E	0.025	STK	0.00	0.00	AFA	LI	MULL REVOCABLE TRUST DATED 1/15/1999
	V09523			08-19-05	VST	STR	NW	NW	02	09N	64E	1.000	STK	0.00	0.00	AFA	LI	MULL REVOCABLE TRUST DATED 1/15/1999
	V09524			08-19-05	VST	SPR	NW	NW	23	10N	64E	0.333	STK	0.00	0.00	AFA	LI	MULL REVOCABLE TRUST DATED 1/15/1999
	V0[illegible]			08-19-05	VST	SPR	NW	SE	22	10N	[illegible]E	0.333	STK	0.00	0.00	AFA	LI	MULL REVOCAB[illegible] TRUST

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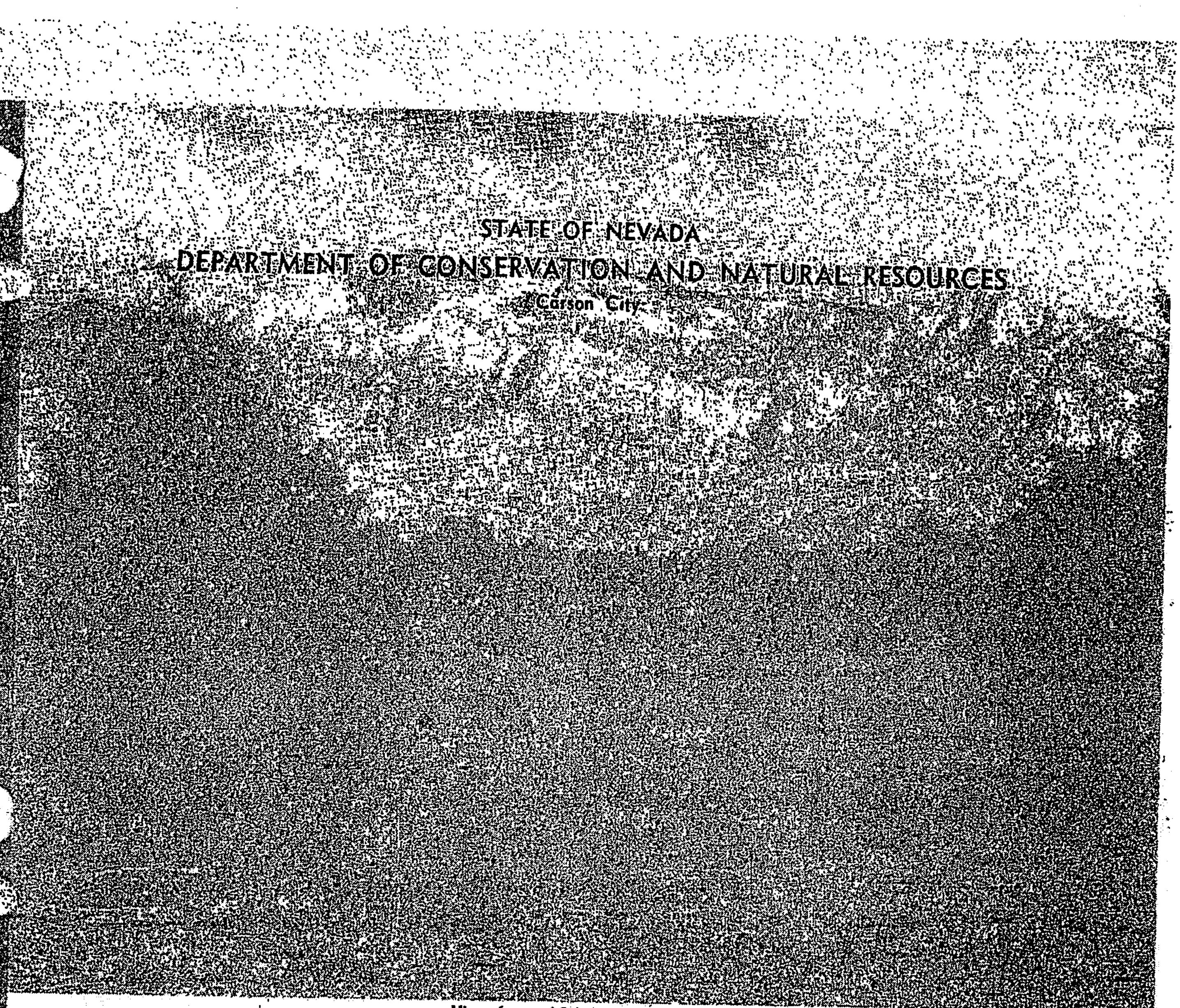
												0.333						DATED 1/15/1999
	V09526			08-19-05	VST	SPR	SW	SE	11	09N	64E	0.025	STK	0.00	0.00	AFA	LI	MULL REVOCABLE TRUST DATED 1/15/1999
	V09527			08-19-05	VST	SPR	SE	NW	13	09N	64E	0.025	STK	0.00	0.00	AFA	LI	MULL REVOCABLE TRUST DATED 1/15/1999

STATE OF NEVADA
DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
Carson City



View of part of Schell Creek Range

GROUND-WATER RESOURCES – RECONNAISSANCE SERIES
REPORT 13

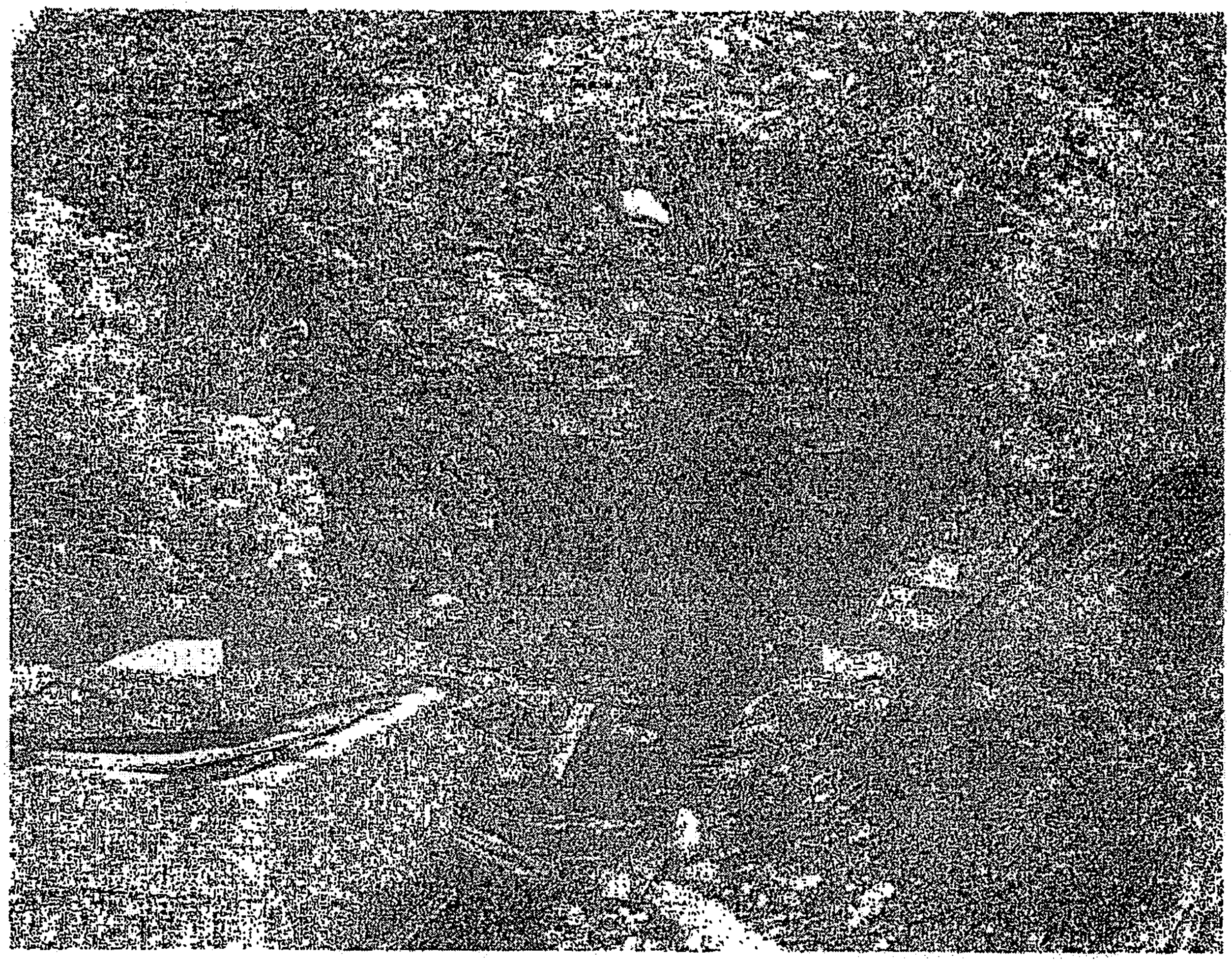
GROUND–WATER APPRAISAL OF CAVE VALLEY IN LINCOLN AND WHITE PINE COUNTIES, NEVADA

By
THOMAS E. EAKIN
Geologist

Price $1.00

Prepared cooperatively by the
Geological Survey, U. S. Department of Interior

DECEMBER 1962



SPRING NEAR GARDNER RANCH

View southeast of spring SW¼NE¼, sec. 16, T. 9 N., R. 64 E., about ¼ mile east of Gardner Ranch. Spring discharge estimated to be less than 10 gallons per minute, October 1962. Spring has been "developed" by cleaning out natural opening in Paleozoic (Cambrian) limestone, which crops out in an isolated hill north and east of Gardner Ranch.

COVER PHOTOGRAPH

View northeast of Schell Creek Range north of Patterson Pass. Bold cliffs are composed largely of Paleozoic (Cambrian) carbonate rocks. Thick and extensive Paleozoic carbonate rocks afford favorable conditions for ground-water recharge where they are exposed in the mountains. Ground water moves through fractures and solution openings. Paleozoic carbonate rocks supply many of the larger springs in eastern Nevada, and also provide a means for ground water to move from one valley to another where hydraulic gradients are favorable.

GROUND-WATER RESOURCES - RECONNAISSANCE SERIES

Report 8

GROUND-WATER APPRAISAL OF INDEPENDENCE VALLEY, WESTERN ELKO COUNTY, NEVADA

by

Thomas E. Eakin,
Geologist

Prepared Cooperatively
by the

Geological Survey
U. S. Department of the Interior

May
1962

GROUND-WATER RESOURCES - RECONNAISSANCE SERIES

Report 13

GROUND-WATER APPRAISAL OF CAVE VALLEY IN LINCOLN AND WHITE PINE COUNTIES, NEVADA

by

Thomas E. Eakin

Prepared cooperatively by the

Geological Survey

U. S. Department of the Interior

1962

FOREWORD

This report, No. 13 in the reconnaissance ground-water series, covers Cave Valley in Lincoln and White Pine Counties, and considers the problem of inter-valley movement of ground water. Mr. Thomas E. Eakin, Geologist with the U. S. Geological Survey who made this study and report, suggests that information accumulated as a result of ground-water investigations in Nevada seemingly indicates that the Paleozoic carbonate rocks control the ground-water hydrology in many areas in eastern and southern Nevada.

Mr. Eakin points out that apparently one regional unit of this type is associated with the White River system which extends from north of the latitude of Ely to the vicinity of Muddy River Springs near Moapa, a distance of more than 200 miles. Available information suggests the interbasin movement of ground water through bedrock, largely Paleozoic carbonate rocks, may involve Long, Jakes, White River, Cave, Dry Lake, Delamar, Garden, Coal, Pahranagat, Kane Springs, and possibly Penoyer, and Desert Valleys in the White River regional system.

I feel that we should definitely start studies of the interbasin movement of ground water in the various regional systems. Such studies will take years to develop answers but may at some future time make possible the optimum use of all of our ground water resources.

Studies such as this one indicate the desirability and necessity of ground-water studies in all of the valleys in Nevada. We hope that during the next biennium we can increase this reconnaissance ground water report program.

Hugh A. Shamberger
Director
Department of Conservation
and Natural Resources

January, 1963.

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GROUND-WATER APPRAISAL OF CAVE VALLEY IN LINCOLN AND WHITE PINE COUNTIES, NEVADA

by

Thomas E. Eakin

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SUMMARY

The results of this reconnaissance indicate that the average annual ground-water recharge may be on the order of 14,000 acre-feet. This estimate cannot be checked directly against an estimate of ground-water discharge as apparently a substantial part of the average annual discharge leaves Cave Valley by subsurface underflow west, southwest or south principally through Paleozoic carbonate rocks. Ground water discharged by evapotranspiration from Cave Valley probably is not more than a few hundred acre-feet a year. Therefore by difference, discharge by subsurface underflow may closely approach the estimated average annual ground-water recharge.

The perennial yield could be substantially larger than the few hundred acre-feet a year estimated as discharged by evapotranspiration. This would be possible through partial interception of ground water that is contained in the valley fill. Interception probably could be accomplished best by development along the main channel of the valley and its tributaries northward from T. 8 N. The magnitude of the perennial yield cannot be estimated, as it would depend largely on the distribution of and amount pumped from wells, the permeability of the water-bearing zones, and the proportion of total recharge that passes through the valley fill in the vicinity of the well development.

Ground water in storage in Cave Valley is substantial and is estimated to be about 1,000,000 acre-feet in the upper 100-feet of saturated valley fill beneath a 100,000-acre area in the lower part of the valley.

The most favorable area for ground-water development appears to be along the main channel of the valley and its principal tributaries in T. 9 N. and the south half of T. 10 N., where the depth to water is relatively shallow. Elsewhere moderate yields might be obtained along the lower part of the alluvial apron northward from the playa. However, in most areas of the alluvial apron, the non-pumping depth to water commonly may be 300 or more feet.

INTRODUCTION

The development of ground water in Nevada has shown a substantial increase in recent years. Part of this increase is due to the effort to bring new land into cultivation. The increasing interest in ground-water development has created a substantial demand for information of ground-water resources throughout the State.

Recognizing this need, the State Legislature enacted special legislation (Chapt. 181, Stats. 1960) for beginning a series of reconnaissance studies of the ground-water resources of Nevada. As provided in the legislation, these studies are being made by the U. S. Geological Survey in cooperation with the Nevada Department of Conservation and Natural Resources.

Interest in ground-water resources currently includes many areas and is extending to additional areas almost continuously. Thus, the emphasis of the reconnaissance studies is to provide as quickly as possible a general appraisal of the ground-water resources in particular valleys or areas where information is urgently needed. For this reason each study is limited severely in time, field work for each area generally averaging about two weeks.

Additionally, the Department of Conservation and Natural Resources has established a special report series to expedite publication of the results of the reconnaissance studies. Figure 1 shows the areas for which reports have been published in this series. A list of the titles of previous reports published in the series is given at the end of this report. The present report is the thirteenth in the reconnaissance series. It describes the physical conditions of Cave Valley and includes observations of the interrelation of climate, geology, and hydrology as they affect ground-water resources. It includes also a preliminary estimate of the average annual recharge to and discharge from the ground-water reservoir.

The investigation was made under the general direction of G.F. Worts, Jr. District Chief, Water Resources Division, U.S. Geological Survey. Some of the well data were supplied by C. T. Snyder, Water Resources Division, and were obtained as part of the soil and moisture conservation program of the U.S. Geological Survey.

Location and General Features

Cave Valley, in eastern Nevada, lies within an area enclosed by lat 38°15' and 38°51' N. and long 114°43' and 114°58' W. The north end of the valley is about 30 miles south of Ely, Nevada. North-trending Cave Valley is about 41 miles long and has a maximum width, between drainage divides, of about 13 miles in the latitude of Mount Grafton (pl. 1). The valley as defined has an area of about 365 square miles.

Improved roads provide access to the north end of the valley from southern Steptoe Valley. Additionally, access to the valley may be attained

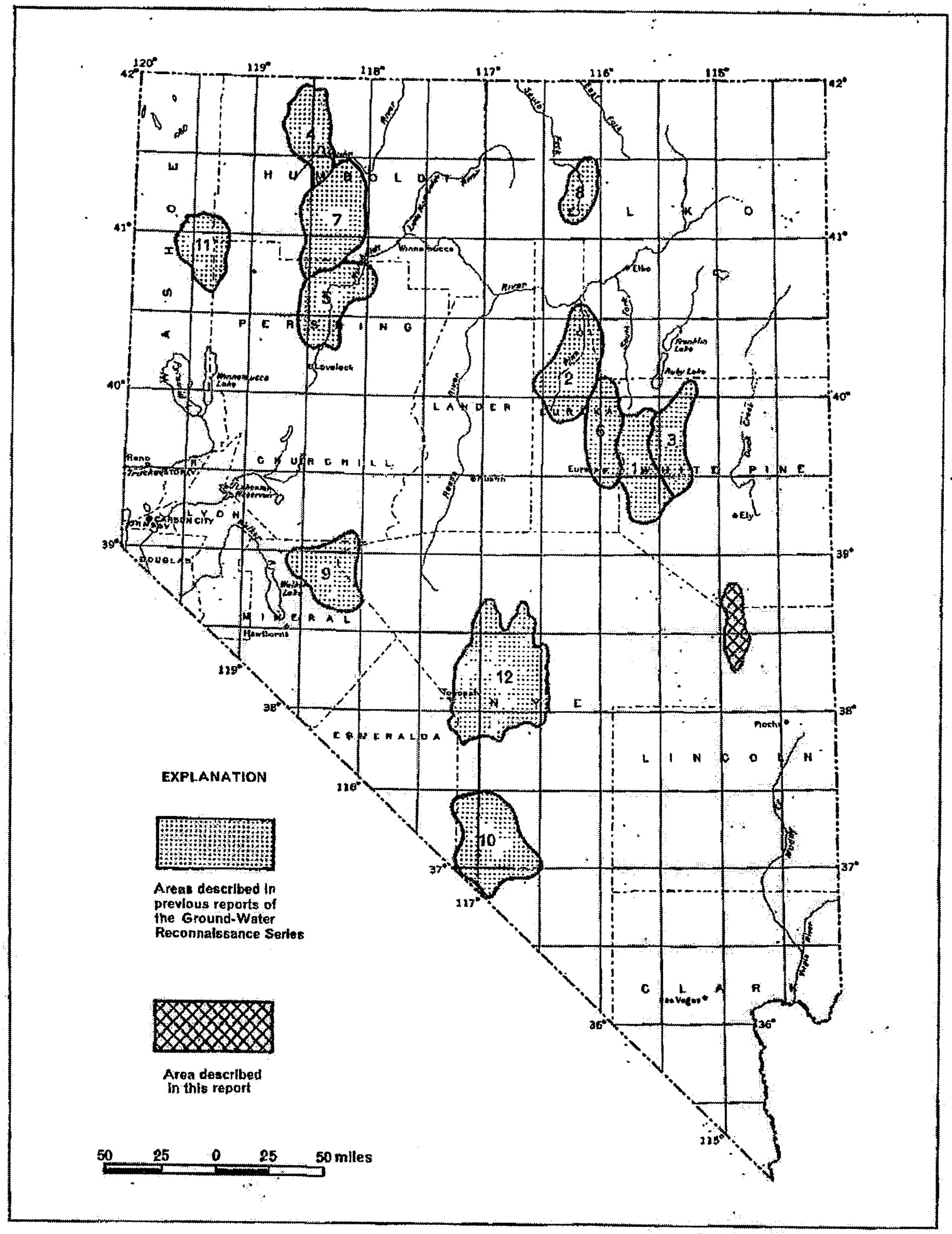

Figure 1. MAP OF NEVADA
showing areas described in previous reports of the ground water reconnaissance series and the area described in this report.

through Patterson Pass from the east and principally through Shingle Pass from the west. Unimproved trails permit general access to principal points in the valley during good weather.

Cave Valley is used for livestock range. Several ranches are in the northern part of the valley; however, they are occupied only for short periods during the year.

Climate

The climate of eastern Nevada is semi-arid in the valleys and sub-humid to humid in the higher mountains. In the valleys, precipitation and humidity are generally low and summer temperatures and evaporation rates are high. Precipitation is irregularly distributed but generally is least on the valley floor and greatest in the mountains. Winter precipitation occurs largely as snow distributed through several months. Summer precipitation commonly occurs as localized thundershowers. The daily and seasonal range in temperature is relatively large, and the growing season is relatively short.

Precipitation has not been recorded in Cave Valley. An approximate indication of precipitation in Cave Valley may be obtained from the U.S. Weather Bureau precipitation records for Ely airport and Kimberly, about 30 miles north of Cave Valley. (See table 1.)

Table 1.--Average monthly and annual precipitation at Ely airport and Kimberly for period of record

(from published records of the U.S. Weather Bureau)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Ely 1/	.64	.57	.92	.96	.88	.61	.57	.48	.59	.70	.59	.55	8.06
Kimberly 2/	1.55	1.49	1.55	1.32	1.07	.66	.90	.83	.68	.89	.84	1.51	13.30

1/ Altitude 6,257 feet. Location Sec. 35, T. 17 N., R. 63 E. Period of record, 23 years, 1939-1961 (continuing).

2/ Altitude 7,230 feet. Location Sec. 8, T. 16 N., R. 62 E. Period of record, 27 years, 1931-58.

The maximum recorded annual precipitation has been 13.52 and 19.95 at Ely and Kimberly, respectively. The minimum recorded annual precipitation has been 5.22 and 7.82 at Ely and Kimberly, respectively. It is inferred that the range and distribution of precipitation at Ely airport and Kimberly are broadly representative of precipitation in Cave Valley.

The average growing season in Cave Valley has not been determined, but a crude approximation may be obtained by reference to a nearby area. Houston (1950, p. 6) states that the average growing season at McGill, in Steptoe Valley, is about 119 days (May 26 to September 22). Killing-frost conditions vary with the type of crop. Weather Bureau records beginning in 1948 list freeze data rather than killing frosts. The dates are listed for the occurrence of the last spring minimum and the first fall minimum for the following temperature groups; 32°F or below, 28°F or below, 24°F or below, 20°F or below, and 16°F or below. From these data, the number of days between the last spring minimum and the first fall minimum occurrence for the respective temperature groups are given. Table 2 lists the number of days between the last spring minimum and the first fall minimum for the first three of these groups at Ely airport and McGill during the 10-year period ending 1961.

Table 2.--Number of days between the last spring minimum and the first fall minimum for Ely airport and McGill during the 10-year period 1952-61

(from published records of the U.S. Weather Bureau)

	32°F or below		28°F or below		24°F or below	
	Ely airport	McGill	Ely airport	McGill	Ely airport	McGill
1952	88	150	88	204	188	216
1953	70	117	90	--	128	191
1954	97	114	97	174	124	178
1955	7*	116	114	141	143	183
1956	86	137	130	164	153	194
1957	75	121	96	136	139	151
1958	91	120	112	151	172	180
1959	53	120	113	126	130	130
1960	63	90	63	93	96	143
1961	133	113	118	139	141	141

*The record shows frost on June 30 and July 7, but no frost during the succeeding 72 days to September 17th.

The topography of Cave Valley favors the flow of heavy cold air toward the lower parts of the valley during periods of little or no wind movement. Therefore, the length of the growing season, although relatively short because of the latitude and because of the rather high altitude of the valley floor, undoubtedly varies considerably from one locality to another depending upon the pattern of flow of cold air currents. This may be illustrated, in part, by a comparison of the records of temperature at the climatological stations at Ely and McGill. The station at McGill is on the alluvial apron along the east side of Steptoe Valley. It is 250 to 300 feet above the axis of the valley. The station at the Ely airport, although only about 80 feet lower than the McGill station, is near the topographic low of the valley in that latitude.

The 10-year average number of days between temperatures of 32°F or below, is 121 days at McGill and 72 days at Ely airport; 28°F. or below, 133 days at McGill and 100 days at Ely airport; and for 24°F. or below, about 176 days at McGill and 140 days at Ely airport. Thus, the average growing season at McGill apparently averages 36 to 49 days more than at Ely airport. Similar local variations may be expected in Cave Valley.

On the basis of altitude and topographic environment it would appear that the conditions controlling minimum temperature in the lower parts of Cave Valley are more nearly comparable with those at Ely airport than with those at McGill.

Physiography and Drainage

Cave Valley is a topographically closed valley in the central part of the Great Basin section of the Basin and Range physiographic province of Fenneman (1931, p. 328). It is a north-trending valley bounded on the west by the Egan Range and on the east by the Schell Creek and Ely Ranges. The Ely Range trends south-southwest from the Schell Creek Range and closes the south end of the valley by merging with the Egan Range in a low bedrock divide. The Egan and Ely Ranges terminate a few miles south of Cave Valley. A low alluvial divide separates the north end of Cave Valley from Steptoe Valley.

The lowest part of Cave Valley is at the playa, altitude 6,000 feet, near the south end of the valley. The highest point in the adjacent mountains is Mount Grafton, altitude 10,993 feet, in the Schell Creek Range. Accordingly, the maximum relief in the area is about 5,000 feet.

North of Patterson Pass for a distance of about 8 miles, the crest of the Schell Creek Range (cover photograph) is above an altitude of 9,000 feet. The crest of the Egan Range in this latitude generally is lower, although it has three peaks which reach an altitude of more than 9,000 feet. The altitude of the unnamed peak south of Shingle Pass is 9,861 feet.

The principal drainage in the valley lowlands is southward toward the playa. The main drainage channel contains streamflow only during the spring runoff or for short periods after high intensity storms. North of the playa the gradient along the main channel is about 50 feet per mile. The gradient increases northward and, in the latitude of Mount Grafton, is about 80 feet per mile. Between the mountains and lower parts of the valley gradients on the alluvial apron commonly range from 100 to 300 feet per mile. In the mountains erosion has produced steep sided canyons, and stream-channel gradients commonly are more than 300 feet per mile.

In late Pleistocene time a lake occupied the lower part of Cave Valley. Beaches, bars, and spits locally are prominent adjacent to the playa. Several shore lines were noted at an altitude of about 6,100 feet. An inspection of aerial photographs and topographic map indicates that the maximum altitude of the lake was not more than about 6,100 feet; therefore, it is unlikely that the lake overflowed into White River Valley to the south. The dissection of the main channel and its tributaries in the valley lowlands probably occurred at the time of the late Pleistocene lake when there was more runoff than under present climatic conditions.

GENERAL GEOLOGY

A reconnaissance geologic map of Lincoln County (Tschanz and Pampeyan, 1961), which includes most of Cave Valley, is available as a result of the cooperative program between the U.S. Geological Survey and the Nevada Bureau of Mines. Other geologic reports are available for areas adjacent to Cave Valley. Most of these stem from interest in oil and mineral exploration or development in eastern Nevada. Among those of particular pertinence to Cave Valley are reports by Kellog (1960) and Tschanz (1960). Additionally, several other papers published in the "Guidebook to the Geology of East-central Nevada" (1960) provide useful information.

The rocks of Cave Valley have been divided into two general groups, bedrock in the mountains and valley fill in the lowlands, and further into four major units. The distribution of the four units is shown on plate 1.

The bedrock includes Paleozoic carbonate and clastic rocks and Tertiary volcanic and sedimentary rocks. These crop out in the mountains and underlie the valley fill.

The valley fill includes deposits ranging in age from Tertiary to Quaternary and consists of younger unconsolidated clay, silt, sand, and gravel, which has been eroded from the surrounding mountains, and older partly consolidated pyroclastic deposits of welded tuffs, and sedimentary deposits. The subsurface lithology and water-bearing properties of the rocks are not known. However, it is inferred that the sediments of Quaternary age were deposited under subaerial and lacustrine environments. The rocks of Tertiary age underlying the Quaternary deposits are believed to be similar in character to the Tertiary rocks exposed in the mountains.

Bedrock in the Mountains

Paleozoic rocks in the Egan Range have a maximum thickness of more than 30,000 feet, according to Kellog (1960, p. 189). He indicates that Paleozoic rocks include about 5 percent quartz sandstone, about 15 percent shale, and about 80 percent carbonate rocks. Kellog (1960, pl. 2) indicates a maximum thickness of more than 9,000 feet of Tertiary rocks, of which about one-half comprise the Sheep Pass Formation of Winfrey (1958), of Eocene age. The Tertiary rocks include conglomerate, sandstone, siltstone, clay, and some fresh-water limestone. They also include volcanic tuffaceous deposits, welded tuff, and lava flows.

Most of the formations described by Kellog in the Egan Range also occur in the Schell Creek and Ely Ranges in the latitude of Cave Valley.

The Paleozoic and Tertiary rocks that crop out in the mountains have been deformed substantially by faulting. Because of differences in their hydrologic properties, the bedrock shown on plate 1 is divided into two units, those in which Paleozoic carbonate rocks predominate, and those in which clastic or volcanic rocks predominate.

Valley Fill

The valley fill shown on plate 1 is divided into two units: older unconsolidated to partly consolidated sedimentary deposits of late Tertiary and Quaternary age, and unconsolidated clay, silt, sand, and gravel of late Quaternary age. The valley fill, of which both the older and the younger units are exposed at land surface, was deposited partly under subaerial and partly under lacustrine conditions.

Water-Bearing Properties of the Rocks

The rocks of Paleozoic age generally have had their primary permeability substantially reduced, if not wholly eliminated, by consolidation or alteration. However, because they have been substantially fractured, some of these rocks locally may contain secondary openings through which water may be transmitted to some degree. Further, joints in carbonate rocks may be enlarged from solution by water moving through them.

Inspection of the Paleozoic rocks shows considerable fracturing and the cave and spring openings (see photograph on inside cover) near the Gardner Ranch attest to the development of solution conduits in the Paleozoic carbonate rocks. The occurrence and movement of ground water in carbonate rocks are further identified by the many springs issuing from or adjacent to those rocks in eastern Nevada. As many of these springs, such as Hot Creek and Lund in nearby White River valley, discharge relatively large quantities of water, it is further indicated that carbonate rocks locally may transmit substantial quantities of ground water.

The Tertiary volcanic rocks and older Tertiary sedimentary deposits exposed in the mountains are moderately consolidated. Although there may be some interstitial permeability probably much of the limited amount of water transmitted is through fractures. In general it is believed that the capability of the Tertiary rocks to transmit water is relatively low.

The unconsolidated sand and gravel deposits of Quaternary age are capable of transmitting ground water freely. However, the finer sand, silt, and clay have low permeability and transmit water slowly. These deposits occupy a large volume and have a relatively high porosity. Thus, where saturated, the Quaternary deposits contain a large volume of water in storage.

GROUND-WATER APPRAISAL

General Conditions

Most of the ground water in Cave Valley is derived from precipitation within the drainage area of the valley. Some of the precipitation on the upper parts of the alluvial apron percolates downward to the ground-water reservoir in the valley fill, but most of the recharge results from runoff in the mountains or percolation into the bedrock of the mountains and then lateral movement to the valley fill. Ground water in the valley fill moves from the areas of recharge in the northern part of the valley generally southward toward the playa.

In typical valleys in Nevada, most of the ground water is discharged naturally by evaporation and transpiration where the water table is at or near land surface. The principal means of natural ground-water discharge are transpiration by salt grass, native meadow grasses, rabbitbrush, greasewood, and other phreatophytes and evaporation from free-water surfaces and through the soil where the water table is shallow. Under ordinary conditions the area of principal evapotranspiration is in the topographically low part of the valley.

The water table is at shallow depth along the main channel and adjacent tributary channels from the middle of T. 9 N. into the northern part of T. 10 N. Here the depth to water may be nearly at land surface, as indicated by the 2-foot depth to water in well 9/63-1a1. The depth to water increases northward and is about 20 feet below land surface in well 10/63-25a1. At the playa, however, in the vicinity of T. 6 N., which is the lowest part of Cave Valley and where the principal area of natural discharge of ground water ordinarily would be found, the depth to water is substantial.

No wells were found in the immediate vicinity of the playa. However, the reported depth to water in well 7/63-15c1 and the measured depth to water in well 8/64-30c1 are both about 330 feet below land surface, and water-level altitudes are about 5,850 and 5,700, respectively. The indicated gradient of the water table between the two wells is about that of the land surface, or about 30 feet per mile. This gradient cannot be projected toward the playa because it is an apparent gradient only and the actual direction of the water-table gradient in this area is not known. It does indicate, however, that the depth to water beneath the playa is substantial and may be on the order of 300 feet. This depth to water virtually precludes any significant amount of ground-water discharge from the ground-water reservoir in this area.

Most of the ground water must be discharged from Cave Valley by underflow through bedrock. This conclusion is based on a comparison of the magnitude of recharge to the valley and the magnitude of discharge by evapotranspiration from the valley in parts of Tps. 9 and 10 N., as discussed in subsequent sections of this report.

In this area the Paleozoic carbonate rocks offer the most favorable conditions for ground-water movement between topographically closed valleys (cover photograph). Springs, such as Lund and Hot Creek Springs in adjacent White River Valley, for example, discharge from carbonate rocks. Indeed, springs discharging from or adjacent to Paleozoic carbonate rocks in this part of Nevada are commonplace. Thus, although much is unknown about the role of Paleozoic rocks in the ground-water hydrology of this area, it is evident that these rocks to large degree control the movement of ground water in this part of the State.

The discharge of ground water through bedrock from Cave Valley is not sufficient to drain completely the valley fill. Indeed, available data permit only a generalization of the system. However, on the basis of information of the few stock wells developed in the valley fill, it is evident that at least limited supplies can be obtained from the more permeable zones in the zone of saturation in the valley fill.

If the Paleozoic rocks are capable of transmitting ground-water discharge from Cave Valley by underflow, the inference is that ground-water recharge to the valley also could be accomplished by a similar mechanism. Ground water in Cave Valley occurs at a minimum known altitude of about 5,700 feet; lower water-level altitudes occur in parts of White River Valley to the west and southwest and in Dry Lake Valley to the south. Higher water-level altitudes occur in the valley fill in the northern part of Geyser (Lake) Valley to the east and Steptoe Valley to the north. Thus, based on the difference in water-level altitudes in the several valleys, the potential direction of ground-water discharge from Cave Valley is limited to the south and west.

By a similar line of reasoning it could be postulated that ground water is recharged to Cave Valley from Steptoe and Geyser Valleys. However, the principal recharge from precipitation in Cave Valley is derived from the Egan and Schell Creek Ranges, which bound the east and west sides of the valley, and most of this recharge occurs north of T. 7 N. The area of recharge probably is an area of a relative high water level compared to the ground-water levels in the adjacent valleys. Thus, it is inferred that the water-level altitudes beneath the mountains in this part of Cave Valley are sufficiently high to form a hydraulic divide and thus, to preclude ground-water underflow from Steptoe and Geyser Valleys to Cave Valley. This contrasts with the south end of Cave Valley where the mountains are much lower and recharge from precipitation is small to negligible; thus, an hydraulic barrier to underflow through the Paleozoic carbonate rocks from the valley probably does not exist.

The above discussion of the regional ground-water system in the carbonate rocks in the vicinity of Cave Valley is greatly simplified. However, the system actually has a much greater complexity. For example, locally there are perched ground-water bodies which tend to obscure the regional system to some extent. Thus, many of the small springs issuing in the mountains probably are related to perched ground-water bodies and do not reflect the position of the regional ground-water system in that locality. Indeed, it is not unlikely that the ground-water system in the valley fill in the vicinity of Cave Valley playa might appropriately be classified as semiperched with respect to the underlying regional ground-water system in the bedrock.

Estimated Average Annual Recharge

The average annual recharge to the ground-water reservoir may be estimated as a percentage of the average annual precipitation within the valley (Eakin and others, 1951, p. 79-81). A brief description of the method follows: Zones in which the average precipitation ranges between specified limits are delineated on a map, and a percentage of the precipitation is assigned to each zone which represents the probable average recharge from the average annual precipitation on that zone. The degree of reliability of the estimate so obtained, of course, is related to the degree to which the values approximate the actual precipitation, and the degree to which the assumed percentages represent the actual percentage of recharge. Neither of these factors is known precisely enough to assure a high degree of reliability for any one valley. However, the method has proved useful for reconnaissance estimates, and experience suggests that in many areas the estimates probably are relatively close to the actual long-time average annual recharge.

The precipitation map of Nevada (Hardman and Mason, 1949, p. 10) has been modified by Hardman (oral communication, 1962) in part to adjust to recent topographic base maps for the region. This is the same base used for plate 1 of this report. Five precipitation zones were selected: the boundary between the zones of less than 8 inches and 8 to 12 inches was delineated at the 6,000-foot contour; between 8 to 12 inches and 12 to 15 inches at the 7,000-foot contour; between 12 to 15 inches and 15 to 20 inches at the 8,000-foot contour; between 15 to 20 inches and more than 20 inches at the 9,000-foot contour.

The average precipitation used for the respective zones, beginning with the zone of 8 to 12 inches of precipitation, is 10 inches (0.83 feet), 13.5 inches (1.12 feet), 17.5 inches (1.46 feet), and 21 inches (1.75 feet).

The recharge estimates as a percentage of the average precipitation for each zone are: less than 8 inches, 0; 8 to 12 inches, 3 percent; 12 to 15 inches, 7 percent; 15 to 20 inches, 15 percent; and more than 20 inches, 25 percent.

Table 3 summarizes the computation of recharge. The approximate recharge (column 5) for each zone is obtained by multiplying the figures in columns 2, 3, and 4. Thus, for the zone receiving more than 20 inches of precipitation, the computed recharge is 3,500 acres x 1.75 feet x 0.25 (25 percent) = about 1,500 acre-feet. The estimated average annual recharge to the ground-water reservoir in Cave Valley is about 14,000 acre-feet.

Table 3.--Estimated average annual ground-water recharge from precipitation in Cave Valley

(1) Precipitation zone (inches)	(2) Approximate area of zone (acres)	(3) Average annual precipitation (feet)	(4) Percent recharged	Estimated recharge (acre-feet) (2 x 3 x 4 + 100)
20+	3,500	1.75	25	1,500
15 to 20	19,500	1.46	15	4,300
12 to 15	69,000	1.12	7	5,400
8 to 12	114,000	.83	3	2,800
8-	29,000	--	-	--
	235,000	Estimated average annual recharge (rounded)		14,000

Estimated Average Annual Discharge

Some ground water is discharged from Cave Valley by transpiration of water-loving vegetation (phreatophytes) and by evaporation along stream channels and a smaller amount is discharged from wells. However, most ground-water discharge from the valley probably is by underflow through bedrock to the west, southwest, or south. The quantity of this underflow could not be estimated directly, because the hydrologic and geologic data are inadequate. However, an indirect estimate of the average annual underflow from Cave Valley can be made, based on the fundamental concept that over the long term, assuming no change in storage, recharge must equal discharge.

Ground-water discharge by evapotranspiration probably does not exceed a few hundred acre-feet a year. Evapotranspiration of ground water is limited to the area along the main drainage channel in the valley fill in Tps. 9 and 10 N.

adjacent tributary channels, and along channels in the upper parts of the alluvial apron where the water table is at shallow depth, such as in the vicinity of stock wells 9/62-1a1 and 10/63-25a1, and to the spring areas in sec. 9, T. 9 N., R. 64 E. and near the Gardner Ranch. Pumpage from stock wells probably does not exceed 100 acre-feet a year. Thus, the estimated average annual discharge of ground water by evapotranspiration and pumpage from wells is not more than several hundred acre-feet. In contrast, the estimated average annual recharge to ground water is about 14,000 acre-feet (table 3). If the values of recharge and discharge are of the correct magnitude, then by difference the discharge of ground water by underflow through the bedrock is only several hundred acre-feet less than the 14,000 acre-feet estimated for annual recharge.

Inasmuch as the estimate of discharge is based on the estimate of recharge, the estimated discharge in no way provides an independent check on the accuracy of the estimate of recharge.

Perennial Yield

The perennial yield of a ground-water system is limited ultimately by the average annual recharge to and natural discharge from the ground-water system. It is the upper limit of the amount of water than can be withdrawn from the system for an indefinite period of time without causing a permanent depletion of ground water in storage. The average recharge from precipitation and the average discharge by evapotranspiration, discharge to streams, and underflow from a valley are measures of the natural inflow and outflow from the ground-water system.

In an estimate of perennial yield, consideration should be given to the effects that ground-water development of wells may have on the natural circulation in the ground-water system. Development by wells may or may not induce recharge in addition to that received under natural conditions. Part of the water discharged by wells may re-enter the ground-water reservoir by downward percolation, especially if the water is used for irrigation. Ground water discharged from wells theoretically is offset eventually by a reduction of the natural discharge. In practice, however, it is difficult to offset fully the discharge from wells by a decrease in the natural discharge, except when the water table has been lowered to a level that eliminates both underflow and evapotranspiration in the area of natural discharge. The numerous pertinent factors are so complex that, in effect, specific determination of perennial yield of a valley requires a very extensive investigation, based in part on data that can be obtained economically only after there has been substantial development of ground water for several years.

The apparent substantial ground-water underflow out of Cave Valley further complicates the evaluation of perennial yield. Pumping from wells might not salvage much of this discharge unless the wells were drilled so as to intercept the discharge or unless pumping resulted in the removal of a substantial part of the ground water in storage in the valley fill. To accomplish the required lowering of water levels in the valley fill, pumping lifts probably would have to be considerably in excess of present economic pumping lifts for irrigation.

However, to the extent that ground water occurs in the valley fill, development is possible in Cave Valley. On a perennial basis the amount would be limited to the ground water actually recharging the permeable water-yielding zones in the valley fill and in which the depth to water is shallow enough to pump economically. The rate at which ground water in Cave Valley could be pumped perennially under the above conditions is not known but may not exceed a few thousand acre-feet per year. The extent to which the yield could be increased above this amount is related largely to the amount of underflow from the valley that could be salvaged. In any event, assuming that all natural discharge could be salvaged, the yield could not exceed the average annual recharge on a continuing basis.

Storage

A considerable amount of ground water is stored in the valley fill in Cave Valley. It is many times the volume of the average annual recharge to the ground-water reservoir. The magnitude of this stored ground water may be estimated by the following calculation: The surface area of the valley fill below the 7,000-foot contour is a little more than 143,000 acres. If it is assumed that only about 100,000 acres overlies a reasonably thick section of valley fill that is saturated, and if a value of 10 percent is assumed as the specific yield (drainable pore space) of the saturated deposits, then about 10,000 acre-feet of water is in storage for each foot of saturated valley fill. Thus, the amount of water in storage in the upper 100 feet of saturated valley fill would be about 70 times the estimated average annual recharge to the ground-water reservoir. Because the depth to water commonly may be 300 feet or more in this part of the valley, pumping in quantity from this area probably would not be economically feasible for most uses.

The principal point to be recognized is that the volume of ground water in storage provides a reserve for maintaining an adequate supply for pumping during protracted periods of drought or for temporary periods of high demand under emergency conditions. This reserve, in effect, increases the reliability of ground water as a dependable source of supply and is an important asset in semiarid regions where surface-water supplies vary widely from year to year.

Chemical Quality

The chemical quality of the water in most ground-water systems in Nevada varies considerably from place to place. In the areas of recharge the chemical concentration of the water normally is very low. However, as the ground water moves through the system to the areas of discharge it is in contact with rock materials which have different solubilities. The extent to which the water dissolves chemical constituents from the rock materials is governed in large part by the solubility, volume, and distribution of the rock materials, by the time the water is in contact with the rocks, and by the temperature and pressure in the ground-water system.

No samples of water were collected for chemical analysis, and as a matter of fact there are not yet sufficient sampling points available in Cave Valley to determine the general chemical character of the ground water in the various parts of the valley. On the basis of the general chemical character of water associated with Paleozoic limestone and dolomite rocks elsewhere in eastern Nevada, the ground water in Cave Valley, at least in the marginal parts of the valley fill adjacent to the area of recharge, probably is a calcium-magnesium bicarbonate type and probably slightly to moderately mineralized. To the writer's knowledge, no serious effort to raise crops by irrigation has been attempted in Cave Valley, but should an attempt be made, the water developed for irrigation should be analyzed to determine its chemical suitability for the proposed crop.

Development

Ground water presently is used to a minor extent for stock supplies in Cave Valley, and well 9/63-1a1 is equipped with a small turbine pump. Water from this well may have been used to a limited extent for the irrigation of native meadow grasses. The volume of water discharged from wells and springs probably is less than 100 acre-feet a year. Although data are not available to indicate where moderate-to large-capacity wells might be developed, yields of a few hundred gallons a minute probably could be developed along the principal channel and its tributaries in the latitude of T. 9 N., and the southern part of T. 10 N. Initial efforts to develop ground water in Cave Valley might well take advantage of the shallow depth to water in this area; that is, carefully constructed wells or infiltration systems may result in development of moderate supplies at a reasonable cost.

Moderate supplies also might be developed locally in the middle segment of the alluvial apron on both sides of the main channel north of the playa, although the water-yielding character of the water-bearing zones is not known. Adjacent to principal canyons ground water may locally be within 100 feet of land surface, but for much of the alluvial apron and in the immediate vicinity of the playa the water table probably is in excess of 200 feet. Before extensive development is attempted, it would seem prudent to put in one or more test holes in favorable localities to determine whether moderate to large supplies can be obtained from wells.

PROPOSALS FOR ADDITIONAL GROUND-WATER STUDIES

In compliance with the request of Hugh A. Shamberger, Director, Nevada Department of Conservation and Natural Resources, the special studies listed below are suggested as necessary for obtaining basic data for a better understanding of the factors that influence or control ground water in Cave Valley and other areas in Nevada. These studies are separate from the normal areal investigations that commonly are needed after development of ground water in a given valley becomes substantial.

1. An investigation of the geologic and hydrologic factors that control the discharge of ground water from the valley fill into the bedrock and out of the drainage basin of Cave Valley should be made. This study probably would have substantial value to the State in that the knowledge and understanding gained from a study in this valley could be applied to other areas where similar physical conditions exist.

Information has been accumulating during the course of ground-water investigations in Nevada which strongly suggest that the Paleozoic carbonate rocks control the ground-water hydrology in many areas in eastern and southern Nevada.

Apparently one regional unit of this type is associated with the White River system which extends from north of the latitude of Ely to the vicinity of Muddy River Springs near Moapa--a distance of more than 200 miles. Present information suggests that interbasin movement of ground water through bedrock, largely Paleozoic carbonate rocks, may involve Long, Jakes, White River, Cave, Dry Lake, Delamar, Garden, Coal, Pahranagat, Kane Springs, and possibly Penoyer and Desert Valleys in the White River regional system.

The desirability of a full definition of the character of this system will be of increasing economic value in future years. Because the cost of obtaining a full definition of this system would be substantial, it would be prudent to examine the system in successive steps to obtain maximum information at a minimum cost. The first step includes a reconnaissance examination of the valleys that comprise the overall system. This step, or phase, is currently in progress. The next step is an evaluation of the overall system, based on information collected during the reconnaissance studies. The conclusions of the second study would provide the basis for specific proposals for future studies.

DESIGNATION OF WELLS

In this report the number assigned to a well is both an identification number and a location number. It is referenced to the Mount Diablo base line and meridian established by the General Land Office.

A typical number consists of three units. The first unit is the township north of the Mount Diablo base line. The second unit, a number separated by a slant line from the first, is the range east of the Mount Diablo meridian. The third unit, separated from the second by a dash, is the number of the section in the township. The section number is followed by a lower case letter, which designates the quarter section, and finally, a number designating the order in which the well was recorded in the quarter section. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarters of the section.

Wells on plate 1 are identified only by the section number, quarter-section letter, and serial number. The township in which the well is located can be ascertained by the township and range numbers shown on the margin of plate 1. For example, well 7/63-15c1 is shown on plate 1 as 15c1 and is within the rectangle designated as T. 7 N., R. 63 E.

Table 4.--Records of selected wells in Cave Valley, Lincoln and White Pine Counties, Nevada.

7/63-15c1. Owner, Bureau of Land Management. Sawmill well. Drilled stock well; depth 385 feet, casing diameter 6 inches. Equipped with cylinder pump and windmill. Reported depth to water below measuring point 300 feet.

8/64-30c1. Owner, M. Urrutia. Drilled stock well; depth unknown, casing diameter 6 inches. Equipped with cylinder pump and windmill. Measuring point, top of casing which is 1.5 feet above land surface. Depth to water below measuring point 332.4 feet, April 22, 1960, and 330.48 feet, October 16, 1962.

9/63-1a1. Owner not determined. Dug well, 3- b 3-foot wood cribbing. Equipped with 4-inch turbine pump. Depth to water 2 feet below land surface, October 16, 1962.

10/63-25a1. Owner, M. Urrutia. Drilled stock well; depth 20 feet. Equipped with cylinder pump and windmill. Measuring point, top of well cover which is at land surface. Depth to water below measuring point 17.8 feet, July 15, 1958, and 19.6 feet, October 16, 1962.

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NEVADA DEPARTMENT OF CONSERVA...

COOPERATIVE PUBLICATIONS

Report No.

1. Ground-Water Appraisal of Newark Valley, White Pine County, Nevada.
Dec. 1960 By Thomas E. Eakin

2. Ground-Water Appraisal of Pine Valley, Eureka and Elko Counties, Nevada.
Jan. 1961 By Thomas E. Eakin

3. Ground-Water Appraisal of Long Valley, White Pine and Elko Counties, Nevada.
June 1961 By Thomas E. Eakin

4. Ground-Water Resources of Pine Forest Valley, Humboldt County, Nevada.
Jan. 1962 By William C. Sinclair

5. Ground-Water Appraisal of the Imlay Area, Humboldt River Basin, Pershing County, Nevada.
Feb. 1962 By Thomas E. Eakin

6. Ground-Water Appraisal of Diamond Valley, Eureka and Elko Counties, Nevada.
Feb. 1962 By Thomas E. Eakin

7. Ground-Water Resources of Desert Valley, Humboldt County, Nevada.
April 1962 By William C. Sinclair

8. Ground-Water Appraisal of Independence Valley, Western Elko County, Nevada.
May 1962 By Thomas E. Eakin

9. Ground-Water Appraisal of Gabbs Valley, Mineral and Nye Counties, Nevada.
June 1962 By Thomas E. Eakin

10. Ground-Water Appraisal of Sarcobatus Flat and Oasis Valley, Nye County, Nevada.
Oct. 1962 By Glenn T. Malmberg and Thomas E. Eakin

11. Ground-Water Resources of Hualapai Flat, Washoe, Pershing, and Humboldt Counties, Nevada.
Oct. 1962 By William C. Sinclair

12. Ground-Water Appraisal of Ralston and Stonecabin Valleys, Nye County, Nevada.
Oct. 1962 By Thomas E. Eakin

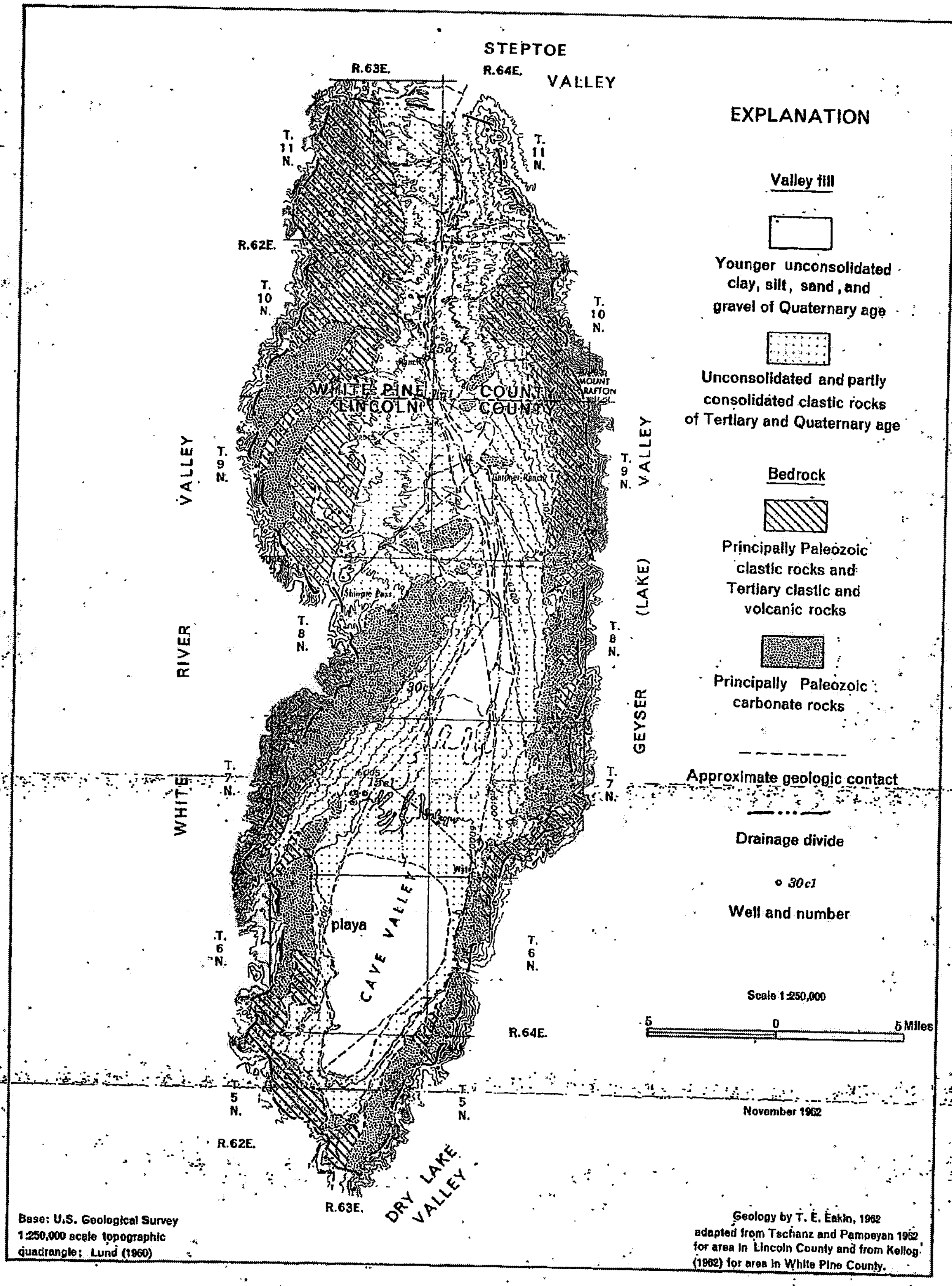

PLATE 1. MAP OF CAVE VALLEY IN LINCOLN AND WHITE PINE COUNTIES, NEVADA SHOWING AREAS OF BEDROCK, VALLEY FILL, AND LOCATION OF WELLS.

In Cooperation with the Southern Nevada Water Authority

Gravity Studies of Cave, Dry Lake, and Delamar Valleys, East-Central Nevada

By Daniel S. Scheirer

Open-File Report 2005-1339

U.S. Department of the Interior
U.S. Geological Survey

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Gravity Studies of Cave, Dry Lake, and Delamar Valleys, East-Central Nevada

By Daniel S. Scheirer

Abstract

Analysis of gravity anomalies in Cave, Dry Lake, and Delamar valleys in east-central Nevada defines the overall shape of their basins, provides estimates of the depth to pre-Cenozoic basement rocks, and identifies buried faults beneath the sedimentary cover. In all cases, the basins are asymmetric in their cross section and in their placement beneath the valley, reflecting the extensional tectonism that initiated during Miocene time in this area. Absolute values of basin depths are estimated using a density-depth profile calibrated by deep oil and gas wells that encountered basement rocks in Cave Valley. The basin beneath southern Cave Valley extends down to ~6.0 km, that of Dry Lake Valley extends to ~8.2 km, and that of Delamar Valley extends to ~6.4 km. The ranges surrounding Dry Lake and Delamar valleys are dominated by volcanic units that may produce lower-density basin infill, which in turn, would make the maximum depth estimates somewhat less. Dry Lake Valley is characterized by a slot-like graben in its center, whereas the deep portions of Cave and Delamar valleys are more bowl-shaped. Significant portions of the basins are shallow (<1 km deep), as are the transitions between each of these valleys. A seismic reflection image across southern Cave and Muleshoe valleys confirms the basin shapes inferred from gravity analysis. The architecture of these basins inferred from gravity will aid in interpreting the hydrogeologic framework of Cave, Dry Lake, and Delamar valleys by placing estimates on the volume and connectivity of potential unconsolidated alluvial aquifers and by identifying faults buried beneath basin deposits.

Introduction

In the southern half of Nevada, ground water is organized into a number of extensive regional flow systems (e.g., Harrill and Prudic, 1998) where ground water can flow between adjacent topographic ranges and basins. Subsurface flow occurs within permeable units or along permeable geologic structures. In east-central Nevada, the main flow system is the White River regional ground water flow system (e.g. Eakin, 1966), or alternatively termed the Colorado regional flow system (Harrill and Prudic, 1998). Aquifer units include widely distributed Paleozoic carbonate rocks, locally significant Tertiary volcanic rocks, and Cenozoic basin-fill deposits (cf., Plume and Carlton, 1988, Dettinger and others, 1995, and Harrill and Prudic, 1998). Regional aquifer recharge in the White River flow system occurs by precipitation in primarily the northern mountainous areas with the primary discharge occurring at Muddy River Springs, which form the Muddy River (Dettinger and others, 1995; Page and others, in press).

The valleys that are the focus of this study: Cave, Dry Lake, and Delamar, are situated near the center of the White River regional ground-water flow system, in Lincoln and White Pine counties (Figure 1). Precambrian crystalline basement does not crop out in this area, but is thought to form a deep barrier to ground water transport (D'Agnese and others, 1997). The ranges surrounding the study basins primarily consist of Paleozoic marine rocks, predominantly carbonate units but also minor shale, conglomerate, and quartzite rocks that formed on the western continental margin of North America, and of Tertiary volcanic rocks, Figure 1b (e.g., Tschanz and Pampeyan, 1970; Stewart, 1980). Marine deposition was nearly continuous in this area throughout the Paleozoic, and deposition ceased until continental volcanism, minor intrusion and plutonism, and associated sedimentation occurred during Oligocene and Miocene times. The Caliente caldera complex, in the southern portion of the study area, forms a thick and variable sequence of volcanics that comprise some of the ranges in the south (Figure 1b).

Tectonism initiated in the study area in Miocene time and deformed the Paleozoic units and older volcanics via extensional block-faulting and subsidiary faulting, leading to the present-day basin and range landscape. Erosion of the ranges filled adjacent valleys with alluvial sequences that are unconsolidated or poorly consolidated, and basin-fill occupies about 50% of the exposure within the study area (Figure 1b). In the study area, the geological structures defining the northern ranges, Egan and Schell Creek, are simpler than their counterparts to the south. In the north, the units comprising the ranges dip primarily to the east with steep, range-front normal faults marking their western margins; in the south, the ranges are built of a combination of Paleozoic marine rocks and variably-thick Tertiary volcanic rocks, and they are disrupted by complex arrays of faults related both to the regional extension and to stresses from volcanic processes (Tschanz and Pampeyan, 1970).

The U.S. Geological Survey conducted gravity experiments along Cave, Dry Lake, and Delamar valleys (Figure 1) to help delineate the subsurface configuration of the valleys and to identify faults that may lie beneath alluvial cover. Because of the substantial density contrast between unconsolidated sediments and older marine sedimentary rocks, gravity is a useful tool for this goal.

Gravity Observations and Analysis

In 2003 and 2004, the U.S. Geological Survey collected gravity observations at 468 new sites (Appendix Table A1) to supplement the prior compilation of ~3500 stations in this area (Snyder and others, 1981; Bol and others, 1983; Snyder and others, 1984; Ponce, 1992, 1997). For the recent fieldwork, we established local gravity base stations at the Lanes Ranch Motel, Lund, Nev., at the Hot Springs Motel, Caliente, Nev., and at the Union Pacific Train Station, Caliente, Nev. (Table 1). Values of gravity at these local bases were tied to the IGSN71 gravity datum (Morelli, 1974) via double-loop surveying to the ELYA benchmark at the Ely (Nev.) Airport. New data were collected with a LaCoste-Romberg gravity meter, and station positions were recorded with a Trimble GeoXT Global Positioning System (GPS) receiver. By using fixed GPS reference stations within ~100 km of the gravity observations, latitude and longitude values were calculated via post-processing to have a precision generally better than 1 meter, and elevations had precisions of about 1 meter. At gravity stations situated on outcrop, we collected 153 rock hand-samples at 152 of the stations (Appendix Table A2), and we measured their density and magnetic susceptibility properties in the lab (Johnson and Olhoeft, 1984).

Values of observed gravity were calculated at the new stations by accounting for fluctuations related to tidal accelerations and for instrument drift constrained at the beginning and end of each field day. New gravity stations were collected within coverage gaps of the prior data, especially in the ranges adjacent to the study basins. We used a helicopter to collect many of the stations in rugged terrain (138 sites). Characterizing the gravity variations within the ranges is required to allow accurate separation of the observed gravity anomalies into pre-Cenozoic and Cenozoic contributions, as described in the depth to basement technique below.

For both the prior and new gravity stations, we compared measured station elevations to corresponding elevations of the 10 m (and 30 m in a few areas where higher resolution was unavailable) digital elevation models (DEMs). Where the station elevations differed by 80 feet (24.4 m) or more from the DEM, the gravity station was omitted from further analysis. Where the station elevations differed by a lesser but still significant amount, we inspected those cases and manually removed some of these stations, as well. We then calculated a series of predictable gravity corrections for all of the stations to account for: the global gravity field, the reduction in gravity with increasing elevation (free-air correction), the effect of mass between the station and the geoid (simple Bouguer correction), the effect of topographic variation near the station (terrain correction), and the effect of compensating mass near the base of the crust (isostatic correction). The final gravity anomaly after application of these corrections is termed the isostatic gravity anomaly and is useful for interpretation because it primarily reflects the density variations in the upper- and mid-crust (Simpson and others, 1986). For new gravity stations, estimates were made of the field terrain correction in a zone from the station out to a radius of 68 m; for the prior stations, this innermost terrain correction was not available. For all stations, digital terrain corrections beyond 68 m were calculated from DEMs in two stages: from 68 m to 2 km and from 2 km to 167 km using the algorithm of Plouff (1997). Other parameters that were used in the calculation of gravity corrections are typical for gravity studies in the Basin and Range Province; these include an upper crustal density of 2.67 g/cc, a mantle-crust density contrast of 0.4 g/cc, and a nominal crustal thickness at sea level of 25 km. A typical error of the new gravity stations is estimated to be ~0.2 mGal, and a typical error of the prior gravity stations is thought to be 0.5-1 mGal. In all cases, the errors are primarily due to elevation and terrain correction uncertainties, and they are small relative to the size of the anomalies that arise from basin structures.

Gravity station data were gridded with a 500 m spacing, which is somewhat finer than the average station-spacing in the valleys (~1 km) and significantly finer that the spacing in the ranges, where gaps up to 4 km exist despite filling in many gaps via helicopter. During the gridding process, we identified a number of prior stations that had gravity values significantly different from their neighbors. To aid in identifying these noise spikes, we upward-continued (e.g., Blakely, 1996) the isostatic gravity field by 500 m, then calculated the difference between the original and upward-continued grids. This difference highlights short-wavelength anomalies in the grid, and individual gravity stations that contributed significant noise were identified and omitted from further analysis. Of the ~3900 gravity stations in the study area, 67 were omitted because their station elevations differed significantly from the DEM values, and 9 of the remaining stations were omitted because of gravity noise spikes. All of the stations collected in 2003 and 2004 passed the noise-editing tests.

Gridded isostatic gravity anomaly data were used to guide the gravity analysis in two modes: to detect significant lateral density interfaces in the subsurface using a maximum horizontal gradient technique (Blakely and Simpson, 1986) and to create models of the depth to pre-Cenozoic basement using the anomaly separation technique of Jachens and Moring (1990). Maximum horizontal gradients of gravity fields are situated above vertical or near-vertical density boundaries in the subsurface, especially for shallow sources. The positions of local maxima of the gravity gradient can help delineate lithologic contacts at depth, especially those related to faults juxtaposing low-density basin fill against consolidated rock. The magnitude of the gradient is a function of the depth to the density boundary and the size of the density contrast, and in practice, the presence of noise in the gravity grid may lead to false identifications of geological boundaries using this technique. The interpretive power of this method is best where maximum gradients are spatially identified in clusters or lineaments.

The depth-to-basement technique endeavors (1) to separate contributions to the isostatic gravity anomaly that arise from Cenozoic sedimentary and volcanic deposits and those from pre-Cenozoic rocks and (2) to convert the low-density contributions from the young deposits into a model of basin depth (Jachens and Moring, 1990). This is an inverse geophysical approach because it calculates model geometry from observations of gravity, constrained by outcrop patterns and with *a priori* assumptions about the density contrast of basin fill relative to surrounding rocks. This method is iterative and has been successfully applied to the entire Basin and Range Province (Saltus and Jachens, 1995) and to individual basins and groups of basins in southern Nevada (e.g., Langenheim and others, 2000). The depth-to-basement method first separates those gravity stations that lie on Cenozoic deposits (termed "basin") vs. those that lie on pre-Cenozoic rocks; these older units are termed "basement" in this description, a usage that differs from the common description of old, crystalline rocks as basement in many areas. The isostatic gravity anomalies at basement stations are then interpolated across the intervening basins, and differences between the interpolated basement gravity values and those measured at basin stations are attributed to the low-density basin infill. Using a 1-D approximation, the depth of the basin fill is estimated from the size of the basin gravity anomaly at each grid point, and then the gravitational attraction of these interpreted basins is calculated. Where a basement gravity station lies close to basin material, some of the attraction of the low-density infill will influence its gravity value; thus, the calculated basin attraction must removed from the gravity value at each basement station. This process yields estimates of basement gravity, basin gravity, and depth to basement beneath the basins. This sequence is then repeated for multiple iterations until the estimates of basin depth converge. In this study, gravity stations are separated based on their placement on three geological units: pre-Cenozoic basement, Cenozoic sedimentary fill, and Cenozoic volcanic deposits. The depth of the resulting basement surface is assumed to be the thickness of sedimentary deposits where sediments are at the surface and to be the thickness of volcanic deposits where volcanics crop out, although it is likely that sediments overly volcanic deposits in some areas.

A critical input to the depth-to-basement method is the depth variation of the density contrast of the basin fill material relative to the surrounding rock; this density profile is the link to convert basin gravity anomalies to basin depth estimates. Measured density-depth functions are available from deep boreholes in other parts of the Basin and Range Province (e.g. Healey and others, 1984) but not from the study area. We first utilized the density-depth functions used in Jachens and Moring (1990) that were deemed appropriate for the entire Basin and Range Province (Table 2). After some experimentation, discussed below, we adopted density-depth relationships (Table 2) with smaller density contrasts, leading to deeper estimated basins that matched better independent constraints on basement depths. In these density-depth functions, density increases with depth, especially within the uppermost 600 m. Near the surface, sedimentary deposits are less dense than the volcanics; deeper than 600 m, the density-depth functions are identical. This relationship demonstrates why it is very difficult to separate the geophysical effects of sedimentary and volcanic deposits using gravity methods.

Measured depths to the base of Cenozoic deposits can be used as important constraints to the depth-to-basement estimation. These measurements are available typically from deep boreholes associated with oil and gas exploration (Table 3 indicates those available in Cave and Dry Lake valleys, Hess, 2004), and even if a borehole does not penetrate the entire basin deposit, its bottom depth may be used as a minimum constraint on the depth-to-basement solution. In this area, four deep wells from the MX project (Bunch and Harrill, 1984) are also available for comparison with gravity models (Table 3). Independent basement depth constraints may be applied to the modeling using two approaches: either as *a priori* exact and minimum depth constraints that must be satisfied as the depth-to-basement algorithm iterates, or as post-modeling validation of the depth-to-basement solution. Deciding on which approach to use depends on the distribution of depth constraints and on the availability of measured density-depth functions in the study area. The latter post-modeling approach is utilized in this study for two reasons: deep borehole constraints are sparse, and systematic differences in measured basin depths (from boreholes) and estimated depths (from gravity analysis) will allow testing and modification of the assumed density-depth function. As noted above and described below, we modified the density-depth function of Jachens and Moring (1990) to match borehole depths in Cave Valley more closely.

Rock property measurements are summarized in Table 4 as averages grouped by rock type. While physical properties of individual hand-samples may not represent well the bulk properties of in situ volumes of rock, especially those at depth, the measurements can aid in establishing the density variations among the units. The most common rock types sampled, carbonate and felsic volcanic rocks, have statistically distinct average densities of 2.70 g/cm^3 and 2.34 g/cm^3, respectively. The Paleozoic rock samples, as a whole, average to a density value very close to the 2.67 g/cm^3 assumed for the Bouguer and isostatic gravity corrections. The young volcanic rocks are less dense and more porous (2-10%) than the older sedimentary rocks (<3% porosity). The volcanic rocks are also the only samples to have significantly non-zero magnetic susceptibility.

Results

The results of the gravity analysis are presented as a series of maps in Figure 2 for Cave and northernmost Dry Lake valleys (including Muleshoe Valley) and in Figure 3 for Dry Lake and Delamar valleys.

Cave Valley is bounded by the sinuous Egan and Schell Creek ranges and is segmented into northern and southern halves by the Shingle Pass Fault that bends the southern Egan Range towards the northeast and across much of the oval-shaped valley floor (Figure 2b, Tschanz and Pampeyan, 1970). These ranges are primarily eastward-dipping tilt-blocks with steep normal faults defining their western margins. Smaller faults cross the ranges, segment the ranges into distinct sections, and create topographic passes. Volcanic units are present in a number of areas surrounding Cave Valley but not with significant thickness (Tschanz and Pampeyan, 1970). The southern portion of Cave Valley has a playa and is much flatter than the floor of the northern valley, which is dissected by streams and is marked by a handful of isolated outcrops (Figure 2b).

For Cave Valley, the prior gravity station distribution was adequate for much of the valley area, but there were large gaps in the surrounding Egan and Schell Creek ranges that were filled using helicopter access (Figure 2a). Many of the gaps that remain within the ranges were investigated by air but deemed unsafe as landing sites. Numerous stations in the valley floors were collected to fill existing gaps, to survey along the ECN-01 seismic line, and to collect gravity observations at well sites that provide independent information on depth to the base of valley-fill deposits. In Cave Valley proper, there are 8 oil and gas wells that penetrated basement, and 1 MX well that encountered basement (Figure 2a and Table 3).

The isostatic gravity anomaly of Cave and Muleshoe valleys is characterized by 20-30 mGal lows centered on the valleys relative to the isostatic values in the surrounding ranges. There are significant gravity fluctuations within the ranges, reflecting the lithologic variation within them; for example, the low-relief range along the southeastern margin of Muleshoe Valley is comprised of volcanic rocks and has a relative gravity low (Figures 2b, 2c). The maximum horizontal gradients of the isostatic anomaly over areas with surface sediments are displayed as pink symbols on the isostatic gravity map (Figure 2c). Larger and more continuous maximum gradient picks are present in southern Cave Valley relative to northern Cave Valley. In the south, two main lines of maximum gradients are found paralleling the eastern and western margins of the valley, with the western group close to the axis of the valley and the eastern group close to the front of the Schell Creek Range. Muleshoe Valley is also lined by steep isostatic gravity gradients along its eastern and western margins, and is marked by diffuse and small gradients on its southern margin where it crosses a small rise that leads into northernmost Dry Lake Valley (Figure 2a, 2c).

The depth-to-basement algorithm separates the isostatic gravity anomaly into portions that arise from the Cenozoic deposits ("basin-fill") vs. those from the pre-Cenozoic rocks ("basement"), and the resulting basin gravity anomaly is illustrated in Figure 2d. The basin gravity anomaly is zero or slightly negative for areas of pre-Cenozoic outcrop, and it achieves the most negative values towards the centers of basins. This anomaly is transformed, via the assumed density-depth function, into a basement depth map, Figure 2e. Basin depths estimated from gravity extend to ~6.0 km in Cave Valley. Maximum depth estimates from the adjacent valleys to the west (White River) and to the east (Lake) are greater, but the gravity coverage is not complete in these areas and careful calibration with independent basement depth constraints has not been performed. In northern Cave Valley, typical basement depths are hundreds of meters, and no site has an estimated depth greater than 1 km. Isolated outcrops extending to the northeast of the Shingle Pass Fault are surrounded by sediments no thicker than 100 m, based on this gravity analysis (Figure 2e). In southern Cave Valley, the basin has depth-to-basement estimates >1 km for more than half of its length; its deepest inferred depth is just east of the valley's axis. The borehole picks to the base of the alluvium are superimposed on the depth-to-basement map (Figure 2e) and show broad agreement in map-view. For comparison, the depth-to-basement map for this area from Saltus and Jachens (1995) is illustrated in Figure 2f. The most striking difference between these two solutions is the 4-fold (500 m vs. 2000 m) resolution increase of the new analysis and its attendant ability to characterize better the geological structures, such as range-front faults, in the study valleys. In addition, the depths of the new estimates are nearly 50% deeper because of the improved density-depth functions (Table 2).

The results of comparisons between the base of alluvium picks from oil and gas wells (Hess, 2004) and MX wells (Table 3) and the depth-to-basement values from the gravity inversion are illustrated in Figure 4. Over the 0 to 2000 m depth range of basement identifications from wells, the estimated basement depths from gravity are centered about the 1:1 equivalence line. Using the greater density-contrast profiles of Jachens and Moring (1990) yielded results where the deeper wells significantly and systematically underestimated the measured basement depths. The match between measured and estimated basement depths is not perfect, and this might stem from a number of reasons: the downhole basement identification might be in error, the identification for a single borehole might not be representative of the true interface at depth averaged over the lateral dimension that contributes to the gravity anomaly measured at the earth's surface, errors in observed or reduced gravity will translate into errors in inferred depth, and densities in the basin deposits likely vary from place to place. While there is some scatter, the overall consistency between the basement depth estimates in this study indicate that the overall form of the depth-to-basement inversions are as correct as can be achieved with the available subsurface observations. It is important to note that observed borehole depths in Cave Valley extend to at most 1900 m, so we cannot test the density-contrast function values between that depth and depths more than twice as great. The two minimum depth constraints, gray circles in Figure 4, should fall to above the 1:1 equivalence line; these wells are located in Dry Lake and Delamar valleys and are discussed below.

An additional view into the subsurface structure of southern Cave Valley and Muleshoe valley is provided by a portion of the industry-shot ECN-01 seismic reflection line (Figure 5). The seismic line crosses near the maximum depth position of Cave Valley (Figure 2e). The seismic reflection image illustrates the asymmetric character of Cave Valley cross section, with a steeper eastern side where the range-front fault of the Schell Creek Range lies and a less-steep western floor leading up to the dip-slope of the Egan Range (Figure 5a). Strong reflectors mark the base of Cave Valley, and a discordant and more horizontal packet of reflectors characterizes much of the deeper valley fill. Weaker subhorizontal reflectors are present in the upper valley fill. The reflectors in the shallow portions of Muleshoe Valley are weak or absent, but in its deeper section exhibit characteristics similar to those of the Cave Valley reflectors. These seismic data are displayed in travel-time, so a quantitative appraisal of seismic depths to basement is not possible. Nevertheless, the inferred basin structure from gravity analysis (Figure 5b) shares a number of similarities with the seismic image: Cave Valley is asymmetric and reminiscent of a half-graben and the overall shapes of Cave vs. Muleshoe, in deeper portions, look similar between the seismic and gravity models. American Petroleum Institute (API) well 27-017-05221 is superimposed schematically on Figure 5b to illustrate its general agreement with the gravity depth-to-basement estimate and to show its position with respect to the seismic structures.

Dry Lake Valley is bounded by the North Pahroc Range in the west and the Highland and Bristol ranges in the east, and the valley is marked by low saddles to the north and south. The surrounding ranges are intensely faulted and are comprised more of volcanic units than are the ranges surrounding Cave Valley (Tschanz and Pampeyan, 1970). Stations were added throughout the valley and adjacent ranges (Figure 3a). The isostatic gravity anomaly has a >30 mGal negative value in the center of the valley; large maximum horizontal gradients mark an area slightly displaced to the east of the valley axis, and smaller gradients delineate the ends of the basin (Figure 3c). The basin gravity anomaly (Figure 3d) emphasizes the narrowness of the central basin gravity anomaly, which has an aspect ratio of ~5 and a magnitude ~10 mGal greater than the anomaly in Cave Valley.

The depth-to-basement solution for Dry Lake Valley exhibits a narrow slot-like depression along most of the valley that is slightly displaced to the east of the valley's centerline. Away from the slot, basin depths are generally <1 km, and within the slot most depths are >3 km and some are as deep as 8 km. No deep oil and gas or MX wells provide independent measures of basin depth in Dry Lake Valley, so the accuracy of the gravity to depth conversion depends on the appropriateness of the assumed density-depth function utilized in this study (Table 2) that was constrained in Cave Valley. Because the ranges surrounding Dry Lake Valley are composed predominantly of Tertiary volcanics, the sedimentary infill might have lower density than in Cave Valley, in which case the density contrasts with bedrock would be larger and the inverted basin depths would be shallower. Using the density-depth function of Jachens and Moring (1990), Dry Lake Valley would have a maximum basin depth of 6 km. Notwithstanding the question of the magnitude of the basin floor topography, the shape of the basin slot, with relatively flat shelves leading to the adjacent ranges, is robust and independent of any particular density-depth assumptions. No seismic lines are available across Dry Lake Valley, so models of the basin geometry depend on the analysis and interpretation of gravity data alone.

Delamar Valley (Figure 3) is surrounded by volcanic ranges to the west, south, and east that are highly faulted. The isostatic gravity anomaly is similar to those in the other valleys in the study area, but the maximum horizontal gradients are only sporadically clustered along some sections of the South Pahroc (to the west) and Delamar (to the east) ranges. These ranges have lower isostatic gravity anomalies relative to ranges comprised of older, non-volcanic rocks, illustrating their low average densities (Figure 3c), despite the presence of shallow and dense Proterozoic rocks at the Delamar mining district to the east of the valley. The basin gravity anomaly (Figure 3d) has a minimum restricted to the southern half of Delamar Valley, which leads to the bowl-shaped basin inferred from the gravity inversion (Figure 3e). The maximum depth is almost 6.5 km, and it is located west of the center of the southern portion of Delamar Valley. Elsewhere, much of the valley has depths of 1-2 km. Again, no exact constraints on basement depth are available from well picks, so the inferred depths are based on calibration at Cave Valley. Like Dry Lake Valley, the volcanic ranges surrounding Delamar Valley likely create lower-density basin infill than in Cave Valley, where the density-depth profile was validated. Assuming the Jachens and Moring (1990) density function that utilizes lower-densities that used in this study, the deepest part of Delamar Valley would be ~4 km below the valley floor.

Discussion

The basin shapes of Cave, Dry Lake, and Delamar valleys are well discerned by gravity analysis, and they have distinct characters. The northern Cave Valley basin is filled by a thin (<1 km) accumulation of sediments that is discontinuous, except for a <100 m layer, with the deeper southern Cave Valley basin. The deeper basin has the form of an elongate bowl, with asymmetric sides that reflect the block faulting of the Egan and Schell Creek ranges. Muleshoe Valley is a shallower basin that is more symmetric than Cave Valley. In Dry Lake Valley, the deep basin is a narrow slot within the interior of the valley and running along most of its length. While the surrounding ranges are highly tectonized, the most significant faults buried beneath the sedimentary deposits are displaced away from the range fronts to form a slot-like graben in Dry Lake Valley. Whether the shoulders to the graben are simply buried, erosional pediment surfaces or whether they are regions between distinct fault systems proximal and distal to the range-fronts is unknown without further geological and geophysical observations. The southern portion of Delamar Valley is bowl-shaped and significantly deeper than the northern half of the valley. A small, ~1-km deep basin-divide between the Delamar and Dry Lake valley basins occurs ~5 km north of the subtle topographic divide between the valleys. One common feature of all of the study basins is that their maximal depths occur where the valley elevations are lowest, indicating a long-term connection between the geologic structures that deepen the basins and those that govern geomorphology in the study area. In Cave, Dry Lake, and Delamar Valleys, the size and shape of the surface playas are good proxies for the locations of maximal basin depths.

Uncertainty in the density-depth profiles utilized in the depth-to-basement process translates into the greatest uncertainties in magnitude of basin depths. For Cave Valley, the oil and gas wells that penetrate basin infill to depths ~35% of the maximum modeled depths are useful to constrain the density-depth function at shallow levels. Performing velocity analysis and depth migration of the ECN-01 seismic reflection line would add another independent constraint of the deep basin depths across southern Cave Valley, but the accuracy of these depths would depend on the quality of the velocities recovered from the seismic records. In the Dry Lake and Delamar valleys, neither deep borehole nor seismic constraints are available, so the actual basin depths could vary from those shown in this study. If the material filling the southern valleys is dominated by lower density volcanic units than the dominant Paleozoic rocks of Cave Valley, then the basin-fill density contrasts in Dry Lake and Delamar valleys are likely to be greater, which would lead to shallower basement surfaces inferred from gravity analysis in these southern basins. The trade-off between the assumed physical properties of the basin material and the magnitude of the resultant depth solutions is a fundamental limitation of interpreting potential fields, such as gravity.

Analysis of gravity anomaly gradients indicates that buried faults generally bound the deepest portions of basins and that these faults are continuous and steep over much of the length of the basins. There is no clear association of inferred buried faults and those that criss-cross the surrounding ranges, indicating that if the exposed faults continue beneath the basin infill, they do not juxtapose units of significant density contrast nor do they play a major role in defining the gross architecture of the basin.

The basin architecture inferred from gravity analysis will aid in interpreting the hydrogeologic framework of Cave, Dry Lake, and Delamar valleys in a number of ways. First, the depth-to-basement analysis allows estimation of the placement and volumes of basin-fill aquifers and their potential connections between basins. As noted above, most of the basins are asymmetric in shape and position within a valley, and they have only shallow connections from one basin to another. Second, buried valley-parallel faults are continuous along all of the basins, but these occur in different positions with respect to the valley center and range-fronts. The faults within Dry Lake Valley form a slot-like graben that is distinct from the bowl-shaped basins of southern Cave and Delamar valleys. Other geophysical or geological observations are required to assess how continuous these faults are beneath the basin fill, continuity that would have significant implications for ground-water connections in the carbonate aquifer system.

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Table 1. Gravity base stations used for data collected in 2003 and 2004.

[Datums: latitude and longitude, NAD27; elevations, NGVD29; gravity values, IGSN71]

Base name	Latitude	Longitude	Elevation (m)	Observed gravity (mGal)	Description
ELYA[1]	39° 17.593'N	114° 50.513'W	1906.0	979,480.08	Ely Airport, Nev.
LUNDLR	38° 54.839'N	115° 02.591'W	1711.2	979,504.86	Lanes Ranch Motel, Lund, Nev.
CALHSM	37° 37.266'N	114° 30.588'W	1343.8	979,516.06	Hot Springs Motel, Caliente, Nev.
CALTRN	37° 36.732'N	114° 30.831'W	1336.2	979,515.51	Union Pacific Stn., Caliente, Nev.

[1]Part of the World Reference Gravity Network (Jablonsky, 1974)

Table 2. Cenozoic density-depth functions.

[Density contrasts are basin infill-density minus surrounding bedrock density]

Depth range (km)	Sedimentary density contrast (g/cm3) (Jachens & Moring, 1990)	Volcanic density contrast (g/cm3) (Jachens & Moring, 1990)	Sedimentary density contrast (g/cm3) (this study)	Volcanic density contrast (g/cm3) (this study)
0-0.2	-0.65	-0.45	-0.60	-0.40
0.2-0.6	-0.55	-0.40	-0.50	-0.35
0.6-1.2	-0.35	-0.35	-0.30	-0.30
>1.2	-0.25	-0.25	-0.20	-0.20

Table 3. Deep borehole basement constraints.

[Datums: latitude and longitude, NAD27; elevations, NGVD29]

Well ID[1]	Valley	Latitude	Longitude	Surface elevation (m)	Total depth (m)	Depth to basement (m)
27-033-05200	Cave	38° 46.70'N	114° 50.21'W	1981	1529	1027
27-017-05210	Cave	38° 31.25'N	114° 48.20'W	1856	1191	366
27-017-05220	Cave	38° 27.61'N	114° 50.91'W	1832	1707	995
27-017-05001	Cave	38° 26.59'N	114° 49.44'W	1840	2141	1891
27-017-05200	Cave	38° 26.11'N	114° 55.59'W	1890	149	4
27-017-05228	Cave	38° 25.67'N	114° 53.10'W	1825	1856	635
27-017-05229	Cave	38° 25.67'N	114° 53.10'W	1822	1621	547
27-017-05221	Cave	38° 22.31'N	114° 50.35'W	1820	2073	1554
27-017-05224	Dry Lake	37° 55.00'N	114° 36.80'W	2012	3535	325
Cave Valley	Cave	38° 28.12'N	114° 52.17'W	1831	141	111
Dry Lake Valley	Dry Lake	38° 05.52'N	114° 53.70'W	1695	730	104
Dry Lake Valley	Dry Lake	37° 42.25'N	114° 45.52'W	1414	398	N/A
Delamar Valley	Delamar	37° 26.65'N	114° 52.15'W	1436	370	N/A

[1]API number for oil and gas wells; valley name for MX wells.

Table 4. Average physical properties of rock samples, grouped by rock type.

[Average property values are followed by 1-standard deviation values in parentheses.]

Rock type	Number of samples	Grain density (g/cm3)	Saturated bulk density (g/cm3)	Dry bulk density (g/cm3)	Porosity (%)	Susceptibility (10-3 SI)
Carbonate	57	2.73 (0.09)	2.70 (0.11)	2.68 (0.13)	1.7 (1.9)	0.0 (0.1)
Sandstone	12	2.59 (0.07)	2.55 (0.10)	2.53 (0.11)	2.4 (2.1)	0.1 (0.2)
Quartzite	6	2.62 (0.03)	2.61 (0.04)	2.60 (0.04)	0.8 (0.4)	0.0 (0.0)
Felsic Volcanic	60	2.46 (0.12)	2.34 (0.17)	2.25 (0.23)	9.7 (8.2)	3.3 (3.7)
Interm. Volcanic	14	2.53 (0.17)	2.50 (0.17)	2.48 (0.17)	2.1 (1.4)	6.4 (5.6)
Mafic Volcanic	3	2.50 (0.21)	2.43 (0.28)	2.37 (0.35)	6.3 (8.6)	5.2 (3.7)
Granite	1	2.51 (N/A)	2.49 (N/A)	2.47 (N/A)	1.4 (N/A)	0.2 (N/A)

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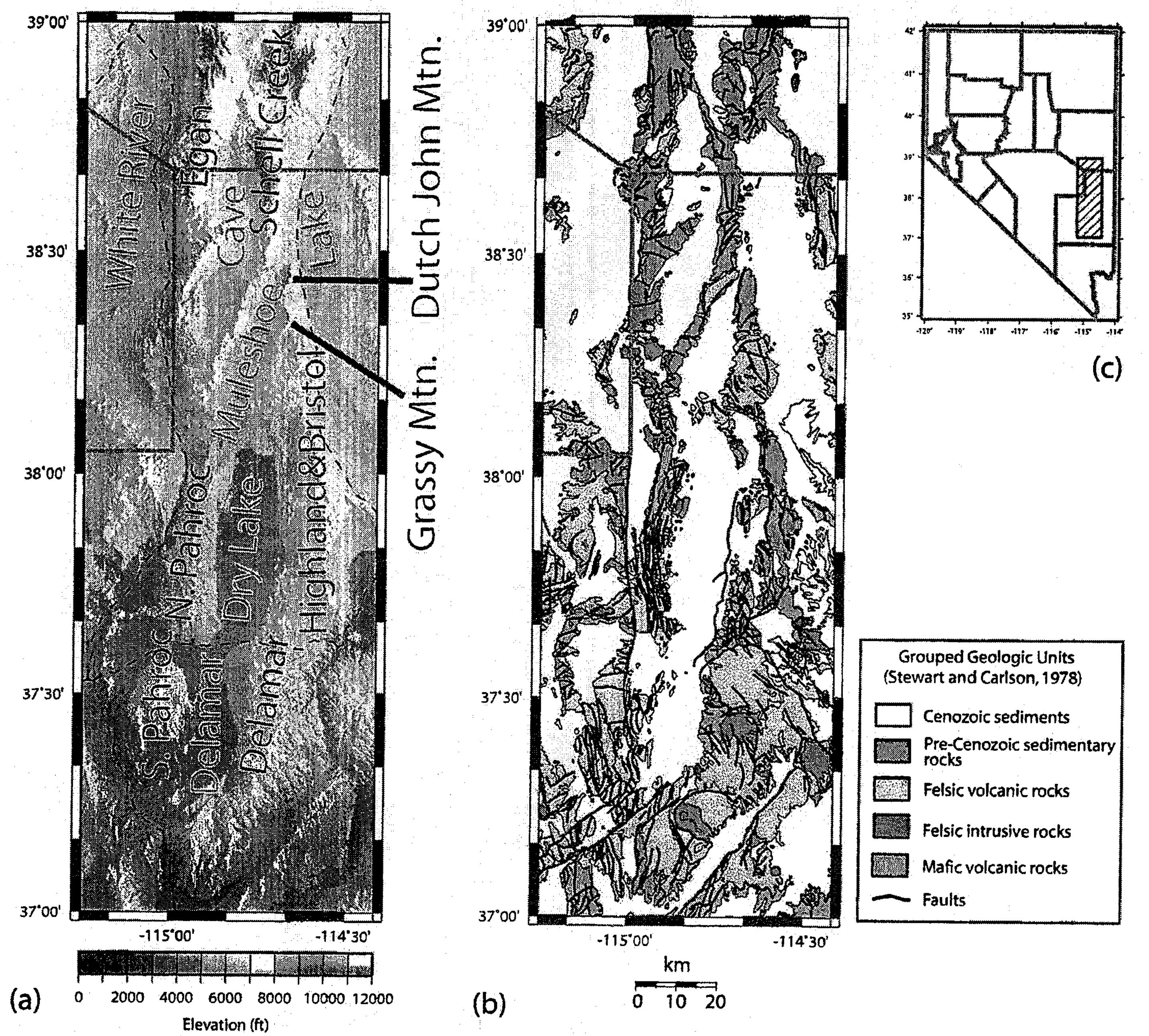

Figure 1. Index map of the study area. 1a) Shaded-relief topography, with labels of the major basins and ranges. Gray lines indicate boundaries of Lincoln, White Pine, and Nye counties in this and subsequent maps. Dashed lines indicate US Highway 93 and Nevada Route 318. 1b) Generalized geology from Stewart and Carlson (1978). 1c) Index map of Nevada showing study area (hachured).

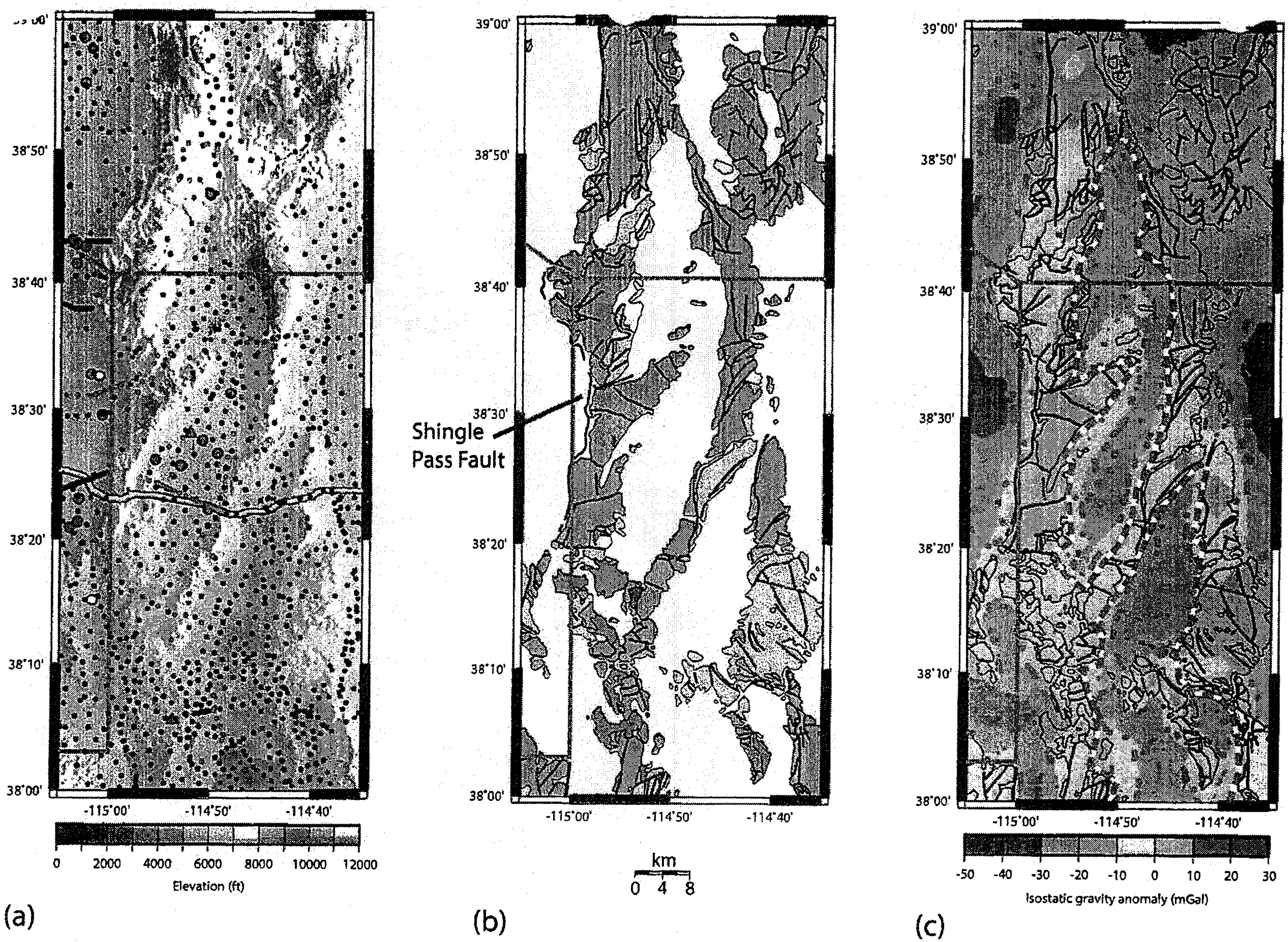

Figure 2 . Cave and Muleshoe valley results. 2a) Shaded -relief topography, with small black circles indicating gravity stations collected prior to 2003 and small magenta circles indicating gravity stations collected by the USGS in 2003 and 2004. Larger circles indicate oil and gas wells; red -fill indicates wells that pass through the entire alluvial section, and white-fill indicates those that bottom in alluvium. Red triangles indicate MX wells that pass t hrough the entire alluvial section. Yellow line indicates the position of the ECN -01 seismic reflection line. 2b) Geology, as in Figure 1b). 2c) Isostatic gravity anomaly map. Red dashed line indicates the outline of the alluvial basins, and thin lines mark the generalized geology of Figure 2b). Pink circles denote the locations of local maxima of the horizontal gradient of the isostatic anomaly field. Only those locations that fall on mapped alluvium are shown, and they are sized according to whether they fall in the lower, middle, or upper thirds of the gradient magnitude distribution.

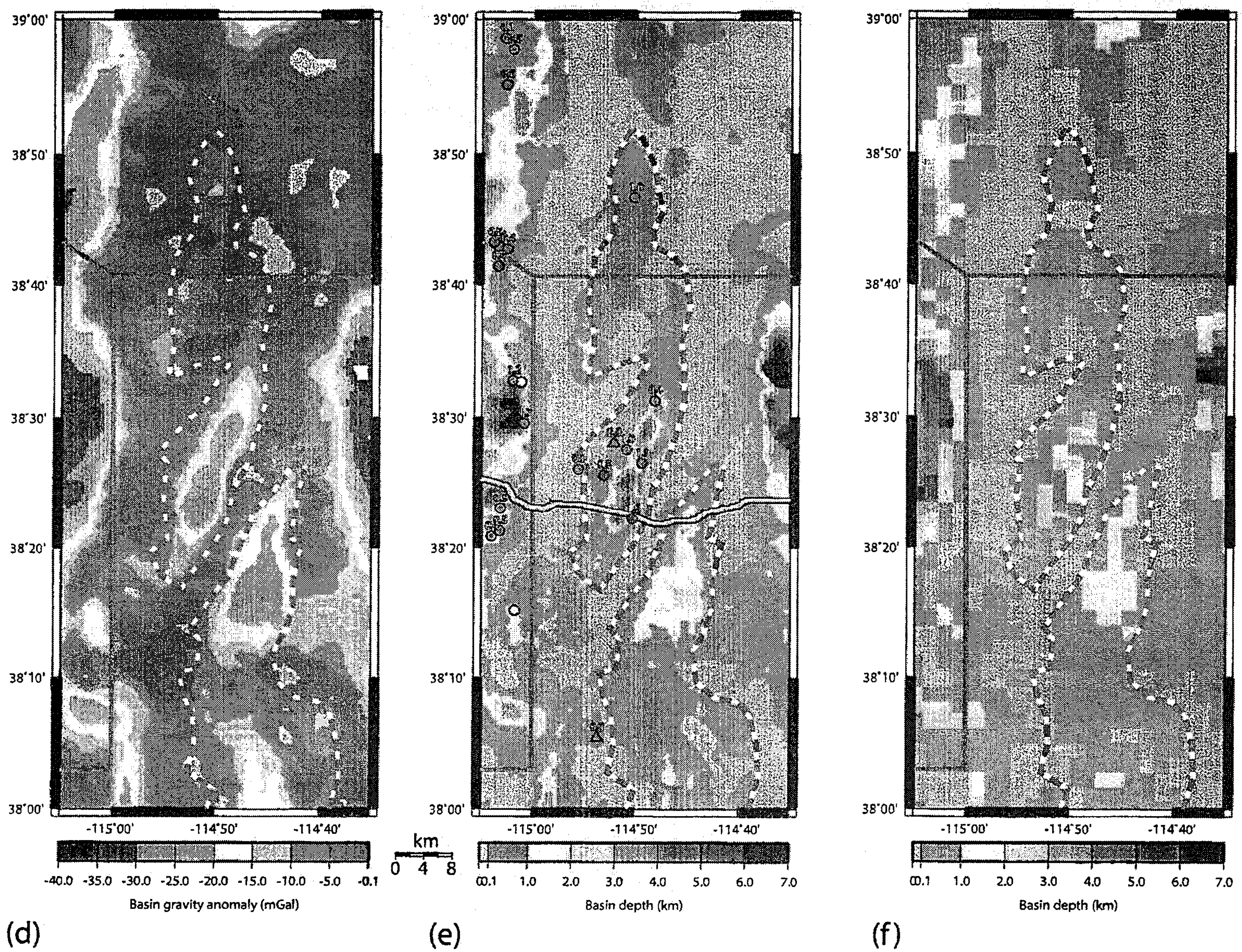

Figure 2 (continued). 2d) Basin gravity anomaly derived from the depth-to-basement algorithm described in the text. 2e) Calculated basin depth, based on the basin gravity anomaly (2d). Symbols of oil and gas and MX wells are as in (2a), and depths in kilometers to the base of the alluvium are annotated above the symbols. Yellow line indicates the position of the ECN-01 seismic reflection line.

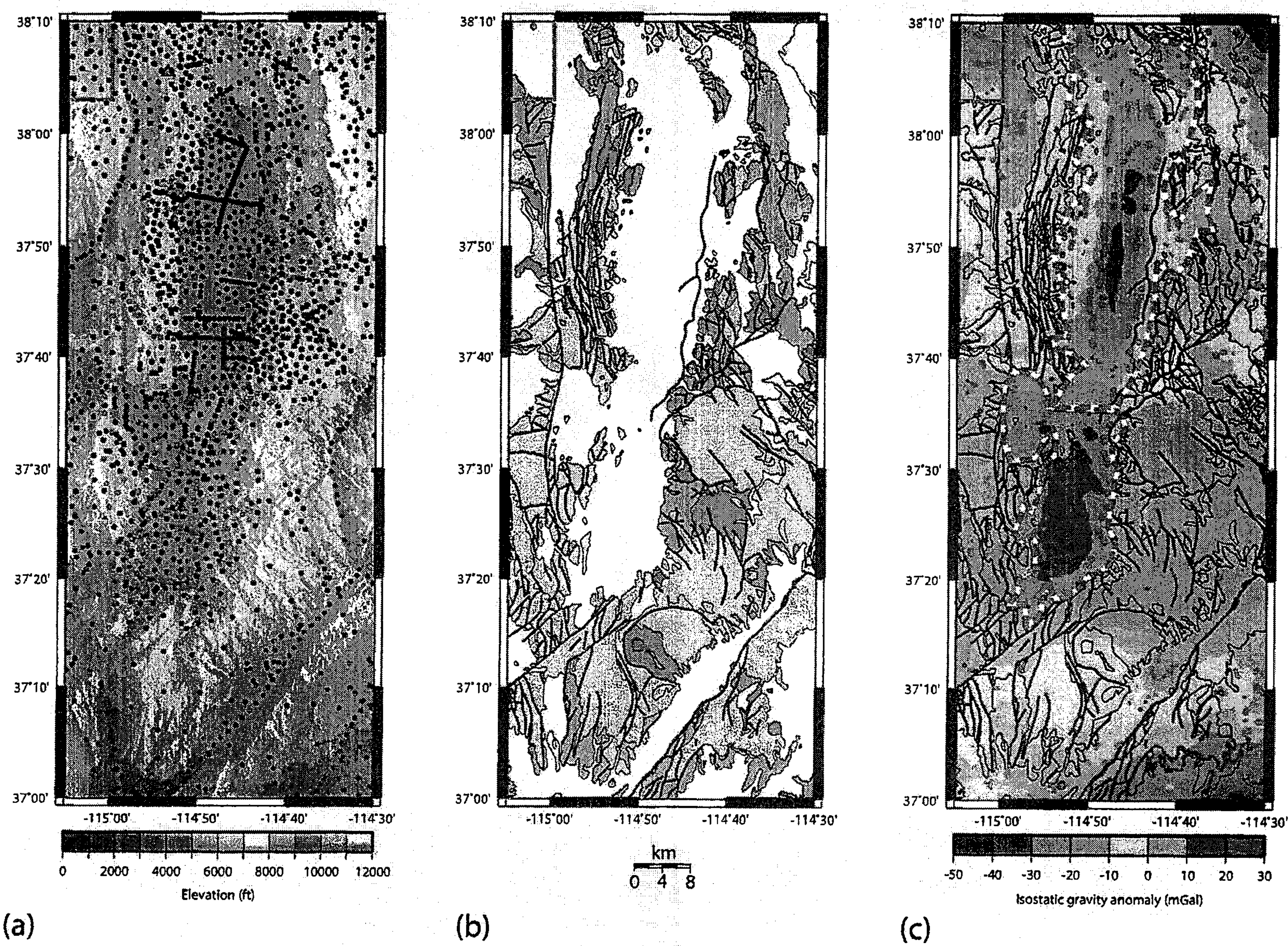

Figure 3. Dry Lake and Delamar valley results. 3a) Shaded-relief topography, with small black circles indicating gravity stations collected prior to 2003 and small magenta circles indicating gravity stations collected by the USGS in 2003 and 2004. Larger circles indicate oil and gas wells; red-fill indicates wells that pass through the entire alluvial section, and white-fill indicates those that bottom in alluvium. Red triangles indicate MX wells that pass through the entire alluvial section, and white triangles indicate MX wells that bottom in alluvium. 3b) Geology, as in Figure 1b). 3c) Isostatic gravity anomaly. Red dashed line indicates the outline of the alluvial basins, and thin lines mark the generalized geology of Figure 3b). Pink circles denote the locations of local maxima of the horizontal gradient of the isostatic anomaly field. Only those locations that fall on mapped alluvium are shown, and they are sized according to whether they fall in the lower, middle, or upper thirds of the gradient magnitude distribution.

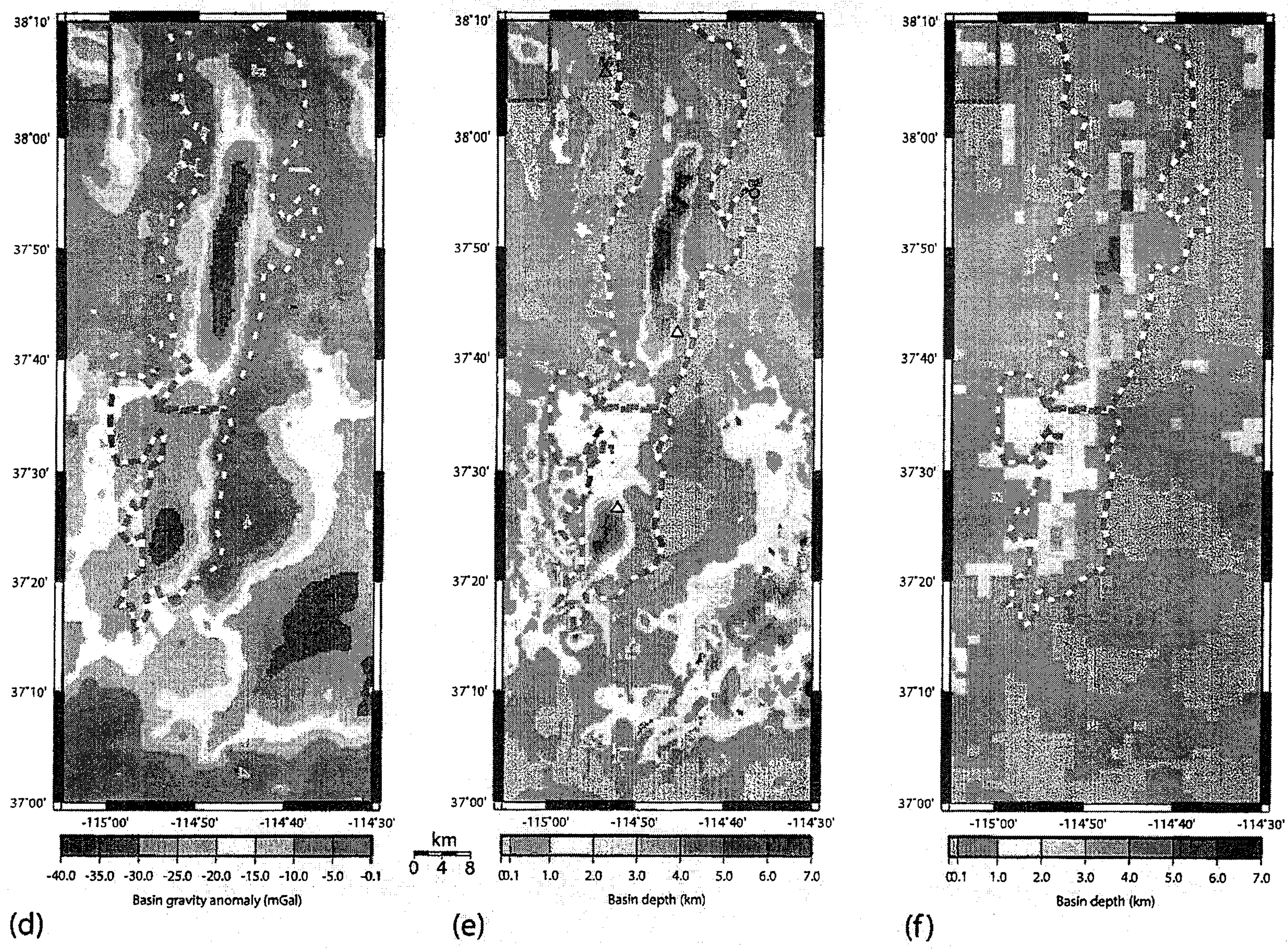

Figure 3 (continued). 3d) Basin gravity anomaly derived from the depth-to-basement algorithm described in the text. 3e) Calculated basin depth, based on the basin gravity anomaly (3d). Symbols of oil and gas and MX wells are as in (3a), and depths in kilometers to the base of the alluvium are annotated above the symbols. 3f) Calculated basin depth from Saltus and Jachens, 1995.

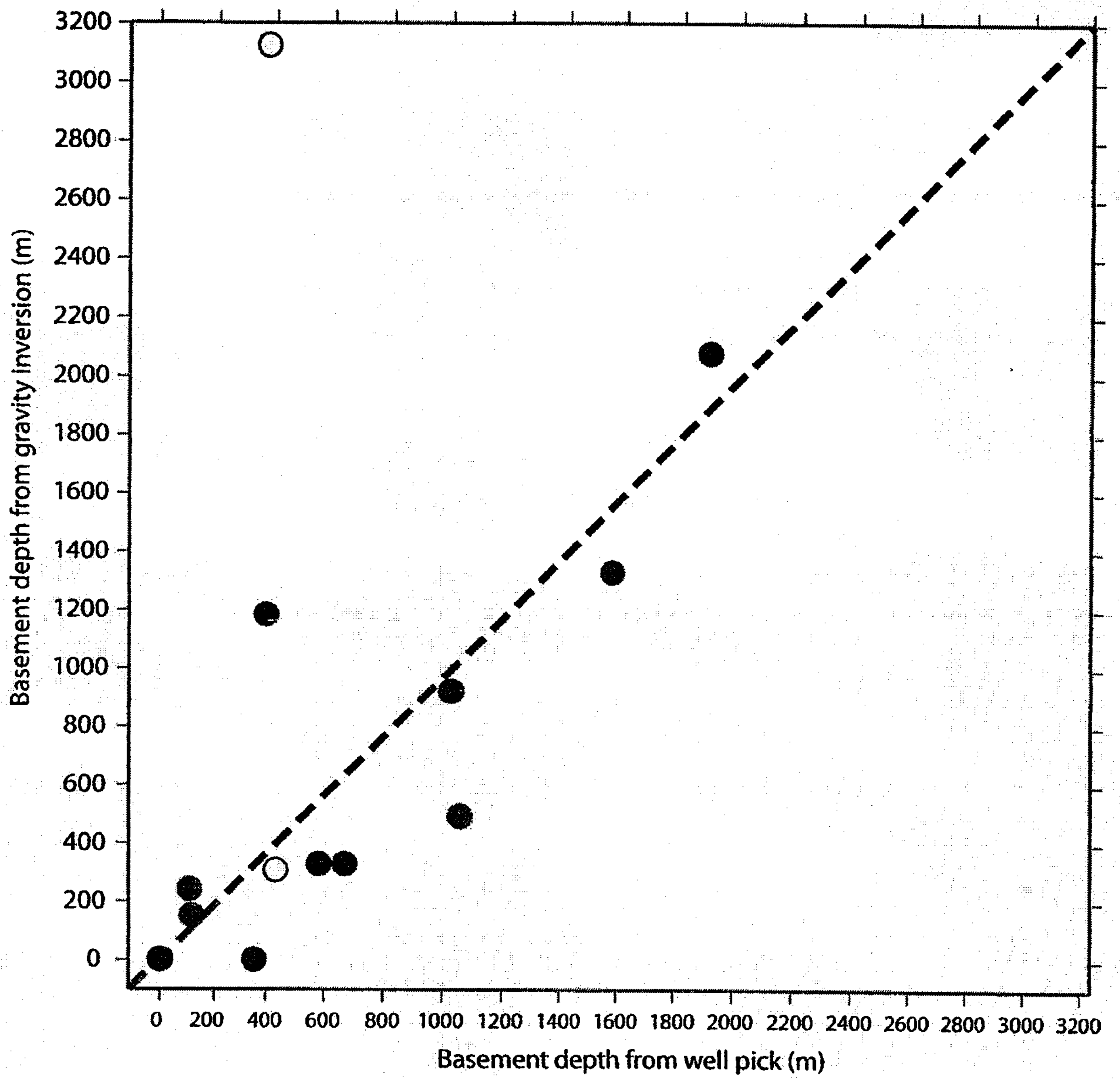

Figure 4. Comparison of basement depths from borehole picks (x-axis) vs. those from gravity depth-to-basement analysis (y-axis). Black circles are wells where exact basement depth constraints were available; gray circles denote wells that bottomed in Cenozoic deposits, and hence their depth is a minimum estimate. Because the black points cluster along the 1:1 dashed line, the density-depth relationship is appropriate for this area.

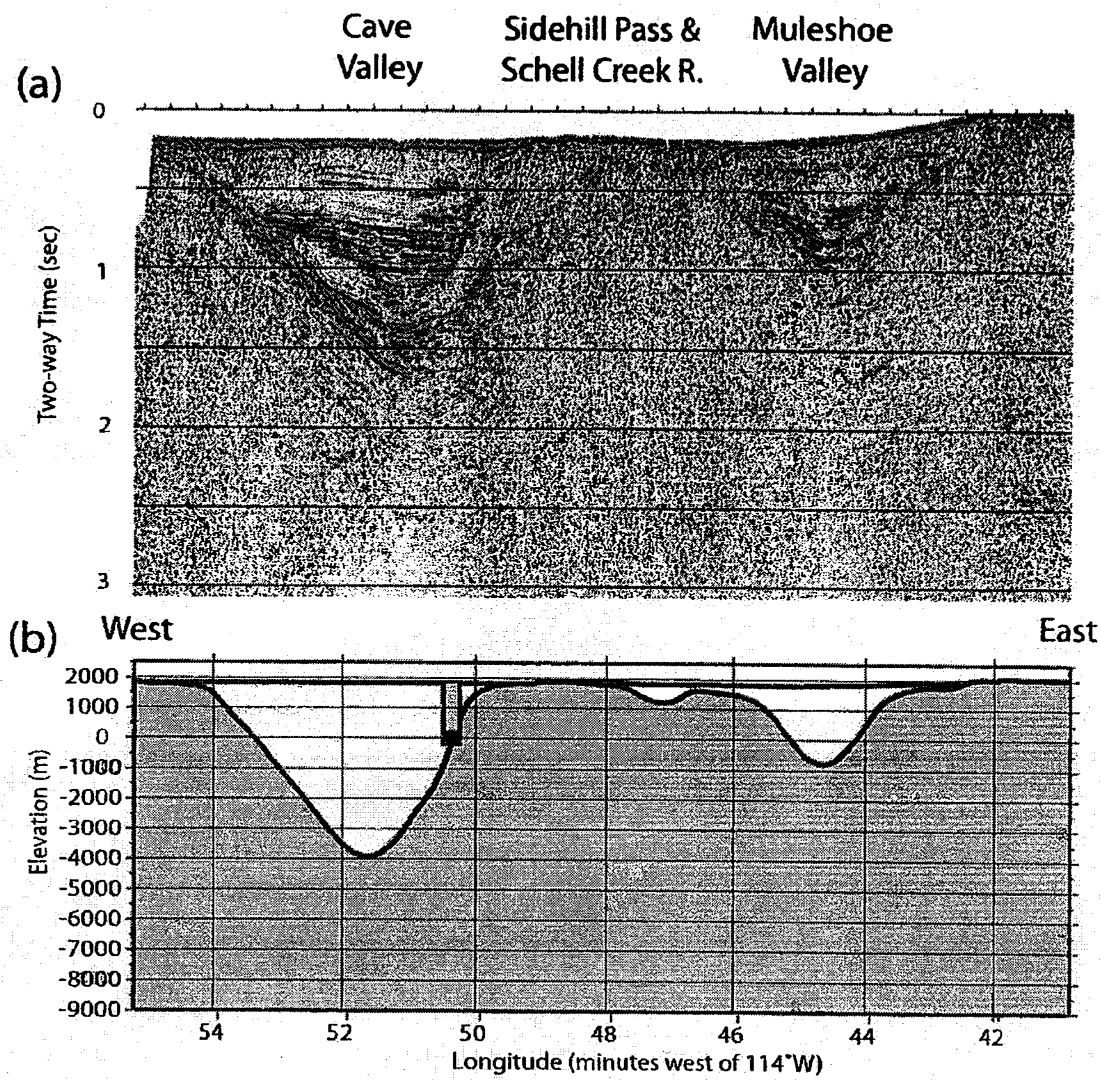

Figure 5. Cross section of southern Cave and northern Muleshoe valleys (cf. Figures 2a, 2e). 5a) ECN-01 seismic reflection section displayed in time. 5b) Results of gravity depth-to-basement inversion with low density basin-fill in yellow; vertical exaggeration = 1.5. API well 27-017-05221 is displayed on the section, and its alluvial interval is shown in dark yellow.

Appendix

Table A1. Principal facts for gravity stations collected in 2003 and 2004 in Cave, Dry Lake, and Delamar Valleys.

[Datums: latitude and longitude, NAD27; elevations, NGVD29. FAA, free-air anomaly; ITC, inner terrain correction calculated out to 2 km; TTC, total terrain correction; CBA, complete Bouguer anomaly, ISO, isostatic anomaly]

Station	Latitude north (deg min)	Longitude west (deg min)	Elevation (feet)	Observed gravity (mGal)	FAA (mGal)	ITC (mGal)	TTC (mGal)	CBA (mGal)	ISO (mGal)
03L001	38 49.24	114 57.67	6433.2	979460.49	0.98	0.60	3.82	-216.13	-11.56
03L002	38 47.48	114 58.40	7647.9	979376.37	33.59	12.90	18.44	-210.30	-7.01
03L003	38 45.00	114 57.83	7407.7	979402.94	41.24	1.97	5.02	-207.88	-5.45
03L004	38 44.47	114 55.65	8214.0	979344.73	59.57	3.15	7.31	-214.71	-12.46
03L005	38 44.21	114 55.36	8140.2	979350.89	59.18	2.53	6.31	-213.60	-11.39
03L006	38 42.68	114 56.04	8211.4	979349.03	66.26	1.10	5.34	-209.91	-8.54
03L007	38 41.46	114 57.42	8312.7	979346.75	75.29	0.63	5.58	-204.09	-3.56
03L008	38 40.44	114 58.85	8503.3	979331.73	79.68	1.26	8.12	-203.63	-3.92
03L009	38 40.79	115 00.20	8185.2	979348.76	66.31	2.72	10.33	-203.98	-4.27
03L010	38 40.84	115 01.43	6976.7	979424.68	28.60	2.31	5.96	-204.90	-4.88
03L011	38 42.80	114 57.50	7397.7	979402.94	43.54	2.11	4.51	-205.76	-4.30
03L012	38 39.06	115 01.56	6564.6	979448.76	16.58	2.46	5.20	-203.62	-4.26
03L013	38 37.08	115 00.37	6477.0	979452.10	14.59	1.72	4.16	-203.66	-5.04
03L014	38 35.75	115 00.16	6143.9	979470.30	3.45	1.55	3.28	-204.31	-6.12
03L015	38 34.74	114 58.42	6324.9	979458.67	10.31	0.97	2.68	-204.23	-6.24
03L016	38 32.76	114 57.27	6730.1	979433.21	25.84	1.77	3.64	-201.57	-4.47
03L017	38 31.37	114 57.42	7712.6	979362.00	48.99	14.28	20.61	-194.94	1.05
03L018	38 33.61	114 55.82	7490.5	979376.78	39.61	5.24	8.16	-209.19	-11.70
03L019	38 34.25	114 55.45	7566.2	979370.60	39.60	3.37	6.25	-213.69	-15.86
03L020	38 35.41	114 56.28	7746.6	979362.68	46.93	1.77	5.46	-213.31	-15.12
03L021	38 30.03	114 58.38	6099.1	979473.50	10.84	1.40	3.98	-194.70	1.10
03L022	38 28.08	114 58.46	5971.6	979478.88	7.10	1.90	4.17	-193.89	0.99
03L023	38 25.76	115 00.03	6018.6	979470.09	6.13	4.60	6.39	-194.24	-0.81
03L024	38 23.60	114 59.75	6290.8	979460.52	25.31	2.22	3.97	-186.78	5.61
03L025	38 22.02	115 00.45	6056.6	979470.91	16.01	3.12	4.52	-187.53	4.02
03L026	38 19.91	115 01.48	5838.9	979482.14	9.88	1.12	1.87	-188.88	1.62
03L027	38 19.53	114 58.48	6933.9	979403.19	34.39	5.16	7.50	-196.11	-5.69
03L028	38 21.04	114 57.73	7312.4	979393.04	57.59	1.39	4.90	-188.42	2.71
03L029	38 22.55	114 56.47	7158.3	979401.56	49.41	2.52	5.30	-190.93	1.19
03L030	38 24.51	114 56.19	7203.6	979398.29	47.53	3.31	6.42	-193.25	-0.13
03L031	38 27.14	114 54.28	6326.3	979456.57	19.50	0.88	2.08	-195.69	-0.62
03L032	38 28.86	114 56.38	8755.2	979299.35	87.98	7.70	21.44	-190.57	3.99
03L033	38 30.50	114 55.63	9782.7	979222.22	104.96	13.66	37.11	-192.80	2.33
03L034	38 37.29	114 45.06	7588.8	979374.58	41.24	4.26	7.89	-211.19	-10.45
03L035	38 40.60	114 46.89	7294.3	979396.21	30.33	0.80	3.91	-216.05	-13.90
03L036	38 40.66	114 45.93	7957.2	979352.84	49.16	3.41	8.00	-215.70	-13.72
03L037	38 42.54	114 45.94	8703.8	979307.26	70.95	3.63	9.47	-217.83	-15.41
03L038	38 43.88	114 47.17	8468.1	979325.29	64.87	2.75	7.42	-217.95	-14.97
03L039	38 44.70	114 47.08	8117.7	979349.24	54.69	1.82	4.80	-218.83	-15.34
03L040	38 49.47	114 54.44	8515.1	979338.38	74.15	1.22	6.21	-211.48	-7.21
03L041	38 47.50	114 55.32	8436.4	979339.63	70.90	1.17	6.02	-212.23	-8.76
03L043	38 47.04	114 46.65	7964.8	979363.82	51.46	0.90	3.02	-218.64	-14.18
03L044	38 43.57	114 47.80	7642.8	979380.32	42.82	1.18	3.36	-215.98	-12.86
03L045	38 40.36	114 43.96	10277.3	979194.66	109.36	5.61	25.44	-216.83	-15.89
03L046	38 39.99	114 44.89	9028.2	979284.11	82.03	5.74	14.44	-212.80	-11.50
03L047	38 34.64	114 50.82	6505.6	979450.26	19.03	0.51	1.58	-202.78	-3.52

03L048	38 31.41	114 50.66	6288.8	979464.18	17.32	0.77	2.49	-196.18	1.62
03L049	38 30.60	114 44.05	7995.7	979346.40	61.12	4.20	9.81	-203.24	-5.53
03L050	38 32.95	114 44.26	8564.2	979304.18	68.86	10.91	20.61	-204.03	-5.52
03L051	38 34.46	114 45.52	6916.2	979418.62	26.24	2.54	4.34	-206.82	-7.11
03L052	38 36.56	114 44.03	9196.9	979263.68	82.49	7.79	21.29	-211.22	-11.38
03L053	38 37.51	114 43.72	9316.6	979261.72	90.38	4.39	17.70	-210.98	-10.77
03L054	38 39.09	114 43.80	9804.6	979229.65	101.82	4.77	20.67	-213.12	-12.41
03L055	38 38.10	114 43.68	9812.3	979225.29	99.64	6.59	24.18	-212.06	-11.79
03L056	38 34.06	114 52.33	6831.7	979431.45	31.71	0.69	1.98	-200.82	-2.20
03L057	38 29.29	114 45.78	6871.4	979422.68	33.68	2.90	4.37	-197.82	-0.47
03L058	38 27.78	114 46.07	6632.6	979436.22	27.00	1.54	2.64	-198.09	-1.40
03L059	38 26.85	114 44.79	7345.9	979378.29	37.46	2.49	5.26	-209.32	-13.13
03L060	38 24.40	114 47.23	6449.6	979438.22	16.76	1.02	1.70	-203.01	-8.03
03L061	38 18.73	114 49.89	7019.8	979400.64	41.08	2.62	5.20	-194.65	-3.16
03L062	38 14.92	114 52.21	6361.5	979442.43	26.60	0.98	1.82	-190.06	-0.69
03L063	38 11.99	114 53.88	7006.7	979393.63	42.72	1.99	4.97	-192.79	-5.45
03L064	38 11.37	114 56.67	7057.0	979389.48	44.21	3.59	7.23	-190.77	-4.12
03L065	38 17.16	114 55.35	6263.7	979442.86	14.55	0.50	0.99	-199.59	-9.57
04L001	38 31.23	115 12.57	5337.0	979520.01	-16.04	0.03	0.50	-199.01	-4.69
04L002	38 31.10	115 11.49	5304.3	979523.56	-15.37	0.02	0.36	-197.36	-2.95
04L003	38 31.10	115 10.34	5270.8	979519.90	-22.18	0.01	0.27	-203.11	-8.50
04L004	38 31.11	115 09.47	5250.5	979515.95	-28.05	0.01	0.23	-208.33	-13.62
04L005	38 31.13	115 08.42	5265.6	979514.16	-28.45	0.02	0.21	-209.27	-14.43
04L006	38 31.16	115 07.28	5254.5	979510.32	-33.38	0.01	0.21	-213.82	-18.75
04L007	38 31.16	115 06.15	5252.4	979503.42	-40.48	0.02	0.26	-220.80	-25.58
04L008	38 31.16	115 04.46	5258.7	979493.98	-49.33	0.01	0.36	-229.75	-34.21
04L009	38 31.16	115 03.31	5290.8	979489.46	-50.83	0.02	0.49	-232.23	-36.55
04L010	38 31.16	115 02.22	5352.0	979485.76	-48.78	0.03	0.65	-232.11	-36.26
04L011	38 35.69	114 40.69	6330.1	979448.85	-0.42	0.17	1.75	-216.07	-15.14
04L012	38 35.87	114 41.78	6640.1	979432.64	12.24	0.43	2.76	-212.98	-12.21
04L013	38 35.55	114 43.66	7412.5	979389.62	42.27	1.90	4.66	-207.38	-7.15
04L014	38 35.35	114 44.81	6941.0	979417.75	26.39	2.63	4.79	-207.07	-6.87
04L015	38 35.25	114 45.27	6747.9	979430.20	20.84	1.68	3.80	-207.01	-6.84
04L016	38 35.62	114 46.21	6434.2	979444.86	5.48	0.37	2.30	-213.18	-12.77
04L017	38 35.32	114 46.65	6378.6	979449.02	4.85	0.13	1.67	-212.53	-12.29
04L018	38 50.04	114 49.71	7245.3	979407.20	22.82	0.08	1.22	-224.57	-18.92
04L019	38 50.46	114 50.63	7309.8	979403.54	24.60	0.06	1.28	-224.92	-19.27
04L020	38 50.55	114 52.53	7461.9	979403.27	38.49	0.19	2.01	-215.50	-10.05
04L021	38 50.02	114 53.07	7560.8	979395.25	40.55	0.47	2.49	-216.33	-11.22
04L022	38 49.33	114 53.03	7543.1	979396.23	40.88	0.60	2.46	-215.42	-10.60
04L023	38 47.85	114 53.44	7681.1	979387.76	47.55	0.40	2.34	-213.57	-9.39
04L024	38 47.77	114 52.38	7534.1	979392.71	38.81	0.31	1.85	-217.80	-13.41
04L025	38 47.81	114 51.37	7391.1	979395.14	27.75	0.22	1.49	-224.35	-19.82
04L026	38 44.98	114 50.10	6804.3	979426.50	8.13	0.29	1.68	-223.77	-19.88
04L027	38 44.53	114 52.13	6910.9	979425.22	17.53	0.75	1.97	-217.72	-14.35
04L028	38 35.39	114 48.91	6305.2	979459.53	8.36	0.09	1.08	-207.11	-7.10
04L029	38 35.50	114 50.18	6406.0	979456.93	15.07	0.18	1.10	-203.81	-3.97
04L030	38 35.86	114 52.27	6588.9	979443.53	18.33	0.07	1.00	-206.90	-7.29
04L031	38 35.36	114 52.98	6712.8	979436.52	23.70	0.20	1.20	-205.56	-6.38
04L032	38 34.95	114 53.53	6799.1	979428.44	24.33	0.41	1.49	-207.58	-8.75
04L033	38 34.37	114 54.15	6966.3	979415.23	27.69	0.18	1.43	-209.99	-11.64
04L034	38 33.92	114 54.67	6805.9	979421.95	20.00	0.68	2.00	-211.64	-13.53
04L035	38 32.46	114 56.03	6437.3	979451.65	17.20	1.11	3.52	-200.34	-3.03
04L036	38 32.19	114 57.01	6228.1	979466.71	13.00	1.00	3.37	-197.55	-0.48
04L037	38 32.19	114 58.01	6055.9	979476.67	6.78	0.91	2.75	-198.51	-1.60
04L038	38 32.02	114 59.00	5808.3	979487.84	-5.07	0.14	1.73	-202.92	-6.17
04L039	38 31.69	115 00.06	5595.3	979494.52	-17.93	0.07	1.25	-208.98	-12.55
04L040	38 31.36	115 01.11	5434.9	979490.97	-36.07	0.04	0.91	-221.97	-25.83

04L041	38 31.19	115 01.65	5378.9	979487.13	-44.92	0.03	0.77	-229.05	-33.04
04L042	38 31.49	115 00.70	5495.5	979493.22	-28.31	0.06	1.04	-216.16	-19.90
04L043	38 31.83	114 59.60	5691.3	979492.17	-11.46	0.09	1.42	-205.62	-9.06
04L044	38 37.16	114 50.88	6530.4	979449.28	16.67	0.04	0.90	-206.66	-6.21
04L045	38 46.99	114 50.56	6999.0	979414.63	11.60	0.40	1.60	-227.02	-22.51
04L046	38 46.47	114 51.93	7501.4	979386.94	31.88	0.91	2.36	-223.10	-19.17
04L047	38 46.38	114 48.72	7101.7	979412.32	19.84	0.72	2.03	-221.85	-17.42
04L048	38 46.56	114 47.53	7322.4	979402.61	30.60	1.16	2.55	-218.09	-13.60
04L049	38 43.15	114 50.70	6682.3	979437.29	10.15	0.14	1.46	-217.81	-14.75
04L050	38 42.59	114 49.87	6828.6	979425.85	13.28	0.19	1.49	-219.64	-16.75
04L051	38 40.09	114 50.05	6489.7	979448.37	7.63	0.08	1.35	-213.87	-11.96
04L052	38 37.72	114 48.64	6354.6	979454.94	4.99	0.02	1.33	-211.92	-10.84
04L053	38 38.77	114 48.10	6542.0	979446.17	12.29	0.19	1.84	-210.50	-8.97
04L054	38 38.23	114 47.96	6436.9	979451.77	8.81	0.14	1.81	-210.43	-9.05
04L055	38 37.23	114 47.52	6379.5	979451.26	4.37	0.09	1.75	-212.97	-12.00
04L056	38 35.95	114 47.13	6309.5	979453.38	1.79	0.07	1.62	-213.28	-12.78
04L057	38 34.30	114 47.31	6211.1	979459.51	1.10	0.04	1.27	-210.97	-11.27
04L058	38 32.59	114 47.11	6139.2	979460.46	-2.19	0.04	1.22	-211.86	-12.85
04L059	38 30.98	114 47.15	6105.4	979460.65	-2.81	0.05	1.09	-211.45	-13.22
04L060	38 28.13	114 47.89	6057.4	979460.03	-3.76	0.03	0.75	-211.10	-14.32
04L061	38 26.33	114 48.47	6013.5	979468.31	3.04	0.06	0.70	-202.85	-6.98
04L062	38 26.32	114 47.62	6078.0	979473.34	14.14	0.74	1.44	-193.21	2.79
04L063	38 26.67	114 49.47	6003.7	979454.50	-12.19	0.01	0.51	-217.93	-22.04
04L064	38 24.85	114 48.64	6011.1	979474.12	10.79	0.45	0.97	-194.74	0.38
04L065	38 22.32	114 49.25	6005.8	979474.74	14.63	1.44	1.98	-189.72	4.06
04L066	38 20.33	114 50.87	6041.1	979466.19	12.31	0.59	1.51	-193.71	-1.19
04L067	38 32.92	114 48.94	6149.3	979468.07	5.88	0.15	1.45	-203.90	-5.00
04L068	38 31.75	114 49.50	6091.4	979472.32	6.41	0.11	1.50	-201.34	-3.07
04L069	38 27.80	114 52.95	6024.0	979473.90	7.46	0.06	1.23	-198.27	-2.52
04L070	38 24.97	114 53.91	5982.1	979467.60	1.37	0.01	0.65	-203.50	-9.31
04L071	38 24.35	114 55.46	6238.1	979460.84	19.58	1.08	1.89	-192.79	0.74
04L072	38 24.31	114 55.33	6180.0	979464.28	17.62	0.80	1.61	-193.05	0.52
04L073	38 24.26	114 55.20	6121.1	979467.48	15.36	0.59	1.41	-193.50	0.07
04L074	38 24.21	114 55.06	6098.7	979468.53	14.38	0.38	1.19	-193.94	-0.36
04L075	38 24.17	114 54.92	6075.4	979471.35	15.06	0.27	1.06	-192.58	1.01
04L076	38 24.12	114 54.78	6050.6	979470.17	11.63	0.19	0.96	-195.27	-1.64
04L077	38 24.07	114 54.63	6028.3	979470.79	10.22	0.16	0.91	-195.97	-2.35
04L078	38 24.03	114 54.53	6000.0	979471.89	8.72	0.10	0.83	-196.57	-2.94
04L079	38 23.99	114 54.40	5984.0	979471.84	7.23	0.06	0.76	-197.59	-3.96
04L080	38 23.89	114 54.12	5977.4	979469.39	4.31	0.02	0.63	-200.42	-6.76
04L081	38 23.75	114 53.71	5978.7	979464.81	0.05	0.02	0.53	-204.82	-11.14
04L082	38 23.58	114 53.21	5977.4	979459.71	-4.92	0.01	0.44	-209.83	-16.15
04L083	38 23.35	114 52.57	5974.7	979454.76	-9.79	0.01	0.39	-214.66	-20.96
04L084	38 23.13	114 51.95	5973.3	979451.65	-12.71	0.01	0.37	-217.55	-23.86
04L085	38 22.97	114 51.49	5972.0	979450.92	-13.32	0.01	0.37	-218.12	-24.42
04L086	38 22.79	114 50.96	5974.3	979451.69	-12.07	0.01	0.40	-216.92	-23.20
04L087	38 22.65	114 50.55	5977.9	979454.22	-9.00	0.01	0.45	-213.92	-20.22
04L088	38 22.53	114 50.23	5979.2	979459.23	-3.69	0.03	0.53	-208.57	-14.86
04L089	38 22.48	114 50.08	5980.9	979462.03	-0.66	0.06	0.59	-205.54	-11.83
04L090	38 22.27	114 50.32	5979.0	979460.65	-1.91	0.03	0.56	-206.76	-13.21
04L091	38 22.40	114 49.86	5979.4	979466.46	3.75	0.16	0.71	-200.96	-7.27
04L092	38 22.33	114 49.66	5975.6	979470.77	7.81	0.34	0.91	-196.57	-2.85
04L093	38 22.26	114 49.44	5981.9	979473.66	11.39	0.67	1.24	-192.88	0.86
04L094	38 22.20	114 49.29	6003.0	979473.76	13.56	0.99	1.56	-191.11	2.60
04L095	38 22.14	114 49.11	6045.6	979471.70	15.59	1.32	1.88	-190.22	3.49
04L096	38 22.09	114 48.94	6100.5	979468.71	17.84	1.35	1.90	-189.83	3.85
04L097	37 26.25	114 44.18	5892.3	979419.52	30.66	0.26	1.78	-170.01	-9.36
04L098	37 25.48	114 44.29	5772.6	979426.45	27.46	0.52	1.99	-168.90	-8.96

04L099	37 25.97	114 45.04	5667.7	979428.72	19.16	0.93	2.38	-173.24	-12.87
04L100	37 26.30	114 45.75	5557.5	979434.42	14.02	1.34	2.77	-174.21	-13.58
04L101	37 26.52	114 46.22	5485.9	979437.92	10.47	1.71	3.15	-174.94	-14.14
04L102	37 26.52	114 46.99	5379.1	979444.86	7.37	1.76	3.08	-174.45	-13.69
04L103	37 26.93	114 50.40	4889.4	979461.31	-22.80	0.05	0.74	-190.21	-29.28
04L104	37 19.68	114 53.02	4665.6	979474.54	-20.07	0.02	0.65	-179.91	-25.78
04L105	37 19.82	114 54.12	4603.3	979477.79	-22.88	0.02	0.55	-180.68	-26.44
04L106	37 19.02	114 55.77	4532.3	979481.93	-24.25	0.01	0.51	-179.66	-26.22
04L107	37 19.60	114 57.11	4542.8	979484.48	-21.55	0.02	0.43	-177.40	-23.44
04L108	37 18.75	114 56.23	4543.5	979482.29	-22.44	0.01	0.50	-178.25	-25.06
04L109	37 19.55	114 56.07	4536.7	979480.02	-26.51	0.00	0.43	-182.15	-28.22
04L110	37 39.69	114 44.40	5016.9	979491.57	0.86	0.23	0.83	-170.83	-0.07
04L111	37 41.28	114 44.94	4774.4	979499.16	-16.66	0.08	0.58	-180.30	-8.54
04L112	37 42.09	114 44.55	4788.3	979501.51	-14.19	0.11	0.61	-178.27	-6.01
04L113	37 42.91	114 44.15	4772.1	979506.56	-11.86	0.34	0.85	-175.14	-2.35
04L114	37 44.16	114 43.52	4853.0	979507.11	-5.52	0.17	0.70	-171.74	1.85
04L115	37 45.05	114 43.04	4829.6	979510.21	-5.92	0.63	1.16	-170.87	3.38
04L116	37 45.81	114 42.63	4955.6	979503.73	-1.67	0.93	1.41	-170.68	4.07
04L117	37 47.25	114 41.18	4991.3	979502.23	-1.91	0.21	0.70	-172.85	3.08
04L118	37 47.36	114 40.27	5085.9	979494.96	-0.45	0.08	0.63	-174.70	1.42
04L119	37 47.20	114 39.38	5188.4	979487.27	1.73	0.11	0.70	-175.95	0.28
04L120	37 46.58	114 37.22	5375.6	979478.36	11.32	0.12	0.75	-172.72	3.48
04L121	37 47.58	114 36.20	5571.4	979466.60	16.50	0.28	1.00	-173.98	3.08
04L122	37 48.06	114 35.04	5736.4	979454.69	19.40	0.08	0.91	-176.82	0.70
04L123	37 48.64	114 34.58	5882.3	979454.69	32.26	0.12	1.17	-168.67	9.28
04L124	37 49.34	114 34.94	6060.2	979436.36	29.63	0.35	1.73	-176.82	1.38
04L125	37 49.31	114 34.21	6093.9	979436.65	33.13	0.68	2.10	-174.10	4.24
04L126	37 51.22	114 36.00	6373.2	979420.44	40.38	1.98	4.34	-174.15	4.95
04L127	37 51.60	114 36.09	6442.4	979416.91	42.80	1.69	4.29	-174.15	5.10
04L128	37 52.56	114 35.80	6887.2	979387.82	54.11	3.68	7.30	-175.01	4.77
04L129	37 52.93	114 36.37	6649.6	979404.16	47.58	2.17	5.57	-175.16	4.81
04L130	37 54.10	114 36.46	6743.7	979397.80	48.35	2.51	5.97	-177.20	3.43
04L131	37 54.56	114 36.33	6846.3	979392.15	51.67	2.63	6.17	-177.17	3.71
04L132	37 54.99	114 35.94	7037.0	979378.41	55.22	5.00	8.61	-177.68	3.49
04L133	37 55.59	114 36.34	6891.6	979389.78	52.05	1.69	4.84	-179.67	1.86
04L134	37 54.99	114 36.78	6603.6	979407.81	43.89	0.86	3.88	-178.96	2.18
04L135	37 55.10	114 37.46	6323.9	979426.10	35.74	0.34	2.73	-178.72	2.40
04L136	37 55.13	114 38.29	6065.5	979439.15	24.46	0.25	2.10	-181.81	-0.75
04L137	37 54.50	114 39.24	5751.0	979456.60	13.27	0.19	1.68	-182.67	-2.13
04L138	37 53.21	114 39.89	5423.6	979480.87	8.66	0.37	1.57	-176.20	3.54
04L139	37 52.16	114 39.60	5370.5	979482.96	7.29	0.13	1.30	-176.02	3.14
04L140	37 51.82	114 38.95	5498.7	979474.51	11.39	0.15	1.46	-176.15	2.92
04L141	37 51.16	114 39.67	5303.6	979485.12	4.62	0.12	1.15	-176.56	1.98
04L142	37 50.65	114 41.42	4951.5	979499.26	-13.59	0.06	0.70	-183.16	-5.15
04L143	37 52.10	114 43.24	4747.4	979509.54	-24.61	0.07	0.59	-187.31	-8.78
04L144	37 58.83	114 41.13	5170.3	979492.44	-11.80	0.21	1.18	-188.38	-5.44
04L145	37 58.48	114 38.21	5913.8	979446.75	12.91	0.30	2.04	-188.24	-5.08
04L146	37 58.36	114 37.09	6323.5	979424.69	29.53	0.75	2.94	-184.71	-1.51
04L147	37 58.62	114 36.10	6766.3	979397.24	43.31	2.16	4.64	-184.34	-0.85
04L148	38 04.91	114 44.81	5114.5	979494.81	-23.56	0.02	0.43	-198.99	-13.30
04L149	38 11.21	114 47.23	5482.3	979483.06	-9.97	0.05	0.37	-198.03	-9.48
04L150	38 11.78	114 48.04	5422.8	979485.39	-14.06	0.04	0.38	-200.09	-11.34
04L151	38 13.35	114 50.86	5696.7	979470.59	-5.42	0.18	0.82	-200.36	-11.39
04L152	38 13.95	114 52.53	6159.9	979454.26	20.90	0.75	1.49	-189.20	-0.31
04L153	38 13.99	114 53.57	6324.6	979443.96	26.02	0.44	1.22	-189.97	-1.27
04L154	38 14.67	114 55.23	6084.5	979455.60	14.10	0.06	0.55	-194.36	-5.53
04L155	38 15.42	114 56.73	5916.8	979465.10	6.74	0.03	0.40	-196.14	-7.08
04L156	38 15.93	114 57.87	5925.8	979464.02	5.76	0.07	0.40	-197.44	-8.31

04L157	38 07.50	114 49.63	5110.6	979502.49	-20.04	0.08	0.41	-195.35	-9.18
04L158	38 06.29	114 49.62	5095.3	979499.39	-22.81	0.03	0.28	-197.72	-12.23
04L159	38 05.69	114 49.33	5068.2	979499.31	-24.56	0.03	0.27	-198.55	-13.34
04L160	38 05.06	114 48.92	5042.5	979501.72	-23.64	0.03	0.27	-196.76	-11.80
04L161	38 04.41	114 48.60	5016.3	979506.53	-20.34	0.03	0.26	-192.57	-7.92
04L162	38 03.96	114 48.82	4999.8	979509.78	-17.98	0.01	0.24	-189.67	-5.29
04L163	38 02.29	114 50.72	5105.9	979506.22	-9.13	0.04	0.30	-184.39	-1.29
04L164	38 02.88	114 47.44	4946.7	979502.67	-28.51	0.03	0.28	-198.34	-14.30
04L165	38 01.55	114 46.39	4890.1	979502.00	-32.55	0.02	0.31	-200.42	-16.95
04L166	38 00.80	114 45.97	4851.9	979504.74	-32.30	0.01	0.33	-198.84	-15.69
04L167	37 59.80	114 49.06	4854.0	979518.34	-17.04	0.03	0.37	-183.62	-1.63
04L168	37 58.94	114 49.29	4853.3	979517.82	-16.37	0.03	0.37	-182.92	-1.46
04L169	37 47.27	114 50.59	4667.7	979511.04	-23.55	0.03	0.40	-183.72	-9.21
04L170	37 42.47	114 51.22	4813.9	979495.20	-18.65	0.04	0.42	-183.79	-12.25
04L171	37 41.72	114 52.94	5077.1	979482.97	-5.04	0.09	0.63	-178.99	-8.18
04L172	37 40.99	114 52.99	5051.4	979485.00	-4.36	0.16	0.69	-177.37	-6.98
04L173	37 41.81	114 54.42	5307.5	979476.43	9.94	0.26	1.13	-171.38	-0.70
04L174	37 41.90	114 55.19	5422.0	979471.07	15.21	0.49	1.59	-169.57	1.02
04L175	37 42.31	114 55.71	5547.5	979461.32	16.66	1.29	2.32	-171.68	-0.92
04L176	37 42.63	114 56.27	5680.1	979450.02	17.36	2.29	3.25	-174.59	-3.73
04L177	37 43.79	114 56.90	5851.1	979439.51	21.23	0.50	1.47	-178.35	-6.89
04L178	37 44.45	114 57.20	5793.2	979443.71	19.02	0.56	1.44	-178.60	-6.71
04L179	37 45.05	114 58.01	5571.1	979458.41	11.97	0.27	0.99	-178.51	-6.29
04L180	37 45.50	114 58.65	5453.6	979465.70	7.56	0.31	0.93	-178.96	-6.45
04L181	37 45.06	114 59.90	5335.5	979470.44	1.84	0.09	0.61	-180.96	-8.70
04L182	37 43.76	114 59.82	5270.0	979477.98	5.12	0.61	1.23	-174.82	-3.35
04L183	37 36.73	114 43.41	5673.5	979443.44	18.76	0.36	1.35	-174.87	-6.02
04L184	37 36.35	114 44.23	5663.9	979444.49	19.46	0.50	1.52	-173.66	-5.21
04L185	37 35.93	114 44.57	5780.1	979434.97	21.47	0.53	1.65	-175.50	-7.35
04L186	37 34.50	114 45.28	5829.9	979425.16	18.43	0.38	1.66	-180.23	-13.19
04L187	37 33.65	114 46.30	5934.9	979415.36	19.73	0.49	1.93	-182.24	-15.98
04L188	37 34.26	114 46.34	5774.7	979427.40	15.83	0.44	1.66	-180.94	-14.25
04L189	37 33.22	114 47.25	5735.6	979425.06	11.33	0.19	1.45	-184.32	-18.42
04L190	37 32.73	114 48.48	5495.4	979432.81	-2.78	0.14	1.12	-190.55	-25.05
04C001	37 37.66	114 30.57	4443.3	979515.13	-26.54	1.14	2.33	-177.08	-5.02
04C002	37 40.11	114 29.29	4603.4	979502.29	-27.90	0.22	1.17	-185.09	-11.14
04C003	37 39.58	114 29.61	4479.1	979509.40	-31.70	0.54	1.81	-183.99	-10.40
04C004	37 36.50	114 50.97	4838.2	979473.28	-29.58	0.02	0.37	-195.61	-27.70
04C005	37 35.93	114 51.32	4850.9	979471.41	-29.42	0.01	0.36	-195.89	-28.36
04C006	37 35.55	114 51.52	4857.9	979470.36	-29.26	0.02	0.38	-195.96	-28.70
04C007	37 36.29	114 50.75	4867.6	979471.30	-28.49	0.03	0.39	-195.51	-27.70
04C008	37 35.27	114 51.04	4917.5	979467.65	-25.96	0.03	0.41	-194.66	-27.53
04C009	37 36.50	114 50.06	4906.0	979470.13	-26.36	0.03	0.40	-194.68	-26.68
04C010	37 36.51	114 49.27	4981.0	979465.68	-23.77	0.04	0.46	-194.60	-26.50
04C011	37 36.51	114 48.50	5050.0	979463.85	-19.11	0.06	0.56	-192.20	-24.02
04C012	37 33.10	114 48.29	5525.5	979433.69	0.39	0.12	1.09	-188.43	-22.65
04C013	37 14.79	114 58.16	4257.9	979507.52	-18.31	2.43	3.76	-161.07	-11.59
04C014	37 15.25	114 57.76	4403.3	979497.28	-15.55	1.01	2.21	-164.84	-14.96
04C015	37 15.63	114 57.42	4675.7	979478.49	-9.28	0.29	1.31	-168.81	-18.66
04C016	37 16.14	114 57.17	4620.6	979480.71	-12.98	0.12	1.02	-170.91	-20.27
04C017	37 17.24	114 56.64	4573.6	979483.44	-16.27	0.04	0.73	-172.88	-21.16
04C018	37 17.76	114 56.99	4549.3	979486.14	-16.61	0.03	0.60	-172.51	-20.26
04C019	37 18.38	114 57.27	4539.9	979484.24	-20.29	0.01	0.50	-175.98	-23.17
04C020	37 18.74	114 57.11	4541.5	979483.80	-21.11	0.01	0.47	-176.88	-23.73
04C021	37 18.60	114 57.66	4535.9	979485.44	-19.79	0.04	0.50	-175.33	-22.31
04C022	37 18.93	114 57.88	4539.1	979486.55	-18.86	0.11	0.55	-174.46	-21.14
04C023	37 20.34	114 58.13	4577.6	979483.03	-20.81	0.15	0.56	-177.72	-23.10
04C024	37 21.12	114 58.26	4656.3	979479.28	-18.29	0.18	0.64	-177.83	-22.55

04C025	37 35.82	114 43.63	6294.4	979397.82	32.82	2.58	4.53	-178.83	-10.87
04C026	37 35.89	114 41.99	6337.8	979395.15	34.13	1.07	2.84	-180.70	-12.40
04C027	37 35.33	114 44.60	6098.3	979411.93	29.21	0.80	2.36	-177.91	-10.28
04C028	37 36.02	114 44.80	5994.2	979423.91	30.40	1.00	2.51	-173.02	-4.93
04C029	37 34.75	114 42.87	6758.6	979362.93	43.11	1.40	4.55	-184.36	-17.14
04C030	37 32.85	114 45.64	6730.2	979361.12	41.40	3.32	6.80	-182.85	-17.33
04C031	37 31.52	114 44.82	6804.8	979355.94	45.17	1.27	4.49	-183.94	-19.31
04C032	37 31.52	114 46.24	6941.1	979344.14	46.18	5.15	10.09	-181.98	-17.60
04C033	37 30.06	114 45.70	6924.0	979341.91	44.46	7.87	12.35	-180.85	-17.53
04C034	37 27.36	114 44.49	6409.8	979382.71	40.87	2.20	4.52	-174.72	-13.31
04C035	37 26.38	114 44.47	6135.1	979402.71	36.48	1.08	2.83	-171.43	-10.80
04C036	37 24.64	114 46.70	6524.5	979368.34	41.24	6.56	10.84	-171.96	-13.25
04C037	37 23.40	114 46.60	5907.6	979412.33	29.06	1.75	3.76	-170.16	-12.38
04C038	37 22.57	114 47.00	5722.9	979419.99	20.56	2.42	4.21	-171.89	-14.91
04C039	37 21.48	114 47.18	5758.7	979409.90	15.42	2.06	3.95	-178.51	-22.61
04C040	37 19.72	114 47.88	6692.7	979345.96	41.82	7.45	13.71	-174.25	-20.47
04C041	37 18.06	114 48.01	5552.2	979421.12	12.20	0.95	2.82	-175.81	-23.39
04C042	37 19.34	114 50.32	5239.3	979440.90	0.71	1.84	3.06	-176.35	-22.64
04C043	37 18.30	114 51.13	5659.8	979414.14	14.99	3.58	5.91	-173.61	-21.08
04C044	37 17.48	114 51.64	5842.8	979404.53	23.77	4.80	7.73	-169.26	-17.62
04C045	37 17.81	114 52.95	5483.9	979430.41	15.44	3.64	5.55	-167.51	-15.46
04C046	37 20.65	114 55.84	4710.5	979466.28	-25.52	1.37	1.88	-185.66	-30.72
04C047	37 17.15	114 55.88	4637.6	979482.09	-11.47	0.07	0.97	-170.04	-18.40
04C048	37 16.15	114 56.38	4639.6	979480.95	-10.97	0.18	1.24	-169.33	-18.71
04C049	37 14.52	114 56.90	5804.8	979401.07	21.04	3.61	8.40	-170.02	-21.25
04C050	37 14.52	114 58.74	4986.9	979455.74	-1.17	4.52	6.46	-166.20	-17.12
04C051	37 15.45	115 00.10	5795.9	979397.56	15.34	5.56	12.06	-171.76	-21.96
04C052	37 16.25	114 59.30	5507.3	979418.68	8.17	3.88	7.48	-173.63	-23.08
04C053	37 16.91	114 58.43	5224.7	979440.72	2.69	1.65	3.65	-173.29	-22.02
04C054	37 17.65	114 59.36	5060.0	979452.50	-2.08	1.27	2.84	-173.23	-21.21
04C055	37 22.79	114 56.74	4730.8	979475.05	-17.95	0.37	0.86	-179.81	-23.01
04C056	37 21.66	114 56.96	4643.0	979478.68	-20.93	0.40	0.83	-179.82	-24.01
04C057	37 19.79	114 59.21	5012.0	979452.44	-9.77	2.41	3.64	-178.47	-24.51
04C058	37 21.20	114 59.69	4994.1	979456.00	-9.94	1.72	2.81	-178.86	-23.62
04C059	37 25.26	115 00.51	6368.2	979373.00	30.31	7.61	13.01	-175.39	-17.14
04C060	37 26.61	115 00.15	6073.4	979399.36	27.00	2.45	5.42	-176.22	-16.71
04C061	37 27.92	114 59.11	5801.2	979411.85	12.00	0.50	2.48	-184.86	-24.23
04C062	37 28.00	114 56.80	5707.6	979413.22	4.46	3.86	6.10	-185.58	-24.67
04C063	37 29.09	114 58.40	5925.3	979400.62	10.73	2.96	5.33	-187.51	-25.93
04C064	37 28.70	115 00.46	6001.4	979404.77	22.60	1.04	3.59	-179.99	-18.84
04C065	37 30.92	115 00.76	5685.5	979426.99	11.90	1.44	3.46	-180.02	-17.17
04C066	37 32.97	114 54.40	5110.4	979451.99	-20.14	1.14	1.50	-194.36	-29.29
04C067	37 33.26	114 59.84	5462.2	979435.10	-4.39	1.75	2.75	-189.39	-24.70
04C068	37 34.96	115 00.72	5391.4	979448.38	-0.24	0.99	1.80	-183.76	-17.91
04C069	37 36.51	115 00.71	5223.6	979461.63	-5.02	0.52	1.02	-183.58	-16.66
04C070	37 37.41	114 54.00	5213.6	979457.39	-11.51	0.58	0.96	-189.80	-21.76
04C071	37 40.33	114 52.41	5535.5	979445.35	2.45	2.17	3.14	-184.66	-14.82
04C072	37 40.68	114 56.70	6535.8	979387.70	38.30	0.88	4.44	-181.68	-12.29
04C073	37 42.66	114 54.61	5993.0	979428.49	25.19	2.62	4.31	-176.39	-5.48
04C074	37 44.59	114 56.33	6002.5	979431.83	26.61	0.54	1.77	-177.84	-5.90
04C075	37 45.75	114 56.59	6561.0	979391.16	36.73	3.67	6.94	-181.61	-9.20
04C076	37 46.87	114 56.91	6622.6	979386.43	36.16	4.78	8.41	-182.82	-9.80
04C077	37 45.25	114 54.51	5990.6	979429.43	22.13	4.57	6.19	-177.49	-5.03
04C078	38 00.13	114 49.38	5004.0	979511.55	-10.22	0.47	0.72	-181.57	0.51
04C079	37 59.86	114 52.46	5924.3	979446.29	11.42	1.76	2.85	-189.28	-8.12
04C080	37 58.72	114 53.38	6434.0	979411.34	26.03	2.73	5.60	-189.31	-9.05
04C081	37 57.61	114 53.55	6292.6	979419.99	23.02	2.68	5.07	-188.03	-8.39
04C082	37 57.21	114 54.36	6169.7	979429.69	21.75	2.30	4.14	-186.03	-6.63

04C083	37 56.46	114 51.96	5550.4	979470.24	5.19	1.59	2.23	-183.33	-3.90
04C084	37 53.30	114 55.72	6551.8	979398.39	32.08	4.40	8.00	-184.89	-8.03
04C085	37 52.52	114 56.00	6419.6	979408.23	30.63	3.52	6.38	-183.44	-6.99
04C086	37 49.12	114 56.53	6121.0	979427.75	27.05	2.12	3.76	-179.45	-4.93
04C087	37 47.89	114 56.38	6562.0	979393.99	36.53	4.42	7.82	-180.96	-7.27
04C088	37 43.62	114 54.11	5579.6	979456.82	13.27	0.93	1.80	-176.70	-5.04
04C089	37 58.31	114 40.64	5689.1	979462.65	7.94	1.83	3.02	-184.55	-2.02
04C090	37 56.47	114 40.13	6618.1	979402.26	37.54	5.93	9.97	-179.72	1.50
04C092	37 55.72	114 41.36	5762.7	979456.97	12.96	3.45	5.02	-180.04	0.78
04C093	37 54.88	114 41.36	5729.8	979457.96	12.09	4.00	5.50	-179.31	1.00
04C094	37 54.13	114 41.05	5408.7	979480.82	5.86	1.11	2.17	-177.89	2.16
04C095	37 50.21	114 38.02	6105.3	979436.50	32.74	1.99	3.76	-173.23	4.83
04C096	37 49.14	114 36.91	6182.4	979431.06	36.11	1.76	3.38	-172.88	4.71
04C097	37 46.50	114 33.56	6139.1	979433.87	38.70	1.73	3.21	-168.97	7.77
04C098	37 36.74	114 47.17	5060.1	979475.16	-7.19	0.24	0.94	-180.24	-11.76
04C099	37 34.29	114 48.37	5355.1	979442.36	-8.69	0.10	0.86	-191.92	-25.31
04C100	37 28.93	114 50.23	4988.1	979454.18	-23.56	0.06	0.75	-194.34	-31.78
04C101	37 28.32	114 50.34	4961.4	979456.66	-22.71	0.06	0.75	-192.58	-30.56
04C102	37 20.10	114 50.92	4802.5	979467.65	-14.70	0.06	0.94	-178.94	-24.32
04C103	37 20.59	114 50.44	4870.2	979463.10	-13.60	0.12	1.05	-180.04	-24.94
04C104	37 17.78	114 49.72	4996.4	979454.73	-6.02	0.06	1.31	-176.53	-24.30
04C105	37 17.17	114 47.28	5545.7	979421.92	13.69	1.33	3.42	-173.50	-22.05
04C106	37 17.17	114 47.88	5367.7	979433.90	8.94	0.71	2.61	-172.97	-21.44
04C107	37 17.48	114 48.45	5213.1	979442.47	2.52	0.44	2.08	-174.62	-22.75
04C108	37 14.64	114 50.26	5431.5	979439.00	23.71	1.28	2.83	-160.16	-11.36
04C109	37 13.86	114 52.48	5105.0	979460.22	15.37	0.31	1.53	-158.63	-10.50
04C110	37 14.11	114 51.96	5102.8	979462.88	17.46	0.30	1.55	-156.44	-8.09
04C111	37 14.35	114 51.51	5165.2	979460.99	21.09	0.46	1.73	-154.77	-6.21
04C112	37 14.68	114 51.17	5222.9	979455.24	20.28	0.54	1.82	-157.46	-8.55
04C113	37 14.93	114 50.86	5283.6	979449.52	19.90	0.59	1.92	-159.81	-10.64
04C114	37 15.31	114 50.66	5364.1	979444.38	21.78	0.57	1.99	-160.63	-11.13
04C115	37 15.78	114 50.36	5298.4	979444.96	15.50	0.52	1.87	-164.77	-14.75
04C116	37 16.24	114 50.12	5165.1	979452.42	9.76	0.53	1.85	-165.97	-15.43
04C117	37 17.24	114 50.26	5004.1	979455.78	-3.46	0.09	1.28	-174.26	-22.63
04C118	37 17.80	114 50.21	4957.3	979459.14	-5.32	0.15	1.26	-174.53	-22.28
04C119	37 18.85	114 50.18	4886.5	979465.24	-7.40	0.41	1.49	-173.95	-20.60
04C120	37 19.36	114 50.68	4833.5	979468.82	-9.54	0.35	1.31	-174.46	-20.61
04C121	37 19.39	114 51.53	4773.0	979470.27	-13.82	0.08	0.91	-177.07	-23.20
04C122	37 19.75	114 53.52	4634.4	979476.29	-21.35	0.01	0.59	-180.18	-25.99
04C123	37 19.89	114 54.63	4575.4	979478.29	-25.10	0.01	0.50	-182.00	-27.71
04C124	37 20.04	114 55.84	4538.9	979478.94	-28.10	0.01	0.43	-183.82	-29.40
04C125	37 20.41	114 56.32	4538.4	979484.36	-23.26	0.20	0.60	-178.79	-24.06
04C126	37 20.84	114 57.46	4598.2	979482.77	-19.86	0.06	0.48	-177.56	-22.47
04C127	37 22.10	114 58.10	4830.2	979469.19	-13.46	0.47	1.06	-178.53	-22.42
04C128	37 22.78	114 58.12	4879.5	979465.45	-13.56	0.28	0.93	-180.44	-23.73
04C129	37 23.28	114 58.06	4825.1	979468.47	-16.38	0.25	0.85	-181.47	-24.31
04C130	37 23.69	114 57.50	4770.6	979472.18	-18.39	0.09	0.65	-181.82	-24.25
04C131	37 23.95	114 56.90	4719.2	979478.23	-17.55	0.04	0.56	-179.31	-21.44
04C132	37 24.16	114 56.40	4667.4	979480.44	-20.51	0.12	0.60	-180.46	-22.39
04C133	37 20.79	114 56.21	4555.7	979483.02	-23.53	0.36	0.77	-179.49	-24.40
04C134	37 21.39	114 56.20	4543.8	979483.60	-24.94	0.46	0.87	-180.38	-24.72
04C135	37 22.02	114 56.12	4544.4	979482.86	-26.54	0.24	0.66	-182.22	-26.02
04C136	37 22.70	114 55.91	4552.8	979480.31	-29.29	0.32	0.75	-185.16	-28.30
04C137	37 23.26	114 55.82	4564.8	979479.58	-29.71	0.19	0.62	-186.12	-28.76
04C138	37 23.80	114 55.75	4604.6	979477.60	-28.73	0.13	0.56	-186.57	-28.76
04C139	37 24.05	114 54.02	4579.1	979467.81	-41.28	0.00	0.43	-198.37	-40.19
04C140	37 24.18	114 55.37	4607.0	979474.90	-31.76	0.02	0.45	-189.79	-31.62
04C141	37 24.62	114 56.19	4658.7	979479.12	-23.32	0.03	0.51	-183.06	-24.57

04C142	37 24.37	114 57.18	4768.5	979474.32	-17.43	0.05	0.62	-180.82	-22.63
04C143	37 24.67	114 56.76	4717.5	979478.51	-18.47	0.05	0.58	-180.16	-21.70
04C144	37 25.57	114 55.63	4649.8	979476.48	-28.18	0.03	0.51	-187.61	-28.27
04C145	37 26.06	114 54.27	4619.5	979470.45	-37.77	0.00	0.44	-196.24	-36.34
04C146	37 26.33	114 53.56	4636.3	979467.31	-39.72	0.00	0.45	-198.76	-38.59
04C147	37 26.11	114 52.35	4664.0	979463.92	-40.19	0.03	0.54	-200.08	-39.99
04C148	37 34.28	114 48.37	5360.1	979442.34	-8.23	0.09	0.85	-191.63	-25.03
04C149	37 26.11	114 52.36	4661.8	979463.94	-40.37	0.03	0.54	-200.19	-40.10
04C150	37 23.49	114 50.19	4777.5	979463.04	-26.59	0.05	0.85	-190.06	-32.13
04C151	37 24.23	114 50.03	4777.4	979464.10	-26.61	0.03	0.83	-190.09	-31.47
04C152	37 24.28	114 50.77	4721.5	979462.97	-33.07	0.02	0.71	-194.76	-36.14
04C153	37 24.74	114 52.08	4637.2	979462.99	-41.64	0.01	0.55	-200.61	-41.68
04C154	37 24.05	114 54.02	4572.0	979467.90	-41.86	0.01	0.44	-198.70	-40.51
04C155	37 19.88	114 54.63	4580.9	979478.40	-24.46	0.01	0.50	-181.55	-27.27
04C156	37 20.16	114 52.06	4710.5	979468.86	-22.22	0.01	0.70	-183.55	-28.89
04C157	37 19.25	114 52.28	4705.2	979473.62	-16.64	0.04	0.82	-177.66	-23.95
04C158	37 24.16	114 56.40	4668.4	979480.42	-20.44	0.11	0.59	-180.43	-22.36
04C159	37 22.10	114 58.09	4828.8	979469.12	-13.66	0.49	1.08	-178.66	-22.55
04C160	37 23.28	114 58.06	4825.7	979468.48	-16.31	0.25	0.85	-181.43	-24.27
04C161	37 23.69	114 57.50	4766.8	979472.17	-18.75	0.09	0.65	-182.06	-24.49
04C162	37 23.95	114 56.90	4714.9	979478.22	-17.96	0.04	0.56	-179.58	-21.71
04C163	37 25.53	114 56.42	4731.3	979477.32	-19.62	0.19	0.74	-181.61	-22.39
04C164	37 26.36	114 56.05	4722.7	979476.32	-22.63	0.08	0.64	-184.43	-24.48
04C165	37 26.91	114 55.70	4665.0	979478.78	-26.40	0.10	0.67	-186.19	-25.75
04C166	37 27.72	114 54.94	4691.7	979474.66	-29.18	0.02	0.54	-190.03	-28.87
04C167	37 28.11	114 54.54	4725.5	979471.68	-29.55	0.01	0.49	-191.61	-30.13
04C168	37 29.10	114 53.66	4766.4	979467.97	-30.86	0.01	0.44	-194.36	-31.97
04C169	37 30.00	114 52.95	4763.2	979469.72	-30.72	0.01	0.45	-194.11	-30.97
04C170	37 30.23	114 55.82	4961.3	979463.30	-18.86	0.12	0.58	-188.89	-25.93
04C171	37 30.11	114 54.85	4895.7	979463.45	-24.70	0.03	0.44	-192.62	-29.65
04C172	37 30.03	114 54.27	4851.1	979464.46	-27.76	0.01	0.42	-194.19	-31.16
04C173	37 29.94	114 53.63	4799.9	979467.08	-29.82	0.01	0.42	-194.49	-31.43
04C174	37 29.86	114 52.25	4775.7	979466.77	-32.29	0.03	0.51	-196.04	-32.95
04C175	37 29.70	114 51.31	4863.5	979460.68	-29.90	0.03	0.58	-196.58	-33.48
04C176	37 30.37	114 52.47	4783.1	979469.24	-29.87	0.03	0.49	-193.89	-30.42
04C177	37 31.32	114 52.05	4836.1	979466.89	-28.62	0.03	0.50	-194.45	-30.27
04C178	37 32.05	114 52.49	4821.1	979470.46	-27.52	0.02	0.44	-192.89	-28.20
04C179	37 31.62	114 51.08	4964.1	979458.69	-25.23	0.04	0.57	-195.37	-30.86
04C180	37 32.37	114 51.67	4912.3	979462.93	-26.95	0.04	0.49	-195.39	-30.40
04C181	37 32.93	114 50.73	5073.0	979454.48	-21.11	0.05	0.56	-194.99	-29.48
04C182	37 34.19	114 52.25	4869.2	979468.45	-28.13	0.02	0.38	-195.21	-29.02
04C183	37 34.98	114 52.98	4839.7	979472.43	-28.07	0.00	0.32	-194.20	-27.52
04C184	37 35.32	114 53.31	4863.3	979472.10	-26.68	0.01	0.30	-193.63	-26.76
04C185	37 35.73	114 53.66	4895.7	979471.44	-24.89	0.01	0.28	-192.98	-25.84
04C186	37 36.37	114 54.25	4961.4	979470.96	-20.13	0.02	0.28	-190.46	-23.04
04C187	37 37.20	114 45.07	5313.1	979468.89	9.65	0.39	1.20	-171.80	-2.80
04C188	37 36.03	114 41.69	6070.4	979414.11	27.75	0.61	1.80	-178.98	-10.45
04C189	37 34.29	114 48.37	5370.7	979442.36	-7.23	0.09	0.85	-190.99	-24.39
04C190	37 36.38	114 54.25	4966.0	979470.99	-19.68	0.02	0.28	-190.17	-22.75
04C191	37 54.74	114 51.85	4988.6	979509.56	-5.78	0.08	0.44	-176.89	1.71
04C192	37 55.06	114 52.30	5044.2	979504.69	-5.89	0.08	0.46	-178.88	-0.18
04C193	37 55.84	114 52.78	5164.1	979500.52	0.07	0.09	0.48	-177.00	2.08
04C194	37 56.18	114 53.18	5272.2	979494.06	3.28	0.22	0.63	-177.34	1.88
04C195	37 55.55	114 54.44	5281.4	979492.81	3.81	0.09	0.51	-177.24	1.45
04C196	37 55.63	114 53.90	5246.8	979495.29	2.92	0.17	0.59	-176.87	1.95
04C197	37 55.52	114 53.41	5199.1	979498.20	1.51	0.07	0.48	-176.76	2.05
04C198	37 54.83	114 52.50	5055.7	979503.58	-5.58	0.05	0.44	-178.98	-0.42
04C199	37 55.02	114 52.92	5100.7	979502.48	-2.73	0.05	0.47	-177.64	0.95

04C200	37 54.91	114 53.37	5176.3	979498.68	0.74	0.07	0.49	-176.74	1.73
04C201	37 53.67	114 52.26	4977.5	979510.79	-4.03	0.09	0.51	-174.68	3.23
04C202	37 53.47	114 53.80	5322.7	979486.84	4.76	0.45	1.00	-177.22	0.36
04C203	37 53.31	114 53.40	5226.8	979490.83	-0.03	0.44	0.94	-178.78	-1.23
04C204	37 52.92	114 52.84	5074.0	979500.13	-4.52	0.36	0.82	-178.17	-0.77
04C205	37 52.46	114 52.77	5035.4	979502.94	-4.67	0.45	0.91	-176.90	0.22
04C206	37 51.27	114 52.36	4929.4	979506.36	-9.47	0.07	0.49	-178.50	-1.96
04C207	37 51.29	114 50.94	4772.8	979510.46	-20.12	0.03	0.34	-183.94	-7.16
04C208	37 52.00	114 48.26	4617.8	979504.12	-42.07	0.00	0.25	-200.67	-23.10
04C209	37 51.93	114 49.59	4678.3	979517.33	-23.07	0.01	0.27	-183.73	-6.38
04C210	37 52.45	114 50.71	4751.7	979515.12	-19.14	0.02	0.35	-182.23	-4.74
04C211	37 49.29	114 50.67	4714.7	979511.69	-21.43	0.02	0.33	-183.27	-7.64
04C212	37 49.37	114 51.68	4831.5	979504.40	-17.86	0.04	0.40	-183.63	-8.14
04C213	37 36.38	114 54.25	4963.8	979470.98	-19.90	0.02	0.28	-190.31	-22.88

Table A2. Physical property measurements of rock samples collected in 2003 and 2004.

Station	Rock type	Grain density (g/cm^3)	Saturated bulk density (g/cm^3)	Dry bulk density (g/cm^3)	Porosity (%)	Susceptibility (10^{-3} SI)
03L002	Carbonate	2.71	2.70	2.69	0.7	0.02
03L003	Carbonate	2.67	2.67	2.67	0.2	0.03
03L004	Interm. Volcanic	2.64	2.62	2.62	0.8	12.00
03L005	Felsic Volcanic	2.44	2.41	2.40	1.8	3.83
03L009	Carbonate	2.70	2.70	2.69	0.3	0.01
03L010	Sandstone	2.42	2.37	2.34	3.6	0.03
03L038	Quartzite	2.64	2.62	2.61	1.1	0.03
03L039	Felsic Volcanic	2.56	2.52	2.49	3.1	0.04
03L012	Carbonate	2.82	2.79	2.77	1.7	0.02
03L013	Carbonate	2.66	2.59	2.55	4.0	0.01
03L014	Carbonate	2.68	2.64	2.62	2.3	0.02
03L016	Carbonate	2.70	2.69	2.69	0.3	0.01
03L017	Carbonate	2.70	2.69	2.68	0.7	0.02
03L018	Granite	2.51	2.49	2.47	1.4	0.15
03L019	Interm. Volcanic	2.43	2.41	2.40	1.4	0.27
03L020	Felsic Volcanic	2.55	2.51	2.48	2.9	5.32
03L021	Carbonate	2.69	2.64	2.62	2.7	0.04
03L034	Sandstone	2.62	2.59	2.57	1.9	0.03
03L037	Sandstone	2.60	2.59	2.59	0.7	0.02
03L023	Carbonate	2.84	2.83	2.83	0.4	0.01
03L024	Carbonate	2.84	2.81	2.79	1.5	0.02
03L025	Carbonate	2.85	2.82	2.81	1.2	0.01
03L026	Carbonate	2.80	2.77	2.75	1.7	0.01
03L027	Felsic Volcanic	2.24	2.14	2.05	9.4	1.84
03L028	Carbonate	2.64	2.60	2.57	2.6	0.05
03L029	Carbonate	2.66	2.64	2.62	1.5	0.03
03L030	Carbonate	2.70	2.68	2.67	0.8	0.02
03L031	Carbonate	2.68	2.66	2.64	1.4	0.01
03L032	Carbonate	2.69	2.66	2.65	1.5	0.02
03L033	Carbonate	2.85	2.84	2.83	0.7	0.00
03L040	Carbonate	2.70	2.69	2.68	0.7	0.03
03L041	Sandstone	2.56	2.53	2.51	1.8	0.03
03L043	Carbonate	2.69	2.66	2.64	2.1	0.02
03L044	Quartzite	2.64	2.63	2.63	0.3	0.04
03L045	Quartzite	2.61	2.60	2.59	0.5	0.04
03L046	Quartzite	2.65	2.65	2.64	0.5	0.06
03L048	Carbonate	2.70	2.68	2.67	1.1	0.03
03L049	Carbonate	2.70	2.69	2.69	0.3	0.02
03L050	Carbonate	2.85	2.84	2.84	0.6	0.02
03L051	Carbonate	2.81	2.78	2.76	1.8	0.02

03L052	Carbonate	2.68	2.61	2.57	4.0	0.01
03L053	Carbonate	2.70	2.69	2.69	0.7	0.27
03L054	Sandstone	2.60	2.58	2.56	1.9	0.02
03L055	Sandstone	2.56	2.48	2.43	5.4	0.05
03L057	Carbonate	2.85	2.85	2.85	0.2	0.03
03L058	Carbonate	2.68	2.67	2.66	0.8	0.02
03L059	Felsic Volcanic	2.59	2.52	2.48	4.5	8.53
03L060	Felsic Volcanic	2.61	2.57	2.54	2.8	12.40
03L061	Carbonate	2.70	2.69	2.69	0.4	0.01
03L062	Carbonate	2.84	2.84	2.83	0.3	0.03
03L063	Carbonate	2.86	2.86	2.85	0.2	0.02
03L064	Carbonate	2.67	2.62	2.59	3.3	0.01
03L065	Interm. Volcanic	2.36	2.32	2.29	2.9	7.43
04L015	Carbonate	2.71	2.70	2.69	0.8	0.02
04L020	Felsic Volcanic	2.06	1.73	1.43	44.7	0.88
04L021a	Felsic Volcanic	2.07	1.98	1.90	9.2	0.64
04L021b	Felsic Volcanic	2.50	2.46	2.43	2.9	6.34
04L023	Sandstone	2.47	2.37	2.30	7.2	0.71
04L053	Carbonate	2.72	2.71	2.71	0.7	0.03
04L062	Carbonate	2.73	2.72	2.71	0.6	0.03
04L097	Carbonate	2.74	2.72	2.72	0.8	0.04
04L098	Carbonate	2.72	2.70	2.69	1.3	0.03
04L100	Sandstone	2.65	2.64	2.64	0.5	0.13
04L101	Sandstone	2.64	2.62	2.61	1.0	0.02
04L114	Carbonate	2.70	2.68	2.67	1.0	0.05
04L120	Carbonate	2.85	2.84	2.83	0.6	0.03
04L125	Carbonate	2.76	2.74	2.72	1.2	0.02
04L127	Sandstone	2.66	2.61	2.58	3.1	0.12
04L128	Carbonate	2.70	2.67	2.66	1.2	0.04
04L137	Felsic Volcanic	2.51	2.32	2.19	14.6	5.91
04L147	Carbonate	2.69	2.66	2.65	1.7	0.02
04L171	Felsic Volcanic	2.48	2.38	2.31	7.2	4.56
04L138	Quartzite	2.60	2.59	2.59	0.7	0.00
04L174	Felsic Volcanic	2.41	2.29	2.21	9.2	1.57
04L177	Felsic Volcanic	2.52	2.39	2.30	9.5	5.07
04L186	Felsic Volcanic	2.58	2.54	2.51	3.0	8.15
04L188	Felsic Volcanic	2.59	2.55	2.52	2.8	16.90
04C013	Felsic Volcanic	2.41	2.22	2.09	15.2	0.10
04C025	Felsic Volcanic	2.60	2.58	2.57	1.3	8.14
04C026	Felsic Volcanic	2.39	2.32	2.28	4.8	2.72
04C028	Carbonate	2.85	2.84	2.84	0.4	0.02
04C029	Interm. Volcanic	2.57	2.52	2.49	3.1	11.40
04C030	Felsic Volcanic	2.61	2.56	2.53	3.4	7.37
04C031	Felsic Volcanic	2.53	2.43	2.36	7.4	0.71
04C032	Felsic Volcanic	2.57	2.54	2.52	2.0	2.43
04C033	Felsic Volcanic	2.60	2.45	2.36	10.1	0.12
04C034	Sandstone	2.63	2.61	2.60	0.9	0.06
04C035	Carbonate	2.70	2.64	2.60	3.7	0.01
04C036	Carbonate	2.81	2.80	2.79	0.8	0.01
04C037	Carbonate	2.75	2.74	2.73	1.1	0.02
04C038	Carbonate	2.83	2.82	2.81	0.8	0.01
04C039	Felsic Volcanic	2.58	2.46	2.39	7.7	4.77
04C040	Felsic Volcanic	2.53	2.40	2.32	8.9	0.36
04C041	Felsic Volcanic	2.47	2.27	2.13	15.9	0.35
04C057	Felsic Volcanic	2.45	2.35	2.28	7.2	0.84
04C058	Felsic Volcanic	2.49	2.32	2.21	12.7	0.27
04C059	Felsic Volcanic	2.40	2.28	2.20	8.8	1.25
04C060	Felsic Volcanic	2.42	2.25	2.13	13.5	5.94

04C061	Felsic Volcanic	2.34	2.27	2.22	5.5	1.42
04C062	Felsic Volcanic	2.46	2.23	2.08	18.4	0.18
04C063	Felsic Volcanic	2.44	2.23	2.08	17.4	2.00
04C064	Felsic Volcanic	2.41	2.33	2.27	6.4	2.09
04C042	Felsic Volcanic	2.45	2.18	1.99	23.1	1.16
04C043	Felsic Volcanic	2.52	2.43	2.36	6.4	0.30
04C044	Mafic Volcanic	2.28	2.11	1.97	16.2	1.44
04C045	Interm. Volcanic	2.55	2.48	2.43	4.9	0.34
04C046	Felsic Volcanic	2.43	2.30	2.22	9.6	0.75
04C049	Felsic Volcanic	2.47	2.33	2.24	10.4	0.20
04C050	Felsic Volcanic	2.49	2.34	2.24	10.9	0.27
04C051	Felsic Volcanic	2.47	2.29	2.17	13.6	0.11
04C052	Felsic Volcanic	2.43	2.38	2.34	3.6	0.45
04C053	Felsic Volcanic	2.45	2.32	2.23	10.0	0.21
04C054	Interm. Volcanic	2.40	2.36	2.34	2.6	1.31
04C066	Felsic Volcanic	2.35	2.27	2.21	6.5	2.58
04C067	Carbonate	2.45	2.34	2.26	8.2	0.70
04C068	Interm. Volcanic	2.36	2.33	2.31	1.8	0.92
04C069	Felsic Volcanic	2.52	2.43	2.37	6.6	6.41
04C070	Interm. Volcanic	2.68	2.66	2.64	1.6	12.40
04C071	Interm. Volcanic	2.78	2.75	2.74	1.5	14.70
04C072	Felsic Volcanic	2.40	2.09	1.87	28.8	0.52
04C073	Felsic Volcanic	2.20	2.09	1.99	10.5	1.37
04C074	Mafic Volcanic	2.69	2.65	2.63	2.2	8.89
04C075	Felsic Volcanic	2.47	2.44	2.43	1.7	3.90
04C076	Felsic Volcanic	2.22	2.08	1.96	13.3	2.74
04C077	Felsic Volcanic	2.44	2.25	2.13	14.9	2.29
04C078	Quartzite	2.57	2.55	2.54	1.4	0.03
04C079	Interm. Volcanic	2.66	2.64	2.63	1.1	8.30
04C080	Felsic Volcanic	2.54	2.51	2.49	2.2	8.25
04C081	Interm. Volcanic	2.56	2.49	2.45	4.5	4.11
04C082	Interm. Volcanic	2.61	2.58	2.57	1.8	2.48
04C083	Felsic Volcanic	2.59	2.58	2.57	1.0	14.20
04C084	Felsic Volcanic	2.75	2.73	2.72	1.2	9.00
04C085	Felsic Volcanic	2.32	2.20	2.11	10.2	1.55
04C086	Felsic Volcanic	2.31	1.95	1.67	38.5	0.69
04C087	Felsic Volcanic	2.45	2.28	2.15	14.0	3.09
04C089	Interm. Volcanic	2.66	2.66	2.65	0.5	13.40
04C090	Carbonate	2.85	2.84	2.83	0.5	0.01
04C091	Carbonate	2.81	2.77	2.75	2.0	0.03
04C092	Carbonate	2.39	2.28	2.20	8.8	0.00
04C093	Carbonate	2.61	2.49	2.41	8.1	0.03
04C094	Carbonate	2.79	2.76	2.74	1.8	0.00
04C095	Carbonate	2.67	2.61	2.58	3.5	0.05
04C096	Carbonate	2.63	2.58	2.56	2.8	0.01
04C097	Carbonate	2.76	2.73	2.71	1.6	0.02
04C108	Felsic Volcanic	2.43	2.30	2.22	9.5	1.68
04C109	Felsic Volcanic	2.40	2.25	2.14	12.3	0.26
04C163	Felsic Volcanic	2.46	2.35	2.28	8.2	6.00
04C176	Interm. Volcanic	2.17	2.16	2.15	0.8	0.47
04C194	Felsic Volcanic	2.57	2.53	2.51	2.1	5.79
04C196	Sandstone	2.63	2.62	2.62	0.5	0.13
04C200	Felsic Volcanic	2.47	2.35	2.26	9.6	1.21
04C202	Mafic Volcanic	2.53	2.52	2.51	0.6	5.36
04C203	Felsic Volcanic	2.34	2.20	2.09	11.8	0.37

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Prepared in cooperation with the Bureau of Land Management

This report is based on work by the U.S. Geological Survey, in collaboration with the Desert Research Institute, and the State of Utah

A Report to Congress

Water Resources of the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah—Draft Report

Open-File Report 2007–1156

U.S. Department of the Interior
U.S. Geological Survey

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Water Resources of the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah—Draft Report

By Alan H. Welch and Daniel J. Bright, Editors

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U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007

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Foreword

Water demands from the lower Colorado River system are increasing with the rapidly growing population of the southwestern United States. To decrease dependence on this over allocated surface-water resource and to help provide for the projected increase in population and associated water supply in the Las Vegas area, water purveyors in southern Nevada have proposed to utilize the ground-water resources of rural basins in eastern and central Nevada. Municipal, land management, and regulatory agencies have expressed concerns about potential impacts from increased ground-water pumping on local and regional water quantity and quality, with particular concern on water-rights issues and on the future availability of water to support springflow and native vegetation. Before concerns on potential impacts to pumping can be addressed, municipal and regulatory agencies have recognized the need for additional information and improved understanding of geologic features and hydrologic processes that control the rate and direction of ground-water flow in eastern and central Nevada.

In response to concerns about water availability and limited hydrogeologic information, Federal legislation (Section 131 of the Lincoln County Conservation, Recreation, and Development Act of 2004: PL 108-424) was enacted in December 2004 that directs the Secretary of the Interior, through the U.S. Geological Survey (USGS), the Desert Research Institute (DRI), and a designee from the State of Utah, to conduct a water-resources study of the basin-fill and carbonate-rock aquifers in White Pine County, Nevada, and smaller areas of adjacent counties in Nevada and Utah. The primary objectives of the Basin and Range Carbonate-rock aquifer system (BARCAS) study are to evaluate: (1) the extent, thickness, and hydrologic properties of aquifers, (2) the volume and quality of water stored in aquifers, (3) subsurface geologic structures controlling ground-water flow, (4) ground-water flow directions and gradients, and (5) distributions and rates of recharge and ground-water discharge. Geologic, hydrologic, and supplemental geochemical information will be integrated to determine basin and regional ground-water budgets.

Results of the study will be summarized in a USGS Scientific Investigations Report (SIR), to be prepared in cooperation with DRI and the State of Utah, and submitted to Congress by December 2007. The BARCAS study SIR is supported by USGS and DRI reports that document, in greater detail than the summary SIR, important components of and estimates made in support of the BARCAS study. These reports are varied in scope and include documentation of basic data including spring location and irrigated acreage, and interpretive studies of ground-water flow, recharge, evapotranspiration, and geology.

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Conversion Factors and Datums

Conversion Factors

Multiply	By	To obtain
acre	4046.856	square meter (m^2)
acre	0.4047	hectare (ha)
calorie	4.184	joule (J)
calories per second per square foot	45.045	watt per square meter (W/m^2)
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
mile per hour (mph)	0.44704	meter per second (m/s)
ounce, avoirdupois (oz)	28.35	gram (g)
square mile (mi^2)	2.58999	square kilometer (km^2)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8.$$

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32.$$

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NVGD of 1929).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83) unless otherwise stated.

Altitude, as used in this report, refers to distance above the vertical datum.

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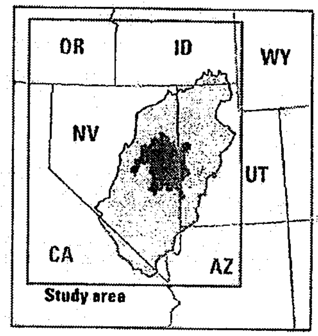
Water Resources of the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada and Adjacent Areas in Nevada and Utah—DRAFT REPORT



By Alan H. Welch and Daniel J. Bright, Editors

Summary of Major Findings

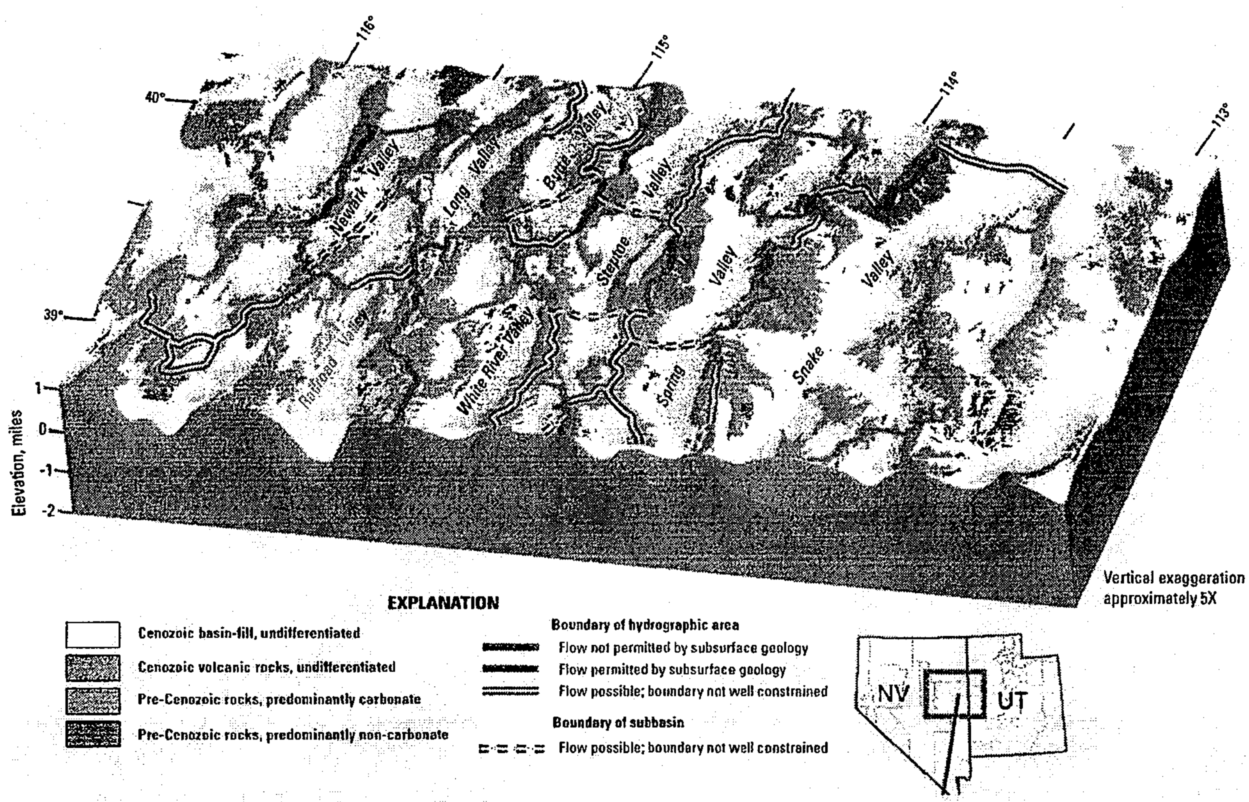
This report summarizes results of a water-resources study for White Pine County, Nevada, and adjacent areas in east-central Nevada and western Utah. The Basin and Range carbonate-rock aquifer system (BARCAS) study was initiated in December 2004 through Federal legislation (Section 131 of the Lincoln County Conservation, Recreation, and Development Act of 2004) directing the Secretary of the Interior to complete a water-resources study through the U.S. Geological Survey, Desert Research Institute, and State of Utah. The study was designed as a regional water-resource assessment, with particular emphasis on summarizing the hydrogeologic framework and hydrologic processes that influence ground-water resources.

The study area includes 13 hydrographic areas that cover most of White Pine County; in this report however, results for the northern and central parts of Little Smoky Valley were combined and presented as one hydrographic area. Hydrographic areas are the basic geographic units used by the State of Nevada and Utah and local agencies for water-resource planning and management, and are commonly defined on the basis of surface-water drainage areas. Hydrographic areas were further divided into subbasins that are separated by areas where bedrock is at or near the land surface. Subbasins represent subdivisions used in this study for estimating recharge, discharge, and water budget. Hydrographic areas represent the subdivision used for reporting summed and tabulated subbasin estimates.

Aquifer System

Most ground water in the study area flows through three types of aquifers—a shallow basin-fill aquifer, a deeper volcanic-rock aquifer, and an underlying carbonate-rock aquifer that forms the base of the ground-water flow system. Relatively impermeable basement rocks underlie the carbonate-rock aquifer throughout most of the study area. The basin-fill aquifer underlies every valley and is the primary source of ground water for the area. The thickness of basin fill beneath most valleys is about 6,600 feet; however, in Steptoe and Lake Valleys, it exceeds 13,000 feet. The volcanic-rock aquifer is thickest beneath the western and southern parts of the study area, extending laterally beneath the basin-fill aquifer and multiple hydrographic areas. Although some springs issue from volcanic rocks, these aquifers are not utilized as a significant source of water supply in the study area. Fractured, permeable carbonate rocks are regionally extensive, form many of the mountain ranges, and underlie the basin-fill and volcanic-rock aquifers throughout much of the study area. Ground water in the carbonate-rock aquifer discharges at perennial-flowing valley-floor springs and, because of the lateral continuity and relative high permeability of the carbonate rocks, most ground-water flow between adjacent valleys occurs through this aquifer. Although not a primary source of water supply in the study area, some ground water is pumped from the carbonate-rock aquifer for various uses.

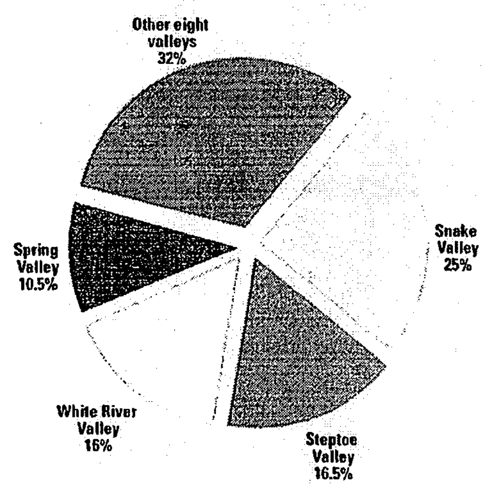
The distribution of aquifers and units of low permeability along hydrographic area boundaries is a primary control on ground-water flow between hydrographic areas. Ground-water flow across some hydrographic area boundaries may be negligible where carbonate or volcanic rocks are absent, or if the aggregate permeability of aquifers beneath a hydrographic area boundary is relatively low.



Perspective view of the primary aquifer systems.

Aquifer Storage

For equivalent volumes of aquifer material, the capacity of the basin-fill aquifer to store water is significantly greater than that of the carbonate-rock aquifer. For example, permeable deposits in the upper 100 ft of saturated basin-fill aquifer beneath valley floors throughout the study area store about 36 million acre-ft of water. In contrast, the upper 100 ft of saturated carbonate-rock aquifer beneath valley floors stores about 30,000 acre-ft of water, or about 3-orders of magnitude less than the basin-fill aquifer. About 75 percent of the water stored in the upper 100 ft of basin-fill and carbonate-rock aquifers occur in the four largest hydrographic areas—Snake, Steptoe, White River, and Spring Valleys. The evaluation of aquifer storage assumes ground-water is pumped from equivalent volumes of basin-fill and carbonate-rock aquifers, but does not consider the potential impacts to changes in storage caused by ground-water extractions, such as declining water levels in wells, decreasing spring discharge, diminished water quality, or loss of native vegetation.



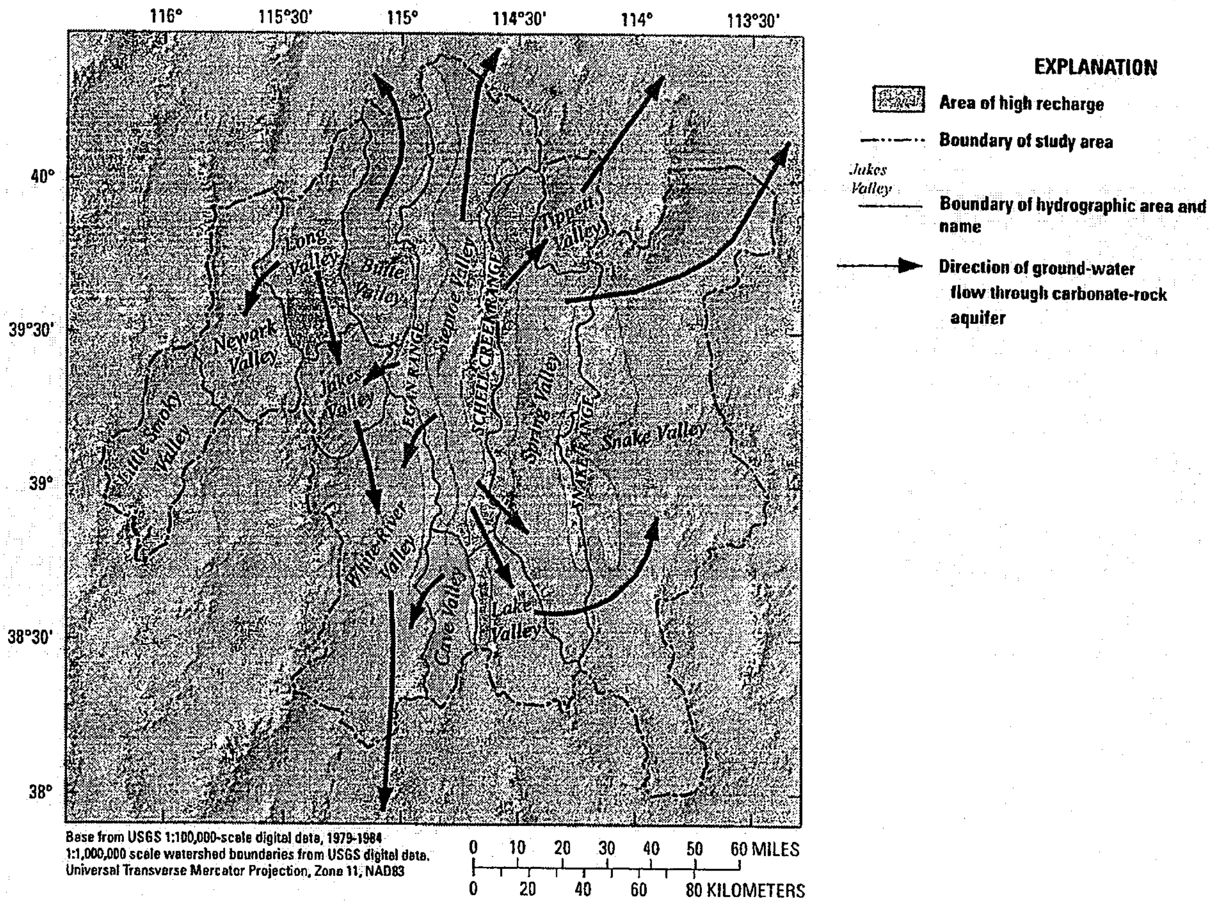
Percentage of water stored in basin-fill and carbonate aquifers.

Aquifer Water Quality

The inorganic chemical quality of ground water generally is acceptable for human consumption. No discernable patterns of poor water quality have been found except for chloride concentrations in some ground water in northern Snake Valley that exceed secondary drinking-water standards. Only a small number of analyses of anthropogenic organic compounds in ground water are available. No exceedances of drinking-water standards have been reported.

Regional Ground-Water Flow

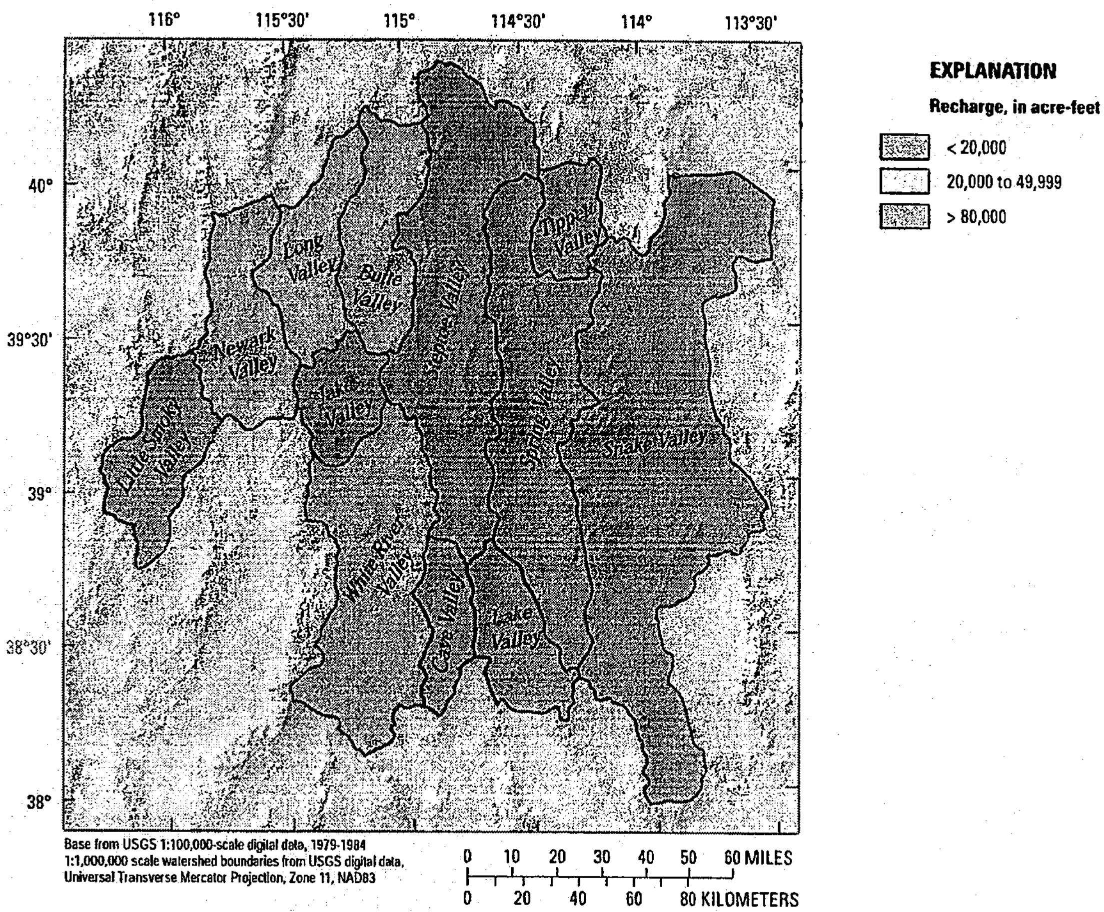
Carbonate rocks form much of the Egan, Schell Creek, and Snake Ranges, and the relatively high precipitation and recharge in these mountain ranges are the source for regional ground-water flow in the carbonate-rock aquifer. The Egan Range is the primary source area for northward ground-water flow through Butte Valley, and southward flow through Long, Jakes, and White River Valleys, where ground water exits the study area and flows toward the Colorado River. The Egan and Schell Creek Ranges are the primary source areas for ground water in Steptoe Valley, where the highest water-level altitudes in the basin fill are found in the study area. Ground water flows northward through Steptoe Valley and southeastward through southern Steptoe, Lake, Spring, and Snake Valleys. The Schell Creek and Snake Ranges are the primary source areas for northeastward ground-water flow through northern Spring, Tippett, and Snake Valleys. Ground water exits the study area from Snake and Tippett Valleys and flows northeastward toward a terminal discharge area in the Great Salt Lake Desert.



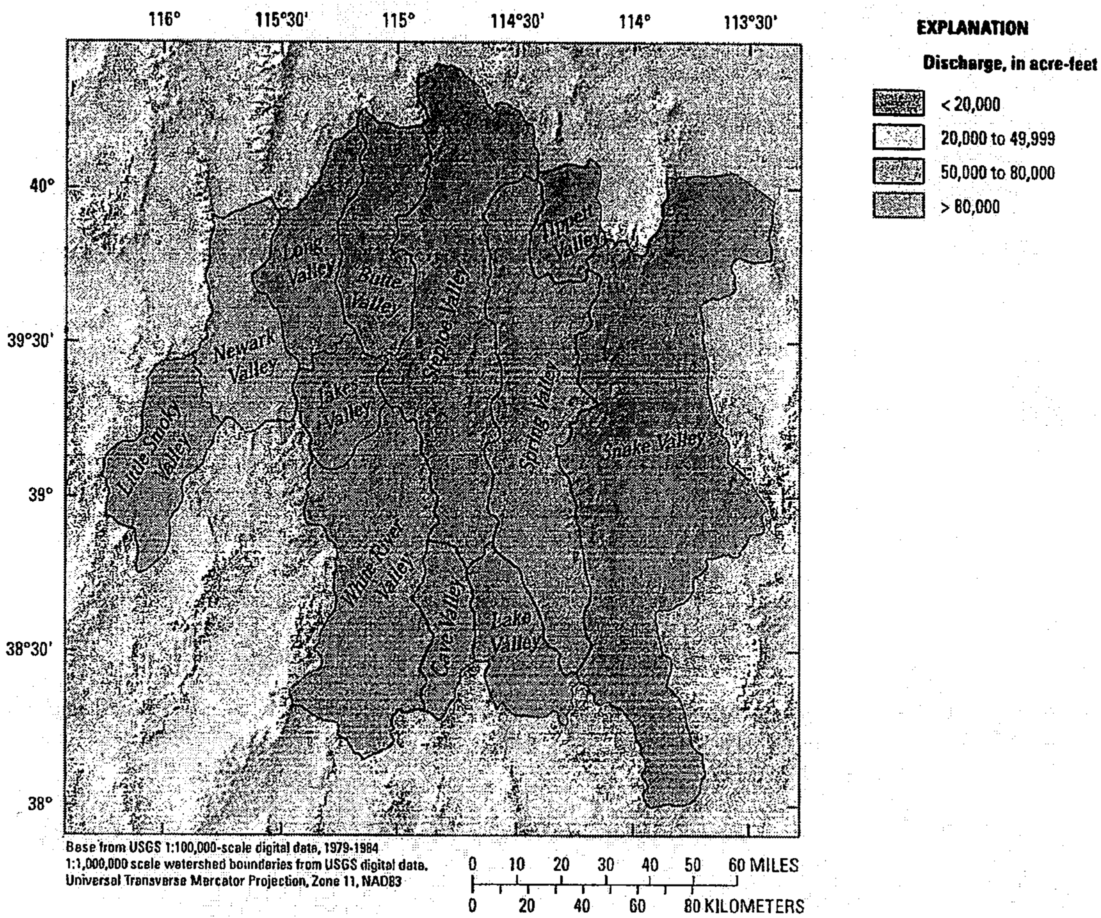
Regional ground-water flow through the carbonate-rock aquifer.

Basin Recharge and Discharge

The larger valleys in the study area, such as Steptoe, Snake, Spring, and White River Valleys, have the highest average annual ground-water recharge and discharge. The highest annual recharge occurs in Steptoe Valley (about 150,000 acre-ft) and Snake Valley (about 110,000 acre-ft). Estimated annual recharge for Steptoe Valleys is about 20,000 acre-ft higher than the highest previous estimate for this valley. The highest annual discharge occurs in Snake Valley (about 130,000 acre-ft) and Steptoe Valley (about 100,000 acre-ft). Estimated annual discharge for Snake Valley is significantly higher (about 45,000 acre-ft) than the highest previous estimate for this valley; estimated annual discharge for Steptoe Valley is within the range of previous estimates.



Average annual recharge to the ground-water system.

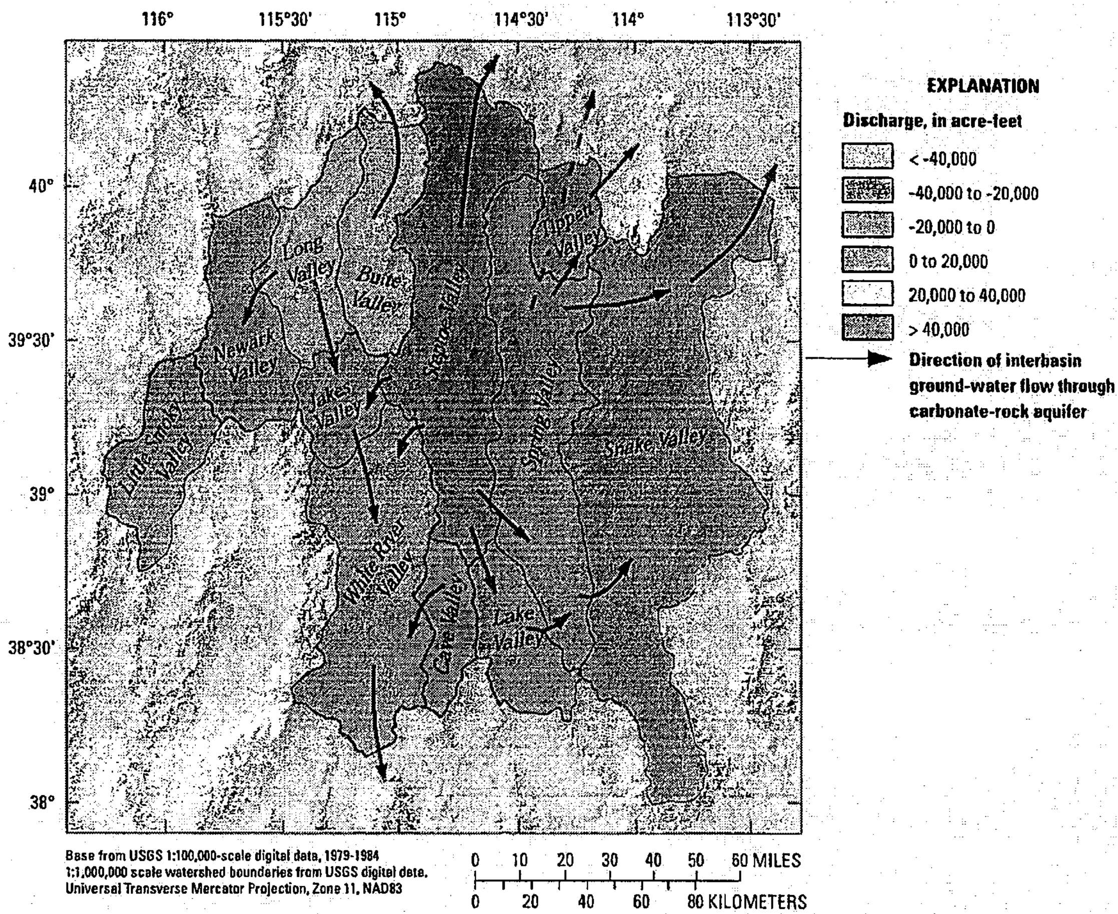


Average annual discharge from the ground-water system by evaporation and transpiration of vegetation.

Interbasin Ground-Water Flow

Differences in basin recharge and discharge provide a surplus or deficit of water that is balanced by ground-water flow entering or exiting a valley as inter-basin ground-water flow. For one-half of the hyrographic areas (6 of 12), recharge exceeds pre-development discharge by 10,000 acre-ft or more on an average annual basis. The high recharge in Steptoe Valley annually exceeds pre-development discharge by more than 50,000 acre-ft. The surplus of water in Steptoe Valley is the source of inter-basin ground-water flow to multiple valleys—to the north where ground water exits the study area, to the southeast toward Lake and southern Spring Valley, and to the west toward Jakes and northern White River Valleys. The latter two flow paths from southern and western Steptoe Valley have not been proposed in previous investigations. Flow from Steptoe Valley to other valleys suggest that parts of southern Steptoe and Lake Valleys may be included in the Colorado or Great Salt Lake Desert regional flow systems.

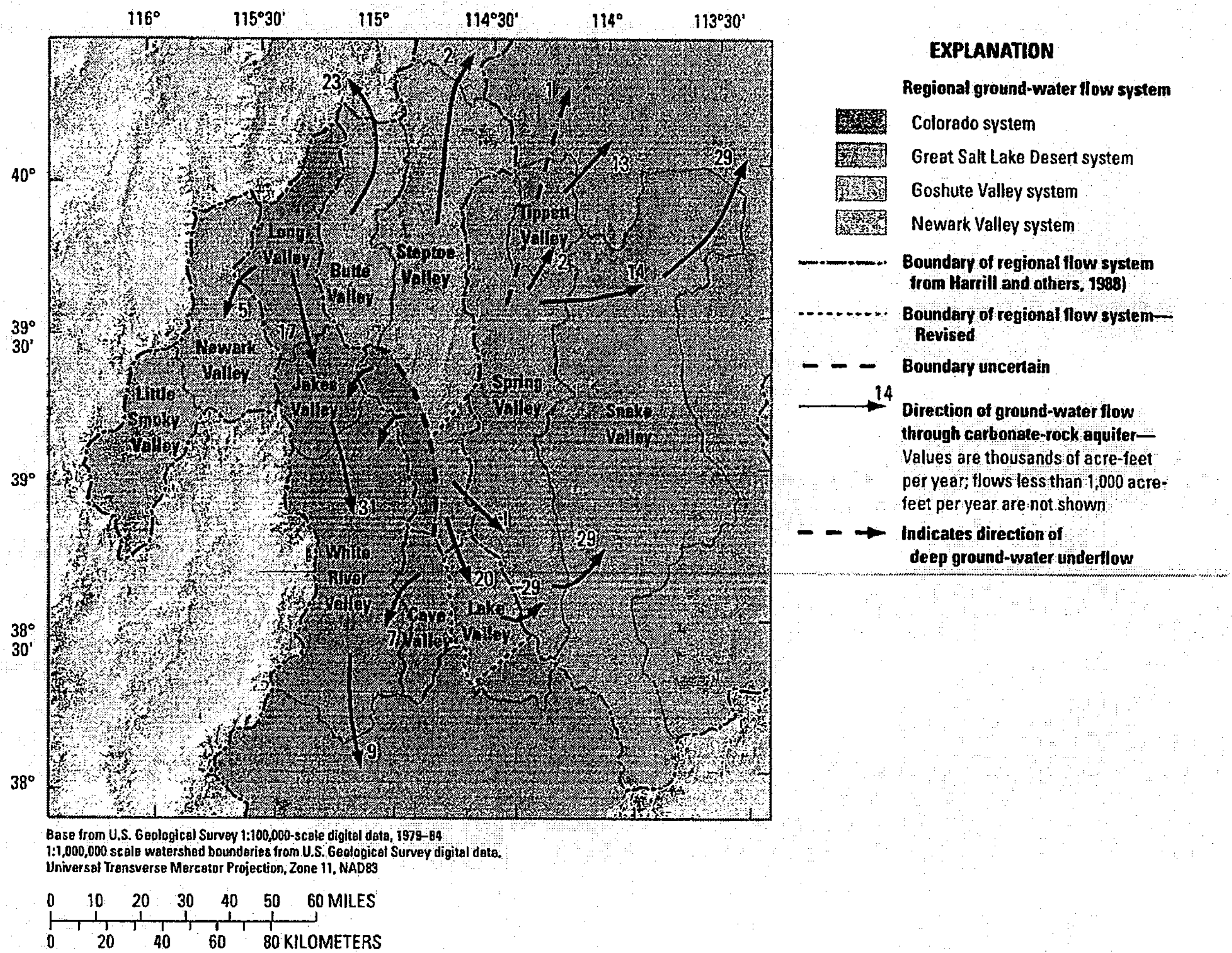
In contrast to Steptoe Valley, pre-development discharge annually exceeds the relatively low annual recharge in White River Valley by more than 40,000 acre-ft, indicating that water lost from evapotranspiration on the valley floor must be supported, in part, by subsurface inflow from adjacent valleys. The deficit of ground water in Whiter River Valley is balanced by inter-basin flow from Steptoe Valley to the northeast, Jakes Valley to the north, and Cave Valley to the east. Estimates of the magnitude of inter-basin flow differ from previous estimates for some hydrographic area boundaries. The largest differences are for estimated outflow from southern Steptoe Valley, where previous investigations proposed zero outflow, and for southern Spring Valley. The estimated 29,000 acre-ft/yr of ground-water flow from southern Spring Valley to Snake Valley is about twice the highest previous estimate.



Average annual recharge minus average annual ground-water discharge, and areas of inter-basin ground-water flow.

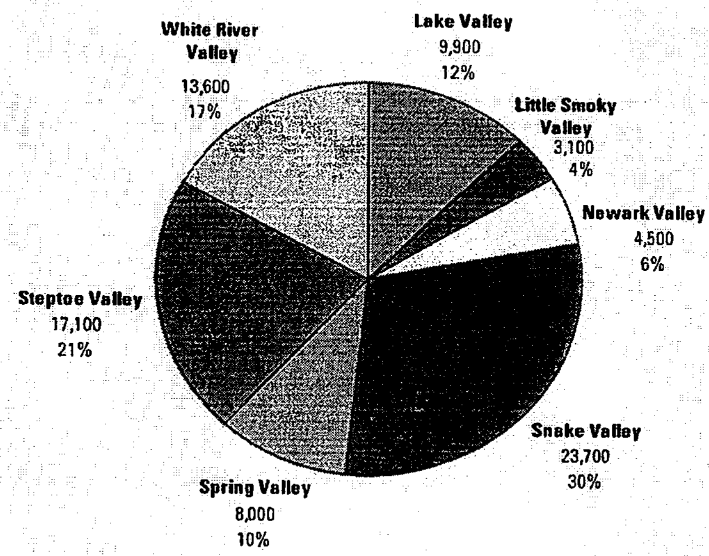
Regional Recharge and Discharge

For the entire study area, average annual recharge equals 530,000 acre-ft, and average annual ground-water discharge equals 440,000 acre-ft under pre-development conditions. The difference between recharge and discharge indicates that about 90,000 acre-ft of ground water exits the study area annually by subsurface outflow. Most ground-water flow likely exits the study area through Snake (29,000 acre-ft/yr), Butte (23,000 acre-ft/yr), Tippett (13,000 acre-ft/yr), and White River Valleys (9,000 acre-ft/yr).



Regional ground-water flow through the Colorado, Great Salt Lake Desert, and other regional flow systems.

The net amount of water removed by ground-water pumping was estimated to evaluate the significance of water withdrawals to ground-water discharge under pre-development conditions. Net ground-water pumpage represents the amount of water pumped from wells or diverted from regional springs minus excess water returned from mining, irrigation applications, or public supply that infiltrated and recharged the ground-water system. Of the 127,000 acre-ft of ground-water use in 2005, about 46,000 acre-ft returned to the aquifer system. The remaining 80,000 acre-ft nearly equals the estimated quantity of ground-water outflow from the study area (about 90,000 acre-ft/yr). On a regional scale, this condition suggests that long-term ground-water withdrawals equal to those estimated for 2005 could potentially capture much of the estimated average annual volume of ground water exiting the study area under pre-development conditions. These withdrawals also could, in some combination, reduce other discharge components such as inter-basin flow, spring discharge, or discharge by vegetation, or increase subsurface recharge from adjacent basins. However, actual reductions in ground-water outflow would be controlled by a number of factors, particularly, the spatial distribution of ground-water withdrawals, and the volume of ground-water removed from storage. For example, reductions in outflow would be less likely in Butte or Tippett Valleys where net pumpage was zero in 2005. Reductions in outflow would be more likely in sub-basins or hydrographic areas where net pumpage is nearly equal or greater than the estimated outflow, such as in Snake Valley where net pumpage was 24,000 acre-ft in 2005 and average annual ground-water outflow was estimated at 29,000 acre-ft. However, for ground-water withdrawals from the basin-fill aquifer, the relatively large volume of water stored in this aquifer likely will mitigate current or near-future reductions in the volume of ground-water outflow or other pre-development discharge components. Water-level measurements, water-use records, and data on pre-development discharge indicate that ground-water pumpage currently (2005) has not significantly altered evapotranspiration rates, the distribution of native vegetation, or regional springflow in the study area.



Percent distribution and volume of net regional ground-water pumpage from hydrographic areas

Although some uncertainty exists on estimated differences between annual recharge and pre-development discharge, a prevalence of hydrographic areas where recharge exceeds discharge and a significant quantity of subsurface outflow from the entire study area (90,000 acre-ft/yr) are not unexpected. Recharge estimates were model-derived; the accuracy of these estimates depends on the accuracy with which a number of hydrologic, atmospheric, and soil parameters were estimated. Estimates of pre-development discharge were derived through field measurements and, as a result of a more direct method of measurement, the uncertainty of estimated pre-development discharge is likely less than the uncertainty of estimated recharge. Future studies may reduce uncertainties of estimated recharge and discharge by evaluating a regional ground-water flow system bounded by ground-water divides, such as the Colorado or Great Salt Lake Desert regional flow systems. Evaluating entire regional flow systems provides the constraint that ground-water inflow and outflow across the study area boundary is minimal; therefore, cumulative recharge and pre-development discharge must balance for hydrographic areas within the regional flow system.

Introduction

A study initiated by Federal legislation (Lincoln County Conservation, Recreation, and Development Act of 2004; PL 108-424) directed the Secretary of the Interior, through the U.S. Geological Survey (USGS), the Desert Research Institute (DRI), and a designee from the State of Utah, to evaluate the basin-fill and carbonate-rock aquifers in White Pine County, Nevada, and adjacent areas in Nevada and Utah. This report is a draft that will be revised in response to a public comment period as required by the legislation. A final report will be transmitted to Congress no later than December 1, 2007. The congressionally mandated study is termed the Basin and Range carbonate-rock aquifer system (BARCAS) study, and was completed in cooperation with the Bureau of Land Management.

White Pine County in east-central Nevada (fig. 1) is a sparsely populated area, with less than 10,000 residents in 2006, most of which reside in and adjacent to the city of Ely, Nevada, the county seat (2001). The county contains typical basin and range topography—north-south trending valleys and mountains that range in altitude from 5,000 to 7,000 ft above sea level for valley floors, and above 10,000 ft for most mountain ranges. The mountain ranges are the principal source of recharge to four regional ground-water flow systems (fig. 1). Most ground water in White Pine County is used for irrigation and mining purposes. Lesser amounts of ground water are used for municipal and domestic purposes in and adjacent to the city of Ely.

Water purveyors in southern Nevada have proposed to use ground-water resources in White Pine County to help meet water needs associated with the projected increases in the population of Clark County in southern Nevada. As populations in southern Nevada and elsewhere in the Southwest continue to increase, the reliance on water from the Colorado River Basin becomes increasingly important, and the prospects of obtaining additional allotments of water from the Colorado River system, stipulated in the Colorado River Compact of 1922, are confounded by the legal and socio-political issues derived from the competition for those scarce resources by the seven Compact States. Alternatively, ground-water resources in rural basins north of Clark County, including basins in White Pine County, have been targeted as potential sources of imported water supply. Municipal and regulatory agencies have expressed concerns about potential impacts on water quantity and quality, water rights, sensitive wildlife habitats, and other beneficial uses from the proposed activities. As a first step in assessing potential impacts from ground-water development, agencies and stakeholders have recognized the need for additional hydrologic data and an improved understanding of hydrogeologic processes that control the rate and direction of ground-water flow in eastern and central Nevada.

Purpose and Scope

The purpose of this report is to summarize hydrogeologic factors affecting the occurrence and movement of ground water in the aquifer system of the study area. Ground-water resources were evaluated by focusing on the following hydrogeologic characteristics: (1) the extent, thickness, and hydrologic properties of aquifers, (2) subsurface geologic structures controlling ground-water flow, (3) ground-water flow directions and gradients, (4) the volume and quality of water stored in aquifers, and (5) the distribution and rates of recharge and discharge. Moreover, geologic, hydrologic, and supplemental geochemical information were evaluated to determine ground-water budgets in the study area. Finally, hydrogeologic characteristics were compiled and integrated to develop a three-dimensional hydrogeologic framework and conceptual understanding of ground-water flow in the study area.

Description of Study Area

The study area encompasses about 13,500 mi^2 and covers about 80 percent of White Pine County, Nevada, and smaller areas of adjacent counties in Nevada and Utah (fig. 1). White Pine County lies within the eastern part of the Great Basin—a unique internally drained physiographic feature of the Western United States. Basin and Range topography—north-south trending valleys and adjacent mountain ranges—dominates the region.

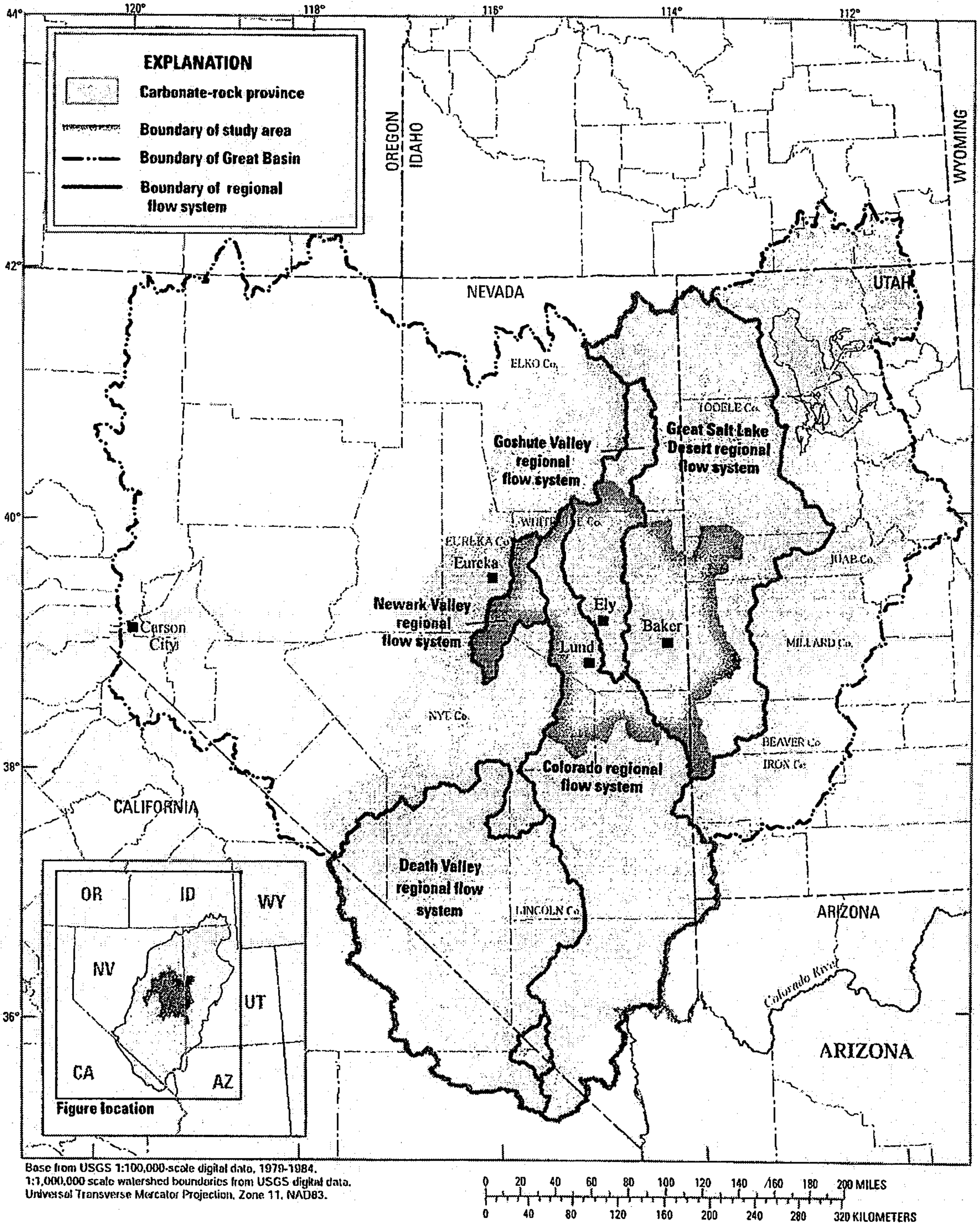


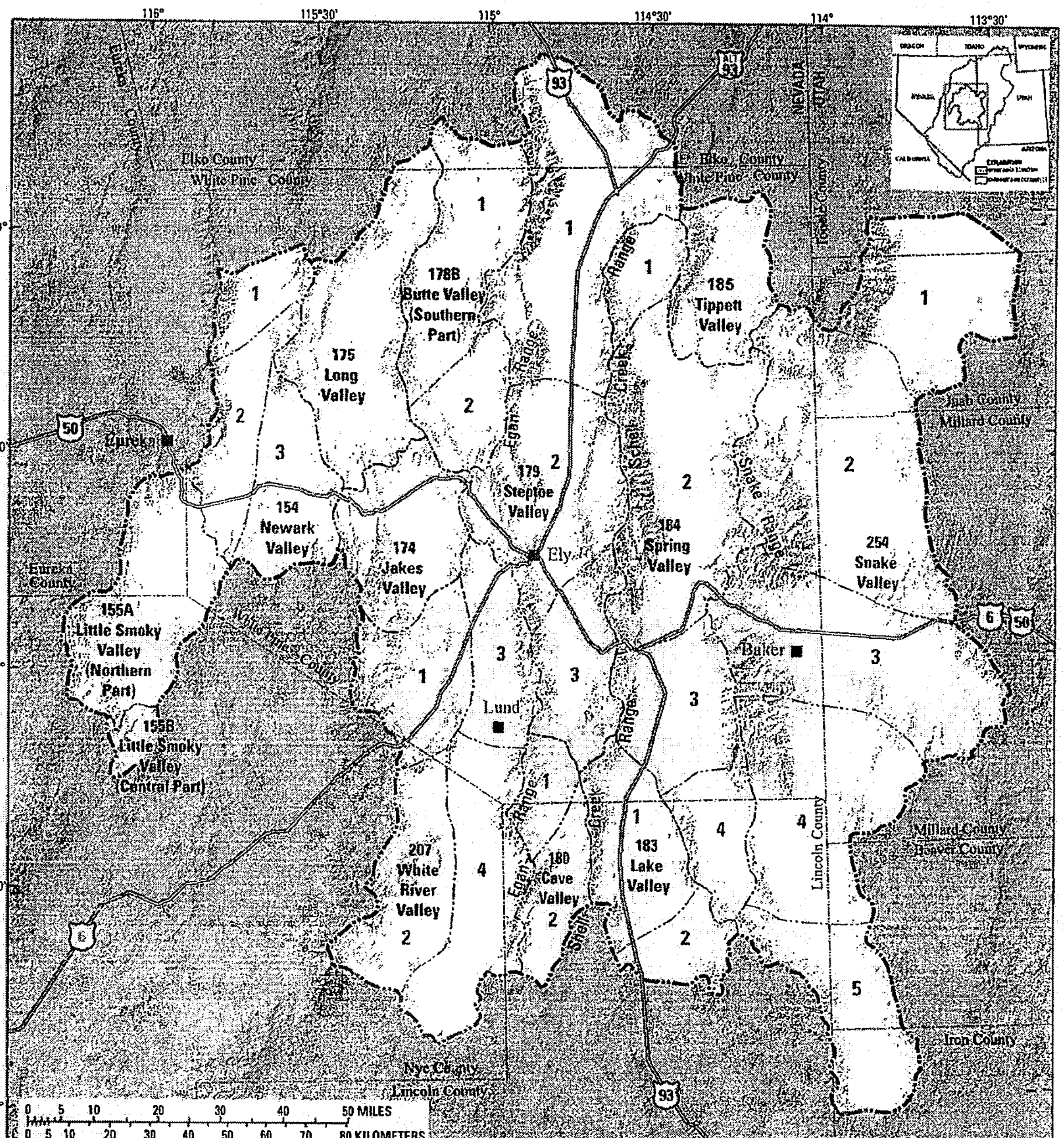
Figure 1. Carbonate-rock province, Basin and Range carbonate-rock aquifer system, and associated regional ground-water flow systems, Nevada and Utah.

The study area encompasses 13 hydrographic areas (HAs)[1] (pl. 4; fig. 2). Past studies have combined HAs to delineate intermediate or regional ground-water flow systems, primarily based on the direction of interbasin ground-water flow in the underlying carbonate-rock aquifer and the location of terminal discharge areas (Harrill and Prudic, 1998). Although most boundaries between HAs coincide with actual topographic basin divides, some are arbitrary divisions that have no basis in topography. In this report, HAs also are referred to as basins, and ground-water flow within these areas is referred to as intrabasin ground-water flow. Moreover, HAs were further divided into subbasins that are separated by areas where pre-Cenozoic rocks are at or near the land surface. For purposes of this report, areas that separate subbasins are referred to as intrabasin divides. Subbasins represent subdivisions used in this study for estimating recharge, discharge, and water budget. HAs represent the subdivision used for reporting summed and tabulated subbasin estimates. HAs within this report refer to formal HAs of Harrill and others (1988) with two exceptions: (1) 'Little Smoky Valley' refers to both HAs 155A and 155B, which are the northern and central parts of Harrill's description of Little Smoky Valley, respectively, and (2) 'Butte Valley' refers only to HA 178B, which is the southern part of Harrill and others' description of Butte Valley. For most figures and tables in this report, water-budget components were estimated for the northern and central parts of Little Smoky Valley, but were combined and reported as one value.

Precipitation in the study area provides recharge to four regional ground-water flow systems—the Newark Valley, Goshute Valley, Great Salt Lake Desert, and Colorado regional flow systems (fig. 1)—that headwater in White Pine County. These regional flow systems are characterized by flow across HA boundaries and discharge as warm springs. All these regional flow systems extend to areas outside of White Pine County. The Newark Valley and Goshute Valley flow systems are relatively small, internally drained flow systems. The remaining two flow systems terminate in areas hundreds of miles from their source area in White Pine County. The Great Salt Lake Desert regional flow system terminates at the Great Salt Lake, with intermediate discharge at Fish Springs in Juab County, Utah. The Colorado regional flow system terminates at Lake Mead and the Colorado River, with a principal intermediate discharge area at Muddy River Springs in Lincoln County, Nevada. In addition to these and other perennial valley-floor springs, numerous high-altitude ephemeral and perennial springs are found in the study area. Many of these perennial and ephemeral springs support native vegetation; some springs support protected aquatic or wildlife species, such as the Pahrump poolfish (*Empetrichthys latos*) in southeastern Spring Valley, and the White River spinedace (*Lepidomeda albivallis)* in White River Valley near Lund.

Regional ground-water flow in the study area primarily is controlled by carbonate rocks. Much of the carbonate-rock aquifer is fractured and these fractured rocks, where continuous, form a regional flow system that receives recharge in high-altitude mountain ranges in the study area where these rocks are exposed. Some water flows from the carbonate-rock aquifer into basin-fill aquifers. This regional discharge sustains many of the larger, perennial low-altitude springs in the study area. The basin-fill aquifers that overlie the carbonate-rock aquifer typically are more than 1,000-ft-thick deposits of volcanic rocks, gravel, sand, silt and clay (Harrill and Prudic, 1998). Basin-fill deposits locally can exceed 10,000 ft. Gravel and sand deposits yield water readily to wells and are the aquifers most commonly developed for agricultural, domestic, and municipal supply.

[1]Formal hydrographic areas in Nevada were delineated systematically by the U.S. Geological Survey and Nevada Division of Water Resources in the late 1960s (Cardinalli and others, 1968; Rush, 1968) for scientific and administrative purposes. The official hydrographic-area names, numbers, and geographic boundaries continue to be used in U.S. Geological Survey scientific reports and Division of Water Resources administrative activities.



Base from U.S. Geological Survey digital data 1:100,000, 1978–89.
Universal Transverse Mercator Projection, Zone 11, NAD83.
Shaded relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon.

EXPLANATION

—··— Boundary of study area

174 Jakes Valley —··— Boundary of hydrographic area and name and number

4 —·—·— Boundary of subarea and No.

Figure 2. Hydrographic areas and subbasins, Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

Hydrogeologic Framework

By Donald S. Sweetkind, Lari A. Knochenmus, David A. Ponce, Alan R. Wallace, Daniel S. Scheirer, Janet T. Watt, and Russell W. Plume, U.S. Geological Survey

A variety of geologic and geophysical approaches have been used to improve the understanding of the hydrogeologic framework of the study area. Geologic map units and structures were compiled from digital versions of the Nevada (Stewart and Carlson, 1978; Raines and others, 2003) and Utah (Hintze and others, 2000) 1:500,000-scale State geologic maps. Drilling records and accompanying geophysical logs for oil and gas wells and exploration wells also were evaluated to understand down-hole lithology and stratigraphy, to estimate relative permeabilities of different rock types, and to augment the regional hydrogeologic framework. The new geologic data were integrated with existing information to develop a generalized hydrogeologic map (pl. 1) that portrays the configuration of rock units in the study area. The hydrogeologic map combines geologic units into hydrogeologic units (HGUs)—groupings of rock units that have reasonably similar hydrologic properties. HGU designations were based on lithologic, stratigraphic, and structural characteristics from published descriptions and from data collected during field mapping as part of the study. A generalized stratigraphic column and corresponding hydrogeologic unit designation for the study area are shown in figure 3.

Surface geophysical techniques were applied to take advantage of characteristic density, magnetic, electrical, and acoustic properties of different rocks in a way that provides additional insight into the subsurface geology. Detailed gravity, magnetic, electromagnetic, and seismic geophysical data (fig. 4) are used to identify faults, subsurface structure, and the interconnectivity of adjacent basins. The results of most of the geophysical investigations conducted for the BARCAS study are presented in Watt and Ponce (2007).

Geologic History

The geologic history of the eastern part of Nevada is preserved in rocks and geologic structures that span more than a billion years, ranging from Precambrian sedimentary rocks to widespread Quaternary alluvial deposits and active faults. The geologic framework that has resulted from the geologic events during this time profoundly affects ground-water flow. Thus, any water-resource assessment of the area must take into account the complex geologic history and consider the distribution of the diverse rocks types and geologic environments.

The geologic evolution of the study area since the end of Precambrian time may be subdivided into three general phases (Levy and Christie-Blick, 1989): (1) a late Precambrian to middle Paleozoic interval when dominantly marine sediments were deposited along a passive continental margin; (2) late Devonian to Eocene crustal shortening, compressive deformation, and changes in sedimentation patterns related to the accretion of exotic terrains along the western continental margin in western Nevada; and (3) middle to late Cenozoic extension, faulting, volcanism, and continental sedimentation. Within the context of this three-phase evolution, numerous tectonic events and accompanying changes in sedimentation patterns and igneous activity have occurred throughout geologic time in the study area (fig. 5). These tectonic-induced events have been summarized by De Courten (2003).

During the first phase of geologic events, from late Precambrian until middle Devonian time, the rocks in east-central Nevada were deposited in shallow to deep marine water in a stable continental shelf environment similar to that of modern-day Atlantic and Gulf Coast margins of the United States (Blakely, 1997; available at http://vishnu.glg.nau.edu/rcb/paleogeogwus.html). The stable shelf environment produced thick, extensive carbonate, quartzite, and shale deposits. Most of the widespread units of the older Paleozoic limestone and dolomite rocks (hydrogeologic unit LCU, pl. 1) were deposited in shallow water on a broad, stable continental shelf, known as a "carbonate platform" (Jackson, 1997; Cook and Corboy, 2004). To the west of the study area, correlative rocks were deposited on a gently sloping submarine surface that gradually deepened seaward of the platform (fig. 6). Sedimentary rocks accumulated to thicknesses of about 30,000 ft during this time (Kellogg, 1963; Stewart and Poole, 1974) and form the vast majority of the consolidated rocks exposed in the study area. These limestone and dolomite rocks have long been recognized as an aquifer in the Great Basin (Winograd and Thordarson, 1975; Bedinger and others, 1989; Dettinger and others, 1995; Harrill and Prudic, 1998). These rocks typically consist of an upper Precambrian and Lower Cambrian section of quartzite and shale, a Middle Cambrian to Lower Ordovician limestone section, a distinctive Middle Ordovician quartzite, and an Upper Ordovician to Middle Devonian dolomite section (Kellogg, 1963; Poole and others, 1992) (fig. 3).

Eon	Era	Period	Epoch
Phanerozoic	Cenozoic	Quaternary	Holocene
			Pleistocene
		Tertiary	Pliocene
			Miocene
			Oligocene
			Eocene
			Paleocene
	Mesozoic	Cretaceous	
		Jurassic	
		Triassic	
	Paleozoic	Permian	
		Pennsylvanian	
		Mississippian	
		Devonian	
		Silurian	
		Ordovician	
		Cambrian	
Proterozoic Eon*			
Archean Eon*			

* The Archean and Proterozoic Eons are major subdivisions of Precambrian time.

Hydrogeologic unit	Description of hydrogeologic unit	Examples of Nevada geologic formation names	Examples of Utah geologic formation names
FYSU	Fine-grained younger sedimentary rock unit; Holocene to Pliocene fine-grained playa and lake deposits of fine sand, silt, and clay.	Unconsolidated basin fill, includes playa, marsh, lake and alluvial-flat deposits.	Quaternary surficial deposits including Lake Bonneville deposits, marsh, salt and mudflat deposits.
CYSU	Coarse-grained younger sedimentary rock unit; Holocene to Pliocene alluvium, colluvium, and local fluvial deposits.	Unconsolidated basin fill, includes alluvial fan and stream channel deposits.	Quaternary and Pliocene Basin and Range valley-filling alluvial, and eolian deposits.
VFU	Volcanic flow unit; basalt, andesite and rhyolite lava flows.	Cenozoic basalt, andesite and rhyolite lava flows.	Miocene-Quaternary basalt, andesite and rhyolite lava flows.
VTU	Volcanic tuff unit; welded and nonwelded silicic ash-flow tuffs.	Shingle Pass Tuff, Cottonwood Wash Tuff, Lund Formation, and the Kalamazoo Tuff.	Oligocene Isom Formation and Needles Range Formation, Miocene volcanic rocks
OSU	Older sedimentary rock unit; consolidated Cenozoic (Eocene to Miocene) sedimentary rocks.	Includes Sheep Pass Formation (Eocene) and related units and unnamed tuffaceous sedimentary rocks	Various Paleocene and Eocene consolidated sedimentary rocks
MSU	Mesozoic sedimentary rock unit; includes limestone, sandstone and shale.	Moenkopi Formation, Thaynes Formation, and related rocks (Lower Triassic), in Butte Mountains.	Triassic Chinle, Moenkopi and Thaynes Formations (north of Confusion Range).
UCU	Upper carbonate-rock unit; predominantly limestone and silty limestone.	Ely Limestone (mostly Lower and Middle Pennsylvanian) and Lower Permian Arcturus Formation in White Pine County.	Pennsylvanian Ely Limestone and Permian Arcturus Formations.
USCU	Upper siliciclastic-rock unit; predominantly mudstone, sandstone, conglomerate, minor limestone.	Pilot Shale, Joana Limestone, Chainman Shale, and also Diamond Peak Formation in northern and western White Pine County	Mississippian Chainman Shale.
LCU	Lower carbonate-rock unit; predominantly limestone and dolomite with relatively thin sandstone and shale interbeds.	Cambrian Pioche Shale, Eldorado Dolomite, Geddes Limestone, Secret Canyon Shale, Hamburg Dolomite, Dunderberg Shale, and Windfall Formation; Ordovician Pogonip Group, Eureka Quartzite, and Ely Springs Dolomite; Silurian Laketown and Lone Mountain Dolomites; Devonian Sevy and Simonson Dolomites, Guilmette and Nevada Formations, and Devils Gate Limestone.	Cambrian Trippe Limestone, Wheeler Shale, Howell Limestone, Pioche Formation, Notch Peak Formation; Ordovician Ely Springs Dolomite, Eureka Quartzite, Lehman Formation, Kanosh Shale, Juab Limestone, Wah Wah Limestone, Fillmore Limestone, House Limestone; Silurian Laketown Dolomite; Devonian Pilot Shale, Guilmette Formation, Simonson Dolomite, Sevy Dolomite; Mississippian Ochre Mountain Limestone and Woodman Formation.
LSCU	Lower siliciclastic-rock unit; sandstones, siltstones and metamorphic equivalents.	Cambrian Prospect Mountain Quartzite, Proterozoic McCoy Creek Group and metamorphic rocks.	Cambrian Prospect Mountain Quartzite, Proterozoic McCoy Creek Group and metamorphic rocks.
[illegible]	Intrsuive-rock unit; includes plutonic igneous rocks such as granite and granodiorite.	Jurassic through Oligocene intrusive rocks.	Jurassic through Oligocene intrusive rocks.

Figure 3. Generalized stratigraphic column and hydrogeologic units in the Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

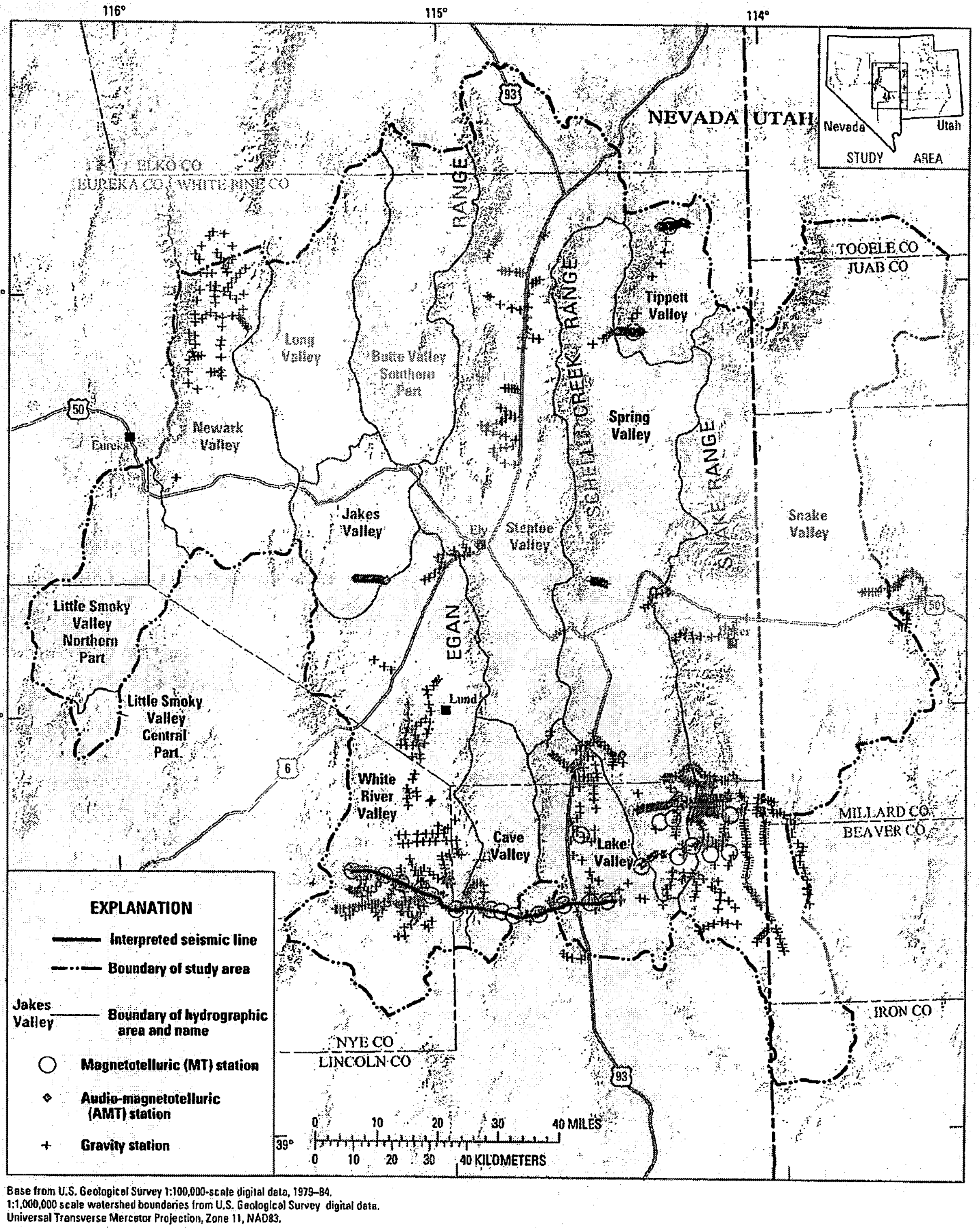
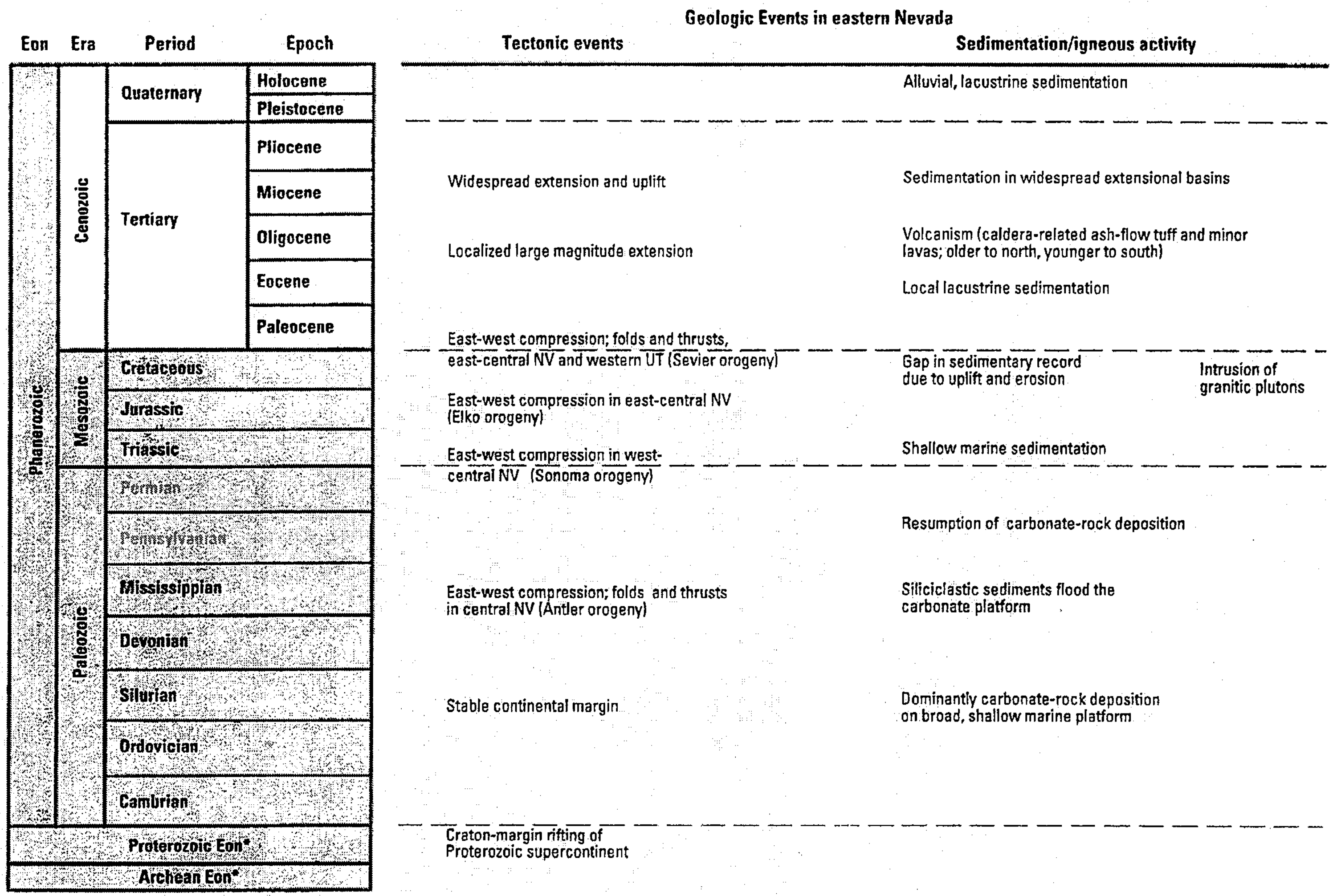
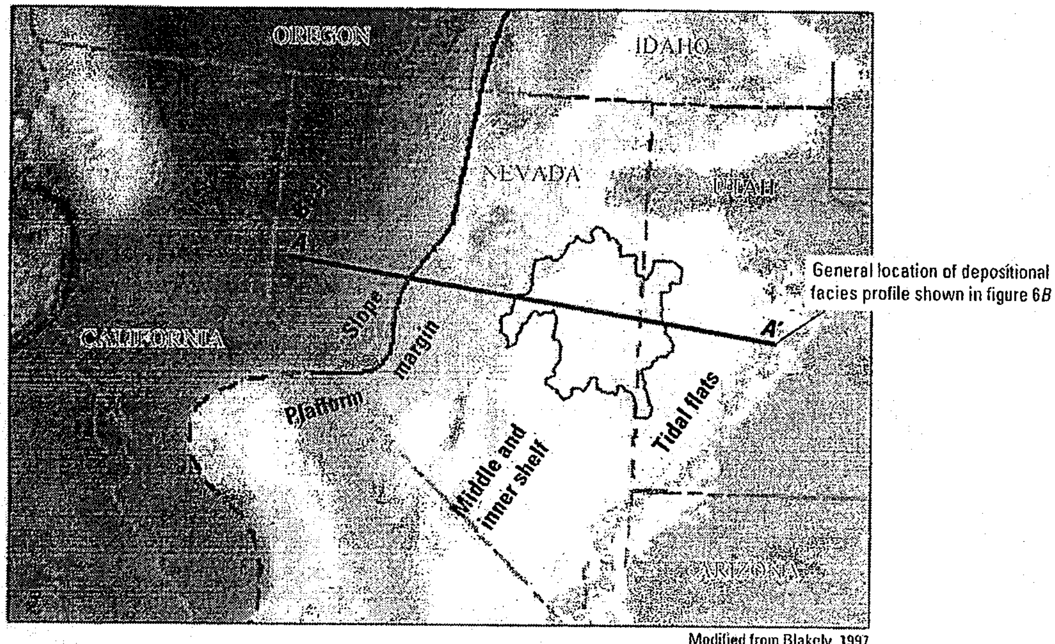


Figure 4. Location of new geophysical data for the Basin and Range carbonate-rock aquifer system study area, Nevada and Utah, 2005–06.



* The Archean and Proterozoic Eons are major subdivisions of Precambrian time.
** Million years before present

Figure 5. Major geologic events in eastern Nevada.



A. Schematic representation of Silurian paleogeography

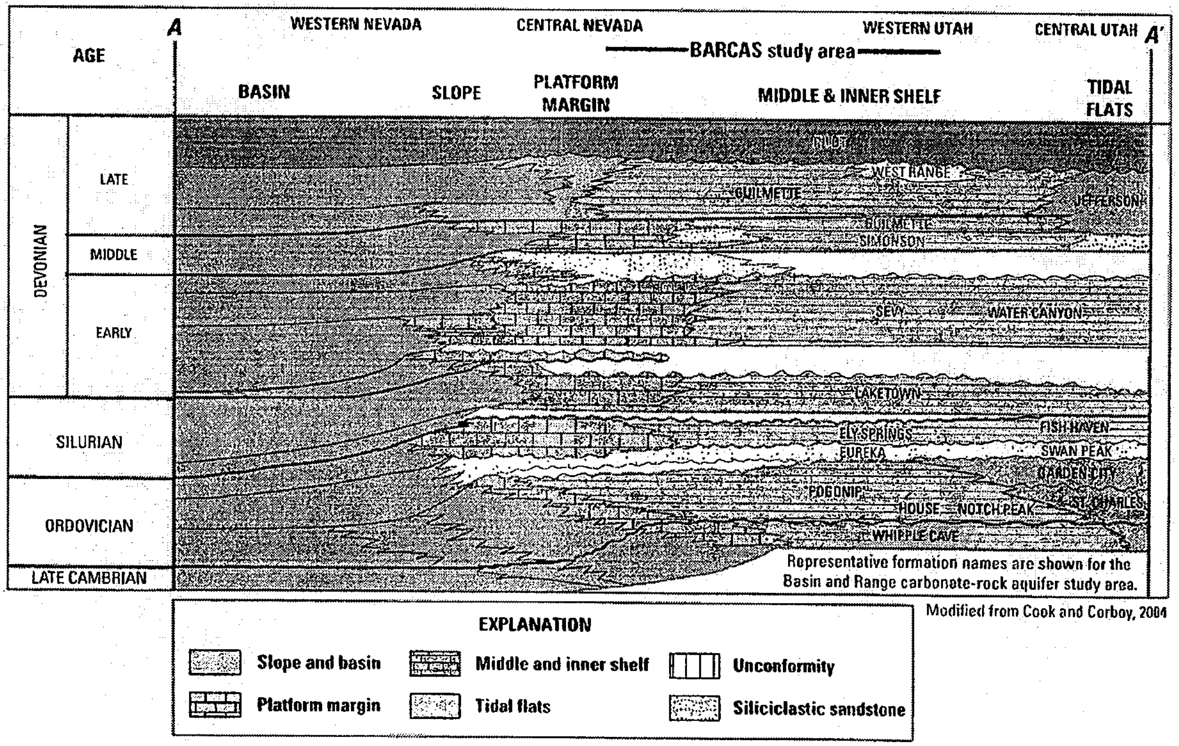


Figure 6. Depositional facies and paleogeography, eastern Great Basin, Nevada and Utah.

From late Devonian to Eocene time, during the second major geologic phase of evolution, several episodes of east-directed compressive deformation that affected the central and western parts of Nevada and also influenced rocks in the study area (fig. 5). A Late Devonian to Early Mississippian compressive event, known as the Antler orogeny, interrupted deposition of carbonate rocks in the study area, resulting deposition a of thick sequence of siliciclastic rocks (Poole and Sandberg, 1977). Carbonate-shelf sedimentation resumed in Pennsylvanian and Permian time, again generating thick, widespread carbonate rocks in the study area. A late Jurassic through earliest Tertiary compressive event called the Sevier orogeny (fig. 5) resulted in the formation of regional-scale folds in the study area (Armstrong, 1968).

Starting in the middle to late Eocene through the remainder of the Tertiary period, extensional uplift and faulting, volcanism, and continental sedimentation characterized the third phase of in the geologic evolution of the study area (fig. 5) and adjacent areas in northern and eastern Nevada. During this time, modern basin-and-range landforms were created as a result of motion along both gently dipping and relatively high-angle faults, causing the relative rising of the ranges and sinking of adjacent basins. Generally accompanying the regional extension was the eruption of relatively large volumes of volcanic rocks, particularly ash-flow tuffs, that were deposited by caldera-forming eruptions during the Tertiary (Best and others, 1989). Caldera-forming eruptions from two major centers, the Indian Peak caldera complex and the Central Nevada caldera complex (pl. 1) resulted in deposition of volcanic rocks that extended across Nevada and Utah. Following Tertiary volcanism, unconsolidated sediments were deposited in the intermontane basins of the study area during the late Tertiary and Quaternary. These sedimentary deposits include Pliocene to Pleistocene-age fine-grained lake sediments (Reheis, 1999), and Quaternary age stream and alluvial-fan sediments of sand and gravel deposited along the basin margins, and changing to finer grained silt and clay sediments within playas along basin axes.

Structural Geology

East-central Nevada features structural domains that vary in style and intensity of deformation (Gans and Miller, 1983; Smith and others, 1991; Dettinger and Schaefer, 1996). Three principal structural domains are evident in the study area—compressional, extensional, and transverse (pl. 1). Compressional and extensional domains generally alternate spatially in the study area; for example, compressional domains represented by regional thrust belts or folds alternate with extensional domains of normal-faulted, highly attenuated stratigraphic sections (Gans and Miller, 1983). Transverse zones are regional scale, east-west structural alignments that generally perpendicular to the regional north-south alignment of mountain ranges and valleys. Salient structural features in the study area, including compressional thrust belts, large-magnitude extensional normal and detachment faults, and transverse zones, are shown on pl. 1.

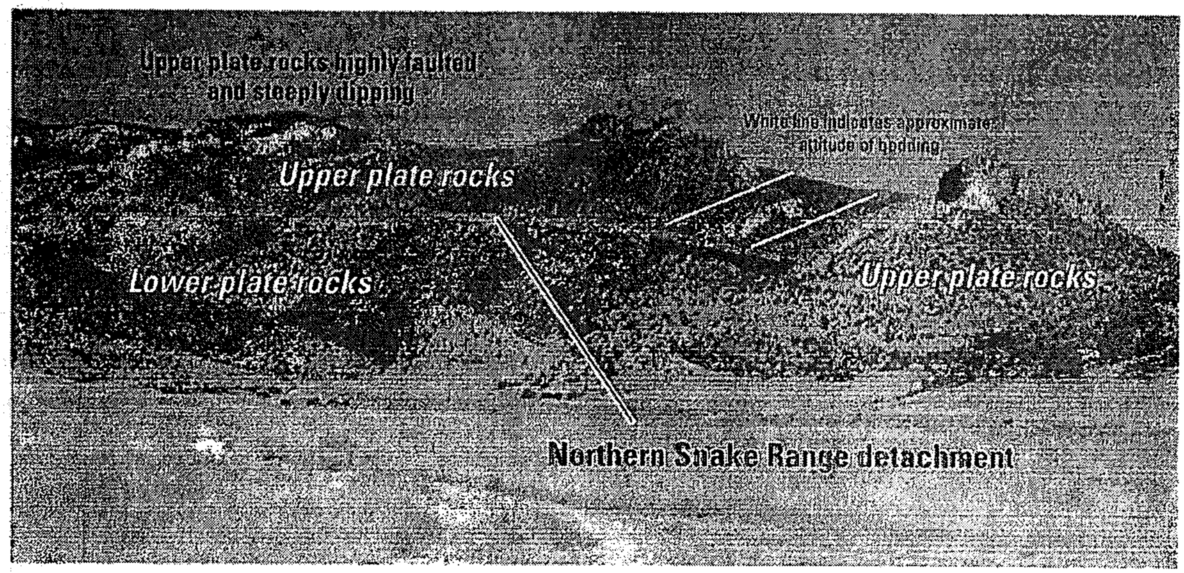
Thrust Belts

The only significant manifestation of the Mesozoic Sevier orogenic belt within the study area are two broad regional synclines, or downfolds, termed the Butte and Confusion Range synclinoria (Hose, 1977). These large folds are characterized by broadly sinuous but generally north-trending fold axes that preserve Triassic rocks and the entire underlying Paleozoic carbonate-rock section (pl. 1). The Butte synclinorium is present in the Maverick Springs Range and Butte Mountains, the central part of the Egan Range and the southern part of the Schell Creek Range (section *A-A*', pl. 1); the Confusion Range synclinorium is present in the Needle and Confusion Ranges of western Utah (section *B-B*', pl. 1).

Extension and Normal Faults

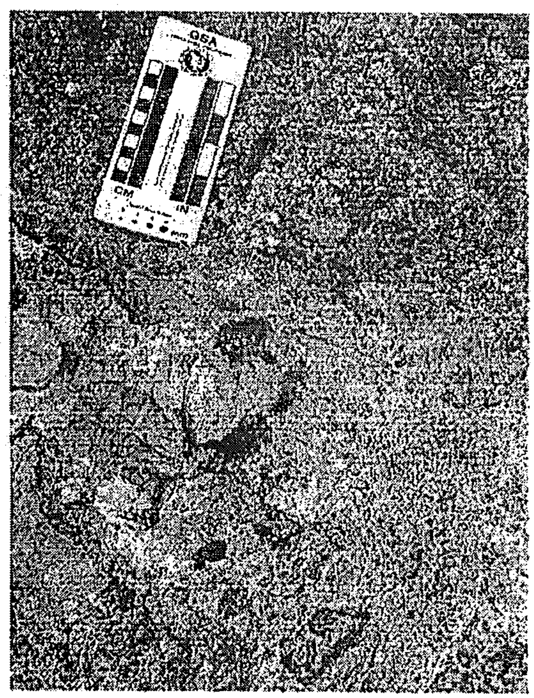
During Cenozoic time, north-south aligned mountain ranges of carbonate, siliciclastic, or metamorphic rocks were formed in the study area by episodes of structural extension. Structural extension was not uniform across the study area, but was segmented into domains of large-magnitude or relatively minor amounts of extension. Each domain generally is represented by specific HGUs that influence regional ground-water flow. The highly extended domains often have uplifted Precambrian to Cambrian siliciclastic rocks or metamorphic rocks of low permeability at or near the surface; whereas less-extended domains tend to preserve the entire thickness of Paleozoic carbonate rocks of higher permeability (pl. 1). Dettinger and Schaefer (1996) compared the structural setting and distribution of Paleozoic carbonate rocks with the location of regional ground-water flow systems within the carbonate-rock province. The two major ground-water flow systems in the study area, the Great Salt Lake Desert and the Colorado regional flow systems (fig. 1) were shown to correspond to areas with thick sections of Paleozoic carbonate rocks in parts of the study area that had been extended only slightly. However, the low-permeability siliciclastic rocks typically found in highly extended domains appear to completely disrupt carbonate-rock aquifer continuity and to partition ground-water flow into flow systems of limited lateral extent.

Within highly extended domains, extension was accomplished along gently to moderately dipping, large-offset extensional detachment faults. For example, in the northern Snake Range, an abrupt, gently dipping detachment fault brings low permeability granitic rocks and ductilely deformed and metamorphosed Cambrian and Precambrian quartzite, marble and pelitic schist to the surface (fig. 7; Miller and others, 1983). On the basis of seismic reflection



A. Low-angle detachment fault, eastern flank of northern Snake Range, Nevada.

B. Folded lower plate rocks, northern Snake Range, Nevada.



C. Brecciated upper plate rocks, northern Snake Range, Nevada.

Figure 7. Example of low-angle detachment, northern Snake Range, eastern Nevada.

data, interpretive cross sections suggest that the moderately dipping detachment fault dips beneath Snake Valley (section *B-B'*, pl. 1) and beneath the Confusion Range to the east of the northern and southern Snake Range. Similar structures that bring low-permeability rocks to the surface exist in the southern Grant Range in northern Nye County (pl. 1) (Kleinhampl and Ziony, 1984; Lund and others, 1993) in the northern Egan and southern Cherry Creek Ranges (Armstrong, 1972; Gans and Miller, 1983) (section *A-A'*, pl. 1), and the Schell Creek Range (Dechert, 1967; Drewes, 1967; Armstrong, 1972).

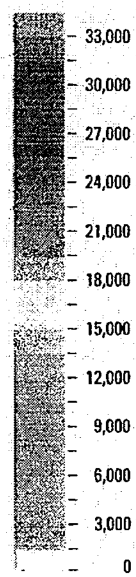
A second style of Tertiary extension is characterized by steeply dipping, range-bounding normal faults that produced elongate mountain ranges and have controlled the subsidence of intervening, down-faulted valleys (Zoback and others, 1981; Stewart, 1998). The range-bounding faults strike northeast and have displacements of several thousands of feet, typically juxtaposing the consolidated rocks within the range blocks against Cenozoic basin fill (Kleinhampl and Ziony, 1984). Basins commonly have a half-graben form in which the basin fill and basin floor are tilted toward a major fault on one side of the basin; this fault accommodates much of the extensional deformation and subsidence, producing a tilted, asymmetric basin (Stewart, 1998). Less commonly, basins have the form of a symmetric graben, with major faults bounding both sides of the basin. Symmetric grabens typically are located along the valley axis, with shallow pediments on either side. General relations between extensional range-bounding faults and associated asymmetric and symmetric grabens are annotated on cross section *C-C'* on pl. 1. Geophysical data show that basins in the study area vary in their complexity of faulting and relative development (Saltus and Jachens, 1995; Dohrenwend and others, 1996). For example, in White River Valley, along the western part of seismic line ECN-01 (section *C-C'*, pl. 1), there are three east-dipping half-grabens increasing in size from west to east. These half-grabens are largely buried and are not evident from surface topography or bedrock outcrops. In contrast, Cave Valley is a single east-dipping half-graben, where the floor of the graben mimics the dip of the Paleozoic rocks on the west side of the basin and a steeply dipping fault zone bounds its eastern edge.

Analysis of regional gravity data provides the basis for assessing the thickness of the Cenozoic basin-fill deposits (fig. 8). Cross sections that incorporate the geophysical data portray the three-dimensional shape of pre-Cenozoic basement, the location of major basin-bounding structures, and the presence of significant intrabasin faults (fig. 9). The thickness of basin fill in the study area generally is about 6,600 ft; however, in some basins, such as Steptoe and Lake Valleys, the thickness of basin fill is more than 13,000 ft (fig. 8). With the exception of Steptoe Valley in the north, basins in the southern part of the study area contain thicker basin-fill deposits than basins in the northern part of the study area.

Gravity-derived models of pre-Cenozoic bedrock, integrated with seismic, aeromagnetic, and drilling data, indicate that many of the basins in the study area contain buried bedrock highs (sections *C-C'* and *F-F'*, fig. 9). These bedrock highs represent intrabasin divides that separate most basins into two or more subbasins; geologically, they are referred to as accommodation zones (fig. 8) that developed in response to differential extension or tilting in different parts of the basin. In selected cases where the intrabasin divides are particularly shallow or distinctly separate deeper basins, these locations were chosen to subdivide hydrographic areas into subbasins (fig. 4). Subbasins do not necessarily represent individual ground-water basins, but merely areas separated by intrabasin divides where pre-Cenozoic bedrock has been uplifted and overlying basin-fill deposits are relatively thin. The geometry and structure of basins and associated subbasins in the study area are summarized in table 1.

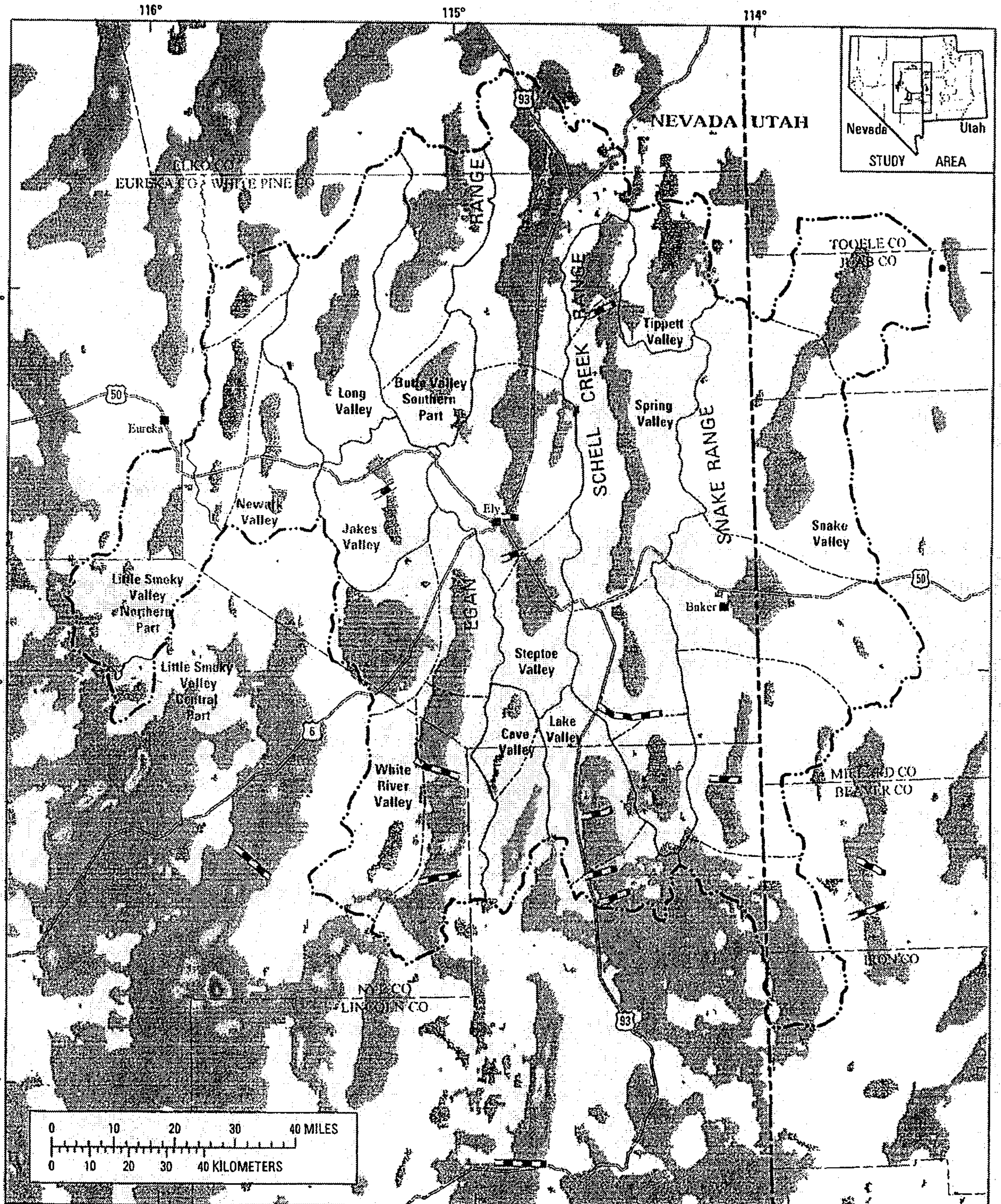
EXPLANATION FOR FIGURE 8

Depth to pre-Cenozoic basement, in feet



Structures interpreted from geophysical data

- Accommodation zone
- Boundary of study area
- Boundary of hydrographic area and name
- Boundary of intrabasin bedrock high-forming subbasin



Base from U.S. Geological Survey 1:100,000-scale digital data, 1979–84.
1:1,000,000 scale watershed boundaries from U.S. Geological Survey digital data.
Universal Transverse Mercator Projection, Zone 11, NAD83.

Caldera boundaries modified after Williams and others (1997), Loucks and others (1989), Raines and others (1996), Workman and others (2002), and Gans and others (1989).

Figure 8. Depth-to-bedrock map of the study area showing interpreted lineaments or features, Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

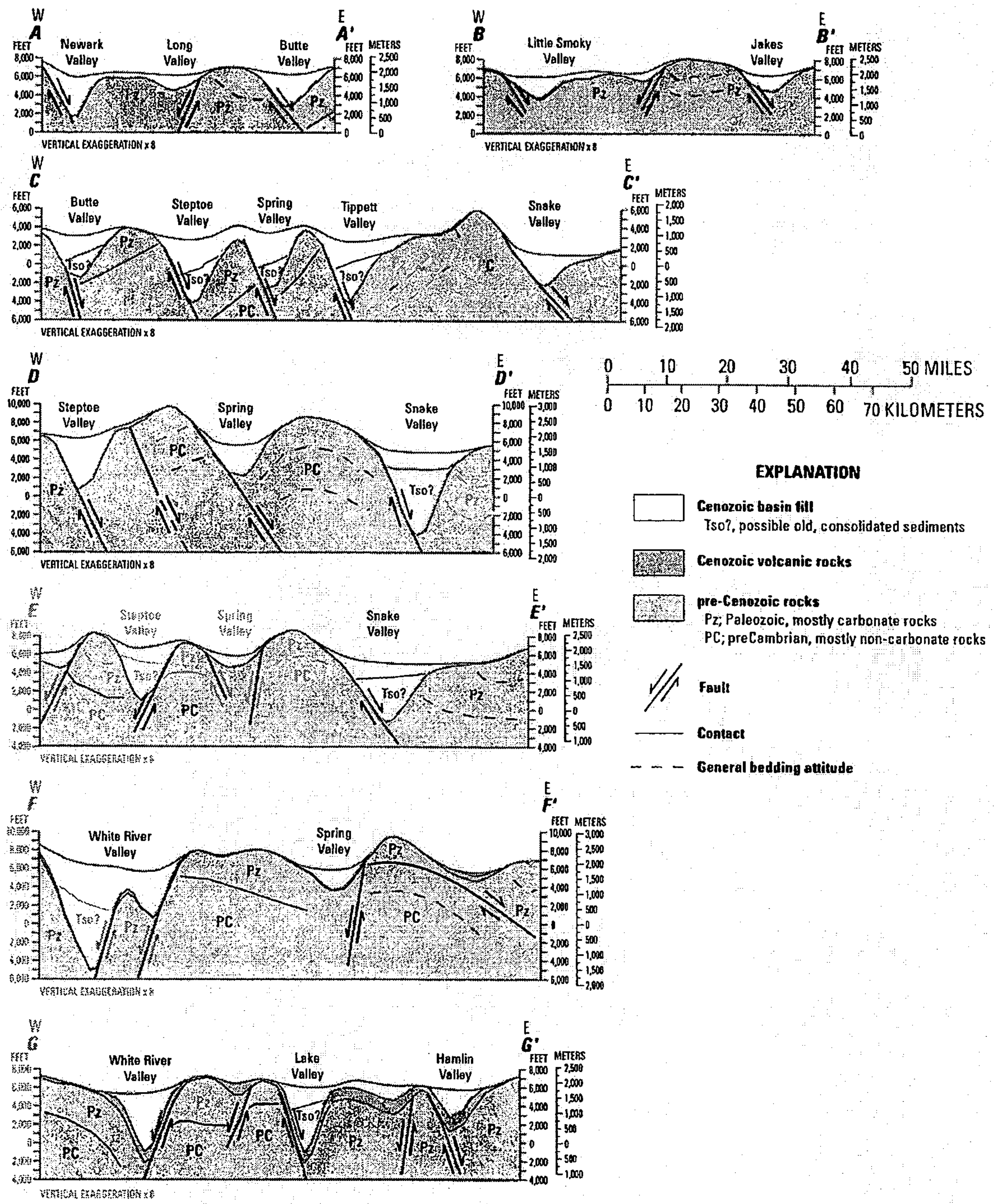


Figure 9. Modeled depth to pre-Cenozoic rocks and location of sections, Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.