Case No. 84739

IN THE SUPREME COURT OF THE STATE OF NEVADA

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ADAM SULLIVAN, P.E., NEVADA STATE ENGINEER, et al.

Appellants,

vs.

LINCOLN COUNTY WATER DISTRICT, et al.

JOINT APPENDIX

VOLUME 7 OF 49

Docket 84739 Document 2022-35234

MUDDY SPRINGS AREA MONITORING REPORT
FOR JANUARY 2012 THROUGH DECEMBER 2012

Prepared for:
Moapa Valley Water District
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August, 2011
In cooperation with:
Nevada Energy
National Park Service

SE ROA 10430

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INTRODUCTION

In January 1996, the Moapa Valley Water District (MVWD) submitted the Muddy Springs Area Monitoring Plan to the Nevada Division of Water Resources for approval. This plan was prepared in cooperation with the U.S. Department of Interior's National Park Service, U.S. Fish and Wildlife Service (USFWS), and Nevada Energy (formerly Nevada Power Company). In September 1997, the plan was approved by the Nevada State Engineer. In 2002, the plan was revised to change some trigger levels and monitoring frequencies. This report covers the results of monitoring for calendar year 2012.

The locations of monitoring sites are shown on Figures 1 and 2. Table 1 provides summary information on the baseline discharge rates for springs and baseline water levels for monitoring wells. Also included in Table 1 are the trigger levels that were developed as part of the monitoring effort. Initial trigger levels were established that, if reached, would lead to notification of each cooperating organization so that the cause of the spring discharge or water level decline can be determined and appropriate actions identified. Mitigation trigger levels were also established for each monitoring station; if these levels are reached, mitigation measures would be implemented as quickly as possible following approval by the cooperating organizations. Pursuant to a request by the U.S. Fish and Wildlife Service, the trigger levels were modified in March 1999 to establish a less arbitrary set of action levels.

SPRING DISCHARGE AND TEMPERATURE MONITORING

The Fish and Wildlife Service monitors discharge at Pederson Spring and Warm Springs West and temperature at Pederson Spring. Final discharge data for Warm Springs West, Pederson Spring, Pederson East Spring, and Muddy Spring at LDS were obtained from the USGS for the period 1 Jan 2012 to 31 Dec 2012.

Pederson Spring

The Pederson Spring gage was damaged in the fire of 1994 and the reliability of the discharge records was brought into question because of leaks that were probably caused by the mechanical removal of palm trees around the station. The gage was removed and replaced, and other restoration activities were completed in April, 2004.

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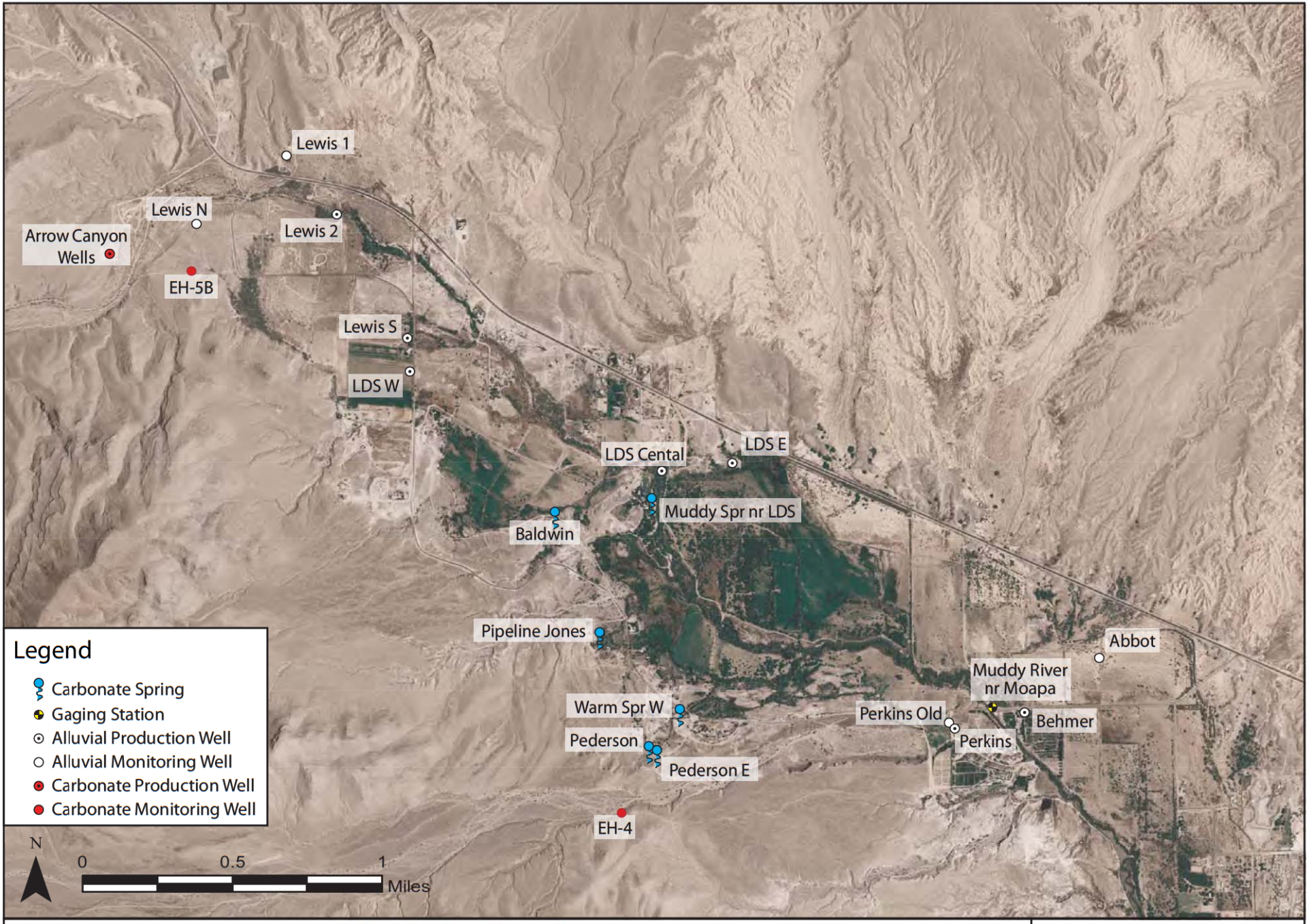

Muddy Springs Area Annual Monitoring Report

Figure 1: Location of Alluvial & Carbonate Wells, Carbonate Springs, and River Gage within ~2.5 Miles of the Moapa Valley National Wildlife Refuge

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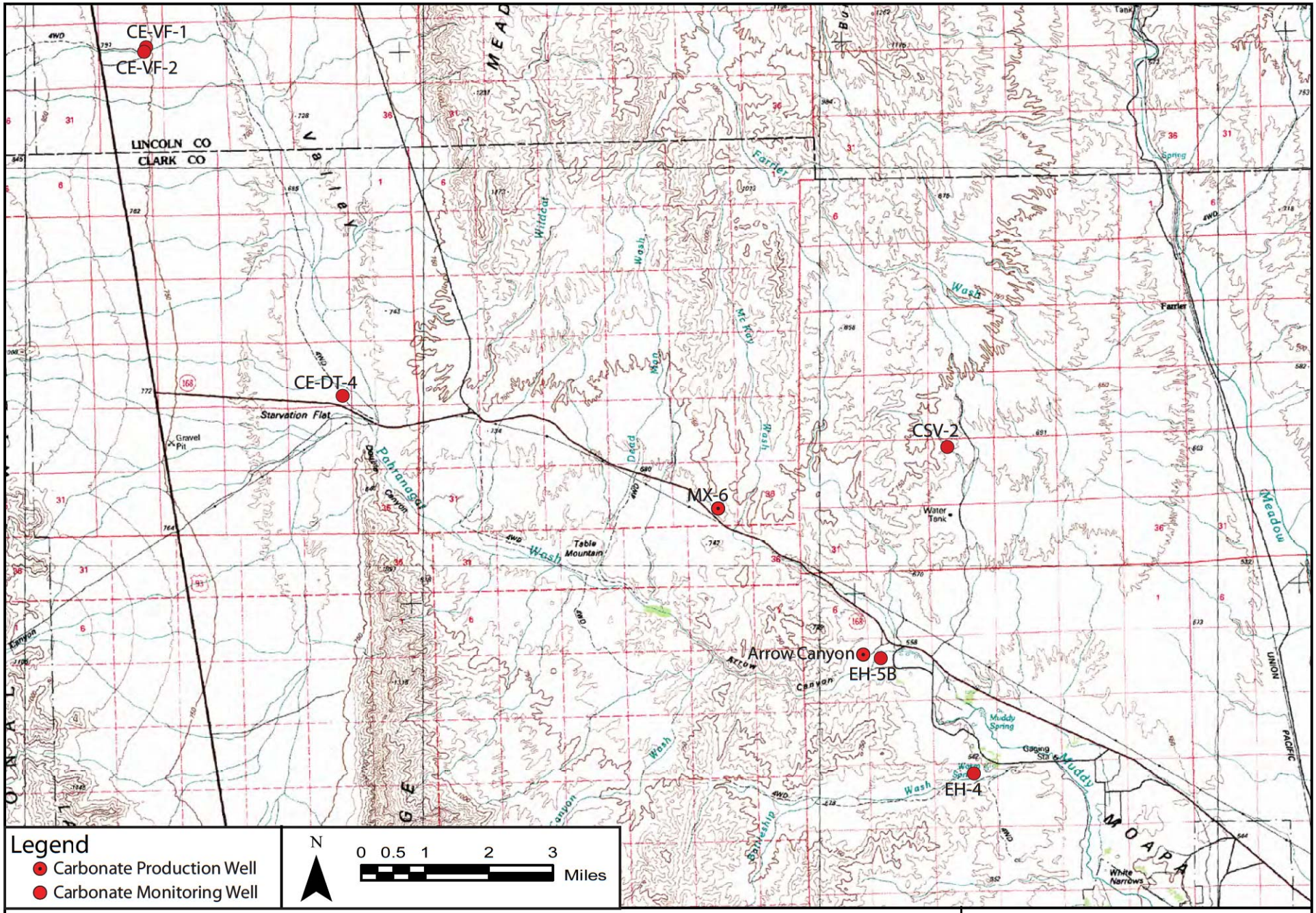

Muddy Springs Area Annual Monitoring Report

Figure 2: Location of Carbonate Production and Monitoring Wells in Muddy River and Coyote Springs Valley Area

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Table 1. Baseline conditions and trigger levels

Spring or Well	Source Aquifer	Baseline Conditions Discharge or Minimum Water Level (cfs or ft bls)		Upstream Diversions	Transmission Losses	Trigger Levels (cfs, degrees C, or ft below land surface)	
		30-day min	annual mean			Initial	Mitigate
Baldwin Spring	Carbonate	n/a	n/a	No	No	none	none
Pipeline Jones Spring	Carbonate	n/a	n/a	No	No	none	none
Muddy Spring	Carbonate	6.43	7.38	Yes	Yes	5.79 (60 days)	5.14 (30 days)
Pederson Spring	Carbonate	n/a	n/a	No	No	30°C (60 days)	28°C (30 days)
Warm Spring West	Carbonate	3.14	3.59	No	Yes	3.17 30°C (60 days)	2.94 28°C (30 days)
Muddy River at Moapa		28.0	42.7	Yes	Possible Seasonal	30.3 (annual)	22.4 (30-day)
EH-5b	Carbonate	29	n/a	n/a	n/a	34	39
EH-4	Carbonate	117	n/a	n/a	n/a	122	127
CSV-2	Carbonate	392	n/a	n/a	n/a	397	402
CE-DT-4	Carbonate	354	n/a	n/a	n/a	359	364
MX-6	Carbonate	n/a	n/a	n/a	n/a	tbd	tbd
Lewis Old	Alluvial	40	n/a	n/a	n/a	43	50
Lewis 2	Alluvial	42	n/a	n/a	n/a	45	52
Lewis North	Alluvial	33	n/a	n/a	n/a	36	43
Perkins Old	Alluvial	29	n/a	n/a	n/a	32	39
CE-VF-1	Carbonate	550	n/a	n/a	n/a	553	560
CE-VF-2	Carbonate	612	n/a	n/a	n/a	615	622

n/a not available or not applicable
tbd - to be developed, baseline data lacking

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In addition to the replacement of the Pederson Spring gage, a gage has been installed at the Pederson East Spring. Beginning in May 2002, records for this new location became available and are evaluated along with the information from springs with longer periods of record.

The long-term discharge records for Pederson Spring and Pederson East Spring are shown on Figure 3. During 2012, the daily discharge at Pederson Spring ranged from 0.06 to 0.18 and averaged 0.12 cfs. There is no discharge trigger level for Pederson Spring.

At Pederson East Spring, the discharge in ranged from 0.12 to 0.19 cfs. The average for the year was 0.14 cfs. There are no trigger levels associated with this spring gage. The record for both Pederson East and Pederson Spring showed a decrease in discharges since 2011. The declines in discharge can most likely attributed to the SNWA pumping test of MX-5 that began in fall 2010, since MVWD diversions have changed comparatively little (See Figure 9 below).

Warm Springs West

Long-term discharge records for Warms Springs West are shown on Figure 3. The discharge at Warm Springs West varied between 3.3 and 3.6 cfs during 2012. The baseline conditions for this spring are 3.14 cfs (30 day min) and 3.59 cfs (annual mean). The mean annual discharge for the period was 3.49 cfs. Even though discharges are declining since 2011, all values exceeded the initial trigger level of 3.17 cfs.

Muddy Spring

The long-term discharge records for Muddy Spring near LDS are shown on Figure 3. The discharge at Muddy Spring ranged between 7.2 and 8.4 during 2012. Discharge rates during this period all exceeded the trigger level of 5.79 cfs. The average discharge in 2012 was 8.01 cfs, which is above the baseline of 7.38 cfs.

Baldwin Spring

The District monitors monthly discharge at Baldwin Spring. During 2012, the average monthly discharge rate from the spring ranged from 2.58 to 2.70 cfs and averaged 2.65 cfs. The long-term record for Baldwin Spring is shown in Figure 4. Breaks in the record are associated with meter failures and anomalous decreases or increases in discharge following meter replacements may represent differences in meters rather than in actual discharge.

Pipeline Jones Spring

The District also monitored monthly discharge at Pipeline Jones Spring. The average monthly discharge rate ranged from 1.56 to 1.62 cfs with an overall average of 1.59 for 2012. The long-term record for Pipeline Jones Spring is shown in Figure 4.

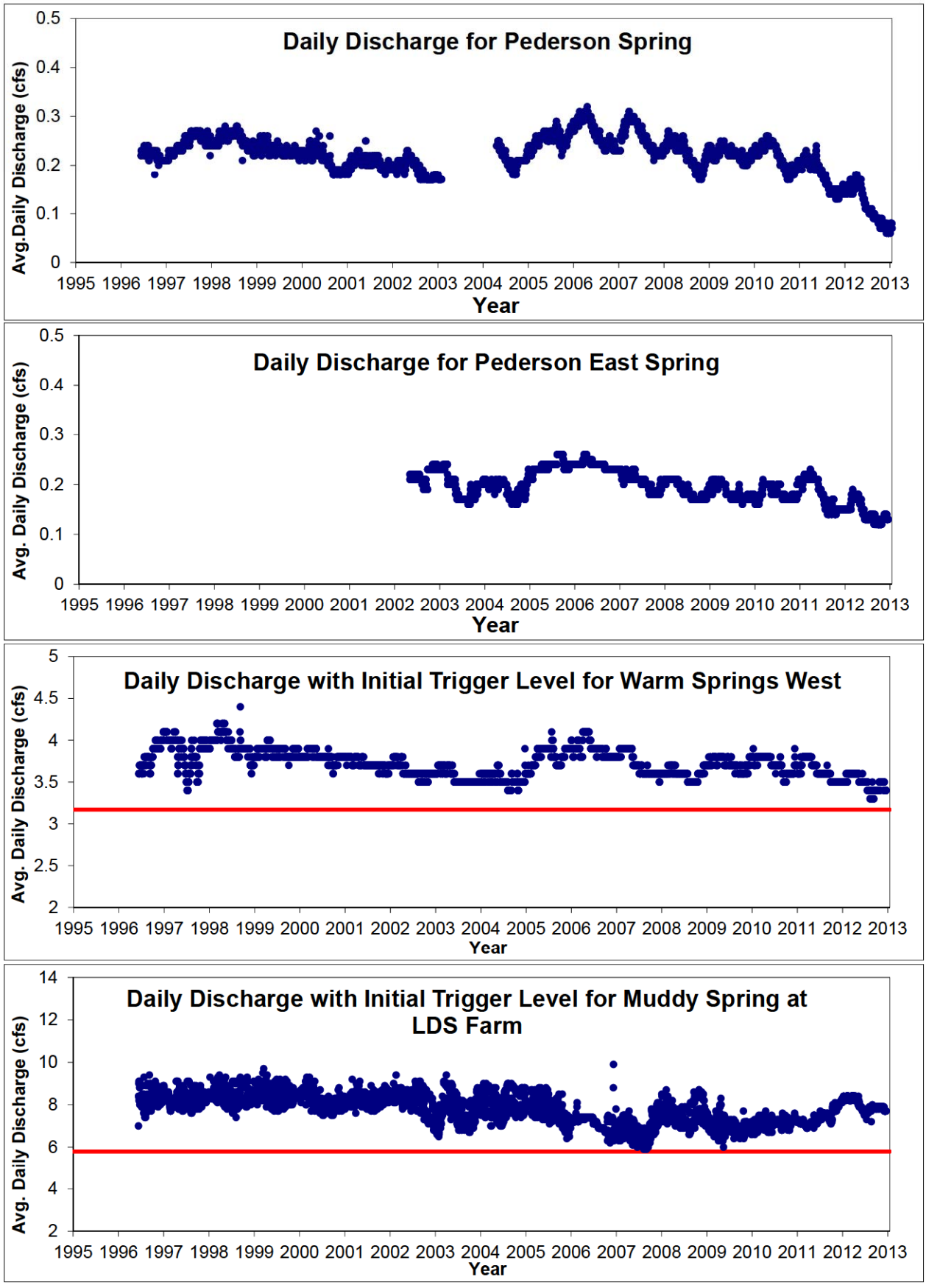

Figure 3. Daily Discharge at Monitoring Springs.

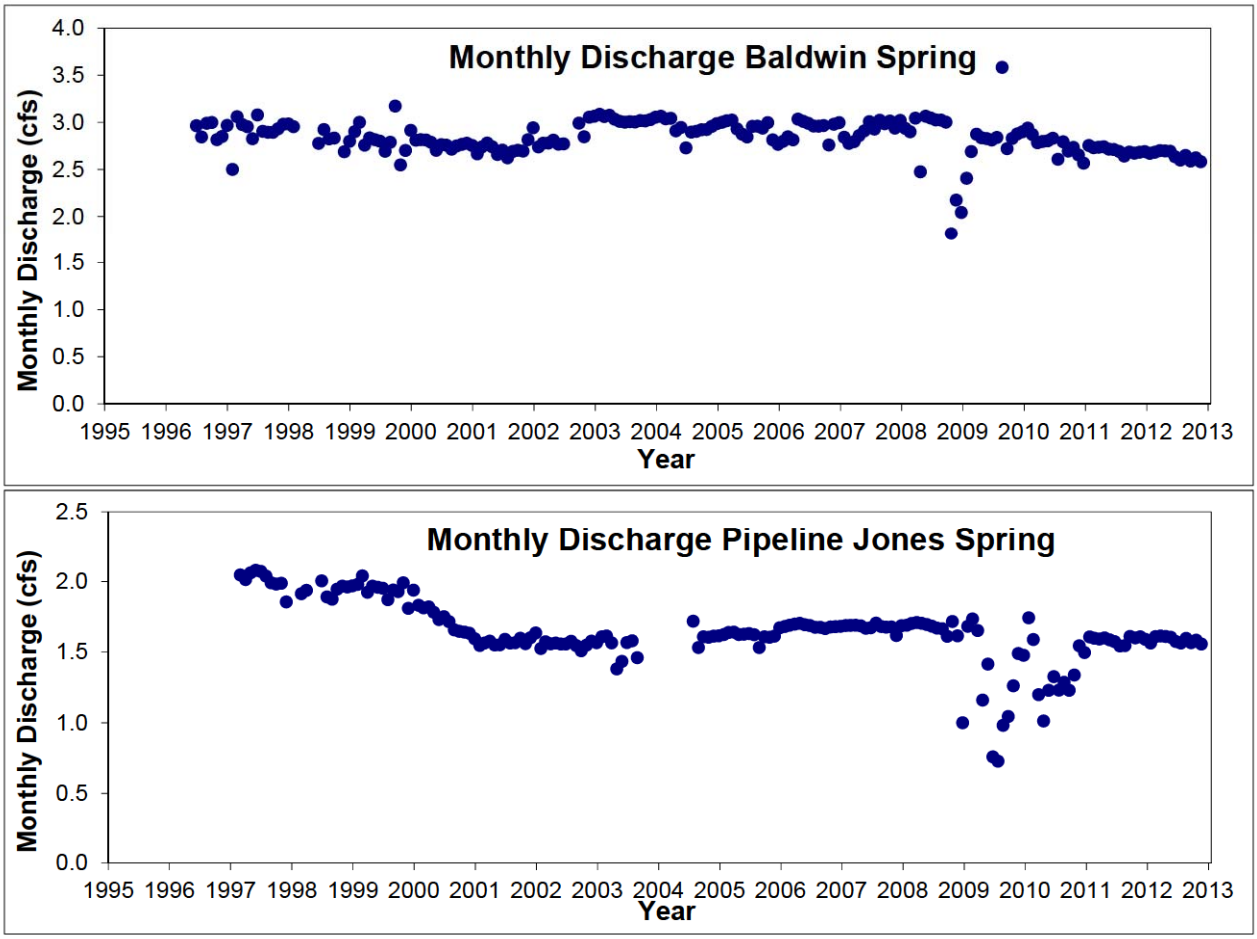

Figure 4. Discharge at Baldwin Spring and Pipeline Jones Spring
Note: Anomalous readings in May and June 2001 for Pipeline Jones are not plotted.

Rogers Spring and Blue Point Spring

The National Park Service contracts with USGS to monitor spring discharge rates at Rogers Spring and Blue Point Spring in Lake Mead National Recreation Area, and data for Rogers Spring was available online via USGS. Rogers Spring showed slightly higher discharges in 2012 than 2011 (Figure 5). Blue Point Spring showed a brief peak in discharge in early 2011 after which discharge declined below the long-term average. Discharge rates stabilized in 2012 at this below-average level.

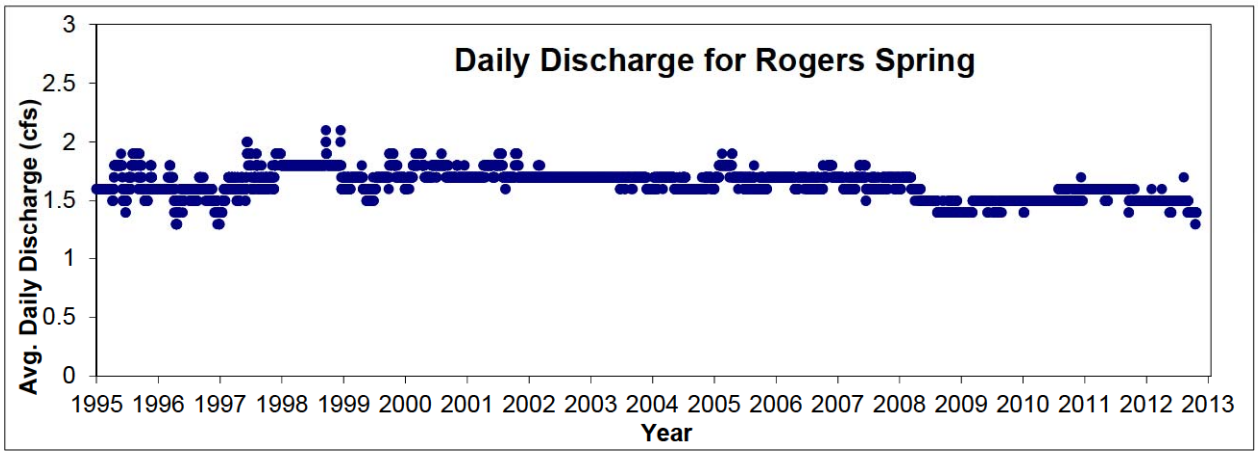

Figure 5. Discharge at Rogers Spring from USGS website.

WATER LEVEL MONITORING

The District monitored water levels on a monthly basis at the Arrow Canyon Well and MX-6 well during 2012. Nevada Energy continued their extensive water level monitoring program and provided the monthly water level data for seven wells in the upper Muddy River Valley that are included within the Muddy Springs Area monitoring network. Water levels in Coyote Spring Valley at CE-DT-4 and in the Muddy Spring area at CSV-2 were obtained from the USGS website.

Carbonate Aquifer Monitoring

The results of monitoring of the carbonate aquifer are presented as hydrographs in Figure 6 and Table 2. Data for EH-5B and EH-4 were collected monthly by NV Energy while data for CSV-2 and CE-DT-4 represent daily averages obtained from the USGS. At CE-VF-2, the USGS read water levels approximately six times per year with the last reading available from 7/31/2009. Because of lacking current data this well is excluded from this report.

Records for all wells showed 2-ft or smaller fluctuations between the minimum and maximum depth to water. All wells had water levels above the initial trigger levels. The declines in water levels since 2010/2011 can most likely be attributed to the SNWA pumping test of MX-5 that began in fall 2010.

Table 2: Depth to Water Levels (ft) for Carbonate Wells in 2012.

Well	Minimum	Maximum	Annual Average	Initial Trigger
EH-5B	30.75	32.10	31.48	34
EH-4	119.81	121.14	120.49	122
CSV-2	394.28	396.25	395.27	397
CE-DT-4	355.16	357.36	356.43	359

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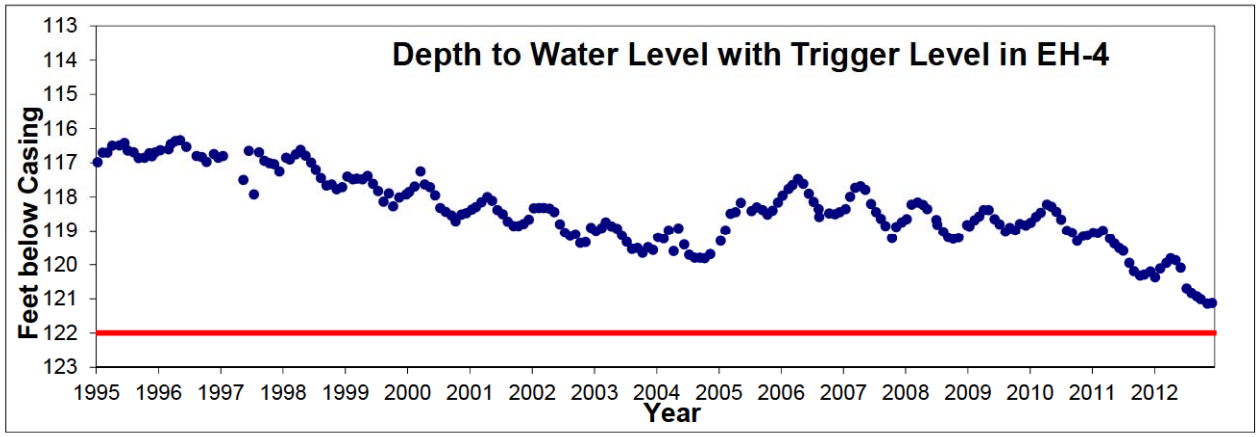

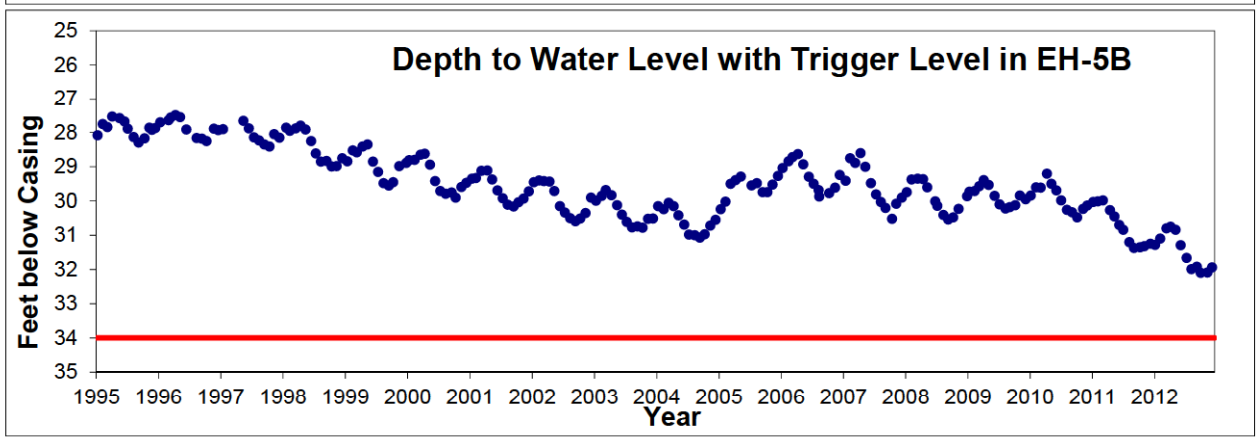

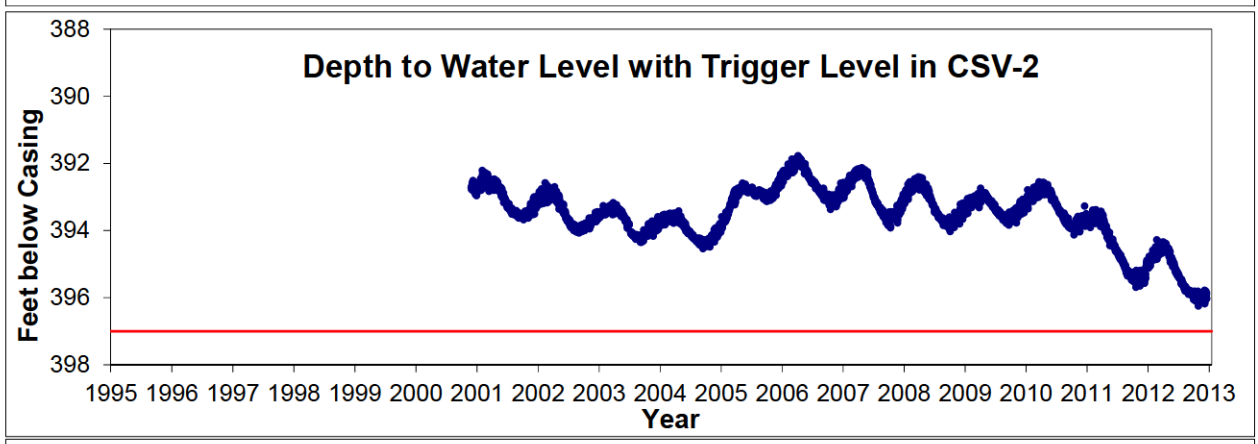

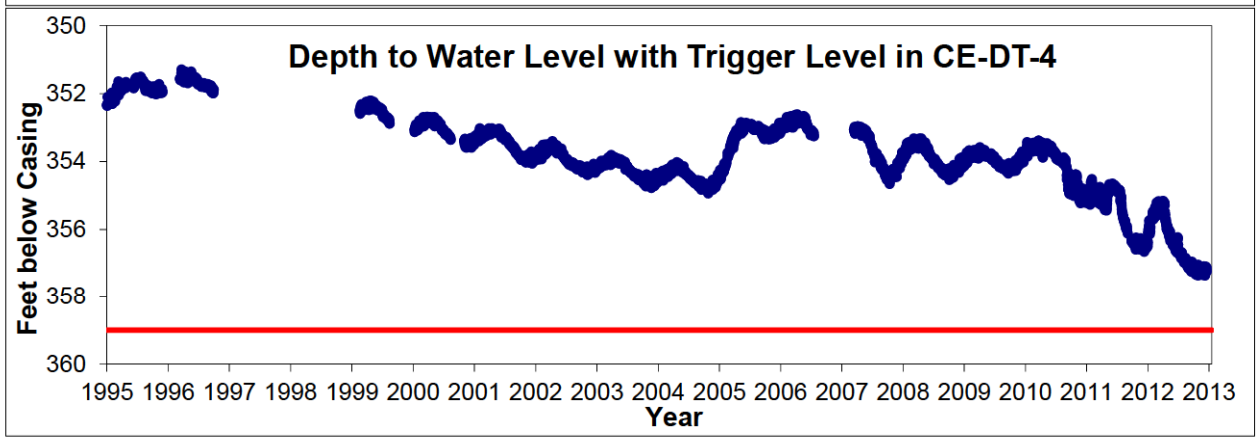

Figure 6. Hydrographs for Monitoring Wells in the Carbonate Aquifer

Alluvial Aquifer Monitoring

The results of monitoring of the alluvial aquifer are presented as hydrographs in Figure 7 and Table 3. These hydrographs are based on monthly water level measurements provided by NV Energy.

Lewis N showed the smallest seasonal fluctuations of the alluvial wells and continued the slow decline in overall water levels that began in 2007, reaching trigger levels for the first time. Lewis 1 & 2 had smaller fluctuations than in 2011. For Perkins Old the lowest water levels were well below both the initial and mitigate trigger levels and continued to drop during the latter months of 2012. However, since the three Lewis wells, which are closer to the Arrow Canyon wells, did not show similar trends, the most likely cause for the low levels in Perkins Old are alluvial water withdrawals.

Table 3: Depth to Water Levels (ft) for Alluvial Wells in 2012.

Well	Minimum	Maximum	Annual Average	Initial Trigger
Lewis N	32.80	35.93	34.67	36
Lewis 1	28.89	37.59	32.14	43
Lewis 2	27.21	39.15	31.08	45
Perkins Old	27.54	41.04	33.94	32

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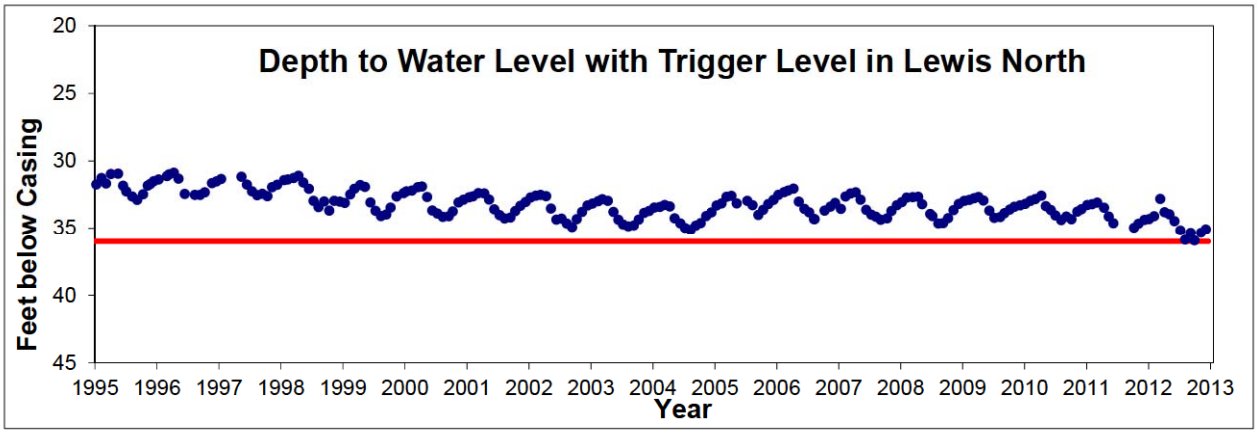

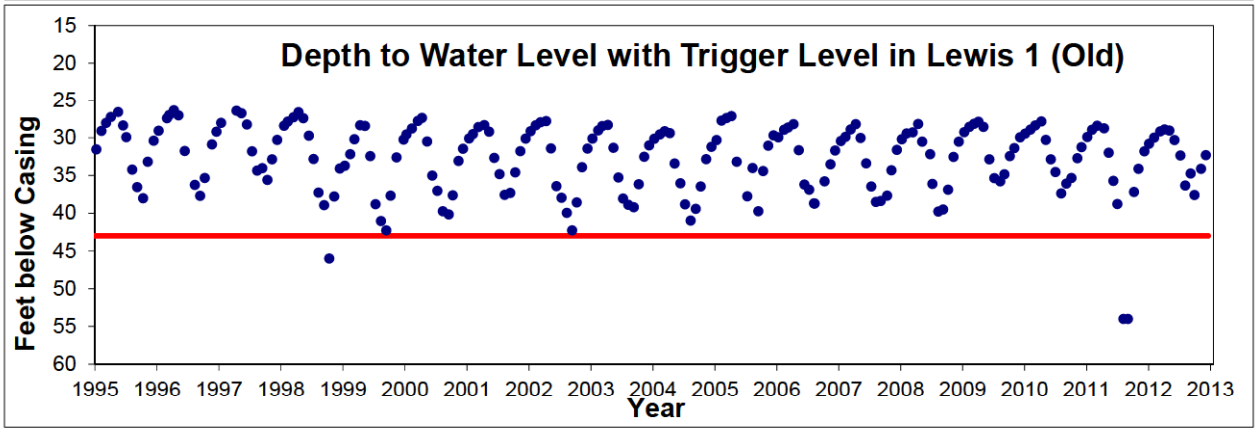

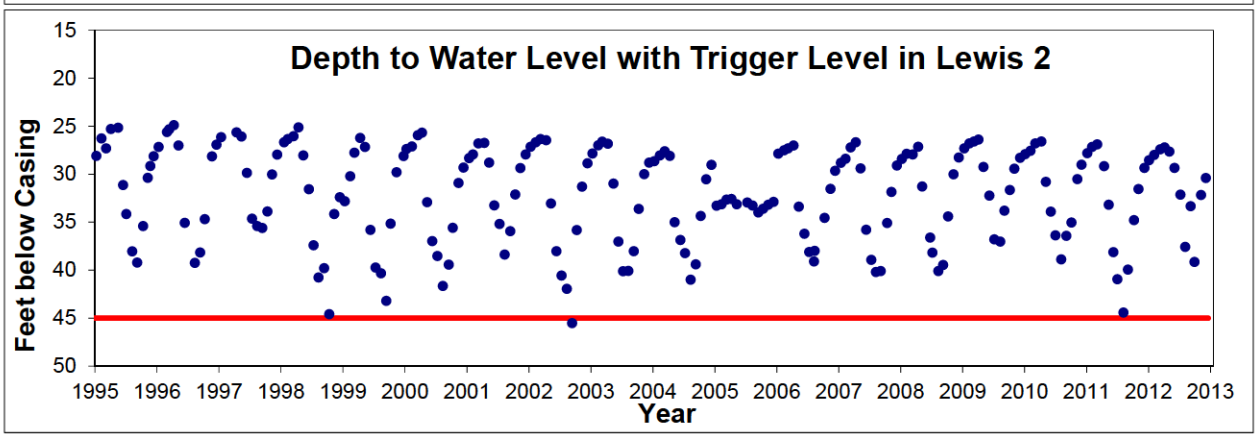

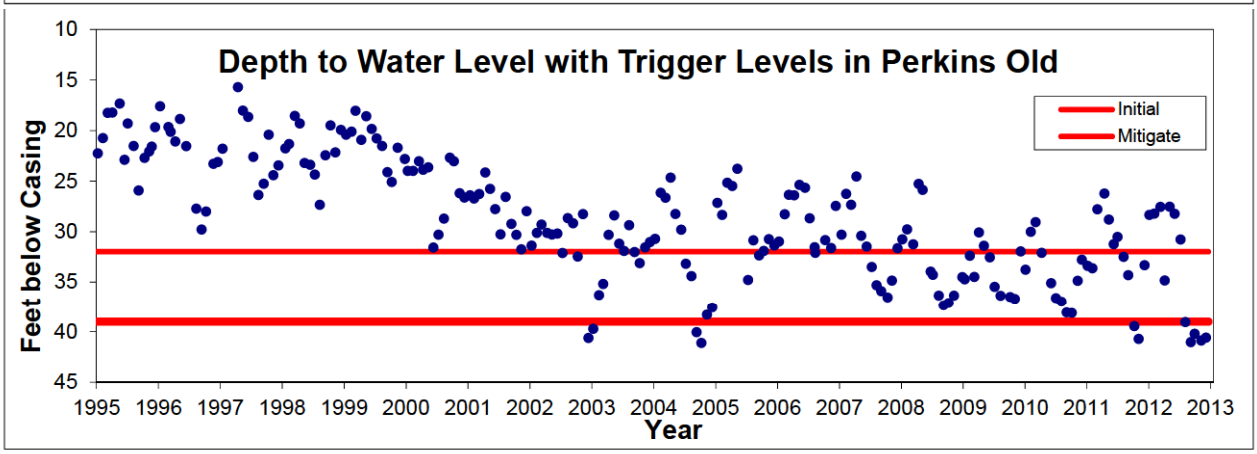

Figure 7. Hydrographs of Monthly Water Levels for Monitoring Wells in the Alluvial Aquifer

RIVER DISCHARGE MONITORING

The USGS continued monitoring the daily discharge of the Muddy River at the gage near Moapa (USGS 09416000 MUDDY RV NR MOAPA, NV) and the final data for that location was obtained from the USGS Nevada web page. During 2012, the minimum unadjusted 30-day average discharge rate was 33 cfs, well above the mitigating trigger of 22.4 cfs (Figure 8). The annual average unadjusted discharge was 38.4 cfs, above the respective trigger level of 30.3 cfs. Because these discharges were already above the trigger levels, no adjustments were done.

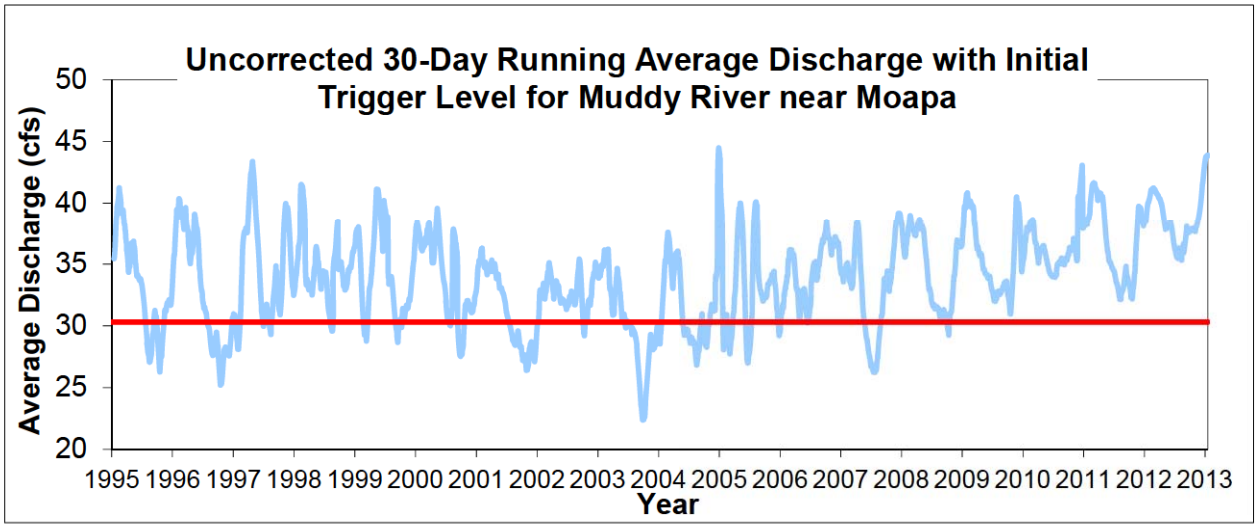

Figure 8. Thirty-day Running Average Discharge for the Muddy River near Moapa Uncorrected for Upstream Diversions

PRECIPITATION MONITORING

Because of repeated vandalism and difficulty in collecting precipitation data, the District discontinued the precipitation data collection effort.

WATER WELL WITHDRAWLS

Total carbonate pumpage has increased over the last several years in the vicinity of the Muddy River Springs. Coyote Springs Investment, LLC has been diverting carbonate water from the Coyote Springs Valley from the CSI wells since 2006, and in 2010 the Southern Nevada Water Authority began the pumping test on MX-5 (Figure 9). These additional diversions exceed MVWD carbonate diversions in recent years.

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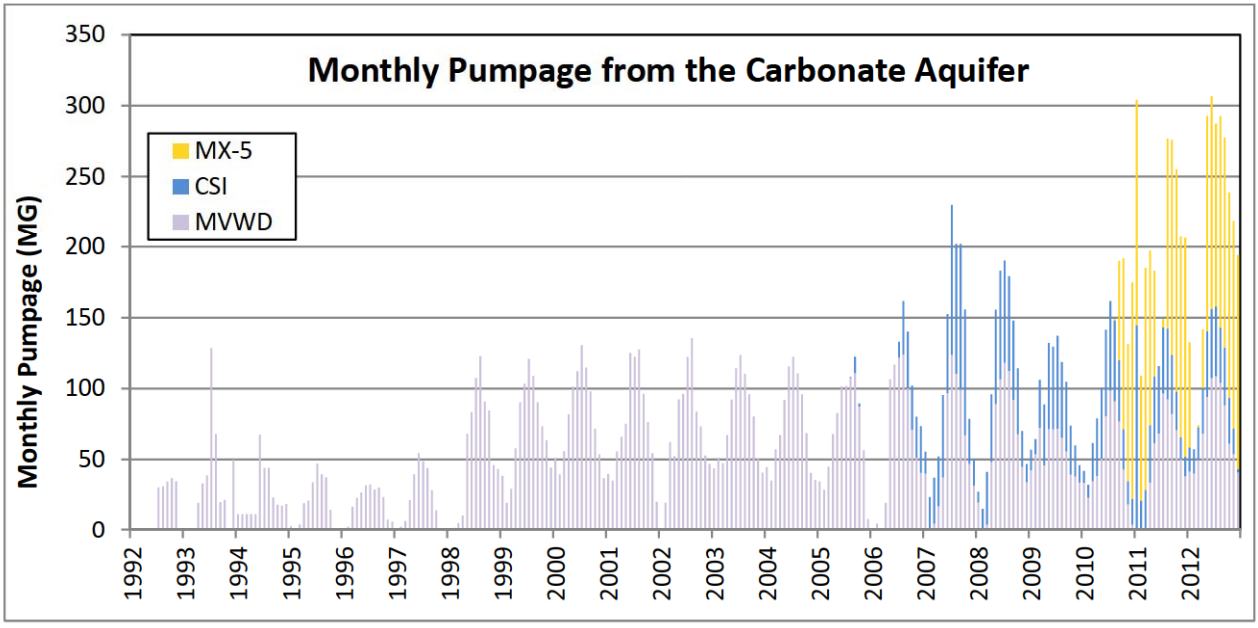

Figure 9: Carbonate Pumpage (millions of gallons) in the Carbonate Aquifer in the Muddy River and Coyote Springs Valley by the District, Coyote Springs Investment, LLC and Southern Nevada Water Authority (MX-5).

In 2012, the NV Energy withdrawals totaled 3,076 acre feet excluding RG4 and RG3-1, which is approximately 1100 acre feet lower than in 2011. NV Energy pumpage data were obtained from the SNWA data portal since the quarterly reports NV Energy provided did not include these data. Production from MVWD's three carbonate wells in 2012 was 625 acre feet higher than in 2011. The District's withdrawals from Arrow Canyon #1, Arrow Canyon #2, and MX-6 totaled 2,638 acre feet in 2012; 93.3 percent of this production was from the Arrow Canyon wells.

WATER USE AND DEMAND

In 2012, total withdrawals by the Moapa Valley Water District from the wells and springs in the Muddy Springs area were 2,667 acre feet (Tables 4, 5). These diversions represented a 223-acre-feet increase from the total withdrawals in 2011. The Arrow Canyon diversions were 625 acre-feet higher than in 2011.

Table 4: Total Water Diversions by the Moapa Valley Water District in 2012.

Source	Acre Feet
Arrow Canyon Wells	2,460
MX-6 Well	178
Baldwin Spring	26.6*
Pipeline Jones Spring	2.9*
Total Diversions	2,667

* Meter overestimated diversions due to air bubbles in the lines.

Table 5: Historic Diversions by the Moapa Valley Water District from the Arrow Canyon Wells.

Actual Versus Permitted Withdrawals from the Arrow Canyon Wells		
Calendar Year	Permitted Withdrawals	Actual Withdrawals (Acft)
1995	2.0 cfs 1,464 afy	304
1996	3.2 cfs 2,342 afy	274
1997	3.9 cfs 2,855 afy	501
1998	4.5 cfs 3,294 afy	1,969
1999	5.2 cfs 5,068 afy	2,434
2000	6.0 cfs 5,937 afy	2,777
2001	6.0 cfs 5,937 afy	2,434
2002	6.0 cfs 5,937 afy	2,264
2003	6.0 cfs 5,937 afy	2,468
2004	6.0 cfs 5,937 afy	2,505
2005	6.0 cfs 5,937 afy	2,289
2006	6.0 cfs 5,937 afy	1,971
2007	6.0 cfs 5,937 afy	1,844
2008	6.0 cfs 5,937 afy	1,888
2009	6.0 cfs 5,937 afy	2,033
2010	6.0 cfs 5,937 afy	1,815
2011	6.0 cfs 5,937 afy	1,835
2012	6.0 cfs 5,937 afy	2,460

MONITORING ISSUES

No new monitoring issues have been have been raised.

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APPENDIX

This appendix contains the data and transmittals from the cooperating organizations.

1. Moapa Valley Water District Production Data

2. Nevada Energy Groundwater Data (excerpts from quarterly reports)

3. National Park Service Report

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MOAPA VALLEY WATER DISTRICT
MONTHLY DIVERSIONS
2011 - 2012

2011	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL
MX	0	0	0	0	0	0	0	0	0	0		460,864	460,864
A/C #1	703,352	1,446,436	926,064	33,922,484	61,641,615	49,240,036	96,620,335	92,426,542	82,146,360	70,773,027	50,362,934	7,227,391	547,436,576
BALDWIN	630,632	5,436	4	4	0	19,275,314	4	12	22,536	-	0	30,620,804	50,554,746
JONES	18,979,632	23,380,566	31,480,858	22,831,846	23,372,114	31,051,734	14,617,988	20,605,404	10,650,300	6,041	31,838	71,680	197,080,001
LOG WELL	4,304	42	38	95,386	110	234	332,156	621,668	68	36	98	594	1,054,734
A/C #2	1	0	1	4	4	256	24	1	0	4	0	0	295
TOTAL	20,317,921	24,832,480	32,406,964	56,849,720	85,013,839	99,567,318	111,570,483	113,653,626	92,819,264	70,779,104	50,394,870	38,381,333	796,586,921

2012	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL
MX	0	0	2,084,505	15,527,907	16,242,318	15,838,456	8,185,344	0	0	0	0	0	57,878,530
A/C	0	0	0	45,714,498	77,989,123	91,664,675	100,550,499	104,196,459	88,332,183	61,354,108	53,985,179	18,133,444	641,920,168
A/C #2	41,719,785	40,316,714	47,727,277	7,065,922	0	0	11,407	0	0	0	0	22,943,971	159,785,076
BALDWIN	96,606	1,034,116	4,347,590	2,487,808	105,344	331,520	219,632	37,252	-328	-76	-288	(266)	8,658,910
JONES	354 *	935,868	2,362 *	0	0	0	720 *	2,172 *	328 *	76 *	288 *	266 *	942,434
LOG WELL	1,895 *	9 *	16 *	0	16 *	0	43 *	19 *	14 *	0	0	7 *	2,019
TOTAL	41,818,640	42,286,707	54,161,750	70,796,135	94,336,801	107,834,651	108,967,645	104,235,902	88,332,197	61,354,108	53,985,179	41,077,422	869,187,137

* This meter is off. No water went thru it this month; there were bubbles in the line.

Appendix C

Field Data Sheets

SE ROA 10448

JA_3312

NV Energy

WATER LEVEL READINGS (By: ACO Date: 2-16-12)

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / GPM	WELL CONDITION
Upper Muddy River Valley						
Abbot (uM7)	monthly	0915	17.67	—	—	good
LDS East (**unlock 6001**)	monthly	1930	7.15	220298	Ø	good
LDS Central	monthly	0935	3.22	335923	Ø	good
Lewis-1 Old (uM55)	continuous	0943	29.98	—	86%	new dessicant, good
Lewis-2 (uM74)	continuous	0955	27.99	—	85%	good
Lewis North (uM45)	continuous	1005	34.09	—	100%	good
EH-5b	continuous	1010	31.10	—	96%	new dessicant, good
Lewis South (uM43)	continuous	1015	14.00	—	80%	good; programed new test
LDS West	monthly	1025	18.88	641583	Ø	good, iris not connected for flow — disregard, not electrical
EH-4	continuous	1050	120.11	—	79%	new dessicant, good water
Perkins Production	monthly	1100	29.21	403381	Ø	good
Perkins Old	continuous	1105	28.21	—	77%	Need socket set to access well good
Behmer (uM14)	monthly	No Access, need key				
CSV-2	monthly	1200	395.23	—	—	— NWIS website

*RW-2 (1140) temp leveltroll pulled static wl = 382.80'
SN: 116693
replaced w/ leveltroll 500
SN: 304091

SE ROA 10449
JA_3313

NV Energy

WATER LEVEL READINGS (By: ACD Date: 1-17-12)

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / GPM	WELL CONDITION
Upper Muddy River Valley						
Abbot (uM7)	monthly	1210	18.14	—	—	good
LDS East **(unlock 6001)**	monthly	1220	7.13	220298	Ø	good
LDS Central	monthly	1225	3.22	335923	Ø	good
Lewis-1 Old (uM55)	continuous	1230	30.8	—	87%	replaced desiccant good
Lewis-2 (uM74)	continuous	1240	28.55	—	86%	replaced desiccant good
Lewis North (uM45)	continuous	1300	34.30	—	100%	good SN. 123086 firmware new + st
EH-5b	continuous	1312	31.28	—	97%	replaced dessicant update
Lewis South (uM43)	continuous	1320	14.55	—	81%	replaced dessicant, new test
LDS West	monthly	1325	19.48	611583	Ø	good
EH-4	continuous	1350	120.37	—	79%	good
Perkins Production	monthly	1420	29.24	397653	Ø	good
Perkins Old	continuous	1425	28.35	—	77%	Need socket set to access well replaced dessicant
Behmer (uM14)	monthly	No Access	—	—	—	—
CSV-2	monthly	1200	~~395.46~~	—	—	NWIS website

*RW-2 : Temporary transducer SN: 116693 installed w/ spaired cable SN: 202263
1100 383.33 — 76%

Nevada Power Company

Initials: ACD Date: 3-22-12 / 3-23-12 WATER LEVEL READINGS

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / Flowrate	deg. C / pH	Salinity/ eC	Well Condition
Dry Lake Basin								
RW-1	continuous	0845	273.37	—	Ø	—	—	pulled - no connection
Crystal 1 (bailer)	continuous	0930	260.90	—	95%	26.7	0.7/1.53	good
Crystal 2	continuous	0950	257.91	—	95%	—	—	good
Garnet Basin								
WS-2	quarterly	0752	433.00	16044775	Ø	—	—	good
Mesa/Weiser Wash								
EH-7 (bailer)	continuous	1505	116.26	—	71%	23.3	0.6/1.21	good
EH-3 (bailer)	continuous	1450	~~196~~ 196.50	—	99%	—	—	good (bailer won't fit)
Meadow Valley								
NPC-5 Old	quarterly	1230	25.44	—	Ø	21.1	0.4/0.781	good
NPC-4a	quarterly	1245	5.55	—	Ø	17.8	1.2/2.27	good
TH-12	quarterly	1255	23.00	—	Ø	20.5	0.7/1.34	good
EH-6	quarterly	1312	28.88	—	Ø	22.8	0.3/0.512	good
TH-8	quarterly	1300	18.44	—	Ø	21.2	1.0/1.97	good
EH-8a (1 inch) *	quarterly	1400	13.05	—	Ø	20.7	1.4/2.62	good
EH-8b (2 inch) *	quarterly	1401	14.07	—	—	—	—	good
NPC-2	quarterly	1410	14.70	—	Ø	21.2	0.7/1.83	mudg new lock
TH-35	quarterly	1405	12.30	—	Ø	~~20.9~~ 21.1	2.1/3.80	good
TH-31	quarterly	no access, need permission from owner						
Upper Muddy River Valley								
Abbot	monthly	0915	16.85	—	—	21.5	0.8/1.59	good
LDS East (**unlock 6001**)	monthly	0925	7.10	220298	Ø	—	—	good
LDS Central	monthly	0932	3.31	335923	Ø	—	—	good
Lewis-1 Old	continuous	0945	29.16	—	86%	27.6	0.6/1.174	new desiccant check test status for Feb
Lewis-2	continuous	1000	27.41	—	85%	30.2	0.4/0.90	new desiccant check test status for Feb
Lewis North ✱	continuous	1013	32.80	—	—	31.5	0.4/0.88	no correction pulled for repairs
EH-5b	continuous	1037	30.80	—	96%	29.2	0.4/0.874	good
Lewis South	continuous	1045	13.58	—	80%	29.6	0.4/0.852	download January log
LDS West	monthly	1055	18.40	641583	Ø	—	—	good
EH-4 (bailer)	continuous	1145	119.95	—	78%	24.6	0.5/0.97	good
Perkins Production	monthly	~~1140~~ 1140	32.54	404635	820 gpm	26.5	0.6/1.1	good
Perkins Old	continuous	1125	27.55	—	76%	26.3	0.5/1.07	good
Behmer	monthly	No Access lock changed						
CSV-2 (NWIS)	monthly	1200	394.91	—	—	—	—	NWIS website
Coyote Spring Valley								
RW-2 (bailer) *	continuous	~~1100~~ 1100	382.60	—	100%	30.7	0.4/0.90	good

* Water level reading from Top of Casing

✱ Lewis N: no correction pulled; temp SN 132 688 Troll 4 222200 cable installed

NV Energy

WATER LEVEL READINGS (By: GPS Date: 4/17/12)

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / GPM	WELL CONDITION
Upper Muddy River Valley						
Abbot (uM7)	monthly	11:55	18.32	—	—	GOOD
LDS East (**unlock 6001**)	monthly	12:07	7.23	238652	NOT PUMPING	GOOD
LDS Central	monthly	12:15	3.51	335923	NOT PUMPING	GOOD
Lewis-1 Old (uM55)	continuous	12:26	28.89	—	85%	GOOD
Lewis-2 (uM74)	continuous	12:39	27.21	—	84 %	GOOD
Lewis North (uM45)	continuous	12:51	53.79	—	80 %	GOOD - RESET TEST
EH-5b	continuous	13:04	30.75	—	96 %	GOOD
Lewis South (uM43)	continuous	13:14	13.33	—	79 %	GOOD - RESET TEST
LDS West	monthly	13:24	18.1	641583	NOT PUMPING	GOOD
EH-4	continuous	13:37	119.81	—	80%	GOOD
Perkins Production	monthly	13:54	43.75	434888	1200GPM	GOOD
Perkins Old	continuous	14:02	34.84	—	76%	Need socket set to access well
Behmer (uM14)	monthly	14:15	—	—	—	NO ACCESS / LOCK CHANGED
CSV-2	monthly	12:00	394.85	—	—	FROM WEBSITE

* Please download data from December 2011 → April for:
  - EH-3
  - EH-7

SE ROA 10452
JA_3316

NV Energy

WATER LEVEL READINGS (By: HMS Date: 5-16-13)

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / GPM	WELL CONDITION
Upper Muddy River Valley						
Abbot (uM7)	monthly	13:05	17.31 ft.	—	—	good
LDS East (**unlock 6001**)	monthly	13:20	7.24 ft	238652	0	good
LDS Central	monthly	13:26	3.78ft	335923	0	good
Lewis-1 Old (uM55)	continuous	13:39	29.06 ft	—	85%	*29.06ft set new test new large desiccant
Lewis-2 (uM74)	continuous	14:03	27.64	—	84%	new large desiccant
Lewis North (uM45)	continuous	14:22	33.94	—	80%	1.
EH-5b	continuous	14:47	30.84	—	95%	new large desiccant
Lewis South (uM43)	continuous	15:09	13.49	—	79%	new large desiccant
LDS West	monthly	15:23	18.29	641583	0	good
EH-4	continuous	15:30	119.87	—	77%	New large desiccant
Perkins Production	monthly	15:49	28.60	438530	0	good
Perkins Old	continuous	15:54	27.54	—	75%	Need socket set to access well
Behmer (uM14)	monthly	—	—	—	—	no access
CSV-2	monthly	12:00	395.04	—	—	NWIS website

1. pulled temp. transducer 220200-old cable transducer 132688
installed new cable 213090 transducer 312674 100% battery
installed large desiccant

SE ROA 10453
JA_3317

NV Energy

Initials: LMS Date: 6-14-12/6-15-12

WATER LEVEL READINGS

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / Flowrate	deg. C / pH	Salinity/ oC	Well Condition
Dry Lake Basin								
RW-1	continuous							no access
Crystal 1 (bailer)	continuous	0917	261.3	—	93%	27.5/7.6	1.4/.883	new large desiccant
Crystal 2	continuous	0940	857.28	—	93%	—	—	good
Garnet Basin								
WS-2	quarterly	0820	462.2	172756	0	—	—	good
Mesa/Wesa Wash								
EH-7 (bailer)	continuous	1052	118.8*	—	~~95%~~	25.2/9.4	0.5/1.02	* corrugation pulled cable
EH-3 (bailer)	continuous	1133	196.46	—	98%	—	—	large desiccant
Meadow Valley								
NPC-5 Old	quarterly	1206	26.61	—	—	21.4/8.47	.4/.854	good
NPC-4a	quarterly	1235	6.89	—	—	27.8/11.2	.2/.223	good
TH-12	quarterly	1244	25.94	—	—	23.4/11.2	.7/.867	good
EH-6	quarterly	1257	29.69	—	—	25.2/10.5	.5/	good
TH-8	quarterly	1315	28.23	—	—	24.2/10.7	1.0/.198	good
EH-8a (1 inch) *	quarterly	1325	15.56			23.4/11.2	1.3/.854	good
EH-8b (2 inch) *	quarterly	1325	14.50	—	—	—	—	good
NPC-2	quarterly	1402	16.91			26.0/11.2	.9/.183	good
TH-35	quarterly	1350	15.65			23.7/10.9	1.3/.253	good
TH-31	quarterly	—	—	—	—	—	—	No access
Upper Muddy River Valley								
Abbot	monthly	0900	17.71	—	—	26.8/12.7	.8/.157	
LDS East (unlock 6001)	monthly	0915	7.28	238632	8	—	—	good
LDS Central	monthly	0930	4.02	335923		—	—	good
Lewis-1 Old	continuous	0938	30.01	—	84%	28.3/10.7	0.6/1.13	well scale knocked
Lewis-2	continuous	1002	29.35	—	84%	28.9/11.5	0.4/0.876	good
Lewis North	continuous	1015	34.46	—	100%	26.6/11.0	.4/.0819	good
EH-5b	continuous	1032	31.29	—	95%	35.1/10.7	.4/.845	good
Lewis South	continuous	1045	14.48	—	79%	35.3/10.8	.4/.783	good
LDS West	monthly	1055	19.38	641583	0	—	—	good
EH-4 (bailer)	continuous	1430	120.09	—		35.9/10.8	0.4/6.820	good
Perkins Production	monthly	1457	29.27	438530	0	—	—	good
Perkins Old	continuous	1445	28.24	—	75%	30.7/7.5	0.6/.115	good
Behmer	monthly	~~1200~~	—	—	—	—	—	No access
CSV-2 (NWIS)	monthly	1200	395.39	—	—	—	—	
Coyote Spring Valley								
RW-2 (bailer) *	continuous	1430	383.6		99%			good

* Water level reading from Top of Casing

* pH probe malfunction

SE ROA 10454

JA_3318

NV Energy

WATER LEVEL READINGS (By: HMS Date: 7-30-12

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / GPM	WELL CONDITION
Upper Muddy River Valley						
Abbot (uM7)	monthly	0935	19.67	—	—	good
LDS East (**unlock 6001**)	monthly	0952	22.45	255525	9.5 GPM	good
LDS Central	monthly	0958	9.69	349719	8.1 GPM	good
Lewis-1 Old (uM55)	continuous	1007	32.36	—	84%	good
Lewis-2 (uM74)	continuous	1026	32.13	—	83%	good
Lewis North (uM45)	continuous	1040	35.16	—	99%	good
EH-5b	continuous	1047	31.66	—	94%	good
Lewis South (uM43)	continuous	1101	17.38	—	78%	good - watch battery
LDS West	monthly	1108	29.13	660238	11.8 GPM	good
EH-4	continuous	1122	120.70	—	76%	good - watch battery
Perkins Production	monthly	1140	31.89	460406	0 GPM	good
Perkins Old	continuous	1150	80.77	—	75%	Need socket set to access well good
Behmer (uM14)	monthly	—	—	—	—	no access
CSV-2	monthly					

NV Energy

WATER LEVEL READINGS (By: JPS Date: 2-17-16)

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / GPM	WELL CONDITION
Upper Muddy River Valley						
Abbot (uM7)	monthly	09:53	22.70	—	—	GOOD
LDS East (**unlock 6001**)	monthly	10:05	21.30	283920	1000	GOOD
LDS Central	monthly	10:11	4.64	357948	NOT PUMPING	GOOD
Lewis-1 Old (uM55)	continuous	10:26	36.34	—	83%	GOOL
Lewis-2 (uM74)	continuous	10:38	37.58	—	83%	GOOD
Lewis North (uM45)	continuous	10:51	35.87	—	75%	GOOL
EH-5b	continuous	11:01	31.99	—	94%	GOOL
Lewis South (uM43)	continuous	11:11	19.75	—	78%	GOOL - RESET TEST
LDS West	monthly	11:26	31.06	623822	1075	GOOL
EH-4	continuous	11:38	120.83	—	76%	GOOL
Perkins Production	monthly	11:54	45.38	484813	925	GOOL
Perkins Old	continuous	12:01	39.05	—	74%	Need socket set to access well GOOD
Behmer (uM14)	monthly	12:15				NO ACCESS
CSV-2	monthly	12:00	396.17			FROM WEBSITE

NV Energy

Initials: JPS Date: 9-18-12 / 9-19-12 / 9-26-12 **WATER LEVEL READINGS**

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / Flowrate	deg. C / pH	Salinity/ eC	Well Condition
Dry Lake Basin								
RW-1	continuous	1142	277.55	—	—	—	—	NO PROBE
Crystal 1 (bailer)	continuous	0925	262.23	—	WON'T CONNECT	25.0/6.65	1.6/3.020	GOOD - COMPUTER WON'T CONNECT
Crystal 2	continuous	1011	259.12	—	92%	24.7/6.69	0.9/4.300	GOOD - RESET TEST
Garnet Basin								
WS-2	quarterly	0919	433.85	9102346	NOT PUMPING	—	—	GOOD
Mesa/Weiser Wash								
EH-7 (bailer)	continuous	1303	116.42	—	—	24.2/9.43	0.6/1.2	NO PROBE
EH-3 (bailer)	continuous	1428	196.55	—	96%	—	—	GOOD RESET TEST
Meadow Valley								
NPC-5 Old	quarterly	1147	26.77	—	—	17.1/8.78	0.5/1.04	GOOD
NPC-4a	quarterly	1130	7.89	—	—	17.8/9.18	1.3/2.52	GOOD
TH-12	quarterly	1119	26.36	—	—	18.9/8.07	0.7/1.42	GOOD
EH-6	quarterly	1106	30.41	—	—	21.4/7.10	0.3/0.5	GOOD
TH-8	quarterly	1051	20.73	—	—	18.3/7.81	1.1/2.18	GOOD
EH-8a (1 inch) *	quarterly	1038	15.22	—	—	19.8/7.75	1.4/2.61	GOOD
EH-8b (2 inch) *	quarterly	1039	15.13	—	—	—	—	GOOD
NPC-2	quarterly	1012	16.12	—	—	18.4/8.74	1.0/1.95	GOOD
TH-35	quarterly	1025	15.82	—	—	16.9/7.85	1.6/3.05	GOOD
TH-31	quarterly	1257	25.83	—	—	20.7/8.07	0.9/1.65	GOOD
Upper Muddy River Valley								
Abbot	monthly	1316	23.59	—	—	17.6/7.84	0.9/1.71	GOOD
LDS East (**unlock 6001**)	monthly	1333	25.80	313136	1125	25.8/7.62	0.5/1.19	GOOD
LDS Central	monthly	1351	4.43	363885	NOT PUMPING	—	—	GOOD
Lewis-1 Old	continuous	1401	34.73	—	83%	25.6/7.82	0.6/1.23	GOOD
Lewis-2	continuous	1418	33.34	—	82%	26.5/7.52	0.6/1.10	GOOD
Lewis North	continuous	1433	35.33	—	99%	26.9/7.67	0.5/1.06	GOOD
EH-5b	continuous	1448	31.92	—	93%	25.8/8.47	0.5/1.04	GOOD
Lewis South	continuous	1501	17.91	—	77%	24.9/8.24	0.0/0.80	GOOD
LDS West	monthly	1511	23.25	693468	NOT PUMPING	—	—	GOOD
EH-4 (bailer)	continuous	1704	120.98	—	75%	22.3/7.70	0.0/0.86	GOOD
Perkins Production	monthly	1723	50.35	518861	1225	21.8/7.75	0.6/1.20	GOOD
Perkins Old	continuous	1744	41.04	—	74%	22.1/7.47	0.7/1.29	GOOD
Behmer	monthly	1800	—	—	—	—	—	NO ACCESS
CSV-2 (NWIS)	monthly	1200	395.88	—	—	—	—	FROM WEBSITE
Coyote Spring Valley								
RW-2 (bailer) *	continuous	1555	384.33	—	97%	COULD NOT OBTAIN SAMPLE		GOOD - RESET TEST

* Water level reading from Top of Casing

NV Energy

WATER LEVEL READINGS (By: JPS Date: 10/11/12)

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / GPM	WELL CONDITION
Upper Muddy River Valley						
Abbot (uM7)	monthly	10:03	23.02	—	—	GOOD
LDS East **(unlock 6001)**	monthly	10:14	22.15	336912	975	GOOD
LDS Central	monthly	10:21	9.10	366018	800	GOOD
Lewis-1 Old (uM55)	continuous	10:30	37.59	—	83%	GOOD
Lewis-2 (uM74)	continuous	10:43	39.15	—	82%	GOOD
Lewis North (uM45)	continuous	11:00	35.93	—	98%	GOOD
EH-5b	continuous	11:13	32.10	—	93%	GOOD
Lewis South (uM43)	continuous	11:23	18.76	—	77%	GOOD
LDS West	monthly	11:30	23.84	694209	NOT PUMPING	GOOD
EH-4	continuous	11:49	121.01	—	75%	GOOD
Perkins Production	monthly	12:04	47.70	546724	1000	GOOD
Perkins Old	continuous	12:11	40.21	—	73%	Need socket set to access well GOOD
Behmer (uM14)	monthly	12:25	—	—	—	★
CSV-2	monthly	12:00	395.98	—	—	FROM WEBSITE

★ LOCK ON GATE IS NOW #2754
BUT WE DON'T HAVE KEY TO LOCK ON WELL PERIMETER FENCE. WELL APPEARS TO HAVE BEEN PARTIALLY DISASSEMBLED.

SE ROA 10458
JA_3322

NV Energy

WATER LEVEL READINGS (By: JPS Date: 11/19/12)

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / GPM	WELL CONDITION
Upper Muddy River Valley						
Abbot (uM7)	monthly	11:54	22.72	—	—	Good
LDS East (**unlock 6001**)	monthly	12:07	19.45	368648	700	Good
LDS Central	monthly	12:13	9.46	290431	825	GOOD
Lewis-1 Old (uM55)	continuous	12:23	34.12	—	82%	DESSICANT GETTING LOW/RESET TEST
Lewis-2 (uM74)	continuous	12:38	32.17	—	81%	GOOD
Lewis North (uM45)	continuous	12:49	35.33	—	98%	GOOD / RESET TEST
EH-5b	continuous	13:02	32.09	—	92%	GOOD
☆ Lewis South (uM43)	continuous	13:14	17.26	—	0%	BATT. DEAD - COULDN'T DOWNLOAD - PULL PROBE
LDS West	monthly	13:22	22.51	706344	NOT PUMPING	GOOD
EH-4	continuous	13:41	121.14	—	75%	GOOD
Perkins Production	monthly	14:09	49.93	601607	1200	GOOD
Perkins Old	continuous	14:15	40.87	—	73%	Need socket set to access well GOOD
Behmer (uM14)	monthly	~~14:30~~				NO ACCESS
CSV-2	monthly	12:00	396.10	—	—	FROM WEBSITE

SE ROA 10459

JA_3323

Nevada Power Company

Initials: JPS AD Date: 1-4-13 1-8-13

WATER LEVEL READINGS

WELL I.D.	FREQUENCY	TIME	DEPTH TO WATER	TOTAL DISCHARGE	% Power / Flowrate	deg. C / pH	Salinity/ eC	Well Condition
Dry Lake Basin								
RW-1	continuous	—	—	—	—	—	—	NO ACCESS Need to verify manual WL in Dec
Crystal 1 (bailer)	continuous	1100	262.25	—	—	25.9/8.92	24.07/-	no data since May no conjunction
Crystal 2	continuous	1125	259.15	—	90%	—	—	good
Garnet Basin								
WS-2	quarterly	1025	444.85	3573980	Ø	—	—	data logger deployed NOT DOES ?
Mesa/Weiser Wash								
EH-7 (bailer)	continuous	1345	116.20	—	—	21.4/9.21	-/1.4	Probe missing
EH-3 (bailer)	continuous	1330	196.65	—	95%	—	—	probe installed
Meadow Valley								
NPC-5 Old	quarterly	1405	25.15	—	—	19.4/8.31	-/1.38	good
NPC-4a	quarterly	1425	6.20	—	—	—	—	WO, no access
TH-12	quarterly	1435	23.08	—	—	20.12/7.5	/1.34	good
EH-6	quarterly	1445	29.40	—	—	22.11/7.4	/0.49	good
TH-8	quarterly	1500	18.8	—	—	21.44/7.32	-/1.0	good
EH-8a (1 inch) *	quarterly	1515	13.15					
EH-8b (2 inch) *	quarterly	1515	14.50					
NPC-2	quarterly	1530	14.42			20.76/7.29	-/1.33	good
TH-35	quarterly	1520	13.33			20.06/7.20	/2.82	good
TH-31	quarterly	—	—	—	—	—	—	no access
Upper Muddy River Valley								
Abbot	monthly	12:39	23.57	—	—	probe not hit		GOOD
LDS East (unlock 6001)	monthly	12:54	18.99	398352	750	—	—	GOOD
LDS Central	monthly	13:04	14.52	413747	—	—	—	GOOD
Lewis-1 Old	continuous	13:18	32.30	—	82%	probe wire fell		GOOD measure 32.3
Lewis-2	continuous	13:28	30.40	—	81%	29.26/7.35	/0.915	GOOD
Lewis North	continuous	13:45	35.07	—	97%	30.7/7.56	-/0.885	GOOD
EH-5b	continuous	13:52	31.94	—	97%	29.01/7.4	-/0.829	GOOD
Lewis South * 1-8-13	continuous	15:50	15.30	—	76%	30.12/7.9	-/0.836	good *
LDS West	monthly	14:06	21.06	706908	—	—	—	GOOD
EH-4 (bailer)	continuous	14:18	121.12	—	74%	—	—	GOOD
Perkins Production	monthly	14:33	46.54	632269	850	—	—	GOOD
Perkins Old	continuous	14:40	40.59	—	72%	—	—	GOOD - DEEP 76 ST
Behmer	monthly	14:54	—	—	—	—	—	NO ACCESS
CSV-2 (NWIS)	monthly	12:00	395.99	—	—	—	—	unable
Coyote Spring Valley								
RW-2 (bailer) *	continuous	1245	384.50	—	96%	31.8/7.65	0.771	good

* Water level reading from Top of Casing

* Lewis South probe S/N: 136229 pulled - battery dead
temp probe S/N: 132685 installed

1) no access to RW-1 probe needs replaced

2) Crystal 1 = no conjunction, pulled for repairs

United States Department of the Interior

NATIONAL PARK SERVICE

LAKE MEAD NATIONAL RECREATION AREA
601 NEVADA WAY
BOULDER CITY, NEVADA 89005

IN REPLY REFER TO:

April 12, 2013

Mr. Joe Davis, General Manager
Moapa Valley Water District
P.O. Box 257
Logandale, NV 89021

Subject: NPS Submittal to *Muddy Springs Area Monitoring Plan* for Permits Nos. 55450 and 58269 of the Moapa Valley Water District to Appropriate the Public Waters of the State of Nevada

Dear Mr. Davis:

The National Park Service (NPS) agreed to conduct hydrologic monitoring and provide information in conjunction with the above-referenced monitoring plan. The NPS contracts with the U.S. Geological Survey to measure the discharge of Rogers Spring and Blue Point Spring in the Overton Arm area of Lake Mead National Recreation Area (Lake Mead NRA).

The NPS submits herein:

(1) USGS 2011 water data reports (2) containing tables of the daily mean values of discharge and hydrographs for Rogers Spring and for Blue Point Spring for the 2011 water year (i.e. Oct. 2010 through Sep. 2011);

(2) NPS-generated hydrographs (2) of the monthly mean discharge of Rogers Spring for the 26-year period of record (August 1985 through September 2011), and of Blue Point Spring for the 12-year period of record (October 1999 through September 2011);

(3) USGS 2012 water data reports (2) containing tables of the daily mean values of discharge and hydrographs for Rogers Spring and for Blue Point Spring for the 2012 water year (i.e. Oct. 2011 through Sep. 2012); and

(4) NPS-generated hydrographs (2) of the monthly mean discharge of Rogers Spring for the 27-year period of record (August 1985 through September 2012), and of Blue Point Spring for the 13-year period of record (October 1999 through September 2012).

This constitutes the NPS annual reports for 2011 and 2012 regarding the springs in the Overton Arm area of Lake Mead NRA. If you have any questions, please contact Gary Karst, hydrologist for the NPS Pacific West Region stationed at Lake Mead NRA, at 702-293-8935.

Sincerely,

William K. Dickinson
Superintendent, Lake Mead National Recreation Area

Enclosures (4)

cc: (With enclosures)
FWS (Portland, OR) – Tim Mayer
FWS (Reno) – Sue Braumiller
FWS (Las Vegas) – Laurie Averill-Murray
BLM (Reno) – Sarah Peterson
BLM (Las Vegas) – Boris Poff
BIA (Phoenix) – Ray Roessel
Moapa Paiutes consultant – Marty Mifflin
NV Energy – Bob Ott
SNWA – Jeff Johnson
CSI – Carl Savely
Vidler –Greg Bushner
Virgin Valley WD – Ken Rock
Nevada State Engineer's Office (Carson City) – Rick Felling
Nevada State Engineer's Office (Las Vegas) – John Guillory
2380 (EMAIL) - Hansen, Van Liew, Hughes

cc: (Without enclosures)
Pacific Great Basin SSO – Kolipinski
SOL (Sacramento) - Palmer
SOL (Lakewood) - Fahmy
2380 (EMAIL) – Harvey

USGS
science for a changing world

Water-Data Report 2011

09419550 Rogers Spring Near Overton Beach, NV

Lower Colorado-Lake Mead Basin
Lake Mead Subbasin

LOCATION.--Lat 36°22'35.7", long 114°26'36.9" referenced to North American Datum of 1983, in SE ¼ SE ¼ sec.12, T.18 S., R.67 E., Clark County, NV, Hydrologic Unit 15010005, on right bank, approximately 200 ft downstream of spring pool, in Lake Mead National Recreation Area, 6.6 mi southwest of Overton Beach, and 14 mi south of Overton on North Shore Road.

DRAINAGE AREA.--Indeterminate.

SURFACE-WATER RECORDS

PERIOD OF RECORD.--Aug. 1985 to current year.

GAGE.--Water-stage recorder. Elevation of gage is 1,560 ft above National Geodetic Vertical Datum of 1929, from topographic map.

REMARKS.--Records fair. Flow sometimes affected by temporary regulation of spring pool outlet for human recreation upstream and animal use.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 26 ft^3/s, Aug. 16, 1990, gage height, 3.31 ft, from rating curve extended above 2.2 ft^3/s, on basis of velocity-area study; minimum daily, 0.90 ft^3/s, Aug. 25, 1992.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 3.5 ft^3/s, Dec. 22, gage height, 1.05 ft; minimum daily discharge, 1.5 ft^3/s, on several days.

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

Suggested citation: U.S. Geological Survey, 2012, Water-resources data for the United States, Water Year 2011: U.S. Geological Survey Water-Data Report WDR-US-2011, site 09419550, accessed at http://wdr.water.usgs.gov/wy2011/pdfs/09419550.2011.pdf

09419550 Rogers Spring Near Overton Beach, NV—Continued

DISCHARGE, CUBIC FEET PER SECOND
WATER YEAR OCTOBER 2010 TO SEPTEMBER 2011
DAILY MEAN VALUES

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
2	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
3	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
4	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
5	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
9	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
10	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
11	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
12	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
13	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
14	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
15	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
16	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
17	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
18	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
19	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
20	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
21	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
22	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
23	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
24	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
25	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
26	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
27	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
28	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
29	1.6	1.6	1.6	1.6	---	1.6	1.6	1.5	1.6	1.6	1.6	1.6
30	1.6	1.6	1.6	1.6	---	1.6	1.6	1.6	1.6	1.6	1.6	1.6
31	1.6	---	1.6	1.6	---	1.6	---	1.6	---	1.6	1.6	---
Total	49.6	48.0	49.7	49.6	44.8	49.6	48.0	48.1	48.0	49.6	49.6	48.0
Mean	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.55	1.60	1.60	1.60	1.60
Max	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Min	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6
Ac-ft	98	95	99	98	89	98	95	95	95	98	98	95

STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1985 - 2011, BY WATER YEAR (WY)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	1.66	1.67	1.65	1.64	1.65	1.63	1.62	1.61	1.65	1.65	1.65	1.64
Max	1.85	1.92	1.89	2.16	2.28	1.94	1.82	1.80	1.89	1.88	2.02	1.91
(WY)	(2000)	(1991)	(1993)	(1993)	(1993)	(1993)	(2000)	(1995)	(1993)	(1993)	(1993)	(1993)
Min	1.42	1.47	1.43	1.27	1.23	1.25	1.22	1.37	1.46	1.38	1.35	1.41
(WY)	(2009)	(2009)	(1997)	(1986)	(1992)	(1987)	(1987)	(1992)	(1992)	(1992)	(1992)	(2008)

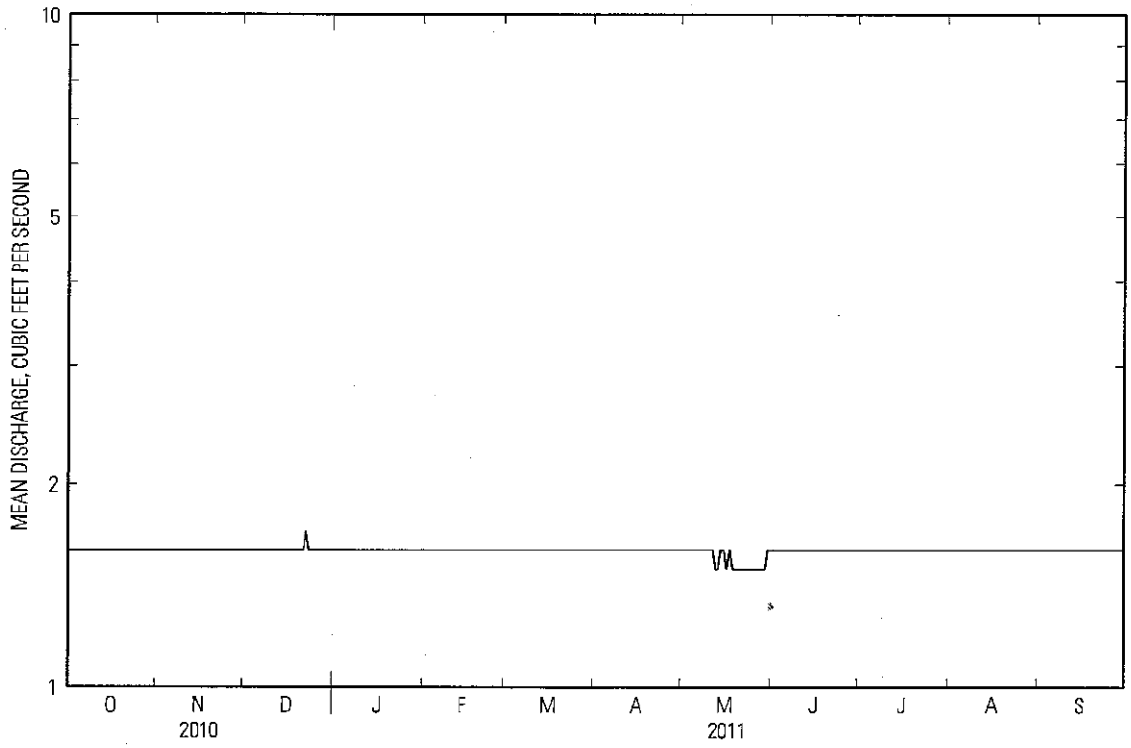
SE ROA 10464

JA_3328

09419550 Rogers Spring Near Overton Beach, NV—Continued

SUMMARY STATISTICS

	Calendar Year 2010		Water Year 2011		Water Years 1985 - 2011	
Annual total	558.7		582.6			
Annual mean	1.53		1.60		1.64	
Highest annual mean					1.88	1993
Lowest annual mean					1.45	2009
Highest daily mean	1.7	Dec 22	1.7	Dec 22	2.8	Aug 16, 1990
Lowest daily mean	1.4	Jan 15	1.5	May 12	0.90	Aug 25, 1992
Annual seven-day minimum	1.4	Jan 13	1.5	May 18	1.1	Feb 25, 1986
Maximum peak flow			3.5	Dec 22	26	Aug 16, 1990
Maximum peak stage			1.05	Dec 22	3.31	Aug 16, 1990
Annual runoff (ac-ft)	1,110		1,160		1,190	
10 percent exceeds	1.6		1.6		1.8	
50 percent exceeds	1.5		1.6		1.7	
90 percent exceeds	1.5		1.6		1.5	

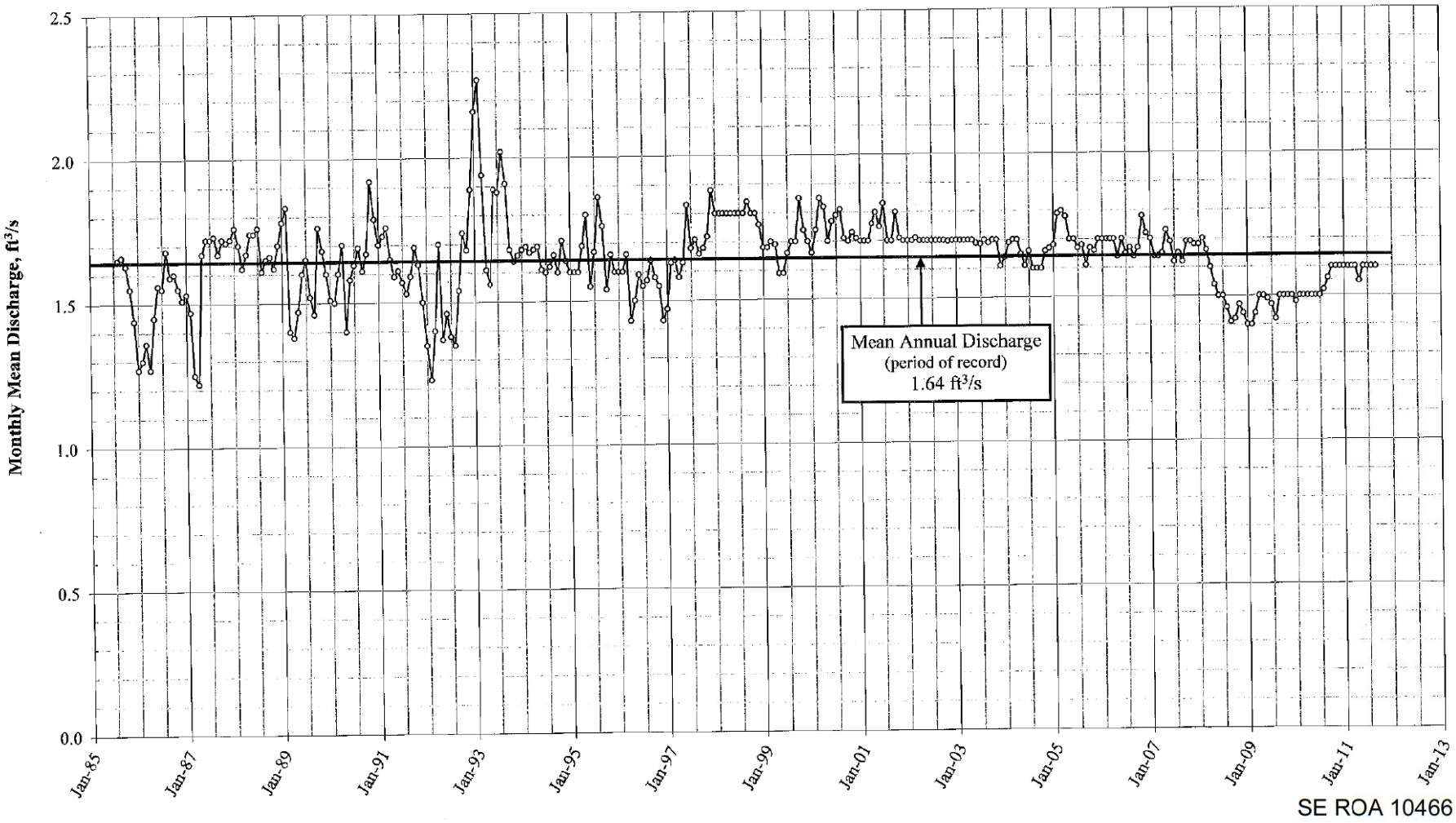


SE ROA 10465

JA_3329

ROGERS SPRING

Lake Mead National Recreation Area



SE ROA 10466

JA_3330

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Water-Data Report 2011

09419547 Blue Point Spring Near Valley Of Fire State Park, NV

Lower Colorado-Lake Mead Basin
Lake Mead Subbasin

LOCATION.--Lat 36°23'21.67", long 114°25'58.57" referenced to North American Datum of 1927, in NW ¼ NE ¼ sec.7, T.18 S., R.68 E., Clark County, NV, Hydrologic Unit 15010005, in Lake Mead National Recreation Area, on right bank, about 4 mi east of Valley of Fire State Park, and 13 mi south of Overton.

DRAINAGE AREA.--Indeterminate.

SURFACE-WATER RECORDS

PERIOD OF RECORD.--Dec. 1998 to Sep. 1999 (discharge measurements only); Oct. 1999 to current year.

GAGE.--Water-stage recorder. Elevation of gage is 1,540 ft above National Geodetic Vertical Datum of 1929, from topographic map.

REMARKS.--Records poor.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 0.70 ft^3/s, Oct. 16, 18, 19, 1999, gage height 4.04 ft; maximum gage height, 4.05 ft, Mar. 6, 2011; minimum daily, 0.45 ft^3/s, Mar. 8, 9, 2000.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 0.66 ft^3/s, on several days, gage height, 4.05 ft; minimum daily discharge, 0.51 ft^3/s, on many days.

Suggested citation: U.S. Geological Survey, 2012, Water-resources data for the United States, Water Year 2011: U.S. Geological Survey Water-Data Report WDR-US-2011, site 09419547, accessed at http://wdr.water.usgs.gov/wy2011/pdfs/09419547.2011.pdf

09419547 Blue Point Spring Near Valley Of Fire State Park, NV—Continued

DISCHARGE, CUBIC FEET PER SECOND
WATER YEAR OCTOBER 2010 TO SEPTEMBER 2011
DAILY MEAN VALUES

[e, estimated]

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	0.59	0.56	0.56	0.56	0.58	0.58	0.58	0.56	0.56	0.53	0.51	0.51
2	0.59	0.56	0.56	0.56	0.58	0.58	0.58	0.56	0.54	0.53	0.51	0.51
3	0.59	0.56	0.56	0.56	0.58	0.60	0.58	0.56	0.53	0.53	0.51	0.51
4	0.59	0.56	0.56	0.56	0.58	0.61	0.58	0.56	0.53	0.53	0.51	0.51
5	0.59	0.56	0.56	0.56	0.58	0.63	0.58	0.56	0.53	0.53	0.51	0.51
6	0.59	0.56	0.56	0.56	0.58	0.64	0.58	0.56	0.53	0.53	0.51	0.51
7	0.59	0.56	0.56	0.56	0.58	0.64	0.58	0.56	0.53	0.53	0.51	0.51
8	0.59	0.56	0.56	0.56	0.58	0.63	0.58	0.56	0.53	0.53	0.51	0.51
9	0.58	0.55	0.56	0.56	0.58	0.63	0.57	0.56	0.53	0.53	0.51	0.51
10	0.56	0.56	0.56	0.56	0.58	0.63	0.56	0.56	0.53	0.53	0.51	0.51
11	0.56	0.54	0.56	0.56	0.58	0.63	0.57	0.56	0.53	0.53	0.51	0.51
12	0.56	0.54	0.56	0.56	0.58	0.63	0.58	0.56	0.53	0.53	0.51	0.51
13	0.56	0.55	0.56	0.56	0.58	0.63	0.58	0.56	0.53	0.53	0.51	0.51
14	0.56	0.56	0.56	0.56	0.58	0.64	0.56	0.57	0.53	0.53	0.51	0.51
15	0.56	0.56	0.56	0.56	0.58	0.66	0.56	e0.57	0.53	0.53	0.51	0.51
16	0.57	0.56	0.56	0.56	0.60	0.66	0.57	0.56	0.53	0.53	0.51	0.51
17	0.57	0.54	0.56	0.56	0.58	0.63	0.58	0.56	0.53	0.53	0.51	0.51
18	0.57	0.56	0.56	0.56	0.59	0.65	0.58	0.56	0.53	0.53	0.51	0.51
19	0.57	0.56	0.56	0.55	0.60	0.66	0.56	0.56	0.53	0.53	0.51	0.51
20	0.57	0.56	0.56	0.55	0.59	0.65	0.56	0.56	0.53	0.53	0.53	0.51
21	0.58	0.56	0.56	0.56	0.58	0.65	0.56	0.56	0.53	0.53	0.53	0.51
22	0.58	0.56	0.57	0.56	0.58	0.63	0.56	0.57	0.53	0.53	0.53	0.51
23	0.59	0.56	0.56	0.56	0.58	0.64	0.56	0.56	0.53	0.53	0.53	0.51
24	0.59	0.56	0.56	0.56	0.58	0.64	0.56	0.56	0.53	0.53	0.52	0.51
25	0.59	0.54	0.56	0.56	0.59	0.64	0.56	0.56	0.53	0.53	0.52	0.51
26	0.58	0.55	0.56	0.56	0.61	0.63	0.56	0.56	0.53	0.53	0.52	0.51
27	0.58	0.56	0.56	0.56	0.59	0.62	0.56	0.56	0.53	0.53	0.51	0.51
28	0.59	0.56	0.56	0.56	0.58	0.58	0.57	0.56	0.53	0.53	0.51	0.51
29	0.59	0.54	0.58	0.56	---	0.58	0.56	0.56	0.53	0.53	0.51	0.51
30	0.57	0.54	0.56	0.56	---	0.58	0.56	0.56	0.53	0.53	0.51	0.51
31	0.56	---	0.56	0.58	---	0.58	---	0.56	---	0.53	0.51	---
Total	17.91	16.65	17.39	17.36	16.35	19.38	17.08	17.39	15.94	16.43	15.92	15.30
Mean	0.58	0.56	0.56	0.56	0.58	0.63	0.57	0.56	0.53	0.53	0.51	0.51
Max	0.59	0.56	0.58	0.58	0.61	0.66	0.58	0.57	0.56	0.53	0.53	0.51
Min	0.56	0.54	0.56	0.55	0.58	0.58	0.56	0.56	0.53	0.53	0.51	0.51
Ac-ft	36	33	34	34	32	38	34	34	32	33	32	30

STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 2000 - 2011, BY WATER YEAR (WY)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	0.56	0.56	0.55	0.56	0.55	0.56	0.56	0.55	0.55	0.56	0.56	0.56
Max	0.60	0.62	0.61	0.65	0.59	0.63	0.59	0.59	0.59	0.62	0.62	0.63
(WY)	(2009)	(2000)	(2000)	(2000)	(2008)	(2011)	(2007)	(2007)	(2001)	(2010)	(2001)	(2001)
Min	0.52	0.52	0.49	0.46	0.48	0.51	0.52	0.50	0.48	0.48	0.48	0.49
(WY)	(2001)	(2010)	(2002)	(2002)	(2002)	(2010)	(2010)	(2000)	(2002)	(2002)	(2002)	(2002)

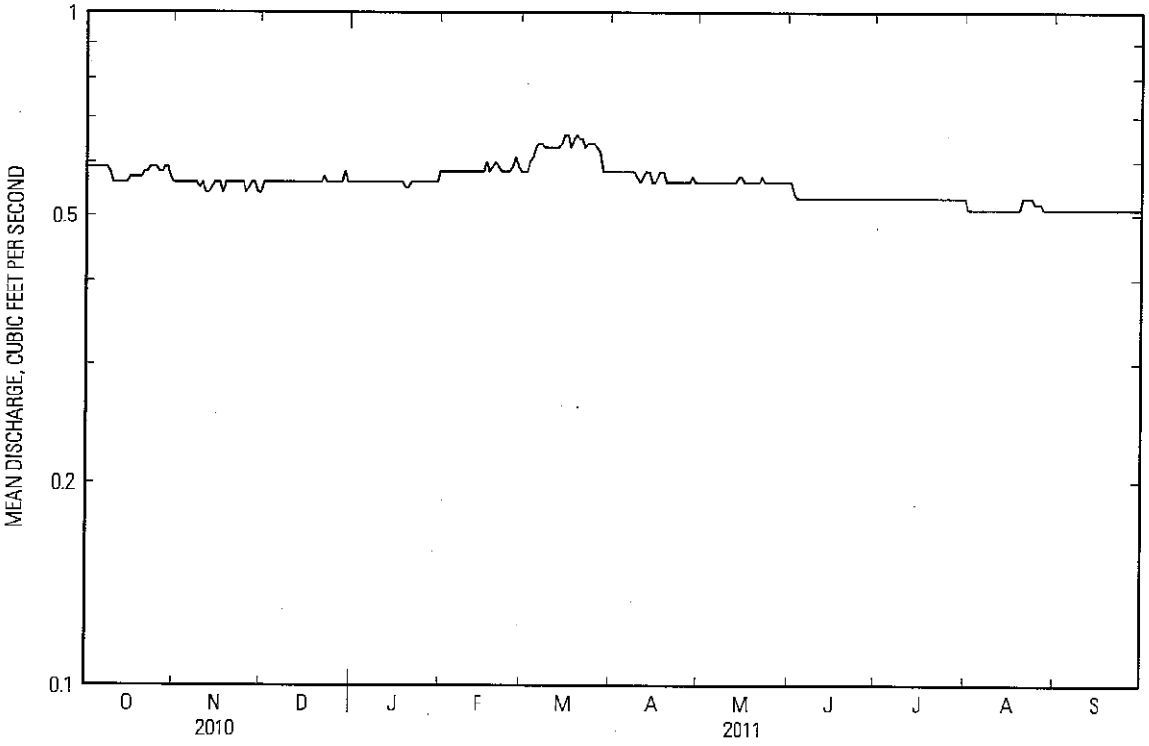
SE ROA 10468

JA_3332

09419547 Blue Point Spring Near Valley Of Fire State Park, NV—Continued

SUMMARY STATISTICS

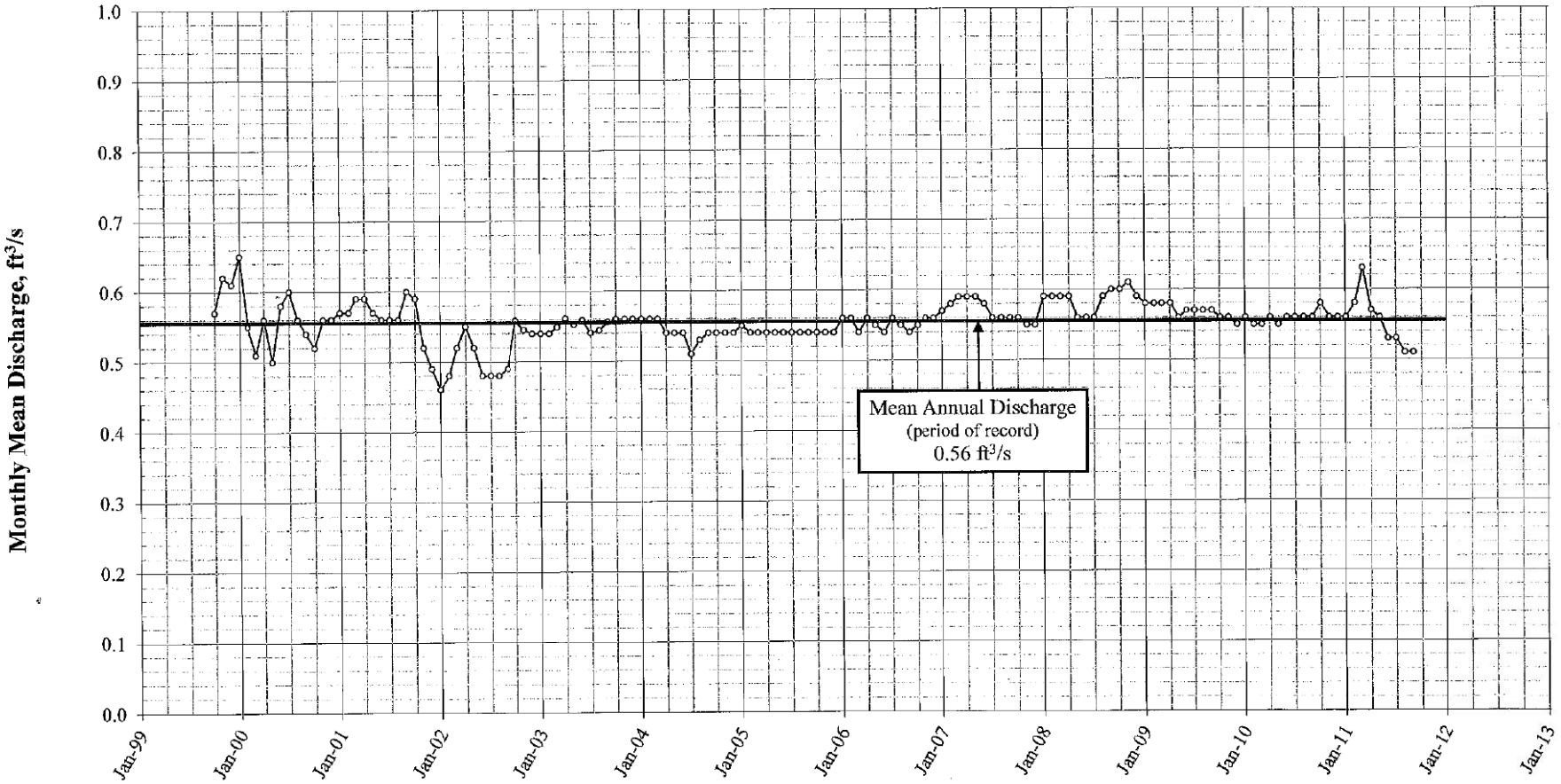
	Calendar Year 2010		Water Year 2011		Water Years 2000 - 2011	
Annual total	206.03		203.10			
Annual mean	0.56		0.56		0.56	
Highest annual mean					0.58	2009
Lowest annual mean					0.50	2002
Highest daily mean	0.64	Jul 21	0.66	Mar 15	0.67	Oct 19, 1999
Lowest daily mean	0.47	Mar 11	0.51	Aug 1	0.45	Mar 8, 2000
Annual seven-day minimum	0.50	Mar 10	0.51	Aug 1	0.45	Jan 10, 2002
Maximum peak flow			0.66	Mar 6	0.70	Oct 16, 1999
Maximum peak stage			4.05	Mar 6	4.05	Mar 6, 2011
Annual runoff (ac-ft)	409		403		403	
10 percent exceeds	0.62		0.59		0.59	
50 percent exceeds	0.56		0.56		0.56	
90 percent exceeds	0.52		0.51		0.52	



SE ROA 10469

JA_3333

BLUE POINT SPRING
Lake Mead National Recreation Area



SE ROA 10470

JA_3334

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Water-Data Report 2012

09419550 Rogers Spring Near Overton Beach, NV

Lower Colorado-Lake Mead Basin
Lake Mead Subbasin

LOCATION.--Lat 36°22'35.7", long 114°26'36.9" referenced to North American Datum of 1983, in SE ¼ SE ¼ SE ¼ sec.12, T.18 S., R.67 E., Clark County, NV, Hydrologic Unit 15010005, on right bank, approximately 200 ft downstream of spring pool, in Lake Mead National Recreation Area, 6.6 mi southwest of Overton Beach, and 14 mi south of Overton on North Shore Road.

DRAINAGE AREA.--Indeterminate.

SURFACE-WATER RECORDS

PERIOD OF RECORD.--Aug. 1985 to current year.

GAGE.--Water-stage recorder. Elevation of gage is 1,560 ft above National Geodetic Vertical Datum of 1929, from topographic map.

REMARKS.--Records fair. Flow sometimes affected by temporary regulation of spring pool outlet for human recreation upstream and animal use.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 26 ft^3/s, Aug. 16, 1990, gage height, 3.31 ft, from rating curve extended above 2.2 ft^3/s, on basis of velocity-area study; minimum daily, 0.90 ft^3/s, Aug. 25, 1992.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 2.2 ft^3/s, Aug. 22, gage height, 0.78 ft; minimum daily discharge, 1.4 ft^3/s, on many days.

09419550 Rogers Spring Near Overton Beach, NV—Continued

DISCHARGE, CUBIC FEET PER SECOND
WATER YEAR OCTOBER 2011 TO SEPTEMBER 2012
DAILY MEAN VALUES

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5
4	1.5	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5
5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5
6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5
7	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5
8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5
9	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5
10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
11	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
12	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
13	1.5	1.5	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.4
14	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.5
15	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
16	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
17	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
18	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
19	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4
20	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4
21	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4
22	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.7	1.4
23	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4
24	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4
25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4
26	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4
27	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4
28	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4
29	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5	1.4
30	1.5	1.5	1.5	1.5	---	1.5	1.5	1.5	1.5	1.5	1.5	1.4
31	1.5	---	1.5	1.5	---	1.5	---	1.5	---	1.5	1.5	---
Total	46.4	45.1	46.5	46.5	43.6	46.5	45.1	46.4	44.3	46.5	46.7	43.7
Mean	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.48	1.50	1.51	1.46
Max	1.6	1.6	1.5	1.5	1.6	1.5	1.6	1.5	1.5	1.5	1.7	1.5
Min	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.5	1.5	1.4
Ac-ft	92	89	92	92	86	92	89	92	88	92	93	87

STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1985 - 2012, BY WATER YEAR (WY)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	1.66	1.66	1.64	1.63	1.64	1.63	1.61	1.61	1.64	1.64	1.65	1.63
Max	1.85	1.92	1.89	2.16	2.28	1.94	1.82	1.80	1.89	1.88	2.02	1.91
(WY)	(2000)	(1991)	(1993)	(1993)	(1993)	(1993)	(2000)	(1995)	(1993)	(1993)	(1993)	(1993)
Min	1.42	1.47	1.43	1.27	1.23	1.25	1.22	1.37	1.46	1.38	1.35	1.41
(WY)	(2009)	(2009)	(1997)	(1986)	(1992)	(1987)	(1987)	(1992)	(1992)	(1992)	(1992)	(2008)

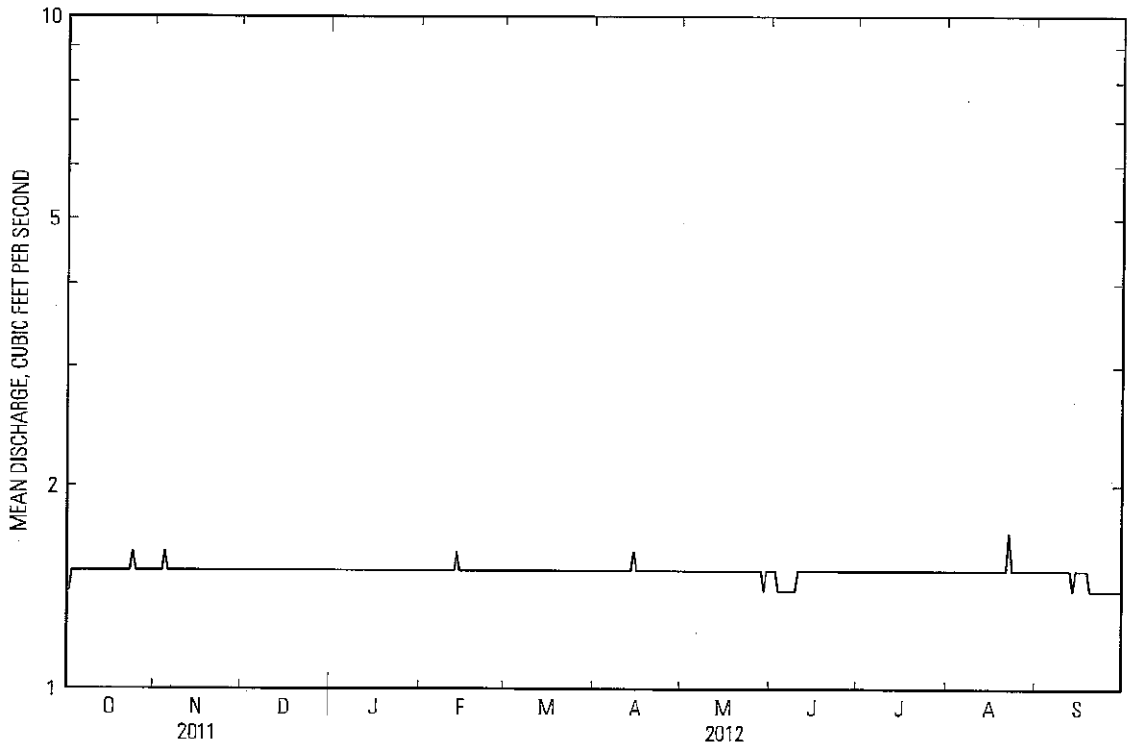
SE ROA 10472

JA_3336

09419550 Rogers Spring Near Overton Beach, NV—Continued

SUMMARY STATISTICS

	Calendar Year 2011		Water Year 2012		Water Years 1985 - 2012	
Annual total	573.3		547.3			
Annual mean	1.57		1.50		1.64	
Highest annual mean					1.88	1993
Lowest annual mean					1.45	2009
Highest daily mean	1.6	Jan 1	1.7	Aug 22	2.8	Aug 16, 1990
Lowest daily mean	1.4	Oct 1	1.4	Oct 1	0.90	Aug 25, 1992
Annual seven-day minimum	1.5	Oct 1	1.4	Jun 3	1.1	Feb 25, 1986
Maximum peak flow			2.2	Aug 22	26	Aug 16, 1990
Maximum peak stage			0.78	Aug 22	3.31	Aug 16, 1990
Annual runoff (ac-ft)	1,140		1,090		1,190	
10 percent exceeds	1.6		1.5		1.8	
50 percent exceeds	1.6		1.5		1.7	
90 percent exceeds	1.5		1.5		1.5	

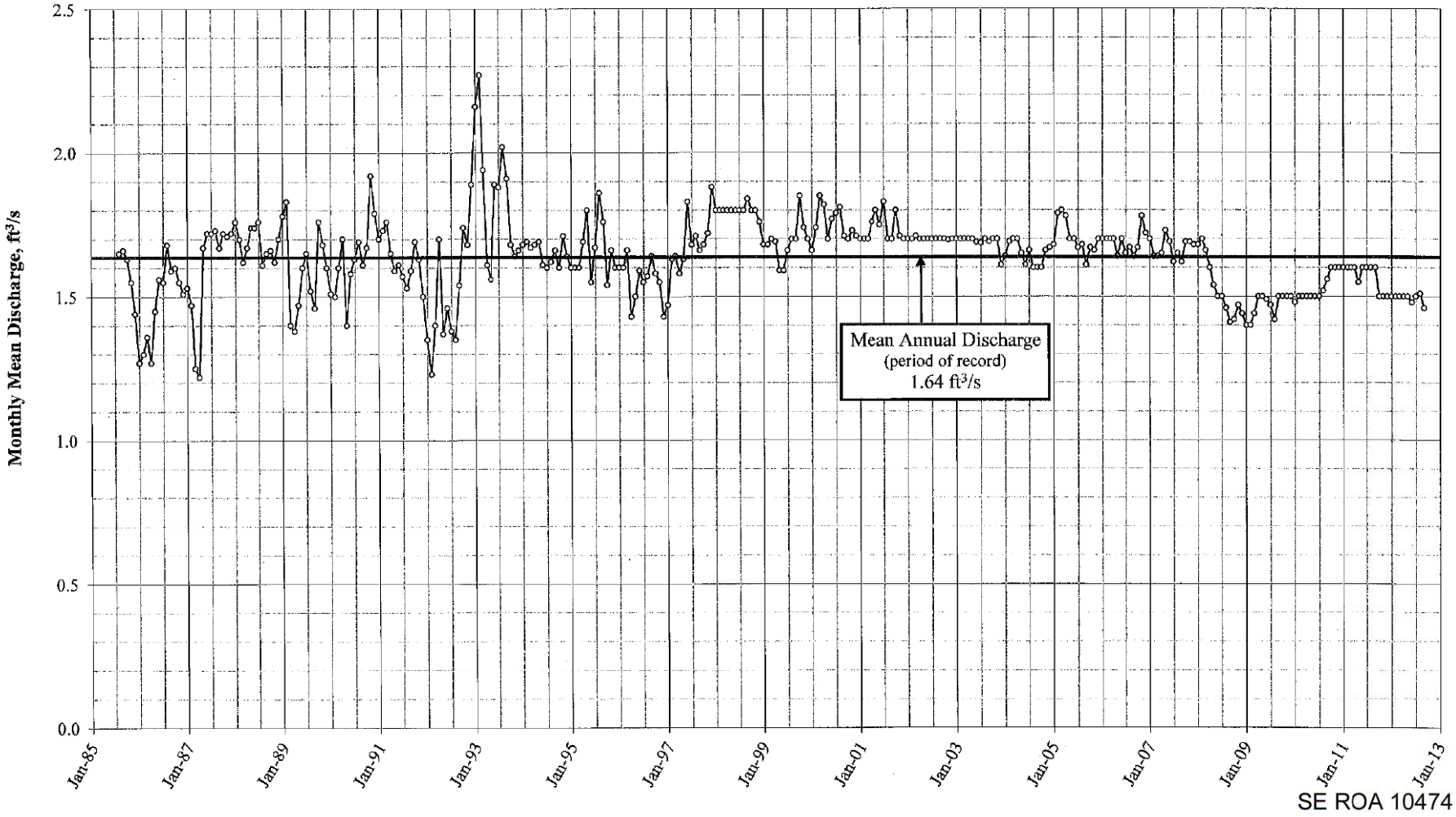


SE ROA 10473

JA_3337

ROGERS SPRING

Lake Mead National Recreation Area



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JA_3338

USGS
science for a changing world

Water-Data Report 2012

09419547 Blue Point Spring Near Valley Of Fire State Park, NV

Lower Colorado-Lake Mead Basin
Lake Mead Subbasin

LOCATION.--Lat 36°23'21.74", long 114°25'58.49" referenced to North American Datum of 1983, in NW ¼ NW ¼ NE ¼ sec.7, T.18 S., R.68 E., Clark County, NV, Hydrologic Unit 15010005, in Lake Mead National Recreation Area, on right bank, about 4 mi east of Valley of Fire State Park, and 13 mi south of Overton.

DRAINAGE AREA.--Indeterminate.

SURFACE-WATER RECORDS

PERIOD OF RECORD.--Dec. 1998 to Sep. 1999 (discharge measurements only); Oct. 1999 to Oct. 2012; discontinued Oct 2012.

GAGE.--Water-stage recorder. Elevation of gage is 1,540 ft above National Geodetic Vertical Datum of 1929, from topographic map.

REMARKS.--Records poor.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 0.70 ft^3/s, Oct. 16, 18, 19, 1999, gage height 4.04 ft; maximum gage height, 4.05 ft, Mar. 6, 2011; minimum daily, 0.45 ft^3/s, Mar. 8, 9, 2000.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 0.56 ft^3/s, Mar. 2, 6, Aug. 22, but may have been higher during periods Oct. to May, gage height, 4.01 ft; minimum daily discharge, 0.50 ft^3/s, June 28.

Suggested citation: U.S. Geological Survey, 2013, Water-resources data for the United States, Water Year 2012: U.S. Geological Survey Water-Data Report WDR-US-2012, site 09419547, accessed at http://wdr.water.usgs.gov/wy2012/pdfs/09419547.2012.pdf

09419547 Blue Point Spring Near Valley Of Fire State Park, NV—Continued

DISCHARGE, CUBIC FEET PER SECOND
WATER YEAR OCTOBER 2011 TO SEPTEMBER 2012
DAILY MEAN VALUES

[e, estimated]

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	e0.51	e0.51	e0.51	e0.51	e0.51	e0.52	e0.53	0.53	0.52	0.51	0.51	0.51
2	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.53	0.52	0.52	0.51	0.51	0.51
3	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.53	0.52	0.52	0.51	0.51	0.51
4	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.53	0.52	0.53	0.51	0.51	0.51
5	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.53	0.52	0.52	0.51	0.51	0.51
6	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.53	0.52	0.51	0.51	0.51	0.51
7	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.53	0.52	0.51	0.51	0.51	0.51
8	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.53	0.52	0.53	0.51	0.51	0.51
9	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.52	0.53	0.53	0.51	0.51	0.51
10	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.52	0.53	0.51	0.51	0.51	0.51
11	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.52	0.51	0.51	0.51	0.51
12	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.51	0.51	0.51	0.51	0.51
13	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.52	0.51	0.51	0.51	0.51
14	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.52	0.51	0.51	0.51	0.51
15	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.51	0.52	0.51	0.51
16	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.51	0.53	0.51	0.51
17	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.51	0.53	0.51	0.51
18	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.53	0.53	0.51	0.51
19	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.52	0.53	0.52	0.51	0.51
20	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.52	0.52	0.51	0.51
21	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.52	0.52	0.51	0.51
22	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.53	0.51	0.51	0.51
23	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.53	0.51	0.51	0.51
24	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.51	0.51	0.51	0.51
25	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.51	0.51	0.51	0.51
26	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.52	0.51	0.51	0.51
27	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	e0.51	0.53	0.51	0.51	0.51	0.51
28	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	0.51	0.53	0.50	0.51	0.51	0.51
29	e0.51	e0.51	e0.51	e0.51	e0.51	e0.53	0.51	0.53	0.51	0.51	0.51	0.51
30	e0.51	e0.51	e0.51	e0.51	---	e0.53	0.52	0.52	0.51	0.51	0.53	0.51
31	e0.51	---	e0.51	e0.51	---	e0.53	---	0.52	---	0.51	0.53	---
Total	15.81	15.30	15.81	15.81	14.79	16.42	15.49	16.28	15.50	15.91	15.85	15.30
Mean	0.51	0.51	0.51	0.51	0.51	0.53	0.52	0.53	0.52	0.51	0.51	0.51
Max	0.51	0.51	0.51	0.51	0.51	0.53	0.53	0.53	0.53	0.53	0.53	0.51
Min	0.51	0.51	0.51	0.51	0.51	0.52	0.51	0.51	0.50	0.51	0.51	0.51
Ac-ft	31	30	31	31	29	33	31	32	31	32	31	30

STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 2000 - 2012, BY WATER YEAR (WY)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	0.55	0.55	0.55	0.55	0.55	0.55	0.56	0.55	0.55	0.55	0.55	0.55
Max	0.60	0.62	0.61	0.65	0.59	0.63	0.59	0.59	0.59	0.62	0.62	0.63
(WY)	(2009)	(2000)	(2000)	(2000)	(2008)	(2011)	(2007)	(2007)	(2001)	(2010)	(2001)	(2001)
Min	0.51	0.51	0.49	0.46	0.48	0.51	0.52	0.50	0.48	0.48	0.48	0.49
(WY)	(2012)	(2012)	(2002)	(2002)	(2002)	(2010)	(2012)	(2000)	(2002)	(2002)	(2002)	(2002)

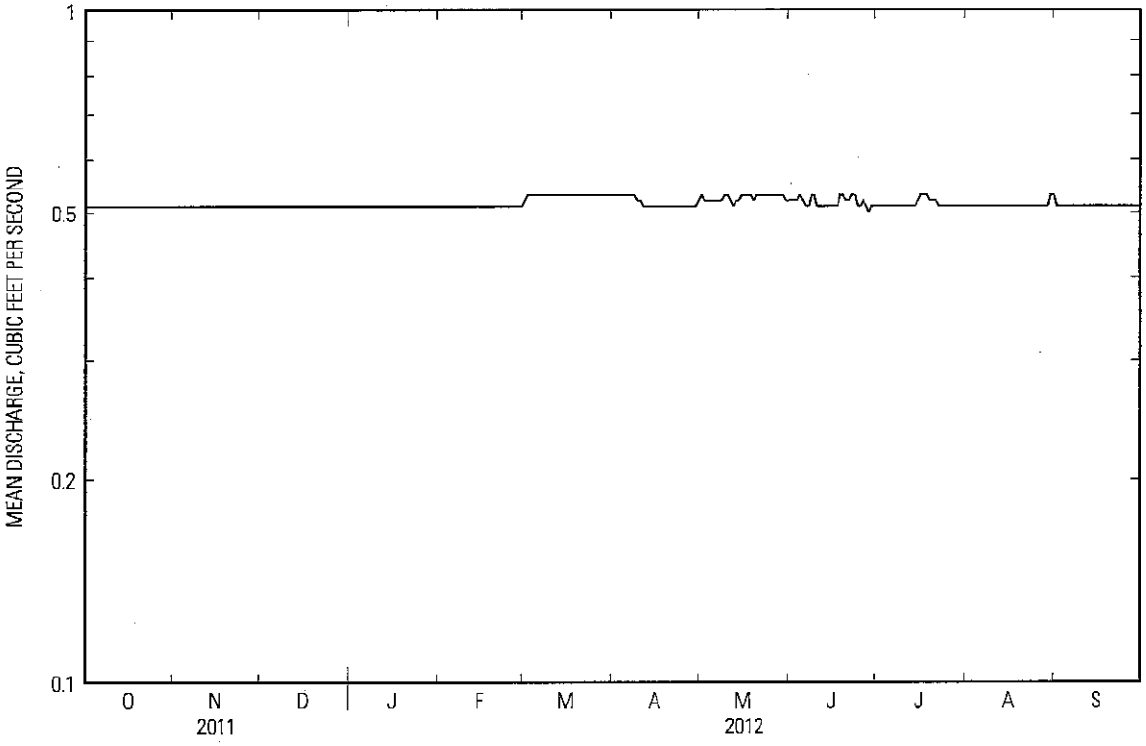
SE ROA 10476

JA_3340

09419547 Blue Point Spring Near Valley Of Fire State Park, NV—Continued

SUMMARY STATISTICS

	Calendar Year 2011	Water Year 2012	Water Years 2000 - 2012
Annual total	198.07	188.27	
Annual mean	0.54	0.51	0.55
Highest annual mean			0.58 2009
Lowest annual mean			0.50 2002
Highest daily mean	0.66 Mar 15	0.53 Mar 2	0.67 Oct 19, 1999
Lowest daily mean	0.51 Aug 1	0.50 Jun 28	0.45 Mar 8, 2000
Annual seven-day minimum	0.51 Aug 1	0.51 Jun 27	0.45 Jan 10, 2002
Maximum peak flow			0.70 Oct 16, 1999
Maximum peak stage			4.05 Mar 6, 2011
Annual runoff (ac-ft)	393	373	400
10 percent exceeds	0.58	0.53	0.59
50 percent exceeds	0.53	0.51	0.56
90 percent exceeds	0.51	0.51	0.51



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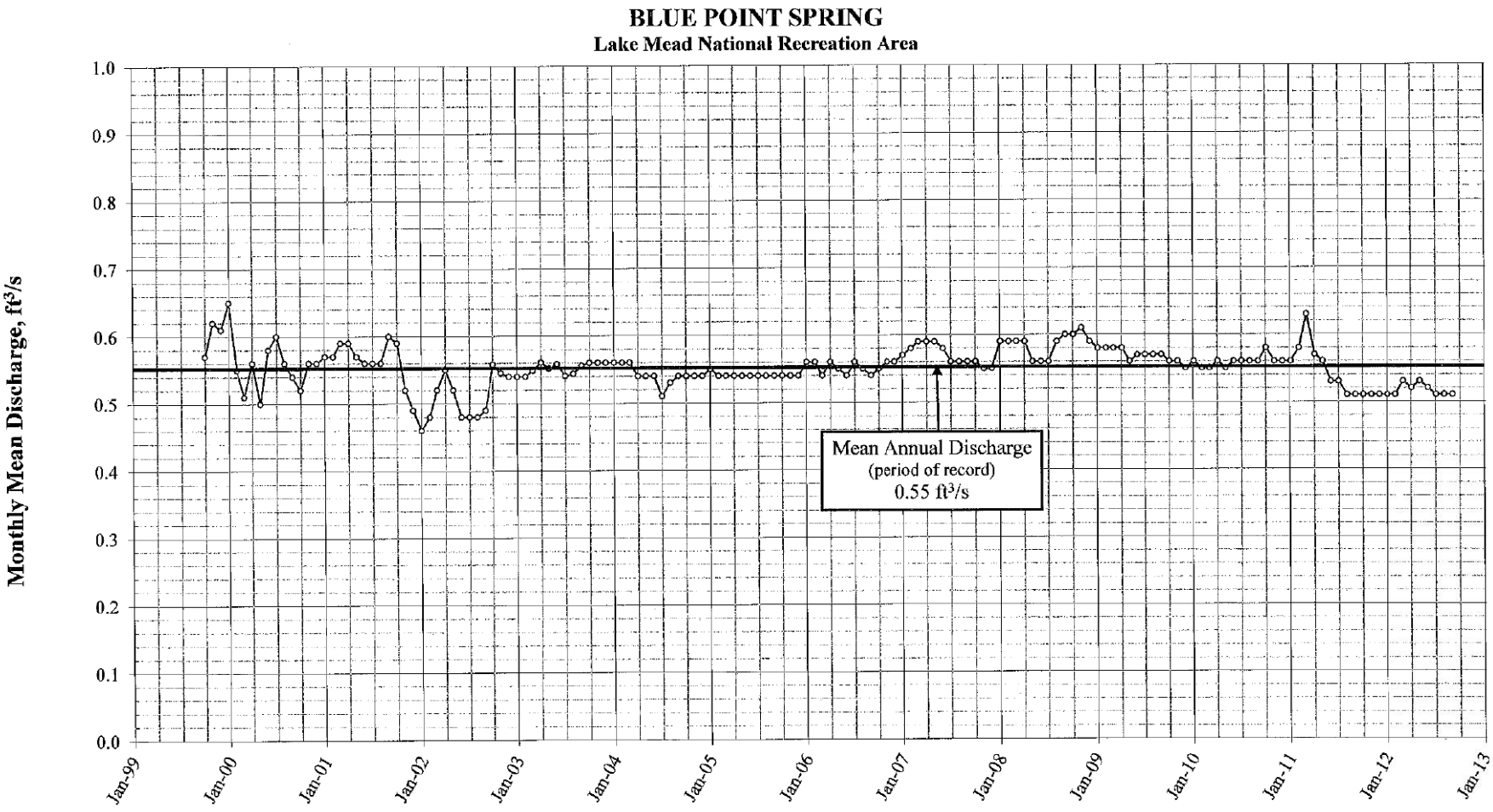

SE ROA 10478

JA_3342

Summary of Order 1169 Testing Impacts, per Order 1169A

A Report Prepared in Cooperation with the Moapa Band of Paiutes

Cady Johnson and Martin Mifflin

June 28, 2013

Fossil spring mound in west-central Moapa Indian Reservation

Summary of Order 1169 Testing Impacts, per Order 1169A

Cady Johnson and Martin Mifflin
Mifflin & Associates, Inc.

June 28, 2013

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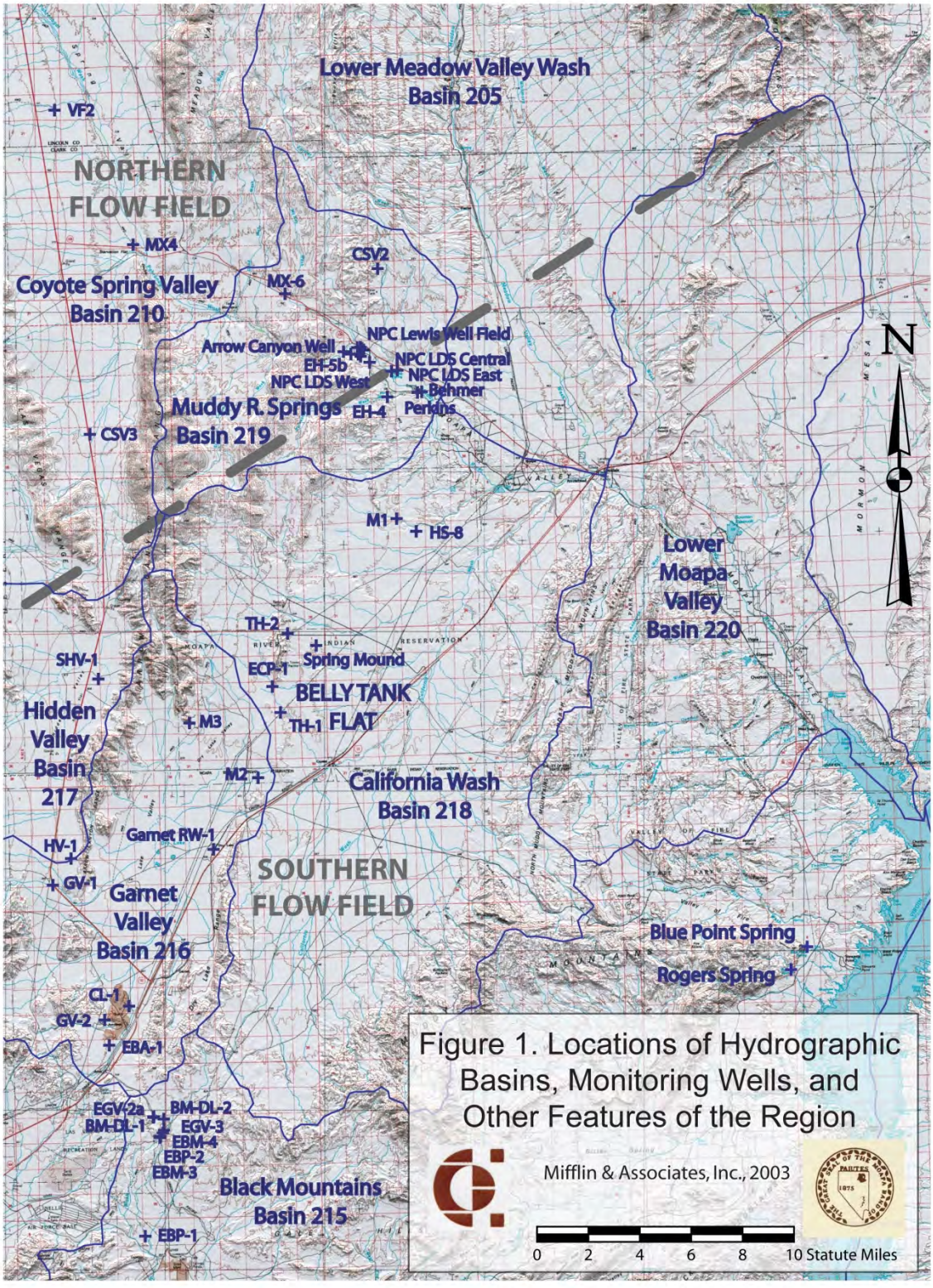
Introduction

The Order 1169 test, prescribed by State Engineer Order 1169A, offers Study participants the opportunity to file reports addressing impacts of pumping and availability of water pursuant to the pending applications. Mifflin and Associates, Inc. (MAI), most recently on behalf of the Moapa Band of Paiute Indians (MBOP) has been collecting and analyzing hydrologic data from the Reservation and surrounding areas (Figure 1) for over two decades. We have developed groundwater models, reviewed those of others (notably "Exhibit 54" of 2001 and the TetraTech models of 2012), estimated hydrologic parameters from aquifer tests, reviewed geochemical and isotopic data, estimated ephemeral recharge from runoff measurements, and accounted for the effects of tributary groundwater diversions and climate on streamflow in the Muddy River system. Numerous MAI analysis reports have been distributed to the Hydrologic Review Team (HRT) for consideration. Base-flow reductions in the Muddy River system in response to pumping in Coyote Spring Valley were predicted by MAI (2010), and those predictions were refined by Johnson and Mifflin (2011, 2012a, 2012b) and are supplemented by analyses reported herein.

Tributary groundwater diversions are responsible for historic and ongoing flow reductions in the Muddy River, though natural discharge variations may mask pumping effects. The following discussions and analyses provide several lines of quantitative evidence that up-gradient groundwater diversions



[file CalpineFigure1A.jpg]

have and will continue to impact the Muddy River in direct proportion to their magnitudes, and that discharge reductions are partitioned unequally between large springs and seepage from the alluvial aquifer. Water-balance accounting reconstitutes the natural groundwater flux sustaining the Muddy River to variable rates that lag multi-year climate cycles. Removal of water from the alluvial aquifer in the headwaters area captures water in transit from the underlying Carbonate-Rock Aquifer, which passes through the Muddy Creek Formation via conduits and into the alluvial aquifer, to form the base flows of the Muddy River. Decreased supply from the Carbonate-Rock Aquifer to the alluvial aquifer is equivalent to removal of water directly from the alluvial aquifer, though the time scales over which remote diversions are expressed as River discharge reductions may be prolonged and depend on where groundwater in the up-gradient flow system is diverted (Bredehoeft, 2011).

Background

There has been a long and continuing history of claims and actions that anticipated the regional carbonate aquifer in and up-gradient of the Muddy River Springs area contains a separate (available for appropriation) groundwater resource. The primary water-management questions from past groundwater development proposals in the Muddy River Springs area were related to uncertain relationships between the alluvial aquifer, the underlying carbonate aquifer, and the springs and seepage that give rise to the Muddy River. Now these basic questions have expanded to address more distant up-gradient areas in Coyote Spring Valley and Kane Springs Valley, where fluid-potential relationships, highly-transmissive carbonate-aquifer characteristics, similar water chemistry, and isotopic trends indicate close hydraulic continuity within a groundwater flow system extending to the Springs area and discharging to establish the Muddy River base flows. The earlier questions related to groundwater development in the Muddy River Springs area have been answered by the subsequent history of decline in Muddy River discharge, and water-balance analyses that show the declines are proportional to diversions of tributary groundwater from above the Moapa gage in the Springs area. Now the Order 1169-related groundwater applications in Coyote Spring Valley raise a similar question: is this region of the carbonate aquifer flow field tributary to the Muddy River and in close hydraulic continuity?

The massive and unprecedented water-rights applications of 1989 affect a region where quantitative hydrologic information is sparse and expensive to acquire, and where decades could elapse before pumping effects propagated from up-gradient areas are recognized by monitoring, if indeed they can be recognized at all (Bredehoeft, 2011). Impacts of Order 1169 testing are overprinted on two historic cycles of evaluation, debate, and decision-making that led to large increments of groundwater export from the headwaters area and impacts on the Muddy River system. The first cycle was initiated by the 1963 Nevada Power Company (NPC) purchase of the Lewis Well Field (Figure 2) and NPC's subsequent change applications to increase the associated water rights and export the water for industrial purposes. In testimony before the State Engineer on June 29, 1966, Dr. George B. Maxey explained his report (Maxey and others, 1966) and stated his conviction that it would be impossible for pumping from the Lewis Well Field to decrease springflow in the headwaters area. Significantly, Maxey did not mention the findings of Eakin (1964) and Eakin and Moore (1964) that show seepage from the

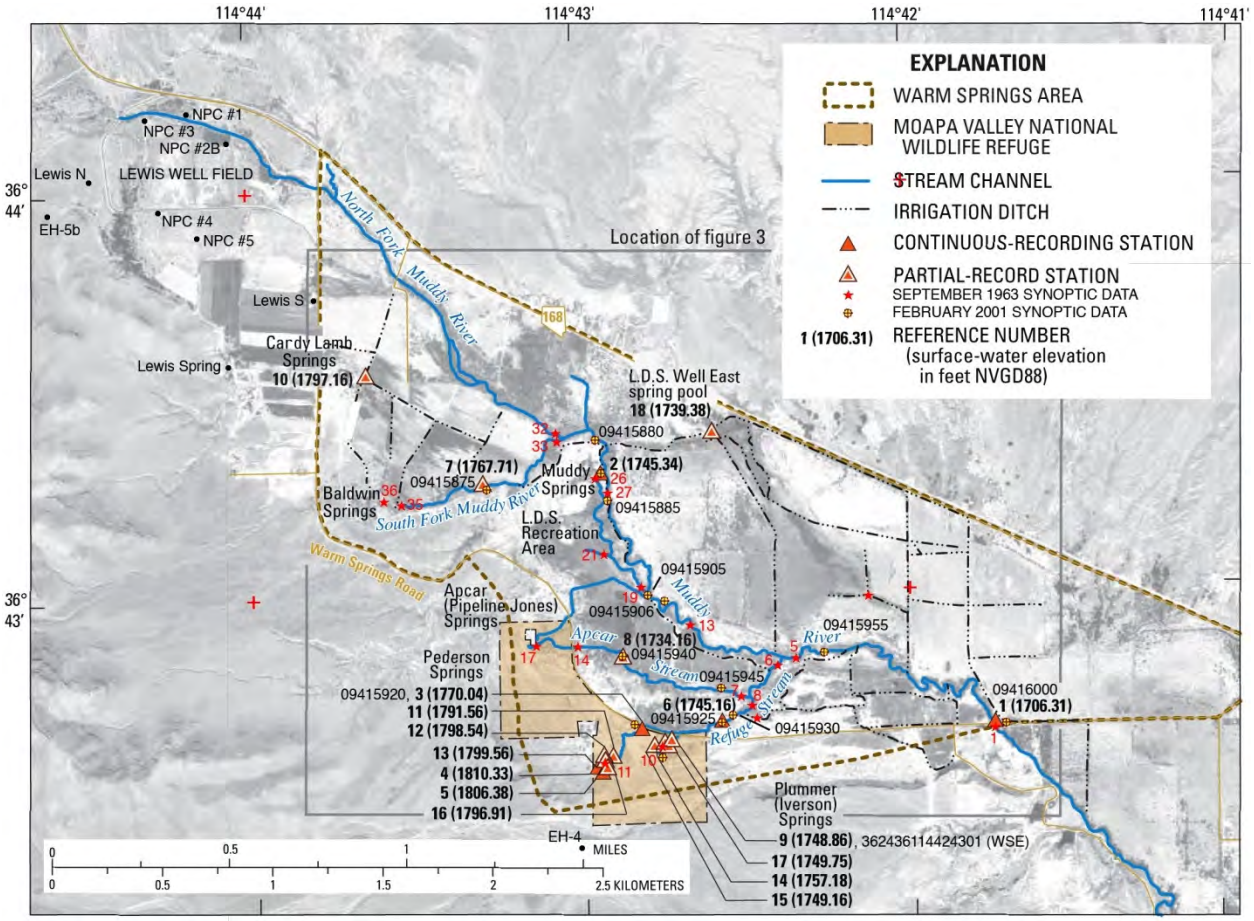


Figure 2. Muddy River headwaters area, selected monitoring and measurement sites, and area of Eakin (1964) Figure 3. The Arrow Canyon wells are 485 meters ((0.3 mile) west of Lewis N, near the west margin of the map area. [file HeadwatersMapGR83c.jpg, modified after Beck and others, 2006, Figure 2]

alluvial aquifer contributes as much or more water to the base flow of the Muddy River as does tributary flow originating directly from large springs. In Ruling 957, the State Engineer overruled protests to the change applications on the grounds that "their granting will not impair the value of existing water rights or be otherwise detrimental to the public welfare". A citation of Eakin and Moore (1964) in Ruling 957 relates to a 15-20-year time lag between regional precipitation and spring discharge response proposed by Eakin (1964). Eakin (1964, p. 14) also states: "Although some recharge to the ground-water reservoir in the valley fill is derived from local precipitation, most is derived from surface and sub-surface discharge of the Muddy River Springs." Water temperatures in the Lewis Well Field (Appendix D) demonstrate that Eakin was correct, and that export of Lewis Well Field water diminishes seepage into the headwater channels of the Muddy River and therefore impacted base flows measured at the Moapa Gage.

The second cycle of groundwater development for export began in 1990, when Moapa Valley Water District (MVWD) filed Application 55450 to appropriate 3.0 cubic feet per second (cfs) from an underground source (the Carbonate-Rock Aquifer) for municipal purposes. In 1992, MVWD filed Application 58269 to appropriate an additional 5.0 cfs from the same underground source for municipal

purposes. The Arrow Canyon #1 well was the proposed point of diversion for both applications. On Page 10 of Ruling 4243 of October, 1995, the State Engineer recognized the need to address the issue of whether additional diversions from the Carbonate-Rock Aquifer at the Arrow Canyon Well would reduce the inflow to the alluvial aquifer to a point where the water available in the basin would not satisfy the existing rights within the basin. On Page 9 of Ruling 4243 the State Engineer accepted evidence (testimony) from hearings held during January and February of 1995 that unappropriated water from California Wash, Lower Meadow Valley Wash, and surface inflows was available for appropriation. The Applications were approved by Ruling 4243, contingent upon approval of a comprehensive monitoring plan and review of monitoring records that would continue through 2004. This may be the first instance of the State Engineer justifying appropriations in one water-management basin because there was judged to be unappropriated, related water in adjacent basins. Ruling 4243 hints at recognition of the inter-basin relationships of the Carbonate-Rock Aquifer, but seems to ignore the Muddy River Decree of 1920 which established senior water rights for all Muddy River flow and protected all tributary sources from subsequent appropriations.

The diverse body of evidence currently available is inconsistent with the notion that "new" water is available in up-gradient extents of the Carbonate-Rock Aquifer, which is definitively in close hydraulic continuity with the Springs-area discharge. We have reviewed and analyzed varying lines of evidence in the attached appendices, beginning with classical hydrogeology and then treating water mass balance, climate effects, base flow separation, water demand for power generation, selected water temperature records, mixing and mass balance calculations, EC response to pumping at NPC #2A, and temperature profiles in the Lewis Well Field. We conclude that the hydrogeological evidence is internally consistent with ~1:1 impacts on Muddy River flows resulting from the production of groundwater from the Carbonate-Rock and alluvial aquifers in the Springs area and the up-gradient flow regime in Coyote Spring Valley and Kane Springs Valley.

Reconstitution of Groundwater Discharge and Natural Flux

SNWA and MAI have adopted fundamentally different approaches to evaluating the impact of diversions on the discharge of the Muddy River, and obtain substantially different results. SNWA *subtracts* measured and estimated annual diversions from average 1946 base flow derived by the "Median + 20" method of Johnson (1999), and compares the result to the Median + 20 impacted base flow separated from the observed Muddy River hydrograph as a measure of validity. The underlying assumption by SNWA is that 1946 base flow is representative of the natural (non-impacted) discharge rate and is invariant. MAI begins with the premise that groundwater flux to the headwaters area varies as a function of regional climate, and after separating impacted base flow from the observed hydrograph by the method of Wahl and Wahl (2007) *adds* measured and estimated diversion rates to obtain a "reconstituted hydrograph" that represents total groundwater *flux*, as contrasted with discharge. Temporal variations in this derived natural flux are expected, and the MAI measure of validity is the absence of an overall trend of reconstituted flux for the 7 continuous decades of discharge recordkeeping at the Moapa Gage on the main stem of the Muddy River.

An observation has been put forth by the Southern Nevada Water Authority (SNWA) that pumping from the Carbonate-Rock Aquifer in the headwaters area does not affect Muddy River discharge, supported by Slide 21 (SNWA PowerPoint presentation, HRT meeting of November 15, 2012), and reproduced here as Figure 3. The slide updates Figure 5-11 of Exhibit 54 (LVVWD, 2001), but differs substantially from 1996-2000, the period of overlap. Figure 5-11 (the 2001 version of Slide 21) highlights "a better correlation is achieved by subtracting only the valley-fill pumpage" for 1995-2000. In contrast, Slide 21 shows better correlation until 2006 with "1946 flow less all pumpage/diversions". To our knowledge SNWA has made no explicit finding or acknowledgment that Arrow Canyon Well pumpage is impacting the River, but that is the implication in the evolution of Slide 21.

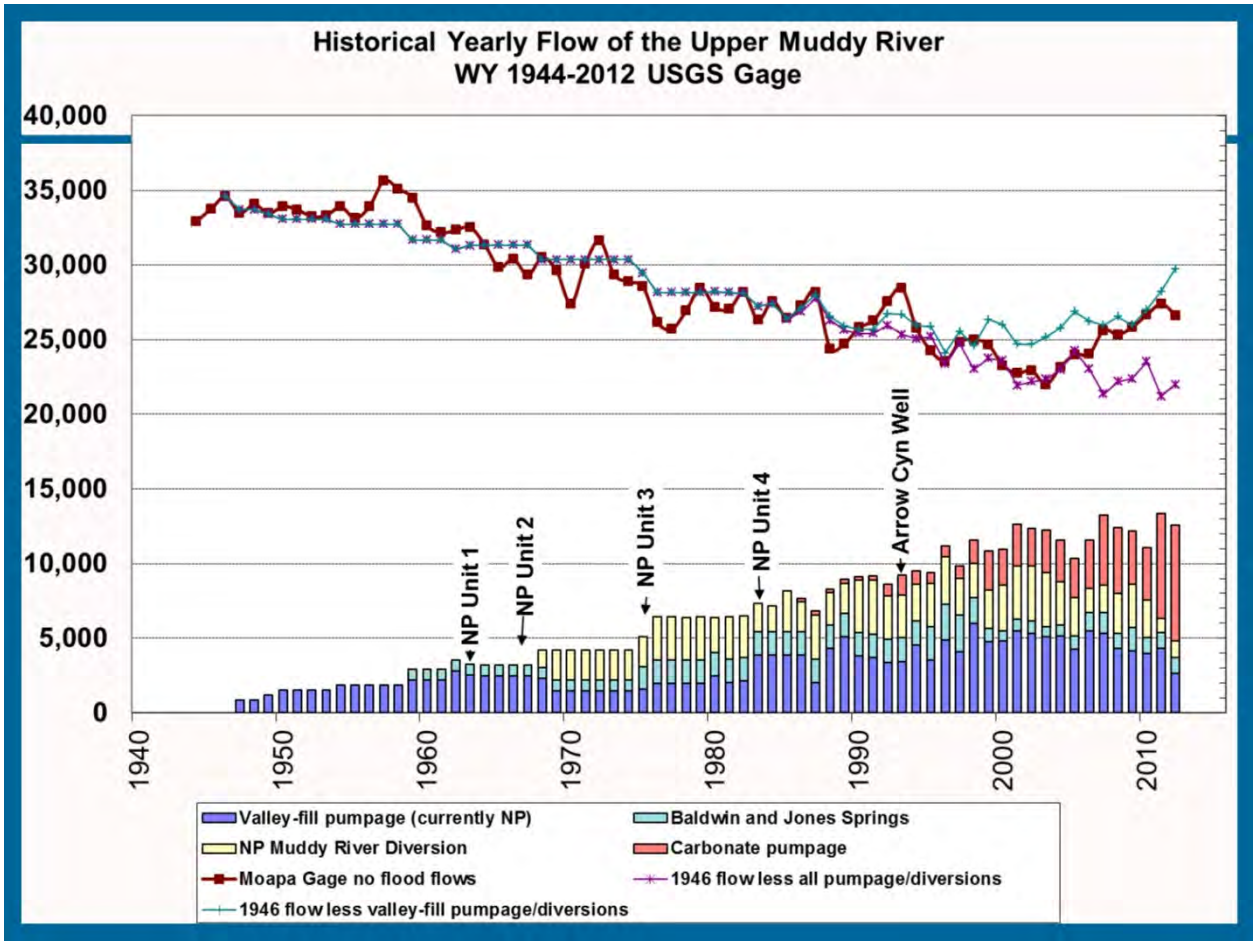


Figure 3. Slide 21 from the HRT presentation by Jeff Johnson, November 15, 2012. The differences (negative in 1957-1959, positive in 1976-1978, for example) argue against the assumption that natural flux (and therefore non-impacted base flow) has remained constant at 1946 levels [file SNWAoriginalReconst.jpg, rasterized from "SNWA Monitoring update 11-01-12.pdf"]

To illustrate the differences between SNWA and MAI analyses of diversion impacts on the Muddy River, we overlay the Slide 21 data with equivalent MAI reconstitution results (Figure 4). The hazed graphics on Figure 4 are the SNWA content of Figure 3, supplied for reference; the bold overlay is the result of our analyses, registered to the x-y grid of Figure 3. The salient differences and their explanations are as follows:

1. The annualized natural-flux hydrograph at the top of the chart is the result of MAI's reconstitution effort. It is consistently above the constant base flow assumed by SNWA for two reasons: surface-water diversions equivalent to the post-2007 Intentionally-Created Surplus (ICS) and evapotranspiration (ET) have been restored to improve the resolution of other seasonal impacts and permit the resolution of lag times. SNWA does not explicitly consider either of these factors in their water-balance model.
2. Impacted base flow, based on observed discharge and represented by the bold purple trace labeled "Reconst (VF+BJ+RI+Carb+ET+ICS)" on Figure 4, is the starting point for the MAI reconstitution and close to the SNWA target hydrograph labeled "Moapa Gage no flood flows" in Figure 3. Small differences arise from different methods of base flow separation from flood flows (Appendix B).
3. SNWA assumes that the Behmer and Perkins wells, which are located down-river from the Moapa Gage, in an area where the alluvial aquifer is confined (Mifflin and others, 1991), participate in reducing discharge at the Moapa Gage, whereas MAI assumes they do not.
4. SNWA does not account for the time lags associated with groundwater exports from the headwaters area, documented by Mifflin and others (1991) as pumping cones that migrate seasonally in the alluvial aquifer to eventually capture flows that nourish the Muddy River by the end of the summer pumping season. SNWA apparently assumes that effects from pumping in Coyote Spring Valley are also expressed instantaneously, rather than building with time as storage in the up-gradient aquifer system is depleted and the decrease in regional flow is propagated to the Springs area; this creates mass-imbalance after 2006 in their model.
5. SNWA utilizes a model of total NPC water demand based on generating capacity; MAI uses measured demand for Reid Gardner Unit 1 and Units 1+2+3 to interpolate Unit 2 demand from 1968-1976 (Appendix B).

The MAI analysis of system responses depicted in Figure 4 accounts for all of the factors itemized above. The most important conclusion to be drawn from the comparison with Figure 3 is that when the natural groundwater flux sustaining the Muddy River is reconstituted rather than prescribed, an entirely different picture of impacts emerges. The divergence of "1946 flow less all pumping/diversions" (Figure 3) from the measurement record is largely an artifact of 1) the assumption that annualized base flow is constant, and 2) the expectation that pumping in Coyote Spring Valley (CSV) would be expressed instantaneously in the Moapa Gage discharge record, which Bredehoeft (2011) demonstrates to be highly unlikely. When CSV pumping is represented as a backward-looking 3-year average, reconstituted natural groundwater flux ("Reconst MR" on Figure 4) remains well within the historic range. Appendix B provides a step-by-step explanation of the reconstitution process.

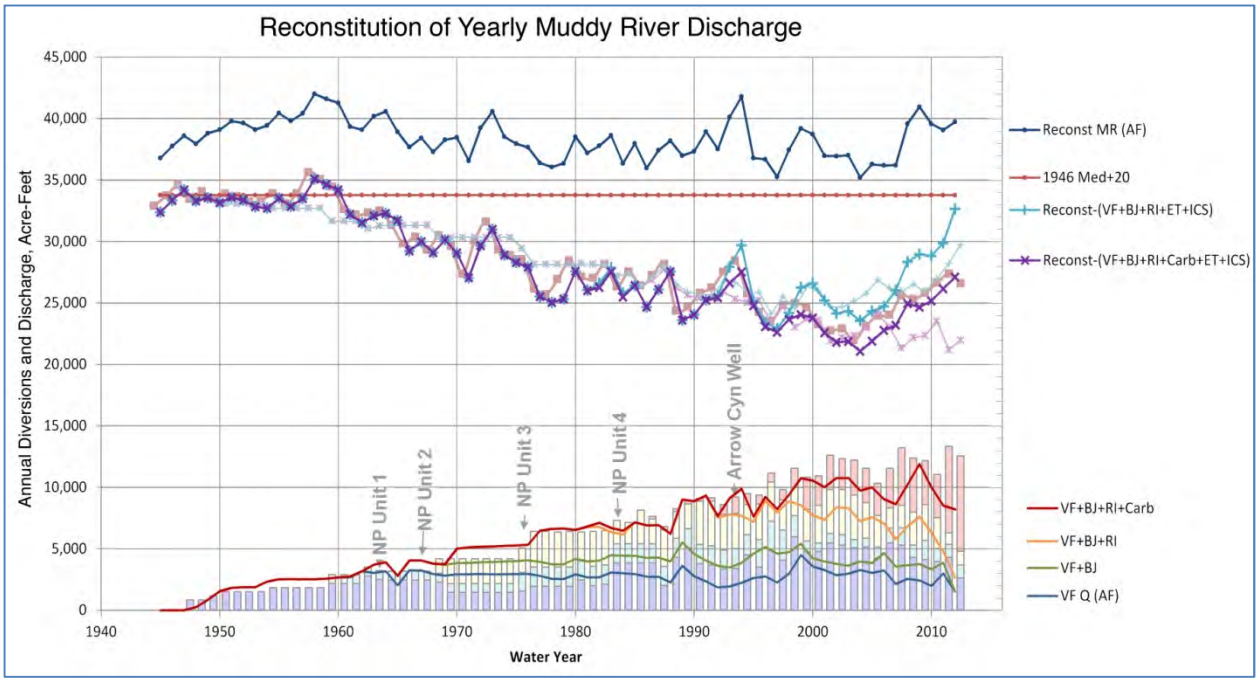


Figure 4. Comparison of *effective* annual diversion rates accounting for lag, ICS, and base flow variations with the SNWA model of Figure 2. The data curves at the bottom of the chart are designed to drape the corresponding SNWA column chart segments for ease of comparison. Mis-alignment of bold and hazed content along the x (time) axis is likely the result of MAI plotting water-year data at the exact x-value of the water year (e.g., data from Water Year 1980 plot directly above "1980" on the horizontal axis), whereas SNWA appears to use Excel dates with the year-value corresponding to the start of the year or water year. Reconstitution of flows provides an exact match to the "Reconst MR" curve at the top of the chart, which is historical yearly natural flux according to our analysis. The flat-line base flow and other assumptions by SNWA (particularly the expectation of instantaneous impacts from Coyote Spring Valley pumping) result in the divergence of "1946 flow less all pumpage/diversions" of Figure 3 from "Reconst-(VF+BJ+RI+Carb+ET+ICS)" of Figure 4, which represents observations, after 2006. [file SNWAcomparisonChart.jpg, derived from file ReconstSimple4.xlsx, sheet 'WYsummary']

Predicting Future Effects

"Climate" refers to variable weather patterns that have produced multi-year droughts and exceptionally wet periods in the general region, resulting in variations in natural groundwater flux to the headwaters area. These climate variations, which cause flux to vary by ±9% about the long-term average (Figure 4), are likely complex and potentially involve both differing response (lag) times and magnitudes due to multiple recharge zones of the regional Carbonate-Rock Aquifer, and variations in magnitude and distribution of weather-related events. There are also occasional, direct surface-water runoff events from local storms that produce shorter periods of increased flow and local recharge along ephemeral streams. Complicating the timing of impacts on natural flux to the headwaters area are the effects of aquifer storage capacity and flow-path lengths, which delay the arrival of flux components in the Muddy River headwaters area. Expressions of these climate-derived signals in Muddy River base flows are varied in timing and magnitude due to variable location and intensity of their origins. While it

appears that some distant source area dominates the pattern of variable natural groundwater flux (Appendix C), the effect of combining numerous climate-signal components of non-stationary frequency, variable intensity, and multiple travel paths results in net amplification at some times, and cancellation at others as combinations of wet+wet, dry+dry, or wet+dry signals reach the headwaters area to determine instantaneous flux.

The observations of Eakin (1964) and Eakin and Moore (1964) have been extended to provide a refined estimate of the time required for the natural flux from which the Muddy River is derived to be influenced by climate (Figure 5). A composite climate index was developed for this study using the same monthly precipitation record from Adaven used by Eakin and referenced by Maxey and others (1966), which continued until 1980, combined with monthly infiltration estimates from Lower Meadow Valley Wash (based on losses between Caliente and Rox) and storm runoff measured at the Glendale gage (Appendix C). The sum of squared differences between the climate index and the Muddy River hydrograph reaches a minimum when the climate signal is lagged 248 months (about 21 years) with a secondary minimum at 183 months (about 15 years), validating Eakin's 15-20-year lag-time estimate (Figure C-3). Particularly noteworthy is the deep, historic minimum in the climate index associated with the 2000-2004 drought, which will be impacting the Muddy River in about 10 years.

We emphasize the distinction between the "correspondence" illustrated in Figure 5 and "correlation". The climate and discharge signals are statistically uncorrelated, but correspond best with a response-lag time of 248 months (Appendix C). Attempts to apply linear regression models to relate a climate index to discharge from a regional flow system (e.g., Avon and Durbin, 1994) have failed for reasons discussed by Harrill and Bedinger (2005). In essence, a regional-scale groundwater flow system contains multiple recharge areas, and precipitation on each of the recharge areas will differ as will geologic conditions affecting infiltration and recharge. The recharge areas are at different distances from the common discharge area, and consequently recharge or pressure changes will have different lag times before arriving at the discharge area. The correspondence relations depicted in Figure C-3 are the result of several climate signals, with different intensities and lag times, combining to determine the natural flux arriving at the headwaters of the Muddy River. As identification of recharge areas progresses and monitoring of factors affecting recharge becomes more comprehensive, the reliability of climate indices as predictors of Muddy River discharge may improve.

Muddy River Tributary Groundwater Components

The complex discharge environment in the Springs area, which receives groundwater flux from multiple fracture and porous-media flow paths, integrates flux components with a range of origins and residence histories into the mixture that constitutes the Muddy River. Trigger levels incorporated in the Memorandum of Agreement (MOA) were based on speculation in the Biological Opinion (USFWS, 2006) that the highest-elevation springs would be impacted first by pumping in CSV, and to a limited degree this idea has been validated by discharge reductions in the Pederson Springs area (Figure 6).

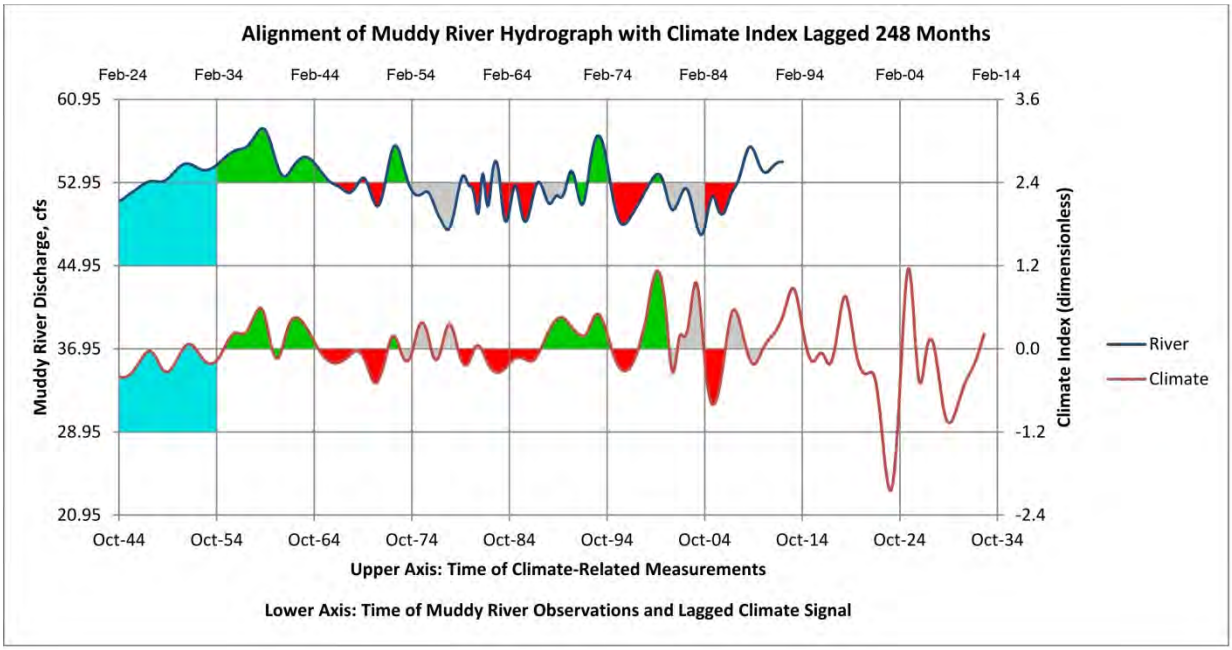


Figure 5. Correspondence of lagged climate index and natural groundwater flux represented as a reconstituted Muddy River hydrograph. The composite climate index is projected 248 months forward in time as an indicator of model-forecasted River response. This revises and extends Figure 4 of Eakin (1964). Aqua tint highlights the early trend, green and red highlight times of relatively good correspondence, and gray indicates generally poor correspondence. According to this predictive model the Muddy River is in for a wild ride over the next two decades due to the increasing frequency and strength of extreme weather events (Hansen and others, 2012) [file ClimateLag5.jpg, enhanced from file 3climateIndicesV5.xlsx, sheet 'ProjectIndex']

Recognition that seepage flux, as contrasted to conduit discharge from the major springs, is a major contributor to the overall water budget of the Muddy River invites analysis of where the seepage occurs across the headwaters area and how different tributary reaches have been impacted by Order 1169 pumping. In principle, this can be accomplished by mixing and mass-balance calculations, where sufficiently comprehensive monitoring records exist. Underlying this approach is the idea that mixing of end-member waters produces a mixture that is intermediate with respect to temperature and those dissolved constituents that do not react or otherwise enter or leave the mixing system. Such constituents are referred to as *conservative*, meaning they are conserved in the mixing process. Conservative natural tracers include the stable isotopes of oxygen and hydrogen, generally non-reactive ions such as chloride and fluoride, electrical conductivity (EC), and temperature (subject to open-channel heat exchange uncertainties).

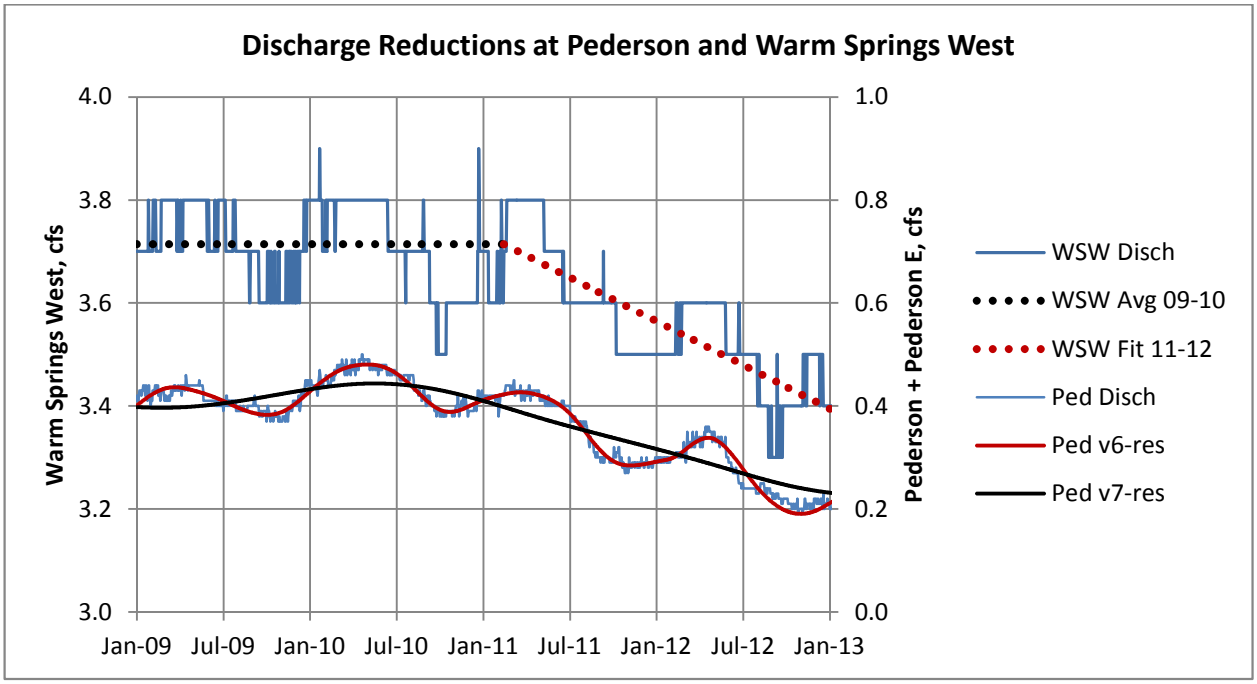


Figure 6. Reduction of discharge at the combined Pederson and Pederson East springs appears to have stabilized at a rate of 0.09 cfs/year, which would result in extinction of the Springs in ~2.5 years if this rate of reduction continues. At Warm Springs West the reduction rate is 0.17 cfs/year, and ~20 years would be required for elimination of flow at that location at the present rate. These relations indicate that seepage gains along headwaters channels dominate the flows measured at Warm Springs West. [file CompareSpringsRiver.xlsx, sheet 'ComparePedWSW']

In the headwaters area of the Muddy River, which contains the largest thermal spring in Nevada, Big Muddy Spring (Garside and Schilling, 1979), numerous springs discharge water very close to 32°C into a closely-interconnected alluvial-aquifer and stream system that maintains the flux sustaining the Muddy River within about ±9% of its historic average (Figure 4, curve "Reconst MR"). There are four major, recognized areas of tributary groundwater inflow to the Muddy River: North Fork (Pahranagat Wash), South Fork (Baldwin and Jones Springs), Refuge Stream (confluence of Plummer and Pederson flows), and Muddy Springs Tributary (Figure 2). Large springs characterize the latter three areas, and based on synoptic sampling by ERTEC (1981) the water quality in the large springs is virtually identical. During 1963 and 1964, Eakin and Moore (1964) monitored discharge from the largest spring groups at several localities (Figure 7) and found minimal seasonal variation in spring discharge, in contrast to the discharge of the Muddy River, which is influenced by the annual ET cycle (Figure 8).

When seepage gains along a tributary reach are documented by simultaneous discharge measurements and accompanied by electrical conductivity (EC) measurements, the EC of the seepage flux can be established by a simple mixing calculation using EC as a conservative tracer. Eakin's (1964) study provides the baseline data needed to evaluate pre-development mixing kinematics in the headwaters area, and from which to evaluate the evolution of water quality in the area in terms of diminished seepage gains along specific tributary reaches.

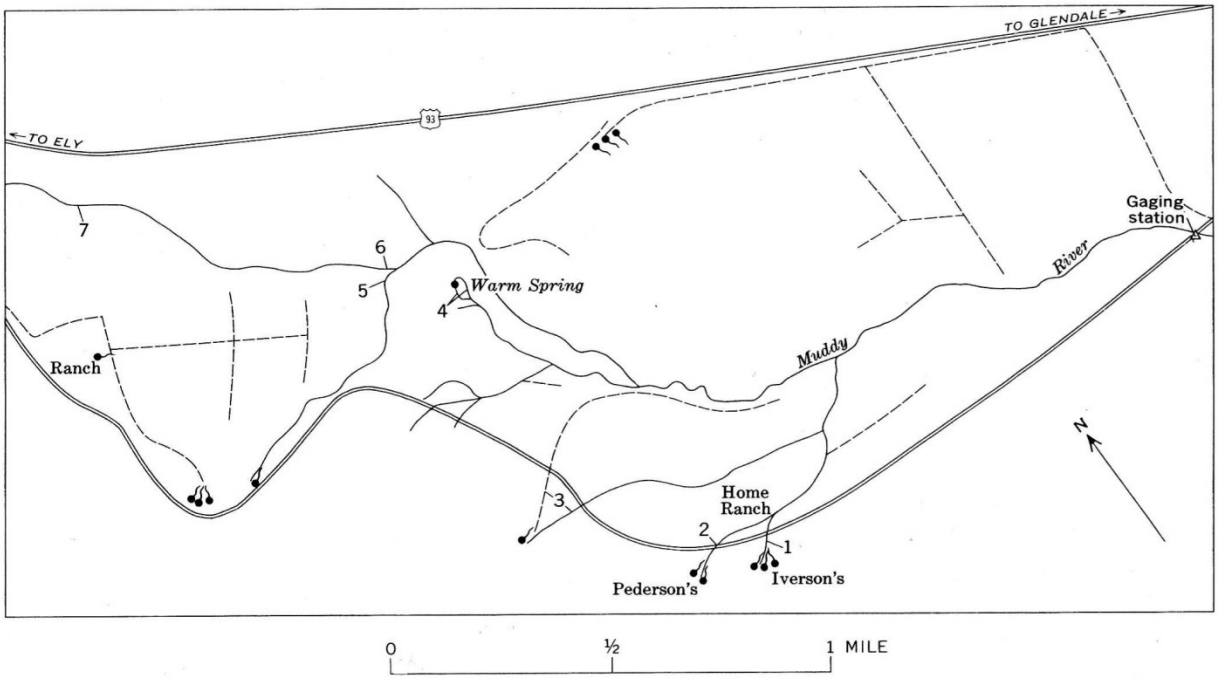


Figure 7. Numbering scheme for selected monitoring stations on the Muddy River and tributaries used by Eakin and Moore (1964); locations correspond with measurements reported by Eakin (1964), as shown in Figure 2, but numbering differs. [file EakinMoorePP501Dfig2.jpg]

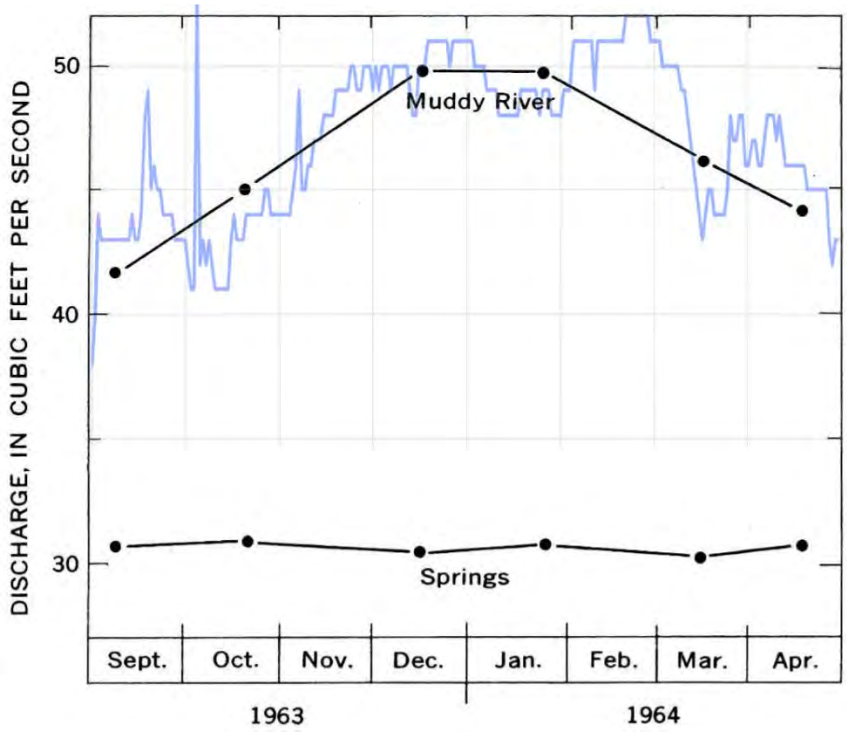


Figure 8. Field measurements reported by Eakin and Moore (1964) with daily discharge (blue haze) from the Moapa Gage, USGS ID 09416000. "Springs" refers to the total discharge at stations 1-6 in Figure 5, apparently adjusted upward by ~1 cfs to account for MVWD diversions from Apcar (Pipeline Jones) Spring. [file EakinMoorePP501Dfig3b.jpg]

No subsequent survey of discharge, temperature, and EC of the Muddy River and its tributaries was as comprehensive as that of Eakin (1964) in terms of spatial coverage. Numerous entities have contributed measurement data, but EC records are particularly problematic because of variable relations between field measurements and laboratory-determined values. We assume that instrument calibration and therefore quality control of laboratory measurements is sufficient to allow direct comparison of laboratory EC data from different laboratories, but field measurements must be adjusted to equivalent laboratory values for inter-comparison of field data from the various sources. We further assume that when laboratory EC measurements are not available, *differences* between close-in-time field measurements are reliable but their absolute values are not. These assumptions allow us to use less-frequent laboratory measurements to normalize field EC data to, hopefully, a measure of internal consistency (Appendix E).

Has a reduction of perennial flow in North Fork gone unnoticed? Flow in North Fork abruptly decreased in 1992-93, coinciding with increases in water exports from the headwaters area (Figure 9). In September of 1963 D.O. Moore (as reported by Eakin, 1964) measured 4.23 cfs and a field EC of 1,330 µS/cm above the confluence with South Fork (point 32 on Figure 2 and point 6 on Figure 7), and in March of 1987 the average of 2 USGS measurements was 4.81 cfs without supporting EC data. MAI measured a field EC of 1,018 µS/cm in April of 1987 at the historical "Big Wash Flume" (NDWR) site in lower North Fork (Figure 2, near Eakin point 32), slightly greater than the median of 938 µS/cm from profiles in the Lewis Well Field during the same month with the same instrument.

Median groundwater temperatures were 31.0°C in the Lewis Well Field in April of 1987, 11°C greater than the mean annual air temperature at Nellis Air Force Base (Appendix E), and surface flow passing the remnant of the Big Wash Flume was 29.3°C. ***These temperatures could not be sustained without constant throughput of deeply-circulated (Carbonate-Rock Aquifer) water***. In 2001, when a synoptic streamflow and water-quality survey was conducted by the USGS and affiliated agencies (Beck and Wilson, 2006), no measurement of flow or EC in North Fork was made and there is no mention of any such flow (or absence of flow) in their report. Where the 2001 measurement locations do coincide with those of Eakin, however, changes in the discharge regime can be quantified.

Eakin (1964) recognized that waters associated with the alluvial aquifer and entering the Muddy River as seepage flow were of slightly poorer quality than those discharging directly to surface streams from the larger springs. Deterioration of water quality is attributable to a small contribution of discharge from the Muddy Creek Formation, which separates the Carbonate-rock Aquifer and alluvial aquifer in the headwaters area, and to evaporative concentration of solutes near the surface as natural recharge and irrigation return flows infiltrate into the permeable gravels. Eakin's relatively high (1,330 µS/cm) EC in North Fork compared to the 1,170 µS/cm he reports in South Fork allows the EC of a discharge-weighted mixture below the confluence to be calculated, and mixing-cell models to be developed for discrete reaches of the Muddy River and its tributaries between points where synoptic data exist. Calculations of seepage flux along discrete reaches of the Muddy River are presented in Appendix E.

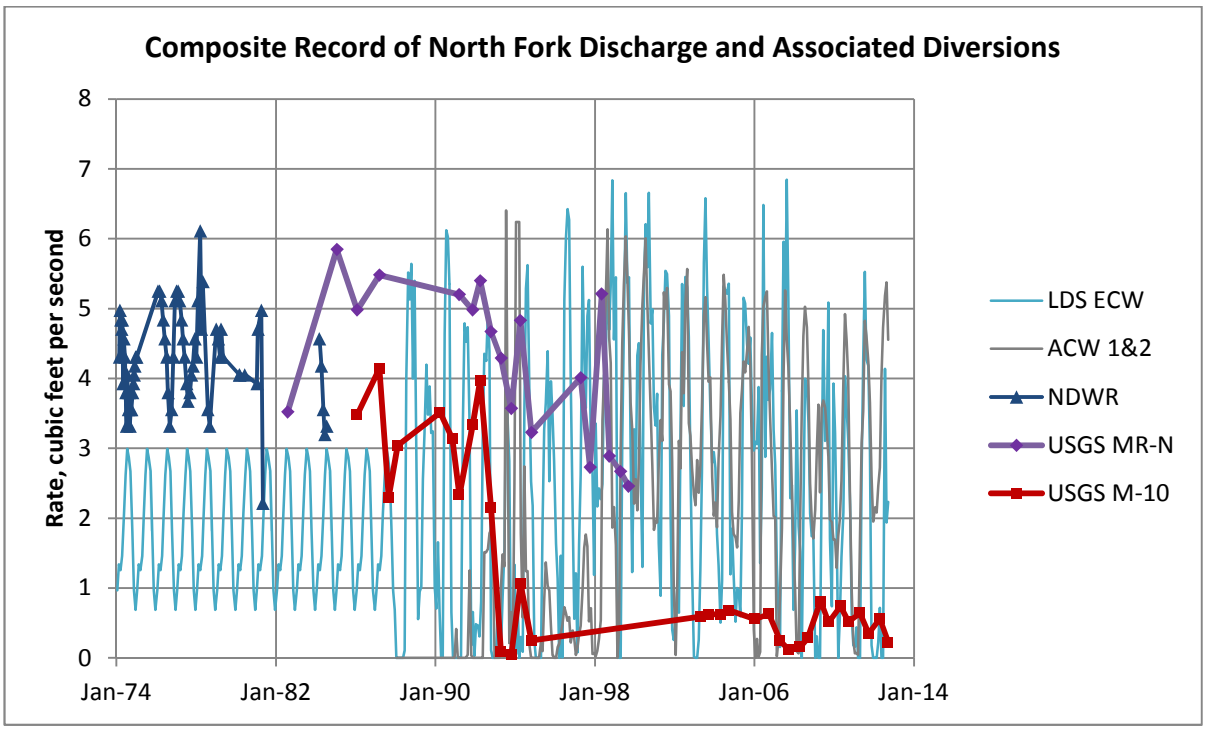


Figure 9. Exports of groundwater to meet demand by Reid Gardner Unit 4 ("LDS ECW") and MVWD's municipal service area ("ACW 1&2") are temporally associated with an almost complete elimination of surface flow in the North Fork of the Muddy River. Consumptive use prior to 1987 is based on estimated irrigation demand at the Taylor wells, later known as LDS East and LDS West. Data from Tables B2 and B47 of Beck and others (2006), who mis-located M-10 as documented by Mifflin & Associates (2010), and the USGS data archive for site 364316114431901. [file NorthForkBigWashM10v2.xlsx]

Stable isotopes, particularly deuterium, are the most reliable tracers known, and Thomas and others (2001) provide a useful compilation of hydrochemical and isotopic data from the region. Limited sampling reported by SNWA and DRI complements the Thomas dataset. Unfortunately no stable-isotope samples from the main-stem Muddy River, Arrow Canyon Well #1 or #2, the Lewis Well Field, or Pahranagat Wash are known to have been analyzed. Still, the Carbonate-rock Aquifer is reasonably well-characterized in terms of the chemical and isotopic composition of its waters, as represented by samples from wells in Coyote Spring Valley, large springs in the Muddy River headwaters area, and two wells on the Moapa Indian Reservation.

The isotopic evolution of groundwater as it moves from Coyote Spring Valley to the headwaters of the Muddy River can be characterized as reflecting admixture of small proportions of isotopically-heavier waters along generally southeasterly flow paths, with the most likely sources including infiltration in Pahranagat Wash and Lower Meadow Valley Wash, and recharge in the Sheep Range. Deuterium concentrations (δD) decreasing from -99.8‰ at CSI-3, to -99.4‰ at MX-5, to about -97.7‰ in large springs of the headwaters area (Thomas, 2001) indicates that Coyote Spring Valley provides the conduit for most, but not all, water discharging in the headwaters area. The δD from Reservation wells is -99.0‰; Johnson and others (2001a, pp. 24-31) and Mifflin and Johnson (2005, pp. 30-32) concluded that available isotopic and geochemical data support groundwater upwelling in the Reservation area.

Regional Water Levels

Well hydrographs from Coyote Springs Valley, through the Springs area and Moapa Indian Reservation, to the Apex area share a pattern of seasonality that cannot be explained by localized pumping with any realistic choice of aquifer parameters. There is no discernible lag or attenuation of the yearly water-level fluctuations with distance from Apex, where pumping is concentrated and seasonal (Figure 10) or from the Muddy River Springs area, where there are seasonal pumping cones developed within the alluvial aquifer that are approximately synchronous in recovery with the annual water-level cycle in the Carbonate-Rock Aquifer. Many have, and continue to, interpret the seasonal water-level cycle as resulting from seasonal pumping or recharge, but the widespread and synchronous nature, as well as the similar and widespread amplitudes between the pumping centers do not support the notions of seasonal recharge or localized pumping signals as forcing agents. Therefore an annual loading phenomenon potentially qualifies based on available evidence.

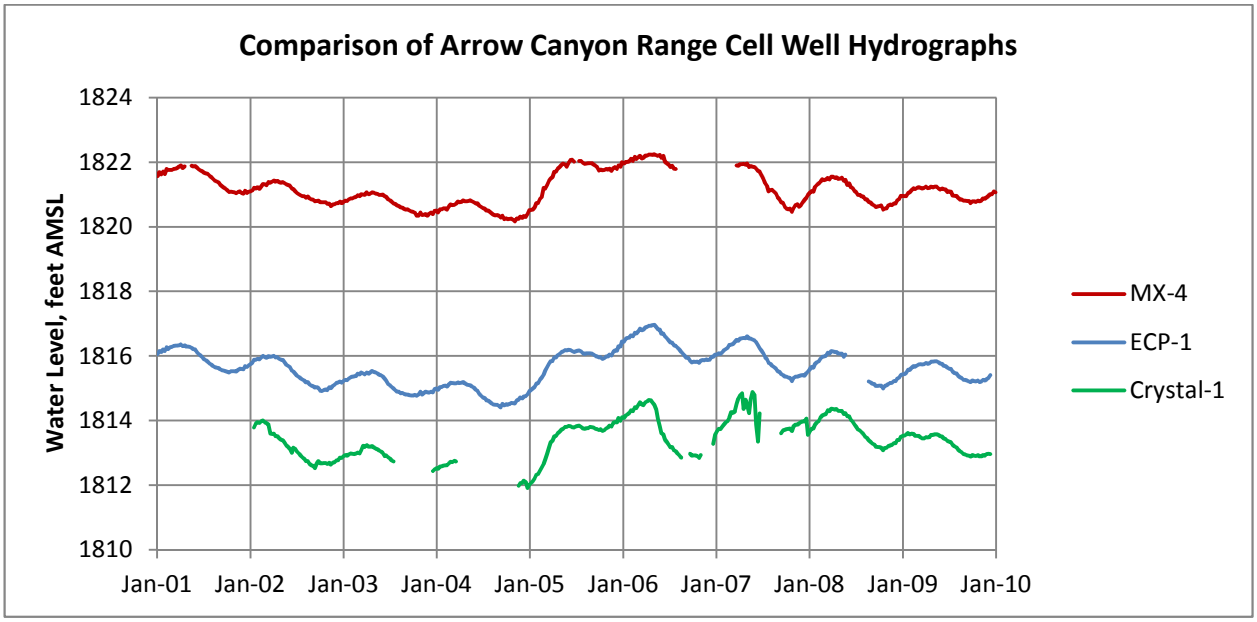


Figure 10. Hydrographs from 3 widely-separated monitoring wells share the same overall trend and seasonality, regardless of distance from pumping centers. [file Compare10yrWL.xlsx]

Smith and others (2004) suggested that the annual cycle might be the result of barometric-pressure fluctuations, but this seems impossible (Figure 11). The seasonal water-level fluctuations are much larger than the corresponding barometric-pressure fluctuations, unlike the pattern at Devils Hole (Harrill and Bedinger, 2005, p. 34). When detrended, however, the inverse relationship between atmospheric pressure and water level is evident (Figure 12). When plotted in terms of detrended total head a barometric efficiency (B.E.=76%) is resolved with high confidence (R^2=0.92; Figure 13). Since atmospheric pressure does not explain the annual cycle in the well hydrographs, it is also apparently not responsible for the seasonality in discharge at Pederson Springs discussed by Smith and others (2004). Barometric effects on water level are nonetheless systematic and important, particularly as the first step in noise reduction procedures that are essential to resolving very small pumping responses (Johnson and Mifflin, 2012b).

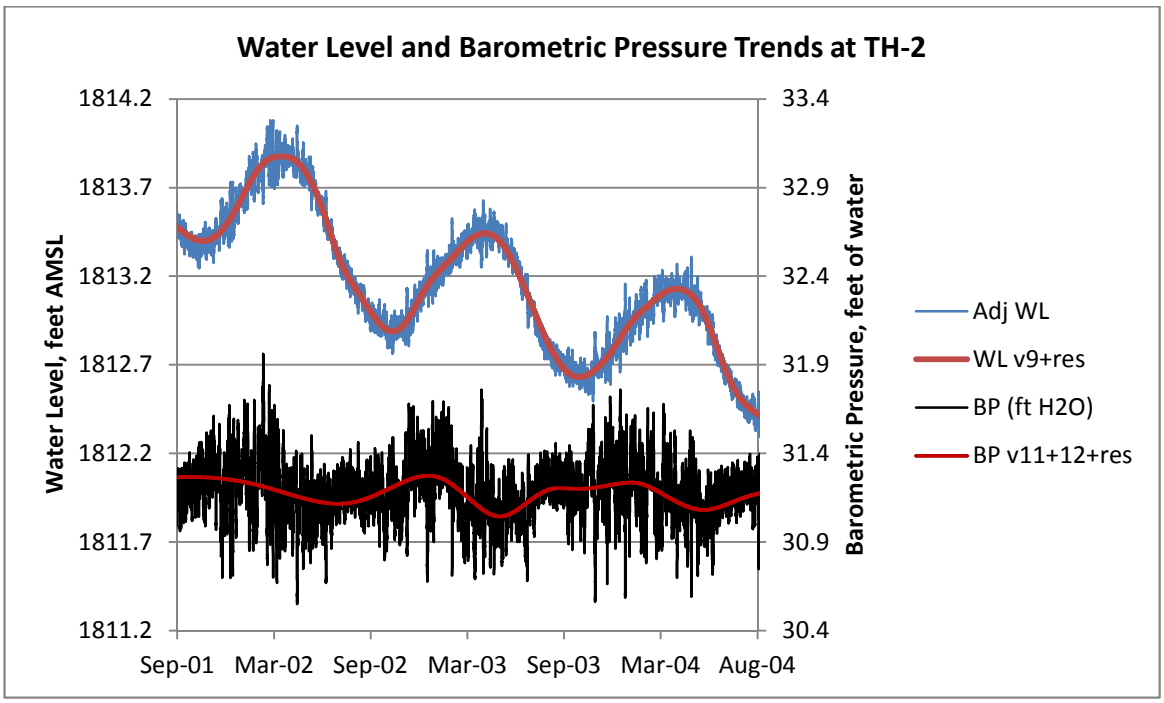


Figure 11. Comparison of daily water-level and barometric-pressure data from monitoring well TH-2 on the Moapa Indian Reservation, with annual trends derived by empirical mode decomposition. [file xTH2wlCumulative2.xlsx, sheet ComparisonPlots]

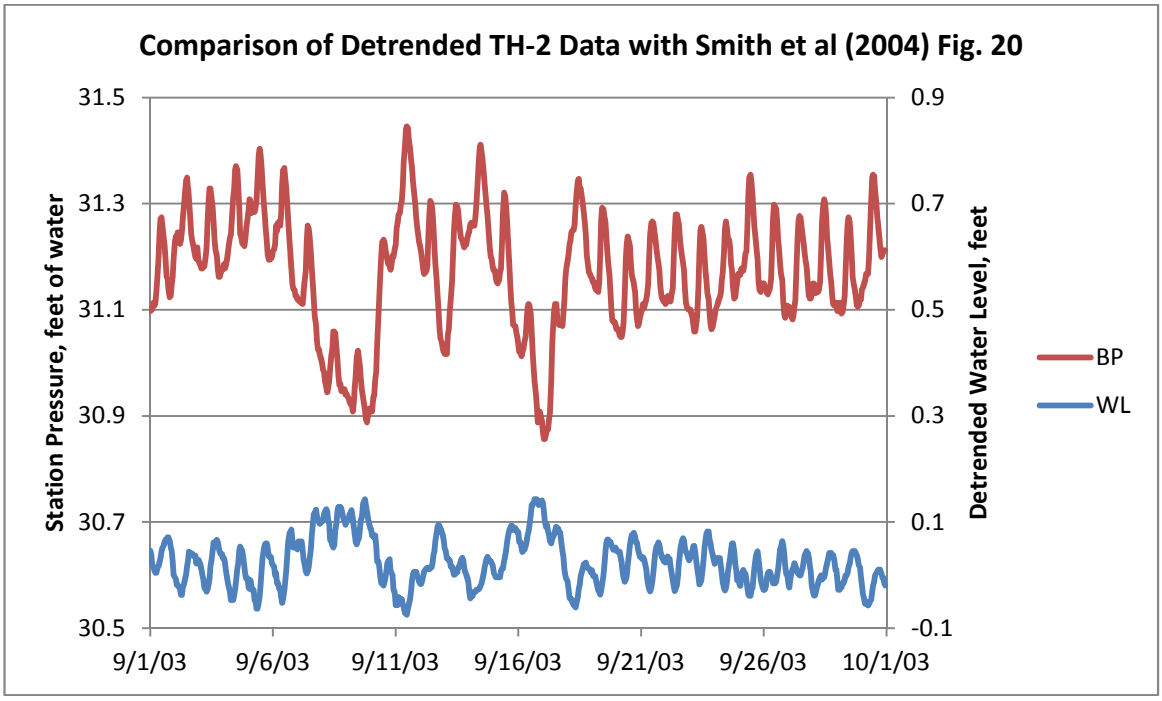


Figure 12. Inverse relationship between detrended water level and barometric pressure illustrated by September 2003 records from TH-2. [file xTH2wlCumulative2.xlsx, sheet ComparisonPlots]

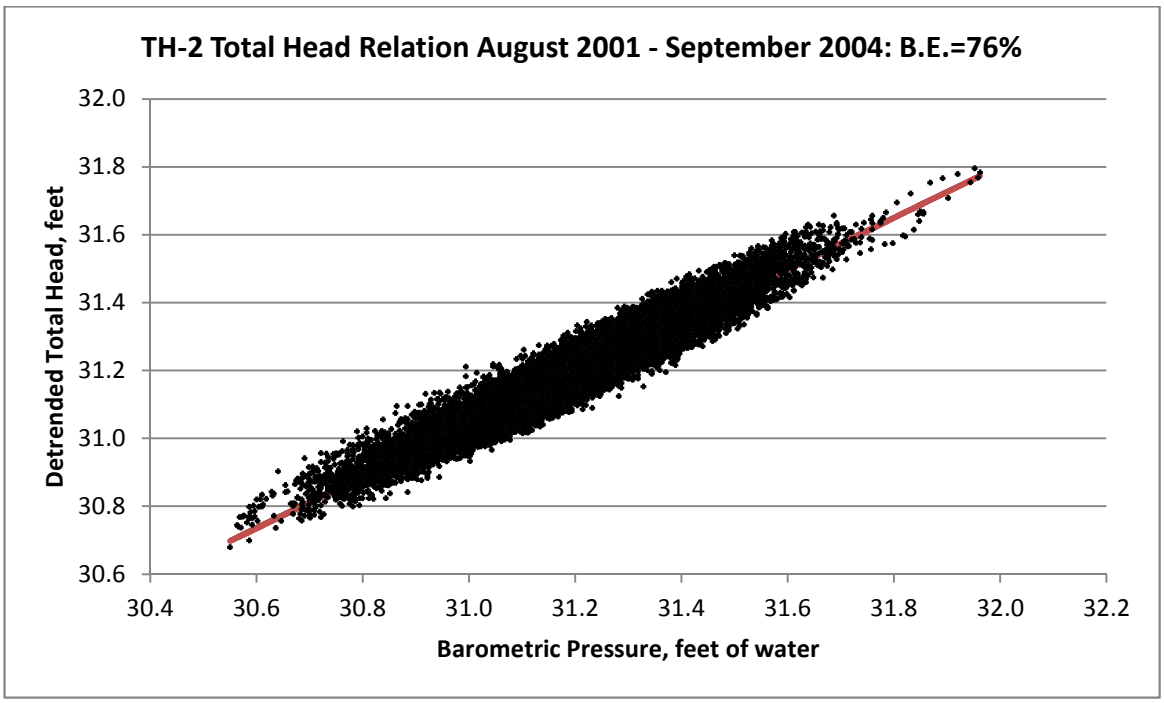


Figure 13. Total head is superior to water level for deriving barometric efficiency relations (Mackley and others, 2010; Rasmussen and Crawford, 1997; Spane, 2002; Toll and Rasmussen, 2007). Compare Figure 19 of Smith and others (2004). [file xTH2wlCumulative2.xlsx, sheet ComparisonPlots]

There is no direct evidence of a discharge area other than the Muddy River Springs for groundwater flux passing through Coyote Spring Valley in the Carbonate-Rock Aquifer, but upwelling beneath the Moapa Indian Reservation does occur based on groundwater temperatures, the presence of paleo-discharge features (cover photo), the fluid-potential gradient toward the south and east beneath the Reservation, and hydrochemical mass balance. The chemical evolution of groundwater moving from the Reservation area toward the east and southeast requires an upwelling source distinct from that feeding the Muddy River Springs (Johnson and others, 2001a, pp. 26-27). These multiple lines of internally-consistent evidence of upwelling and lateral groundwater flux were dismissed by the State Engineer as "speculative" on Page 22 of Ruling 5115, without the benefit of data and discussions in Johnson and others (2001a). At the hearings of July 16-24, 2001, only Johnson and others (2001b), an abstracted version of modeling results, was submitted as evidence (Exhibit 66). Groundwater flux of several thousand AFY toward the Lake Mead area clearly occurs, though no major springs along the lower Virgin River were documented prior to filling of the Lake (Carpenter, 1915; Longwell, 1936).

After using empirical mode decomposition (EMD) to extract the annually-fluctuating components of Lake Mead water levels and comparing them with the annual cycle observed in MBOP monitoring wells, a lag between Lake Mead fluctuations and those in the monitoring wells is evident as recognized by Buqo (2004) (Figure 14). This relationship may help explain the widespread seasonality of groundwater levels as resulting from some combination of loading-related pore pressure changes and pore volume reductions or, as Buqo (2004) suggested, propagation of head changes at the outflow boundary up-gradient into a confined-aquifer system. With no outflow boundary in evidence, however, the Buqo thesis of hydraulic continuity with Lake Mead is problematic.

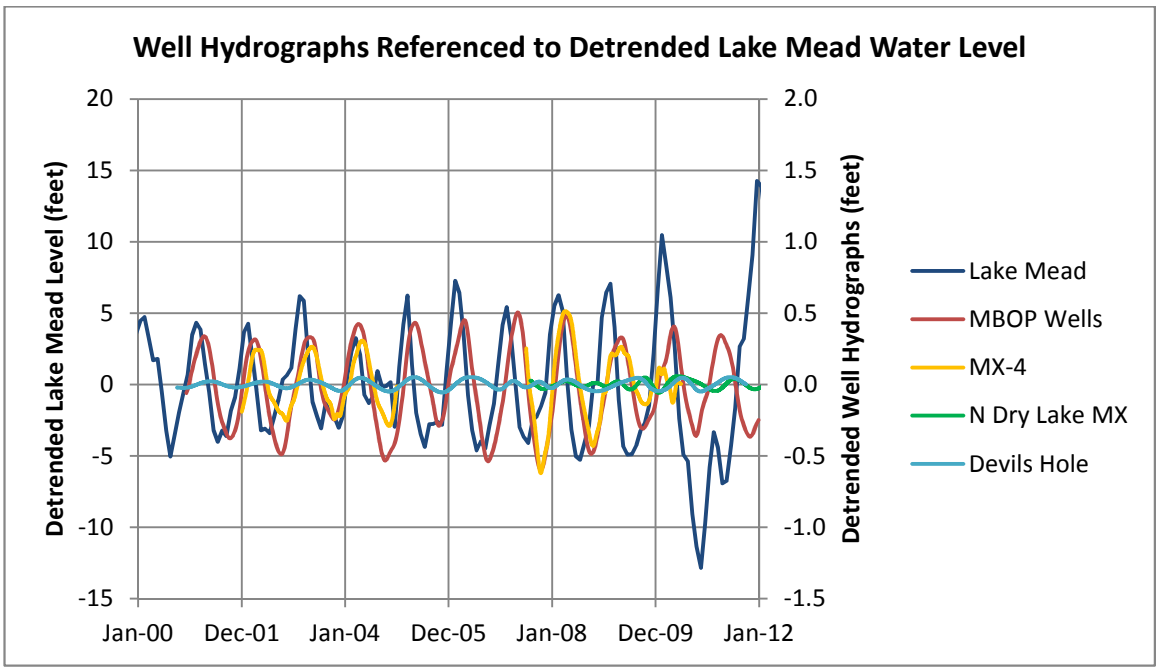


Figure 14. Detrended MBOP water levels lag detrended Lake Mead stage, with annual variability that is about 10% that of Lake Mead. There is a slight lag and attenuation of MX-4 levels with respect to the synthetic MBOP hydrograph. Only weak annual cycles attributable to barometric and earth-tide effects are resolvable in the Carbonate-Rock Aquifer 100 miles (160 km) north of Moapa in the North Dry Lake Valley MX well (Log #22450, USGS Site ID 380531114534201) and at Devils Hole (USGS Site ID 362532116172700) 100 miles to the west. [file LakeMeadMonthly.xlsx, sheet 'LakeMeadEMD']

Between the Moapa Indian Reservation and Lake Mead there are multiple potential lithologic and structural barriers to eastward groundwater flow, accompanied by a large hydraulic gradient (Figure 15). Rogers and Blue Point Springs discharge a combined total of only about 2.2 cfs at near 30°C and 4,200 µS/cm along the Rogers Spring Fault (Pohlmann and others, 1998) at an elevation of ~ 1,550 feet AMSL. Discharge from Rogers Spring appears to reflect the effects of long-term climate seen in the overall trend of regional well hydrographs shown in Figure 10, but not the seasonality (Figure 16). If Buqo's (2004) conceptual model were correct, Rogers Spring would be very sensitive to Lake-stage changes due to its proximity.

Comparison of hydrographs from MBOP monitoring wells M2 and M3 reveal a systematic lag and attenuation of the annual cycle from southeast (M2) to northwest (M3) (Figure 17). These wells are nominally 30 miles northwest of Lake Mead, a possible forcing agent for the seasonal cycles in well hydrographs (Figure 18). Lake Mead declined in a stepwise fashion from an average level of 1185.09 feet AMSL in 2001 to 1162.19 feet in 2002, and just as the departures from declining trends are illustrated in Figure 14, departures from the declining trends of groundwater levels at M2 and M3 are shown in Figure 17. According to Tighi and Callejo (2011) the decrease in lake storage associated with the 22.9-foot drop was 2.914 million acre-feet, or 127,249 acre-ft per foot; the seasonal component of variability, roughly 10 feet (Figure 14), represents cyclic loading by the order of 1.2 million acre-feet (1.6

gigatons) of water in the Lake Mead Basin in 2001-2002. Less-well-documented seasonal sedimentation adds to the loading cycle.

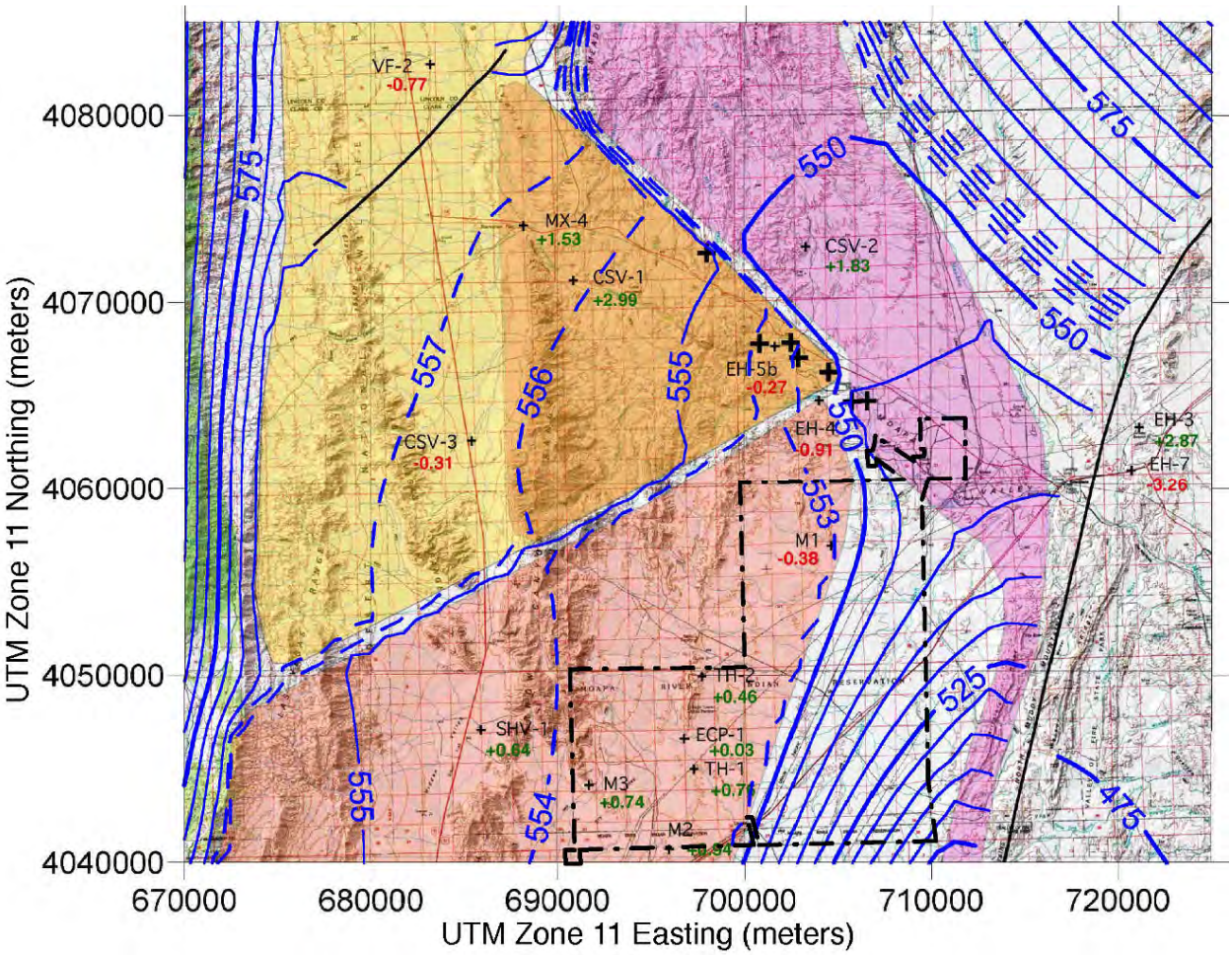


Figure 15. Model-derived water levels (meters AMSL) and calibration residuals in the vicinity of Moapa Indian Reservation. Contour interval 5 meters, 1 meter where dashed [file AshGroveFig3topGR27.jpg]

Crustal loading by large water (and ice) loads results in both elastic and viscous responses (Walcott, 1970), but the annual cycle in crustal loading resulting from water-level changes in Lake Mead is less studied or understood. The area of crustal deformation produced by the filling of Lake Mead clearly extended throughout the Arrow Canyon Range Cell (Figure 18). Paleozoic carbonate rocks extend at depth to the Lake Mead area (Tetra Tech 2012a, Figure 4.2-1) and are widely exposed east of the Lake. Isostatic equilibrium with the water load was reached ~1980 as the viscous substratum was displaced (Kaufmann and Amelung, 2000); subsequent elastic responses in confined portions of the Carbonate-Rock Aquifer to short-term cyclic changes in water load are likely reflected as equal changes in pore water pressure (Mifflin, 1970; Hoffmann and others, 2001).

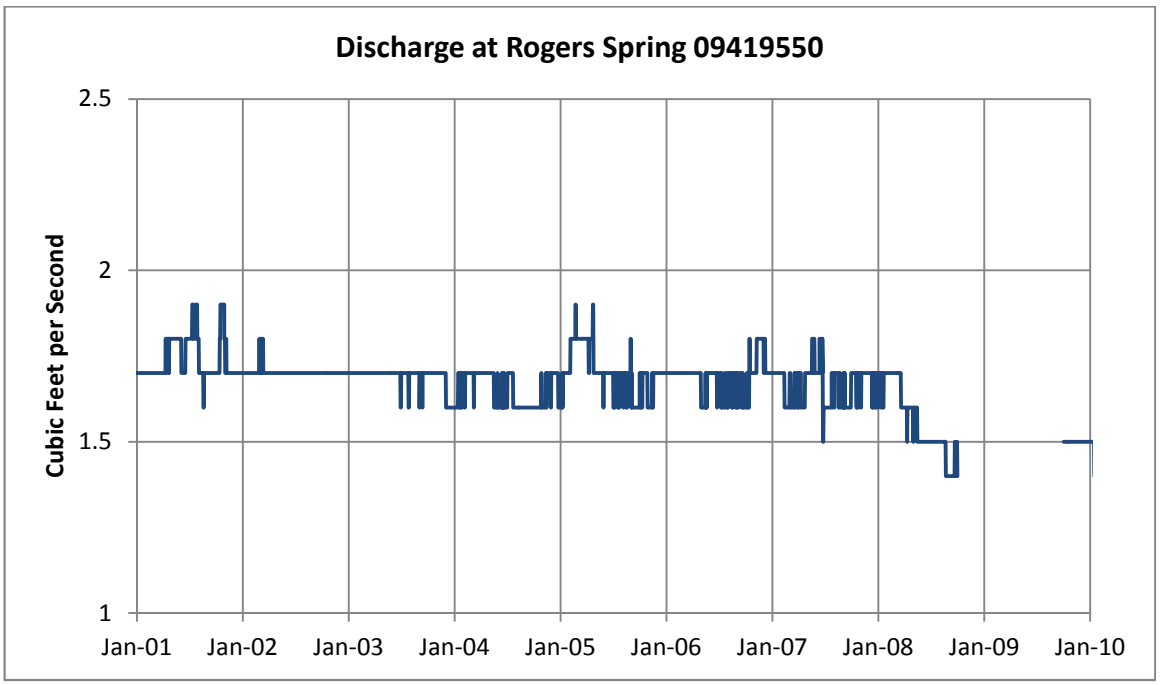


Figure 16. Though relatively coarse in terms of precision, the record of discharge from Rogers Spring appears to show decline from 2001-2004, recovery in 2005, and marked decline beginning in 2008 without the seasonality that Buqo's (2004) thesis suggests. [file RogersSpring85-11.xlsx]

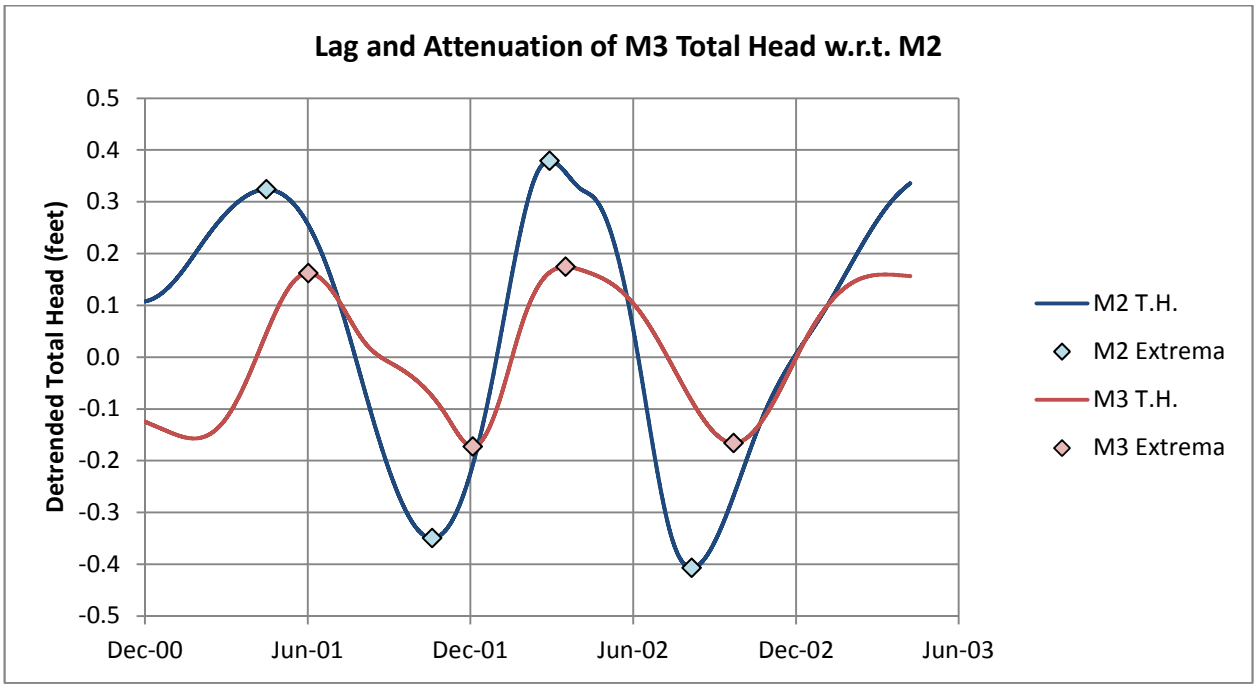


Figure 17. The M3 hydrograph lags the M2 hydrograph by 46 days and is attenuated by 54%, strongly suggesting signal propagation from southeast to northwest, consistent with forcing by loading of the Lake Mead basin [file CompareM2M3.xlsx, sheet 'Compare']

Smith (1999) provides a methodology to utilize cyclic loading as expressed in the detrended M2 and M3 hydrographs (Figure 17) to estimate aquifer diffusivity. The median lag = $F_\theta - R_\theta$ = 46.4 days, where F_θ is the phase of tidal forcing and R_θ is the phase of tidal response. The average peak-to-peak amplitudes are 0.730 feet at M2 and 0.337 feet at M3. M3 is 18,038 feet northwest of M2. If we treat M2 as a tidal boundary, the tidal efficiency TE = R_a/F_a = 0.337/0.730 = 0.462, where F_a is the forcing amplitude at the tidal boundary (M2) and R_a is the response amplitude at a point in the aquifer (M3). The period P of the tidal signal is 365.25 days, so the angular frequency $\omega=2\pi/P$ is 0.0172/day. Smith (1999) gives efficiency-based and lag-based expressions for hydraulic diffusivity (T/S) in terms of tidal efficiency and lag:

$$T/S = \pi x^2/(\ln TE)^2 P = \pi(18{,}038\text{ ft})^2/(\ln(0.462))^2(365.25\text{ days}) = 4.69 \times 10^6\text{ ft}^2/\text{day}$$

$$T/S = x^2 P/4\pi(\text{lag})^2 = (18{,}038\text{ feet})^2(365.25\text{ days})/4\pi(46.4\text{ days})^2 = 4.39 \times 10^6\text{ ft}^2/\text{day}$$

With these results we can evaluate the aquifer-test interpretation of Mifflin and Johnson (2005) and conversely, the present approach. Johnson and Mifflin (2005) obtained unconfined and confined hydraulic diffusivities of 1.02 X 10^6 and 4.74 X 10^6 ft^2/day, respectively, from aquifer tests at ECP-1, bracketing the above results obtained by Smith's tidal method. If unconfined conditions and a specific yield of 0.03 apply, the required transmissivity would be 1.36 X 10^5 ft^2/day, a factor of four higher than derived from our aquifer-test data. If the transmissivity measured in the aquifer test is representative of the larger area, a storage coefficient of 6.72 X 10^{-3} is indicated; this is an order of magnitude greater than we derived from re-analyzing aquifer-test data in 2005. If the storage coefficient of 0.0006437 from the aquifer test applies to the tidal forcing, a regional transmissivity of 2,922 ft^2/day is indicated. These results are not inconsistent, since the loading signal is being propagated transverse to the prominent northerly structural grain of the area, whereas the aquifer test at ECP-1 was conducted at a high-yield supply well that penetrated local permeable zones within a north-trending corridor that contains paleo-discharge features and evidence of upwelling groundwater. The large-scale anisotropy indicated by the geologic setting has not been incorporated into prior modeling analyses, and it has become clear that the system cannot be considered to be purely confined or unconfined. The great thickness of the Carbonate-Rock Aquifer, several thousand feet based on water temperatures, allows ill-defined, confined flow domains to co-exist and interact with thick and well-mixed unconfined domains that to date have sustained most groundwater development in the Arrow Canyon Range Cell of Mifflin (1992).

Down-gradient from the Moapa Indian Reservation, groundwater in the Arrow Canyon Range Cell is bounded by less-transmissive lithologies. If confined portions of the Carbonate-Rock Aquifer system extend to areas affected by elastic crustal responses to Lake Mead, they would respond to loading phenomena and propagate pressure signals. Hydraulic continuity in a confined system between the Reservation and the Lake-loading induced deformation would transmit pressure pulses as responses to rise and fall of the Lake, possibly explaining the annual periodicity and the lag and directional attenuation between M2 and M3 (Figure 15). Cavalié and others (2007) discuss "pore pressure diffusion" below Lake Mead in response to loading, indicating that a poroelastic model could explain the observed deformation pattern. "Important delayed effects" should then be expected, and we suggest

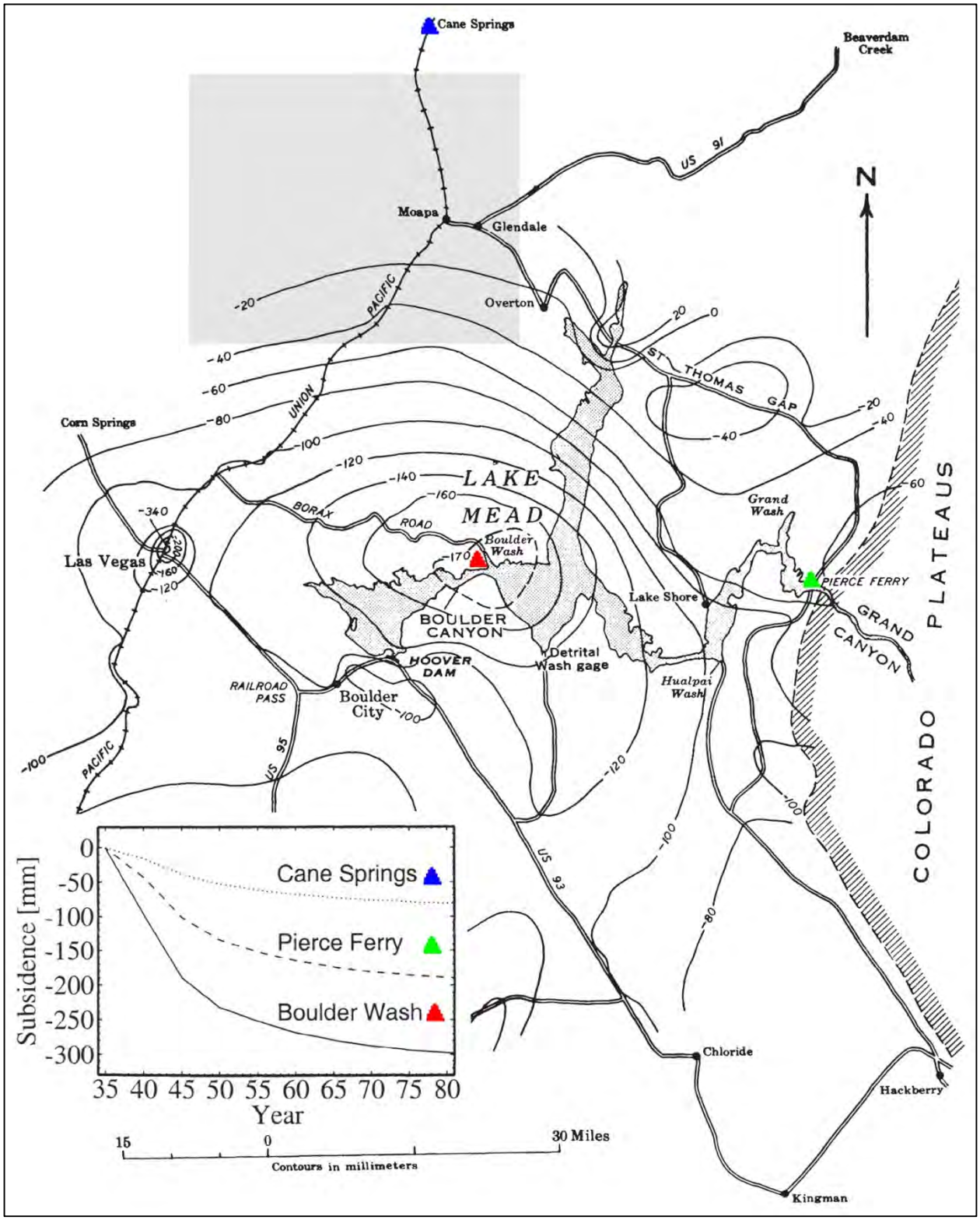


Figure 18. Subsidence in the Lake Mead Region from the 1948-1949 survey and model trends toward isostatic equilibrium from Kaufmann and Amelung (2000). Regional subsidence resulted from the filling of the Lake; superimposed local subsidence near Las Vegas was from groundwater pumping. Shading shows area of Figure 14. [modified after Figure 8 of Longwell (1960); file LakeMeadPP295fig8.jpg]

the anomalous annual periodicity of water levels observed in the Arrow Canyon Range Cell could be one manifestation of such effects. The signal is derived from the pore water carrying the majority of the high-frequency loading changes.

Resolution of Order 1169 Pumping Effects

Available aquifer-test data indicate that pumping responses in the Northern and Southern Flow Fields of Figure 1 are profoundly different with respect to the types of boundary conditions revealed by the well hydraulics (Figure 19). In the Southern Flow Field, the response curve flattens to about half its initial slope within one day, indicating a single recharge boundary was encountered by the spreading pumping cone. In the Northern Flow Field, the response curve increases to about four times its initial slope after about one day, then again after the first week of pumping, indicating multiple hydraulic barriers. The conceptual model for the groundwater flow system in Coyote Spring Valley is therefore that of a well-mixed (based on temperature) and channelized flow system. At least two boundaries of lower transmissiviy were encountered by the spreading pumping cone in the first week.

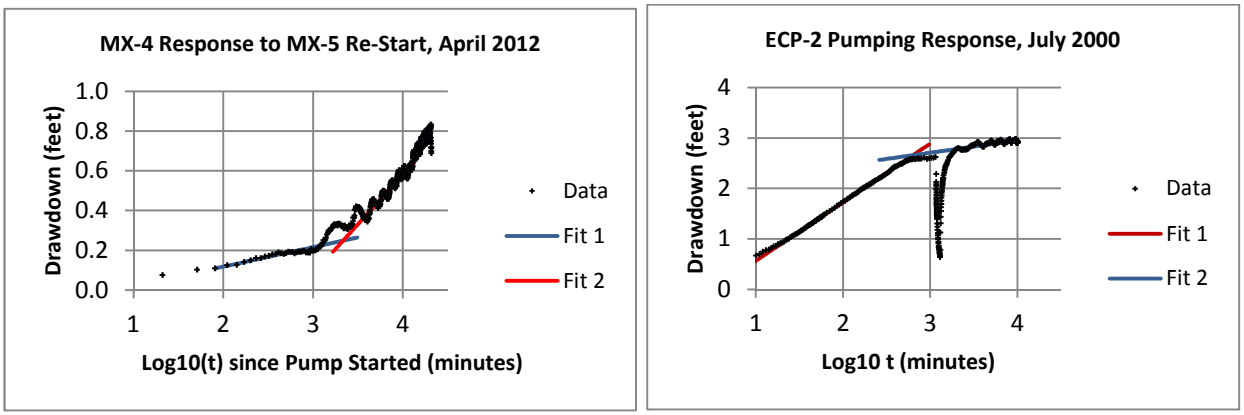


Figure 19. Semi-log plots of time versus drawdown at MX-4 when MX-5 was pumped (left) and at ECP-2 when ECP-1 was pumped (right). Deflections at the end of the test data set (left diagram; Johnson and Mifflin, 2012b) and at about 10^3 minutes (right diagram; Mifflin and Johnson, 2005) reflect pump stoppage. [files MX4_Apr12response.xlsx and ECP2adjustedDD.xlsx]

Reconstitution of net groundwater flux to the Muddy River headwaters area indicates that average flux increased from 50.2 cfs in 2001-2007 to 54.9 cfs in 2008-2012 (Figure 4). During this time interval there is a prominent rise in regional water levels from 2004-2006, general stability in 2007-2009, and decline from 2010 onward (Figure 20). The magnitudes of these multi-year trends as well as seasonal variations are markedly subdued in the CSVM-4 record from the north end of Coyote Spring Valley. Attenuation of an annual loading-related forcing signal from southeast to northwest (Figure 17) and its eventual disappearance within 100 miles north and west of the Moapa Indian Reservation (Figure 14) is a dominant influence on regional water levels in monitoring wells.

Groundwater flux entering the Coyote Spring Valley flow domain is determined by recharge boundary conditions, independent of pumping or loading-related water-level changes in the down-gradient areas. The hydrograph of the Paiutes M1 monitoring well is representative of well hydrographs throughout the Moapa Indian Reservation, which for over a decade have been generally absent any

demonstrated pumping effects. When the Paiutes M1 hydrograph is aligned with pre-Order-1169 water levels at MX-4 and UMVM-1 the pumping effects at those wells are resolved (Figure 21).

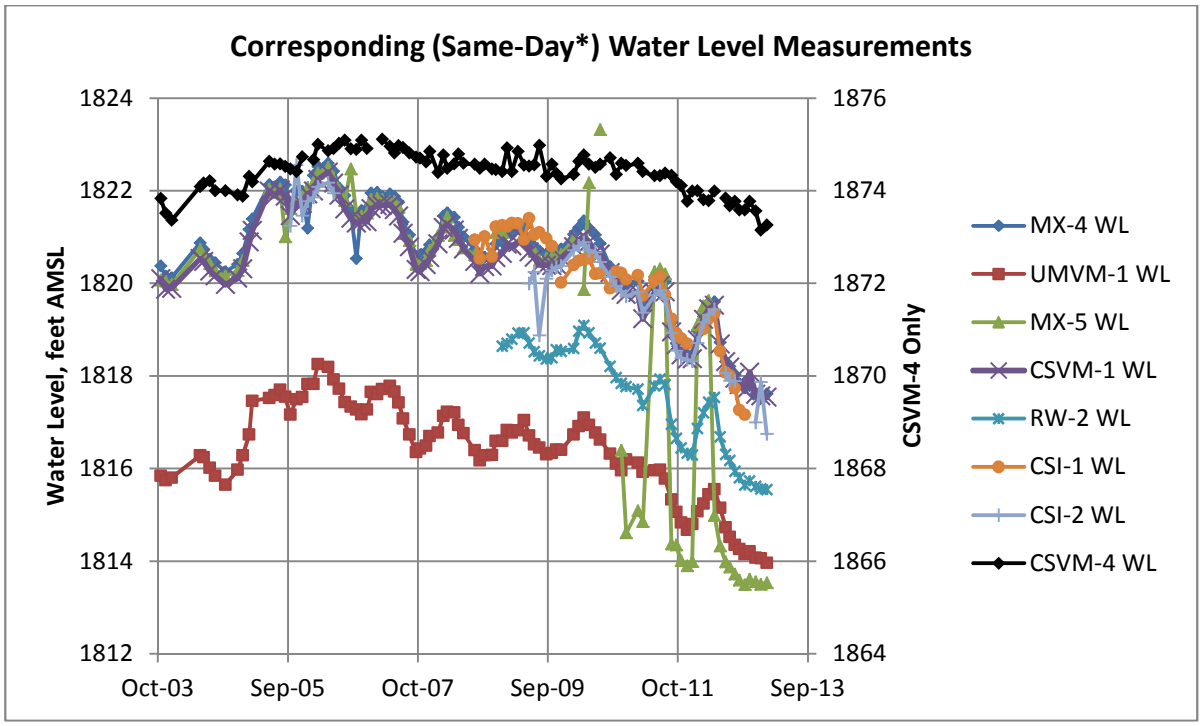


Figure 20. Water level measurements by SNWA in the Coyote Spring Valley area. *With the exception of CSVM-4 after mid-2007, monthly measurements shown here are from the same day each month, with non-corresponding measurements excluded [file MX4-UMVM1gradient.xlsx, sheet 'CorrespondingWLs']

To address the question of how greater groundwater fluxes at the end of the Order 1169 test are consistent with lower water levels in the region, we emphasize changes to the hydraulic gradient rather than declining water levels that have attracted so much attention. Under pre-test (2009) conditions, the hydraulic gradient in Coyote Spring Valley was about 7.69 X 10^{-4}, based on a 3-point solution of water levels at CSVM-4, CSI-1, and UMVM-1. With a transmissivity of 1.26 X 10^{6} ft^2/day and porosity of 0.126 (Johnson and Mifflin, 2012b) a flow corridor 0.85 miles (4,480 feet) wide and 4000 feet thick would transmit the requisite 50.2 cfs of pre-2008 groundwater flux under this gradient.

The hydraulic gradient in Coyote Spring Valley had increased to about 8.23 X 10^{-4} by October of 2012 in response to Order 1169 pumping and unloading of the Lake Mead Basin (Figure 22). Under the new (late-test) gradient the calculated flux in Coyote Spring Valley based on Darcy's Law is 53.7 cfs, substantially in agreement with the reconstituted flux of 54.9 cfs for 2008-2012 presented in Figure 4. Note that the 3-point pumping solution presented in Figure 22 (middle) over-predicts water levels at MX-4 by 0.23 m (0.75 ft) so the effective hydraulic gradient is actually larger than represented (compare Figure 22, right), with greater flux than that derived from the uniform flow field obtained from a 3-point solution using wells remote from the center of pumping. The evidence indicates drawdowns from groundwater development in Coyote Spring Valley and regional lowering of water levels in response to unloading of the Lake Mead Basin have allowed a post-2004 recharge pulse to propagate through the

system without a corresponding increase in water levels after 2007, as a result of larger hydraulic gradients.

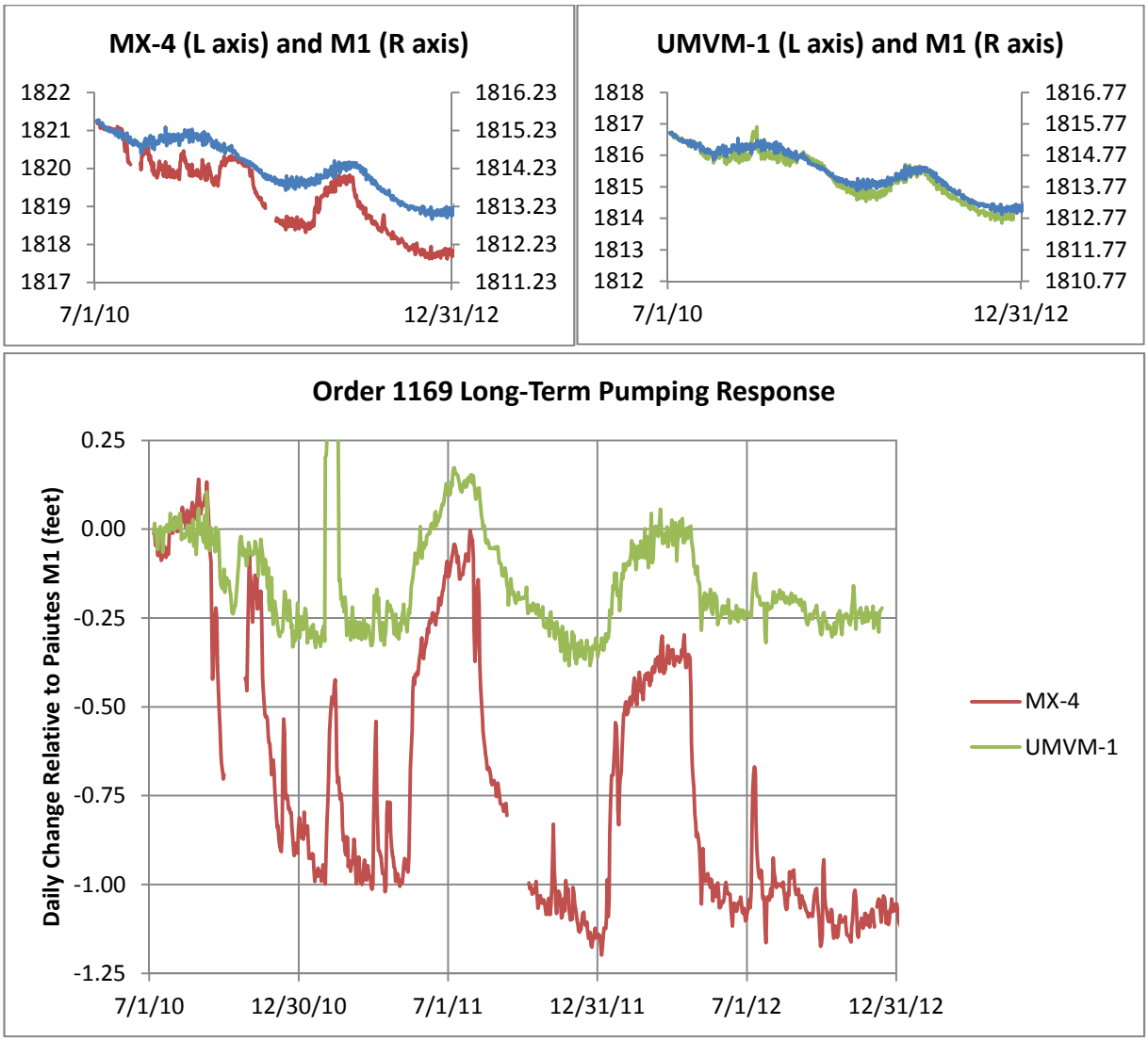


Figure 21. The hydrograph of the Paiutes M1 well (blue) is aligned with the MX-4 hydrograph (top left) and the UMVM-1 hydrograph (top right) by offsets to match pre-test water levels. The differences represent pumping response (bottom). In the fourth quarter of 2012, drawdown at MX-4 stabilized at about 1.09 feet and at UMVM-1 about 0.25 feet. Note that monitoring well UMVM-1 is less than 5 miles from the pumping well MX-5, a distance approaching the practical limit of detection for drawdown effects of the Order 1169 test. [file MX4-UMVM1gradient.xlsx, sheet 'M1vsMX4daily']

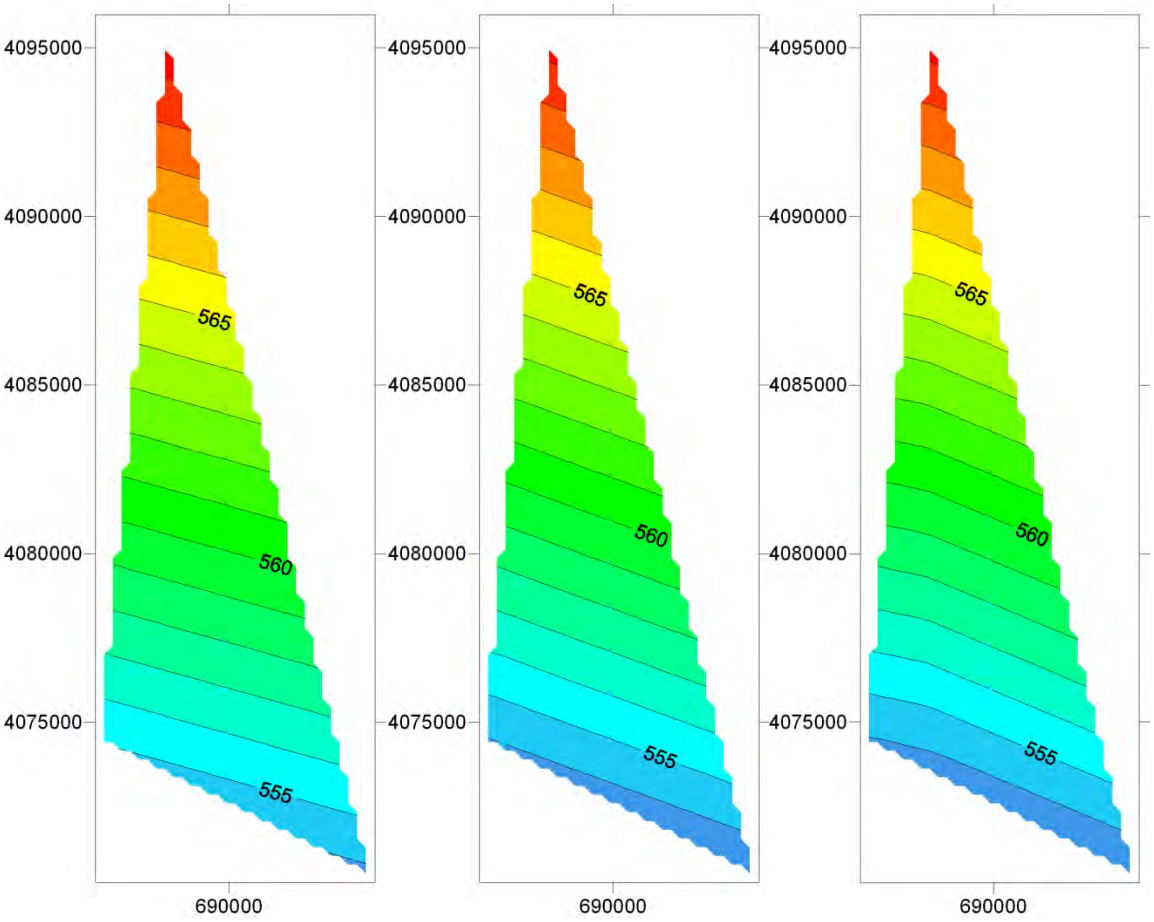


Figure 22. Three-point solutions for water levels and hydraulic gradients in Coyote Spring Valley prior to (left) and at end (middle) of Order 1169 test. Control points for 3-point solutions are CSVM-4 (north), CSI-1 (southwest) and UMVM-1 (southeast). Right-hand diagram illustrates conservatism of 3-point solution by including the pumping water level at MX-4, near center of cone of depression from MX-5 pumping. Map coordinates are NAD83 Zone 11 meters, elevations in meters AMSL based on SNWA reporting [plots exported from file CSVsurface1.srf, basic data in files 3ptCSVM4-CSI1-UMVM1.xls and 3ptCSVM4-CSI1-UMVM1a.xls]

Water-Resource Potential

The water resource potential of the Carbonate-Rock Aquifer of the southern extent of the Arrow Canyon Range Cell is constrained by very few well-controlled tests, associated monitoring, and derived analyses (Mifflin and Associates, 2010). Order 1169 test results and other existing databases define the sustainable water-resource potential of the Carbonate-Rock Aquifer from the Kane Springs Valley area down-gradient to the Springs area, the Northern Flow Field (NFF) of the Carbonate-Rock Aquifer (Figure 1). Basically, the sustainable water-resource potential is the historic base flow plus direct flood runoff flows of the Muddy River at the Moapa Gage. The sustainable water-resource potential remains less certain for the Southern Flow Field (SFF) of the Carbonate-Rock Aquifer in the Arrow Canyon Range Cell (Figure 1). Available databases and analyses (Johnson and others, 2001; Johnson and Mifflin, 2006) suggest regional, unconfined flux to the south and southeast is characteristic of the upper portions of the SFF, potentially up to the order of 15,000 to 20,000 AFY. Water chemistry and isotopic-signature

relationships suggest the unconfined flux may originate as upwelling of regional flow that has not evolved directly from the same flow field in the Carbonate-Rock Aquifer that discharges at the Springs area.

Flow system theory, modeling analyses, and regional observations (Mifflin, 1968) indicate that flow-system bypass configurations may exist in areas where there are deep, transmissive zones which may occur in some areas of thick sequences of Paleozoic carbonates. The elevated fluoride concentrations and isotopic signatures observed in the central and southern Arrow Canyon Range Cell suggest a regional source area (with felsic volcanic terrain) similar to the Muddy River Springs flow system source area, but the gross water chemistry precludes an origin as chemically-evolved Coyote Spring Valley / Muddy River Springs flow field water (i.e. shallow flux that bypasses the Springs discharge area). Some evidence is indicative of compartmentalization and barriers within (Johnson and Mifflin, 2003) and bounding (Johnson and others, 1986) the Arrow Canyon Range Cell, and modeling analyses show that low-permeability boundaries down-gradient of the Springs area are required for discharge to occur (Johnson and others, 2001; Mifflin and Johnson, 2005; Johnson and Mifflin, 2006; Tetra Tech, 2012a, 2012b). To date, the outflow boundaries of the SFF in the Apex area have not been sufficiently well-characterized for outflow locations to be identified or confident quantitative estimates of outflow flux to be made.

There are at least 2 water-management incentives for establishing and maintaining better monitoring records throughout the entire southern extent of the Arrow Canyon Range Cell. It is already clear that hydrologic impacts in the Apex area do not respect the boundary between the Garnet Valley (216) and Black Mountains (215) hydrographic areas, but measurement locations are too sparse and measurement frequency generally too coarse to effectively track pumping effects outward from the major pumping centers.

1. With upgraded monitoring the existing pumping stresses may help to indicate longer-term responses and how pumping cones develop and expand, which in turn may allow a better assessment of regional gradients (which indicate the order of magnitude and pattern of flux).

2. In this down-gradient region of the Arrow Canyon Range Cell it may be possible to heavily exploit (mine) groundwater without measurable impacts on the Springs-area flows or other groundwater resources currently in use. This portion of the Arrow Canyon Range Cell may be a region of the Carbonate-Rock Aquifer where the large volume of water in storage could be mined without impacts on water resources in use.

There is no plan in sight to control global warming, and consequential impacts (longer and more extreme droughts) are predicted by modeling analyses and statistical studies (Hansen and others, 2012). Warming impacts as reduced average annual flows have apparently begun in the Colorado River catchment basins, and signal more of similar impacts on Colorado River flows in the foreseeable future. The Apex area is adjacent to Las Vegas, and potentially a better (more timely) target for emergency water supplies than distant groundwater basins to the north. Its resource potential needs to be better

understood, as currently available evidence suggest it might be possible to heavily exploit the groundwater in storage without impacts on other water sources.

Perhaps the most confident approach for evaluation of the resource potential (without impacts on existing supplies) is a large pumping stress developed in the Reservation area, and monitoring the development of the pumping cone development. In Ruling 5115, the State Engineer granted one application (54075) for a reduced quantity (5.0 cfs and 2,500 AFY annual duty) and held the other (54076) in abeyance until the Order 1169 study was completed, reasoning that gradual, staged development, monitoring, and mitigation (if necessary) would best advance scientific understanding of the complex, interbasin, regional flow systems under consideration. Consistent with Ruling 5008 and Order 1169, the State Engineer found in Ruling 5115 that previous analyses of perennial yield of hydrographic basins did not contemplate the carbonate-rock aquifer resource as perhaps changing the analysis of the water available for appropriation, and only by stressing the system can such a determination be made. A pumping stress of similar order of magnitude and duration as the Order 1169 test would refine understanding of the groundwater resource potential of the Moapa Indian Reservation, as well as the resource potential of the SFF. Application 54076 released from abeyance may be necessary for the large pumping stress. The framework of the ICS and Forbearance Agreements may present an opportunity for a testing strategy directed at evaluating the groundwater-resource potential of the SFF. The primary question that needs to be resolved is the degree of hydraulic continuity extending to the Springs area, if any, and a large pumping in the northern portion of the SFF creates the best opportunity to determine impacts, if any.

Conclusions and Recommendations Regarding Availability of Water

Order 1169 was prescribed by the Nevada State Engineer to establish a large (~8,000 AFY) and prolonged pumping stress, based on half of existing groundwater permits in Coyote Spring Valley, to be applied for at least 2 years to better determine potential impacts on the Muddy River system from existing groundwater permits. Exhibit 54, a groundwater modeling analysis presented as evidence by SNWA in 2001, predicted very small incremental impacts on the Muddy River (flow reduction of only ~2.5 cfs by the end of a 60 year period) from adding the pumping stress proposed in LVVWD's 1989 applications (27,512 AFY) to existing undeveloped permitted rights in Coyote Spring Valley (16,100 AFY) and groundwater permits held by MVWD in the Muddy River Springs area (4,981 AFY). The minimal impacts forcasted by the Exhibit 54 model raised sufficient questions to justify Order 1169.

The pumping stress prescribed by Order 1169, ~8000 acre-ft/year (AFY) is equal to about 22% of the long-term average discharge in the Muddy River Springs area (Eakin and Moore, 1964), about 11 cubic feet per second (cfs). Reconstitution of Muddy River base flow (Figure 4) indicates annual variability of ±9% (~4.5 cfs) from the long-term average. Discharge reductions of 11 cfs occurring from two years of testing would be evident from cursory inspection of the Muddy River hydrograph if attenuation (peak spreading) were minimal. However, an annualized pumping stress of less than 7 cfs has been realized, at a time when the Muddy River is experiencing short-term base-flow variability related to the exceptionally wet period in 2010-11 superimposed on longer-term effects of 2004-05 and earlier wet seasons as revealed by the relationship between the long-term climate index and natural-

flux hydrograph (Figure 5). Natural variations of base flow are of elevated importance because the two years of Order 1169 pumping stresses in Coyote Spring Valley were of the same order of magnitude as climatically-induced variations in Muddy River base flows based on Moapa Gage records. **If natural-flux variations are ignored in water-balance analyses, the impacts resulting from less-than-anticipated Coyote Spring Valley pumpage (Carbonate-Rock Aquifer production) are effectively masked by climatically-induced variation in Muddy River base flows mixed in with more local pumping impacts**.

In order to evaluate past and current claims that have been made (that the carbonate aquifer is a large, separate water resource in this local region that constitutes the Springs area and extending into and through Coyote Spring Valley/Kane Springs Valley) it is useful to review the evidence that establishes: 1) that Muddy River base flows are largely derived from discharge waters from the underlying carbonate aquifer, and 2) that Muddy River base flows have been impacted by the amount of groundwater production with appropriate lag times in the regions of the aquifers that are tributary sources for the Muddy River flows as measured at the Moapa gage (Appendix B). **Monitoring records developed during Order 1169 continue to support the long-standing lines of evidence (fluid-potential relationships, evidence from well hydraulics of highly transmissive carbonate aquifers, similar hydrogeochemistry, water temperatures universally higher than mean annual air temperature, and stable-isotope trends) that provide internally consistent evidence that groundwater in the Carbonate-Rock Aquifer of Coyote Spring Valley is the primary tributary source to the Muddy River Springs-area groundwater-discharge system that gives rise to the Muddy River base flows.**

Figure 4 reconstitutes the history of a slowly developing “perfect” water-management storm that began in the 1960’s as a consequence of Ruling 957. In 1920 the Muddy River flows were adjudicated by the Muddy River Decree, with the point of reference for enforcement of the Decree on the historic Holmes and Knox property near the present-day Glendale gage, with the objective of the Decree to protect tributary flows from additional development that would reduce flows above the control point. Subsequent granting of groundwater rights, all junior to the 1920 Decree, in the Springs headwaters area and export of surface-water diversions for industrial and municipal uses have resulted in decreasing Muddy River flows at the Moapa and Glendale gages. The pattern of groundwater development now targets the Carbonate-Rock Aquifer in up-gradient areas where well-established hydrogeologic databases demonstrate the Carbonate Rock Aquifer is the source for nearly all of the groundwater discharge in the headwaters area. The developing “perfect” water-management storm relates to the total of undeveloped but permitted groundwater rights that have been issued. If also fully developed, the totals are approximately equal to the minimum daily-average flow to date (19 cfs) that was recorded at the Moapa gage in 2003. On an annualized basis 19 cfs equals 13,765 acre-ft. The minimum flow occurred during a multi-year period of below-normal base flows when discharge rates were reflecting a lagging net effect from earlier multi-year droughts affecting source areas of the regional flow system that discharges in the Springs area. Reconstituted Muddy River base flows shown in Figure 4 demonstrate similar “climate” variations have occurred in the period of record shown, as well as variations producing greater than average base flows.

The relationships displayed by Figure 4 and supporting analyses forecast that the existing permitted rights that are as yet to be developed are of the right order of magnitude to allow Muddy River base flows to be totally exhausted by the combination of current surface-water and groundwater diversions and undeveloped but permitted amounts in the Muddy River Springs area, Coyote Spring Valley, and Kane Springs Valley, all of which anticipate additional production from the Carbonate-Rock Aquifer. The recommendations that follow are based on the general intent of Nevada water law to foster sustainable development of the State's water resources, with appropriations governed by the Prior Appropriation Doctrine. The preservation of habitats for ESA-listed or endangered species is consonant with conditions of the 1920 Muddy River Decree.

Recommendation I: Integrate at least four water-management basins that include and extend upgradient from the Muddy River Springs area into a new water-management unit to include the extents of the Carbonate Rock Aquifer where the hydrogeologic evidence indicates the aquifers are in close hydraulic continuity with the Muddy River Springs discharge area and therefore the tributary source region for sustaining the base flow of the Muddy River. Rationale: the sustainable capacity of the water-resources base (at a realistic total) is ~37,500 AFY plus any flood flows that might be captured. Both the surface-water base flow and the groundwater development must be managed on an integrated basis for sustainable development.

Recommendation II: Order 1169 test results indicate that the 1989 LVVWD applications for ~27,000 AFY should be denied. Rationale: these applications equal about 72% of the flux in the Carbonate Rock Aquifer discharging to form the pre-development base flows of the Muddy River. All hydrogeological evidence indicates such production would reduce the flux to the discharge area by a similar amount over a relatively short time. Almost one third of predevelopment Muddy River flows are currently consumed before reaching the Moapa gage, and these applications should be denied on the grounds that they would impact senior rights by the full amount.

Recommendation III: If future periods of eliminated Muddy River base flows in the Springs-area headwater reaches are to be avoided, the currently undeveloped permits within the proposed management unit must be largely revoked, restricted, or otherwise creatively managed because they total up to a similar order of magnitude as remaining minimum base flows resulting from current diversion impacts in the Springs area. Rationale: There is only about 37,500 AFY on average of Carbonate Aquifer derived base flow, with multiyear periods of less than 35,000 AFY (Figure 4), and varying additions of short term flood flows. The sustainable development management objective limits the combined total of surface-water and groundwater rights to the sustainable total. Ideally, valid senior rights should be based on the Prior Appropriation Doctrine, but also be geographically distributed in a manner that maintains sufficient Muddy River flows to satisfy the ESA constraint. A potential management strategy to meet the general objectives of Nevada water law is an integrated approach to surface and groundwater rights that considers senior (both surface and groundwater) to be interchangeable rights. An effective strategy would require temporal and geographic distribution of

diversions, to maintain at least current levels of Muddy River base flows, or improve them in the upper reaches of the Muddy River.

Recommendation IV: The water-resource potential of the Southern flow Field (SFF) of the Arrow Canyon Range Cell should be evaluated with a large interim pumping experiment in the northern portion of the SFF. Rationale: Available databases indicate a large sustainable yield for the SFF, and perhaps even interim mining (over-exploitation) may be possible without negative impacts on Springs-area flows or other water resources in use. The recommended approach to further determine the resource potential of the SFF is a large interim pumping stress in the Reservation area, since the only apparent exploitation constraints would result from pumping-induced water-level declines propagating from the SFF into the Springs area. The current ICS agreement provides for a testing approach that would route groundwater pumped during the test to the Muddy River. The water-resource potential of the SFF is important to establish because of its close proximity to Las Vegas, favorable boundary conditions, and large reserves of water in storage, particularly if Colorado River flows continue to be reduced by drought.

The hydrogeology of the region, and the naturally-available (reconstituted) base flows of the Muddy River have not changed much since the early work of Eakin (1964, 1966) when the regional hydrogeology was correctly interpreted in terms of required knowledge to allocate the available water resources. **There may be alternative, creative approaches for the State Engineer to maintain Muddy River flows, given the opportunities afforded by SNWA's Forbearance and ICS agreements**.

The Tribe has negotiated in good faith for senior surface-water and groundwater rights, and also supports the preservation of sufficient flows to maintain the natural aquatic habitats required by the Moapa dace. **Flows of 19 cfs or less through the Reservation reach are unacceptable, in that exercise of the full Tribal surface-water rights would result in significant impacts on aquatic habitats from the point of diversion through downstream reaches, and thereby place the Tribe's diversion rights at risk**.

A final observation that cannot be over-emphasized is the distinction between water-level changes and drawdown. Several environmental factors other than drawdown contribute to water-level fluctuations, including local and regional climate, atmospheric pressure, tides, and crustal loading phenomena (Lake Mead?). Throughout HRT interactions, there has been a tendency to equate regional water-level declines since 2010 to drawdown, which is specifically defined as the *component* of water-level decline attributable to pumping. If pumping were responsible for the long-term water-level changes we see (Figure 23) then the prominent rise in 2004-2006 should be associated with a reduction of pumping somewhere, which it is not (Figure 24). Documented pumping response and associated parameter estimates for the Carbonate-Rock Aquifer derived from aquifer tests (Appendix F) provide quantitative evidence against the notion that similar water-level trends across several hydrographic basins constitute pumping response.

The significance the distinction between water-level decline and pumping-induced drawdown is profound. If regional drawdowns were as great as the observed water-level declines since late 2010, affecting several hydrographic basins, groundwater derived from *storage* would have supplied most or all of the groundwater that has been diverted from the headwaters area during the Order 1169 experiment. On the other hand, as we conclude, if groundwater pumped for Order 1169 is being captured and diverted from Springs-area discharge, the next cycle of low River flows will be exacerbated. Our findings indicate that *boundary conditions*, not storage, dominate Order 1169 pumping response.

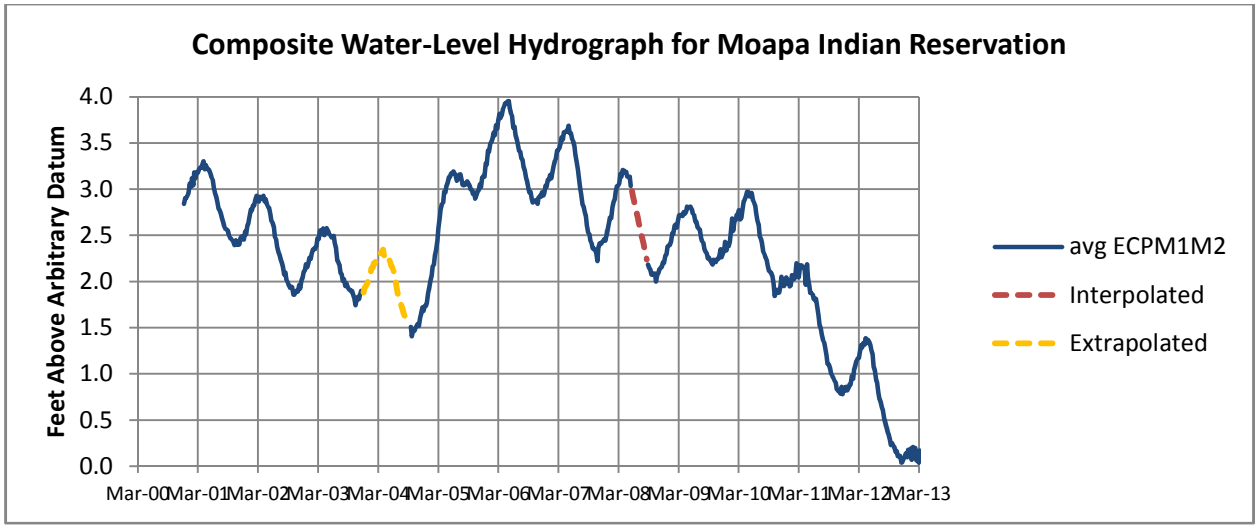


Figure 23. Weekly water levels beneath the Moapa Indian Reservation, offset to a common datum using the average difference between individual wells during overlapping periods of record. [file RefWeeklyHydrograph2.xlsx]

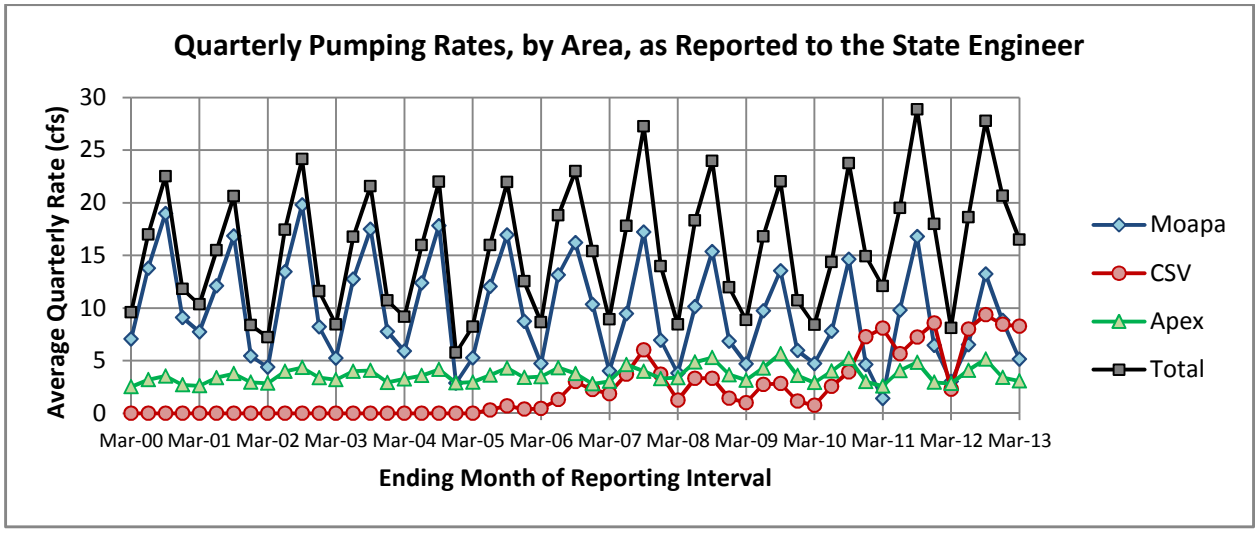


Figure 24. Pumping histories in upper Moapa Valley (Lewis, LDS, Perkins, Behmer, Arrow Canyon, and MX-6 wells), Coyote Spring Valley (CSI, RW-2, and MX-5 wells) and Apex area (Republic Services, Nevada Cogeneration, Chemical Lime, Duke, Mirant and Pinnacle West wells) [file AllAreasQuarterlyQ.xlsx]

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Appendix A . Hydrogeologic Overview

A general consensus has existed during the past ~50 years that the Muddy River Springs and associated Muddy River base flows are largely the result of the discharge from the regionally extensive Carbonate-Rock Aquifer, with evidence of interbasin flows indicated by hydrographic basin water-balance studies, supplemented by other hydrogeological relationships and the general distribution of Paleozoic carbonate rocks. Eakin's (1966) initial delineation of regional interbasin flows (the White River Regional Flow System, "WRRFS") has often been followed in subsequent water -balance studies, as his delineation balanced the regional basin-water budgets with discharge at the headwaters of the Muddy River. However, the fundamental problem with Eakin's water-balance-based delineation of this regional flow system is sparse fluid-potential information in nearly all areas of mountainous terrain, which prevents rigorous evaluation of hydrochemical evidence from large springs that indicates there is likely far more interbasin flow than is generally believed (Mifflin, 1968). There may be no unique delineation solution based solely on basin water-budget evidence in terms of participating sources to any regional flow system, or related discharge areas, typically large springs with water chemistry and discharge characteristics indicating regional sources.

The extent to which adjacent basins are hydraulically connected is not clearly defined by comparison of shallow fluid-potentials between basins. Supplemental evidence developed since Eakin's pioneering work suggest alternative delineations for some "WRRFS" basins. Mifflin and Wheat (1979) in studies of pluvial (glacial state) climates based on catchment basin areas and areas of respective pluvial lakes throughout Nevada, noted that Long Valley and Jakes Valley (the two northern-most basins of Eakin's White River Regional Flow System) apparently leaked to the west (rather than south) to Newark Valley based on an oversized pluvial lake in Newark Valley, and undersized lakes in the other two basins. The three basins, when combined, gave hydrologic indices that matched the regional trend. If the interbasin contributions of Eakin's two northern basins are eliminated in his regional water balance, the White River Regional Flow System water budget balances at Pahranagat Valley. Supporting this alternative delineation is the absence of isotopic or geochemical evidence for a significant amount of Pahranagat Valley-derived water in Coyote Spring Valley. Elevated fluoride (nominally 2 µg/l in Coyote Spring Valley) is absent in the major carbonate-aquifer springs of Pahranagat Valley, and isotopic evidence presented by Thomas and others (2001) requires either a significant component of isotopically heavy water mixing with Pahranagat Valley water to produce compositions observed in Coyote Spring Valley, or an entirely different source.

The large area with relatively high fluoride concentrations in groundwater, likely derived primarily from weathering of peralkaline volcanic rocks overlying or adjacent to carbonate-rock terrain in the Upper Meadow Valley Wash region, underlies Coyote Spring Valley and the Arrow Canyon Range Cell of Mifflin (1992). Regional relationships indicated by water chemistry, stable isotopes, and other evidence, have potential significance in terms of issued groundwater permits in other basins where interbasin flow is evident. Coyote Spring Valley may not be a significant part of Eakin's classical WRRFS, but Muddy River flows are definitely dominated by Coyote Spring Valley waters, and are likely related to interbasin flows from some northern candidate basins displaying fluoride-bearing waters (Kane Springs

Valley, perhaps Dry Lake Valley and Delamar Valley, and Upper Meadow Valley Wash tributary basins). Monitoring activities in the northern candidate source basins, where permits have been issued, need to prioritize the development of databases of conservative tracers (water chemistry and isotopes) as well as fluid-potential relationships indicating presence or absence of close hydraulic continuity with down-gradient basins.

In addition to the regional flow from distant recharge areas, base flow of the Muddy River in the Springs area is influenced by more localized and often ephemeral sources of recharge which include infiltration from storm flows in Pahranagat Wash, Meadow Valley Wash, and recharge in the Sheep Range. Exceptionally wet periods, drought periods, and occasional short-term runoff events influence the base flows in the river with differing lag periods in terms of the timing and magnitude of influences on the Muddy River base flows. Impacts from pumping stresses in the alluvial aquifer and carbonate aquifer also display varied lag times for impacts on flows.

Generally underlying the alluvial gravels of lower Pahranagat Wash and Moapa Valley (Arrow Canyon is the exception) are fine-grained, unconsolidated sediments of the Muddy Creek Formation. Erosionally inset into the fine-grained sediments of the Muddy Creek Formation are highly transmissive gravel lenses of the alluvial aquifer. The alluvial aquifer varies in total thicknesses up to ~100 feet in the Lewis Well Field area. The Muddy River Springs, including some essentially extinct spring areas, are related to localized conduit zones that occur along at least two north-trending, parallel lineaments resulting from extensional faulting. Localized conduit zones pass from the underlying carbonate rocks through the Muddy Creek sediments, which were deposited on a high-relief, carbonate-rock-dominated paleotopography. The conduits, locally bounded by secondary calcium carbonate precipitates within the alluvial aquifer, pass into and through the alluvial gravels at the still active spring areas.

Within the Muddy Creek Formation, generally much higher-TDS (total dissolved solids) groundwater is the result of gypsum dissolution that dominates the chemical evolution of Muddy Creek waters as compared to the carbonate-aquifer waters. The alluvial aquifer waters are a dilute mix due mostly to a small percentage of Muddy Creek Formation water mixing into carbonate aquifer derived water. Only about half of the discharge forming Muddy River base flows at the Moapa gage was derived directly from large springs (via conduits in close hydraulic continuity with the underlying carbonate-rock aquifer) and half originated as seepage from the alluvial aquifer into the headwaters channels. The slightly higher TDS of the alluvial-aquifer waters within the Springs area indicates a small amount of discharge is likely from the Muddy Creek Formation and some concentrated salts related to ET in the local areas of phreatic vegetation and irrigation.

In the lower Meadow Valley Wash area north of Glendale, similar alluvial gravels of Meadow Valley Wash occupy paleovalleys eroded into the Muddy Creek Formation. When high-yield production wells were pumped over a period of several years, water quality in the alluvial gravels was markedly degraded by induced inflow of higher TDS waters from the underlying Muddy Creek Formation. Similar intrusion of poor quality water occurred in the confined portion of the alluvial aquifer below the Moapa Gage when the Perkins replacement well was accidentally over-pumped in 1989. Domestic wells tapping the Muddy Creek Formation throughout the general area yield high TDS water.

Gravel lenses within the alluvial aquifer are highly transmissive, and in both the unconfined aquifer area (between Arrow Canyon and the Springs area) and the confined area (below the Springs area) seasonal pumping cones develop and extend each pumping season to the Springs area, and downstream to White Narrows area (the extent of monitoring wells available to monitor the pumping cone developments). Seasonal pumping cones generally recover fully between September and March both above and below the Springs area.

The primary source of water in the alluvial aquifer in the Springs area, including the Lewis Well Field area, is from the carbonate aquifer as indicated by both water temperature and water quality. Below the Springs area the Muddy River is not in direct hydraulic continuity with the alluvial aquifer, which in turn displays confined aquifer responses to pumping. Below White Narrows there is insufficient monitoring well control to determine the hydraulic characteristics of the alluvial aquifer or if the Muddy River remains hydraulically isolated from it.

Appendix B. Reconstitution of Natural Groundwater Flux to the Headwaters Area

"Reconstitution" refers to the process of computing the natural groundwater flux to the Muddy River headwaters area by restoring (adding) the quantities of water diverted upstream of the Moapa Gage (USGS Station ID 09416000) to discharge measurements made at the Gage. Reconstitution of the Muddy River hydrograph to represent flux was accomplished by a series of steps documented in supplemental dataset ReconstSimple4.xlsx, in which successive diversion-rate adjustments are applied to daily-average discharge measurements from the Moapa Gage. Daily equivalents of monthly diversion rates were derived by empirical mode decomposition (Huang and others, 2008; Kim and Oh, 2009) so category-specific lag times between diversion occurrences and Muddy River discharge reductions could be derived with daily resolution. Beginning with base-flow separation and evapotranspiration (ET) adjustments, which affect even the earliest measurements, diversion effects are cumulatively restored to the hydrograph in the order of when they first appear in the historical record.

The first step in reconstitution is to remove the effects of runoff from intense local storms by the process of base flow separation. The Base Flow Index (BFI) method (Wahl and Wahl, 2007) allows "raw" base flow (unadjusted for ET and diversions) to be isolated (Figure B-1). In contrast, SNWA employs the "Median + 20" technique of Johnson (1999) for separating the Muddy River hydrograph into base flow and storm flow components (Figure B-2). Both methods utilize daily-average discharge records from the USGS as basic data. The base-flow index is the ratio of base flow to total flow; minima

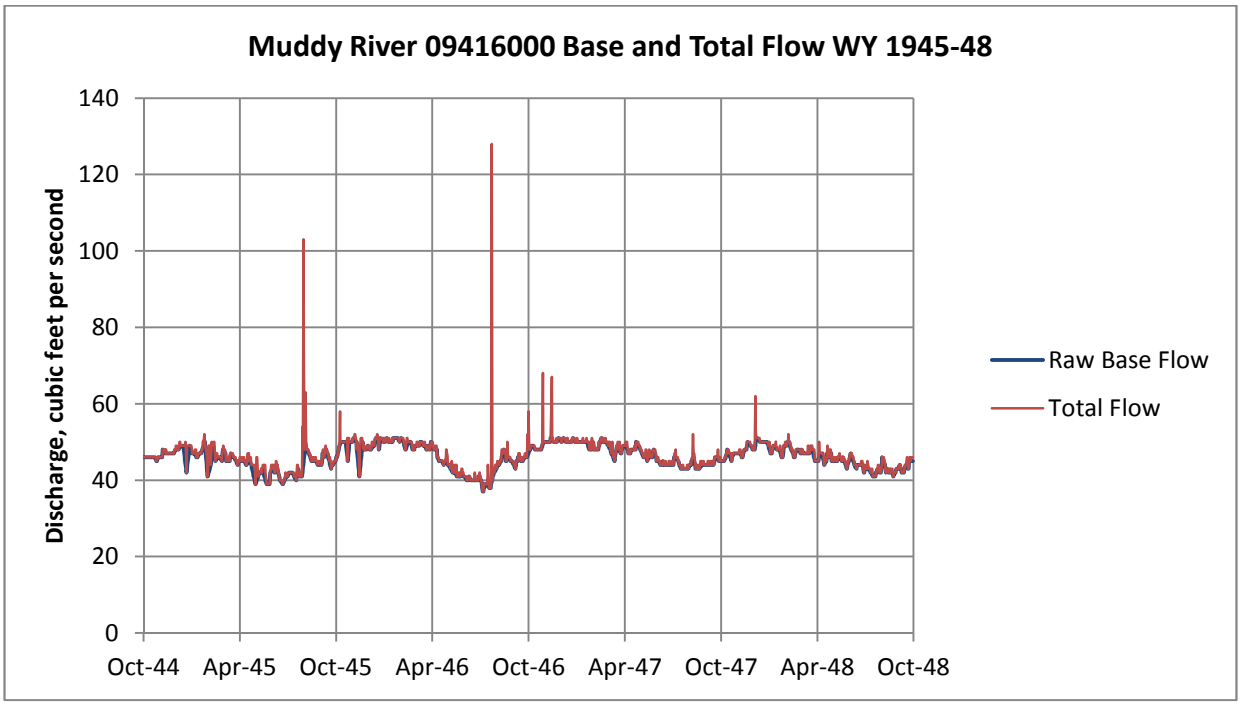

Figure B-1. Local climate typically results in intense summer thunderstorms resulting in flash floods, as shown by the hydrograph in the summers of 1945 and 1946. In contrast, winter storms generally produce soaking rains with less direct runoff and a greater residual contribution to base flow, as in the winter of 1946-47. [file ReconstSimple4.xlsx, sheet 'ETfromEarlyBaseFlow']

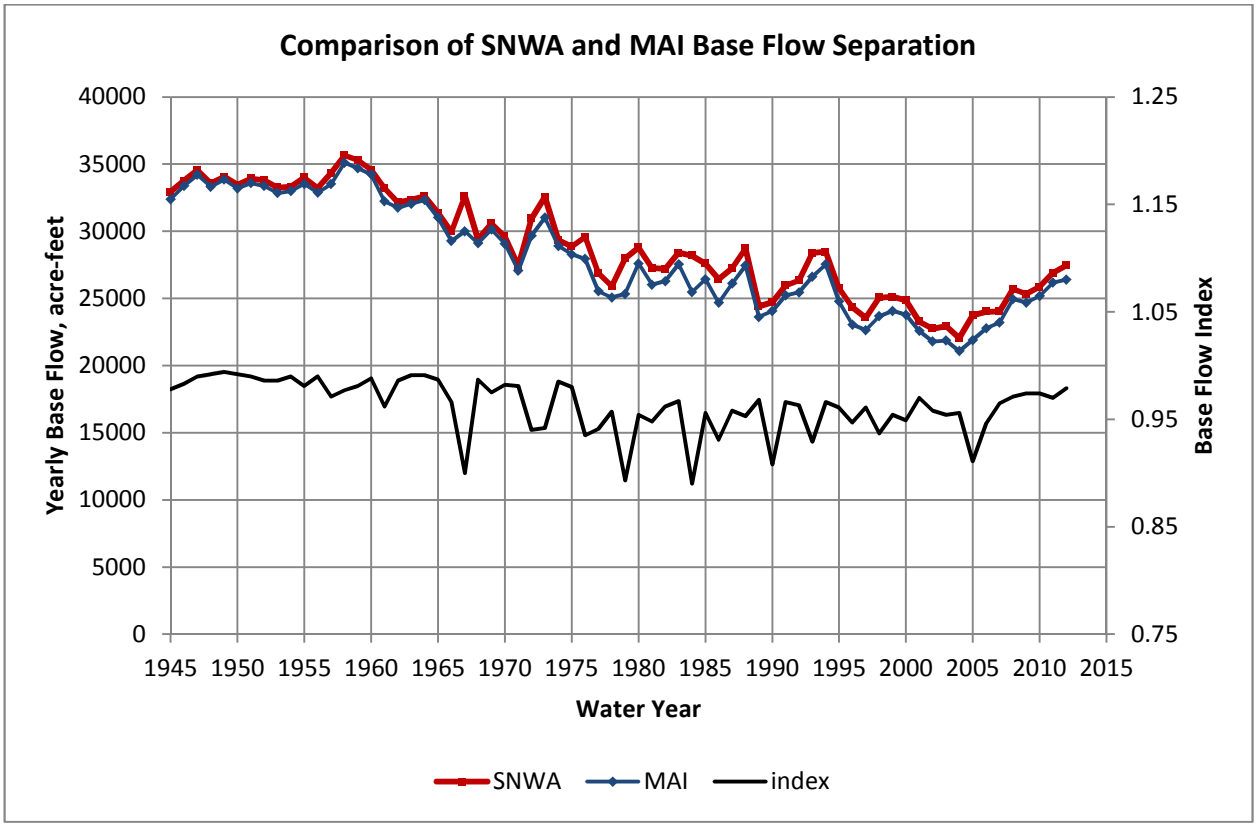

Figure B-2. Annual base-flow separation by SNWA (Median + 20 method) and MAI (BFI method) [file SNWAreconst.xlsx, sheet 'BFI']

in the BFI are indicators of years with a relatively great proportion of storm (surge) runoff. Note that base-flow estimates by the Median + 20 method are significantly greater than those derived by the BFI method in years of above-average storm runoff, as illustrated by low base-flow indices in those years.

The next preliminary step is to add back the losses from evapotranspiration (ET) that produce the seasonal fluctuations in base flow. The relationship between discharge of large springs (nearly constant) and discharge of the Muddy River (seasonally variable; Figure 8) indicates an ET effect on Gage readings (Eakin, 1964; Eakin and Moore, 1964). We fit a sinusoidal function to WY 1945 daily-average discharge data after removing storm surges as described in the previous section, and find ET to vary between 0.45 cfs in winter and 5.90 cfs in summer, a mean annual rate of 3.2 cfs (Figure B-3). These rates correspond to a participating area of 450 acres with average ET varying between 0.002 ft/day (winter) and 0.026 ft/day (summer), consistent with DeMeo and others (2008, Figure 6). The ET signal is 180° (π radians) out of phase with the model hydrograph. Adding the ET loss rate to the raw base flow produces a partially-reconstituted hydrograph that still contains a seasonal component attributable to surface-water diversions for flood irrigation (Figure B-4).

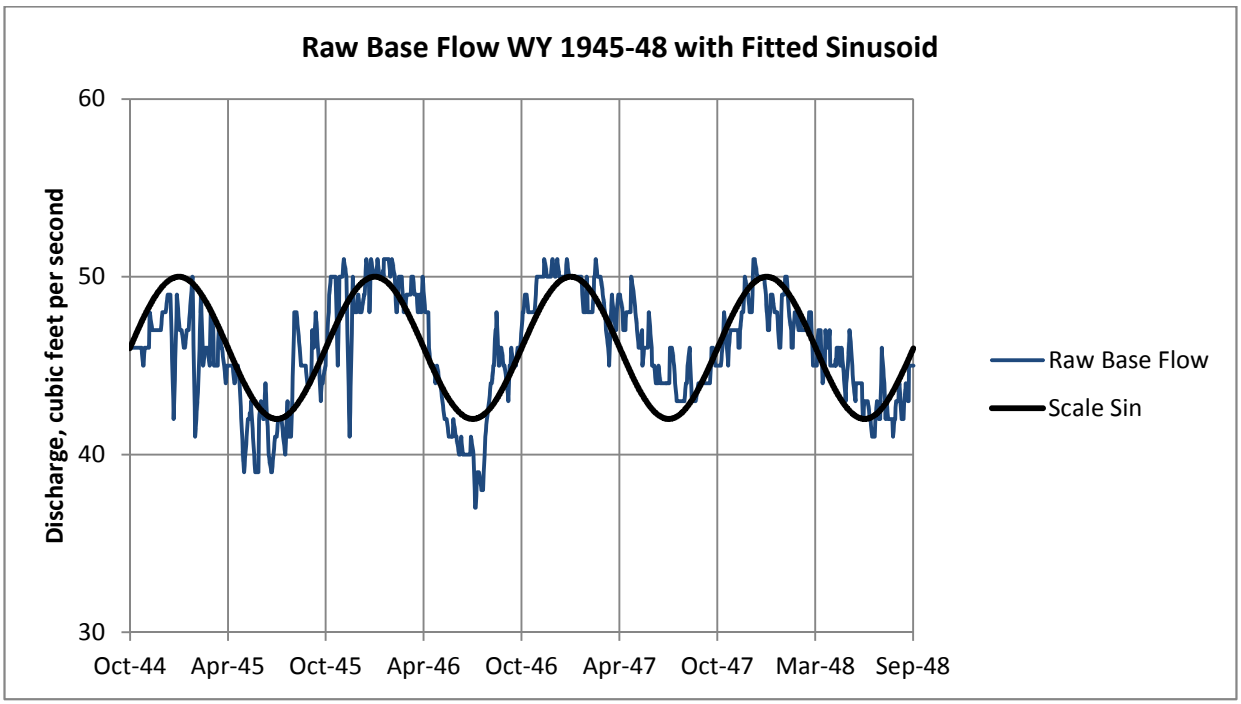

Figure B-3. Approximating the raw base flow of the Muddy River with a sinusoid provides daily estimates of ET losses in the headwaters area. [file ReconstSimple4.xlsx, sheet 'ETfromEarlyBaseFlow']

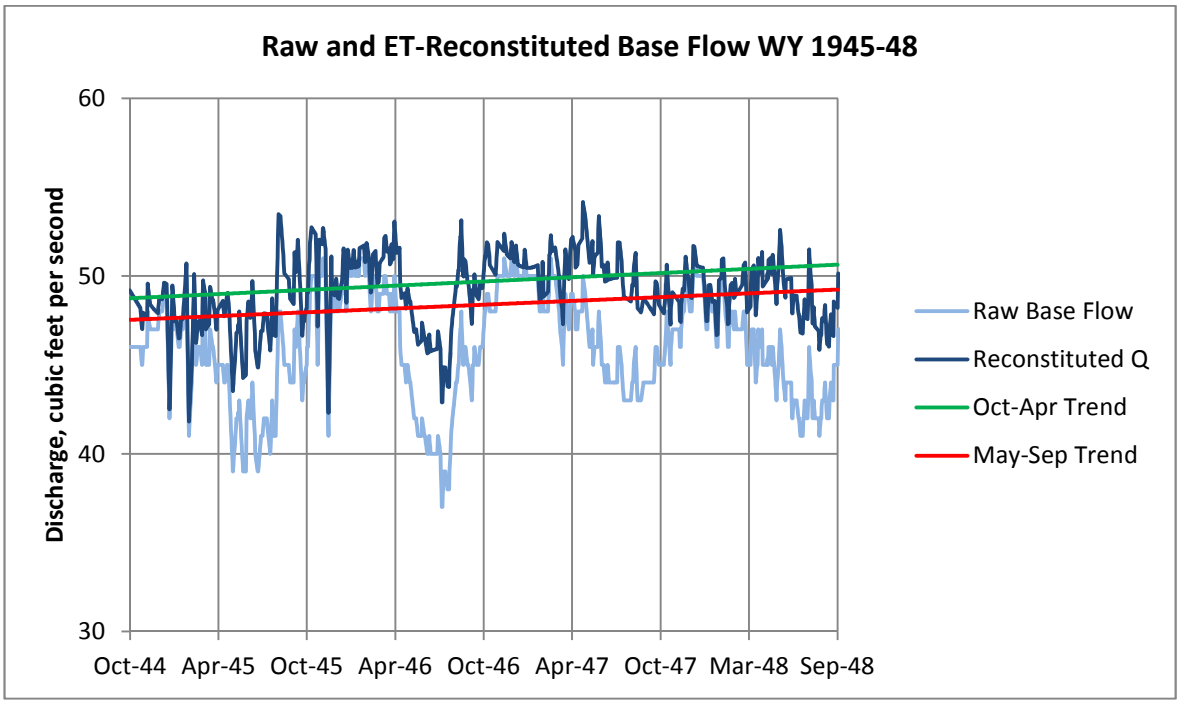

Figure B-4. The wet winter of 1946-47 resulted in significantly higher discharge rates the following summer than in either of the previous two years, which began with relatively dry winters (Figure B-1). There is no reason to believe flood irrigation practices were any different or less intense in 1947 than in 1946, yet compared to the prominent flow reduction in the summer of 1946, the summer deficit was more modest in 1947. [file ReconstSimple4.xlsx, sheet 'ETfromEarlyBaseFlow']

The difference between winter and summer discharge rates shown in Figure B-4 is consistent with SNWA's Intentionally Created Surplus (ICS) that was claimed after retirement of irrigated lands was complete in 2008 (SNWA, 2011). On that basis, a "Reverse ICS" approach restores waters diverted directly from tributary channels for flood irrigation prior to 2008 to the Moapa Gage record, removing most of the residual seasonality in the base-flow hydrograph of Figure B-4 and providing an estimate of minimum natural groundwater flux to the headwaters area before the era of irrigation wells creates the need for additional adjustments beginning in 1948 (Figure B-5).

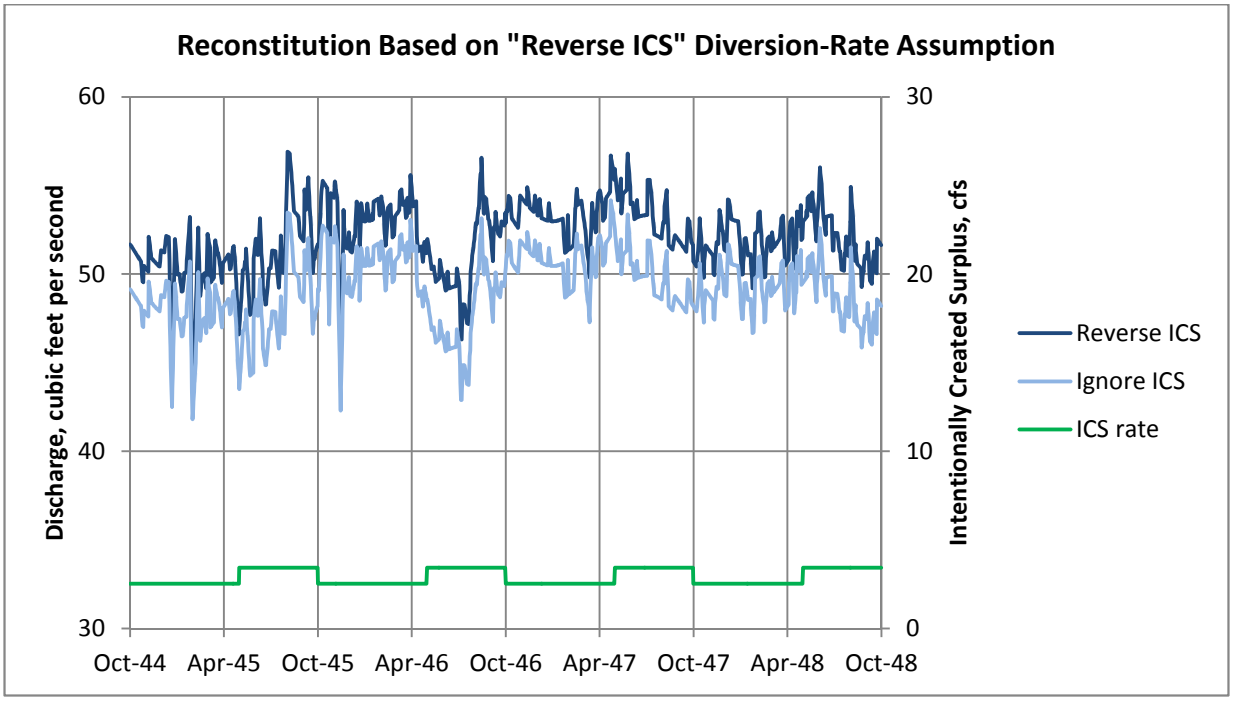

Figure B-5. The Intentionally Created Surplus (ICS) claimed by SNWA after 2007 is applied retroactively to account for seasonal surface-water diversion rates [file ReconstSimple4.xlsx, sheet 'ReverseICS']

The next step is to utilize sparse diversion records from the two decades following 1947, when the first wells were drilled in the headwaters area, to isolate the effects of those wells prior to any exports of groundwater. The data presented by Eakin and Moore (1964) and Maxey and others (1966) are essential in this regard, since together they identify active irrigation wells and pumping records from 1961-1965. If the well inventory is assumed to be complete and the pumping rates representative (over the history of each well), diversion rates from groundwater pumping can be reconstructed.

The Taylor E well, drilled in 1948, was the precursor to LDS E; Eakin (1964) reported a pumping rate of 1,400 gallons/minute (gpm) on September 12, 1963, and James Haworth (oral testimony June 29, 1966) indicated 2.5 second-feet (1,122 gpm) had been pumped each year since 1951. Diversion rates at Taylor E were estimated by scaling measurements at Taylor W provided by Maxey and others (1966) to the greater irrigated acreage serviced by Taylor E (Figure B-6); peak rates by this method are 2.66 cfs, generally consistent with Eakin's observation and Haworth's testimony.

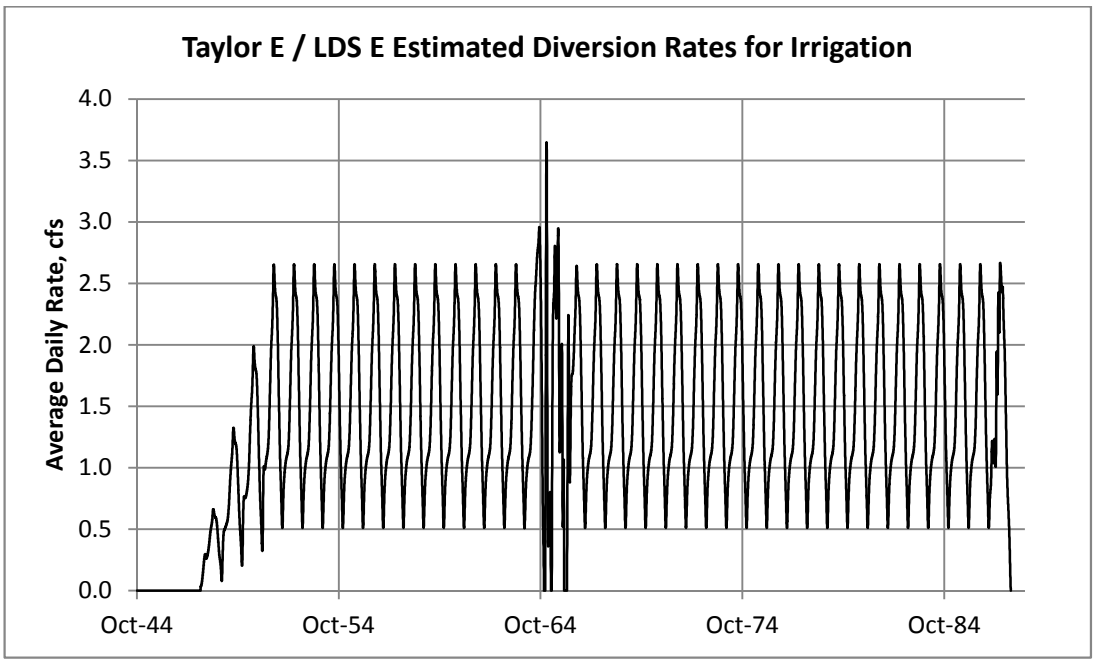

Figure B-6. Daily diversion rates prior to 1988, when monthly reporting began, were estimated by scaling monthly-average rates from 1961-1963 reported by Maxey and others (1966) for the Taylor W well in proportion to irrigated acreage. [file ReconstSimple4.xlsx, sheet 'FloodIrrCU4487']

Moapa Valley Water District (MVWD) spring diversions were estimated based on Eakin's (1964) observation of about a 1 cfs rate, and an exponential growth model with seasonality based on usage patterns from monthly records that began in January of 1988 (Figure B-7).

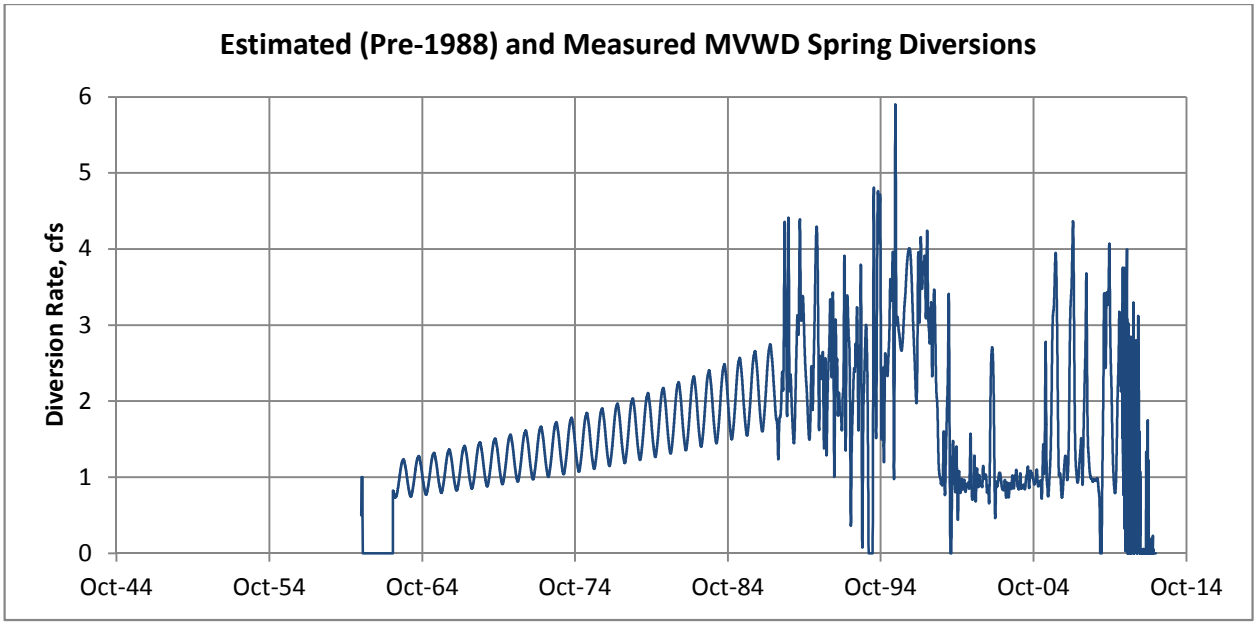

Figure B-7. Exponential growth model for pre-1988 derived from 1 cfs 1963 diversion rate estimated by Eakin (1964), and monthly diversion rates reported by MVWD after 1988 [file ReconstSimple4.xlsx, sheet 'FloodIrrCU4487']

Maxey and others (1966) provide monthly records of production from the 7 active wells in the headwaters area for the period 1961-1965, which overlaps the startup of MVWD diversions from springs feeding South Fork in 1960. These 7 wells (Lewis 1-5, Taylor W, and the Lewis Farm well) were completed in unconfined gravels of the alluvial aquifer in the Lewis Well Field area (Figure 2), from which pumping signals were later shown to propagate down-valley over the course of the summer pumping season (Mifflin and others, 1991). Comparison of monthly pumping records from November, 1961 through October, 1963 and the corresponding, partially-reconstituted Muddy River hydrograph allow the time lag between pumping and River-discharge reductions to be determined.

Diversion records are intermittent and when available were reported as monthly totals, with rare exceptions, from 1988 through 2005. In order to utilize the daily discharge record from the Muddy River to their full advantage, as opposed to degrading the data by averaging to some lower sampling frequency, monthly diversion records are approximated as daily equivalents using empirical mode decomposition (EMD). This allows the lag time between occurrences of the diversions and corresponding responses at the Moapa Gage to be discretized in terms of days instead of months, which are of unequal length and offer too coarse a time interval for effective correlation of impulse (pumping) and response (flow reduction) signals. Application of EMD to the Muddy River hydrograph, after base flow separation (removal of storm surge effects), objectively and systematically isolates underlying trends from day-to-day noise.

To illustrate the application of EMD to the reconstitution effort, Figure B-8 shows the monthly pumping from Lewis 1-5, reported from November of 1961 through October of 1963 by Maxey and others (1966), and the daily approximation of the pumping record derived by EMD (lower curves and right-hand axis). The upper curves and left-hand axis represent a trial reconstitution based on a consumptive use factor of 50%, such that half the EMD-derived daily pumping rate is added to the sum of measured base flow + ET + ICS + Taylor E + MVWD Springs.

EMD is applied to the trial reconstitution of daily discharge to quantify the relationship of residual seasonality in the hydrograph to the pattern of pumping. A prominent maximum in the pumping history occurred on July 15, 1963 (green diamond on Figure B-8), and a prominent minimum in the trial hydrograph followed on October 24 (pink diamond on Figure B-8), suggesting a lag of 101 days between pumping in the Lewis Well Field area and corresponding reductions in the discharge of the Muddy River. Repeating the reconstitution process, this time adding the daily Lewis-area pumping stress to the base flow + ET + ICS + Taylor E + MVWD Springs hydrograph 101 days after the pumping occurs, and at full strength rather than applying the 50% consumptive-use scale factor used for trial purposes, we obtain the reconstituted hydrograph shown in Figure B-9. For the 2-year interval when diversion-rate measurements are available, a rising trend with minimal seasonality characterizes the reconstituted Muddy River hydrograph. Extrapolating the 1961-1963 pumping rates backward according to the time each individual well entered service, and forward until irrigation from individual wells ceased, and applying the 101-day lag universally, the reconstituted hydrograph of Figure B-10 is obtained. Lewis wells 1-5 were converted to industrial use in April of 1965, while Taylor W remained in service as an irrigation well until 1988.

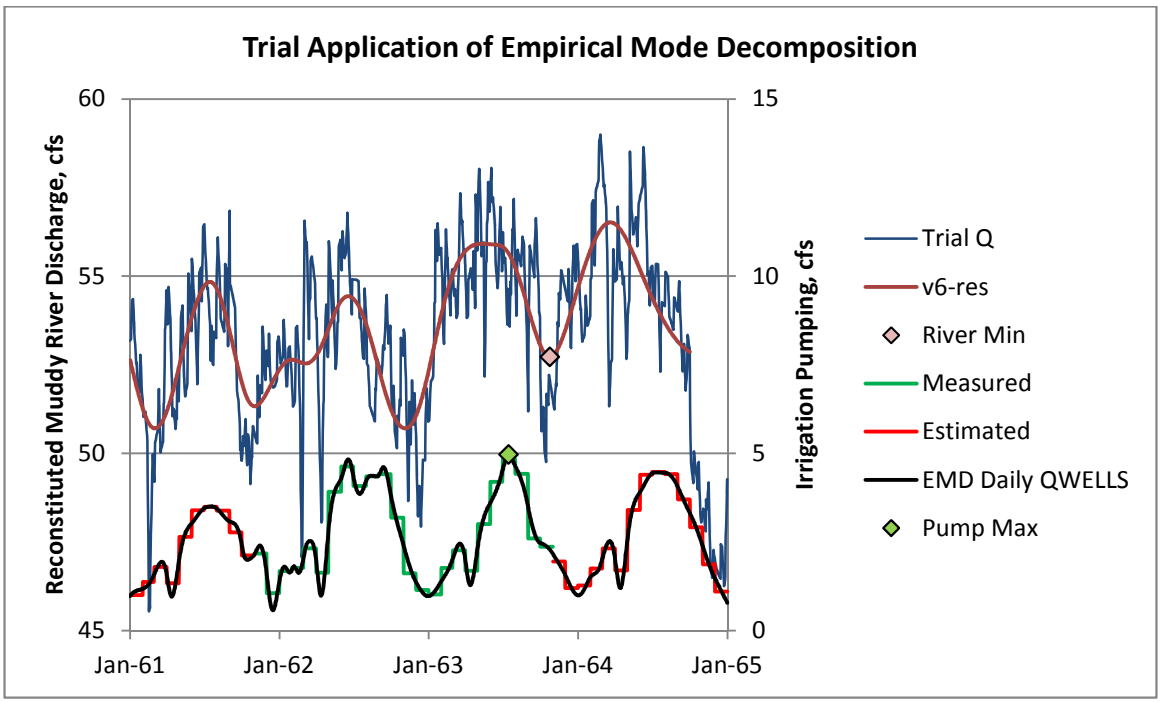

Figure B-8. Trial reconstitution of the Muddy River hydrograph based on an assumed consumptive use factor of 50% and no lag between pumping and River response. Monthly production from the Lewis Well Field area reported by Maxey and others (1966), monthly estimates, and EMD approximation of the monthly rates as daily values are shown for reference. [file IllustrateEMD.xlsx, sheet 'TrialSF.5']

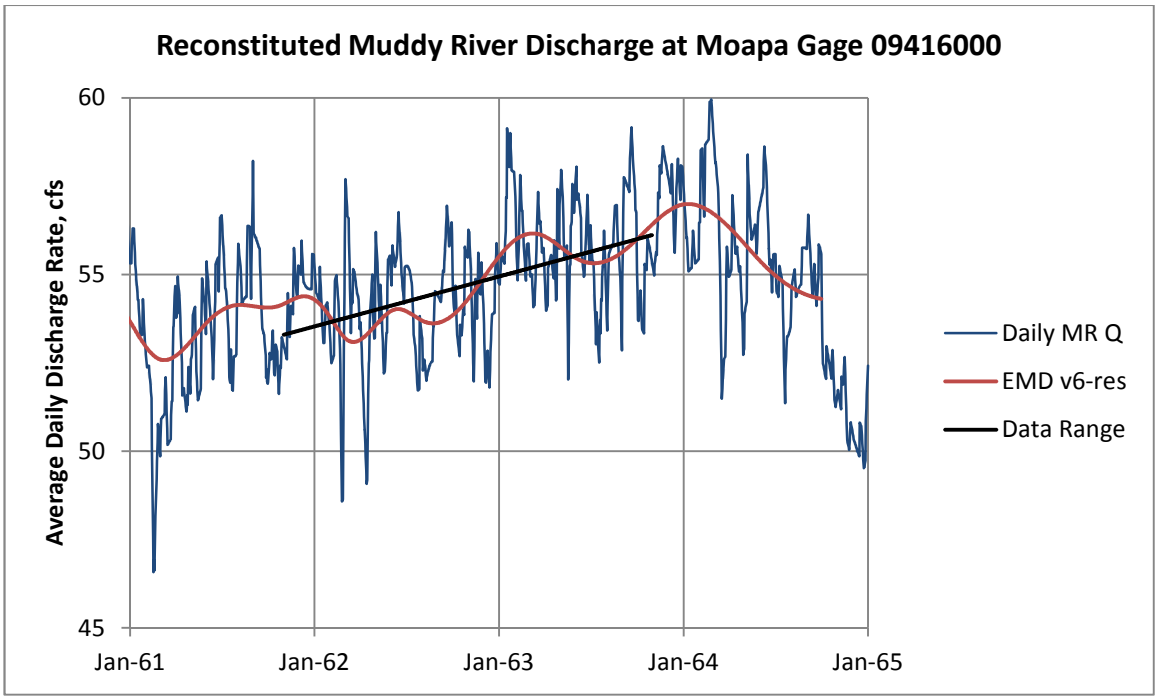

Figure B-9. Accounting for lag indicated by the green (Pump Max) and pink (River Min) symbols in Figure B-8 and 100% consumptive use removes seasonality from the reconstituted record in the 1961-1963 data range and reveals a 2-year rising trend in base flow [file IllustrateEMD.xlsx, sheet Lag101SF1]

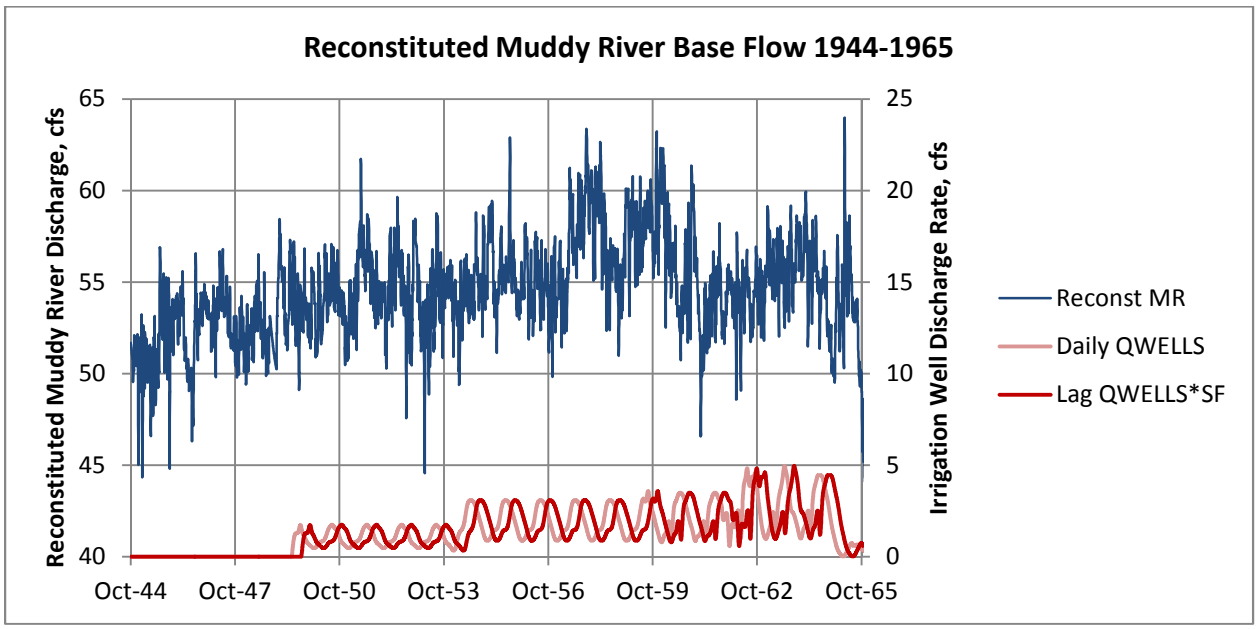

Figure B-10. Aggregate diversion rate of wells monitored by Maxey and others (1966) are lagged to minimize seasonality in the November 1961 – October 1963 interval of the reconstituted hydrograph; the result is generally valid until April of 1965, when groundwater export to Reid Gardner Generating Station began. The scale factor (SF) here is 1.0. [file ReconstSimple4.xlsx, sheet 'FloodIrrCU4487']

Annual energy deliveries from Reid Gardner Station Units 1-3 were reported from 1991 and 2000-2010, years when water consumption was also metered. Diversions from the Lewis and Behmer wells and the River intake are used for Units 1-3; calendar-year totals are given in Table B-1.

Table B-1. Water demand and energy deliveries from Reid Gardner Units 1-3 [file NPCgeneration2.xlsx, sheet 'WaterDemand']

Year	RG 1-3 KWh	RG 1-3 GWh	Acre-ft	Fit	Hours	Avg Rate (Mw)	**acre-ft/Mw**	
		0	0	0				
1991	1,854,444,000	1,854	3,605	3872	8760	211.69	17.03	
2000	2,390,602,000	2,391	5,133	4992	8784	272.15	18.86	
2001	2,164,141,000	2,164	5,005	4519	8760	247.05	20.26	
2002	2,372,245,000	2,372	5,149	4953	8760	270.80	19.01	
2003	2,320,199,000	2,320	4,839	4845	8760	264.86	18.27	
2004	2,292,950,000	2,293	4,388	4788	8784	261.04	16.81	
2005	2,149,283,000	2,149	4,397	4488	8760	245.35	17.92	
2006	2,010,884,000	2,011	4,016	4199	8760	229.55	17.49	
2007	1,954,011,000	1,954	3,094	4080	8760	223.06	13.87	
2008	1,883,622,000	1,884	4,442	3933	8784	214.44	20.72	
2009	1,604,615,000	1,605	3,687	3351	8760	183.18	20.13	
2010	1,724,277,000	1,724	3,928	3600	8760	196.84	19.95	
							18.36	**Average**
							1.93	**Std Dev**

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SNWA has used generating capacity of Reid Gardner Station as the basis for estimating water demand for power generation between 1965 and 1986 (LVVWD, 2001, Table B-11). A conversion factor of 12 acre-feet of water per megawatt was used to estimate total annual water demand, and by subtracting annual surface-water diversions the annual groundwater demand was derived.

The slope of the water consumption versus energy generation plot (Figure B-11) is 2.088 acre-ft/GWh, equivalent to 18.4 ± 1.9 acre-ft/MW, roughly 50% higher than assumed by SNWA. Instead of relying on generating capacity or energy deliveries, MAI has utilized measured groundwater consumption for Unit 1 as reported by Maxey and others (1966) (Figure B-12), and interpolated groundwater demand for the 1968-76 interval when Units 1-2 were operating (Figure B-13) using measurements of combined Units 1-3 demand from 1989-94 (Figure B-14); Unit 4 diversions from the headwaters area have been measured since diversions there began in 1988.

With Reid Gardner Unit 1 demand (1965-1968) estimated from Maxey's data, combined Units 1+2+3 demand (1976-present) from the 1989-1994 measurement record, and combined Units 1+2 demand (1968-1976) derived by interpolation, a lag estimate for the industrial phase of the Lewis Well Field can be derived. Figure B-15 represents Water Years 1978 through 1985, when daily measurements of power diversions from the Muddy River were made by the USGS. When the Muddy River hydrograph is reconstituted to account for all known diversions through 1985 and compared with EMD-derived daily pumping rates from the Lewis Well Field, an average lag time of 58 days between maximum pumping and minimum River discharge is obtained (Figure B-15). Applying this lag to the Lewis diversion record and adding the lagged diversion rates day-by-day to the River hydrograph produces the reconstituted hydrograph of Figure B-16, minimizing residual seasonality during the evaluation interval.

The question arises as to where surface water from the Muddy River was diverted between 1968 and 1976, when Reid Gardner Unit 2 imposed water demands that could not be met by the Lewis Well Field (Figure B-13). To test the hypothesis that surface water was diverted below the Moapa Gage, we examine a reconstituted hydrograph that does not account for the portion of winter demand met by River diversions (Figure B-17). The prominent winter deficits beginning in the winter of 1969-1970 suggest that winter diversions above the Moapa Gage occurred from that time to the present. With this information, the reconstitution of Figure B-18 incorporates all major diversions and their associated lags through 1987, except for testing activities at MX-5 that occurred in 1981.

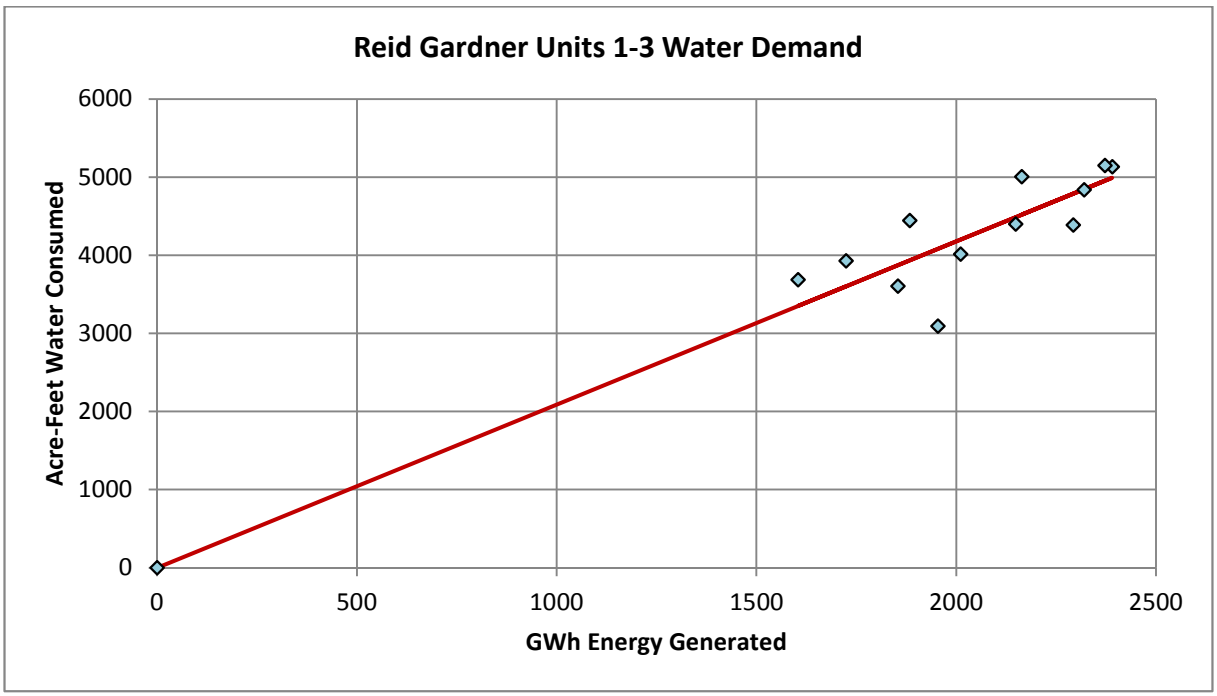

Figure B-11. Relationship of water demand to energy deliveries from Reid Gardner Units 1-3 [file NPCgeneration2.xlsx, sheet 'WaterDemand']

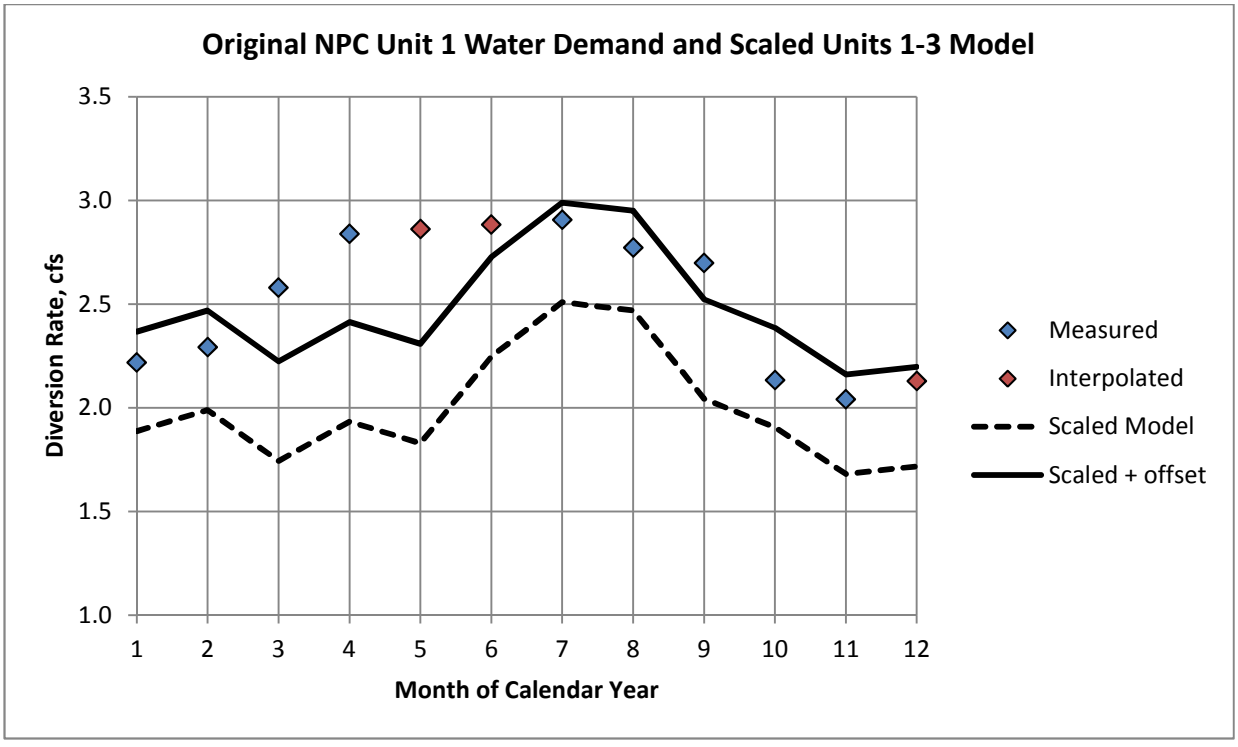

Figure B-12. Reid Gardner power diversions 1965-68, based on measurements by Maxey and others (1966) for the first year of operation. "Scaled Model" represents 1/3 of combined Units 1+2+3 total demand; offset fits Maxey's data. [file Maxey1965-66Qv3.xlsx, sheet '1964-66']

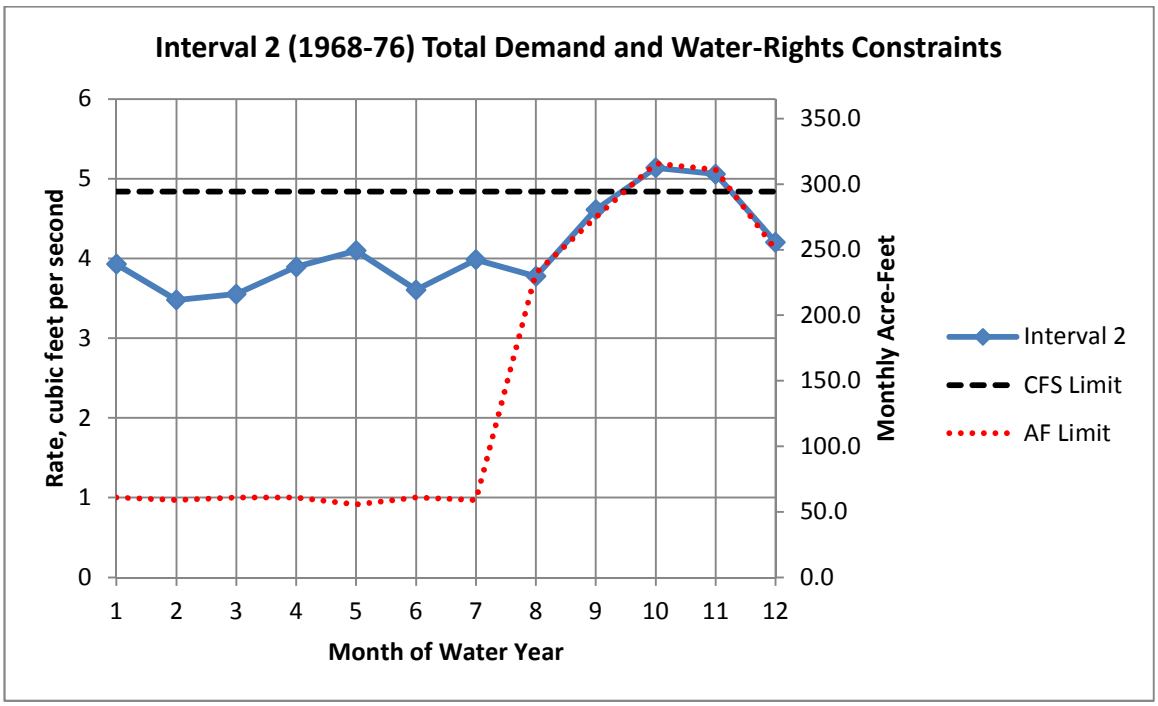

Figure B-13. Reid Gardner total water demand 1968-76 for combined Units 1-2. Summer demand was met by the Lewis well field; the acre-ft limit (deficit) imposed by Ruling 957 was met by a lease of winter Muddy River water of up to 7 cfs and total duty of 2,000 acre-ft. May-September demand is assumed to have been met by the Lewis Well Field; total duty constrains Lewis production during winter (October-April) to about 1 cfs. [file Maxey1965-66Qv4.xlsx, sheet '1964-66']

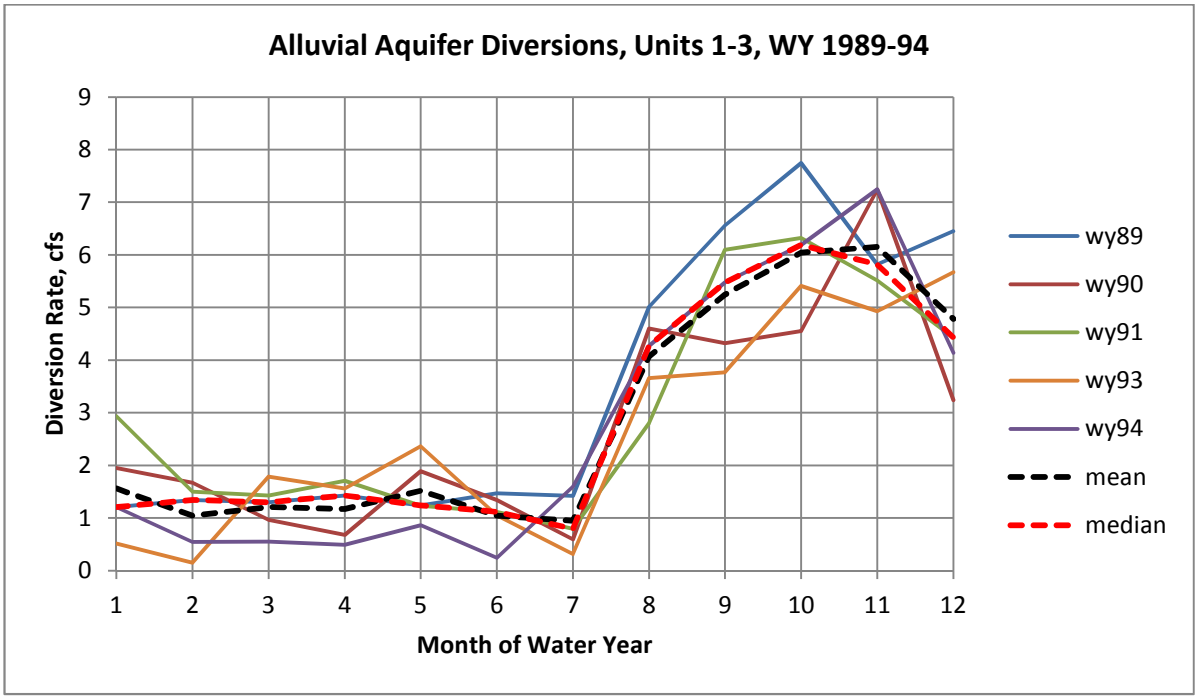

Figure B-14. Reid Gardner alluvial aquifer diversions used as basis for estimating groundwater demand of combined Units 1-2 (1968-76), interpolating between Unit 1 (1965-68) demand shown in Figure B-5 and those of Units 1-3 (1989-94) shown here. [file Units123demand88-11.xlsx, sheet 'MonthlyData']

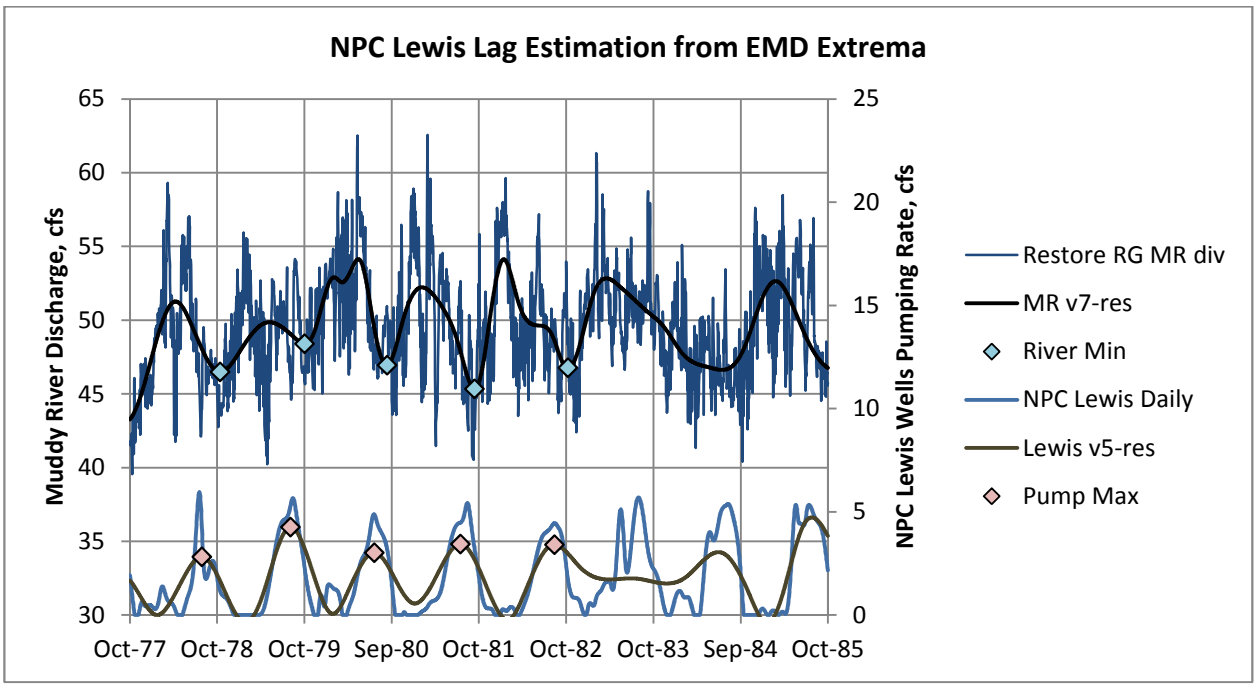

Figure B-15. When the Muddy River hydrograph is reconstituted to account for all known diversions *except* those from the Lewis Well Field and compared with the EMD approximation of daily Lewis Well Field pumping rates, an average lag of 58 days between maximum pumping rate and minimum River discharge is derived. [file IllustrateEMD.xlsx, sheet 'TrialNPCLewis']

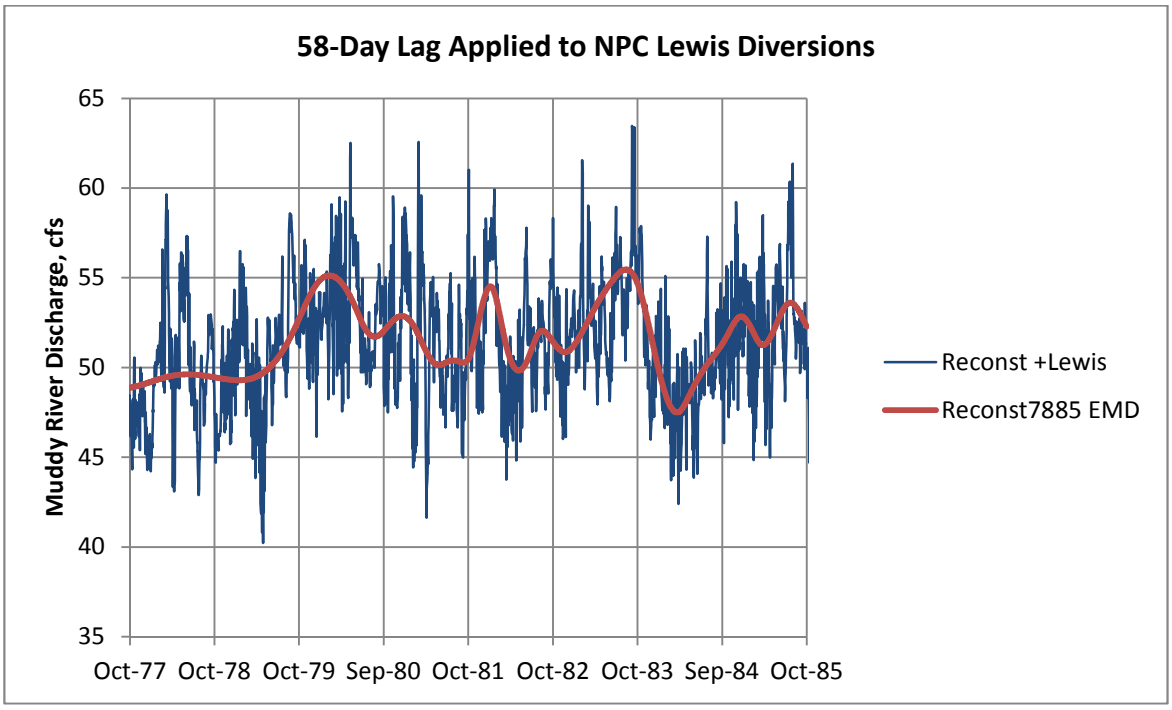

Figure B-16. Reconstituted base flows for Water Years 1978-1985 based on a 58-day lag associated with Lewis Well Field pumping and groundwater export by NPC [file ReconstSimple4.xlsx, sheet 'RG123']

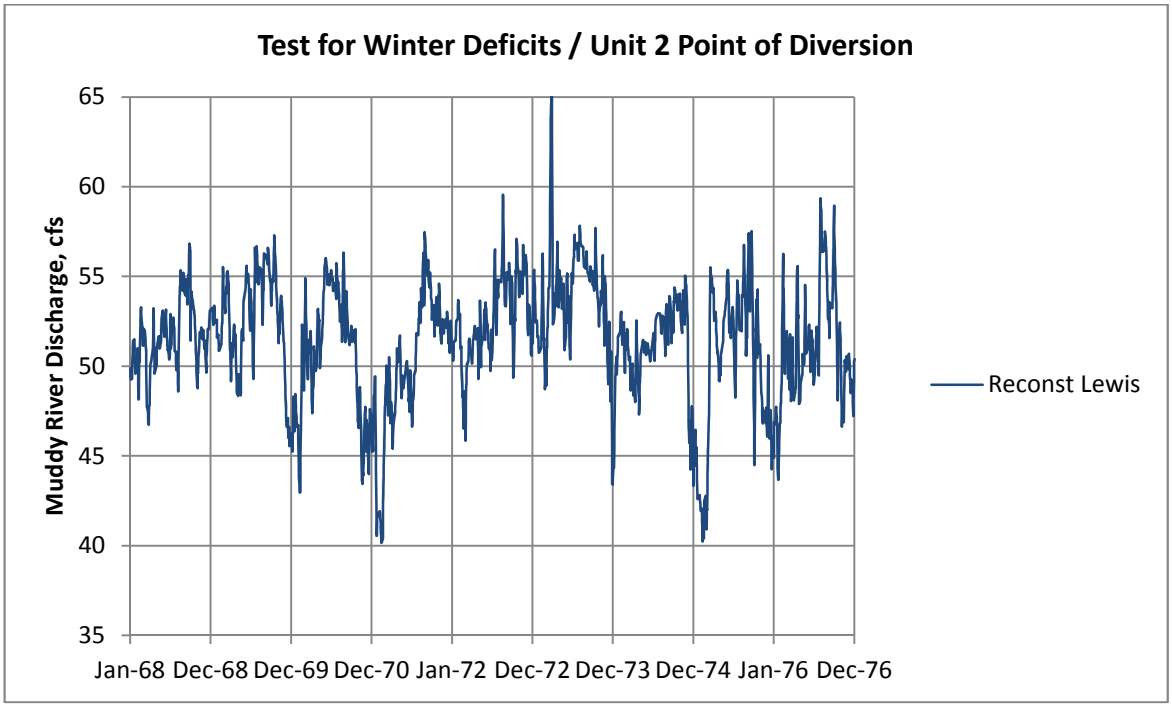

Figure B-17. Prominent winter deficits occur if surface-water diversions above the Moapa Gage are not included in the reconstitution from the winter of 1969-1970 onward [file ReconstSimple4.xlsx, sheet 'RG123']

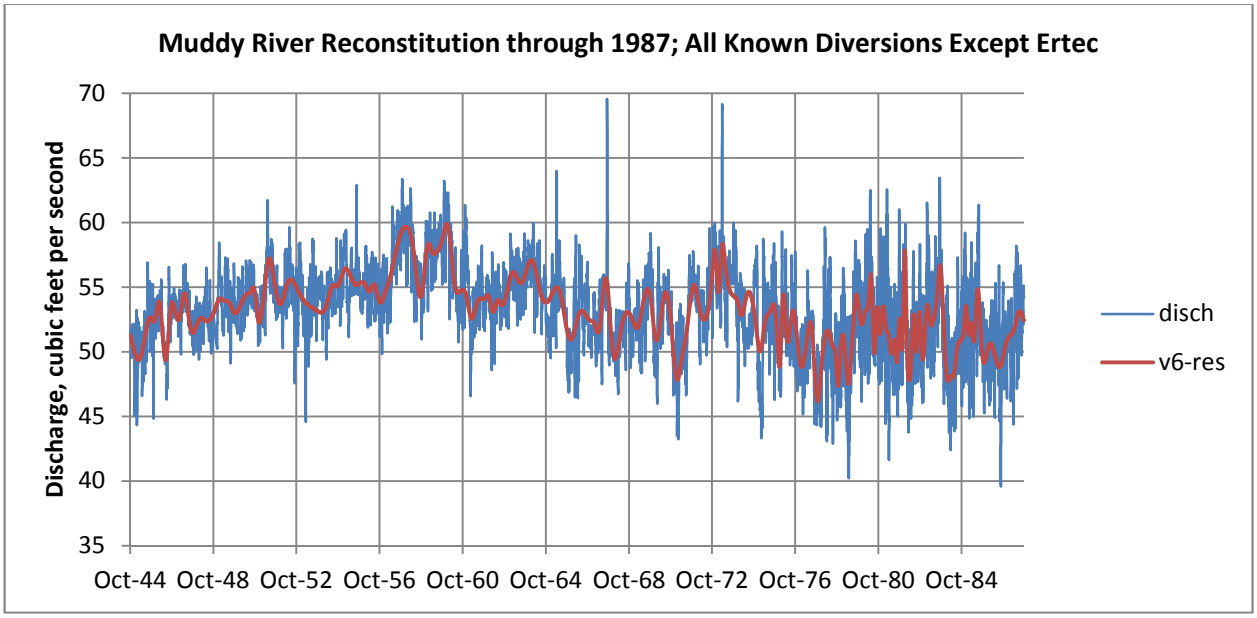

Figure B-18. Reconstituted base flow of the Muddy River through 1987, accounting for all major diversions except Ertec's MX-5 aquifer test in 1981. Sustained pumping in Coyote Spring Valley did not begin until late 2005; diversions associated with the Ertec test are incorporated with the final reconstitution step. [file ReconstSimple4.xlsx, sheet 'ReconstMR4487EMD']

Reid Gardner Unit 4 entered service in 1983, but all water demand was met by the Meadow Valley Wash well field until mid-1988. Deteriorating water quality from that source caused deterioration of concrete in the cooling towers, and forced NPC to acquire additional water rights in the headwaters area. The Taylor E well was rehabilitated to become LDS E, the LDS C well was drilled, and separate pumps for Unit 4 were installed above the Moapa Gage. The LDS E and C wells are adjacent to Big Muddy Spring and the Muddy River, so we assume there is no significant lag between pumping at these wells and reduction of River flow. LDS E entered service in June of 1988, and LDS C in July of the same year. River diversions for Unit 4 began the following winter, and monthly diversion records from all 3 sources are available from January of 1988 to the present. Reconstitution to account for Unit 4 demand is therefore straightforward, and results in the base-flow hydrograph of Figure B-19, which does not yet include the effects of Arrow Canyon Well (ACW) and Coyote Spring Valley (CSV) pumping.

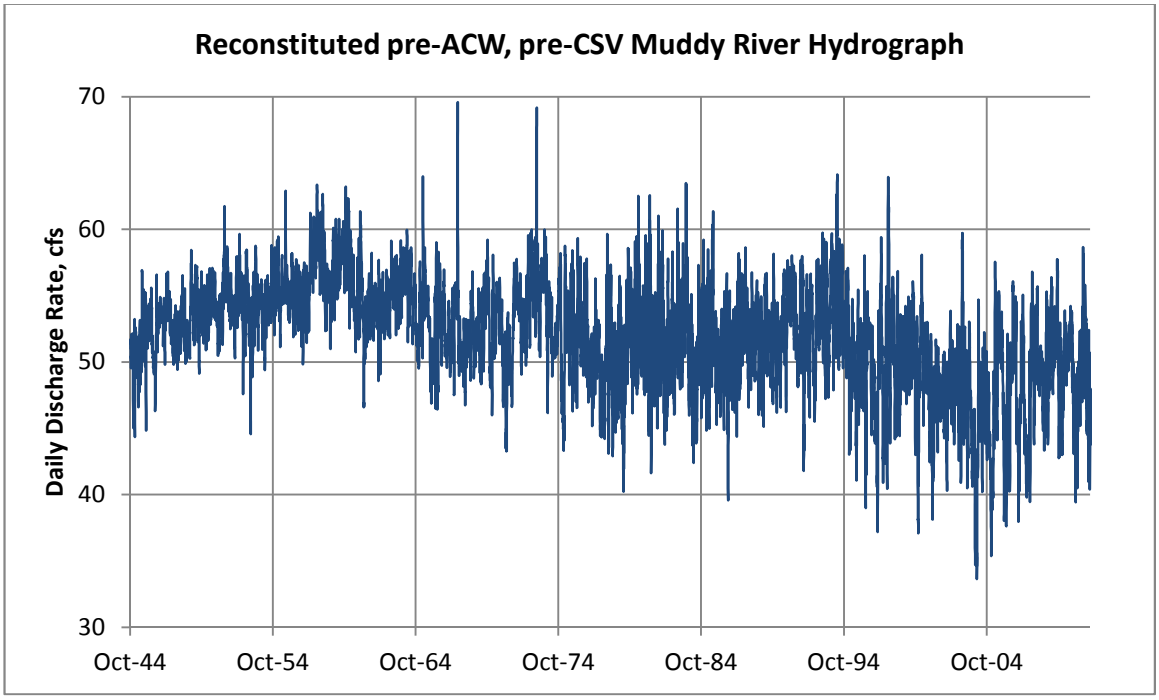

Figure B-19. Reconstituted Muddy River hydrograph, incorporating all major diversions except those from the Arrow Canyon Well(s) and Coyote Spring Valley [file ReconstSimple4.xlsx, sheet 'RG4']

The Arrow Canyon #1 well went online in June of 1992, operating at 900 gpm. A 31-day constant-discharge test at 606-793 gpm was conducted in April-May 1993, and step-drawdown and 72-hour constant-discharge tests were conducted in October of 1993. A 121-day constant-discharge test at 2,900 gpm was conducted between December of 1993 and April of 1994. Minima in the reconstituted hydrograph of Figure B-19 best align with pumping maxima when the pumping is lagged 156 days (Figure B-20).

The final step in the reconstitution is to include pumping in Coyote Spring Valley, which is represented as a backward-looking 3-year average pumping rate for all active wells (CSI-1, CSI-2, CSI-3, CSI-4, and MX-5), consistent with the derivation of Bredehoeft (2011). The reconstituted natural-flux hydrograph of Figure B-21 remains within the historic range for 2011-2012, the Order 1169 testing interval.

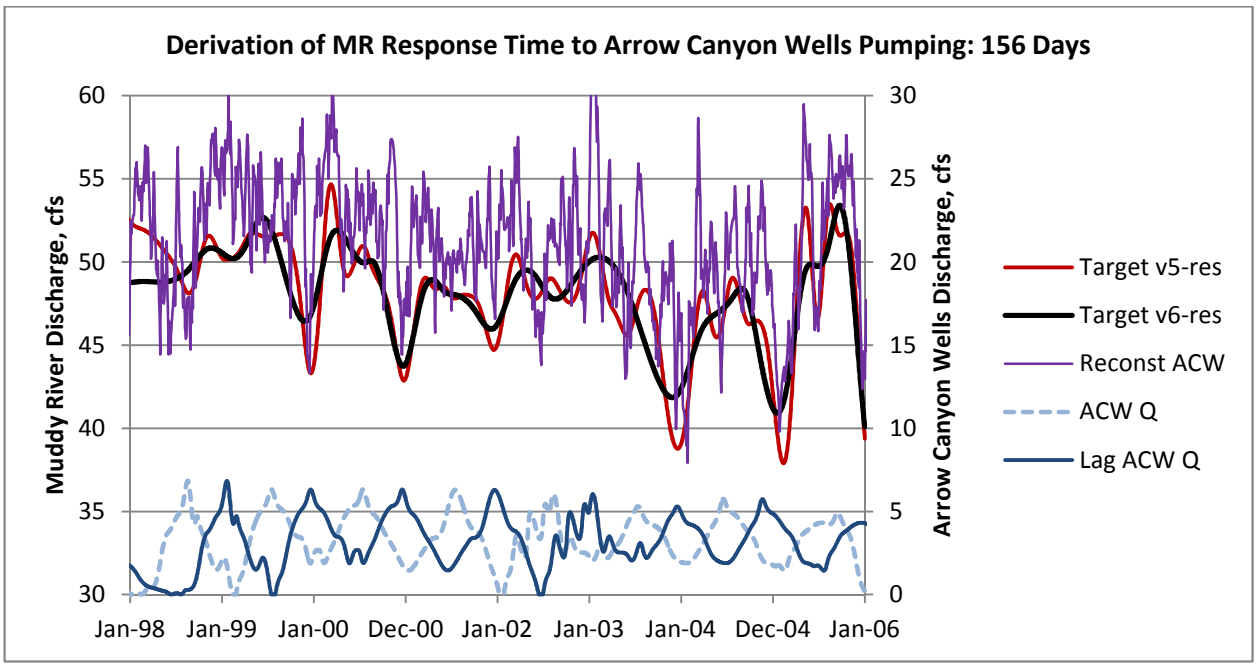

Figure B-20. Alignment of pumping maxima with target minima occurs with a 156-day lag, and produces a reconstituted hydrograph with minimum seasonality. There is no evidence the Arrow Canyon Wells are not equally responsible (in proportion to diversion rates) for seepage reductions, since they intercept deeply-circulated groundwater that would otherwise transit the Lewis Well Field to discharge in the headwaters area. [file ReconstSimple4.xlsx, sheet 'ACW']

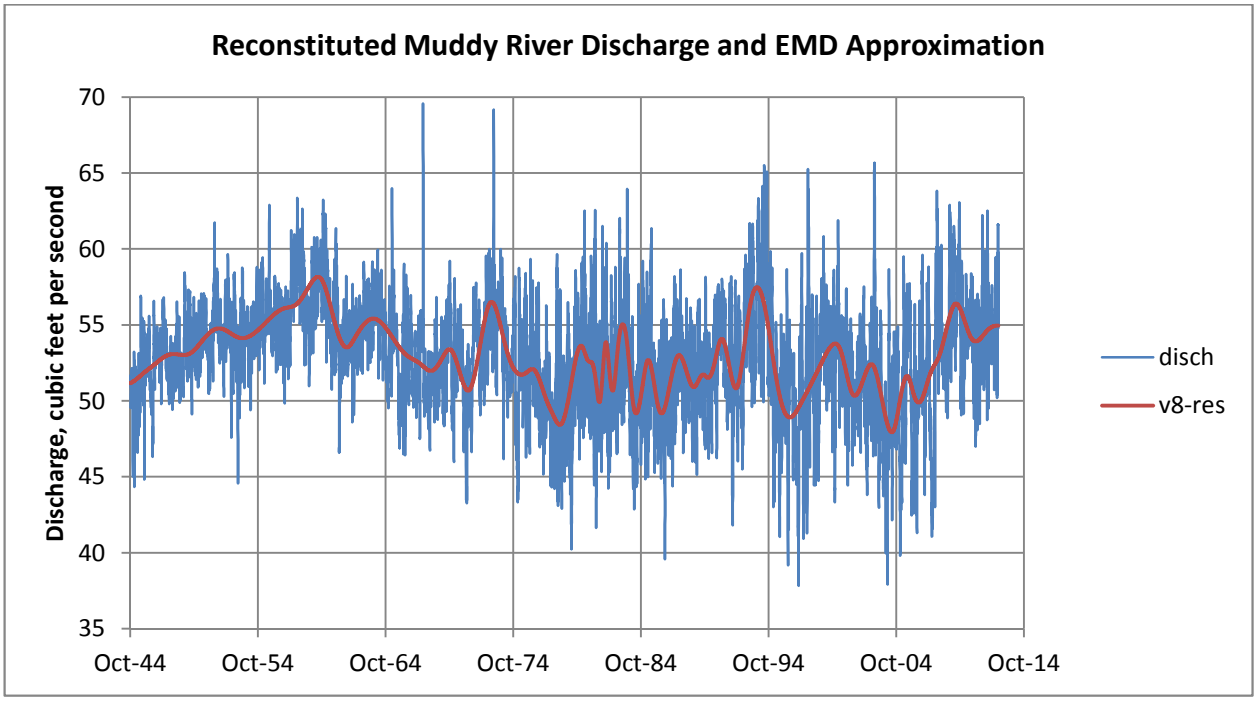

Figure B-21. Fully reconstituted Muddy River hydrograph expressed as natural groundwater flux to the headwaters area, based on backward-looking 3-year average for Carbonate-Rock Aquifer production [file ReconstSimple4.xlsx, sheet 'ReconstMR4412EMD']

Appendix C. Climate Index

Estimates of infiltration losses in Meadow Valley Wash and surge flows recorded at the Glendale gage extend the 60-year record of precipitation at Adaven that was used by Eakin (1964, 1966), providing a composite indication of moisture availability in the region (Figure C-1). Using the logarithms of infiltration losses and surge flows, and the month-by-month departures from the cumulative average precipitation at Adaven for a given month, a composite moisture-availability index was prepared by scaling and averaging the three parameters (Figure C-2). Comparing the lagged climate signal to reconstituted base flow in the Muddy River reveals that the River responds to climate on decadal time scales, as postulated by Maxey and others (1966) and Eakin (1966); the signals align best with a lag of 248 months (Figures C-3, C-4).

The lag of over two decades between climate extremes and River responses allows the future discharge trends of the Muddy River to be forecast with a 20-year event horizon, as indicated in Figure 5 of the main body of this report.

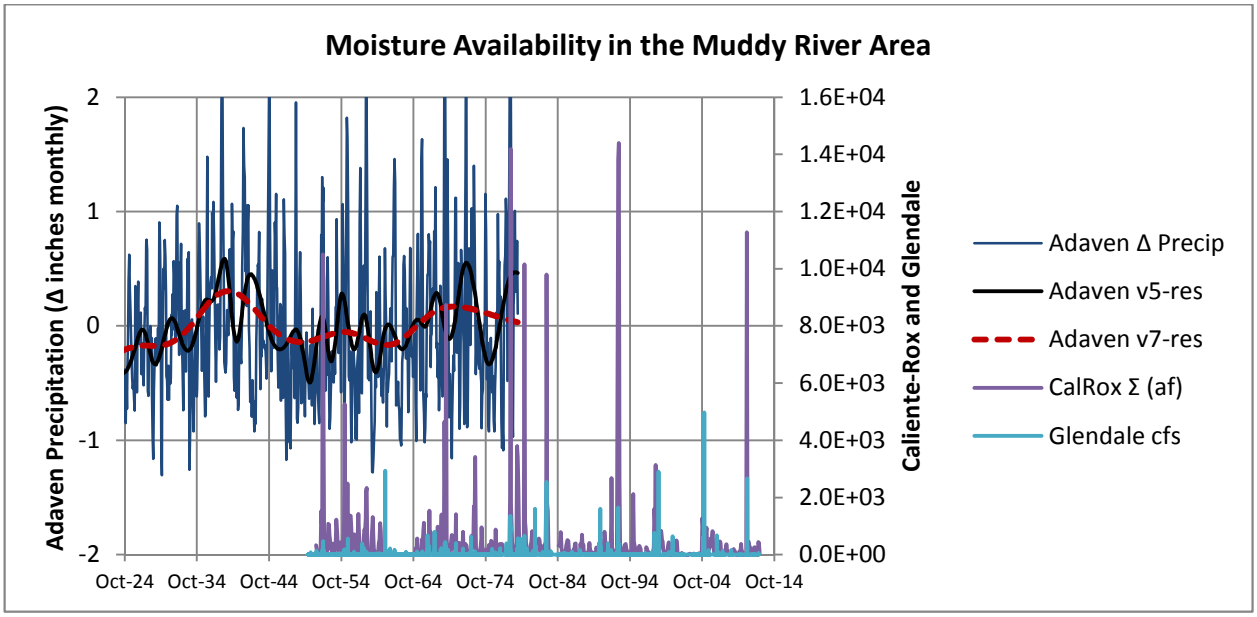

Figure C-1. Components of the composite climate index: Adaven precipitation departure from monthly average, shown with EMD-derived intrinsic modes; infiltration losses between the Caliente and Rox gages; and storm runoff at the Glendale gage derived by base flow separation [file 3climateIndicesV4.xlsx, sheet 'MonthlyDaily']

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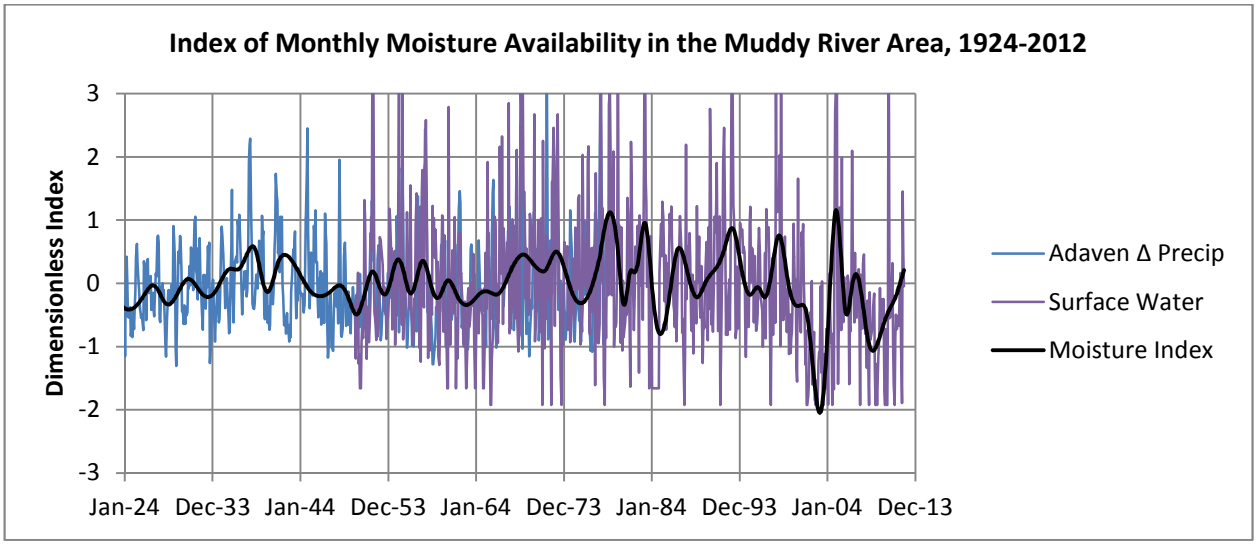


Figure C-2. Surface-water components of the climate index scaled and offset to combine with the Adaven precipitation record, with the composite moisture index derived by empirical mode decomposition [file 3climateIndicesV4.xlsx, sheet 'PlotData']

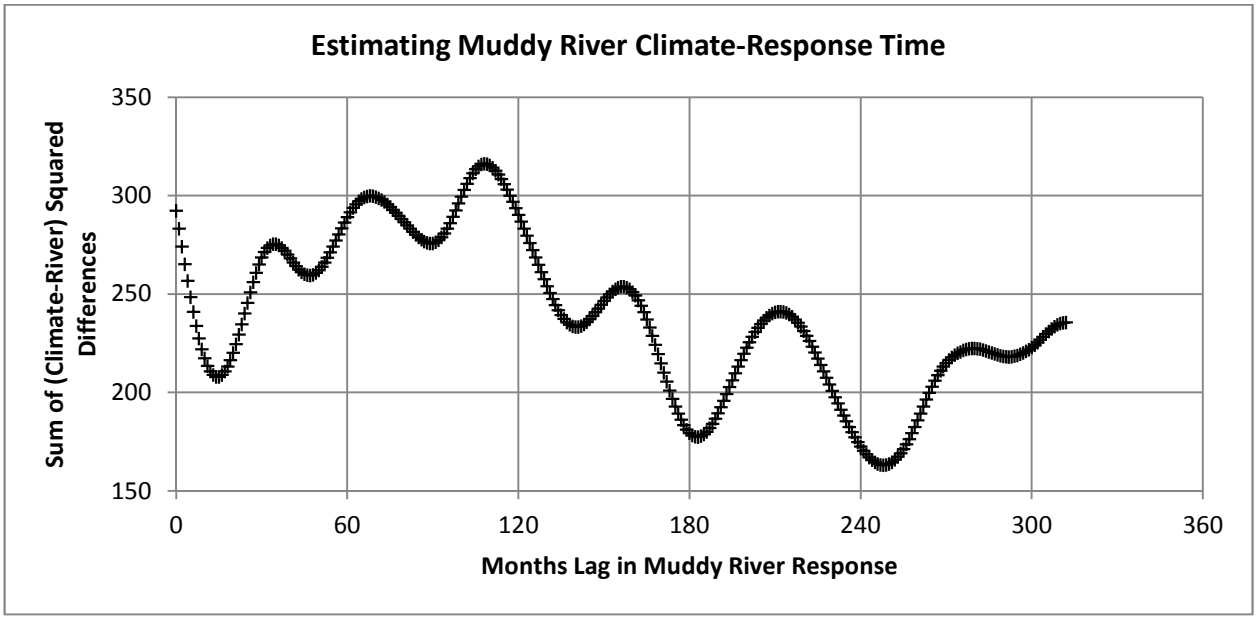


Figure C-3. Derivation of climate-response time by minimizing the sum of squared differences between the climate index and the reconstituted Muddy River hydrograph for Water Years 1945-2005 [file 3climateIndicesV5.xlsx, sheet 'LagHydrograph']

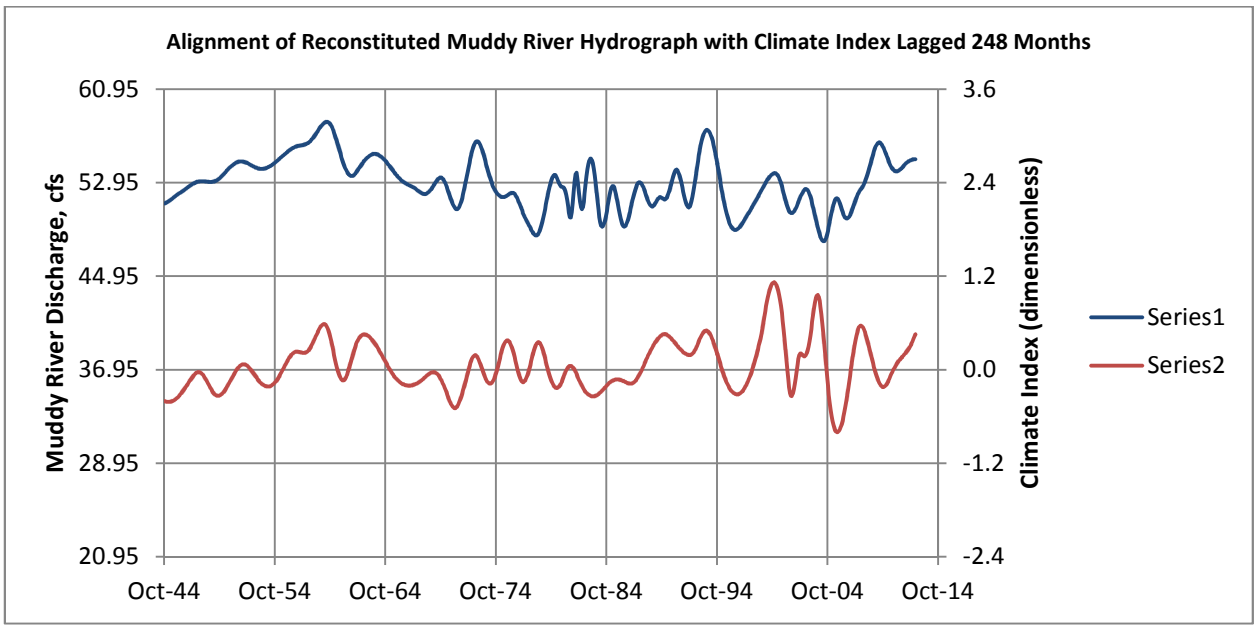


Figure C-4. Best match of reconstituted Muddy River hydrograph to climate index occurs when River discharge lags climate by 248 months. [file 3climateIndicesV4.xlsx, sheet 'LagHydrograph']

Appendix D. Selected Temperature Records

Mean annual water temperatures of the Muddy River at the Moapa Gage exceed mean annual air temperatures recorded at Nellis Air Force Base in Las Vegas Valley (Figure D-1). Temperatures at RW-2 in Coyote Spring Valley are of the order of 35°C (Figures D-2 and D-3), decreasing along groundwater flow paths to the order of 30°C at EH-5b (Figure D-4) and the Lewis Well Field (Figures D-6 and D-7) in upper Moapa Valley. At EH-4, shallow groundwater is much cooler, of the order of 25°C (Figure D-5), reflecting the effects of continued cooling along flow paths, hydraulic isolation from the proximal Pederson and Plummer Spring areas, and infiltration of relatively cool waters along Battleship Wash. Still, groundwater at EH-4 is 5°C warmer than the mean annual air temperature, reflecting its origins in a deeply-circulating flow system.

Continuous spring and stream temperatures in the headwaters area are available from March of 2008 until April of 2013, with an important data gap from July of 2010 until March of 2012. Temperatures of the Refuge and Apcar Streams (Figures T1 and T2) indicate a warming trend over the 5-year period of record, consistent with the recent interval of relatively high natural groundwater flux to the headwaters area derived by reconstitution and illustrated by the top curve in Figure 4. Annual variability of the Apcar Stream is greater than the Refuge Stream, but diurnal variations appear to be similar. The "ecohydraulic" model reported by Hatten and others (2013) appears to represent a snapshot in time with respect to stream temperature, for their Figure 3B shows a range of less than 1°C from a (presumably daytime) survey in the spring of 2009. Their finding that water temperature was less associated with dace locations than water depth, substrate, Froude number, or velocity is therefore questionable.

Figures D-8 and D-9 indicate an overall warming trend from 2008-2013, but the data gap prevents confirmation that the trend persisted during the majority of the Order 1169 test. There may be a recent trend reversal, however, based on the 2012-2013 data. Peak annual temperatures occur during the summer, but winter temperatures at some downstream stations over the period of record are less than the maxima by 9° C, and in Apcar Stream for many successive days have been less than the 26°C environmental threshold for Moapa dace cited by Hatten and others (2013). A temperature trend reversal could be very significant to the dace population.

One of the important yet unresolved questions is that of recruitment-habitat temperature requirements. During the earliest studies when dace populations were much larger and more widely distributed, the impression developed that outflow-channel reaches ("springbrooks") close to the spring-orifice areas were the probable recruitment habitats. As flows have been reduced in some of the habitat reaches, it is possible that the temperature variability might have been less than the present 9° C in Apcar Stream and 4° C in Refuge Stream. If flows continue to decrease, flow velocities will decrease correspondingly, and winter water temperatures will reach new lows as more heat loss to the atmosphere is favored. We think USFWS needs to prioritize temperature monitoring and rectify known problems their subcontractors have experienced maintaining continuous, reliable temperature records and effectively integrating those records with dace-population studies.

The temperature-monitoring network should be restored to its full pre-2010 configuration to include North Fork, South Fork, Cardy Lamb, and mainstem Muddy River locations that were decommissioned in 2010. USFWS and its subcontractors should elevate the priority of stream-temperature monitoring if possible, and attempt to recover disorganized and error-prone data.

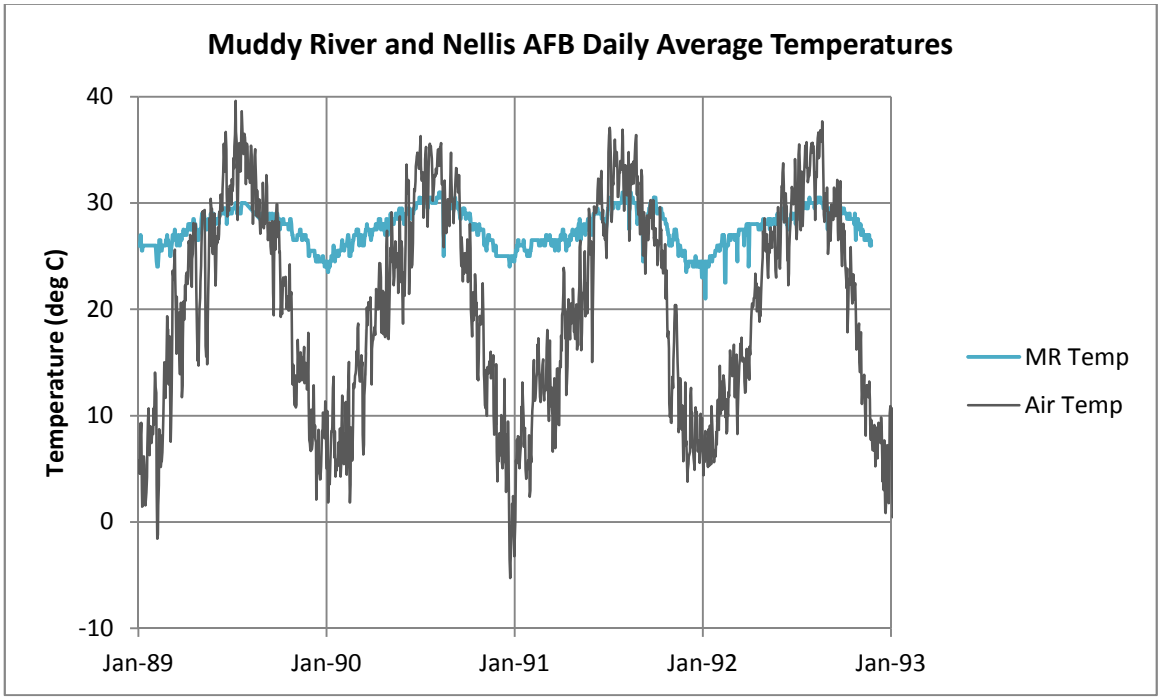


Figure D-1. Average daily water temperatures of the Muddy River and air temperatures at Nellis Air Force Base. The mean annual temperature of the Muddy River is 27.5°C, 7.5°C greater than the mean annual air temperature at Nellis. In the spring and fall, when the air and water temperatures correspond, open-channel heat exchange between the water and air is at a minimum, and the water temperature at those times is representative of a mixture of source waters. [file MRdailyTempEC.xlsx, sheet 'NellisAirT']

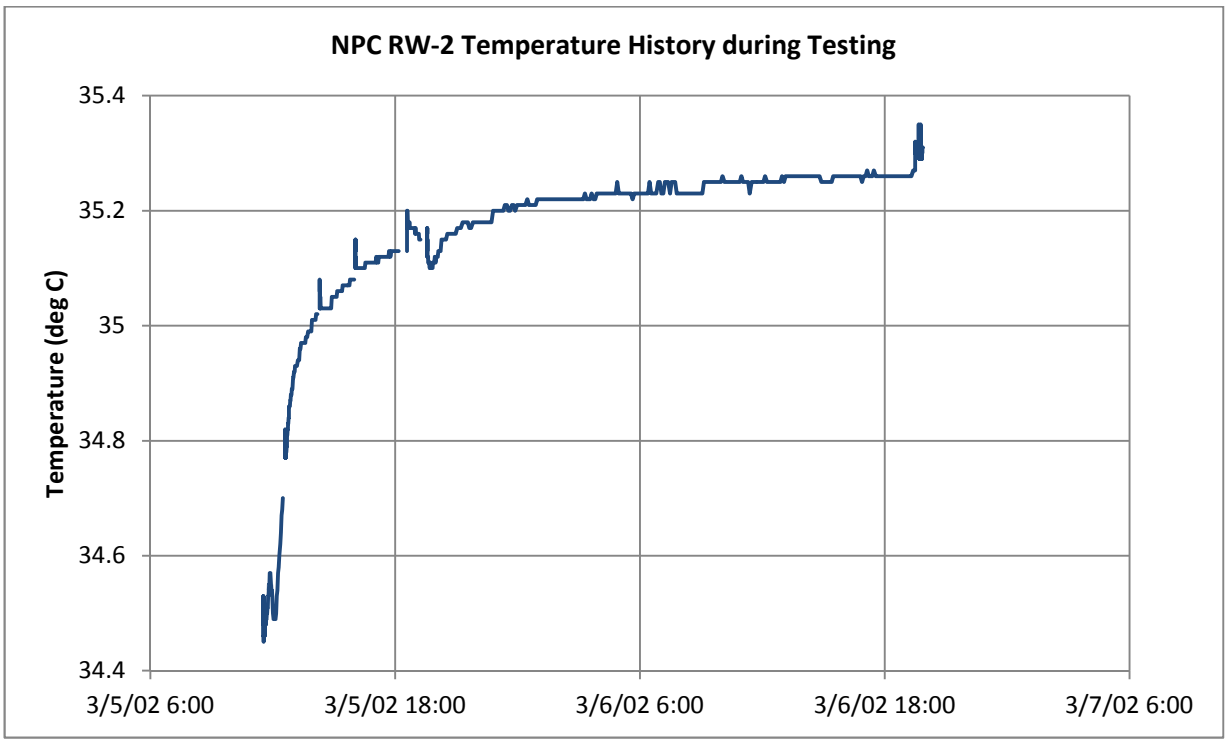


Figure D-2. RW-2 temperature data provided by Converse Consultants [file RW2allDataCJ.xlsx]

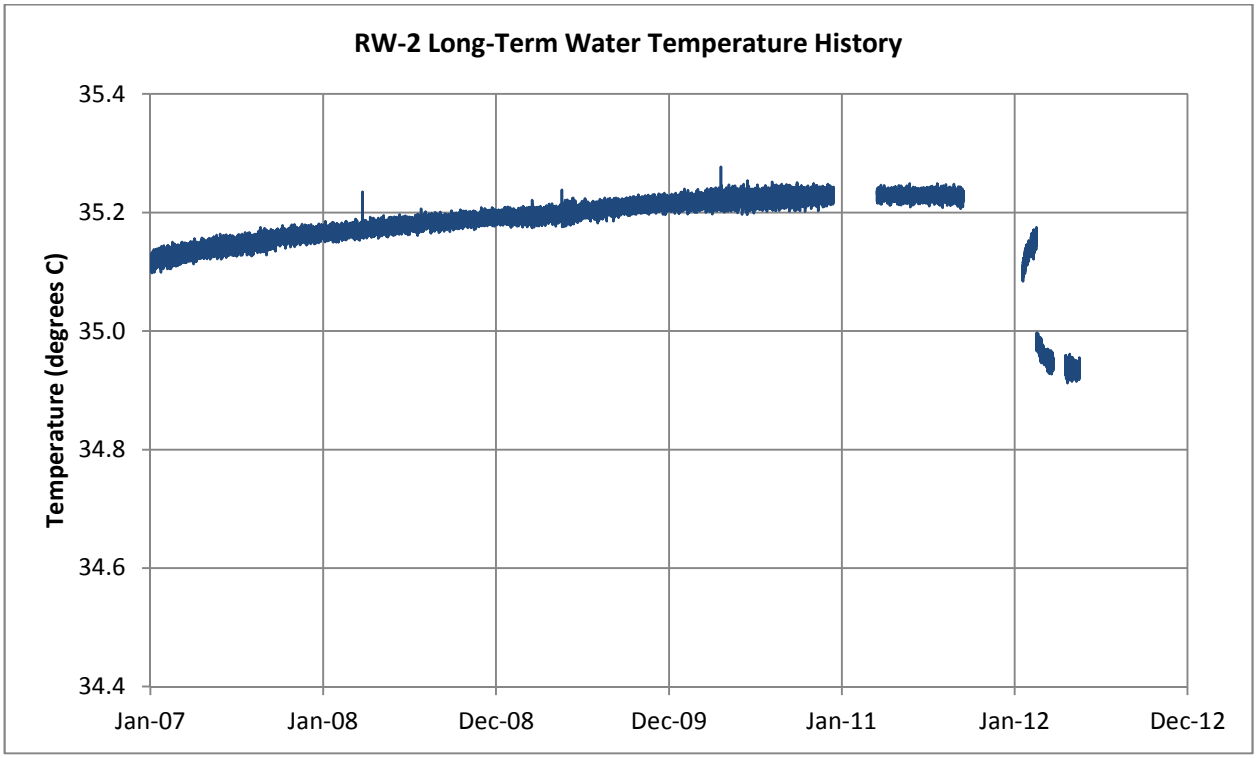


Figure D-3. RW-2 temperature data provided by Converse Consultants [file RW-1, RW-2, Eh-4, Eh-5b Houly 2003-2012V2.xlsx, sheet 'RW-2']

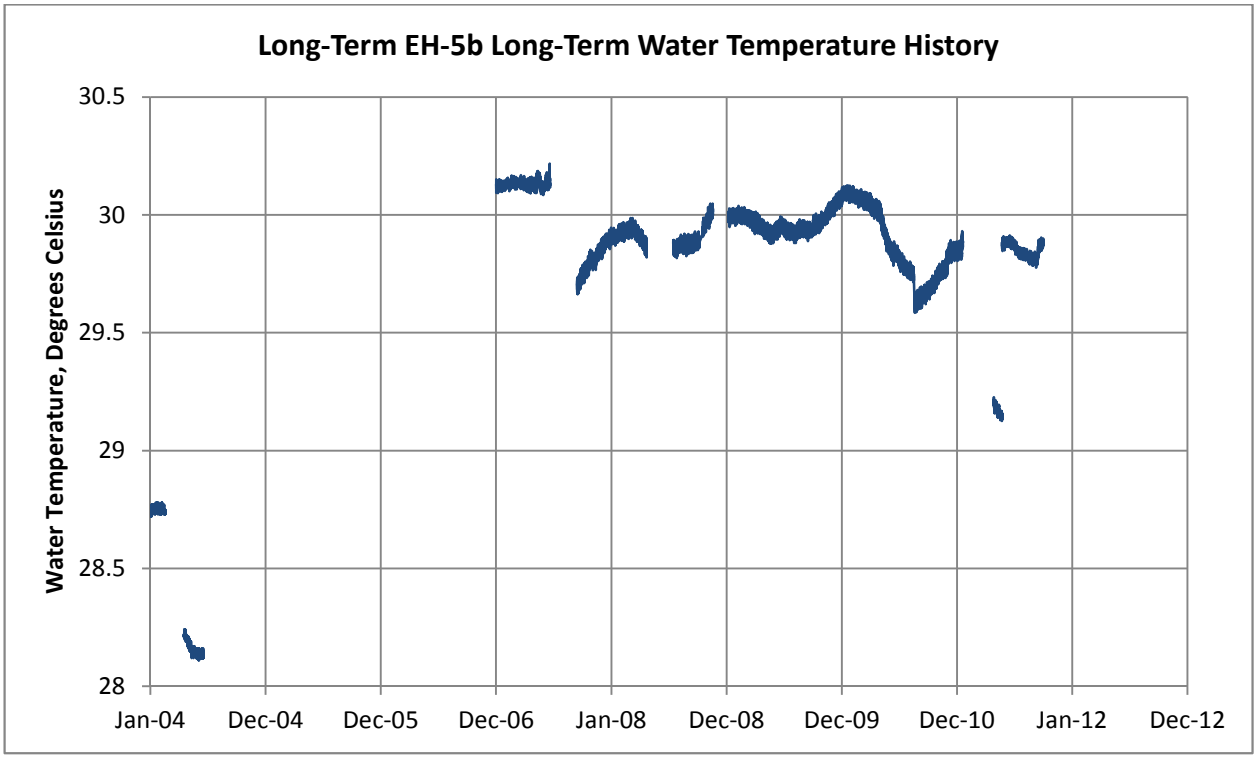


Figure D-4. EH-5b temperature data provided by Converse Consultants [file RW-1, RW-2, Eh-4, Eh-5b Houly 2003-2012V2.xlsx, sheet 'Eh-5b']

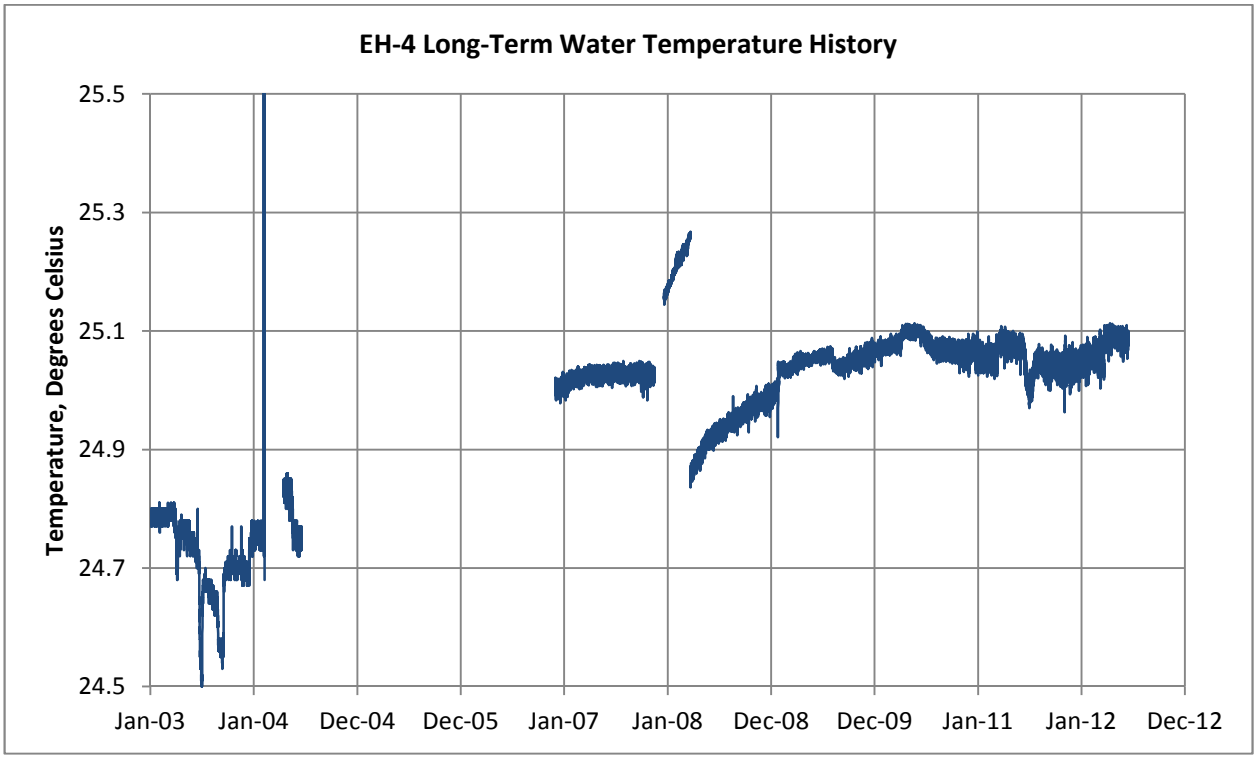
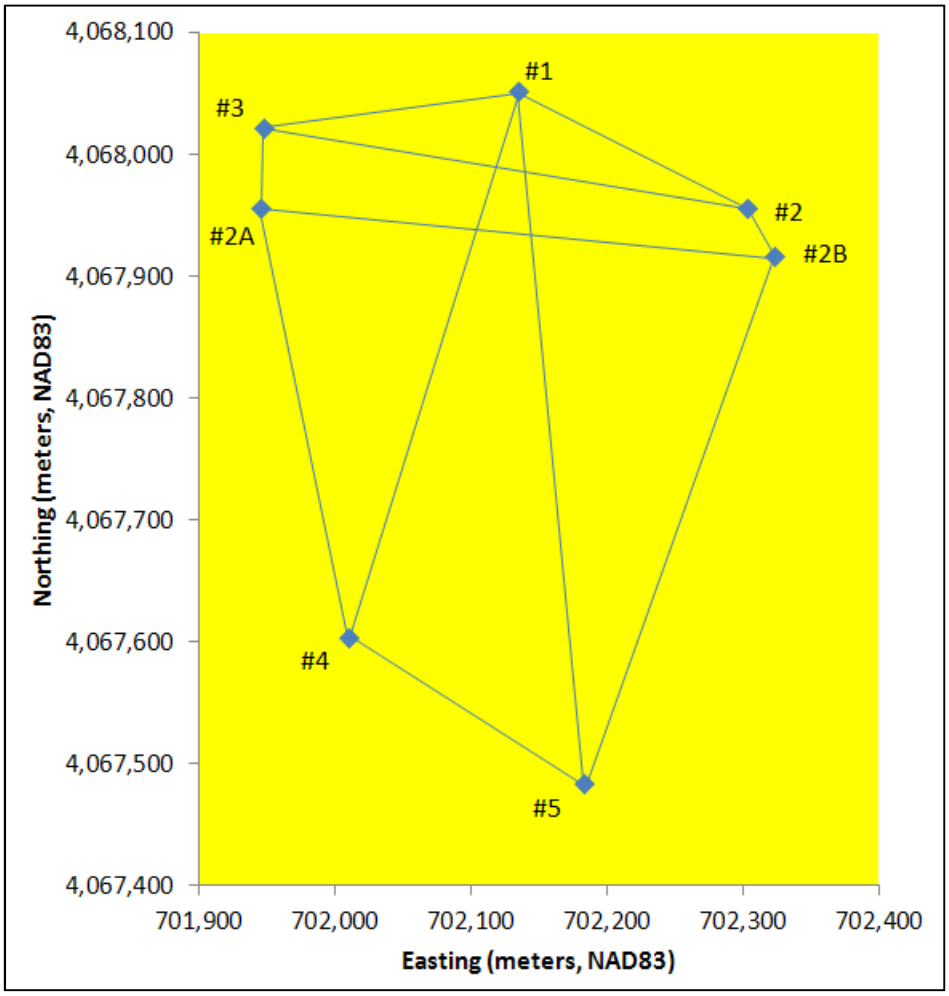


Figure D-5. EH-4 temperature data provided by Converse Consultants [file RW-1, RW-2, Eh-4, Eh-5b Houly 2003-2012V2.xlsx, sheet 'Eh-4']

Figures D-6 and D-7 (following 2 pages). Fence diagrams represent contrasting 3-dimensional temperature distribution in the Lewis Well Field. Temperature profiles were measured in the 7 Lewis wells between 1987 and 1995; the wells and fence locations are identified as follows:



The distribution of pumping in the Lewis Well Field is represented qualitatively as a bi-quadratic trend surface in the upper left of each figure for months when pumping occurred, and the average monthly discharge rate of the Muddy River is shown as a bar chart in the lower left.

With no Lewis production after a dry winter and reaming of the Arrow Canyon #1 well in late 1990, temperatures in NPC #4 are elevated (Figure D-6); after an unusually wet 1992-93 winter and minimal Lewis production temperatures in NPC #1 are depressed (Figure D-7) [files Mar91LewisTempFence2.jpg and Mar93LewisTempFence2.jpg , modified after file LewisTvsProduction89-96.pptx]

Lewis Well Field

Production Effects on Groundwater Temperatures

- Measured Temperatures

No Pumping

Lewis Well Field

Production Effects on Groundwater Temperatures

- Measured Temperatures

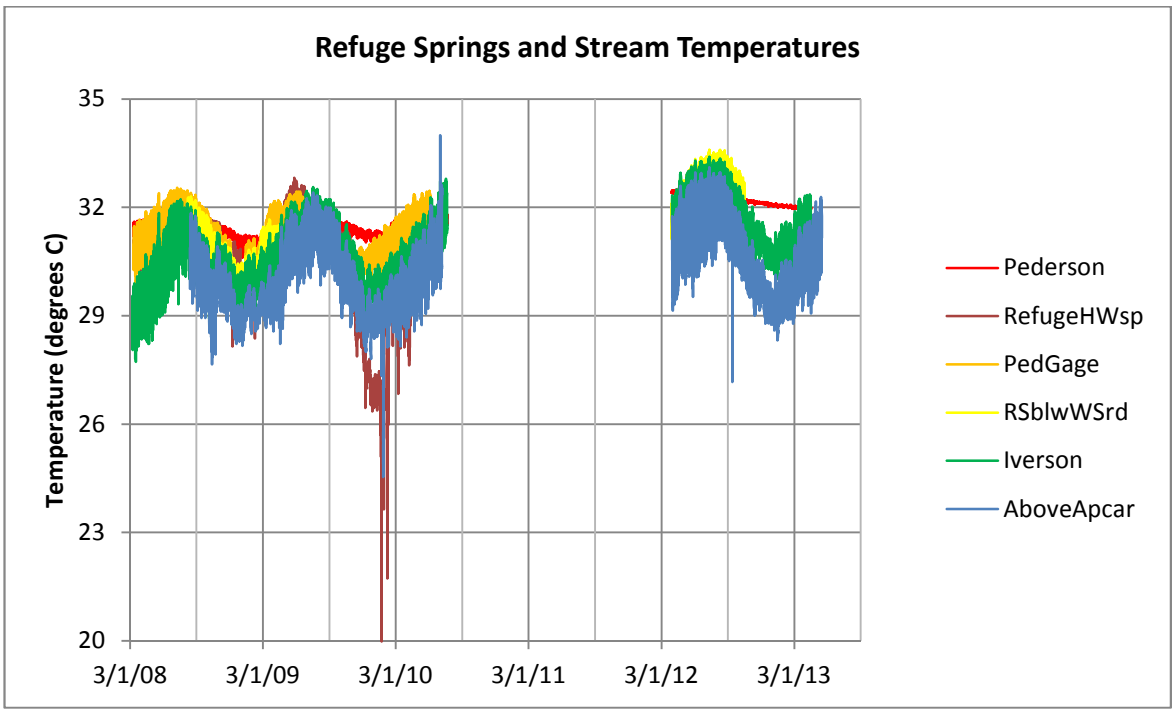


Figure D-8. Temperature record from the Refuge Stream and tributary springs: Pederson Spring (N56178), "Headwaters Spring Refuge Tributary" (N56179?), Pederson Gage (N56170), Below Warm Springs Road (N56185), Iverson Flume (N56168), and Above Apcar Confluence (N56182) [RefugeStreamComparison.xlsx]

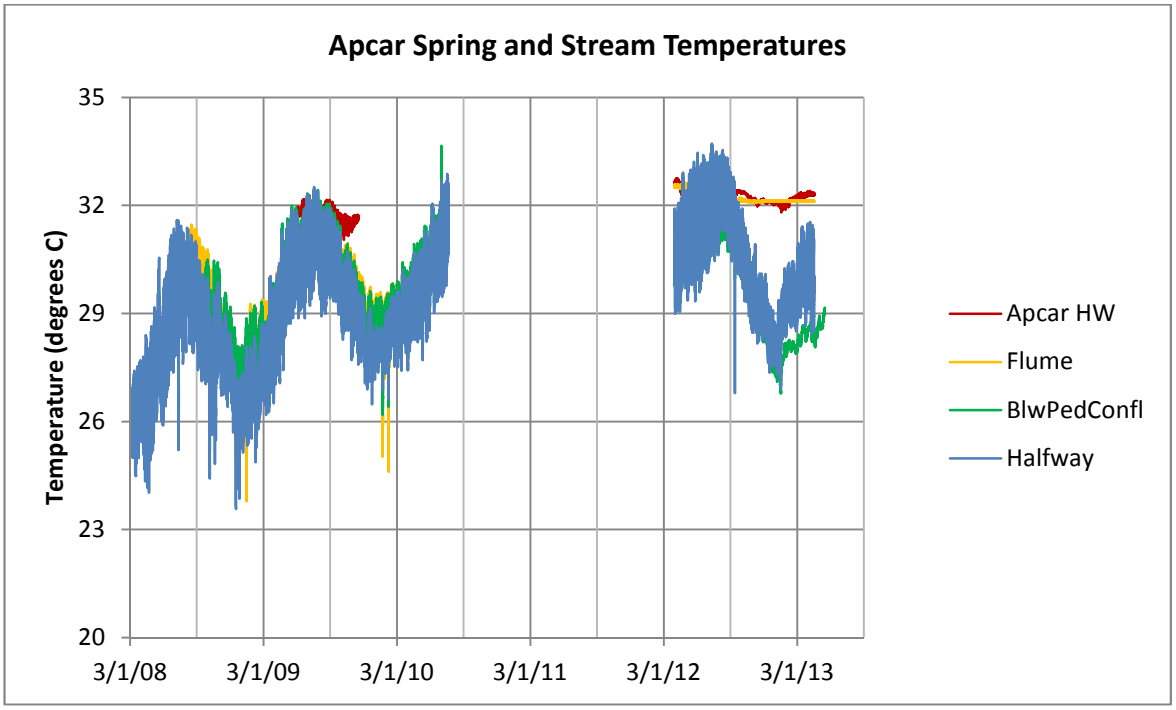


Figure D-9. Temperature record from Apcar Headwater Spring (N56186?), NDWR Flume (N56177), below the "new" (October 2008) Pederson confluence (N56172), and "halfway up Apcar at culvert" (N56181) [ApcarComparison.xlsx]

Appendix E. Mixing and Mass-Balance Observations and Calculations

In the Eakin (1964) dataset, EC at three field-measurement sites was determined in the USGS laboratory (sites 1, 10, and 11 from the 1963 synoptic survey as shown in Figure 2 of this report).

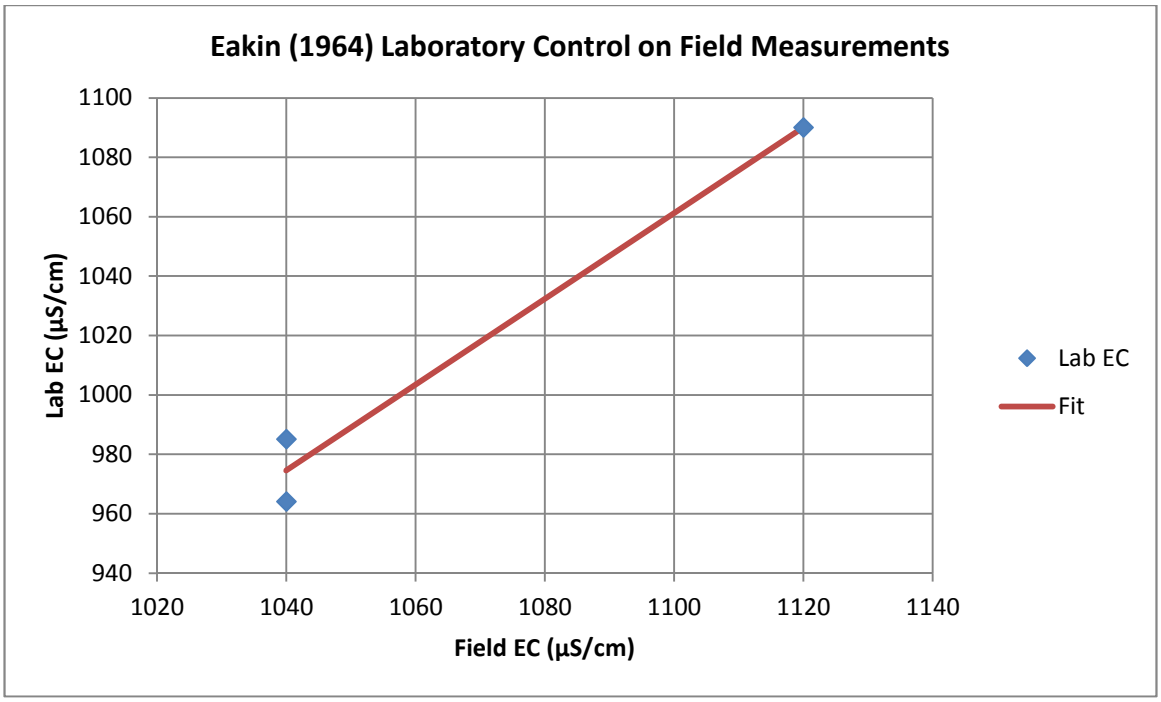


Figure E-1. Laboratory and field EC measurements reported by Eakin (1964, Figure 3 and Table 6) from the Muddy River, "Warm Spring" (Big Muddy) and Iverson Spring (Plummer); EC_{LAB} = 1.444*EC_{FIELD}-527 µS/cm. Note that Eakin's laboratory measurements do *not* correspond in time with his field measurements; the mean daily EC of the Muddy River from automated monitoring by the USGS between 1988 and 1993 was 1,013 µS/cm, with a standard deviation of 42 µS/cm (Figure E-2). This standard deviation gives an indication of the representativeness of a River sample taken at the Moapa Gage, and therefore the uncertainty in the upper-right data point here. [file EakinLabFieldEC.xlsx]

During the synoptic survey of February 2001, Beck and others (2006) made field measurements of discharge, EC, and temperature on South Fork and below the North and South Fork confluence (Figure 2). At the Baldwin Springs flume (partial-record station 7 on Figure 2), the USGS measured 4.10 cfs; below the confluence (upstream of continuous-record station 2 on Figure 2) they measured an average of 15.55 cfs, a gain of 11.45 cfs along about 0.3 miles of stream. Temperature and EC were not measured in the field at the flume, but EC measurements from samples taken to the USGS laboratory in Las Vegas were 977 µS/cm at the flume and 989 µS/cm below the confluence. Temperature below the confluence was 28.2°C on February 6, 2001. The 11.45 cfs of seepage can be characterized using Equation 2, where X = 4.10/15.55 = .264, as C2 = (989-0.264*977)/(1-0.264) = 993 µS/cm.

Earlier observations help us constrain the amount and quality of seepage inflow to the uppermost reach of South Fork. ERTEC (1981) monitored Baldwin Spring (Figure 2) during early aquifer tests at MX-5; discharge, temperature, and EC at Baldwin Spring and closely-adjacent Baldwin Cut were monitored from June 28 to September 30, 1981. The combined discharge of Baldwin Spring and

Baldwin Cut averaged 0.99 cfs during the ERTEC study. Note that ERTEC monitored Baldwin Spring itself, not the "Baldwin Spring" flume on South Fork (Beck and others, 2006, Tables B-40 and B-42), from which the Nevada Division of Water Resources (NDWR) recorded daily discharge (but not temperature or EC) for the same time interval. Flow at the flume, shown as site 7 on Figure 2, averaged 1.72 cfs during the ERTEC test, close to the historic minimum. The only known close-in-time measurements of temperature and EC at Baldwin Spring and the Baldwin Spring flume were made by MAI on April 8 of 1987; temperatures were 31.9 and 30.3 degrees Celsius and field ECs were 966 and 1021 µS/cm from the Spring and flume, respectively, indicating cooling and quality degradation associated with influx of seepage along about 0.2 miles at the headwaters of the South Fork tributary.

Laboratory EC measurements on samples collected from the Baldwin Springs pump house by MVWD indicate 941 µS/cm on December 9, 1997 and 944 µS/cm on January 5, 1999 (Beck and others, 2006, Table B-43). Virtually identical values of 948 and 947 µS/cm were obtained from Apcar (Pipeline Jones) Spring on the same days (Beck and others, 2006, Table B-39). ERTEC's laboratory measurements on Baldwin Springs samples were 870 µS/cm on June 5, 1981 and 930 µS/cm on September 30, 1981. At the closely-associated Baldwin Cut, ERTEC (1981) reports laboratory values of 837 µS/cm and 950 µS/cm on the same dates. Beginning in mid-April 2009 Apcar water was transferred to a sump at Baldwin Spring before being treated and distributed or bypassed to the Baldwin Springs flume; pumping at Apcar Spring ceased in late 2010 (Joseph Davis, MVWD General Manager, personal communication, 2013).

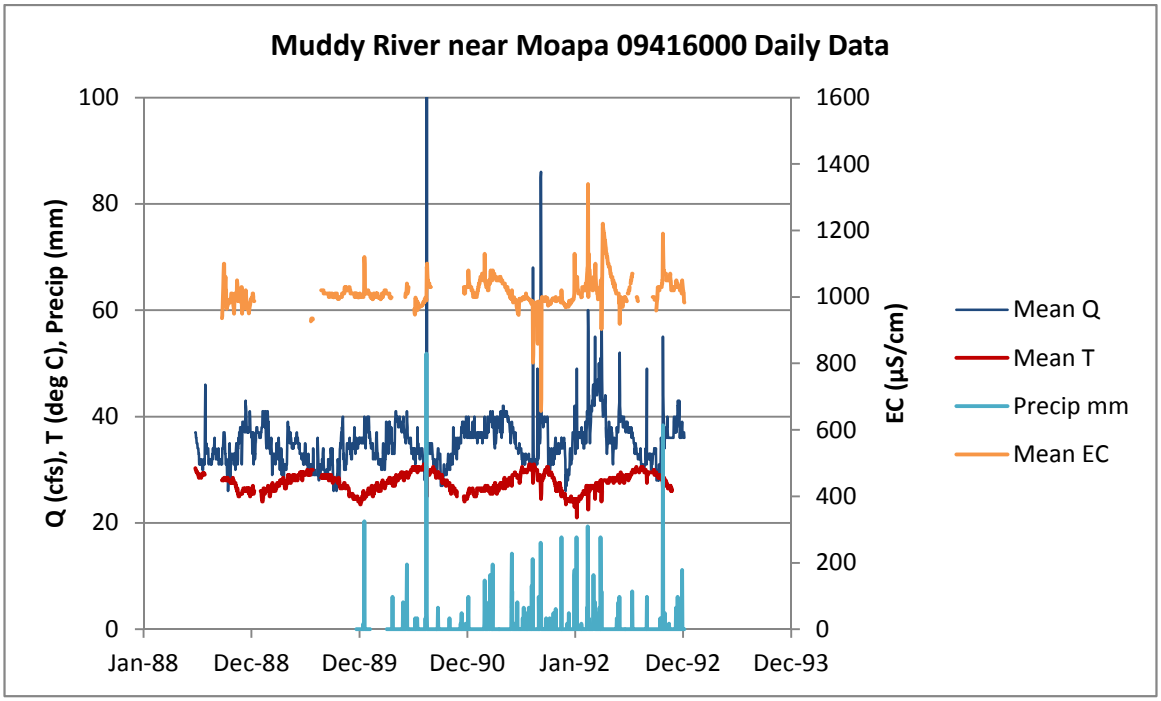


Figure E-2. Average daily discharge, temperature, electrical conductivity, and precipitation at the Moapa gage from USGS records [file MRdailyTempEC.xlsx, sheet 'MRtempEC']

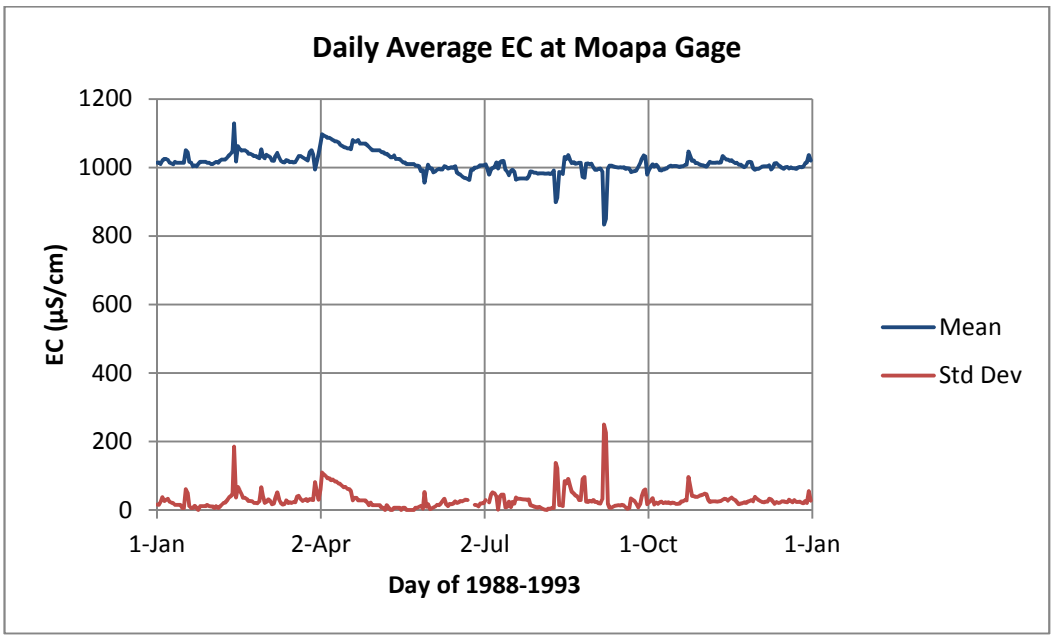


Figure E-3. Average electrical conductivity of the Muddy River at the Moapa gage for individual days during the period when temperature and EC data were collected by the USGS [file MRdailyTempEC.xlsx, sheet 'MRtempEC']

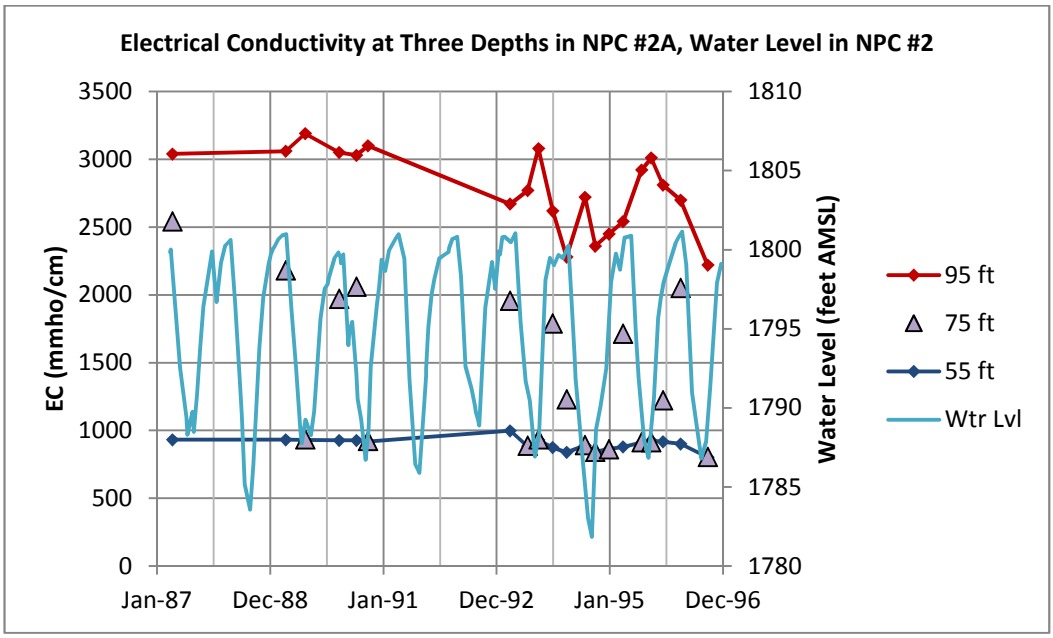


Figure E-4. With the single exception of July 1990, recovery from summer pumping in the Lewis well field is associated with incursion of poor-quality water into the lower portion of monitoring well NPC #2A. This counter-intuitive relationship may be due to the lag associated with delayed yield (leakage) from the Muddy Creek Formation. Note also the trend toward improvement in overall water quality over the 10 years of record, suggesting that pumping stress is inducing inflow of low-TDS water from the Carbonate-rock Aquifer and slowly flushing pathways through the Muddy Creek Formation of stagnant waters. The interface between brackish and fresh waters fluctuates about the 75-foot depth level (1750 feet AMSL), rising and falling in synchronicity with pumping as the water table does, without evidence of upconing that is typical of these situations in, for example, coastal areas.

Using the 4.23 cfs at 1,330 µS/cm for North Fork and 9.22 cfs at 1,170 µS/cm for South Fork that Eakin (1964) reports (points 32 and 33, respectively, on Figure 2), the EC of the calculated 13.45 cfs of combined flow immediately below the confluence is obtained by the mass-balance relation

$$C_{MIX} = XC_1 + (1-X)C_2 \quad (1)$$

where C_1 and C_2 are concentrations of the constituent of interest (EC in this case) in the mixing end-members, C_{MIX} is concentration in the mixture, and X is the mixing fraction of constituent C_1 in the mixture. Taking C1 to represent the EC of North Fork water so X = 4.23/13.45 = 0.314 (the mixing fraction of North Fork water), C_{MIX} = 0.314*1330+(1-0.314)*1170 = 1,220 µS/cm for the mixture.

Downstream roughly 0.3 mile from the confluence of North and South Forks, before inflow from the Muddy Springs Tributary occurs, Eakin (1964) reports a flow rate of 19.5 cfs and EC of 1,290 µS/cm (point 27 on Figure 2). The gain is 6.05 cfs, and the calculated EC of the water entering the Muddy River between the North Fork / South Fork confluence and Eakin's Point 27 is

$$C_2 = (C_{MIX}-XC_1)/(1-X) \quad (2)$$

where C_1 is the previously computed EC of water entering the reach and X is its fraction of the 19.5 cfs, 13.45/19.5 = 0.690, so C2 = (1290-0.690*1220)/(1-0.690) = 1,447 µS/cm. Between the Lewis Well Field and Big Muddy Spring, prior to 1990, the degradation in quality of seepage entering the Muddy River along the trend of North Fork is evident. Underflow associated with North Fork represents the poorest-quality water entering the Muddy River as seepage. This relationship allows a test of the hypothesis that this poor-quality underflow has been diminished by export of groundwater from the headwaters area, and therefore water quality in the Muddy River should have improved as flows have decreased.

Considering 1963 and 2001 measurements on the Muddy River near the LDS Farm (points 27 and 09415885 on Figure 2), measured flow was 3.55 cfs less in 2001, unadjusted for ET, which would increase the difference by perhaps 1-2 cfs by normalizing September (1963) and February (2001) measurements for seasonal ET. Based on the limited control provided by Eakin's 3 laboratory EC measurements (Appendix E), Eakin's field EC of 1290 µS/cm at his point 27 is equivalent to a laboratory EC of 1335 µS/cm. In 2001, at the same location, a field EC of 942 µS/cm and laboratory EC of 988 µS/cm were obtained (Beck and others, 2006, Table E3). This significant freshening and discharge decrease is consistent with elimination of relatively poor-quality seepage into the Muddy River. Using the laboratory-equivalent EC of seepage obtained above with Equation (2), 1,562 µS/cm, the seepage flux reduction required to cause the improvement can be calculated independently by:

$$X = (C_{MIX}-C_2)/(C_1-C_2) \quad (3)$$

where X is the fraction of C_1=1,563 µS/cm seepage that previously mixed with C_2=988 µS/cm River water to produce the C_{MIX}=1,335 µS/cm of Eakin (1964) at point 27. The result, 0.605, implies a loss of seepage flux since 1963 double that obtained by available discharge measurements. This loss is consistent with **hydraulic continuity between the alluvial aquifer in the Lewis Well Field area and the headwaters of the Muddy River, and diminished seepage to the River is a consequence of diminished throughput of groundwater in the Lewis Well Field gravels.**

Appendix F. Parameter Estimation for Order 1169

A common mistake nearly all have made in past efforts to determine how water-level changes are related to pumping stresses in the Carbonate-Rock Aquifer of the Arrow Canyon Range Cell (ACRC) of Mifflin (1992) is the assumption that the most dominant features of well hydrographs throughout the ACRC, multiyear water-level trends and superposed annual water-level cycles, are pumping signals. These large fluctuations "look" like pumping-induced responses because pumping is also seasonal, but they are not. The widespread, synchronous nature of water-level fluctuations leads to interpretations that pumping is the causative factor, but no significant lag or attenuation of the superposed pumping responses with distance from any of the three candidate pumping centers (upper Moapa Valley, southeastern Coyote Spring Valley, or the Apex area) has been detected. Instead, northwestward propagation of the water-level signal between monitoring wells in both California Wash (Figure 17) and Coyote Spring Valley (Figure 20) is evident, suggesting that crustal loading rather than pumping is forcing the annual fluctuations. Climate is the most probable cause of multi-year trends.

Hydrogeologic assessment of water-level monitoring records should begin with the development of aquifer-parameter estimates from the well hydraulics of pumped wells (Kruseman and de Ridder, 1994) and by tidal methods that rely on lag and attenuation of a water-level signal where the signal is found to propagate from a system boundary (Smith, 1999). The well-hydraulics and supporting modeling analyses summarized below have provided aquifer-parameter estimates and evidence of boundary conditions that constrain the possible configurations of pumping-related cones of depression that can be demonstrably attributed to pumping stress. These cones are much shallower and more localized than one would infer by mistakenly equating regional water-level changes with drawdown.

Johnson and Mifflin (2012b) derived transmissivity and storage coefficient estimates for the unconfined Carbonate-Rock Aquifer in southeastern Coyote Spring Valley from drawdowns resulting from pump starts at production wells MX-5 and RW-2. Barometric efficiency, tidal effects, and antecedent trends were accounted for as detailed in the referenced HRT report. Relatively impermeable boundaries cause drawdown rates to increase in that area after just a few hours of pumping, requiring parameter estimates to be based only on the earliest phase of drawdown history. Optimized matches of early pumping-response data to a theoretical type curve are given in Figures F1 through F5, and a good match to late data was achieved using a finite-difference model of a bounded domain (Table F1 and Figure F6).

Mifflin and Johnson (2005) conducted and analyzed a 7-day aquifer test in the Southern Flow Field at ECP-1, where transmissivities an order of magnitude lower than those characteristic of southeastern Coyote Spring Valley and a recharge (upwelling) boundary to the unconfined Carbonate-Rock Aquifer were identified (Figure F7). A sub-regional analytic element model (Johnson and Mifflin, 2006) incorporating parameters derived from this test and consistent with the later Coyote Spring Valley results described above, satisfies water-level and boundary constraints in the model domain (Figure F8, Table F2).

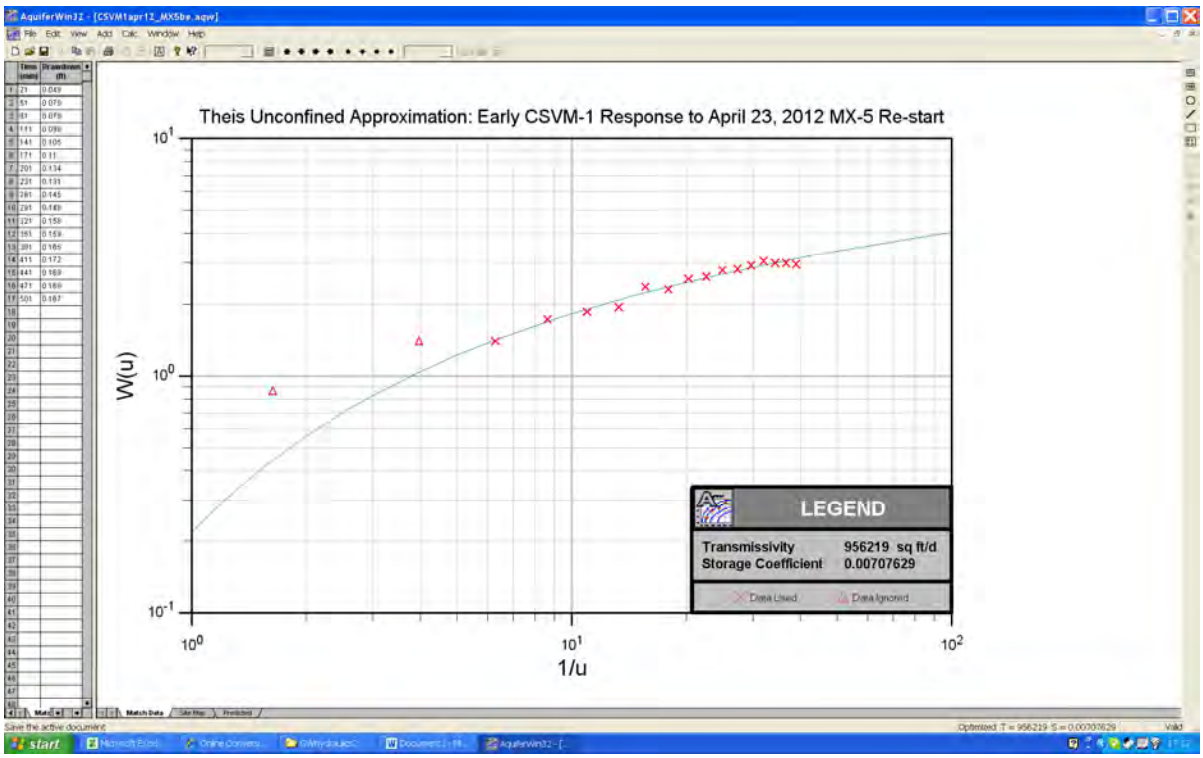


Figure F1. Optimized match to early-time drawdown data, MX-5 pumping rate 3,551 gpm [File CSVM120120423be.tif, screenshot from file CSVM1apr12_MX5be.aqw]

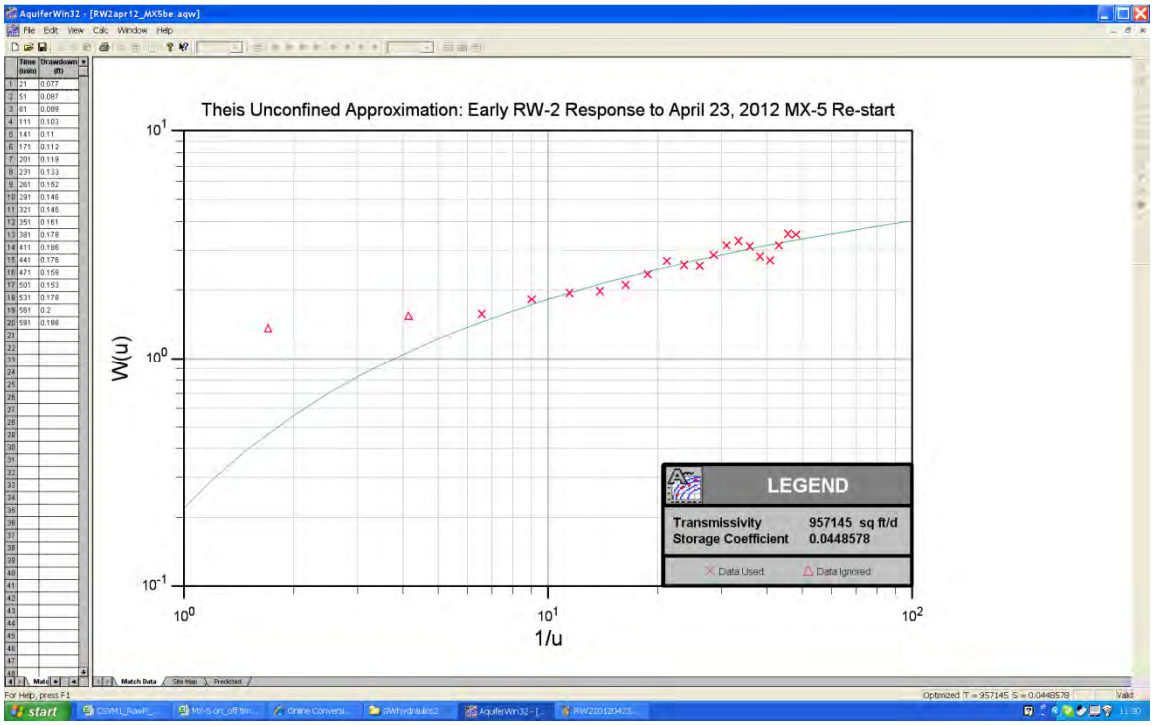


Figure F2. Optimized match to early-time drawdown data, MX-5 pumping rate 3,551 gpm [File RW2120120423be.tif, screenshot from file RW2apr12_MX5be.aqw]

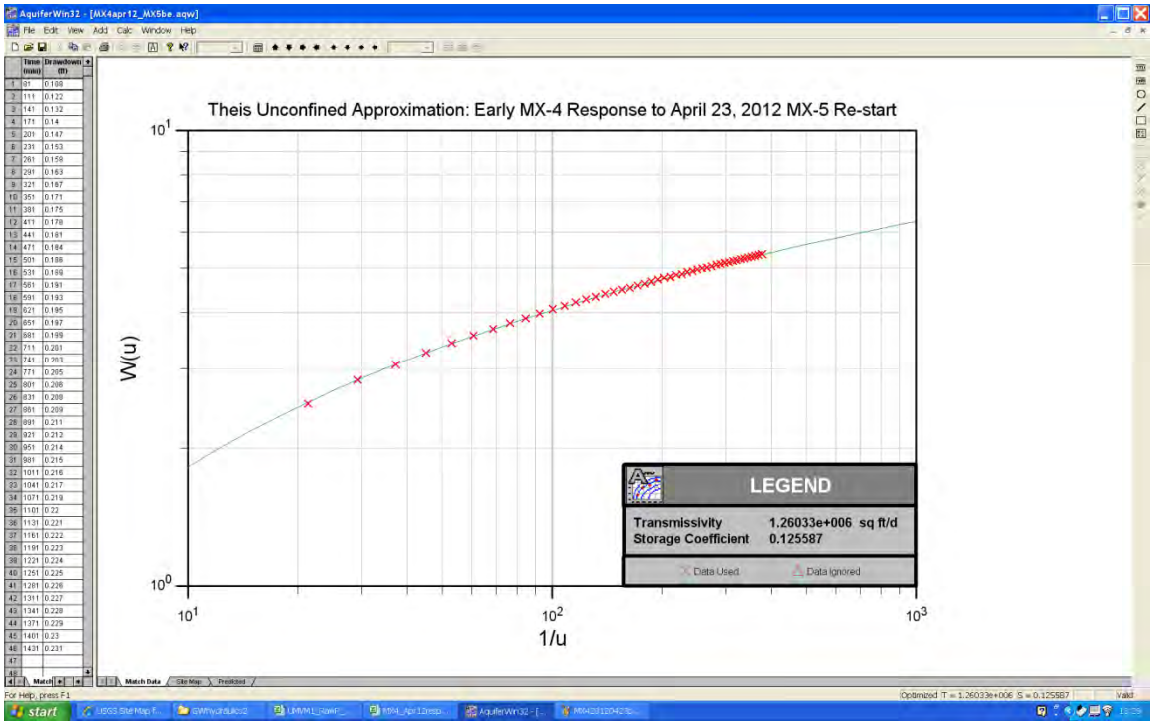


Figure F3. Optimized match to early-time drawdown data, MX-5 pumping rate 3,551 gpm [File MX4120120423be.tif, screenshot from file MX4apr12_MX5be.aqw]

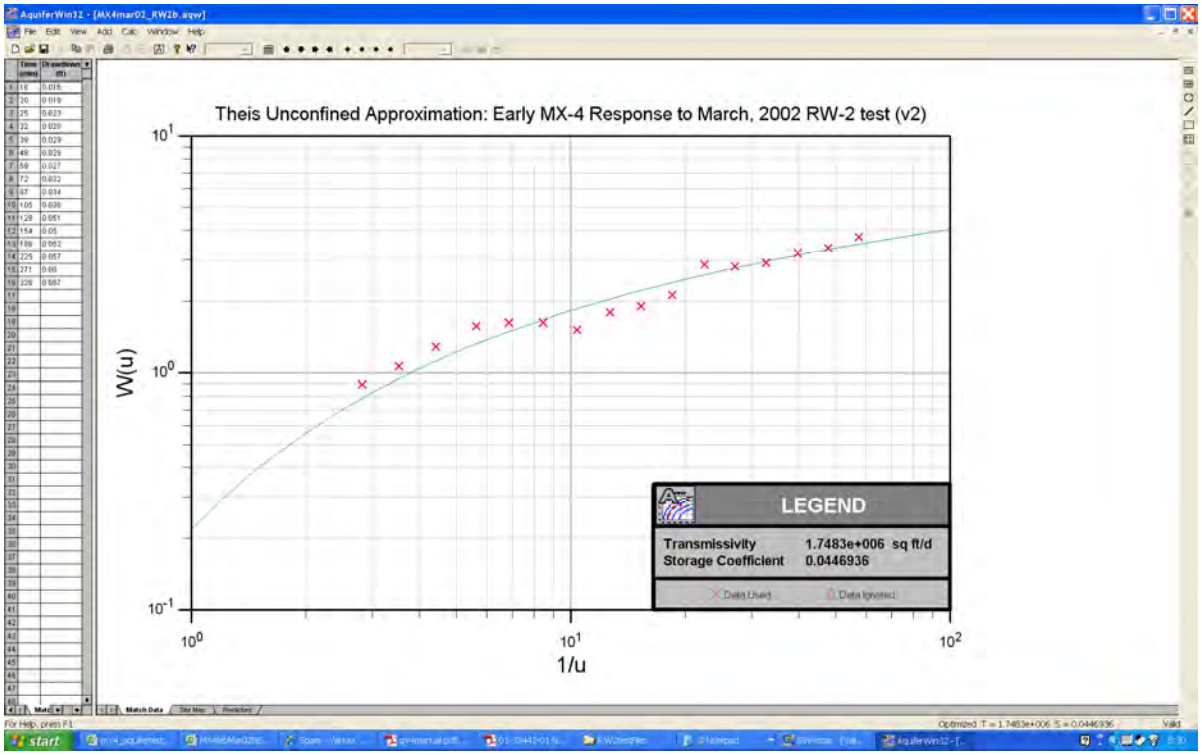


Figure F4. Parameter estimates from early MX-4 response to RW-2 constant-rate test, March 5-6, 2002 [File MX42002RW2v2.tif, screenshot from file MX4mar02_RW2b.aqw]

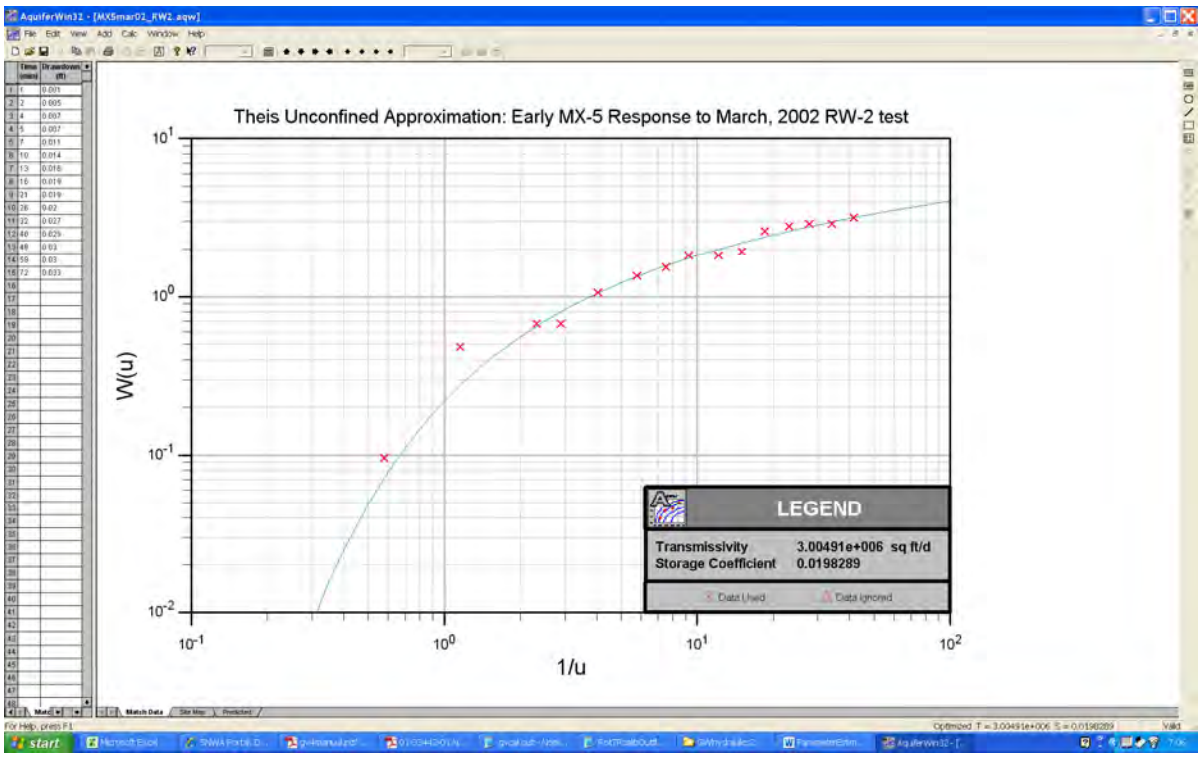


Figure F5. Parameter estimates from early MX-5 response to RW-2 constant-rate test, March 5-6, 2002 [File MX52002RW2.tif, screenshot from MX5mar02_RW2.aqw]

Table F1. Single-Layer Finite-Difference Model Configuration

Domain Extent:	20 miles NW-SE, 10 miles SW-NE, 4000 feet thick		
Grid Origin Location:	E 673742 m, N 4073832 m, UTM Zone 11,NAD83		
Rotation about Origin:	35.62° clockwise		
Number of Cells:	5000		
Cell Dimensions:	x	1056 ft	
	y	1056 ft	
	z	4000 ft	
Parameters:	K_X	329 ft/day	
	K_Y	274 ft/day	
	S_Y	0.003	
Boundary Conditions:	Inflow	4,320,000 ft^3/day	50 cfs specified steady-state flux
	Outflow	1846 ft	specified total head (includes barometric pressure)
	MX-5	-683615 ft^3/day	(3551 gpm)
MX-5 Stress Periods:	1	730 days	70 time steps, 1.2 time step multiplier

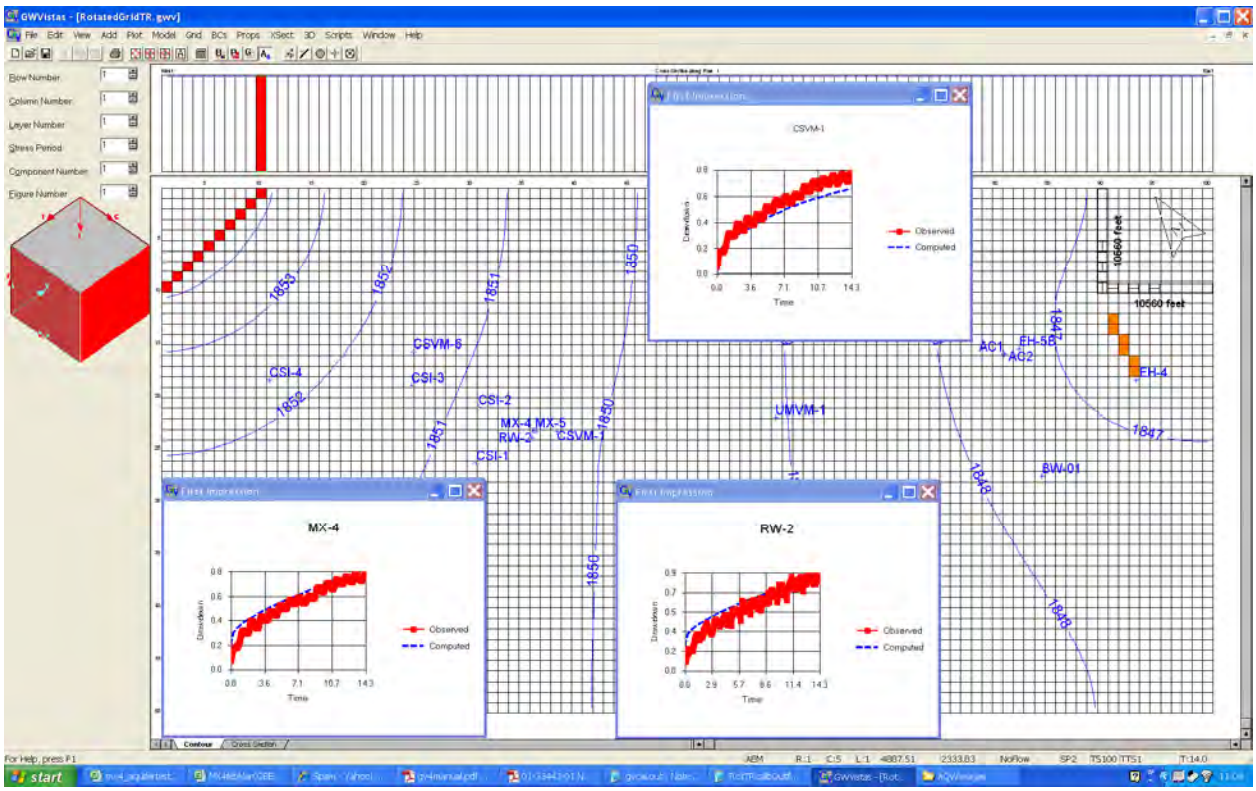


Figure F6. Simulated responses to April 23, 2012 re-start of MX-5 in anisotropic, bounded domain with properties given in Table 1. [File MX42012GWV.tif, screenshot from file RotatedGridTR.gwv]

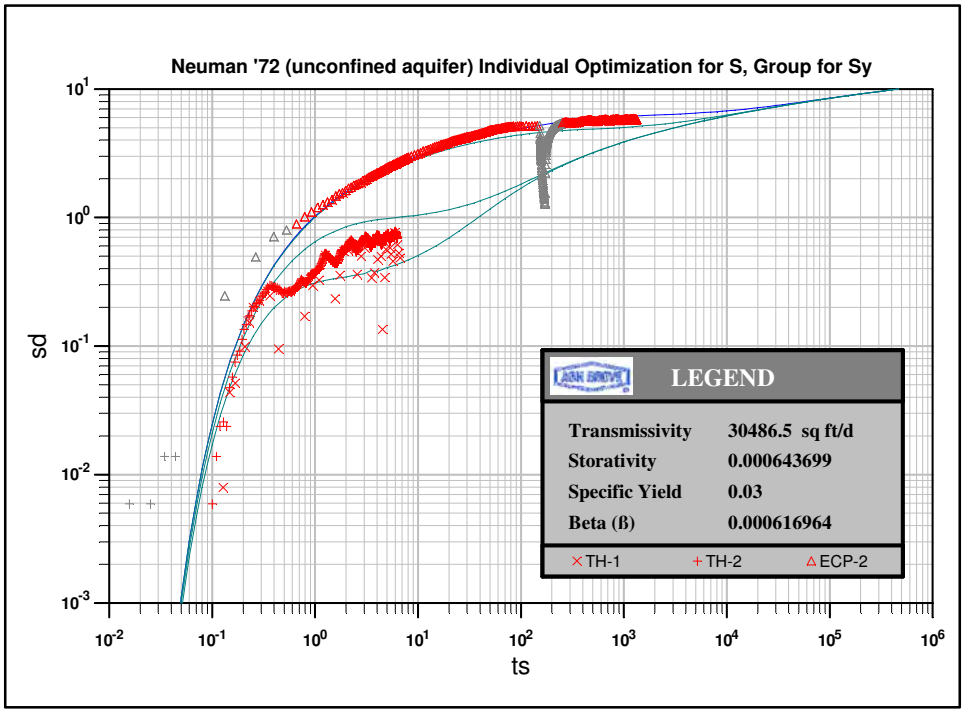


Figure F7. Parameter estimation based on the model of Neuman (1972), from 7-day test in July of 2000 in which ECP-1 was pumped at 1005 gpm. [Mifflin and Johnson, 2005]

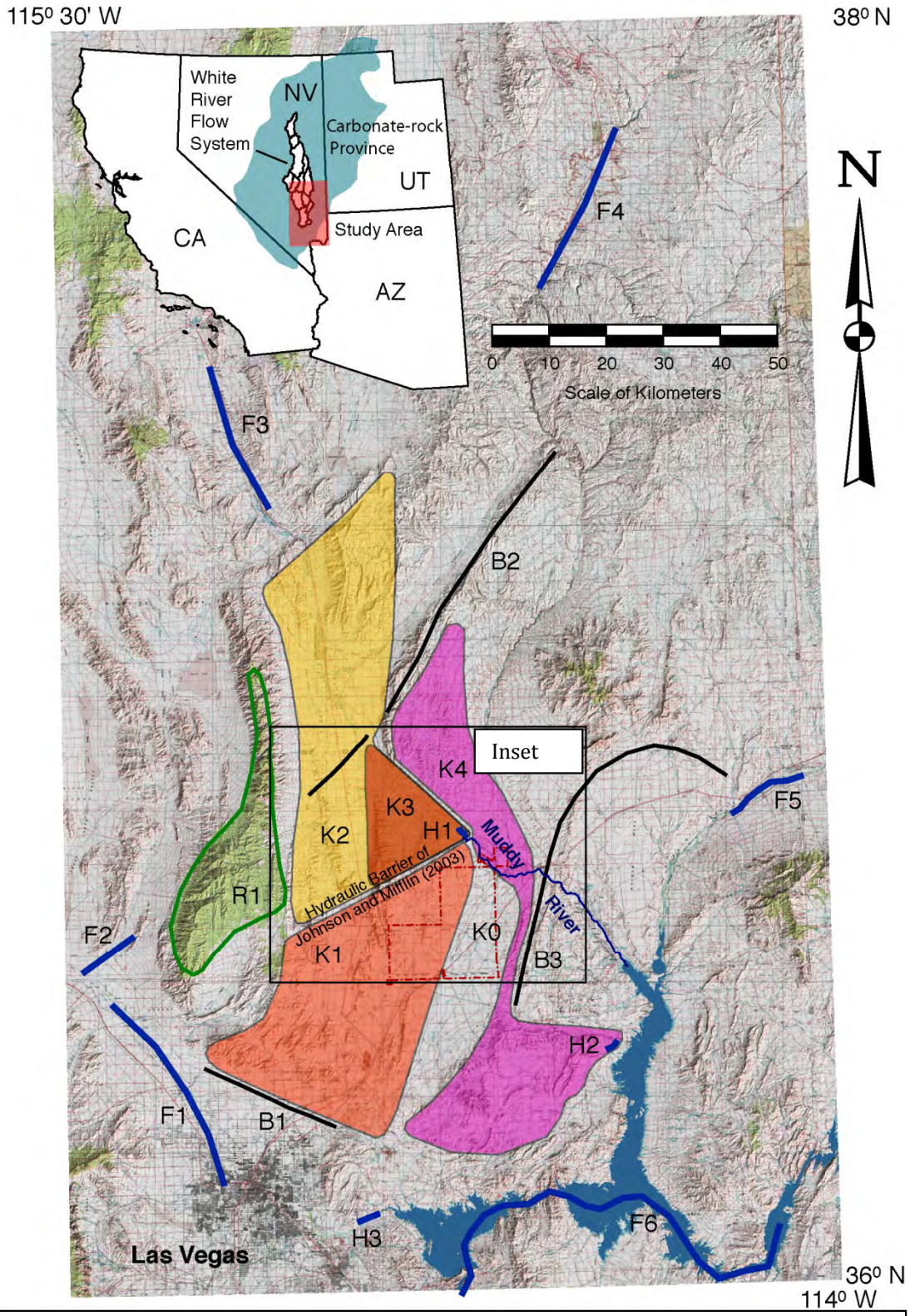


Figure F8. Analytic element representation of the study area, showing hydraulic-conductivity domains (K), no-flow barriers (B), far-field features (F), near-field discharge (H), and recharge (R); reference Table F2 for details [file AshGroveFig2.tif; Johnson and Mifflin (2006)]

Table F2. Features and properties of the analytic element model (from Figure F8)

Far-field controls		
F1	Corn Creek to Las Vegas	Specified heads 892 to 652 m
F2	Divide Well to Cow Camp	Specified heads 895 to 867 m
F3	Pahranagat Valley	Specified heads 1100 to 900 m
F4	Upper Meadow Valley Wash	Specified heads 1500 to 1300 m
F5	Virgin River	Specified heads 500 to 450 m
F6	Colorado River	Specified heads 250 to 200 m
Inhomogeneities		
K0	Far-field zone	K=0.064 m/day, obtained by calibration
K1	Southern flow field	K=6.1 m/day from 7-day aquifer test reported by Johnson et al. (2001). Bounded on south and west by Las Vegas Shear Zone and Gass Peak Thrust, respectively (Longwell et al., 1965); on north by sub-regional hydraulic barrier described by Johnson and Mifflin (2003 and this report), and on east by down-faulted Tertiary (K0) sediments of California Wash (Johnson et al., 1986; Langenheim et al., 2001,2002)
K2	Northern flow field	K=12.2 m/day, obtained by calibration. Bounded on west by Gass Peak Thrust, on north by Menard Lake Fault, and on east by Delamar Mountains Thrust and fold belt (Tschanz and Pampeyan, 1970).
K3	Arrow Canyon zone	K=36.6 m/day from analysis of seasonal pumping response, 1997-2001 (Johnson and Mifflin, 2003 and this report). Bounded on west by normal fault on west side of Arrow Canyon Range.
K4	Glendale cell	K=5.5 m/day, obtained by calibration. Isotopic data reviewed by Pohlmann et al. (1998).
Near-Field Discharge		
H1	Muddy River springs	Specified heads 536 to 530 m, hydraulic resistance 1.35 days
H2	Rogers / Blue Point Springs	Specified heads 488 to 463 m, hydraulic resistance 2.7 days
H3	Southern receptor zone	Specified heads 450 to 396 m at south end along Las Vegas Wash, hydraulic resistance 2 days
No-flow barriers		
B1	Las Vegas Shear Zone	Accounts for large hydraulic gradient between Southern flow field (K1) and Las Vegas Valley, and absence of candidate outflow component in Las Vegas Valley groundwater (Johnson et al., 2001)
B2	Kane Springs Wash Fault	Diverts flow from north around area of exposed basement rock in Mormon Mountains (Tschanz and Pampeyan, 1970); southwestward extension in Coyote Spring Valley required to fit VF-2 and CSV-3 water levels (Figure 3).
B3	Weiser Syncline	Continuous feature per Axen et al. (1990), bent and rotated clockwise at northern end by Moapa Peak Shear Zone; required to match EH-3 and EH-7 water levels (Figure 3)
Recharge		
R1	Sheep Range	0.7 cm/yr in forested highlands, by calibration. Recharge area encompasses 420 km^2, total 2.94 x 10^6 m^3/yr (2380 acre-ft/yr). Previous estimates include 2,000 acre-ft/yr (Eakin, 1966), 5,000 to 6,000 acre-ft/yr (Kirk and Campana, 1990) and 14,000 acre-ft/yr (Thomas et al., 1996).

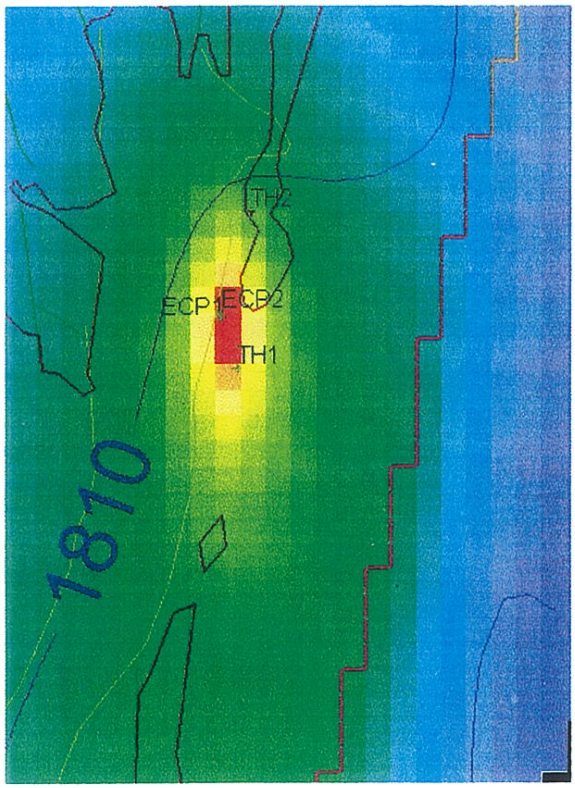
Mifflin & Associates, Inc.

HYDROGEOLOGIC AND GROUNDWATER MODELING ANALYSES for the MOAPA PAIUTE ENERGY CENTER

A Calpine Company Project
In Cooperation with the Moapa Band of Paiute Indians

CALPINE

Moapa Indian Reservation
Clark County, Nevada



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February, 2001

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F. Supplemental Analyses of Outyears and Heavy Development Scenarios

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1.0 Executive Summary

An extensive regional hydrogeologic database, and new hydrogeologic information developed in this study at Belly Tank Flat and surrounding areas of the Moapa Indian Reservation, Nevada, are the basis for this assessment of the long term groundwater supply for the proposed Moapa Paiute Energy Center (Project). Exploratory drilling and test pumping were performed between March and December 2000 in and around Belly Tank Flat, the Project site. The Belly Tank Flat area of the Moapa Indian Reservation will support a well field in the Carbonate Aquifer producing 7,000 acre-feet per year (afy) for up to 45 years, the Project life. The Project is equidistant from the northern and southern most areas of the Arrow Canyon Range Cell, and 15 miles from existing water development or regional spring discharge.

The Project is within the Arrow Canyon Range Cell, an approximate 40 by 30-mile region dominated by carbonate-rock terrain where groundwater fluid potentials are almost uniform. The Carbonate Aquifer in this Cell is a potential source of water for a large region, including the Project. About 15 miles to north of the Project site, in the Muddy River Springs Area, an average of 51 cubic feet per second (cfs) (≈37,000 afy) flows to the area in the Carbonate Aquifer. The Project site is within the California Wash hydrographic basin #218, where at this time, groundwater withdrawals are minimal.

The Arrow Canyon Range Cell, based on geochemical, isotopic, and water-level data, contains two distinct flow fields as described in this investigation:

- A northern flow field originates from mixing of end-member waters from Pahranagat Valley, southern Meadow Valley Wash, and the Sheep Range discharges at the Muddy River Springs Area.
- A southern flow field, first recognized in this study, displays nearly flat hydraulic gradients in some areas, an overall southerly regional gradient, generally uniform isotopic compositions, and water geochemistry that differs from the northern flow field. It lacks any component of Meadow Valley Wash water, and may originate from a mix of roughly 4,000 afy of northern regional flow with up to 6,500 afy of groundwater derived from the Sheep Range.

Calibration studies of a steady state groundwater model (GFLOW) yield ≈9,500 afy of flux in the southern flow field as compared to ≈10,500 afy of flux suggested by the above stated isotopically constrained water balance of potential source waters to the southern flow field. These independently derived estimates indicate the general order of magnitude of flux that may be present in the southern flow field, but the estimates should be considered soft numbers.

The two flow fields are separated by an interface zone within 10 miles of the Project area where no physical basis for separation of the two flow fields has been recognized.

The objectives of groundwater modeling analyses established in the study are 1) to evaluate the long term availability of groundwater resources and 2) study credible regionally propagated impacts resulting from pumping 7,000 afy for as many as 45 years. The Analytic Element Method (GFLOW) was adopted and calibrated with observed water levels and spring flows for a

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regional steady state model. This approach helped to evaluate regional groundwater flow and to establish aquifer and boundary conditions for a 40 x 40 mile finite difference grid (MODFLOW transient state analyses) centered over the Project area. A 7-day aquifer test at the Project area helped to establish aquifer properties of transmissivity and storage that were utilized in the modeling. Three prescribed boundary condition scenarios were used in the MODFLOW transient state analyses to explore and bound a range of credible system responses to pumping from the proposed well field at Belly Tank Flat. The modeling analyses result from combinations of computer-based calculations and professional judgment. The modeling analyses incorporate:

- Highly developed hydraulic continuity in the Carbonate Aquifer between the northern and southern flow fields, a conservative approach that allows (encourages) pumping impacts to be projected into the northern flow field.
- Three transient scenarios of boundary conditions that address the level of uncertainties related to regional conditions and sparse data.

The three transient scenarios, established by varied boundary conditions, forecast regional drawdowns and the percentages of reduction in groundwater flow to the Muddy River Springs Area after 25 and 45 years of pumping 7,000 afy at the Project site. Within this modeling framework two are considered bounding scenarios to address hydrogeologic uncertainty, Cases 2 and 3, below.

The Case 2 boundary condition scenario incorporates prescribed heads at the model boundaries where there is transmissive terrain. This is the non-conservative case that allows induced inflow to compensate pumping effect.

The Case 3 boundary condition scenario is the overly conservative case, which prescribes flux at the model boundaries, forcing all water pumped from the proposed well field over time to be derived from storage in the 40 x 40 mile modeled domain or captured flux from the northern flow field. It therefore forecasts the greatest impacts on flows to the Muddy River Springs Area over time and produces the greatest regional drawdowns. Although extremely unlikely, Case 3 useful for discussions of environmental impacts because effects compatible to those associated with Case 3 have already been expressed in the historic record.

The most probable boundary condition scenario, Case 1, incorporates a combination of prescribed constant heads and fluxes at the model boundaries (the hybrid case).

1.1 Forecasts Derived from Modeling Analyses

The following table gives the model-derived forecasts of decreases in regional flux to the Muddy River Springs, absent any physical barrier between the northern and southern flow fields.

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Modeling Forecasts of Decreases in Regional Flux to the Muddy River Springs Area Project Area Pumping 7,000 afy

	25 years		45 years
Run ID	**Discharge Decrease, %**	**Run ID**	**Discharge Decrease, %**
Case 1 Hybrid25yr	0.7	Case 1 Hybrid45yr	1.3
Case 2 Head25yr	1.1	Case 2 Head45yr	1.1
Case 3 Flow25yr	7.5	Case 3 Flow45yr	10.4

Case 1 and Case 2 would produce very minor impacts on flow and no impacts on aquatic habitat.

Case 3, which mirrors historic effects in many respects, begins to produce significant decreases in groundwater flow to the Muddy River Springs Area by 25 years. About half of the water extracted at 45 years from the Project well field in Case 3 (about 5 cfs) would be derived from the flow field contributing to the Muddy River Springs Area. The flux of the northern flow field to the Muddy River Springs Area is approximately 51 cfs and a 5 cfs reduction would be likely manifested as approximately 3 cfs of reduction in baseflow from the local Carbonate Aquifer fed alluvial aquifer to the headwater Muddy River channels, and a total of about 2 cfs of reduction in distributed discharge from the springs of the area.

It is emphasized that magnitudes of the impacts on the discharge area hydrologic features with the Case 3 reductions of flow forecasted at 25 and 45 years are generally within the historic envelope of flow and aquatic habitat conditions. Local pumping impacts, annualized, are twice as large, and natural long term variations due to drought and wet periods are about the same order of magnitude (5 or 6 cfs). However, during prolonged multiyear drought periods, some intermittent flow segments of the uppermost reaches of the Muddy River would likely become ephemeral channels without baseflow periods, and transitions of short reaches from perennial to intermittent flow would likely occur as far downstream as the Big Muddy Spring area. Discharge to spring supported aquatic habitats would be reduced by up to 10% less flow than historic minimums during extreme multiyear drought periods. The impacted river channel segments are currently, for the most part, intermittent, displaying baseflow supported flows for up to several months each year. Most if not all spring flows would persist, and spring flow supported aquatic habitats would not likely be subject to significant changes.

The Case 3 projected hydrologic and aquatic habitat impacts in the Muddy River Springs Area are judged unlikely due to the extremely conservative assumptions imbedded in the Case 3 model analysis. The two flow fields with distinctive water geochemistries suggest that the well developed hydraulic continuity imbedded in the model between the two flow fields is likely absent, and if so, there would be more limited or no impacts on spring flow. The water geochemistry evidence for deeply circulated regional flow in the general vicinity of the pumping

center suggests an upwelling zone between the pumping center and spring area. This would likely have an equal or stronger net affect on a northward propagating pumping cone as the prescribed head boundaries applied in Case 1 and Case 2 (located at ≥20 miles from the pumping center). The interface zone between the two flow fields is less than 10 miles from the Project area, and a zone of upwelling of deeply circulated water would likely behave similar to a constant head boundary, but with a stronger net effect of limiting northward propagation of pumping impacts due to its proximity to the pumping center.

A monitoring program has been designed and implemented by Calpine Company and the Moapa Band of Paiutes, and is providing continuous records of barometric pressure and water levels at one site and water levels at 4 locations at and surrounding the proposed pumping center. The new monitoring wells complement and extend monitoring in the Muddy River Springs Area and Coyote Spring Valley. The monitoring well network is designed to allow recognition of regionally propagated pumping effects decades prior to measurable impacts at sensitive areas, as well as provide databases needed for groundwater model refinements. Plans for mitigation could be activated in accordance with model projections.

1.2 General Conclusions

1. Water balances based on isotopic signature of mixing water sources and steady state regional model calibration indicate as much as 10,500 afy of flux may occur in the southern flow field. The regional steady state modeling calibration (GFLOW) indicates about 9,500 afy of flux exiting the southeastern portion of the cell southeast of the Apex Industrial area. The two independently derived estimates are comparable, but these estimates are clearly soft numbers. Other estimates have been both larger and smaller, and they too are accompanied by considerable uncertainty.
2. The primary source of groundwater in the Project area is regional flow in a separate flow system (southern flow field) than that supplying the Muddy River Springs Area (northern flow field), based on fluid potentials, geochemical, and isotopic evidence. The modeling analyses do not impose any physical barrier between the two flow fields to assure conservative forecasts. The evidence for an upwelling regional water source supplying the southern flow field reduces the probability that impacts from Project pumping will be propagated to the Muddy River Springs Area.
3. Geochemical data, isotopic data, and an ≈200 foot difference in fluid potentials of waters in the Belly Tank Flat area and Rogers/Blue Point Springs area, as well as variable spring discharges at Rogers/Blue Point Springs area support a projection of no impacts at the Rogers/Blue Point Springs area due to Project pumping.
4. Two bounding modeling scenarios both of which conservatively assume the range of credible system responses to the production of 7,000 afy from the Project area. Case 2, judged to be somewhat non-conservative, produces essentially no decreases in discharge in the Muddy River Springs Area for over 45 years, no impact at Rogers and Blue Point Springs, and therefore, no impacts on aquatic habitat. Case 3, highly conservative and unlikely, would produce significant reduction of flows by 25 years and 45 years, but still not of a magnitude to markedly impact perennial flow supported aquatic habitats. Approximately 5 cfs of reduced flow to the Muddy River Springs Area is forecasted at 45 years in Case 3.
5. There will be no significant impacts to groundwater users to the south because of the

deep water table and forecasted small-scale drawdowns that would result from prolonged Project pumping.

6. The Project is accompanied by a monitoring well network designed to establish refined knowledge of regional aquifer characteristics which in turn allow improved model forecasts. The monitoring well network is in place and operating. It is designed to recognize greater than anticipated water-level declines between the Project area and Muddy River Springs Area. The monitoring well records will allow accurate forecasts of pumping impacts of regional scale decades before unacceptable impacts could develop in surrounding areas.

In summary, within the limitations of the local and regionally available databases, this study projects a groundwater-resource base that support the proposed Project. The most probable regionally propagated pumping impact over 45 years produced by 7,000 afy of production at the Project site, Belly Tank Flat, would not produce significant impacts on regional discharge areas of the Carbonate Aquifer. The Project would produce small regionally propagated water-level declines over large areas. A monitoring well network has been designed and implemented to verify and refine these forecasts.

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2.0 Introduction

2.1 Purpose of this Report

This report summarizes and interprets regional databases and establishes modeling analyses for the proposed 7,000 acre-feet per year (afy) of groundwater extraction from the California Wash hydrographic basin, Clark County, Nevada (Figure 1) by the Moapa Band of Paiutes and Calpine Company, for purposes of electric power generation.

The modeling analyses studied the regional flux and storage conditions of the Carbonate Aquifer in and around the Project area, and the extent and nature of impacts if such waters are withdrawn for beneficial use. A model of the regional, steady-state flow was developed using GFLOW (Haitjema, 1995), a modeling environment based on the Analytic Element Method (AEM). Three scenarios and associated impacts of the proposed 7,000-afy appropriation were evaluated using numerous MODFLOW (McDonald and Harbaugh, 1988) simulations to estimate 25 and 45-year drawdowns in the site area and hydrologic impacts in major spring areas to the northeast and southeast. A fundamental, conservative assumption has been incorporated into these modeling scenarios that allows for pumping impacts to be efficiently propagated into flow fields supplying the regional spring area to the north, even though hydrochemical and isotopic databases provide evidence that such well-developed regional hydraulic continuity may not be present.

Finally, a comprehensive data set are provided as appendices to this report and include:

- Appendix A, ECP-1 Aquifer Tests Summary Report
- Appendix B, Geochemical and Isotopic Data for the Arrow Canyon Range Cell and Surrounding Areas
- Appendix C, Horizontal and Vertical Elevation Control and Water Levels for Carbonate Rock and Associated Wells Located in the Apex, California Wash, Hidden Valley, Coyote Spring and Moapa Areas
- Appendix D, Nevada State Engineer Hydrographic Basin Abstracts of Active Water Rights Status, Current Through 8/17/00
- Appendix E, Monitoring Plan, Moapa Band of Paiutes
- Appendix F, A Summary of Groundwater Development Impacts in the Upper Muddy River Valley

A full listing of boundary conditions exported by GFLOW and used to establish a model flow field in the sub-regional MODFLOW domain are provided, as well as diagrams of all parameter zones incorporated in these models.

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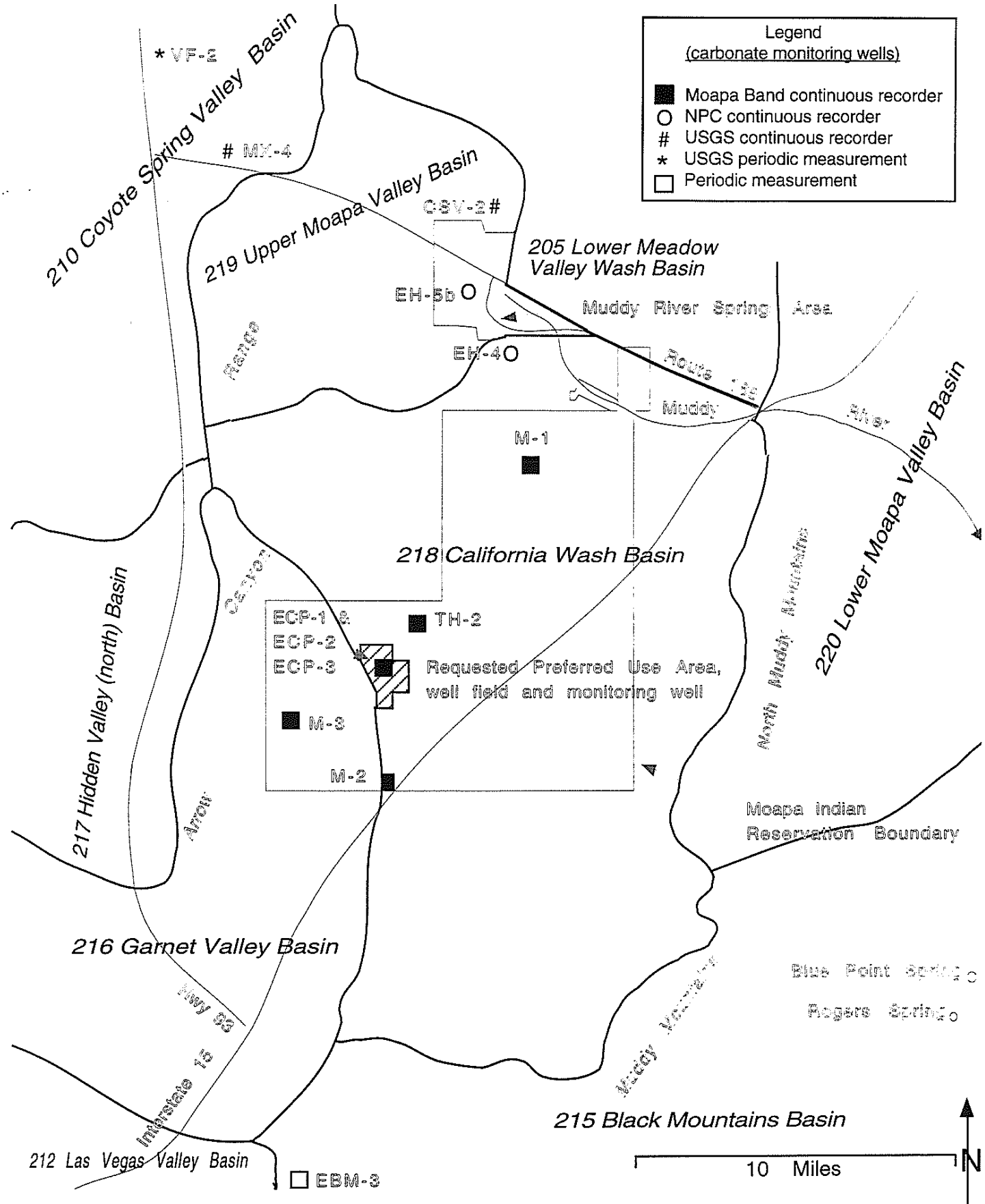

Figure 1. Groundwater basins surrounding California Wash basin.

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2.2 Model Considerations and Background

Modeling analyses and evaluations of hydrologic data from wells and springs have been made to study the effects of the production of 7,000 afy from the Carbonate Aquifer in and around Belly Tank Flat of the Moapa Indian Reservation, an area included by the Requested Preferred Use Area (Figure 2). The proposed 7,000 afy of production on the Moapa Indian Reservation would be the first major pumping stress on the Carbonate Aquifer other than local, heavy production in the Muddy River Springs Area. The production for power generation would occur for a minimum of 25 years and renewable for 20 years for a total of 45 years based on leased water-right agreements between the Moapa Band of Paiutes and the Calpine Company. The well field is distant (15 and 22 miles) from existing production from, or springs fed by, the carbonate rock aquifers.

The large transmissivities measured in the Carbonate Aquifer in the Belly Tank Flat Well Field (Appendix A) and other local areas far to the north (MX-4 and Muddy River Springs Area) and south (Apex and Nevada Cogeneration well field), and the small differences in water-level elevations suggest that well-developed regional hydraulic continuity might extend throughout much of the extent of the Arrow Canyon Range Cell (Mifflin, 1992) an area as large as approximately 40-mile (N-S) by 30 mile (E-W). Small fluid-potential gradients apparently persist throughout a portion of this carbonate terrain in an area 30-mile (N-S) by 10-mile (E-W). However, there is compelling evidence that groundwater flow within the Arrow Canyon Range Cell is compartmentalized into at least two distinct flow fields, a northern and southern flow field. Portions or all of seven groundwater management basins are superposed on the Arrow Canyon Range Cell of the Carbonate Aquifer (Figure 1).

The most refined approach to projecting potential impacts in time and space is through groundwater modeling that incorporates transient responses to pumping and geologically appropriate boundary conditions. Pumping cones of depression in the potentiometric surface will vary over time and these variations and projected effects on spring flow are the subject of modeling analyses. The carbonate-rock terrain that constitutes the Arrow Canyon Range Cell incorporates both recharge areas and one major spring discharge area, and is bounded by generally less permeable basin or bedrock lithologies. Boundary conditions adopted in modeling analyses are critical to the accuracy of predictive modeling results, yet very poorly documented by direct measurement or observation in the region under study. Therefore, model boundaries must be prescribed through use of varying degrees of professional judgement and refined during the model calibration process. To an important extent, the flow-field databases within the cell yield indirect evidence of the distribution and probable nature of the boundary conditions, but fail to constrain the modeling analyses to a single or unique configuration that confidently simulates the natural system. Therefore, even though the modeling codes that have been applied are extremely useful in terms of accurate simulation of groundwater flow fields and transient changes which may occur due to pumping stresses, uncertainties remains in the application of boundary conditions and flow-field over such a large area.

Applications of boundary conditions and flow-field properties included:

- A trial-and-error process of varying aquifer properties and boundary conditions until the model produces a reasonable representation of *both* the fluid-potential surface in the area

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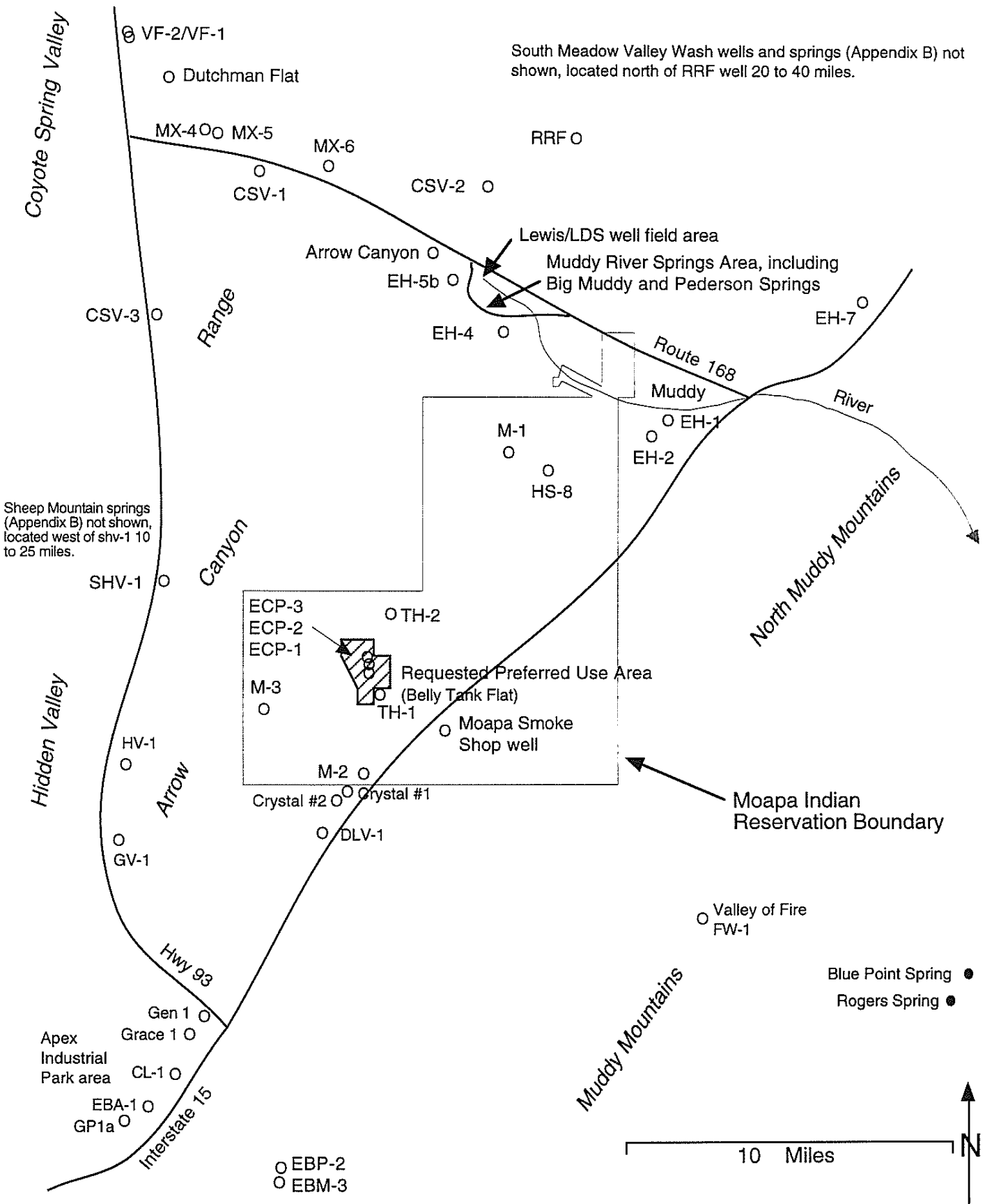

Figure 2. Map showing well and spring locations referenced in Appendix B and used in this report.

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of interest and discharge rates at the regional spring areas. This process of stepwise refinement constrains the flow model to what has been observed, and restricts the range of boundary condition scenarios that calibrate the model.

- Applying expert judgment from the perspective of isotopic and geochemical databases (Appendix B). Such independent databases help identify possible sources of recharge, and quantify mixing relations and hydrologic mass balances.

Evidence has been assembled to support that there are two flow fields in the Arrow Canyon Range Cell:

- the northern flow field which discharges at the Muddy River Springs Area, and

- the southern flow field, a deeper-sourced flow field that is identified in the southern portion of the cell which probably upwells in the vicinity of the Belly Tank Flat.

Isotopic data indicate that the Rogers-Blue Point area of discharge is unlikely to be a discharge point for the Arrow Canyon Range Cell waters. Multiple lines of evidence indicate that well developed hydraulic continuity between the southern flow field and Rogers and Blue Point Springs is absent, and therefore these springs are not subject to impacts induced by the Calpine Project (Project) pumping stresses.

3.0 Regional Databases

3.1 Geology

The regional aquifer is a westward-thickening section of Paleozoic carbonate rocks, in part unconformably overlain by generally fine-grained sediments of the Muddy Creek Formation, (Figure 3), (Longwell and others, 1965; Bohannon, 1983). Structurally, the Paleozoic rocks have experienced two major episodes of deformation:

- Compression characterized by thrust faults and intense folding during the Cretaceous Sevier Orogeny, and

- Normal faulting during subsequent Basin and Range extension.

Locally, thick sections of Mesozoic redbeds, Middle Tertiary volcaniclastic sediments, and late Tertiary Muddy Creek Formation form aquitards in contact with the more transmissive carbonate rocks. Exposed upper Paleozoic strata near the Project area are steeply dipping to vertical, and constitute the lower plate of the Dry Lake Thrust (Longwell and others, 1965). The carbonate rocks of the Arrow Canyon Range Cell are bounded along the east side by an extensional fault that down drops the Muddy Creek Formation and Middle Tertiary volcaniclastic rocks, and on the south by the Las Vegas Shear Zone and related eastern splay faults. The diagrammatic hydrostratigraphic sections shown on Figures 4 and 5 illustrate these relations.

3.1.1 Hydrogeology Background

The hydrogeology of the Arrow Canyon Range Cell is recognized as unique yet poorly

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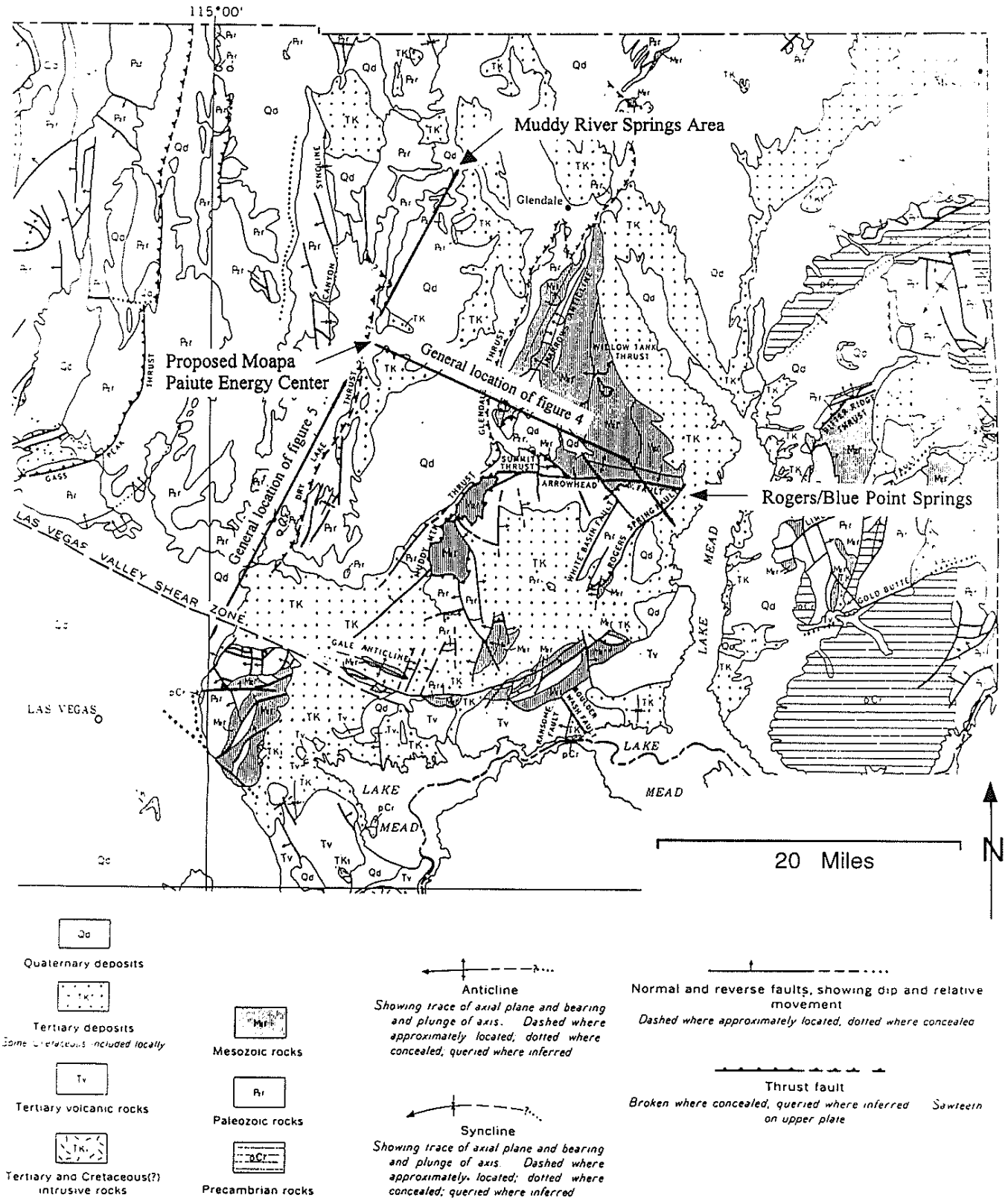

Figure 3. Tectonic base map used to define boundaries of modeling domains (modified from Longwell and others, 1965).

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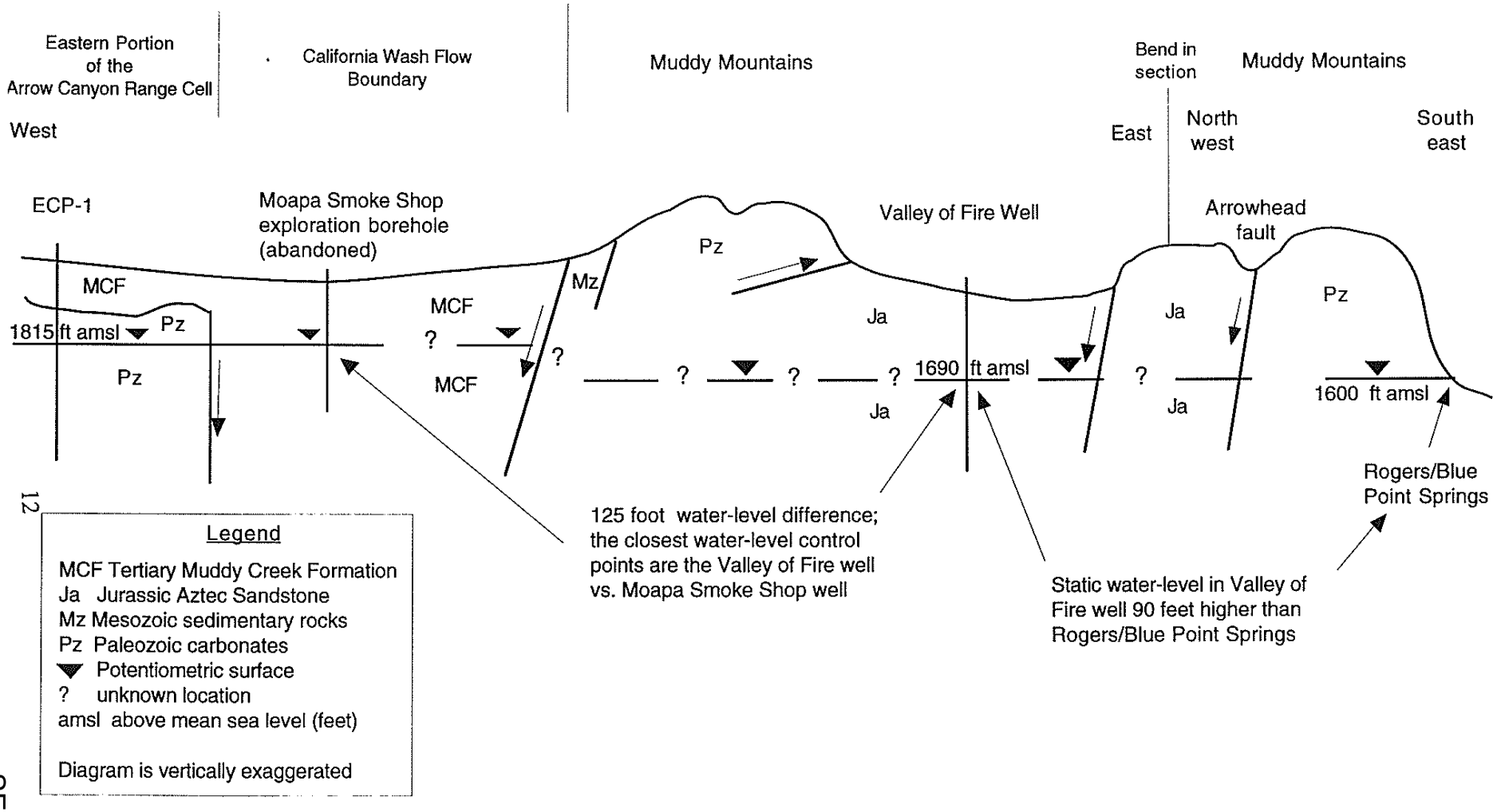

Figure 4. A diagrammatic 22 mile cross section showing the interpreted hydrogeology from the Moapa Paiute Energy Center (MPEC) area (ECP-1) in the west to Rogers/Blue Point Springs in the east (refer to Figure 3 for general location). Note the 200 foot change in water level from the Arrow Canyon Range Cell and California Wash Boundary region to the Muddy Mountains area and Rogers/Blue Point Springs.

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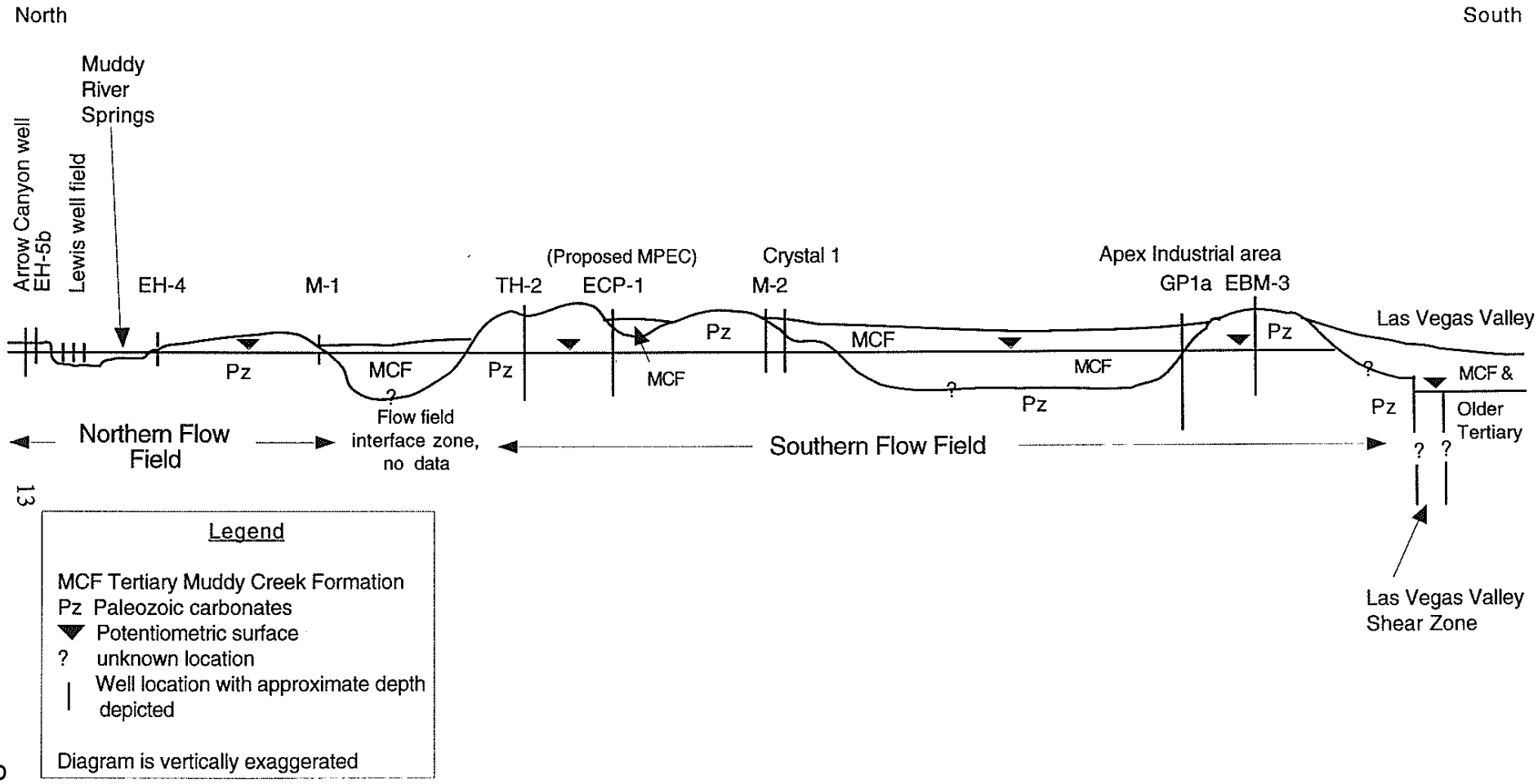

Figure 5. An approximate 40 mile north-south diagrammatic cross section showing the interpreted hydrogeology from the Muddy River Springs area in the north to Las Vegas Valley in the south (refer to Figure 3 for general location). Northern and southern flow field groundwater show different geochemical and isotopic signatures and are separated by an interface zone. The general location and nature of the interface zone is shown.

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understood in terms of detailed documentation. This and other studies have expanded hydrogeologic databases and identified important relationships, but there remains a high degree of uncertainty concerning conditions at depth due to the sparse data in this vast and complex terrain.

Mifflin (1988) reviewed the dominant factors which determine the hydrogeologic characteristics of the Great Basin, which are applicable to the Arrow Canyon Range Cell and include:

1. Extensional faulting has resulted in marked topographic differences and lithologic contrasts between geologically diverse range blocks and intermontane sedimentary basins. The Arrow Canyon Range Cell consists, at least in part, of carbonate rock terrain of the Sheep Range on the west and the Las Vegas Range in the southwest, the basement carbonate terrain of Hidden Valley – Coyote Spring Valley basin structural block, the Arrow Canyon Range and related extensions in the central region, and the Dry Lake Range to the east and intervening basins. These basins and ranges are generally north-south trending structural blocks composed primarily of Paleozoic carbonate rocks, with the intermontane basins partially filled with a relatively shallow veneer of Cenozoic basin deposits directly overlying Paleozoic carbonate rocks. Bounding the eastern domain of the Arrow Canyon Range Cell is the intermontane extensional basin, the southern Meadow Valley Wash - California Wash formed by downfaulted Tertiary sediments (at least 4,000 feet thick) which acts as a regional barrier to carbonate terrain flow.
   The Meadow Valley Wash – California Wash basin, bounding the Arrow Canyon Range Cell on the east, hydrogeologically differs from many intermontane basins in that there are only limited extents of Quaternary and Holocene alluvial aquifers inset within the fine-grained Muddy Creek Formation sediments. Those that do exist form local, but relatively shallow transmissive, alluvial aquifers in the centralized areas of the basin along the Muddy River, Meadow Valley Wash, and California Wash. The thin alluvial aquifers inset into the Muddy Creek Formation generally are highly transmissive and initially yielded good quality water, but water qualities have markedly declined in some areas (Meadow Valley Wash) due to pumping induced migration of Muddy Creek Formation water into the heavily pumped alluvial aquifer. The majority of groundwaters of the Meadow Valley Wash – California Wash basin sediments are not closely related to Arrow Canyon Range Cell carbonate terrain water, but the Muddy River – Moapa Valley alluvial gravel aquifers are directly related to Muddy River Springs Area discharge.
2. Regional patterns of precipitation combined with terrain altitude results in the highest mountain ranges receiving the majority of precipitation that becomes recharge. The carbonate terrain is efficient in retaining a relatively high percentage of precipitation as recharge, and well to the north of the Arrow Canyon Range Cell, the mountain ranges of east central Nevada, nearly all carbonate terrain, may contribute to the regional interbasin flow of White River Flow System of Eakin (1966), some of which flows to the south of the Pahranagat shear zone and into the Arrow Canyon Range Cell. The recharge values in the mountainous terrain adjacent and within the Arrow Canyon Range Cell have been estimated through various techniques, but there is considerable uncertainty as to real values of recharge or even patterns of flow. There is little direct recharge from precipitation in basin lowlands.
3. Surface drainage and groundwater flow systems may or may not be congruent, i.e.,

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confined to hydrographic basins. In the arid terrain of southern Nevada, the interbasin flow in the carbonate rock terrain often ignores the hydrographic basins of surface water drainage. The Arrow Canyon Range Cell, which is interpreted to be constituted by two flow fields (described in this report), incorporate several surface-water hydrographic basins with drainage integrated to the Colorado River (White River – Coyote Spring Valley, Muddy River (upper Moapa Valley), California Wash, Lower Meadow Valley Wash, and small areas of Black Mountains and Las Vegas Valley surface-water drainage) and two hydrographically closed basins, Hidden Valley, and Dry Lake Valley (Garnet Valley) (Figure 1).

4. Quaternary climate variations produced more effective moisture and associated groundwater recharge and surface-water runoff in paleohydrologic systems that have imprinted existing hydrologic systems in a variety of often subtle, but important ways. The Carbonate Aquifer transmissive nature within the Arrow Canyon Range Cell may be related to former discharge areas and much larger fluxes, and the localization of the Muddy River Springs Area is the result of pluvial climate headward erosion cycles of the White River – Muddy River drainage system graded to the Colorado River. In the Glendale area, for example, the alluvial aquifer is inset into the Muddy Creek Formation, is either late Quaternary or Holocene in age, and incorporates only a maximum of 35 feet of basal, highly sorted and productive sands and gravels. The overall basin geomorphologies are related to a prolonged down cutting history of erosion of the Muddy Creek Formation in the drainages that are integrated with the Colorado River. In hydrogeologically closed basins, Quaternary and Holocene coarse alluvial deposits bury the fine-grained Muddy Creek Formation, and provide extensive basin aquifers.

3.1.2 Arrow Canyon Range Cell Hydrologic Boundaries

The Arrow Canyon Range Cell is composed of a series of north-south trending structural blocks related to extensional faulting (which began in Oligocene or early Miocene and continues to present) that are almost entirely composed of Paleozoic carbonate rock (Figures 3, 4, and 5). The structurally downfaulted block, Hidden Valley – Coyote Spring Valley, remains structurally high enough to form a basin floored by Paleozoic carbonate rocks that appear to dominate that hydrology of the basin; that is, the alluvial/Muddy Creek Formation basin deposits are limited in thickness and extent, and do not form large thick body of saturated sediments that dominate the groundwater hydrology. Throughout the region, thick Quaternary aged deposits are often transmissive, whereas middle and late Tertiary basin sediments, such as Horse Spring Formation and Muddy Creek Formation, are less transmissive and most faces are aquitards. The Arrow Canyon Range Cell is bounded on the east side by the Hogan Springs Fault zone, a several mile wide zone of north – south oriented lineaments, some of which have vertical displacements, east side downthrown. These lineaments localize Muddy River Springs Area conduits to the alluvial gravels near the Lewis well field and to several spring areas, as well as localize extensive paleo-discharge spring deposits that occur from the White Narrows area to the west into the carbonate rock terrain. At EH2b, west of the Reid Gardner generation station, 4,000 feet of Muddy Creek – Horse Spring Formations indicate the minimum throw along this fault zone, and further to the south, in the general vicinity of Hogan Spring, a middle to late Quaternary pediment surface is displaced by a relatively young fault movement on one of the lineaments. Hogan Spring and Jackass Spring are seep springs associated with these lineaments, and are at elevations that suggest sources from the carbonate aquifer. Seeps and springs in the northern area of California

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Wash (e.g., Nungwu and springs and seeps near the Hidden Valley Ranch) are not known to be associated with features that would localize discharge from the Arrow Canyon Range Cell.

The southern boundary of the Arrow Canyon Range Cell is the Las Vegas Valley Shear Zone, which appears to be a structural zone of Tertiary rocks juxtaposed against Paleozoic carbonate rocks (Figures 3 and 5). In Las Vegas Valley the Las Vegas Valley Shear Zone is buried by basin sediments, and it is interpreted as a major right lateral strike-slip fault zone. Nevertheless, it is clear that whatever the detailed nature of the structure, it behaves as a barrier to flow, and leakage from the Arrow Canyon Range Cell into the Las Vegas Valley groundwater basin is either highly localized, or very minor, as evidence for Arrow Canyon Range Cell water is generally unrecognized. The eastward splay of the Las Vegas Valley Shear Zone appears to be the zone of possible outflow from the Arrow Canyon Range Cell. Another possibility of southern outflow is flow in the fault zone the bounds the west side of Frenchman Mountain. There have not been detailed studies focused on outflow from the Arrow Canyon Range Cell, and such studies are hindered by the general absence of useful wells in the candidate areas for outflow.

The western boundary of the Arrow Canyon Range Cell remains undefined by water-level control, but is assumed to be in the Las Vegas Range – Sheep Mountain Range zone, constituted by mounded groundwater related to recharge. The limited water-level data in Hidden Valley and south Coyote Spring Valley indicates the Cell extends into these areas at a minimum. The northern boundary of the Arrow Canyon Range Cell may be defined as the Pahranagat Shear Zone. There is a regional step down in fluid potentials south of this major structure as compared to fluid potentials observed in Pahranagat Valley, where there are three major carbonate terrain springs that discharge waters classified as derived from regional carbonate rock flow systems (Mifflin, 1968). Eakin (1966) and Mifflin (1968) as well as all subsequent investigators, recognized interbasin flow southward to the Coyote Spring Valley area, but the estimated amounts have varied and are difficult to confidently quantify.

3.1.3 General Hydrogeology Concepts Considered and Developed in this Study

Important hydrogeologic questions revolve around the Carbonate Aquifer of the Arrow Canyon Range Cell. Aquifer characteristics (and distribution) such as porosity, thicknesses, regional scale transmissivities, and sources and sinks of fluxes remain defined by very limited databases.

The general thickness of the carbonate terrain participating in the flow fields remains generally unknown. The stratigraphic thickness of the Paleozoic section in the area is in excess of 10,000 feet, and folding and thrusting (low angle) has the potential to both decrease or increase the total thicknesses of carbonate rock strata that participate in groundwater circulation. Petroleum test wells in the carbonate rock province of the Great Basin suggest depth of active circulation locally may be 12,000 feet deep. However, the total thickness of the carbonate rocks, as well as the thicknesses of well developed vertical hydraulic continuity, remains generally unknown.

The older compressional structures (folds and low angle thrust faults) are not known to control the hydrology (distribution of hydraulic conductivity) of the Carbonate Aquifer. Rather, the much younger extensional faulting and associated fracturing, and subsequent dissolution provide the majority of secondary hydraulic conductivity. There are likely more transmissive areas than others based on exploratory test drilling, and at least some transmissive areas display paleo karst

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development (solution cavities) in settings where the carbonate rocks are buried by the Muddy Creek Formation. The most transmissive areas recognized to date are the MX-4 - MX-5 - MX-6 - Muddy River Springs Area corridor, and more localized transmissive areas occur in the Apex – Nevada Cogeneration Associates and Belly Tank Flat areas. Many areas display local evidence for paleodischarge (ancient spring discharge) and the karstic developments may relate, in part, to spring conduits.

This current study developed a pump test in Belly Tank Flat that yielded excellent databases for aquifer property analyses. Other controlled pump tests (Apex, Nevada Cogeneration well field, Arrow Canyon well, and MX-5) have varied durations and database utilities, but all indicate highly transmissive aquifers properties. Nevertheless, other wells are less productive, such as TH-2, TH-1, Chemical Lime (Apex) and Dry Lake LLC test production well. This wide range of well yield and apparent aquifer properties is not uncommon in terrain where hydraulic conductivity is related to secondary features such as fractures and solution cavities.

The thickness of the active portion of the aquifer is unknown by direct evidence. The abnormal temperatures observed in the Belly Tank Flat area and at the Muddy River Springs Area suggest deep circulation in a thick, active, aquifer zone, through upwelling (which is clearly the case in the Muddy River Springs Area) or through bouyancy-induced vertical circulation due to deeply-penetrating vertical hydraulic continuity. Upwelling is the postulated source of the southern flow field water (discussed later in the text) because of the distinctive water geochemistry and the isotopic signatures, and general uniformity around the Belly Tank Flat area. Available information suggests that the thickness of the Carbonate Aquifer in the Belly Tank Flat is around 5,000 feet, and the water temperatures in the Muddy River Springs Area argue for a similar thickness for the average source zone. There are no data that directly demonstrate thickness. If the average porosities are smaller than those adopted in the analyses of this study, a thicker aquifer zone is indirectly indicated by barometric efficiency relationships. Nevertheless, a 5,000 foot thick aquifer with well developed vertical hydraulic continuity is highly unusual if not unique, and additional data and analyses are warranted.

Evidence for a vertical component of fluid potential change has not been noted in the drilling of 14 boreholes where careful records of water levels were taken as the boreholes were deepened after first water was encountered and measured (MAI-constructed boreholes). Therefore, it is clear that the general unconfined water-table state is common in much of the Arrow Canyon Range Cell. There are areas where confined conditions could exist based on the geology, but large extents, where the water levels are within the carbonate rocks, are likely to be unconfined (water table) conditions.

3.2 Fluid Potential

The fluid potential gradients of the groundwater flow fields of the region are represented by observed depths to water in wells (water-level elevations) and elevations of discharge points at spring areas. The fluid potential of an aquifer is used to estimate a gradient (which supports a flow direction) and as indicators to barriers to flow such as varied permeability zones, faults, sink and source areas. However, the unique Arrow Canyon Range Cell carbonate-rock aquifer characteristics of great thickness and possible well developed vertical hydraulic continuity coupled with small fluid potential gradients may limit the utility of water-level elevations.

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Water-level elevations measured in some wells may be reflecting the average density of groundwater due to markedly varying thicknesses of the aquifer resulting from the total depth of vertical hydraulic continuity with well bore. Therefore, density differences (due either to temperature or dissolved-solids differences) could give rise to head differences of a few tenths of a foot even if fluid potentials were identical.

3.2.1 Static Water Levels

Static water levels measured in wells completed in the Carbonate Aquifer are the basis for determining the potentiometric surface or changes in fluid potential to help predict the direction of groundwater flow. It is difficult to analyze water levels in a bounded area such as the Arrow Canyon Range Cell, where the difference in water level (referenced to mean sea level) between wells is small or non-existent. An important part of this work was the performance of accurate field surveys to benchmark each observation well and depth to water measurements (Appendices C and E).

The water levels measured on Moapa Indian Reservation and surroundings areas (Figure 6) were verified by field surveys and equipment calibrations (Appendix C, Table C2). The static water levels in a portion of the Arrow Canyon Range Cell (about 300 square miles) were measured at 1,815 ft +/- 3 ft above mean sea level (amsl), this small variance follows the initial definition of the Arrow Canyon Range Cell by Mifflin (1992). With the help of modeling analyses, a gentle east-southeast gradient, a southeast groundwater flow direction and a north-south dominant anisotropy was interpreted. No systematic changes in water level with depth have been observed in the six holes drilled and completed during this study on the Moapa Indian Reservation. Upwelling is inferred based on abnormal water temperatures and hydrogeologic data supporting the existence of the southern flow field. Vertical hydraulic continuity of the aquifer appears to be well developed and no fluid potential increases with depth have been observed during drilling of 6 boreholes in the project area and at 10 other boreholes in carbonate rock within the Arrow Canyon Range Cell. In one area of the northern segment of Coyote Spring Valley, paired boreholes (VF-1 and VF-2) display greater fluid potential in overlying basin fill as compared to the underlying Carbonate Aquifer, suggesting active recharge (Figure 2 and Appendix C). The water-level data collected is one of the criteria for calibration of the models that were applied in scenario development and prediction of outcomes.

3.2.2 Aquifer Pump Testing

Several important objectives were satisfied by the pump test of ECP-1, the first exploration borehole at Belly Tank Flat completed as a production well. Because of varying problems with other pump tests in the Arrow Canyon Range Cell, the resulting databases were often of limited value for analytical purposes. The ECP-1 seven-day pump test yielded an excellent database useful for delayed yield (fracture drainage) studies necessary for characterizing aquifer responses to long term pumping effects, and demonstrated the projected performance of production wells in the Belly Tank Flat for the Project water supply. At the time of the pump test an expanded monitoring program was in the planning stage and currently consists of the wells shown in Appendix E, Table E-1. Figure 7 shows the test design and borehole stratigraphy.

In order to obtain large-scale estimates of aquifer parameters in the Project area and allow sufficient time for delayed-yield effects to develop, a 7-day aquifer test was conducted in July of

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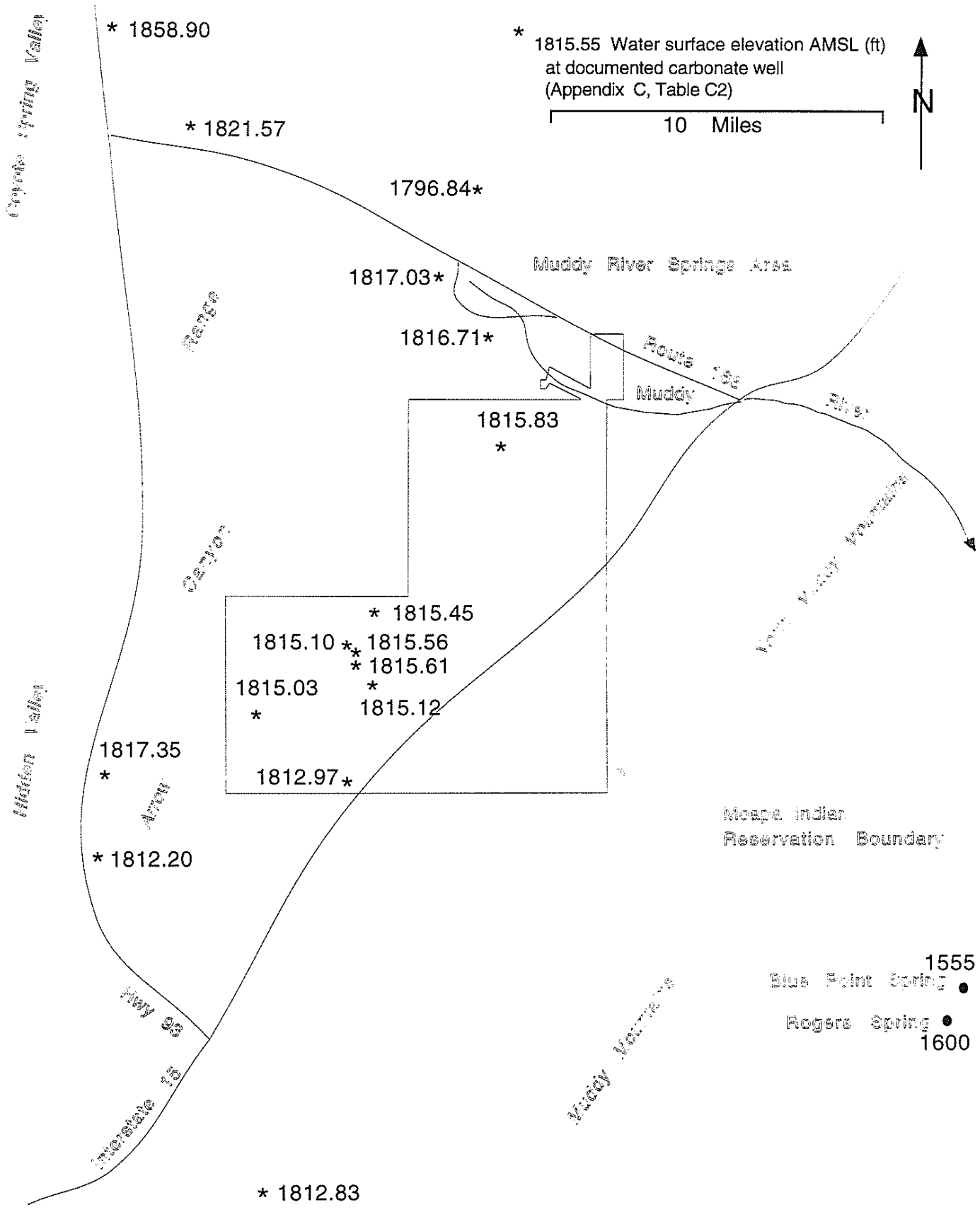

Figure 6. Arrow Canyon Range Cell carbonate aquifer fluid potentials.

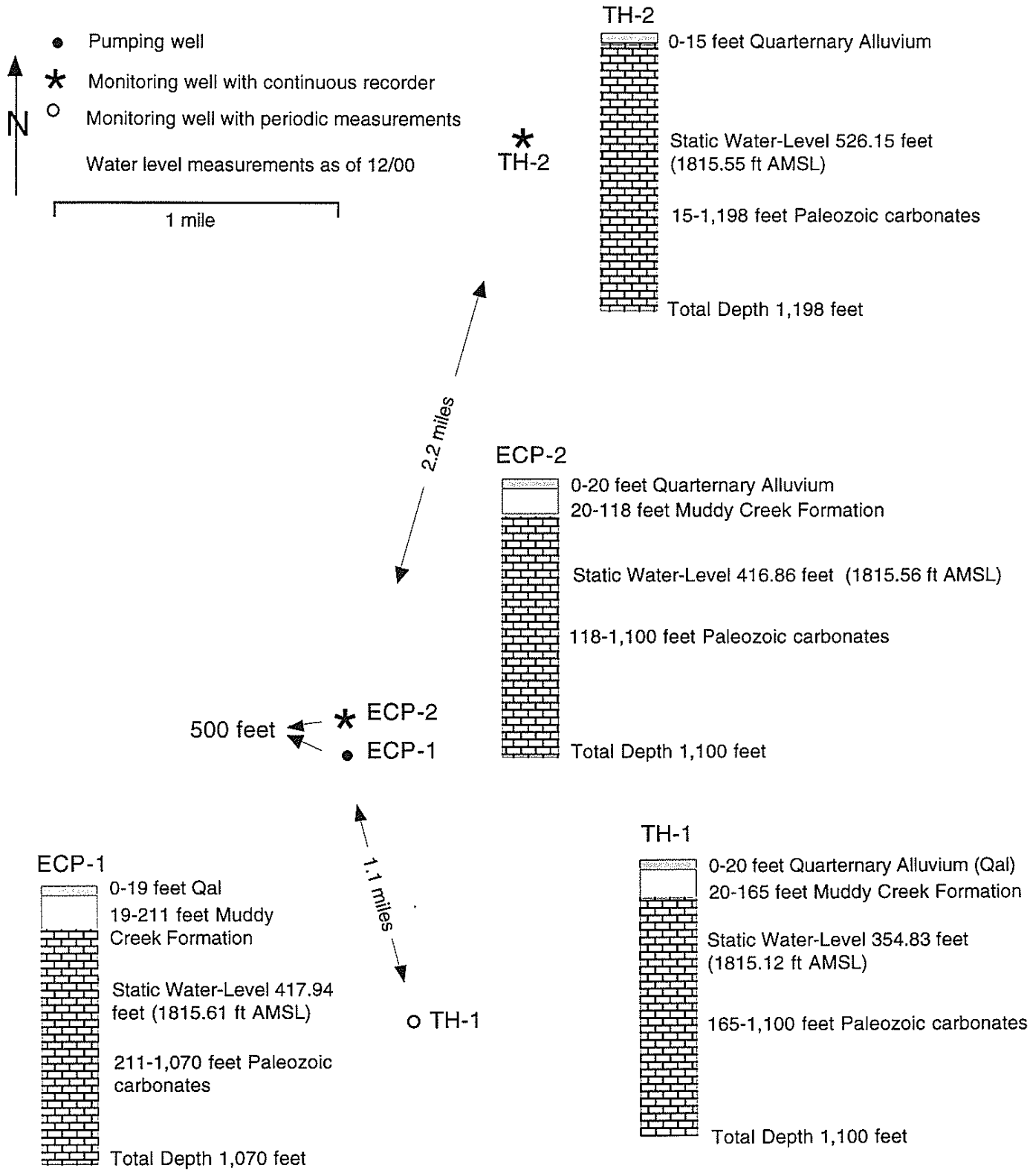

Figure 7. Moapa Paiute Energy Center seven day test pumping monitoring network and borehole stratigraphy.

2000 (Appendix A), with the following conditions:

- Steady discharge of 1005 gpm from ECP-1 for 7 days; a 2-hour 20-minute pump failure had negligible influence on outcome
- Continuous water-level observations at ECP-2 and TH-2, manual water-level measurements at TH-1, and continuous barometric-pressure record at TH-2
- Analyzable response at ECP-2 and TH-2; signal-to-noise at TH-1 roughly 1:1 (provisional analyzable)

The major findings of the 7-day aquifer test were as follows:

- Transmissivities on order of 50,000 to 100,000 ft^2/day
- Unconfined conditions indicated by response curves; specific yield S_y order of 0.03
- Existence of barometric effects in the unconfined system is thought to be due to an effective pneumatic cap (Muddy Creek Formation)
- On the basis of aquifer test and barometric efficiency data the estimated hydraulic conductivity of Arrow Canyon Range Cell was increased and the thickness estimate was corroborated by the application of the barometric efficiency and storativity (Appendix A, p20) to support model refinement

3.2.3 Dynamic Water Levels: Application of a Tidal Method for Aquifer Storage

A specific yield S_y of the order of 0.03 has been used to characterize the storage conditions in the Project model based on aquifer tests described in Appendix A. To test the validity of this S_y value the tidal method described by Jacob (1950) and Ferris (1951) has been utilized. This method demonstrates the consistency between parameters estimated from pumping response and those derived from analysis of the lag and attenuation at MX-4 of large-scale effects of seasonal pumping in the Muddy River Springs Area (primarily the Lewis well field; Figure 2). Although this analysis applies to the region where transmissivities are thought to be two to five times higher than in Belly Tank Flat, it offers strong evidence of unconfined conditions in an important portion of the model domain.

The tidal method is a simple technique for estimating aquifer diffusivity (defined as the quotient of transmissivity and storage, T/S) based upon the response of water levels in an aquifer to periodic water-level changes at a boundary. There are two possible mechanisms for tidal propagation: (1) movement of water into and out of an unconfined aquifer, and (2) compression and expansion of the aquifer-fluid system due to tidal loading. The attenuation of the tidal signal at locations in the aquifer remote from the tidal boundary is normally described by two quantities, *tidal efficiency* and *lag* (Smith, 1999).

3.2.3.1 Relevant Data

To apply the tidal method, monitoring data from the Muddy River Springs Area groundwater

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withdrawal (Lewis and LDS well fields) and the MX-4 well in Coyote Spring Valley were analyzed. Review of the multi-year record of water levels and groundwater withdrawals (Mifflin and Adenle, 1994, 1996, and Mifflin, 1995 of Appendix F) has made possible the analysis of MX-4 response to annual cycles of pumping in the Muddy River Springs Area. Calendar year 1991 was selected for detailed analysis for of the following reasons:

- There was no groundwater withdrawal from the largest Muddy River Springs Area well fields for the three months prior to May, 1991, when production ramped up abruptly
- Water-level measurements at MX-4 were recorded more frequently than at any time before or since, consequently a water-level drop of 1.3 ft beginning near the end of July is evident
- Drought conditions, prevalent from 1987 and ending in 1992, were still occurring
- The Landers Earthquake, which appears to have caused a 0.6-ft rise in water levels at EH-4 and EH-5b, had not yet occurred
- The Arrow Canyon Well had not yet begun significant groundwater withdrawal

The most important piece of missing data is the average drawdown in the Carbonate Aquifer beneath the Lewis wellfield (the largest pumping center), which represents the tidal signal seen about 90 days later at MX-4, 9.2 miles away. This sub-Lewis-wellfield signal is needed to accurately derive the tidal efficiency. Quarterly water-level measurements made by Mifflin & Associates from 1992 through1995 are used to estimate this "forcing function" beneath the Lewis wellfield for 1991 (Appendix F).

The carbonate-rock monitoring wells EH-5b and EH-4, 0.5 and 2 miles from the Lewis wellfield, respectively, appear to respond to Muddy River Springs Area pumping with annual drawdowns of about 2 ft but without clearly resolvable lag; these are the nearest monitoring wells to the pumping center that are completed in carbonate rock. Average seasonal drawdowns in alluvium in the Lewis wellfield are of the order of 10 ft. Corresponding drawdowns in carbonate rock directly beneath the Lewis wellfield are not known, but clearly are bounded by values in the alluvium (about 10 ft) and those in nearby carbonate rock (about 2 ft). According to Mifflin and Adenle (1996, p. 20-21) Nevada Power Company alluvial wells LDS East and LDS Central appear to be in good hydraulic connection with the regional carbonate aquifer (diagrammatically illustrated in Appendix F), but matching individual pumping centers in the Muddy River Springs Area to the drawdowns in carbonate monitoring wells cannot be resolved with available data. The scoping calculations presented here utilize an interpolated value of 5 ft to represent drawdown in carbonate rock beneath the Lewis well field.

3.2.3.2 Basis of Method

Tidal efficiency, *TE*, relates the magnitude of head fluctuations in the aquifer to the amplitude of fluctuations at the tidal boundary. In mathematical notation,

$$TE = R_a/F_a$$

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where F_a is the forcing amplitude at the tidal boundary, and R_a is the response amplitude at a point in the aquifer.

Lag is a measure of the speed of propagation of a tidal signal as it moves through the aquifer

$$lag = F_\theta - R_\theta$$

where F_θ is the phase of tidal forcing and R_θ is the phase of tidal response at a point in the aquifer. Tidal efficiency and lag in one-dimensional, semi-infinite and homogeneous aquifer with uniform transmissivity are derived by solving the equation of 1-D transient groundwater flow (Ferris, 1951) with a tidal or harmonic boundary condition at x=0,

$$\partial^2 h/\partial x^2 = s/T \bullet \partial h/\partial t$$

$$h(0,t) = H_a cos(\omega t - H_\theta)$$

where H_a is the amplitude of head fluctuations at the tidal boundary [L] and H_θ is the phase measured in radians. The groundwater flow problem described by these linear equations can be decomposed into a steady-state flow problem and a harmonic flow problem that comprises one or more frequencies. For the single (annual) frequency considered here, the harmonic solution is rearranged to yield efficiency-based and lag-based expressions for diffusivity (T/S) in terms of tidal efficiency and lag

$$T/S = \pi x^2/(\ln TE)^2 P$$

$$T/S = x^2 P/4\pi(lag)^2$$

where P is the period [T] of the tidal signal (365 days in these analyses) and $\omega = 2\pi/P$ is the corresponding angular frequency [T^{-1}].

3.2.3.3 Results of Analysis

Applying the tidal method using 1991 data from MX-4 as the response and the estimate for drawdown in the carbonate aquifer beneath the Lewis wellfield as the forcing function, we find R_a = 1.3 ft and F_a = 5 ft; therefore tidal efficiency $TE = R_a/F_a$ = 0.26. The efficiency-based diffusivity estimate using this value of TE is $T/S = 1.12 \times 10^7$ ft^2/day. Using the *lag* estimate of 90 days, the lag-based expression gives $T/S = 8.47 \times 10^6$ ft^2/day. The mean of these independent estimates using the tidal method is close to $T/S = 10^7$ ft^2/day.

Therefore, to evaluate the validity of parameters utilized in the model, parameters used for the conceptual model include hydraulic conductivity K = 60 ft/day, thickness b = 5,000 ft, and specific yield S_y = 0.03 gives diffusivity $T/S = Kb/S_y = 10^7$ ft^2/day. In the model, described in Section 4.0, a high-K corridor extending northwestward from the Muddy River Springs Area was assigned a hydraulic conductivity of 100 ft/day, and was surrounded by a transition region of 50 ft/day. The tidal method yields results that are in excellent agreement with Belly Tank Flat aquifer test interpretations, and support model parameter assignments.

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3.2.4 Summary

In summary, the Belly Tank Flat ECP-1 pump test analytical results are consistent with independent lines of evidence reviewed above. Pump and step-drawdown testing of the carbonate aquifer near the proposed pumping center yielded data to compute a range of transmissivity of 50,000 to 100,000 ft^2/day, hydraulic conductivity of 20 ft/day and specific yield S_y of 0.03 and S of 0.008. Unconfined conditions were justified on the basis of drilling observations (cuttings and no water-level changes after first water) barometric records, computation of S (0.003) by the conventional and Tidal Method for aquifer storage. A porosity reported by the US Geological Survey of 0.047 was used in the analyses. The tests support prolong pumping at 1,000 gallons per minute with minimal drawdown at the pumping well. Thermal gradient, barometric efficiency and the storativity were used to verify the estimated of thickness of the aquifer of 5,000 feet. The details and results of the aquifer pump tests at ECP-1 are presented in Appendix A, ECP-1 Aquifer Test Summary Report.

3.3 Geochemistry and Isotope Hydrology

The evolution and concentration of cation and anion constituents in groundwater and the concentration of isotopes of deuterium (H^3) and oxygen 18 (O^{18}) in groundwater are useful to track the evolution of water in aquifers from infiltration (recharge areas) to discharge points (wells, springs, lakes, rivers, other receptors) along a flow path. The flow path can be theorized as that path a molecule of water takes from the point of origin to a discharge point (location). At the point of origin the infiltrating water has a distinctive stable isotopic signature based on the fractionation history up to that point and maintains this characteristic signature until mixed with other water sources with differing signatures.

The water chemistry (cation and anion) generally evolves in concentrations of cation and anion constituents along flow paths through geologic media due to pathway interactions with minerals encountered. Careful analyses of the isotopic signatures and water chemistries may allow definition of flow paths, evidence for mixing water sources, and identification of related or unrelated water over large areas.

In the Arrow Canyon Range Cell, water chemistries and isotopic signatures are generally very distinctive, so much so that a few wells that have been interpreted to be closely associated with the carbonate aquifer (for example CSV-3 and SHV-1, Appendix B), but yielding anomalous water chemistry and isotope signatures, are likely influenced by the overlying basin sediments. Such data points have not been relied upon for water levels or geochemistry.

The isotopic signatures of deuterium and oxygen-18 combined with the water chemistries of the Arrow Canyon Range Cell (Appendix B) are the basis for describing two separate populations of water that define two separate flow fields in the Carbonate Aquifer, the northern and southern flow fields. Stiff and Piper diagrams are typically used to differentiate and compare the origin and evolution of water and illustrate local similarities and regional differences in the composition of groundwater in and adjacent to the Arrow Canyon Range Cell (Appendix B, Figures B1 and B2). By presenting the quantities and relative proportions of the major dissolved cations and anions, waters that share common origins often are recognized. Waters that are significantly different with respect to their ionic compositions either occupy different positions on an

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evolutionary pathway, or are unrelated.

The stiff diagrams of Figure B-1, Appendix B, dramatically illustrate the patterns of water chemistries of the Carbonate Aquifer in the Arrow Canyon Range Cell and adjacent areas. An indication of initial water chemistry in recharge areas is illustrated by the perched spring waters of the Sheep Range, where TDS is generally less and the waters have a Ca-Mg or Mg-Ca bicarbonate signature.

Based on geochemical data analyzed at the Muddy River Springs Area-Coyote Springs Valley flow field (northern flow field) and flow field water of the Project area (southern flow field) are different. Waters discharging in the Muddy River Springs Area and in Coyote Spring Valley (up gradient wells) have bicarbonate as their predominant anion and total dissolved solids (TDS) generally less than 600 mg/l. Waters of the southern Arrow Canyon Range Cell display water chemistries of 900 to 1000 TDS, with sulfate and chloride as predominant anions. Isotopic signatures are similar with respect to deuterium values, but southern flow field waters are slightly lighter than northern flow field waters in Oxygen-18 ratios. In a general sense, both flow fields appear to be closely related isotopically, but are clearly different in terms of water chemistries. There is no evidence of the southern flow field (poorer quality water) in the Muddy River Springs Area discharge. Waters discharging at Rogers and Blue Point Springs are much more saline than groundwater of the Arrow Canyon Range Cell; TDS values are 2,900 and 4,000 mg/l, respectively, probably originating from dissolution of the evaporite minerals gypsum and halite along groundwater flow paths, (Appendix B).

A spectrum of stable isotopic compositions is in evidence in the study area (Appendix B). The isotopically lightest waters, such as those at MX-4 and VF-2 (del D=-101.0) are interpreted to represent waters recharged thousands of years ago during the generally colder pluvial (ice age) climates or to be from recharge in a more northerly, colder climatic setting. In contrast, isotopically heavier waters, such as Mormon Well Spring in the Sheep Range (del D=-91.8) or the Hidden Valley Stock Well (del D=-90.5) are considered to be much younger and locally derived. The differences in isotopic composition are because of: 1) the differing extent to which these waters have been subjected to fractionation before precipitation and 2) to evaporation, which drives the isotopic composition toward heavier values. Isotopic compositions are useful because they are insensitive to most chemical reactions and will not change substantially unless the water is subjected to evaporation or mixed with another water type. Isotopic compositions support the interpretation of the mixing of groundwater along a flow path within one or more flow fields.

Rogers and Blue Point Springs water (del D =-92.0 and -93.0, respectively) are isotopically similar to waters with evidence of local origins indicating that hydrodynamically these springs are not fed by groundwater from the Arrow Canyon Range Cell. Secondly, the Calpine production well ECP-1 (del D=-99.0) and observation well TH-1 (del D=-99.0) is intermediate in isotopic composition between MX-4 (del-D=-101.0) and Big Muddy Spring (del D=-97.8). The USGS estimated that 38% Sheep Range water mixes with 62% Coyote Spring Valley water to produce Big Muddy Spring water (Thomas and others, 1997, p. C46). Geochemical and isotopic evidence indicates that the flow field of Belly Tank Flat and areas to the south and that supplying the Muddy River Springs Area are two separate flow fields, and allows an estimate of

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groundwater flux that may be present in the southern flow field.

3.3.1 Hydrochemical Evidence that Belly Tank Flat Waters are Unrelated to Muddy River Springs Area Waters

The concept of chemical evolution, the net effect of solution-mineral interactions and mixing along ground-water flow paths, can be used to infer relationships (or the absence of relationships) between water types. In the Arrow Canyon Range Cell of the regional carbonate aquifer, three distinct water types are present (Appendix B analyses, Figures B-1 and B-2).

Muddy River Springs type	Na - HCO_3	TDS 610-640 mg/l
Belly Tank Flat type	Ca - SO_4	TDS 750-900 mg/l
Apex type	Na - SO_4	TDS ≈ 1,000 mg/l

The possible of a hydraulic connection between Belly Tank Flat and the Muddy River Springs Area is evaluated by looking for a mechanism that could cause one type of water to evolve compositionally into the other.

This exercise will focus on dissolved calcium and sulfate, both of which are constituents of the common rock-forming mineral gypsum (CaSO4 • 2H2O). Available analyses (Thomas and others, 1996; Appendix B of this report) give the following data:

Location	Ca^{2+} mg/l	SO_4^{2-} mg/l
Big Muddy Spring	66	190
Calpine Well ECP-1a	120	290

The saturation index of calcite in water from carbonate-rock aquifers of southern Nevada indicate near-equilibrium conditions (Thomas and others, 1996, p. C44) that is, any addition of dissolved calcium would be moderated by precipitation of dissolved calcium as calcite. This is known as the common-ion effect. Noting that ECP-1a water has higher dissolved calcium and sulfate than Big Muddy Spring water, therefore the hypothesis is tested that water resembling that discharging at Big Muddy Spring could have evolved into ECP-1a water by dissolving gypsum along its flow path is probable. A disproportionate increase of sulfate over calcium in the resultant water is expected if this hypothesis is valid, since dissolved calcium is buffered in the presence of calcite. Instead, a proportional increase of calcium over sulfate is observed:

Δ Ca = (120-66)/66 = .82, or 82% $\quad$ Δ SO_4 = (290-190)/190 = .53, or 53%

These relations argue against a water characteristic of the Muddy River Springs Area evolving, through gypsum dissolution, to the water characteristic of Belly Tank Flat. Gypsum dissolution accompanied by common-ion precipitation of calcite has probably influenced the evolution of Belly Tank Flat waters, but because there is no disproportionate increase in SO_4 over Ca in Muddy River Springs Area waters, it appears that Belly Tank Flat waters did *not* evolve from Muddy River Springs Area waters.

Derivation of Apex-type waters from Belly Tank Flat-type waters is not problematic

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Location	Na^+ mg/l	Ca^{2+} mg/l	SO_4^{2-} mg/l
Calpine Well ECP-1a	110	120	290
Georgia Pacific GP-1a	129	120	380

Additional gypsum dissolution and possibly ion exchange could produce Apex area waters from a precursor resembling Belly Tank Flat waters, since there is a proportionate increase in dissolved sodium over calcium in the more southerly waters, and elevated sulfate.

3.3.2 Isotopic Evidence of Flow System Configuration

The stable isotopes of hydrogen and oxygen have proven to be extremely useful hydrologic tracers, primarily because they are conservative, that is, their abundance in groundwater are not influenced by most chemical reactions. Climate and contributing recharge areas impart an isotopic "fingerprint" to groundwater, allowing sources of the water to be inferred from its isotopic composition. If representative-mixing end-members can be identified, the relative contributions of the end-members to a suspected mixture can be inferred from considerations of isotopic abundance.

Muddy River springs waters are isotopically distinct from Belly Tank Flat and Apex waters (Appendix B, Figure B-3). The latter are isotopically lighter with respect to Oxygen-18 than Muddy River springs waters, suggesting greater age; deuterium values of the two groups overlap, and display greater variation in Muddy River springs-Coyote Spring Valley waters than in southern flow field waters. Waters occurring in the Belly Tank Flat and Apex areas, if originating from a different flow system than that supplying Muddy River Springs Area, this may be supported by utilizing mixing calculations with isotopic indicators.

The principle of mixing model analyses is demonstrated by the following mixing calculation and illustrates the use of isotopic compositions of Big Muddy Spring and the Valley of Fire well to explain Rogers Spring water as a mixture of these two hypothetical end-members (Appendix B). The basic relationship is

$$xC_1 + (1-x)C_2 = C_3$$

where C_1 and C_2 are concentrations of a conservative constituent in the mixing end-members, and C_3 is the concentration of that constituent in the mixture, and x is the mixing fraction of C_1. Rogers Spring water as a mixture of waters observed at Big Muddy Spring and Valley of Fire Well water is postulated; the del ^{18}O values for these waters are:

C_1	Big Muddy Spring	-13.0
C_2	Valley of Fire Well	-10.6
C_3	Rogers Spring	-12.2

Given these concentrations, $x = (C_3-C_2)/(C_1-C_2)$

$= -1.6/-2.4$

$= 0.666$

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which indicates 2 parts Big Muddy Spring water mixed with 1 part Valley of Fire Well water would yield the Oxygen-18 composition observed at Rogers Spring. Although this example is for illustrative purposes only, it demonstrates two parts Muddy River spring-type water (regional flow mixed with local recharge (one part) could yield the observed isotopic signature).

The U.S. Geological Survey (Thomas and others, 1996) has studied the origins of groundwater in the Muddy River Springs Area by considering stable isotopic compositions of potential source waters in the region. The USGS Mixing Model for the Muddy River springs is based on 2-step mixing using deuterium compositions in hypothetical mixing end-members, as calculated below:

Step 1. 64% (14,000 afy) White River Flow System water (del D = -109 permil) + 36% (8,000 afy) Southern Meadow Valley Wash Flow System water (del D = -87 permil) to Coyote Spring Valley Water (del D = -101 permil)

Step 2. 62% (22,000 afy) Coyote Spring Valley Water (del D = -101 permil) + 38% (14,000 afy) Sheep Range water (del D = -93 permil) to Muddy River springs (del D = -98 permil)

These results challenge earlier estimates regarding the origin of the Muddy River springs. Notably, the estimated Sheep Range contribution to Muddy River Springs (14,000 afy) is greater than the Maxey-Eakin based estimate of recharge for the entire Sheep Range (11,000 afy). The estimated White River Flow System contribution to Muddy River springs (14,000 afy) is much less than the 35,000 afy proposed by Eakin (1966), and less than the 18,000 afy underflow from Pahranagat Valley to Coyote Spring Valley estimated by Welch (1988) or the 16,500 to 19,000 afy by Kirk and Campana (1990).

Adopting the USGS findings concerning water balance in the region and the earlier estimates of underflow to Coyote Spring Valley from Pahranagat Valley results in a conceptual model that is consistent with all studies cited above. A mixing model for Belly Tank Flat is as follows:

- Conceptually there is deep southward flow of White River Flow System water (del D = -109 permil) beneath Coyote Spring Valley, but no contribution from the Meadow Valley Wash Flow System
- This deep underflow of White River Flow System water from the north mixes with Sheep Range water (del D = -93 permil)
- The Hidden Valley Dry Lake LLC production well HV-1 (del D = -97 permil) would be 25% White River Flow System water and 75 % Sheep Range water
- Belly Tank Flat and Apex area waters (del D = -99 permil) would be 38% White River Flow System water and 62% Sheep Range water
- If the southern flow field waters include the 4,000 afy that flows southward from Pahranagat Valley but does not discharge at Muddy River springs, another 6,500 afy from the Sheep Range (doubling the Maxey-Eakin estimate) is required for isotope

balance in Belly Tank Flat. Therefore, as much as 10,000 afy of flux may occur in the southern flow field (the Belly Tank Flat - Apex area).

According to this model, derivation of Belly Tank Flat and Apex waters directly from Muddy River Springs Area waters is improbable. This finding is consistent with all USGS and DRI hydrologic balances cited above, and with geochemical evidence indicating that Muddy River springs - type water is not a precursor to Belly Tank Flat - Apex waters in terms of chemical evolution.

The above analysis and the GFLOW regional modeling steady state calibration (Section 4.4) both yield similar 9,000 to 10,000 afy estimate of flux for the southern flow field. Specific analyses in Thomas others (1996, Appendix B) suggest that underflow to northeastern Las Vegas Valley is plausible but there are no waters recognized that fit both the isotopic and geochemical signatures of the southern flow field waters. Two observations are made:

- First, the Craig Ranch Country Club well #2 (analysis #66, del D=-106) is extremely light isotopically, resembling White River flow system waters.

- Second, the Lake Mead Base well #3 (analysis # 64, del D=-101.5 and -103 for duplicate analyses) is intermediate isotopically and in terms of total dissolved solids between White River / Craig Ranch water and Apex water.

While not particularly compelling, these data are consistent with deep underflows from the north mixing with Las Vegas Valley groundwater along the northern and northeastern margins of Las Vegas Valley.

Summarizing, two populations of water are recognized:

1. A northern flow field that is discharging in the northern portion in the Muddy River Springs Area
2. A southern flow field that is in part a deeply circulated regional flow system upwelling within the central part of the Arrow Canyon Range Cell, and evolving to a more sodic, higher TDS water as it flows southward.

Both flow fields are clearly characteristic of regional flow systems in carbonate rock terrain in terms of water chemistries (see Mifflin, 1968) but with isotopic signatures and water chemistries that are best explained by different mixing histories. These are very suggestive of Toth's (1963) and Freeze and Witherspoon's (1967) conceptual and theoretical studies of local, intermediate and regional flow-systems (Figure 8). The Sheep Range may be an important contributor to both flow fields. The northern flow field discharges at the Muddy River Springs Area and fits an intermediate configuration flow system with shorter flow paths than occur at depth and with important contributions from "local" sources (southern Meadow Valley Wash) that apparently do not contribute to the deeper system. The southern flow field, with very uniform water chemistry (Appendix B) characterized by a greater load of the relatively conservative ions (Na, K, Cl, SO4) conforms to a deep regional flow system configuration with longer flow paths and less local flow contributions. In conceptual diagrams and idealized modeling analyses, the most

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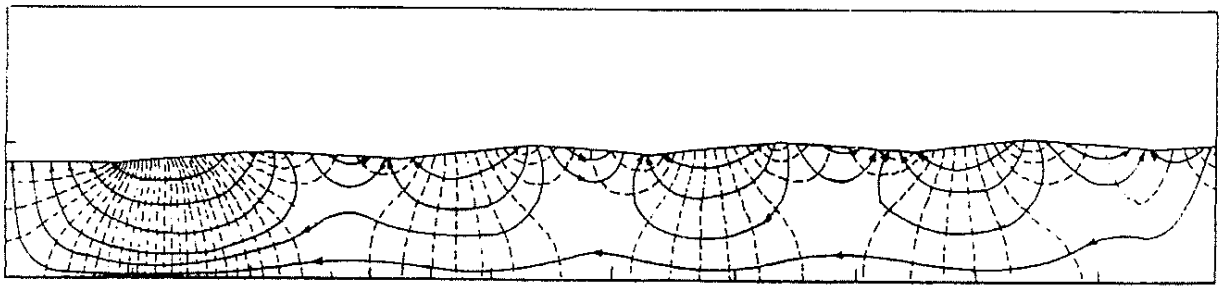

Figure 8. Freeze and Witherspoon's (1967) numeral solution to Toth's (1963) conceptual model of regional groundwater flow. Water that enters the flow system may be discharged locally or intermediately, or may be transmitted to a regional discharge area. Solid lines with arrows on diagram represent groundwater flow paths, with the beginning of a line a recharge area and the terminus of a line a discharge area.

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deeply circulated, longest flow path waters (regional) ascend to shallower levels at or near a regional barriers to flow, and may be overlain by more local circulation cells or flow systems with overall shorter flow paths, Figure 8.

The discussed relationships observed in the Arrow Canyon Range Cell are suggestive of a deeply circulated regional flow system upwelling within the southern part of the Arrow Canyon Range Cell of the Regional Carbonate Aquifer, and an intermediate regional system discharging in the northern portion at the Muddy River Springs Area. Nevertheless, lacking specific physical evidence of a flow barrier between the southern flow and the northern flow field, the combined area, as one hydraulic continuum, was modeled and described in this report. This allows pumping cones of the southern flow field to migrate into the northern flow field and impact Muddy River spring flows to various degrees.

3.4 Hydrogeology of the Muddy River Springs Area

The Muddy River Springs Area was believed to represent the primary area of discharge for the majority, if not all, of the White River Regional Flow System (Eakin, 1966). The flux to this area passes through Coyote Spring Valley and adjacent areas. On average, approximately 51 cubic feet per second (cfs) of flow reaches the area and discharges through spring flow, base flow to the Muddy River channel, and through evapotranspiration. Local pumping stresses and associated groundwater diversions occur in the carbonate aquifer, as well as the alluvial aquifer which also is in hydraulic continuity with the carbonate aquifer. A detailed inventory and monitoring program sponsored by Nevada Power Company began in 1987 to augment more limited monitoring of some springs and the Muddy River discharge at Warm Spring Road Bridge (USGS). This expanded monitoring has been continued to the present, and demonstrates a relatively complex hydrologic system, in which it is difficult to measure variations and correlate the causes of such measured variations (Appendix F).

During a State Engineer hearing of several protests to water rights applications 55450 and 58269 by the Moapa Valley Water District, the hydrologic relationships of water development in the area and measured impacts as well as characteristics of the hydrologic systems were summarized and entered into the hearing record by Mifflin & Associates, Inc. (Appendix F). The key relationships are outlined in the summary and supported by an Appendix of figures, tables, and graphs.

A good understanding of this important locus of groundwater discharge is required if the effects of distant pumping centers in the Carbonate Aquifer are to be determined. Pumping impacts recognized in monitoring wells near the Muddy River Springs Area have been analyzed to provide perspectives on effects that might propagate toward the spring area from distant pumping centers. Appendix F details the nature of pumping impacts recognized and interpreted in this area to support several relationships used in model development. A logical symmetry argument is as follows: if signals representing pumping stresses in the Muddy River Springs Area are propagated southward and detected in the Belly Tank Flat area, then signals propagated north from the Calpine Project would be subject to the same physical controls. It is therefore very important to understand the "forcing function" (see discussion of the tidal method in Section 3.2.3) represented by pumping in the Muddy River Springs Area now that a new

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monitoring network capable of detecting its effects is in place in the southern flow field (Appendix E).

The appropriate storativity to assign to large, unexplored tracts of Carbonate Aquifer is indicated by the delayed responses to pumping stresses in wells affected by activities in the Muddy River Springs Area. Delays that range from 3 months at approximately 9 miles distance (MX-4) to as little as a few days in a closely adjacent Carbonate-Aquifer well (EH-5b) are summarized and hydrographs presented in Appendix F . The lag and attenuation of the pumping signals with time and distance are illustrated graphically by a set of figures that demonstrates delayed responses to local-area pumping stresses arising from substantial storage in the aquifer.

Based on the above, around the Muddy River Springs Area extensive reaches of the Carbonate Aquifer behave as an unconfined system requiring a certain amount of dewatering before pumping stresses are transmitted over large distances. However, locally, there are areas where confinement also exists, which is compatible with areas where the Muddy Creek Formation and/or other Tertiary strata may overlie Paleozoic carbonate rocks within the zone of saturation. Large areas within the Arrow Canyon Range Cell, however, are underlain by Paleozoic carbonate terrain that either crops out well above the level of regional saturation, or though partly covered by younger sediments, the unconformable contact is well above the regional saturation. Therefore, it is concluded that distant pumping cones will likely be delayed in transmission over long distances due to a predominance of water-table conditions, particularly in the region of the southern flow field north of Belly Tank Flat.

Impacts from major pumping stresses that occur in the southern flow field, if they indeed are able to propagate northward into the northern flow field, would likely be reflected as modulated water-level declines in a relatively small portion of the northern flow field. This scenario would result in very small, and very slowly-increasing declines in regional flow to the spring area. Because of the secular nature of the effects of drought and wet periods and delays to responses of the northern flow field, recognition through monitoring in the Muddy River Springs Area would be unlikely until the impacts were at least greater than the range of secular changes (about 5 cfs annualized) due to the natural variations in multi-year recharge periods. However, it is possible to identify if pumping effects are reaching the northern flow field through water-level monitoring in a monitoring program that has been designed and implemented (Appendix E). It is anticipated that the pumping at the Belly Tank Flat well field would yield a distinctive pumping signal, just as the Muddy River Springs Area pumping signal can be traced to the MX-4 area. In this manner it is anticipated that pumping impacts entering the northern flow field would be identified long before they would be measurable in the Muddy River Springs Area.

Extensive monitoring in the Muddy River Springs Area indicates that some aquatic habitats may be impacted by existing local pumping stresses on a seasonal basis. However, these local seasonably distributed pumping impacts are poorly correlated with aquatic habitat in the area. The magnitude of pumping-produced hydrologic variations are two to three times greater than natural hydrologic variations that appear to be real from the long-term records (Appendix F). Working to moderate impacts on many aquatic habitats is the locally confined nature of the Carbonate Aquifer in the spring areas and conduits that feed the alluvial aquifer; there are head losses within the feeder conduits, and therefore fluid potential variations deep in the Carbonate

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Aquifer do not necessarily result in proportional decreases in discharge supplied by conduits. The result is that flows may be decreased in conduit-fed hydrologic features, but few flows, if any, have been markedly reduced or totally eliminated. The exception may be the base-flow discharge from the unconfined alluvial gravels in the uppermost reaches of the Muddy River channels. Upstream from the area of Big Muddy Spring, pre-1961 perennial flow reaches may have been reduced to seasonal flow in local segments of the river channel. All observations are based on detailed monitoring accomplished from 1987 through 1995, when water levels in the Carbonate Aquifer in the Muddy River Springs Area generally recovered every year to historic levels even during periods of drought, as shown in Appendix F.

3.5 Conceptual Models

3.5.1 Conceptual Model of the Arrow Canyon Range Cell

Conceptual models develop as knowledge and experience increases with time. They are fundamental in understanding observed natural phenomena and, as new information is developed, tested or refined, to better predict the characteristics of natural and generally very complex systems. The amount of relevant data determines the confidence in the conceptual model. Many groundwater basins are lacking in data to confidently project water resources available. The data within the Arrow Canyon Range Cell is not abundant, however much is of high quality and there exists data that describe the aquifer hydraulics locally.

Mifflin (1992) recognized similar fluid potentials within the Carbonate Aquifer over an extensive region, extending on the north from the Muddy River Spring Area to as far south as the Apex-Pabco area (Figure 6). Mifflin (1992) called it the Arrow Canyon Range Cell of the White River Flow System, speculating that it may be a large body of essentially stagnant water, a subterranean embayment with possible hydraulic continuity with the active flow system discharging at the Muddy River Springs Area at the northeast corner of the Cell. At the time data points (wells) were very sparse, isotopic analyses were unpublished, and geochemistry known only in the extreme north and south of the Cell. The eastern and southern boundaries, the Hogan Spring Fault Zone and the Las Vegas Shear Zone and its eastern splay, respectively, were recognized. Fluid potential gradients were recognized to the northwest of the Muddy River Springs Area at the MX and other wells, and the Sheep Range was assumed to be the western boundary.

3.5.1.1 Flow Fields

This study has confirmed the relatively uniform fluid potentials (but with firmer evidence for slight gradients). A number of additional data points for fluid potentials (Figure 6) and geochemistry and isotopic signatures (Appendix B) have become available. These new data indicate two separate populations of water associated with two flow fields (northern and southern flow fields) that likely incorporate similar waters from a distant northern source area, but differ in terms of their more locally-derived components. This in turn suggests deeply-circulated waters that either bypass (or flow under?) the Coyote Spring Valley-Muddy River Springs Area flow field that occurs in the northern area of the Arrow Canyon Range Cell.

The northern flow field originates from mixing of at least three end-member sources of water in Coyote Spring Valley, and discharges into the Muddy River Springs Area. Coyote Spring Valley

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is recharged by regional underflow from Pahranagat Valley, the Sheep Range, and Meadow Valley Wash, in proportions estimated by the U.S. Geological Survey (USGS) using isotopic mass balance.

The uniformity of the isotopic signatures associated with the southern flow field, as well as geochemistry of the water, indicates that most mixing of Sheep Range waters into regionally-derived flow must either occur at depth or considerably up-gradient of the Belly Tank Flat and monitoring well TH-2 area. Only the new M-3 monitoring well (Figure 2 and Appendix B) suggests a somewhat possible of westerly-derived waters. The primary upwelling zone is postulated to be near or at the area of TH-2, ECP-1, and TH-1, and that farther to the south in the Apex - Nevada Cogeneration Associates (NCA) well field area the flow field waters have traveled laterally and have passed through more Muddy Creek Formation to evolve to somewhat higher concentrations of conservative ions derived from evaporite minerals (Figure B-2). The HV-1 data suggest a more local component of water (water isotopically heavier) has been mixed into the more deeply-circulated component of flow in the deep test well, that is over 2,000 feet into the saturated zone, and with similar water chemistry of the Apex area. A configuration of deep regional flow from the north, similar to theoretical configurations of Toth (1963) and Freeze and Witherspoon (1967; Figure 8) best explains the databases developed to date.

3.5.2 Conceptual Model Issues

Unresolved questions are two-fold: 1) What is the nature of the interface between the northern and southern flow fields, and 2) Where does the flux of the southern flow field go? The first is an important question in terms of modeling analyses of pumping impacts from the Belly Tank Flat well field. The uncertainty raised by the questions encouraged adoption of a conservative modeling approach that may be, overall, too conservative in terms of the propagation of pumping cones northward into the northern flow field, with resulting capture, over time, of northern flow field waters. If the interface zone (Figure 5) is a local zone of decreased hydraulic continuity within the Paleozoic rocks due to faulting and/or a less permeable zone of strata, the propagation northward of the pumping effects would be impeded, and either reduce or eliminate impacts in the northern flow field. On the north side of this interface zone at the M-1 monitoring well, the geochemical data suggests an edge zone of the northern flow field, and preliminary interpretation of the short monitoring record to date suggests hydraulic continuity with the Muddy River Springs Area. Because of the relatively uniform fluid potentials to the north and the north-south structural grain in the carbonate terrain, a conservative approach in the modeling analyses was adopted by embedding into the model the same highly-developed N-S transmissivity evident from aquifer-test data in the Belly Tank Flat area.

The issue of total flux through the southern flow field is important in terms of water resource management. A range of estimates of the magnitude of this flux has been obtained through the modeling process, but it is accompanied by uncertainty. For example, if relatively small changes are made to regional aquifer properties, and/or gradients, or western boundary area recharge, and the calibration value would change. It is clear that considerable flux is necessary to meet the strong evidence for a gradient between the central and southern areas, but aquifer properties are just as important, and they are unproven over very large areas. One consequence of this uncertainty is that while modeling analyses described below have provided order-of-magnitude flux estimates the question of specific outflow locations may never be resolved. Outflow

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locations may be to the southeast in a highly faulted zone north of Frenchman Mountain, or perhaps dispersed along the Las Vegas Shear Zone, or even south along the frontal fault zone on the west side of the Frenchman Mountain structural block. The problem of outflow recognition is twofold; 1) sparse or no data points in many areas, and 2) mixed water from wells typically designed to capture water from any producing zone, beginning in uppermost saturated alluvial fill and continuing to the total depth of the well. Therefore, the only areas where there may be opportunity to recognize Arrow Canyon Range Cell waters is from wells that do not penetrate saturated alluvium.

This aspect of uncertainty is not significant in terms of projecting impacts from the Project, as the fluid potentials in the Las Vegas basin are significantly lower. There are no recognized water sources that are of similar geochemistry, and therefore impacts from even markedly lowered water levels within the Carbonate Aquifer of the Arrow Canyon Range Cell along the Las Vegas Shear Zone would not likely produce any measurable or recognized impacts. Further, based on the discontinuity of water levels between the Arrow Canyon Range Cell and all adjacent areas to the south and southeast of the projected trace of the Las Vegas Shear Zone, and the highly faulted Tertiary strata exposed to the east along the eastward splay of the Las Vegas Shear Zone, much or all of the outflow may be distributed and pass through strata rich in evaporites. Only in the Lake Mead Basin area and south of Pabco are there candidate waters in terms of permissible water chemistry and isotopic signatures without opportunity for major dilution by low-TDS waters.

4.0 Modeling Analyses

Modeling analyses derive from a combination of professional judgment and applications of flow equations, and forecasts may or may not prove to be accurate over time. They are extremely useful, nevertheless, because the modeling codes are, in themselves, very powerful tools that allow for analysis of flow in complex geologic settings that could not be quantitatively evaluated in any other manner. They allow the study of spatial and temporal impacts of groundwater development, often and provide insight into problem areas where databases are necessary. Model forecasts should be tested and refined through monitoring wherever possible, allowing stepwise improvements in accuracy.

4.1 Previous Modeling Studies

Others have conducted comprehensive modeling studies at regional, sub-regional, and local scales in the general area. The one known regional study was sponsored by Federal agencies, two known sub-regional studies by the Las Vegas Valley Water District (District), and one local study by Nevada Power Company (NPC). After careful review and evaluation, some have a potential to be non-conservative, as outlined below.

4.1.1 Regional Model

A two-layer model of the simulated effects of pumping from 17 basins in east central and southern Nevada (Schaefer and Harrill, 1995) reported the potential effects of a proposed 180,800 afy appropriation *for a period of 30 years* by the Las Vegas Valley Water District. This work was requested by several Departments of the Interior agencies, and performed by the U.S. Geological Survey. A two-layer MODFLOW grid, originally developed for the Great Basin Regional Aquifer-System Analysis (RASA) project, was applied (Prudic and others, 1993). The

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model grid contains 61 rows by 60 columns, and cells 5 miles wide by 7.5 miles long.

The Schaefer and Harrill study resulted in qualified predictions of effects on water levels including: 670 ft decline in Garden Valley, a 22 percent decrease of the flow in Muddy River Springs and groundwater discharge by evapotranspiration (54% decrease in Spring Valley) if steady-state conditions were established in the distant future. The report noted, "results reported should be used only as indications of possible generalized effects". At 30 years into the simulation, roughly comparable to the cases considered evaluated for the proposed MPEC, a 10% decrease in the flow of Muddy River Springs was predicted. According to Schaefer and Harrill (1995, p.7) general-head boundaries (GHB's) were prescribed along the northeast, northwest, southeast, and southwest borders of the model, i.e. on all sides (citing Prudic and others, 1993, p. 18). This appears to be inconsistent with the statement (Schaefer and Harrill, 1995, p. 42) that "The boundaries for this simulation do not allow additional water to be made available to the groundwater system of the Great Basin...". It is unclear, therefore, how conservative these predictions of pumping effects actually are, given the incomplete description of the boundary conditions applied to this model. A GHB is a prescribed-head boundary with some resistance, designed to simulate a more distant constant head and thereby "soften" what would otherwise act as a nearby source of infinite amounts of water. GHB's would allow inflow of additional water to the model domain. The southeastern and southwestern boundaries appear to be impacted by the simulated withdrawals, and should therefore yield some additional water.

4.1.2 Sub-Regional Model of California Wash and Coyote Spring Valley

Sub-regional models of the California Wash (Hydrographic Basin 218) and Coyote Spring Valley (Hydrographic Basin 210) have been prepared by Montgomery Engineers for the Las Vegas Valley Water District. The first (Wildermuth and others, 1990) was an assessment of the groundwater resource potential of the California Wash Basin, and was conducted to estimate the impacts of the District's proposed 20,000 afy diversions from the Basin. The model consisted of a 2-layer MODFLOW grid, 32 rows by 30 columns and grid spacings of about one mile. Using prescribed heads on the east and west borders of the model grid and prescribed inflows to the north, the conclusion was reached that steady-state inflow and outflow are about 22,000 afy, in contrast to the work done by Rush (1968), who estimated about 9,000 afy. This increase is attributed to "...subsurface inflow in the consolidated rocks flowing through the Basin from the west to the east." (Wildermuth and others, 1990, p. 14).

On page 24 of the Montgomery report it is stated: "The model boundaries are rectangular and have been set arbitrarily far from the hydrographic boundaries. This was done to insure [sic] that assumptions on the model boundaries will not bias drawdown estimates". In contrast to this assumption, modeling analyses conducted relative to the MPEC indicates that using the scale of this model, six to ten miles from the east and west boundaries is too close for a prescribed-head boundary and a general-head boundary could have been used to lessen the effect of induced inflow.

In addition, the treatment of resistance between the two model layers in the Montgomery report is questioned. Given the major differences in head between upper and lower aquifers for all modeling runs, the effective resistance for most of the model area must be close to infinity. The consequence of this high resistance (low leakance) is that wells are forced to draw water from the

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prescribed-head boundaries. The net effect is to minimize potential impacts on regional spring flow and shallow water levels.

4.1.3 Sub-Regional Model of Coyote Spring Valley

A sub-regional steady-state model of Coyote Spring Valley (Buqo and others, 1992) was also developed to study the District's water-right filings. The model consists of a 2-layer MODFLOW grid, 49 rows by 24 columns and one-mile grid spacing. The presence of the sensitive environment at the Muddy River Springs Area was recognized as an important factor to be taken into account for a development scheme. The study concluded that undeveloped water resources are available in Coyote Spring Valley, especially in the carbonate aquifer. However, there was an absence of any transient analyses of pumping stresses on the basin even though storage properties were assigned to the hydrostratigraphic model units. Transient analyses could have predicted impacts on the regional springs.

4.1.4 Sub-Regional Model of the Muddy River Springs Area

A local three-layer model of the Muddy River Springs Area was developed by Bredehoeft and Hall (1996), to assess the hydrologic impacts of proposed pumping of 6.2 cfs by the Moapa Valley Water District in the Warm Springs - Moapa area. The Bredehoeft study utilized a MODFLOW grid with a locally refined mesh. The model predicted that while impacts on water levels would be minimal, river/spring flow would decrease by exactly the amount pumped from the well. The report also contains a compilation of seasonal pumping and response trends.

4.1.5 Summary of Previous Modeling Efforts

Such analyses correlate most closely with the bounding Case 2 modeling scenario of this study (Section 4.6) which incorporate constant head model boundaries. The previous models do not address uncertainty associated with this natural system. A goal in this study is to bound uncertainty related to hydrologic boundary conditions, while maintaining an underlying conservative assumption of regional hydraulic continuity.

4.2 Model Code Selection

The groundwater modeling presented here is based on a comprehensive literature review, data collection, analysis and interpretation, professional familiarity and experience with the area of interest (Arrow Canyon Range Cell) and the choice of models that will satisfy the following objectives:

- Prediction of the effects of pumping 7,000 afy from the Belly Tank Flat site for 25 and 45 year periods from the Paleozoic carbonate aquifer in the California Wash Basin
- Prediction of the effects of pumping on the Muddy River Springs Area approximately 15 miles northeast of the Project area
- Prediction of the effects on pumping in the Apex Industrial Area 15 miles south of the Project area
- Prediction of the effects of pumping on the Rodgers/Blue Point Springs area 22miles southeast of the Project area.

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The model developments are tools to enhance the understanding of a complex hydrogeologic system. A philosophical distinction between a model and a simulator is made; the latter is a comprehensive predictor of a full range of effects, whereas the former is an efficient path to improved understanding of natural system. Modeling is developed with the specific intent of improving forecasts of future effects on water levels in the interior of the sub-regional model domain.

A stepwise approach was developed where the model evolves iteratively relative to the objective and level of detail as the understanding of the hydrogeological system increases by the modeling process. The approach described herein integrates two complementary modeling technologies.

4.2.1 The Analytic Element Method (AEM)

The Analytic Element Method (AEM), as implemented in the computer program GFLOW 2000 (Haitjema, 1995), was selected for the analysis of regional groundwater flow conditions in the Arrow Canyon Range Cell surrounding the California Wash Basin, and in assessing potential long-term impacts on existing water resources resulting from pumping at the Proposed Project site. The AEM does not utilize a model grid nor require checks on mass balance. The AEM is appropriate to analyze areas where the lateral extent of the flow field is large compared to its thickness and where hydrogeologic data are sparse. The ease with which various scenarios of pumpage, material-property distributions, or recharge, for example, can be examined and adjusted formed an incentive to apply this technology to the project.

In particular, the AEM proved useful in screening the numerous conceptual models of regional flow that might apply to the Arrow Canyon Range Cell and environs. In the absence of a model grid the AEM could be applied to a very large domain without loss of local detail. Regional variations of recharge and aquifer transmissivity were accounted for by inhomogeneity domains in the AEM GFLOW 2000 model. Fault zones, believed to offer obstruction to flow, could be represented as no-flow boundaries or boundaries with a specified resistance to flow. GFLOW 2000 facilitates the extraction of local MODFLOW models, whereby the conditions on the MODFLOW grid perimeter are obtained from the GFLOW regional solution to groundwater flow. This MODFLOW extract feature was used to create a local MODFLOW model of the project area and its surroundings to analyze possible regional transient effects of the proposed project on regional water levels and groundwater discharge in the Muddy River Springs Area. The approach to groundwater modeling by using that regional AEM model GFLOW to define boundary conditions for a sub-regional MODFLOW model have been documented in the peer reviewed literature, e.g., Hunt et al. (1998 a & b), Hunt and Krohelski (1996).

4.2.2 MODFLOW Sub-regional analyses of groundwater flow

MODFLOW Sub-regional analyses of groundwater flow, and in particular transient phenomena, were analyzed using the finite-difference code MODFLOW (MacDonald and Harbaugh, 1988), as implemented in the Groundwater Vistas (Environmental Simulations, Inc., 1999) modeling environment. MODFLOW grids were extracted from GFLOW 2000 (Figure 9) ,with material properties (hydraulic conductivity, storage and porosity), recharge, (three zones), boundary conditions (constant head, river, well, general head boundary (GHB), and no flow domains) and calibration targets (heads and spring discharges), Figures 10 through 14.

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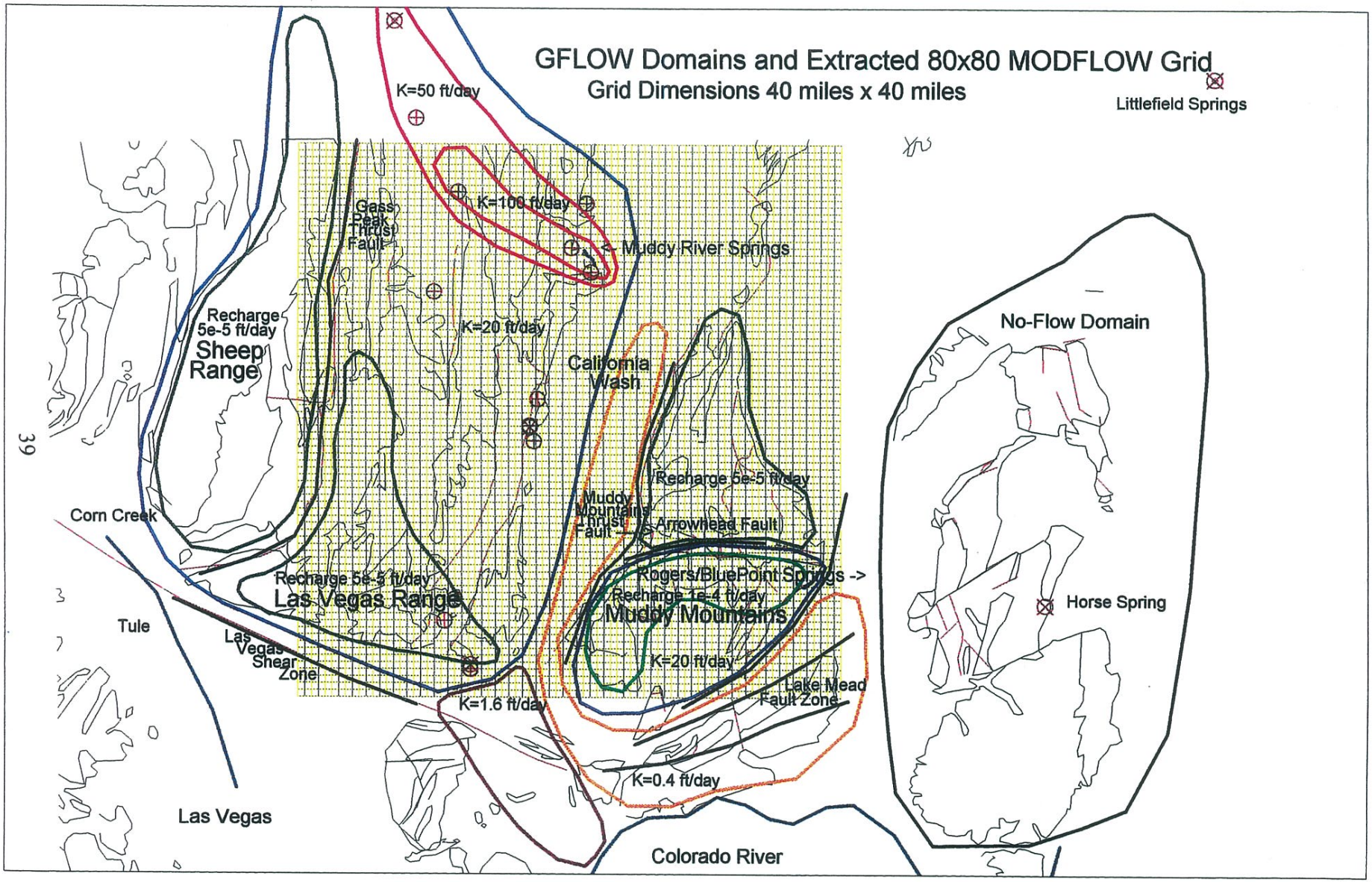

Figure 9. GFLOW domains (hydraulic conductivity and recharge) with superposed 80 x 80 MODFLOW grid. Refer to text for description of domains. North is at the top of the page.

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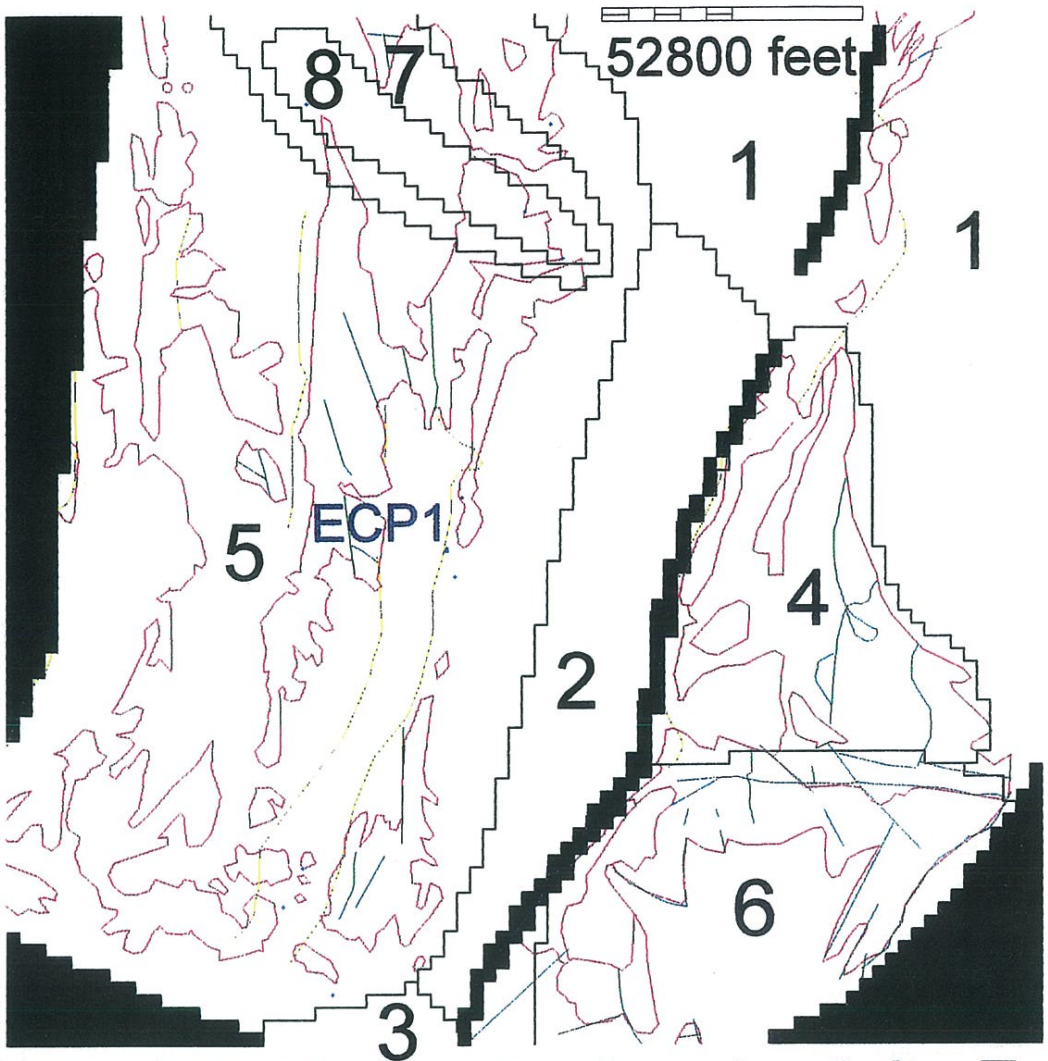

MODFLOW Hydraulic Conductivity Zones

Zone 1	Kx=0.1 ft/day Ky=0.1 ft/day	Zone 5	Kx=5 ft/day Ky=30 ft/day
Zone 2	Kx=0.4 ft/day Ky=0.4 ft/day	Zone 6	Kx=20 ft/day Ky=20 ft/day
Zone 3	Kx=1.6 ft/day Ky=1.6 ft/day	Zone 7	Kx=50 ft/day Ky=50 ft/day
Zone 4	Kx=2 ft/day Ky=2 ft/day	Zone 8	Kx=100 ft/day Ky=100 ft/day

Single Layer ,Type 1, Thickness 5000 feet

Figure 10. MODFLOW vertical and horizontal conductivity. Black are no flow boundaries. North is at the top of the page.

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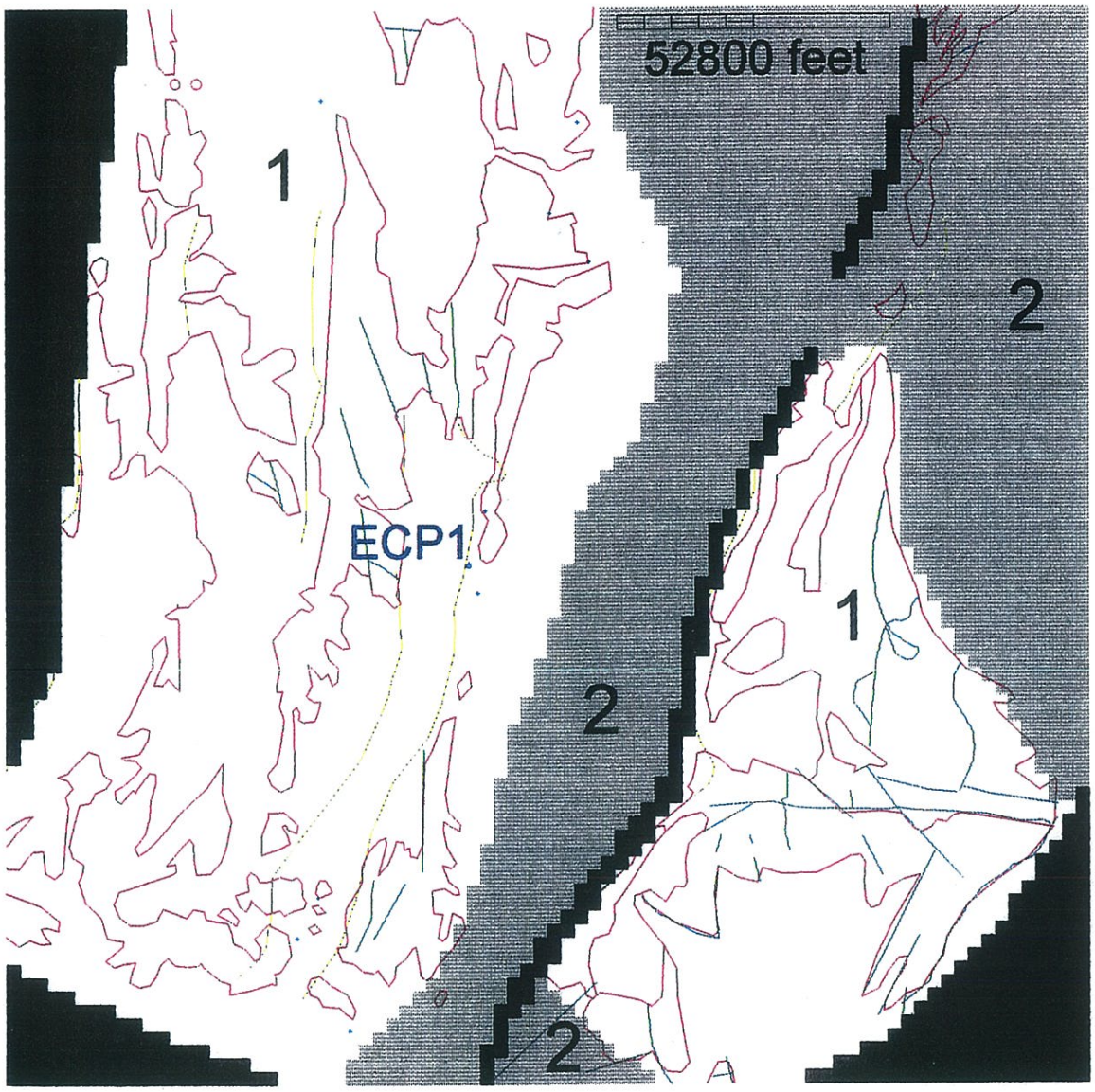

MODFLOW Storage/Porosity Zones

Zone 1	Zone 2
S=.008	S=.01
Sy=.03	Sy=.2
porosity=.047	porosity=.3

Figure 11. MODFLOW storage and porosity zones. Black are no flow boundaries. North is at the top of the page.

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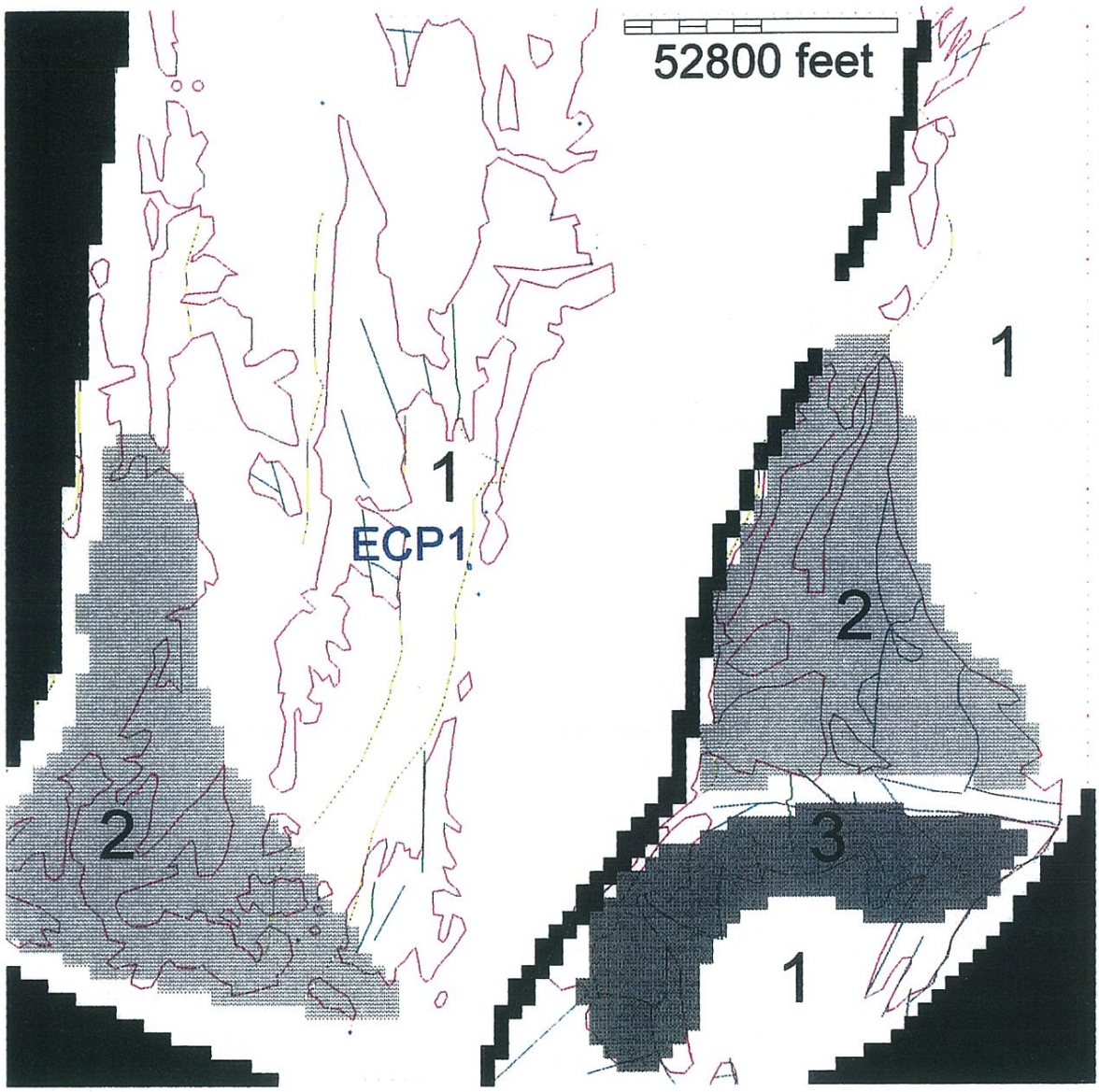

MODFLOW Recharge Zones

Zone 1: 0 ft/day

Zone 2: 5e-5 ft/day

Zone 3: 1e-4 ft/day

Figure 12. MODFLOW recharge zones. Black are no flow boundaries. North is at the top of the page.

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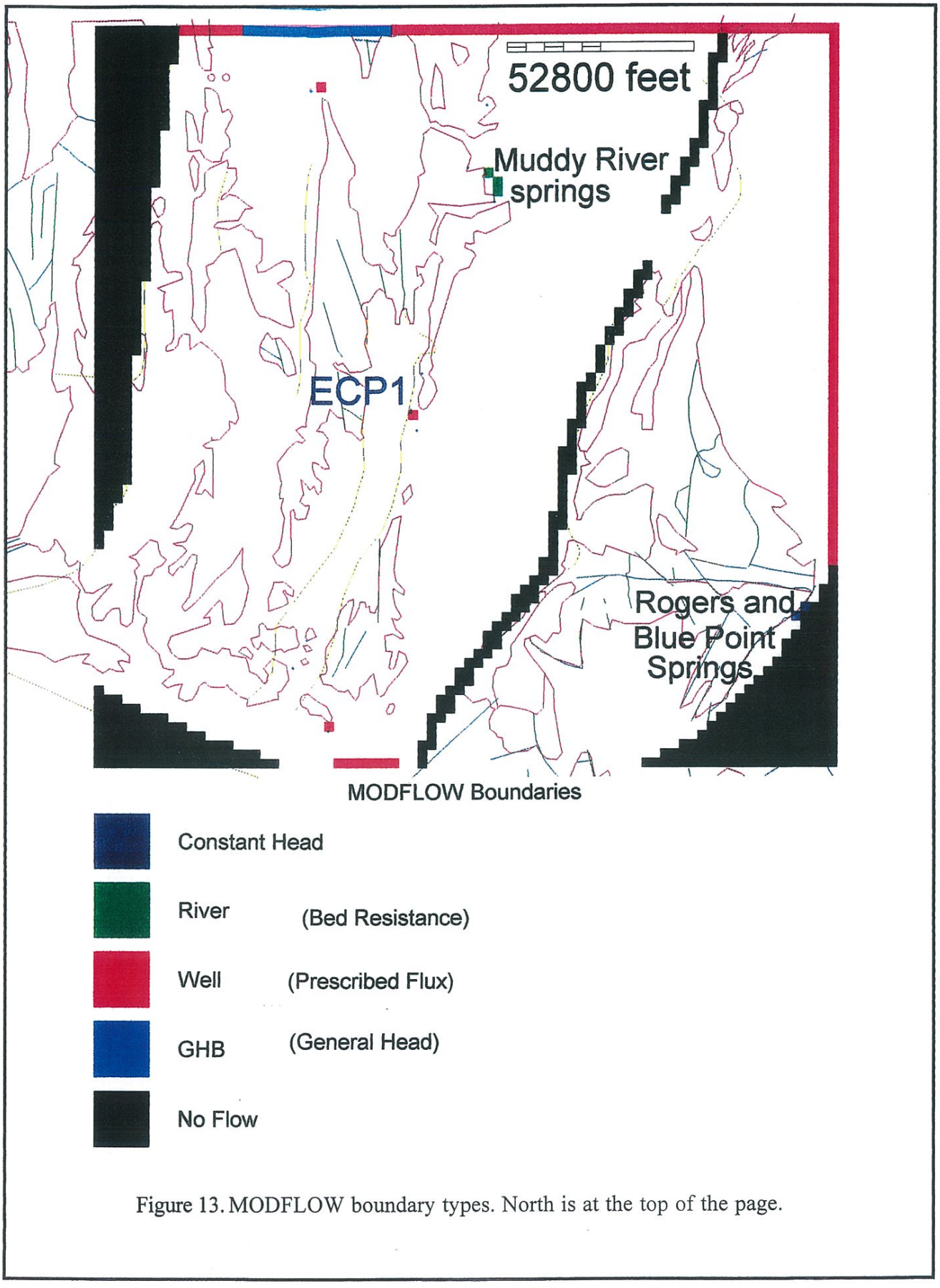

Figure 13. MODFLOW boundary types. North is at the top of the page.

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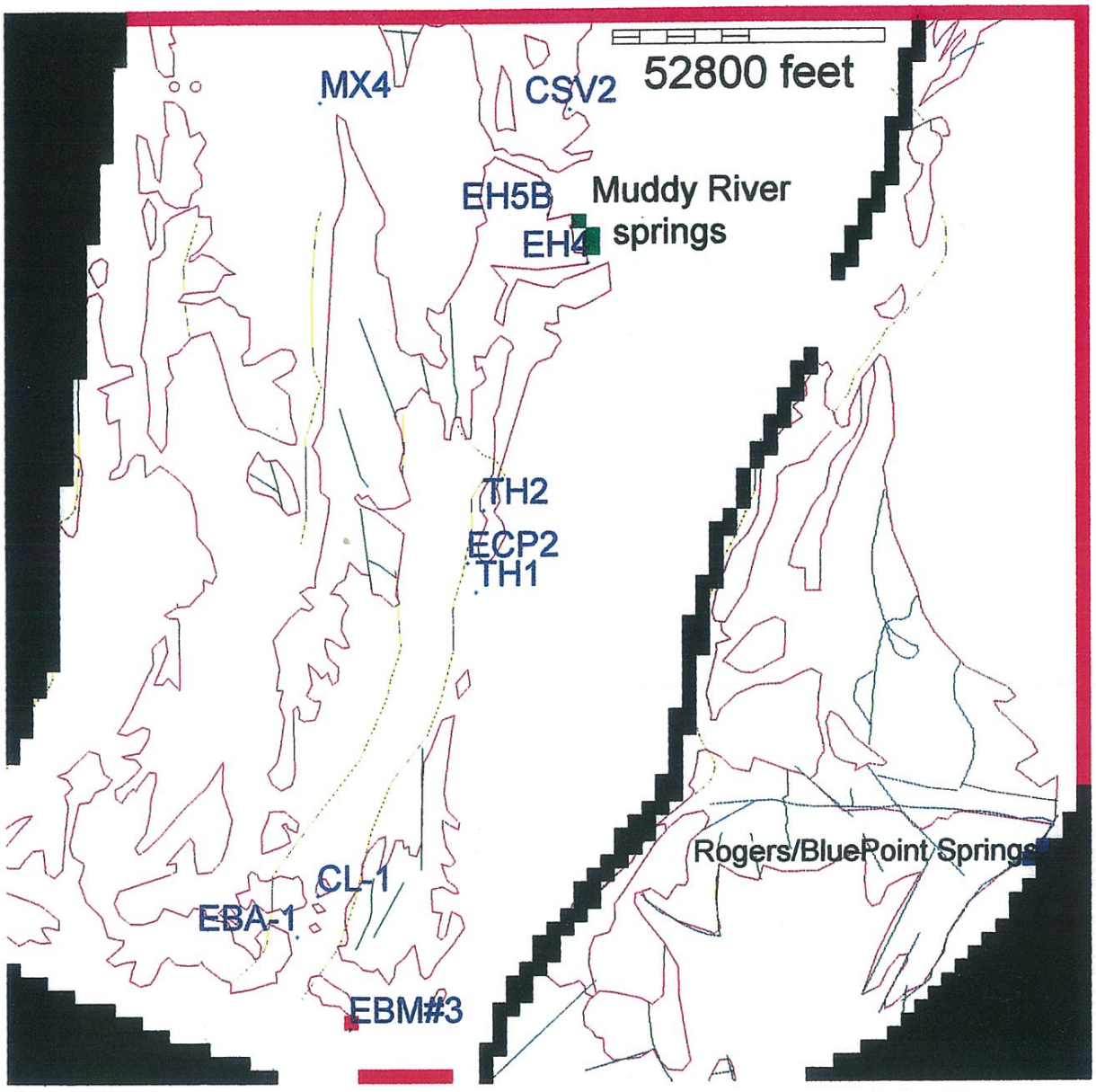

MODFLOW Calibration Targets

Basis for calibration:

1. Observed head in surveyed wells, and
2. Measured discharge in spring outflow areas.

Figure 14. MODFLOW calibration targets as head and discharge. Refer to figure 13 for boundary types. North is at the top of the page.

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The following denotes the utility of this modeling approach:

- The requirement to evaluate transient effects on Muddy River springs is satisfied
- Regional modeling using the AEM as implemented in GFLOW 2000 had constrained material-property distributions sufficiently to warrant mesh-building
- GFLOW 2000 supports automated generation and export of MODFLOW grids, facilitating a seamless transition to transient evaluations
- MODFLOW is one of the most and widely-understood finite-difference codes in existence
- MODFLOW has become extremely applicable through the Groundwater Vistas modeling environment
- In addition to material properties, MODFLOW boundary condition files can be exported by GFLOW
- Minor adjustments to material-property boundaries and recalibrations to include anisotropy provided a consistent set of alternate conceptual models based on differing boundary conditions

4.3 Assumptions and Constraints

Fundamental requirements for a successful modeling effort include knowledge of hydrogeologic boundary conditions and the distribution of material properties within the study area including:

- Far-field boundary conditions were established using elevations of perennial streams and water levels in springs and wells associated with the Carbonate Aquifer of southern Nevada.
- Major streams and regional carbonate-aquifer springs were utilized as far-field, specified-head boundary conditions. Known total discharge to the Muddy River Springs Area on the order of 50 cfs and from the Rogers - Blue Point Spring area on the order of 5 cfs were used as calibration targets, as were heads in wells surveyed specifically for this project.
- Near field conditions were established by the analysis of a 7-day aquifer test at well ECP-1 that yielded transmissivity estimates of 5×10^4 to 1×10^5 ft^2/day and evidence of unconfined conditions (Appendix A).
- Anisotropy of the aquifer in a north-south direction was observed by the results of the pumping response at ECP-1 and was incorporated into the sub-regional model during the calibration process.

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- An aquifer thickness of 5,000 feet was estimated from groundwater temperatures in the Muddy River Springs Area inferring that depths of circulation of several thousand feet would be required for the geothermal gradient to warm groundwater to observed temperatures.

- An analysis of the relationship between barometric efficiency and storativity (Walton, 1996, p.18) was used to obtain an independent estimate of aquifer thickness (4,739 feet), which is in general agreement with the 5,000-foot estimate from thermal data (Appendix A, p. 20).

- A porosity value of 0.047 (4.7%) was used, based on the average porosity of carbonate rocks in the Coyote Spring Valley obtained from geophysical logs and reported by the USGS (Berger,1992).

- Given the maximum transmissivity indicated by pumping experiments, 10^5 ft^2/day, and an estimated thickness of 5,000 feet, the nominal hydraulic conductivity, K is computed as 20 ft/day.

- The near-field value of K was adjusted upward in the high-permeability corridor extending northwest from Muddy River Springs Area

- The near-field value of K was adjusted downward outside the carbonate-dominated sub region that underlies the study area.

- Fine-grained Tertiary sediments of the Muddy Creek and Horse Spring Formations occupy a band several miles wide within the high-permeability "Arrow Canyon Range Cell" (Mifflin, 1992). This band is designated as a sub-regional domain or low-permeability domain that extends to infinity in the AEM. These Tertiary sediments have yielded transmissivity estimates of 251 ft^2/day (Pohlmann and others, 1988) and 605 ft^2/day (Johnson and others, 1986). A hydraulic conductivity value of 0.4 ft/day was arrived at by trial-and-error during model calibration, and appears to be generally consistent with the limited aquifer-test data.

- A conservative assumption is incorporated into all modeling scenarios. The Carbonate Aquifer transmissivity and anisotropic characteristics in the Belly Tank Flat area is modeled as extending northward unmodified into the flow field that supplies water to the Muddy River Springs. This hydraulic connection, however, might not be present because there is neither evidence for discharge of the waters typical of the southern flow field in the Muddy River Springs Area nor evidence of northern flow field waters to the south. The assumption of hydraulic continuity as adopted allows the Belly Tank Flat pumping cone to efficiently extend north and south, and therefore impact the flow field in the north that supplies the Muddy River Springs. A physical (stratigraphic or structural) barrier would limit the northward migration of the Belly Tank Flat Well Field pumping cone into the Muddy River Springs flow field, and cause actual pumping impacts on spring area discharge to be less than projected.

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4.4 Conceptual Model and Modeling Design

The most fundamental and significant element of the conceptual model is that groundwater flow in the region of interest can be adequately represented by Dupuit-Forchheimer flow in a single, unconfined layer. These conditions are met because the lateral extent of the aquifer system is large compared to its thickness as the distances between features are over ten times the aquifer thickness. Summarizing:

- There is no geologic evidence that a multi-layer model is warranted because within the zone of saturation, Tertiary sediments and Mesozoic red beds are known to generally bound, rather than stratigraphically cap upper Paleozoic carbonate rocks of the Arrow Canyon Range Cell. There are relatively small localized areas of exception.

- No credit is taken for large-scale leakage resistance between layers, which would artificially isolate shallow and deep systems in the model

- A direct hydraulic connection with the Muddy River Springs Area is embodied in the model, although a growing body of geochemical and isotopic evidence suggests that the springs are fed by a completely different flow system than that supplying Belly Tank Flat

- The lateral extent of the model domain is great as compared to its vertical thickness, and head changes with depth have not been observed while drilling in carbonate rocks in the Project area; these suggest that a 2-D Dupuit-Forchheimer model is applicable

- There are no conceptual difficulties with deep underflow occurring beneath a discharge area, as pointed out by Haitjema (1995) in his discussions of 3-D flow in a Dupuit-Forchheimer model.

A single-layer model was also judged to be more appropriate for the locally relevant California Wash area than the two- and three-layer models used in previous studies. The choice of a single-layer conceptual model is clearly supported in the Glendale area, where Johnson and others (1986) report at least 4,000 feet of fine-grained sediments at the eastern margin of the Arrow Canyon Range Cell and no evidence of substantial eastward underflow. In the Belly Tank Flat area, there is no known basis for subdividing the saturated zone into more than one layer. In addition, a section of Tertiary sediments was observed in exploratory boreholes a few miles to the east in the vicinity of Moapa Tribal Enterprises that is similar to that observed at Glendale supporting the assumption of the application of a one-layer model, (Figure 2).

In addition to the Paleozoic carbonates, which are the most transmissive rocks of the region, there are thick sections of Mesozoic and Cenozoic sedimentary and volcaniclastic rocks that were judged to be generally an order of magnitude and locally two orders of magnitude lower in permeability then the carbonates. Salt deposits in the Muddy Creek Formation east of Overton Arm would be expected to be highly non-transmissive, (Figure 3). Steep potentiometric gradients across the Las Vegas Shear Zone from the Apex area to Las Vegas Valley imply the existence of a structural flow barrier south Arrow Canyon Range Cell (Figure 5). As a result, the Lake Mead Fault Zone was inferred to be a hydraulic barrier based on the model calibration process. There appears to be subsurface leakage of on the order of 10,000 afy across this barrier

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southward out of the California Wash Hydrographic Basin into an area characterized by complex faulting, gypsiferous rocks and no known potable groundwater resources. Stable isotopic data and regional fluid-potential gradients suggest that the Gass Peak Thrust (the western MODFLOW boundary) is not a water-tight barrier to eastward flow from the Sheep Range to the Project area. In order to maintain conservatism it has been modeled as a no-flow boundary to maintain consistency with the historical treatment of the "Lower Clastic Aquitard" that outcrops along this important structure. The Sheep and Las Vegas Ranges may in fact be significant sources of subsurface inflow, as assumed by Wildermuth and others (1990) and suggested by the isotopic data contained in Appendix B; Figure B-3.

The nature of the interface zone (a six mile gap with no data) between the two flow fields with characteristic waters is important with respect to how pumping cones may spread from pumping centers within the two regions of the Arrow Canyon Range Cell, (Figure 5). Normally, it could be assumed that the two flow fields, with distinct water populations, would not be in close hydraulic continuity. However, because no major differences in water-level elevations or hydrogeologic features that would limit transmissivity between the two flow fields are detected, a conservative assumption is applied to the modeling scenarios that describes well-developed hydraulic continuity between the two. This assumption allows efficient propagation of pumping impacts from one flow field to the other, and it is an important assumption in terms of when, and how strong, the Belly Tank Flat pumping impacts are manifested at the Muddy River Spring Area, as an example.

The correct conceptualization of the configurations and characteristics of regional carbonate-rock flow systems may prove useful in predicting the water-resource potential of the Carbonate Aquifer throughout much of the Carbonate Rock Province of the Great Basin. The potential for exceptionally large volumes of storage in close hydraulic continuity with a deep regional system as compared to more intermediate-scale flow systems, such as the one supplying Muddy River Springs Area, exists. If the southern flow field of the Arrow Canyon Range Cell proves not to be in close hydraulic continuity with adjacent flow systems, the water-resource potential of the southern Arrow Canyon Range Cell is enhanced. Current databases and the developing conceptual model of two independent flow fields argue for a large southern region of the Arrow Canyon Range Cell to be isolated (in terms of propagating pumping impacts) from adjacent groundwater basins.

Modeling using the Dupuit-Forchheimer assumption of horizontal flow is consistent with recognition of a probable upwelling zone within the model domain. The conceptual model developed from isotopic and geochemical data indicates separate sources of water in the northern and southern flow fields, some of which is deeply circulated. Mathematically and conceptually, distributed recharge and upwelling are equivalent. As an example, the recharge specified for the Las Vegas Range could be considered upwelling recharge, or a combination of both. Calibration of the GFLOW model could probably be improved by increasing distributed flux and disassociating it from local topography, but such changes would be conjectural until controls on upwelling are better understood. Similarly, the induced inflows allowed by the prescribed-head boundaries in Cases 1 and 2 are analogous to the effects of an upwelling zone. In effect, new water from beyond the model domain is made available as the system is stressed by pumping, lessening the net impact. It is cause-and-effect relationships such as these, and not the geometric

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details of the vertical dimension, that the modeling analyses have explained.

4.5 The Base Case, Regional, Steady-State GFLOW Model

The base case model shown on Figure 15 was constructed by successive refinements of hydraulic conductivities in the model sub-regions while maintaining prescribed heads at Muddy River Springs and Rogers/Blue Point Springs:

- Thickness of the aquifer was assumed to be 5,000 feet throughout the model domain
- Hydraulic conductivities in the Belly Tank Flat region were estimated through a process of manual calibration of the regional steady-state flow model; several hundred GFLOW runs were required to obtain a satisfactory match to observed conditions.
- Hydraulic conductivities were adjusted using targets of observed water levels and maintaining the outflow in the Muddy River Springs Area near 51 cfs, and Rogers/Blue Point Springs near 5 cfs (double actual measured discharge).
- A barrier to eastward flow was prescribed in the vicinity of the Muddy Mountains Thrust in order for discharge to occur in the Muddy River Springs Area
- A high-permeability corridor extending northwestward from the Muddy River Springs Area was prescribed for sufficient groundwater discharge to occur

Scenarios that correctly predicted outflows at the two major spring areas (Muddy River Springs Area and Rogers/Blue Point Springs) and a good approximation of regional water levels were computed within a small variance in residuals. Table 1 shows wells that were used as calibration targets, (Figure 2).

Table 1. Target Wells and Heads used in Model Calibration

Target ID	Grid Coordinate	Grid Coordinate	Target Heads, ft	Improved Estimates
	X	Y	September 2000	December 2000
EH5b	106,148	171,630	1,817	1,817.03
CSV2	110,414	192,028	1,796.8	1,796.84
EH4	113,891	162,172	1,816.7	1,816.71
EBA-1	56,752	28,878	1,818.7	1,819.99
CL-1	60,803	36,935	1,815	1,815.38
MX4	61,640	193,464	1,821.6	1,821.57
EBM#3	66,886	10,594	1,811	1,812.83
ECP2	90,259	103,123	1,812.9	1,815.56
TH1	91,935	97,296	1,813.3	1,815.12
TH2	93,412	113,540	1,814	1,814.45

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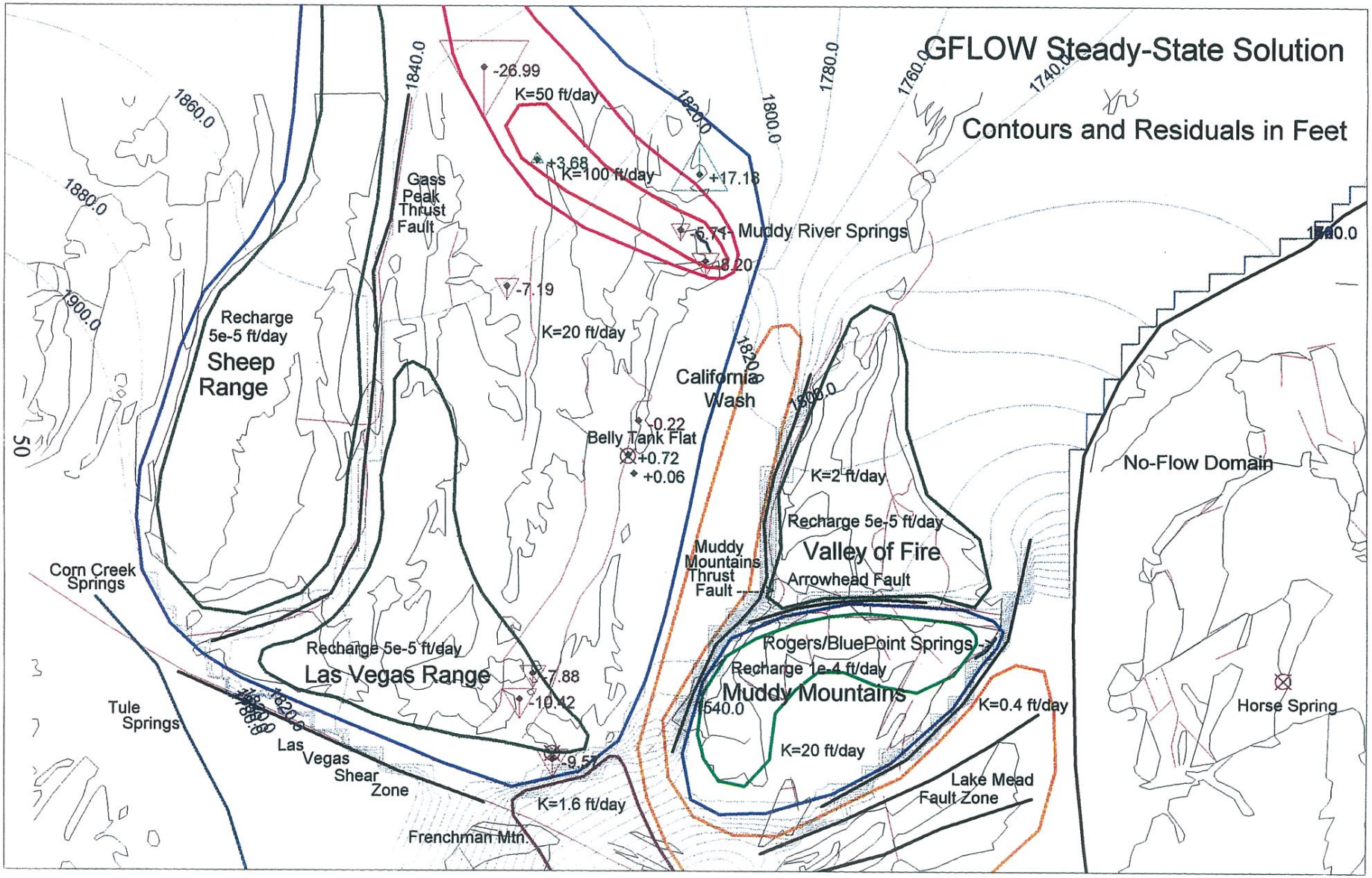

Figure 15. GFLOW steady-state solution showing fluid potential contours in feet above mean sea level (amsl) and residuals in feet at calibration points. North is at the top of the page.

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Generated flow paths were evaluated qualitatively for their consistency with isotopic data. The model domain was subdivided into central and outer regions each with smaller zones where material-property or recharge adjustments could be applied. The quantitative features of the base case regional model are shown on Figure 15 and are summarized with detail below:

1. **Arrow Canyon Range Cell and Muddy Mountains Block of the Carbonate Aquifer.** A large region of K=20 ft/day, shown in blue outline in the left-central portion of Figure 15, encloses the Project area. This central region includes the Sheep Range and Gass Peak thrust, and is bounded on the south by the Las Vegas Valley shear zone. The eastern boundary of the central region generally follows the North Muddy Mountains, but is offset to the west from the north Muddy Mountains to accommodate a strip of Tertiary volcaniclastic rocks inferred to be several miles wide that was encountered while drilling borehole EH-2a near Reid Gardner station (Johnson and others, 1986). The Muddy Mountains block was also assigned K=20 ft/day since it is underlain by carbonates lithologically and stratigraphically similar to those of the Arrow Canyon Range Cell.

2. **Tertiary Sediments of the Muddy Creek and Horse Spring Formations.** The thick section of Tertiary sediments reported by Johnson and others (1986) is thought to underlie California Wash in a structural block that parallels the North Muddy Mountains, effectively cutting off eastward flow from the Arrow Canyon Range Cell. Portions of the Las Vegas Shear Zone and Lake Mead Fault Zone have been included in this crescent-shaped zone of K=0.4 ft/day, shown in orange outline east and south of the Muddy Mountains on Figure 15.

3. **North Muddy Mountains and Valley of Fire.** The Valley of Fire block, shown as a pear-shaped outline of dark green in Figure 15, was assigned K=2 ft/day. The boundary between the Muddy Mountains and Valley of Fire follows the Arrowhead Fault.

4. **Gypsiferous Sediments of the Southern Outflow Zone.** A key element of the conceptual model presented herein is that regional flux exits the Arrow Canyon Range Cell through a southern outflow zone, represented by purple outline near bottom center of Figure 15. Calibration of the model scenarios required that such a zone exist to allow water to drain from the southern margin of the Arrow Canyon Range Cell so that water levels in the Apex area could be approximated. The hydraulic conductivity estimate of 1.6 ft/day was an outcome of the calibration process.

5. **Outer Region**. The outer region, extending from the border of the Central Region to infinity, is assigned k=0.1 ft/day (Shown as the white background).

6. **Nested Muddy River Springs-Coyote Spring Valley High-K Zones**. A high-permeability zone in the vicinity of the MX4 well, shown in nested red outlines in the top cent portion of Figure 15, is indicated by cavernous conditions and aquifer-test results suggesting transmissivities of several million gallons per day per foot. This zone was assigned a hydraulic conductivity k=50 ft/day by trial and error to achieve the desired quantity of outflow at Muddy River Springs. A core zone within the High-K zone was assigned K=100 ft/day. This zone defines a high-transmissivity area surrounding the Muddy River Springs

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where a relatively flat potentiometric gradient is observed in boreholes. The substantial head differences between the springs are attributed to head losses in the discharge conduits.

7. **Las Vegas Shear Zone-Lake Mead Fault Zone.** The Las Vegas Shear zone joins the Lake Mead Fault Zone in the vicinity of the Hamblin - Cleopatra Volcano, southeast of the Muddy Mountains. Discrete zero-permeability horizontal flow barriers have been associated with individual strands of these major faults (Shown as black lines on Figure 15).

8. **Muddy Mountains and Gass Peak Thrust Faults.** Heads that are uniformly greater than 1800 feet AMSL west of the North Muddy Mountains and up to 200 feet lower (1,600 feet AMSL) in the Valley of Fire - Rogers Spring area suggest a step-down from west to east, most likely due to the presence of a barrier to eastward flow of groundwater. A discrete, zero-permeability horizontal flow barrier was associated with the Muddy Mountains Thrust from east of Apex to east of Glendale. Similarly, the Gass Peak Thrust was treated as a no-flow boundary, using a discrete zero-permeability horizontal-flow barrier (both are shown as black lines on Figure 15).

9. **Sheep Range Recharge.** The Sheep range was included in the model based on USGS interpretations of its significance as a source area for Muddy River Spring discharge. Sheep Range Central-Region has been assigned a recharge rate of 5×10^{-5} ft/day, equivalent to 0.02 ft/yr. This recharge area is shown in dark green outline in the left-central portion of Figure 15.

10. **Las Vegas Range Recharge**. The Las Vegas Range was assigned a recharge rate of 5×10^{-5} ft/day, as shown in dark green outline in the lower left portion of Figure 15.
11. **Northern Muddy Mountains Recharge**. The Northern Muddy Mountains were assigned a recharge rate of 5×10^{-5} ft/day. The recharge area is the same pear-shaped, dark green outline that was assigned K=2 ft/day.
12. **Muddy Mountains Recharge.** The Muddy Mountains were assigned a recharge rate of 10^{-4} ft/day (0.03 ft/yr) to support model spring flow from Rogers and Blue Point Springs that are roughly double observed values. The rationale for this approach was that unrecognized eastward underflow beneath the spring area warranted consideration in the model. As understanding of the region evolved and it became clear that Rogers and Blue Point Springs and essentially isolated from the Arrow Canyon Range Cell, this recharge rate remained as a historical artifact of the calibration process.
13. **Regional Recharge.** A large rectangular area surrounding the Central Region was made available for assignment of regional recharge. The base case value was zero.

The regional, steady-state (GFLOW 2000) model illustrates the isolation of Rogers and Blue Point Springs from the southern flow field of the Arrow Canyon Range Cell. Regional water levels and appropriate spring flows could not be reproduced without an extensive and effective barrier to eastward groundwater flow in the vicinity of the Muddy Mountains and Glendale Thrust faults (Figure 3). Similarly, the presence of a highly transmissive corridor extending northwestward from the Muddy River Springs Area was revealed, consistent with observations at wells MX-4 and MX-5, which are in this corridor. Finally, the GFLOW model provided a basis for selecting a subdomain for detailed analysis of alternative scenarios, and for specification of

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boundary conditions surrounding this smaller area.

The steady-state model also provides an estimate of flux leaving the southern flow field. Summing the individual outflows in row 80, columns 24 through 35 of the exported MODFLOW grid (Table 2) gives 9,543 afy. Outflow on the order of 10,000 afy is consistent with estimates based on isotopic mass balance, and with MODFLOW Case 2 (described below).

4.6 Transient Sub-Models: Extraction and Application of MODFLOW Grids

A finite-difference grid geometry was defined and GFLOW results extracted to define boundary conditions for sub-regional, transient simulations. Initially, two identical grids were exported as sets of MODFLOW input files, each consisting of 6,400 square grid blocks, each individual block 1/2 x 1/2 mile in dimension. The first grid, designated FlowGrid, was extracted with flux boundary conditions defined, and the second, designated HeadGrid, contained heads derived from the GFLOW solution. The results are contained in Table 2.

The three alternative conceptual models consist of MODFLOW grids extracted from GFLOW and different sets of boundary conditions. Minor re-calibrations were required as boundary conditions were re-defined, but material properties and geometry are the same for all three scenarios. The manner in which the boundaries between adjacent material property zones are represented is quite different in GFLOW and MODFLOW, and "clean up" of the exported grids is thought to have been the reason the new (MODFLOW) models required individual recalibration. Consider two subzones within a larger background zone, and the modeler wishes to represent the subzones as sharing a common boundary. In GFLOW, a "screen" of the background materials will remain between the two subzones as they are brought closely adjacent. If the "screen" properties are very different from either of the subzones, flow between the subzones will be misrepresented. There are obviously workarounds to avoid these geometries, but workarounds are not always feasible or necessary. In the present study a barrier to flow (the Muddy Mountains – Glendale Thrust) was associated with one harder "screen" between subzones, so recalibration requirements were minor. Solutions were sensitive, however cleanup of the model grid in the southern outflow area (southeast of Apex), and recalibrations resulted in a range of outflows that varied by a factor of 3 (Table 3).

The MODFLOW boundary conditions used in the transient state scenarios are 1) the constant head boundary scenario, which supplies an unlimited supply of water when pumping cones reach the boundary; 2) the prescribed flux boundary scenario, which prescribes the supply of water to the model domain; the supply is finite, and no induced recharge along the boundaries occurs when water levels are lowered, and 3) a hybrid boundary response scenario, where some boundaries are prescribed flux and some are prescribed heads. In any given terrain situation, some areas of a model boundary are more realistic with a constant head boundary and some are more realistic with a prescribed flux boundary.
The three bounding condition scenarios are:

Case 1, is a *hybrid* of a combination of *constant head and prescribed flux boundaries*, distributed on the basis of regional relationships and considered the *most probable boundary condition scenario*.

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Table 2: Heads and Fluxes Extracted from GFLOW

Values in BLUE were utilized in runs HeadGrid and TransHG
Values in RED were utilized in runs FlowGrid and TransFG
Values in PURPLE were utilized in runs HybridBC and TranHYB
Values in BLACK were included with no-flow boundary cells, which include all cells not given explicitly below.

NOTES related to calibration of hybrid case:

1. Hybrid heads are uniformly 5 feet lower than extracted values.
2. Hybrid fluxes in cells R80C27-R80C33 are double the average of extracted values in those cells.

NOTES on boundary conditions at SPRINGS:

1. Muddy River Springs were represented by 3 river cells with H = 1758 ft, conductance = 22,400.
2. Rogers and Blue Point Springs were treated as prescribed-head "wells", H = 1590 ft, with no resistance.

Row	Col	Head (ft)	Q (ft3/day)	Hybrid H	Hybrid Q
1	9	1842.41	347100.0		
1	10	1841.64	224300.0	1836.64	
1	11	1840.86	165500.0	1835.86	
1	12	1840.15	135600.0	1835.15	
1	13	1839.49	117800.0	1834.49	
1	14	1838.86	106200.0	1833.86	
1	15	1838.25	98270.0	1833.25	
1	16	1837.64	92980.0	1832.64	
1	17	1837.03	231300.0	1832.03	
1	18	1836.45	227500.0	1831.45	
1	19	1835.85	226600.0	1830.85	
1	20	1835.20	231400.0	1830.20	
1	21	1834.50	247700.0	1829.50	
1	22	1833.79	297000.0	1828.79	
1	23	1833.28	268100.0	1828.28	
1	24	1832.83	257500.0	1827.83	
1	25	1832.46	250100.0	1827.46	
1	26	1832.16	186400.0	1827.16	
1	27	1831.75	177100.0	1826.75	
1	28	1831.28	170800.0	1826.28	
1	29	1830.78	166100.0	1825.78	
1	30	1830.25	162300.0	1825.25	
1	31	1829.69	158900.0	1824.69	
1	32	1829.12	156100.0	1824.12	
1	33	1828.47	55970.0	1823.47	
1	34	1827.80	54650.0	1822.80	
1	35	1827.11	53370.0	1822.11	
1	36	1826.42	51940.0	1821.42	
1	37	1825.72	50280.0	1820.72	
1	38	1825.03	48390.0	1820.03	
1	39	1824.34	46300.0	1819.34	
1	40	1823.67	44020.0	1818.67	
1	41	1823.02	41460.0	1818.02	
1	42	1821.62	-14.5	1816.62	
1	43	1821.86	-1213.0	1816.86	
1	44	1820.46	-1142.0	1815.46	
1	45	1818.02	-814.9	1813.02	
1	46	1815.31	-537.3	1810.31	
1	47	1812.60	-360.7	1807.60	
1	48	1809.95	-273.1	1804.95	

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Table 2 continued: Heads and Fluxes Extracted from GFLOW

1	49	1807.46	-239.9	1802.46	
1	50	1805.03	-225.6	1800.03	
1	51	1802.56	-205.3	1797.56	
1	52	1800.02	-169.7	1795.02	
1	53	1797.47	-118.8	1792.47	
1	54	1794.86	-58.9	1789.86	
1	55	1792.23	5.2	1787.23	
1	56	1789.62	69.2	1784.62	
1	57	1787.02	130.2	1782.02	
1	58	1784.47	186.6	1779.47	
1	59	1781.94	238.6	1776.94	
1	60	1779.50	285.2	1774.50	
1	61	1777.10	327.0	1772.10	
1	62	1774.79	363.9	1769.79	
1	63	1772.59	396.4	1767.59	
1	64	1770.42	425.1	1765.42	
1	65	1768.35	449.6	1763.35	
1	66	1766.36	471.1	1761.36	
1	67	1764.44	488.7	1759.44	
1	68	1762.63	503.6	1757.63	
1	69	1760.84	515.6	1755.84	
1	70	1759.16	524.8	1754.16	
1	71	1757.55	532.0	1752.55	
1	72	1756.02	536.8	1751.02	
1	73	1754.57	539.9	1749.57	
1	74	1753.18	541.0	1748.18	
1	75	1751.87	540.6	1746.87	
1	76	1750.65	538.9	1745.65	
1	77	1749.44	536.1	1744.44	
1	78	1748.32	531.7	1743.32	
1	79	1747.25	526.6	1742.25	
1	80	1746.29	43.3	1741.29	
56	1	1825.86	32280.0		
57	1	1826.33	43470.0		
58	1	1826.77	53660.0		
59	1	1827.13	59210.0		
60	1	1827.43	63220.0		
61	1	1827.66	66420.0		
62	1	1827.84	68880.0		
63	1	1827.96	70710.0		
64	1	1828.03	71960.0		
65	1	1828.04	72660.0		
66	1	1828.01	72820.0		
67	1	1827.93	72430.0		
68	1	1827.80	71490.0		
69	1	1827.63	70010.0		
70	1	1827.43	68090.0		
71	1	1827.20	66080.0		
72	1	1826.96	64760.0		
73	1	1824.93	2018.0		
74	1	1825.61	1571.0		
80	24	1664.59	-86320.0		
80	25	1659.77	-90050.0		
80	26	1654.60	-93970.0		
80	27	1648.86	-95540.0		-189550.0
80	28	1642.59	-94910.0		-189550.0
80	29	1636.03	-92750.0		-189550.0
80	30	1629.59	-92210.0		-189550.0
80	31	1623.46	-93880.0		-189550.0
80	32	1617.57	-95940.0		-189550.0

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Table 2 continued: Heads and Fluxes Extracted from GFLOW

80	33	1611.89	-98190.0	-189550.0
80	34	1606.46	-100900.0	
80	35	1601.33	-104300.0	
80	36	1597.06	-7257.0	
80	37	1591.83	-30890.0	
80	38	1586.82	-30760.0	
80	39	1580.56	-29730.0	
80	40	1573.40	-27110.0	
80	41	1565.06	-4144.0	
80	42	1567.72	-27360.0	
80	43	1567.68	-23820.0	
80	44	1567.64	-21720.0	
80	45	1567.62	-19730.0	
80	46	1567.62	-17410.0	
80	47	1567.65	-15620.0	
80	48	1567.71	-14470.0	
80	49	1567.82	-16600.0	
80	50	1567.93	-16390.0	
80	51	1568.04	-15640.0	
80	52	1568.15	-14630.0	
80	53	1568.26	-13510.0	
80	54	1568.37	-12490.0	
80	55	1568.49	-11780.0	
80	56	1568.60	-11520.0	
80	57	1568.71	-11620.0	
80	58	1568.83	-11820.0	
80	59	1568.97	-11190.0	
80	60	1567.99	-259.0	
2	80	1745.17	-470.6	1740.17
3	80	1744.03	-462.5	1739.03
4	80	1742.80	-453.0	1737.80
5	80	1741.54	-442.1	1736.54
6	80	1740.27	-429.6	1735.27
7	80	1738.83	-415.8	1733.83
8	80	1737.37	-400.2	1732.37
9	80	1735.83	-383.4	1730.83
10	80	1734.27	-364.1	1729.27
11	80	1732.61	-343.6	1727.61
12	80	1730.89	-321.4	1725.89
13	80	1729.09	-297.4	1724.09
14	80	1727.27	-272.0	1722.27
15	80	1725.29	-245.4	1720.29
16	80	1723.34	-217.8	1718.34
17	80	1721.30	-189.1	1716.30
18	80	1719.23	-159.6	1714.23
19	80	1717.03	-130.9	1712.03
20	80	1714.84	-102.3	1709.84
21	80	1712.59	-75.1	1707.59
22	80	1710.25	-49.8	1705.25
23	80	1707.90	-27.0	1702.90
24	80	1705.52	-7.2	1700.52
25	80	1703.07	8.6	1698.07
26	80	1700.58	20.5	1695.58
27	80	1698.03	27.0	1693.03
28	80	1695.44	28.7	1690.44
29	80	1692.82	25.0	1687.82
30	80	1690.08	15.1	1685.08
31	80	1687.32	-1.0	1682.32
32	80	1684.46	-23.6	1679.46
33	80	1681.52	-53.2	1676.52

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Table 2 continued: Heads and Fluxes Extracted from GFLOW

34	80	1678.47	-90.9	1673.47
35	80	1675.31	-137.1	1670.31
36	80	1671.98	-193.9	1666.98
37	80	1668.56	-262.4	1663.56
38	80	1664.97	-344.5	1659.97
39	80	1661.23	-443.6	1656.23
40	80	1657.32	-562.0	1652.32
41	80	1653.21	-703.8	1648.21
42	80	1648.88	-874.2	1643.88
43	80	1644.38	-1079.0	1639.38
44	80	1639.67	-1329.0	1634.67
45	80	1634.78	-1636.0	1629.78
46	80	1629.75	-2022.0	1624.75
47	80	1624.56	-2517.0	1619.56
48	80	1619.37	-3169.0	1614.37
49	80	1614.47	-4044.0	1609.47
50	80	1610.52	-5144.0	1605.52
51	80	1609.24	-5768.0	1604.24
52	80	1612.33	-4481.0	1607.33
53	80	1617.72	-2379.0	1612.72
54	80	1622.46	-529.4	1617.46
55	80	1624.84	927.9	1619.84
56	80	1623.65	2068.0	1618.65
57	80	1618.10	3007.0	
58	80	1409.95	2902.0	

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Case 2, is a *constant head* boundary scenario, considered to be a *less probable bounding scenario* that is optimistic in terms of the induced recharge on responses to water-level declines.

Case 3, is a *prescribed flux* boundary scenario, a *bounding scenario* that is *least probable*, as only the fluxes of steady state enter and leave the modeling domain, this boundary condition maximizes water-level declines as it does not allow for any induced recharge at the modeling domain boundaries.

The transient modeling included the re-calibration of steady-state conditions using the grids representing each of the three alternative conceptual models. These runs provide initial heads required to begin the transient simulations; it is the differences between the transient solutions and these starting heads that define drawdowns in the models. Current conditions represented by the steady-state solutions are shown on Table 3.

Table 3. Current Conditions Represented by Steady State Solutions

Boundary Type	Run ID	Q_{south} (afy)	Q_{mrs} (cfs)	Head-save File
n/a	GFLOW	9,543	47.8	n/a
Case 1, Hybrid Figure 16	Hybrid BC2	6,450	54	HybridBC.hds
Case 2, Head BC Figure 17	HeadBC2	9,170	54	HeadGrid.hds
Case 3, Flux BC Figure 18	FlowBC2	3,050	50	FlowGrid.hds

4.6.1 Case 1: The Hybrid Boundary Condition, the Most Probable Response Scenario

The Case 1 hybrid boundary condition, the most probable response scenario prescribes that head remains constant with time north and east of the Muddy River, but flow across the domain boundary remains constant south and west of the Project area. The results of Hybrid25yr Figure 19, illustrates that this case is a compromise between the credible but unrealistic Case 3 and the perhaps optimistic Case 2. The prescribed-head boundary condition on the north and east edges of the model domain and the prescribed-flow condition on the south and west were applied to the domain. To achieve calibration it was necessary to lower heads 5 feet from their Case 2 values, restrict the Case 3 inflow from the southern Las Vegas Range and outflow along the Lake Mead Fault Zone to zero flux, and double outflow from a strip of 7 grid blocks along the southern model boundary. As a result, groundwater discharge to the Muddy River Springs Area decreases by only 0.7% after 25 years. The results of Hybrid45 Figure 20, predicts that in 45 years groundwater discharge in the Muddy River springs Area will decrease by 1.3%.

The cone of depression for Case 1 is asymmetric in a north-south direction; the prescribed-head boundary is protecting the Muddy River Springs Area. Although outflow is held to a constant value to the south, in reality this Belly Tank Flat pumping would cause a reduction in these natural outflows and capture water that would otherwise be lost to the postulated outflow zone in the southeast corner of the Arrow Canyon Range Cell.

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Boundary heads from FlowGrid and HeadGrid

Root File ID: HybridBC

N and E heads from HeadGrid lowered 5 ft. to calibrate;
also, W inflow from FlowGrid eliminated
and S outflow from FlowGrid adjusted

52800 feet

File HybridBC2; 20-foot Head Contours and Residuals in feet

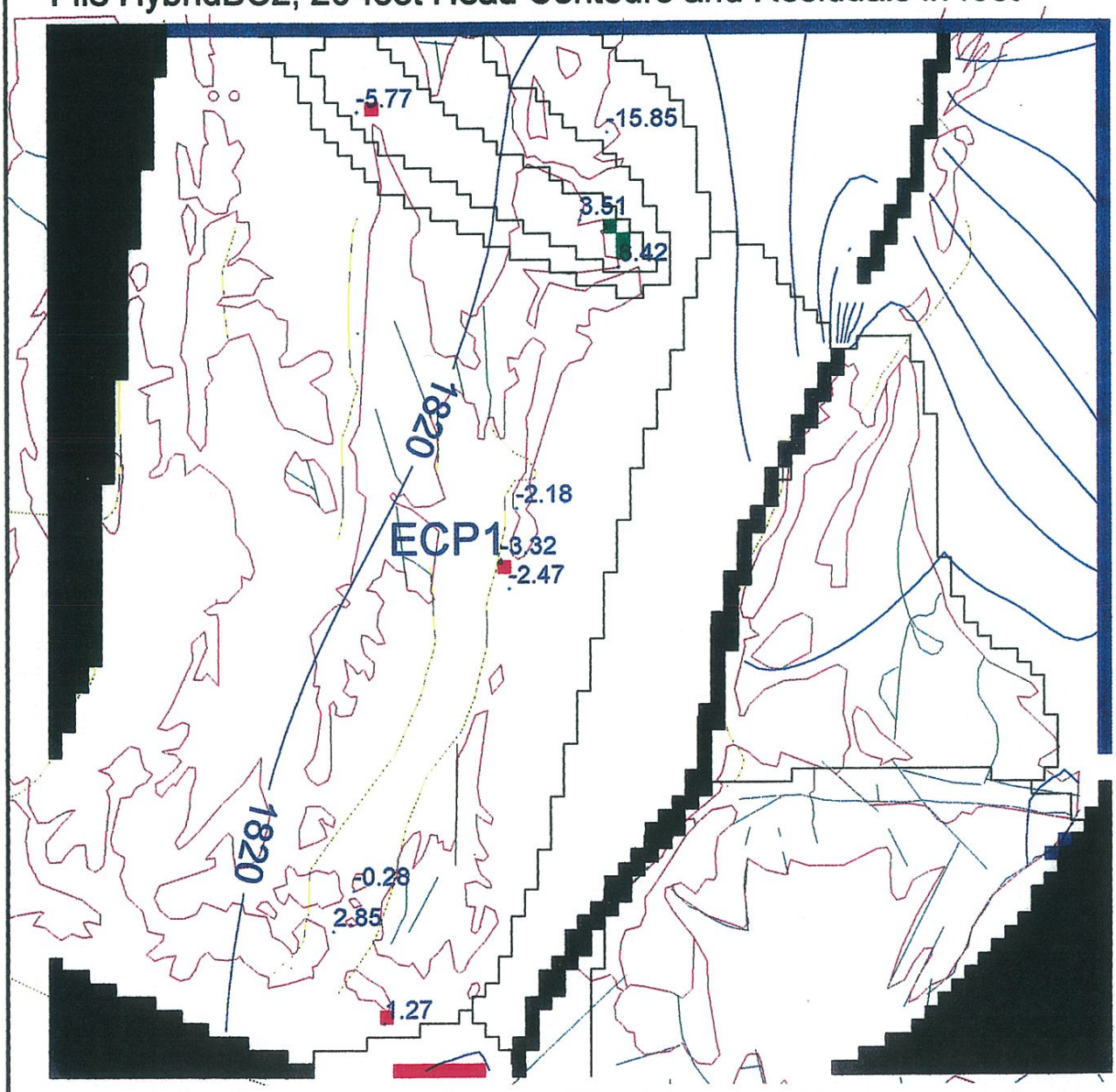

Figure 16. Case 1, the hybrid boundary condition, the most probable scenario, steady state solution. Refer to figure 13 for boundary types. North is at the top of the page.

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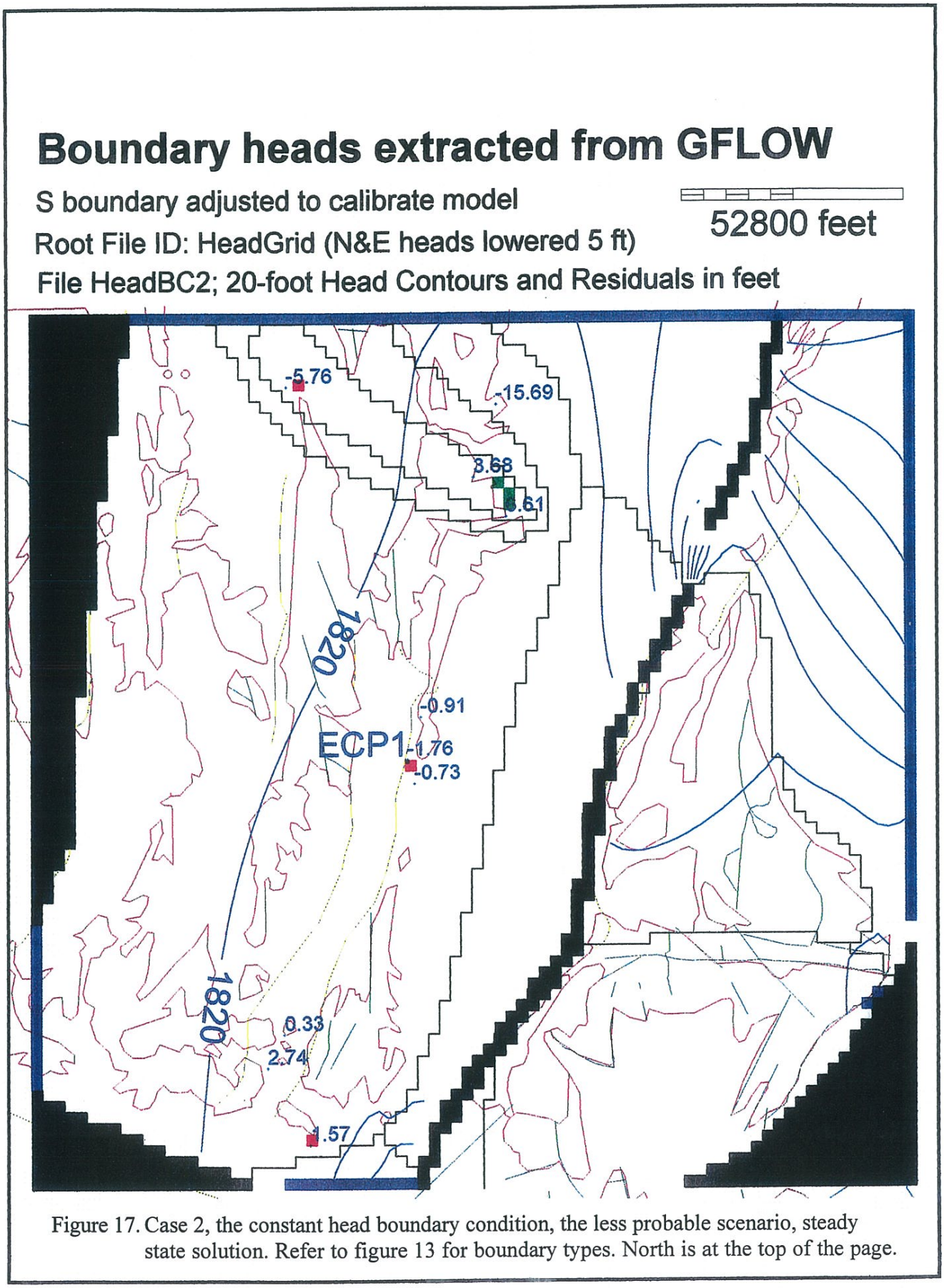

Figure 17. Case 2, the constant head boundary condition, the less probable scenario, steady state solution. Refer to figure 13 for boundary types. North is at the top of the page.

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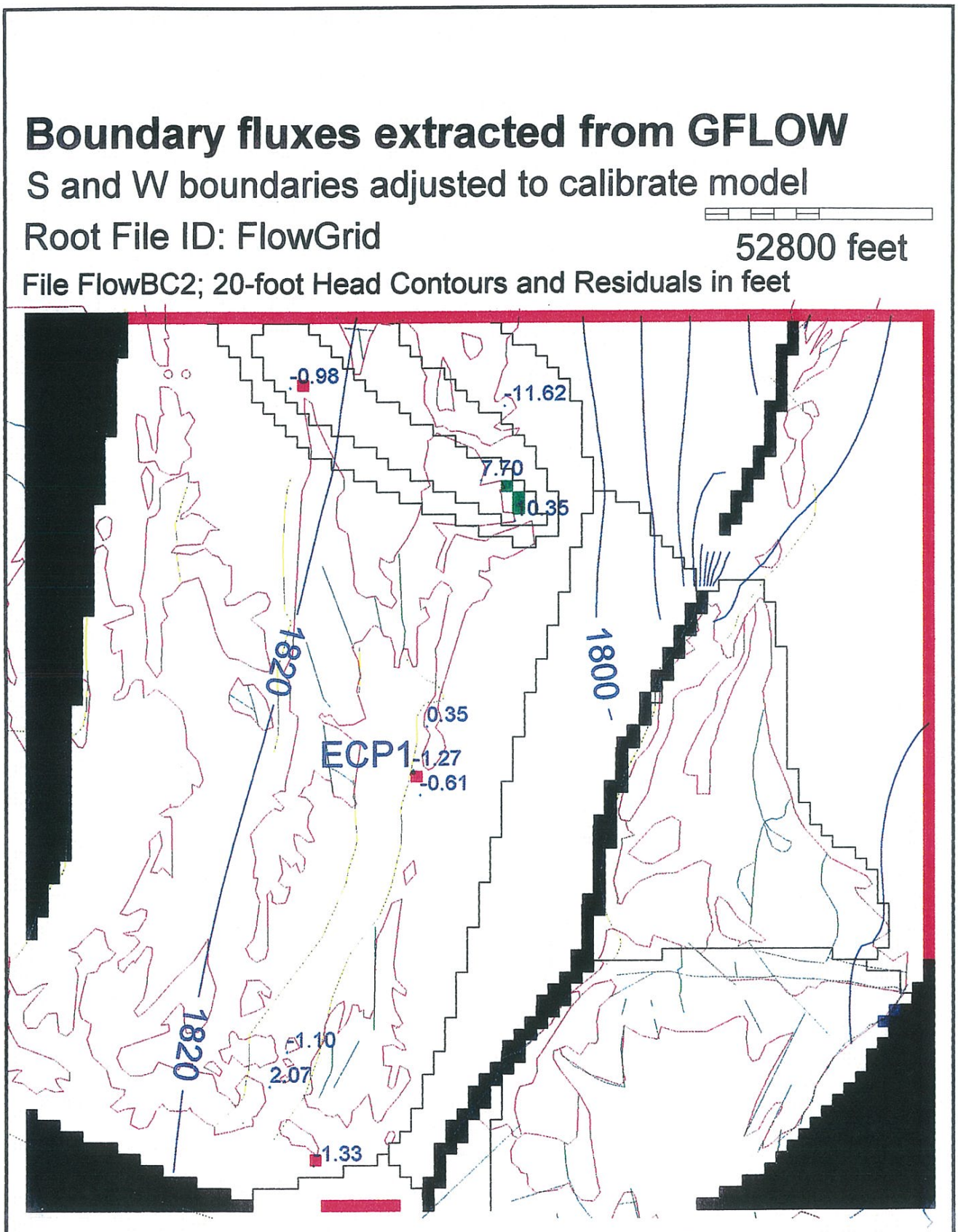

Figure 18. Case 3, the prescribed flux boundary condition, the least probable scenario, steady state solution. Refer to figure 13 for boundary types. North is at the top of the page.

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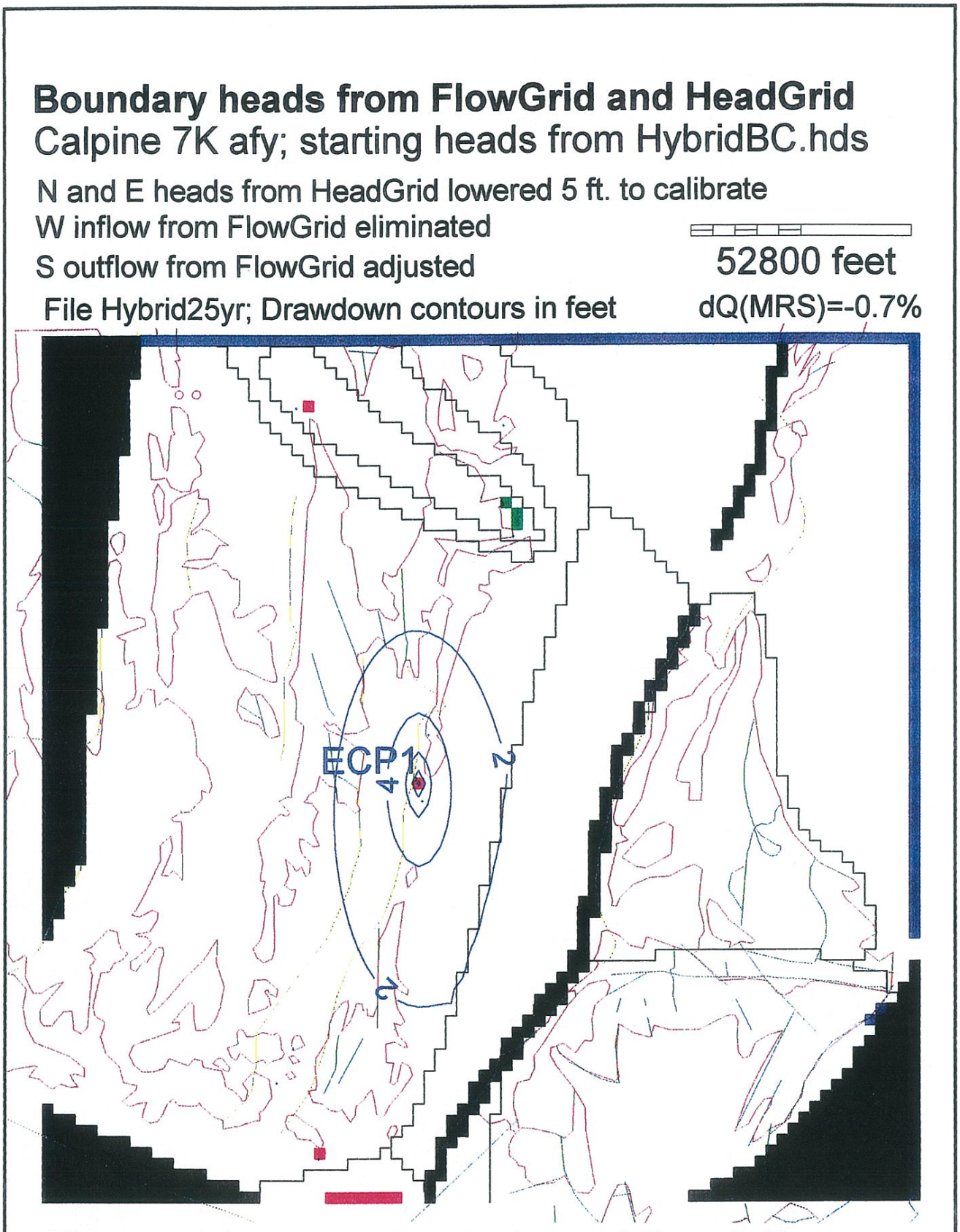

Figure 19. Case 1, the hybrid boundary condition, the most probable scenario, 25-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

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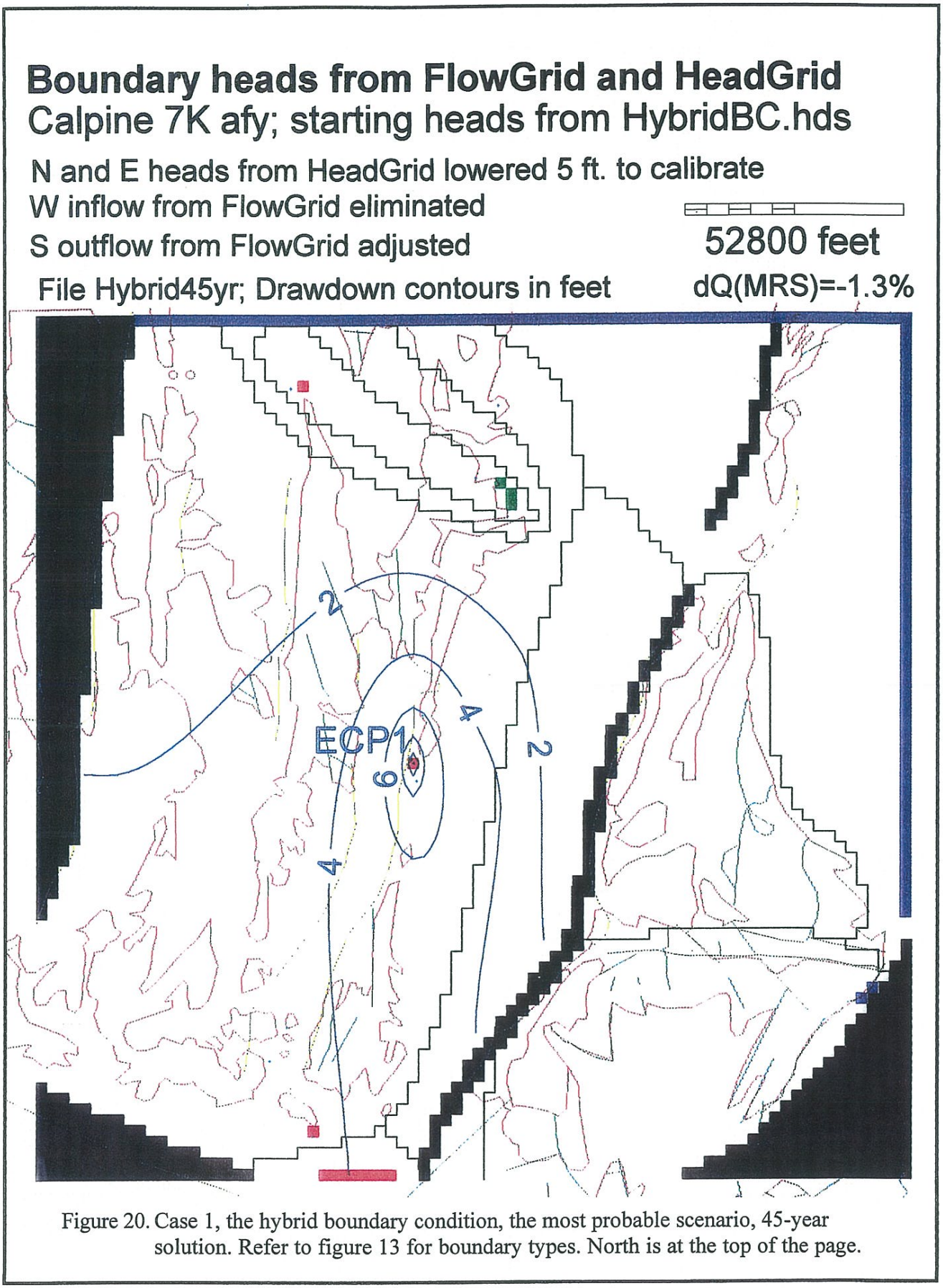

Figure 20. Case 1, the hybrid boundary condition, the most probable scenario, 45-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

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4.6.2 Case 2: The Constant Head Boundary Condition, the Less Probable Bounding Scenario

The Case 2 constant head boundary condition, the less probable bounding scenario, prescribes that head (water level) at the domain boundary remains constant with time. In dramatic contrast to Case 3, this case is where heads at the model boundary remain constant with time and allow pumped water to be compensated by induced "recharge" at the model boundary (an unlimited supply of imaginary water in some areas).

The results of Head25yr Figure 21, illustrates the application of a constant-head boundary, an unlikely scenario with respect to some boundary conditions. Impacts on groundwater discharge to the Muddy River Springs Area were minimal, amounting to 1.1% reduction after 25 years. The results of Head45yr Figure 22, predicts that 1.1% (unchanged) reduction occurs at 45 years. The cone of depression from this scenario is much more restricted at any point in time than in the following Case 3 and is (by definition) zero at the model boundaries.

4.6.3 Case 3: The Prescribed Flux Boundary Condition, the Least Probable Bounding Scenario

The Case 3 prescribed flux boundary condition, the least probable bounding scenario prescribes flux across the domain boundary that remains constant with time. Case 3 scenario for pumping would be constant inflows and outflows at the model boundary. Any extraction of water would ultimately be compensated by a decrease in groundwater discharge elsewhere. Depletion of stored water would mitigate these effects in a temporal sense, but given sufficient time the end result would be the same regardless of the system's storage capacity.

The results of Flow25yr shown on Figure 23 illustrates the extent to which groundwater discharge at the Muddy River Springs Area will be impacted after 25 years of pumping 7,000 afy from the Belly Tank Flat well field. A decrease in groundwater discharge in the Muddy River Springs Area of 7.5% (3.8 cfs), is forecasted at 25 years. The cone of depression is elongate in a north-south direction due to the system anisotropy, and asymmetrical about the center of pumping due to hydraulic barriers west of the North Muddy Mountains. The results of Flow45yr shown on Figure 24 illustrates that groundwater discharge in the Muddy River Springs Area has decreased by 10.4% after 45 years. Since there are no inflows from outside the model domain in this scenario, all water must come from storage (which has a delaying effect on impacts), or ultimately from the Muddy River Springs Area. At infinite time, withdrawals from within the model domain would be exactly balanced by a decrease in groundwater discharge at the Muddy River Springs Area.

4.7 Conclusions Derived from Modeling Analyses

Based on the analyses described above, uncertainty in sub-regional boundary conditions results in forecasts and a range of possible responses in terms of reduced discharge with the assumed condition of well-developed hydraulic continuity and transmissivity between the northern and southern flow fields. However, independent isotopic and geochemical evidence suggest that such connection may be absent. Impacts on spring flow may be minimal either with or with out the well developed hydraulic continuity case based on regional upwelling near the pumping center that has the same net effect as the prescribed-head boundaries that have incorporated in

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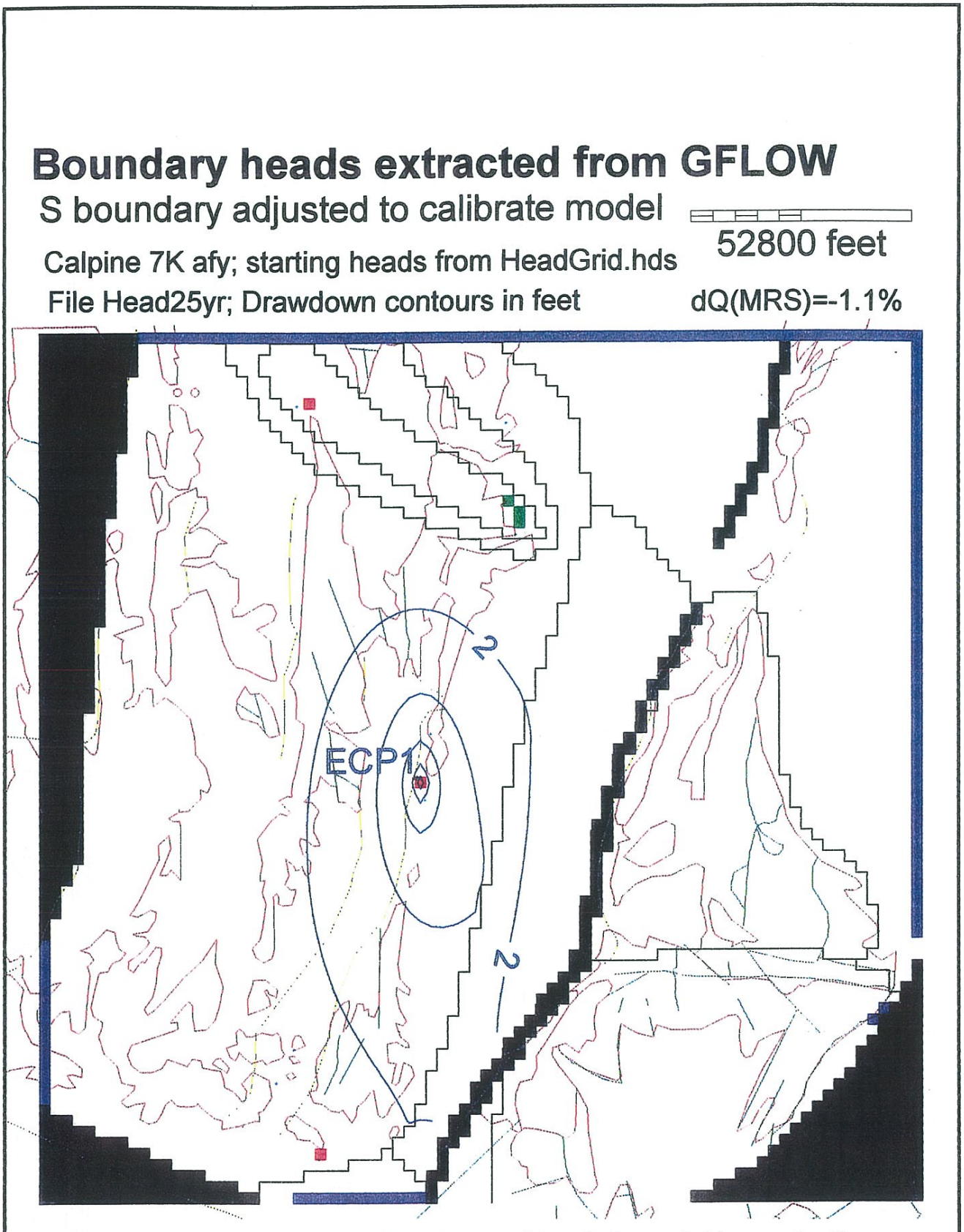

Figure 21. Case 2, the constant head boundary condition, the less probable scenario, 25-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

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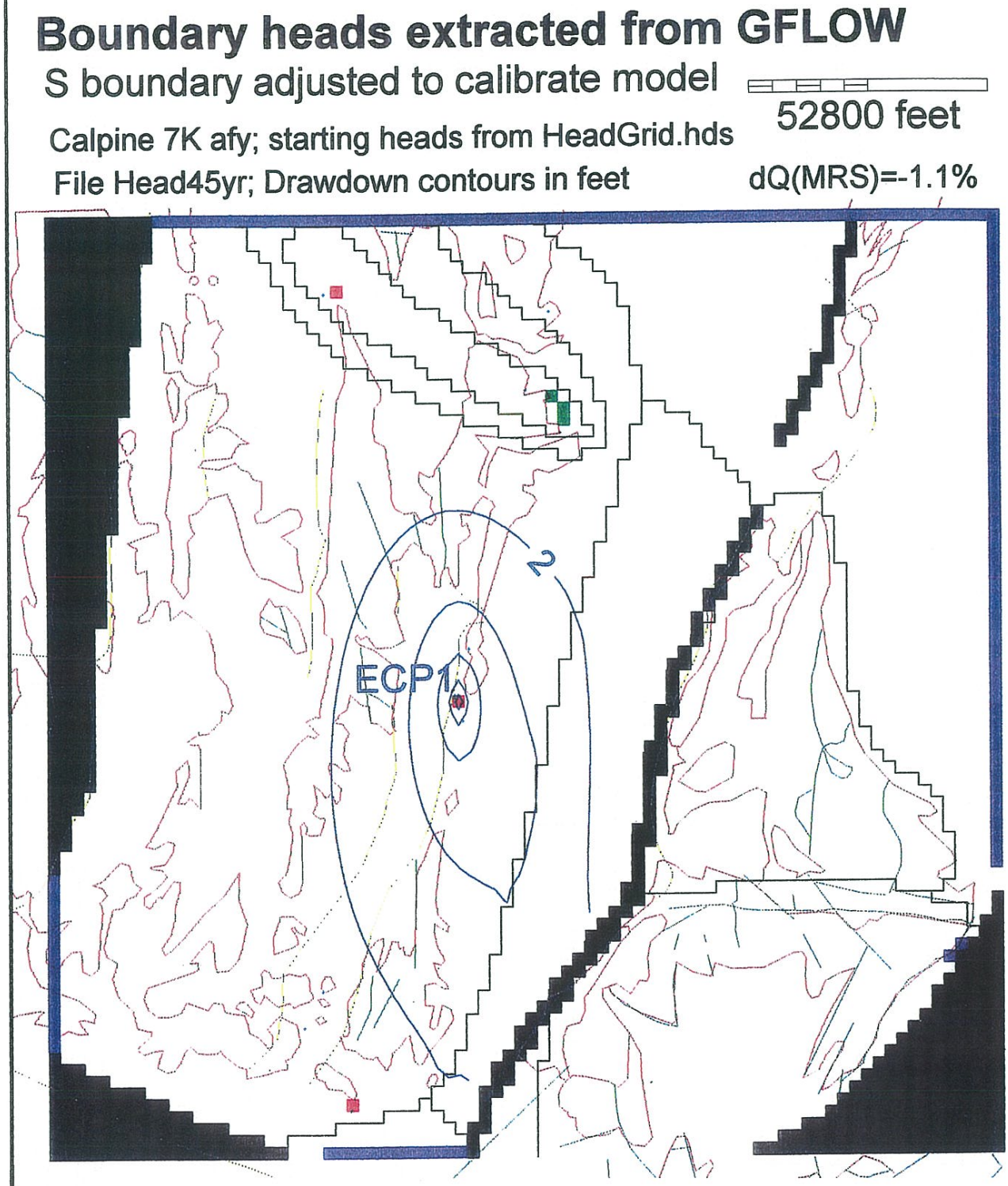

Figure 22. Case 2, the constant head boundary condition, the less probable scenario, 45-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

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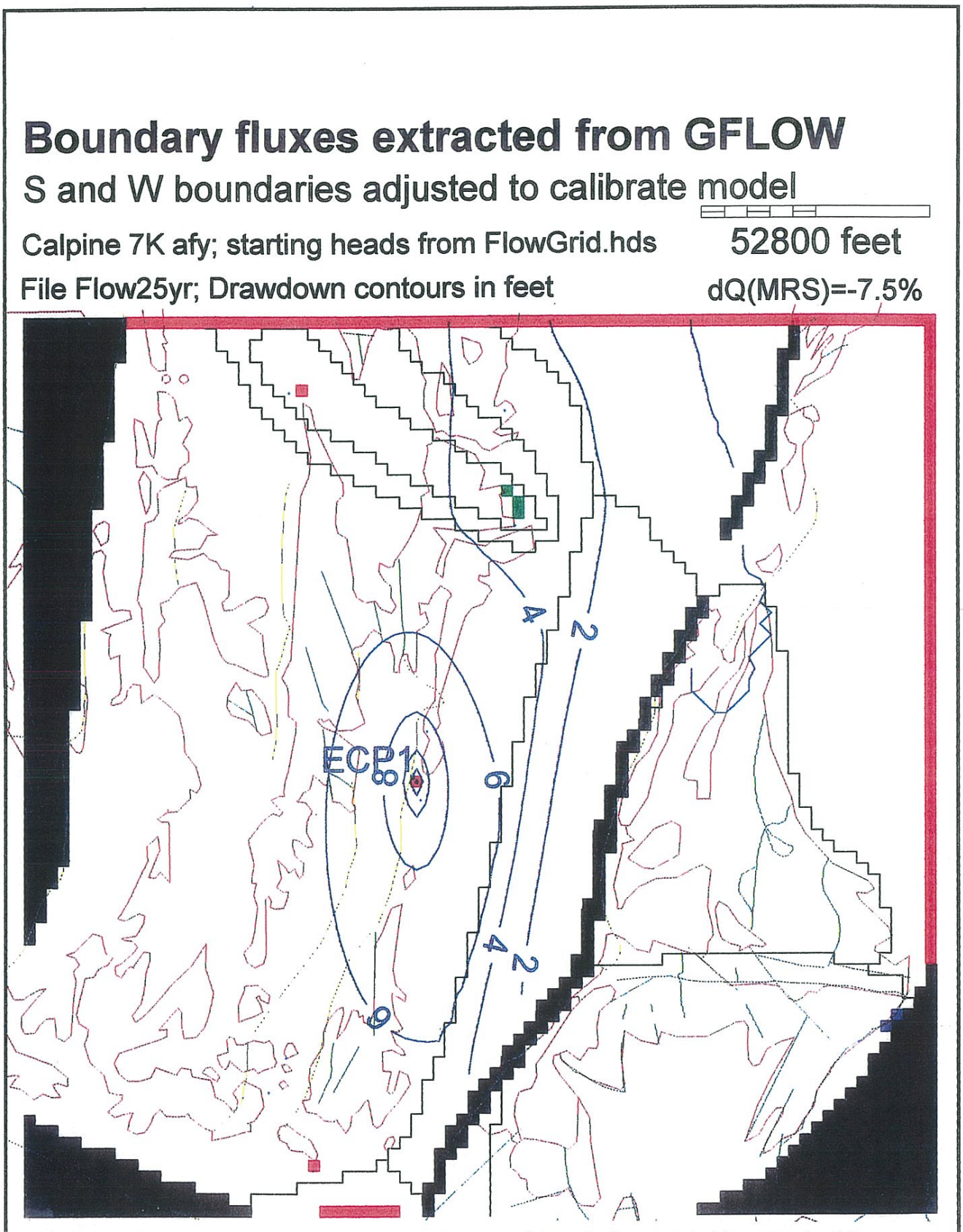

Figure 23. Case 3, the prescribed flux boundary condition, the least probable scenario, 25-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

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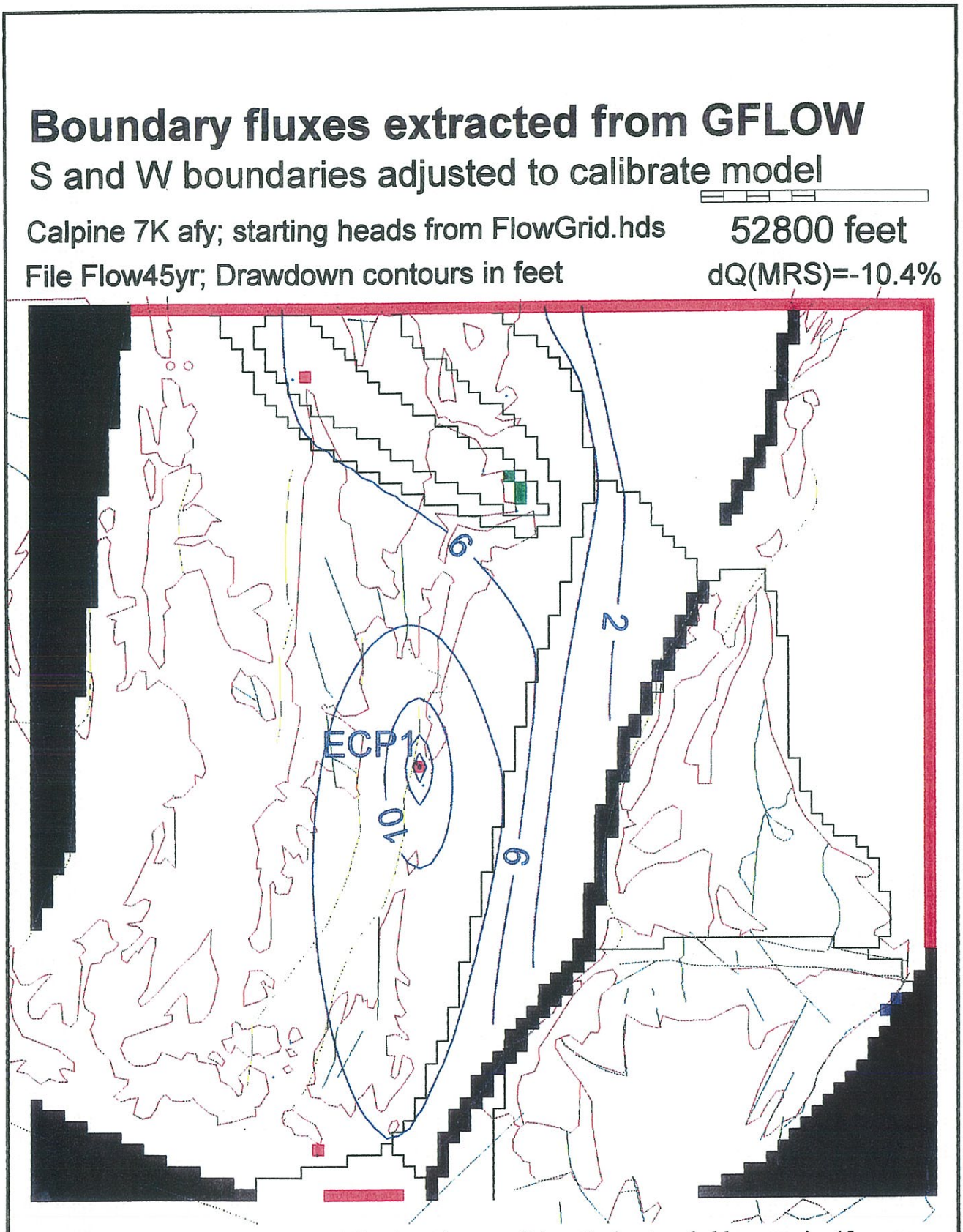

Figure 24. Case 3, the prescribed flux boundary condition, the least probable scenario, 45-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

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two of the scenarios, Case 1 and Case 2. The modeling results are summarized in Table 4.

Table 4. Transient Effects on Muddy River Springs Area resulting from the Belly Tank Flat Pumping

	25 years		45 years
Run ID	**Discharge Decrease, %**	**Run ID**	**Discharge Decrease, %**
Case 1 Hybrid25yr	0.7	Case 1 Hybrid45yr	1.3
Case 2 Head25yr	1.1	Case 2 Head45yr	1.1
Case 3 Flow25yr	7.5	Case 3 Flow45yr	10.4

The following are conclusions from the modeling analyses and supporting information:

1. Modeling analyses indicate that between 3,000 and 9,000 afy of flux occurs in the southern portion of the Arrow Canyon Range Cell of the Regional Carbonate Aquifer. These estimates are an outcome of the model calibration process, which could not be successfully accomplished without allowing for outflow to the south.

2. Bounding scenarios and a more probable scenario forecast a range of system responses to production of 7,000 afy. The most probable response scenario would produce minimal impacts in discharge in the Muddy River Spring Area after 45 years and no impact at Rogers and Blue Point Springs. The prescribed flux boundary condition, the least probable bounding scenario, is over conservative and would produce significant impacts before 45 years.

3. There are no foreseen impacts to groundwater users to the south given depths to water in the region of hundreds of feet and maximum drawdowns of only several feet for the life of the Project.

4. The modeling analyses point out the potential for, and indeed the need for, characterizing the water-resource potential of the still-unperturbed Arrow Canyon Range Cell of the Carbonate Aquifer. This can be accomplished through careful monitoring of the effects of Belly Tank Flat pumping, (7,000 afy) which could, on the basis of conservative modeling projections, be sustained for decades without adverse consequences.

5. Boundary condition responses are uncertain and this aspect of uncertainty can not be resolved without observations of responses to large pumping stresses. If the conceptual model of upwelling deeply-circulated flow proves correct, and it seems necessary in terms of the geochemical and isotopic characteristics of the southern flow field, upwelling in the general area of Belly Tank Flat leads to a boundary condition that may well limit the magnitude and spread of the pumping cone. A pumping cone reaching the upwelling zone effectively encounters a recharging boundary, which, as demonstrated in the Case 1 and Case 2 scenarios, has the effect of limiting impacts at the Muddy River

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Springs Area to 1 percent of discharge at 45 years.

5.0 Discussion and Conclusions

There are new relationships that have developed from widely distributed but sparse databases relevant to the Arrow Canyon Range Cell. This study has developed and analyzed new hydrogeologic data from the Moapa Indian Reservation, central to the Arrow Canyon Range Cell. The process has generated a new level of understanding, confidently documenting two distinct flow fields: a northern flow field discharging at the Muddy River Springs Area, a southern flow field probably discharging southeast of the Apex Industrial Area. There is little question that the Carbonate Aquifer of the Arrow Canyon Range Cell is very unusual, if not unique, in terms of its great apparent thickness, hydraulic continuity across major structural features, very low fluid potential gradients in the southern flow field, and regional origins of flow.

Some key uncertainties have been revealed by modeling analyses conducted during this study, notably the magnitude of steady-state flux beneath Belly Tank Flat. There is little question that the Carbonate Aquifer has the resource potential to supply the 7,000 afy for the proposed Moapa Paiute Energy Center. There is also good evidence for considerable total flux, but no matter what assessment technique adopted, the soft numbers will remain soft until it there are opportunities to observe transient responses to major pumping stresses.

Forecasting regionally transmitted pumping impacts decades into the future without records of large-scale transient responses and comparable magnitude in key areas does not allow high confidence in constrained modeling analyses. A basic decision was necessary as to how to treat the interface zone between two flow fields that were evident from field data but not explicit in the model. The decision was made to conservatively treat the aquifer as highly transmissive through the interface zone. The three modeling cases may therefore all be over-conservative, and not fully bound what is credible within the context of the geochemical databases of the region. Two flow fields may indeed be separated by an extensive region with limited transmissive properties, but, because such has not been identified by a candidate geologic feature, the conservative and more defensible approach as been to evaluate the consequences of a highly transmissive connection between the Belly Tank Flat and Muddy River Springs Area.

The Case 1 and Case 2 scenarios simulate reasonably well the effect of an upwelling zone of the Belly Tank Flat area, whether or not hydraulic continuity exists between the two flow fields. A nearby upwelling source of essentially a constant head boundary could limit or prevent the migration of the pumping cone to the Muddy River Springs Area.

It is worth noting that even if the level of current understanding were to prove highly flawed, that even the least probable Case 3 scenario assures a protracted period of time before pumping impacts would become large enough to be important at the discharge area. A monitoring plan (Appendix E) has been designed and implemented to document pumping impacts that would develop along a transect between the Muddy River Springs Area and the Belly Tank Flat pumping center, with three carbonate aquifer monitoring wells, TH-2, M-1, and EH-4 located between the two areas. Net drawdowns in water levels developed at either end of the transect of monitoring wells should document and confirm the pumping cone propagation well before any

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adverse impacts of important magnitude would develop, and allow model predictions to be tested by observation.

5.1 Projected Impacts on Muddy River Springs Area

Three modeling scenarios were developed by varying boundary conditions to demonstrate the range of credible impacts of 7,000 afy pumping stress from the Belly Tank Flat area on the Muddy River Springs Area, assuming hydraulic continuity between the areas. The modeling scenarios bound the impacts in a conservative manner. Table 4 summarizes the results for operation of the proposed project for 25 years, the length of the proposed lease, and for 45 years, the length of the proposed lease plus the possible 20-year lease extension.

The Case 1 scenario, a hybrid case, which incorporated both prescribed head and prescribed flux boundaries, is judged the most probable response of the natural system to pumping, and produces a decrease in the Muddy River Springs Area discharge of about 1% at 25 years and 1.3% in 45 years. These are equivalent to about 0.5 cfs of the 51 cfs which, on average, flows to the discharge area. For perspective, the natural regional flux to the discharge area based on analyses of monitoring records probably ranges from about 47 cfs to 54 or 55 cfs (Appendix F, page 27). The actual discharge of the Muddy River as measured below the Muddy River Springs Area has been decreased by more than 10 cfs due to the local groundwater diversions which began in the spring area in 1959 (Appendix E, Figure E-2).

The Case 2 scenario, a less probable case with prescribed-head boundaries, would result in the reduction of the Muddy River Springs Area discharge by approximately 1 % in 25 years and 1.1 % in 45 years. Case 2 and Case 1 are almost identical in results because they share large areas where the boundaries of the model can yield additional water by responding as they are impacted by pumping effects, inducing flux to the model domain.

The Case 3 scenario, the least probable case with prescribed-flux boundaries, forces all new withdrawals to be supplied from within the model domain, from storage, and from diversion of the Muddy River Springs Area flow field. After 25 years of operation it forecasts 7.5% reduction in flow to Muddy River Springs Area. If the pumping under Case 3 were to continue for 45 years, the reduction in flow to the discharge area gradually increases to approximately 10%, or about 5 cfs.

It is important to note that nearby pumping stresses in the Muddy River Springs Area had produced greater annualized reductions in stream flow at the Warm Springs Road gauging station by the mid-1990's than those projected to occur for the Case 3 scenario after several decades of pumping (Appendix F). Because of the seasonal variation in water demands, for several months each year the pumping impacts are more than double Case 3 annualized average impact of 5 cfs at 45 years, or 20 times those forecast for Cases 1 and 2. These pumping centers are located within the general discharge area, and therefore produce very strong effects on local hydrologic features.

None of the three modeling scenarios at 25 years produces impacts on Muddy River Spring Area flows that are large enough to be confidently separated out as attributable pumping impact based on discharge observations alone, because of the pre-existing pattern of relatively long term

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secular (natural) variations in flow. Uncertainties in gauging accuracy and natural variations (effects of drought and wet years) in the discharge of the springs and the river results in uncertainty of measurement of approximately 10% of the flow or 5 cfs. Therefore, a very slow acting change in regional flow that is less than 10% of the existing flow could be statistically demonstrated once it had been expressed in the record for several years, but not with confidence as to the causes. If, as in Case 3, reductions began to exceed roughly 10% of discharge approximately 45 or so years after pumping began, recognition of impact is likely, but actual magnitude of impact from the project pumping would be difficult to evaluate. Until then, the plus or minus 10% accuracy of stream flow measurements and natural variations of the same order of magnitude might prevent confident separation of the Case 3 scenario impacts from pre-existing or other contributing causes of variations. The important role of modeling analyses in the monitoring program is apparent, where net drawdowns within the impacted flow fields are projected and monitoring well records are continuously available for comparison with projections.

Any reduction of flows that result from the proposed project would be distributed uniformly over the annual flow regimen and throughout the multitude of discharge features. In contrast, in a seasonal sense the local area pumping impacts are not as well distributed, thus they are intensified during portions of the annual cycle. It has been observed that even with large seasonal fluctuations in flow resulting from the localized pumping there has been little or no documented aquatic habitat loss. Such a result attests to the buffering effect produced by the carbonate aquifer discharging via both conduits to springs and in a distributed fashion to the local alluvial gravel aquifer (see Appendix F diagrammatic cross section, p. 25).

5.2 Impacts on Aquatic Habitats

The Case 3 scenario, an improbable bounding case because of the highly conservative prescribed flux boundary conditions presents a useful hydrologic state for consideration of maximum credible impacts on aquatic habitats of the Muddy River Spring Area. The historic record (Appendix F, p. 27) demonstrates that the strong, seasonal, local pumping impacts in the discharge area are about double (when annualized) the projected Case 3 scenario impact of 5 cfs at around 45 years of pumping 7,000 afy at Belly Tank Flat. The well-documented secular variations, caused by 6 years of drought (1985-91) and back-to-back wet years (1992-93), have resulted in a natural range of about 5 to 6 cfs of discharge variation as well. For much of the detailed historic records, uniformly superposing the forecasted 45-year 5-cfs decrease in flow to the area would result in changes within the historic range of observed hydrology and associated impacts on aquatic habitats. During future prolonged (multiyear) droughts hydrologic states would be potentially changed, and the nature of these may be projected based on observations derived from the historic records.

Roughly one-third of discharge from the Carbonate Aquifer passes via conduits directly to springs and two-thirds directly to the alluvial aquifer. Assuming that about two-thirds of the 5-cfs reduction in flow (3 cfs) would occur to the alluvial aquifer, the headwater reaches of the Muddy River would experience the most impact (with reduced baseflow discharge to intermittent and perennial channels). These occur from decreases in baseflow discharges that would be upstream of Warm Springs Road Bridge (an undocumented location on the LDS farm) to around Big Muddy Spring area. The other 2 cfs of reduction would be distributed as approximately 10%

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reduction in spring flows, and probably some decreases in evapotranspiration losses. Much of the decreases in baseflow discharge fall within the historic envelope of channel flows and associated aquatic habitat conditions; impacts on aquatic habitats would be similar to past years of heavy local pumping stresses and/or drought periods of the record. However, during future prolonged drought periods, up to about 3 cfs (annualized) reduced baseflow discharge into these uppermost river channels would occur, perhaps eliminating some presently intermittent flow segments, and causing transitions of short channel reaches from perennial to intermittent flow, as far downstream as Big Muddy Spring. Such may or may not reduce the Muddy River Springs Area quality aquatic habitat, as these uppermost intermittent channel reaches currently carry flows only for up to several months each year. Beginning at Big Muddy Spring, perennial channel flows are great enough, if reduced by about 10% of the historic record, to maintain aquatic habitats of the river channels. Most of the about 2 cfs reduction routed through conduits to spring discharge areas during the drought years would likely be manifested as about 10% reduction in flows below historic minimum flows.

Based on these historic observations and assumptions that the complex hydrologic systems would behave similar to observed hydrologic responses, no impacts on aquatic habitats resulting from the markedly smaller impacts forecasted for the most probable scenario, Case 1 or Case 2 are projected for even prolonged drought periods. However, if the least probable bounding Case 3 were to occur during prolonged drought, the majority if not all of hydrologic impacts with potential to alter aquatic habitats would occur in the upper channel reaches of the Muddy River where there is baseflow discharge to both intermittent and perennial channel reaches of the headwaters area of the Muddy River.

5.3 Project Area Drawdown Impacts

Pump and step-drawdown testing of the carbonate aquifer near the proposed pumping center yielded data to compute a range of transmissivity of 50,000 to 100,000 ft^2/day, hydraulic conductivity of 20 ft/day and specific yield S_y of 0.03 and S of 0.008. A porosity reported by the US Geological Survey of 0.047 was used in the analyses. The tests support the feasibility of prolonged pumping at 1,000 gallons per minute with minimal drawdown except at the pumping well. Two additional exploration boreholes in the same area have been subjected to air lifted pumping tests, and indicate similar production potential. Thermal characteristics of groundwater, barometric efficiency, and geologic information were used to evaluate the estimated of thickness of the aquifer at 5,000 feet. Modeling forecasts for Case 1, the most probable response scenario, after 25 years estimated drawdowns north and south of the pumping location are forecast at 2 feet 8 miles distant and 10 miles distant, respectively, Figure 19. After 45 years, the drawdowns are forecast to be 2 feet to the north and up to 4 feet at the south boundary 20 miles distant as a result of the Belly Tank Flat pumping (Figure 20). Other modeling scenarios forecast distant drawdowns that do not exceed several feet over the 45-year period.

5.4 Rogers and Blue Point Springs

Pumping impacts on Rogers/Blue Point Springs were also considered. Analysis of available hydrogeological data indicates that the origin of water discharging at Rogers/Blue Point Springs appears to be in part local, and in part possibly regionally derived flow. The Rogers/Blue Point Spring is not subject to impacts from the Project however. These conclusion are based on multiple lines of evidence including:

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1. Isotopic evidence indicates the minimum contribution of local recharge is approximately one third of the flow to Rogers and Blue Point Springs, (based on mass balance calculations using stable isotopic data from Thomas and others, 1996). These results are obtained using Big Muddy Spring Area (northern flow field) and Valley of Fire well water as mixing end members, and by assuming that Valley of Fire well water from Aztec Sandstone was locally recharged. Although the modeling assumed even more local origins in the Muddy Mountains, the flow system supporting these important springs may originate as far away as the Mormon Mountains, as postulated by Pohlmann and others (1998). Such a flow system would necessarily be isolated from any potentiometric trough associated with the lower Muddy River.

2. The discharge history of Rogers Spring (based on unpublished National Park Service records) is highly variable at times, which would require corresponding large-magnitude water-level fluctuations in the Arrow Canyon Range Cell if the Spring were to be fed primarily by this aquifer. This follows by observing a head difference of approximately 200 feet between the Arrow Canyon Range Cell and the two springs. The observed flow variations of up to 50% at the spring area would require up to 100 feet of head variation in the Arrow Canyon Range Cell, if it were to be the primary source of water for the springs. Therefore, since almost no variation in head has been observed in the Arrow Canyon Range Cell, it is unlikely to be a primary source of water for the springs, and small water-level declines of several feet over 45 years can not result in any credible impacts.

3. The physiography of the Muddy Mountains suggests an environment of effective recharge. There is little evidence of active channel erosion in the high carbonate terrain, suggesting that precipitation infiltrates rather than running off into active runoff channels. This is in marked contrast to active channel conditions on surrounding bajadas, where evidence of frequent runoff events involving sediment transport and down cutting is widespread. The flow variations in the spring discharge record are best correlated with a major component of local recharge, possibly superposed on a component of regional flow from the north.

5.5 Monitoring Program

Recognizing and assessing regional impacts is best accomplished through a carefully designed monitoring program. A useful monitoring network is in place, operating, and will be maintained throughout the period of pumping. The results will be the basis for modeling refinements at periodic intervals. The monitoring network is designed to allow real time recognition of regionally propagated pumping effects, decades prior to their becoming detectable at sensitive areas. Plans for mitigation could be activated if necessary.

Appendix E outlines the monitoring initiated by the Calpine Corporation and the Moapa Band of Paiutes to complement monitoring already established within the Arrow Canyon Range Cell. Integral to the overall monitoring strategy is the existing monitoring in the Muddy River Springs Area, which includes water-level monitoring in the local aquifers, and gauging spring and river discharges. In addition, monitoring of discharge at Rogers and Blue Point Springs is established

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and has yielded important records that lend insight into source(s) of the flows. The design for expanded monitoring that has been adopted by the Moapa Band to augment existing monitoring networks is a series of monitoring wells finished in the Carbonate Aquifer north, west, and south of the Belly Tank Flat Well Field. In this manner the extent and magnitude of water-level changes over time will be established in directions where it is feasible to monitor the Carbonate Aquifer within the Moapa Indian Reservation boundary. Monitoring wells TH-2, M-1, and EH-4 (Figure 2) are aligned between the proposed Belly Tank Flat well field and the Muddy River Springs Area, and will allow pumping signals propagating out of or into either area to be recognized. Monitoring wells M-2 and M-3 are also ideal to identify and document water-level signals that may propagate toward or away from other pumping centers south and southwest, respectively, of the Reservation boundaries.

6.0 Conclusions

Conclusions of the groundwater analyses are summarized below:

- Three modeling scenarios were used to bound the range of potential impacts on discharge in the Muddy River Springs Area. Only under Case 3, the prescribed flux boundary condition, an improbable bounding scenario, are observable changes to the Muddy River Springs Area hydrology predicted, and these would occur only during prolonged drought periods.

- A substantial body of evidence from isotopic hydrology, comparison of dynamic water-levels, geologic evidence of compartmentalization, and geomorphologic evidence of effective local recharge argues against hydraulic continuity between the Project area and the Rogers/Blue Point Spring area. As a result of these empirical observations, supported by model calibration requirements, no impacts on these springs are predicted.

- There will be no significant impacts to distant groundwater users because of small-scale drawdowns beyond the immediate vicinity of the well field.

7.0 Acknowledgements

A number of individuals and organizations have contributed to the database development effort and modeling analyses. Jeff Johnson, Erin Cole, and Gavin Kisinger of the Las Vegas Valley Water District; Karl Pohlmann of the Desert Research Institute; Van Robinson of the Moapa Valley Water District; and Richard Willer of Nevada Power Company (NPC) were key sources of hydrologic information. Jon Wilson of the U.S. Geological Survey and Don Shettel of Geoscience Management collaborated with Mifflin & Associates, Inc. (MAI) personnel on hydrologic and geochemical field measurements, respectively. Randy Felix (MAI) was the on-site supervisor of drilling operations, and Jack Johnson (MAI) was responsible for conducting field measurements around the clock to produce an excellent data set from the 7-day aquifer test. Nevada Cogeneration Associates and Georgia Pacific granted access to their monitoring wells. Jim Werle of Converse Consultants coordinated NPC monitoring at the Crystal switching station during the aquifer tests. U.S. Department of Interior representatives from the National Park Service, U.S. Fish and Wildlife, Bureau of Indian Affairs, Bureau of Land Management, and U.S. Geological Survey provided valued comment and criticism in a technical review workshop organized by PBS&J.

Members of the Moapa Band of Paiutes have set a positive tone in a complex cooperative effort;

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in particular, we owe past and present Chairpersons Candace Grayman, William Anderson, and Eugene Tom a debt of thanks for their consistent support in maintaining the momentum of the Project. Tribal Council members Calvin Meyers and Anthony Frank, and tribal member Colleen Trujillo directly participated in drilling and testing operations and/or were instrumental in coordinating activities. Their efforts materially improved on the timely execution of the program.

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APPENDIX A

ECP-1 Aquifer Tests

Summary Report

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ECP-1 Aquifer Tests

Summary Report
prepared by Cady Johnson August 25, 2000
minor editorial revision December, 2000

Overview

Two aquifer tests utilizing borehole ECP-1 as the production well were conducted July 21 and July 30, 2000. The first, a step-drawdown test, began at 8:30 PM on July 21 and ended at 2:44 AM on July 22. As indicated in Figure 1, the test showed that ECP-1 is capable of sustained production of 1000 gpm (192,500 ft^3/day) with estimated well losses of 81 feet and aquifer losses of 25 feet.

The second test was a 7-day constant-discharge test utilizing observation wells ECP-2, TH-1, and TH-2. Distances to the observation wells are 500 feet, 1 mile, and 2.3 miles, respectively (Table 1). Water levels in ECP-2 and TH-2 were recorded by a Stevens AxSys datalogger, but were measured manually at TH-1. Barometric pressure was recorded at the TH-2 wellhead.

			Dist. From ECP-1	
	meters N	meters E	m	ft
ECP-1	4,046,586	696,726	0	0
ECP-2	4,046,738	696,726	152	499
TH-1	4,044,962	697,237	1,703	5,586
TH-2	4,049,913	697,687	3,463	11,362

Table 1. UTM coordinates of Calpine boreholes, July, 2000

Production well ECP-1 was pumped at a steady rate of 1005 gpm for 7 days beginning at 8:50 PM on July 23, except for an interruption caused by equipment failure between 4:09 PM and 6:29 PM on July 24. There was full data recovery from the observation wells.

Methods

The computer program AQUITEST (William C. Walton, 1996, "Aquifer Test Analysis with Windows Software") was used to perform barometric pressure corrections and derive aquifer parameters from pumping response. AQUITEST was chosen for the excellent documentation available in the companion textbook; however, the graphical output is somewhat primitive in terms of labeling and input files cannot exceed 100 data points.

Barometric-pressure adjustments were accomplished by first defining a trend period and a change period to allow calculation of barometric efficiency, then applying barometric efficiency corrections to the raw water-level data. The corrected data were then fit to type curves to obtain parameter estimates. These are standard, automated procedures in the protocol of Walton (1996).

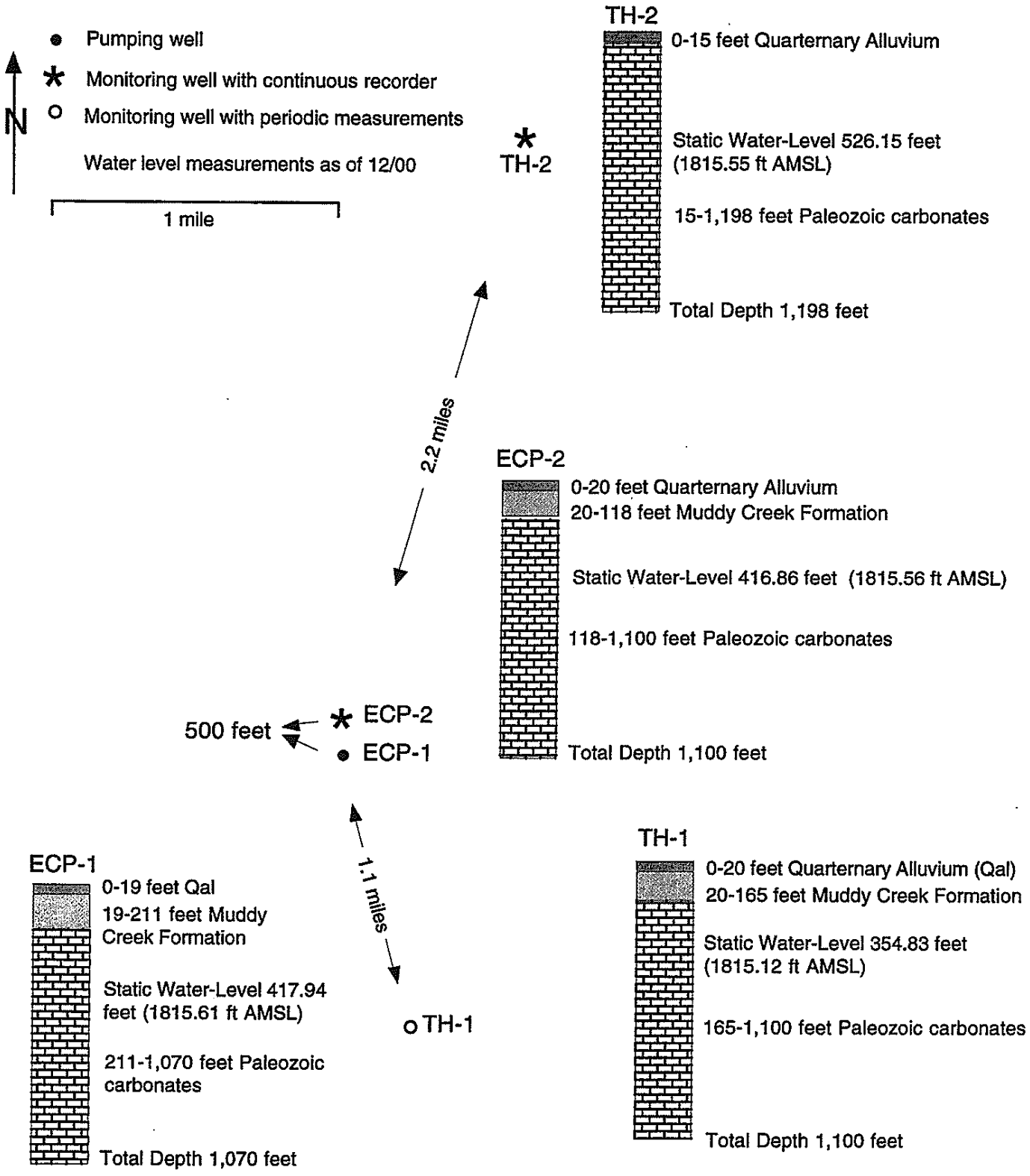


Figure A 1. Moapa Paiute Energy Center seven day test pumping monitoring network and borehole stratigraphy.

Appendix A , Figure A 1

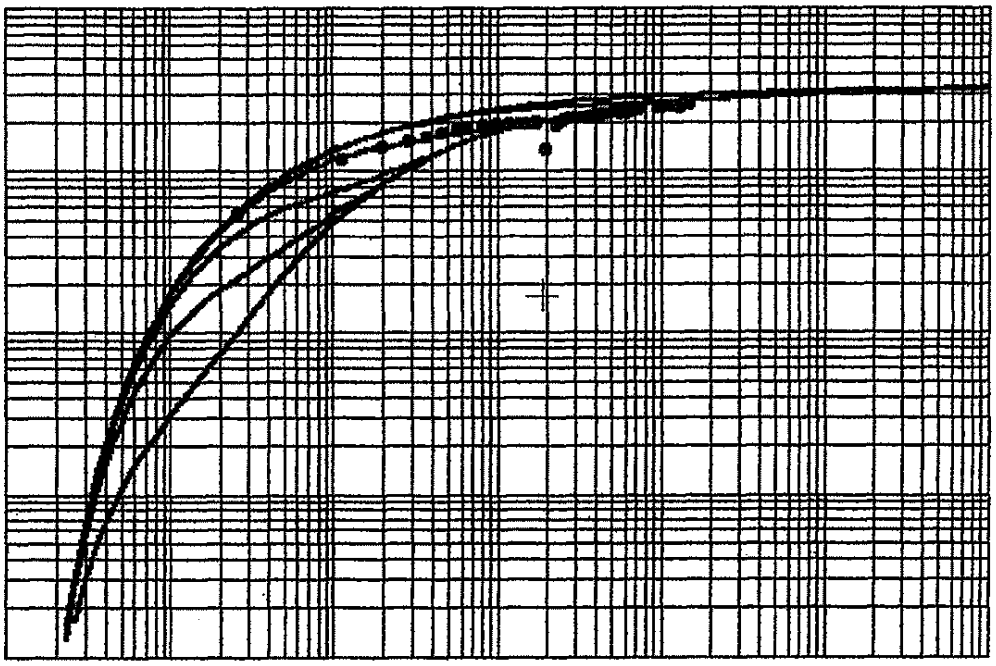
Results

Drilling records from the wells utilized for this study indicate unconfined hydrologic conditions; the barometric perturbations are enigmatic and therefore warrant some discussion. It appears that the great depths to saturation (minimum 350 feet) and low-permeability cover give rise to a system that is air-tight on a 6-hour (diurnal) time scale.

In order to obtain meaningful barometric corrections while limiting data files to 100 points or less, 6-hour averages of barometric pressure were used throughout the 7-day antecedent trend period needed for the barometric efficiency calculation. The idea is to select a "quiet" period of time after which the barometer makes a pronounced jump that is accompanied by a water-level change, and to utilize these cause-and-effect changes (with knowledge of antecedent trends) to calculate the barometric efficiency. Averaging during the "quiet" period is of little consequence. Figure 2 and the accompanying spreadsheet table illustrate the barometric correction setup for ECP-2, and Figure 3 and accompanying table document the process at TH-2. Figures 4 and 5 give raw and corrected drawdowns for ECP-2 and TH-2, respectively. Note also the increasing sampling interval after pumping began at day 11.87, necessary due to the 100-point data limit. Antecedent data were insufficient for meaningful barometric corrections at observation well TH-1.

ECP-2 Response

Adjusted ECP-2 Drawdowns fit to Unconfined Type Curve

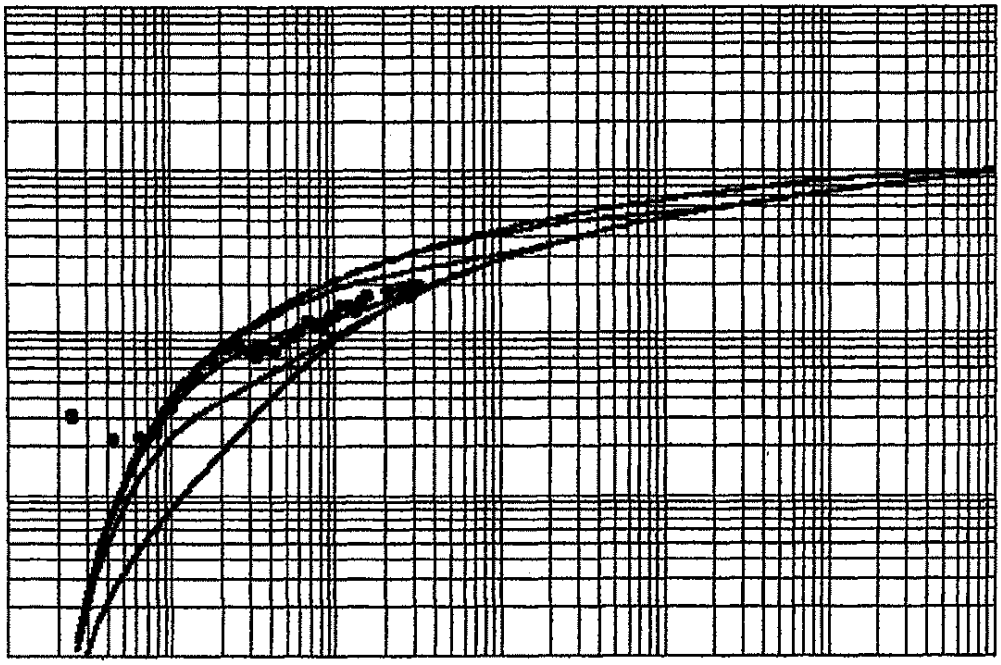


SE ROA 10652

JA_3506

TH-2 Response

Adjusted TH-2 Drawdowns fit to Unconfined Type Curve



Parameter Estimates

The processing steps and curve-matching gave the following results for aquifer parameters:

ECP-2 **TH-2**

Match Point Coordinates

Well Function = 1.689E+00	Well Function = 6.248E-01
1/U Argument = 1.895E+02	1/U Argument = 5.286E+00
Beta Argument = 3.643E-01	Beta Argument = 9.679E-01
Drawdown = 2.375E-01 ft	Drawdown = 1.787E-01 ft
Elapsed Time = 8.800E-01 day	Elapsed Time = 1.136E+00 day

SE ROA 10653

JA_3507

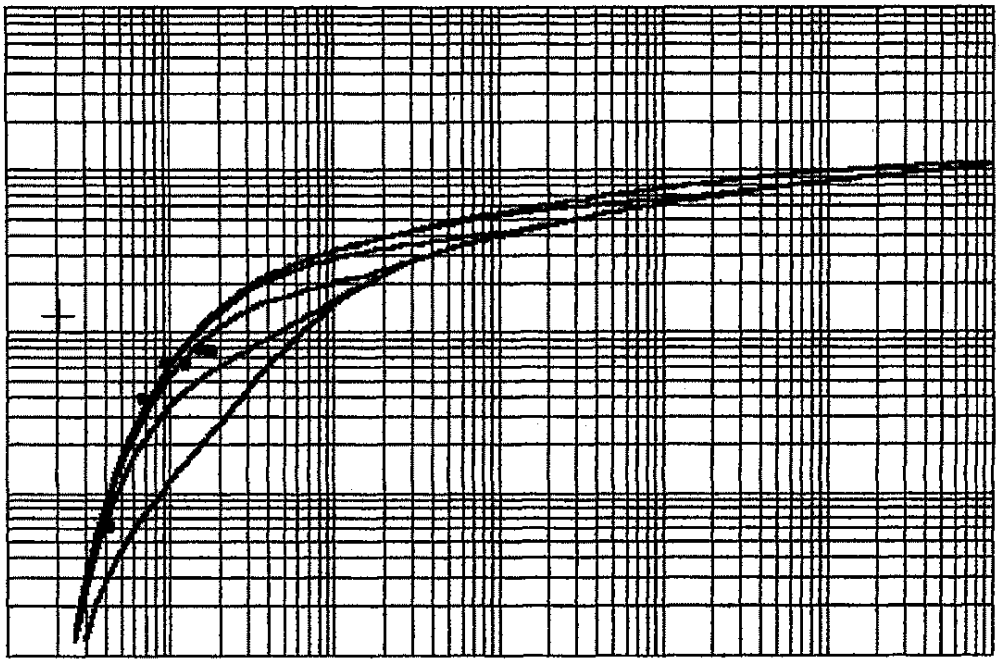
Aquifer System Hydraulic Characteristics

Aquifer Transmissivity = 1.095E+05 ft^2/day
Aquifer Storativity = 8.136E-03
Aquifer Specific Yield = 3.089E-02
Vertical Hyd. Cond. = 7.712E+01 ft/day

Aquifer Transmissivity = 5.382E+04 ft^2/day
Aquifer Storativity = 3.138E-04
Aquifer Specific Yield = 1.162E-03
Vertical Hyd. Cond. = 5.861E-01 ft/day

TH-1

Daily Average TH-1 Drawdowns fit to Unconfined Type Curve



TH-1 results are included here only for completeness; the signal-to-noise ratio of these data was so great (about 1) that a reasonable time-drawdown plot could be obtained only by averaging across the semi-diurnal fluctuations, i.e. taking daily averages of water level. Since the signal did not arrive at TH-1 the first day, only six points are available for plotting. These give the following result:

Match Point Coordinates

Well Function = 1.271E+00
1/U Argument = 2.073E-01
Beta Argument = 6.933E-01
Drawdown = 2.443E-01 ft
Elapsed Time = 7.855E-01 day

SE ROA 10654

JA_3508

Aquifer System Hydraulic Characteristics

Aquifer Transmissivity = 8.011E+04 ft^2/day
Aquifer Storativity = 3.890E-02
Aquifer Specific Yield = 1.459E-01
Vertical Hyd. Cond. = 1.975E+00 ft/day

Conclusion

Transmissivities of 50,000 to 100,000 ft^2/day and unconfined conditions are indicated by the test data. The observation that barometric effects are expressed in an unconfined system is thought to be due to an effective pneumatic cap over the aquifer system. Since estimated transmissivities vary by only a factor of two, there are no indications of extreme anisotropy in the project area.

SE ROA 10655

JA_3509

Figures to accompany Summary Report: "ECP-1 Aquifer Tests"

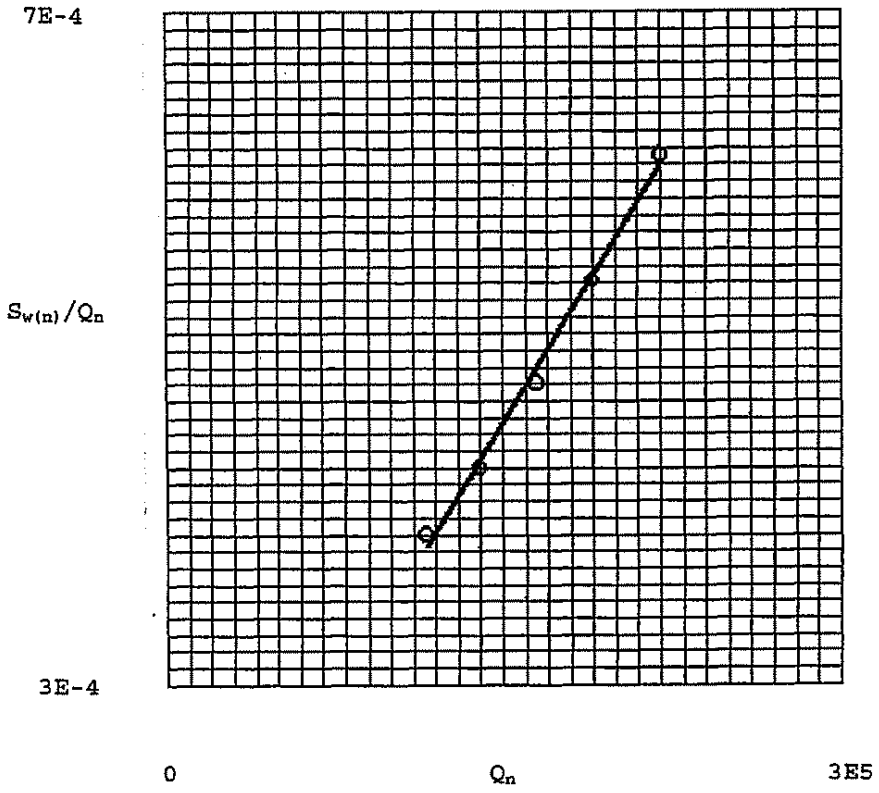
1. ECP-1 Step Drawdown Test
2. Barometric Correction Setup for Monitoring Well ECP-2
3. Barometric Correction Setup for Monitoring Well TH-2
4. ECP-2 Drawdown Adjustments
5. TH-2 Drawdown Adjustments
6. TH-1 Drawdowns, 7-day test
7. TH-1 Smoothed Drawdowns

SE ROA 10656

JA_3510

Figure 1

ECP-1 Step Drawdown Test
July 21-22, 2000



Data Summary

date	time	swl	delta s	Q gpm	Q ft3/day
21-Jul-00	8:30:00 PM	415.2	0	0	0
21-Jul-00	10:00:00 PM	460.5	45.3	603	116086
21-Jul-00	11:00:00 PM	475.3	14.8	725	139572
22-Jul-00	12:00:00 AM	494.5	19.2	857	164984
22-Jul-00	1:30:00 AM	518.0	23.5	986	189818
22-Jul-00	2:44:00 AM	550.6	32.6	1142	219850

Straight Line Analysis Results

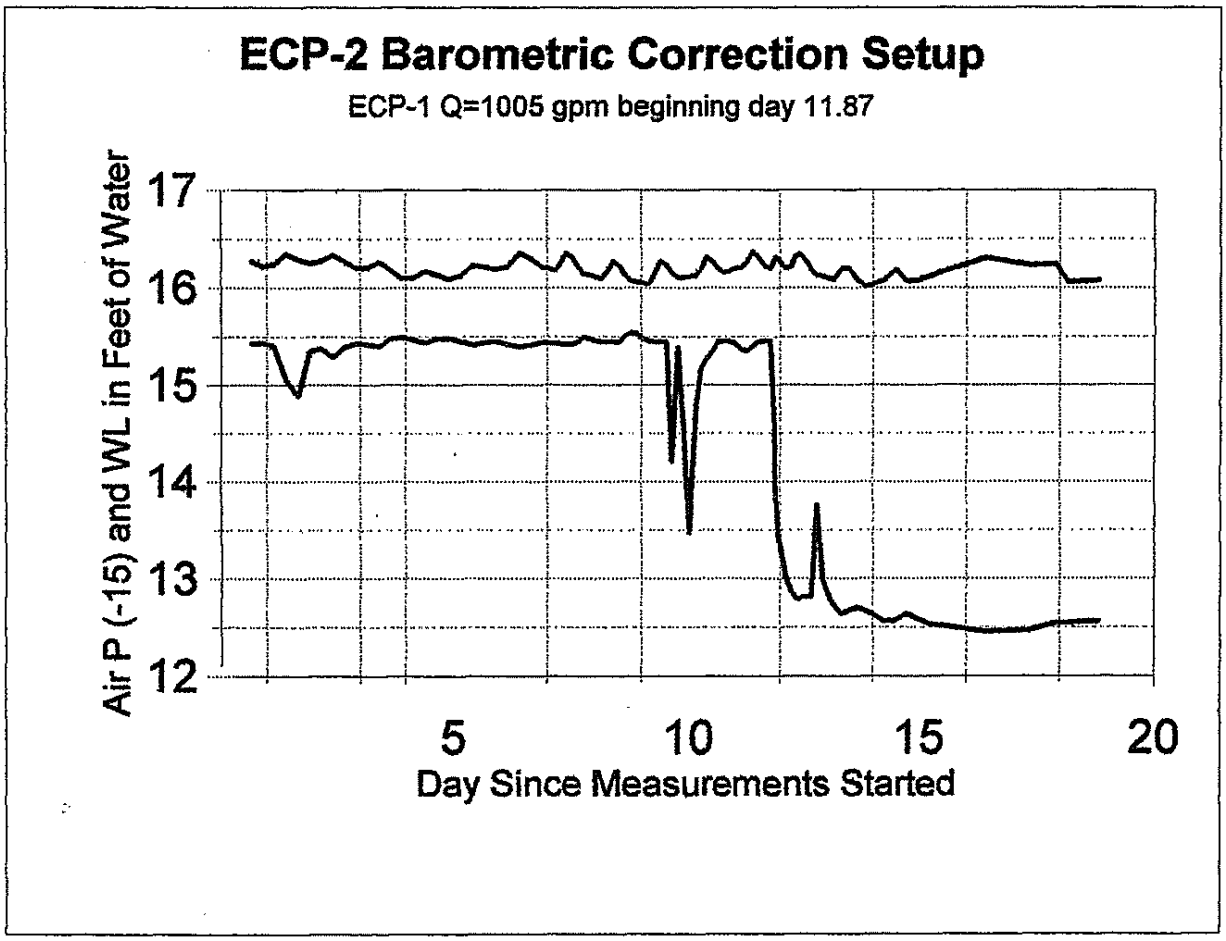
B-factor = 1.285E-04
Well loss coefficient C = 2.188E-09

For discharge rate = 1.925E+05 (1000 gpm)
Aquifer loss = 2.474E+01 (25 ft)
Well loss = 8.108E+01 (81 ft)

SE ROA 10657

JA_3511

Figure 2


ECP-2 Barometric Correction Setup
ECP-1 Q=1005 gpm beginning day 11.87
Air P (-15) and WL in Feet of Water
17
16
15
14
13
12
5
10
15
20
Day Since Measurements Started

ECP-2 Pumping Response and Barometric Pressure for 7-Day Test Drawdown Adjustments

3-point smoothing for 6-hr average to day 7 for trend, then 3-hour data until test begins

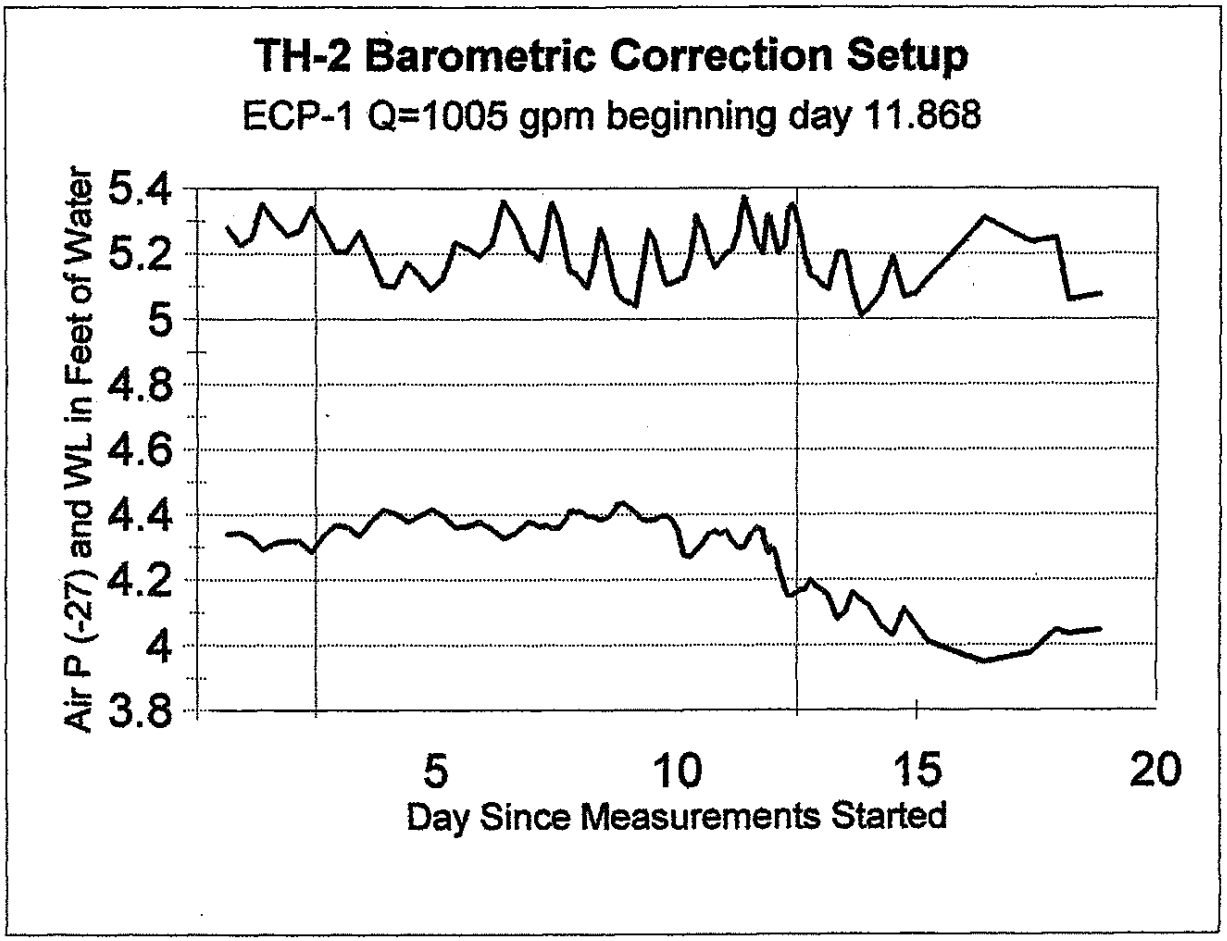
start@day 36719

Pumping was 1005 gpm from ECP-1 beginning 8:50 PM July 23, 2000 (began @11.868 days)

seq no	date	time	bp (ft h2O)	t (days)	wl (feet)	bp-15	pump t
1	07/12/00	04:00 PM	31.278	0.67	15.433	16.28	start trend period for BE
2	07/12/00	10:00 PM	31.228	0.92	15.433	16.23	
3	07/13/00	04:00 AM	31.248	1.17	15.403	16.25	
4	07/13/00	10:00 AM	31.352	1.42	15.057	16.35	
5	07/13/00	04:00 PM	31.297	1.67	14.887	16.30	
6	07/13/00	10:00 PM	31.256	1.92	15.343	16.26	
7	07/14/00	04:00 AM	31.272	2.17	15.380	16.27	
8	07/14/00	10:00 AM	31.340	2.42	15.287	16.34	
9	07/14/00	04:00 PM	31.279	2.67	15.387	16.28	
10	07/14/00	10:00 PM	31.207	2.92	15.430	16.21	
11	07/15/00	04:00 AM	31.207	3.17	15.423	16.21	
12	07/15/00	10:00 AM	31.268	3.42	15.397	16.27	
13	07/15/00	04:00 PM	31.190	3.67	15.480	16.19	
14	07/15/00	10:00 PM	31.104	3.92	15.493	16.10	
15	07/16/00	04:00 AM	31.100	4.17	15.467	16.10	
16	07/16/00	10:00 AM	31.172	4.42	15.433	16.17	
17	07/16/00	04:00 PM	31.138	4.67	15.477	16.14	
18	07/16/00	10:00 PM	31.091	4.92	15.483	16.09	
19	07/17/00	04:00 AM	31.125	5.17	15.450	16.13	
20	07/17/00	10:00 AM	31.234	5.42	15.417	16.23	
21	07/17/00	04:00 PM	31.216	5.67	15.437	16.22	
22	07/17/00	10:00 PM	31.194	5.92	15.453	16.19	
23	07/18/00	04:00 AM	31.227	6.17	15.423	16.23	
24	07/18/00	10:00 AM	31.360	6.42	15.393	16.36	
25	07/18/00	04:00 PM	31.304	6.67	15.417	16.30	
26	07/18/00	10:00 PM	31.213	6.92	15.440	16.21	end trend period for BE
27	07/19/00	01:00 AM	31.20	7.04	15.43	16.20	
28	07/19/00	04:00 AM	31.18	7.17	15.43	16.18	
29	07/19/00	07:00 AM	31.25	7.29	15.43	16.25	
30	07/19/00	10:00 AM	31.35	7.42	15.42	16.35	
31	07/19/00	01:00 PM	31.32	7.54	15.42	16.32	
32	07/19/00	04:00 PM	31.22	7.67	15.45	16.22	
33	07/19/00	07:00 PM	31.15	7.79	15.50	16.15	
34	07/19/00	10:00 PM	31.14	7.92	15.48	16.14	
35	07/20/00	01:00 AM	31.12	8.04	15.46	16.12	
36	07/20/00	04:00 AM	31.10	8.17	15.45	16.10	
37	07/20/00	07:00 AM	31.17	8.29	15.45	16.17	
38	07/20/00	10:00 AM	31.28	**8.42**	15.45	16.28	start change period for BE
39	07/20/00	01:00 PM	31.23	8.54	15.45	16.23	
40	07/20/00	04:00 PM	31.14	8.67	15.51	16.14	
41	07/20/00	07:00 PM	31.08	8.79	15.54	16.08	
42	07/20/00	10:00 PM	31.06	8.92	15.53	16.06	end change period for BE
43	07/21/00	01:00 AM	31.05	9.04	15.48	16.05	
44	07/21/00	04:00 AM	31.04	9.17	15.46	16.04	
45	07/21/00	07:00 AM	31.15	9.29	15.45	16.15	
46	07/21/00	10:00 AM	31.27	9.42	15.45	16.27	
47	07/21/00	01:00 PM	31.24	9.54	15.45	16.24	
48	07/21/00	04:00 PM	31.17	9.67	14.21	16.17	
49	07/21/00	07:00 PM	31.11	9.79	15.39	16.11	
50	07/21/00	10:00 PM	31.11	9.92	14.48	16.11	Step-Drawdown test
51	07/22/00	01:00 AM	31.12	10.04	13.48	16.12	Step-Drawdown test
52	07/22/00	04:00 AM	31.13	10.17	14.70	16.13	
53	07/22/00	07:00 AM	31.19	10.29	15.17	16.19	start WL trend period for test
54	07/22/00	10:00 AM	31.32	10.42	15.28	16.32	
55	07/22/00	01:00 PM	31.27	10.54	15.35	16.27	
56	07/22/00	04:00 PM	31.20	10.67	15.45	16.20	
57	07/22/00	07:00 PM	31.16	10.79	15.46	16.16	

58	07/22/00	10:00 PM	31.18	10.92	15.45	16.18		
59	07/23/00	01:00 AM	31.20	11.04	15.43	16.20		
60	07/23/00	04:00 AM	31.21	11.17	15.37	16.21		
61	07/23/00	07:00 AM	31.27	11.29	15.35	16.27		
62	07/23/00	10:00 AM	31.37	11.42	15.40	16.37		
63	07/23/00	01:00 PM	31.32	11.54	15.45	16.32		
64	07/23/00	04:00 PM	31.24	11.67	15.46	16.24		
65	07/23/00	07:00 PM	31.20	11.79	15.46	16.20	end WL trend period for test	
66	07/23/00	09:00 PM	31.29	11.88	14.73	16.29	0.0069	
67	07/23/00	10:00 PM	31.32	11.92	13.84	16.32	0.0486	
68	07/23/00	11:00 PM	31.30	11.96	13.53	16.30	0.0903	
69	07/24/00	12:00 AM	31.27	12.00	13.35	16.27	0.1319	
70	07/24/00	01:00 AM	31.25	12.04	13.23	16.25	0.1736	
71	07/24/00	02:00 AM	31.23	12.08	13.14	16.23	0.2153	
72	07/24/00	03:00 AM	31.20	12.13	13.03	16.20	0.2569	
73	07/24/00	04:00 AM	31.21	12.17	12.96	16.21	0.2986	
74	07/24/00	06:00 AM	31.23	12.25	12.87	16.23	0.3819	
75	07/24/00	08:00 AM	31.33	12.33	12.81	16.33	0.4653	
76	07/24/00	10:00 AM	31.35	12.42	12.79	16.35	0.5486	
77	07/24/00	12:00 PM	31.32	12.50	12.81	16.32	0.6319	
78	07/24/00	02:00 PM	31.26	12.58	12.81	16.26	0.7153	
79	07/24/00	04:00 PM	31.19	12.67	12.81	16.19	0.7986	pump failure
80	07/24/00	07:00 PM	31.13	12.79	13.76	16.13	0.9236	1609 to 1829
81	07/24/00	10:00 PM	31.12	12.92	13.00	16.12	1.0486	
82	07/25/00	01:00 AM	31.10	13.04	12.82	16.10	1.1736	
83	07/25/00	04:00 AM	31.09	13.17	12.73	16.09	1.2986	
84	07/25/00	08:00 AM	31.20	13.33	12.64	16.20	1.4653	
85	07/25/00	12:00 PM	31.20	13.50	12.67	16.20	1.6319	
86	07/25/00	04:00 PM	31.09	13.67	12.70	16.09	1.7986	
87	07/25/00	08:00 PM	31.01	13.83	12.67	16.01	1.9653	
88	07/26/00	12:00 AM	31.03	14.00	12.64	16.03	2.1319	
89	07/26/00	06:00 AM	31.08	14.25	12.56	16.08	2.3819	
90	07/26/00	12:00 PM	31.19	14.50	12.57	16.19	2.6319	
91	07/26/00	06:00 PM	31.07	14.75	12.64	16.07	2.8819	
92	07/27/00	12:00 AM	31.08	15.00	12.59	16.08	3.1319	
93	07/27/00	06:00 AM	31.12	15.25	12.53	16.12	3.3819	
94	07/28/00	10:00 AM	31.31	16.42	12.453	16.31	4.5487	
95	07/29/00	09:00 AM	31.24	17.38	12.468	16.24	5.5070	
96	07/29/00	10:00 PM	31.25	17.92	12.546	16.25	6.0487	
97	07/30/00	04:00 AM	31.06	18.17	12.546	16.06	6.2987	
98	07/30/00	08:00 PM	31.08	18.83	12.562	16.08	6.9653	

Figure 3


TH-2 Barometric Correction Setup
ECP-1 Q=1005 gpm beginning day 11.868
Air P (-27) and WL in Feet of Water
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
5
10
15
20
Day Since Measurements Started

TH-2 Pumping Response and Barometric Pressure for 7-Day Test Drawdown Adjustments

3-point smoothing for 6-hr average to day 7 for trend, then 3-hour data until test begins

Pumping was 1005 gpm from ECP-1 beginning 8:50 PM July 23, 2000 (began @11.868 days)

seq no	date	time	bp (ft h2O)	t (days)	wl (feet)	bp-26	pump t
1	12-Jul-00	04:00:00 PM	31.278	0.67	4.341	5.278	start trend period for BE
2	12-Jul-00	10:00:00 PM	31.228	0.92	4.346	5.228	
3	13-Jul-00	04:00:00 AM	31.248	1.17	4.328	5.248	
4	13-Jul-00	10:00:00 AM	31.352	1.42	4.291	5.352	
5	13-Jul-00	04:00:00 PM	31.297	1.67	4.313	5.297	
6	13-Jul-00	10:00:00 PM	31.256	1.92	4.318	5.256	
7	14-Jul-00	04:00:00 AM	31.272	2.17	4.318	5.272	
8	14-Jul-00	10:00:00 AM	31.340	2.42	4.285	5.340	
9	14-Jul-00	04:00:00 PM	31.279	2.67	4.332	5.279	
10	14-Jul-00	10:00:00 PM	31.207	2.92	4.366	5.207	
11	15-Jul-00	04:00:00 AM	31.207	3.17	4.361	5.207	
12	15-Jul-00	10:00:00 AM	31.268	3.42	4.335	5.268	
13	15-Jul-00	04:00:00 PM	31.190	3.67	4.381	5.190	
14	15-Jul-00	10:00:00 PM	31.104	3.92	4.415	5.104	
15	16-Jul-00	04:00:00 AM	31.100	4.17	4.403	5.100	
16	16-Jul-00	10:00:00 AM	31.172	4.42	4.377	5.172	
17	16-Jul-00	04:00:00 PM	31.138	4.67	4.394	5.138	
18	16-Jul-00	10:00:00 PM	31.091	4.92	4.417	5.091	
19	17-Jul-00	04:00:00 AM	31.125	5.17	4.396	5.125	
20	17-Jul-00	10:00:00 AM	31.234	5.42	4.360	5.234	
21	17-Jul-00	04:00:00 PM	31.216	5.67	4.364	5.216	
22	17-Jul-00	10:00:00 PM	31.194	5.92	4.376	5.194	
23	18-Jul-00	04:00:00 AM	31.227	6.17	4.357	5.227	
24	18-Jul-00	10:00:00 AM	31.360	6.42	4.327	5.360	
25	18-Jul-00	04:00:00 PM	31.304	6.67	4.344	5.304	
26	18-Jul-00	10:00:00 PM	31.213	6.92	4.378	5.213	end trend period for BE
27	19-Jul-00	01:00:00 AM	31.20	7.04	4.37	5.202	
28	19-Jul-00	04:00:00 AM	31.18	7.17	4.36	5.181	
29	19-Jul-00	07:00:00 AM	31.25	7.29	4.37	5.254	
30	19-Jul-00	10:00:00 AM	31.35	7.42	4.36	5.355	
31	19-Jul-00	01:00:00 PM	31.32	7.54	4.36	5.316	
32	19-Jul-00	04:00:00 PM	31.22	7.67	4.38	5.220	
33	19-Jul-00	07:00:00 PM	31.15	7.79	4.41	5.150	
34	19-Jul-00	10:00:00 PM	31.14	7.92	4.41	5.142	
35	20-Jul-00	01:00:00 AM	31.12	8.04	4.41	5.119	
36	20-Jul-00	04:00:00 AM	31.10	8.17	4.39	5.097	
37	20-Jul-00	07:00:00 AM	31.17	8.29	4.39	5.168	
38	20-Jul-00	10:00:00 AM	31.28	8.42	4.39	5.276	start change period for BE
39	20-Jul-00	01:00:00 PM	31.23	8.54	4.39	5.230	
40	20-Jul-00	04:00:00 PM	31.14	8.67	4.40	5.142	
41	20-Jul-00	07:00:00 PM	31.08	8.79	4.43	5.079	
42	20-Jul-00	10:00:00 PM	31.06	8.92	4.44	5.059	end change period for BE
43	21-Jul-00	01:00:00 AM	31.05	9.04	4.42	5.053	
44	21-Jul-00	04:00:00 AM	31.04	9.17	4.40	5.041	
45	21-Jul-00	07:00:00 AM	31.15	9.29	4.39	5.147	
46	21-Jul-00	10:00:00 AM	31.27	9.42	4.38	5.272	
47	21-Jul-00	01:00:00 PM	31.24	9.54	4.39	5.240	
48	21-Jul-00	04:00:00 PM	31.17	9.67	4.39	5.165	
49	21-Jul-00	07:00:00 PM	31.11	9.79	4.40	5.108	
50	21-Jul-00	10:00:00 PM	31.11	9.92	4.39	5.111	Step-Drawdown test
51	22-Jul-00	01:00:00 AM	31.12	10.04	4.35	5.119	Step-Drawdown test
52	22-Jul-00	04:00:00 AM	31.13	10.17	4.28	5.126	
53	22-Jul-00	7:00:00 AM	31.19	10.29	4.27	5.191	start WL trend period for test
54	22-Jul-00	10:00:00 AM	31.32	10.42	4.29	5.316	
55	22-Jul-00	1:00:00 PM	31.27	10.54	4.31	5.271	
56	22-Jul-00	4:00:00 PM	31.20	10.67	4.34	5.203	
57	22-Jul-00	7:00:00 PM	31.16	10.79	4.35	5.158	
58	22-Jul-00	10:00:00 PM	31.18	10.92	4.34	5.180	

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59	23-Jul-00	1:00:00 AM	31.20	11.04	4.35	5.203		
60	23-Jul-00	4:00:00 AM	31.21	11.17	4.32	5.214		
61	23-Jul-00	7:00:00 AM	31.27	11.29	4.30	5.271		
62	23-Jul-00	10:00:00 AM	31.37	11.42	4.30	5.373		
63	23-Jul-00	1:00:00 PM	31.32	11.54	4.34	5.316		
64	23-Jul-00	4:00:00 PM	31.24	11.67	4.36	5.237		
65	23-Jul-00	7:00:00 PM	31.20	11.79	4.35	5.203	end WL trend period for test	
66	23-Jul-00	9:00:00 PM	31.29	11.88	4.30	5.293	0.0069	
67	23-Jul-00	10:00:00 PM	31.32	11.92	4.28	5.316	0.0486	
68	23-Jul-00	11:00:00 PM	31.30	11.96	4.30	5.305	0.0903	
69	24-Jul-00	12:00:00 AM	31.27	12.00	4.29	5.271	0.1319	
70	24-Jul-00	1:00:00 AM	31.25	12.04	4.29	5.248	0.1736	
71	24-Jul-00	2:00:00 AM	31.23	12.08	4.27	5.225	0.2153	
72	24-Jul-00	3:00:00 AM	31.20	12.13	4.24	5.203	0.2569	
73	24-Jul-00	4:00:00 AM	31.21	12.17	4.22	5.214	0.2986	
74	24-Jul-00	6:00:00 AM	31.23	12.25	4.18	5.225	0.3819	
75	24-Jul-00	8:00:00 AM	31.33	12.33	4.15	5.327	0.4653	
76	24-Jul-00	10:00:00 AM	31.35	12.42	4.15	5.350	0.5486	
77	24-Jul-00	12:00:00 PM	31.32	12.50	4.16	5.316	0.6319	
78	24-Jul-00	2:00:00 PM	31.26	12.58	4.17	5.259	0.7153	
79	24-Jul-00	4:00:00 PM	31.19	12.67	4.17	5.191	0.7986	pump failure
80	24-Jul-00	7:00:00 PM	31.13	12.79	4.20	5.135	0.9236	1609 to 1829
81	24-Jul-00	10:00:00 PM	31.12	12.92	4.18	5.124	1.0486	
82	25-Jul-00	1:00:00 AM	31.10	13.04	4.17	5.101	1.1736	
83	25-Jul-00	4:00:00 AM	31.09	13.17	4.15	5.090	1.2986	
84	25-Jul-00	8:00:00 AM	31.20	13.33	4.08	5.203	1.4653	
85	25-Jul-00	12:00:00 PM	31.20	13.50	4.10	5.203	1.6319	
86	25-Jul-00	4:00:00 PM	31.09	13.67	4.16	5.090	1.7986	
87	25-Jul-00	8:00:00 PM	31.01	13.83	4.14	5.010	1.9653	
88	26-Jul-00	12:00:00 AM	31.03	14.00	4.12	5.033	2.1319	
89	26-Jul-00	6:00:00 AM	31.08	14.25	4.06	5.078	2.3819	
90	26-Jul-00	12:00:00 PM	31.19	14.50	4.03	5.191	2.6319	
91	26-Jul-00	6:00:00 PM	31.07	14.75	4.11	5.067	2.8819	
92	27-Jul-00	12:00:00 AM	31.08	15.00	4.06	5.078	3.1319	
93	27-Jul-00	6:00:00 AM	31.12	15.25	4.01	5.124	3.3819	
94	28-Jul-00	10:00 AM	31.31	16.42	3.95	5.310	4.5487	
95	29-Jul-00	09:00 AM	31.24	17.38	3.98	5.238	5.5070	
96	29-Jul-00	10:00 PM	31.25	17.92	4.05	5.248	6.0487	
97	30-Jul-00	04:00 AM	31.06	18.17	4.04	5.059	6.2987	
98	30-Jul-00	08:00 PM	31.08	18.83	4.05	5.077	6.9653	

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Figure 4

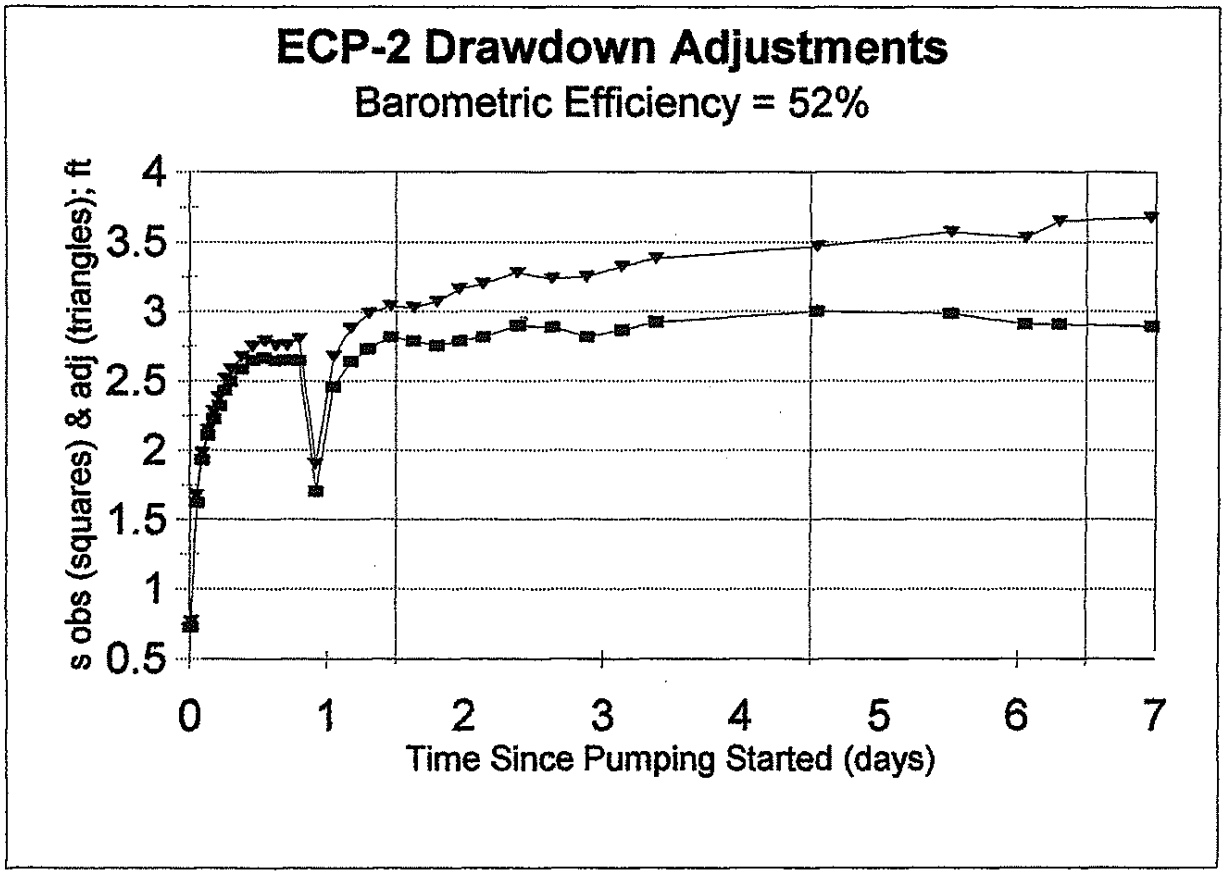

ECP-2 Drawdown Adjustments
Barometric Efficiency = 52%
s obs (squares) & adj (triangles); ft
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
Time Since Pumping Started (days)

Figure 5

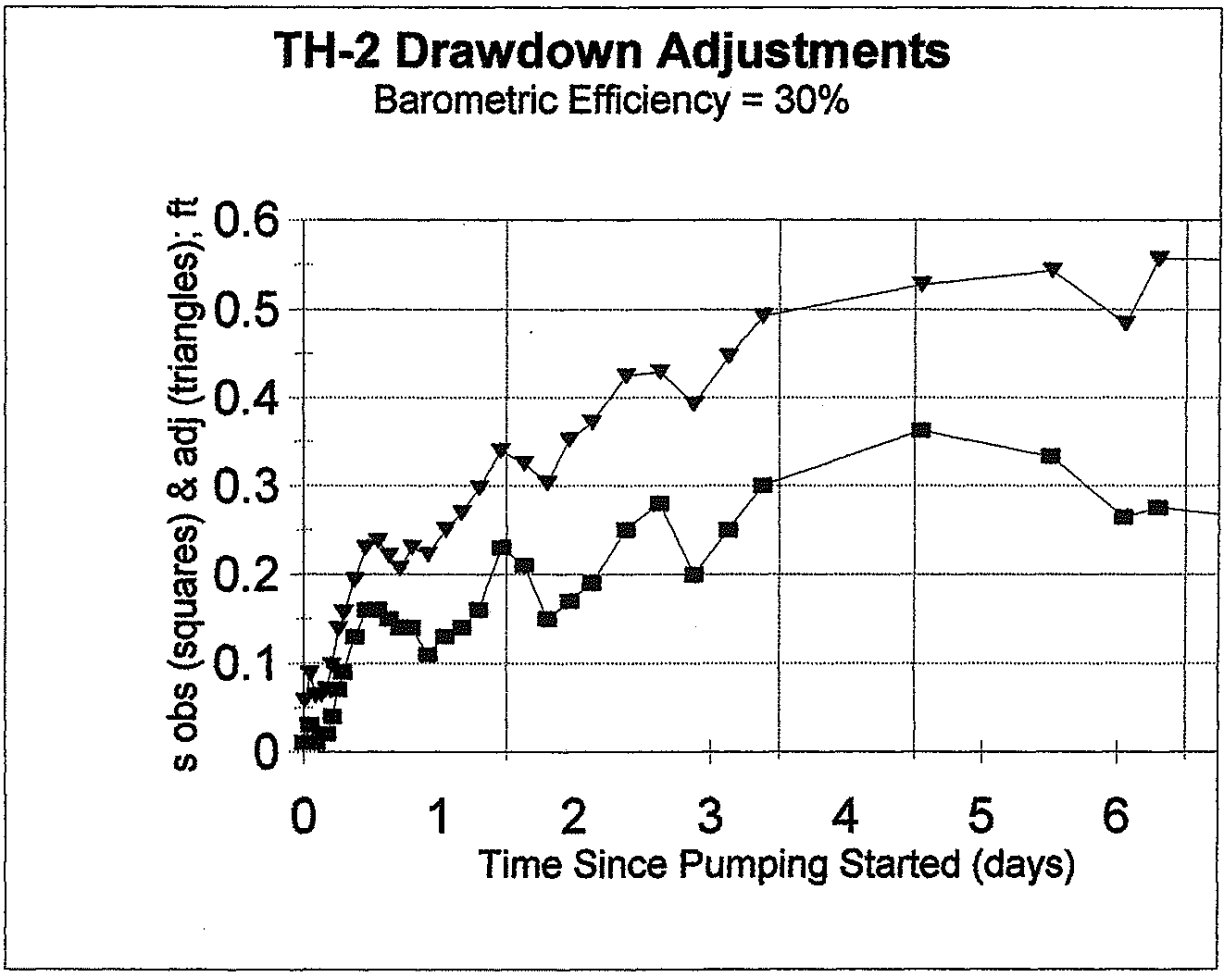

TH-2 Drawdown Adjustments
Barometric Efficiency = 30%
s obs (squares) & adj (triangles); ft
0
0.1
0.2
0.3
0.4
0.5
0.6
0
1
2
3
4
5
6
Time Since Pumping Started (days)

Figure 6

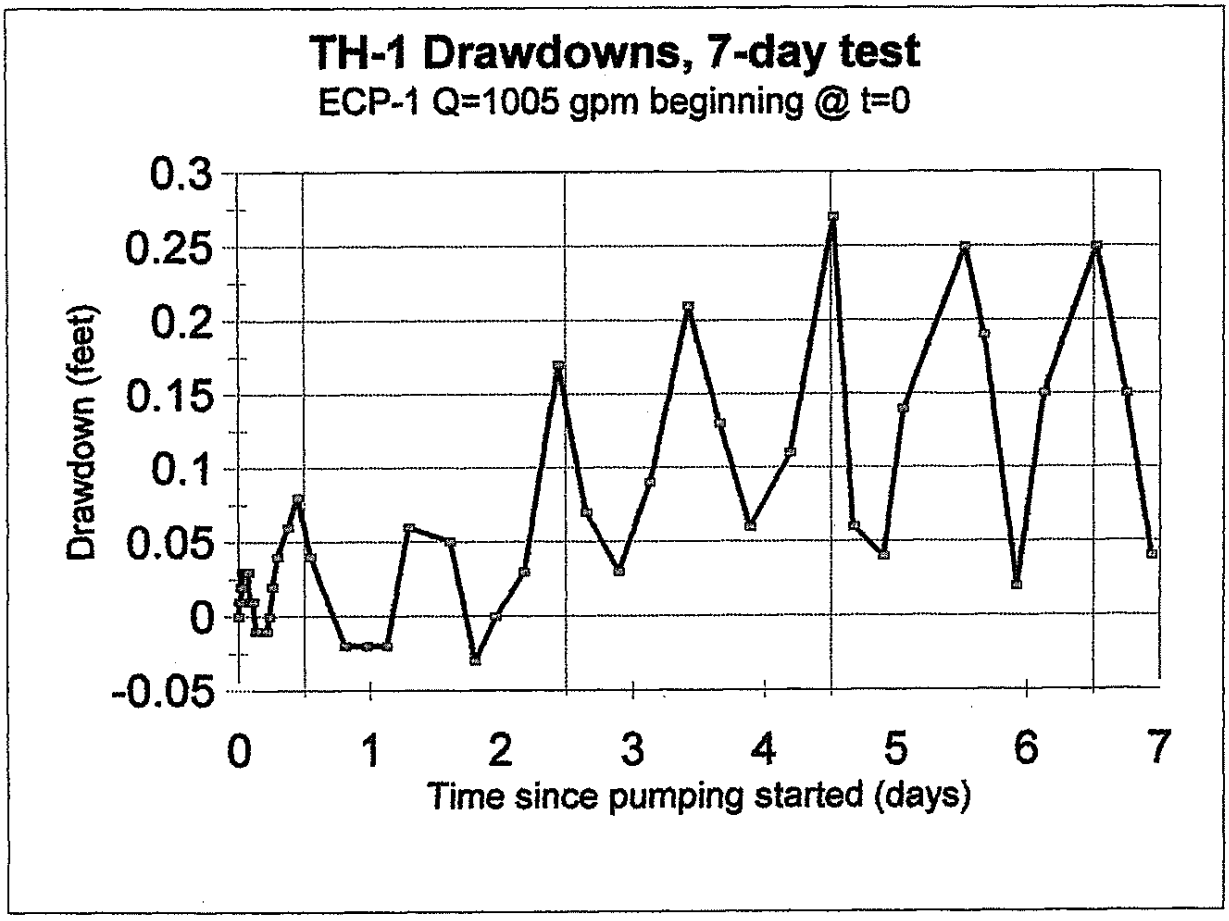
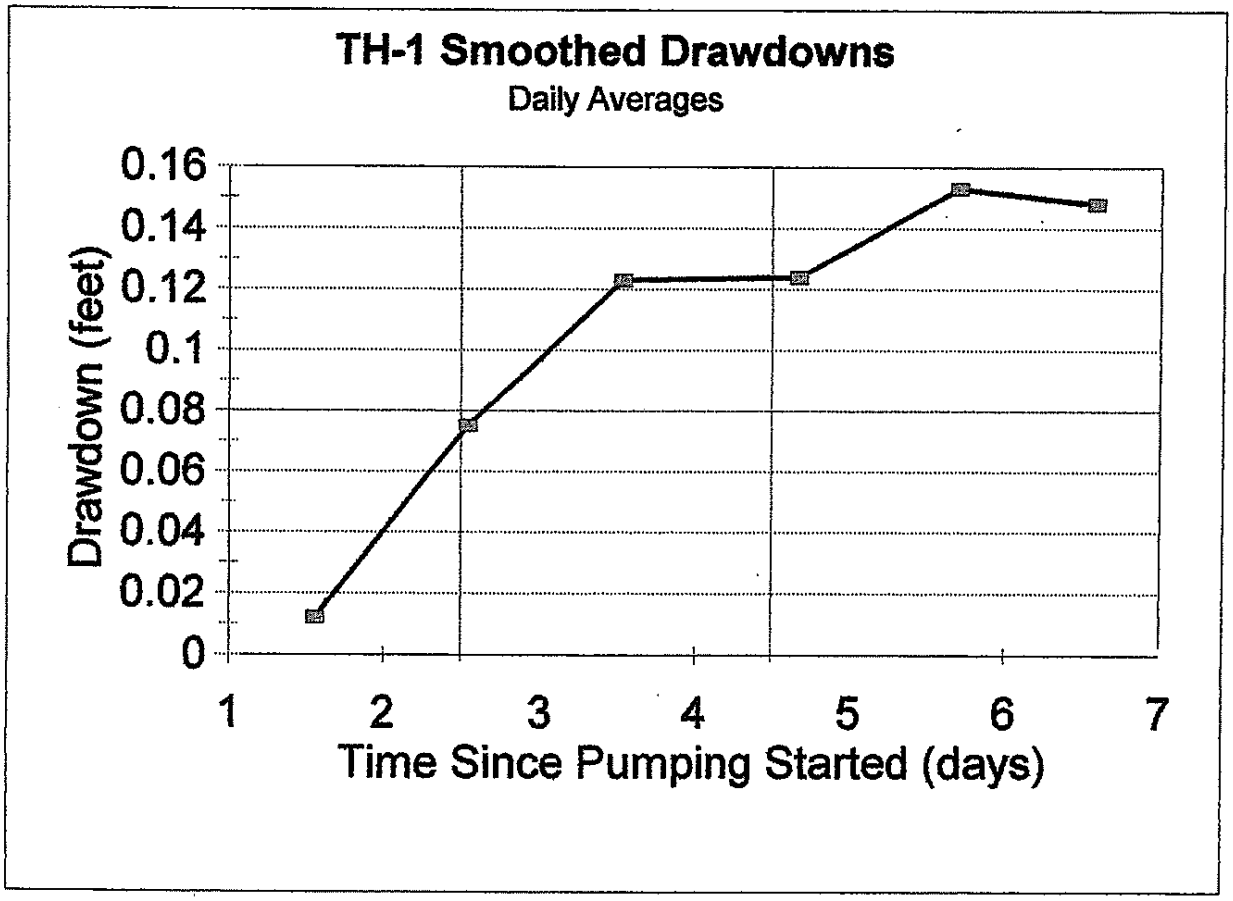

TH-1 Drawdowns, 7-day test
ECP-1 Q=1005 gpm beginning @ t=0
Drawdown (feet)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
1
2
3
4
5
6
7
Time since pumping started (days)

Figure 7


TH-1 Smoothed Drawdowns
Daily Averages
Drawdown (feet)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
Time Since Pumping Started (days)

TH-1 Water Level and Drawdown Summary for 7-day Test

Pumping was 1005 gpm from ECP-1 beginning 8:50 PM July 23, 2000

Date	Time	t (days)	386-WL	t pump	s (ft)
23-Jul-00	07:43 PM	11.822	30.86		
23-Jul-00	08:00 PM	11.833	30.86		
23-Jul-00	08:10 PM	11.840	30.86		
23-Jul-00	08:20 PM	11.847	30.85		
23-Jul-00	08:45 PM	11.865	30.80		
23-Jul-00	08:50 PM	11.868	30.80	**pump on**	
23-Jul-00	08:53 PM	11.870	30.80	0.0021	0
23-Jul-00	08:56 PM	11.872	30.80	0.0042	0
23-Jul-00	09:00 PM	11.875	30.79	0.0069	0.01
23-Jul-00	09:05 PM	11.878	30.79	0.0104	0.01
23-Jul-00	09:10 PM	11.882	30.79	0.0139	0.01
23-Jul-00	09:15 PM	11.885	30.79	0.0174	0.01
23-Jul-00	09:20 PM	11.889	30.78	0.0208	0.02
23-Jul-00	09:25 PM	11.892	30.78	0.0243	0.02
23-Jul-00	09:30 PM	11.896	30.78	0.0278	0.02
23-Jul-00	09:35 PM	11.899	30.77	0.0313	0.03
23-Jul-00	09:40 PM	11.903	30.77	0.0347	0.03
23-Jul-00	09:45 PM	11.906	30.77	0.0382	0.03
23-Jul-00	09:50 PM	11.910	30.77	0.0417	0.03
23-Jul-00	10:00 PM	11.917	30.77	0.0486	0.03
23-Jul-00	10:10 PM	11.924	30.77	0.0556	0.03
23-Jul-00	10:20 PM	11.931	30.77	0.0625	0.03
23-Jul-00	10:30 PM	11.938	30.77	0.0694	0.03
23-Jul-00	10:40 PM	11.944	30.77	0.0764	0.03
23-Jul-00	10:50 PM	11.951	30.79	0.0833	0.01
23-Jul-00	11:00 PM	11.958	30.79	0.0903	0.01
23-Jul-00	11:30 PM	11.979	30.79	0.1111	0.01
24-Jul-00	12:00 AM	12.000	30.81	0.1319	-0.01
24-Jul-00	12:30 AM	12.021	30.81	0.1528	-0.01
24-Jul-00	01:00 AM	12.042	30.81	0.1736	-0.01
24-Jul-00	02:00 AM	12.083	30.81	0.2153	-0.01
24-Jul-00	02:32 AM	12.106	30.80	0.2375	0
24-Jul-00	03:02 AM	12.126	30.78	0.2583	0.02
24-Jul-00	04:00 AM	12.167	30.76	0.2986	0.04
24-Jul-00	05:50 AM	12.243	30.74	0.3750	0.06
24-Jul-00	07:47 AM	12.324	30.72	0.4563	0.08
24-Jul-00	10:03 AM	12.419	30.76	0.5507	0.04
24-Jul-00	04:25 PM	12.684	30.82	0.8160	-0.02
24-Jul-00	08:23 PM	12.849	30.82	0.9813	-0.02
25-Jul-00	12:00 AM	13.000	30.82	1.1319	-0.02
25-Jul-00	04:00 AM	13.167	30.74	1.2986	0.06
25-Jul-00	11:35 AM	13.483	30.75	1.6146	0.05
25-Jul-00	04:10 PM	13.674	30.83	1.8056	-0.03
25-Jul-00	08:00 PM	13.833	30.80	1.9653	0
26-Jul-00	01:12 AM	14.050	30.77	2.1819	0.03
26-Jul-00	07:35 AM	14.316	30.63	2.4479	0.17
26-Jul-00	12:30 PM	14.521	30.73	2.6528	0.07
26-Jul-00	06:22 PM	14.765	30.77	2.8972	0.03
27-Jul-00	12:08 AM	15.006	30.71	3.1375	0.09
27-Jul-00	07:10 AM	15.299	30.59	3.4306	0.21
27-Jul-00	12:50 PM	15.535	30.67	3.6667	0.13
27-Jul-00	06:17 PM	15.762	30.74	3.8938	0.06
28-Jul-00	01:31 AM	16.063	30.69	4.1951	0.11
28-Jul-00	09:20 AM	16.389	30.53	4.5208	0.27
28-Jul-00	01:00 PM	16.542	30.74	4.6736	0.06
28-Jul-00	06:35 PM	16.774	30.76	4.9063	0.04
28-Jul-00	10:12 PM	16.925	30.66	5.0569	0.14
29-Jul-00	09:28 AM	17.394	30.55	5.5264	0.25
29-Jul-00	12:58 PM	17.540	30.61	5.6722	0.19

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29-Jul-00	07:00 PM	17.792	30.78	5.9236	0.02
30-Jul-00	12:05 AM	18.003	30.65	6.1354	0.15
30-Jul-00	09:30 AM	18.396	30.55	6.5278	0.25
30-Jul-00	02:50 PM	18.618	30.65	6.7500	0.15
30-Jul-00	07:20 PM	18.806	30.76	6.9375	0.04

Corroboration of Aquifer Thickness

An aquifer thickness of 5000 feet was inferred from groundwater temperatures in the Muddy River Springs area; depths of circulation of a few thousand feet would be required for the geothermal gradient to warm groundwater to observed temperatures. An analysis of the relationship between barometric efficiency and storativity (Walton, 1996, p.18) was used to obtain an independent estimate of aquifer thickness, which is in general agreement with the 5000-foot estimate from thermal data. A porosity value of 0.047 (4.7%) was used, based on the average porosity of carbonate rocks in the Coyote Spring Valley obtained from geophysical logs and reported by the USGS (Berger,1992). To summarize corroboration of the thickness estimate,

- We observe a water-level change ΔW in response to a barometric-pressure change ΔB
- Barometric efficiency BE is defined as $\Delta W/\Delta B$, and is related to the aquifer storativity S in the following manner (Ferris and others, 1962, p. 90):

$$S = (\gamma\theta b\beta)[1/BE]$$

- Using early response, prior to the onset of delayed yield, we found $S=6.37\times10^{-4}$
- Our records of water level and barometric pressure indicate that BE is nominally 50% (0.50)
- We let porosity $\theta=0.047$ based on USGS geophysical logs (Berger, 1992)
- Bulk density and compressibility of water are physical constants: $\gamma=62.4$ lb/ft^3, $\beta=2.3\times10^{-8}$ ft^{2}lb
- Solving for thickness b, we obtain b=4739 ft, remarkably close to our 5000-ft initial estimate

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APPENDIX B

Geochemical and Isotopic Data For the Arrow Canyon Range Cell and Surrounding Areas

Raw Data
Stiff Diagrams
Piper Diagram
Stable Isotope Plot

Table B1: Geochemical and Isotopic Data
for the
Arrow Canyon Range Cell and Surrounding Areas, southern Nevada

ID Number	Name	North Latitude	West Longitude	Collection Date	Lab Analyzing Data	Reference
CSV-2	MRS4 well	364650	1144320	1/26/86	USGS	1
MX-6	CV7 well	364604	1144713	1/26/86	USGS	1
MS-1	Big Muddy Spring	364320	1144248	7/22/81	USGSa	1
PS-1	Pederson Spring	364236	1144254	3/00/70	USGS	1
ECP-1a	Calpine test well	363246	1144807	4/7/00	NEL, DRI	6
ECP-1	Calpine well	363246	1144807	7/27/00	NEL	6
ECP-2	Calpine well	363245	1144807	12/7/00	NEL	6
ECP-3	Calpine test well	-	-	10/31/00	NEL	6
TH-1	Moapa well	363153	1144748	4/7/00	NEL, DRI	6
DLV-1	Dry Lake Valley well	362718	1145038	7/1/85	USGS	1
Gen 1	Genstar well	362329	1145414	3/31/86	USGS	1
Grace 1	Grace Petroleum well	362258	1145500	4/26/82	USGS	1
GP1a	Georgia Pacific well	362028	1145536	9/30/86	USGS	1
EPB-2	NV Cogeneration well	361731	1145319	6/21/90	DRI	3
EBM-4	NV Cogeneration well	361740	1145314	-	-	5
VF-2	CV-2 well	365230	1145644	2/5/86	USGS	1
VF-1	CV-1 well	365232	1145544	1/6/88	USGS	1
MX-4/5	CV4/5 wells	364744	1145332	-	USGS	1
CSV-3	CV3 well	364127	1145530	10/7/87	USGS	1
SHV-1	Hidden Valley Stock well	363308	1145530	3/28/86	USGS	1
HV-1	DLLLCHidden Valley	-	-	6/5/00	DRI	9
DDL-2*	Desert Dry Lake well	365711	1151151	3/18/87	USGS	1
LS-1*	Lamb Spring	365642	1150621	5/19/88	USGS	2
SS-1*	Sheep Spring	365342	1150653	5/19/88	USGS	1,2
WRS-1*	White Rock Spring	364230	1151420	-	USGSa	1
SM-1*	Sawmill Spring	364050	1151034	5/19/88	USGS	2
MW-1*	Mormon well Spring	363838	1150552	-	USGSa	1,2
WS-1*	Wamp Spring	363830	1150412	3/20/87	USGS	1
WG-1*	Wiregrass Spring	363800	1151229	-	USGSa	1
FW-1	Valley of Fire well	362521	1143252	6/24/85	DRI	1
BP-1	Blue Point Spring	362321	1142526	7/1/85	USGS	1
RS-1	Rogers Spring	362239	1142638	unknown	USGS	1
EH-1	Nevada Power Co	-	-	10/3/85	DRI	7
EH-2	Nevada Power Co	-	-	10/14/85	DRI	7
EH-7	Nevada Power Co	-	-	3/19/87	USGSa	1
RRF	Railroad Farrier well	-	-	2/4/84	USGS	1
M-1	Moapa Monitor well	363815	1144244	10/11/00	NEL	6
M-2	Moapa Monitor well	362936	1144848	10/17/00	NEL	6
M-3	Moapa Monitor well	363130	1145139	10/21/00	NEL	6
KSV-1†	Willow Spring	370534	1144952	2/3/84	USGS	1
KSV-2†	Grapevine Spring	370808	1144202	2/3/84	USGS	1
KSV-3†	Kane Spring	371446	1144221	2/2/84	USGS	1
KSV-4†	Boulder Spring	371612	1143844	2/2/84	USGS	1
Jen-1†	Jensen well	371103	1142752	4/10/85	USGS	1
Ran-1†	Randono well	371926	1143008	2/3/84	USGS	1
Brad-1†	Bradshaw well	372057	1143238	2/1/84	USGS	1
RR-1†	Railroad well	372104	1143202	1/31/84	USGS	1
Ash"	Ash Spring	372749	1151134	n/a	USGS	1,4
Crystal"	Crystal Spring	373153	1151358	n/a	USGS	1,4

Units used are mg/l unless otherwise noted

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Table B1: Geochemical and Isotopic Data
for the
Arrow Canyon Range Cell and Surrounding Areas, southern Nevada

ID Number	Na	K	Ca	Mg	Cl	HCO3	SO4	SiO2	Fluoride
CSV-2	100	10	60	27	61	276	160	30	2.3
MX-6	87	10	58	25	53	271	159	30	2.1
MS-1	96	10	66	26	61	270	190	29	2.1
PS-1	110	8.8	75	26	59	280	190	25	2.1
ECP-1a	110	17	120	52	150	200	290	20	2.2
ECP-1	110	14	110	46	110	160	270	10	2.1
ECP-2	93	14	110	44	120	180	260	20	2.3
ECP-3	99	13	100	45	120	180	260	11	2.3
TH-1	110	15	110	49	130	180	240	7.3	2.2
DLV-1	120	13	110	48	170	210	360	21	2.1
Gen 1	140	1.3	120	47	180	226	370	23	1.6
Grace 1	140	16	120	46	190	230	360	21	1.6
GP1a	129	12	120	46	200	226	380	23	1.4
EPB-2	134	15.9	120	54.5	183	225	388	20.3	1.4
EBM-4	134	21	117	53	217	199	374	21	-
VF-2	81	11	47	21	34	303	90	34	1.7
VF-1	34	1.2	41	7.5	42	156	20	14	0.5
MX-4/5	81	11	46	20	34	295	105	33	1.9
CSV-3	38	10	51	25	26	299	54	24	1.2
SHV-1	86	12	33	30	64	245	90	27	1.2
HV-1	120	12.9	101	53.2	148	223	358	19.1	-
DDL-2*	35	5.7	22	27	8.9	207	48	49	0.6
LS-1*	8.7	0.6	37	41	8.6	289	24	12	0.2
SS-1*	7.9	1.1	31	40	7.1	276	13	13	0.2
WRS-1*	14	7.2	37	30	10	275	8.5	46	0.2
SM-1*	1.8	0.6	12	29	2.1	162	5.9	6.1	0.2
MW-1*	12	0.6	77	42	18	395	13	16	0.1
WS-1*	10	2.1	71	13	4.9	293	8.4	24	0.2
WG-1*	3	1.7	70	33	3.1	370	7	12	0.1
FW-1	39	8.2	118	53	21	164	449	8.3	0.2
BP-1	360	23	510	170	500	160	2300	18	1.4
RS-1	290	20	430	136	333	163	1633	18	1.4
EH-1	-	-	-	-	-	-	-	-	-
EH-2	-	-	-	-	-	-	-	-	-
EH-7	-	-	-	-	-	-	-	-	-
RRF	-	-	-	-	-	-	-	-	-
M-1	110	13	94	41	74	240	220	23	-
M-2	110	15	110	50	140	170	290	17	-
M-3	79	14	130	49	100	190	300	14	-
KSV-1†	56	4.6	20	2.7	22	140	34	65	1.1
KSV-2†	17	2.3	75	22	27	280	40	22	0.9
KSV-3†	20	5.9	44	13	17	210	14	60	2.8
KSV-4†	12	2.3	21	4.9	7.8	100	6	41	1.7
Jen-1†	100	7.2	55	14	45	340	80	56	2.1
Ran-1†	100	8.4	46	14	44	350	63	54	2.3
Brad-1†	120	11	85	28	52	550	76	63	2.3
RR-1†	98	8.8	42	14	42	300	60	51	2.3
Ash"	29	7.7	46	15	8	259	33	30	0.9
Crystal"	22	5.3	44	22	8.7	258	33	24	0.3

Units used are mg/l unless otherwise noted

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Table B1: Geochemical and Isotopic Data
for the
Arrow Canyon Range Cell and Surrounding Areas, southern Nevada

ID Number	Temp°C	pH	EC µmhos/cm @25°C	Constituents Sum/TDS(7)	Constituents TDS(8)	Dissolved Oxygen	Deuterium (permil)	Oxygen-18 (permil)
CSV-2	27.0	7.4	1000	590	-	4.0	-98.0	-12.85
MX-6	33.5	7.2	980	560	-	3.7	-97.0	-12.95
MS-1	32.5	7.2	930	610	-	3.0	-97.8	-12.90
PS-1	32.2	-	1000	640	-	-	-97.0	-12.75
ECP-1a	30.5	8.1	1100	894	996	-	-99.0	-13.50
ECP-1	30.5	7.5	897	754	757	-	-	-
ECP-2	29.7	8.0	1170	750	727	-	-	-
ECP-3	30.6	8.2	1050	742	771	-	-	-
TH-1	-	7.6	-	832	917	-	-99.0	-13.40
DLV-1	29.0	7.3	1400	960	-	2.0	-97.5	-13.30
Gen 1	24.0	7.4	1500	1000	-	4.8	-97.0	-13.05
Grace 1	26.5	7.3	1600	1000	-	0.5	-96.0	-13.70
GP1a	31.0	7.0	1570	1000	-	5.5	-98.0	-13.45
EPB-2	-	7.9	1580	-	-	-	-	-
EBM-4	-	6.8	1463	1136	-	-	-	-
VF-2	34.0	7.4	800	470	-	2.9	-101.0	-13.0
VF-1	28.0	7.0	460	230	-	-	-94.0	-12.6
MX-4/5°	34.7	7.3	750	480	-	2.9	-101.0	-13.0
CSV-3	41.0	7.4	650	380	-	-	-	-
SHV-1	25.0	7.8	820	470	-	3.8	-90.5	-11.2
HV-1	-	7.9	1400	922	-	-	-97.0	-12.9
DDL-2*	19.0	8.0	400	300	-	-	-98.0	-13.1
LS-1*	13.5	7.7	500	n/a	-	6.1	-92.5	-13.2
SS-1*	15.0	7.8	520	n/a	-	6.6	-96	-13.35
WRS-1*	12.5	7.5	420	290	-	5.7	-83.5	-9.8
SM-1*	-	-	-	-	-	-	-92.0	-12.9
MW-1*	11.2	7.4	670	370	-	5.1	-91.8	-12.7
WS-1*	7.0	8.1	320	420	-	-	-81.0	-10.6
WG-1*	8.6	7.3	560	310	-	5.4	-94.3	-12.8
FW-1	28.0	7.4	1100	780	-	-	-82.0	-10.6
BP-1	30.0	7.0	3800	4000	-	3.4	-93.0	-12.4
RS-1	30.0	7.4	3800	2900	-	2.3	-92.0	-12.2
EH-1	-	-	-	-	-	-	-96.0	-13.4
EH-2	-	-	-	-	-	-	-99.0	-12.1
EH-7	-	-	-	-	-	-	-91.0	-12.45
RRF	-	-	-	-	-	-	-97.5	-12.5
M-1	29.2	8.1	983	636	666	-	-	-
M-2	29.0	8.1	1130	817	781	-	-	-
M-3	27.8	8.0	1410	779	680	-	-	-
KSV-1†	-	7.5	-	270	-	-	-88.0	-11.6
KSV-2†	-	7.3	-	340	-	-	-87.5	-12.0
KSV-3†	-	7.2	-	280	-	-	-86.5	-11.9
KSV-4†	-	7.9	-	140	-	-	-87.0	-12.6
Jen-1†	-	7.7	840	520	-	-	-88.5	-11.6
Ran-1†	-	7.6	760	500	-	-	-87.5	-11.7
Brad-1†	-	7.3	1100	710	-	-	-88.5	-11.4
RR-1†	-	7.6	730	460	-	-	-86.0	-11.6
Ash"	-	7.2	460	290	-	-	-108.0	-14.1
Crystal"	-	7.3	410	290	-	-	-109.0	-14.3

Units used are mg/l unless otherwise noted

SE ROA 10674

JA_3528

Table B1: Geochemical and Isotopic Data
for the
Arrow Canyon Range Cell and Surrounding Areas, southern Nevada

ID Number	C-13 (permil)	C-14 (pmc)	H3 pCi/L	Carbonate Well or spg	Number of samples
CSV-2	-5.5	8.4	4.0	yes	1
MX-6	-8.0	8.4	1.8	yes	1
MS-1	-6.0	6.7	<1.0	yes	1
PS-1	-	-	-	yes	1
ECP-1a	-	-	-	yes	1
ECP-1	-	-	-	yes	1
ECP-2	-	-	-	yes	1
ECP-3	-	-	-	yes	1
TH-1	-	-	-	yes	1
DLV-1	-4.2	3.0	7.0	possible	1
Gen 1	-4.9	1.5	<1.0	possible	1
Grace 1	-	-	-	yes	1
GP1a	-5.5	2.7	<0.3	yes	1
EPB-2	-	-	-	yes	1
EBM-4	-	-	-	yes	1
VF-2	-6.1	7.0	<1.0	yes	1
VF-1	-	-	-	no	1
MX-4/5	-	7.6	<2.0	yes	2
CSV-3	-	-	-	no	1
SHV-1	-	-	<1.0	possible	1
HV-1	-	-	-	yes	1
DDL-2*	-5.3	1.3	<0.6	yes	1
LS-1*	-	-	-	yes	-
SS-1*	-	-	-	yes	-
WRS-1*	-8.3	-	-	yes	2
SM-1*	-	-	-	yes	-
MW-1*	-9.9	-	-	yes	3
WS-1*	-	-	-	yes	1
WG-1*	-10.2	96.8	89.6	yes	8
FW-1	-8.5	18.7	-	no	1
BP-1	-5.3	7.2	-	yes	1
RS-1	-4.05	1.6	-	yes	-
EH-1	-	-	-	no	1
EH-2	-	-	-	no	1
EH-7	-	-	-	no	1
RRF	-	-	-	possible	1
M-1	-	-	-	yes	1
M-2	-	-	-	yes	1
M-3	-	-	-	yes	1
KSV-1†	-	-	-	probable	1
KSV-2†	-	-	-	probable	1
KSV-3†	-	-	-	probable	1
KSV-4†	-	-	-	probable	1
Jen-1†	-	-	-	probable	1
Ran-1†	-	-	-	probable	1
Brad-1†	-	-	-	probable	1
RR-1†	-	-	-	probable	1
Ash"	-	-	-	probable	1
Crystal"	-	-	-	probable	1

SE ROA 10675

JA_3529

Table B1: Geochemical and Isotopic Data
for the
Arrow Canyon Range Cell and Surrounding Areas, southern Nevada

Legend and References

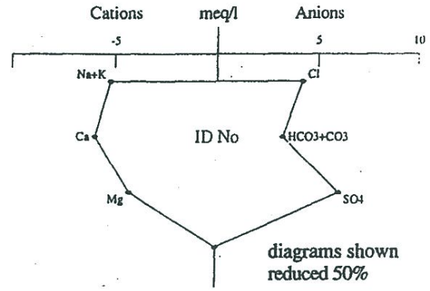
* Located in the Sheep Mountains
† Located in Southern Meadow Valley
" Part of the White River Flow System
1 Thomas, J.M., Welch, A.H., and Dettinger, M.D., 1996, Geochemistry and isotope hydrology of representative aquifers in the Great Basin of Nevada, Utah, and adjacent states: U.S. Geological Survey Professional Paper 1409-C, 100 p.
2 Schafer, D.H., Morris, T.M., and Dettinger, M.D., 1992, Hydrogeologic and geophysical data for selected wells and springs in the Sheep Range area, Clark and Lincoln Counties, Nevada: U.S. Geological Survey Open File Report 89-425, 26 p.
3 Mifflin and Associates, Inc., 1990, Water quality analysis for Nevada Cogeneration Associates. Inc.
4 Winograd, I. J. and Pearson, F.J.., 1976, Major Carbon-14 anomaly in a regional carbonate aquifer-Possible evidence for megascale channeling, south central Great Basin, Water Resources Research, v. 12, no. 6, p. 1125-1143.
5 Geraghty & Miller, 1994, Water quality analysis for Nevada Cogeneration Associates, Inc.
6 Mifflin and Associates, Inc., 2000, Water quality analysis for Calpine Company
7 Calculated by multiplying HCO3 by 0.4916 to make comparable to residue upon evaportation value (per reference 1 above)
8 TDS value from residue upon laboratory evaporation
9 Southern Nevada Water Authority (SNWA)
MX 4/5° USGS average for Deuterium and Oxygen is shown. Measured value for MX-4 is -102.5 and -13.0 and MX-5 is -99.5 and 12.9, respectively.
USGSa average of multiple measurements

SE ROA 10676

JA_3530

Stiff Diagrams of Geochemistry in and adjacent to the Arrow Canyon Range Cell, Clark and Lincoln Counties, Nevada

Site locations are approximate.
No scale is intended.



diagrams shown reduced 50%

SHEEP RANGE

COYOTE SPRING VALLEY

ARROW CANYON RANGE

HIDDEN VALLEY

APEX

CALIFORNIA MOUNTAINS

MOAPA VALLEY

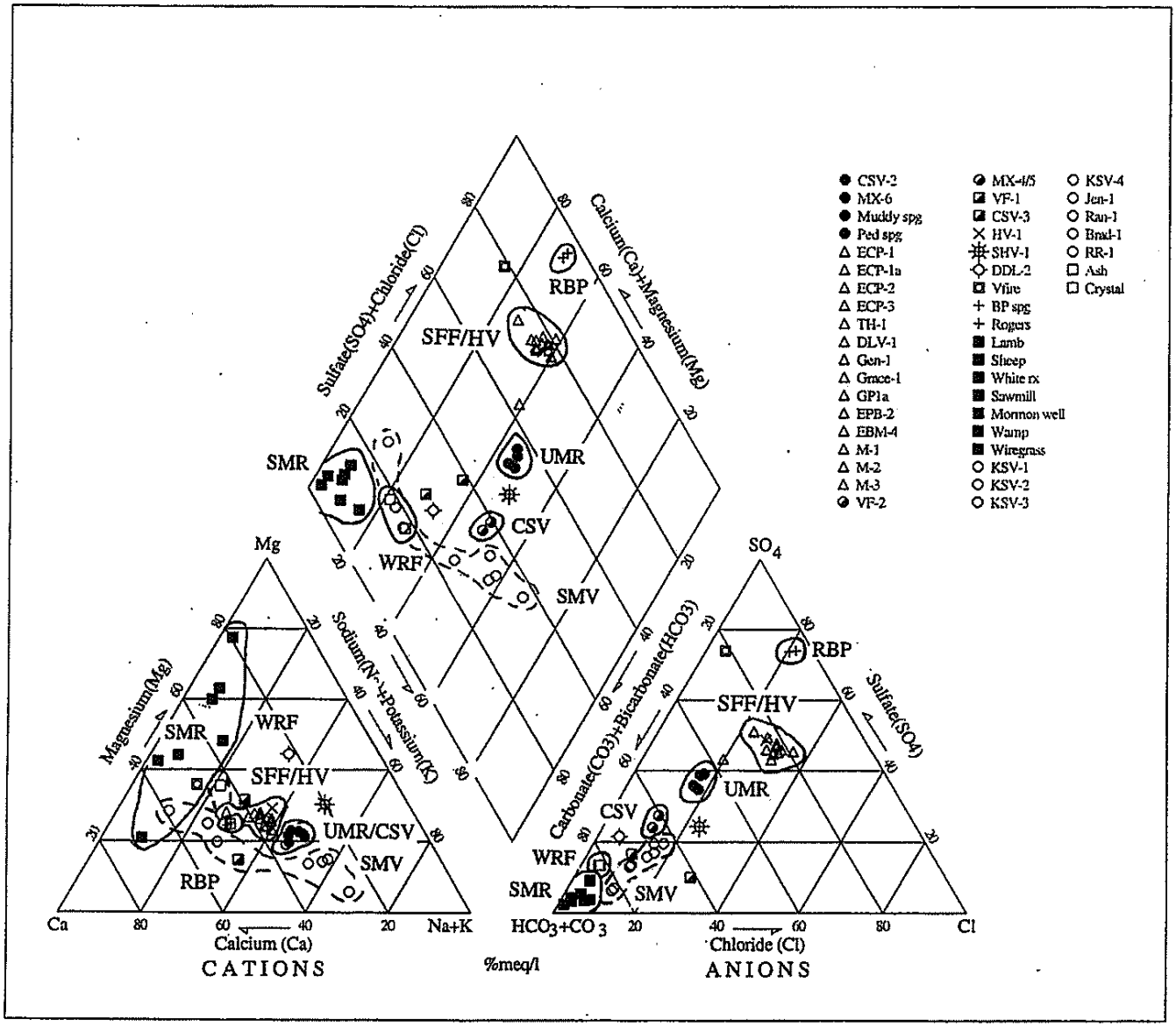
MUDDY

Approximate Geochemical Boundary

Approximate Geochemical Boundary

N

Appendix B Figure A1



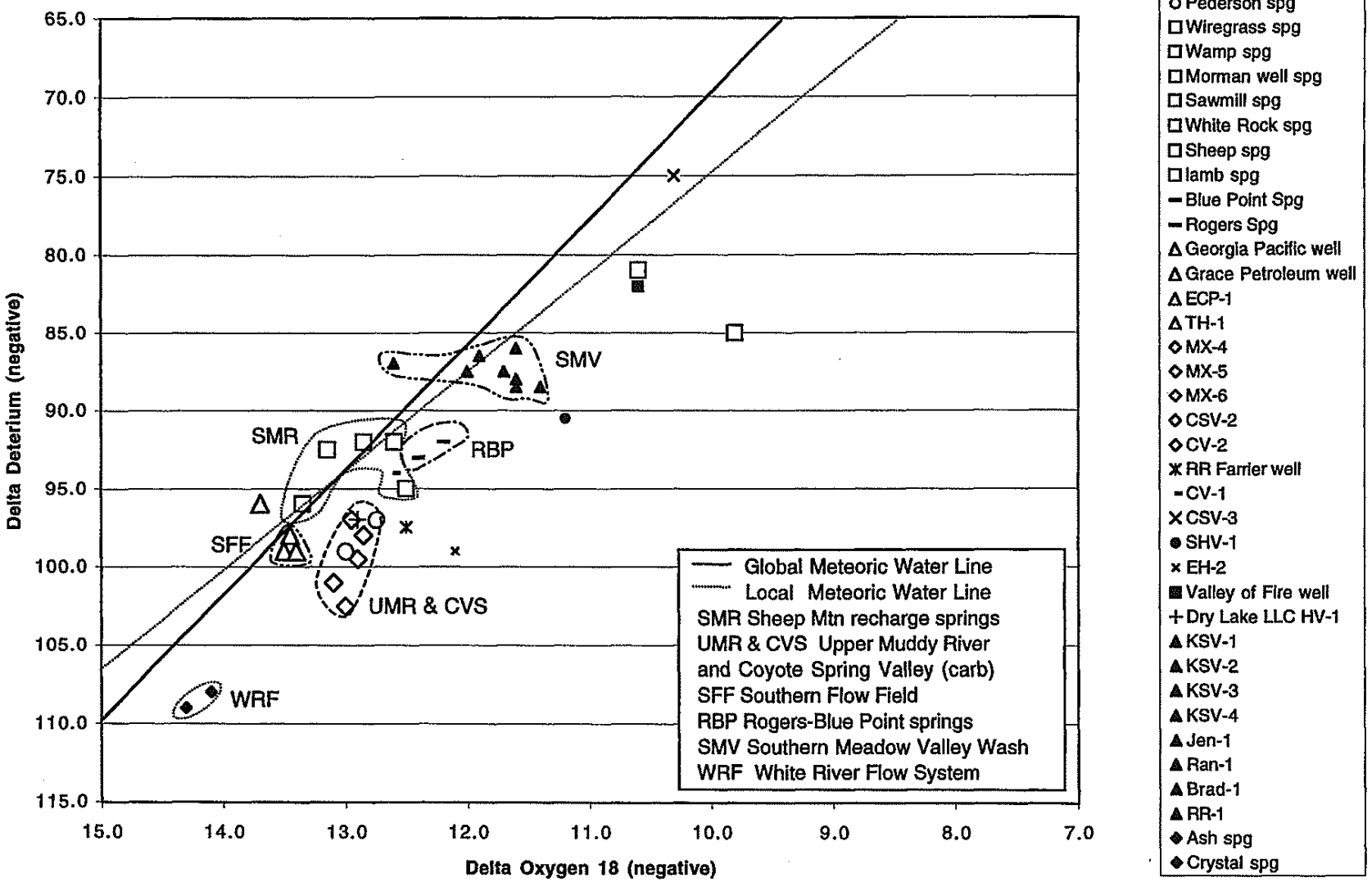
SMR	Sheep Mtn. recharge springs	RBP	Rogers-Blue Point springs
SFF	Southern flow field carbonate wells	WRF	White River Flow System
UMR	Upper Muddy River carbonate wells & springs	SMV	Southern Meadow Valley Wash
CSV	Coyote Spring Valley carbonate wells	HV	Hidden Valley carbonate well

Figure B2. Geochemistry in and adjacent to the Arrow Canyon Range Cell

SE ROA 10678

JA_3532

Stable Isotopes in and adjacent to the Arrow Canyon Range Cell



Appendix B, Figure B3

SE ROA 10679

JA_3533

APPENDIX C

Horizontal and Vertical Elevation Control And Water Levels

For

Carbonate Rock and Associated Wells Located In the Apex, California Wash, Hidden Valley, Coyote Spring, and Moapa Areas

Lincoln and Clark Counties, Nevada

Horizontal and Vertical Elevation Control for Carbonate Rock and Associated Wells Located in the Apex, California Wash, Hidden Valley, Coyote Spring, and Moapa Areas, Lincoln and Clark Counties, Nevada

Data Source					2000 Johnson Professional Surveying			2000 PBS&J			2000 USGS computer database	
Well Number	Well Name	Well Name 2	UTM Zone 11 Easting	UTM Zone 11 Northing	88 datum MAI^^ sfc elev (ft)	88 datum MAI^^ flange (ft)	88 datum MAI^^ measure pt (ft)	88 datum MAI^^ sfc elev (ft)	88 datum MAI^^ flange (ft)	88 datum MAI^^ measure pt (ft)	USGS° MP correction (negative) (ft)	USGS° MP correction established
VF1	CV1										2.1	3/18/92
VF2	CV2	CE-VF-2	684598°°	4082712							0.9	9/12/87
CSV3	CV3		685386°°	4062379							1.5	9/13/87
MX4	CV4	CE-DT-4	688003^^	4074274	2174.7	n/a	2175.69				1.0	6/1/86
MX5	CV5	CE-DT-5	688160°°	4073972							1.1	11/13/90
CSV1	CV6		690832°°	4070947							1.3	12/17/85
MX6	CV7	CE-DT-6	697525°°	4071192							1.3	3/14/85
EH-4	MRS2		703929^^	4064736	1932.2	n/a	1933.54					
EH-5b	MRS3		701569^^	4067619	1843.5	n/a	1845.03					
CSV2	MRS4		703217^^	4072967	2188.3	n/a	2189.29				1.3	9/11/87
SHV-1	H1	Hidden Valley	685841°°	4047065							0.6	11/2/87
DF-1	Dutchman Flat										1.3	3/14/85
EBM-3	NV Cogen		689602^^	4018535	2388.4	2388.88	2389.88					
EBA-1	Georgia Pacific		686513^^	4024108	2425.7	2425.95	2426.99					
CL-1	Chem Lime		687748^^	4026564	2284.7	n/a	2286.48					
xtal-1	NPC Crystal											
xtal-2	NPC Crystal											
ECP-1	Calpine		696735^^	4046586	2230.7	2231.00	n/a	2229.8	2230.31	2233.55		
ECP-2	Calpine		696726^^	4046738	2229.4	2230.90	2233.07	2228.5	2230.50	2232.42		
ECP-3	Calpine							2242.3	2243.43	2243.63		
TH-1	Moapa		697237^^	4044962	2167.7	n/a	2170.29					
TH-2	Moapa		697687^^	4049913	n/a	2340.04	2341.70					
GV-1	Garnet Valley	Dry Lake LLC	683063"	4033946								
HV-1	Hidden Valley	Dry Lake LLC	684198"	4035619								
M-1	M-1							1895.71`	1896.64``	1898.11		
M-2	M-2							2108.77`	2109.42``	2111.02		
M-3	M-3							2235.34	2236.53``	2238.03		
HS-8	Hogan Springs well							1873.38	1877.24```			

MP = Measurement Point
sfc = ground surface
grd = ground surface

SE ROA 10681
JA_3535

Horizontal and Vertical Elevation Control for Carbonate Rock and Associated Wells Located in the Apex, California Wash, Hidden Valley, Coyote Spring, and Moapa Areas, Lincoln and Clark Counties, Nevada

Data Source	1981 & 2000 USGS computer database/Ertec			2000 SNWA	2000 MAI conversion		DRI	1981 USGS/Ertec Data		2000 Integrated Water Resources	
Well Number	29 datum USGS * ° sfc elev (ft)	88 datum''' USGS * ° sfc elev (ft)	USGS * ° survey type and accuracy (ft)	29 Datum SNWA ** Pad elev (ft)	88 Datum SNWA ** Pad elev (ft)	SNWA MP ** correction (negative) (ft)	DRI*** MP elev (ft)	29 Datum ERTEC grd elev (ft)	ERTEC top casing negative(ft)	88 Datum Dry Lake Co Pad elev (ft)	88 Datum Dry Lake Co MP elev (ft)
VF1	2464.2°	2,466.6	Level, 0.1	2464.2††				2464.18	grd level		
VF2	2,466.9	2,469.3	Level, 0.1	2466.9††		0.9	2466.9	2466.86	1.18		
CSV3	2,414.3	2,416.9	Level, 0.1	2414.3††		1.59	2414.3				
MX4	2,172.6		Level, 0.1	2182.0^		1.0	2172.6	2172.58	1.20		
MX5	2169.1'	2,171.4	Level, 0.1	2177.0^		1.0	2169.1	2169.08†	n/a		
CSV1	2,158.6	2,160.9	Level, 0.1	2158.6††		1.3					
MX6	2,274.6	2,276.8	Level, 0.1	2281^				2274.57	1.34		
EH-4							1932.77				
EH-5b							1842.69				
CSV2	2,185.9		Level, 0.1				2187.2				
SHV-1			Level, 0.1	2648.8††°	2651.4'''	0.6				2652.26	2652.75
DF-1	2222'		map, 10	2223.6††		1.5					
EBM-3											
EBA-1											
CL-1											
xtal-1											
xtal-2											
ECP-1											
ECP-2											
ECP-3											
TH-1											
TH-2											
GV-1										2991.18	2692.70
HV-1										2695.95	2699.85
M-1											
M-2											
M-3											
HS-8											

MP = Measurement Point
sfc = ground surface
grd = ground surface

SE ROA 10682
JA_3536

Horizontal and Vertical Elevation Control for Carbonate Rock and Associated Wells Located in the Apex, California Wash, Hidden Valley, Coyote Spring, and Moapa Areas, Lincoln and Clark Counties, Nevada

Legend

*OFR 87-679
** SNWA data
*** DRI data
† elevation: top of rebar set 0.05 ft above grd at well casing
†† ERTEC survey data used (per Gavin Kistinger, SNWA)
††° Possible ERTEC survey data used (per Gavin Kistinger, SNWA)
^ SNWA elevation using a resource grade GPS, ± 6 feet vertical (per Gavin Kistinger, SNWA)
° usgs computer database
°°usgs lat-longs converted to UTM
'usgs computer database uses an elevation of 2222 feet determined from a map with a 10 foot accuracy
" Dry Lake LLC/ Integrated Water Resources, Inc. survey data (2000)
'" MAI conversions from 29 to 88 datum
¨ top of eight inch steel casing
¨¨ top of six inch steel casing
` pad elevation

^^ MAI elevations and horizontal established with a survey grade GPS. Survey notes include:
TH-2 and CSV-2: upper measurement is top of casing = measuring point
TH-1 measuring point is the top of 1" stand pipe which is 0.82 feet above the surveyed well head elevation of 2169.47 feet
Eh5b upper measurement is right edge of box lip
Eh4 upper measurement is left edge of box lip
MX-4 ground level measurement is cement pad elevation at gate. USGS determined ground level at casing 2174.76 and top of casing measurement point at 2175.69
CL-1 lid thickness is 0.11 feet
EBA-1 lid thickness is 0.035 feet
EBM-3 upper measurement is top of casing = measuring point
Vertical accuracy is ±0.02 feet except for CSV-2 is ±0.06 feet and EBM-3 is +0.07 feet

SE ROA 10683
JA_3537

Appendix C, Table C2

Water Levels for Carbonate Rock and Associated Wells Located in the Apex, California Wash, Hidden Valley, Coyote Spring, and Moapa Areas, Lincoln and Clark Counties, Nevada

Well Number	Well Name	88 datum Elevation measure pt (ft)	Depth water level (ft)	88 datum AMSL water elevation (ft)	Elevation Survey Source	Date of water measurement meter used
VF1*	CV1	2468.7	549	1919.7	USGS/Ertec	6/24/00 USGS calibrated meter
VF2	CV2	2470.2	611.30	1858.90	USGS/Ertec	8/17/00 USGS calibrated meter
CSV3*	CV3	2418.4	594.89	1823.51	USGS/Ertec	8/17/00 USGS calibrated meter
MX4	CV4	2175.69	354.12	1821.57	MAI	8/17/00 USGS calibrated meter
MX5	CV5	2172.5			USGS/Ertec	
CSV1*	CV6	2162.2	348.66	1813.54	USGS/Ertec	8/17/00 USGS calibrated meter
MX6	CV7	2278.1	457.5	1820.6	USGS/Ertec	Average of four USGS measurements in 1981
EH-4	MRS2	1933.54	116.83	1816.71	MAI	Average 10/1-3/31 for 1987 -1997, DRI recorder measurement
EH-5b	MRS3	1845.03	28.00	1817.03	MAI	Average 10/1-3/31 for 1987 -1997, DRI recorder measurement
CSV2	MRS4	2189.29	392.45	1796.84	MAI	8/17/00 USGS calibrated meter
SHV-1**	Hidden Valley	2652.75	836.60	1816.15	Dry Lake LLC	8/17/00 USGS calibrated meter, Dry Lake LLC measured 828.75 = 1824.00 on 6/4/00
EBM-3	NV Cogen	2389.88	577.05	1812.83	MAI	8/21/00 USGS calibrated meter
EBA-1	Georgia Pacific	2426.99	607	1819.99	MAI	1990 MAI open hole after borehole's total depth
CL-1	Chem Lime	2286.48	471.1	1815.38	MAI	5/21/99 MAI airline measurement
xtal 2	NPC Crystal		256.34			8/21/00 USGS calibrated meter
ECP-1	Calpine	2233.55	417.94	1815.61	MAI	12/05/00 MAI calibrated meter
ECP-2	Calpine	2232.42	416.86	1815.56	MAI	12/05/00 MAI calibrated meter
ECP-3	Calpine	2243.63	428.53	1815.10	MAI	12/05/00 MAI calibrated meter
TH-1	Moapa	2169.95	354.83	1815.12	MAI	12/05/00 MAI calibrated meter
TH-2	Moapa	2341.70	526.25	1815.45	MAI	12/04/00 MAI calibrated meter
M-1	Moapa	1898.11	82.28	1815.83	MAI	12/04/00 MAI calibrated meter
M-2	Moapa	2111.02	298.05	1812.97	MAI	12/04/00 MAI calibrated meter
M-3	Moapa	2238.03	423.00	1815.03	MAI	12/04/00 MAI calibrated meter
GV-1	Garnet Valley	2692.70	880.5	1812.20	Dry Lake LLC	6/4/00 Integrated Water Resources, Inc. measurement
HV-1	Hidden Valley	2699.85	882.5	1817.35	Dry Lake LLC	5/10/00 Integrated Water Resources, Inc. measurement

* none carbonate well

** possible carbonate well

SE ROA 10684

JA_3538

APPENDIX D

Nevada State Engineer Hydrographic Basin Abstracts

Of

Active Water Rights and Applications and Relative Status

Current through August 8, 2000

Appendix D

Nevada State Engineer Hydrographic Basin Abstracts
of Active Water Rights and Applications and Relative Status
current through 8/17/00
for

Basin Number	Basin Name
210	Coyote Spring
215	Black Mountains
216	Garnet Valley
217	Hidden Valley
218	California Wash
219	Muddy River Spgs
220	Lower Moapa V.

Abbreviations

App	Water right application
Cer	Certificate
Per	Permit
RFA	Ready for action
RFP	Application protested
VST	Vested
STK	Stock
Wld	Wildlife
Ind	Industrial
MM	Mining and milling
Mun	Municipal
Qm	Quasimunicipal
Irr	Irrigation
Pwr	Power
Com	Commercial
Env	Environmental
UG	Underground
MGA	Million gallon annually
AFA	Acre feet annually

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
***** START OF SECTION FOR BASIN NUMBER: 210 *****																	
3294		1391	03/08/1915	CER	SPR	NW	SE	24	11S	63E	0.013	STK			2.92	MGA LI	BALLOW, RACHAEL; SCHLARMAN, RACHAEL
4213		468	11/11/1916	CER	SPR	SW	NE	12	11S	61E	0.025	STK			5.89	MGA LI	LAMB, WM. G.; LAMB, WM. S.
10449		2721	12/04/1939	CER	RES	NE	NW	05	09S	64E	0.013	STK			2.92	MGA LI	LDS
10478		3946	03/18/1940	CER	STR	SW	SE	11	10S	62E	0.007	STK			5.00	AFA LI	BUCK HORN CATTLE CO
11641		3370	07/26/1946	CER	SPR	NE	SE	35	11S	61E	0.001	WLD			0.24	MGA LI	FISH AND WILDLIFE SERVICE-U.S.
11645		3366	07/26/1946	CER	SPR	NE	SE	29	14S	61E	0.001	WLD			0.14	MGS CL	FISH AND WILDLIFE SERVICE-U.S.
12632		3791	09/13/1948	CER	SPR	SE	NE	01	13S	61E	0.003	WLD			0.71	MGA LI	FISH AND WILDLIFE SERVICE-U.S.
13519		3785	10/16/1950	CER	SPR	NW	NE	30	14S	61E	0.000	STK			0.02	MGA CL	FISH AND WILDLIFE SERVICE-U.S.
19306		6011	11/01/1960	CER	SPR	SE	SE	30	14S	61E	0.001	STK			0.04	AFA CL	FISH AND WILDLIFE SERVICE-U.S.
19708		6069	03/31/1961	CER	SPR	NE	SE	07	15S	62E	0.001	STK			0.02	MGA CL	FISH AND WILDLIFE SERVICE-U.S.
19709		6070	03/31/1961	CER	SPR	NE	SW	12	15S	61E	0.001	STK			0.09	MGA CL	FISH AND WILDLIFE SERVICE-U.S.
46777			03/31/1983	PER	UG	SE	SE	23	13S	63E	10.000	IND	Y	0.00	5,000.00	AFA CL	NEVADA POWER COMPANY

SE ROA 10687
JA_3541

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
49414			09/27/1985	PER	UG	SE	SE	23	13S	63E	6.000	IND	Y	0.00	4,000.00	AFA CL	SOUTHERN NEVADA WATER AUTHORITY
49608			12/30/1985	PER	UG	NW	NE	26	13S	63E	10.000	IND	Y	0.00	5,000.00	AFA CL	NEVADA POWER
49660			01/27/1986	PER	UG	SW	NW	13	11S	63E	0.138	IND	Y	0.00	100.00	AFA LI	COYOTE SPRINGS INVESTMENT, LLC
49661			01/27/1986	PER	UG	SE	NE	10	12S	63E	0.138	IND	Y	0.00	100.00	AFA LI	COYOTE SPRINGS INVESTMENT, LLC
49662			01/27/1986	PER	UG	SE	NE	10	13S	63E	0.138	IND	Y	0.00	100.00	AFA CL	COYOTE SPRINGS INVESTMENT, LLC; SOUTHERN NEVADA WATER AUTHORITY
49978			07/15/1986	PER	UG	SW	NW	13	11S	63E	2.000	IND	Y	0.00	1,447.93	AFA LI	COYOTE SPRINGS INVESTMENT, LLC
49979			07/15/1986	PER	UG	SE	SE	28	11S	63E	2.000	IND	Y	0.00	1,447.93	AFA LI	COYOTE SPRINGS INVESTMENT, LLC
49980			07/15/1986	PER	UG	NE	NE	03	12S	63E	2.000	IND	Y	0.00	1,447.93	AFA LI	COYOTE SPRINGS INVESTMENT, LLC
49981			07/15/1986	PER	UG	SE	NE	10	12S	63E	2.000	IND	Y	0.00	1,447.93	AFA LI	COYOTE SPRINGS INVESTMENT, LLC
49982			07/15/1986	PER	UG	NW	SE	29	12S	63E	2.000	IND	Y	0.00	1,447.93	AFA LI	COYOTE SPRINGS INVESTMENT, LLC
49983			07/15/1986	PER	UG	NW	NW	03	13S	63E	2.000	IND	Y	0.00	1,447.93	AFA CL	COYOTE SPRINGS INVESTMENT, LLC
49984			07/15/1986	PER	UG	SE	NE	10	13S	63E	2.000	IND	Y	0.00	1,447.93	AFA CL	SOUTHERN NEVADA WATER AUTHORITY

SE ROA 10688
JA_3542

SPECIAL HYDROGRAPHIC ABSTRACT

RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
49985			07/15/1986	PER	UG	NE	NE	20	13S	63E	2.000	IND	Y	0.00	1,447.93 AFA	CL	COYOTE SPRINGS INVESTMENT, LLC
49986			07/15/1986	PER	UG	NE	NE	21	13S	63E	2.000	IND	Y	0.00	1,447.93 AFA	CL	COYOTE SPRINGS INVESTMENT, LLC
49987			07/15/1986	PER	UG	NE	NE	01	13S	63E	2.000	IND	Y	0.00	1,447.93 AFA	CL	COYOTE SPRINGS INVESTMENT, LLC
54055			10/17/1989	RFP	UG	SE	SW	05	13S	63E	6.000	MUN		0.00	1,415.46 MGA	CL	LAS VEGAS VALLEY WATER DISTRICT
54056			10/17/1989	RFP	UG	SE	SE	32	13S	63E	6.000	MUN		0.00	1,415.56 MGA	CL	LAS VEGAS VALLEY WATER DISTRICT
54057			10/17/1989	RFP	UG	SE	NW	16	14S	63E	6.000	MUN		0.00	1,415.46 MGA	CL	LAS VEGAS VALLEY WATER DISTRICT
54058			10/17/1989	RFP	UG	NE	NE	01	13S	63E	10.000	MUN		0.00	2,359.10 MGA	CL	LAS VEGAS VALLEY WATER DISTRICT
54059			10/17/1989	RFP	UG	NW	NW	19	13S	64E	10.000	MUN		0.00	2,359.10 MGA	CL	LAS VEGAS VALLEY WATER DISTRICT
61458			08/11/1995	PER	UG	SW	NE	24	11S	62E	1.000	MM	Y		200.00 AFA	LI	BEDROC, INC.
62462			09/13/1996	PER	SPR	E2	W2	24	11S	62E	0.350	MM	Y		200.00 AFA	LI	PIPES, WILLIAM B.
62865			02/20/1997	RFP	UG	SE	NW	13	11S	62E	0.500	MM				LI	C.S., INC.
63272			07/24/1997	RFP	UG	SE	SW	23	12S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63273			07/24/1997	RFP	UG	SE	NE	25	12S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63274			07/24/1997	RFP	UG	NE	NE	15	13S	63E	10.000	QM				CL	COYOTE SPRINGS

SE ROA 10689
JA_3543

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
																	INVESTMENT LLC
63275			07/24/1997	RFP	UG	SE	SE	23	12S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63276			07/24/1997	RFP	UG	NE	SW	36	11S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63867			02/24/1998	RFP	UG	NW	SW	12	13S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63868			02/24/1998	RFP	UG	NW	SW	13	13S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63869			02/24/1998	RFP	UG	SW	SW	11	13S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63870			02/24/1998	RFP	UG	NE	SW	07	13S	64E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63871			02/24/1998	RFP	UG	NW	SW	18	13S	64E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63872			02/24/1998	RFP	UG	SE	SW	11	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT LLC
63873			02/24/1998	RFP	UG	SW	SW	25	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT LLC
63874			02/24/1998	RFP	UG	SW	SW	13	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT LLC
63875			02/24/1998	RFP	UG	SW	SW	36	11S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT LLC
63876			02/24/1998	RFP	UG	NE	NE	22	11S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT LLC

SE ROA 10690
JA_3544

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
64039			04/17/1998	RFP	UG	NE	SE	28	14S	63E	10.000	QM				CL	DRY LAKE WATER, LLC
64186			06/03/1998	RFP	UG	NW	SE	36	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64187			06/03/1998	RFP	UG	SW	SE	35	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64188			06/03/1998	RFP	UG	NE	SW	34	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64189			06/03/1998	RFP	UG	NE	SW	27	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64190			06/03/1998	RFP	UG	NW	NE	25	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64191			06/03/1998	RFP	UG	NW	SW	24	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64192			06/03/1998	RFP	UG	NE	SW	26	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
V01353			03/08/1915	VST	SPR	NE	SW	13	11S	62E	0.125	STK			1.10 MGA	LI	LDS
V01808			03/21/1921	VST	SPR				13S	64E		STK				CL	LYTLE, GEORGE H.
V04545			10/24/1985	VST	UG	E2	W2	24	11S	62E	0.350	IRR		0.00	4.00 AFS	LI	PIPES, WILLIAM B.
***** END OF SECTION FOR BASIN NUMBER: 210 *****																	
***** START OF SECTION FOR BASIN NUMBER: 215 *****																	
6061		1408	04/21/1920	CER	STR	SW	NE	13	17S	68E	0.316	IRR		31.55	228.00 AFA	CL	ARMFIELD, LYMAN; WARD, ERNEST G.

SE ROA 10691
JA_3545

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
10092		4476	02/16/1937	CER	SPR	SE	SE	12	18S	67E	0.440	WLD		0.00	0.00 *	CL	BLM
15725			06/06/1954	RFP	SPR	NW	NE	07	18S	68E	1.000	MM		0.00	0.00	CL	MCDONALD, W. H.
16129			02/23/1955	RFA	SPR	SW	SE	06	18S	68E	1.500	OTH				CL	MCDONALD, W.H.
19936		5621	06/23/1961	CER	UG	SW	SW	05	19S	68E	0.248	QM		0.00	58.50 MGA	CL	LAKE MEAD; NATIONAL PARK SERVICE-U.S.
29368		9933	05/05/1975	CER	UG	NW	NE	30	17S	67E	0.016	QM	Y	0.00	0.78 MGA	CL	PARKS DIVISION-NEVADA
CHANGE BY:	48816			-CER													
29814			11/28/1975	PER	OSW	NE	NW	11	22S	64E	638.000	MUN		0.00	0.00	CL	COLORADO RIVER RESOURCES; STATE OF NEVADA
CHANGE BY:	53766T			-WDR													
41206		11261	04/30/1980	CER	UG	SW	SW	25	22S	64E	0.170	COM		0.00	12.30 MGA	CL	LAKEVIEW COMPANY; THE GOLD STRIKE INN (DBA)
41786		11262	07/16/1980	CER	UG	SW	SW	25	22S	64E	0.150	COM		0.00	22.58 MGA	CL	LAKEVIEW COMPANY; THE GOLD STRIKE INN (DBA)
42678		14933	10/16/1980	CER	UG	SE	SE	28	21S	63E	0.152	MM		0.00	15.54 MGA	CL	MEEK, LEROY; THOMPSON, CHARLES
CHANGE BY:	47477			-RFP													
	64578			-APP													
46029			08/18/1982	PER	UG	NE	NW	23	21S	63E	5.000	QM	Y	0.00	716.87 MGA	CL	LAKE LAS VEGAS JOINT VENTURE, INC.
46030			08/18/1982	PER	UG	NE	NE	22	21S	63E	5.000	QM	Y	0.00	716.87 MGA	CL	LAKE LAS VEGAS

SE ROA 10692
JA_3546

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
																	JOINT VENTURE, INC.
47477	42678		12/01/1983	RFP	UG	SE	NE	28	21S	63E	0.891	MM		0.00	75.00	MGA CL	MEEK, LEROY; THOMPSON, CHARLES
48816	29368	13552	02/01/1985	CER	UG	NW	SW	30	17S	67E	0.045	QM	Y	0.00	1.46	MGA CL	CONSERVATION AND NATURAL RESOURCES
53829			09/08/1989	PER	UG	NW	SW	22	21S	63E	1.000	QM	Y	0.00	235.90	MGA CL	LAKE LAS VEGAS JOINT VENTURE, INC.
53831			09/08/1989	PER	UG	NW	NE	15	21S	63E	1.000	QM	Y	0.00	235.90	MGA CL	LAKE LAS VEGAS JOINT VENTURE, INC.
CHANGE BY:	56233			-WDR													
55268			09/13/1990	RFP	UG		LT0326		21S	63E	5.000	QM		0.00	2,016.25	AFA CL	THREE KIDS ENTERPRISES, INC.
55269	54129		09/13/1990	PER	UG			01	20S	63E	1.150	IND	Y	0.00	271.29	MGA CL	NEVADA COGENERATION ASSOCIATES #1; NEVADA COGENERATION ASSOCIATES #2
56150	53830		04/05/1991	PER	UG	NE	NE	15	21S	63E	1.000	QM	Y	0.00	723.97	AFA CL	LAKE LAS VEGAS JOINT VENTURE INC.
58031	55270		08/31/1992	PER	UG	NE	SE	13	19S	63E	1.150	PWR	Y		832.57	AFA CL	NEVADA COGENERATION ASSOCIATES #1; NEVADA COGENERATION

SE ROA 10693

JA_3547

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
																	ASSOCIATES #2
58032	55271		09/13/1990	PER	UG	NE	SE	13	19S	63E	2.300	PWR	Y		1,665.00	AFA CL	NEVADA COGENERATION ASSOCIATES
58047			09/04/1992	PER	UG	SE	SW	08	20S	65E	1.500	MM	Y		718.00	AFA CL	OGLEBAY NORTON COMPANY
58048			09/04/1992	PER	UG	SW	SE	08	20S	65E	1.500	MM	Y		718.00	AFA CL	OGLEBAY NORTON COMPANY
58049			09/04/1992	PER	UG	NE	SE	08	20S	65E	1.500	MM	Y		718.00	AFA CL	OGLEBAY NORTON COMPANY
58050			09/04/1992	PER	UG	SE	NW	08	20S	65E	1.500	MM	Y		718.00	AFA CL	OGLEBAY NORTON COMPANY
58051			09/04/1992	PER	UG	SW	SE	05	20S	64E	1.500	MM	Y		718.00	AFA CL	OGLEBAY NORTON COMPANY
58390		14303	12/11/1992	CER	OSW	SE	SW	22	21S	63E		QM			2,029.00	AFA CL	LAKE AT LAS VEGAS JOINT VENTURE
58589			03/09/1993	RFP	STR	NE	NW	11	22S	64E	100.000	MUN			30,000.00	AFA CL	SOUTHERN NEVADA WATER AUTHORITY
58590			03/09/1993	RFP	STR	NE	NW	11	22S	64E	700.000	MUN			150,000.00	AFA CL	SOUTHERN NEVADA WATER AUTHORITY
58592			03/09/1993	RFP	UG	NE	SE	13	19S	63E	0.274	PWR				CL	NEVADA COGENERATION ASSOCIATES 1 & 2
58593			03/09/1993	RFP	UG	NE	SE	13	19S	63E	0.274	PWR				CL	NEVADA COGENERATION ASSOCIATES 1 & 2

SE ROA 10694
JA_3548

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
58594			03/09/1993	RFP	UG	SE	SE	13	19S	63E	0.274	PWR				CL	NEVADA COGENERATION ASSOCIATES 1 & 2
61597			10/10/1995	PER	UG	NW	SW	05	20S	64E	2.010	MM	Y		1,088.80 AFA	CL	OGLEBAY NORTON COMPANY
61598			10/10/1995	PER	UG	NE	NE	15	20S	64E	2.010	MM	Y		1,088.80 AFA	CL	OGLEBAY NORTON COMPANY
61599			10/10/1995	PER	UG	SW	NW	07	20S	65E	2.010	MM	Y		1,088.80 AFA	CL	OGLEBAY NORTON COMPANY
61600			10/10/1995	PER	UG	NE	NE	07	20S	65E	2.010	MM	Y		1,088.80 AFA	CL	OGLEBAY NORTON COMPANY
62691	52254		12/24/1996	PER	UG	SE	SE	29	20S	64E	0.750	MM	Y		542.98 AFA	CL	INTERNATIONAL SILICA CORPORATION
CHANGE BY:	64542			-ABR													
62692	52614		12/24/1996	PER	UG	NE	SE	29	20S	64E	0.750	MM	Y		543.01 AFA	CL	INTERNATIONAL SILICA CORPORATION
CHANGE BY:	63312			-PER													
	64541			-ABR													
63312	62692		08/08/1997	PER	UG	NE	SE	29	20S	64E	0.395	MM	Y		285.96 AFA	CL	INTERNATIONAL SILICA CORPORATION
CHANGE BY:	64540			-ABR													
63313	62693		08/08/1997	PER	UG	NE	SE	29	20S	64E	0.330	MM	Y		78.63 MGA	CL	INTERNATIONAL SILICA CORPORATION

SE ROA 10695
JA_3549

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
64041			04/17/1998	RFP	UG	NE	NW	36	19S	63E	10.000	QM				CL	DRY LAKE WATER, LLC
64578	42678		11/02/1998	APP	UG	SE	SE	28	21S	63E	0.500	QM			90.54 MGA	CL	THOMPSON, PHYLLIS E.
64960E			03/09/1999	PER	UG	NW	SW	05	19S	68E	0.005	ENV			0.01 MGS	CL	ECHO BAY RESORT (DBA); SEVEN RESORTS, INC.
66085E			02/17/2000	PER	UG	NW	SW	05	19S	68E	0.005	ENV				CL	(DBA) ECHO BAY RESORT; SEVEN CROWN RESORTS, INC
66108			02/28/2000	PER	UG	NE	NW	35	21S	63E	0.060	COM			0.44 MGA	CL	ADDI, PAUL
66163	64547		03/17/2000	PER	UG	SW	NW	18	19S	64E	2.000	QM	Y		592.06 AFA	CL	DRY LAKE WATER, L.L.C.
66164	64541		03/17/2000	PER	UG	SW	NW	18	19S	64E	0.190	QM	Y		137.55 AFA	CL	DRY LAKE WATER, L.L.C.
66165	64542		03/17/2000	PER	UG	SW	NW	18	19S	64E	0.750	QM	Y		542.98 AFA	CL	DRY LAKE WATER COMPANY, L.L.C.
66166	64540		03/17/2000	PER	UG	SW	NW	18	19S	64E	0.165	QM	Y		119.44 AFA	CL	DRY LAKE WATER COMPANY, L.L.C.
***** END OF SECTION FOR BASIN NUMBER: 215 *****																	
***** START OF SECTION FOR BASIN NUMBER: 216 *****																	
18140		5115	07/24/1959	CER	UG	SW	SW	21	17S	64E	0.070	DOM		0.00	16.51 MGA	CL	TRANSPORTATION DEPARTMENT-NEVADA
26277	24015	8462	08/30/1971	CER	UG	NW	NE	14	18S	63E	0.220	MM		0.00	49.00 MGA	CL	CHEMICAL LIME COMPANY OF

NEVADA DIVISION OF WATER RESOURCES
WATER RIGHTS DATABASE

SPECIAL HYDROGRAPHIC ABSTRACT RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
																	ARIZONA
CHANGE BY:	64880			-PER													
	65125T			-EXP													
50663			03/06/1987	PER	UG	SW	SW	04	18S	64E	1.340	MM		0.00	58.00 MGA	CL	GREAT STAR CEMENT CORPORATION
53322	52585		05/26/1989	PER	UG	SW	NE	18	18S	64E	0.010	IND		0.00	0.11 AFA	CL	REPUBLIC ENVIRONMENTAL TECHNOLOGIES
CHANGE BY:	59216T			-EXP													
	59237			-CER													
	60623			-ABR													
	61750			-WDR													
	62494T			-EXP													
	62934T			-EXP													
	62935T			-EXP													
	63585			-PER													
	63586			-PER													
	63587			-PER													
54073			10/17/1989	RFP	UG	SW	SW	32	17S	63E	10.000	MUN		0.00	0.00	CL	LAS VEGAS VALLEY WATER DISTRICT
54130			10/30/1989	RFP	UG	SE	NE	34	18S	63E	2.300	IND		0.00	0.00	CL	BONNEVILLE NEVADA CORPORATION
54232			12/14/1989	RFA	UG	NW	NW	16	18S	63E	0.300	COM		0.00	0.00	CL	KERR-MCGEE CHEMICAL CORPORATION
54348			01/19/1990	RFA	UG	SW	SW	12	18S	63E	0.300	IND		0.00	0.00	CL	ADAMS, JAMES W.
54349			01/19/1990	RFA	UG	SE	SE	11	18S	63E	0.150	IND		0.00	0.00	CL	ADAMS, JAMES W.
54350			01/19/1990	RFA	UG	NW	SE	11	18S	63E	0.300	IND		0.00	0.00	CL	ADAMS, JAMES W.

SE ROA 10697

JA_3551

SPECIAL HYDROGRAPHIC ABSTRACT

RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
54351			01/19/1990	RFA	UG	SW	NE	11	18S	63E	0.230	IND		0.00	0.00	CL	ADAMS, JAMES W.
54352			01/19/1990	RFA	UG	SE	NW	11	18S	63E	0.230	IND		0.00	0.00	CL	ADAMS, JAMES W.
54483			02/26/1990	RFA	UG	NW	NW	16	18S	63E	1.000	COM		0.00	0.00	CL	KERR-MCGEE CHEMICAL CORPORATION
55099			07/19/1990	RFP	UG	SE	SE	07	18S	64E	1.000	IND		0.00	0.00	CL	CONSTRUCTION PRODUCTS INC.
55674	44664		01/24/1991	PER	UG	NW	NW	16	18S	63E	0.015	COM		0.00	10.02 AFA	CL	KERR-MCGEE CHEMICAL CORPORATION; KERR-MCGEE CHEMICAL LLC; WESTERN GYPSUM, INC.
CHANGE BY:	61041			-ABR													
	61367			-CAN													
	63261			-PER													
	63348			-PER													
	63356T			-EXP													
56855	50316	14449	10/22/1991	CER	UG	SE	NE	34	18S	63E	0.350	IND		0.00	46.97 MGA	CL	GEORGIA PACIFIC CORPORATION
57011			12/16/1991	RFA	UG	NW	NE	11	18S	63E	8.800	IND		0.00	0.00	CL	ADAMS, JAMES W.
59237	53322	15391	09/16/1993	CER	UG	NW	NE	19	18S	64E	0.250	IND			68.50 AFA	CL	REPUBLIC ENVIRONMENTAL TECHNOLOGIES
CHANGE BY:	60624			-PER													
60022	44173		04/27/1994	PER	UG	NW	SW	21	17S	64E	0.000	IND			0.00 MGA	CL	NEVADA POWER COMPANY
CHANGE BY:	63610T			-WDR													

SE ROA 10698
JA_3552

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
	64452T			-EXP													
60624	59237		10/28/1994	PER	UG	SE	SE	07	18S	64E	0.001	IND	Y		0.11	AFA CL	REPUBLIC ENVIRONMENTAL TECHNOLOGIES
CHANGE BY:	63590			-PER													
63261	55674		07/21/1997	PER	UG	NE	NE	14	18S	63E	0.149	COM	Y		100.00	AFA CL	CHEMICAL LIME COMPANY OF ARIZONA
63348	55674		08/19/1997	PER	UG	N2		13	18S	63E	0.006	COM			4.00	AFA CL	WESTERN GYPSUM, INC.
63585	53322		11/25/1997	PER	UG	NE	NW	20	18S	64E	0.001	IND	Y		0.11	AFA CL	REPUBLIC ENVIRONMENTAL TECH., INC.
63586	53322		11/25/1997	PER	UG	SE	SE	07	18S	64E	0.149	IND	Y		40.78	AFA CL	REPUBLIC ENVIRONMENTAL TECH., INC.
63587	53322		11/25/1997	PER	UG	NW	NE	19	18S	64E	0.100	IND	Y		27.50	AFA CL	REPUBLIC ENVIRONMENTAL TECH., INC.
63588	61041		11/25/1997	PER	UG	SE	SW	19	18S	64E	0.290	IND	Y		194.00	AFA CL	RUPUBLIC ENVIRONMENTAL TECH., INC.
63589	60623		11/25/1997	PER	UG	NW	NE	19	18S	64E	0.250	IND	Y		68.50	AFA CL	REPUBLIC ENVIRONMENTAL TECH., INC.
63590	60624		11/25/1997	PER	UG	SE	SE	07	18S	64E	0.250	IND	Y		68.39	AFA CL	REPUBLIC ENVIRONMENTAL TECH., INC.

SE ROA 10699
JA_3553

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
64040			04/17/1998	RFP	UG	NW	NW	29	17S	64E	10.000	QM				CL	DRY LAKE WATER, LLC
64045			04/17/1998	RFP	UG	NE	NE	32	17S	63E	10.000	QM				CL	DRY LAKE WATER, LLC
64222			06/12/1998	RFP	UG	SE	SE	09	17S	64E	1.110	IND				CL	NEVADA POWER COMPANY
64223			06/12/1998	RFP	UG	SW	SW	10	17S	64E	1.110	IND				CL	NEVADA POWER COMPANY
64880	26277		03/01/1999	PER	UG	SW	SE	23	18S	63E	0.220	MM	Y		150.38 AFA	CL	CHEMICAL LIME COMPANY
***** END OF SECTION FOR BASIN NUMBER: 216 *****																	
***** START OF SECTION FOR BASIN NUMBER: 217 *****																	
38758			08/08/1979	RFA	UG	SE	SE	08	16S	63E	2.700	IRC		160.00	800.00 AFA	CL	PAGLIUSO, ERNEST P.
CHANGE BY:	66316			-RFA													
54074			10/17/1989	RFP	UG	SW	SW	25	16S	62E	10.000	MUN		0.00	0.00	CL	LAS VEGAS VALLEY WATER DISTRICT
64038			04/17/1998	RFP	UG	NW	NE	16	16S	63E	10.000	QM			7,239.70 AFA	CL	DRY LAKE WATER, LLC
CHANGE BY:	66162			-RFP													
66162	64038		03/17/2000	RFP	UG	SW	SE	21	17S	63E	10.000	QM			7,239.70 AFA	CL	DRY LAKE WATER, L.L.C.
66316	38758		04/28/2000	RFA	UG	SE	SE	29	17S	63E	2.700	IND				CL	NICHOLS, CHRIS D. (C/O); NORTH VALLEY HOLDINGS, LLC

SPECIAL HYDROGRAPHIC ABSTRACT

RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
***** END OF SECTION FOR BASIN NUMBER: 217 *****																	
***** START OF SECTION FOR BASIN NUMBER: 218 *****																	
12803			01/25/1949	RFP	UG	SE	SE	06	15S	66E	5.000	IRR		640.00	0.00	CL	HIDDEN VALLEY RANCH
26371	25355	9404	10/20/1971	CER	UG	NE	SW	25	14S	65E	0.370	IRR		18.00	90.00 AFA	CL	MOAPA VALLEY WATER COMPANY
50558			02/02/1987	PER	UG	NE	SW	05	15S	66E	0.040	ENV	Y	0.00	9.44 MGA	CL	NEVADA POWER COMPANY
50559		13823	02/02/1987	CER	UG	SE	SW	05	15S	66E	0.500	OTH		0.00	117.95 MGA	CL	NEVADA POWER COMPANY
50560			02/02/1987	PER	UG	NE	SW	05	15S	66E	0.040	ENV	Y	0.00	9.44 MGA	CL	NEVADA POWER COMPANY
53091			04/04/1989	PER -APP -RFA	UG	NW	SW	25	14S	65E	0.200	IRR		5.00	25.00 AFA	CL	WHEELER, ELMER
CHANGE BY:	66319T 66320																
54075			10/17/1989	RFP	UG	NE	SW	04	16S	66E	10.000	MUN		0.00	0.00	CL	LAS VEGAS VALLEY WATER DISTRICT
54076			10/17/1989	RFP	UG	NW	NW	16	15S	64E	10.000	MUN		0.00	7,239.70 AFA	CL	LAS VEGAS VALLEY WATER DISTRICT
54202			11/30/1989	RFA	UG	NE	SE	29	14S	66E	3.000	IND		0.00	0.00	CL	OXFORD ENERGY COMPANY
57441E			04/16/1992	PER	UG	SW	NE	02	15S	66E	0.045	ENV			10.62 MGA	CL	TRANSPORTATION DEPARTMENT-NEVADA
64037			04/17/1998	RFP	UG	NE	NE	33	17S	65E	10.000	QM				CL	DRY LAKE WATER, LLC

SE ROA 10701
JA_3555

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
65197			06/14/1999	RFP	UG	SE	NW	31	16S	65E	0.500	COM				CL	MOAPA BAND OF PAIUTES
65722			12/15/1999	RFP	UG	NE	NW	27	16S	65E	1.000	MM				CL	STALLION SAND AND GRAVEL, LLC.
65944			01/28/2000	APP	UG			26	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65945			01/28/2000	RFP	UG			26	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65946			01/28/2000	RFP	UG			35	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65947			01/28/2000	RFP	UG			35	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65948			01/28/2000	RFP	UG			15	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65949			01/28/2000	RFP	UG			15	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65954			01/28/2000	RFP	UG			34	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65955			01/28/2000	RFP	UG			34	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
66319T	53091		05/02/2000	APP	UG	NE	SE	10	17S	55E	0.200	MM			25.00 AFA	CL	WHEELER, ELMER
66320	53091		05/02/2000	RFA	UG	NE	SE	10	17S	65E	0.200	MM				CL	WHEELER, ELMER
66473			06/19/2000	APP	UG	NE	NE	15	16S	64E	6.000	PWR				CL	MOAPA BAND OF PAIUTES

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
66474			06/19/2000	APP	UG	SW	SE	15	16S	64E	6.000	PWR				CL	MOAPA BAND OF PAIUTES
66475			06/19/2000	APP	UG	SE	NE	15	16S	64E	6.000	PWR				CL	MOAPA BAND OF PAIUTES
66476			06/19/2000	APP	UG	SW	NW	23	16S	64E	1.000	PWR				CL	MOAPA BAND OF PAIUTES
***** END OF SECTION FOR BASIN NUMBER: 218 *****																	
***** START OF SECTION FOR BASIN NUMBER: 219 *****																	
6169	1611		06/14/1920	RFP	STR	NW	NE	16	14S	65E	1.000	IRR		100.00		CL	MOAPA & SALT LAKE PRODUCE CO.
6419	V01621	6795	03/09/1921	CER	STR	NW	NW	15	14S	65E	0.340	IRR		14.00		CL	LDS
18437		5683	11/20/1959	CER	UG	SE	SE	09	14S	65E	0.267	IRR		15.11	20.15 AFA	CL	CINKOWSKI, LOIS A.
CHANGE BY:	50934			-CER													
21466		6293	08/15/1963	CER	UG	SE	SE	08	14S	65E	1.000	IRR		36.64	183.20 AFA	CL	LEWIS, MALCOLM L.
22632	14345	7164	06/14/1965	CER	UG	NW	SE	08	14S	65E	1.500	IND		0.00	315.00 AFA	CL	NEVADA POWER COMPANY
22633	12774	7165	06/14/1965	CER	UG	SW	NE	08	14S	65E	1.500	IND		0.00	297.50 AFA	CL	NEVADA POWER COMPANY
22635	17754	7166	06/14/1965	CER	UG	SE	NE	08	14S	65E	1.200	IND		0.00	25.00 AFA	CL	NEVADA POWER COMPANY
CHANGE BY:	49842			-WDR													
22636	14344	7167	06/14/1965	CER	UG	NW	SE	08	14S	65E	1.500	IND		0.00	260.00 AFA	CL	NEVADA POWER COMPANY

SE ROA 10703
JA_3557

SPECIAL HYDROGRAPHIC ABSTRACT

RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
22738		8331	08/25/1965	CER	UG	NE	NE	22	14S	65E	0.250	COM		0.00	18.81	AFA CL	CLAY, LENORE P.; CLAY, WAYNE J.; COOK, ANTONE R.; THORNTON, L.G.; THORNTON, PATRICIA
CHANGE BY:	27216			-CER													
22739	DMUD-266	10060	08/25/1965	CER	STR	NW	SE	16	14S	65E	1.000	MUN		0.00	235.85	MGA CL	MOAPA VALLEY WATER DISTRICT; MUDDY VALLEY IRRIGATION CO. (32%); OVERTON WATER COMPANY
CHANGE BY:	28659			-CAN													
22949		7168	02/02/1966	CER	UG	SE	NE	08	14S	65E	2.945	IND	Y	0.00	433.00	AFA CL	NEVADA POWER COMPANY
CHANGE BY:	49844			-WDR													
22950		7169	02/02/1966	CER	UG	SW	NE	08	14S	65E	2.945	IND	Y	0.00	433.00	AFA CL	NEVADA POWER COMPANY
22951		7170	02/02/1966	CER	UG	NW	SE	08	14S	65E	2.945	IND	Y	0.00	433.00	AFA CL	NEVADA POWER COMPANY
22952		7171	02/02/1966	CER	UG	NW	SE	08	14S	65E	2.945	IND	Y	0.00	433.00	AFA CL	NEVADA POWER COMPANY
23600	21876	7316	01/11/1967	CER	STR	SE	SE	15	14S	65E	7.000	IND	Y	0.00	2,000.00	AFS CL	MUDDY VALLEY IRRIGATION COMPANY
24185	22948	7172	10/20/1967	CER	UG	NW	NE	08	14S	65E	2.945	IND	Y	0.00	433.00	AFA CL	NEVADA POWER COMPANY
24186	22634	7173	10/20/1967	CER	UG	NW	NE	08	14S	65E	1.340	IND		0.00	101.01	MGA CL	NEVADA POWER

SE ROA 10704
JA_3558

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
																	COMPANY
25310		7844	10/09/1969	CER	UG	SE	NE	08	14S	65E	1.200	IND		0.00	52.00 MGA	CL	NEVADA POWER COMPANY
CHANGE BY:	49843			-WDR													
25861		10944	11/12/1970	CER	SPR			16	14S	65E	0.432	IRR		113.50	1,980.14 AFA	CL	LDS
CHANGE BY:	26317			-CER													
	26318			-CER													
26316	25860	10951	09/15/1971	CER	STR	SE	SE	15	14S	65E	0.829	IRR		58.00	0.00 *	CL	LDS
26317	25861	10952	09/15/1971	CER	SPR	NW	SE	16	14S	65E	0.059	IRR		4.00	18.02 AFS	CL	LDS
26318	25861	10953	09/15/1971	CER	STR	SE	SE	15	14S	65E	0.536	IRR		37.50	0.00 *	CL	LDS
27216	22738	12758	01/02/1973	CER	UG	NW	SE	16	14S	65E	0.250	COM		0.00	0.45 MGA	CL	APCAR, FREDERIC S.
28791	21876	13445	10/11/1974	CER	SPR	SW	NW	16	14S	65E	3.000	MUN		0.00	694.73 MGA	CL	MUDDY VALLEY IRRIGATION CO.
CHANGE BY:	52351			-CAN													
29295	V01620	9609	03/25/1975	CER	OSW	SE	SE	15	14S	65E	1.357	IND			*	CL	LEWIS, LOU JEANNE; LEWIS, PAUL C.
29296	12244	9691	03/25/1975	CER	UG	NW	NW	23	14S	65E	0.576	IND		0.00	300.00 AFA	CL	BEHMER, B.R.; BEHMER, ROSEMARY; BROWN, RUTH
29298	25699	9750	03/25/1975	CER	UG	NW	NW	23	14S	65E	0.452	IND		0.00	327.50 AFA	CL	NEVADA POWER COMPANY
29764	22603	9661	11/13/1975	CER	STR	SE	SE	15	14S	65E	0.414	IND		0.00	0.00 *	CL	NEVADA POWER CO.
38871	12244	10166	08/28/1979	CER	UG	NW	NW	23	14S	65E	0.144	IRR		15.00	75.00 AFA	CL	EGTEDAR, ASCAR

SE ROA 10705

JA_3559

SPECIAL HYDROGRAPHIC ABSTRACT

RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
42100		10920	08/18/1980	CER	SPR	NE	NE	21	14S	65E	0.003	DOM			0.66	MGA CL	PEDERSEN, LOREENA; PEDERSEN, RICHARD
46932			05/19/1983	PER	UG	NE	NE	35	13S	64E	2.000	MUN		0.00	325.90	MGA CL	MOAPA VALLEY WATER DISTRICT
CHANGE BY:	59062T			-WDR													
	63496T			-EXP													
	64724T			-EXP													
50272	25697	13507	10/13/1986	CER	UG	NE	NE	22	14S	65E	0.230	IND	Y	0.00	99.51	AFA CL	NEVADA POWER COMPANY
50273	25698	13508	10/13/1986	CER	UG	NE	NE	22	14S	65E	0.670	IND	Y	0.00	289.91	AFA CL	NEVADA POWER COMPANY
50274	29328	13509	10/13/1986	CER	UG	NE	NE	22	14S	65E	1.000	IND	Y	0.00	432.70	AFA CL	NEVADA POWER COMPANY
50275	12679	13510	10/13/1986	CER	UG	NE	NE	22	14S	65E	0.520	IND	Y	0.00	32.88	AFA CL	NEVADA POWER COMPANY
50723	11960	13381	03/24/1987	CER	UG	NW	NW	15	14S	65E	0.320	IND	Y	0.00	88.00	AFA CL	LDS
50724	13074	13382	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.920	IND	Y	0.00	162.55	AFA CL	LDS
50725	26313	13383	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.302	IND	Y	0.00	65.00	AFA CL	LDS
50726	26314	13384	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.302	IND	Y	0.00	65.00	AFA CL	LDS
50727	26315	13385	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.271	IND	Y	0.00	60.00	AFA CL	LDS
50728	26319	13386	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.580	IND	Y	0.00	158.00	AFA CL	LDS
50729	26320	13387	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.440	IND	Y	0.00	120.00	AFA CL	LDS

SE ROA 10706
JA_3560

SPECIAL HYDROGRAPHIC ABSTRACT

RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
50730	22559	13388	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.117	IND	Y	0.00	25.00	AFA CL	LDS
50731	25862	13389	03/24/1987	CER	UG	NW	NW	15	14S	65E	2.160	IND	Y	0.00	586.00	AFA CL	LDS
50732	25864	13390	03/24/1987	CER	UG	NE	NE	16	14S	65E	2.330	IND	Y	0.00	930.00	AFA CL	LDS
50733	25887	13391	03/24/1987	CER	UG	NE	NE	16	14S	65E	0.180	IND	Y	0.00	70.00	AFA CL	LDS
50734	21876	13851	03/24/1987	CER	STR	SE	SE	15	14S	65E	3.500	IND	Y	0.00	1,000.00	AFS CL	NEVADA POWER COMPANY (LESSEE)
50851	12679	14294	04/23/1987	CER	UG	NW	NW	23	14S	65E	0.288	IRR	Y	8.33	30.00	AFA CL	PERKINS, G.M.; PERKINS, SHIRLEY
CHANGE BY:	56428			-WDR													
	64840			-PER													
50934	18437	13581	05/14/1987	CER	UG	NE	NE	22	14S	65E	0.733	IND	Y	0.00	55.40	AFA CL	NEVADA POWER COMPANY
52520	49825		09/19/1988	PER	UG	SE	NE	07	14S	65E	2.000	MUN		0.00	471.81	MGA CL	MOAPA VALLEY WATER DISTRICT
52587	29297		10/04/1988	PER	UG	NW	NW	23	14S	65E	0.445	IND		0.00	322.50	AFA CL	NEVADA POWER COMPANY
55450			11/09/1990	PER	UG	SE	NE	07	14S	65E	3.000	MUN		0.00	707.73	MGA CL	MOAPA VALLEY WATER DISTRICT
56059			03/25/1991	RFA	UG	NE	NE	35	13S	64E	3.000	IND		0.00	0.00	CL	OXFORD ENERGY OF NEVADA INC.
56668		15097	08/15/1991	CER	SPR	SE	SE	16	14S	65E	3.500	WLD		0.00	825.69	MGA CL	FISH AND WILDLIFE SERVICE-U.S.
58269			10/27/1992	PER	UG	SE	NE	07	14S	65E	5.000	MUN			1,179.55	MGA CL	MOAPA VALLEY WATER DISTRICT
CHANGE BY:	66043			-RFP													

SE ROA 10707
JA_3561

SPECIAL HYDROGRAPHIC ABSTRACT

RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
58787			04/23/1993	RFP	UG	NE	SE	07	14S	65E	6.000	PWR				CL	MOAPA VALLEY WATER DISTRICT; OVERTON POWER DISTRICT
59253	43160	15460	09/20/1993	CER	UG	SW	NE	23	14S	65E	0.198	IRR		8.78	43.88 AFA	CL	LEAVITT, UTE
59256	43160	15104	09/20/1993	CER	UG	SW	NE	23	14S	65E	0.130	IRR		5.78	28.88 AFA	CL	WHITMORE, DAN; WHITMORE, LATRICE
59257	43160	15105	09/20/1993	CER	UG	SW	NE	23	14S	65E	0.068	IRR		3.00	15.00 AFA	CL	BRUNDY, LARRY
59369			11/05/1993	RFP	UG	NE	NE	33	13SH	64E	10.000	MUN				CL	MOAPA VALLEY WATER DISTRICT
61427			07/26/1995	PER	UG	SE	SW	09	14S	65E	0.007	COM			0.44 MGA	CL	S & R, INC.
63504	59254		10/14/1997	PER	UG	SW	NE	23	14S	65E	0.068	IRR		3.00	15.00 AFA	CL	KOLHOSS, KELLY; KOLHOSS, RUTH
63505	59254		10/14/1997	PER	UG	SW	NE	23	14S	65E	0.130	IRR	Y	0.00	28.88 AFA	CL	ROBINSON, MARLEY
63535	59255		10/28/1997	PER	UG	SW	NE	23	14S	65E	0.198	IRR	Y	8.78	43.88 AFA	CL	ROBINSON, MARLEY
64840	50851		02/08/1999	PER	UG	NW	NW	23	14S	65E	0.192	IRR	Y	3.33	19.98 AFA	CL	PERKINS, DAVID (C/O); PERKINS, G.M.; PERKINS, SHIRLEY
66043	58269		02/03/2000	RFP	UG	SE	NE	07	14S	65E	5.000	MUN				CL	MOAPA VALLEY WATER DISTRICT

***** END OF SECTION FOR BASIN NUMBER: 219 *****

SE ROA 10708
JA_3562

SPECIAL HYDROGRAPHIC ABSTRACT

RUN DATE: 08/17/00

Selection Criteria: BASIN IN (220) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
***** START OF SECTION FOR BASIN NUMBER: 220 *****																	
1802		296	08/22/1910	CER	SPR	SW	NW	20	16S	68E	0.560	IRR		56.00	280.00	AFA CL	ANGELL, SANFORD A.
2860		554	12/18/1913	CER	SPR	SE	SW	07	16S	68E	0.354	IRR		35.45	177.25	AFA CL	MORRISON, NORMAN H.
8321	DMUD-01618	2298	09/16/1927	CER	STR	SE	NE	21	15S	67E	0.014	IRR		0.70	3.50	AFA CL	LOS ANGELES & SALT LAKE RAILROAD CO.
10188		5216	12/31/1937	CER	STR	NW	SE	19	16S	68E	2.500	IRR		0.00	2,247.28	AFA CL	NATIONAL PARK SERVICE-U.S.
11632		4906	07/10/1946	CER	OSW	NW	SE	12	16S	67E	2.000	IRR		143.88	863.28	AFA CL	PERKINS, JOHN F.; PERKINS, JOHN G.
CHANGE BY: 49332				-RFA													
13638		4119	02/15/1951	CER	STR	NE	SW	35	15S	67E	0.500	IRR		34.77	173.85	AFA CL	ADAMS, LOUIS
18101		6059	07/10/1959	CER	UG	NW	SW	01	15S	66E	0.018	IRR		100.15	25.75	AFA CL	LEWIS, PAUL C.
21847	DMUD-31	8324	02/26/1964	CER	STR	NW	NE	21	15S	67E	3.980	IRR	Y	3,498.66	1,436.75	AFS CL	MUDDY VALLEY IRRIGATION CO
21873	1611	8325	03/16/1964	CER	STR	NW	NE	21	15S	67E	9.700	IRR	Y	3,498.66	4,078.83	AFS CL	MUDDY RIVER IRRIGATION CO
21874	31	8326	03/16/1964	CER	STR	NW	NE	21	15S	67E	0.029	IRR	Y	3,498.66	17.09	AFA CL	MUDDY VALLEY IRRIGATION CO
21875	1372	8327	03/16/1964	CER	STR	NW	NE	21	15S	67E	0.800	IRR	Y	3,498.66	288.79	AFS CL	MUDDY VALLEY IRRIGATION CO
21876	DMUD-266	8328	03/16/1964	CER	STR	NW	NE	21	15S	67E	10.506	IRR	Y	3,498.66	13,256.63	AFA CL	MUDDY VALLEY IRRIGATION CO.
CHANGE BY: 23600				-CER													

SE ROA 10709
JA_3563

Selection Criteria: BASIN IN (220) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
	28791			-CER													
	50734			-CER													
21877	31	8327	03/16/1964	CER	STR	NW	NE	21	15S	67E	4.252	IRR	Y	3,498.66	4,599.55	AFA CL	MUDDY RIVER IRRIGATION CO
23872		8600	05/16/1967	CER	UG	NW	NW	22	15S	67E	0.890	MUN		0.00	0.00 *	CL	MOAPA VALLEY WATER CO.; OVERTON WATER DISTRICT
23949		7594	06/23/1967	CER	UG	SE	NW	02	16S	67E	0.070	IRR		2.50	12.50	AFS CL	HORN, ERICH; HORN, LOUISE
24007		8601	07/18/1967	CER	UG	NW	NW	22	15S	67E	5.010	IRR		370.00	1,850.00	AFA CL	MOAPA VALLEY WATER CO.; OVERTON WATER DISTRICT
CHANGE BY:	59394T			-EXP													
	60979T			-EXP													
	62176T			-EXP													
26329		8814	09/22/1971	CER	UG	NE	NE	34	15S	67E	1.300	IRR		75.93	379.65	AFA CL	ROBISON, DELL H.; ROBISON, PEARL W.
26747		9232	05/26/1972	CER	UG	NW	NE	11	16S	67E	0.500	IRR		7.03	35.15	AFA CL	LAHM, ROBERT L.
27411			04/16/1973	PER	STR	SW	NE	19	16S	68E	25.000	IRR		650.00	2,600.00	AFA CL	WILDLIFE DIVISION-NEVADA
27412		13110	04/16/1973	CER	STR	SW	NE	19	16S	68E	10.000	WLD		0.00	666.40	AFA CL	FISH AND GAME COMMISSION-NEVADA
28093		12168	02/11/1974	CER	UG	SW	SE	01	15S	66E	2.500	IRR		109.64	548.20	AFA CL	LEWIS, PATRICIA; LEWIS, PAUL C.; LEWIS, PAUL R.

SE ROA 10710
JA_3564

Selection Criteria: BASIN IN (220) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
29631		13246	09/05/1975	CER	UG		LT0407	15S	67E		1.000	COM		0.00	37.67 MGA	CL	LEWIS, PATRICIA; LEWIS, PAUL R.
30774		10003	10/19/1976	CER	UG	NE	NW	02	16S	67E	1.400	IRR		108.80	544.00 AFA	CL	MARSHALL, KARL
CHANGE BY:	66052			-RFA													
	66053			-RFA													
	66210			-RFA													
35590		13598	07/03/1978	CER	UG	NE	SW	34	15S	67E	0.021	IRR		3.04	15.20 AFA	CL	BUSH, JACQUELINE P.; BUSH, JAMES H.; IVAN WOLLENZIEN CHILDRENS TRUST; MITCHELL, TERESA; MITCHELL, TIM; PULSIPHER, CHARLES STACY; PULSIPHER, PAULA; WAITE, D. LANNY; WAITE, MAXINE; WHEELER, KATHY; WHEELER, PAUL; WOLLENZIEN, IVAN ROBERT; WOLLENZIEN, LORETTA LINA
36523		12764	01/24/1979	CER	UG	NE	NE	11	16S	67E	0.500	IRR		20.00	100.00 AFA	CL	RAMOS, MIGUEL
38683		11427	07/25/1979	CER	UG	NE	SW	02	16S	67E	0.250	IRD		4.51	22.58 AFA	CL	GAMBOA, DARLENE A.; GAMBOA, JOHN PETE
40167		11429	12/24/1979	CER	UG	NE	SW	15	15S	67E	0.033	IRR		4.94	14.70 AFA	CL	FAY, BOBBY B.; FAY, DORTHY M.; STREETT, DAWN; STREETT, KEVIN

SE ROA 10711

JA_3565

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

Selection Criteria: BASIN IN (220) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
CHANGE BY:	56654			-PER													
43476		11420	04/08/1981	CER	UG	SW	NW	02	16S	67E	0.167	IRR		24.15	120.75	AFA CL	LEAVITT, VALERIE CLAIRE; LEAVITT, WILLIAM J.
44473		15367	09/23/1981	CER	UG	NE	NE	13	16S	67E	0.981	IRR		120.90	604.50	AFA CL	MOAPA VALLEY DAIRY FARMS
CHANGE BY:	52265			-ABR													
	52721			-CAN													
	52900			-CAN													
	53400			-RFA													
	58104			-ABR													
	60652			-WDR													
	64841			-WDR													
48763	29630		01/23/1985	PER	UG	SW	SW	01	15S	66E	1.000	IRR		40.00	200.00	AFA CL	LEWIS, PATRICIA; LEWIS, PAUL R.
49332	11632		09/04/1985	RFA	OSW	NW	SE	12	16S	67E	2.000	IRR		143.88	863.28	AFA CL	PERKINS, BRUCE G.; PERKINS, MURRAY L.
50947			05/20/1987	PER	UG	NW	NE	09	15S	67E	0.500	COM		0.00	32.60	MGA CL	LAS VEGAS CEMENT CO. INC.
51749	11499	13380	01/06/1988	CER	UG	NW	NE	11	17S	67E	0.305	MM		0.00	46.79	MGA CL	DBA SIMPLOT SILICA PRODUCTS; SIMPLOT INDUSTRIES
53400	44473		06/21/1989	RFA	UG	SE	NE	12	15S	66E	0.571	IRR		80.00	400.00	AFA CL	MOAPA VALLEY DAIRY FARMS
56654	40167		08/08/1991	PER	UG	NW	SW	15	15S	67E	0.023	IRR		2.00	10.00	AFA CL	STREETT, DAWN; STREETT, KEVIN

SE ROA 10712
JA_3566

Selection Criteria: BASIN IN (220) AND APP_STATUS IN (APP,CER;PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
59368			11/05/1993	RFP	UG	NW	NW	10	13S	67E	10.000	MUN				CL	MOAPA VALLEY WATER DISTRICT
59370			11/05/1993	RFP	UG	SW	NW	32	15S	67E	5.000	MUN				CL	MOAPA VALLEY WATER DISTRICT
59371			11/05/1993	RFP	UG	SE	SE	19	15S	67E	5.000	MUN				CL	MOAPA VALLEY WATER DISTRICT
61319			06/16/1995	PER	EFF	NE	NW	20	16S	68E	0.540	OTH			390.94 AFA	CL	CLARK COUNTY SANITATION DISTRICT
62066	39719		04/23/1996	PER -RFA	UG	NW	SW	01	15S	66E	0.940	MM			25.00 MGA	CL	LEWIS, PAUL R.
CHANGE BY:	66051																
62846	52265		02/07/1997	PER	UG	SE	SE	21	15S	67E	0.173	IRR		122.30	125.00 AFA	CL	ISOLA, TOM; TAI ARABIAN RANCH; TOM ISOLA AND THE TAI ARABIAN RANCH
62847	58104		02/07/1997	PER	UG	SE	SE	21	15S	67E	0.173	IRR		122.30	125.00 AFA	CL	ISOLA, TOM; TAI ARABIAN RANCH; TOM ISOLA AND THE TAI ARABIAN RANCH
66051	62066		02/07/2000	RFA	UG	NW	SW	01	15S	66E	0.940	MM				CL	LEWIS, PAUL R.
66052	30774		02/07/2000	RFA	UG	NW	SW	01	15S	66E	0.257	MM				CL	LEWIS, PAUL R. (C/O); MARSHALL, MELVIN K.
66053	30774		02/07/2000	RFA	UG	SW	SW	01	15S	66E	0.515	MM				CL	LEWIS, PAUL R. (C/O); MARSHALL, MELVIN K.
66210	30774		03/24/2000	RFA	UG	NE	SE	12	15S	66E	0.615	MM			239.00 AFA	CL	(C/O) PAUL R.

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Selection Criteria: BASIN IN (220) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
																	LEWIS; MARSHALL, MELVIN K.

***** END OF SECTION FOR BASIN NUMBER: 220 *****

APPENDIX E

Monitoring Plan

For

Moapa Band of Paiutes

APPENDIX E

Monitoring Plan
(Implemented and Proposed Elements)

Moapa Band of Paiutes - Calpine Company

Background

The proposed Calpine Power Generation Project (Project), with a projected consumptive use of 7,000 acre-ft./yr (afy) of production from the Carbonate Aquifer, elevates the importance of existing monitoring of groundwater levels and discharge relationships in the regional spring areas (Muddy River Springs Area, Rogers and Blue Point Springs near Lake Mead). However, because the Project is 15 miles from the nearest area of regional groundwater discharge, new monitoring wells to the north and south of the Belly Tank Flat Well Field are in operation to provide detection of both near- and far-field water-level changes. The Belly Tank Flat well field on the Moapa Indian Reservation (Fig. E-1) occupies a location about midway between the Muddy River Springs Area to the north and the Apex area to the south, areas where there is present development of the Carbonate Aquifer. Additional, heavier exploitation of the Carbonate Aquifer is possible in the future in these areas and other basins of the Arrow Canyon Range Cell. This Monitoring Plan will ensure that pumping impact in the Carbonate Aquifer associated with the Belly Tank Flat well field will be well-characterized both northward and southward. Figure E-1 illustrates the geographic relationships of the Belly Tank Flat well field, the new monitoring wells (shown by solid square symbols), and other monitoring wells within the Arrow Canyon Range Cell of the Carbonate Aquifer.

Objectives and Considerations

There are several basic objectives associated with monitoring the Carbonate Aquifer. First, because the aquifer is very extensive and poorly understood as to detailed behavior or responses when stressed by heavy pumping, an adequate network of widely-spaced monitoring wells is desirable to trace the development and extent of pumping cones that expand outward from the pumping center(s). In order to identify the manner in which individual pumping centers are contributing to net changes in water levels, it is also desirable to establish monitoring records of water levels closer to and therefore more clearly associated with individual pumping centers to document the unique characteristics of pumping signals (such as periodicities and magnitudes) produced by specific water-development activities.

Often the pumping history of the well(s) varies daily, monthly, or seasonally, and therefore may transmit a distinctive signal of water-level changes within the portion of the aquifer affected by the pumping. At the present time, the number of large production wells and/or well fields are limited in number and widely spaced, conditions ideal for the recognition of distinctive pumping signals in the water-level records. These signals may

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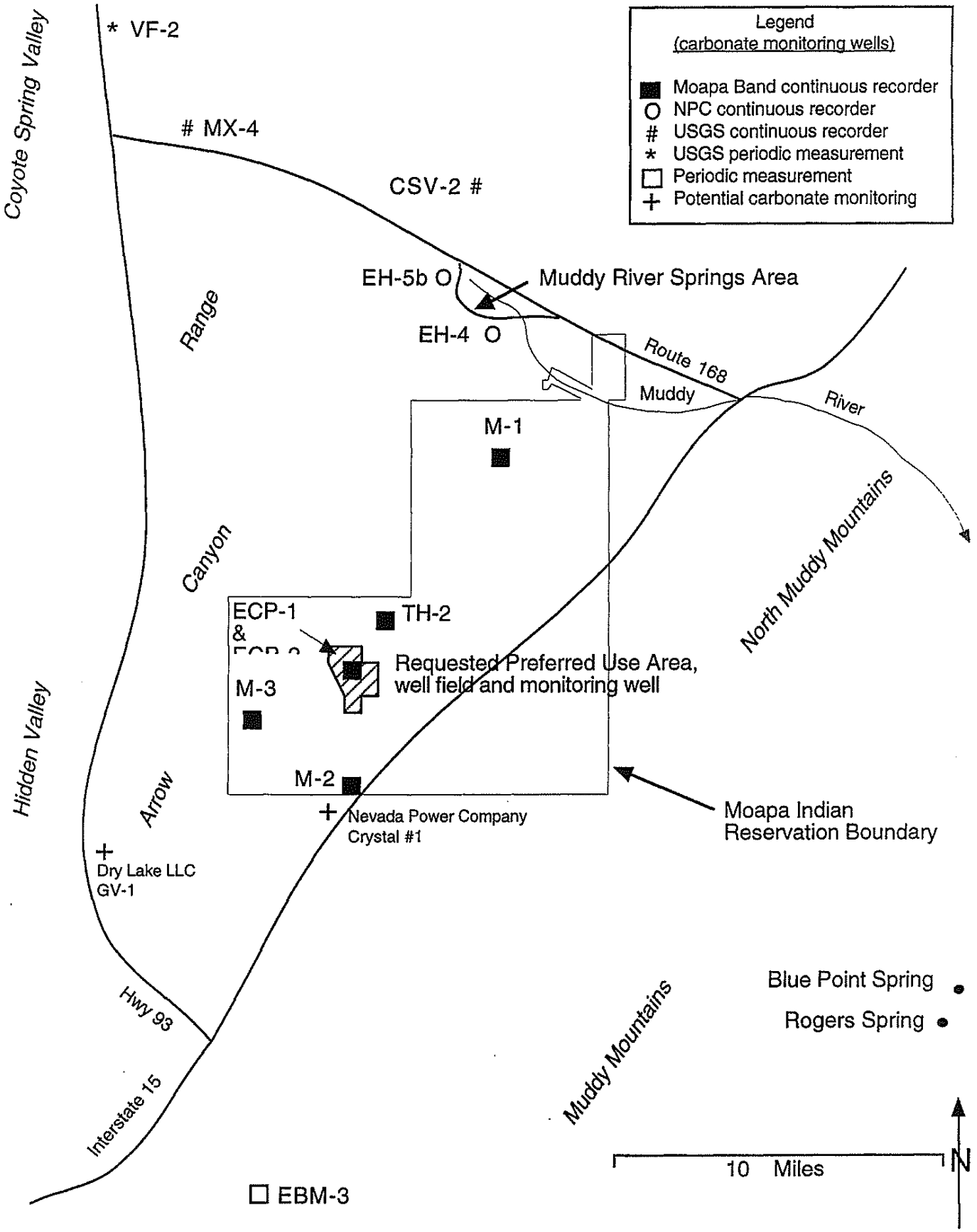

Figure E1. Moapa Band of Paiutes carbonate aquifer well monitoring status through 01/10/01.

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vary in strength daily and/or seasonally as the water demands of individual users vary; water-level monitoring near these pumping centers will document the variations in signals. In this manner, characteristic signals of the local pumping stresses may be established, allowing individual components of net drawdown in the region to be discriminated. Furthermore, analyses of the response of aquifers to periodic pumping can be used to obtain large-scale estimates of transmissivity and storage without the expense of dedicated test pumping.

As pumping stresses travel outward to more distant regions of the Carbonate Aquifer, water-level changes become smaller, and short term variations may be dampened out to more uniform changes over time. It is important to establish water-level records which are sensitive enough to recognize water-level responses to natural stresses on the Aquifer that may be of similar magnitude as pumping-induced water-level changes. In monitoring accomplished to date, diurnal and longer-term natural water-level variations have been recorded that relate to barometric-pressure changes. Hourly measurements are ideal to record such "noise" in terms of water-level changes that are not related to any pumping signals of wells or well fields. Close into a large production well, or a well field, the pumping signals are large enough so that the natural signals are relatively small in comparison. However, several miles distant from the pumping centers, the natural signals may be of similar or larger magnitudes than those produced by short term pumping variations. Natural signals are usually systematic, due to the cyclic behavior of atmospheric heating and tidal forcing, and can be reduced (i.e. signal-to-noise ratio increased) by appropriate processing.

The proposed monitoring plan therefore has multiple objectives:

1) Of greatest interest is to establish long-term trends in water levels using continuous recorders in monitoring wells, and establish the causal relationships of the water-level trends. Longer-duration trends producing water-level changes may be related to pumping stresses on the aquifer, or they may be related to drought conditions or exceptionally wet years that causes recharge to vary over time. Multiyear declines and shorter-term recoveries have been observed in monitoring records established near the Muddy River Springs and up-gradient in Coyote Spring Valley. Separating out the natural long-term trends from long-term pumping effects normally requires long, continuous records that begin before pumping stresses occur at the monitoring location. The time-drawdown behavior of individual pumping centers is needed to resolve each separate contribution to net drawdown in the region.
2) Conduct an inventory of minor springs and seeps in the potentially-affected region to establish baseline conditions. Semiannual visits would be used to document changes to vegetation patterns, outflow quantity, or other characteristics.
3) Maintain the modeling environment in an appropriate state of readiness for validation exercises. The impacts of large-scale pumping will provide opportunities for model refinement, which should occur in concert with the

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expanding database. A proactive approach to modeling will limit the potential for unpleasant surprises as transient characteristics of the large-scale system are revealed. Groundwater models will be recalibrated as new information becomes available.

Monitoring Design

The first priority of the Moapa Band/Calpine monitoring plan is to characterize the Belly Tank Flat well-field area aquifer properties (Appendix A). This has been accomplished by a monitoring well within the local pumping cone of at ECP-2 and monitoring at TH-2 and TH-1 during a 7-day aquifer test at ECP-1. To date, test wells ECP-2 and ECP-1 have been instrumented on an interim basis during and after drilling. At greater distances (monitoring wells M-1, M-2, and M-3), monitoring points have the potential to record and track the pumping stresses as they propagate with time outward from the well field area to the north, south, and west over greater distances. The far-field water-level declines due to pumping by the Project should be recognizable, if of impact-producing magnitude, decades before any important impacts develop at distant regional discharge areas. To the north, the Muddy River Springs Area is fed by discharge from the Carbonate Aquifer. It is not known with certainty if the Belly Tank Flat Well Field pumping stresses may be transmitted, over prolonged time, to this area or into the up-gradient flow field at a large enough magnitude to cause impacts on spring or river flows. It is important to note that the nature of the Muddy River regional discharge area is such that impacts on the discharge would not be measured with confidence until they were well developed. Water-level changes of great enough magnitude in the Carbonate Aquifer to produce important impacts on spring flow or river flow would be confidently recognized in the monitoring well records between the two areas decades before long-term decreases in flow could be resolved from a seasonally noisy record (Figure E-2, USGS internet data).

A secondary but very important priority is to identify, with confidence, all major pumping stresses that produce detectable changes in flow in the Muddy River Springs Area. This monitoring objective is demanding as well as important because nearby pumping stresses impact Muddy River flows, and some of these pumping stresses will likely increase in the future. Further, other water-right permits and applications for water rights may be acted upon during the time frame of the Moapa Band/Calpine lease agreement (45 years) to establish new pumping centers. Such may either 1) impact the Muddy River flows after only short periods of heavy pumping, if located upgradient in the Coyote Spring Valley area, or 2) tap the Carbonate Aquifer to the south of the Moapa Indian Reservation, and add significantly to the overall pumping stresses in the southern

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Monitoring and Mitigation

Mitigation measures are not anticipated to be necessary for model forecast Project impacts to aquatic habitats in the Muddy River Springs Area. However, if observations of water-level drawdowns in monitoring wells TH-2, M-1, and EH-4 were to be consistent with or greater than those projected by Case 3 in the first 5 to 10 years, mitigation measures might be required to prevent impacts at the Muddy River Springs Area at advanced stages of the Project.

Consideration of mitigation strategies are judged important in the context of the purpose of the monitoring network and plan that has been established. The monitoring of the Carbonate Aquifer water-level responses to the proposed pumping allows for the model forecasts to be evaluated, and the model to be recalibrated if found to be inaccurate in projections through the available period of record. Secondly, the water-level records may also aid in recognizing the regional propagation and impacts of other pumping stresses, and therefore the combined, or cumulative regional impacts of all pumping stresses. These may be forecasted by modeling into the future, and determine not only the Project's impacts, but combined pumping impacts. Mitigation measures in terms of the Calpine Project should be considered within the context of which pumping center is producing the impacts that may have the potential to impact other senior water rights or aquatic habitats at a defined (forecasted) point in time.

The rate of development of pumping cones with regional extent are anticipated to be very slow based on Carbonate Aquifer properties determined from pump tests in several areas, and therefore mitigation strategies, most of which require time to design and implement, are feasible for the Project. Mitigation strategies, if indeed proven necessary by model projections, generally require predictions of the magnitude and timing of the potentially unacceptable impacts. Groundwater extraction during the first 5-10 years of Project operation would impose the appropriate pumping stress on the Carbonate Aquifer for refined modeling analyses. The water-level histories at monitoring wells distant from the Project pumping center (M-1, M-2, M-2, TH-2, and EH-4) will allow the directions and magnitudes of regionally propagated pumping stresses of the Project to be characterized using modeling technology.

In summary, the Monitoring Plan is designed to track Carbonate Aquifer water levels and regionally-propagated pumping impacts, refine groundwater model projections of future regional impacts, identify non-Project regional pumping impacts, forecast states of the hydrologic system that may require mitigation, and aid in the decision framework for mitigation measures that might become necessary. An effective monitoring program might even help the Project avoid costly and unjustified mitigation measures.

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Monitoring Supplement E-1

Groundwater Monitoring Protocols

February 2001

Purpose of this Document

This document provides standardized procedures for the installation, maintenance, and retrieval of hydrologic data from Stevens dataloggers comprising the part of the groundwater monitoring network for the Project. In addition, procedures for data management and archival are presented to ensure the quality and consistency of essential hydrologic information.

Scope of Water-Level Monitoring

There are several types of activities, beginning with the selection of an automatic data recording system and ending with retrieval and distribution of archived data, that constitute a successful monitoring program. Long-term water-level monitoring for the Project is being accomplished by submerged pressure transducers at selected wells. The transducers are suspended by a cable containing electrical conductors and a capillary tube that provide power and an atmospheric-pressure reference, respectively. Additional instrumentation is in place to sense barometric pressure, which is known to influence water levels. A Stevens AxSys datalogger senses 4-20 mA transducer current and records to non-volatile memory in user-defined pressure units (feet of water or inches of mercury, for example). The measurement system requires a minimum of 12 volts DC for operation.

Borehole conditions influence the choice of cable length and dynamic range of the transducer, and the configuration of wellhead support. Station logs provide a hardcopy record of manual observations such as water levels and battery voltages, and must be understood and utilized effectively to maintain calibration of the measurement system. Uncertainties in the elevation of the water table arise from the combined uncertainties of the surveyed elevation of the measuring point, measured depth to water below the measuring point, and pressure sensed by the transducer. It is therefore essential that depths to water be periodically measured and recorded, and that inaccuracies associated with individual measuring tapes be characterized.

Downloading and archival must be accomplished without loss or corruption of the basic data, and retrieval must provide a product whose format and content is unambiguous and useful to a broad cross-section of potential users. Records are downloaded from the dataloggers using a solid-state memory card, so a computer is not needed in the field. Data are uploaded for processing using Stevens AxRead software

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running on a Windows platform. After using a word processor (WordPerfect or equivalent) to assemble monthly records from each well, a spreadsheet program (Quattro Pro or equivalent) is used to perform some routine numerical conversions and to format the data for archival. Yearly records, organized by month, are written to a compact disk (CD) for distribution.

Specific Protocols

1. Downhole configuration and wellhead support.

The first consideration in selecting the transducer in the dynamic range that will be necessary to monitor the expected range of water-level fluctuations. For example, pre-test design calculations indicated that 11 feet of drawdown could occur at ECP-2 from pumping ECP-1, 500 feet away, for 7 days (figure 7). On that basis, a transducer with a dynamic range of 25 feet was selected. At TH-2, on the other hand, far from any proposed pumping, a more sensitive transducer with 10-foot dynamic range was selected. Cabling was selected to place the transducer between the water table and the limit of its dynamic range, i.e. 12.5 feet below water in ECP-2 and 5 feet in TH-2. Now that it is known that seasonal fluctuations in water elevation are less than a foot in the Project area, future transducers can be placed closer to the lower limit of their dynamic range below the water table. This will allow somewhat greater drawdowns to be recorded without cable adjustments.

Given that the combined weight of transducer and cable is on the order of 20 pounds, sturdy wellhead support is required. Every effort must be taken to limit the possibility of slippage, which would require a substantial recalibration effort and adjustments to data to maintain consistency in the record. All units are supported on 4-inch, ABS plastic sanitary tees, by wrapping the cable in a figure "8" as one would secure rope to a cleat. It is essential that there are no kinks in the tubing, as this would impair sensing of reference pressure. This setup also provides both access for manual water-level measurements and secure mounting for the junction box, and in the case of TH-2, a barometric-pressure transducer. Desiccant must be kept in the junction box to prevent condensation from blocking the reference pressure signal, and the bag of desiccant should be replaced when it swells to twice its original size. Openings at the wellhead should be sealed to the extent possible to prevent animals or debris from entering the borehole and interfering with the measurement process.

Equipment Checklist

A minimum of two persons are required for installation of transducer and cabling, one person is needed to suspend the weight of the cable while the other organizes the wellhead support and makes adjustments. Considerable equipment and preparation is needed for suspending a transducer in the borehole and hooking up a few wires. Safety of personnel is important during this process as is the security of the monitoring. Included are the ingredients of a proven system of wellhead support and layout of measurement

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apparatus that are reasonably secure from natural elements and vandals. For each one-channel installation the following is required:

Stevens water-level measurement system and related supplies
(1) Stevens AxSys MPU datalogger
(1) Stevens SDT-II pressure transducer with cable of appropriate length
(1) 12-volt automotive battery, freshly charged, with 5/16-inch threaded posts and wing nut
(1) 1/2-inch x 8-inch x 12-inch wood (to set under battery)
(1) 8-inch x 3/4-inch galvanized steel pipe nipple (to weight transducer and uncurl cable)
(1) 3/4-inch female adapter (to attach nipple to base of transducer)
(1) roll 1/2-inch teflon tape (for joining steel to plastic threads)

Slab and equipment vaults
pick (for digging holes for vaults)
shovel (ditto)
spirit level (to level concrete forms)
box 3 1/2-inch nails
claw hammer
(4) 4-foot lengths 2x4 lumber (for concrete forms)
(10-15) 60-pound bags pre-mixed concrete
(10-15) gallons water (1 gal per bag concrete) plus sufficient for cleanup
wheelbarrow (to mix and pour concrete)
hoe (to mix concrete)
4-foot length of 3/4-inch electrical conduit (to pass datalogger wiring through concrete slab)
(1) 12x16 rectangular sprinkler valve box (Home Depot #052063171135)
(1) 10-inch round sprinkler valve box (Home Depot #052063101118)

Plastic fittings and other supplies for wellhead support
(1) 4-inch ABS-DWV double tee (Home Depot #039923205506)
(1) 4-inch ABS threaded cleanout plug (for mounting junction box)
(2) 4-inch ABS end caps (to seal main openings of wellhead tee)
(1) 4-inch ABS threaded male adapter (base of wellhead system)
(1) 4-inch ABS threaded female adapter (mounts to well casing, accepts wellhead system)
(3) 3- inch (approximate) pieces of 4-inch ABS pipe (to mate female fittings)
whiteout ("liquid paper") for marking the black ABS plastic
(4) #8x3/4-inch pan head self-tapping screws (to secure junction box)
aluminum tape (to seal irregular holes in wellhead)

Hand tools and miscellaneous supplies
heavy gloves
measuring tape
electric driver-drill with drill bits from 1/16 to 3/8-inch (to start jigsaw cuts and drive

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screws)
#1 phillips screwdriver and driver drill bit (to mount and open/close junction box)
electric jigsaw (to cut transducer access port)
hacksaw
half-round and rat-tail files (to dress transducer access port and wiring cutouts)
Safety glasses
"Red Hot Blue" or equivalent PVC/ABS cement
jewelers screwdriver with 3/32-inch blade (for tiny slotted screws on terminal strip)
desiccant for junction box (prevents condensation in reference pressure line)
whiteout ("liquid paper")

Electrical equipment and supplies
24-inch or larger nylon cable ties (to secure wire and cable to wellhead tee)
4 feet flex coil, spiral wrap or equivalent wire shield (to protect wire against rodents)
wire stripper
red-collar (22-18 AWG) 5/16 or 3/8-inch ring terminals (to fit battery posts)
crimping tool for solderless connectors

Station log box
(1) Rubbermaid "Servinsaver", 1-quart rectangular (Target #002030251)
(1) economy field book (Holman's)
(1) mercury thermometer (Holman's)
(1) penny for opening latches on datalogger cover
(3) bags Stevens desiccant (for junction box, datalogger faceplate, and station log box)
(1) pen with waterproof black ink

The objective is to provide a secure support for the transducer, which hangs in the hole on its cable, in a way that will not put any strain whatsoever on the junction box. The port must be large enough to insert and withdraw the transducer and its attached weight for servicing, and the support must not kink the transducer cable.

Fabrication requires no more than two hours if the supplies are on hand. Safety glasses are required during the installation process. Care must be taken when cutting the flats off that end cap. Cut a clean port in the tee, beneath where the cable is supported by one of the arms of the tee, and file smooth and round so the transducer cable does not lie taut across any sharp corners or edges. The junction box fits in one arm of the tee, screwed to the male cleanout plug which is cemented in place after cutting out the raised wrenching flats to provide a smooth base for mounting. Notches in opposite sides of that arm provides clean cable entry to the recessed box. Using whiteout ("liquid paper") as a layout marker works well on the black ABS plastic.

When attaching the piece of galvanized pipe to the base of the transducer as a cable weight, DO NOT STICK ANYTHING UP INTO THE TRANSDUCER. DO NOT BLOW INTO IT OR DROP IT. Make sure the transducer and its attached piece of galvanized pipe can be inserted and withdrawn from the tee; it is a tight fit in 4-inch pipe

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for the combined piece that is over a foot long. The main reason for using the threaded male adapter at the base of the tee is that filing and fitting may be accomplished before taking the equipment to the field. Everything opens up beneath the threaded male fitting, so if it fits it will pass into the well.

The arm of the tee opposite the junction box is sealed with an end cap and a stub of pipe, glued in place. The top is not sealed permanently; this is for access to measure water levels. Glue a pipe stub into and end cap, but not into the tee. This results is a cap with a slip fit that can be removed for water-level measurements. The measuring point will be the lip of the tee. Finally, seal the gaps around the transducer port with aluminum tape. In this way, no leaves, lizards, bugs, etc., will find their way into the monitoring well.

Secure the wraps of cable on the tee with the big cable ties, to minimize the possibility of cable slippage. Cover the cable with the protective sheath (spiral wrap or equivalent) to help protect it from rodents and bury the remainder. The battery is housed in the rectangular sprinkler box and the datalogger in the smaller round sprinkler box. The Battery sits on a piece of wood and the datalogger sits on the plastic container containing the station log.

Safety Considerations

Wear safety glasses when assembling all wellhead equipment. Use care when cutting the ABS fittings with the jigsaw have been previously covered. PVC cement may splash in your eyes as glue may squirt at least 10 feet when attaching fittings. Batteries, especially lead-acid batteries, contain acid which is a potential hazard. Do not across the positive and negative terminals with hand tools, etc. Transport with great respect, given their mass and sulfuric acid content.

Protective well cover removal requires proper technique and two persons. Wear gloves during removal and installation. Prior to placing hands in equipment vaults or protective covers inspect for black widows, scorpions, rattlesnakes, etc.

The electric field from the high-voltage power lines that run through the project area can give you a shock. Do not work under electric lines.

2. Datalogger and battery.

A 12-volt battery is need for set up of the Stevens AxSys MPU datalogger. Without power to the external leads, the display will remain blank even with the front-panel toggle switch in the "**ON**" position. Use a "maintenance-free" automotive/marine lead-acid batteries with threaded 5/16-inch terminal posts and wing nuts. The datalogger is shipped with non-terminated + and - wires, so these will need two red-collar (22-18 AWG) 5/16 to 3/8-inch ring terminals and a crimping tool to connect the datalogger to the battery. Power up and view the factory settings and make any adjustments that are needed, as outlined below. Check the settings before taking the datalogger to the field,

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especially if you are unfamiliar with the menu system and settings. Several of the factory settings will probably need to be reset prior to putting the datalogger in service:

1. **Time:** Use PACIFIC DAYLIGHT TIME. Adjust the clock an hour at the appropriate time to correspond with daylight savings and standard times. In the future clocks may be set to Coordinated Universal Time (formerly called Greenwich Mean Time),

2. **Channel ID:** This will, in most cases, be "FT H2O" for Channel 1. Only one recorder has a second channel (it records barometric pressure in inches of mercury, "IN HG").

3. **Interval:** Use 01:00:00 for hourly sampling.

4. Set **Dataview:**: to MIN/MAX. This is most convenient.

5. **Scale:** Set this to 0.000 for best precision.

6. **4 mA Reading** 0.000 and **20 mA Reading** 10.000 for a transducer with 0-10 foot range.

7. **System ID:** Name the well. There are 17 characters, for example, "SECTION 9 WELL M1."

8. **Card Copy:** Select **New Data Only**. The alternative is **All Data**, which will write everything in memory to the card; this is not wanted. When New Data Only is selected, a copy to the card will be followed by a prompt to Set new data mark (>) to accept or **MENU** to reject; always set a new data mark after doing a download.

The Stevens AxSys MPU datalogger and battery are installed in buried vaults near the well. The vaults are sprinkler valve boxes, which are judged to provide adequate concealment and protection for the equipment. Wiring is buried to the extent possible, with sufficient slack within the vaults to allow the datalogger and/or battery to be removed without being disconnected. Where exposed, wiring should be enclosed by spiral wrap or equivalent to protect against gnawing rodents. Since the dataloggers are kept underground, a bag of desiccant should be kept on the front panel, under the instrument cover. Press down on the latches when opening the cover to avoid damage to the plastic retainers.

3. Station log.

A surveyor's notebook, pen with waterproof ink, mercury thermometer, and bag of desiccant are stored in a Tupperware container in the datalogger vault. In this way site visits can be logged, along with pertinent data such as manual water level measurements

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and battery voltages. Slippage or stretching of the transducer cable and weak batteries should be recognizable by reference to the station log. Battery voltage should not be allowed to fall below 12.0 volts; a fresh battery is to be kept available for rotation through the system as batteries are removed for recharging. Additional, pertinent environmental information or station operation data should be recorded on the station log. In particular, offset values (described below) should be recorded prominently near the front of the station log.

4. Understanding OFFSET

"Offset" is a number. For example, imagine standing on a hill that is 1000 feet above sea level. Assume that the hilltop is 1000 feet above sea level, and there is a 2-foot bush on the hilltop that is measured with a yard stick. Then add the 1000-foot *offset*, and find that the top of the bush is 1002 feet above sea level. That is exactly what is done with a datalogger that does not utilize the exact values of interest.

It is important to understand offset as the AxSys MPU will only allow a record in the ranges -299.99 to +299.99, or -29.999 to +29.999. It is like the yardstick, that can not measure the whole thing of interest. There is a menu item called **Scale:** in the **>Channel Setup** menu (described below) that is used to select which range is used, use the sensitive range (three decimal places). So, what if we want to measure something that varies from 26.000 to 31.000? The system needs to be "tricked" since it can not handle numbers greater than 29.999. Set it to record, for example, 6.000 to 11.000 and add the constant value of 20.000 in later. That value of 20.000 is the *offset*. An understanding of the way offset is handled in the Stevens AxSys MPU is important because without this background the readings will be misleading.

It is possible to program the offset into the datalogger, so that the readings that are recorded have the offset added in and therefore correspond to what might be measured manually. The user may edit the reading between -499.99 and 19999.99 (0.00 scale) or -49.999 and 1999.999 (0.000 scale), using the keypad in the *Edit* mode. Changing the displayed reading in this way will produce an *offset* to the actual analog reading from the sensor. To view this offset, press the > key while in the **"Reading"** display, and the offset will be displayed directly below the reading. No offset has been applied for the reasons described below.

There are reasons not to use the built-in capabilities of the AxSys dataloggers to apply offsets in the field. First, the dataloggers have an internal lithium battery, so once programmed they will not lose their settings. WITH ONE EXCEPTION. If an offset is specified when programming the AxSys MPU, it will be lost if the front-panel switch is turned off. Second, the sensor at TH-2 has been calibrated, so it is known that the 4 to 20 mA signal representing barometric pressure corresponds to pressures between 23.997 and 30.001 inches of mercury (dataloggers can only record numbers in the range -29.999 to +29.999). The choices are to either use a tiny offset like 0.002, or alternatively to use 20 mA and cause a value of 29.999 to be recorded, instead of the strictly correct 30.001.

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With the tiny offset, this would never be noticed when reviewing the data if it had been dropped due to the datalogger being turned off. With this approach, the whole purpose of calibration is defeated. It is reasonable, instead, to record numbers in the range 3.997 to 10.001 and add the constant 20 later, in the office. For example, a reading of 7.256 is actually 27.256, and there is no need to continually check whether re-programming of an offset is necessary. The offset value for each channel at each instrument station should of course be clearly recorded near the front of the station log so that it can be checked in the field when servicing the dataloggers.

5. Reading the AxSys datalogger display.

This section describes the operation of the Stevens AxSys Monitoring/Processing Unit (MPU) datalogger. Each MPU stores water-level data from a downhole sensor, and the system at borehole TH-2 also stores barometric-pressure data. A removable data card is used to extract and transport data from several MPU's to the office for processing. Generally, the dataloggers will be set up by Mifflin & Associates and will require no servicing other than periodic checks of battery voltage, battery changes, and data downloads. The purpose of this section is to familiarize field personnel with the menus and display, so that the operation of the datalogger can be verified during field visits.

In addition to the **MENU** key and **ON/OFF** toggle switch on the front panel, there are three keys labeled "_", "_", and ">". The MENU key enters information from the current (displayed) menu and advances the display to the next menu item. If the value is to be selected or edited (changed), modify it as desired with the "_", "_", and ">" keys. Then press **MENU** to enter the new value into memory and advance to the next menu. Do this if changing the sampling "**Interval:**" during a pumping test, for example, or adjusting the "**Channel ID:**" at TH-2 so to view the reading in the other channel. Note that for now the system is set up on PACIFIC DAYLIGHT TIME.

The "_" and "_" keys have two possible effects, depending on the operation being performed. When a menu has an item that can be selected or edited, the *first* press of either key selects the *Edit* mode, causing that item to blink repeatedly on the display. The *second* (and subsequent) presses of either key cycle through possible selections of the blinking display item if it is a condition, or character values if it is a single alphanumeric character.

The ">" key has *three* possible effects, depending on the operation being performed.

(1) When a character value is being Edited, press ">" to advance to the next character in a character string.

(2) If a menu has just been selected and is preceded by a ">", press ">" to enter the next level of that menu.

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(3) When in channel status menu, press ">" to jump to channel setup menu, providing a convenient means of setting up a multi-channel MPU.

Stevens provides complete user instructions for the setup of their instruments in a series of instruction booklets for transducers, dataloggers, software, etc. This information is not repeated here. The published instructions are not perfect, however. The data card reader presented several installation difficulties, as did the card-reading software. The technical representative of Stevens Water Monitoring Systems, Inc. is Larry Graeme (503/469-8000). The booklets are available through Mifflin & Associates, Inc.

The input signal to the AxSys MPU (datalogger) is a small electrical current in the 4-20 milliamp (mA) range. This means that by using a downhole transducer that senses 0-10 feet of water pressure, it will send 4 mA to the datalogger if there is no water pressure, and 20 mA when the sensor is 10 feet under water. An important programming step is the selection by the user of how these values will be represented in the datalogger's memory. The concept of offset, described above, needs to be understood first because the "reading" displayed by the AxSys MPU depends on how the instrument is set up with respect to offset. It is important to understand what offset is and how to handle offset when setting up the dataloggers and checking their readings.

Assuming that the concept of offset is understood, the following are steps for understanding the menus and checking the settings and readings on the AxSys MPU datalogger. The whole idea is that during site visits to measure the water level and check it against the reading on the datalogger to see if there is some problem like cable slippage. Check the battery voltage and know what to record in the station log. Most important, as described in the next section, is to be able to download data from the AxSys MPU.

Wake the MPU up by depressing the **MENU** key for approximately 1 second. When the MPU is first powered up, it performs an initialization routine, as indicated on the display, and then switches to the channel status display:

>Channel: ANALOG 420
PWR: 12.4V 90XXX A

This is the channel status menu. Push **MENU** once to advance to the next menu item:

>Reading: 0000.000

The "Reading:" value is part of a menu structure containing 9 main levels; those menus preceded by a ">" have added menu levels. The user can cycle the display through the 9 main displays by repeatedly pressing the **MENU** key. The other menus are **Time:**, **Date:**, **Chan ID:**, **Interval:**, **>DataView:**, **>Channel Setup**, and **>System Setup**.

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6. Extracting data from the datalogger.

Downloads are extremely simple. "Wake up" the datalogger by depressing the menu key for a couple of seconds, insert the solid-state data card, and the AxSys MPU will automatically perform the data transfer. The display will show

Copying to card...

A small green light (LED) to the right of the card slot will illuminate, and the second line of the display will display blocks that show copy progress. When the copy is complete, the LED will go off and the following message is displayed:

Set NEW DATA mark?

followed by alternating messages on the second line:

Press > to accept -or-
Press MENU to reject.

We press >, so future copies to the card will only include data recorded after the mark is set. This configures the system so that next time someone does a download they will just get the new data and not all data in the datalogger. After this last selection the display shows

Copy successful
****REMOVE DATA CARD****

The card must be removed at this time so recording can resume. Remove the card and that completes the download process.

7. Uploading from the card to your computer.

This section describes how to transfer the water-level and barometric-pressure data off the memory card onto the computer, what the resultant file looks like, and how to save and rename it. This is not a step-by-step guide to installation of the card reader and AxRead software, for it is somewhat troublesome and does not always proceed exactly as presented in the Stevens booklets. This guide is meant for the user who has (perhaps with assistance from Mifflin & Associates) installed the system on his or her computer and needs his or her memory refreshed prior to the monthly processing.

The data card is a PCMCIA-type, 256K "Flash" memory card. Although in principle it should be readable by any computer with a PCMCIA slot (i.e. most laptops), have been found that the CSM OmniDrive card reader must be used. The card reader

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connects to the parallel port and is controlled by a Windows driver. Installation difficulties seem to vary from computer to computer. For technical support contact CSM GmbH (in Germany) via their website at http://www.csm-gmbh.de/en_supportform.htm or by e-mail at csm@csm-gmbh.de Updates and additional downloads are available from http://www.csm-gmbh.de/en_index.htm.

Stevens provides AxRead software that can be configured to read the card and save the data to disk as a batch process. Installation difficulties had to do with configuring the parallel port, and several phone calls to Larry Graeme at Stevens (503/469-8000) were required before things worked properly. When installed, there will be a blue "S" AxRead icon on your desktop. Double-clicking it brings up the "AxSys Data Utility Program" window, from which you highlight "**AxSys Data Card Xfer...**" from the File menu, then select "**Batch Process**" from the pop-up submenu. The selection can also be made simply by pressing the **F5** key. This prompts to "**Insert Data Card**"; do it then click the "**OK**" button. A series of black and white DOS windows will appear and disappear, indicating progress of the various subtasks. Close them manually if they do not close themselves. When the card has been read, "**Processing Complete**" will appear in the "AxSys Data Utility Program" window. Now look at the data set and begin the monthly processing routine.

The files (one from each instrument) end up on the host computer strung together as one text file named "axtrxfer.txt" in the C:\Program Files\axread directory. This file must be re-named and saved before it is over-written by the next upload. Double-click its spiral-notebook icon to open it up. If Windows says it is too large for NotePad to open, click **Yes** to open it with WordPad. Use the naming convention FullDump_MM_DD_YY to designate these files with the download date, and store them in a folder called Raw Data Dumps in the Desktop\WtrLvls folder . The FullDump file downloaded from TH-2 and ECP-2 on October 3, 2000 looks like this:

```
0004.328  14:00:00  09/02/00  "SYS ID  CALPINE TH-2      "
0004.340  15:00:00  09/02/00
0004.343  16:00:00  09/02/00
                .
                .
                .
0004.343  14:00:00  10/03/00
0004.336  15:00:00  10/03/00
0004.328  16:00:00  10/03/00



0007.543  14:00:00  09/02/00  "SYS ID  CALPINE TH-2      "
0007.523  15:00:00  09/02/00
0007.498  16:00:00  09/02/00
                .
```


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.
.
0007.468 14:00:00 10/03/00
0007.447 15:00:00 10/03/00
0007.422 16:00:00 10/03/00

0015.375 15:00:00 09/02/00 "SYS ID CALPINE ECP-2 "
0015.390 16:00:00 09/02/00
0015.406 17:00:00 09/02/00
.
.
.
0015.265 15:00:00 10/03/00
0015.265 16:00:00 10/03/00
0015.328 17:00:00 10/03/00

As is observed, there are three blocks of data representing the hourly measurements. Each block covers a period of time from September 2 to October 3 (most of the middle data have deleted out for brevity). Each line contains a reading, time, and date, and the first line of each block contains station identification. There are some blank lines between blocks and at the end of the file, which ends with the "^" symbol.

This format, designated "F3" in Stevens AxRead parlance, is the most convenient for subsequent import to a spreadsheet. Beware that the "F5" format, which is supposed to be best for spreadsheet use, does not work. The result is using a format with no channel identifiers. The only station with more than one channel is TH-2, and the other channel is Channel 1 which contains water levels and is written first. Channel 2 requires the offset value of 20.000 (discussed at length above) to be added back in.

8. Separating the records and organizing by month.

Two (or perhaps more) FullDump files are then cut up using any word processor to create monthly records for each sensor. The naming convention here is WELLIDwlMonthYY.txt or WELLIDbpMonthYY.txt, as appropriate. Continuing with the TH-2 September example, find the file FullDump_09_02_00 in the Raw Data Dumps directory; the bottom of the TH-2 water-level segment of that file (which covers the first part of September) looks like this:

0004.351 00:00:00 09/01/00
0004.343 01:00:00 09/01/00
0004.336 02:00:00 09/01/00
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.
.
0004.317 11:00:00 09/02/00
0004.324 12:00:00 09/02/00
0004.332 13:00:00 09/02/00

Copy and paste the data from these first couple of days of September into a new file, "Save As" TH2wlSept00, then append it with a cut and paste of the September portion of FullDump_10_03_00, deleting the Station ID label ("SYS ID CALPINE TH-2") from the first line. One clean text file is the result containing the September, 2000 water level record from borehole TH-2, saved in the Processed Text directory:

0004.351 00:00:00 09/01/00
0004.343 01:00:00 09/01/00
0004.336 02:00:00 09/01/00
.
.
.
0004.362 21:00:00 09/30/00
0004.351 22:00:00 09/30/00
0004.343 23:00:00 09/30/00

It is named TH2wlSept00; then create files named TH2bpSept00 (with raw barometric-pressure data), ECP2wlSept00 with water levels from borehole ECP-2, and so on for any other sensors in the network.

The last step in archival of the monthly data is to read the monthly records into a spreadsheet program for a minimal amount of processing and re-formatting, and plot the data to check for integrity. This is where offset is added in to the barometric-pressure readings and convert the water pressures to water elevations using the wellhead elevations and cable lengths. Here is an example of the type of plot that can be prepared with a spreadsheet program:

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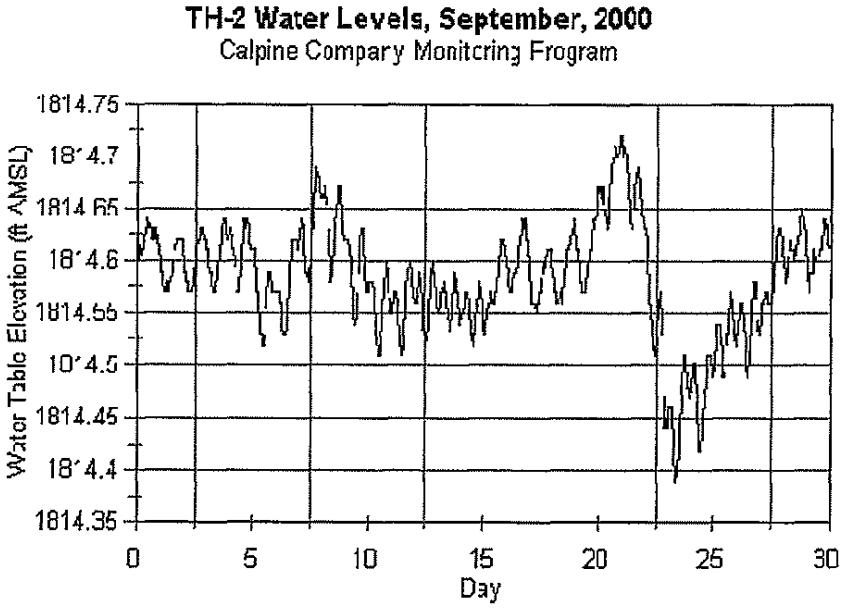
Create a column defined as date+time and subtract the value of the first entry from all subsequent ones to get decimal day of the month. Convert the raw barometric-pressure reading to inches of mercury by adding the constant 20, as explained above, then convert this quantity to feet of water by multiplying by the constant 1.133. Convert water pressures to elevations using the surveyed elevation of the measuring point and cable length derived from manual water-level measurements (see discussion of cable length files, below). Templates (blank spreadsheets containing formulas and constants) are being prepared to facilitate these operations and keep them consistent from month to month. For now, just refer to the previous month's results for guidance. Then just plot the data with day on the x-axis and the parameter (water elevation or barometric pressure) on the y-axis, and save the hardcopy plots.



To prepare a spreadsheet using Quattro Pro, do the following:

1. Start up Quattro Pro using the calculator icon, then **OPEN** the text file with the monthly record. You'll need to navigate to the Desktop\WtrLevls\Processed Text folder and set the file type to **ASCII Text (*.txt)** in the lower left of the "Open File - Processed Text" window.

2. A "Quick Columns Expert" window comes up - choose "**Fixed Width Auto**" Parse Settings, the **OK** button.

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3. Type "**=b1+c1**" in cell d1, then copy and paste this formula to the rest of the cells in column d.

4. Type "**=d1-d1**" in cell e1, then copy and paste this formula to the rest of the cells in column e.

5. In column f convert sensor readings to water elevations (**=surveyed MP elevation - cable length + sensor reading**) or barometric pressures in feet of water (**=(reading+20)*1.133**), as appropriate.

6. Save your work in Desktop\WtrLevls\Spreadsheet Format as a Quattro Pro file with the same root name as the text file you started with.

To plot the data from the spreadsheet, do the following:

1. Select the rightmost two columns of data in the spreadsheet by clicking and dragging to highlight them; the first will be decimal day, the other will be water elevation or barometric pressure.

2. Select "**Chart...**" from the **Insert** menu.

3. Click the **Next>** button when the first Chart Expert window appears.

4. Choose the **Line or Area** button from the second Chart Expert window, then click **Next>**.

5. Choose the top-right chart type button from the third Chart Expert window, then **Next>**.

6. The fourth Chart Expert window allows entry of a title, subtitle, and axis labels. Refer to the example above for guidance, then **Next>**.

7. In the last Chart Expert window the color scheme is chosen. Pick **No Change**, then click **Finish**. The cursor changes to a little histogram, allowing it to click/drag to define the area where the chart will be drawn. Do it, and save the work.

8. Cosmetic changes can now be made to the chart. In general, the fonts are too big, the data too light in color, and the number of days does not match the number of days in the month. After cleaning up these details and re-saving, print the chart.

The root names for the saved spreadsheet files should be the same as for the monthly text files, i.e. WELLIDwlMonthYY.qpw or WELLIDbpMonthYY.qpw are

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Quattro Pro files containing water-level and barometric-pressure data, respectively for a full calendar month. At the end of the year a recordable CD will be prepared with the full years' data in a variety of formats, including popular .xls to facilitate use by Microsoft Excel users.

Cable Length Files

The length of the cable on which the pressure sensor is suspended in the borehole is critically important to the accuracy of the water-level measurements. The cable length is the distance between the surveyed measuring point on the wellhead and the pressure-sensing element, i.e. the sum of the depth to water and the height of water above the sensor. We should be able to measure the static water level with a well sounder, read the datalogger, and get the same sum no matter what the water level in the well, because these two values add to the cable length. However, it is not that simple. Watch the display on the datalogger, and it jumps around a little. Measure water levels a few times in a row, and they do not all come out exactly the same. We end up with some scatter in our estimates of cable length, which would make it difficult to recognize minor slippage or stretch-related increases in length. It is a judgement, at any point in time, as to what is the "best" estimate of cable length. Usually this will be the mean of available measurements, excluding spurious values, and the standard deviation will give us an estimate of the precision of the measurement. Accuracy, however is a different issue.

Side-by-side comparisons of measuring tapes used to measure depths to water have revealed differences on the order of one foot, requiring constant vigilance as to which tape is being used for a particular measurement. The question here is one of accuracy, i.e., which tape is closest to being correct? The potential errors associated to measured depths to water are much greater than the errors associated with wellhead surveys or of transducer readings. The challenge is how to report water-level records in a consistent fashion that will allow for upgrading as calibration of the measuring tapes is improved. Measurements, assumptions, and traceability information are contained in cable length files, key support documents that must accompany and be referenced from within each archive of water-level data.

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Monitoring Supplement E-2

Procedure for Electric Well Sounder Cable Calibration and Water-Level Measurements Using Calibrated Cables

prepared by

Cady Johnson
and
R.J. Johnson

November, 2000

I. Purpose

While quite precise, manual water-level measurements are often inaccurate due to such factors as poor manufacturing controls of electric well sounder cables (cables), downhole cable stretch, and damage. This procedure seeks to improve the accuracy of downhole water-level measurements through a side-by-side comparison of Calpine Project or Moapa Band of Paiutes (Project) cables with a calibrated steel tape (reference tape). A stepwise process for establishing downhole weights (Form A), elastic properties (Form B), and proportional length corrections (Form C) for cables used for measuring depths to water by Project personnel is presented. The procedure provides a basis for equipment intercomparisons and for referencing measurements to a traceable standard. The accuracy of water-level measurements is established through a two-step sequence of first adjusting field observations to a "zero-tension state" of the cable and then developing a proportional correction factor that can be applied to the adjusted observations. This allows a single proportional correction factor **C** (dimensionless) to be established for each cable. Form D outlines the use of a calibrated cable and data from Forms A, B, and C to convert observed water-level readings to accurate values.

II. Assumptions and Variable Definitions

The central assumption in this procedure is that Hooke's law of elasticity applies to the well sounder cable, that is, that cable stretch is a linear function of load (tension). This assumption is checked directly during the calibration process, as several tensions are applied to the well sounder cable and readings corresponding to known values on the reference tape are obtained. To accomplish a reproducible calibration, factors such as vertical vs. horizontal tension, cable stretch properties, and zero-tension state are part of the calibration process and are described below. This procedure does <u>not</u> include provisions for establishing thermal effects on Project cable length, i.e. the coefficient of thermal expansion.

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A. Vertical vs. Horizontal Calibration

When a cable is suspended vertically to obtain a water-level measurement $\mathbf{R_{OBS}}$, its stretch characteristics will be completely different than when pulled under horizontal tension $\mathbf{W_H}$ during calibration. Each point on the cable will "feel" a pull from the weight of cable and probe below it, so the higher portions of the cable will stretch more than the lower portions. A vertical cable that obeys Hooke's law will exhibit overall stretch identical to the case where the probe weight plus *half* of the downhole cable weight is applied to the downhole cable. This is because the full weight of the cable and probe are "felt" only at the wellhead, and the tension decreases to only the probe weight at the bottom of the cable. Hooke's law is a statement of linearity, meaning that we can use a force $\mathbf{W_V}$ equal to half the cable weight plus probe weight to represent the tension causing stretch of a vertically suspended cable. Conceptually, we are simply distributing the stretch uniformly as if the cable were being pulled horizontally under tension $\mathbf{W_V}$. Form A provides the format for recording the weights of well sounder components and computing $\mathbf{W_V}$, the *effective* hanging cable weight associated with a water-level observation.

B. Cable Stretch Properties

The stretching properties of a specific cable must be established by direct measurement of its length under a range of tension loads. During calibration, readings from the cable are obtained at each 100-foot mark on the reference tape to help recognize cable damage or other sources of non-linearity in cable stretch. In this way an elastic constant, **k**, can be established that represents the relative elongation of the cable per pound of pull. In practice, **k** will be required (in conjunction with effective hanging cable weight $\mathbf{W_V}$ and cable reading $\mathbf{R_{OBS}}$) to adjust cable readings for tension effects prior to applying error corrections that are proportional to the adjusted readings. The dimensions of **k** will be lb^{-1}, i.e. "per pound".

To find **k**, lay out the cable alongside a reference tape, set the cable tension, and record the cable readings at 100-foot intervals as indicated by the steel tape. As the tension is increased, the readings opposite the reference marks will *decrease* as the cable stretches relative to the stationary reference tape. Form B provides the format for recording stretch data, and includes a hypothetical data set for an ideally elastic cable. The relative elongation of the cable is given by $(\mathbf{R_o}-\mathbf{R_n})/\mathbf{R_o}$, where $\mathbf{R_o}$ is an original cable reading (at some fixed tension) and $\mathbf{R_n}$ is the new cable reading (at increased tension). If the horizontal tension increase in pounds is $\mathbf{W_H}$, we define $\mathbf{k}=[(\mathbf{R_o}-\mathbf{R_n})/\mathbf{R_o}]/\mathbf{W_H}$, the relative elongation per pound of (additional) horizontal tension. Note that obtaining a *reading* at zero tension is impractical, since the cable would not lie straight and Hooke's law would not apply at very low values of tension. Relative elongation must be observed as increments of tension greater than the minimum needed to straighten the cable and overcome static friction with the ground are applied.

It is possible that a well-made cable will not exhibit significant stretch when subjected to the 5- to 25-pound tension range explored by this calibration procedure. In a

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case where the cable does not stretch measurably, the plot of reading vs. tension as given in Form B would be horizontal (i.e. constant), and extrapolation back to zero tension would be trivial; any reading at any tension would be equivalent to its corresponding zero-tension reading.

C. Zero-Tension State

Although a zero-tension cable reading cannot be obtained from observations, the concept of a zero-tension state is important to the error correction process. The zero-tension state of the cable is the starting point for applying corrections for systematic errors, i.e. those that are proportional to the cable reading. The idea is to first *compute* a zero-tension reading to remove stretch effects, then apply a proportional (to the magnitude of the reading) correction to the zero-tension cable reading. During calibration, the zero-tension cable reading opposite a reference mark is obtained by extrapolating a plot of cable reading vs. tension back to zero tension. When a cable is suspended in a borehole, we use algebra to rearrange the defining expression for **k** and find the zero-tension reading $\mathbf{R_Z}$ as $\mathbf{R_Z}=\mathbf{R_{OBS}}/[(1-\mathbf{k}(\mathbf{W}/2+\mathbf{p}))]$, where $\mathbf{R_{OBS}}$ is the actual cable reading, **W** is the weight of cable in the hole, and **p** is the probe weight. We define an effective downhole cable weight $\mathbf{W_V} = \mathbf{W}/2+\mathbf{p}$ (Form A).

III. Calibration

A. Equipment

1. Procure a 500- to 1000-foot, NBS-traceable steel (or equivalent, i.e. Invar) surveyors calibrated tape (reference tape) with documentation such as thermal correction data and certification papers; procure two appropriate and compatible tensioning devices (40-pound fish scales would be appropriate).

2. Procure a mechanical postage scale (or visit a post office to weigh the probe containing the sensing element of the Project cable), and a mercury thermometer for recording air temperature at the time of the calibration to assure accuracy of the reference tape.

3. Forms A (weights), B (stretch), C (proportional correction) and D (use of a calibrated well sounder) for recording, checking, and applying calibration data.

B. Procedure

1. Find a dry grassy area (a large park or golf course would be ideal) without interfering vehicular or pedestrian traffic where the Project cable can be laid out alongside the reference tape for direct comparison.

2. Establish the zero point of the Project cable with a water bucket, and mark the probe with a Sharpie pen or other indelible ink to facilitate alignment.

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3. Weigh the entire Project well sounder, spool and all, using the fish scale to obtain total weight **s** (lb); record on Form A, Item 1.

4. Weigh the probe of the Project cable, using the postage scale, to obtain probe weight **p** (lb); record on Form A, Item 2. This could be done at a post office prior to unwinding the spool for calibration.

5. Lay out and stake the reference tape at the tension designated in the calibration documents, and record air temperature (Form A Note 3a).

6. Lay out the Project cable and weigh the empty spool with the fish scale, obtaining empty spool weight **e** (lb); record on Form A, Item 3. Estimate the force needed to overcome static friction between cable and grass by dragging the cable a short distance using the fish scale; record on Form A, Note 3a.

7. Calculate the cable weight by subtracting the empty spool weight **e** and the probe weight **p** from the total well sounder weight **s** to obtain the cable weight **c**: **c=s-e-p** (lb); record on Form A, Item 4.

8. Calculate the weight per unit length (**w**) in pounds per foot of the Project tape by dividing weight of the cable **c** by the length of the cable **a**: **w=c/a**.(lb/ft); record on Form A Items 5 and 6. Note that all cable weights are referenced to cable markings, not the reference tape. Note also that weight per indicated length will not change as the cable stretches.

9. Stake the Project cable alongside the reference tape so that the zero points align; some creativity may be required, depending on the configuration of the probe end that must be secured. Ring clamps and a turnbuckle might be useful, but a procedure such as this cannot anticipate all probe configurations that might be encountered. The idea is simply to keep the zero points aligned as various tensions are applied to the Project cable.

10. Using the fish scale attached to the cable spool, apply 5 pounds of tension to the Project cable.

11. Observe and record on Form B the reading from the Project cable opposite each 100-foot mark on the reference tape. These data will be used to check for discontinuities such as splice effects in the cable.

12. Repeat readings for 10-, 15-, 20-, and 25-pound loadings, completing the Form B table. Results (reading vs. load) from the longest cable readings should be plotted on Form B graph paper in the field as a check on linearity and to graphically obtain the corresponding zero-tension reading $\mathbf{R_Z}$.

13. Calculate the elastic constant **k** (lb^{-1}) of the cable from the Form B stretch data, using the longest cable-to-reference-tape readings available. Use a linear portion of the reading

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vs. load graph (Form B) to obtain the relative elongation $(R_o-R_n)/R_o$ associated with a difference in horizontal tension W_H to obtain $k=[(R_o-R_n)/R_o]/W_H$.

IV. The Error Correction Process

A. Correction to Reading

In the simplest case of error correction the Form B graph is horizontal and we can neglect cable stretch. When a reading R_{OBS} is obtained from a Project cable, it differs from the "true" value **x** by some reading error E_R. For example, if we read 999 feet on the cable opposite the 1,000-foot mark on the reference tape, we have an error E_R of -1 feet and the corresponding reading correction C_R that should be applied is +1 feet. The proportional correction factor **C** is 1 foot for each 999 indicated feet of cable, or 1/999, and the correction to *any* reading C_R is simply the proportional correction **C** multiplied by the observed reading R_{OBS}. An example using these values is given in Form C.

B. Correction for Cable Stretch

The case where cable stretch is significant is only slightly more complex. The errors (and corrections) for a cable that stretches under its own weight are defined for the zero-tension state of the cable. Using the elastic constant **k** obtained in Step 13 above, the zero-tension reading for a tape suspended in a borehole is given by $R_Z=R_{OBS}/(1-kW_V)$, where R_{OBS} is the observed cable reading and $W_V = wR_{OBS}/2 + p$ is the *effective* downhole tension with **w** the weight of cable per foot and **p** the probe weight.

V. Summary

Now corrections to measured water levels are easy. We simply correct out the stretch, if necessary, then add (algebraically) a correction factor that is linearly proportional to the reading to the zero-tension reading to get an accurate water level. Validation of this procedure can be accomplished by side-by-side, in-hole comparisons of Project cables that have been calibrated in accordance with this protocol. Uncertainties in the process can be readily estimated from the goodness-of-fit of experimental data to the approximating linear functions.

VI. Appendices

Form A. Record of Weights

Form B. Record of Cable Stretch

Form C. Determination of Proportional Correction

Form D. Use of a Calibrated Well Sounder

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Electric Well Sounder Cable Calibration

Form A - Record of Weights with Hypothetical Example

Purpose. This form provides a location for recording the weights of well sounder components and cable length so that weight per unit length of cable is available for stretch corrections.

1. Weight **s** of complete Project well sounder:

s = 36 Pounds

2. Weight **p** of probe at end of cable:

p = 1 Pounds

3. Weight **e** of empty spool, or partial spool if only part of the cable is being calibrated:

e = 5 Pounds

NOTE 3a: At time cable is laid out, record:
date _____,
time_____,
temperature_____,
and weight (force) in pounds of pull needed to overcome static friction and drag the cable through the grass _____ Pounds.

4. Cable weight **c** by difference:

c = s-p-e = 30 Pounds

5. Total length **a** of cable being calibrated:

a = 1000 Feet

6. Weight per unit length **w** of well sounder cable:

w = c/a = 0.03 Pounds per foot

Given a reading $\mathbf{R_{OBS}}$, the effective downhole cable weight is given by

$$\mathbf{W_V = wR_{OBS}/2 + p}$$

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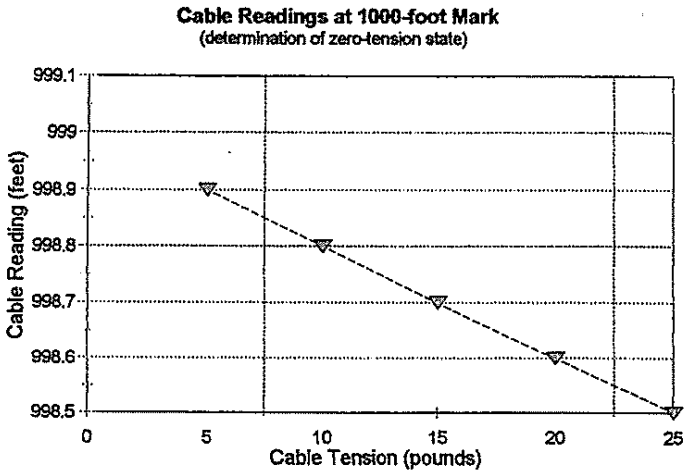
Electric Well Sounder Cable Calibration

Form B - Record of Cable Stretch with Hypothetical Example

Purpose. This form provides a location for recording cable readings as the Project well sounder cable is tested for stretch by applying several tension loads. These data allow an elastic constant and zero-tension state for stretch corrections to be computed.

	Cable Readings under Tension (ft)				
Reference Mark(ft)	5 lb	10 lb	15 lb	20 lb	25 lb
100.00	99.89	99.88	99.87	99.86	99.85
200.00	199.78	199.76	199.74	199.72	199.70
300.00	299.67	299.64	299.61	299.58	299.55
400.00	399.56	399.52	399.48	399.44	399.40
500.00	499.45	499.40	499.35	499.30	499.25
600.00	599.34	599.28	599.22	599.16	599.10
700.00	699.23	699.16	699.09	699.02	698.95
800.00	799.12	799.04	798.96	798.88	798.80
900.00	899.01	898.92	898.83	898.74	898.65
1,000.00	998.90	998.80	998.70	998.60	998.50

For greatest precision, graph the 1000-foot readings vs. tension, fit a straight line to the data, and obtain the zero-tension 1000-foot reading as the y-intercept of the best-fit line, in this case 999.0 ft:



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The zero-tension reading corresponding to a reference mark is carried forward to Form C for development of the proportional correction. The elastic constant k is obtained from the stretch data using any two points on the tension vs. reading graph. If we choose the readings at 5 and 25 pounds of tension, $\mathbf{R_o}$=998.9, $\mathbf{R_n}$=998.5, $\mathbf{W_H}$=20 pounds and

$$\mathbf{k}=[(\mathbf{R_o}-\mathbf{R_n})/\mathbf{R_o}]/\mathbf{W_H}$$

$$=[(998.9 \text{ ft} - 998.5 \text{ ft})/998.9 \text{ ft}]/20 \text{ lb}$$

$$=0.00002 \text{ lb}^{-1}$$

The elastic constant is carried forward to Form D for use in computing the zero-tension reading from a downhole observation.

Note: The static friction between cable and grass is not explicitly considered in calculating k by this calibration procedure. As tension is applied, it will be necessary to walk the length of the cable and raise it to make sure the tension is distributed uniformly. This is especially important if crude splices (such as tape wraps) or other sources of roughness are present on the cable.

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Electric Well Sounder Cable Calibration

Form C - Determination of Proportional Correction with Hypothetical Example

Purpose. This form allows data needed for a proportional correction $\mathbf{C}=\mathbf{C}_{RZ}/\mathbf{R}_Z$ to be recorded in a systematic fashion.

Mark (ft)	Zero-Tension Reading $\mathbf{R}_Z$ (ft)	Reading - Mark $\mathbf{E}_{RZ}$= Error (ft)	Zero-Tension Correction $\mathbf{C}_{RZ}$= -$\mathbf{E}_{RZ}$ (ft)	Proportional Correction $\mathbf{C}=\mathbf{C}_{RZ}/\mathbf{R}_Z$
1,000	999.00	-1.00	+1.00	0.001001

We find the "true" water level $\mathbf{x}=\mathbf{R}_Z+\mathbf{R}_Z\mathbf{C}$ where $\mathbf{R}_Z$ is the zero-tension reading and **C** is the proportional correction factor. In the example above,

$\mathbf{R}_Z = 999$ ft. and
$\mathbf{C}_{RZ} = 1$ ft, so
$\mathbf{C}=\mathbf{C}_{RZ}/\mathbf{R}_Z = 1/999 = 0.001001$

the "true" water level $\mathbf{x}=\mathbf{R}_Z+\mathbf{R}_Z\mathbf{C}$
$= 999 \text{ ft} + 999 \text{ ft } (1/999)$
$= 999 \text{ ft} + 1 \text{ ft}$
$= 1{,}000 \text{ ft}$

which is the value of the reference mark, as it should be. The **C**-value of course works for any zero-tension reading. If we had found $\mathbf{R}_Z$=416.07 feet, for example,

$\mathbf{x} = 416.07 \text{ ft} + 416.07 \text{ ft } (1/999)$
$= 416.07 \text{ ft} + 0.42 \text{ ft}$
$= 416.49 \text{ ft.}$

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Electric Well Sounder Cable Calibration

Form D. Use of a Calibrated Well Sounder with Hypothetical Example

Purpose. This form sets forth the steps for converting a water level observation using a calibrated cable to an accurate depth to water.

Steps.

1. Read the indicated water level $\mathbf{R}_{OBS}$ on the cable using the appropriate measuring point, and record (at minimum) the well ID, water level, tape identifier, date, time, and your name;

2. Compute the effective cable weight $\mathbf{W}_V = \mathbf{w}\mathbf{R}_{OBS}/2 + \mathbf{p}$ using data from Form A;

3. Compute the zero-tension reading $\mathbf{R}_Z = \mathbf{R}_{OBS}/(1-\mathbf{k}\mathbf{W}_V)$ using $\mathbf{W}_V$ from Step 2 above and $\mathbf{k}$ from Form B;

4. Apply proportional correction $\mathbf{C}$ from Form C to find the "true" depth to water $\mathbf{x} = \mathbf{R}_Z + \mathbf{R}_Z\mathbf{C}$.

Example.

1. Say you measure a water level of 500.00 feet with a calibrated cable: $\mathbf{R}_{OBS} = 500.00$

2. From Form A, $\mathbf{w} = 0.01$ pounds per foot and $\mathbf{p} = 1$ pound, so

$$\mathbf{W}_V = (0.03 \text{ lb/ft})(500.00 \text{ ft})/2 + 1 \text{ lb}$$
$$= 8.5 \text{ lb}$$

3. From Form B, $\mathbf{k} = 0.00002$ so $\mathbf{R}_Z = (500.00 \text{ ft})/[1-(0.00002 \text{ lb}^{-1})(8.5 \text{ lb})] = 500.09$ ft

4. From Form C, $\mathbf{C} = 0.001001$, so $\mathbf{x} = 500.09 \text{ ft} + (500.09 \text{ ft})(0.001001) = \underline{500.59 \text{ ft}}$

This is the "true" depth to water we were seeking. The same value should be obtained with any calibrated cable.

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APPENDIX F

Summary of Ground-Water Development Impact

In the

Upper Muddy River Valley, Nevada

SUMMARY OF GROUND-WATER DEVELOPMENT IMPACTS IN THE UPPER MUDDY RIVER VALLEY, NEVADA

by

M. D. Mifflin

Mifflin and Associates, Inc.

Presented at:

Nevada State Engineer's Hearing on Applications 55450 and 58269

January 24, 25, 26 1995

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Las Vegas, Nevada

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JA_3605

QUALIFICATIONS SUMMARY
DR. M.D. MIFFLIN, PRESIDENT & SENIOR HYDROGEOLOGIST, MIFFLIN AND ASSOCIATES, INC.

Education

- B.S., Geology, University of Washington, 1960.
- M.S., Applied Science, Montana State University, 1963.
- Ph.D., Hydrogeology, University of Nevada, Reno, 1968.

Experience

- 36 years of Professional Experience in the fields of geology and hydrogeology.
- Professional Specialties: Arid zone hydrogeology, paleohydrology, exploration and development of ground-water resources, international ground-water resource planning, assessment and development.
- Professional experience in Southern Nevada began in 1963, and first experience in the Upper Muddy River Valley began the same year.
- Experience began on the regional Carbonate Rock Province flow systems in 1965. Studied, defined the Carbonate Rock Province, and delineated the regional flow systems in Nevada in 1965 – 1968.
- Began water development research on the Carbonate Aquifer in 1976.
- Began Upper Muddy River Valley Carbonate Aquifer studies for Nevada Power in the mid-1980's (EH-4, EH-5b and other monitoring points established).
- Designed and executed the detailed NPC water resource inventory continuing and monitoring program in cooperation with DRI beginning in 1987.

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OBJECTIVES OF PRESENTATION

- ☆ Review documented Hydrogeological Relationships of the Upper Muddy River Valley as established by water-level monitoring records, river gaging records, water balance studies, and regional ground-water studies.
- ☆ Review quantitative aspects from a water-balance perspective.
- ☆ Demonstrate that the MVWD Conceptual Hydrogeological Model is not credible.
- ☆ Demonstrate that MVWD pump-test interpretations and impact projections are the result of errors and omissions.
- ☆ Review the evidence that indicates the two protested MVWD applications, if granted and used, would produce unacceptable damage to existing senior water rights and endangered species habitat.
- ☆ Review the evidence which argues that the existing 2 cfs permit for the Arrow Canyon Well, if fully used, also has the potential to produce unacceptable impacts on senior water rights and endangered species habitat.
- ☆ Present recommendations consonant with the evidence.

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UPPER MUDDY RIVER VALLEY
MVWD CONCEPTUAL MODEL
Key Points / Conclusions

- The Muddy Creek Formation acts as an aquitard to separate the regional Carbonate Aquifer from the Alluvial Aquifer.
- The Carbonate Aquifer is large and very transmissive, and Arrow Canyon Well permit applications would only cause minor drawdowns over prolonged time.
- There is little or no Carbonate Aquifer discharge to the Alluvial Aquifer or Muddy River Springs.
- There would be no significant impacts on senior water rights and endangered species habitat.
- The above are based on the MVWD Arrow Canyon pump-test interpretations and local well-log interpretations in Arrow Canyon Well area.

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JA_3608

UPPER MUDDY RIVER VALLEY
DOCUMENTED HYDROGEOLOGIC MODEL

- Approximately 51 cfs of remarkably steady flow reaches the Upper Muddy River Valley via the Carbonate Aquifer and discharges in the area.
- Average maximum winter flow was about 51 cfs (during cold weather, no evapotranspiration losses or diversions) between 1914 and 1961 water years.
- About 19 cfs has been measured in 1963 to discharge via conduits through the Alluvial Aquifer as localized spring discharge.
- About 32 cfs discharged as upward leakage from the Carbonate Aquifer to the Alluvial Aquifer and then discharged as baseflow to the Muddy River channels above Warm Springs Road Bridge during months of no evapotranspiration.
- The above establish the White River System regional Carbonate Aquifer discharge as measured in Muddy River flow at Warm Springs Road Bridge gaging station.

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UNCONFINED ALLUVIAL AQUIFER (Arrow Canyon to LDS Farm Reach of Upper Muddy River Valley)

- Lenticular alluvial gravels display large transmissivities and unconfined aquifer behavior. Pumping cones migrate slowly, aquifer lenses dewater within the Lewis Well Field pumping cone.

- Deep, well-developed Lewis Well Field area pumping cone is recovering between October, when heavy pumping stops, and as late as the end of March, when heavy pumping begins. Full recovery of the pumping cone persists for zero to two months with the pre-1994 level of exploitation.

- Source of water for the full annual pumping cone recovery is leakage from the Carbonate Aquifer. Overall water quality is similar to the Carbonate Aquifer water quality. Water temperature varies with location; local slightly higher temperatures indicate localized areas of conduit connections from the Carbonate Aquifer to the Alluvial Aquifer.

- Calcium carbonate cement-sealed conduits pass *through* the Alluvial Aquifer, and *into* the Alluvial Aquifer, both on a local basis. These are active and paleospring conduit-orifice systems, respectively, and reflect Carbonate Aquifer heads and water chemistry.

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JA_3610

- Most production wells produce from the Alluvial Aquifer lenses. However, LDS Central and LDS East are in paleoconduit zones and respond as if they are closely connected to the Carbonate Aquifer.

- The Lewis Well Field area pumping cone in the Alluvial Aquifer is transmitted to the Carbonate Aquifer. The Arrow Canyon Well pumping test demonstrated that the pumping stress in the Carbonate Aquifer was transmitted to the Alluvial Aquifer as well.

- The Muddy River channel and tributary channels are in hydraulic communication with the unconfined Alluvial Aquifer.

- Approximately 32 cfs of the 51 cfs of the annual Carbonate Aquifer discharge rate passes into the unconfined Alluvial Aquifer above the Warm Springs Road Bridge gaging station.

- Ground-water production in this reach of valley proportionally reduces the measured annual flow of the Muddy River at the Warm Springs Road Bridge gaging station.

- Pumping cone impact on measured Muddy River flow is delayed until the slowly expanding cone reaches the Big Muddy Spring area (about a five-month delay) and limits baseflow to the Muddy River channel until the cone fully recovers, historically between January and April.

CONFINED ALLUVIAL AQUIFER
(Warm Springs Bridge to White Narrows)

- Lenticular alluvial gravels display large transmissivities and confined aquifer behavior. Pumping cones migrate rapidly over large areas.
- Well-developed pumping cones recover with seasonal pumping cycles.
- Over-pumping has produced water-quality declines in some lenses. NPC well production is managed to prevent the water-quality impacts.
- The induced poor-quality water rapidly passes from the production well area in less than one year. The Muddy Creek Formation is the source of the poor-quality water.
- There is no evidence for hydraulic connections between the Muddy River and the confined Alluvial Aquifer throughout this reach of valley.
- The hydraulic separation between the Alluvial Aquifer and Muddy River occurs upstream of Warm Springs Bridge, but the detailed location has not been documented on the LDS Farm.

SE ROA 10758
JA_3612

UPPER MUDDY RIVER VALLEY
WARM SPRINGS ROAD BRIDGE GAGE MEASUREMENTS AND GROUND-WATER DEVELOPMENT

- Gage records between 1914 and 1961 indicate about 51 cfs of regional Carbonate Aquifer discharge occurs, and may vary only about 2 cfs from the mean.

- Since 1961, measured annual Muddy River flow at the Warm Springs Road Bridge has decreased in response to ground-water development and river-water diversions above the gaging station.

- Measured ground-water development in the Alluvial Aquifer is not immediately reflected in the gaging records during the heavy pumping season, but it is fully accounted for in the gaging records on an annualized flow basis.

- Annual measured Muddy River flow adjusted for estimated annual evapotranspiration, measured annual Muddy River diversions, and measured annual ground-water pumpage above the gage yields adjusted Muddy River flows equal to pre-diversion/pre-ground-water development Muddy River flows of about 51 cfs.

SE ROA 10759
JA_3613

ARROW CANYON WELL
121-DAY PUMPING TEST RESPONSES

- The 121-day Arrow Canyon Well pumping test produced widespread, but small, observed *net water-level changes* in both the Carbonate Aquifer and the Alluvial Aquifer.

- Establishing the *true drawdown* produced by the Arrow Canyon Well during the 121-day pump test is complicated by the seasonal water-level *recovery* from the Lewis Well Field area seasonal pumping.

- Total *recoveries* during the 121-day test were of similar relative magnitude as *true drawdowns*.

- Pumping stresses are algebraically additive at monitoring wells when more than one pumping-induced stress is acting. Therefore, *observed net water-level change* is equal to *true drawdown* (negative) plus *recovery* (positive).

- Long-term NPC monitoring well records have been used to estimate the rates of *recovery* at each monitoring well during the pump test (positive water-level changes) caused by the seasonal Lewis Well Field area pumping cone.

SE ROA 10760
JA_3614

- A 1992/93 regional recharge event to the Carbonate Aquifer creates uncertainty in calculating *recovery* corrections. DRI has used years prior to the recharge event (1992/93) to estimate recovery rates (most conservative), whereas MAI incorporated 1992/93 rates with three prior year rates to incorporate a 25% weight of greater recovery rates at the higher water-level state.

- Arrow Canyon Well pump-test true *drawdowns* are about two times (DRI corrections) or three times (MAI corrections) the *observed net water-level change*.

- MVWD did not recognize the need for *recovery* corrections to establish *true drawdowns* in the Carbonate Aquifer, and failed to recognize Arrow Canyon Well pumping impacts of similar magnitude in the Alluvial Aquifer.

- *True drawdowns,* two or three times *observed net water-level changes*, result in Theis equation long-term drawdown projections that are two or three times those calculated by MVWD.

SE ROA 10761
JA_3615

CARBONATE AQUIFER PARAMETERS AND PROJECTED IMPACTS

- Pump-test databases are of limited utility for determining accurate aquifer parameters to project future impacts because of three factors:
  A. Recovery corrections are required but are of uncertain magnitudes.
  B. The poor quality of observed drawdown datasets (scatter, small magnitudes, and limited early time data).
  C. The leakage between the Carbonate Aquifer and Alluvial Aquifer — localized but complex boundary conditions.

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- Hantush-Jacob leaky curves (Theis equation modified with leaky boundary conditions) produce reasonable aquifer parameters when recovery-corrected Carbonate Aquifer drawdown databases are plotted for early and mid-time periods.

- However, the future drawdown projections produced by uncertain aquifer parameters/complex boundary conditions must then be added to the senior right impacts. Confident analyses from the pump-test databases are unlikely using this general strategy.

- It is concluded that protested permit impacts are better estimated through analyses of the water-level monitoring records and water balances based on Muddy River flow at Warm Springs Bridge.

SE ROA 10762
JA_3616

PRODUCTION HISTORY, AQUIFER RESPONSES, AND ARROW CANYON PUMPING TEST IMPACTS

- Ground-water production, river-diversion records, Muddy River stream-flow records, and monitoring-well hydrographs in the Alluvial Aquifer and Carbonate Aquifer document the timing of water extraction, water-level responses in the aquifers, and changes in spring and river discharge.

- An annual seasonal cycle of pumping cone development and recovery can be seen in the hydrographic records of both the Carbonate Aquifer and the Alluvial Aquifer.

- Muddy River discharge records at the Warm Springs Bridge document timing and amount of unconfined Alluvial Aquifer pumping cone impact on stream flow.

- Spring-flow records reflect pumping impacts on Carbonate Aquifer heads as well, but the records are compromised by above-gage diversions and other measurement problems.

- Lewis Well Field area pumping-cone developments and recoveries in the unconfined Alluvial Aquifer are transmitted to the Carbonate Aquifer. The hydrograph at MX-4 replicates the pumping-induced hydrograph at EH-5b and EH-4 with a three-month delay at nine miles of separation. The hydrograph at EH-4 (two miles of separation) demonstrates about a one-month delay. EH-5b responds within days at less than one-half mile from the center of the Lewis Well Field.

- Muddy River flow at Warm Springs Bridge correlates with degree of pumping cone recovery of the Alluvial Aquifer. The Lewis Well Field pumping cone migrates down-valley to impact river flow over a five-month period (April to August). River flow is reduced during the fall and winter months until complete cone recovery.

- Analysis of monthly records of the Muddy River flow at Warm Springs Bridge indicate that each month of full recovery of the Alluvial Aquifer is about equal to 0.5 cfs of annualized flow. Prior to 1994, zero to three months of full recovery has been observed.

- The 1994 (December, 1993 through November, 1994) Arrow Canyon Well production was about 2.7 cfs of annualized pumpage, and therefore exceeded the margin of 0 to 1.5 cfs for complete annual recovery.

- The regional recharge event of 1992/93 raised the water-level state of the Carbonate Aquifer by about 0.8 feet. The addition of the Arrow Canyon Well 1994 production established a net downward trend, through December, 1994, that dissipated the 0.8 water-level rise.

SE ROA 10764
JA_3618

ANALYTICAL STRATEGIES AND CONCLUSIONS
MVWD ARROW CANYON WELL PERMIT APPLCATIONS

MVWD STRATEGY:

Arrow Canyon Well 121-day pumping test, application of Theis equation to observed net drawdown databases, projected water-level declines in the Carbonate Aquifer from the derived Transmissivity and Coefficient of Storage.

MVWD CONCLUSION:

Highly transmissive aquifer, no hydraulic communication with Alluvial Aquifer or Muddy River Springs, and only minor drawdown over 20 years. No evidence for an unacceptable impact for one or both permits if granted.

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NPC STRATEGY:

Long-term detailed monitoring of Carbonate Aquifer and Alluvial Aquifer, analyses of Arrow Canyon pumping-test drawdown in both aquifers, analyses of water-level changes, ground-water production, spring and Muddy River flow.

NPC CONCLUSION:

Arrow Canyon Well impacts the Carbonate and Alluvial Aquifers, spring and river flow, and, if either or both applications were to be granted, unacceptable impacts on senior water rights and endangered species would occur.

SE ROA 10765

JA_3619

☹ ☺ Production data for 1994 indicate that the added-on Arrow Canyon Well production (December, 1993 to November, 1994) was about 2.7 cfs if annualized.

☹ The Carbonate Aquifer hydrographs illustrate that water-level recovery did not occur in 1994 as normal. The Alluvial Aquifer pumping cone was deeper in 1994.

☹ The 1992/93 recharge event caused about 0.8 feet of Carbonate Aquifer regional water-level rise. The combined NPC and Arrow Canyon Well production prevented the normal recovery, and about 0.8 feet of net decline occurred by December, 1994.

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☹ ☺ The continued 1994 net decline in the Carbonate Aquifer verifies that the water balance-derived 0 to 1.5 cfs margin of available additional exploitation from the two aquifers is, unfortunately, approximately accurate.

☹ The protested MVWD applications, at 3 cfs and 5 cfs, are clearly sufficient to change the state of head in the Carbonate Aquifer when 2.7 cfs is sufficient to produce an unprecedented downward net loss of 0.8 feet in one year.

☹ ☹ The existing Arrow Canyon Well 2 cfs permit, when used, may also be sufficient produce a multi-year net downward trend in Carbonate Aquifer levels and associated impacts on the Alluvial Aquifer, river and springs.

SE ROA 10766

JA_3620

RECOMMENDATIONS

I. Do not permit the protested applications. The evidence is clear that either, or both combined, if pumped, would prevent the pumping cones from fully recovering on an annual basis. Drawdowns which carry over year after year will lower heads in the Carbonate Aquifer and Alluvial Aquifer and, instead of modest seasonal impacts on spring and river flow, quantitatively important changes in spring and/or river flow must occur as discharge is reduced by the magnitude of added Arrow Canyon Well production.

II. Review, on an annual basis, the hydrographs of the two aquifers as the permitted 2 cfs of the Arrow Canyon Well is added to the total ground-water production. The Arrow Canyon Well 1994 production of 2.7 cfs is more than the capacity of the two aquifer systems to sustain and continue to annually recover. The permitted 2 cfs may also prove to be more than the steady-state optimum.

III. Adjust, over several years of monitoring, the permitted production for the Arrow Canyon Well to the total amount that allows annual pumping cone recoveries.

SE ROA 10767
JA_3621

APPENDIX

Figures and Tables Supporting

SUMMARY OF GROUND-WATER DELEVOPMENT IMPACTS IN THE UPPER MUDDY RIVER VALLEY, NEVADA

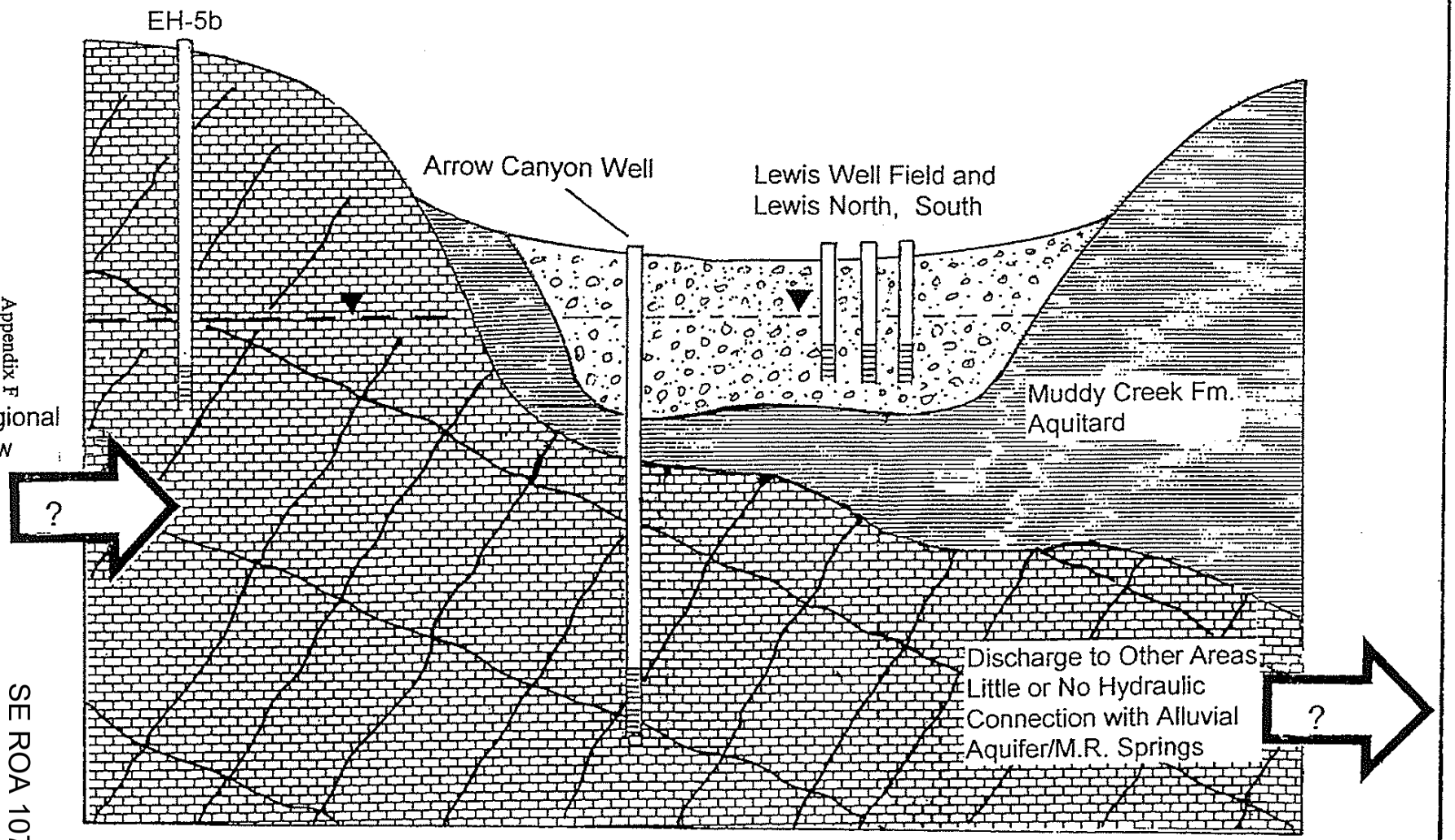
by
M.D. Mifflin

SE ROA 10768

JA_3622

INCOMPATIBLE ELEMENTS OF THE MWVD CONCEPTUAL MODEL

I. Muddy River Springs are the location of regional White River System discharge and the documented amount of Carbonate Aquifer flux.
II. The Carbonate Aquifer is the only source of water for the annual recovery of the Lewis Well Field area Alluvial Aquifer pumping cone.
III. The Carbonate Aquifer is the only source of water (~51 cfs) for the Alluvial Aquifer discharge to the Muddy River and Muddy River Springs.
IV. The Lewis Well Field area pumping cone (Alluvial Aquifer) is transmitted to the Carbonate Aquifer monitoring wells (EH-5b, EH-4, MX-4).
V. The Arrow Canyon Well pumping stresses were transmitted to the Alluvial Aquifer monitoring wells during the pump test (Lewis North, others).



DIAGRAMMATIC, MVWD CONCEPTUAL MODEL HYDROGEOLOGICAL RELATIONSHIPS

1995

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SE ROA 10769
JA_3623

DIAGRAMMATIC, DOCUMENTED HYDROGEOLOGIC RELATIONSHIPS

SE ROA 10770

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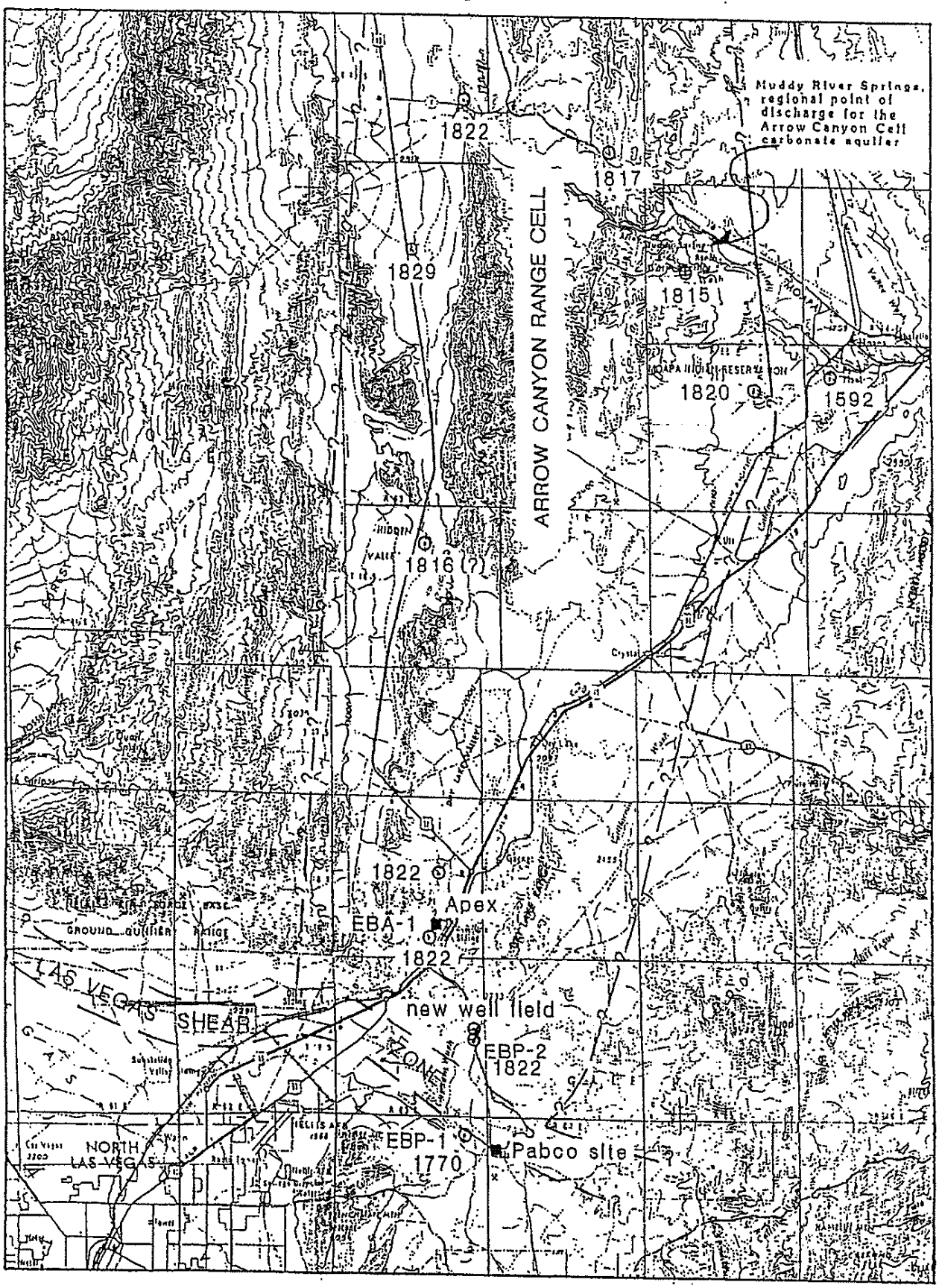
Figure 4



Appendix F

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SE ROA 10772

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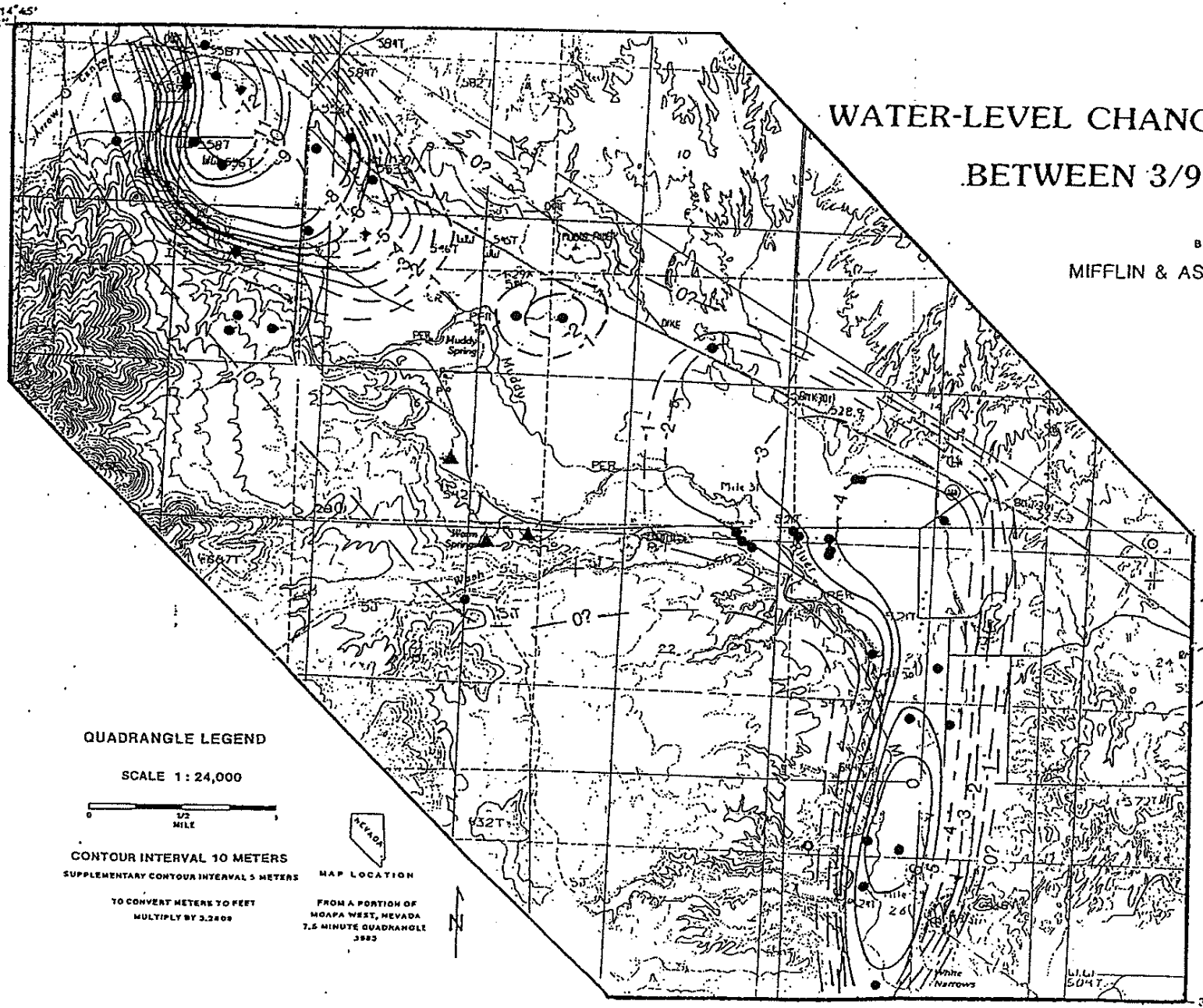

MAP XI

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SE ROA 10773

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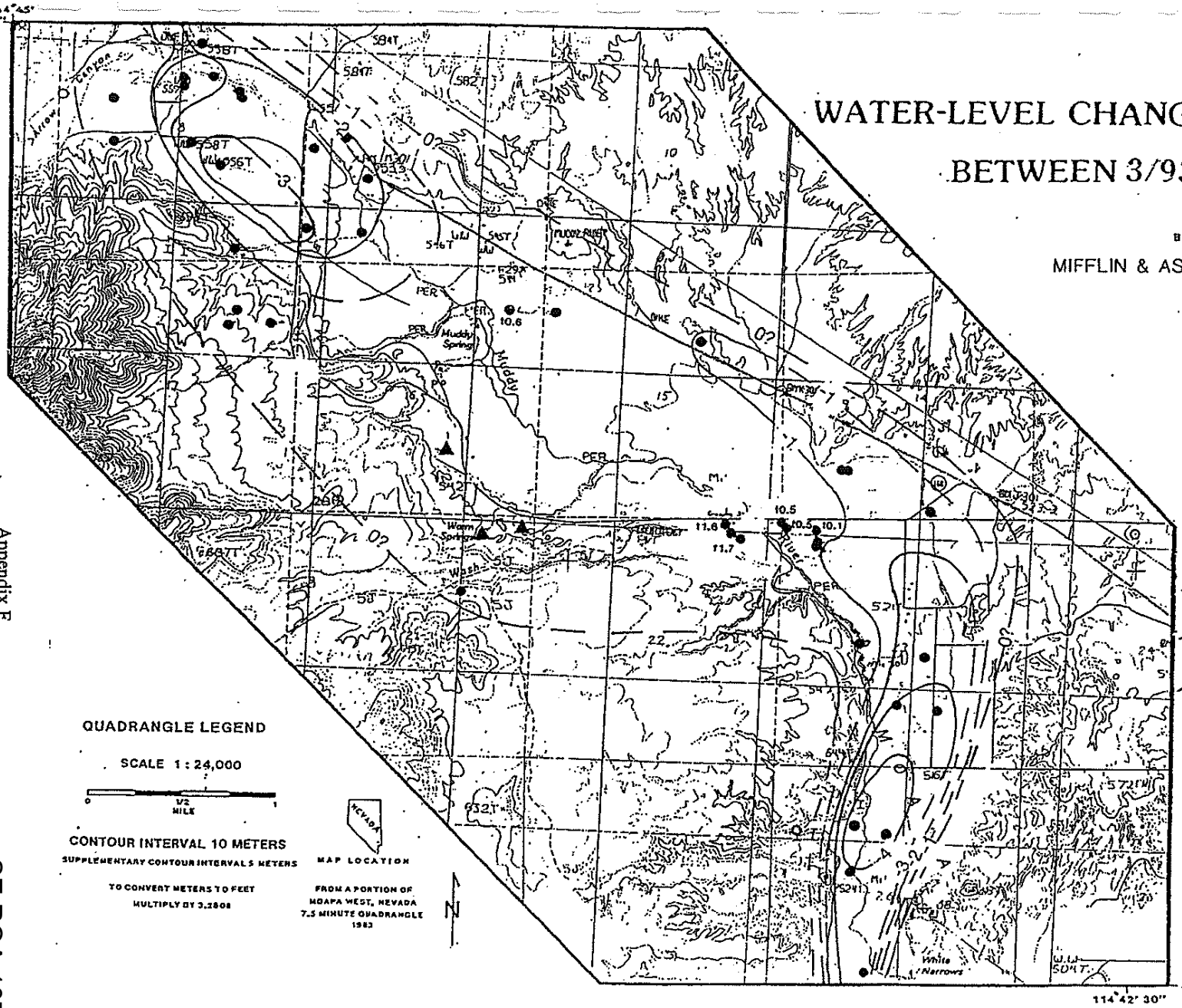

MAP XIV

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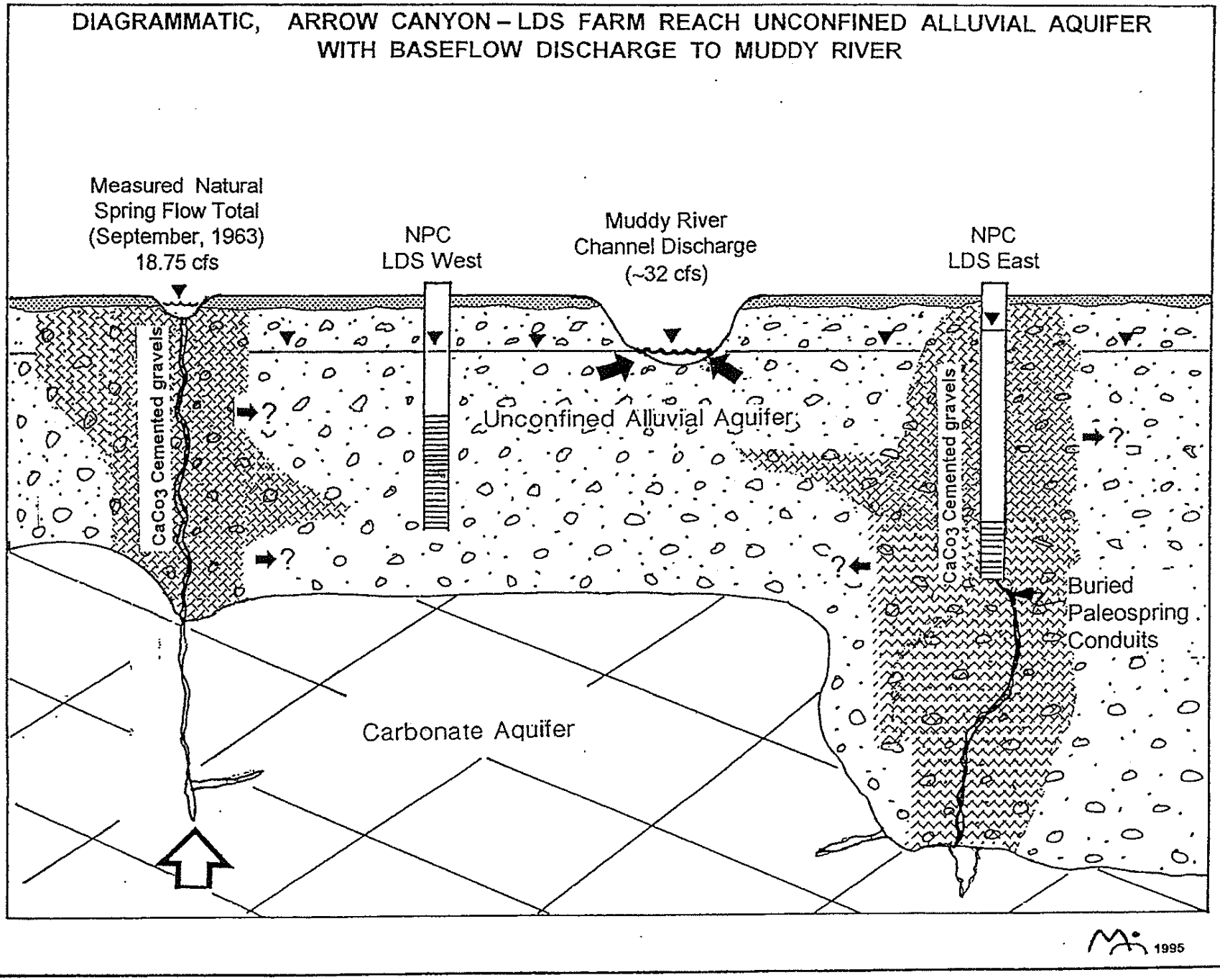

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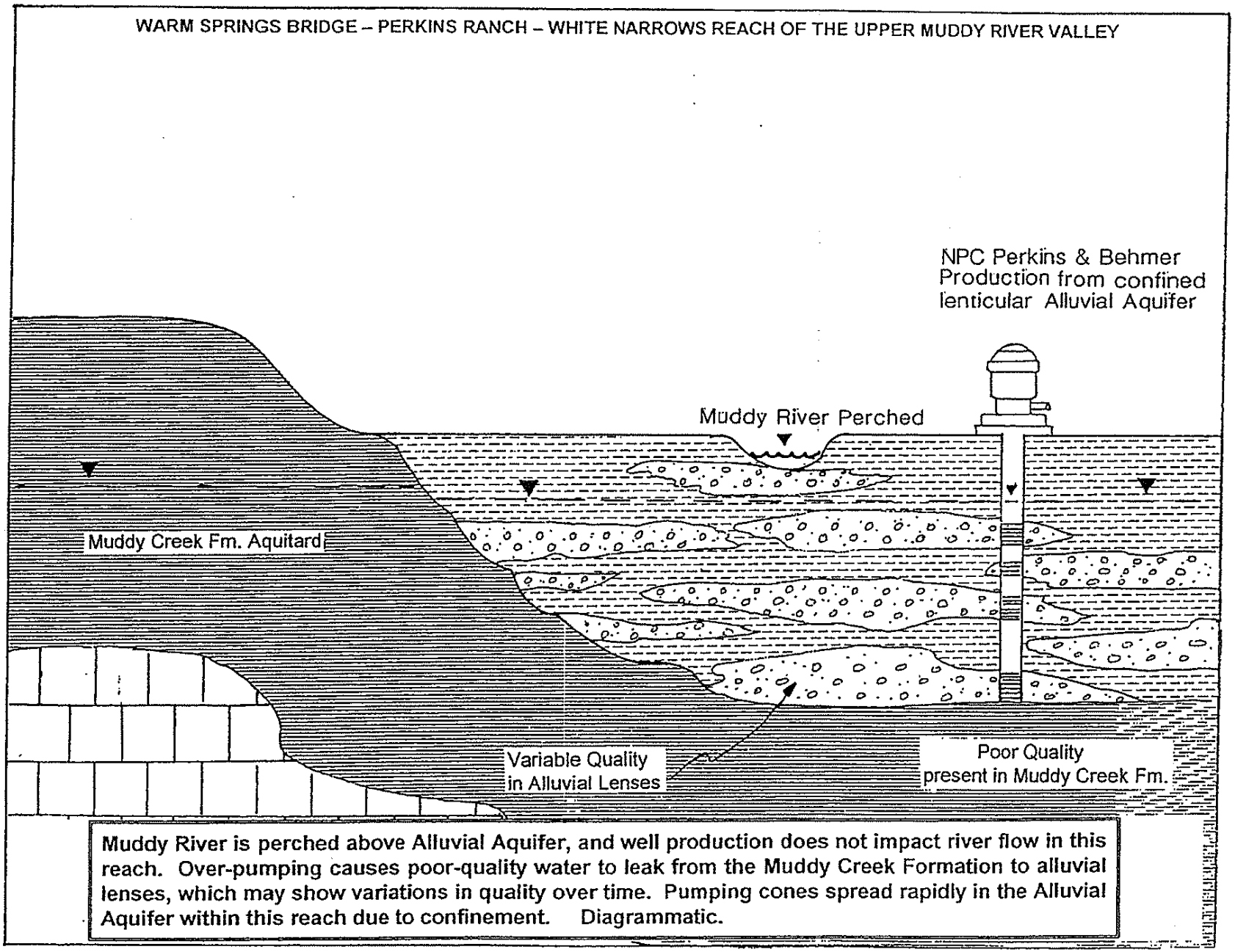
WARM SPRINGS BRIDGE – PERKINS RANCH – WHITE NARROWS REACH OF THE UPPER MUDDY RIVER VALLEY
NPC Perkins & Behmer
Production from confined
lenticular Alluvial Aquifer
Muddy River Perched
Muddy Creek Fm. Aquitard
Variable Quality
in Alluvial Lenses
Poor Quality
present in Muddy Creek Fm.
Muddy River is perched above Alluvial Aquifer, and well production does not impact river flow in this reach. Over-pumping causes poor-quality water to leak from the Muddy Creek Formation to alluvial lenses, which may show variations in quality over time. Pumping cones spread rapidly in the Alluvial Aquifer within this reach due to confinement. Diagrammatic.
1995

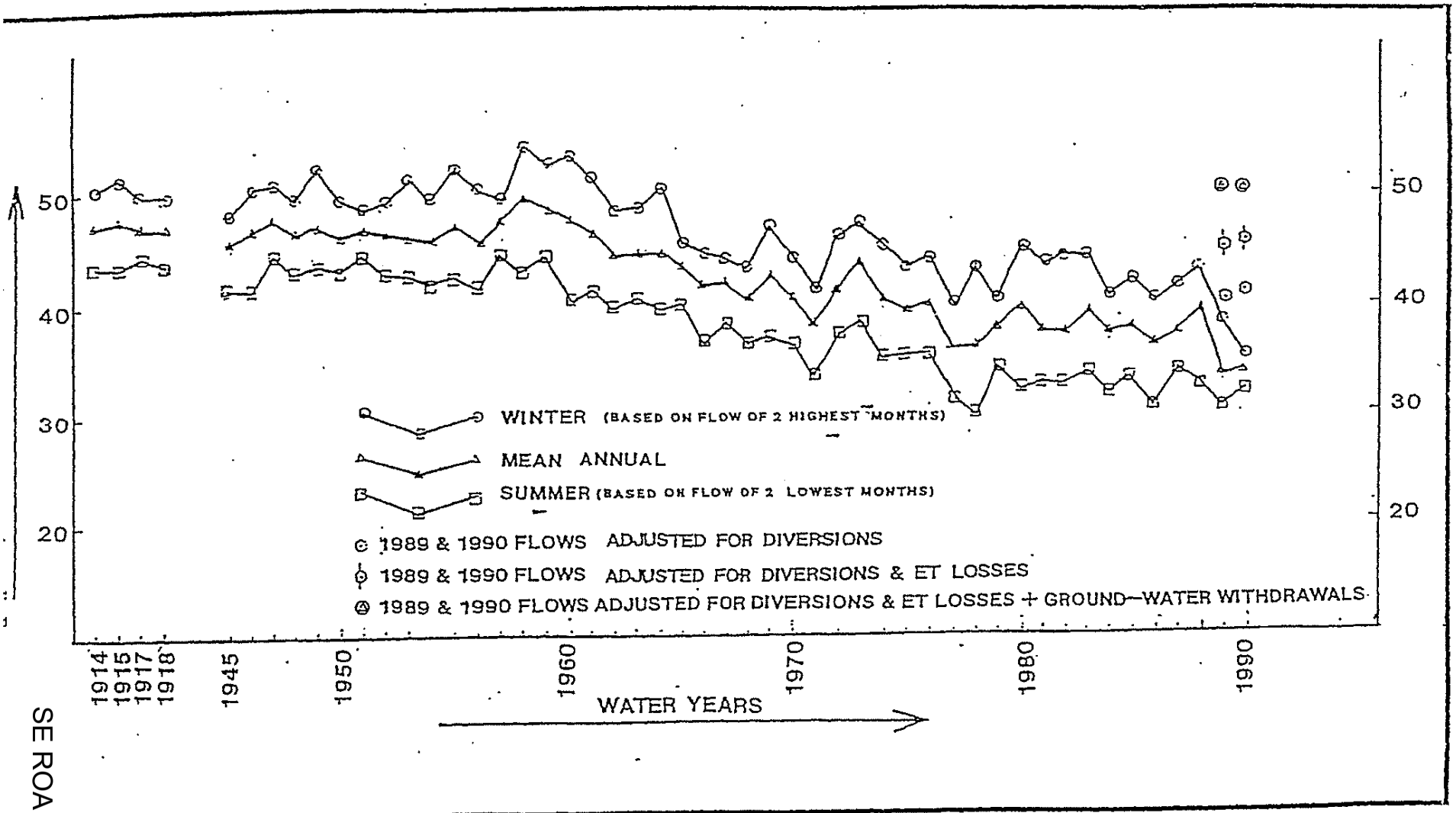

Figure 1. Historical Comparison of Mean Annual, Maximum Winter, and Minimum Summer Discharge, Muddy River At Warm Springs Road, Nevada, Data Modified from U.S.G.S. (from Mifflin, et al., 1991)

SE ROA 10777

JA_3631

TABLE 2
1989 And 1990 Water Year Muddy River Flows
Adjusted for Diversions and ET Losses

WATER YEAR 1989 (mean monthly flows in cfs)

	O	N	D	J	F	M	A	M	J	J	A	S	Mean Annual
M.R. Gage	31.5	34.3	38.8	35.8	38.6	32.9	31.3	35.8	33.6	31.0	30.4	30.7	(33.7)
NPC Divs.	4.4	3.9	3.6	6.6	4.8	7.9	8.4	1.6	1.7	1.6	1.8	1.7	
MVWD Divs.	2.5	2.0	1.9	1.9	1.3	2.6	2.9	3.1	3.9	3.3	3.0	3.2	(6.6)
M.R. Gage Divs.	38.4	40.2	44.3	44.3	44.7	43.4	42.6	40.5	39.2	35.9	35.2	35.6	
Est. ET Losses	4.5	2.9	m	m	m	3.9	5.7	7.2	9.1	8.7	7.7	6.2	(4.7)
Total Adjusted	42.9	43.1	44.3	44.3	44.7	47.3	48.3	47.7	48.3	44.6	42.9	41.8	(45.0)

WATER YEAR 1990 (mean monthly flows in cfs)

	O	N	D	J	F	M	A	M	J	J	A	S	Mean Annual
M.R.Gage	29.4	34.0	34.5	36.7	34.6	31.9	35.9	39.2	35.7	33.4	[32.8] 61.1	32.2	(34.2)
NPC Divs.	6.2	5.8	8.6	7.2	8.1	8.0	5.7	0.8	0.8	1.3	0.7	1.1	
MVWD Divs.	2.4	2.4	1.7	1.9	1.6	2.3	2.0	2.4	3.7	3.3	3.5	2.0	(6.9)
M.R.Gages Divs.	38.0	42.2	44.8	45.8	44.3	42.2	43.6	42.4	40.2	38.0	37.0	35.3	
Est. ET Losses	4.5	2.9	m	m	m	3.9	5.7	7.2	9.1	8.7	7.7	6.2	(4.7)
Total Adjusted	42.5	45.1	44.8	45.8	44.3	46.1	49.3	49.6	49.3	46.7	44.7	41.5	(45.8)

m = minor, probably less than 0.5 cfs
[ ] = flood flow subtracted

(from Mifflin, et al., 1991)

NPC9262.mnr/c1/mw/ms
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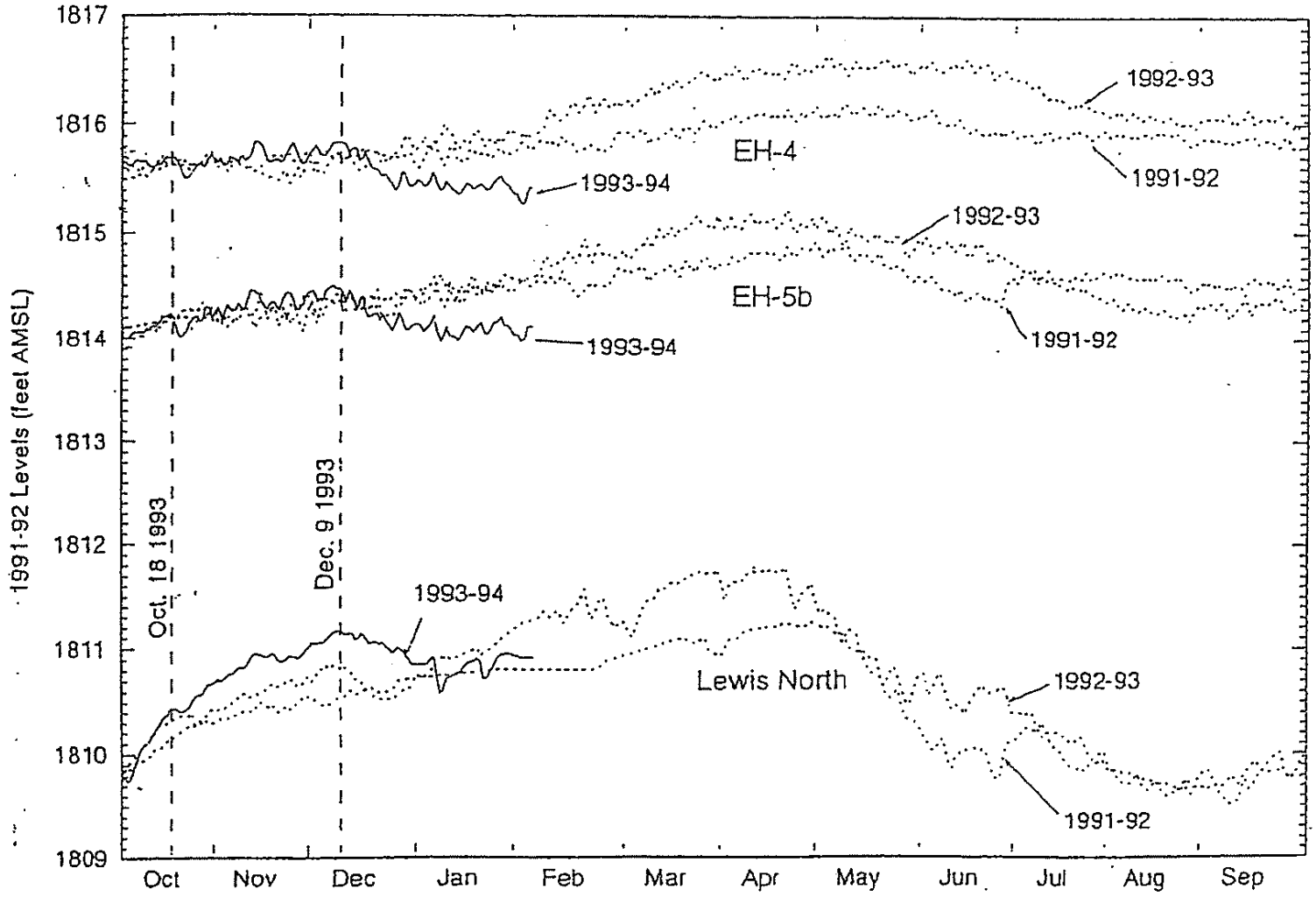
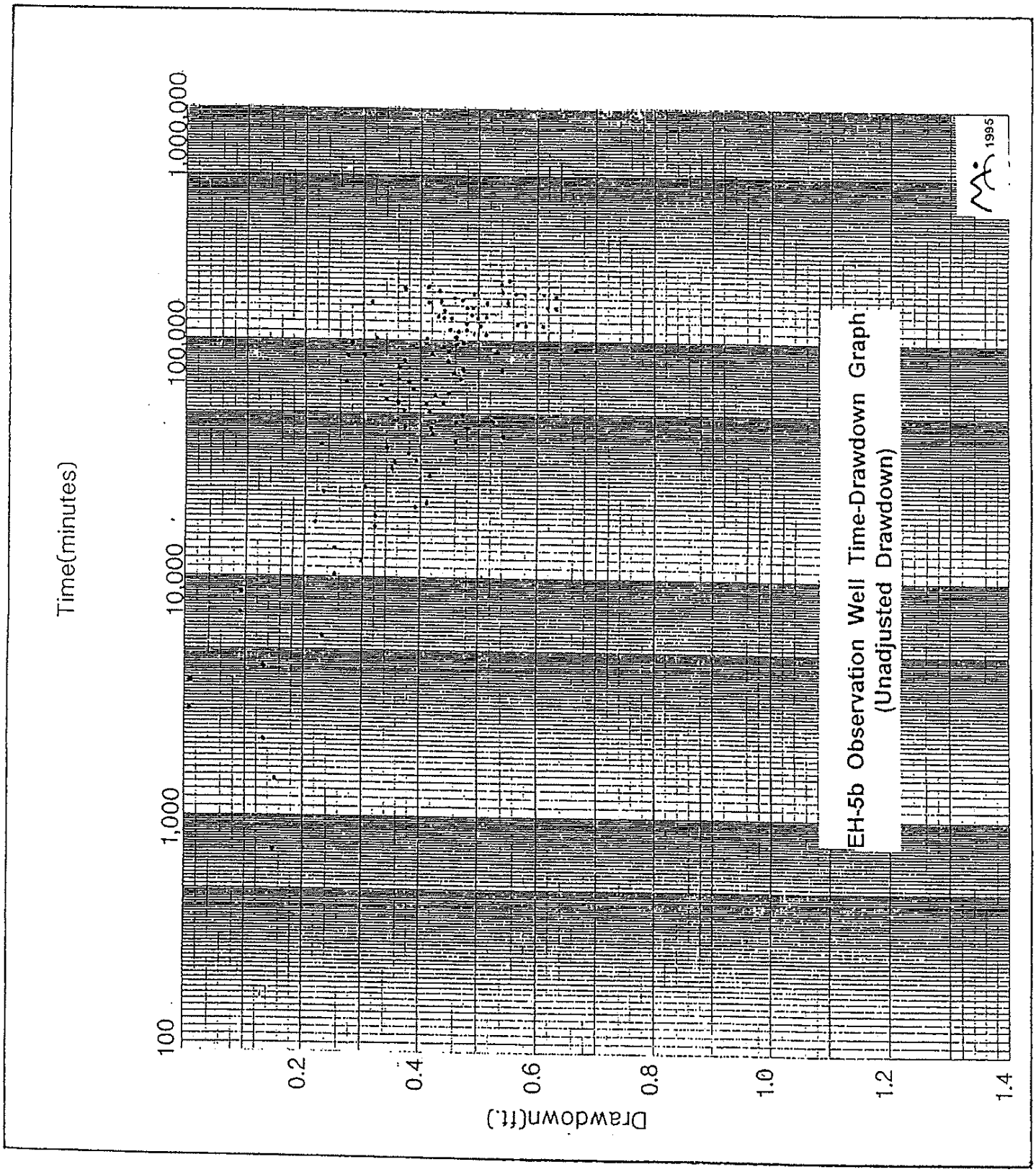
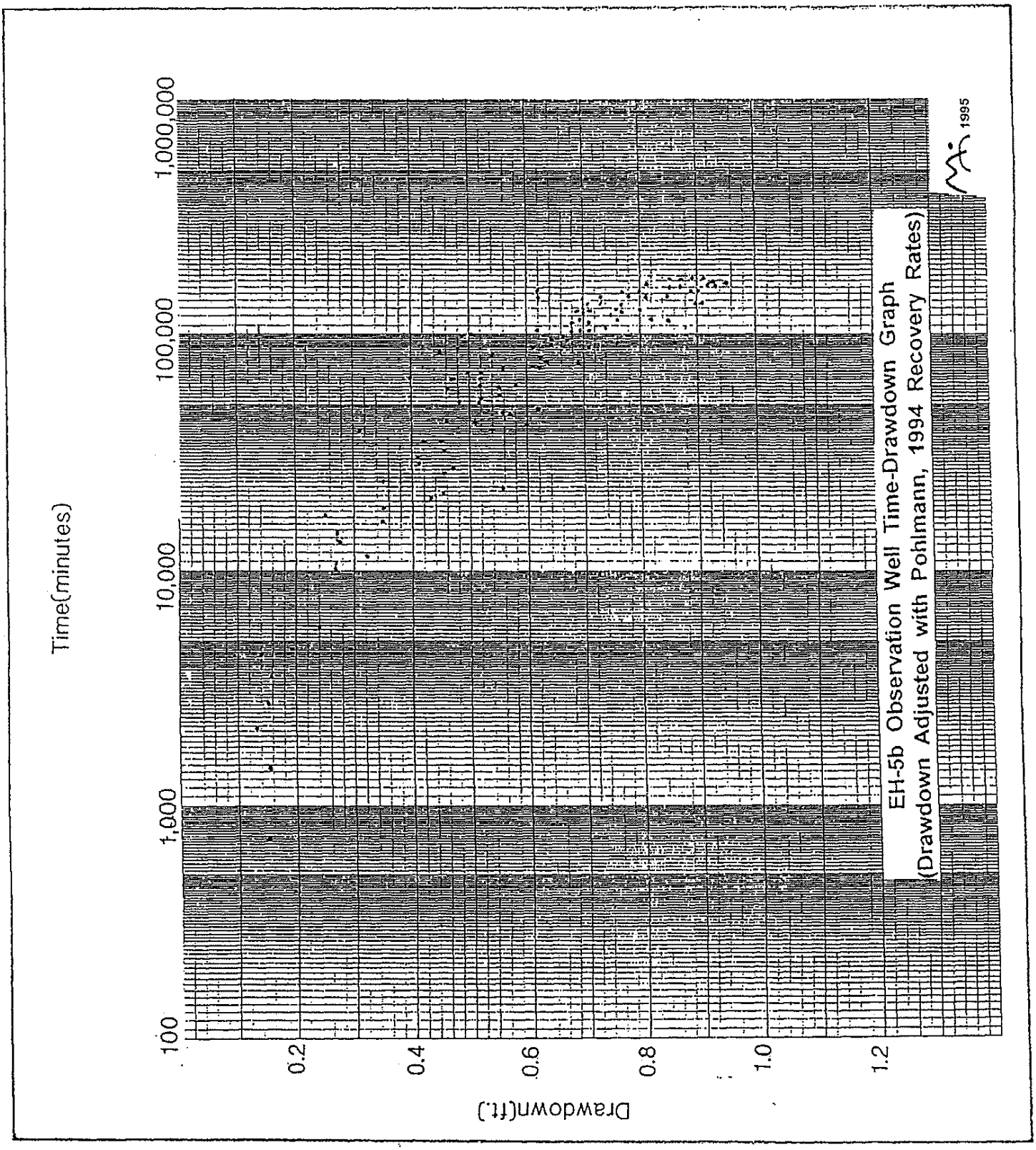


Figure 5. Relative ground–water levels in selected wells in the upper Muddy River Valley for the period 1September 1991 through 5 February 1994. Wells EH–4 and EH–5b monitor the carbonate aquifer and well Lewis North monitors the alluvial aquifer. 1992–93 and 1993–94 levels have been normalized to 1 September 1991 for comparison. Pohlmann (1994)


EH-5b Observation Well Time-Drawdown Graph
(Unadjusted Drawdown)
Time(minutes)
Drawdown(ft.)
100
1,000
10,000
100,000
1,000,000
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1995



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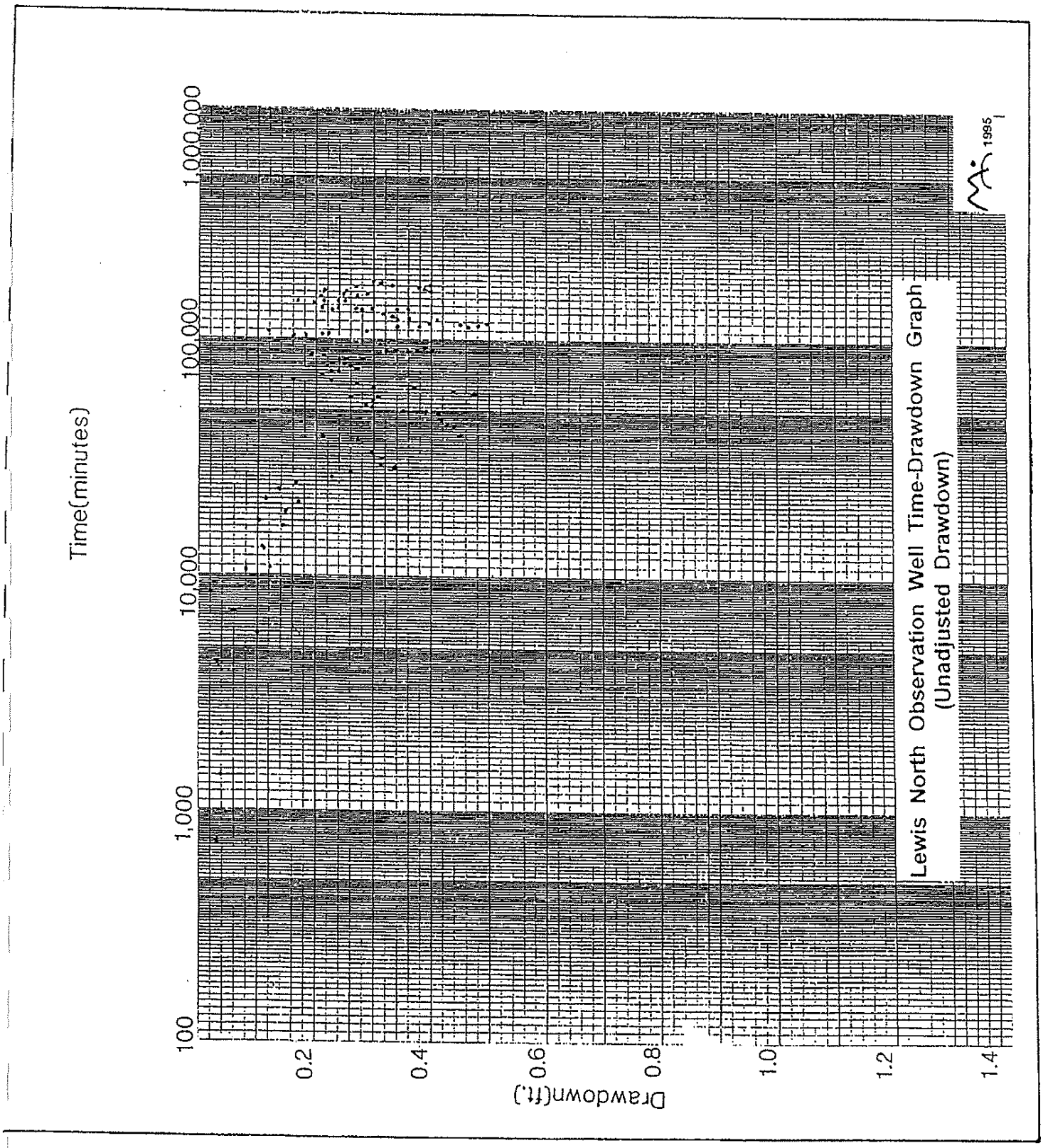

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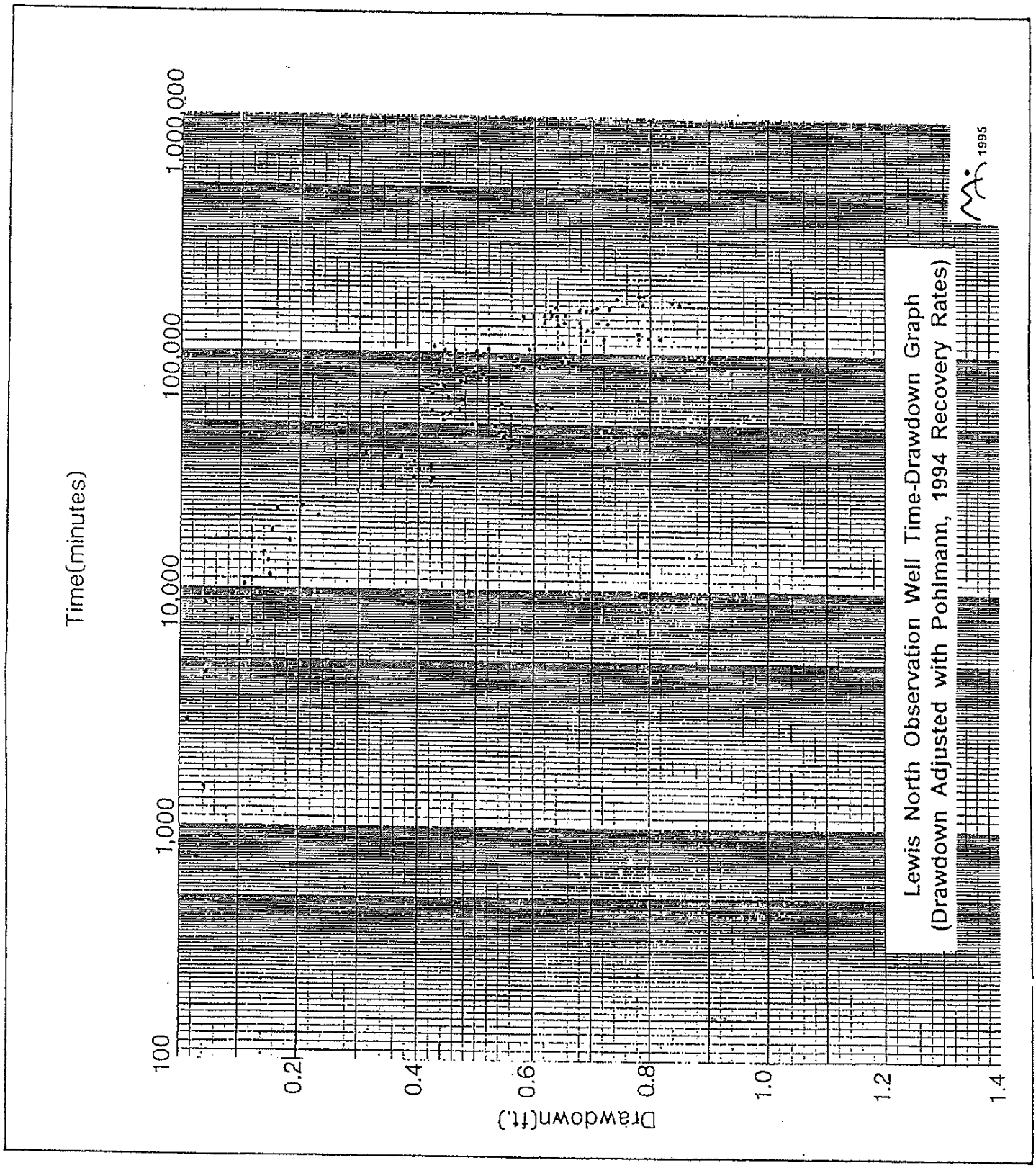

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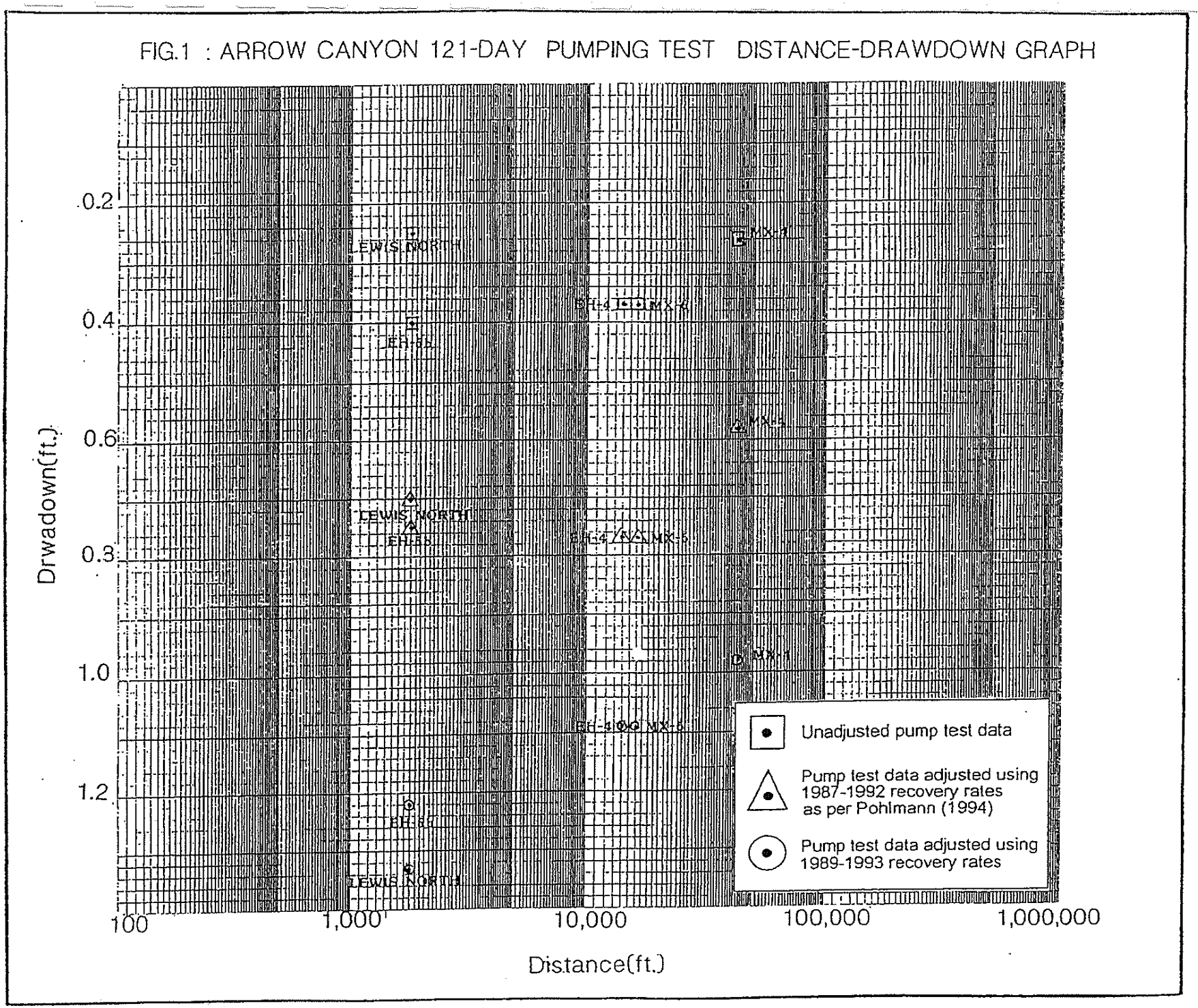
FIG.1 : ARROW CANYON 121-DAY PUMPING TEST DISTANCE-DRAWDOWN GRAPH
Drawdown(ft.)
0.2
0.4
0.6
0.3
1.0
1.2
100
1,000
10,000
100,000
1,000,000
Distance(ft.)
LEWIS NORTH
EH-4
MX-1
MX-2
MX-3
MX-4
MX-5
MX-6
Unadjusted pump test data
Pump test data adjusted using 1987-1992 recovery rates as per Pohlmann (1994)
Pump test data adjusted using 1989-1993 recovery rates

TABLE 2

TRANSMISSIVITIES AND STORATIVITIES
BASED ON THE LATE TIME DATA OF THE
TIME-DRAWDOWN GRAPH FOR
MX-4, MX-6, EH-5b AND LEWIS NORTH

WELL	Q (Pumping Rate) (gpm)	Δs (ft.) (Drawdown per One Log Cycle)	t_o (Zero Intercept on Time-Axis) (minutes)	T··· (Transmissivity) gpd./ft.	S (Storativity)
MX-4	2,900	1.2	37,000	638,000	0.0026
MX-6	2,900	1.2	35,000	638,000	0.0176
EH-5b	2,900	1.08	19,000	593,488	0.7248
Lewis North	2,900	1.3	20,000	588,923	0.7577

SE ROA 10785

JA_3639

ATTACHMENT 1

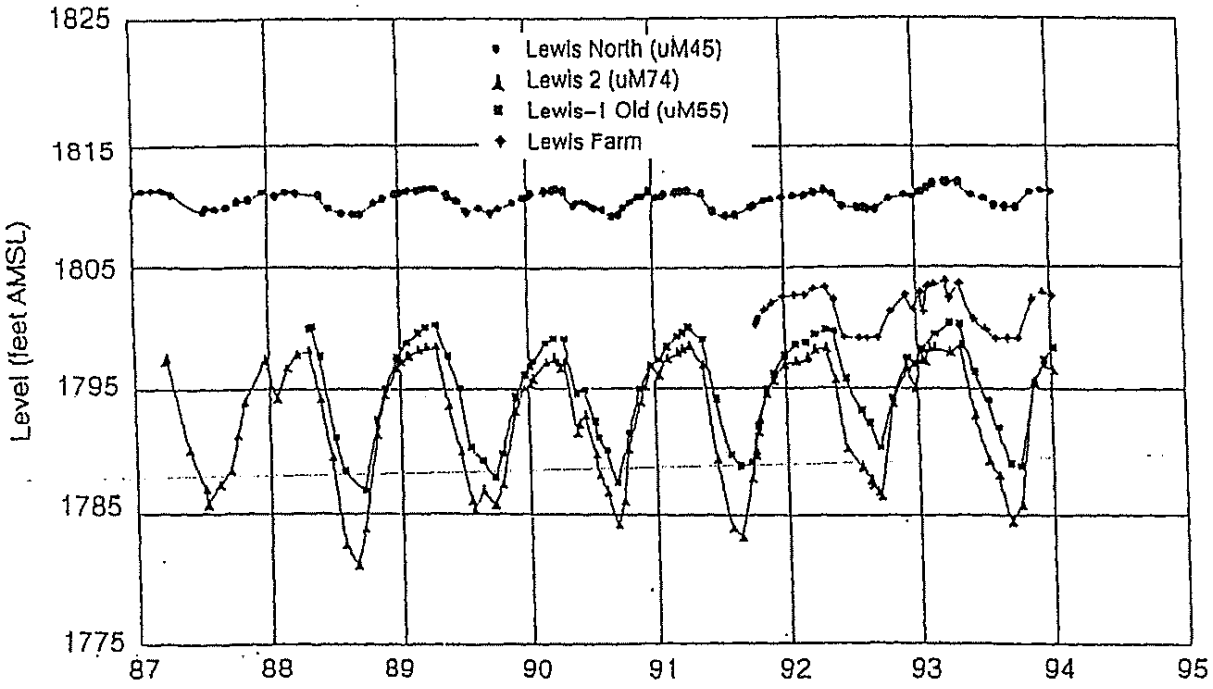

Figure C-1 Pohlmann (1994)

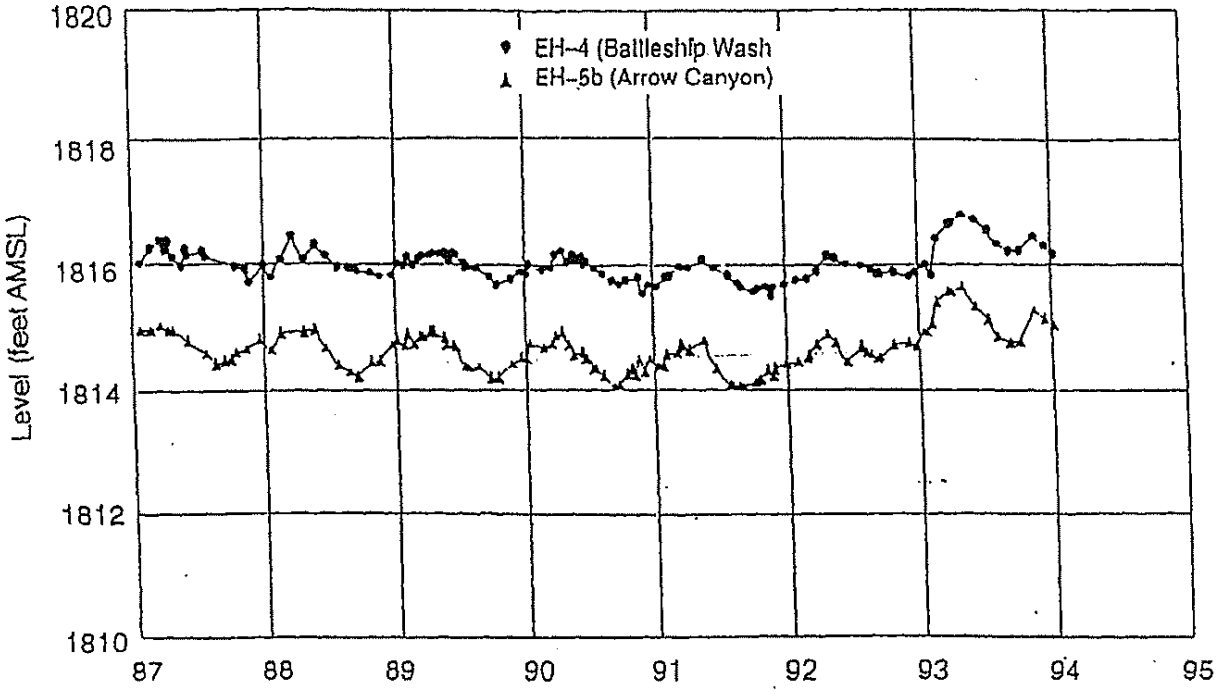

Figure C-2 Pohlmann (1994)

SE ROA 10786

JA_3640

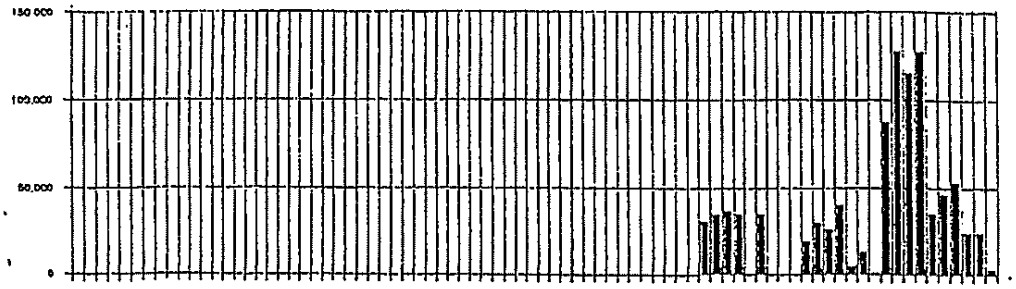

FIG. 6a. : Arrow Canyon Well Production ('000s of gallons) Aug. 1992 - Sept. 1994

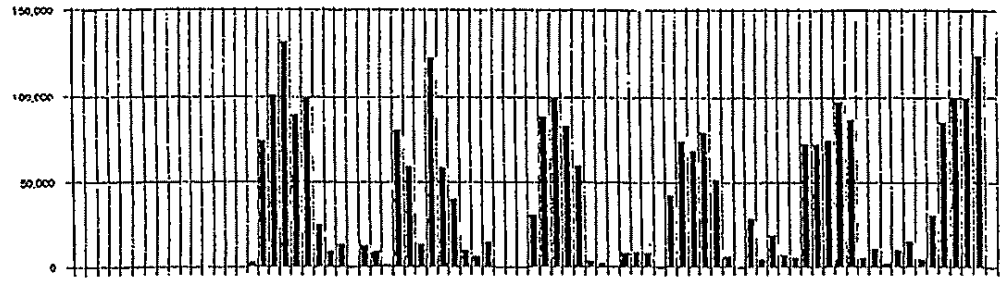

FIG. 6b. : Lewis Well Field Monthly Diversions ('000 of gallons) 1989 - 1994

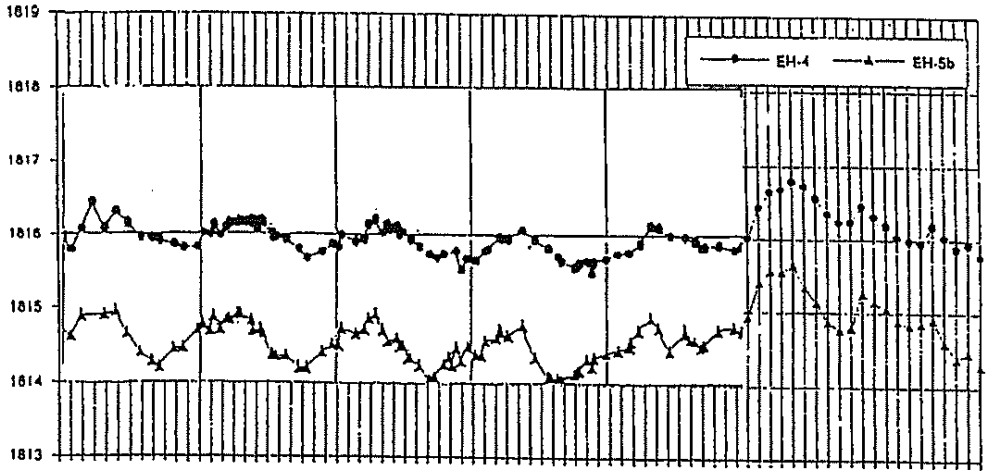

FIG. 6c. : Hydrograph of EH-4 & EH-5b for January 1988 through September 1994

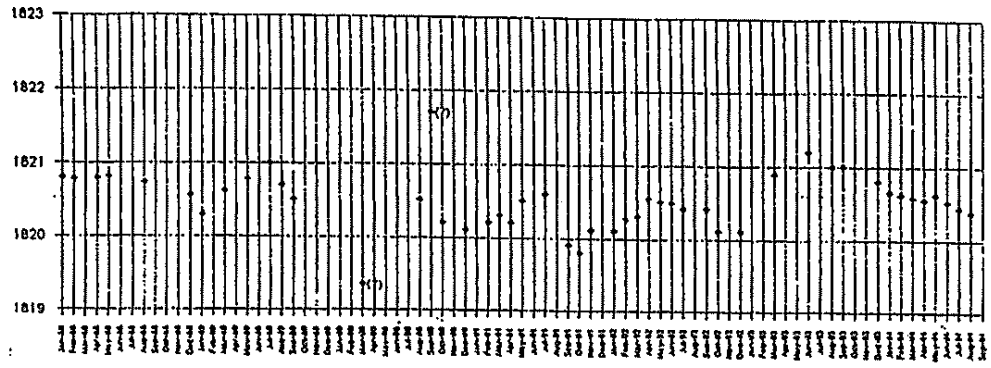

FIG. 6d. : Hydrograph of MX-4 for January 1988 through August 1994

1995

SE ROA 10787

JA_3641

MUDDY SPRING

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1989	6.97	7.07	7.11	7.17	7.16	7.19	7.36	7.39	7.43	7.07	7.21	7.21
1990	7.13	7.27	7.58	7.36	7.29	7.37	7.45	7.15	7.10	7.00	7.03	7.25
1991	7.52	7.28	6.70	6.93	6.85	7.13	8.26	7.86	7.49	7.70	7.26	7.16
1992	7.69	7.47	7.99	6.40	7.45	7.46	7.28	7.50	7.53	7.08	6.94	5.73
1993	7.23	7.47	7.54	8.39	9.22	8.15	6.98	6.69	6.64	6.43	6.58	6.57
1994	7.33	7.02	7.17	7.33	7.02	7.02	7.17	7.02	8.29	8.79		

PEDERSON SPRING

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1989	0.18	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.19	0.20	0.21	0.19
1990	0.18	0.18	0.18	0.20	0.21	0.21	0.23	0.23	0.23	0.22	0.22	0.22
1991	—	0.21	0.21	0.19	0.19	0.18	—	0.20	0.20	0.22	0.21	0.20
1992	0.20	0.19	0.19	0.18	0.20	0.21	0.22	0.21	0.20	0.22	0.22	0.22
1993	0.22	0.23	0.22	0.23	0.24	0.24	0.25	0.25	0.26	0.27	0.22	0.22
1994	0.23	0.25	0.24	0.23	0.22	0.23	0.22	0.24	0.25	—	0.27	

WARM SPRINGS WEST

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1989	3.33	3.46	3.48	3.37	3.41	3.47	3.43	3.52	3.46	3.48	3.44	3.55
1990	3.50	3.78	3.73	3.76	3.84	4.02	3.79	3.94	3.87	3.87	3.89	3.80
1991	3.60	3.53	3.57	3.75	3.81	3.61	3.73	3.32	3.69	3.64	3.57	3.53
1992	3.58	3.63	4.00	3.35	3.37	3.23	3.14	3.12	3.20	3.19	3.17	3.38
1993	3.20	3.37	3.53	3.61	3.71	3.74	3.73	3.70	3.57	3.37	3.41	3.29
1994	4.06	4.12	4.06	4.06	4.06	3.82	3.70	3.76	3.76			

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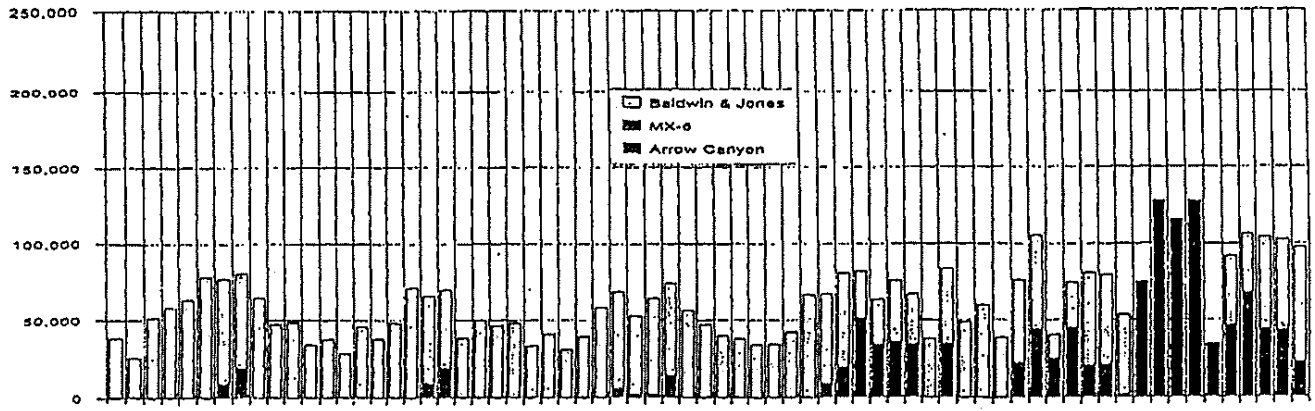
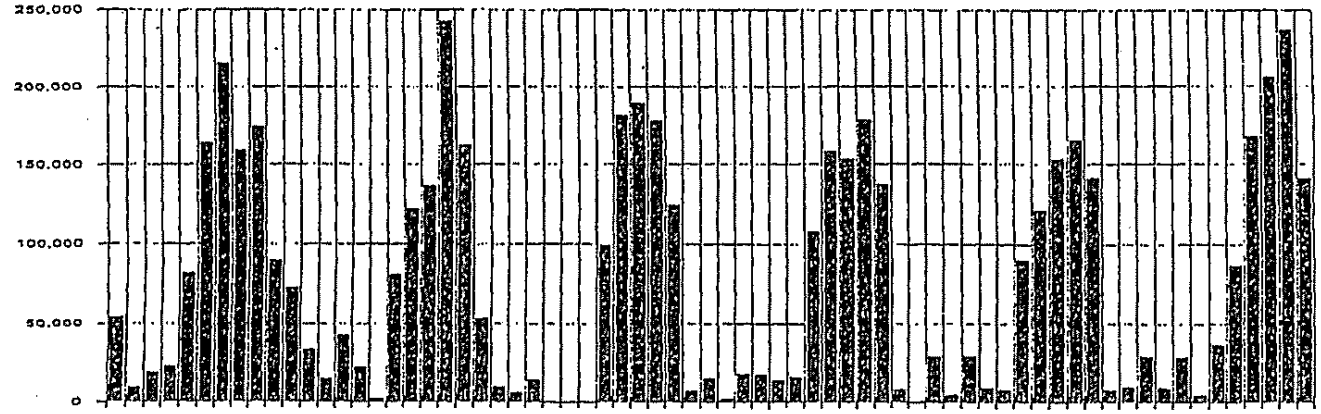
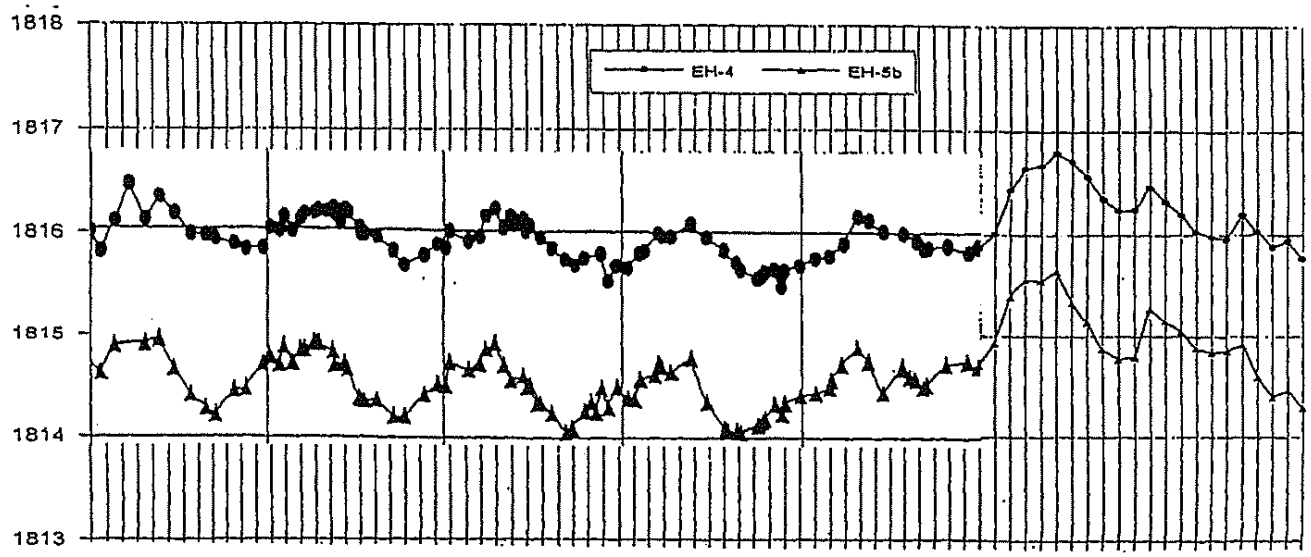


Arrow Canyon and MX-6 Wells, Baldwin and Jones Springs
Diversions ('000 gallons) 1989–1994



Lewis/LDS West and LDS East/LDS Central Well Fields
Diversions ('000 gallons) 1989–1994



Hydrographs of EH-4 & EH-5b for January 1988 through September 1994

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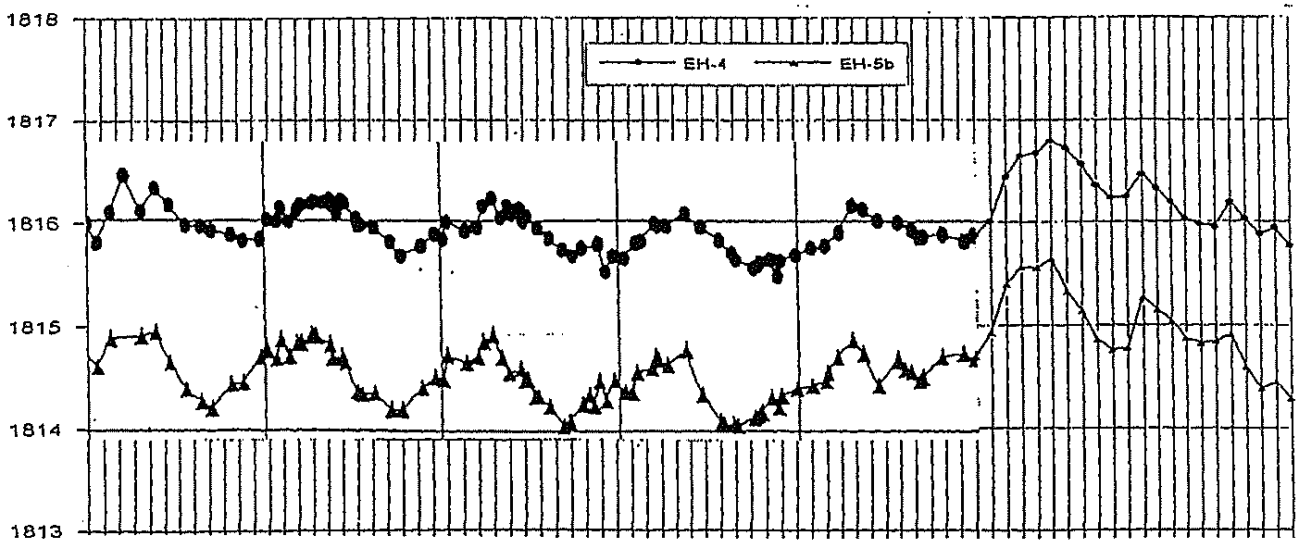
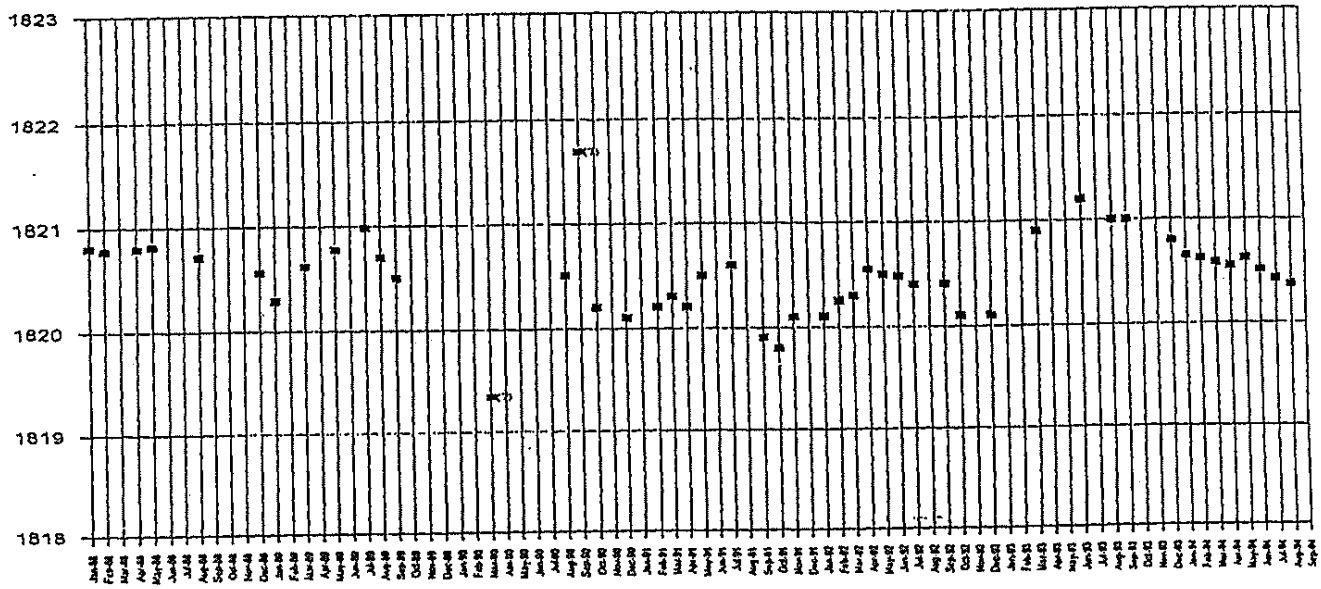


Hydrographs of EH-4 & EH-5b for January 1988 through September 1994



Hydrograph of MX-4 for January 1988 through August 1994

1995

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